

Environmental Impact Assessment

Liza Phase 2 Development Project

Esso Exploration and Production Guyana Limited

Volume II

June 2018

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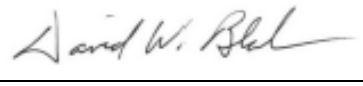
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APPENDIX A

List of Preparers

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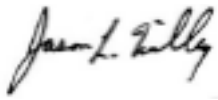
LIST OF PREPARERS



David Blaha, Program Lead



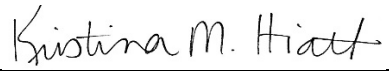
Todd Hall, Partner-in-Charge



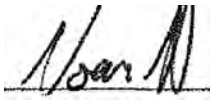
Jason Willey, Project Manager, Biological Resource Specialist



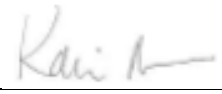
Matt Erbe, Project Controls Lead



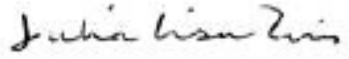
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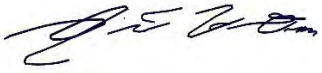
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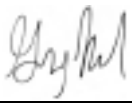
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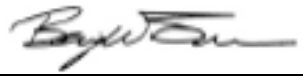
Julia Tims, Biological Environment Lead, Avian and Terrestrial Wildlife Specialist



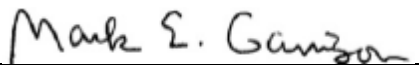
Rick Osa, Air Quality Monitoring Lead



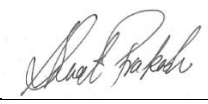
Greg Lockard, Cultural Heritage Assessment Lead



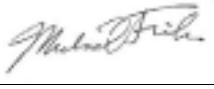
Benjamin Sussman, Transportation Assessment Lead



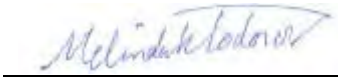
Mark Garrison, Air Emission Dispersion Modeling Lead



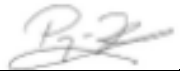
Shwet Prakash, Water Quality Assessment Lead



Mike Fichera, Senior Water Quality Specialist



Melinda Todorov, Senior Marine Scientist



Peyun Kok, Socioeconomic and Community Health Specialist



Dusty Insley, Geological Resource Specialist



Jon Connelly, Biological Resource Specialist



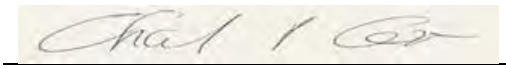
Michael Fraser, Acoustics Specialist



Vanessa Cottle, Cumulative Impact Assessment Lead



Rowena Cerro, Cumulative Impact Assessment Specialist



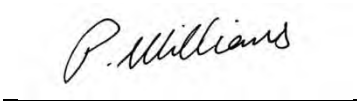
Charles Ceres, GSEC Project Director



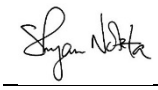
Hance Thompson, GSEC Senior Specialist



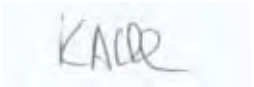
Raeburn Jones, GSEC Biological Resource Specialist



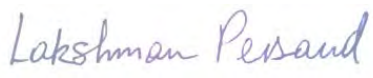
Patrick Williams, GSEC GIS Analyst



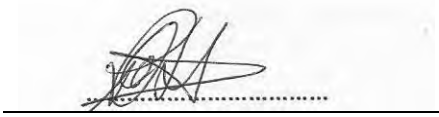
Shyam Nokta, EMC Principal and Environmental Management Specialist



Khalid Alladin, EMC Project Manager



Richard Persaud, EMC Community Resources Specialist



Romeo De Freitas, EMC Biological Resource Specialist

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APPENDIX B

EIA Team Curricula Vitae

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David W. Blaha, AICP

Program Lead



Mr. Blaha has 35 years of experience in environmental and social impact assessment, natural and cultural resource management, sustainable development and stakeholder engagement. He routinely provides strategic advice for public and private sector clients in managing the environmental and social risks relating to obtaining regulatory approvals, lender financing, and the social license to operate for large (>$US 1 billion) mining, infrastructure, and power projects. He is thoroughly familiar with good international industry practice (e.g., IFC Performance Standards, IDB Environment and Safeguard Polices and Directives, and Equator Principles) and the application of those standards in preparing Environmental and Social Impact Assessments. Mr. Blaha has worked with many Equator Banks, bilateral and multilateral banks, and other lenders to conduct appropriate environmental and social due diligence, gap analyses, and construction/operation compliance assessments.

Professional Affiliations & Registrations

- American Institute of Certified Planners
- International Association of Impact Assessment
- American Planning Association
- American Water Resources Association

Education

- Master of Environmental Management, Duke University, 1981
- Bachelor of Arts, Biology, Gettysburg College, 1978

Honors & Awards

- Phi Beta Kappa

Key Industry Sectors

- Financial
- Oil & Gas
- Power
- Mining

Key Projects

Environmental Impact Assessment and Permitting Support, Exploration Activities, EEPGL (ExxonMobil). Project Director for comprehensive impact assessment, management planning, and environmental permitting services for ExxonMobil's local affiliate in Guyana since 2013. Worked closely with the local Exxon affiliate in Guyana to help navigate the regulatory structure in Guyana and deliver the necessary approvals to meet the client's accelerated schedule for exploration and assessment of resources in the Stabroek Block.

Guyana Goldfields Aurora Mine ESIA, Guyana. Project Director for an Environmental and Social Impact Assessment of a proposed gold mine in northwestern Guyana. Key issues included socioeconomic impacts and impacts on soil and water quality from accidental spills.

Matthews Ridge Manganese Mine IFC Gap Analysis, Guyana. Project Manager for a site assessment and document review to determine a proposed mining project's compliance with the IFC performance standards and identify any gaps.

Crown Landing Liquefied Natural Gas Project, US. Project Manager for a US$1.4 billion LNG import terminal for BP consisting of a marine terminal and an on-shore regasification facility. Responsible for advising BP on securing all necessary federal, state, and local environmental permits.

Golden Pass LNG Project, Texas. Technical coordinator for preparation of environmental resource reports for a 1.0 BCFD LNG import terminal at Sabine Pass, Texas for ExxonMobil.

Camellia Bay LNG Project (AL). Technical coordinator for preparation of environmental resource reports for a 1.0 BCFD LNG import terminal south of Mobile, AL for ExxonMobil.

Maritime Administration Deepwater Port Workshop. Project Director for coordinating a LNG Deepwater Port Conference for potential applicants and applicable state and federal agencies on behalf of MARAD,

including preparing educational and reference materials on licensing process.

HEMCO Gold and Silver Mine, Nicaragua. Project Director for an Environmental and Social Due Diligence of a proposed gold and silver mine and associated hydropower project as part of project financing on behalf of the Inter-American Investment Corporation.

Buenaventura Industrial Port Expansion ESDD, Colombia. Project Director for due diligence of a proposed Pacific container port expansion in Buenaventura on behalf of the IFC. Key issues relate to potential impacts on water quality, and temporary disruption of subsistence fishing.

Keystone XL Pipeline Environmental Impact Statement, US. Overall Senior NEPA Lead and coordinator for the alternatives and cumulative effects assessment for Supplemental EIS on behalf of the U.S. State Department for a highly controversial oil pipeline requiring a Presidential Permit for a US/Canada border crossing.

Northeast Gateway Deepwater Port LNG Import Terminal, U.S. Project Director for 400 MMcfd LNG deepwater port project proposed by Excelerate as the 3rd Party EIS contractor for the U.S. Coast Guard. The Project is located 13 miles offshore from Gloucester MA in approximately 280 feet of water and will use special purpose LNG carriers called Energy Bridge Regasification Vessels to transport and regasify the LNG. The deepwater port will connect to the interstate natural gas system via a 16.1 mile submerged pipeline lateral. The Project has been permitted and constructed.

Inter-American Development Bank (IDB) Support Services Contracts. Project Director for multi-year support contract with the IDB to provide E&S advisory services for both public sector and private sector projects throughout Latin America.

Cerrejon Coal Mine, Colombia. Serving as Project Director for an independent evaluation of a proposed expansion of the world's largest open pit bituminous coal mine. Provided advisory services regarding managing environmental and social risks, including river diversions and effects on indigeneous lands.

Pebble Gold Mine ESIA, U.S. Serving as Technical Director for an independent environmental and social evaluation of the reportedly largest gold deposit and 5th largest copper deposit in the world. Key issues include assessing effects of the project, especially the tailings storage facility, on salmon and indigeneous subsistence lifestyles in the area.

SIEPAC Construction Phase Monitoring, Central America. Project Director for the construction phase of environmental and social monitoring on behalf of the IDB for the SIEPAC transmission line project in Panama, El Salvador, and Guatemala.

Xacbal Hydroelectric Project, Guatemala. Project Director for environmental and social due diligence review of a 94 MW hydropower and 125 km transmission line project on the Xaclbal River for the Inter-American Investment Corporation. Key issues focused on ecological base flows, compensation for land acquisition, and community investment program.

Pando – Monte Virio Hydropower Project, Panama. Project Director for construction and operation phase monitoring of an 83 MW hydropower project with a 19-km transmission line located on the Chiriqui River, which forms the border with Costa Rica, to ensure project complies with lender requirements, IFC performance standards, Panamanian regulations, and the project's E&S Management Plan on behalf of the lenders, which include the IDB, IFC, and GED.

TapaJai Hydropower Project ESIA, Suriname. Project Director for a hydropower project that would divert water from the Marowijne River, which forms the international border with French Guiana, to augment flow to increase hydropower generation.

Camisea Block 56 Gas Field and Pipeline EIA, Peru; 2005. Project Director for EIA evaluating the effects of developing three gas fields, 30 km of gas flowlines, and the Malvinas gas plant in Peru for Hunt Oil/Pluspetrol. The EIA is being developed to meet Inter-American Development Bank standards.

Lake Gaston Environmental Impact Statement, US. Project manager for the development of an EIS evaluating alternative water supply sources for the City of Virginia Beach. Mobilized and coordinated 30 multidisciplinary staff from 3 offices in order to complete the project in 6 months. The FEIS was appealed to the US Supreme Court and upheld.

Nassau Plateau Bauxite Mine ESIA, Suriname. Serving as Project Director for baseline studies and preparation of an ESIA for a bauxite mine to meet both Suriname and international standards for Alcoa. Key issues include effects on endangered fish, habitat fragmentation, and water quality. Coordinating stakeholder engagement with local Maroon and Amerindian communities.

Todd H. Hall, P.E.

Partner-in-Charge



Mr. Todd Hall is a Principal Partner with ERM based in Denver, Colorado. He has over 21 years of experience in environmental consulting, focusing on environmental, social and health impact assessment, management plan development, multi-media permitting, site planning & licensing, remediation, and risk assessment.

Mr. Hall's primary focus is on the energy sector, with expertise in power generation and transmission; mining operations; downstream, midstream, and upstream oil and gas facilities; and petrochemical complexes. He has prepared environmental, social and health impact assessments, and management plans for dozens of development projects in North America, Asia/Pacific, Africa, the Middle East, and South America.

Mr. Hall has conducted impact assessments in accordance with international best practice, U.S. National Environmental Policy Act (NEPA), client-specific methodologies, and ERM standard methodology (led the development of the ERM Impact Assessment Standard). He has provided lifecycle support services for energy facilities and organizations, including sustainability advisory, regulatory compliance assurance, remediation and risk assessment, stakeholder engagement, and environmental and social performance monitoring.

Professional Affiliations & Registrations

- Registered Professional Engineer – Texas
- National Society of Professional Engineers
- International Association for Impact Assessment

Fields of Competence

- Environmental, social and health impact assessment and management plan development
- International Best Practice (EP, IFC PS, etc.) requirements
- National Environmental Policy Act (NEPA) requirements
- Environmental planning, siting, and licensing for U.S. and international energy projects
- Multi-media environmental permitting
- Environmental engineering design
- Site investigation and remediation
- Risk assessment (human and ecological)
- Regulatory compliance assessment

Education

- M.E. Civil (Environmental) Engineering, Texas A&M University, 1995
- B.S. Civil Engineering, Texas A&M University, 1994

Languages

- English, native speaker

Key Industry Sectors

- Mining
- Oil and Gas
- Power

Key Projects

Project Director and Environmental Lead for an Environmental, Social and Health Impact Assessment (ESHIA) and associated Environmental and Social Action Plan (ESAP) prepared in accordance with international best practice (EBRD and ADB) standards for the Ukhaa Khudag (UHG) Project, including a coal mine, coal-fired power generation facilities, a groundwater abstraction field and other supporting facilities in southern Mongolia. Project activities included extensive social and environmental baseline data gathering, air dispersion modeling and noise modeling, and support of stakeholder engagement and consultation activities. Additional project support activities included preparation of Railway Construction Ecological Best Practices and Resettlement Best Practices white papers, and completion of environmental and social action plan monitoring and evaluation.

Project Director and Environmental Lead for the proposed Hyperion Energy Center project, a proposed greenfield petroleum refinery and integrated power plant in South Dakota. Project activities included completion of an environmental critical issues analysis, preparation of a permitting strategy, completion of an ecological reconnaissance, wetland delineation, and cultural resources intensive survey, preparation for and participation in public open houses and public zoning board hearings, preparation of draft re-zoning language, completion of a socioeconomic baseline study and economic impact analysis, and preparation of a human health risk assessment regarding forecasted air emissions from the facility.

Project Manager for an Environmental Impact Assessment for the proposed Ras Tanura Refinery Expansion Project in the Kingdom of Saudi Arabia, including completion of extensive CALPUFF air dispersion modeling.

Project Manager for an Environmental Impact Assessment for the proposed Wasit Gas Plant Project in the Kingdom of Saudi Arabia, including completion of extensive CALPUFF air dispersion modeling.

Project Director for a Phase I HSEIA under ADNOC's Code of Practices for the Integrated Gas Development – Project Habshan Platforms located in the Umm Shaif Field offshore Abu Dhabi.

Project Director for air dispersion modeling conducted in support of the Saudi Kayan Petrochemical Complex development project in Jubail Industrial City, Saudi Arabia.

Project Director for preparation of the environmental component of a Public Utility Commission application for construction of a transmission line project from east Texas into the Houston area. Project involved completion of intensive environmental field surveys and preparation of an Environmental Assessment triggered from the project crossing Federal lands.

Project Director for provision of support to the regulatory approvals process for LNG Canada's proposed LNG export terminal in western British Columbia. Prepared Environmental Assessment (EA) summary documentation to aid in dissemination of EA findings and proposed mitigations to internal and external stakeholders and interested parties. Provided advice related to project design alternatives with respect to air quality regulatory ramifications. Assisted with GHG management strategy including support for lifecycle analysis and development of recommendations for use in influencing and managing emerging GHG regulations applicable to the BC LNG industry.

Project Director for environmental site assessment and licensing for the Golden Pass LNG Terminal and associated Golden Pass Pipeline system in East Texas and Northwest Louisiana. Activities included development of permitting and development strategies, preparation of Environmental Resource Reports to be submitted with separate Natural Gas Act Section 3(a) and Section 7(c) applications to FERC, and preparation of related Federal, State, and local environmental permit applications. Coordinated ancillary studies to support the application (e.g., traffic study, bird strike monitoring). Directed field activities in support of licensing, including extensive field wetland delineation and archaeological surveys.

Project Director for completion of a socio-economic baseline study for a series of Texas counties and Louisiana parishes along the U.S. Gulf Coast. The study involved collection of an extensive socio-economic data set and creation of a methodology to 'rate' a number of socio-economic aspects of each parish/county with respect to their development needs and the degree to which they are expected to support future oil and gas development growth in the region.

Project Director for development of environmental management plan, waste management plan, regulatory compliance plan, and environmental monitoring plan for the Golden Pass LNG regasification terminal and pipeline's transition from development/construction to operations. Led development of a detailed Compliance Register identifying all environmental, health and safety regulations applicable to terminal and pipeline operations, the basis for applicability, and the specific actionable requirements stemming from these regulations.

Project Director for an environmental feasibility study conducted for development of a liquefaction facility in the Caribbean Islands. Project involved rating and ranking of several candidate sites based on environmental and social impact criteria.

Project Director for an Environmental, Social and Health Impact Assessment (ESHIA) for the proposed Congo River Crossing Canyon Project offshore Angola.

Project Director for an Environmental and Social Impact Assessment for a 370km segment of a proposed crude oil pipeline in Colombia, including preparation of a gap analysis between local licensing requirements and the requirements that would apply under an international financing approach. Project included extensive primary data collection, identification of and socialization of planned Project details with stakeholder groups including protected communities, and completion of a topographic and geotechnical survey of the pipeline segment route.

Senior Technical Reviewer for social and health impact assessment for unconventional production operations across a >100,000 acre shale gas formation in the Eagle Ford formation.

Project Director for completion of three separate hazard studies conducted to assess the risk associated with operation of flares on gas production platforms offshore Equatorial Guinea.

Project Manager for completion of an Environmental and Social Due Diligence Assessment for the proposed 'farm-in' acquisition of unconventional natural gas production operations in Eastern Louisiana. The Project involved completion of a Risk Analysis transaction, and included interviews with the firm's management and other personnel at the firm's headquarters, as well as site visits to representative facilities summary of findings, and included an assessment of the priority of findings based on a risk categorization structured to inform decision making.

Project Director for development of environmental control design philosophy, oil and hazardous materials spill response philosophy, environmental management plan, environmental monitoring plan, waste management plan and regulatory compliance plan for a component of the Barzan gas development project offshore Qatar.

Project Director for preparation of a Waste Management Plan for oil and gas operations in the Western Desert of Egypt.

Project Director for environmental and regulatory framework assessment for the area of a proposed exploration and production effort offshore Barbados.

Senior Technical Reviewer for a desktop environmental, regulatory, and social review and ecological resource assessment for an exploration and production area of interest in Colombia.

Project Director for an Environmental Impact Assessment for a proposed offshore natural gas pipeline in Angola and for three separate Supplemental EIAs for offshore oil and gas developments offshore Angola.

Project Director for several Environmental Impact Assessments for proposed exploratory drilling projects offshore Angola. Project activities included completion of social baseline data gathering, oil spill modeling, cuttings discharge modeling, and regulatory licensing support.

Project Director for an Environmental Impact Assessment for proposed production platform expansions offshore Angola.

Project Director for a seismic exploration campaign offshore Angola.

Project Director for an air modeling study conducted for a proposed floating production, storage, and offloading facility offshore Angola. Modeling utilized the Offshore Coastal Dispersion Model to predict transport of air pollutant concentrations from offshore sources to onshore receptors.

Part of the senior technical advisory team for preparation of a preliminary Environmental and Social Impact Assessment (ESIA) for a major copper/gold mine in Alaska. Provided strategic direction relative to the ESIA approach and conducted technical reviews of project deliverables.

Project Director for development of an internal Environmental and Regulatory Management Plan detailing the division of environmental and regulatory responsibilities and interfaces between exploration, geo-operations, and drilling business units within a major oil and gas company.

Project Director for an environmental and social baseline and due diligence exercise conducted for a prospective farm-in of unconventional gas production operations in East Texas and Northwest Louisiana. Activities included assessment of potential environmental and social risks associated with increased production in the area.

Project Director for a production well re-entry, Environmental Assessment (NEPA), to support development of oil and gas resources on property managed by the National Park Service (Big Thicket National Preserve).

Project Director for a project supporting preparation of a Department of Energy (DOE) Environmental Assessment and associated State-level environmental review documentation for a major solar energy development in the Northeast U.S. Project involved completion of a viewshed analysis to assess visual impacts from construction of the project.

Project Director for a project involving planning, impact assessment, and licensing of a natural gas storage cavern project in East Texas. Activities included engineering and pipeline route analysis and preparation of Environmental Resource Reports for submittal to FERC under the Natural Gas Act.

Project Director for a socioeconomic baseline and impact assessment supporting a gold mining project in Kazakhstan.

Project Director for a project supporting sustainability reporting for a major wind energy development in accordance with Global Reporting Initiative (GRI G3) guidelines. Activities involved collection of necessary reporting information, preparation of an internal reporting handbook, and development of documentation demonstrating methodology utilized for reporting.

Environmental lead on a due diligence assessment for a major petroleum refinery in the U.S. Virgin Islands. Conducted a review of investigation, remediation, permitting requirements, and status of associated refinery activities.

Project Director for over 100 site screening studies for proposed wind power projects in the U.S., each including an assessment of biological and cultural resource characteristics and concerns, and development of a permitting matrix. For some sites, studies included coordination of assessments for aviation navigation and microwave communications obstructions.

Project Director for a wind power project permitting and impact assessment project in New York State. Project involved licensing through the New York State Public Service Commission and preparation of an EIS pursuant to the State Environmental Quality Review process. Project support activities included wetland delineation, cultural resource surveys, noise surveys, and visual impact simulations.

Project Director for a project involving a hazard assessment for two proposed natural gas storage caverns in the Southwestern U.S. Activities involved development of worst-case failure scenarios and analysis of the expected consequences of the failure.

Project Director for a project involving acquisition of drilling licenses and completion of environmental impact analyses associated with a proposed production well drilling and testing project in northern Brazil.

Jason Willey

Project Manager, Biological Resource Specialist



Mr. Willey has fifteen years experience in ecology and natural resource management with specific expertise in marine and estuarine ecology. Most of his ecological work has supported environmental impact assessments and permitting projects for industrial projects, particularly for oil and gas clients. He has assessed environmental impacts of onshore and offshore components of upstream and downstream developments. various oil and gas clients in the United States and Australia for Mr. Willey works mostly in the USA, having prepared numerous impact assessments to the US National Environmental Policy Act standards, but he has also applied international environmental impact assessment protocols to projects in Southeast Asia, South America, Australia, New Zealand, Greenland, and the Caribbean.

Fields of Competence

- Environmental and Social Impact Assessment
- Aquatic and estuarine ecology, including quantitative and qualitative fish community survey methods (EPA rapid bioassessment protocol), aquatic macroinvertebrate ecology, water quality sampling, and in-stream macrohabitat assessment
- Threatened and Endangered Species Consultations (NMFS and USFWS)
- Essential Fish Habitat (EFH) assessment
- Aerial photograph, landscape feature, and habitat interpretation
- Wetland delineation and functional assessment

Education

- B.S., Biology, University of Richmond, Richmond, VA, May 1997
- M.S., Environmental Science and Policy, Johns Hopkins University, MD, May 2007

Key Projects

Environmental Impact Assessment and Permitting Support, Exploration Activities, EEPGL (ExxonMobil). Project manager for a Strategic Environmental Assessment of exploration activities in the Stabroek Block, a deepwater exploration block offshore of Guyana. Was also responsible for delivering the associated management plans and various environmental approvals for associated activities including metocean and geophysical/geotechnical surveys. Assisted ExxonMobil staff with an audit of potential service providers in Guyana and Trinidad as part of the tender evaluation process for waste management services. Has worked closely with the local Exxon affiliate in Guyana to manage several regulatory and environmental management deliverables since the inception of EEPGL's involvement in Guyana in 2013.

ION Geoventures. Managing regulatory and environmental assessment processes in Guyana, Trinidad, and Suriname for ION's planned 2D GuyanaSPAN seismic survey in October 2013.

Environmental Impact Assessment and Planning, Woodside Energy Ltd. Provided general environmental impact assessment and planning services for several petroleum exploration and production facilities around Australia. Prepared EPBC Act (Australia) referrals and environmental management plans for offshore exploration projects in the Torosa 3 gas field offshore of Western Australia. Coordinated oil spill contingency planning and sediment transport modeling to support EIA process for another offshore project in a potentially sensitive marine environment on Scott Reef (Western Australia).

Impact Assessment and Regulatory Compliance , Bass Strait Seismic Exploration, Total. Prepared EPBC Act (Australia) referrals and environmental management plans for seismic exploration in the Bass Strait, north of Tasmanaia. Assessed the potential for acoustic impacts on marine mammals and for disturbance of seabirds and fish. Determined that the project was unlikely to cause significant impacts to marine resources and that no further environmental

assessment was necessary in order to comply with the applicable Australian regulations.

Environmental Impact Assessment, Great South Basin, ExxonMobil. Managed an EIA for a marine seismic survey in the Great South Basin off the coast of New Zealand's South Island. Key issues include potential impacts on endangered marine mammals, marine fisheries, and seabirds, as well as ecosystem-level effects on sensitive habitats including the Sub-Antarctic island archipelago. Project required collating results of recent and ongoing scientific research on the effects of vessel noise, seismic noise sources, and near- to mid-field interactions with vessels on rare, threatened, and endangered marine mammals. Impact assessment process included consultation with several key government stakeholders, and resulted in finding of no significant impacts and favorable feedback from NZ regulators.

Confidential Client. Provided on-call environmental support to an Australian engineering firm bidding on the design and construction phase of a large, confidential oil and gas production project in Western Australia. Project would involve routing four gas trunklines from offshore fields through sensitive near-shore coral reef and under sea turtle nesting beaches. Recommended several key measures that could be incorporated into the project approach and design that could maximize efficiency while avoiding or minimizing environmental impacts.

Environmental Resource Report and EIS Review, Crown Landing (BP). Fisheries and aquatic biology lead on the EIS and Federal and state permit efforts for a LNG terminal and associated pipeline connections on the Delaware River in southern New Jersey. Led consultations with NMFS regarding potential impacts of the project on marine mammals, particularly the critically endangered North Atlantic right whale and the Federally listed Atlantic and shortnose sturgeons (*Acipenser oxyrhynchus* and *A. brevirostrum*).

Environmental Impact Statement, Excelerate Energy Northeast Gateway. Lead marine biologist on an EIS for a proposed offshore natural gas offloading facility in Massachusetts waters. Key biological issues included potential effects on marine mammals, loss of ichthyoplankton to ballast intakes, and effects on shellfisheries and groundfisheries. Integrated a third-party entrainment modeling and equivalent adults assessment into the EIS for the project. Developed a life stage-specific assessment of the risks posed to vulnerable life stages of over 15 species of crustaceans, fish, and marine mammals from various project related activities based on life history parameters. Particular emphasis was placed on balancing safety concerns with minimizing impacts on key resources such as Atlantic herring (*Clupea harengus*) and American lobster (*Homarus americanus*) with seasonally-dependent sensitivities to specific project-related activities.

Environmental Resource Report and EIS Review, ExxonMobil Golden Pass. Authored the FERC aquatic resources resource report for a proposed natural gas terminal on Sabine Pass in eastern Texas. Performed a preliminary assessment of potential impacts on mud, sand, and shell-hash intertidal and sub-tidal littoral habitats on the Sabine River. Evaluated potential losses of planktonic finfish and shrimp larvae from entrainment in ballast water intakes and open-rack vaporizers. Consulted with NMFS and USFWS concerning potential effects on listed species, particularly sea turtles and Gulf sturgeon (*A. desotoi*).

Confidential Client. Lead marine biologist on the Environmental and Social Impact Assessment (ESIA) for a resort planned on New Providence Island, The Bahamas. Resources of concern included listed marine reptiles, corals, seagrasses, and commercially and recreationally important fish and invertebrates. Particular emphasis was placed on the potential effects of dredging an access channel on nearshore biological communities such as patch reef, and on water quality within the proposed marina basin. Conducted ministerial-level consultations with natural resource agencies to ensure governmental support for the ESIA.

Feasibility Assessment, Aquatic Biological Survey, and Training, Suralco, Suriname. Lead aquatic ecologist on a feasibility assessment for a bauxite mine at a greenfield site in central Suriname. Supervising a multi-year aquatic survey of high altitude streams on the Nassau plateau, a laterite capped plateau in the undeveloped interior. Responsible for training Surinamese HSE staff in low-impact ecological sampling and monitoring protocols. Replaced rotenone-based collection protocols with a combination of modern electroshocking and traditional methods.

Trained local field teams, which include scientists and native assistants in new survey protocols. ERM's low-impact survey methodologies have been highly effective; work in 2009 documented seven rare species of loricariid catfish on the plateau, including one species that is new to science.

Matthew W. Erbe, P.G.

Project Controls Lead



Matt Erbe is a Principal Consultant within Environmental Resources Management, a global provider of environmental, health, safety, risk and social consulting services. He assists clients with implementing multi-disciplinary environmental projects across multiple client sectors and industries. Matt has a Master of Science in Hydrogeology from Syracuse University.

He has 19 years of comprehensive experience managing contaminated site investigations and remediation projects, environmental and social baseline studies, and impact assessments with project revenues exceeding of $26MM. He is recognized for his performance management capabilities to consistently meet and exceed client and stakeholder expectations and project deadlines, subcontractor management, budgets and specifications for ERM's largest projects.

Project work has included environmental reviews for power plant modifications, hydrogeological assessments to support coal combustion by-product (CCB) beneficial use assessments, CCB leachate impact analysis and fate & transport modeling, corrective measures evaluations for ground water and surface water impacts related to fly ash management and disposal, use of CCB grouts at underground abandoned coal mines for water quality stabilization, and ground water supply and impact analysis for proposed power plant withdrawals. He provides technical consulting for the characterization of impacts from chemical and manufactured gas plants, evaluation of corrective measures for soil and groundwater impacts, groundwater flow and contaminant transport modeling; coal combustion product beneficial use and leachate impact analysis; and groundwater resource and supply analysis.

Education & Training

- MS, Hydrogeology, Syracuse University, 1997
- BS, Natural Sciences - Geology, Towson State University, 1995
- Fundamentals of Ground Water Geochemistry, Geochemical Modeling of Aqueous Systems, Advanced Ground Water Modeling Workshop
- 40-Hour OSHA Health and Safety Training for Hazardous Material Operations and Emergency Response, Current on Annual 8-Hour Update

Professional Affiliations & Registrations

- Professional Geologist, State of Tennessee

Publications

- D. Aeiker, M. Erbe and L. Rafalko, V. Gardner and R. Cleary. "Mapping Preferential Groundwater Flow Pathways for Contaminant Migration within a Karst Aquifer System", **paper presented** at the Fifth International Symposium and Exhibition on the Redevelopment of Manufactured Gas Plant Sites, Destin, FL, 2014.
- Erbe, M., and J. Ryan, "Use of In-situ Bioventing to Mitigate Diesel Range Petroleum Hydrocarbons in Saprolite", **paper presented** at the Battelle Ninth International In-Situ and On-Site Bioremediation Symposium, Baltimore, MD, 2007.
- Erbe, M., "Evaluation of Water Quality Conditions Associated with the Use of Coal Combustion Products for Highway Embankments", **talk given at** the 2005 EPA Region III By-Products Symposium, Philadelphia, PA, 2005.
- Erbe, M., R. Keating, C. Travers, L. Norman, W. Cutler, and T. Martin, "Assessing the Role of Structural Elements in Aquifer Hydraulics and Plume Management", **talk and paper presented at** U.S. EPA/NGWA Fractured Rock Conference Proceedings, Portland, Maine, 2004.
- Erbe, M.W. and D.I. Siegel, "Using Ternary Diagrams to Characterize the Natural Attenuation of Chlorinated Ethenes in Ground Water", **published in** *Journal of Environmental Hydrology*, Vol. 9. March 2001.

Key Projects

Impact Assessment

Nicaragua Grand Canal. Project Manager for $26.5MM contract to complete an environmental and social impact assessment for the proposed 275 km interoceanic shipping canal in Nicaragua. Accountable for overseeing the physical, biological, cultural and social studies under an extremely challenging schedule utilizing more than 200 ERM engineers and scientists from Canada, China, Colombia, Mexico, Panama, Peru, and the US Northern, Southern and Western divisions. The work is also being conducted in partnership with international NGOs and Nicaraguan experts.

Hangar 21, San Juan, Puerto Rico. LANTDIV. Managed the environmental baseline study of a former a WW II era military base. Oversaw investigations of groundwater impacts relating to the historic fuel distribution system from a 1991 release of gasoline at an upgradient and off-site gasoline station. As a result, the Puerto Rico EQB has since identified additional responsible parties to the contamination. Current remediation includes AST removals, ground water monitoring and asbestos abatement of the hangar.

Municipal Landfill Evaluations

68th Street Landfill Superfund Site, Rosedale, Maryland. Remedial Investigation Task Manager overseeing the remedial investigation of a 270-acre area containing multiple former landfills and five USEPA-designated "source areas," as well as sensitive environmental features such as streams, wetlands, and floodplains. The investigation approach incorporates human health and ecological risk assessments as well as the future redevelopment of areas of site.

Millersville Landfill, Maryland. Anne Arundel County DPW. Project Manager and Hydrogeologist overseeing the development of the Assessment of Corrective Measures for impacts to ground water, replacement of residential supply wells, hydrogeologic investigation of seeps to support landfill cells design, and risk assessments.

Confidential Project, Maryland. Managed proposed landfill information review and fatal flaw analysis. Support included review of County's WMP, zoning requirements, environmental resources, design criteria, and estimation of landfill capacity.

Methane Gas Investigation, St. Mary's County, Maryland. Managed investigation of a methane gas plume migrating beneath a proposed housing development.

Corrective Measures

MFRI, Prince Georges County, Maryland. University of Maryland. Completed evaluation of corrective measures for impacts to ground water resulting from the release of gasoline from an UST. EPA Region III approved the use of monitored natural attenuation as the remedial alternative for cleanup of the non-potable aquifer.

CREO Manufacturing Plan, Middleway, West Virginia. Kodak. Evaluating remedial technologies to reduce source concentrations of trichloroethylene in the ground water within a karst aquifer system. Leading technologies being evaluated include electric resistance and radio frequency heating, bio augmentation, and dual-phase extraction with vapor extraction.

Anne Arundel County, Maryland. Alliant Techsystems. Completed a remedial alternatives analysis of measures to eliminate the potential for off-site migration of ground water plume and reduce the residual contaminant mass to reduce client's long-term liabilities and financial obligations associated with the site.

Sykesville Oil Site, Maryland. Managed the investigation and remediation of a 10,000-gallon diesel fuel spill that entered the saprolite and bedrock aquifers and discharged to surface water. Prepared the design and installation of an in-situ bioventing remedy to reduce hydrocarbon concentrations to a risk tolerable level. Work is being completed through a Consent Order with the EPA Region III.

Manufactured Gas Plant

Site Investigation, Hagerstown, Maryland. NiSource. Project Manager for the site characterization and ISCO pilot test to remediate residuals (BTEX and PAHs) at a former manufactured gas plant. Investigation activities included electrical resistivity survey to identify bedrock basins and ridges, direct-push and split-spoon sampling, soil gas sampling, overburden and bedrock well installation, implementation of a pilot test using sodium persulfate and calcium peroxide to reduce residual contamination.

Phase II ESA, Binghamton, New York. NYSEG. Geologist responsible for remedial investigation of ground water contaminated by coal tar at a former manufactured gas. Project included geologic site characterization and NAPL delineation, well installation, ground water sampling, aquifer testing, client and regulatory agency communication, and health and safety monitoring.

Groundwater Flow Model, Frankfort Indiana. NiSource. Project Manager for an investigation of the potential impacts to ground water related to a former MGP facility. Used analytical element models to simulate water table aquifer and capture zone for a City production well adjacent to the facility. Modeling indicated that the capture zone in the confined aquifer extends beneath the former MGP facility; however, ground water in the water table aquifer flows away from the City wells and is not hydraulically connected to the deeper aquifer.

Hydrogeologic Assessment

Fallstaff Property, Harford County, Maryland. Managed hydrogeologic investigation for ground water appropriations permit. The 23 lot parcel under development is adjacent to a fuel terminal which released gasoline to the saprolite and bedrock aquifers. Project included the use of an analytical element model to simulate future pumping conditions at the development and assess the migration and fate of BTEX and MTBE in ground water.

Groundwater Investigation, FMC Avtex Fibers Superfund Site in Front Royal, Virginia. Project Manager and Senior Hydrogeologist for a deep bedrock aquifer (DBA) investigation and closure of several former basins at the site. The project required installation of multiple deep groundwater monitoring wells using conventional and multi-level systems, ambient ground water and river level monitoring, conduct of single and multi-well pumping tests in fractured shale, and preparation of a dense aqueous phase liquid (DAPL) flow and transport model to evaluate the role of structural geologic elements in plume migration and aquifer hydraulics.

Site Characterizations, Parkersburg and Nitro, West Virginia. FMC Corporation. Managed the evaluation of environmental impacts at two former rayon manufacturing facilities under the West Virginia Voluntary Remediation Program. Primary contaminants included carbon disulfide and PAHs.

Gardiner Road, Charles County, Marylsn. Chaney Enterprises. Managed an assessment of hydraulic impacts relating to the proposed mineral extraction (i.e., sand and gravel mine). Assessment included a review of water quantity and quality impacts to first order streams and wetlands.

Piney Branch Bog, Charles County, Maryland. PPRP. Managed the hydrogeologic evaluation of the site to characterize the pre-development hydrology of the gravel bog and establish baseline hydrologic conditions prior to development in the region.

FIFRA Investigations. Carried out hydrogeologic investigations of agricultural chemicals under the EPA's Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Responsibilities included: supervision of drilling, hydrogeologic characterization, vadose zone hydraulic conductivity analyses, installation of shallow soil lysimeters, test and control substances application rate verification, and sampling soil, ground water, soil water, and surface water for residue analysis.

CCP Use and Disposition

BBSS Mine Site, Crofton, Maryland. PPRP. Principal Investigator for the evaluation of impacts to groundwater quality resulting from the use of fly ash to reclaim a sand and gravel mine. Used statistical analysis of metals concentration data collected from monitoring wells and residential water supply wells both adjacent to the mine site and the surrounding communities. The investigation concluded that although natural soil conditions were contributing to elevated metal concentrations in the ground water, mining and reclamation activities had contributed to the deterioration of the shallow potable aquifer system.

Faulkner Fly Ash Storage Site, Charles County, Maryland. PPRP. Principal Investigator for evaluation of long-term surface water quality and the effectiveness of the wetland treatment systems to mitigate impacts to ground water from the ash fill. The studies provide stakeholders a basis for determining future requirements for monitoring and evaluating the effectiveness of preventive measures for sulfate reduction at existing and future CCP storage facilities and upgrading the treatment systems.

Kris Hiatt

Document Production Manager



Kris Hiatt is a document manager and technical editor based in Rolling Meadows, Illinois. She has more than 15 years of professional experience in writing, technical editing, document management and development, formatting, layout, and knowledge management. Ms. Hiatt has managed the editing and production of high-profile, complex, multi-volume environmental impact statements (EISs) and environmental, social, and impact assessments (ESIAs). In addition, she has extensive experience preparing proposals, presentations, and other marketing materials.

Ms. Hiatt has developed review processes, templates, style guides, consistency guides, editing checklists, and review processes for the Keystone XL draft and final Supplemental EIS, the Canal de Nicaragua ESIA, the draft and final FirstNet Programmatic EIS, and the San Juan Mine Deep Lease Extension EIS. These projects have fine-tuned her writing, editing, and organizational skills, allowing her to successfully manage document production projects of varying size, budget, and timeline.

Many of the documents managed by Ms. Hiatt were produced in accordance with the National Environmental Policy Act (NEPA) and Section 508 of the U.S. Rehabilitation Act. She is also experienced at responding to public and agency comments, as well as creating and maintaining administrative records.

Fields of Competence

- Document management
- Technical and copy editing
- Consistency and style guides
- Editing and review workflows
- Template development
- NEPA requirements
- Section 508 compliance
- Formatting
- Marketing and proposals

Education

- B.A., English, Indiana University, 1990

Key Projects

San Juan Mine Deep Lease Extension Environmental Impact Statement, Office of Surface Mining Reclamation and Enforcement, 2017-Ongoing
Technical editor and production manager on a multi-volume EIS analyzing the impacts of the proposed extension of an existing underground coal mine. Developed the EIS template and production procedures in compliance with Section 508 and the project style guide. Under the direction of the lead consultant, providing edits and consistency reviews to present one voice despite multiple authors. The draft report is in progress.

FirstNet Supplemental Programmatic Environmental Impact Statement, U.S. Department of Commerce, 2017-Ongoing
Document and production manager and lead editor on a supplemental programmatic EIS for a nationwide wireless broadband network dedicated to public safety. This report is in progress. Providing technical and copy edits, consistency reviews, and formatting. Developed procedures for Section 508 compliance.

Upper Trishuli Hydroelectric Power Project Non-Technical Updated Environmental and Social Assessment Summary Report, International Finance Corporation, 2017
Document and production manager and lead editor for an updated non-technical ESIA for the Upper Trishuli 1 Hydropower Project in Nepal. Providing technical and copy edits, consistency reviews, and formatting on all sections of the approximately 500-page report.

FirstNet Programmatic Environmental Impact Statement, U.S. Department of Commerce, 2015-2017
Document and production manager and lead editor on a multi-volume Programmatic EIS for a nationwide wireless broadband network dedicated to public safety. Developed a template, style and consistency guide, and editing procedures. Provided technical and copy edits, consistency reviews, and formatting on all sections of the report. Edited text to be concise and consistent with the style guide and to present one voice despite multiple authors. Developed procedures for and managed Section 508 compliance. Worked closely with the project management team, client, editors, and subject matter experts to coordinate and develop the eight-volume, 4,700-page draft report.

Canal de Nicaragua Environmental and Social Impact Assessment, HKND Group, 2014-2015
Document and production manager and lead editor for the Canal de Nicaragua ESIA. This major infrastructure project, if built, will be one of the largest civil works projects ever undertaken. This complex report was delivered in both Spanish (hard copy and electronic copy) and English (electronic copy only). The ESIA was approximately 11,000 pages in 14 volumes. Developed and maintained report template, consistency guide, report schedule, tracking sheets, and editing checklists. Managed flow of report sections through authors, senior reviewers, editors, and translators. Edited text to be concise and consistent with the style guide and to present one voice despite multiple authors. Worked closely with an outside translation company and internal translation reviewers.

Keystone XL Pipeline Supplemental Environmental Impact Statement, U.S. Department of State, 2012-2014
Document and production manager and lead editor on both the draft and final Supplemental EIS. Developed and maintained consistency guides, report template, tracking sheets, and editing checklists. Assembled and managed editing and production team. Provided technical and copy edits, consistency reviews, and formatting on all sections of the report. Worked closely with the project management team, editors, and subject matter experts to coordinate and develop both the 11-volume, 7,000-page final report and the 4-volume draft report. After release of the final Supplemental EIS, helped theme and code more than 2.5 million public comments.

Noam Raffel

Senior GIS Analyst



Noam is a GIS specialist for the Impact Assessment team in the Washington DC office.

Noam has 5 years of experience in the field of GIS in various different sectors. In the public sector, Noam managed geodatabases for the City of Worcester GIS Department. In the private sector Noam interned for the GIS consulting company iMapdata helping manage fast response online maps, and digitizing and updating databases for the media company New England Fiber. He also worked for the GIS software company Idrisi. Noam also interned at the nonprofit organization Groundwork London creating and managing a crime database for the whole of England and developed methods for managing surveying related GIS databases.

Noam's work at ERM is focused on helping the Impact Assessment team collect, manage, and analyze data from various projects. He focuses on organizing geospatial data for ESIA reports on a variety of large international and domestic projects.

Fields of Competence

- Esri ArcGIS
- Clark Labs IDRISI
- CrimeStatIII
- Windows VBA
- Python coding language

Key Industry Sectors

- Cultural Heritage
- Social
- Urban Planning

Education

- Master of Arts in Geographic Information Systems, Clark University, Worcester, MA, 2014
- Bachelor of the Arts in Geography, Clark University, Worcester, MA, 2013

Languages

- English, native speaker
- Hebrew, semi fluent

Key Projects

Nicaragua Canal Project (HKND)
ERM was tasked to assess the impact of a potential canal through Nicaragua. Noam was responsible for managing the data of the archeological and built heritage data that may be potentially affected by the canal. He assisted in the development of a sensitivity model to assess high risk location of archeology. Noam modeled and mapped the cumulative impact assessment of the project.

Guinea Alumina Corporation, Mine, Guinea
The Guinea Alumina Corporation tasked ERM to find potential cultural heritage sites in the location of a potential mine in Guinea. Noam created sensitivity model from LIDAR imagery to assess where potential sites are located. The model was tested against to known sites and proved to be highly accurate.

Confidential Client, Manufacturing Plant
A Confidential Client plan on building a manufacturing plant in rural West Virginia. Noam was responsible for reviewing LIDAR data and satellite imagery to inspect for potential cultural heritage finds. He is also tasked for on the ground data collection to assist with both archeology and built heritage.

Shell Appalachia, Pennsylvania

Noam has been tasked to create and manage a database of all cultural heritage finds in Pennsylvania. The sites are managed in a geographical database which has been manipulated to display areas of higher sensitivity.

Ascent, Unconventional Gas Project, West Virginia
Noam was responsible for developing a method for surveying and collecting archeological data from a potential unconventional gas site in West Virginia. Noam developed a mapping survey using Arcpad to improve the efficiency of archeological monitoring the site.

City of Worcester, GIS Department, Massachusetts
In 2013 Noam interned for the City of Worcester, Massachusetts, GIS department organizing GIS databases used by different departments to manage city resources. His main tasks was the development of a SDE database for the roads file that would be used by all city departments for online maps.

Idrisi Clark Labs, Worcester Massachusetts
Noam worked for the GIS software company Clarklabs testing for bugs in the software Idrisi and the Earth Change Modeler plugin for ArcGIS 10.1.

Karin K. Nunan

Socioeconomic and Stakeholder Engagement Lead;
Ecosystems Services Specialist



Ms. Karin Nunan is a Principal Consultant within ERM based in Washington DC and coordinating the Human Rights working group for North America. She has over 20 years of experience in the fields of human rights, social performance, stakeholder engagement, diplomacy and government affairs. Over the past several years, Karin has been providing extractives clients with project management and technical support on social performance, with a focus on human rights impact assessments and training; social impact assessment and auditing; policy development and management planning; stakeholder engagement; CSR programs; OHS and labor and working conditions audits; and overall E&S lender compliance for international financing, including IFC PS, World Bank EHS, EP III, FMO, MCC, JBIC, USAID, OPIC, ADB, AfDB, and EBRD. In this capacity, she has acted as both the lender and client representative for E&S due diligence of project financing.

Prior to consulting, Karin was in the oil and gas sector where she spent several years in the social performance departments within the HSEE departments of two major US oil and gas companies working on development and production projects for social issues in Europe and the Middle East. During this time she developed and implemented social performance policies, standards and audit procedures; created KPIs; and ensured projects complied with all social corporate guidelines and international best practice. She worked closely with the legal, procurement, human resources, and public affairs functions on issues pertaining to human rights implementation and compliance.

Fields of Competence

- Human Rights
- Social Performance
- Environmental and Social Lender Due Diligence
- Environmental and Social Impact Assessments
- Community Health, Safety and Security
- Labor and Working Conditions
- Community Investment Planning
- Stakeholder Engagement

Key Industry Sectors

- Oil and Gas
- Mining

Education

- MSc, International Relations and Conflict Resolution, AMU, 2012
- MBA, International Business, UMass, 2000
- BSc, Civil Engineering, Norwich University, 1994

Professional Affiliations & Registrations

- Society of Petroleum Engineers
- Chevron Qualified Environmental Facilitator (QEF)
- US Institute for Peace Certification in Conflict Analysis, 2010
- US Government Human Rights Officer Training and Trafficking in Persons training 2002 - 2007

Languages

- English, native speaker
- Russian, intermediate
- French, Arabic, beginner

Key Recent Projects

Human Rights and Supply Chain Due Diligence, Israel, Confidential Client

Led social impact assessment due diligence for all offshore and onshore existing and planned operations. Conducted gap assessment of oil and gas company's principles and policies on social issues including labor management, supply chain and human rights against international standards. Made recommendations to align policies more closely with international standards and reduce non-technical risks of operations.

Stakeholder Engagement and Social and Health Impact Assessment, Nicaragua, HKND

Led senior review and preparation of the social impact assessment for a major infrastructure development crossing the country of Nicaragua. Assessed a suite of social and health impacts related to labor, human rights, influx, conflict, health, natural resource, livelihoods and project security linked to development and operations. Developed management plans pertaining to influx, stakeholder engagement, and indigenous people.

South Stream Pipeline Project, Russia, Bulgaria, Turkey, SSTTBV

Technical editor for three lender ESHIAs and three national ESIAs for all three countries. Worked alongside the South Stream ESIA teams to lead the issues-based Human Rights Due Diligence and Impact Assessment process for Bulgaria, Russia and Turkey. Educated the client's key departments, including HSE, Procurement, HR and Security, on the importance of adhering to international Human Rights standards as outlined by ILO, WB, IFC and other IOs. Developed Project-wide standards and a Human Rights tool kit and due diligence method which can be applied on a regular basis to ensure constant improvement and continuous adherence.

Masela Offshore LNG Facility, Indonesia, INPEX

Provided social performance expertise to an ESHIA submission for an offshore LNG facility in Indonesia being developed by an O&G major. Provided input into the feasibility study, scoping report, ESMP framework, health impact due diligence, human rights due diligence and social impact baseline. Developed human rights and supply chain auditing procedures.

Oil Refinery Expansion, Venezuela, PDVSA

Responsible for conducting E&S due diligence focused on Social Performance for the expansion to an existing oil refinery in Venezuela with significant social challenges. Project included ESIA due diligence, SIA management plan, Human Rights Impact Assessment and management recommendations, Human Rights due diligence workshop development and supply chain audits.

Offshore LNG Facility, Louisiana

Provided social consulting for a major oil and gas client looking to build an offshore LNG facility with associated facilities onshore. Managed the E&S Due Diligence process. Despite US FERC approval, conducted analysis to ensure the project met its Lender financing requirements – including IFC, WB EHS, JBIC, and EP.

LNG Import Project, Benin, UK-based gas company

Managed a project to provide support for the development of company and project E&S standards, policies, plans, and procedures to meet Lenders review expectations and allow for the company to receive fast tracked Lenders approval for Projects. Responsible for managing the creation of Corporate Social Responsibility policies (including human rights); Social Performance KPIs; ESAP and ESMP to meet IFC standards.

Oil Export Feasibility Study, E. Africa, O&G Major

Provided the social expertise for expertise to an oil and gas major investigating potential locations along the Tanzania and Kenyan coastline for an oil export terminal and SPM. This involved identifying significant positive and negative social constraints along the coastlines and likely mitigation measures which will ultimately contribute to the ESIA.

Subsea Systems Plant, Angola, BP

Conducted a social risk assessment and socioeconomic expertise as part of the official submission for a Subsea Systems Plant located off of the coast of Angola. Provided input into the Social Impact Baseline and Assessment chapters and conducted technical editing and peer review for the entire submission.

Previous Related Experience

Socioeconomics Manager, ExxonMobil Iraq
Working under the Safety, Health and Environment Manager, created procedures and processes for social performance, socioeconomic investment, human rights impact assessments, grievance resolution, community engagement, and land management related to a $4b operation in Southern Iraq. Also managed the socioeconomic portion of the ESHIA submission, as well as oversaw site-specific stakeholder engagement, corporate social responsibility planning and strategic community investment. Developed and provided human rights training for various functions within the development and production functions.

Socioeconomics Advisor, ExxonMobil Development Company
Developed corporate guidelines and frameworks for global social performance, and participated in development of human rights monitoring plans, CSR frameworks, grievance management mechanisms, gender equality, stakeholder engagement review and ESAPs for development projects, including those with significant stakeholder opposition.

Regional Analyst, Chevron Middle East/North Africa
Assisted in creation of stakeholder engagement mapping, planning, and interaction for various Chevron Middle East projects in the development phase. Conducted initial Human Rights due diligence assessments and identified potential socioeconomic and community investment projects, including health, education and job training/placement programs with a focus on disenfranchised groups. Worked on internal SIA and social management plans.

Technical Manager for USAID programs, Chemonics, Middle East
As technical manager for MENA projects, assisted with design of project scopes for various development initiatives funded by USAID related to community engagement and capacity building of community action groups, local governments, and civil society. Focused on integrating gender and human rights into project scopes and implementation.

Voluntary Principles on Security and Human Rights policy development, extractives sector
As a senior manager for a global risk company, provided social risk planning, with a focus on the development of VPSHR corporate standards and policies for several major mining companies headquartered in the US and Europe with operations in Africa and Latin America. Developed management guidelines for regional operations.

Social Development Advisor, Confidential
As part of a non-profit Board membership, worked on behalf of several O&G companies to prepare tactical, ground-level community investment plans in the WASH, health and education sectors in Vietnam, Thailand, Tanzania, Kenya, Zambia, Ghana, and Sierra Leone. Work included stakeholder analysis and mapping, project benchmarking and feasibility, community needs assessments, stakeholder engagement, and project management of smaller corporate strategic investments conducted as part of larger social risk mitigation programs. This included managing a dam and watershed project in northern Kenya, health and environmental surveys in southern Sudan, sanitation and hygiene programs throughout schools and refugee camps in Sierra Leone, and clean drinking water initiatives and job creation programs in urban communities throughout East Africa.

Political Officer, US Embassy, Baghdad, Iraq
Prepared country-specific input into the annual Human Rights Report. Developed professional relationships with Iraqi political and religious leaders to promote U.S. policy objectives; reported to senior U.S. policymakers on the changing political and security climate; spearheaded counterinsurgency and counterterrorism initiatives in coordination with USAID and local NGOs.

Political Officer, U.S. Embassy, Almaty, Kazakhstan
As Human rights officer, prepared country-specific input into the annual Human Rights Report, which included working with civil society and local NGOs to document and investigate where possible Human Rights abuses; assisted with supervision of joint DoS and USAID projects in remote areas; reported to senior U.S. policymakers on the political and economic climate; monitored Central Asia, China, and Russia's regional partnerships.

Energy and Policy Officer, US Government
Based in Washington, D.C. and in Baghdad, Iraq, acted as Liaison to the U.S. Department of Energy; focused on analyzing international O&G policy implications, primarily in the Middle East, Caspian region, and Africa; provided regional assessments on energy security and geopolitical machinations; responsible for coordinating O&G sector analysis across various U.S. Government entities.

International Airport Affairs Manager, American Airlines/United Airlines
Lobbied domestic and international governments, political leaders, airport authorities, airlines and businesses to promote corporate expansion programs and strategic planning inititiatives; managed all legal aspects of corporate properties; responsible for design, construction, and ESIA new build and expansion projects in 30 major international cities in Asia and Europe; managed teams of designers, engineers, contractors and administrative staff globally.

Julia L. Tims

Biological Environment Lead, Avian and Terrestrial Wildlife Specialist



Ms. Tims is a professional ornithologist with twenty five years of experience specializing in terrestrial biodiversity and technical leadership for international Environmental and Social Impact Assessment (ESIA) projects around the world, primarily within the energy, mining, and infrastructure sectors. Ms. Tims has extensive experience in ESIA best practice and international standards, including IFC Performance Standards, IDB Safeguard Policies, Equator Principals, and other lender standards. Ms. Tims has particular expertise in terrestrial biodiversity baseline study design and execution, impact assessment, and designing management programs to minimize impacts or improve biodiversity values. Ms. Tims regularly provides technical biodiversity expertise involving protected areas and leads consultations with NGOs and other stakeholders regarding sensitive biodiversity issues.

Fields of Competence

- Environmental due diligence
- Environmental impact assessment
- Terrestrial biodiversity baseline study design and execution
- Biodiversity management, and monitoring
- International standards, including Equator Principles, IFC Performance Standards, and others
- Application of the mitigation hierarchy
- Biodiversity offsets
- Ecosystem services assessment
- Project permitting and documentation
- Endangered Species Act Section 7 Consultation
- Peer review/expert support
- Project planning/design to address ecological issues
- Wetland delineation and permitting
- Stakeholder engagement
- Alternatives analysis
- Cumulative impact assessment

Professional Affiliations

- American Ornithologist's Union
- The Wildlife Society
- Waterbird Society
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Key Industry Sectors

- Energy, particularly renewables
- Oil and gas development
- Infrastructure (transportation and pipelines)
- Agriculture
- Government (National and local)

Credentials

- M.S., Natural Resources Management/Ecology, Cornell University, 1999, With Distinction
- B.S., Entomology and Applied Ecology/Wildlife Conservation, University of Delaware, 1990
- Habitat Evaluation Procedures (HEP), U.S. Fish and Wildlife Service

Select Experience

Environmental and Social Impact Assessment, Nicaragua Canal Project, Nicaragua. Led the biodiversity component of the ESIA for the world's largest infrastructure project, the proposed Nicaragua Canal. Developed specialist team of over 100 Nicaraguan and international experts to conduct marine, terrestrial, and freshwater biodiversity studies across the country and led wet and dry season field surveys. Led the data analysis and terrestrial biodiversity impact assessment and prepared detailed biodiversity and protected areas management plans and offsetting proposals and developed the environmental and biodiversity components of the ESMS. Key issues included loss of primary rainforest, impacts to sea turtles, impacts to over 80 rare species, habitat fragmentation, impacts to protected areas and the Mesoamerican Biological Corridor, and impacts to critical habitat. Led the Ramsar consultation regarding impacts to the San Miguelito Wetland Ramsar site, including a site visit with Ramsar Headquarters staff and development of the mitigation and offset proposal for submittal to Ramsar.

Environmental and Social Impact Assessment, Offshore Oil Exploration Project, Guyana. Led the avian component of the ESIA for an offshore oil exploration project in Guyana. Conducted a baseline assessment focusing on seabirds and waterbirds and assessed the potential impacts of the proposed project, including unplanned events such as oil spills, on bird populations in the Caribbean region, including rare species.

Crown Landing Liquefied Natural Gas Environmental Studies and Permitting. Logan Township, NJ. Technical lead for endangered species and terrestrial ecological issues associated with a proposed liquefied natural gas (LNG) import terminal located on the Delaware River in New Jersey. Conducted terrestrial investigations at the site including wetland delineation, vegetation community characterization, wildlife habitat assessment, and threatened and endangered species investigations. Prepared Federal Energy Regulatory Commission (FERC) resource reports and worked closely with client to address ecological issues associated with the project and provided guidance for potential avoidance and mitigation measures to offset potential impacts of the project. Primary ecological issues with the project included impacts to wetlands, bald eagles, and other listed species. Addressed ecological issues with the regulatory agencies and prepared state and federal permit applications for the project.

Biological Assessment for Texas LNG, Brownsville, TX. Prepared the Biological Assessment pursuant to the Endangered Species Act for FERC to assess the potential impacts of the proposed Texas LNG project on 16 federally listed species. The assessment covered marine and terrestrial species, with particular emphasis on wintering shorebirds that concentrate in coastal Texas during winter, northern Aplomado falcon, ocelot, and gulf coast jaguarundi. The project was precedent setting in that is was one of the first in Texas to consider compensatory mitigation (i.e., offset or conservation bank) for wetlands and listed species (red knot, piping plover, ocelot, and jaguarondi) in one integrated offset/conservation bank. Consultation with USFWS and COE regarding mitigation requirements and offsetting options is ongoing.

Environmental Impact Assessment for Golden Pass LNG, Sabine Pass, TX. Technical lead for ecological issues associated with a LNG import terminal located along the Port Arthur Ship Channel in Jefferson County, Texas. Assessed the ecological impacts of the proposed project on tidal and freshwater wetlands, coastal plain habitats, migratory birds, endangered species, and habitat connectivity. Prepared FERC Resource Reports detailing existing conditions at the site and the potential effects of the project on these resources. Significant issues included large-scale impacts to freshwater and tidal wetlands and the removal and disturbance of critical migratory bird stopover habitat.

Environmental Impact Assessment for Camelia Bay LNG, Mobile, AL. Technical lead for ecological issues on a feasibility assessment for development of a LNG import terminal at a former Navy facility located on Mobile Bay, AL. Conducted wetland and terrestrial habitat investigations and identified environmental constraints to development at the site. Primary issues at the site involved impacts to a large, ecologically significant wetland located adjacent to Mobile Bay that provided breeding habitat for colonial waterbirds and significant nursery habitat for fish.

Environmental and Social Feasibility Study of Proposed Industrial Sites, Trinidad and Tobago. Project manager and environmental specialist on an industrial siting project in Trinidad. The objective of this assessment was to determine the suitability of

four sites for a major industrial development project from environmental and social perspectives and to compare the assets and liabilities of each site to rank them in terms of environmental and social considerations. The study resulted in a preferred alternative and ranking of options based on environmental, social, and engineering inputs.

Massachusetts Division of Fisheries and Wildlife Tern Restoration Project, Buzzards Bay, MA. Lead researcher on a long term population biology and demographics study of roseate and common terns nesting on several islands in Buzzards Bay, MA. The islands are protected by the state as part of the Wildlife Management Area system, which allows some recreational use of selected sites. Developed the management plan for the islands, which involved an assessment of the potential effects of different types of recreational use of the islands on the nesting birds and their habitats. The study determined that recreational use was incompatible with the waterbird nesting and made specific recommendations that were adopted and incorporated in the management plan which is in effect today.

Environmental and Social Impact Assessment, St. Vincent Geothermal Project, St. Vincent and the Grenadines. Led the biodiversity and stakeholder engagement components of the ESIA for a geothermal energy project on the island of St. Vincent. Cooperated with local experts to conduct terrestrial and aquatic biodiversity baseline studies and water resource assessments. Led the stakeholder engagement aspects of the ESIA, including government communication and coordination and execution of the public meetings and focus group discussions in relation to the ESIA. The ESIA was conducted on budget, under an expedited 4-month timeframe, and was unanimously approved by the Government of St. Vincent and the Grenadines.

Environmental and Social Impact Assessment, Alcoa Chatham Aluminum Smelter, Trinidad and Tobago. Led the environmental portion of the ESIA for a proposed aluminum smelter in southwestern Trinidad. The key environmental issues with the project included potential impacts to groundwater, habitat fragmentation, and changes in land use from agricultural to industrial. The project involved significant stakeholder consultation, including consultation with Trinidad's Environmental Management Authority regarding the scope of the ESIA and related public consultations. The project was highly controversial and put on hold before the publication of the ESIA. Based on the history of the project, ERM developed a lessons learned document that outlined recommendations for strategic approaches to the project if it is reactivated.

Environmental and Social Impact Assessment, Staatsolie Sugarcane to Ethanol Project, Suriname. Project manager and lead biodiversity specialist for the ESIA for Staatsolie's proposed sugarcane to ethanol project located in Wageningen, northwestern Suriname. The 15,000 hectare site is bordered to the north, east, and south by nature reserves and undeveloped land, and to the west by rice fields. The project contains agricultural (sugarcane plantation) and industrial (ethanol and sugar processing and production facility) components. ERM developed the ESIA to conform with Suriname National Institute for Environmental and Development Standards (NIMOS) and IFC Performance Standards. Key issues addressed in the ESIA included impacts to biodiversity, forest loss, water quality, water use/demands from the project and other users, impacts to nationally registered historic sites, impacts to protected areas, maintenance of ecosystem services, land use management and ownership, and greenhouse gas (GHG) production. Prepared various environmental management plans for the Project, which included a Coastal Management Plan to address the project's water management needs and climate change-related issues including sea level rise, salt intrusion into estuarine and freshwater wetlands and Suriname's coastal agricultural zone, and drought.

Environmental Assessment of Demolition and Reconstruction of Port Facilities, Jamaica. Led the environmental assessment of proposed demolition and reconstruction activities at Alcoa Jamaica's (Jamalco) port facilities, following extensive damage imposed by Hurricane Dean in late 2007. Developed and executed a plan to assess the nature of the hurricane damage to the port facilities and the shoreline, to evaluate the potential environmental impacts associated with the reconstruction of damaged facilities, and to recommend measures to avoid or minimize potential negative environmental impacts to the region caused by reconstruction activities. Worked closely with the project's engineering team to evaluate several reconstruction options and determine what design offered the best engineering solution with the least environmental damage.

Environmental and Social Impact Assessment, Suralco Aluminum Refinery, Suriname. Led the biodiversity aspects of the ESIA related to a proposed expansion of Alcoa's aluminium refinery in northeastern Suriname. Led an international team of biodiversity experts to conduct a rapid assessment biodiversity survey of the undeveloped area surrounding the refinery. The survey assessed the biological condition and value of the site based on: 1) habitat heterogeneity; 2) a preliminary survey of the organisms that characterize each of the habitats; and 3) the intactness of the habitats, and their capacity to support important biological resources and ecological processes. The results of the survey were used to evaluate the impact of the proposed refinery expansion on the local ecology and to recommend ways to minimize adverse effects on sensitive habitats and species.

Sustainable Development and Ecotourism Assessment, Haiti. Led the natural resources component of a sustainable development assistance project in Haiti that assessed opportunities and challenges of sustainable development in the central and western portions of the country, a major component of which was consideration of threats from climate change and the country's adaptability to current and future changes and the resources needed to address the threats.

Rick Osa

Air Quality Monitoring Lead



Mr. Richard H. Osa, QEP is a Senior Consultant within ERM's North American operations. He has over 30 years of experience in the fields of air quality and environmental management.

Mr. Osa has obtained air emission source permits (construction and operating) for over 200 facilities (major, minor, synthetic minor) in 17 states and seven EPA regions. Facilities were located in attainment and non-attainment areas, and some were subject to MACT for control of Hazardous Air Pollutants.

He has developed greenhouse gas inventory algorithms and a management system for long-haul freight network and facilitated executive-level "sustainability" workshops and needs analyses.

Mr. Osa is expert in a broad range of air management topics, having performed Clean Air Act legislative and regulatory analyses—as well as compliance planning and implementation.

In the area of environmental management systems, he has managed the development of over 150 procedures, work instructions, and standardized forms in support of a Fortune 100 company's environmental management system. He provides training in the development, implementation, and auditing of environmental management systems.

Mr. Osa has supported biogas, wind, biomass, and other renewable energy facilities with environmental permitting and monitoring.

Professional Affiliations & Registrations

- Qualified Environmental Professional—Institute for Professional Environmental Practice
- Air & Waste Management Association
- American Counsel of Engineering Companies—Energy and Environmental Committee

Fields of Competence

- Air emission source permitting
- Ambient air monitoring
- Atmospheric dispersion modeling
- Noise monitoring and modeling
- Environmental management systems

Key Industry Sectors

- Electric power
- Natural gas processing and transmission
- Food processing
- Manufacturing
- Pulp and paper
- Iron and steel
- Ethanol manufacturing
- Nonmetallic mining

Education

- Master of Engineering Management, Northwestern University, 1992
- Graduate Studies, Environmental Engineering, Illinois Institute of Technology, 1976 - 1978
- Bachelor of Science, Physics, Illinois Institute of Technology, 1976

Languages

- English, native speaker

Publications

R.H. Osa and T. Palmer: *Analysis of EPA's Proposed Clean Air Restrictions on Oil and Gas Operations*, World Oil Online, December, 2011.

R.H. Osa: *The New Transformer Sequel: Transportation Engineer Becomes Atmospheric Scientist*, presented at: Mn/DOT – ACEC/MN Annual Consultant Conference, March 1, 2011, Earle Brown Heritage Center, Minneapolis MN.

R.H. Osa et al.: *Can I Get Credit For These GHG Emission Reductions?*, presented at the 102nd annual meeting and exhibition of the Air and Waste Management Association, Detroit, MI, June, 2009.

R.H. Osa: *Residuals Management: A Key To Shrinking Your Mill's "Carbon Footprint"*, Lake States TAPPI Symposium on the Management and Utilization of Paper Mill Residuals, Green Bay, WI, February, 2008.

R.H. Osa: *Residuals Management: A Key To Shrinking Your Mill's "Carbon Footprint"*, Lake States TAPPI Symposium on the Management and Utilization of Paper Mill Residuals, Green Bay, WI, February, 2008.

R.H. Osa and D. Hermann: *Carbon Sequestration in the Heartland*, 11th Annual Electric Utility Environmental Conference, Tucson, AZ, January, 2008.

R.H. Osa, R. Paine, and W. Campbell: *New Source Review Permitting Challenges*, 11th Annual Electric Utility Environmental Conference, Tucson, AZ, January, 2008.

R.H. Osa: *Environmental Compliance – The EMS Approach to Regulatory Assurance*, Invited Presentation: Acordia-Wells Fargo Risk Management Seminar, January 25, 2006.

R.H. Osa: *BART and LAER – Clean Air Requirements, Handle with CAIR*, presented at the annual meeting of the Recycled Paperboard Technical Association, February 10, 2005.

R.H. Osa et al.: *Constructing an Objective Environmental Aspect Ranking System,* presented at the 96th annual meeting and exhibition of the Air and Waste Management Association, San Diego, CA, June, 2003.

R.H. Osa: *Mercury Source-Receptor Relationships Expert Panel: Proceedings*, Electric Power Research Institute, EPRI 1000632, October 2000.

R.H. Osa: *Mercury Toxicity,* presented at the Air and Waste Management Association "Mercury in the Environment" Specialty Conference, Minneapolis-St. Paul, MN, September, 1999.

R.H. Osa: *Natural Gas Environmental Research & Development: A Market Analysis*, Electric Power Research Institute: EPRI TR-109895, December 1997.

R.H. Osa, and C. Hakkarinen: *PRIME – An Improved Downwash Model*, presented at the 21st NATO/CCMS International Technical Meeting on Air Pollution Modeling and its Application, Baltimore, MD, November 6-10, 1995.

R.H. Osa et al.: *Environmental Consequences of FERC Order No. 636*, Gas Research Institute: GRI-95/0048, September 1994.

R.H. Osa: *Mercury Atmospheric Processes: A Synthesis Report*, workshop proceedings from the Expert Panel on Mercury Atmospheric Processes, Tampa, FL, March 16-18, 1994.

R.H. Osa, R.I. Sykes and C. Hakkarinen: *Applications of Advanced Plume Modeling Techniques to Combustion Turbines*, presented at the 9th World Clean Air Congress & Exhibition, Montreal, Canada, August 30-September 4, 1992.

R.H. Osa and G.R. Retzlaff: *Proceedings: Photochemical Modeling Workshop*, workshop held in Cambridge, MA, August, 1992.

R.H. Osa and H. Chromy: *Clean Air Compliance Framework: A Tool for Compliance Planning*, presented at the 85th annual meeting and exhibition of the Air and Waste Management Association, Kansas City, MO, June, 1992.

R.H. Osa: *Implications of 1990 Clean Air Act Amendments*, presented at the 2nd Annual International Maintenance Institute Exposition, Racine, WI, May, 1990.

Key Projects

Ambient Air and Meteorological Monitoring Program, Convent, LA, Nucor Steel Louisiana, LLC
Designed, installed, commissioned, and am managing data collection at this multi-year, three site pre-construction monitoring network. Measured parameters consit of $PM_{2.5}$, SO_2, NO_2, CO, wind speed, wind direction, sigma theta, and ambient temperature. Data are digitally recorded onsite and telemetered to ERM office via wireless modem.

Ambient Air Total Particulate, Manganese, Particulate Mercury, and Meteological Monitoring Program, Marion, OH, Nucor Steel Marion, LLC
Designed, installed, commissioned, and am managing data collection at this multi-year, two site monitoring network. Manual (filter-based) and continuous automated particulate matter samplers are employed to document ambient air concentrations. Wind speed and direction observations will be used to identify culpable source(s) in the event of high concentrations.

Ambient PM10 Monitoring, New Auburn, WI, Superior Silica Sand
Designed, installed, commissioned, and managed a one site PM_{10} program for a non-metallic mining operation. Data quality was certified by Wisconsin DNR.

Title V Operating Permits, Multiple Locations (Iowa, North Dakota, Illinois, Ohio, Indiana), Archer Daniels Midland Company
Developed initial Title V operating permit applications for grain processing and oil extraction and refining facilities. Responsibilities included developing detailed emissions inventories of point and fugitive emission sources, defining alternative operating scenarios, identifying applicable Clean Air Act requirements, and preparing applications in accordance with guidance of the permitting authority.

Greg Lockard, PhD

Cultural Heritage Assessment Lead



Greg Lockard, PhD, has over 20 years of professional experience and over 13 years of experience working as a consultant on development projects in the United States and Latin America. He is a professional anthropologist and cultural heritage specialist with training and experience in social work. He is a native English speaker and is fluent in Spanish. Dr. Lockard is an experienced contract and project manager, developing, negotiating, and managing multiple contracts with a value of over $10 million for environmental services. He has extensive experience supervising cultural resource contractors and coordinating with government agencies and construction managers to ensure compliance with local and national requirements. From 2008 to 2010, he served as the lead heritage specialist for the $3.8B PERU LNG Project, which involved the construction of a natural gas pipeline, liquefaction plant, and marine terminal in Peru. Dr. Lockard is an expert in multilateral lender requirements, including the Equator Principles, the International Finance Corporation Performance Standards, the World Bank Group's EHS Guidelines, and the Inter-American Development Bank's Environment and Safeguards Compliance Policy.

At ERM, Dr. Lockard serves as an environmental consultant managing and working on international projects, especially in Latin America and the United States. His experience in Latin America includes projects in Peru, Chile, Colombia, Haiti, Nicaragua, Brazil, and Mexico, and includes environmental and social impact assessments (ESIAs), environmental and social due diligence (ESDD), and monitoring compliance with environmental, social, and cultural heritage lender requirements.

Professional Registrations & Affiliations

- Register of Professional Archaeologists (RPA), No. 15932
- Registro Nacional de Arqueólogos (RNA) del Perú, No. DL-0081
- Colegio Profesional de Arqueólogos del Perú (COARPE), No. 040780
- Society for American Archaeology (SAA)
- International Association for Impact Assessment (IAIA)
- American Anthropological Association (AAA)
- Archaeological Institute of America (AIA)
- Pre-Columbian Society of Washington, DC

Fields of Competence

- U.S. and international cultural heritage
- E&S Project Management
- U.S. cultural resource laws and regulations
- International lender requirements

Key Industry Sectors

- Oil & Gas
- U.S. Federal

Education

- PhD, Anthropology, University of New Mexico, 2005
- MA, Anthropology, University of New Mexico, 1999
- BA, History and Political Science, George Washington University, 1995

Languages

- English, native speaker
- Spanish, fluent

ERM Experience

IIC E&S Manual / Inter-America Investment Corporation (IIC) (2/17-present).
Project Manager. ERM has been retained to prepare a manual on the IIC's internal procedures for managing environmental and social risk during its investment cycle. The manual will be utilized internally by the IIC's Social and Environmental Governance (SEG) group. A summary, public version of the manual will also be prepared to educate clients and the general public on the IIC's environmental and social procedures.

E&S Monitoring of India Projects / Overseas Private Investment Corporation (OPIC) (2/17-present).
Project Manager. ERM is serving as an Independent Consultant to prepare a report to assess the Office of Investment Policy's (OIP's) current monitoring process for five projects in India to ensure that the risks associated with the use of client-reported data and limited site visits for monitoring are acceptable and meet OPIC's requirements.

E&S Monitoring of Mexico Projects / Overseas Private Investment Corporation (OPIC) (2/17-present).
Project Manager. ERM is serving as an Independent Consultant to prepare a report to assess the Office of Investment Policy's (OIP's) current monitoring process for five projects in Mexico to ensure that the risks associated with the use of client-reported data and limited site visits for monitoring are acceptable and meet OPIC's requirements.

San Juan EIS / Office of Surface Mining Reclamation and Enforcement (OSMRE) (2/17-present).
Cultural Heritage Lead. Conducting the cultural resources impact assessment for an Environmental Impact Statement for the expansion of a coal mining operation in San Juan County, New Mexico.

Liza Phase I Development Project / Esso Exploration and Production Guyana Limited (EEPGL) (9/16-present).
EIA Coordinator. Coordinating the development of an Environmental Impact Assessment (EIA) for an oil field development project located approximately 190 km off the coast of Guyana.

PTTGC America Project / Mizuho Bank (9/16-present).
Project Manager. Managing an Environmental and Social Due Diligence (ESDD) of a petrochemical project at Dilles Bottom in Ohio. The ESDD assesses the project's alignment with the Equator Principles and the IFC Performance Standards.

Dolet Hills, Beaumont, and Baytown Projects / Universal Pegasus International (UPI) (9/16-present).
Cultural Heritage Lead. Conducting cultural resources desktop research and risk analysis and coordinating State Historic Preservation Office (SHPO) consultation for a series of oil and gas pipelines proposed by Exxon Mobil Pipeline Company at the Dolet Hills Oxbow Mine in Louisiana and in and around Beaumont and Baytown, Texas.

Driftwood LNG Project / Driftwood LNG, LLC (3/16-present).
Cultural Heritage Lead. Overseeing the preparation of Resource Report 4 (cultural resources) for an environmental report to be filed with the Federal Energy Regulatory Commission (FERC) for a 1200-acre liquefied natural gas (LNG) liquefaction export facility in Calcasieu Parish, Louisiana. Also coordinating consultation with the Louisiana SHPO and American Indian tribes with historic ties to the region, and reviewing cultural resource survey reports for the project.

AMA1 CHMP / Anadarko Moçambique Área 1, Lda (AMA1) (11/16-12/16).
Consultant. Assisted in the preparation of a Cultural Heritage Management Plan (CHMP), including a Salvage Protocol and Chance Find Procedure, for a liquefied natural gas (LNG) project in Mozambique.

Gasoducto Sur Peruano Project, Independent Environmental & Social Consultant / Citi and Sumitomo Mitsui Banking Corporation (1/15-10/16).
Consultant. Worked on a small team conducting a due diligence, including alignment with the Equator Principles and the IFC performance standards, for an 1100 km natural gas pipeline project in southern Peru. Assisted in the preparation of an Environmental and Social Due Diligence (ESDD) Report and Environmental and Social Action Plan (ESAP) for the project. Also conducted two pre-close monitoring visits to assess the

project's progress towards addressing ESAP requirements.

Annual Environmental and Social Performance Report (AESPR) / Corporación Interamericana para el Financiamiento de Infraestructura, S.A. (CIFI) (3/16-9/16).
Project Manager. Conducted an annual review of CIFI's internal Environmental and Social Management System (ESMS) and its application on 33 projects for which the bank had an active loan in 2015. Authored the 2015 AESPR. Coordinated CIFI's annual Environmental and Social Training, which was held in Panama City and attended by the bank's staff.

Silenus Project / Shell (8/16-9/16).
Cultural Heritage Lead. Wrote the cultural resource sections for an Environmental, Social, and Health Impact Assessment (ESHIA) and a High Cultural Value (HCV) Assessment for an ethanol plant in Arkansas.

Leviathan Project / Noble Energy (7/16-9/16).
Environmental Consultant. Assisted in the preparation of an Overarching Environmental and Social Assessment Document for a natural gas drilling, production, and pipeline project in Israel. Also prepared a Chance Find Procedure for the project.

Ituango Project / IIC (7/16-9/16).
Cultural Heritage Lead. Participated in an Environmental and Social Due Diligence (ESDD) for a hydroelectric project in Colombia. Assessed the project's alignment with lender standards for cultural heritage, specifically IFC Performance Standard 8.

Cerro Pabellon Project / Inter-American Investment Corporation (IIC) (8/16).
Cultural Heritage Lead. Participated in an ESDD for a 100 MW geothermal power project and 80 km transmission line in the Antofagasta Region of Chile. Assessed the project's alignment with lender standards for cultural heritage, specifically IFC Performance Standard 8.

Vía Expresa Sur (VESUR) Project / Sumitomo Mitsui Banking Corporation (SMBC) (6/16-8/16).
Environmental Consultant. Participated in an ESDD for a 9 km highway project in Lima, Peru. Assisted in assessing the project's alignment with lender standards, specifically the Equator Principles and IFC Performance Standards. Lead author of the ESDD Report.

Tres Mesas Project / OPIC (5/16-7/16).
Project Manager. Conducted an ESDD for a wind farm project in Tamaulipas, Mexico. Travelled to Mexico as part of the ESDD to visit the project site and interview project personnel, regulators, and affected communities (ejidos). Assessed the project's alignment with lender standards (assisted by a biodiversity specialist). Authored the ESDD Report.

Red Vial 4 Highway Project, Environmental and Social Monitoring / Banco de Crédito del Perú, Corporación Andina de Fomento, and Crédit Agricole (5/15-7/16).
Cultural Heritage Lead. Environmental and Social (E&S) Monitoring for a 283 km highway project in northern Peru. Assessed the project's alignment with lender standards for cultural heritage, specifically IFC Performance Standard 8.

Lafito Industrial Free Zone and Power Plant Project / CIFI (4/16-6/16).
Project Manager. Conducted an ESDD for a port, industrial free zone, and power plant in Haiti. Sent a team of social specialists to Haiti as part of the ESDD to visit the project site and interview project personnel and affected communities. Assessed the project's alignment with lender standards (assisted by the social team). Lead author of the ESDD Report.

Susquehanna West, Triad, and Orion Projects / Tennessee Gas Pipeline Company (7/15-6/16).
Technical Section Lead. Conducting third party reviews of the cultural resource sections of environmental reports filed with the Federal Energy Regulatory Commission (FERC) for three separate and independent looping projects along a 300 mile pipeline system in Pennsylvania. Also preparing the cultural resource sections of Environmental Assessments (EAs) for the projects.

Luz del Norte Photovoltaic Project, Environmental and Social Construction Monitoring / First Solar, Inc. (2/15-6/16).
Cultural Heritage Lead. Monitoring review, including evaluation of alignment with IFC performance standards, of the cultural heritage program for a solar power project in northern Chile.

Kingfisher Project / CNOOC Limited (4/16).
Cultural Heritage Lead. Participated in a GAP analysis of an ESIA for an oil field development project in Uganda. Assessed the ESIA's alignment with lender standards for cultural heritage, specifically IFC Performance Standard 8.

Fields Point Liquefaction Project / National Grid LNG, LLC (4/16).
Technical Section Lead. Conducting third party review of the cultural resource sections of an environmental report filed with the Federal Energy Regulatory Commission (FERC) for a gas liquefaction project in Rhode Island. Also preparing the cultural resource section of an Environmental Assessment (EA) for the project.

Project Andes / EIG (11/15-4/16).
Project Manager. Environmental and Social Due Diligence (ESDD) for investment in an offshore LNG terminal, gas to power plant, and solar project in Chile.

G2 Project / G2 LNG, LLC (2/16-3/16).
Cultural Heritage Lead. Preparing Resource Report 4 (cultural resources) for an environmental report to be filed with the Federal Energy Regulatory Commission (FERC) for a 777-acre liquefied natural gas (LNG) liquefaction export facility and 42 miles of pipeline in Cameron Parish, Louisiana. Also coordinating consultation with the Louisiana State Historic Preservation Office (SHPO) and American Indian tribes with historic ties to the region, and reviewing cultural resource survey reports for the project.

TISUR Amarradero "F" Expansion Project / Terminal Internacional del Sur S.A. and Mizuho Bank, Ltd. (12/15-2/16).
Project Manager. Conducted E&S Environmental Monitoring of a port facility in southern Peru to assess compliance with the project's Environmental and Social Action Plan (ESAP) and general alignment with the Equator Principles and the IFC Performance Standards.

Mississippi River LNG Project / Louisiana LNG Energy, LLC (10/15-2/16).
Cultural Heritage Lead. Preparing Resource Report 4 (cultural resources) for an environmental report to be filed with the Federal Energy Regulatory Commission (FERC) for a 250-acre liquefaction export facility and 5.2 miles of pipelines in Plaquemines Parish, Louisiana. Also coordinated consultation with the Louisiana State Historic Preservation Office (SHPO) and American Indian tribes with historic ties to the region, and reviewed cultural resource survey reports for the project.

Leach XPress Project / Columbia Gas Transmission, LLC (2/15-2/16).
Technical Section Lead. Conducted a third party review of the cultural resource sections of an environmental report filed with the Federal Energy Regulatory Commission (FERC) for a 161 mile natural gas pipeline project in West Virginia and Ohio. Also prepared the cultural resource sections of an Environmental Impact Statement (EIS) for the project.

Offshore Cape Three Points (OCTP) Project / eni Ghana (12/15).
Senior Reviewer. Reviewed the Cultural Heritage Management Plan (CHMP) for a hydrocarbon reserves development project in Ghana. The project includes offshore drilling, a 63 km subsea gas pipeline, and onshore receiving facilities.

Sucden Sugar and Bio-Energy Lending Program / Inter-American Development Bank (IDB) (7/15-12/15).
Project Manager. Prepared an Environmental and Social Due Diligence (ESDD) and an Environmental and Social Management System (ESMS) Protocol for a Financial Intermediary (FI) to utilize to ensure the alignment of their Sub-Borrowers (sugarcane mills in Brazil) with IDB policies and directives.

Project Traverse / EIG (10/15).
Cultural Heritage Lead. Environmental and Social Due Diligence (ESDD) for investment in three natural gas pipeline projects in West Virginia, Pennsylvania, Ohio, and Michigan.

Benjamin Sussman, AICP

Transportation Assessment Lead



Mr. Ben Sussman is a consultant with ERM based in Annapolis, Maryland, US. He has more than sixteen years' experience evaluating the socioeconomic, land use, transportation, recreation, and visual impacts of proposed energy, mining, and other industrial projects. His experience includes third-party NEPA assessments on behalf of the U.S. Army Corps of Engineers, FERC, and other federal and state government agencies. Mr. Sussman addresses similar subject matter for international Environmental and Social Impact Assessments (ESIA) for energy and mining projects around the world.

In addition to serving as a subject matter expert in the topics listed above, Mr. Sussman oversees large public comment management processes. Mr. Sussman has managed extensive public engagement as a critical part of impact assessment and planning projects. He is adept at managing public meetings, stakeholder interviews, public communications and other forms of information gathering and dissemination.

As a land use planner, Mr. Sussman has prepared comprehensive land use plans and community plans for small and large cities and unincorporated communities, with emphasis on the linkages between land use, growth, and water resources. Mr. Sussman has also evaluated vehicular and rail transportation corridor options for industrial, commercial, and residential land uses using quantitative measures such as Highway Capacity Software (HCS), combined with qualitative measures such as internal and external stakeholder interviews.

Professional Affiliations & Registrations

- American Institute of Certified Planners (2003)
- American Planning Association

Fields of Competence

- Environmental and Social Impact Assessments (ESIA, ESHIA, EIS)
- NEPA
- Socioeconomics
- Transportation planning
- Comprehensive planning/land use planning
- Public Scoping and public information management
- Visual impact assessment

Education

- MCRP (City and Regional Planning)
- Georgia Tech, 2002
- B.S., Science, Technology, and Society
- Stanford University, 1998

Key Industries

- Oil and Gas
- Transportation
- Mining
- Government

Key Projects

Visual Impact Assessment, Proposed Natural Gas Pipeline, WV and VA; Confidential Client, Ongoing.
Author of a visual impact assessment focusing on the portions of a proposed 500+ mile natural gas pipeline that cross two national forests. The assessment will be consistent with the U.S. Forest Service's Scenery Management System, a detailed, complex framework for evaluation of visual impacts in national forests.

Programmatic Environmental Impact Statement, FirstNet, AK, HI, and US Territories, Ongoing.
Subject matter expert for Land Use, Recreation, Visual Resources, Socioeconomics and Environmental Justice chapters for a programmatic EIS, evaluating the impacts of implementation of the federally-established First Responder Network Authority (FirstNet) projects in Alaska, Hawaii, and US overseas territories. FirstNet would build, operate and maintain a high-speed, nationwide wireless broadband network exclusively for public safety entities such as police, fire, and EMS.

NorthMet Mine EIS, Minnesota, U.S., Minnesota Department of Natural Resources, US Army Corps of Engineers, and US Forest Service, Ongoing.
Supervisor for the public comment response process for the a third-party Supplemental EIS (SEIS) for what could become the first copper-nickel mine in Minnesota history. The SEIS process generated more than 57,000 comments from agencies, tribes, and individuals. Also served as the initial author and subsequent senior advisor for the Land Use/Recreation/Visual Resources sections of the EIS. ERM is a third-party Contractor for the USACE, USFS, and Minnesota DNR; the project includes the active involvement of USEPA, USFWS, and three tribal governments.

Environmental Impact Statement for Leach XPress Pipeline, WV, PA, and OH, US; FERC, Ongoing.
Land Use, Recreation, and Visual Resources subject matter expert for a FERC third-party EIS. The proposed Leach Xpress natural gas pipeline would traverse more than 160 miles in northern West Virginia and eastern Ohio.

Environmental Assessments for Tennessee Gas Pipeline Segments, Pennsylvania, US; FERC, Ongoing.
Land Use, Recreation, and Visual Resources subject matter expert for three separate FERC third-party EAs. The proposed Susquehanna West, Triad, and Orion natural gas pipeline loops would provide additional capacity and reliability for existing pipelines in northern Pennsylvania.

Socioeconomic and Environmental Justice Analysis for Western Oregon Resource Management Plans and EIS, Bureau of Land Management, Ongoing.
Project Manager for an effort to provide analysis and public outreach that will form the basis of the Socioeconomic and Environmental Justice discussions in the Resource Management Plans for six of BLM's Western Oregon districts. This highly visible project involves analysis and policy recommendations for the region's timber and non-timber economies, while recognizing social values (i.e., protection of threatened and endangered species like the western spotted owl).

Transportation Impact Assessment, FERC Louisiana LNG Energy, Plaquemines Parish, LA, Ongoing.
Supervised data collection, evaluation, and documentation of the traffic and transportation impacts of LLNGE's proposed LNG export terminal on the Mississippi River in Plaquemines Parish, LA. The project proposes to close a portion of a Parish road, and to add additional traffic to Parish and state roads.

NEPA Documentation, National Grid Fields Point LNG Facility, Providence, RI; FERC, Ongoing.
Subject matter expert for review of Resource Report (RR) 5 (Socioeconomics) and RR 8 (Land Use, Recreation, and Visual Resources. Also primary author of related sections in the eventual NEPA document (EA or EIS, depending on the results of scoping to occur in 2015). The Socioeconomics evaluation and assessment would include Environmental Justice.

Keystone XL Pipeline Supplemental EIS and National Interest Determination, U.S. Department of State, 2015.
Author of the Land Use, Recreation, Visual Resources, and Transportation sections of the Supplemental EIS. Supervisor of the public comment response process for the scoping, Draft Supplemental EIS, and National Interest Determination (NID) phases of this highly controversial third-party EIS. Federal and state agencies, tribes, and individuals around the world provided more than 400,000 comments during the scoping period, more than 1.5 million comments on the Draft Supplemental EIS, and more than 3 million comments for the NID.

Impact Assessment for Ethane Cracker Facility, Pennsylvania, Confidential Client, 2015.
Deputy project manager for preparation of a full Impact Assessment document, evaluating the environmental, social, and transportation impacts of construction and operation of a proposed ethane cracker facility. Responsible for overall document preparation, management of budget and deliverable schedule. Also served as Transportation subject matter expert.

Social Impact Assessments, Confidential Clients, Marcellus Shale Region, US, 2014-15.
Lead author for one study and transportation specialist for a separate evaluation of the social impacts of regional unconventional natural gas extraction programs for two separate major oil and gas companies. Responsible for collection and analysis of traffic data, development of future transportation scenarios, description of anticipated impacts, and recommended mitigation measures.

Transportation Study, Confidential Mining Client, Sierra Leone, 2015.
Responsible for development of a traffic study (to be incorporated into an IFC-compliant ESIA) documenting existing and likely future traffic condtions associated with a proposed iron mine in Sierra Leone. The study will evaluate the impact of the project's 45 km haul road, barge port, and barge traffic on land and water transportation facilities and activities. Developed traffic study procedures and supervised traffic data collection and analysis.

Transportation Study, Confidential Mining Client, Dominican Republic, 2014.
Developed a traffic study (to be incorporated into an IFC-compliant supplement to an existing ESIA) for a proposed ferro-nickel mine in the central Dominican Republic. The document focuses on updating baseline conditions from a 2012 ESIA, as well as identification and analysis of a large set of transportation alternatives. Conducted an in-country evaluation of the haul route, and interviewed internal stakeholders.

ESIA Review for Lima Metro System Expansion, Interamerican Development Bank, Peru, 2014.
Conducted a review of the ESIA for an expansion of the Lima metro (mass transit) system (construction of Lines 2 and 4), to identify potential gaps related to traffic, transportation, and safety. Provided recommendations for additional analysis and potential mitigation measures.

Confidential Client, ESIA for Natural Gas Field Expansion, Republic of Kazakhstan, 2014.
Transportation Planner/subject matter expert for an ESIA for a proposed major expansion of a large natural gas field in Kazakhstan. Responsible for compilation of baseline data and information, and analysis of all transportation impacts of the project, which would involve road construction, and extensive vessel and rail deliveries of construction equipment, project components, and construction materials.

Comprehensive Plans in Maryland, U.S.
Project manager, task manager, and senior planner involved in the preparation of comprehensive plans for local governments in Maryland. Comprehensive Plans are the basis for laws and decisions related to land use and investment in public infrastructure and services. For the Charles County comprehensive plan, designed and led an extensive public engagement process that involved ten public work sessions, more than 50 key stakeholder interviews, and multiple rounds of public hearings. The plan shifts development patterns to conform to Maryland's implementation of the Chesapeake Bay TMDL.

EA for Construction Activities, Air National Guard, Ongoing.
Project Manager for the development of separate Environmental Assessments evaluating the impacts multiple proposed construction projects at Pittsburgh International Airport (Pennsylvania Air National Guard) and Joint Base Andrews (District of Columbia Air National Guard). Responsible for baseline research, site visits, document contents, and interagency consultation.

Merian Gold Mine ESIA, Suriname, Newmont (Surgold), 2013.
Task Manager for development of the land use and transportation sections an ESIA for a gold mine in Suriname for Newmont. Developed traffic study procedures and supervised traffic data collection and analysis.

Land Use, Transportation, and Visual Resources Analysis, Various Suralco Mines, Suriname, 2014.
Author of land use, transportation, and visual resources sections of IFC-compliant ESIAs (including baseline conditions, impacts, mitigation, and design of data collection procedures) for the Nassau Plateau, Lelydorp Mine, and Para and Kankantrie bauxite mines.

Traffic Rapid Assessment, Pascua-Lama Mine, Barrick, Chile and Argentina, 2012.
Prepared a comprehensive evaluation of background transportation and traffic conditions affecting haul routes to and from the Pascua-Lama mine, existing and anticipated mine-related traffic, and recommended strategies to minimize and avoid delays and safety concerns for mine traffic. Developed traffic study procedures and supervised traffic data collection and analysis.

Social Impact Assessment, Newmont Mining Corporation, Nevada, U.S., 2012.
Primary author of a Social Impact Assessment (SIA) that evaluates the impacts of a new precious metals mine on nearby communities in a remote area of the Western United States. The project included multiple rounds of stakeholder engagement interviews and briefings, and analysis of a wide variety of topics including economics, public health, water resources, cultural resources, and issues related to Native American tribes.

Environmental and Social Impact Assessment, Nassau Plateau Bauxite Mine, Suriname, Suralco, 2012.
Responsible for analysis and preparation of EIA sections related to land use, infrastructure, visual resources, and transportation for a new bauxite mine and transport road. Designed traffic data collection methodology and incorporated findings into EIA chapters.

Regional Sustainable Growth Management Strategy for the Fort Bragg Region, North Carolina, U.S., BRAC Regional Task Force, 2011.
Green Infrastructure Task Manager, responsible for collection, analysis, and synthesis of data relating to the 11-county region's Green Infrastructure (GI) system. Using existing resources from state, federal, and non-profit agencies, compiled a highly complex GIS database of GI resources in the region (including natural, cultural, and agriculture/forestry resources). Established priorities and weighting through interaction with the project's Technical Advisory Committee and regional experts to develop a "greenprint" map, showing the highest-priority areas for protection.

Environmental Assessment for Construction of a Marine Corps Reserve Training Center, Yakima, WA, U.S., Marine Forces Reserves (MARFORRES), 2011.
Project Manager. Prepared a revised Draft EA and Finding of No Significant Impact (FONSI) for the construction of a new Marine Corps Reserve Center at Yakima Training Center, WA. Responded to comments from MFR and Naval Facilities Engineering Command.

Water Resources Elements, Maryland, 2006-2011.
Project manager for Comprehensive Plan Water Resources Elements (WRE) for six counties and four municipalities in MD. The WRE evaluates the impacts of land use on drinking water and water quality (nitrogen and phosphorus loading). Evaluation of local Low Impact Development (LID) regulations was also required. Representatives from state agencies have publicly praised the WREs prepared by ERM.

Hermosa West Wind Farm Transportation Study, Wyoming, U.S., Shell Wind Energy, 2010.
Prepared a Transportation Study in support of an application to the Wyoming Industrial Siting Division, evaluating the impacts of a proposed 300 MW wind farm on the road, rail, and air transportation network in a two-county area in southeastern Wyoming. Evaluated peak hour levels of service (LOS) and broader safety concerns related to the movement of wind turbine components on public roads.

Environmental Impact Statement for an HCP and ITP for the Buckeye Wind Power Project, Ohio, U.S., US Fish and Wildlife Service, 2010.
Transportation and Visual Resources specialist. Prepared EIS chapters assessing transportation and visual resources impacts of the proposed 250 MW Buckeye Wind Power Project. ERM successfully executed the third party EIS and National Environmental Policy Act (NEPA) public consultation process under an extremely expedited timeframe.

Social Impact Assessment, EBRD Coal Project, Omnogovi, Mongolia, 2010.
Socioeconomic Specialist. Identified and quantified the socioeconomic impacts of a major coal development project in the south Gobi desert, including direct and indirect revenues (taxes, concession fees, and other revenue streams), jobs, and income for residents of the region and the nation. The Social Impact Assessment helped to justify EBRD investment in the project.

Regional Landfill Siting Study, Confidential Client, Maryland, 2010.
Developed GIS based screening criteria to identify land suitable for a solid waste landfill in Maryland. Prepared evaluation criteria to rate candidate sites against each other. Prepared graphics to illustrate the visual impact of various landfill heights and locations, relative to viewers.

Star Spangled Banner National Historic Trail Water Trails Plan, State of Maryland, 2010.
Responsible for all data collection and analysis, and author of portions of the Water Trails Plan. Mapped water proximate resources related to the War of 1812 in Maryland., Virginia, and DC. Developed and applied an extensive criteria system to identify high priority water trail segments and specific projects along the water trails.

Remedial Investigation and Feasibility Study, 68th Street Landfill Site, Baltimore, MD, U.S., 2006-2010.
Planner and GIS Specialist. Participated in the investigation and evaluation of cleanup options for a 270-acre study area, following the U.S. Environmental Protection Agency's (USEPA) Superfund Alternative Site (SAS) process. Prepared the Land Re-Use section of the Sitewide Program Management Plan (SWPMP), and prepared project maps in GIS.

Going Green Downtown, Maryland Department of Natural Resources, 2009.
Project manager. Developed a sustainability guidebook for historic downtowns in Maryland. The Manual, jointly sponsored by two state agencies, gives practical guidance on ways that Maryland's downtown business districts can be more environmentally, economically, and socially sustainable.

Municipal Growth Element, Town of Bel Air, Maryland, 2009.
Project manager. Preparation of a Municipal Growth Element for the County Seat of Harford County, north of Baltimore. The element delineated the Town's future annexation, and demonstrated that the Town has adequate infrastructure and public facilities to accommodate projected population growth.

Condor Airspace Environmental Assessment, Maine and New Hampshire, 2009.
Prepared evaluations of impacts on land use, socioeconomic resources, and cultural resources sections of the EA. The document, which was later converted to a full EIS, analyzed the potential impacts of combining two adjoining airspaces used by the Massachusetts Air National Guard (ANG), and lowering the operational floor of that combined airspace.

Northern Worcester County Transportation Study, Worcester County, Maryland, 2008.
Analyzed land use transportation relationships and transportation policies in the area to the west of Ocean City, MD. Designed a development capacity analysis that helped define trip generation rates as inputs into a custom built traffic model of the study area. Prepared land use policy recommendations to help achieve the desired future transportation conditions identified in the study.

Draft ESHIA, Confidential Client, New Providence Island, Bahamas, 2008.
Evaluated transportation impacts of a planned resort on New Providence Island. Designed and managed traffic data collection and analysis for the existing and future road network. prepared the ESIA section documenting level of service, safety concerns, and other transportation impacts. Conducted consultations with public agencies.

Scenery Management (Visual) Assessment, White Pines Wind Power Project, Manistee National Forest, US Forest Service, Michigan, 2008.
Evaluated visual simulations of a proposed wind farm near Manistee, MI. Developed and applied evaluation criteria based on the US Forest Service's Scenery Management System (SMS).

City Performance Indicators Study, World Bank, 2008.
Conducted research and prepared presentation materials and graphics. The study created a model to help cities throughout the world evaluate and improve their ability to meet the needs of their citizens. The model was ground-tested in six cities: Vancouver and Toronto, Canada; Bogotá and Cali, Colombia; and Sao Paolo and Belo Horizonte, Brazil.

Rail Siting Study, Confidential Client, US, 2007. Transportation Planner.
As part of two separate but related studies, evaluated alternatives to increase fuel delivery capacity for a Midwest energy provider. Each study focused on a distinct portion of the utility's service area. The project involved development of criteria and GIS and CAD mapping to identify and rank candidate rail alignments from multiple points of origin to multiple power plant destinations. The analysis also considered water borne fuel deliveries in conjunction with rail options.

ESHIA for Natural Gas Development Program, Confidential Client, US, 2007.
Land Use and Transportation specialist. Evaluated the land use, transportation, public infrastructure, including water and sewer service, and local services impacts of a large-scale natural gas development project in the western United States. The tasks involved consultation with local and state government officials as well as stakeholders from nearby settlements.

Mark E. Garrison

Air Emission Modeling Lead



Mr. Garrison has more than 28 years of experience as a meteorologist and air quality dispersion modeler in the environmental consulting field, for industry, and the U.S EPA.

Mr. Garrison has several years of experience providing expert consultation related to litigation, including expert testimony. He has extensive experience in the application of air quality models to assess releases of criteria and toxic air pollutants.

Mr. Garrison has detailed knowledge of the technical, regulatory, and policy issues related to dispersion modeling of new and existing sources and modeling the effects of accidental releases of toxic chemicals; he has special expertise in modeling sources in complex terrain and in the application of advanced models (e.g., CALPUFF, AERMOD, CTDMPLUS).

Mr. Garrison has extensive experience in modeling for PSD and NA-NSR permitting, with special emphasis on electric utility power plants. He has extensive experience in modeling concentration and deposition impacts for input to risk assessment.

Mr. Garrison has served as an invited scientific peer reviewer for two new EPA models: AERMOD and CALPUFF. He is the author of numerous papers presented at technical conferences on a wide variety of modeling topics.

Registrations & Professional Affiliations

- Air and Waste Management Association
- American Meteorological Society

Fields of Competence

- Air quality dispersion modeling
- Meteorological data evaluation and processing
- Dispersion model development
- Expert testimony
- PSD and Nonattainment New Source Review (NA-NSR) modeling
- Exposure assessment and toxic pollutant impact evaluations
- Air emissions inventory development
- Ambient impact assessments of hazardous waste sites
- Clean Air Act strategic planning
- Electric utility power plant permitting
- Modeling in support of risk assessment
- Title V permitting

Education

- M.S., Environmental Science, Drexel University, 1981
- B.S., Environmental Engineering Technology, Temple University, 1977

Languages

- English, native speaker

Key Projects

Contributed to an assessment of fine particle contributions to regional haze in collaboration with the NESCAUM organization.
Work included preparation of MM5-based meteorological inputs, and modeling of several hundred coal- and oil-fired generating units in the Northeastern U.S. using the CALPUFF model.

Conducted modeling of the atmospheric transport, transformation and fate of mercury emitted by coal-fired power plants and other source types for the Maryland Department of Natural Resources Power Plant Research Program (PPRP).
Developed a speciated mercury emissions inventories for the Eastern U.S., and developed a simplified mercury transformation scheme that has been incorporated into CALPUFF. Model evaluations were performed comparing model predictions to, and analysis of data collected at Mercury Deposition Network (MDN) sites.

Conducted modeling as part of the Maryland Department of Natural Resources Power Plant Research Program (PPRP).
Review of several new power plant applications, including the use of AERMOD, and Class I AQRV analyses utilizing the CALMET/CALPUFF modeling system and the SACTI model for cooling tower impact assessment. Sources modeled included simple and combined cycle combustion turbines and coal-fired boilers.

Performed and conducting on-going modeling with CALPUFF to determine visibility impacts on Class I areas using MM5-based data for facilities in South Carolina, Pennsylvania, Nebraska, Oklahoma, and Texas.
Modeling was conducted in support of BART exemption and BART engineering analyses.

Performed a cumulative impact analysis for several new electric generation facilities in Maryland.
Utilized CALMET and CALPUFF, including the effect of multiple plants on visibility resources in the Shenandoah National Park and an assessment of ambient standards in Maryland.

Participated in scientific peer review panels for the new AERMOD and CALPUFF models at the invitation of the U.S. EPA.
Developed comments on the scientific and performance aspects of AERMOD and CALPUFF.

Conducted modeling with the Offshore Coastal Dispersion (OCD) model to evaluate the effects of drilling operations off of the coast of Angola.
Project included processing and evaluation of both land and overwater meteorological data.

Conducted extensive air quality modeling to address SO2 ambient standards compliance issues for a refinery in Oklahoma.
Work involved model evaluation comparing predicted to measured ambient concentrations. Models included AERMOD and ISCST3. Project included processing and evaluation of meteorological data for ISCST3 and AERMOD.

Performed a full-scale analysis using the CALMET/CALPUFF modeling system to assess Nitrogen deposition to the Chesapeake Bay resulting from NOx emissions from sources located up to 1000 kilometers from the Bay.
Conducted evaluations of the performance of CALPUFF and developed proposed improvements.

Performed dispersion modeling in support of accidental release assessments for Clean Air Act 112(r) Risk Management Plan for chemical, paper and other industries at over a dozen facilities using the ALOHA, SLAB, and DEGADIS models.

Conducted modeling for input to a risk assessment for a manufacturing facility in Albuquerque, New Mexico using CALPUFF for a local, complex wind application.

Prepared a comprehensive set of input files.
Included MM4, upper air, surface, precipitation, buoy, ozone, land use, and terrain and ran CALMET for Public Service Electric and Gas in New Jersey. Provided evaluation of resultant wind fields.

Conducted air quality modeling to determine exposure assessment input to a human health risk assessment, to

address impacts of airborne pollutants from a dredging operation to clean up the Grand Calumet River near a major steel plant in Gary, IN.

Conducted air quality modeling, including multi-source regional modeling, in support of a NOx PSD application for a manufacturing facility in New York State.

Provided air quality modeling inputs (ISCST3 and AERMOD-PRIME) to a human health risk assessment for a manufacturing facility in New Jersey.

Conducted air quality modeling of benzene and other pollutants released from contaminated soil at a site in Brazil; utilized emissions measured by flux chamber.

Conducted modeling to assess impacts of the excavation and off-site disposal of asbestos-containing materials at a facility in Argentina.

Conducted air quality modeling of several compounds from contaminated soil at a site in West Virginia; utilized emissions measured by flux chamber.

Conducted modeling to determine concentration and deposition impacts for a multi-pathway risk assessment for a hazardous waste incinerator in Puerto Rico.

Prepared an expert report in support of a power company defendant involving the allegation by the government of avoidance of New Source Review (NSR) requirements for a coal-fired power plant in the remedy phase; was deposed in this case.

Assisted in the preparation of an expert report in support of a power company defendant involving allegations by the government of avoidance of New Source Review (NSR) requirements for over a dozen mid-western and eastern coal-fired power plants.

Served as an expert witness and prepared an expert report in litigation involving the air quality impacts of a gasoline spill, successfully avoiding class certification.

Prepared expert reports including dispersion modeling to address exposure to airborne asbestos particles in two court cases, both of which were settled with plaintiffs prior to trial. Prepared an expert report in an additional asbestos litigation case which is ongoing.

Conducted comprehensive modeling analyses to address AB2588 and Prop 65 risk assessment requirements for facilities in Santa Clara (BAAQMD) and Downey (SCAQMD), California.

Conducted modeling to determine HF impacts from a facility in Pennsylvania, including resolution of issues related to HF reactivity and deposition with the state agency.

Performed modeling for two Pennsylvania facilities (refinery and power plant) to address attainment of SO2 NAAQS due to multiple regional sources. Developed an innovative approach to determining background concentrations that was approved by EPA Region III.

Conducted air quality modeling for an industrial facility in Utah to demonstrate compliance with PSD Increments for PM10.

Conducted air quality modeling for two manufacturing facilities in support of insignificant impact determinations of plant modifications requiring PSD review.

Performed air quality modeling of three industrial facilities in New Jersey in support of quantitative risk assessments for the facilities. Worked with NJDEP to ensure compliance with risk modeling policies.

Performed dispersion modeling to demonstrate PM10 NAAQS attainment in the vicinity of an ore mining and processing facility in Nevada.

Conducted a model intercomparison study between the newly released ISC-PRIME model and existing downwash algorithms in ISCST3 to determine regulatory implications. Principal author and programmer of the Integrated Gaussian Model (IGM), an air quality model approved as an equivalent model

by the US EPA, developed to streamline obtaining source contribution information and to efficiently implement procedures for intermediate terrain.

Performed air quality analyses to support PSD application for an 800-MW pulverized coal-fired generating station in South Central Virginia.
Contributed substantially to preparation of PSD application. Developed IGM for use in this project.

Performed dispersion modeling studies in support of present and future plans for additional generating capacity at a utility power plant, including an assessment of existing units.
Models used included IGM in the RTDM/ISCST2 mode, CTSCREEN and CTDMPLUS. Provided interface with New Jersey Bureau of Air Quality Evaluation as needed for permitting modeling support.

Conducted modeling to determine HF impacts of two glass manufacturing facilities in New York state.
Conducted a model intercomparison study between existing complex terrain models and test versions of EPA's new AERMOD model to evaluate AERMOD's performance. Recommended changes in AERMOD formulation were implemented by EPA.

Performed an in-depth analysis of modeling results produced by plaintiffs in a suit alleging wide-spread Arsenic health impacts, significantly reducing the impact area identified by plaintiffs by correcting and improving the plaintiff s modeling.

Performed a deposition modeling study of the long-term (50 years of plant operation) impacts of a pesticide manufacturing plant in New York State. Assisted in interface with NYSDEC and EPA Region II to resolve impact issues.

Served as the work assignment manager for the initial development of Superfund air pathway analysis guidance documents.

Developed and presented a two-day training course for ERM offices nationwide.
Course included modeling fundamentals, application of models in regulatory settings, and overview of models used for accidental release modeling. Managed a fugitive dust quantification study for six coal-fired power plants to identify Title V emissions fees in Pennsylvania and West Virginia.

Managed the development of Title V permit applications for eight coal-fired generating stations in Pennsylvania.

Shwet Prakash

Water Quality Assessment Lead



Shwet Prakash is a senior consultant who has been managing and delivering water resources and modeling services to the oil & gas, power and manufacturing industry. He has been involved in developing state of the art chemical fate and transport models for a variety of water quality and transport applications. His experience over the last 10 years includes managing projects that include hydrodynamic studies, accidental oil spill studies, sediment transport and scour studies, TMDL development and regulatory permitting. Mr. Prakash has provided these services to most of the major oil & gas companies (ExxonMobil, BP, Shell, Chevron, Hess) and power companies (Exelon, PSE&G, Luminant, Progress Energy, Nebraska Public Power District) amongst others. The project site footprint includes Americas (US, Canada, Mexico, Brazil), Europe (Norway, Sweden, Turkey), Africa (Ghana, Angola, Sierra Leone, Uganda), Asia (Qatar, Saudi Arabia, Brunei, Malaysia, Indonesia, Thailand, China, Bangladesh) and Australia.

Fields of Competence

- Computational fluid dynamics
- 1-D, 2-D and 3-D numerical modeling of coastal and shelf processes including hydrodynamics and waves
- Chemical transport and fate and water quality modeling
- Ecological risk assessment
- Sediment transport modeling
- Particle tracking and entrainment modeling
- Groundwater modeling
- Programming in FORTRAN, C, Visual Basic and HTML
- Field data processing and analysis

Credentials

- M.S. (Civil Engineering), University at Buffalo, State University of New York, NY, February 2004
- B.S. (Civil Engineering), Indian Institute of Technology, Bombay, India, May 2001
- Watershed Management Training Certificate, The Watershed Academy, EPA
- Professional Development courses in Environmental Hydrodynamics and Sediment Transport Modeling with POM and ECOMSED, Stevens Institute of Technology, Hoboken, NJ

Key Industry Sectors

- Oil and Gas
- Electric Utility (fossil fuel, nuclear and hydropower)
- Harbors and Ports
- Industrial and Chemical
- Water supply and Wastewater Treatment
- Mining
- Marina design and water quality

Key Projects

Oil & Gas

Water Quality Impact Assessment from Onshore LNG Terminal Expansion, BP, Indonesia.
Managed a comprehensive modeling exercise to quantify environmental impacts related to expansion of an onshore LNG facility in Indonesia. Environmental risks associated to wastewater discharge, dredging, drill cuttings and mud discharge and pipeline hydrotesting were estimated using a 3-D hydrodynamic and transport model. Individual wastewater components were modeled and evaluated against relevant ambient water quality standards.

NRDA Computations, Gulf of Mexico, Confidential Client.

Oil Spill Response Planning and Impact Assessment for various clients and fields, offshore Malaysia.
Currently developing models to estimate the environmental impacts from accidental spills during the

operations of MOPUs and FSOs offshore Malaysia. Responsibilities include overall project management of these modeling projects that include three individual clusters.

Oil Spill Impact Assessment for confidential field development, offshore Western Australia.
Currently developing models to estimate the environmental impacts from accidental spills during the operations of MOPUs and FSOs offshore Australia. Responsibilities include overall project management of these modeling projects that include three individual clusters.

Sunrise Floating LNG Terminal, offshore Western Australia
Involved in modeling the environmental impacts from the operations associated with the proposed Sunrise floating LNG terminal located off the coast of Australia. Involvement included managing the modeling tasks that included thermal discharge modeling, oil spill modeling, PFW discharge modeling and water quality modeling. Findings of the modeling were submitted in a report for agency approval.

Prelude Floating LNG Terminal, offshore Western Australia
Involved in modeling the environmental impacts from the operations associated with the proposed Prelude floating LNG terminal located off the coast of Australia. Involvement included managing the modeling tasks that included thermal discharge modeling, oil spill modeling, PFW discharge modeling and water quality modeling. Findings of the modeling were submitted in a report for agency approval.

Keith Lake drilling fluid discharge model
Involved in the development of a near field Sediment Transport and Hydrodynamic model for Keith Lake, TX. The model application was aimed at analyzing the fate of drilling fluid released into the discharge pits as a result of Horizontal Directional Drilling (HDD) operation. The work included development of modeling cohesive sediment capabilities into GEMSS-STM. The analysis comprised of performing comparative study of the resulting turbidity plume for a varied set of lake flows, lake depths and material properties.

Entrainment Modeling for BP's Crown Landing Regassification Facility, New Jersey. BP proposed development of an LNG import terminal at Crown Landing on the Delaware River in Gloucester County, NJ. During vessel unloading while at berth, LNG carriers take on about 30,000 m^3 of water to maintain hydraulic stability when empty. Concerns exist regarding the entrainment effects and possible fishery losses due to this ballast water intake. Striped Bass, White Perch and Bay Anchovy are the species of concern since they consistently dominate the ichthyoplankton population in the Delaware River. ERM simulated intake effects using a high resolution hydrodynamic model to estimate entrainment rates for various life stages of these species of concern. These rates were used to estimate the loss of equivalent adults using a specialized module developed by ERM.

Buzzards Bay, MA Oil Spill modeling
Involved in development of an oil spill fate model for Buzzards Bay oil spill of April 27, 2003. The model was developed using GEMSS-COSIM (Chemical and Oil Spill Impact Module). The study required analysis of oil spill fate and its shoreline interaction under varying meteorological and hydrodynamic conditions.

Residual LNG Chlorine Study, ExxonMobil Research Qatar (EMRQ), Qatar. A residual chlorine discharge limit of 0.15 mg/L at the outfall was previously permitted by the Supreme Council for the Environment (SCE). At the edge of the mixing zone the residual chlorine concentration is not to exceed 0.01 mg/L limit. ERM was tasked to create a model simulating the chlorine plume discharged from the facility under these new conditions to verify compliance with standards and to modeling of residual chlorine and 15 chlorine by products discharged from the RasGas, Qatargas and RLCC outfalls into the Arabian Gulf. The chlorine model was successfully validated with an extensive field data set.

Mining

Water Quality Modeling for Diamond Mine Support in Snap Lake. ERM's Surfacewater Modeling Group developed hydrodynamic and water quality model for Snap Lake diamond mining operations. Modeling included past and future water quality impacts due to mining operations. Ice conditions were implemented to reproduce winter freeze and affects on the lake water quality.

Surfacewater Modeling for Support for Alberta Tar Sands Impact Assessment. ERM's Surfacewater

Modeling Group provided custom programming through its GEMSS modeling system to allow Cumulative Environmental Management Association (CEMA) estimate recovery time for tailings ponds. Key issues were rate of compaction, resulting morphodynamic changes and transfer of contaminants to surface waters.

Surfacewater Impacts for Marampa Iron Mine, Sierra Leone. ERM provided environmental impact assessment studies for the phased development planned for the Marampa iron ore mine proposed by London Mining. Project involved quantifying impacts due to dredging, minewater runoffs and accidental scenarios due to mining operations.

Water Quality

Lake Whatcom, Washington
ERM was tasked by Brown and Caldwell with evaluating the performance of the reservoir model component of the Lake Whatcom Nutrient Response Model (LWNRM). The LWNRM consists of the reservoir model (CE-QUAL-W2) and the watershed model (HSPF), which provides tributary flows and nutrient loads to the reservoir model. This model had been used to simulate nutrient water quality in the Lake for the two-year period 2002-2003, first to reproduce existing conditions (the calibration), then to simulate natural conditions, and finally to develop the Total Maximum Daily Load (TMDL). Because the TMDL process looks forward in time to predict improvements in water quality, ERM tested the model against field data for 2007-2008 and developed an alternative TMDL using loads for this two-year period. To do so, ERM developed new input files, made specific improvements in DO. It was desirable, therefore, to evaluate the model's performance against a dataset for another period. ERM performed the TMDL analysis for this new period to evaluate the projection capability of these TMDL estimates in to the future.

Budd Inlet Water Quality Modeling
Involved in the development of a carbon based water quality model for Budd Inlet and Capitol Lake, WA. ERM had done a similar study in 1998 for the Lacey, Olympia, Tumwater and Thurston County (LOTT) partnership for wastewater permitting. Current work includes improvement in the water quality calibration performed during the previous study along with the inclusion of Capitol Lake in the modeling domain.

Lower Passaic River Superfund Site Hydrodynamic and Contaminated Sediment Transport Modeling. This confidential study included analysis of current meter and water surface elevation data and modeling of the hydrodynamics and transport of sediments. The purpose of the study was to support our client, a PRP, in the interim allocation process and to help establish the magnitude of dispersal of material introduced into the prominent Newark Bay river-estuary system. This effort also included review of EPA- and Cooperating Parties Group-generated documents and datasets (particularly EPA's Framework Document and modeling reports), submission of comments, and attendance at Technical Committee meetings.

Delaware Bay TMDL
Developed and applied a hydrodynamic, transport and water quality model for Delaware Inland Bays. The objective of the study was to determine the TMDLs for the impaired waters on the State's 303(d) list for nitrogen, phosphorus, and DO within the Inland Bays of southern Delaware. These water bodies included Rehoboth Bay, Indian River, Little Assawoman Bay, and the surrounding tributaries and ponds. This analysis was accomplished using a hydrodynamic and water quality model GEMSS to verify the effectiveness of prescribed point and non-point source load reductions to meet the TMDL objectives.

Hydrodynamic Mixing Zone modeling of the confluence of the Nottawasaga River with Nottawasaga Bay
Involved in performing the hydrodynamic mixing analysis of Nottawasaga River with Nottawasaga Bay using GEMSS-HDM & GEMSS-WQM in support of developing future TMDL for the waterbodies. The work includes estimation of near field mixing zone and its effects on the local water quality. Study will also be done on estimating the extent of the Nottawasaga River mixing zone on various River loading conditions and the subsequent water quality in the near field Bay region.

Janey run mixing zone modeling
Involved in performing mixing zone analysis for a mine tailings discharge into Janey Run, MD. CORMIX was used to estimate the extent of the mixing zone during different tidal and non tidal conditions.

Charlotte Harbor water quality modeling

Involved in development of a Charlotte Harbor water quality model using GEMSS to analyze the relationship between physical and biochemical processes in the estuary. The analysis included study of phytoplankton effect on dissolved oxygen and investigation of the occurrence of hypoxia in the deeper regions of the harbor.

Roxboro power station thermal modeling
Involved in development of a hydrodynamic and thermal plume model for Lake Hyco, SC to analyze the thermal discharge from Progress Energy - Roxboro Generating Station. Updated GEMSS transport module with higher order transport schemes such as QUICKEST and QUICKEST+ULTIMATE to better estimate the stratification.

South Seas Marina Flushing Study
Modeled the South Seas marina for exchange of water with the open seas. It was found that the marina in its planned configurationdid not flush (replace) 90% of the water within 24 hours. Several improvements to the marina configuration were proposed and evaluated. It was found that a combination of widening and deepening of entry channel along with opening of one design breakwater will improve the flushing and increase the degree of exchange with the open sea.

Flushing and Water Quality Study for South Bethany
Assessed improvements to DO, nutrient levels, and other potential changes to the environment due to increasing ocean flushing into Delaware's Inland Bays (Indian River, Rehoboth Bay, and Little Assawoman Bay) using GEMSS HDM and WQM modules. Various methods of providing the flushing improvements and increasing the degree of exchange were examined including tidally driven inlets and pumping systems. Final recommendations were provided along with a cost-benefit analysis for the various options.

Monitoring of Harmful Algal Bloom (HAB) for Lake Ontario
Developed a three-dimensional free surface sigma co-ordinate hydrodynamic model for Lake Ontario based on Princeton Ocean Model (POM) for NOAA: MERHAB Lower Great Lakes. Also developed a Random walk particle-tracking model, to link with the hydrodynamic data to track the movement of algal blooms. Project also included analyzing the impact of Niagara River flow on the southern coastal region of the lake and on bloom movements. The overall goal was to setup a web page for real time simulations, where a user can specify the current bloom location and then monitor the trajectory.

Algae Transport & Water Quality model for Lake Ontario
Developed a FORTRAN based two-dimensional Dissolved Oxygen (DO) and algae transport model for Lake Ontario as a part of the Rochester Harbor project for the US Army Corps of Engineers (USACE) and URS Corporation. The models were developed to monitor the water quality and algae fate for analyzing the efficiency of "herd and pump" approach adopted to solve the algae accumulation at the Ontario beach. Also performed calibrations for the dispersion values in the lake using conductivity data. Submitted a final report on the analysis results to URS suggesting preferred pumping locations.

Sediment Transport

Purari Hydropower Sediment Transport Modeling.
Developed a hydrodynamic model in support of styding sediment transport in Purari River due to the construction of the hydropower facility. Modeling included assessment of net sediment fluxes, impacts on turbidity and evaluation of floodplain erosion.

Lower Passaic River Superfund Site Hydrodynamic and Contaminated Sediment Transport Modeling. This confidential study included analysis of current meter and water surface elevation data and modeling of the hydrodynamics and transport of sediments. The purpose of the study was to support our client, a PRP, in the interim allocation process and to help establish the magnitude of dispersal of material introduced into the prominent Newark Bay river-estuary system. This effort also included review of EPA- and Cooperating Parties Group-generated documents and datasets (particularly EPA's Framework Document and modeling reports), submission of comments, and attendance at Technical Committee meetings.

Thermal Modeling

Salem Generating Station Cooling Water Intake System improvements.
Salem Generating Station (SGS) withdraws water from Delaware Estuary its cooling water (CW) . Detrital material suspended in the Estuary is also drawn into the CW system. ERM's Surfacewater Modeling Group developed a high resolution hydrodynamic and particle

tracking model simulate the movement of detritus. It was found that approximately 40% of the grass collected at the intake structure comes from the grass disposed at the ends of the intake structure. Moving the disposal point from the ends of the intake structure to the CW outfall provided a large reduction in recirculation of grass. It was found that less than 5% of the disposed grass is recirculated to the intakes when it is disposed through the CW outfall. This result reflects an improvement of almost 90% compared to the current procedure (40% down to 5%).

Thermal Plume Modeling, RasGas LNG, Qatar. RasGas operates a liquefied natural gas (LNG) facility on the northeast coast of Qatar, discharging cooling water into the Arabian Gulf through an open canal. The RasGas facility originally consisted of a single LNG train that nominally circulates 27,500 m3/hr of seawater for heat exchanger cooling at a temperature rise of 10°C. RasGas subsequently added a second LNG train and proposed two additional trains. The objectives of this study were to model the thermal plume under existing and proposed operations including for model verification and mixing zone specification for the cooling water discharge plume. Model results showed that the thermal plume was vertically stratified, with a relatively large area on the surface and a relatively small bottom contact area. The advantage of the design was that it maximized heat exchange with the atmosphere, while protecting the benthic organisms from the temperature increase.

Susquehanna River hydrothermal modeling
Involved in the development of hydrodynamic model for Susquehanna River Brunner Island power plant using GEMSS-HDM in support of 316(a) renewal for the PPL Services Corporation, PA. Updated the GEMSS-HDM module for sigma stretching in vertical direction and model several connected waterbodies to accommodate for highly varying surface elevations. Also developed higher order turbulence closure schemes for vertical diffusion.

Ghana Thermal Modeling
Developed and applied a thermal discharge model, GEMSS®-TAM for the proposed TEMA Power Project located in an industrial area near Tema on the coast of Ghana. The Ghana Environmental Protection Agency (EPA) was imposes restrictions on the extent of the 3°C temperature rise isotherm which was modeled for three different plant configurations (two gas fired and one distillate fired). A probabilistic approach was applied to estimate the 3°C temperature rise isotherm under transient tidal conditions. Further model confirmation was done by setting up CORMIX in the near field. It was found that the maximum temperature rise at the surface was always less than 1°C. The 3°C temperature rise isotherm was found to be limited within the 8 m of the discharge port. Under all the proposed configurations, the plant did not violate the regulations imposed by the Ghana EPA.

Jobos Bay hydrothermal and entrainment modeling
Involved in development of a hydrodynamic model for Jobos Bay, Puerto Rico using GEMSS-HDM (Generalized Environmental Modeling System for Surface waters – HydroDynamic Module). The purpose of the modeling was to characterize the thermal plume from Aquirre Power station in support of <316(a)> study and to quantify entrainment rates of ichthyoplanktons in support of <316(b)> study. GEMSS-ENTM (Entrainment Module) was used for the 316(b) entrainment studies.

Temperature Forecasting System
Involved in the development of a temperature forecasting system for Nebraska Public Power District (NPPD), Sutherland, NE. NPPD has wells around its cooling water discharge canal that brings cold groundwater to reduce the heated cooling water used in power generating station. The temperature forecasting system was developed to help NPPD manage the operations of these wells based on the predicted temperature at the end of the canal. The forecasting system was an excel based software that takes waste heat load, flow, meteorological data and well flow data to predict temperatures.

Squaw Creek reservoir hydrothermal modeling
Involved in the development of hydrodynamic model for Comanche Peak Steam Electric Station located at Squaw Creek Reservoir, TX using GEMSS-HDM. The study was oriented towards evaluating the current and historical conditions during the plant full load and identifies different alternatives to decrease the intake water temperature. Several alternatives such as Spray modules, cooling towers and water garden steps were evaluated. Several enhancements to GEMSS were done to include modeling of such alternatives and analyzing their efficiency.

Hydropower

Purari Hydro Project, Papua New Guinea
Purari Hydro Project is a proposed hydroelectric power project aimed at providing electricity to Papua New Guinea, north and far north Queensland, and Australia's National Electricity Market. The project will have a capacity of 1,800 MW of baseload electricity. ERM is currently developing models to asses the impacts related to the development of reservoir on downstream water quality, sediment and hydrodynamic characteristics. The modeling work involves connecting in-reservoir models developed by Électricité de France and downstream impact models developed by ERM. The study is currently underway with models being developed in conjunction with field data collection.

World Bank, Trung Son Reservoir CE-QUAL-W2 Model Application and Software Training, Vietnam
Trung Son Reservoir is a proposed hydroelectric power project on the Trung Son River in central Vietnam for Vietnam Electric Utility (EVU). The client requested assistance with development and training with the 2-dimensional hydrodynamic and water quality model, CE-QUAL-W2. The goal was to assess the water quality of the proposed reservoir and the management options for clearing the flooded areas. The technology transfer took place as a 6-day intensive workshop presented in Nha Trang, Vietnam. The workshop achieved two objectives: the model was fully customized to the Tung Son Reservoir problem definition, and the client (fifteen engineers and scientists) were trained in the use and theory of the model.

Baynes Reservoir, Cunene River, Angola-Zambia
ERM applied two reservoir models to assess potential environmental impacts from the construction and operation of the Baynes Hydroelectric Reservoir on the Cunene River between Angola and Zambia. The primary impacts are (1) the change in the water temperatures in the reservoir and immediately downstream of the dam and (2) the potential for eutrophication in the reservoir. The U.S. Army Corps of Engineers CE-QUAL-W2 model was chosen to assess the impacts of the Project on the temperature structure of the Baynes Reservoir. The U.S. Army Corps of Engineers BATHTUB model was used to estimate its trophic status. Results of the models identified the range of surface water elevations through the year, vertical water temperature distribution and behavior, monthly average discharge water temperatures, and the effectiveness of discharge structure placement. The trophic status of the reservoir was projected to be oligotrophic due to the low level of nutrient loading.

Kalivaç Reservoir, Albania
ERM applied two reservoir models to assess potential environmental impacts from the construction and operation of the Kalivaç Hydroelectric Reservoir in Albania. The primary impacts are (1) the change in the water temperatures in the reservoir and immediately downstream of the dam and (2) the potential for eutrophication in the reservoir. The Generalized Environmental Modeling System for Surface Waters (GEMSS®) model was chosen to assess the impacts of the Project on the temperature structure of the Kalivaç Reservoir. The U.S. Army Corps of Engineers BATHTUB model was used to estimate the trophic status of Kalivaç Reservoir.

Publications

Prakash, S., Kolluru, V. and Young, C. "*Evaluation of the Zone of Influence and Entrainment Impacts for an Intake Using a 3-Dimensional Hydrodynamic and Transport Model*". Journal of Marine Science and Engineering 2014. Vol. 2, 306-325.

Febbo, E., Duggan, J., Kolluru, V. and Prakash, S. "*Integration of a Geospatial Framework with a Suite of Numerical Models for Operational, Environmental and Regulatory Aspects of Cooling Water Usage*". Proceedings of the 2014 International Petroleum Technology Conference, held January 20–22, 2014, in Doha, Qatar.

Mathur, Dilip, Royer, D.R., Long, K, Matty, R.M., Sullivan, T.J., Prakash, S. and Buchak, E.M. "*Retrospective analysis to quantify migration of American Shad in an impondment on the lower Susquehanna River*". Proceedings of the 2013 Georgia Water Resources Conference, held April 10–11, 2013, at the University of Georgia.

Saeed, S., Deb, N., Campbell, R., Prakash, S., Kolluru, V. and Febbo, E. "*Laboratory Experiments to Validate 3D Numerical Modeling of Chlorine Decay in Industrial Cooling Water Discharge*". SETAC Europe 23rd Annual Meeting. May 12th to May 16th, 2013. Glasgow, UK.

Prakash, S., Kolluru, V. and Tutton, P. "*Semi-Lagrangian Approach to Stydying Grassing Issue on a Nuclear Power*

Plant Cooling Water Intake". Proceedings of 10th International Conference on Hydroscence and Engineering. Nov. 4-7, 2012, Orlando, Florida.

Febbo, E.J., Kolluru, V.S. and S. Prakash. "*Numerical Modeling of Thermal Plume and Residual Chlorine Fate in Coastal Waters of the Arabian Gulf*". Society of Petroleum Engineering International Conference 2012. September 11-13. Perth, Australia.

Kolluru, V.S., S. Prakash and E. Febbo. 2012. "*Modeling the Fate and Transport of Residual Chlorine and Chlorine By-Products (CBP) in Coastal Waters of the Arabian Gulf*". The Sixth International Conference on Environmental Science and Technology 2012. June 25-29. Houston, Texas, USA.

Prakash, Shwet, J.A. Vandenberg and E. Buchak. 2012. "*CEMA Oil Sands Pit Lake Model".* CONRAD 2012 Water Conference. April 20-22. Edmonton, Alberta.

Kolluru, V.S. and S. Prakash. 2012. "*Source Water Protection: Protecting our drinking waters"*. India Water Week 2012. April 10-14. New Delhi, India.

Long, K., R.M. Matty, D. Mathur, D. R. Royer, T. Sullivan, S. Prakash and E. Buchak. 2011. "*Assessment of effects of interaction of pumped storage station operations and thermal plume on migration of American Shad (Alosa Sapisissuma) in the Lower Susquehanna River*. EPRI 2011. Third Thermal Ecology and Regulation Workshop. October 11-12, 2011. Maple Grove, Minnesota.

Prakash, S., J.A. Vandenberg and E. Buchak. 2011. "*The Oil Sands Pit Lake Model - Sediment Diagenesis Module."* MODSIM 2011. Modelling and Simulation Society of Australia and New Zealand, December 12-16, 2011. Perth, Australia.

Vandenberg, J.A., S. Prakash, N. Lauzon and K. Salzsauler. 2011. "*Use of water quality models for design and evaluation of pit lakes."* Australian Center for Geomechanics. Mine Pit Lakes: Closure and Management. Page 63-81.

Prakash, Shwet, Atkinson, Joseph F. and Mark L. Green. "*A Semi-Lagrangian study of Circulation and Transport in Lake Ontario*". Journal of Great Lakes Research. Volume 33, Issue 4, 2007, Pages 774–790.

Kolluru, V.S., M.J. Fichera, S. Prakash. 2006. "*Multipurpose modeling tool for aquatic and sediment contaminant fate and effect assessments*". SETAC North America 27th Annual Meeting. Montreal, Canada. November 2006.

Prakash, Shwet and V.S. Kolluru, 2006. "*Implementation of higher order transport schemes with explicit and implicit formulations in a 3-D hydrodynamic and transport model*."published in the 7th International Conference on Hydroscience and Engineering (ICHE 2006), Sep 10 - Sep 13, Philadelphia, USA

Hubertz, J.M., Prakash, S., Krallis, G. and Venkat Kolluru. "*Relationship between Physical and Biochemical Processes in an Estuary"*. 7th International Marine Environmental Modeling Seminar. 2004.

Michael J. Fichera

Senior Water Quality Specialist



Mr. Fichera is a senior project engineer with experience since 1993 in water quality and oil spill modeling, natural resource damage assessments (NRDA), risk assessment, and project management. He is skilled in modeling hydrodynamics, oil spills, dredge disposal / drill cutting transport, thermal plumes, water quality, eutrophication, toxicity, and food web simulations.

His oil spill modeling experience has been applied in response to major accidents for live trajectory predictions and injury estimations, for investigating potential origins of mysteriously oiled shorelines, and for predicting impacts due to hypothetical spills for environmental impact assessments. He has estimated impacts due to dredging in ship channels and from the release of mud and drill cuttings from offshore oil exploration.

Mr. Fichera has performed water quality modeling to estimate impacts due to nutrient runoff load increases from proposed residential development; establish nutrient TMDLs; characterize flushing improvements for stagnant water bodies; and aid permitting of a new discharge location for a phosphorus mine.

Modeling experience includes CORMIX, CE-QUAL-W2, EFDC, VPLUMES, QUAL-2k, and ERM's GEMSS model including expertise in its oil spill module COSIM and dredge / drill cutting module, GIFT. He has performed field measurements of water quality and designed a CSO stormwater sampling program.

Registration

- Professional Engineering License, Delaware, 1998
- Engineer in Training Certificate, New York, 1991

Fields of Competence

- Environmental Engineering
- Oil Spill Modeling
- Drilling Mud and Cuttings Modeling
- Water Quality Modeling
- Environmental Chemistry

Credentials

- M. E., Environmental Engineering, Manhattan College, 1993
- B. S., Civil Engineering, Manhattan College, 1991

Professional Affiliations

- Society of Environmental Toxicology and Chemistry (SETAC)
- Hudson Delaware Chapter of SETAC (HDC-SETAC)
- Inland Bays Scientific Technical Advisory Committee (STAC)
- Water Environment Federation (WEF)
- Chi Epsilon Civil Engineering Society
- Tau Beta Pi Engineering Society

Key Projects

For a strategic initiative to develop a model to estimate the exposure, duration, and potential toxicological impacts of oil and chemical spills, worked to construct the Chemical / Oil Spill Impact Module (COSIM). The module, a plug-in component of ERM's Generalized Environmental Modeling System for Surfacewaters (GEMSS), was designed for use for emergency response, emergency planning or hindcasting. Within the GEMSS framework, COSIM can produce simulations of the fate and transport of the various oil constituents and produce 3-D visualizations and animations.

Performed oil spill and drill cuttings deposition modeling for Environmental Impact Assessments (EIA) for over 50 projects around the world including Argentina, Colombia, Guyana, around the African coast (including Algeria, Morocco, Mauritania, Ghana, Nigeria, Gabon, the Democratic Republic of the Congo, Angola, and Mozambique), northern and western Australian coasts, Southeast Asia (including Malaysia, Brunei, Sulawesi, Vietnam), New Zealand, Italy, and in the Gulf of Mexico.

Provided marine oil spill models for BP's terminals and pipelines as part of regulatory compliance with Washington State Dept. of Ecology and internal Oil Spill Preparedness & Response plans.

Performed a baseline oil spill study for the Aleutian Islands Risk Assessment (AIRA). The goal of this study was to produce a comprehensive evaluation of the risk of vessel accidents and spills in the Aleutian Islands, with the ultimate goal of identifying risk reduction measures that can be implemented to improve the level of safety related to shipping operations in the region.

Assessed the fate, transport, and toxicity of oil during several major US oil spills for Natural Resource Damage Assessments (NRDA). Performed modeling processes concurrently with trustee-appointed modelers to facilitate the cooperative process. Assessed potential aquatic injuries associated with dissolved polyaromatic hydrocarbons (PAHs) in the water column. Designed and directed laboratory oil toxicity experiments. Major c NRDA projects include:

- September 1999 release of IFO-180 oil from the Dredge *M/V Stuyvesant* barge accident off the coast of Humboldt Bay, California
- April 2000 PEPCO Oil Spill, Chalk Point, Maryland approximately 140,000 gallons of a No. 2 / No. 6 fuel oil mixture into the Patuxent River
- April 2003 Bouchard B-120 accidental release of an estimated 98,000 gallons of No. 6 fuel oil into Buzzards Bay Massachusetts
- June 2006 Citgo Lake Charles pipeline rupture, releasing an estimated 53,000 barrels of waste oil into the Indian Marais and Calcasieu Rivers
- April 2010 BP MC-252 Gulf of Mexico blowout and oil spill

Performed NOAA NRDAM/CME ("Type A") oil spill modeling to assess fate, transport, and potential for natural resource damages and water column injury resulting from several oil spills, including the 1997 Texaco Lake Barre, LA oil spill, and the 2004 Bright State freighter vessel collision on the Mississippi River.

Utilized the NOAA Type A oil spill model for three oil releases resulting from Hurricane Katrina for a screening assessment of the magnitude of aquatic and wildlife injuries that may have resulted.

Performed rapid oil spill assessments of the fate, transport, and potential for natural resource damages during the Viking Lady Oil Spill, Casco Bay, Maine.

Provided emergency response site assessment for shoreline oiling and potential injury to local biota for the Port Mobil Explosion and Oil Spill, Staten Island, New York.

Managed hydrodynamic / water quality modeling of the Delaware Inland Bays for TMDL analysis upon impaired waters on the State of Delaware 303(d) list. Modeling included linkage to USGS HSPF model for model input of non-point source loads.

Utilized food chain modeling from sediments, plankton, fish, and birds to determine pesticide contamination liability.

Designed and managed a sediment chemistry survey / toxicity identification evaluation (TIE) for a U. S. Superfund site.

Created an acid attenuation model to estimate the fate and transport of an acidic leak into an aquifer.

Melinda K. Todorov

Senior Marine Scientist



Ms. Melinda Todorov is a Project Scientist within ERM based in Annapolis, Maryland. She has nine and a half years of experience in impact assessment and an additional four years experience in the field of aquatic ecology, including studies of marine invasive species. Her responsibilities have included assisting in the preparation of Environmental Assessments, Environmental Impact Statements, and Integrated Natural Resources Management Plans under the National Environmental Policy Act (NEPA) and other U.S. and international regulations. She specializes in analysis of impacts on biological and water resources. As part of her NEPA experience, Ms. Todorov has assisted in the management of the collection and response to public comments.

Ms. Todorov has field experience with both marine and freshwater systems as well as wetlands. She has assisted in conducting wetland delineations and habitat assessments. In addition, she has provided support for planning and sustainability projects and studies as well as prepared wetland permits.

Fields of Competence

- NEPA implementation
- Environmental Impact Assessments
- Aquatic ecological studies including statistical analysis and macrozooplankton taxonomy and sampling

Education

- M.Sc. Aquatic Ecology (ISATEC), University of Bremen, Germany, 2001
- B.S. Biology, Central Michigan University, 1999

Certificates

- National Environmental Policy Act (NEPA) Certificate, Duke Environmental Leadership Program, Duke University, 2008 – 2012
- 40-hour HAZWOPER, Compliance Solutions, 2010

Languages

- English, native speaker
- German, conversational

Publications

Bednarski, M., Morales-Ramírez, A. 2004. Composition, abundance and distribution of macrozooplankton in Culebra Bay, Gulf of Papagayo, Pacific Coast of Costa Rica and their value as bioindicators of pollution. Revista de Biología Tropical 52 (3A): 105-120.

Cahill, M., K. Olsen, D. Blaha, J. Tims, A. Finio, M. Todorov, J. Ewald, J. Primo, L. Medley, D. Bigger, K. Skrupky, B. Hooker, B. Jordan and A. Dhanju. Atlantic Wind Energy Workshop Summary Report. U.S. Department of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement. Herndon, VA. OCS Study BOEMRE 049- 2011. 78 pp. + apps.

Key Projects

NorthMet Mine EIS, Minnesota, US, Minnesota, Department of Natural Resources, US Army Corps of Engineers, and US Forest Service
Provided project support for preparation of the Draft Environmental Impact Statement (EIS), Supplemental Draft EIS (SDEIS), and Final EIS (FEIS) for a 32,000 tpd open-pit polymetal sulfide mine in Minnesota. Co-authored and coordinated the preparation the water resources chapters of the Supplemental DEIS, including data verification and integration. Deputy task manager of SDEIS public comments process. Subject Matter Expert and lead for Aquatic Resouces chapters as well as Water Resources team coordinator for FEIS.

Keystone XL Pipeline Supplemental Environmental Impact Statement, US
Assisted in preparation of the Supplemental Environmental Impact Statement (SEIS) as well as comment identification and comment response. This highly visible SEIS was completed at an accelerated pace for the U.S. State Department..

Nicaragua Canal Environmental and Social Impact Assessment, Nicaragua, HKND Nicaragua
Provided project support as needed, including coordination of the preparation of the Terms of Reference, Data Gaps report, and section on climate change impacts to biodiversity. Reviewed the Emergency Response Plan for field teams and created a database for worker health and safety survey.

Rosebel Gold Mines Tailing Storage Facility Expansion ESIA, Suriname, IAMGold
Assisted in the preparation of Terms of Reference and Environmental and Social Impact Assessment (ESIA) for the gold mine tailings storage facility expansion project. Authored sections on Legal Framework and Impact Assessment Methodology.

Weda Bay ESHIA, Indonesia, Mining and Metals Sector Client
Assisted in the preparation of an Environmental Social and Health Impact Assessment (ESHIA) for construction and operation of a nickel and cobalt mining operations and an ore processing plant in Central and East Halmahera, North Maluku in the Indonesian archipelago. Supported development of the terrestrial resources chapters and ecosystems services report.

Buckeye Wind Project Environmental Impact Statement, Ohio, US, Buckeye Wind L.L.C.
Assisted in the preparation of the Draft EIS for construction and operation of a 250 MW wind facility in Ohio. Performed data analysis to update avian and bat fatality estimates for cumulative effects discussion.

Columbia Gas Pipeline, Line MB Extension Environmental Assessment, Maryland, U
Assisted in the preparation of an Environmental Assessment (EA) for construction and operation of a gas pipeline. Supported development of alternatives and cumulative effects chapters.

Nassau Plateau Bauxite Mine ESIA, Suriname, Suralco
Assisted in the preparation of an Environmental and Social Impact Assessment (ESIA) for a new bauxite mine on the Nassua Plateau in Suriname. Supported development of biological resources and legislative chapters.

Environmental Impact Assessment Survey, Government (non-US) Client
Completed several surveys covering the National Environmental Policy Act (NEPA) process in the United States. Topics included public involvement, security of documents, mitigation and monitoring requirements, and the differences between programmatic and project EISs.

Crown Landing LNG Terminal, New Jersey, US, BP America
Assisted in the preparation of application materials for LNG terminal to the Federal Energy Regulatory Commission (FERC) and other government agencies. Supported project by updating resource reports, compiling application materials, and assisting in ichthyoplankton data interpretation.

Environmental Impact Statement, Massena, New York, US, Mining and Metals Sector Client
Assisted in the preparation of the state-level Environmental Assessment to comply with the New York State Environmental Quality Review Act (SEQRA). Prepared the Socioeconomic and Transportation sections of the report.

Peyun Kok

Socioeconomic and Community Health Specialist



Peyun Kok is a Community Health and Social Specialist with ERM's Impact Assessment & Planning practice in Houston, TX. With training in Biology, Environmental Studies and Health Policy Research, Peyun specializes in assessing interconnected health, social and environmental impacts of development projects and helping clients mitigate associated risks. Since joining ERM she has conducted social and health baseline studies, impact assessments and due diligence assessments for a diverse range of projects in the United States, South and Central America, and Africa.

Prior to joining ERM, Peyun conducted situational assessments, baseline studies and impact assessments of communities affected by gold and bauxite mining activity in Suriname, including extensive field research at mining camps in the country's interior. She also worked on developing tools, policy and practices to assess the community health and safety impacts of urban and suburban development projects in Canada.

Peyun has worked for Health Canada, the Region of Peel's Public Health department, the Pan-American Health Organization Suriname and the Commissie Ordening Goudsector (Commission to Regulate the Gold Sector - Suriname).

Fields of Competence

- Social and health baseline studies
- Environmental, social and health impact assessment
- Environmental and social due diligence assessments
- Quantitative, qualitative and geospatial analysis
- Development of research frameworks and methodologies
- Stakeholder analysis and engagement
- Development of social investment strategies
- Policy analysis and development
- Public health program planning and evaluation

Education

- Master in Environmental Studies (Urban and Regional Planning). York University, Canada, 2009
- Graduate Diploma in Health Services and Policy Research. Ontario Training Centre in Health Services and Policy Research, Canada, 2009
- Hon B.Sc. Biology, University of Toronto, Canada, 2005.

Languages

- English (native)
- French (proficient)
- Spanish (intermediate)

Key Industry Sectors

- Oil & Gas
- Mining
- Chemical
- Transportation Infrastructure
- Government
- Public Health

Countries Worked In

- Canada
- Suriname
- Guyana
- Taiwan
- United States

Key Projects

Biofuels Site Selection Study and ESHIA, Confidential Oil and Gas Supermajor, United States, 2014-2016
ERM has provided support to a confidential O&G supermajor since 2014 in planning for the development of a proposed biofuel facility in the U.S. ERM has conducted site selection, permitting strategy, impact assessment and stakeholder engagement support for the Project as it has progressed through early stages of planning and decision-making.

ESHIA for chemical facility on the U.S. Gulf Coast, Confidential Client, Texas, 2016
ERM is currently conducting an ESHIA effort for development of a new chemical manufacturing facility and associated waste disposal wells in a coastal Texas location.

Climate Change Adaptation in Mozambique's Health Sector, World Bank, 2016
ERM was engaged to assist the Word Bank and Mozambique's Ministry of Health (MISAU) in furthering understanding on the linkages between climate change and health in the country, and in developing protocols to standardize and streamline emergency preparedness and response to climate change events among the country's provinces and districts. The analysis included GIS mapping and regression analysis to understand correlations among different climate factors and health outcomes at the district level in Mozambique.

FERC Public Participation Planning and Socioeconomic Studies for LNG Export Terminals on the U.S. Gulf Coast, Confidential Clients, Louisiana, 2015-2016
ERM has been assisting several LNG clients in coastal Louisiana with regulatory-driven stakeholder engagement and environmental review requirements, including development of Public Participation Plans and socioeconomic studies (FERC Resource Report 5).

Environmental, Social and Health Impact Assessments, Offshore Exploration Campaigns in the Mexican Gulf of Mexico, Various Geophysical Data Companies, 2015
ERM assisted a number of geophysical data companies in conducting voluntary and mandatory impact assessments for deepwater offshore seismic, multibeam and coring activities in the Gulf of Mexico. The assessments were conducted in the context of continued regulatory uncertainty and change given Mexico's ongoing Energy Reform. A major aspect of these projects was therefore continual communication with regulatory authorities to help clients successfully navigate new and changing requirements.

Mexico Country Entry Non-Technical Risk Screening, Confidential Oil and Gas Supermajor, United States, 2014-2015
In light of Mexico's Energy Reform, a confidential client wished to understand the sources of non-technical risk associated with onshore oil and gas development. NTR sources examined included personal security, corruption, organized crime, environmental liability.

Nicaragua Grand Canal and Development Project ESHIA, Hong Kong Nicaragua Canal Development Company, Nicaragua, 2014-2015
This ESHIA involved extensive research planning to ensure collection and integration of relevant primary and secondary information sources to form a picture of the social and health conditions in diverse communities along a 270-km linear infrastructure project. Tasks included stakeholder engagement planning, research planning, development of data collection tools, data analysis, social baseline development and assessment of social impacts, including cumulative impacts accounting for future climate change.

Strategic Marcellus Shale ESHIA, Confidential Oil and Gas Supermajor, United States, 2014-2015
This ESHIA was conducted to characterize baseline conditions in a 26-county area in the Marcellus Shale, as well as providing a preliminary understanding of the likely impacts of the client's potential future development in the region. Tasks included development of a community health baseline, as well as assessment of likely health impacts.

Country Entry Strategy Stakeholder Analysis Report, Confidential Oil and Gas Supermajor, Angola, 2014
This project involved the compilation of a detailed stakeholder registry and report providing characterization and analysis of stakeholder influence, interest, stance and relationships to support an oil and gas major's early entry strategy to an African country. .

Environmental, Social, Health & Safety Performance Review of a Power Facility, Confidential Power Company, Peru, 2014
This project involved an audit of the social, environmental and health & safety aspects associated with the final stage of construction of a power facility in Peru against the Equator Principles and IFC Performance Standards. Tasks included review of documentation provided by the project proponent and its contractors, data from interviews with onsite personnel, and observations from the construction site to identify social, environmental and health & safety issues requiring improvement.

Case Studies of Climate Change Adaptation, Inter-American Development Bank, Honduras and Nicaragua, 2013
The main objective of this project was to support the process of increasing climate change adaptation capacity in communities in Central America, particularly with respect to water resources management. This included a focus on identifying and laying out future potential investment projects for the IADB in the area of adaptation and resilience. Specific tasks included development of community hazard profiles, and application of community vulnerability assessment criteria used to identify, compare and characterize areas of particular vulnerability to climate change hazards.

Confidential Project Community Health Study, Confidential Oil and Gas Supermajor, United States, 2013
This study was conducted to obtain an in-depth understanding of baseline community health conditions and concerns in the vicinity of the proposed site for a major capital project. Tasks involved primary data collection in the form of interviews with health and social service providers and public safety officials, as well as collection and analysis of secondary health surveillance data and compilation of a final health baseline report.

Gulf of Mexico 5-Parish Social and Health Baseline and Stakeholder Engagement Plan, Confidential Oil and Gas Supermajor, United States, 2013
This project involved development of detailed social and health baseline studies for five coastal Louisiana parishes falling within the footprint of the client's future Gulf of Mexico offshore operations. Specific tasks included collection, integration and analysis of various sources of health surveillance, health financing, hospital, and social indicator data to provide a baseline characterization of health status, vulnerabilities and health services in each parish. Baseline findings were then used in the development of both parish-level and regional stakeholder engagement plans and social investment strategies.

Eagle Ford Shale Gas SHIA, Confidential Oil and Gas Supermajor, United States, 2012-2013
This project was a social and health impact assessment for a shale gas operation in South Texas. Tasks included desktop research, baseline report writing, and assessment of social and health impacts on residential communities in the vicinity of the Project site.

Strategic Plan for the ASGM Sub-sector, Suriname, Ordening Goudsector, 2012
This project consisted of developing a five-year strategic plan for the artisanal and small-scale gold mining sub-sector in Suriname. Tasks included background research, gap analysis, report writing and stakeholder engagement activities such as key informant interviews, public opinion focus groups and a 2-day participatory stakeholder workshop.

Situational Assessment of the ASGM Sub-sector, Suriname, Ordening Goudsector, 2011-2012
Managed and executed the development of a policy-oriented research report to fill gaps in information on health, socio-economic and environmental security issues in the lives of artisanal and small-scale gold miners in Suriname. Tasks included background research and literature review, development of conceptual model and research design, development of interview guide and survey instrument, primary data collection and analysis, generation of recommendations, and report-writing.

Feasibility study and options analysis for mining residual bauxite deposits, Suralco, Suriname, 2011
Assisted with the production of a report and analysis of relocation options to mine residual bauxite deposits adjacent to a Maroon community in Marowijne, Suriname. Tasks included background research, secondary data analysis, generation of recommendations and report writing.

Dusty Insley

Geological Resource Specialist



Ms. Insley is a project manager in ERM's Annapolis, Maryland office, with over five years of professional experience in environmental consulting. She is primarily active in the Site Investigation and Remediation practice at ERM.

Ms. Insley's professional experience includes Phase II Site Assessments of various types of active and inactive commercial and industrial facilities in Maryland, Virginia, and West Virginia. She has also worked on several sites that have been entered into the Maryland Voluntary Cleanup Program, West Virginia Voluntary Remediation Program, and RCRA program, both as a project geologist and as a project manager. Additional experience includes conducting, coordinating, and managing regular ground water monitoring events at various sites.

Ms. Insley is proficient in various types of sampling techniques for soil, ground water, and air (i.e., soil gas, sub-slab vapor and ambient indoor and outdoor air). Additionally, Ms. Insley holds extensive experience overseeing the installation of monitoring wells and piezometers using hollow stem auger, air rotary, wet rotary, mud rotary, and hydraulic direct-push drilling techniques. Ms. Insley also manages large volumes of chemical data in spreadsheet and database formats.

Registrations & Professional Affiliations

- National Ground Water Association

Fields of Competence

- Hydrogeology
- Geochemistry
- Environmental sampling (soil, surface water, ground water, soil vapor, sub-slab vapor, indoor air)

Key Industry Sectors

- Site Remediation and Investigation
- Mining and Minerals
- Oil and Gas
- Chemical Manufacturing

Education & Training

- B.S., Geology, Cum Laude, University of Maryland, 2006.
- 40-Hour OSHA Health and Safety Training for Hazardous Material Operations and Emergency Response, Current on Annual 8-Hour Update

Languages

- English, native speaker

Publications

Aeiker, D.M., Mansur, A.T., Rudnick, R.L., Piccoli, P.M., McDonough, W.F., *Deducing the depth of origin of granulite xenoliths from zircon-rutile thermometry: a case study from Tanzania*. Abstract V41A-03, 2006 AGU Joint Assembly, May 2006, Baltimore, MD.

Key Projects

Former CREO Manufacturing Plant Landfill Monitoring, Middleway, West Virginia. NPEC. Project Manager overseeing the semi-annual sampling of a closed industrial landfill under a West Virginia Landfill Permit and the semi-annual sampling of storm water outfalls under a West Virginia National Pollutant Discharge Elimination System (NPDES) Water Pollution Control Permit. Updates and maintains a DumpStat database for the landfill and generates statistical graphs of monitoring data in compliance with state reporting requirements. Completes NPDES monitoring reports and summary reports for landfill and storm water semi-annual sampling.

USEPA Region III RCRA Corrective Action Support, Winchester, Virginia. Federal-Mogul Corp. Oversaw the installation of injection, recovery, and monitoring wells. Collected ground water samples from wells utilizing low-flow sampling techniques and a multi-parameter probe. Conducted aquifer tests on injection and recovery wells to determine the hydraulic conductivity of the aquifer. Coordinated and conducted a dye trace study to determine ground water flow direction. Provides oversight during injection events, and completes quarterly reports in compliance with state reporting requirements.

USEPA Region III RCRA Corrective Action Support & Corrective Measures Study, Salisbury, Maryland. Dresser Industries, Inc. Coordinates and conducts soil and ground water sampling activities at a former manufacturing facility. Recent activities include coordinating the delineation of an LNAPL plume using direct-push technologies, coordinating a ground water quality vertical delineation using direct-push technologies, installing monitoring and injection wells as part of the *In Situ* Chemical Reduction (ISCR) Interim Corrective Measure (ICM) to address hexavalent chromium impacts in soil and ground water, and coordinating the sampling of all on-site monitoring wells. Assisted in the preparation of documents for submission to the U.S. Environmental Protection Agency (USEPA) as part of ongoing steps to complete the corrective action process for the facility.

Gardiner Road Water Level Monitoring, Charles County, Maryland. Chaney Enterprises. Project Manager overseeing the quarterly water level monitoring as part of the Charles County Board of Appeals approval for the mining operations. Updates and maintains water levels tables and generates quarterly isocontour maps of the water table surface in compliance with County reporting requirements.

Site Characterization at a Former Manufactured Gas Plant, Hagerstown, Maryland. NiSource. Coordinated and conducted field efforts for the site characterization of a former manufactured gas plant site and surrounding properties in Maryland. Investigation activities included electrical resistivity survey to identify an area in which MGP residual tar was placed, direct-push and split-spoon sampling, soil gas sampling, and overburden and bedrock well installation.

Former CREO Manufacturing Plant West Virginia Voluntary Remediation Program Application Support, Middleway, West Virginia. NPEC. Conducted a supplemental assessment of environmental media associated with an industrial site situated in a karst region in West Virginia. Assessment included the characterization of soil throughout the site, characterization of sediment and surface water in bordering streams, and installation of a deep bedrock well. Also collected indoor air samples using Summa® canisters to characterize the nature and extent of Volatile Organic Compounds (VOCs) in indoor air. Determined whether VOC sources in soil and ground water affect indoor air quality.

Ground Water Quality Evaluation, Crofton, Maryland. PPRP - BBSS Fly Ash Site. Assisted in the management and interpretation of geochemical data collected from compliance monitoring wells and residential supply wells surrounding the former mine sine. Used statistical analysis to demonstrate that heavy metals leached from the fly ash used to reclaim the mine were impacting water quality in the down-gradient vicinity of the mine.

Jonathan P. Connelly

Biological Resource Specialist



Mr. Connelly is a Project Scientist within the Impact Assessment and Planning (IAP) Practice at ERM in Annapolis, Maryland. He has approximately 12 years of environmental consulting experience and has worked on numerous domestic and international projects. Since joining ERM in 2011, Mr. Connelly has been a member of the Biodiversity and Ecosystems Services Practice and is well versed in the principles of biology with a focus on terrestrial and wetlands ecologies, and impact assessments. Mr. Connelly has focused on conducting desktop and site reconnaissance for the preparation of Environmental Assessments, Environmental Impact Statements, Environmental and Social Impact Assessments, and permit preparation.

In addition to these roles, Mr. Connelly is skilled in geographic information systems (GIS) for spatial analysis, and database management, especially within the context of managing the receipt, organization, and response to stakeholder input on large scale, controversial projects.

Fields of Competence

- Environmental Impact Assessment
- Habitat and vegetation inventories
- Environmental Permitting
- Environmental regulations and policy research
- Biological Sampling including plant identification and collection; quantitative and qualitative fish community survey methods; fish shocking/netting/catching
- Water quality sampling
- Geographic Information System (GIS)
- Aerial photograph, landscape feature, and habitat interpretation
- Spreadsheet data management

Training & Certifications

- Qualified Professional in Maryland: Forest Stand Delineations and Forest Conservation Plans, 2013
- Pennsylvania State University College: Post-baccalaureate Certificate in Geographic Information Systems, Pennsylvania, 2015
- American Red Cross: Adult First Aid/CPR/AED, May 2016-2018
- 40-hour HAZWOPER, Compliance Solutions, 2016

Education

- Post-baccalaureate Certificate in Geographic Information Systems, PennState University, 2015
- University of Massachusetts – Graduate Course: Soil Sciences, Amherst, MA, 2009
- B.A. in Environmental Studies, Eastern University, PA, 2003

Key Projects

ExxonMobil Strategic Environmental Assessment (SEA) for Offshore Drilling, Guyana, 2014-2015.
Provided project and GIS support for the preparation of a Strategic Environmental Assessment (SEA) for the exploration of offshore petroleum resources along the Guyana coast. Assisted in the development of a Coastal Sensitivity and Spill Response Plan with use of digital and non-digital data in ArcGIS.

Preliminary Environmental Impact Assessment (PEIA) for a Gas-Powered Power Plant, Nigeria, 2015.
Provided project support for the preparation of a PEIA for a proposed Power Plant expansion project in Nigeria. Provided general GIS and spatial analytical support for noise sensitive receptors in and around the Project Site. Conducted research and review of applicable international, national, and local environmental rules

and regulations. Authored the ecological baseline and impact assessment sections.

Proton Energy Environmental and Social Impact Assessment (ESIA), Sapele, Nigeria, 2016. Provided general GIS and spatial analytical support for a proposed gas-fired open cycle power plant. Provided figures of surrounding noise sensitive areas and their approximate distances from the proposed Project.

Nassau Plateau Bauxite Mine, ESIA, Alcoa, 2011-2012. Assisted with the feasibility assessment for a proposed bauxite mine at a greenfield site in central Suriname. Supported development of biological resources chapters by assisting in report writing and fieldwork. Evaluated streams and rivers in the vicinity of the proposed project to collect fish, macroinvertebrate, and sediment samples for analysis of metals. Utilized ArcGIS to provide spatial analysis for the distribution of rare, threatened, and endemic fishes located within the concession boundary.

Alcoa and Rio Tinto Alcan (Alcoa-RTA), Kabata Alumina Refinery ESIA, Guinea, 2013. Assisted in the preparation of an ESIA for the construction of an Alumina Refinery Project in Guinea. Developed habitat and vegetation coverage GIS data within the project area based on a combination of remote data interpretation and biological data collected in the field. Conducted spatial analysis of project-related habitat conversions and mapped protected areas.

Nicaragua Canal Project ESIA, Nicaragua, 2013-2015. Collaborated with multiple GIS professionals across ERM Offices for the collection and organization of field data. Assisted with the integration of the data into GIS for biodiversity-related figures for an ESIA report. Created numerous rare and threatened species figures associated with the ESIA.

Fiat-Chrysler, Michigan, US, Biodiversity Study. Performed a Biodiversity Value Index Study within a 35 square mile radius of a Chrysler Engine Plant Site in Trenton, Michigan. Conducted a biodiversity characterization of the study area through seasonal field surveys of habitats and wildlife species.

NorthMet Mine EIS, Minnesota, US, Minnesota Department of Natural Resources, 2012-2013. Provided project support for preparation of an EIS and Supplemental EIS for construction and operation of a mining and processing operation in northeastern Minnesota (US). Verified water quality data and synthesized these data into a summary subsection of the water chapter in the EIS.

SEIS Keystone XL Pipeline, USA. 2012-September 2013. Assisted with the organization and categorization of stakeholder comments on the Keystone XL Pipeline during the scoping process. Utilized Microsoft Access to organize by topic area and content to enhance the accuracy and thoroughness of the comment review process. Utilized GIS to compile data on private land ownership and home locations along the Project's alternative routes. Supported the socioeconomic component of the alternatives analysis by analyzing the number and location of homes that would be affected by each location of the alternative alignments.

Environmental and Social Impact Assessment (ESIA), Wageningen, Suriname, 2012-2013. Utilized ArcGIS to organize data to depict field survey data during the baseline field studies. Created multiple GIS data of habitat- and vegetation-types within the Project area based on remote sensing data and biological data collected in the field. Provided spatial analysis of Project-related habitat conversions and mapped protected areas adjacent to the Project site. Assisted with writing of the baseline and impact assessment for terrestrial ecology and wildlife species for the ESIA.

ESIA, Mining Project, Weda Bay, Indonesia, 2012. Assisted in the preparation of an ESIA for construction and operation of a nickel and cobalt mining operations and an ore processing plant in Halmahera, North Maluku in Indonesia. Co-authored the vegetation impact assessment based on the spatial analysis of direct and indirect effects on vegetation coverage within the Project area. Supported development of the terrestrial resources chapters, ecosystems services report, conducted online literature reviews to support the impact assessment, and updated GIS figures.

Michael Fraser

Technical Director



Mike Fraser is a Principal Consultant in the ERM Acoustics Team in the UK. He joined ERM 20 years ago after working for in acoustic consultancies in the UK and in Australia. Mike has worked globally on Environmental Assessment projects around the world. He has experience of various projects including Oil and Gas developments, seismic exploration, pipe laying, dredging, offshore windfarms, ports and power projects.

Mike is experienced in modelling using empirical and detailed noise models of underwater noise propagation, and the assessment of the effects of noise on marine fauna. He works extensively with ERM's in-house marine specialists, and internationally recognised external specialists in the field of underwater noise monitoring, prediction and assesssment.

Mike has been responsible for developing ERM's Marine Noise Exposure Tool, which is now being used successfully to manage clients' risks regarding underwater noise, and has recently been used to carryout detailed modelling successfully on a series for projects in the last two years for clients including Shell, BP, PG&E, Statoil, Tullow Oil, ENI, Repsol and Capricorn.

Education

- BSc Electroacoustics - University of Salford UK.

Professional Affiliations & Registrations

- Member of Institute of Acoustics (MIOA)

Languages

- English, native speaker

Key Industry Sectors

- Oil and Gas

Key Projects at ERM

Underwater Noise Assessment of FLNG development Africa, Confidential Client
Mike led the team in modelling and assessment of underwater noise impacts from the FLNG development project including drilling and operational phases.

Underwater Noise Assessment of Offshore Drilling Project in Gabon, Shell
Mike was technical reviewer for ERM's underwater noise assessment for this exploration drilling project.

Environmental Impact Assessments for Exploration Drilling in Offshore West Greenland, Capricorn Energy-1: the exploration arm of Cairn Energy Plc
Mike undertook noise assessment of the effects of underwater noise on marine mammals and fish from multiple drilling sites as part of the 2011 drilling campaign off the coast of Greenland. He has considered the effects of dynamically positioned drill ships and semi-submersible rigs with support vessels.

Shtokman Oil and Gas Project, Shtokman Development AG
Mike undertook and assessment of the effects of this major natural gas project in the Russian Sector of the Barents Sea; conducted a review of the drilling, pipeline and FPSO. The assessment also included service and export harbour construction.

Pipeline Extension to Wellhead, Repsol
Mike lead ERM's in-house Acoustics Team in developing a detailed model using a parabolic equation model of sub-sea sound propagation for vessel and well head pump noise.

Angola, EIA for Block 31 South East, Offshore Angola, BP
Mike wrote the technical EIA chapters for the projects working with specialist prediction team.

Angola, EIA for Block 31 PSVM, Offshore Angola, BP
Mike reviewed technical EIA chapters for the projects working with specialist prediction team.

Sakhalin Island Pipeline, Saipem
Mike led the acoustics team in carrying out initial predictive assessment of the potential for noise impacts on Western Grey Whales.

Seismic Surveys

Confidential Client– Offshore Seismic Survey Confidential Location, Technical Lead
Mike led the team in modelling and assessment of the underwater noise impacts from the seismic survey.

Statoil UK – Offshore Seismic Survey Statfjord Area, North Sea, Technical Lead
Mike led the acoustics team in assessing underwater noise impacts on marine fauna as a result of seismic exploration of the Stratfjord Area. Noise was a key risk for the project, and appropriate mitigation was proposed which allowed the project to gain consent and to proceed as scheduled.

EIA for Seismic Survey off Spanish Coast, Confidential Client
Mike carried out detailed underwater modelling taking account of site specific parameters such as bathymetry. Noise contours were produced to show the overlap with a cetacean corridor.

EIA for 3D Seismic Survey Offshore West Greenland, Petroleum Geo-Services
ERM is preparing an EIA for 3D seismic survey in the Disko West area of offshore Greenland. Mike has written the underwater noise assessment.

EIA for High Resolution Seismic Survey, Greenland, Shell
ERM prepared an EIA for a high resolution seismic survey programme in the Baffin Bay region of West Greenland. ERM also assisted in responding to comments received as part of the public hearing process. Mike has written the underwater noise assessment.

Environmental Impact Assessments for Rig Site Survey and Seismic Survey, Capricorn Greenland Exploration-1
ERM prepared four EIAs for rig site survey one EIA for 3D seismic survey operations in licence blocks located in Disko Bay and Baffin Bay. Mike undertook the underwater noise assessment.

Vanessa Cottle

Principal Consultant



Vanessa is a Principal Environmental Consultant with ERM, based in the San Francisco office. She has 13 years of experience in the fields of impact assessment and sustainable finance.

Vanessa is experienced with international standards and best practices, especially IFC Performance Standards and WBG EHS Guidelines, having lead and conducted multiple environmental and social due diligences (ESDD), environmental and social monitoring, and environmental and social impact assessments (ESIA) on behalf of Development Finance Institutions (including IFC, IDB, IDB Invest, OPIC, CABEI, CAF, KfW, CDB), Equator Principles Finance Institutions, and private investors. Recently she has reviewed and developed the Environmental and Social Management Systems (ESMS) of Financial Intermediaries including regional development banks and renewable energy funds. She has lead and participated in diverse environmental studies including baseline studies, environmental studies for permitting, ESIAs, cumulative impact assessments, monitoring programs, and water resource assessment. The sectors she has experience in cover energy (solar, wind, geothermal, hydropower, LNG), infrastructure (roads, ports, canals), mining, and finance.

Vanessa has worked in projects in Argentina, Barbados, Chile, Colombia, Costa Rica, Dominican Republic, Honduras, Mexico, Nicaragua, Nepal, Pakistan, Panama, Peru, St. Vincent and the Grenadines, and USA. Vanessa is Peruvian and is fluent in English and Spanish.

Professional Affiliations & Registrations

- *Colegio de Biólogos del Perú* – Peruvian Registry of Licensed Biologists (CBP #12329)
- International Association for Impact Assessment (IAIA # 10411250)

Fields of Competence

- Project finance environmental and social due diligence and monitoring
- Environmental impact assessment
- Cumulative impact assessment
- Environmental and social management systems

Education

- MSc in Water Resources Management, University of Wisconsin – Madison, USA – 2011
- BSc in Biology, Universidad Peruana Cayetano Heredia, Peru - 2003

Languages

- Spanish (native)
- English (native)

Key Industry Sectors

- Finance
- Energy
- Infrastructure
- Mining

Honors & Awards

- Doris Duke Conservation Fellow, 2010-2011

Key Projects

ESIA for the Coral LNG Power Plant Project, Dominican Republic – AES Corporation
ERM is developing the ESIA for the project to meet national requirements and IFC Performance Standards. Acts as senior environmental specialists leading the development of the physical baseline, impact assessment, and management plans.

Support in the Development of an Online ESIA Training Course, Regional - IDB
ERM provided expert advice in the development of IDB's online course *Principles of Environmental Impact Assessment Review*. Acted as project manager and ESIA specialist, reviewing and complementing the course strategy, content, and material.

St. Vincent Geothermal Exploration Project ESIA, St. Vincent and the Grenadines - IDB and Caribbean Development Bank (CDB)
Emera Caribbean, Reykjavik Geothermal, and the Government of St. Vincent and the Grenadines are developing the St. Vincent geothermal project (5-20 MW), located in the foothills of La Soufrière Volcano. Exploration activities comprised of two deep exploratory wells, auxiliary facilities, and road improvements. ERM developed the ESIA following national and Lender requirements. Acted as project manager and senior environmental specialist.

Cumulative Impact Assessment of Wind Farms in the Jhimpir Wind Region, Pakistan
The Jhimpir Wind Region, within the Gharo Wind Corridor, includes more than 25 wind farm projects (planned and in operation). The Region is located near Ramsar wetlands and dispersed rural population, in an arid and water-scarce area of southern Pakistan. ERM developed the cumulative impact assessment for OPIC, who has committed financing four of the wind farms (200 MW), using remote sensing and ground-truthing efforts. Following IFC's methodology, lead the study, carried out desktop research to establish VECs baseline conditions, and identify other projects in the area. Developed the assessment of noise and water resources as well project and regional management framework.

ESIA of the Nicaragua Canal Project, Nicaragua - HKND Group
The Nicaragua Canal Project consists of an interoceanic canal, 275 km in length, crossing Nicaragua from the Caribbean Sea to the Pacific Ocean. Carried out fieldwork related to the social study (household surveys) and the cumulative impact analysis data collection. Developed the cumulative impacts assessment based on IFC's methodology. Additionally, led the development of the First Stage Start Up Works ESIA for temporary access roads along the canal corridor.

Semi-Detailed EIA (EIAsd) of the Lima Metro Line 2 and Segment of Line 4 Project, Peru - IDB
Participated in the development of the supplemental analysis of 35 km line of the Lima Metro system, in compliance with IDB Environmental Safeguards. Assisted in the hydrogeological and geotechnical evaluation and developed the preliminary cumulative impact assessment.

Cumulative Impact Assessment for the Upper Karnali Hydropower Project, Nepal – GUKHL and IFC
The Upper Karnali is a peak run of the river project with an installed capacity of 900 MW located in the Mid-Western and Far Western Regions. ERM developed the Supplementary ESIA and supporting Management Plans to meet the provisions of the Nepali Project Development Agreement and IFC Performance Standards. Lead the cumulative impacts assessment based on IFC's methodology, guiding field work efforts, and the desktop review.

Rowena Cerro

Senior Project Manager



Ms. Rowena Cerro is a Senior Project Manager and Environmental Consultant with ERM based in Scottsdale, Arizona. She has experience with international standards and best practices (IFC Performance Standards, WBG EHS Guidelines, IDB, and Equator Principles). She has conducted environmental and social due diligences (ESDD), and environmental and social (E&S) monitoring on behalf of Development Finance Institutions (including IFC, IDB), and Equator Principles Finance Institutions.

Ms. Cerro has experience conducting ESIAs, cumulative impact assessments (CIA), and monitoring programs. She is also experienced with Title V air permits, NESHAP, alternative fuels, state and federal reporting (air emissions, GHG, audits), CEMS, and permitting (NEPA).

Professional Affiliations & Registrations

- International Association for Impact Assessment (IAIA # 10453760)

Fields of Competence

- Environmental impact assessment
- Cumulative impact assessment
- Project finance environmental and social due diligence and monitoring
- Biology and conservation planning
- Air quality
- Continuous Emissions Monitoring Systems (CEMS)

Education

- M.A. Biological Sciences, University of Texas at Austin, Austin, TX, 2008
- B.Sc. Biology, Universidad Peruana Cayetano Heredia, Peru, 2005

Languages

- Spanish (native)
- English (proficient)

Key Industry Sectors

- Energy
- Finance
- Infrastructure
- Mining
- Manufacturing

Publications

- Zafra-Calvo, N., Cerro, R., Fuller, T., Lobo, J.M., Rodríguez, M.A., Sarkar, S. 2010. "Prioritizing areas for conservation and vegetation restoration in post-agricultural landscapes: a Biosphere Reserve plan for Bioko, Equatorial Guinea." Biological Conservation, 143 (3): 787 – 794.

Key Projects

ESIA of a Transmission Line, Nicaragua – 2018
ERM is developing the ESIA for the Project to national requirements and international standards (IDB and IFC). Senior environmental specialists leading the development of the physical components baseline and impact assessment, and management plans.

Review of E&S Safeguards - 2018
A European Development Bank is evaluating starting several lines of credit with a Financial Intermediary (FI) in South America. ERM carried out a gap analysis of the FI's new E&S Safeguards to determine their alignment with IFC performance standards.

Support in the Development of a Regional Development Bank SEG's ESMS Manual - 2018
ERM provided support on Environmental, Social, and Governance (SEG) Division in the development of its internal ESMS manual, describing a regional development bank's environmental and social risk management system, part of their operations and financial cycle. Updated the Bank's ESMS external manual.

ESIA of a LNG Power Plant Project, Dominican Republic – 2017-2018
ERM is developing the ESIA for the Project to national requirements and IFC Performance Standards. Developed the cumulative impact assessment in alignment with IFC Performance Standards and calculated the GHG emissions for the construction and operations phase.

ESDD of a Highway Project, Peru - 2017
The Highway Project is located in northern Peru. ERM conducted an ESDD on behalf of the Lenders to assess the Project's alignment with the Equator Principles (EP), IFC Performance Standards, and Peruvian regulations. Acted as deputy project manager. Coordinated a team of six specialists to prepare the ESDD.

Environmental and Social (E&S) Monitoring of a Geothermal Project, Chile - 2017
ERM conducted the ESDD and provided support of the review of Project compliance with ESAP requirements and IFC Performance Standards of a 100-megawatt (MW) geothermal project in northern Chile. Carried out desktop review of environmental aspects to produce the Project's first monitoring report.

ESDD and E&S Monitoring of a LNG Power Plant Project, Panama - ongoing
ERM conducted the ESDD to assess alignment with IFC Performance Standards and Panamanian regulations of a 360 MW LNG power plant project. After financial closure, ERM provided E&S support services on behalf of the Lenders and reviews Project compliance of ESAP requirements and IFC Performance Standards. Participate in site visits and conduct quarterly desktop reviews of environmental aspects of project construction to produce quarterly monitoring reports.

E&S Monitoring of a Port Project, Colombia - ongoing
The project comprises the operation of a terminal marine port with a 650,000 TU capacity in Colombia. ERM provides E&S support services on behalf of the Lenders and reviews Project compliance of ESAP requirements and alignment with IFC Performance Standards. Participate in site visits and conduct desktop review of environmental aspects to produce semiannual monitoring reports.

E&S Monitoring of a Highway Project, Peru - ongoing
The project, located in northern Peru, is comprised of the widening of 285-km of the Pan-American Highway and its supplemental works. ERM carries out the E&S supervision monitoring on behalf of the Lenders to assess the Project's alignment with the applicable standards (EP, IFC, CAF, and Peruvian regulations), as well as the project's ESAP requirements. Participate in site visits and conduct quarterly desktop reviews of project's management systems and environmental aspects to produce quarterly monitoring reports.

Alternative Fuels Pilot Test – Drake Cement – 2016-2017
Drake Cement is a Portland cement plant in Northern Arizona. As the Environmental Manager, lead the pilot test for alternative and engineered fuels. Obtained permit from Arizona Department of Environmental Quality (ADEQ). Coordinated with external consultants and fuel suppliers (forest service, private ranchers, etc.), and with production, quality and engineering departments to carry out the tests. Analyzed test emissions data and prepared report for Drake's top management and for ADEQ.

Title V Permit Modification – 10% production increase - Drake Cement – 2016-2017
Drake Cement in Northern Arizona has a Title V Air Permit. Corporate decided to request ADEQ for an increase in their clinker production limit. As

Environmental Manager, lead the permit modification effort by coordinating the permitting strategy with an external consultant, meetings and correspondence with ADEQ, coordination with plant managers. Participation in the public hearing. Follow up until approved.

Environmental Assessment (EA) for the Expansion of Drake Cement's Limestone Quarry – 2015-2017
Drake Cement in Northern Arizona has an adjacent limestone quarry. They requested the Forest Service for an expansion of its footprint to use as storage of overburden. As Environmental Manager, lead the EA effort (NEPA process), meetings and correspondence with authorities and stakeholders, coordinated with external consultants, participated in preparation of final EA report. Follow up with authorities until approved.

1st Amendment to the ESIA of the Las Bambas Mining Project, Peru – Glencore-Las Bambas – 2013-2014
Las Bambas is a Greenfield copper concentrator project in Apurimac, Peru. Acted as deputy project manager. Coordinated a team of 20+ specialists for fieldwork, project deliverables and progress presentations to the client. Developed the terrestrial fauna and protected areas impact assessment.

IFC Performance Standards Checklist for Prefeasibility Study (PFS) of the Mina Justa Mining Project, Peru – MARCOBRE S.A.C. – 2013-2014
Mina Justa is an open pit copper mine project in Ica, Peru. During the PFS stage of the project, MARCOBRE requested support to achieve alignment with IFC standards so they could seek financing opportunities from Equator Principle Finance Institutions (EPFI) for future stages of the project. Carried out a detailed review of IFC standards and developed a checklist with the compliance requirements and project gaps.

Review of the 2013 Baseline Study for the Mina Justa Mining Project, Peru – MARCOBRE S.A.C. – 2013
Mina Justa is an open pit copper mine project in Ica, Peru. MARCOBRE hired an independent consultant to review the biological baseline. Conducted the review of terrestrial fauna and marine biology baselines.

Environmental Monitoring for the Semi-Detailed EIA (EIAsd) of the Haquira Mining Project, Peru – First Quantum Minerals – 2012-2014
Haquira is one of the world's major copper deposits. Located in Apurimac, Peru. Coordinated fieldwork for the quarterly environmental monitoring program, conducted desktop review of information and prepared monitoring reports.

Baseline Study Update for the Pampas de Pongo Mining Project, Peru – Jinzhao Mining Peru – 2012-2013
The Pampa de Pongo iron ore project consists of a block of adjoining mining concessions and mining claims. Located on the southern coastal plain of Arequipa, Peru. Coordinated fieldwork, reviewed reports from field teams and prepared the updated baseline for terrestrial and marine fauna.

ESIA of the Pukaqaqa Mining Project, Peru – Compañía Minera Milpo Peru – 2012-2013
The Pukaqaqa copper-gold project is located in the department of Huancavelica in Peru. Developed the terrestrial fauna impact assessment.

Baseline Study for the Sulfuros Chapi Mine Desalintion Plant Project, Peru - Compañía Minera Milpo Peru – 2012-2013
Sulfuros Chapi, located in Arequipa-Peru, needed to install a desalination plant in the coast. Coordinated fieldwork, reviewed reports from field teams and prepared the baseline reports for terrestrial and marine fauna. Presented results to local stakeholder groups during public consultation meetings.

CHARLES P. CERES, PE

EDUCATION:
MS, Drexel University, Philadelphia, PA. 1991 Major: Geotechnical Engineering
B.Sc., Queen's University, Kingston, Ontario, 1979 Major: Civil Engineering
40 Hour Health and Training Certification

AFFILIATIONS

Professional Engineer, New Jersey.
Member, American Society of Civil Engineers.
Member, Association of Soil and Foundation Engineers

EXPERIENCE

1993 to Present **GROUND STRUCTURES ENGINEERING CONSULTANTS LTD, Guyana**
Managing Director

Manages a geotechnical and environmental engineering services firm involved in all aspects of geotechnical engineering, hazardous waste site investigations and the performance of environmental impact assessments and environmental audits. Provided technical review of work performed by junior engineers. Geotechnical engineering facilities include several soil boring rigs and a full service testing laboratory. Prepared project proposals, established scope and managed geotechnical engineering investigations and analyses for facilities that included coastal defence structures, electrical generation stations, transmission lines, mine tailings dams, factories, multistory buildings, bridges, ports and for a proposed space station. Developed hydrogeology of several mining areas and utilized groundwater and contaminant transport models to assess the impact of mining on groundwater quality. Performed seismic wave propagation and slope stability analyses for several municipal waste landfills to assess compliance with RCRA guidelines. Managed several environmental impact assessments (EIA) and environmental audits for existing and proposed facilities. Responsible for marketing and client development for the entire range of services provided by the firm.

1992 to 1993 **GOLDER ASSOCIATES, New Jersey, U.S.A**
Senior Project Manager

Directed geotechnical field and laboratory investigations of municipal landfill sites. Coordinated slope stability analyses of landfills. Managed and performed several parts of remedial investigations/feasibility studies (RI/FS), and remedial designs (RD), and prepared RCRA Part A and B applications for land-based disposal facilities. Prepared work plans for remedial investigations, treatability testing, and background concentration determination at hazardous waste sites. Modeled contaminant transport in groundwater, determined landfill gas concentration at off-site receptors, defined remedial objectives,

identified ARARs, and evaluated remedial alternatives at CERCLA sites. Designed sample plans using geostatistics. Prepared proposals for geotechnical investigations, and RI/FS and RD projects.

1990 to 1992: RAYTHEON ENGINEERS & CONSTRUCTORS, Philadelphia, U.S.A

Project Manager: Environmental Systems and Services Group

Managed geosciences and Phase I Environmental Site Assessments projects. Managed all aspects of geotechnical investigations for fossil fuel, chemical and food processing plants and highways. Performed hydrogeological investigations for wetlands. Managed geotechnical investigations for waste containment facilities and evaluated disposal alternatives for fossil fuel plant waste streams. Designed construction dewatering systems. Performed water resources investigations for power plant siting. Developed coupled surface water and groundwater model for power plant cooling pond to assess impact of suspended solids in plant effluent. Prepared proposals for geotechnical, hydrogeological and contaminated site investigations.

1988 to 1990: SITE ENGINEERS, New Jersey, U.S.A

Project Engineer

Managed geotechnical investigations for low and high-rise buildings. Supervised Phase I and Phase II Environmental Impact Assessments. Supervised quality control field inspectors, laboratory testing and drilling crews. Coordinated closure of RCRA landfill for a major chemical manufacturer. Performed dynamic analyses of foundations for Phalanx Tower for a major defense contractor. Performed multilayer soil deformation analyses for the Pennsylvania Convention Center. Managed groundwater resources investigations for several large office complexes in the Reading, PA. area. Prepared proposals for geotechnical and hydrogeological investigations and for environmental site assessments.

1986 to 1988: EFP ASSOCIATES, New Jersey, U.S.A

Project Engineer

Supervised all geotechnical and hydrogeological investigations for new and expanded municipal waste landfill sites. Supervised site and laboratory investigations and performed slope stability, seepage and deformation analyses for Phase II dam investigations and for several small dams, less than 50 feet high. Analyzed wave and wind records, predicted critical wave heights and performed analyses of wave-loaded piles. Created groundwater hydrology group and implemented standardized procedures for pumping and permeability tests. Modeled the impact of landfill leachate on groundwater quality using numerical and analytical groundwater flow and transport models.

1985 to 1986: WOODWARD CLYDE CONSULTANTS, New Jersey, U.S.A

Assistant Project Engineer

Supervised engineers and geologists inspecting foundation excavation and embankment construction for a 260 ft. earth and rock fill dam. Reviewed and coordinated shift activities with day shift supervisor.

1983 to 1984: GEOTECH ASSOCIATES, Trinidad, W.I.
Geotechnical Engineer

Supervised geotechnical investigations for multistory buildings, roads and housing developments. Supervised laboratory investigation for lime and cement stabilization of high plasticity clays and supervised field stabilization operations. Developed preloading scheme for embankment constructed over organic clays. Supervised quality control inspection of road construction activities including fill placement and surfacing. Supervised all laboratory soil testing activities.

1979 to 1983: GUYANA MINING ENTERPRISE, Guyana, South America
Project Engineer (1979-1981)
Senior Project Engineer (1981-1983)

Redesigned and supervised construction of mills tailings dams using coarse fraction of tailings for fill and saved $12M. Started and supervised a geosciences group two years after graduation. Analyzed slope stability of all open-pit mines and mine waste heaps. Investigated soil competence for mining equipment. Designed preload schemes for soft soils. Determined liquefaction potential of mining waste disposed in ponded water. Supervised mine dewatering investigations. Developed a generic mine drainage plan that coupled groundwater flow and precipitation. Established a soil laboratory, purchased laboratory equipment and trained technicians to perform soil laboratory tests and field quality control tests.

1972 to 1974: MINISTRY OF WORKS; Guyana, South America
Soils and Materials Technician

Performed laboratory tests to determine soils and materials parameters for pavement design and soil laboratory tests to establish parameters for building foundation and earth structure design. Tests performed included CBR, determination of Marshall Stability, Particle Size Distribution, Soil Plasticity tests, soil consolidation tests, direct shear tests, Soil triaxial tests and soil permeability tests. Supervised subsurface investigations.

HANCE THOMPSON

EDUCATION

M.Sc. in Environmental and Earth Resources Management, Kingston University, London **2006/07**
B.Sc. Biology, University of Guyana **1998-2002**

PROFESSIONAL BODIES

Graduate Member of the Institute of Environmental Management and Assessment **(IEMA)- London**

EXPERIENCE

2010 to Present: GROUND STRUCTURES ENGINEERING CONSULTANTS INC

Environmental/Biological Specialist; Responsibilities include; Coordinating and conducting Environmental and Social Impact Assessments (ESIAs); Writing ESIAs and Environmental Management Plans (EMPs); Conducting/coordinating Bio-physical Baseline Surveys; Conducting/coordinating Environmental Site Assessments. Co-coordinated and managed the following projects ; ETK ESIA at Toroparu, Strata Gold ESIA at Tassawini, Guyana Goldfields Inc. (GGI) updated ESIA baseline survey at Aurora and Sulphur Rose, GGI Rapid Biodiversity Assessment at Julian Ross Itabu, Mulgravian Inc. Environmental Liability Assessment at Five Star.

April –October 2010: SYNERGY HOLDINGS (GUYANA) INC.
(AMAILA FALLS HYDRO ACCESS ROAD PROJECT)

Environment, Health and Safety Manager; Duties included; Overall Environmental Management and Monitoring of the Project; Specific Duties included; prioritize risk management strategies with the objective of achieving acceptable environmental and health practices; enforce policy and procedures on health and safety; plan and implement training programmes; liaise with the Project Manager of the Government of Guyana, the EPA, and other regulatory bodies on environment, and health and safety management.

2003 – 2010: ENVIRONMENTAL PROTECTION AGENCY, GUYANA

Post: Senior Environmental Officer (SEO) within the Environmental Management Division (EMD) with responsibilities for Managing and Coordinating activities under the Authorisation and Research and Development Programme Areas of the Environmental Management Programme; Duties included:

SEO of Authorisation - Coordinate and manage the Environmental Authorisation Process including the Environmental Impact Assessment (EIA) Process; Conduct and coordinate the review of EIAs and EMPs; Facilitate/chair public scoping meetings; Develop and review

environmental authorisation; Coordinate and manage the screening of applications for environmental authorization; Coordinate and assist in the development and revision of guidelines, standards and procedures for environmental authorisation;

SEO Research and Development (R&D) – Developed Environmental Standards, Regulations, and Guidelines for Industry; Identify areas for development in Environmental Management in Guyana and formulated proposals for projects; Coordinated and managed the implementation of projects under the Environmental Management Programme of the EPA. These projects included; The development of a National Hazardous Waste Inventory (for year 2007) and Management Strategy for Guyana; An assessment of Marine Litter Management in Guyana; The development of a project to link National Programmes of Action (NPAs) for the Protection of Marine and Coastal Ecosystems and Water Safety Plans (WSPs), developed for the Demerara Watershed and the community of Linden. Other **R&D** duties included; Coordinated and managed the implementation of the Basel Convention on the Control of the Transboundry Movement of Hazardous Waste and their Disposal; Coordinated the preparation of EPA's Recommendation on Guyana's Ratification of the Cartegena Convention.

February, 2003 – October, 2003: GUYANA RICE DEVELOPMENT BOARD (RESEARCH STATION)

Post: Research Assistant to Chief Scientist. Duties included: Managing and planning activities of the plant pathology department; screening new rice plant varieties for resistance against major rice fungus; testing and screening new fungicides for effectiveness against major rice fungus; conducting field and laboratory diagnosis of diseased rice plants for causal pathogens.

Raeburn Anthony Jones

Email: raeburnjones@groundstructures.com

EXPERIENCE

2016 – Present Ground Strurctures Engineering Company. Liliendaal, Georgetown.

Head of Department – Enviromental Unit.

- Planning , scheduling and implementing work programs and for unit(field and office).
- Analyzing data and Preparation of reports.
- Coordinate the development of Environmental and Social Impact Assessment for clients.
- Coordinate and conduct bio – physical and social baseline surveys for ESIAs.

2009 - 2016 Forestry Consultant, Logger and Miner.

- Preparation of Forest Management and Annual Plans.
- Conducting training in Reduce Impact Logging (RIL).
- Conducting training in GPS, compass and mapping.
- Mananging small scale mining and logging operation.
- Designing and implementing forest inventories (Per -Harvest & Post – Harvest).
- Designing, aligning and constructing forest and mining road network.
- Identifying and demarcation of concession boundaries (forest and gold mining).
- Designing, planning and directing construction projects.
- Supervising daily activities of construction site, determining workforce and material demands.
- Procuring materials and ensuring these are efficiently utilized.
- Ensuring that project is completed within the budgetary requirements and on schedule.

2008 – 2009 Guyana School of Agriculture. Mon Repos, E. C. D.

Lecturer – Forestry and Agriculture

- Planning , implementing programs and schedules for students.
- Assisting in student welfare and counselling.
- Supervising subordinate technical staff and students.
- Revising the forestry syllabus to meet the needs of the forest sector.
- Serving as a panel member in both academic and admission committee.
- Lecturing courses as determined by the principal.
- Organizing field trips, laboratory and other relevant training activities.
- Assist in organizing extra curriculum activities for students and staff.
- Performing other duties as determined by the principal.

2007 - 2008 Guyana Forestry Commission. 1, Water Street Kingston, Georgetown.
Assistant Commissioner of Forests – Inventory

- Preparation of work plans and budgets for the Inventory Unit.
- Supervising state forest inventories (Per -Harvest & Post – Harvest).
- Advising communities on Participatory Forest Management.
- Implementing and supervising the Sustainable Forestry Management Program for forest dependent communities (World Wildlife Fund Project).
- Maintaining registers of all inventories on forest resources conducted in Guyana.
- Conducting field audits to verify information provided in Annual Plan of operation of all forest concessions.
- Verifying information on the log tracking database.
- Supervising state forest concession boundary demarcations.
- Supporting the allocation of forest areas for productive uses.
- Designing and implementing national forest resources management databases.
- Conducting training programs in the use of GPS, Compass & Mapping technology for the forest sector and Guyana Forestry Commission.
- Evaluating Forest Management & Annual Operation Plans.
- Working in collaboration with other natural resources agencies.
- Evaluating staff performance, ensuring the maintenance of discipline & the efficient use of resources.

2005 - 2007 Guyana Forestry Commission. 1, Water Street Kingston, Georgetown.
Assistant Commissioner of Forests – Forest Resource Planning

- Managing large concession administration database.
- The preparation of work plans and budgets for the Forest Resource Management Division.
- Advising the forest sector on matters relating to forest resource and forest management planning.
- Evaluating Forest Management & Annual Operation Plans.
- Working in collaboration with other natural resources agencies.
- Advising communities on Participatory Forest Management.
- Supervising state forest inventories (Per -Harvest & Post – Harvest).
- Supervising state forest concession boundary demarcations.
- Conducting training programs in Reduce Impact Logging (RIL) technology for the forest sector.
- Collecting information on communities, monitoring social impacts of forest operations and reporting on social issues.

- Supporting the allocation of forest areas for productive uses.
- Ensuring the participation of communities & stakeholders in forest area management planning and preparing area management plans.
- Supervising the updating of forestry concession maps.
- Compiling the Permanent Sample Plot Guidelines for Guyana.
- Conducting training programs in the use of GPS, Compass & Mapping technology for the forest sector and Guyana Forestry Commission.
- Evaluating staff performance, ensuring the maintenance of discipline & the efficient use of resources.

2003-2005 Guyana Forestry Commission. 1, Water Street Kingston, Georgetown.
Assistant Commissioner of Forests – Forest Resources Information

- Consulting with agencies responsible for natural resources information & assisting with the preparation of forest resource information.
- Supervising data analysis, evaluating resource information & preparing reports.
- Providing mapping services to the Guyana Forestry Commission and the forest sector.
- Research & advise the Guyana Forestry Commission on forest resource information & GIS/GPS & Mapping practices.
- Assisting with the preparation of work plans & budgets for the Division.
- Supporting the allocation of forest resources for productive uses.
- Conducting training programs in the use of GIS/GPS & Mapping technology for the forest sector and the Guyana Forestry Commission.
- Monitoring & evaluating staff performance, ensuring the maintenance of discipline & the efficient use of resources.

2002-2003 Guyana Forestry Commission. 1, Water Street Kingston, Georgetown.
Resource Planning Officer

- Planning forest surveys & inventory programmes.
- Assisting in establishing, training & equipping the survey & inventory field teams.
- Assisting in the procurement & management of approved materials & equipment.
- Preparing & implementing work plans for related field surveys & inventories.
- Drafting of the Code of Practice for the Harvesting of Nibi & Kufa (NTFP).
- Drafting of the Code of Practice for the Harvesting of Manicole (NTFP).
- Monitoring data collection & data processing for non timber forest products.
- Supervising the establishment of Permanent Sample Plots for Nibi & Kufa (NTFP).
- Supervising the maintenance of forest & plantation reserves.

1998-2002 Guyana Forestry Commission. 1, Water Street Kingston, Georgetown.
Senior Field Assistant

- Implementing work plans provided by the Assistant Commissioner Forests & Resource Planning Officers.
- Supervising the provision of equipment, transport & supplies for field operations.
- Managing costs to ensure field exercise objectives are achieved & executed to a high standard according to plans & procedures.
- Providing information, liaising with government agencies, communities & other stakeholders.

1994-1998 Guyana Forestry Commission. 1, Water Street Kingston, Georgetown.
Field Assistant III

- Conducting concession boundary demarcations & verifications.
- Conducting forest inventories.
- Establishing Permanent Sample Plots & assisting in research work.
- Assisting in the preparation of maps for concessionaires & field work.
- Providing training for internal & external stakeholders.

EDUCATION

BSc. Forestry (Credit) **2002**
University of Guyana

Dip. Forestry **1994**
Univesity of Guyana

Curriculum Vitae

Contact Information

Name: Patrick Williams
E-Mail: patrickwilliams@groundstructures.com

Education

High School: Guyana Education Trust College; Saint Stanislaus College (6th Form)

Qualifications

CSEC May/June 2009: Mathematics (Grade 2)
English (Grade 2)
Information Technology (Grade 1)
Physics (Grade 3)
Chemistry (Grade 3)
Biology (Grade 3)
Social Studies (Grade 3)

CAPE May/June 2011: Computer Science Unit 1 (Grade 4)
Computer Science Unit 2 (Grade 5)
Information Technology Unit 1 (Grade 3)
Information Technology Unit 2 (Grade 4)

Global Technology: Autodesk AutoCAD 2014 Certified

Experience:

GT&T - Electrical Engineer (Work Study) – July 2009 – August 2009

Ground Structures Engineering Consultants – Lab Technician – June 2012 – October 2012

Ground Structures Engineering Consultants – IT Manager/GIS Analyst – October 2012 - Present

CURRICULUM VITAE

NAME: SHYAM NOKTA

ADDRESS:
60 Area H Ogle
East Coast Demerara
Guyana

CONTACTS:
Tel: + 592 222 4565
Fax: + 592 222 3172
Email:shyamnokta@gmail.com
Skype: shyam.nokta1

AREAS OF EXPERTISE

- Climate Change and Green Growth Policy and Strategy Development
- Environmental Assessment and Management
- Environmental Monitoring and Auditing
- Biodiversity Assessment and Management Planning
- Ecotourism Planning and Development

QUALIFICATIONS

The University of Oxford Brookes (September 1999)
School of Planning
Masters of Science in Environmental Assessment and Management
(Pass with Distinction)

The University of Guyana (September 1997 - July 1998)
Faculty of Arts
Tourism Studies Unit
Diploma in Tourism Studies
(Pass with Distinction)

The University of Guyana (January 1994 - July 1997)
Faculty of Natural Sciences
Environmental Studies Unit
Bachelors Degree in Environmental Studies
(Pass with Distinction)

SCHOLARSHIPS AND HONORS

2003. Fulbright - OAS Ecology Initiative
Scholarship to pursue Doctoral Studies

1999. Inter-American Development Bank
Japan-IDB Scholarship Programme Award for outstanding academic performance

1998. Inter-American Development Bank
Japan-IDB Scholarship to pursue Masters Studies

University of Guyana

1997. Environmental Studies Unit Award - sponsored by the European Commission
(Best Graduating Student in the Environmental Studies Unit)

1996. Environmental Studies Unit Award
(Best Third Year Student in the Environmental Studies Programme)

1994. University of Guyana Award
(Based on outstanding performance at the Annual University Examination - Faculty of Natural Sciences to a student who obtained a GPA of not less than 2.7)

1994. The Charles - Sue - Wah - Sing Award
(Best First Year Student with a GPA of not less than 2.7 in the Faculty of Natural Sciences)

2003. Organisation of American States (OAS) -Fulbright Scholarship to pursue PhD Studies.

1999. Inter-American Development Bank (IDB), Japan-IDB Scholarship Programme Award for outstanding academic performance

1998. Inter-American Development Bank (IDB), Japan-IDB Scholarship to pursue Masters Studies

WORK EXPERIENCE

Shyam Nokta comes from a background in natural resources management with substantial experience in climate change, green growth strategy development and implementation, environmental and social impact assessments (EIAs), strategic environmental assessment (SEAs), parks and protected areas planning and management, marine turtle conservation, ecotourism planning and management, and sustainable forest management.

Mr. Nokta has accumulated over 15 years' experience from his work with local and international NGOs, Government and the Private Sector and has been associated with many of Guyana's premier climate change and conservation initiatives as well as major infrastructure and development projects. Principal among these include the Low Carbon Development Strategy (LCDS) and Norway Partnership; the National Protected Areas Act and establishment of the National Protected Areas Commission; and the management of the Iwokrama, Kaieteur National Park and Shell Beach Protected Areas.

Mr. Nokta serves as principal for one of Guyana's premier environmental consultancy firms, Environmental Management Consultants (EMC) which specializes in environmental assessments and support services and which works across a range of sectors including forestry, manufacturing, mining, agriculture, infrastructure and oil and gas.

Mr. Nokta has functioned at the policy, management and technical levels where he has managed large teams and diverse stakeholder groups. He has also worked on a number of donor supported initiatives which include The Global Environment Facility (GEF), World Bank, Inter-American Development Bank (IDB), United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP), Caribbean Development Bank (CBD) among others. Mr. Nokta is familiar with all three of the Rio Conventions – the UNCBD, UNFCCC, and UNCCD, having been involved in initiatives to meet the requirements of these Conventions.

EMPLOYMENT BACKGROUND

The Energy and Resources Institute (TERI) (June 2015-Present)
Chief Representative for the Caribbean
Responsible for coordinating TERI's work in the Guyana and the wider Caribbean with specific focus on promoting energy efficiency and renewable energy development.

Office of the President (January 2014 – May 2015)
Consultant to the Office of the President (Pro Bono)
Provided advise and technical guidance on climate change with particular focus on Guyana's Low Carbon Development Strategy (LCDS) and the Partnership with the Kingdom of Norway.

Office of the President (July 2008 – December 2013)
Head, Office of Climate Change
Responsible for coordinating Guyana's response to climate change and the operations of the Office of Climate Change (OCC). Principal tasks included:

- Setting up the Office of Climate Change and overseeing the institutional arrangements and recruitment of personnel.
- Serving as Guyana's focal point to Mc Kinsey and Co. and the Clinton Foundation to develop Guyana's Low Carbon Development Strategy (LCDS) and to coordinate its launch, national stakeholder awareness and engagement, implementation and subsequent revisions and updates.
- Serving as Guyana's Focal Point to the United Nations Convention on Climate Change (UNFCCC) and the Designated National Authority (DNA) to the Clean Development Mechanism (CDM).
- Coordinated the preparation of Guyana's 2nd National Communication to the United Nations Framework Convention on Climate Change (UNFCCC)
- Provided technical support for the preparation of Guyana's R-PIN and R-PLAN for the World Bank financed Forest Carbon Partnership Facility (FCPF).
- Establishing formal links with The Energy and Resources Institute (TERI) through an MoU with the Government of Guyana and which has facilitated technical support to Guyana in energy efficiency, transfer of technology.
- Serving as Convenor of the Steering Committee for Guyana's Low Carbon Development Strategy.
- Serving as Guyana's representative on the High Level Advisory Committee of the UN-ECLAC funded project *A Review of the Economics of Climate Change in the Caribbean.*
- Serving as Guyana's representative on the Board of the Caribbean Climate Change Centre (CCCCC). (October 2013 to May 2015).

Environmental Management Consultants (March 2003 - present)
Principal & Natural Resources and Environment Specialist
Responsible for establishing EMC and overseeing its growth as one of Guyana's leading environmental consultancies offering a range of environmental and other support services to Government, NGOs and the private sector.

Served as project principal for the following consultancies.

Environmental and Social Impact Assessment Studies (ESIAs)	
TOURISM	***Adam Development/Urbahn Associates (ADUA)*** ESIA for Georgetown Marriott Hotel, Casino and Entertainment Complex, Kingston, Georgetown
	BK International ESIA for Agriculture and Tourism Project at Saxacalli, Essequibo River.
FORESTRY	***Simon & Shock International Logging Inc. (SSILI)*** ESIA for Logging and Sawmilling operation in the Upper Essequibo Region.
	CPT Incorporated ESIA for Logging and Sawmilling operation in the Cuyuni District.
	Barama Housing Incorporated ESIA for Logging operation in the Cuyuni-Mazaruni District.
	Demerara Timbers Limited ESIA for Logging operation in the Siparuni District.
	Timber Trader S.A. Incorporated ESIA for Logging and processing operation in the Mazaruni-Puruni District.
	Garner Forest Industries Incorporated ESIA for Logging and processing operation in the Puruni District.
	Jaling Forest Industries Incorporated ESIA for Logging and processing operation in the North West District.
MANUFACTURING	***Rudisa International Guyana Limited*** ESIA for Cement Bagging Facility at Supply, East Bank Demerara.
INFRASTRUCTURE	***Marcel Gaskin & Associates Limited*** ESIA and Environmental Management Plan for the Rehabilitation of the West Coast Demerara Road.
	CEMCO-ND LEA Provided support for the ESIA for the Berbice River Bridge Project.
ENERGY	***ACORN International LLC - Anadarko Petroleum Corporation*** In country partner for Environmental Impact Studies for the Roraima Block, offshore Guyana.
	Environmental Sciences Limited (ESL)- REPSOL N.V In country partner for Environmental Impact Studies for the Jaguar 1 well.
	PMO Global Services - REPSOL N.V In country partner for the SEA for REPSOL's Georgetown Block.
	PMO Global Services - CGX Resources Inc. In country partner for the SEA for CGX's Corentyne Block.
MINING	***Guyana Industrial Minerals Inc. (GINMIN)*** ESIA Addendum and EMP for mining in Bonasika Reserves 1, 2 and 5, Right Bank Essequibo River, construction of the Haul Road and construction and operation of the Processing Facility at Sand Hills on the Demerara River.
	Linden Quarries Incorporated ESIA for stone uarry operations at Arimai Landing, R. B. Mazaruni River, Essequibo.
	Bauxite Company of Guyana Inc. (subsidiary of RUSAL) ESIA for mining operations at 22 Kurubuka, Berbice

Environmental Management Plans (EMP) and Assessment Studies	
TOURISM	***Caribbean Environmental Management Consultants Inc. (CEMCO Inc.)*** Preliminary Environmental Scoping Study: Cricket World Cup 2007 Host Venue Selection Bid Book.
	Celine Atlantic View Resort EMP – Restaurant and Bar at Kitty Seawall, Georgetown.
FORESTRY	***Barama Company Limited*** EMP – Logging operations at Left Bank Amakura River, Left Bank Yarakita River, Left Bank Anabisi River, Right Bank Kaituma River, North West District, Regions 1 & 7.
	The World Bank & Guyana Forestry Commission Revised and Updated the Report *'Law Compliance and Prevention and Control of Illegal Activities in the Forest Sector of Guyana'.*
	Guyana Forestry Commission Community Forest Management Plans for Batavia and Kwebanna.
	Barama Company Limited Road Management Plan for Compartment 5 of Barama Company's operations.
	Barama Company Limited EMP – Sawmill and Plywood Factory operations at Land of Canaan, East Bank Demerara.
	Barama Company Limited Report on the Actions to Address Corrective Action Requests for FSC Forest Management Certification – Compartment 5.
	Guyana Forestry Commission Sector Environmental Assessment of Guyana's Forestry Industry.
FISHERIES	***Shakoor's Trading*** EMP – Salted Fish Processing Plant, Eccles Industrial Site, East Bank Demerara.
	L&T Seafoods EMP – Shark Fin and Fish Glue Processing Plant, Eccles Industrial Site, East Bank Demerara.
MANUFACTURING	***Sterling Products Limited (SPL)*** EMP – Manufacturing Facility at Providence, East Bank Demerara.
	Comfort Sleep EMP – Foam Manufacturing Plant at 49 Eccles Industrial Estate, East Bank Demerara.
	Demerara Distillers Limited EMP – Alcohol Distillery Plant and Waste Treatment and Biomethanisation Plant at Plantation Diamond, East Bank Demerara.
	Avisha Readymix (Guyana) Inc. Readymix and Cement block making facility at Soesdyke, East Bank Demerara.
INFRASTRUCTURE	***Surrey Paving & Aggregates Co. Ltd. & BK International Inc.*** EMP – Rehabilitation of the West Coast Demerara Road.
	Central Housing & Planning Authority (CH&PA) EMP – East Coast–East Bank Road Linkage.
	Marcel Gaskin & Associates Limited EMP – East Coast Demerara Four Lane Extension.
	CGX Resources Inc. EMP – Wharf, Logistics Yard and Storage Facility, Crab Island, Berbice River.

Environmental Management Plans (EMP) and Assessment Studies	
	CEMCO-ND LEA Environmental Assessment component of a Feasibility Study of the Southern Approach Corridor from the Cheddi Jagan International Airport to Georgetown.
	Royal Haskoning – IDB In-country partner for the Strategic Environmental Assessment (SEA) of Transport Infrastructure Initiatives (focus on IIRSA Corridors) in Guyana.
PHARMACEUTICAL	***Essential Supplies Incorporated*** EMP – Pharmaceutical Manufacturing Complex, Eccles Industrial Site, East Bank Demerara.
HOUSING	***VIKAB Consultants*** Environmental Assessment study of the Bartica 4-mile, Good Hope, and Hope Experiment-Waterloo Low Income Housing Development Project.
	CEMCO Inc. Environmental Assessment study of the Diamond Low Income Housing Development Project.
ENERGY	***Shawnee Service Station Inc.*** EMP – Service Station at Block X Soesdyke, East Bank Demerara.
	Demerara Oxygen Company Limited EMP - DOCOL operations at Old Road Eccles, East Bank Demerara.
	Vreed-en-Hoop Service Station EMP – Fuel Station at Vreed-en-Hoop, West Coast Demerara.
	Linden Gas Station EMP – Supermarket, Fuel Station and Wash Bay at Mackenzie, Linden Region 10.
	Eccles Service Station EMP – Fuel Station at Eccles, East Bank Demerara.
	AM Khan Filling Station EMP – Fuel Station at Anna Regina, Essequibo Coast.
	Two Brother's Incorporated EMP – Fuel Bulk Terminal at Parika, East Bank Demerara, Guyana and Service Station, Hotel, Food Restaurant and Convenience Store at Land of Canaan, East Bank Demerara.
	Scott's Service Station EMP – Fuel Service Station at 1st Street, Bartica.
	DELTA Caribbean N.V. EMP - Wind Farm at Hope Beach.
DRAINAGE AND IRRIGATION	***CEMCO Inc.*** Environmental Assessment for the East Demerara Water Conservancy Northern Relief Structure at Hope/Doch Four.
	Ministry of Agriculture/ Agriculture Sector Development Unit (ASDU) Preparation of Environmental/Social Assessment for the Rehabilitation of the Cunha Canal.
	Mott Mc Donald-CEMCO Environmental Assessment component of the Feasibility Study for the Rehabilitation of Guyana's Drainage and Irrigation System.
	CEMCO Terms of Reference for the Environmental Assessment Studies required for the Canje Irrigation Project and the Cozier Dam.

Environmental Management Plans (EMP) and Assessment Studies	
AGRICULTURE	***Ministry of Agriculture/ National Drainage & Irrigation Authority (NDIA)*** EMP – Aurora Land Development Project on the western Essequibo Coast.
	Standard Agro-Forestry Inc. EMP – Integrated Farm Project at the Intermediate Savannahs, Region 10.
	Blue Wave Plantations Inc. EMP – Integrated Farm Project at the Intermediate Savannahs, Regions 6 & 10.
	Santa Fe Inc. EMP – Integrated Farm Project (Crops and Livestock Farming) at the North Rupununi Savannahs, Region 9.
	CEMCO Inc. Conducted an environmental performance analysis of GUYSUCO's Factory Operations including environmental performance and an environmental feasibility of the proposed Skeldon Expansion Project.
MINING	***Benjamin Stone Quarry*** EMP – Stone Quarry at Itaka, East Bank Essequibo.
	Bauxite Company of Guyana Inc. EMP – Bauxite mining at 22 Kurubuka Deposit.
	Bauxite Company of Guyana Inc. EMP – Bauxite mining at Block 38 Cocorite Deposit.
	Guyana Industrial Minerals Inc. (GINMIN) EMP – Bauxite mining in Bonasika 6 and 7 Deposits, Right Bank Essequibo River and Left Bank Demerara River.
	Bauxite Company of Guyana Inc. EMP – Bauxite mining at 2 Manaka and Block 5 North East Deposits.
HEALTH	***Inter-American Development Bank (IDB)*** Environmental and Social Analysis (ESA) including an Environmental and Social Management Plan for the project "Support to Improve Maternal Child Health".

Closure and Decommissioning Plan (CDP)	
MINING	***Bauxite Company of Guyana Inc.*** CDP for bauxite mining at Block 5 North East Deposit.
	Bauxite Company of Guyana Inc. CDP for bauxite mining at Bissaruni and West Pit.

Other Project Areas	
TOURISM	***Amazon Cooperation Treaty Organisation (ACTO)*** Compilation of Guyana data for Amazon-Caribbean Tourism Trail.
PROTECTED AREAS	***Environmental Protection Agency*** Assisted in preparing the National Strategy for the Establishment of a System of Protected Areas in Guyana.
	Iwokrama International Centre for Rainforest Conservation and Development Assessed Iwokrama's potential for nomination as a World Heritage Site or Biosphere Reserve.
WILDLIFE & BIODIVERSITY	***Troy Resources Guyana Inc. (TRGI)*** Prepared Biodiversity Management Plan for TRGI Project Areas.

Other Project Areas	
	Stronghold Guyana Inc. Conducted Baseline Biodiversity and Surface Water Assessment at Eagle Mountain concession.
	Guyana Industrial Minerals Inc. (GINMIN) Prepared Biodiversity Management Plan for GINMIN Project Areas.
	GINMIN Conducted Biodiversity Monitoring at GINMIN Project Areas.
	Saxacalli Rainforest Centre Managing the Centre which promotes environmental awareness and biodiversity research.
	Guyana Sugar Corporation Inc. (GUYSUCO) Conducted a Rapid Biodiversity Assessment of Halcrow and GUYSUCO Conservancies.
RISK MAPPING	***OXFAM*** Conducted flood vulnerability assessment and developed flood risk maps for 20 communities along the lower East Coast Demerara.
ENVIRONMENTAL MONITORING AND AUDITING	***Troy Resources Guyana Inc. (TRGI)*** Conducting Environmental Monitoring for gold mining and processing activities within the Hicks/Kaburi Concession situated at Black Water Creek, Kaburi Area, and Region 7.
	Noble House Seafoods Ltd (NHSL) Conducting Environmental Monitoring for seafood harvesting and processing operation at Block 'X', Eccles, East Bank Demerara.
	Surrey Paving & Aggregates Co. Ltd. & BK International Inc. Conducting Environmental Monitoring for the rehabilitation of the West Coast Demerara Road.
	University of Guyana Conducting Environmental Monitoring for Component 2: Infrastructure Rehabilitation under the University of Guyana Science & Technology Support Project.
	DIPCON Engineering Services Limited (DIPCON) Conducted Environmental Monitoring for the Expansion of the East Coast Demerara Public Road Four Lane (Mon Repos to Triumph) Lot 5.
	Barama Company Limited Conducted Environmental Compliance Monitoring for Land of Canaan and Buckhall Operations.
	GINMIN Conducting Environmental Monitoring at GINMIN Project Areas.
	DIPCON Conducted Environmental Monitoring for the Expansion of the East Bank Demerara Public Road Four Lane (Providence to Diamond) Lot 1.
	CEMCO Inc. Conducted Environmental Monitoring for the Community Roads Improvement Project (CRIP)
	CEMCO Inc. Conducted Environmental Monitoring for the Construction of the East Demerara Water Conservancy Northern Relief Structure and Associated Drainage and Irrigation Canals at Hope/Doch Four.
	SRK'Ngineering Conducted Environmental Monitoring for SRK'Ngineering for the Rehabilitation of the East and West Canje Roads.

Other Project Areas	
	CGX Resources Inc. Conducted Environmental Monitoring of operations of the Wharf, Logistics Yard and Storage Facility at Crab Island, Berbice River.
	CGX Resources Inc. Conducted Environmental Monitoring of Eagle 1 well, including assisting in plans preparation, monitoring of both onshore and offshore activities, and report preparation to ensure regulatory and permitting compliance.
	R. Bassoo & Sons Construction Company Conducted Environmental Monitoring for R. Bassoo & Sons Construction Company on the Rehabilitation of Lot II Structure - Lot A2 project.
	Courtney Benn Contracting Services Limited Conducted Environmental Monitoring for Courtney Benn Contracting Services Limited on the Rehabilitation of Lot II Structure - Lot A1 project.
	Barama Company Limited Conducted Environmental Monitoring for Barama Land of Canaan and Buckhall Operations.
	Bauxite Company of Guyana Inc. Conducting Environmental Monitoring of existing operations at Aroaima and Kwakwani
	Marudi Creek Resort Conducted environmental audit of operations as a requirement of the Environmental Protection Agency.
TRAINING	***Environmental Protection Agency*** Conducted a three-day training workshop on 'Strengthening the capacity of EPA Field Officers to facilitate greater oversight of gold mining operations'.
	Hydroplan Ing. – Solid Waste Management Training Conducted training sessions and prepared manuals for the courses Occupational Health and Safety; Hazardous Waste Management; and Registration of Industrial Waste Generators as part of Georgetown Solid Waste Management Programme.
	Institute for International Cooperation in Agriculture (IICA) Developed and Implemented Awareness Programme on Environmental Issues and Environmental Management within the Tri-Lakes Communities of Mainstay/Whyaka, Tapakuma and Capoey
	Linden Economic Advancement Programme (L.E.A.P.) Conducted a two-day training workshop titled *'Tourism and Environmental Management – A Focus on Region 10'.*
	Bauxite Company of Guyana Inc. Conducted a training programme on environmental awareness and best-practice for BCGI's existing bauxite operations at Aroaima and Kwakwani, Berbice.
	THAG-CPEC Conducted a Tourism Awareness Programme on community-based tourism for communities in the North Rupununi.

Programme Reviews, Proposal Preparations and Technical Assistance	
TOURISM	***Ministry of Tourism, Industry and Commerce*** Providing technical advise to the Minister of Tourism, Industry and Commerce of Guyana on tourism and environment issues and the implementation of the Ministry's Work Programme.
	Grand Coastal Inn Prepared application for Environmental Permits.
	L&D North West Resort Inc.

Programme Reviews, Proposal Preparations and Technical Assistance	
	Prepared a project proposal for the establishing of a small hotel (Georgetown) and interior resort (North West District).
	Wilderness Lodge Assisted in securing Environmental Permit.
ENVIRONMENT	***Environmental Protection Agency*** Conducted Second and Third External Review of Inter-American Development Bank's Environmental Management Programme – Phase II Project to the EPA.
	Environmental Protection Agency Conducted External Review of Inter-American Development Bank's Environmental Management Programme – Phase II Project to the EPA.
MINING	***Aroaima Mining Company Inc. & Bauxite Company of Guyana Inc.*** Provided technical assistance in preparing and submitting its applications for environmental authorization for bauxite mining.
ENERGY	***CGX Resources Inc.*** Provided technical assistance in preparing and submitting its applications for environmental authorization for seismic and exploratory drilling.

Multilateral Environment Agreements (MEAs) and GEF Funded Initiatives	
Biodiversity (UNCBD)	***Environmental Protection Agency*** Prepared the Third National Report on the implementation of the Cartagena Protocol on Biosafety under the United Nations Convention on Biological Diversity.
	Environmental Protection Agency Prepared the Third, Fourth and Fifth National Reports to the United Nations Convention on Biological Diversity.
	Environmental Protection Agency Prepared the Third Phase of Guyana's National Biodiversity Strategy & Action Plan.
	Environmental Protection Agency Prepared the Second Phase of Guyana's National Biodiversity Action Plan
	Environmental Protection Agency Assessed Capacity Building Needs for Initial Assessment and Monitoring, including Taxonomy as part of the Assessment of Capacity Building Needs for National Biodiversity Priorities Project.
	Environmental Protection Agency Conducted Stocktaking of Existing Capacity and Mechanisms as part of the Assessment of Capacity Building Needs for National Biodiversity Priorities Project.
	Environmental Protection Agency Supported the integration of UN Convention Activities into Annual Work Programmes of Agencies as part of the UNDP funded National Capacity Self-Assessment Project (NCSA).
Desertification (UNCCD)	***Guyana Lands & Surveys Commission*** Provided technical support for the aligning of Guyana's National Action Plan to the United Nations Convention to Combat Desertification's 10 Year Strategy (2008-2018)
	Guyana Lands & Surveys Commission Prepared Guyana's Fourth National Report to the United Nations Convention to Combat Desertification.

Multilateral Environment Agreements (MEAs) and GEF Funded Initiatives	
	United Nations Development Programme Prepared a Medium Size Project (MSP) Proposal for Sustainable Land Management.
	Guyana Lands & Surveys Commission Prepared the National Action Programme for the United Nations Convention to Combat Desertification.
	Guyana Lands & Surveys Commission Prepared Guyana's Third National Report to the United Nations Convention to Combat Desertification.
	Environmental Protection Agency Conducted a Stocktaking and Thematic Assessment of the United Nations Convention to Combat Desertification as part of the UNDP funded National Capacity Self-Assessment Project.
Water Resources Management	***Ministry of Housing & Water (MoHW)/ Guyana Wastewater Revolving Fund (GWRF)*** Prepared the Wastewater Management Strategy for Guyana under the GEF CReW Project "*Strengthening policy and institutional frameworks while building capacity for wastewater management in Guyana".*

Ministry of Tourism, Industry and Commerce (November 2002 – April 2009)
Tourism Technical Consultant to the Minister
Providing technical and strategic planning advise to the Minister on tourism and environment issues and the implementation of the Ministry's Tourism Work Programme with the principal achievements being the development and passage of legislation to establish a Tourism Authority and overseeing the setting up of the Authority.

Fauna & Flora International (September 2002 – October 2005)
In-Country Representative
Responsible for coordinating and providing technical guidance and input to activities of the Darwin Initiative Project, funded by the UK Government and with emphasis on training, capacity building and institutional strengthening for Guyana's Protected Areas System with focus on Shell Beach. Principal achievement included the coordination and execution of a series of training workshops on protected areas planning and management.

- Financing Protected Areas – Options for Guyana (30th & 31st March 2005)
- Techniques in Community Resource Evaluation – A Focus on Shell Beach (6th – 9th Sept 2004)
- Management Planning for Protected Areas (9th – 12th Aug 2004)
- Biodiversity Rapid Assessment – A Focus on Shell Beach (15th & 16th April 2004)
- Concepts, Methods and Processes for Community Education and Awareness – A Focus on the Shell Beach Protected Area Process and the Work of the GMTCS CEW's (6th & 17th March 2004)
- Developing a Public Awareness Strategy for Guyana's Protected Areas – A Focus on Shell Beach (3rd – 5th Nov 2003)
- Protected Areas Categories and their Management Implications: A Focus on Shell Beach (29th Sept – 1st Oct 2003)
- Community Consultation Processes: Designing A Model for Shell Beach (19th -21st May 2003)
- Project Management and Administration: A Smorgasbord of the Essentials (9th – 11th April and 14th – 16th April 2003)
- Protected Areas Management in Guyana – Institutional Management, Roles and Responsibilities (2nd – 4th Dec 2002)

World Wildlife Fund (WWF) Protected Areas Project (January 2003 – September 2003)
Project Director
Responsible for the implementation of the WWF funded project focused on the establishment and management of the Shell Beach Protected Area.

The Guyana Marine Turtle Conservation Society (August 2000 – September 2003)
Technical Director
Overall responsible for providing technical guidance to the Society and planning, overseeing and implementing the Society's programmes and activities for education and awareness, community empowerment, research, and protected areas.

The Iwokrama International Rainforest Programme (November 1999 – October 2001)
Professional Development Fellow – Protected Area Management
Responsible for assisting the Iwokrama Forest Manager and Human Resources Development Specialist to prepare and implement management plans for the Wilderness Preserve and other high amenity areas within the Iwokrama Forest; prepare guidelines for rangers and other staff with regard to working with national agencies and local communities in relation to patrolling and law enforcement within the Reserve and along the rivers and transport corridors that pass through the Reserve or form its boundaries; and planning and implementing a 2-year comprehensive ranger-training programme for Iwokrama rangers.

The University of Guyana (September 1999 – July 2001) Faculty of Arts – Department of Caribbean and Tourism Studies
Part-Time Lecturer on Ecotourism and Sustainable Tourism

The Environmental Protection Agency of Guyana (EPA) (August 1997 - June 1998)
Environmental Officer
Directly responsibility for biodiversity, natural resource management and tourism issues at the EPA and represented the EPA on the Natural Resources Management Project (NRMP).

Ministry of Public Works and Communications (July 1994 -August 1995) - Environment Division; Project Executing Unit.
Part - time assistant to the Environmental Officer

PROFESSIONAL DEVELOPMENT TRAINING

2000. November. New York, USA.
Completed the training course *'The Essentials for Successful Project Management'* conducted by Cornell University.

2001. July. Georgetown, Guyana.
Attended the training course *Biodiversity Protection in Forest Concession Area'* conducted by The Tropenbos Guiana Programme.

1999. December. Belem, Brazil.
December 1st – 15th, 1999
Completed the training course '*Techniques in Reduced Impact Logging'* conducted by the Tropical Forest Foundation (TFF).

1998. May. Georgetown, Guyana
Participated in the Inbound Ground Tour Operations Training Programme conducted by the Caribbean Tourism Organization (CTO).

1997. October. Georgetown, Guyana
Participated in the Training Programme on Sustainable Forest Management held by the

Environmental Protection Agency, Guyana Forestry Commission and ORGUT Consulting AB and sponsored by the Government of Guyana and the Inter-American Development Bank

BOARDS AND COMMITTEES

March 2013 to May 2014
Member of the Board of the Caribbean Climate Change Centre (CCCCC).

May 2009 to January 2014
Convenor of the Multi-Stakeholder Steering Committee for Guyana's Low Carbon Development Strategy (LCDS), the body responsible for overseeing the LCDS preparation and implementation.

January 2013 to May 2015
Chairman of the Board of the Protected Areas Commission, the body responsible for overseeing the planning and development of urban parks and protected areas in Guyana.

January 2011 to June 2012
Member of the Board of the Guyana Water Inc.

April 2003 – October 2011
Chairman of the Board of the Kaieteur National Park, the body with overall responsibility for the planning and management of the Park.

January 2004 – December 2005
Member of the Board of the National Trust of Guyana.

August 2002 – December 2003
Member of the Board of Guyana Tourism Authority, the body responsible for overseeing the work of the semi-autonomous Tourism Authority.

July 2001- August 2002
Chairman of the Ministerial Advisory Committee on Tourism (MACT) responsible for advising the Minister of Tourism on tourism and tourism related issues.

January 2001 – July 2001
Coordinator of a National Task Force established to assist the Minister of Tourism and Industry to develop the tourism sector in Guyana.

AFFILIATIONS

Registered Consultant with the Environmental Protection Agency of Guyana
Member of the International Association for Impact Assessment (IAIA)

MEETINGS, SEMINARS AND WORKSHOPS

2015. February. New Delhi, India.
Participated as a member of the Government of Guyana delegation to the 15th Delhi Sustainable Development Summit (DSDS) `*Sustainable Development Goals and Dealing with Climate Change.'*

2014. November. Georgetown, Guyana.
Participated in the workshop *Sharing Experiences on the FLEGT VPA Process* convened by Tropenbos International, Guyana Forestry Commission and other partners.

2014. June. Rome, Italy.
Participated as a member of Guyana's delegation to the 22nd Session of the Food and Agriculture Organisation (FAO) Committee on Forestry (COFO).

2014. February. Buccament, St. Vincent and the Grenadines.
Participated as a member of Guyana's delegation to the 25th Inter-sessional Meeting of the Conference of Heads of Government of the Caribbean Community.

2014. February. Washington, USA.
Participated as Guyana's representative to the Special Meeting of the Organisation of American States (OAS) Committee on Hemispheric Security titled *The Link between Security and Development in the Caribbean.*

2014. February. New Delhi, India.
Participated as a member of the Government of Guyana delegation to the 14th Delhi Sustainable Development Summit (DSDS) `*Attaining Energy, Water and Food Security for All*'.

2013. November. Warsaw Poland.
Participated as a member of the Government of Guyana's delegation at the High Level Segment of the 19th Conference of Parties Meeting of the United Nations Convention on Climate Change (UNFCCC).

2013. August. Paramaribo, Suriname.
Participated as a member of Guyana's delegation to the 3rd International Congress on Biodiversity of the Guiana Shield.

2013. February. New Delhi, India.
Participated as a member of the Government of Guyana delegation to the 13th Delhi Sustainable Development Summit (DSDS) `*The Global Challenge of Resource Efficient Growth and Development*'.

2012. November. London, United Kingdom.
Participated as a member of the Government of Guyana delegation to meeting convened by His Royal Highness Prince of Wales on Forests and Climate Change.

2012. September. Jeju, South Korea.
Participated as a member of Guyana's delegation to the 2012 IUCN World Conservation Congress.

2012. June. Rio De Janeiro, Brazil.
Participated as a member of the Government of Guyana delegation to the Rio+20 Earth Summit.

2012. April. Georgetown, Guyana.
Participated as a member of the Government of Guyana delegation to the 13th Annual Caribbean Conference on Sustainable Tourism Development *"Keeping the Right Balance: Sustaining Our Resources"*.

2012. March. Bonn, Germany.
Participated as Guyana's representative to the 113th Meeting of the United National Convention on Climate Change (UNCCD) CDM-DNA Training Forum and the 1st Sustainable Development Mechanism Joint Coordination Workshop.

2012. February. New Delhi, India.
Participated as a member of the Government of Guyana delegation to the 12th Delhi Sustainable Development Summit (DSDS) `*Protecting the Global Commons: 20 Years Post Rio*'.

2011. February. New Delhi, India.
Participated as Guyana's representative to the 11th Delhi Sustainable Development Summit (DSDS) `*Tapping Local Initiatives and Tackling Global Inertia*'.

2010. December. Cancun, Mexico.
Participated as a member of the Government of Guyana's delegation at the High Level Segment of the 16th Conference of Parties Meeting of the United Nations Convention on Climate Change (UNFCCC).

2010. November. The Hague, Netherlands.
Participated as Guyana's representative to the Global Conference on Agriculture, Food Security and Climate Change organized by the Dutch Government in collaboration with the World Bank and FAO.

2010. November. Georgetown, Guyana.
Participated as a member of the Government of Guyana Delegation to the 4th Ordinary Meeting of the Council of Heads of State and Government of the Union of South American Nations (UNASUR).

2010. February. Washington, USA.
Participated in Forest Carbon Finance 2010 – *Getting to Scale, Getting Results.* Sponsored by WWF, Duke University and Harvard Law School.

2009. December. Copenhagen, Denmark.
Participated as a member of the Government of Guyana's delegation at the High Level Segment of the 15th Conference of Parties Meeting of the United Nations Convention on Climate Change (UNFCCC).

2009. November. Manaus, Brazil.
Participated as a member of Guyana's delegation to the Meeting of Heads of States of the Amazon Countries and Preparatory Meeting of Chief Negotiators on Climate Change.

2009. March. Capitol Hill, Washington USA.
Attended as part of the Government of Guyana's delegation, the forum *"Forests, Finance, People and Climate Change: International Perspectives for US Legislation"* convened by US Congressman Jay Inslee and Senator Robert Menendez.

2009. March. Washington, USA.
Participated in Forest Carbon Finance 2009 – *Making Forest Carbon Markets Work.* Sponsored by WWF, Duke University and Harvard Law School.

2008. December. Posnan, Poland.
Participated as a member of the Government of Guyana's delegation at the High Level Segment of the 14th Conference of Parties Meeting of the United Nations Convention on Climate Change (UNFCCC).

2008. January. Santo Domingo, Dominican Republic.
Represented Guyana at the *16th Meeting of the Forum of Ministers* of Latin America and the Caribbean.

2007. December. Bali, Indonesia.
Participated as Technical Team of the Government of Guyana's delegation at the 13th Conference of Parties Meeting of the United Nations Convention on Climate Change (UNFCCC).

2007. November. New York, USA.
Participated as a member of the Government of Guyana delegation to the High Level Event *The Future in our Hands – Addressing the Leadership Challenge of Climate Change* convened by the

UN Secretary General.

2000 August. Georgetown Guyana.
Attended the 4th Sea Turtle Symposium of the Guianas held to bring together organization and individuals working on marine turtle conservation in the Guianas.

2000 March. Salvador Brazil.
Participated in World Ecotour 2000, An international gathering of professionals from around the world to discuss issues related to ecotourism planning, operation and management.

2000 April. Georgetown Guyana.
Consultation Workshop on National Environmental Action Plan (NEAP) for Guyana (2000 – 2004)

1999 July. Tokyo, Japan.
Three Day Seminar conducted by the IDB Tokyo Office on the role of the IDB and the Japan-IDB Scholarship Program in the IDB Member Countries.

1998 January. Santo Domingo, Dominican Republic.
Regional Expert Workshop on Biodiversity Strategies and Action Plans to assess and identify support activities to be included in the GEF Global Support Programme for Enabling Activities. Global Environment Facility (GEF) in collaboration with United Nations Development Programme (UNDP).

1997. Mon-Repos, Guyana.
Workshop on Sustainable Forest Management and Monitoring in Tropical Forests.
ORGUT in collaboration with the Guyana Forestry Commission and the Environmental Protection Agency.

1997. Georgetown, Guyana.
Ecological and Economic Zoning Workshop for the Americas. Government of Guyana/Amazon Co-operation Treaty (ACT)/Inter-American Development Bank (IDB).

1996. Georgetown, Guyana.
National Environmental Education Workshop to finalise the National Environmental Education and Awareness Strategy.Co-ordinated by the Office of the President.

1995. Georgetown, Guyana.
A Series of Seminars and Workshops to develop a Draft National Biodiversity Strategy of Guyana. Co-ordinated by the Office of the President.

REFERENCES

Available upon request.

CURRICULUM VITAE

NAME:
Khalid Alladin

POSITION:
Projects Manager

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60 Area H Ogle
East Coast Demerara
Guyana

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EDUCATION

The University of Guyana (1996 - 2000)
Bachelors of Arts Degree: Major – Geography, Minor – Law (Best Graduating Student)

WORK EXPERIENCE

February 2009 - present – Projects Manager, Environmental Management Consultants
Responsible for managing projects executed by the firm, including the following specific projects:

Environmental and Social Impact Assessments (EIAs) – Contributed to the following ESIA's preparation:

- Participating in the conduct of the **ESIA for Esso Exploration and Production Guyana Ltd. Liza 2 Project**. (January 2018 to present)
- Participating in the conduct of the **Risk Assessment for Schlumberger Guyana Inc. Drilling Fluids and Dry Bulking Production and Storage Facility** at Houston, EBD. (2017- present)
- Participating in the conduct of the **Ecosystem Services Survey for Esso Exploration and Production Guyana Ltd. Liza 1 Project**. (2017- present)
- Participated in the conduct of the **EIA for Tullow Oil Guyana (Tullow)** 3D seismic operations in the Orindiuk Block Area, offshore Guyana. (2016)
- Participated in the conduct of the **Environmental and Social Analyses** of Component 1 of the project to **Support and Improve Maternal and Child Health** supported by the IDB. (2016)
- Technical Team Leader for the conduct of the **EIA for Simon and Shock International Logging Inc. Logging and Sawmilling Operations** in the North Rupununi Area. (2010 to 2013)
- Technical Team Leader for the preparation of the **EIA for Anadarko Petroleum Corporation Roraima Block** within the offshore Georgetown Concession in collaboration with ACORN International. (2013)
- Technical Team Leader for the preparation of the **ESIA for the West Demerara Road Rehabilitation Project** in collaboration with Marcel Gaskin & Associates Ltd. (2012)
- Participated in the conduct of a **Coastal Sensitivity Survey** for Repsol/ESL (2011)
- Technical Team Leader for the preparation of the **EIA Addendum and Environmental Management Plan for the Bonasika Bauxite Mine and Sand Hills sintered Bauxite Production Plant and Supporting Infrastructure** for Guyana Industrial Minerals Inc. (GINMIN). (2009-2011)
- Technical team Leader for the preparation of the **EIA for Repsol proposed Jaguar 1 Exploratory Drilling Well** within the offshore Georgetown Concession in collaboration with Environmental Sciences Limited. (2010-2011)
- Technical Team Leader for the conduct of the **EIA for CPT Inc. Logging and Sawmilling Operations** in the Pomeroon Area. (2010-2011)
- Technical Team Leader for the preparation of the Environmental and Social Impact Assessment for the Ministry of Agriculture **Cunha Canal Rehabilitation Project.** (2009-2010).
- Technical Team Leader for the revision of the **EIA for the Marriot Hotel**, Kingston, Georgetown. (2010-2011)

- Conducted consultations with Government Agencies and Institutions for the preparation of the **Strategic Environmental Assessment (SEA) for CGX Offshore Exploratory Drilling Activities**. (2009)

Environmental Management Plans (EMPs) – Technical Team Leader for the preparation of the following Management Plans:

- Troy Resources Guyana Inc. Environmental Monitoring Protocols (2018)
- Edward B Beharry & Company Ltd Manufacturing Facility – Mandela Avenue (2017)
- V P Baichan Quarry – Corentyne River (2017)
- Innovative Mining Inc. Airstrip – Aramatta (2017)
- Suresh Jagmohan Asphalt Plant - Timehri (2016)
- Dr. Balwant Singh Hospital (2016)
- Troy Resources Guyana Inc. Biodiversity Management Plan (2016)
- Troy Resources Guyana Inc. Environmental Monitoring Plan (2016)
- Kilroy Mining Inc. Mining Operations at Eagle Mountain (2015-2016)
- Benjamin Stone Quarry at Itaka, Essequibo River (2015)
- Central Housing & Planning Authority East Coast–East Bank Road Linkage (2015)
- Noble House Seafood Ltd Waste Management Plan for Seafood Processing (2015)
- Sterling Products Limited Manufacturing and Processing Operations (2015)
- Ministry of Agriculture/ National Drainage & Irrigation Authority (NDIA) Aurora Land Development Project on the western Essequibo Coast (2014)
- Standard Agro-Forestry Inc. Integrated Farm Project, Intermediate Savannahs, Region 10 (2014)
- Barama Company Limited Logging Operations (2013-2014)
- Blue Wave Plantations Inc. Integrated Farm Project, Intermediate Savannahs, Region 6 & 10 (2013)
- Stronghold Guyana Inc. Baseline Biodiversity & Surface Water Assessment at Eagle Mountain Concession (2013)
- GINMIN Biodiversity Management Plan (2012)
- East Coast Demerara Roadway Four Lane Extension – Better Hope to Belfield (2012-2013)
- Santa Fe Agricultural Project, North Rupununi (2011)
- East Demerara Water Conservancy Northern Relief Structure at Hope/Dochfour, East Coast Demerara. (2010-2011)
- GINMIN Bauxite Mining within the Waratilla – Cartwright Concession (2010-2011)
- CGX Resources Inc at Crab Island, Berbice (2009-2010)
- Demerara Distillers Limited at Pln Diamond, East Bank Demerara (2010)
- Comfort Sleep at Eccles Industrial Estate, East Bank Demerara (2009-2010)
- Shawnees Service Station at Soesdyke, East Bank Demerara (2009)
- Bauxite Company of Guyana Inc. (BCGI) for mining of 2 Manaka and Block Five Deposit in the Berbice area (2009-2010), mining in Block 38 Cocorite Deposit (2012), and mining of the 22 Kurubuka deposit.

Closure and Decommissioning Plan (CDP) - Contributed to the preparation of the following:

- Troy Resources Guyana Inc. Reclamation Plan (2017-present)
- Bauxite Company of Guyana Inc. (BCGI) mining operations at Block Five Deposit in the Berbice area. (2013-2014)
- Bauxite Company of Guyana Inc. (BCGI) mining operations at West Pit and Bissaruni in the Berbice area. (2010-2011)

Environmental Compliance and Biodiversity Monitoring – Coordinated and involved in the Environmental and Biodiversity Monitoring of the following projects:

- **Sterling Products Ltd** manufacturing operation (2017-present)
- **Edward B Beharry & Company Ltd Manufacturing Facility** – Mandela Avenue (2017-present)

- **Agriculture Sector Development Unit** World Bank supported Flood Risk Management Project and the Rehabilitation of the Cunha Canal Relief Channel and Structures projects (2017-present).
- Biodiversity Monitoring for **Troy Resources Guyana Inc.** (2017-2018)
- **Noble House Seafood Ltd** Seafood Processing (2016-present)
- **Troy Resources Guyana Inc.** Environmental Compliance of Mining Operations (2015 - present)
- **University of Guyana** World Bank Supported Science and Technology Support Project (2014-2016).
- Rehabilitation of the **West Coast Demerara Road** (2015-2017)
- **BCGI mining and processing operations** at Aroaima, Kurubuka and Kwakwani (2012 to present).
- **Construction of the East Bank Four Lane Road** for DIPCON Engineering Services Ltd (2013-2015).
- **Construction of the East Coast Four Lane Road** for DIPCON Engineering Services Ltd (2013-2015).
- **Community Roads Improvement Project** executed by the Ministry of Housing and Water**.** (2012-2014)
- Environmental Compliance Monitoring at **Bonasika Deposits for GINMIN** (2012- present)
- Construction of the **Hope-Dochfour Canal and Structures** (2011 to 2014)
- **Crab Island Wharf for CGX Resources Inc.** (2010 to present).
- Biodiversity Monitoring at **Bonasika Deposits for Guyana Industrial Minerals Inc. (GINMIN)** (2010 to 2013 and 2017)
- **Amaila Falls Hydropower Access Road** for SRKN'gineering (2010-2012)
- Rehabilitation of **East and West Canje Roads** for SRKN'gineering (2010 to
- Rehabilitation of **Roadway Structures (Bridges) from Timehri-Rosignol Lot II A2** for R. Bassoo & Sons Construction Company (2009-2012).
- Rehabilitation of **Roadway Structures (Bridges) from Timehri-Rosignol Lot II A1** for Courtney Contracting Services Ltd (2009-2012).

Environmental Reports – *Coordinated the preparation environmental reports including the following:*
- Edward B Beharry & Company Ltd Manufacturing Facility Environmental Report (2017)
- Bauxite Company of Guyana Inc. Environmental Reports (2012-2017)
- CGX Wharf and Logistics Yard Environmental Reports (2011-2017)
- Guyana Industrial Minerals Inc. Environmental Reports (2012-2017)
- Troy Resources Guyana Inc. Environmental Reports (2015-2017)
- Noble House Seafoods Limited Environmental Reports (2015-2017)
- Comfort Sleep Inc. Consolidated Environmental Report (2015)
- Shawnees Service Station Annual Environmental Report. (2013)
- Two Brothers Gas Stations Annual Environmental Reports. (2012)
- Marudi Resort Annual Environmental Report. (2012)
- Barama Company Limited Annual Environmental Reports for Buckhall Complex and Land of Canaan. (2012)

Environmental Audits – Conducted Environmental Audit of Bosai Minerals Bauxite Mining and Processing Operations at Linden (2014)

Natural Resource Management – Participated in the execution of the following projects:
- Contributed to the project **Support the Strengthening of Monitoring and Enforcement of Mining Regulations.** (2017)
- Contributed to the preparation of **Guyana's National Wastewater Management Strategy.** (2015)
- Contributed to the Stocktaking and Preparation of the **Outline for the Aligned National Action Programe to Combat Land Degradation.** (2014-2015)

- Contributed to the preparation of **Guyana's Fifth National Report for the United Nations Convention on Biological Diversity**. (2014)
- Contributed to the preparation of **Guyana's Third National Biodiversity Strategy & Action Plan**. (2014)
- Contributed to the preparation of **Guyana's Fourth National Report for the United Nations Convention on Combating Desertification**. (2011)
- Served as a member of the team conducting a **Stocktaking of Existing Capacity and Mechanisms** for the Assessment of Capacity Building Needs for National Biodiversity Priorities Project. (2009)
- Served as a member of the team **Assessing Capacity Building Needs for Initial Assessment and Monitoring Programmes, including Taxonomy** for the Assessment of Capacity Building Needs for National Biodiversity Priorities Project. (2009)

Training Conducted in Environmental Management - Contributed to the preparation of training manual and delivering of the following training exercises:

- ***Training to Strengthen the Capacity of EPA Field Officers to facilitate greater oversight of the Gold Mining Sector –*** Organised by the Ministry of Natural Resources and funded by GEF with support from UNDP. (2016)
- ***Environmental Awareness and Best Practices Training –*** conducted for Bauxite Company of Guyana Inc.'s personnel in Region 10. (2015)
- ***Georgetown Solid Waste Management Training*** - This was done as part of the Georgetown Solid Waste Management Programme. (2009)
- ***Tourism and Environmental Management Training –*** Organized by Linden Economic Advancement Programme for a group of tourism stakeholders in Region 10.

Tourism

- Contributed to the preparation of the **Guyana Tourism Manual** for Guyana Tourism Authority/Amazonia Cooperation Treaty Organisation. (2011)

February 2009 – Present – Independent Consultant

- **Iwokrama –** Coordinated the conduct of a **Social Impact Assessment** of the Forest Operations. (2017-2018)
- **Basic Needs Trust Fund –** Contributed to the preparation of the 2016-2017 Annual Environmental Report (2017-2018)
- **GuyGas LPG Bottling Plant –** Prepared the Consolidated Annual Environmental Report for 2013-2016. (2017)
- **Iwokrama** – preparation of Environmental Management Plan for Mill Site (2016)
- **Iwokrama** – revision of Closure and Decommissioning Plan for Mill Site (2016)
- **J and R Ranch Environmental and Social Management Plan -** contributed to the preparation of the ESMP for the Ranch and Aqua Farm in the North Rupununi (2015-2016)
- **Energy Plus Service Station Consolidated Environmental Report** – Prepared the Consolidated Environmental Report for the Service Station at Chateau Margot (2014)**.**
- **Stockholm Convention Enabling Activities Project –** Served as National Consultant responsible for the preparation of the Contaminated Sites Inventory and the conduct of the Capacity Assessment (2011 to 2012).
- **Energy Plus Service Station Environmental Management Plan** – Prepared the Environmental Management Plan for the Service Station at Chateau Margot (2012)**.**
- **Durban Quarries** – Coordinated the revision of the Environmental Impact Assessment and Management Plan for the Quarry (2011-2012).
- **GuyGas LPG Bottling Plant –** Prepared the Annual Environmental Report for 2011-2012. (2012)
- **Tigerwoods Guyana Inc. –** Conducted Annual Compliance Audit of the Mill Site within the Iwokrama Forest (2010).
- **GuyGas LPG Bottling Plant –** Prepared Environmental Management Plan for the Bottling Plant at Lan of Canaan, East Bank Demerara (2010).

- **Hazardous Waste Inventory and Strategy for Region 4 –** Served as local consultant to SENES Consulting Firm which is conducted an inventory and developed a strategy for Hazardous Waste Management in Region 4 (2009-2010).
- **TCL Cement Bagging Plant –** Assisted in conducting compliance audit required by the Environmental Protection Agency for the Bagging Plant (2009-2010).
- **Iwokrama –** Conducted an Environmental Assessment for the Permanent Mill Site within the Iwokrama Forest (2009).
- **Port Kaituma Water Safety Plan (WSP) –** Contributed to the preparation of the WSP for the community for Ministry of Health and Pan-American Health Organisation (PAHO) identifying the various risk and problems and recommending measures for improvement (2009).
- **Nauth Service Station Environmental Management Plan** - Contributed to the preparation of an Environmental Management Plan for the Service Station at Unity, Mahaica (2009)**.**

June 2008 to January 2009 – Director (ag) – Environmental Management Division - Environmental Protection Agency
Was responsible for managing the Environmental Management Division, the core Division of the Environmental Protection Agency which consisted of four programme areas of Authorisations, Complaints and Response, Monitoring and Enforcement and Research and Development. The Division consisted of eighteen (18) staff and responsibilities included developing and managing the Environmental Quality Control (EQC) and Environmental Monitoring and Enforcement (EMS) systems, including appropriate regulations, developing and managing the emissions discharge licensing and permitting system, including appropriate procedures, developing and implementing of environmental emergency response procedures, directing the further development of the EIA process, managed its implementation, and provided technical advice and support to the Environmental Assessment Board in conducting its duties, supervising Senior Environmental Officers responsible of the four programme areas. Was responsible for developing and maintaining linkages with Sectoral Agencies, local government and non-governmental organisations and international organizations, prepared environmental programmes including work programmes and budgets, coordinated the development of environmental standards and codes of practice, coordinated and implemented environmental and other programmes for the Agency with assistance from donors included IDB, UNDP and UNEP.

August 2007 to June 2008 - Senior Environmental Officer – Authorisation - Environmental Protection Agency
Was responsible for managing and overseeing the Environmental Authorisations process. This includes coordinating the Environmental Impact Assessment Process, negotiating with staff in developing of annual work plans and budget, developing and implementing training programmes for staff of the division, investigating reports of suspected violations of environmental permits and or hazards to the environment and the development of technical material for environmental awareness and participate in such activities. Also includes effective assigning of resources to achieve results based on the work plan, supporting the work of the Environmental Assessment Board and develop relationship with external and internal stakeholders. Represented the Agency and Guyana at regional and international forums.

February 2006 to July 2007 – Senior Environmental Officer – Research and Development - Environmental Protection Agency
Was responsible for coordinating all research and development activities of the Environmental Management Division which included the development of environmental standards, regulations, and guidelines for industry and natural resources, environmental management instruments and procedures and protocols for their use (e.g. strategic environmental assessments, identifying of areas for development in environmental management and formulate proposals for projects, provide on-going recommendations to improve the EPA's compliance and complaints monitoring and enforcement protocols and programmes, recommend conditions to attach to an environmental authorization pertaining to environmental monitoring, management and emergency response plans and develop field protocols to ensure compliance, review sectoral projects reports and registers of information to evaluate the adequacy and make recommendations to improve value. Also included

the preparation of the annual work plan, budget and annual reports, develop and implement training programmes for officers, develop technical material for environmental awareness, assist in the implementation of the solid and hazardous waste programme, coordinate all activities relating to international conventions and multilateral environmental agreements and coordinate any other programmes in relation to the environment. Managed a consultancy to produce a State of the Environment Report and a Public Disclosure Programme for Guyana. Coordinated projects relating to Hazardous Waste Management including conducting a National Hazardous Waste Inventory.

November 2000 to January 2006 – Environmental Officer Environmental Protection Agency, Guyana (*Environmental Officer - November 2000 to October 2002, Environmental Officer II - November 2002 to January 2006)*
Screened proposed projects to determine significant impacts and reviewed environmental impact assessments, environmental management plans, environmental management systems and social impact assessments for projects including Amaila Falls Hydro Power Project, Camboir Bauxite Mining Project, Marudi Mountain Gold Mining Project, Maple Creek Diamond Mining Project, Case Timbers Logging Project, Iwokrama Timbers Project and Conservation International Conservation Concession. Monitored and reviewed monitoring reports of permitted operations including Omai Gold Mines Ltd and Splashmins Fun Park. Worked closely with sectoral agencies including the Guyana Geology and Mines Commission, Guyana Forestry Commission, Guyana Lands and Surveys Commission and the Central Housing and Planning Authority in the execution of duties. Contributed to the development of environmental regulations, standards and codes of practice including the Environmental Protection Regulations, Mining Environmental Regulations, National Forest Management Standards, Environmental Standards, Codes of Practice for Forest Operations, Sand and Saprolite Mining, Nibi and Kufa Harvesting, and Small Scale Gold Mining. Served as EPA Counterpart to two Hazardous Waste Management Consultancies. Served on several committees including one that recommended the Interim TSS discharge level from mining activities. Organised and executed a Field Training Exercise for the technical staff of the Agency. Trained new staff, developed Training Manual. Prepared Guidelines for Eco Tourism Projects, Wood Working Operations, Abattoirs, Slaughter Houses, Poultry Processing, etc. Developed research programmes for University of Guyana student's final year projects. Conducted a Water Quality Survey of the Essequibo/Konawaruk Rivers. Assisted the Education, Information and Training Division with organizing Environmental Exhibitions, Mining Exhibitions, Green Walks, Calendars, and other public awareness activities and developing public awareness materials. Served as EPA representative on the CIDA funded Guyana Environmental Capacity Development Project which objective was to develop environmental capacity in the mining sector.

PROFESSIONAL DEVELOPMENT

Training

International
Integrated Environmental Planning and Management
Exposure to environmental planning and management in Malaysia and other Third World countries and provided a forum of sharing knowledge and experiences.
National Institute of Public Administration, Kuala Lumpur, Malaysia 28 June – 23 July 2004

Environmental Policy and Environmental Management Systems
Exposure to measures used by Japan to address various environmental problems.
Japan International Cooperation Agency/ Global Environment Centre/ Environment and Sewerage Bureau of Osaka City, Japan, 21 May – 08 July 2003

Environmental Management Systems Internal Auditors Course
Training on conducting audits to determine compliance with ISO Environmental Management Standards, New Japan Certification Service Co., Ltd, Japan, 23-25 June 2003

Environmental Management Systems Implementation Course
Training on Implementing ISO Environmental Management Standards.
New Japan Certification Service Co., Ltd, Japan, 18-20 June 2003

National/Local

Joint Demonstration Project Linking a National Programme of Action with a Water Safety Plan
NOAA, CDC, CEHI, USGS and PAHO. 8th – 9th May 2007

Forest Landscape Restoration
ITTO Guidelines for rehabilitation, restoration and management of degraded tropical forest.
World Conservation Union and International Tropical Timber Organisation. 13th -17th March 2006

Communication and Conflict Resolution Skills
Arthur Lok Jack Graduate School of Business, University of the West Indies.
23rd January – 3rd February 2006

Pollution Abatement for Priority Sectors in Guyana
Training in methods for pollution abatement in the rice, wood, tourism, energy and mining sectors
Clint Edmonds and Associates, Environmental Protection Agency, 2005

Environmental Economics
Exposure to Economic Tools/Instruments that can be used to aid Environmental Management
Environmental Protection Agency – March 2004 - March 2005

Cumulative Environmental Impact Assessment – A Practical Exercise
Training on Conducting Cumulative Impacts Assessments. Executed a Cumulative Environmental Impact Assessment for the Mahdia Area – a gold mining community in Guyana
GENCAPD, Hotel Tower, 26-30 January 2004

Code of Practice for Small Scale Gold Mining
Training on Developing Code of Practices for the Mining Sector. Developed a Code of Practice for small scale gold and diamond mining operations in Guyana.
GENCAPD, Georgetown Club, 21-27 November 2003

Principles in the Development of Code of Practices
Training on Developing Code of Practices. GENCAPD, Hotel Tower, 30 September 2003

Hydro-sedimentology Survey
Survey of the Potaro River, Guyana. Trained in the collection, preservation, storing and analysis of water and sediment samples. Also trained in the recording, reporting and presenting data collected.
Richard Couture, GENCAPD, Potaro River -15th – 20th March 2002

Training for Trainers
Training in the preparation and presentation of environmental related issues to various target groups. Environmental Protection Agency/ UNDP, Plaza Hotel – 9th February 2002

Global Positioning System
The use of GPS devices. Collection storing, analysis and use of GPS data.
GENCAPD, Ocean View International, 6th-9th November 2001.

Use of Environmental Monitoring Equipment
Training on the use of various environmental monitoring equipment for collection and analysis of various samples and parameters. Environmental Management Division
Environmental Protection Agency, Camp Kayuka, Soesdyke, 19th -21st October 2001

Decision Making Environment
Deciding on the most appropriate measures in solving Environmental Conflicts and making Important Environmental Decision, Dr. Clinton Edmonds - SENES Consultant Ltd. EPA/ IAST Boardroom, 19th July 2001

Environmental Information Management Systems
Managing Environmental Data efficiently by the use of appropriate software, etc.
Dr. Clinton Edmonds - SENES Consultant Ltd. EPA/IAST Boardroom, 18th July 2001

Environmental Management Instruments
Techniques used in Environmental Management.
Dr. Clinton Edmonds - SENES Consultant Ltd. EPA/IAST Boardroom, 17th July 2001

Air Quality Management
Managing air quality, standards development, monitoring modeling, collection and analysis of air quality data. Dr. James Young – SENES Consultant Ltd. EPA/IAST Boardroom, 3rd July 2001.

Strategic Environmental Assessment Workshop
Preliminary course on the basics and importance for conducting a Strategic Environmental Assessment. Dr. Maria Partidario, Caribbean Academy of Sciences/University of Guyana/International Association of Impact Assessment. Hotel Tower, June 2001.

Compliance Monitoring and Enforcement
Training on Methodologies of working with non-complying Operators/Developers, Rights and Jurisdiction of Environmental Officers, Evidence Collection and Penalties for non-compliance.
Judy Daniels- International Consultant and Lead Auditor, EPA/IAST Boardroom, May 2001

Environmental Authorisation Writing
Training on Legalities and Pre-requisites of Environmental Authorisations.
Judy Daniels- International Consultant and Lead Auditor, EPA/IAST Boardroom, March 2001

Advance Sectoral EIA Training
Training in the execution of Sectoral EIAs. Worked on a Sectoral EIA for Sand and Saprolite Mining in the Linden- Soesdyke Area, Guyana.
GENCAPD, Ocean View International, March 2001

Introductory Course to Sectoral EIA
Preliminary course on the basics and importance for conducting a Sectoral Environmental Assessment. GENCAPD, Ocean View International February 2001

First Aid Training
Basic training in First Aid, Red Cross International, October 2005

Workshops/Seminars/Conferences
International/Regional

Sixth Session of the Open-Ended Working Group of the Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes and their Disposal
Represented the Government of Guyana. Geneva, Switzerland – September 3rd – 7th 2007

Second Intergovernmental Review Meeting of the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA)
Represented the Government of Guyana. Beijing, China - October 16th-20th

Regional Promotional Workshop on the Protocol Concerning Pollution from Land Based Sources and Activities for the English Speaking Caribbean Countries
Represented the Government of Guyana. St Lucia – July 24th -26th 2006
Reducing Mercury Use in Products in the Americas
Represented the Government of Guyana. Yucatan, Mexico, February 21-23 2006

Regional Awareness Raising Workshop on Mercury Pollution
Represented the Government of Guyana. Trinidad and Tobago January 18th -21st 2005

National/Local
Bio-safety Framework
Workshop to discuss Guyana's Draft Bio-safety Framework under the Cartagena Protocol of the CBD Convention. Environmental Protection Agency, Global Environmental Facility and United Nations Environment Programme, Hotel Tower – 27th November 2006

Sustainable Forest Management Indicators
Identifying indicators for sustainable forest management through the ACTO/TAREPOTO Process
ACTO/Guyana Forestry Commission, 17-19th August 2005

Hazardous Waste Management
Developing Priorities for Implementation of the Hazardous Waste Regulations 2000
Sam Wright – International Consultant - EPA/IAST Boardroom – 26th October 2004

Quarrying Workshop
Regularizing the Quarrying Sector in Guyana. Developing strategies to assist the quarrying sector to comply with national requirements. Guyana Geology and Mines Commission, 30th May 2002

Forest Management Standard Retreat
A technical review of the Draft National Standards for Forest Management. A member of the National Working Group on Forest Certification., Profor (UNDP), GFC, Tropenbos
Emerald Tower – 29-30 Nov and 1 December 2001

Forest Management Standards Workshop
Issues relating to forest certification in Guyana and the experiences of other countries in this process. Tropenbos/ Forest Stewardship Council/ Guyana Forestry Commission – Guyana, Cara Inn, 20th -22nd November 2001.

Forest Certification Workshop
Gap analysis of what is required to achieve certification of one of the pilot certification project in Guyana. Tropenbos, Bamboo Landing, Berbice River, 7th -8th November 2001

Hazardous Waste Management Workshop
Issues relating to Hazardous Waste Management with reference to Guyana
Dr. Murali Ganapathy - SENES Consultant Ltd. EPA/IAST Boardroom, 9th – 10th July 2001

Environmental Impact Assessment Workshop
Requirements of the EIA Process in Guyana for Environmental Consultants
EPA, EPA/IAST Boardroom, December 2000

Land Tenure Regularisation in Guyana
Guyana Land Administrative Support Programme (GLASP), Guyana Lands and Surveys Commission, NARI, Mon Repos, November 2000.

Good Practices in Mining /Gold Recovery Workshop
Demonstration on the Use of Retort for Mercury Recovery and Sluice Boxes in Small Scale Gold Mining. GENCAPD (Guyana Environmental Capacity Development Project), November 2000

BOARDS AND COMMITTEES

National Science and Technology Council
Served as a member of the Council (2014-2015).

Board of Directors – Central Housing and Planning Authority
Served as a member of the Board of Directors of the Authority (January 2008 to January 2009).

Board of Directors - Guyana Forestry Commission
Served as a member of the Board of Directors of the Commission (July 2005 to January 2009).

Board of Directors - National Standards Council, Guyana National Bureau of Standards
Served as Member of the National Standards Council (February 2006 to October 2007).

Guyana Local Organising Committee for Cricket World Cup 2007
Served as a member of the Health and Emergency Committee in preparation for hosting of the World Cup games (January 2005 to March 2007).

Guyana National Initiative on Forest Certification
Served as a member throughout the process of developing a National Standard for Forest Management for endorsement by the Forest Stewardship Council (2000-2004).
Geographical Association of Guyana -1996 to 2000
Served as Vice President (1998 - 2000) and Executive Member (1996 -1998).

University of Guyana Student Society
Served as an Executive Member, Faculty of Arts Representative, the Head of the Publication Unit and a Member of the Sports Committee (1999-2000).

AWARDS

Exceptional Employee of the Year Award (Team Spirited) - Environmental Protection Agency-2001

Bartholomew Atlas Prize – Best Graduating Student Geography – University of Guyana – 2000

CURRICULUM VITAE

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Lakshman Richard Persaud

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Environmental and Social Consultant

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East Coast Demerara
Guyana

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QUALIFICATIONS

University of Nicosia, Cyprus (currently pursuing)
Master of Business Administration, MBA (Online)

The University of Guyana (1999)
Post Graduate Diploma: *Development Studies*

The University of Guyana (1997)
Bachelor of Arts: *Geography/Economics*

WORK EXPERIENCE

April – August 2016 & June 2014 – August 2015 - (Consultant) Project Community Liaison Officer with CEMCO/MMM for the East Bank Demerara Four Lane Extension Road Project

August 2009 - present – Environment and Social Consultant, Environmental Management Consultants

Worked on the following specific projects:

Environmental & Social Impact Assessments (EIAs) – Contributed to the preparation of the following:

- ESIA for the West Demerara Road Rehabilitation Project in collaboration with Marcel Gaskin & Associates Ltd.
- ESIA Addendum and Environmental Management Plan for the Bonasika Bauxite Mine and Sand Hills sintered Bauxite Production Plant and Supporting Infrastructure for Guyana Industrial Minerals Inc. (GINMIN).
- Assisted in the preparation of the EIA in collaboration with Environmental Sciences Limited for REPSOL proposed Jaguar 1 Exploratory Drilling Well within the offshore Georgetown Concession.
- ESIA for CPT Inc. Logging and Sawmilling Operations in the Pomeroon Area.
- ESIA for Simon and Shock International Logging Inc. Logging and Sawmilling Operations in the North Rupununi Area.

Environmental Management Plans (EMPs) - Contributed to the preparation of the following:

- EMP for Central Housing & Planning Authority East Coast–East Bank Road Linkage.
- EMP for Ministry of Agriculture/ National Drainage & Irrigation Authority (NDIA) Aurora Land Development Project on the western Essequibo Coast.
- EMP for Standard Agro-Forestry Inc. Integrated Farm Project, Intermediate Savannahs, Region 10.
- EMP for Santa Fe Inc Integrated Farm Project – Rupununi Savannahs, Region 9

- Environmental Assessment for the East Demerara Water Conservancy (EDWC) Northern Relief Structure at Hope/Dochfour, East Coast Demerara.

Closure and Decommissioning Plan (CDP) - Contributed to the preparation of the following:
- Bauxite Company of Guyana Inc. (BCGI) mining operations at Block Five Deposits in the Berbice area.

Natural Resource Zoning & Mapping

Expertise includes community resource mapping, population density studies, gathering data for land use maps and application of spatial data using satellite and GIS technologies. A few completed works includes:
- Satellite imagery verification by on the ground location analysis and mapping of biomass resource type
- Community resource mapping for communities of Deep South Rupununi
- Mapping of land use types for the 63 Beach and adjoining areas as part of the *Caribbean Regional Environmental Program* Amenity Areas; Demonstration Project – No. 43-74 Villages, Corentyne Coast, and
- Development of village maps for specific areas on the Essequibo Coast.

December 2010 - October 2013 (Consultant) - Community Development Specialist for the Development of Land Use Planning (DULP) Project

The DULP Project is funded by the EU in partnership with the GoG represented by the Guyana Lands and Surveys Commission (GL&SC). The project was hosted by the GL&SC implemented by HTSPE Limited in association with Infoterra and SRKN'gineering.

2011 - Ministry of Agriculture & United Nations Framework Convention on Climate Change Short-term Technical Assistant to the International Consultant in the Enabling Activity for the Preparation of Guyana's Second National Communication to the UNFCCC.

2010- Consultant - World Wildlife Fund Guianas

2008 – 2009 - UNDP Guyana- Special Services Agreement
Project Coordinator – Guiana Shield Initiative Phase II Pilot Project, Iwokrama

2006 – 2007 - Monitoring and Evaluation Specialist, The Poor Rural Communities Support Services Project. Key Responsibilities:

- Monitor Project Implementation and provide status reports to Project Manager and Unit Heads
- Evaluate completed Sub-projects in preparation for Post Project Evaluations
- Conduct resource assessments for completed Sub-project
- Prepare Monthly – Annual Reports for Project (for **2007**)
- Coordinate Project Activities as instructed by Project Manager
    - Sub-project Beneficiary Activities
    - World Food Day
    - Staff Exchange Visits
    - Staff Social & Staff Moral Building Activities
    - Systematization Workshop
    - Project Completion Workshop
- Provide Technical Training to Beneficiary and Staff in Project M&E
- Design and Conduct the Post Project Impact Evaluations
- Design and conduct social surveys as necessary for impact and implementation evaluations
- Provide Technical Support to the Project as required by Unit Heads and Project Manager.

2002 – 2006 - Environmental Officer II – Protected Areas Unit - Natural Resources Management Division, Environmental Protection Agency. Key Responsibilities:

- Monitoring of proposed sites for protection using sustainable use and conservation guidelines;
    - Conduct quarterly site visits to proposed and established sites
- Counterpart Officer for the IDB Phase II ***"Investment Priorities Project";***
    - Conduct investigation along with consultant into possible project proposals for Natural Resources and Environmental Management
- Division representative for the IDB Phase II ***"Capacity Building for Key Stakeholders in Environment and Natural Resources Management"***;
    - Contribute to the Logistics, Planning and delivery of Training Workshops
    - Prepare and Deliver the Training Module as related to Natural Resources Management
- Project Officer (EPA) for the Caribbean Regional Environmental Program Amenity Areas; Demonstration Project – No. 43-74 Villages, Corentyne Coast
    - Contributed to the redefinition of the project
    - Implementation Officer for the project of the EPA
- Operations Officer for the Environmental Protection Agency /Fauna & Flora International Darwin Initiative Project "***Capacity building for Guyana's Protected Areas System"***;
    - Contributed to the planning and organization of Capacity Building workshops, including presenting and facilitating working group sessions
    - Participated in project review and monitoring of project impact on stakeholder communities
    - Contributed to preparation of monthly project financial and technical reports
- Contributed to the development of key documents of the Guyana Protected Areas System Project for the Lead Agencies, The World Bank and KfW;
- Conduct Education & Awareness sessions identifying and educating stakeholders, based on needs analysis of priority conservation sites;
    - Conduct Site visits with project teams including the World Bank, FFI, etc
    - Conduct Needs Analysis for community education programs
    - Prepare presentations for Amerindian communities on Protect Areas and conservation, monitor levels of success of information dissemination and redesign presentations to allow for greater levels of participation
- Facilitate training of local Amerindian Communities of three demographic regions of Guyana in environmental management, sustainable utilization of natural resources and conservation practices;
    - Participate in the planning and training sessions including facilitation of working groups for the development of a Community Based Natural Resource Management Plan for the Communities of the North Rupununi
    - Conduct community consultations representing the EPA in the Amerindian Communities of Regions 1 & 9 for the Guyana Protected Areas System Project
    - Represent the Government of Guyana in the development of the Southern Region Guyana as a Community Conservation Area to be managed by the Wai Wai community of Masakinari.
- Provide key inputs to the preparation of Monthly, Quarterly and Annual Technical and Financial Reports for the Protected Areas Unit, the NRMD and assigned projects; and
    - Monthly Unit Reports
    - Divisional Reports
    - Quarterly Unit and Division Reports
    - Half Year Progress Reports for Unit and Division
    - Annual Report, Workplan, Budget and Technical Submission to the Office of the President
- Support day to day activities of the Natural Resources Management Division.

PROFESSIONAL DEVELOPMENT

Section Four: Technical Qualification by Training & Participation
Global Health eLearning Center
2010

Mapping Biodiversity to assess Carbon densities using Radar Imagery
Sarvision, Netherlands
October-November 2009

Latin America Symposium on REDD
REDD Secretariat, Manaus, Brazil
September 2009

Payment for Ecosystem Services
Global Canopy Program, Grupo de Trabalho Amazônico (GTA) and Manaus Institute of Permacultura, Manaus, Brazil
September 2009

Applied Environmental Economics: Costs of Land Degradation & Benefits of Land management
Dr. Lars Hien
2-6 March, 2009

Systematization of Local Experiences
Brenda Lora, Consultant to IFAD
18-22 June, 2007

Monitoring & Evaluations Training Course - Public Sector Investment Management System
Jorge Max Fernandes, Consultant to the IDB
12-16 March, 2007

Communication and Conflict Resolution Skills
Arthur Lok Jack Graduate School of Business, University of the West Indies
23 January – 3 February 2006

Environmental Economics
Exposure to Economic Tools/Instruments that can be used to aid Environmental Management
Environmental Protection Agency – March 2004 - March 2005

Pollution Abatement for Priority Sectors in Guyana
Training in methods for pollution abatement in the rice, wood, tourism, energy and mining sectors
Clint Edmonds and Associates, Environmental Protection Agency, 2005

First Aid Training
Basic training in First Aid, Red Cross International, March 2005

Financing Protected Areas: Options for Guyana
Environmental Protection Agency/Fauna & Flora International (EPA/FFI)
March 2005

Development of Community Based Natural Resources Management Plan
United Nations Development Program's Capacity Building Project
February 2005

Practical Approaches to Participatory Project Management
Caribbean Regional Environmental Program (CREP)
8-13 October, 2004

Techniques in Community Resource Evaluations
EPA/FFI
6-9 September, 2004

Supervisory Management Course
Levi Lynch Association
30 August – 3 September, 2004

Protected Areas Management
CREP/Caribbean Conservation Association (CCA) Trinidad & Tobago
2-8 May, 2004

Biodiversity Assessment Training Workshop
EPA/FFI
15-25 April, 2004

Community Environmental Workers Training
EPA/FFI
16-17 March, 2004

Developing A Public Awareness Strategy for Guyana's Protected Areas
EPA/FFI
3-5 December, 2003

Project Implementation Workshop
CREP St. Michaels, Barbados
19-21 November, 2003

Protected Areas Categories and their Management Implications
EPA/FFI
29 September – 1 October, 2003

Participatory Planning & Collaborative Management
CREP/CCA Castries, St. Lucia
15-19 September, 2003

Community Consultations Process
EPA/FFI
19-24 May, 2003

Project Management &Project Proposal Preparation
EPA/FFI
11-16 April, 2003

Protected Areas Management in Guyana: Institutional Roles & Responsibilities
EPA/FFI
4-6 December, 2002

CURRICULUM VITAE

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Field Manager

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EDUCATION

Santa Rosa Primary Senior (Community High) School (1983-1988)
High School Diploma

Conservation International (2003)
Rapid Assessment Program (RAP) Training

French Guiana and Suriname (2001 and 2002)
Passive Integrated Transponder (PIT) Tag Training

Iwokrama International Centre for Rainforest Conservation and Development (2000)
Ranger Training in the following areas:

- Tourist Guide
- Bird Spotting and Data Collection
- Forestry
- Fresh water turtle monitoring and research
- Caiman spotting and data collecting
- Community development and management

Chelonian Research Institute (1994 and 2009)
Freshwater Turtle Research in the Rupununi (Guyana)

WORK EXPERIENCE

2017 – present – Field Manager - Environmental Management Consultants (EMC)

- Stakeholder engagements in Region 1 in collaboration with Environmental Resources Management Inc. (ERM) for the Ecosystem Services Survey for Esso Exploration and Production Guyana Ltd. Liza 1 Project.
- Coordinating the turtle telemetry exercise in Region 1 in collaboration with ERM.

2016 – Advisor to The Coordinator - Protected Area Commission – marine Turtle Project Shell Beach

2007- 2015 – Coordinator Guyana Marine Turtle Conservation Society (GMTCS) – CRI, WWF, SOL Inc. KfW, Eeripami German and Repsol Exploration Inc. funded - Marine Turtle Project

Responsible for the following activities as the coordinator:

- Planning and ensuring all activities undertaken by GMTCS were completed.
- Compiling all marine turtle data
- Preparing all technical reports.
- Representing GMTCS at Local, Regional and International meetings/symposiums.
- Fund raising and proposal writing for GMTCS.

2000 – 2007 - GMTCS - Marine Turtle (MT) Project – Field supervisor on the marine turtle Monitoring Site (Shell Beach, Guyana)

- Recruiting and ranger training.
- Coordinate and facilitate MT education camp on the beach.
- Participate in meetings, learning exchanges, and monitoring activities on data collection, data analysis and interpretation, and dissemination.
- Responsible for the collection of monitoring data.
- Plan and prepare for visits to different monitoring sites around Guyana.
- Plan, take part and supervise beach patrol and monitoring activities

1988 – 2000 - Boat Captain for the Guyana Marine Turtle Project (now GMTCS)

- Conduct ocean patrols
- Facilitate marine turtle education camp at Shell Beach
- Marine Turtle monitoring: Measuring, tagging (flipper and PIT), recording all nesting activities.
- Egg relocating, hatchery monitoring, releasing hatchling etc.
- Report to Dr. Peter CH Pritchard (CRI) and Florida Audubon Society seasonally

Protected Area – Shell Beach

Contributed to the following activities:

- Delineation of Shell Beach Protected Area (2009/10)
- Resource mapping (2009-2011)
- Biodiversity assessment of Shell Beach Proposed Protected Area (2007)
- Represent Almond Beach Community on consultation of Shell Beach Protected Area (2001-2014)
- Fresh water species assessment – World Wildlife Fund (2010)

APPENDIX C

EIA Review Checklist

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EIA REVIEW CHECKLIST ROADMAP

EIA Review Checklist Items	Corresponding EIA Reference
1. Adherence to the ToR *Adherence to the ToR must be verified simply by checking that all items and information requested in the ToR have been presented, regardless of the content or quality of such information.*	• Adherence to the approved Terms of Reference (ToR) confirmed (9 April 2018 Interim Approval and 30 May 2018 Final Approval)
2. Multidisciplinary Team *The accuracy of the EIA depends on the qualifications of the multidisciplinary team not only regarding the EIA process and methods but also regarding their knowledge of the several stages of the specific type of project. Therefore, individual CVs should be submitted as part of the EIA Annexes. Signatures of each member of the team must be affixed.*	• Chapter 14, Project Team, lists all team members and references, Appendix A provides signatures, and Appendix B includes all Curricula Vitae
3. Inter-disciplinary Achievement *An EIA must present information regarding the interactions and integration between the physical, biological and socio-economic aspects of the environment in that particular area of the study.*	• Chapter 6 assesses physical resources/receptors • Chapter 7 assesses biological resources/receptors • Chapter 8 assesses socioeconomic resources/receptors
4. Executive Summary *The Executive Summary, also referred to as the non-technical summary, should provide a brief description of the project and information regarding the potential impacts of the project, arranged in order of significance, along with the proposed mitigation/compensatory measures for each impact. The summary should end with the consultants' recommendations.*	• Executive Summary included in Environmental Impact Statement
5. Project Description *The process of environmental impact assessment depends on the full understanding of the project proposal and accurate identification of the project actions. If actions are unclear, sufficiently detailed impacts are not likely to be identified with the accuracy and specificity needed to enable the development of appropriate mitigation measures.*	
5.01 Is the project proposal fully understood?	• Chapter 2, Description of the Project
5.02 Are all phases identified (e.g. planning, construction, operation and decommissioning)?	• Section 2.5, Drilling and Well Design • Section 2.8, Installation, Hookup, and Commissioning • Section 2.9, Production Operations, • Section 2.11, End of Phase 2 Operations (Decommissioning)
5.03 Is the geographical area for each phase identified?	• Section 2.1, Project Area (all stages occur within this same area)
5.04 Are the land use requirements for each phase identified?	• Section 2.4, Onshore, Marine, and Aviation Support (only onshore supply and support activities have any land use requirements)
5.05 Is there an inventory of the nature and quantity of materials used in the production process?	• Section 2.12, Materials, Emissions, Discharges, and Wastes
5.06 Are there inventories of the type and quantity of products, by-products and effluents expected to be produced by the project?	• Section 2.12, Materials, Emissions, Discharges, and Wastes

EIA Review Checklist Items	Corresponding EIA Reference
5.07 Is there an inventory of the type and quantity of residues?	• Section 2.12, Materials, Emissions, Discharges, and Wastes
5.08 Are the levels of emissions expected detailed with respect to *- Noise?* *- Vibration?* *- Light?* *- Heat?* *- Radiation?* *- Gases?* *- Liquids? Are the types and levels of any other emissions included?*	• Noise impacts: Section 6.2.3, Impact Assessment—Sound; Section 7.5.3, Impact Assessment—Marine Mammals • Thermal and liquid discharges: Section 6.4.3, Impact Assessment—Marine Water Quality • Radiation: Section 2.12.5, Radioactive Sources • Air (gaseous) emissions: Section 6.1.3, Impact Assessment—Air Quality and Climate
5.09 Is information on employment provided?	• Section 2.5, Project Workforce
6. Identification and Description of Alternatives *The assessment of sound alternatives is necessary to validate the EIA process. Therefore reasonable alternatives have to be fully and comprehensively considered. As a minimum, one of the following alternatives must be considered: location, project layout, technology, scheduling, project scale.*	• Section 2.8, Alternatives
6.01 Did the developer consider alternatives?	• Section 2.8, Alternatives
6.02 Was the "no-project" scenario considered?	• Section 2.8, Alternatives
6.03 Were the environmental factors adequately presented for each alternative?	• Section 2.8, Alternatives
6.04 Is the final choice adequate?	• Section 2.8, Alternatives • Chapter 12, Conclusions and Summary of Impacts
7. Definition and Justification of Physical Boundaries (Direct and Indirect Area of Influence) *Inconsistency in identifying the correct areas of influence will inevitably lead to inconsistency in the baseline data and the impact analysis. The indirect area of influence is the area likely to be affected by indirect, secondary and/or long term impacts.*	• Section 5.1, The Area of Influence
8. Analysis of the Legal Aspects Involved *The analysis of the legal framework involves more than a list of legal Acts. It involves assessing the consequences for the project of enforcing all the environmental legislation and regulations regarding the proposed site and sectoral requirements related to the proposed activity.*	• Chapter 3, Administrative Framework • Additionally, resource-specific administrative framework discussions are provided in each resource-specific section in Chapters 6, 7, and 8
9. Identification of Other Existing Planned Activities or Projects in the Area of Influence *This information is of utmost importance to ensure that land-use and other types of conflicts do not arise later during the project implementation.*	• Chapter 10, Cumulative Impact Assessment
9.01 Has the compatibility between the proposal and the identified existing activities been analysed?	• Section 10.3, Other Projects and External Drivers
9.02 Are the activities compatible?	• Section 10.3, Other Projects and External Drivers
9.03 Does the inventory of existing activities match what is observed?	• Section 10.3, Other Projects and External Drivers

EIA Review Checklist Items	Corresponding EIA Reference
10. Adequacy and Completeness of Relevant Baseline Data *Baseline data must be specific and relevant to the area of influence. General and superficial information does not allow for the use of adequate impact prediction techniques.*	• Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources • Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources • Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources
10.01 Is the information presented specific and relevant?	• Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources • Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources • Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources
10.02 Were difficulties in attaining information (if any) documented?	• Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources • Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources • Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources
10.03 Have the impact indicators identified been adequately covered (see Section 13)	• Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources • Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources • Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources
11. Appropriateness of EA Methods *The use of appropriate EA methods is necessary to ensure reliability of the results of the EIA study. Each type of EA method has different strengths and vulnerabilities regarding its appropriateness to perform each step of the EIA study. Some EA methods are unable to provide the means of identification of cause-effect relationships; others do not enable the identification of indirect, secondary and/or long-term impacts. Scientific and technical accuracy of the EIA methods used must therefore be evaluated to ensure the reliability of the conclusions drawn from the impact assessment.*	• Chapter 4, Methodology for Preparing the Environmental Impact Assessment • Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources • Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources • Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources

EIA Review Checklist Items	Corresponding EIA Reference
12.1. Physical Impacts *- Have all the identified impacts on air, water, soil, noise, landscape and natural resources been checked against the relevant impacts defined in the ToR?* *- Are impacts characterized (positive/negative, direct/indirect, primary/secondary, short/medium/long term, reversible/irreversible, temporary/permanent, local/regional/national/strategic, avoidable/unavoidable)?* *- Have the magnitudes been estimated?* *- Have the impacts been assigned a significance?* *- Have the social implications of the impacts been assessed?*	• Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources
12.2. Biological Impacts *- Have all the identified impacts on flora, fauna, rare / endangered species, sensitive ecosystems, species habitats and ecological balance been checked against the relevant impacts in the ToR.* *- Are impacts characterized (positive/negative, direct/indirect, primary/secondary, short/medium/long term, reversible/irreversible, temporary/permanent, local/regional/national/strategic, avoidable/unavoidable)?* *- Have the magnitudes been estimated?* *- Have the impacts been assigned a significance?* *- Have the social implications of the impacts been assessed?* *- Have cause/effect relations been properly identified?*	• Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources
12.3. Social and Health Impacts *- Have all the identified impacts on the social and health context been checked against the relevant impacts defined in the ToR?* *- Are impacts identified with respect to human health, demographic and household characteristics, employment opportunities, size and distinguishing characteristics of resident population, the provision of social services and infrastructure?* *- Are impacts characterized (positive/negative, direct/indirect, primary/secondary, short/medium/long term, reversible/irreversible, temporary/permanent, local/regional/national/strategic, avoidable/unavoidable)?* *- Have the magnitudes been estimated?* *- Have the impacts been assigned a significance?* *- Have the social implications of the impacts been assessed?* *- Have cause/effect relations been properly identified?* *- To what extent does the project protect/improve human health?* *- To what extent does the project protect/improve human living conditions?*	• Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources

EIA Review Checklist Items	Corresponding EIA Reference
12.4. Cultural, Historical and/or Archeological Impacts *- Have all the identified impacts related to cultural, historical and/or archeological sites and heritage been checked against the relevant impacts defined in the ToR?* *- Are impacts identified with respect to **cultural heritage**?* *- Are impacts characterized (positive/negative, direct/indirect, primary/secondary, short/medium/long term, reversible/irreversible, temporary/permanent, local/regional/national/strategic, avoidable/unavoidable)?* *- Have the magnitudes been estimated?* *- Have the impacts been assigned a significance?* *- Have the social implications of the impacts been assessed?* *- Have cause/effect relations been properly identified?*	• Section 8.7, Cultural Heritage
12.5. Economic Impacts *- Have all the identified impacts on the economy (local, regional, national) been checked against the relevant impacts defined in the ToR?* *- Are impacts identified with respect to economic assets and activities?* *- Are impacts characterized (positive/negative, direct/indirect, primary/secondary, short/medium/long term, reversible/irreversible, temporary/permanent, local/regional/national/strategic, avoidable/unavoidable)?* *- Have the magnitudes been estimated?* *- Have the impacts been assigned a significance?* *- Have the social implications of the impacts been assessed?* *- Have cause/effect relations been properly identified?* *- Are impacts identified with respect to income generation for the community and at the National Level?* *- Are impacts characterized (positive/negative, direct/indirect, primary/secondary, short/medium/long term, reversible/irreversible, temporary/permanent, local/regional/national/strategic, avoidable/unavoidable)?* *- Have the magnitudes been estimated?* *- Have the impacts been assigned a significance?* *- Have the social implications of the impacts been assessed?* *- Have cause/effect relations been properly identified?*	• Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources
12.6. Other impacts *- Have all other impacts been checked against the relevant impacts defined in the ToR?* *- Are impacts identified with respect to _____?* *- Are impacts characterized (positive/negative, direct/indirect, primary/secondary, short/medium/long term, reversible/irreversible, temporary/permanent, local/regional/national/strategic, avoidable/unavoidable)?* *- Have the magnitudes been estimated?* *- Have the impacts been assigned a significance?* *- Has the social distribution of the impacts been identified?* *- Have cause/effect relations been properly identified?*	• Other potentially impacted resources not specifically listed above have been included, such as marine geology and sediments (Section 6.3), marine use and transportation (Section 8.4), and indigenous peoples (Section 8.10).

EIA Review Checklist Items	Corresponding EIA Reference
13. Cumulative Impacts *There may be cases where an activity/project will contribute to a cumulative impact on the environment although individually it may not have a significant environmental impact. This may be as a result of the presence of similar activities within the vicinity of the project.*	• Chapter 10, Cumulative Impact Assessment
13.01 Have cumulative impacts been adequately identified and characterized?	• Chapter 10, Cumulative Impact Assessment
13.02 Have the magnitudes been estimated?	• Section 10.5, Assessment of Cumulative Impacts on VECs (Valued Environmental and Social Components)
13.03 Have the impacts been assigned a significance?	• Section 10.5, Assessment of Cumulative Impacts on VECs
13.04 Has the social distribution of the impacts been identified?	• Section 10.5, Assessment of Cumulative Impacts on VECs
13.05 Have cause/effect relations been properly identified?	• Section 10.5, Assessment of Cumulative Impacts on VECs
14. Impact Indicators *Impact indicators are the parameters used to estimate the magnitude of the impacts.*	• Chapter 4, Methodology for Preparing the Environmental Impact Assessment
14.01 Were the impact indicators used adequate for all the impacts identified?	• Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources • Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources • Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources
15. Prediction Techniques *Impact prediction techniques are necessary to enable the estimation of the magnitude of the impacts. Without the use of adequate impact prediction techniques, accurate impact analysis is not possible.*	• Chapter 4, Methodology for Preparing the Environmental Impact Assessment
15.01 Have the impact prediction techniques used been described? Are they adequate?	• Chapter 4, Methodology for Preparing the Environmental Impact Assessment • Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources • Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources • Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources

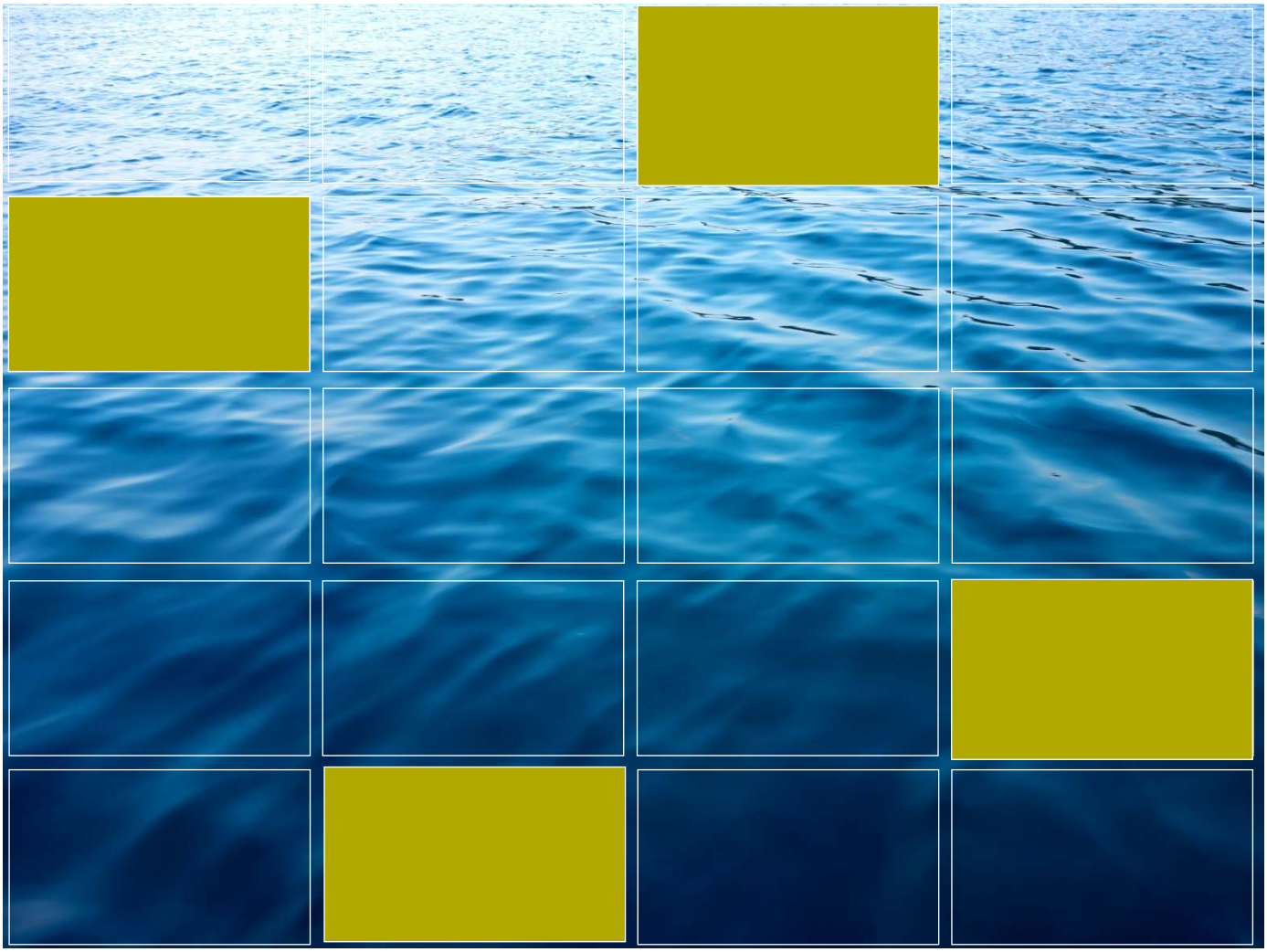
EIA Review Checklist Items	Corresponding EIA Reference
15.02 Are they adequate?	• Chapter 4, Methodology for Preparing the Environmental Impact Assessment • Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources • Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources • Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources
16. Magnitude of Impacts *Magnitude is the estimate of the absolute measure/value/dimension of the difference between the environmental situation of a given parameter before and after the project is implemented. In the majority of cases – physical, biological and economic impacts – it must be expressed in* ***quantitative*** *values. The estimation of the magnitude of each relevant impact is one of the most important steps in impact analysis. It ensures the accuracy of the EIA and allows for the identification of appropriate and cost-effective mitigation measures. Have the magnitude of all the relevant impacts been adequately estimated (refer to impact indicators – Section 14)?*	• Chapter 4, Methodology for Preparing the Environmental Impact Assessment • Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources • Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources • Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources
17.0 Importance/Significance of Impacts *Usual methods involve objective criteria regarding the ecological and social relevance of the project*	• Chapter 4, Methodology for Preparing the Environmental Impact Assessment
17.01 Is the relative importance/significance of each impact with regard to the environmental factor affected, and with regard to the other impacts given?	• Chapter 4, Methodology for Preparing the Environmental Impact Assessment
17.02 Is the significance based on objective criteria in order to minimize subjectivity of judgments?	• Chapter 6, Assessment and Mitigation of Potential Impacts from Planned Activities—Physical Resources • Chapter 7, Assessment and Mitigation of Potential Impacts from Planned Activities—Biological Resources • Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources
18 Social Distribution of Impacts *Identifies which social groups will be affected by the positive and the negative impacts. These groups are often not the same. The balance between positive and negative impacts cannot be done without the correct identification of the social distribution of the impacts, because it would not have scientific and technical relevance.*	• Chapter 8, Assessment and Mitigation of Potential Impacts from Planned Activities—Socioeconomic Resources
19 Stakeholder Participation	
19.01 Are the results of stakeholder participation, such as the results of interviews, hearings etc. clearly documented?	• Section 4.5, Stakeholder Engagement

EIA Review Checklist Items	Corresponding EIA Reference
19.02 Have questionnaires used been included?	• No specific questionnaires were used, but numerous Key Informant Interviews, informal meetings, and capacity building workshops, as well as one sector agency scoping consultation meeting and seven public scoping consultation meetings in Regions 1-6 were held.
19.03 Are the extent and method of stakeholder participation adequate?	• Section 4.5, Stakeholder Engagement
19.04 Are the conclusions drawn valid, based on available data?	• Section 4.5, Stakeholder Engagement
20 Analysis and Selection of Best Alternative *Selection must be based on criteria derived from the impact assessment, and appropriate analysis and decision-making methods must be used.*	• Section 2.16, Alternatives • Chapter 12, Conclusions and Summary of Impacts
21 Environmental Management Plan (EMP) *An EMP is sometimes called an Impact Management Plan. It is a necessary step to ensure that the developer is effectively committed to the implementation of the mitigation measures. It is also a useful corporate management tool. Does the EMP, as a minimum, present* *- The set of mitigation, remedial or compensatory measures?* *- A detailed description of each one, with indication and criteria for their effectiveness?* *- Detailed budgets for each one?* *- Timetables for implementation?* *- Assignment of responsibilities, including an Environmental Manager?* *- The Environmental Policy*	• Environmental and Socioeconomic Management Plan (ESMP) • Chapter 11, Environmental and Socioeconomic Management Plan Framework
22 Monitoring *Monitoring is a necessary step to ensure cost-effectiveness of the EMP. It is usually addressed under the EMP (see Section 20) Does the monitoring plan, as a minimum, address* *- What is going to be monitored (impact indicators)?* *- Where will samples be taken?* *- How the samples will be analysed (method/technique)?* *- Criteria used to evaluate the results?* *- Financial and human resources required?*	• ESMP
23 Implementation Plan for the Mitigation Measures and the Environmental Management Plan *Implementation mechanisms must be in place to ensure effective implementation of the mitigation measures and all other recommendations that might arise from the EIA study. It usually involves the assignment of a person responsible for environmental management and an approved timetable for implementation of measures.*	• ESMP • Chapter 11, Environmental and Socioeconomic Management Plan Framework

APPENDIX D

Ambient Air Quality Monitoring Report

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Ambient Air Quality Monitoring Report
Liza Phase 2 Development Project

May 2018

The business of sustainability

ERM

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ATTACHMENT 1 – VALIDATED DATA RECORD

A. Sulfur Dioxide Monitoring Data
B. Hydrogen Sulfide Monitoring Data
C. Nitrogen Dioxide Monitoring Data
D. Carbon Monoxide Monitoring Data
E. Volatile Organic Compounds Monitoring Data
F. Inhalable Particulate Matter Monitoring Data
G. Fine Particulate Matter Monitoring Data

LIST OF ACRONYMS

$\mu g/m^3$	micrograms per cubic meter
CO	carbon monoxide
ERM	Environmental Resources Management
GPS	global positioning system
H_2S	hydrogen sulfide
NO_2	nitrogen dioxide
PDA	Liza Phase 2 Project Development Area
PM_{10}	inhalable particulate matter with an aerodynamic diameter of < 10 micrometers
$PM_{2.5}$	fine particulate matter with an aerodynamic diameter of < 2.5 micrometers
ppb(v)	parts per billion by volume
ppm	parts per million
ppm(v)	parts per million by volume
SO_2	sulfur dioxide
USEPA	United States Environmental Protection Agency
VOCs	volatile organic compounds
WHO	World Health Organization

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EXECUTIVE SUMMARY

Environmental Resources Management conducted two offshore ambient air quality monitoring campaigns to characterize baseline pollutant concentrations in the Liza Phase 2 Project Development Area (PDA). Monitored air pollutants included inhalable particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), sulfur dioxide, hydrogen sulfide, nitrogen dioxide, carbon monoxide, and volatile organic compounds (VOCs). To mitigate the inherent challenges posed by shipboard monitoring, multiple measurement methods, duplicate sampling, and concurrent meteorological and geographic position measurements were employed.

During the two survey periods, 48 integrated passive samples were collected for laboratory analysis, and supplementary continuous measurements were taken during the monitoring campaigns.

These measurements documented that ambient concentrations of the monitored air pollutants in the Liza Phase 2 PDA are very low - below reporting limits for most parameters. PM_{10}, $PM_{2.5}$, and VOCs were the only air pollutants detected above reporting levels. The maximum and average 24-hour average PM_{10} concentrations measured were 43 micrograms per cubic meter ($\mu g/m^3$) and 38 $\mu g/m^3$, respectively — approximately 86 percent and 76 percent, respectively, of the World Health Organization's (WHO) guideline concentration of 50 $\mu g/m^3$. Supplementary chemical analyses demonstrated that the largest individual component of measured PM_{10} was sodium chloride – most likely from sea salt.

The maximum and average 24-hour average $PM_{2.5}$ concentrations measured were 18 $\mu g/m^3$ and 12 $\mu g/m^3$, respectively—approximately 72 percent and 48 percent, respectively, of the WHO's guideline concentration of 25 $\mu g/m^3$. Supplementary chemical analyses demonstrated that the largest individual component of measured $PM_{2.5}$ was sodium chloride – most likely from sea salt.

Measured concentrations of total VOCs ranged from 1.7 parts per billion by volume [ppb(v)] to a maximum of 28 ppb(v)—very low, by comparison to typical urban environment ambient air concentrations, and consistent with measurements documented in the literature for remote, offshore marine environments (National Research Council, 1991).

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1.0 INTRODUCTION

Environmental Resources Management (ERM) conducted two offshore ambient air quality monitoring campaigns to characterize existing air pollutant concentrations in the Liza Phase 2 Project Development Area (PDA). Monitored air pollutants included inhalable particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), nitrogen dioxide (NO_2), carbon monoxide (CO), and volatile organic compounds (VOCs).

To mitigate the inherent challenges posed by shipboard monitoring, multiple measurement methods, duplicate sampling, and concurrent meteorological and geographic position measurements were employed.

The program was carried out in general conformance with the March 2018 Air Quality Assessment Protocol prepared by ERM. This report summarizes the methodology and results of the monitoring campaigns

2.0 METHODOLOGY

2.1 Monitoring Periods

The initial monitoring campaign was conducted in April 2018. For this initial campaign, PM_{10}, SO_2, H_2S, NO_2, CO, and VOC monitoring instruments were mounted on the top deck, toward the bow, of the 48-meter offshore supply vessel, Sea Service. The Sea Service sailed from Georgetown, Guyana on April 9, 2018, arriving at the Liza Phase 2 PDA on 10 April 10 at approximately 10:00. Sampling commenced and continued until 12 April at approximately 17:00, at which time the vessel left the Liza Phase 2 PDA to return to shore. The Sea Service returned to the Liza Phase 2 PDA on 14 April at approximately 15:00 and resumed data collection. The vessel left the Liza Phase 2 PDA at approximately 15:00 on 15 April, returning to port at approximately 08:00 on 16 April.

For the second campaign, conducted in May 2018, $PM_{2.5}$, SO_2, H_2S, NO_2, and VOC (sensor only, no passive) monitoring instruments were mounted on the top deck, toward the bow, of the approximately 20-meter tuna trawler, Drifter 98. The Drifter 98 sailed from Georgetown, Guyana on 2 May 2018 at approximately 15:00, arriving at the Liza Phase 2 PDA on May 3 at 09:00. Sampling commenced and continued until 4 May at approximately 09:00, at which time the vessel left the Liza Phase 2 PDA to return to shore. The Drifter 98 returned to the Liza Phase 2 PDA on 8 May at approximately 11:00 and resumed data collection. The vessel left the Liza Phase 2 PDA at approximately 11:00 on 12 May, returning to port at approximately 03:00 on 13 May.

2.2 Monitoring Approach

During the course of both air monitoring campaigns, the helmsmen endeavored to maintain the bow in the upwind direction to the extent practicable. This was done in order to reduce the potential bias of the air samples by onboard emission sources, such as the ships' engines.

Primary measurement reliance was on a set of passive samplers, which collected air samples for subsequent laboratory analysis. Collocated real-time sensors were also deployed in order to provide semi-quantitative measurements at 10-minute intervals. In addition to air quality parameters, the following meteorological parameters were measured:

- Relative wind speed and direction,
- Temperature, and
- Relative humidity.

Finally, the location of the air quality instrumentation package was continuously tracked by a global positioning system (GPS) logger.

Upon the survey's conclusion, passive samples were retrieved and shipped for laboratory analysis. The real-time air quality, meteorological, and GPS data were

downloaded from the instruments for further interpretation. Data processing consisted of using the laboratory analytical data to validate and adjust the raw air quality sensor data.

2.3 Instrumentation

Air quality, meteorological, and miscellaneous instrumentation used for the monitoring campaigns are described below. Figures 2-1 and 2-2 illustrate the physical configuration of the instruments. Photographs of the installations are presented in Figures 2-3 through 2-8.

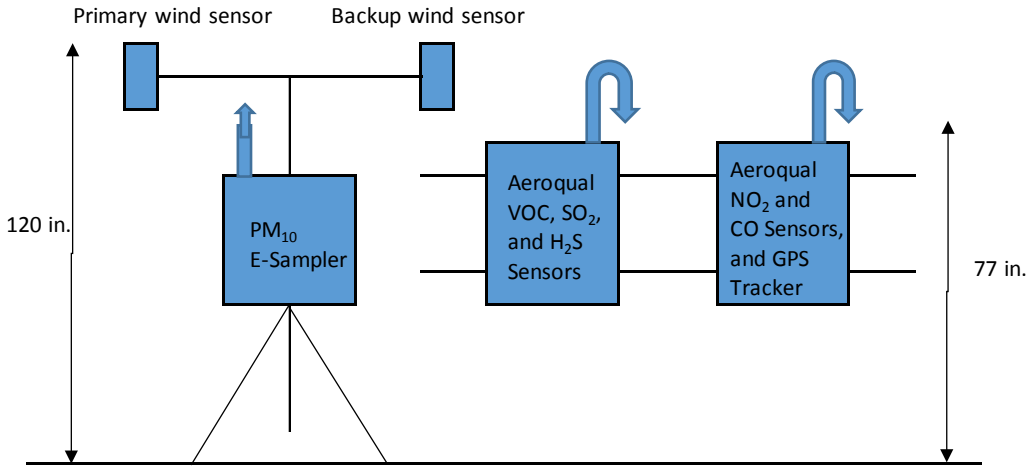


Figure 2-1: Sea Service Instrumentation Configuration

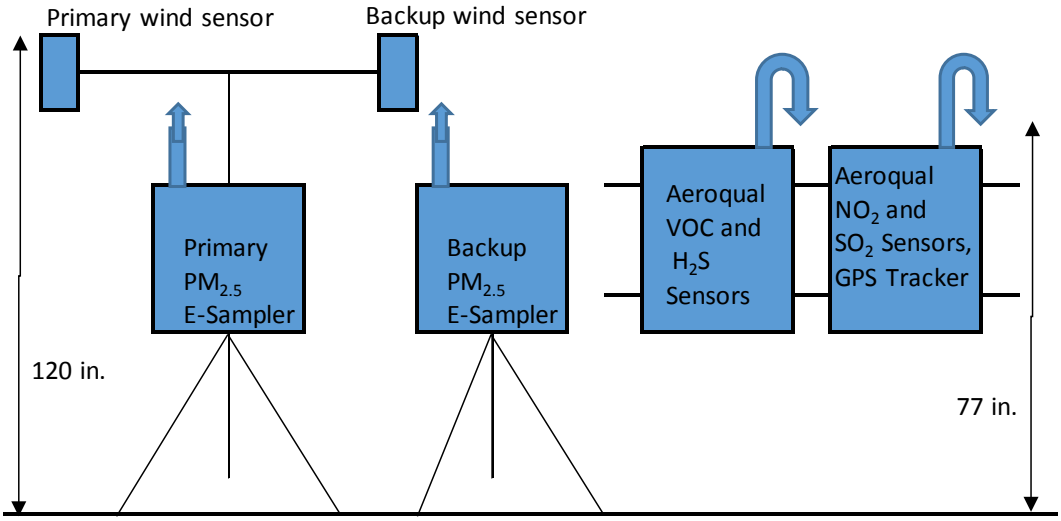


Figure 2-2: Drifter 98 Instrumentation Configuration



Figure 2-3: Sea Service Installation-Aeroqual Shelter Boxes



Figure 2-4: Sea Service Installation-Aeroqual Sensors



Figure 2-5: Sea Service Installation-Pm Sampler and Wind Speed/Direction Sensors

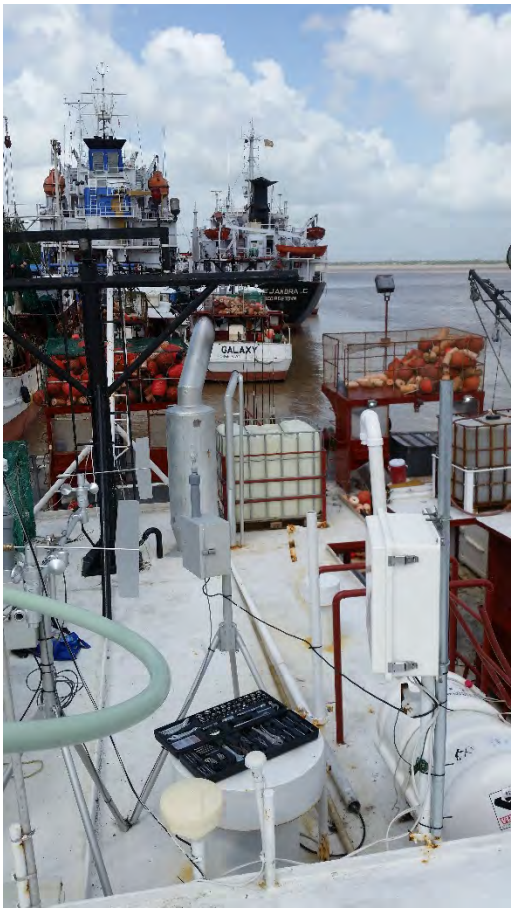


Figure 2-6. Drifter 98 Installation-E-Sampler and Aeroqual Shelter Box



Figure 2-7: Drifter 98 Installation-Aeroqual Sensors and GPS Tracker



Figure 2-8: Drifter 98 Installation-Air Monitoring Instrument Configuration

2.4 Air Quality Parameters

The campaigns collectively measured ambient concentrations of SO_2, H_2S, NO_2, CO, VOCs, PM_{10} and $PM_{2.5}$. Air pollutants were measured with a combination of passive samplers that collected samples for subsequent laboratory analysis, as well as continuous monitoring via sensors. The laboratory results are considered more reliable, and they were used to adjust the sensor data, as appropriate.

Details of the sampling for each pollutant are presented below.

2.4.1 Sulfur Dioxide

SKC passive sampling badges (SKC UMEx 200), as well as an Aeroqual Model 500 monitor equipped with a 0 to 10 parts per million (ppm) SO_2 sensor, were used to measure ambient concentrations during the study. Five passive samples were collected during each campaign. Additionally, the Aeroqual monitor was configured to continuously collect data, recording data at 10-minute intervals throughout the monitoring period for each campaign. Sample badges were exposed for approximately 24 hours, prior to being sealed for subsequent analysis and replaced with a fresh badge. This continued throughout the monitoring period, with each badge exposed sequentially. Duplicate badges were employed for the first few sample periods to provide insight into the method's measurement precision.

2.4.2 Hydrogen Sulfide

Radiello passive sampling tubes (Sigma Aldrich RAD1236), as well as an Aeroqual Model 500 monitor equipped with a 0 to 10 ppm H_2S sensor, were used to measure ambient concentrations during the study. Five passive samples were collected during each campaign. Additionally, the Aeroqual monitor was configured to continuously collect data, recording data at 10-minute intervals throughout the monitoring period for each campaign. Each sample tube was exposed for approximately 24 hours, prior to being sealed for subsequent analysis and replaced with a fresh tube. This continued throughout the monitoring period, with each tube exposed sequentially. Duplicate samples were collected in order to provide an estimate of measurement precision.

2.4.3 Nitrogen Dioxide

The same SKC passive sampling badges (five for each campaign) used to measure SO_2 concentrations were also used to measure NO_2 concentrations. Sample badges were exposed for approximately 24 hours, prior to being sealed for subsequent analysis and replaced with a fresh badge. This continued throughout the monitoring period, with each badge exposed sequentially. Duplicate badges were employed to provide insight into the method's precision. Additionally, an Aeroqual Model 500 monitor was configured to continuously collect data, recording data at 10-minute intervals throughout the monitoring period for each campaign.

2.4.4 Volatile Organic Compounds

Passivated stainless steel ("Summa") canisters, as well as an Aeroqual Model 500 monitor equipped with a 0 to 25 ppm VOC sensor, were employed to measure ambient concentrations during the Sea Service campaign. During the Sea Service campaign, three 24-hour integrated ambient air samples were collected using flow controlled evacuated Summa canisters. The Summa canisters were configured to draw their samples from within the enclosure housing for an Aeroqual Model 500 VOC monitor. An additional five "grab" samples were collected over periods of approximately one

minute at times when the technician determined that the wind was from the bow (i.e., there was no potential for bias from the ship's engine exhaust).

At the conclusion of each 24-hour integrated sampling period, the Summa canister was capped and stored for subsequent laboratory analysis, a fresh canister was installed, and another integrated sample collection was initiated. At the laboratory, each canister was analyzed for speciated VOCs by a gas chromatography/mass spectrometer, in accordance with United States Environmental Protection Agency (USEPA) Method TO-15. Additionally, during both the Sea Service and Drifter 98 campaigns, the Aeroqual monitor was configured to continuously collect data, recording data at 10-minute intervals throughout the monitoring.

2.4.5 Carbon Monoxide

The same Summa canister samples collected during the Sea Service campaign (i.e., the same as those used for VOC analysis) were also analyzed in the laboratory for CO concentrations. Additionally, during both the Sea Service and Drifter 98 campaigns, an Aeroqual Model 500 monitor was configured to continuously collect data, recording data at 10-minute intervals throughout the monitoring period.

2.4.6 Particulate Matter Less than 10 Micrometers in Diameter—(Sea Service Campaign Only)

During the Sea Service campaign, a Met One Instruments E-Sampler measured PM_{10} using the following methods:

- A multi-day integrated sample was collected on a Teflon filter, for subsequent laboratory elemental analysis using USEPA Method IO 3.3 (X-ray fluorescence).
- The E-Sampler also contained a nephelometer. This provided a continuous signal, proportional to ambient PM_{10} concentrations. Due to the nature of the optical system employed, the continuous readings required adjustment for the nature of the specific particulate matter being measured. A previously derived "k-factor" (from the Liza Phase 1 offshore air monitoring campaign) was used to adjust these data.

2.4.7 Particulate Matter less than 2.5 Micrometers in Diameter—(Drifter 98 Campaign Only)

During the Drifter 98 campaign, two redundant Met One Instruments E-Samplers measured $PM_{2.5}$ using two methods.

- Multi-day integrated ambient concentrations were determined by laboratory gravimetric analysis of pre-weighed Teflon filters. The filter samples were also analyzed using USEPA Method IO 3.3 (X-ray fluorescence) to assess their elemental composition.
- The E-Samplers also contained a nephelometer. This provided a continuous signal, proportional to ambient $PM_{2.5}$ concentrations. Due to the nature of the optical system employed, the continuous readings required adjustment for the nature of the

specific particulate matter being measured. The laboratory gravimetric results were used to perform this adjustment.

2.5 Meteorological and Locational Parameters

Wind speed, wind direction (relative to the ship's axis), and sample relative humidity and temperature were continuously monitored by two redundant sets of sensors and the resultant data logged by the two E-Samplers' internal data loggers. The wind data were collected to ascertain whether ship emission sources may have biased measurements. Relative humidity and temperature data were used to identify any periods during which the air quality sensors were operating outside their control limits. These meteorological parameters were used as part of the data validation process.

A Garmin GPS logger was used to identify the location of the instrument package at each point in time, throughout the monitoring periods.

2.6 Quality Control/Quality Assurance

Air monitoring on board an ocean-going vessel introduces numerous challenges to obtaining reliable ambient air quality measurements. These include:

- Potential uncertainty regarding the location at which a measurement is made;
- Exposure to weather that may damage instruments or bias their measurements;
- No access to spare or replacement parts;
- Potential measurement bias due to impacts from onboard emission sources; and
- Reliability of electrical power with which to operate the monitoring instruments.

The Liza Phase 2 ambient air quality monitoring campaigns' passive sampling system equipment proved to be resilient to the challenges encountered at sea.

The constraints of offshore operation (particularly limited electrical power and instrument climate control constraints) necessitated compromises that resulted in limited continuous sensor data recovery during the Sea Service campaign. Electrochemical sensors (Aeroqual Model 500 monitors) were employed since they could be supported with the onboard infrastructure. While these challenges reduced the quantity of continuous monitoring data collected, they did not adversely affect data quality. System improvements implemented for the Drifter 98 survey led to improved continuous monitoring sensor performance.

The campaigns' primary quality assurance mechanism was the teaming of passive samplers (and laboratory analyses) of known reliability with the real-time measurements of electrochemical air quality sensors whose performance quality offshore is less certain. As noted above, the vessels' helmsmen endeavored to maintain the bow of the vessel in the upwind direction to the extent practicable, in order to minimize the potential bias of the air samples by onboard emission sources. The absence of CO measurements above reporting limits indicates this approach was effective.

The passive samples collected during the Sea Service campaign encountered significant delay in shipment to the laboratory. This delay is not expected to have biased the SO_2, NO_2, H_2S, or CO results, as these samples are stable for long periods of time. The delay had the potential of affecting VOC speciation. The maximum reported 24-hour average value for samples analyzed in the laboratory for total VOCs was 28 parts per billion by volume [ppb(v)], so the potential impact of any change in VOC speciation is not significant for the purpose of these campaigns.

The Drifter 98's passive samples (for SO_2, NO_2, and H_2S) were hand-carried back to the U.S. and express-shipped to the laboratories. Analysis was performed within six days of the vessel's return to shore. The results were consistent with those obtained during the Sea Service campaign, despite the large difference in hold times between the campaigns. This confirms that the Sea Service samples' long hold times did not significantly bias the results for these parameters.

The program also relied on traditional quality assurance/quality control measures such as the use of field and laboratory blanks, duplicate samples, chain of custody documentation, and periodic calibrations against certified standards. Additionally, two-point (zero and span) calibrations were performed on each Aeroqual monitor prior to, and following each monitoring campaign. These calibrations were performed using a dynamic dilution calibrator and USEPA "protocol" calibration gas standards. Staff training and reliance on Standard Operating Procedures rounded out the overall quality assurance/quality control program.

3.0 RESULTS

In general, concentrations of the monitored air contaminants in the vicinity of the Liza Phase 2 area were found to be very low when compared with levels typically found in urban environments, and measured concentrations were below international ambient air quality guidelines.

There were no identified periods of potential continuous sensor bias from onboard emissions, based on concurrent measurement of wind direction, relative to the air sampling. While no data were invalidated due to bias from onboard emission sources, there were a few values that were invalidated by nature of being "outliers." These are discussed below.

The results for the various air pollutants measured are discussed below. Summaries of the air quality data are contained in Appendix 1.

3.1 Sulfur Dioxide

The passive samplers yielded 24-hour integrated laboratory values that were all below the 35 ppb(v) reporting limit. For comparative purposes, the World Health Organization (WHO) 24-hour average guideline concentration for SO_2 is 7.6 ppb(v). Since the passive sampler results were all below the reporting limit, it was not possible to adjust the Aeroqual sensor data to align with the reference method. Accordingly, while the Aeroqual sensor data are provided herein (as measured), the data should not be viewed quantitatively.

3.2 Hydrogen Sulfide

The H_2S passive samplers yielded 24-hour integrated laboratory values that were all below the 6 ppb(v) reporting limit. For comparison purposes, the WHO 24-hour average guideline concentration is 110 ppb(v). Since the passive sampler results were all below the reporting limit, it was not possible to adjust the Aeroqual sensor data to align with the reference method. Accordingly, while the Aeroqual sensor data are provided herein (as measured), the data should not be viewed quantitatively.

3.3 Nitrogen Dioxide

All but one of the passive samplers yielded 24-hour integrated laboratory values that were below the 43 ppb(v) reporting limit. For comparison, the WHO 1-hour and annual average guideline concentrations are 106 ppb(v) and 21.3 ppb(v), respectively; WHO has not established a 24-hour average guideline concentration for NO_2.

The one detection was reported at 128 ppb(v). A collocated duplicate sample that ran over the same time period yielded a non-detect result. Since all the other samples, including the duplicate sample, were non-detect, the reported 128 ppb(v) concentration was considered an outlier and was invalidated.

Since the validated passive sampler results were all below the reporting limit, it was not possible to adjust the Aeroqual sensor data to align with the reference method. Accordingly, while the Aeroqual sensor data are provided herein (as measured), the data should not be viewed quantitatively.

3.4 Carbon Monoxide

The 24-hour integrated and grab passive samples yielded laboratory values that were all below the 5 parts per million by volume [ppm(v)] reporting limit. For comparison purposes, the WHO guideline concentrations are 26.2 ppm(v) and 8.7 ppm(v) for 1-hour and 8-hour averages, respectively; WHO does not publish a 24-hour average guideline concentration for CO. No continuous monitoring data for CO were collected.

3.5 Volatile Organic Compounds

The Summa canisters were analyzed for 62 selected VOCs, with volumetric concentration calculated as toluene in accordance with USEPA Method TO-15. The analytical system was comprised of a gas chromatography/mass spectrometer interfaced to a whole-air pre-concentrator.

The passive samples yielded 24-hour integrated laboratory total VOC concentrations ranging from 1.65 ppb(v) to 28 ppb(v). Most of the 62 individual VOC species analyzed were reported as non-detect below their respective reporting limits. WHO has not developed guideline concentrations for VOCs.

The Aeroqual VOC sensor failed during the Sea Service campaign, during which Summa canister samples were collected, so no sensor data are available for this campaign. The Aeroqual VOC sensor was able to collect data during the Drifter 98 campaign, but no passive samples were collected for VOCs during that campaign. For this reason, it was not possible to adjust the Drifter 98 campaign Aeroqual sensor data to align with the reference method. Accordingly, while the Drifter 98 campaign Aeroqual sensor data are provided herein (as measured), the data should not be viewed quantitatively.

3.6 Inhalable Particulate Matter

A single, integrated PM_{10} filter sample was collected during the Sea Service campaign. The laboratory pre-tared filters were lost in transit to Guyana, so gravimetric analysis of this samples was not possible. An un-tared filter were employed to enable elemental analysis. In lieu of gravimetric sample results for the Sea Service campaign, the E-Sampler's nephelometer output for these data was corrected using a "k-factor" (ratio of nephelometer value to filter value) of 1.8, developed from a prior campaign conducted for the Liza Phase 1 monitoring program. The k-factor is a function of the environmental conditions in the measurement area. Since the Liza Phase 1 PDA is within 10 kilometers of the Liza Phase 2 PDA, use of the same "k factor" is reasonable.

The maximum and average corrected nephelometer 24-hour average PM_{10} concentration measurements for the Sea Service campaign were 43 and 38 micrograms per cubic meter ($\mu g/m^3$), respectively. For comparison purposes, the WHO 24-hour average guideline concentration is 50 $\mu g/m^3$.

Based upon elemental analysis, sodium chloride (most likely from sea salt) constituted the largest component (approximately 30 percent) of the measured PM_{10}.

3.7 Fine Particulate Matter

A single integrated $PM_{2.5}$ filter sample was collected during the Drifter 98 campaign. Additionally, continuous measurements were made by each of two collocated E-Samplers. The filters' gravimetric analyses were used to develop E-Sampler-specific "k factors" of 0.93 and 2.14 for Units 1 and 2, respectively. The E-Samplers' nephelometer outputs were corrected using these "k-factors."

Considering the combined daily measurements from the two E-Samplers, the maximum corrected nephelometer 24-hour average $PM_{2.5}$ concentration measurements for the Drifter 98 campaign was 18 $\mu g/m^3$, and the average corrected nephelometer 24-hour average $PM_{2.5}$ concentration measurements for the Drifter 98 campaign was 12 $\mu g/m^3$. For comparison purposes, the WHO 24-hour average guideline concentration is 25 $\mu g/m^3$.

Based upon elemental analysis, sodium chloride (most likely from sea salt) constituted the largest component (approximately 10 to 20 percent) of the measured $PM_{2.5}$.

3.8 Meteorological Parameters

The relative wind direction results confirm that the helmsmen were generally successful in orienting the vessel so as to reduce potential measurement interference from onboard emission sources. The relative wind direction was only from astern during 28 of the 198 hours the vessels were in the Liza Phase 2 PDA.

The temperature and humidity measurements validated that these parameters were within the air quality sensors' acceptable use range throughout the monitoring periods.

4.0 REFERENCES

National Research Council. 1991. Rethinking the Ozone Problem in Urban and Regional Air Pollution. Accessed: May 2018. Retrieved from: https://www.nap.edu/catalog/1889/rethinking-the-ozone-problem-in-urban-and-regional-air-pollution.

Attachment 1
Validated Data Record

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A. Sulfur Dioxide Monitoring Data

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Measured SO_2 Concentrations

Vessel	On		Off		Lab Conc. (ppb)	Aeroqual (ppb)
	Date	Time	Date	Time		
Sea Service	4/9/18	10:27	4/10/18	10:45	ND	NS
	4/10/18	10:45	4/11/18	10:20	ND	NS
	4/11/18	10:20	4/12/18	12:47	ND	NS
	4/14/18	16:05	4/15/18	16:40	ND	NS
	4/14/18	16:05	4/15/18	16:40	ND	NS
Drifter 98	5/3/18	9:00	5/4/18	9:00	ND	8
	5/3/18	9:00	5/4/18	9:00	ND	
	5/8/18	11:00	5/9/18	11:00	ND	2
	5/9/18	11:00	5/10/18	11:00	ND	1
	5/10/18	11:00	5/11/18	11:00	ND	2

ND = below reporting level
NS = not sampled (no valid results)

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B. Hydrogen Sulfide Monitoring Data

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Measured H_2S Concentrations

Vessel	On		Off		Lab Conc. (ppb)	Aeroqual (ppb)
	Date	Time	Date	Time		
Sea Service	4/9/18	10:27	4/10/18	10:45	ND	NS
	4/10/18	10:45	4/11/18	10:20	ND	NS
	4/11/18	10:20	4/12/18	12:47	ND	NS
	4/14/18	16:05	4/15/18	16:40	ND	8
	4/14/18	16:05	4/15/18	16:40	ND	8
Drifter 98	5/3/18	9:00	5/4/18	9:00	ND	13
	5/3/18	9:00	5/4/18	9:00	ND	13
	5/8/18	11:00	5/9/18	11:00	ND	10
	5/9/18	11:00	5/10/18	11:00	ND	9
	5/10/18	11:00	5/11/18	11:00	ND	9

ND = Below reporting level
NS = No valid sample

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C. Nitrogen Dioxide Monitoring Data

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Measured NO_2 Concentrations

Vessel	On		Off		Lab Conc. (ppb)	Aeroqual (ppb)
	Date	Time	Date	Time		
Sea Service	4/9/18	10:27	4/10/18	10:45	ND	NS
	4/10/18	10:45	4/11/18	10:20	ND	NS
	4/11/18	10:20	4/12/18	12:47	ND	NS
	4/14/18	16:05	4/15/18	16:40	ND	NS
	4/14/18	16:05	4/15/18	16:40	ND	NS
Drifter 98	5/3/18	9:00	5/4/18	9:00	ND	4
	5/3/18	9:00	5/4/18	9:00	128	
	5/8/18	11:00	5/9/18	11:00	ND	3
	5/9/18	11:00	5/10/18	11:00	ND	9
	5/10/18	11:00	5/11/18	11:00	ND	18

ND = Below reporting level
NS = Not sampled (no valid results)

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D. Carbon Monoxide Monitoring Data

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Measured CO Concentrations

Vessel	Sample ID	On		Off		CO Concentration [ppm(v)]	
		Date	Time	Date	Time	Summa Lab Analysis	Aeroqual
Sea Service	5G	4/14/2018	1625	4/14/2018	1626	ND	NS
	7G	4/15/2018	1631	4/15/2018	1632	ND	NS
	5I	4/14/2018	1605	4/15/2018	1625	ND	NS
	6G	4/15/2018	1631	4/15/2018	1631	ND	NS
	1G	4/9/2018	1027	4/9/2018	1130	ND	NS
	1I	4/9/2018	1027	4/10/2018	1042	ND	NS
	2G	4/10/2018	1100	4/10/2018	1101	ND	NS
	2I	4/10/2018	1042	4/11/2018	1040	ND	NS

ND = Below reporting level
NS = Not sampled (no valid results)

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E. Volatile Organic Compounds Monitoring Data

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Measured VOC Concentrations

Vessel	Sample ID	Start		Stop		Concentration [ppb(v)]									
						Aeroqual (Uncorrected)	Laboratory								
		Date	Time	Date	Time	Total VOC	Total (62 Target VOCs)	2-Butanone	2-Propanol	Carbon Disulfide	Acetone	Chloromethane	Toluene	Naphthalene	Styrene
Sea Service	5G	4/14/2018	1625	4/14/2018	1626	NS	3.77	2.5	ND	ND	ND	0.55	ND	0.72	ND
	7G	4/15/2018	1631	4/15/2018	1632	NS	1.69	ND	ND	ND	1.3	ND	ND	0.39	ND
	5I	4/14/2018	1605	4/15/2018	1625	NS	25.20	1.4	ND	ND	17	0.70	ND	3.20	2.90
	6G	4/15/2018	1631	4/15/2018	1631	NS	1.65	ND	ND	ND	1.30	ND	ND	0.35	ND
	1G	4/9/2018	1027	4/9/2018	1130	NS	6.66	ND	ND	0.98	4.30	0.56	ND	0.82	ND
	1I	4/9/2018	1027	4/10/2018	1042	NS	27.78	1.0	1.30	ND	15	0.65	0.67	0.96	8.20
	2G	4/10/2018	1100	4/10/2018	1101	NS	9.22	0.88	ND	ND	7.60	0.51	ND	0.23	ND
	2I	4/10/2018	1042	4/11/2018	1040	NS	18.28	1.5	ND	ND	16	0.55	ND	0.23	ND
Drifter 98		5/3/2018	0900	5/4/2018	0900	68	NS	NS	NS	NS	NS	NS	NS	NS	NS
		5/8/2018	1100	5/9/2018	1100	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
		5/9/2018	1100	5/10/2018	1100	3	NS	NS	NS	NS	NS	NS	NS	NS	NS
		5/10/2018	1100	5/11/2018	1100	28	NS	NS	NS	NS	NS	NS	NS	NS	NS
		5/11/2018	1100	5/12/2018	1100	14	NS	NS	NS	NS	NS	NS	NS	NS	NS
					Maximum	**68**	**28**	**3**	**1**	**1**	**17**	**1**	**1**	**3**	**8**
					Average	**23**	**12**	**1**	**1**	**1**	**9**	**1**	**1**	**1**	**6**

ND = Below detection level
NS = No valid sample

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F. Inhalable Particulate Matter Monitoring Data

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Measured PM_{10} Concentrations (Corrected E-Sampler Values)

Date	Corrected PM_{10} Concentration, 24-Hour Avg. ($\mu g/m^3$)
4/11/18	42.8
4/12/18	33.1
4/15/18	39.1
Average	**38.3**

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G. Fine Particulate Matter Monitoring Data

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Measured $PM_{2.5}$ Concentrations (Corrected E-Sampler Values)

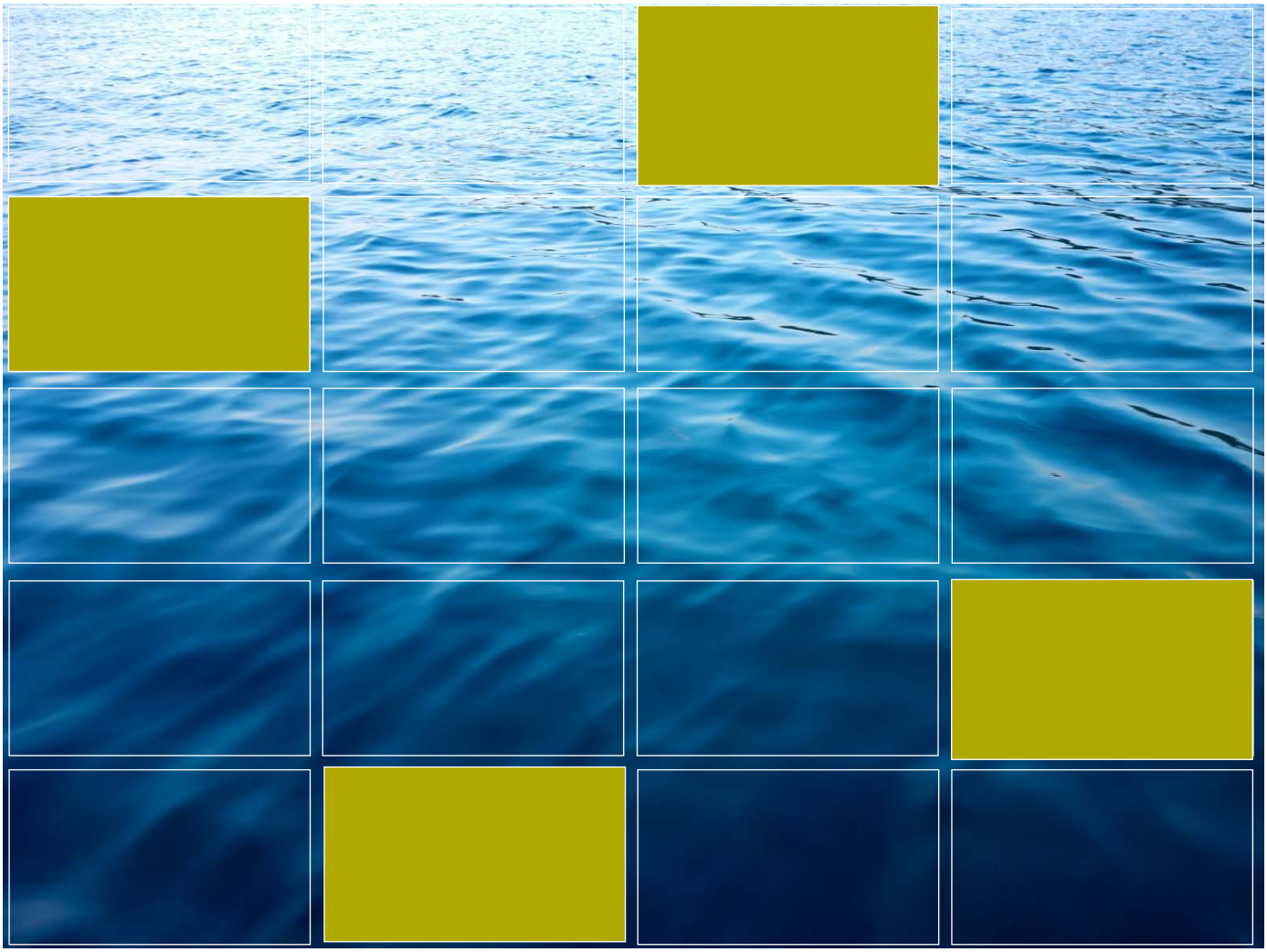
	Corrected $PM_{2.5}$ Concentration, 24-Hour Avg. ($\mu g/m^3$)		
Date	**Unit 1**	**Unit 2**	**Average**
5/4/18	19	16	18
5/9/18	6	8	7
5/10/18	8	14	11
5/11/18	9	9	9
5/12/18	7	20	14
		Average	12
		Maximum	18

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APPENDIX E

Air Quality Modeling

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Air Quality Modeling Report
Liza Phase 2 Development Project

May 2018

The business of sustainability

ERM

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Table 7b: GHG (Kilotonnes CO_2-equivalents) Emissions by Year

LIST OF ACRONYMS

$\mu g/m^3$	micrograms per cubic meter
am^3/hr	actual cubic meters per hour
AOI	Area of Influence
Btu/scf	British thermal units per standard cubic foot
cal/sec	calories per second
CALPUFF	California PUFF model
CO	carbon monoxide
FPSO	Floating Production Storage and Offloading (Vessel)
GHG	greenhouse gas
H_2S	hydrogen sulfide
HHV	higher heating value
HP	high pressure
K	degrees Kelvin
LP	low pressure
LSBC	land-sea breeze circulation
m/s	meters per second
MMBtu/hr	million British thermal units per hour
MMscf/hr	million standard cubic feet per hour
NA	not applicable
NO_x	nitrogen oxides
PM	particulate matter
PM_{10}	particulate matter (aerodynamic diameter less than 10 microns)
$PM_{2.5}$	particulate matter (aerodynamic diameter less than 2.5 microns)
SO_2	sulfur dioxide
VOC	volatile organic compound
UTM	Universal Transverse Mercator (East or North)
WHO	World Health Organization
WRF	Weather Research and Forecasting (meteorological model)

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1.0 INTRODUCTION

In support of the Liza Phase 2 Development Project (Project) Environmental Impact Assessment (EIA), Esso Exploration and Production Guyana Limited (EEPGL) commissioned Environmental Resources Management (ERM) to perform modeling of air emissions from planned Project activities. The purpose of this modeling was to estimate maximum Project-generated ground-level concentrations at onshore locations where community receptors could be exposed to these concentrations. Additionally, in support of the cumulative impact analysis for the Project, combined emissions from the Project and the Liza Phase 1 Development Project were also modeled.

This report provides a description of the modeling methodology, including source characteristics and emissions, receptor locations, model selection, and meteorological data development, and results. Figure 1-1 displays the modeling domain used in this analysis, showing the locations of the main Project point sources (the Floating Production Storage and Offloading vessel [FPSO] and Drill Centers DC3 and DC4), and the Project-related area sources (including support vessels, construction vessels, and other sources without a fixed location), as configured for the modeling. Terrain elevations used in the modeling as well as point sources used in the Liza Phase 1 Development Project are also depicted on this figure.



Figure 1-1: Air Quality Modeling Domain

2.0 AIR QUALITY MODELING METHODOLOGY

2.1 Model Inputs: Source Characteristics and Emissions

Emissions generated by the Project generally emanate from two source categories: (1) specific point sources such as the power generating units and diesel engines on drill ships and on the FPSO, flares used (non-routinely) to combust produced gas when not consumed as fuel gas on the FPSO or re-injected, and vents; and (2) general area sources such as support vessels, construction vessels, tug boats, and helicopters.

Modeling stack sources involves first calculating plume rise (i.e., how high the plume rises due to momentum and buoyancy of the release). Plume rise is added to the physical stack height to determine final plume height, and the plume is tracked as it is transported downwind and dispersed by atmospheric turbulence. Stack parameters needed for model input include the physical stack height, internal diameter, exhaust velocity, elevation of the base of the stack, and exhaust temperature. Table 2-1 displays the values for the parameters used in this analysis, along with the stack locations in Universal Transverse Mercator (UTM) coordinates. Table 2-1 also displays area source characteristics used for the modeling. These values are based on current knowledge of the Project design. It is noted that, due to the distance from Project sources to potential onshore receptors, modeled concentrations are not very sensitive to changes in stack parameters.

Table 2-1: Stack Parameters for Model Input—Phase 2

Name	UTM-E	UTM-N	Base Elevation	Height	Exhaust Flow	Exhaust Temp	Diameter	Exhaust Velocity
	meters	meters	meters	meters	am³/hr	K	meters	m/s
FPSO Sources								
Combustion Turbines	509569	885400	30	28.00	638,716	803.15	3.100	23.507
Flare - HP Normal Flaring [a]	509569	885400	30	136.29	NA	1273.00	0.243	20.000
Flare - LP Normal Flaring [a]	509569	885400	30	135.72	NA	1273.00	0.133	20.000
Flare - HP Full Flaring [a]	509569	885400	30	256.00	NA	1273.00	28.106	20.000
Flare - LP Full Flaring [a]	509569	885400	30	168.11	NA	1273.00	7.246	20.000
Auxiliary Boiler (Heaters)	509569	885400	30	24.40	98,457	681.15	1.150	26.330
Essential Services Generators	509569	885400	30	15.50	14,791	578.15	0.305	56.234
Emergency Generators	509569	885400	30	3.20	15,229	719.15	0.300	59.845
Deck Cranes	509569	885400	30	28.90	7,360	795.55	0.522	9.539

Name	UTM-E	UTM-N	Base Elevation	Height	Exhaust Flow	Exhaust Temp	Diameter	Exhaust Velocity
	meters	meters	meters	meters	am^3/hr	K	meters	m/s
Export Tanker	509569	885400	30	24.40	98,457	681.15	1.150	26.330
Drill Center Sources								
Drill Center 1	504109	892187	0	22.00	73,470	682.60	0.800	40.601
Drill Center 2	506463	896937	0	22.00	73,470	682.60	0.800	40.601
Area Sources								
Support Vessels Project Area	Note c		0	20.00	NA	NA	NA	NA
Support Vessels FPSO shore to Project Area	Note b		0	10.00	NA	NA	NA	NA
Helicopters	Note b		0	300.00	NA	NA	NA	NA
General Project Area (Construction)	Note c		0	10.00	NA	NA	NA	NA

am^3/hr = actual cubic meters per hour; HP = high pressure; K = degrees Kelvin; LP = low pressure; m/s = meters per second; NA = not applicable; UTM-E = Universal Transverse Mercator East; UTM-N = Universal Transverse Mercator North

[a] Effective height/diameter calculated based on heat release to maintain buoyancy flux

[b] Area sources assumed to distribute emissions evenly between shore and Project Development Area

[c] General area source in Project Development Area

Flares associated with the Project were modeled as point sources, with adjustments made to account for and maintain buoyancy of the hot plume. Table 2-2 displays the inputs and results of the calculations that were conducted to estimate an effective diameter and an effective stack height that accomplishes this goal.

Table 2-2: Flare Calculations

Description	Gas Usage	Gas HHV	Total Heat Release	Total Heat Release	Sensible Heat Release	Effective Stack Diameter [a]	Physical Stack Height	Effective Stack Height [a]
	MMscf/hr	Btu/scf	MMBtu/hr	cal/sec	cal/sec	meters		meters
Purge and Pilot Gas								
HP	1.50E-03	1284.6	1.9	1.35E+05	6.07E+04	0.243	135	136.29
LP	3.35E-04	1707.4	0.6	4.00E+04	1.80E+04	0.133	135	135.72
Max Flaring (Commissioning, Non-Routine)								
HP	20.00	1284.6	25,691.2	1.80E+09	8.09E+08	28.106	135	256.00
LP	1.00	1707.4	1,707.4	1.20E+08	5.38E+07	7.246	135	168.11

Btu/scf = British thermal units per standard cubic foot; cal/sec = calories per second; HHV = higher heating value; MMBtu/hr = million British thermal units per hour; MMscf/hr = million standard cubic feet per hour

[a] Effective diameter and effective stack height calculated based on U.S. Environmental Protection Agency guidance, using 20 m/s exit velocity and 1273 K exhaust temperature.

Emissions to air from the Project have been estimated based on a number of factors including activity levels, fuel types, equipment capacities, and standard emission factors that are published by the U.S. Environmental Protection Agency in the publication *AP-42: Compilation of Air Pollutant Emission Factors* (AP-42, USEPA 2018). As described in AP-42, an emission factor is a representative value that relates the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., milligrams of nitrogen oxides [NO_x] emitted per cubic meter of natural gas combusted). In most cases, these factors are averages of available data of an acceptable quality, and are generally assumed to be representative of long-term averages for a particular type of source.

Table 2-3 provides a summary of expected annual emissions from various planned Project activities for three time periods: 2020-2021 (development well drilling; subsea, umbilicals, risers, and flowlines installation and commissioning; FPSO installation; and operation of related support vessels); 2022-2024 (continued development well drilling; operation of related support vessels; FPSO startup and associated temporary, non-routine flaring; beginning of production operations; and tanker loading); and 2025-2042 (production operations following cessation of drilling, including temporary, non-routine flaring; operation of related support vessels; and tanker loading). For each of the time periods, the annual emissions presented for each pollutant in Table 2-3 represents the maximum anticipated annual emissions for that pollutant for any of the years during the indicated time period. While there are some differences in emissions for different years within the time periods, they are relatively minor and the use of maximum emissions for the impact assessment provides a degree of conservatism in the results. Tables with detailed listings of emissions by year are provided in Attachment A).

Table 2-3: Annual Air Emissions Summary

Pollutant	Source Category	Annual Emissions (tonnes)		
		2020-2021	2022-2024	2025-2042
NOx	FPSO	0	2,875	2,780
	FPSO Flaring (temporary, non-routine)	0	575	255
	Tanker Loading	0	305	300
	Area Sources	2,055	590	450
	Drill ships	1,675	840	0
	Total	3,730	5,185	3,785

Pollutant	Source Category	Annual Emissions (tonnes)		
		2020-2021	2022-2024	2025-2042
Sulfur Dioxide (SO_2)	FPSO	0	145	145
	FPSO Flaring (temporary, non-routine)	0	95	45
	Tanker Loading	0	55	50
	Area Sources	75	25	20
	Drill ships	60	30	0
	Total	135	350	260
Particulate Matter (PM)	FPSO	0	65	60
	FPSO Flaring (temporary, non-routine)	0	20	10
	Tanker Loading	0	25	25
	Area Sources	145	45	35
	Drill Ships	120	60	0
	Total	265	215	130
Carbon Monoxide (CO)	FPSO	0	735	715
	FPSO Flaring (temporary, non-routine)	0	3,130	1,370
	Tanker Loading	0	65	65
	Area Sources	430	125	95
	Drill Ships	350	175	0
	Total	780	4,230	2,245
Hydrogen Sulfide (H_2S)	FPSO Flaring (temporary, non-routine)	NA (no emissions)	<5	<1
Volatile Organic Compounds (VOCs)	All Sources	95	4,855	4,410
Greenhouse Gases (GHGs [kilotonnes CO_2-equivalents])	All Sources	195	2,325	1,510

Notes:

1. The annual estimated totals generally reflect the current preliminary Project schedule and remain subject to adjustment.
2. VOC and GHG emissions are shown in this table but were not included in the impact assessment modeling, as no Guyana-specific ambient air quality criteria have been established for these substances.
3. PM emissions represent total PM; for the purpose of the impact assessment, the results from modeling of total PM values were used for comparison to both PM_{10} (particulate matter with an aerodynamic diameter less than 10 microns) standards and $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 microns) standards (a conservative assumption).
4. The emission rates in this table reflect annual totals. In some cases, the activities generating the emission are not continuous during the year, or do not operate at full capacity throughout the year. For these sources, the annual emissions reflect this non-continuous operation over the year. However, for the purpose of modeling conducted to compare with short-term (up to 24-hour) guidelines, activities were assumed to be operating at full capacity for the simulated period, to reflect maximum short-term emission rates.

2.2 Receptors

A grid of potential receptor points was established for onshore areas in the Area of Influence (AOI). For each pollutant, dispersion modeling was used to predict the maximum concentration at any one of the onshore grid points; these maximum predicted concentrations were then compared to concentrations that may potentially result in significant impacts. If the maximum predicted concentrations are determined to be not significant, it follows that potential air quality impacts at any specific receptor location throughout the onshore AOI also would be not significant. For this reason, specific locations of sensitive receptors were not identified at the onset of modeling. Figure 2-1 illustrates the potential receptor location grid used. At each potential receptor grid node, terrain elevations were specified and used by the California PUFF model (CALPUFF) to model plume interaction with onshore terrain.



Figure 2-1: Potential Receptor Grid Used for Air Quality Modeling

2.3 Model Selection

The CALPUFF model (Version 7.2.1, level 150618) used in the assessment is a non-steady-state model used in the United States and around the globe for long-range transport and complex wind modeling. CALPUFF is a Lagrangian "puff" model that treats a plume as a series of puffs that it tracks as the wind carries the plume toward potential receptor locations. The selection of CALPUFF was based on the relatively large distance between the Project Development Area and the potential onshore receptors. As shown in Figure 2-1, the distance from the Project Development Area to the closest shoreline is approximately 190 kilometers. At this distance, emission plumes released from Project point sources would travel for 10 hours, assuming an average wind speed of 5 meters per second (typical for the area). During this transport time, winds can change direction and speed. Accordingly, prediction of plume dispersion is most appropriately accomplished with a non-steady state model. Additionally, due to the vast differences in surface characteristics between open water and land, coastal areas frequently experience a classic meteorological phenomenon known as the land-sea breeze circulation (LSBC). This phenomenon is due to the diurnal surface temperature differences that develop between the land and the open water. LSBC effects can play an important role in the dispersion modeling analysis of emission sources as plumes interact with the onshore receptors. CALPUFF, combined with gridded meteorological data, is capable of accounting for the LSBC phenomenon. CALPUFF was run for each source individually and, post-processing, was used to calculate pollutant-specific totals for applicable averaging periods.

2.4 Meteorological Data

The Weather Research and Forecasting (WRF) model was used to develop hourly meteorology inputs for CALPUFF for 3 years—calendar years 2014, 2015, and 2016. WRF is a prognostic meteorological model that creates profiles of winds and temperature at grid points across a domain. The grid spacing chosen for this analysis was 12 kilometers, so that a two-dimensional profile of hourly winds and temperature was developed every 12 kilometers within the domain shown in Figure 2-1. The profiles were used by CALPUFF to simulate the transport and dispersion of emission plumes from Project sources, allowing the model to calculate ambient constituent concentrations at potential receptor locations, accounting for changes in meteorology as the plumes travel downwind.

Illustrations of how the WRF model accounts for the effects on meteorological variables from height above the surface and underlying land use characteristics (i.e., overland and overwater) are provided in Figures 2-2 and 2-3. These figures display the locations of the 12-kilometer grid points (the WRF model was used to create profiles of wind and temperature for each of these locations). At every other grid point, wind roses were created to illustrate wind direction and speed frequencies at that location. Wind roses shown in Figure 2-2 were created from the profile of wind conditions 10 meters above the surface for the year 2014; wind roses shown in Figure 2-3 were created from the

profile of wind conditions 240 meters above the surface for the year 2014 (240 meters is representative of typical plume heights for the larger Project sources). At a height of 240 meters, the effects of the land surface on winds are considerably less pronounced than the effects at a height of 10 meters. Figure 2-2 (10-meter level) shows a pronounced effect on wind speed over land, where surface friction acts to slow down the wind.

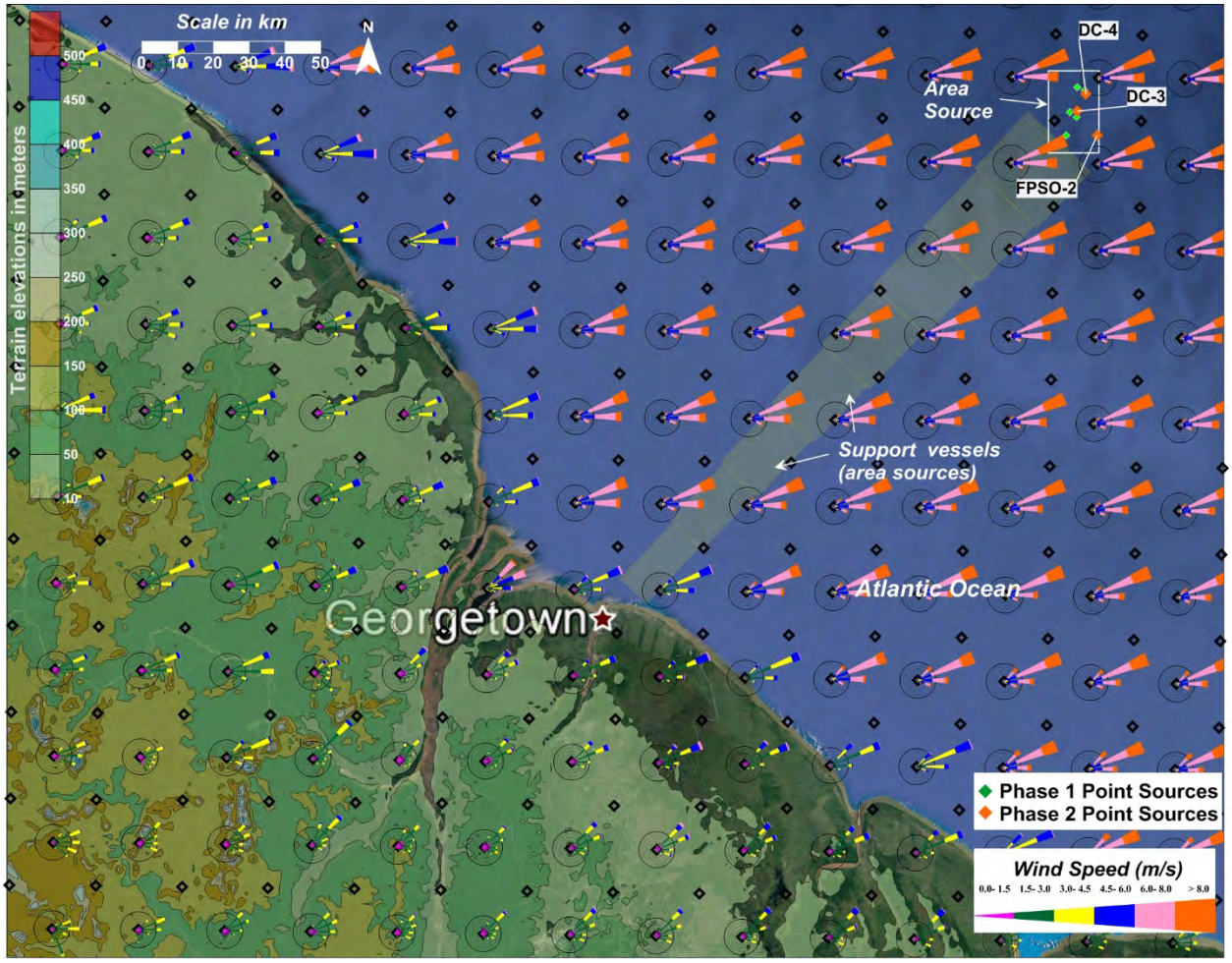


Figure 2-2: Wind Roses—10-Meter Level (2014)

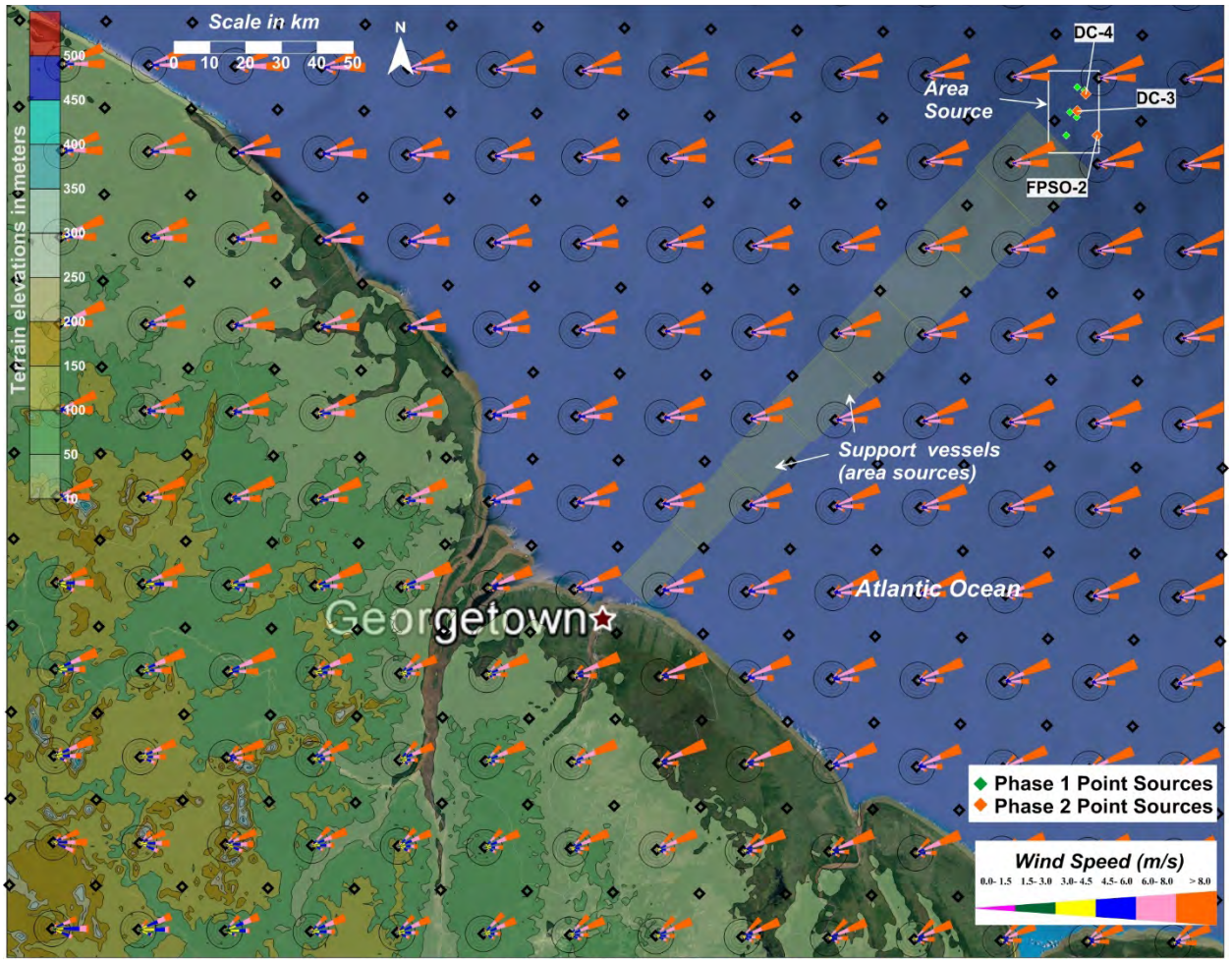


Figure 2-3: Wind Roses—240-Meter Level (2014)

3.0 RESULTS

3.1 Ambient Air Quality Guidelines

Ambient air quality guidelines are concentration levels in air that are established to protect human health in locations where exposure can occur. These generally include a margin of safety to ensure that vulnerable individuals are also protected. Guyana has not established specific ambient air quality standards; therefore, the guidelines used for reference in this assessment were those established by the World Health Organization (WHO). The WHO guidelines are summarized in Table 3-1. These guidelines were published in *WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide - Global Update 2005* (WHO 2005), except for carbon monoxide (CO) and hydrogen sulfide (H_2S), for which guidelines were published in WHO's *Air Quality Guidelines for Europe, 2nd edition, 2000* (WHO 2000).

Table 3-1: WHO Ambient Air Quality Guidelines

Pollutant	Averaging Period	Guideline Concentration (µg/m³)
NO_2	1-hour	200
	Annual	40
SO_2	10-minute	500
	24-hour	20
PM_{10}	24-hour	50
	Annual	20
$PM_{2.5}$	24-hour	25
	Annual	10
CO	1-hour	30,000
	8-hour	10,000
H_2S	30-minute	7

Sources: WHO 2000; WHO 2005
µg/m³ = micrograms per cubic meter

3.2 Predicted Concentrations and Comparison to Guidelines

Using the methodology described above, modeling was conducted with CALPUFF to predict maximum onshore ground-level concentrations of each pollutant as a result of emissions from Project sources. Model results were developed for each modeled pollutant, for each averaging period with an associated WHO guideline concentration (Table 3-1). Additionally, the cumulative impact analysis modeling scenario combined the results from the Project with modeled emissions from Liza Phase 1 Development Project.

All results are summarized in Tables 3-2 (Project only) and 3-3 (Project + Phase 1 Project). For the Project only modeling, maximum predicted concentrations at any potential onshore receptor location are less than 1.5 percent of the applicable guideline for all pollutants and averaging periods. For the cumulative modeling scenario, maximum predicted concentrations at any potential onshore receptor location are less than or equal to 2.5 percent of the applicable guideline for all pollutants and averaging periods. These results are consistent with the expectation that onshore air quality impacts from the Project would be relatively small in magnitude, based on the distance of Project emissions sources from the nearest potential onshore receptors.

Table 3-2: Summary of Modeling Results—Maximum Predicted Concentrations at Potential Onshore Receptor Locations (Project Only)

Pollutant	Averaging Period	WHO Guideline Concentration (µg/m³)	Maximum Predicted Onshore Concentration (µg/m³)			Percent of WHO Guideline		
			2020-2021	2022-2024	2025-2042	2020-2021	2022-2024	2025-2042
NO_2	1-hour	200	1.4	2.8	2.4	0.7%	1.4%	1.2%
	Annual	40	0.1	0.2	0.1	0.3%	0.4%	0.3%
SO_2	10-minute	500	0.1	0.5	0.4	0.0%	0.1%	0.1%
	24-hour	20	0.0	0.1	0.1	0.1%	0.7%	0.6%
PM_{10}	24-hour	50	0.0	0.1	0.0	0.1%	0.1%	0.1%
	Annual	20	0.0	0.0	0.0	0.1%	0.0%	0.0%
$PM_{2.5}$	24-hour	25	0.0	0.1	0.0	0.2%	0.2%	0.2%
	Annual	10	0.0	0.0	0.0	0.1%	0.1%	0.1%
CO	1-hour	30,000	0.4	1.6	1.2	0.0%	0.0%	0.0%
	8-hour	10,000	0.3	1.1	0.8	0.0%	0.0%	0.0%
H_2S	30-minute	7	NA	NA	0.0004	NA	NA	0.0061%

Sources: WHO 2000; WHO 2005

Table 3-3: Summary of Modeling Results—Maximum Predicted Concentrations at Potential Onshore Receptor Locations (Cumulative Scenario)

Pollutant	Averaging Period	WHO Guideline Concentration (µg/m³)	Maximum Predicted Onshore Concentration (µg/m³)			Percent of WHO Guideline		
			2020-2021	2022-2024	2025-2042	2020-2021	2022-2024	2025-2042
NO_2	1-hour	200	2.7	5.0	3.9	1.4%	2.5%	1.9%
	Annual	40	0.2	0.3	0.2	0.6%	0.8%	0.6%
SO_2	10-minute	500	0.2	1.2	1.1	0.0%	0.2%	0.2%
	24-hour	20	0.0	0.4	0.3	0.2%	1.8%	1.7%
PM_{10}	24-hour	50	0.1	0.1	0.1	0.2%	0.2%	0.2%
	Annual	20	0.0	0.0	0.0	0.1%	0.1%	0.0%
$PM_{2.5}$	24-hour	25	0.1	0.1	0.1	0.4%	0.4%	0.3%
	Annual	10	0.0	0.0	0.0	0.2%	0.2%	0.1%
CO	1-hour	30,000	0.7	3.5	3.2	0.0%	0.0%	0.0%
	8-hour	10,000	0.6	2.0	1.8	0.0%	0.0%	0.0%
H_2S	30-minute	7	NA	NA	0.00019	NA	NA	0.0027%

Sources: WHO 2000; WHO 2005

4.0 REFERENCES

USEPA (U.S. Environmental Protection Agency). 2018. Webpage with links to AP42: Compilation of Air Emissions Factors. Accessed: April 2018. Retrieved from: https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors

WHO (World Health Organization). 2000. WHO Air Quality Guidelines for Europe, 2nd edition.

_____. 2005. WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide - Global Update 2005.

Attachment A
Tables—Detailed Emissions by Year

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Table 1a: NOx Emissions by Year

Source Sector	Emissions (tonnes) Modeled for Each Time Period			Emissions (tonnes) Per Year								
	const. 2020-2021	oper/drill 2022-2024	operations 2025-2042	2020	2021	2022	2023	2024	2025	2026	2027	2028
Combustion Turbines	0.00	2761.94	2761.94	0.0	0.0	2762	2762	2762	2762	2762	2762	2762
Flare - HP Normal Flaring	0.00	0.22	0.10	0.0	0.0	0.2	0.0	0.0	0.1	0.1	0.1	0.1
Flare - LP Normal Flaring	0.00	121.92	53.25	0.0	0.0	121.9	19.5	20.1	48.2	35.1	34.8	53.2
Flare - HP Full Flaring	0.00	377.78	164.99	0.0	0.0	377.8	60.5	62.4	149.5	108.8	107.9	165.0
Flare - LP Full Flaring	0.00	74.70	32.62	0.0	0.0	74.7	12.0	12.3	29.6	21.5	21.3	32.6
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Essential Services Gens	0.00	101.68	7.84	0.0	0.0	101.7	7.8	7.8	7.8	7.8	7.8	7.8
Emergency Generators	0.00	0.20	0.20	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Deck Cranes	0.00	9.94	9.94	0.0	0.0	5.0	9.9	9.9	9.9	9.9	9.9	9.9
Export Tanker	0.00	300.03	296.43	0.0	0.0	150.0	300.0	300.0	296.4	260.4	214.8	176.4
Drill Center1	835.04	417.52	0.00	313.1	835.0	417.5	417.5	104.4	0.0	0.0	0.0	0.0
Drill Center2	835.04	417.52	0.00	313.1	835.0	417.5	417.5	104.4	0.0	0.0	0.0	0.0
Support Vessels Project Area	579.41	386.28	297.75	313.8	579.4	386.3	297.8	297.8	297.8	297.8	297.8	297.8
Support Vessels FPSO shore to Project Area	289.71	193.14	148.88	156.9	289.7	193.1	148.9	148.9	148.9	148.9	148.9	148.9
Helicopters	17.43	7.62	2.18	8.7	17.4	7.6	7.1	4.4	2.2	2.2	2.2	2.2
General Project Area (Construction)	1164.87	0.00	0.00	0.0	1165	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum	**3721.50**	**5170.47**	**3776.10**	**1106**	**3721**	**5015**	**4461**	**3835**	**3753**	**3655**	**3608**	**3656**

Table 1b: NOx Emissions by Year

Source Sector	Emissions (tonnes) Per Year													
	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Combustion Turbines	2762	2762	2762	2762	2762	2762	2762	2762	2762	2762	2762	2762	2762	2762
Flare - HP Normal Flaring	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0
Flare - LP Normal Flaring	35.1	33.9	48.9	29.8	18.9	18.9	18.9	18.9	30.1	29.2	27.3	31.1	16.5	14.7
Flare - HP Full Flaring	108.8	105.0	151.4	92.4	58.5	58.5	58.5	58.5	93.4	90.5	84.7	96.3	51.3	45.7
Flare - LP Full Flaring	21.5	20.8	29.9	18.3	11.6	11.6	11.6	11.6	18.5	17.9	16.7	19.0	10.1	9.0
Auxiliary Boiler (Heaters)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Essential Services Gens	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Emergency Generators	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Deck Cranes	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
Export Tanker	148.8	134.4	117.6	104.4	94.8	87.6	80.4	75.6	72.0	64.8	60.0	56.4	54.0	50.4
Drill Center1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drill Center2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Support Vessels Project Area	297.8	297.8	297.8	297.8	297.8	297.8	297.8	297.8	297.8	297.8	297.8	297.8	297.8	297.8
Support Vessels FPSO shore to Project Area	148.9	148.9	148.9	148.9	148.9	148.9	148.9	148.9	148.9	148.9	148.9	148.9	148.9	148.9
Helicopters	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
General Project Area (Construction)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum	**3543**	**3523**	**3577**	**3474**	**3413**	**3405**	**3398**	**3393**	**3443**	**3431**	**3417**	**3432**	**3361**	**3349**

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Table 2a: SO_2 Emissions by Year

Source Sector	Emissions (tonnes) Modeled for Each Time Period			Emissions (tonnes) Per Year								
	const. 2020-2021	oper/drill 2022-2024	operations 2025-2042	2020	2021	2022	2023	2024	2025	2026	2027	2028
Combustion Turbines	0.00	139.73	139.73	0.00	0.0	139.7	139.7	139.7	139.7	139.7	139.7	139.7
Flare - HP Normal Flaring	0.00	0.04	0.02	0.00	0.00	0.04	0.01	0.01	0.01	0.01	0.01	0.02
Flare - LP Normal Flaring	0.00	19.58	8.55	0.00	0.00	19.58	3.13	3.23	7.75	5.64	5.59	8.55
Flare - HP Full Flaring	0.00	60.67	26.50	0.00	0.00	60.67	9.71	10.02	24.01	17.48	17.33	26.50
Flare - LP Full Flaring	0.00	12.00	5.24	0.00	0.00	12.00	1.92	1.98	4.75	3.46	3.43	5.24
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Essential Services Gens	0.00	3.41	0.26	0.00	0.00	3.41	0.26	0.26	0.26	0.26	0.26	0.26
Emergency Generators	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deck Cranes	0.00	0.33	0.33	0.00	0.00	0.17	0.33	0.33	0.33	0.33	0.33	0.33
Export Tanker	0.00	50.30	49.69	0.00	0.00	25.15	50.30	50.30	49.69	43.66	36.01	29.58
Drill Center1	28.00	14.00	0.00	10.50	28.00	14.00	14.00	3.50	0.00	0.00	0.00	0.00
Drill Center2	28.00	14.00	0.00	10.50	28.00	14.00	14.00	3.50	0.00	0.00	0.00	0.00
Support Vessels Project Area	19.43	12.95	9.98	10.52	19.43	12.95	9.98	9.98	9.98	9.98	9.98	9.98
Support Vessels FPSO shore to Project Area	9.71	6.48	4.99	5.26	9.71	6.48	4.99	4.99	4.99	4.99	4.99	4.99
Helicopters	2.12	0.93	0.27	1.06	2.12	0.93	0.86	0.53	0.27	0.27	0.27	0.27
General Project Area (Construction)	39.06	0.00	0.00	0.00	39.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**126.32**	**334.42**	**245.57**	**38**	**126**	**309.1**	**249.2**	**228.4**	**241.8**	**225.8**	**217.9**	**225.5**

Table 2b: SO_2 Emissions by Year

Source Sector	Emissions (tonnes) Per Year													
	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Combustion Turbines	139.7	139.7	139.7	139.7	139.7	139.7	139.7	139.7	139.7	139.7	139.7	139.7	139.7	139.7
Flare - HP Normal Flaring	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Flare - LP Normal Flaring	5.64	5.44	7.85	4.79	3.03	3.03	3.03	3.03	4.84	4.69	4.39	4.99	2.66	2.37
Flare - HP Full Flaring	17.48	16.86	24.32	14.84	9.39	9.39	9.39	9.39	14.99	14.53	13.59	15.46	8.23	7.33
Flare - LP Full Flaring	3.46	3.33	4.81	2.93	1.86	1.86	1.86	1.86	2.96	2.87	2.69	3.06	1.63	1.45
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Essential Services Gens	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Emergency Generators	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deck Cranes	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Export Tanker	24.95	22.53	19.72	17.50	15.89	14.69	13.48	12.68	12.07	10.86	10.06	9.46	9.05	8.45
Drill Center1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drill Center2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Support Vessels Project Area	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98
Support Vessels FPSO shore to Project Area	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99
Helicopters	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
General Project Area (Construction)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**207.1**	**203.8**	**212.3**	**195.6**	**185.8**	**184.6**	**183.3**	**182.5**	**190.5**	**188.5**	**186.3**	**188.5**	**177.2**	**175.2**

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Table 3a: H_2S Emissions by Year

Source Sector	Emissions (tonnes) Modeled for Each Time Period			Emissions (tonnes) Per Year								
	const. 2020-2021	oper/drill 2022-2024	operations 2025-2042	2020	2021	2022	2023	2024	2025	2026	2027	2028
Combustion Turbines	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flare - HP Normal Flaring	0.00E+00	5.20E-04	2.27E-04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flare - LP Normal Flaring	0.00E+00	2.87E-01	1.25E-01	0.00	0.00	0.00	0.29	0.05	0.05	0.11	0.08	0.08
Flare - HP Full Flaring	0.00E+00	8.90E-01	3.89E-01	0.00	0.00	0.00	0.89	0.14	0.15	0.35	0.26	0.25
Flare - LP Full Flaring	0.00E+00	1.76E-01	7.69E-02	0.00	0.00	0.00	0.18	0.03	0.03	0.07	0.05	0.05
Auxiliary Boiler (Heaters)	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Essential Services Gens	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emergency Generators	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deck Cranes	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Export Tanker	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drill Center1	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drill Center2	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Support Vessels Project Area	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Support Vessels FPSO shore to Project Area	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Helicopters	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
General Project Area (Construction)	0.00E+00	0.00E+00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**0.000E+00**	**1.354E+00**	**5.912E-01**	**0.00**	**0.00**	**0.00**	**1.35**	**0.22**	**0.22**	**0.54**	**0.39**	**0.39**

Table 3b: H_2S Emissions by Year

Source Sector	Emissions (tonnes) Per Year													
	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Combustion Turbines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flare - HP Normal Flaring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flare - LP Normal Flaring	0.13	0.08	0.08	0.12	0.07	0.04	0.04	0.04	0.04	0.07	0.07	0.06	0.07	0.04
Flare - HP Full Flaring	0.39	0.26	0.25	0.36	0.22	0.14	0.14	0.14	0.14	0.22	0.21	0.20	0.23	0.12
Flare - LP Full Flaring	0.08	0.05	0.05	0.07	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.02
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Essential Services Gens	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emergency Generators	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deck Cranes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Export Tanker	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drill Center1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drill Center2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Support Vessels Project Area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Support Vessels FPSO shore to Project Area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Helicopters	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
General Project Area (Construction)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**0.59**	**0.39**	**0.38**	**0.54**	**0.33**	**0.21**	**0.21**	**0.21**	**0.21**	**0.33**	**0.32**	**0.30**	**0.34**	**0.18**

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Table 4a: PM Emissions by Year

Source Sector	Emissions (tonnes) Modeled for Each Time Period			Emissions (tonnes) Per Year								
	const. 2020-2021	oper/drill 2022-2024	operations 2025-2042	2020	2021	2022	2023	2024	2025	2026	2027	2028
Combustion Turbines	0.00	56.96	56.96	0.00	0.00	56.96	56.96	56.96	56.96	56.96	56.96	56.96
Flare - HP Normal Flaring	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Flare - LP Normal Flaring	0.00	3.49	1.52	0.00	0.00	3.49	0.56	0.58	1.38	1.00	1.00	1.52
Flare - HP Full Flaring	0.00	10.80	4.72	0.00	0.00	10.80	1.73	1.78	4.27	3.11	3.08	4.72
Flare - LP Full Flaring	0.00	2.14	0.93	0.00	0.00	2.14	0.34	0.35	0.85	0.62	0.61	0.93
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Essential Services Gens	0.00	7.15	0.55	0.00	0.00	7.15	0.55	0.55	0.55	0.55	0.55	0.55
Emergency Generators	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Deck Cranes	0.00	0.70	0.70	0.00	0.00	0.35	0.70	0.70	0.70	0.70	0.70	0.70
Export Tanker	0.00	21.09	20.84	0.00	0.00	10.55	21.09	21.09	20.84	18.31	15.10	12.40
Drill Center1	58.70	29.35	0.00	22.01	58.70	29.35	29.35	7.34	0.00	0.00	0.00	0.00
Drill Center2	58.70	29.35	0.00	22.01	58.70	29.35	29.35	7.34	0.00	0.00	0.00	0.00
Support Vessels Project Area	40.73	27.15	20.93	22.06	40.73	27.15	20.93	20.93	20.93	20.93	20.93	20.93
Support Vessels FPSO shore to Project Area	20.36	13.58	10.47	11.03	20.36	13.58	10.47	10.47	10.47	10.47	10.47	10.47
Helicopters	1.23	0.54	0.15	0.61	1.23	0.54	0.50	0.31	0.15	0.15	0.15	0.15
General Project Area (Construction)	81.88	0.00	0.00	0.00	81.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**261.60**	**202.31**	**117.79**	**77.7**	**261.6**	**191.4**	**172.5**	**128.4**	**117.1**	**112.8**	**109.6**	**109.4**

Table 4b: PM Emissions by Year

Source Sector	Emissions (tonnes) Per Year													
	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Combustion Turbines	56.96	56.96	56.96	56.96	56.96	56.96	56.96	56.96	56.96	56.96	56.96	56.96	56.96	56.96
Flare - HP Normal Flaring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flare - LP Normal Flaring	1.00	0.97	1.40	0.85	0.54	0.54	0.54	0.54	0.86	0.83	0.78	0.89	0.47	0.42
Flare - HP Full Flaring	3.11	3.00	4.33	2.64	1.67	1.67	1.67	1.67	2.67	2.59	2.42	2.75	1.47	1.31
Flare - LP Full Flaring	0.62	0.59	0.86	0.52	0.33	0.33	0.33	0.33	0.53	0.51	0.48	0.54	0.29	0.26
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Essential Services Gens	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Emergency Generators	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Deck Cranes	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Export Tanker	10.46	9.45	8.27	7.34	6.66	6.16	5.65	5.31	5.06	4.56	4.22	3.96	3.80	3.54
Drill Center1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drill Center2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Support Vessels Project Area	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93
Support Vessels FPSO shore to Project Area	10.47	10.47	10.47	10.47	10.47	10.47	10.47	10.47	10.47	10.47	10.47	10.47	10.47	10.47
Helicopters	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
General Project Area (Construction)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**105.0**	**103.8**	**104.6**	**101.1**	**99.0**	**98.5**	**98.0**	**97.6**	**98.9**	**98.3**	**97.7**	**97.9**	**95.8**	**95.3**

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Table 5a: CO Emissions by Year

Source Sector	Emissions (tonnes) Modeled for Each Time Period			Emissions (tonnes) Per Year								
	const. 2020-2021	oper/drill 2022-2024	operations 2025-2042	2020	2021	2022	2023	2024	2025	2026	2027	2028
Combustion Turbines	0.00	707.75	707.75	0.00	0.00	707.7	707.7	707.7	707.7	707.7	707.7	707.7
Flare - HP Normal Flaring	0.00	1.20	0.52	0.00	0.00	1.20	0.19	0.20	0.48	0.35	0.34	0.52
Flare - LP Normal Flaring	0.00	663.40	289.73	0.00	0.00	663.4	106.2	109.6	262.5	191.1	189.4	289.7
Flare - HP Full Flaring	0.00	2055.54	897.72	0.00	0.00	2056	328.9	339.5	813.5	592.3	587.0	897.7
Flare - LP Full Flaring	0.00	406.46	177.51	0.00	0.00	406.5	65.0	67.1	160.9	117.1	116.1	177.5
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Essential Services Gens	0.00	21.18	1.63	0.00	0.00	21.18	1.63	1.63	1.63	1.63	1.63	1.63
Emergency Generators	0.00	0.04	0.04	0.00	0.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Deck Cranes	0.00	2.07	2.07	0.00	0.00	1.04	2.07	2.07	2.07	2.07	2.07	2.07
Export Tanker	0.00	62.51	61.76	0.00	0.00	31.25	62.51	62.51	61.76	54.25	44.75	36.75
Drill Center1	173.97	86.98	0.00	65.24	174.0	86.98	86.98	21.75	0.00	0.00	0.00	0.00
Drill Center2	173.97	86.98	0.00	65.24	174.0	86.98	86.98	21.75	0.00	0.00	0.00	0.00
Support Vessels Project Area	120.71	80.47	62.03	65.39	120.7	80.47	62.03	62.03	62.03	62.03	62.03	62.03
Support Vessels FPSO shore to Project Area	60.36	40.24	31.02	32.69	60.4	40.24	31.02	31.02	31.02	31.02	31.02	31.02
Helicopters	3.63	1.59	0.45	1.82	3.6	1.59	1.47	0.91	0.45	0.45	0.45	0.45
General Project Area (Construction)	242.68	0.00	0.00	0.00	242.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**775.31**	**4216.41**	**2232.23**	**230**	**775**	**4184**	**1543**	**1428**	**2104**	**1760**	**1743**	**2207**

Table 5b: CO Emissions by Year

Source Sector	Emissions (tonnes) Per Year													
	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Combustion Turbines	707.7	707.7	707.7	707.7	707.7	707.7	707.7	707.7	707.7	707.7	707.7	707.7	707.7	707.7
Flare - HP Normal Flaring	0.35	0.33	0.48	0.29	0.19	0.19	0.19	0.19	0.30	0.29	0.27	0.31	0.16	0.15
Flare - LP Normal Flaring	191.1	184.3	265.9	162.3	102.7	102.7	102.7	102.7	164.0	158.9	148.7	169.1	90.0	80.2
Flare - HP Full Flaring	592.3	571.2	824.0	502.7	318.3	318.3	318.3	318.3	508.0	492.2	460.6	523.8	278.9	248.4
Flare - LP Full Flaring	117.1	112.9	162.9	99.4	62.9	62.9	62.9	62.9	100.5	97.3	91.1	103.6	55.2	49.1
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Essential Services Gens	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63
Emergency Generators	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Deck Cranes	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07
Export Tanker	31.00	28.00	24.50	21.75	19.75	18.25	16.75	15.75	15.00	13.50	12.50	11.75	11.25	10.50
Drill Center1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drill Center2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Support Vessels Project Area	62.03	62.03	62.03	62.03	62.03	62.03	62.03	62.03	62.03	62.03	62.03	62.03	62.03	62.03
Support Vessels FPSO shore to Project Area	31.02	31.02	31.02	31.02	31.02	31.02	31.02	31.02	31.02	31.02	31.02	31.02	31.02	31.02
Helicopters	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
General Project Area (Construction)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**1737**	**1702**	**2083**	**1591**	**1309**	**1307**	**1306**	**1305**	**1593**	**1567**	**1518**	**1613**	**1241**	**1193**

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Table 6a: VOC Emissions by Year

Source Sector	Emissions (Tonnes) for Each Time Period			Emissions (tonnes) Per Year								
	const. 2020-2021	oper/drill 2022-2024	operations 2025-2042	2020	2021	2022	2023	2024	2025	2026	2027	2028
Combustion Turbines	0.00	14.76	14.76	0.0	0.0	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Flare - HP Normal Flaring	0.00	1.24	0.54	0.0	0.0	1.2	0.2	0.2	0.5	0.4	0.4	0.5
Flare - LP Normal Flaring	0.00	684.96	299.14	0.0	0.0	685.0	109.6	113.1	271.1	197.4	195.6	299.1
Flare - HP Full Flaring	0.00	2122.32	926.88	0.0	0.0	2122	339.6	350.5	839.9	611.5	606.1	926.9
Flare - LP Full Flaring	0.00	419.66	183.28	0.0	0.0	419.7	67.2	69.3	166.1	120.9	119.8	183.3
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Essential Services Gens	0.00	2.60	0.20	0.0	0.0	2.6	0.2	0.2	0.2	0.2	0.2	0.2
Emergency Generators	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Deck Cranes	0.00	0.25	0.25	0.0	0.0	0.1	0.3	0.3	0.3	0.3	0.3	0.3
Tanks	0.00	414.09	409.12	0.0	0.0	207.0	414.1	414.1	409.1	359.4	296.5	243.5
Vessel Loading	0.00	2717.46	2684.86	0.0	0.0	1359	2717	2717	2685	2359	1946	1598
Export Tanker	0.00	7.68	7.59	0.0	0.0	3.8	7.7	7.7	7.6	6.7	5.5	4.5
Drill Center1	21.37	10.69	0.00	8.0	21.4	10.7	10.7	2.7	0.0	0.0	0.0	0.0
Drill Center2	21.37	10.69	0.00	8.0	21.4	10.7	10.7	2.7	0.0	0.0	0.0	0.0
Support Vessels Project Area	14.83	9.89	7.62	8.0	14.8	9.9	7.6	7.6	7.6	7.6	7.6	7.6
Support Vessels FPSO shore to Project Area	7.41	4.94	3.81	4.0	7.4	4.9	3.8	3.8	3.8	3.8	3.8	3.8
Helicopters	0.01	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
General Project Area (Construction)	29.81	0.00	0.00	0.0	29.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max for Period	**94.81**	**4851.49**	**4538.05**	**28**	**95**	**4851**	**3704**	**3704**	**4406**	**3682**	**3196**	**3282**

Table 6b: VOC Emissions by Year

Source Sector	Emissions (tonnes) Per Year													
	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Combustion Turbines	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Flare - HP Normal Flaring	0.4	0.3	0.5	0.3	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.2	0.1
Flare - LP Normal Flaring	197.4	190.3	274.6	167.5	106.1	106.1	106.1	106.1	169.3	164.0	153.5	174.5	92.9	82.8
Flare - HP Full Flaring	611.5	589.8	850.8	519.1	328.6	328.6	328.6	328.6	524.5	508.2	475.6	540.8	288.0	256.5
Flare - LP Full Flaring	120.9	116.6	168.2	102.6	65.0	65.0	65.0	65.0	103.7	100.5	94.0	106.9	56.9	50.7
Auxiliary Boiler (Heaters)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Essential Services Gens	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Emergency Generators	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Deck Cranes	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Tanks	205.4	185.5	162.3	144.1	130.9	120.9	111.0	104.3	99.4	89.4	82.8	77.8	74.5	69.6
Vessel Loading	1348	1217	1065	945.7	858.7	793.5	728.3	684.8	652.2	587.0	543.5	510.9	489.1	456.5
Export Tanker	3.8	3.4	3.0	2.7	2.4	2.2	2.1	1.9	1.8	1.7	1.5	1.4	1.4	1.3
Drill Center1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drill Center2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Support Vessels Project Area	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
Support Vessels FPSO shore to Project Area	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Helicopters	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
General Project Area (Construction)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max for Period	**2514**	**2330**	**2551**	**1909**	**1519**	**1443**	**1368**	**1318**	**1578**	**1478**	**1378**	**1439**	**1030**	**944**

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Table 7a: GHG (Kilotonnes CO_2-equivalents) Emissions by Year

Source Sector	Emissions (Kilotonnes CO2-equivalents) for Each Time Period			Emissions (Kilotonnes CO2-equivalents) Per Year								
	const. 2020-2021	oper/drill 2022-2024	operations 2025-2042	2020	2021	2022	2023	2024	2025	2026	2027	2028
Combustion Turbines	0.00	954.29	954.29	0.00	0.00	954.3	954.3	954.3	954.3	954.3	954.3	954.3
Flare - HP Normal Flaring	0.00	0.48	0.21	0.00	0.00	0.48	0.08	0.08	0.19	0.14	0.14	0.21
Flare - LP Normal Flaring	0.00	267.19	116.69	0.00	0.00	267.2	42.76	44.13	105.7	76.98	76.30	116.7
Flare - HP Full Flaring	0.00	827.87	361.56	0.00	0.00	827.9	132.5	136.7	327.6	238.5	236.4	361.6
Flare - LP Full Flaring	0.00	163.70	71.49	0.00	0.00	163.7	26.20	27.04	64.78	47.17	46.75	71.49
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Essential Services Gens	0.00	5.25	0.40	0.00	0.00	5.25	0.40	0.40	0.40	0.40	0.40	0.40
Emergency Generators	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deck Cranes	0.00	0.51	0.51	0.00	0.00	0.26	0.51	0.51	0.51	0.51	0.51	0.51
Export Tanker	0.00	15.49	15.30	0.00	0.00	7.74	15.49	15.49	15.30	13.44	11.09	9.11
Drill Center1	43.11	21.55	0.00	16.17	43.11	21.55	21.55	5.39	0.00	0.00	0.00	0.00
Drill Center2	43.11	21.55	0.00	16.17	43.11	21.55	21.55	5.39	0.00	0.00	0.00	0.00
Support Vessels Project Area	29.91	19.94	15.37	16.20	29.91	19.94	15.37	15.37	15.37	15.37	15.37	15.37
Support Vessels FPSO shore to Project Area	14.96	9.97	7.69	8.10	14.96	9.97	7.69	7.69	7.69	7.69	7.69	7.69
Helicopters	3.11	1.36	0.39	1.55	3.11	1.36	1.26	0.78	0.39	0.39	0.39	0.39
General Project Area (Construction)	60.14	0.00	0.00	0.00	60.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**194.33**	**2322.88**	**1557.45**	**58**	**194**	**2308**	**1253**	**1227**	**1506**	**1367**	**1359**	**1546**

Table 7b: GHG (Kilotonnes CO_2-equivalents) Emissions by Year

Source Sector	Emissions (Kilotonnes CO2-equivalents) Per Year													
	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Combustion Turbines	954.3	954.3	954.3	954.3	954.3	954.3	954.3	954.3	954.3	954.3	954.3	954.3	954.3	954.3
Flare - HP Normal Flaring	0.14	0.13	0.19	0.12	0.07	0.07	0.07	0.07	0.12	0.12	0.11	0.12	0.07	0.06
Flare - LP Normal Flaring	76.98	74.25	107.1	65.35	41.37	41.37	41.37	41.37	66.03	63.98	59.87	68.09	36.26	32.29
Flare - HP Full Flaring	238.5	230.1	331.9	202.5	128.2	128.2	128.2	128.2	204.6	198.2	185.5	211.0	112.3	100.1
Flare - LP Full Flaring	47.17	45.49	65.62	40.04	25.35	25.35	25.35	25.35	40.46	39.20	36.68	41.72	22.21	19.79
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Essential Services Gens	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Emergency Generators	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deck Cranes	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Export Tanker	7.68	6.94	6.07	5.39	4.89	4.52	4.15	3.90	3.72	3.35	3.10	2.91	2.79	2.60
Drill Center1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drill Center2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Support Vessels Project Area	15.37	15.37	15.37	15.37	15.37	15.37	15.37	15.37	15.37	15.37	15.37	15.37	15.37	15.37
Support Vessels FPSO shore to Project Area	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69
Helicopters	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
General Project Area (Construction)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**1356**	**1342**	**1495**	**1297**	**1183**	**1182**	**1181**	**1181**	**1297**	**1286**	**1267**	**1305**	**1155**	**1136**

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APPENDIX F

Underwater Sound Modeling Report

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Underwater Sound Assessment for Liza Phase 2 Development Project EIA; Offshore Guyana; Stabroek Block

Submitted to:

Mike Jenkerson
ExxonMobil Exploration Co.
Houston, TX

04 Apr 2018

Request: Assess the applicability of the previously modeled underwater sound levels associated with the Liza Phase 1 Development Project for the Liza Phase 2 Development Project.

In December 2016, JASCO Applied Sciences (JASCO) carried out a modeling study for Esso Exploration and Production Guyana Limited (EEPGL) to predict underwater sound levels associated with the Liza Phase 1 Development Project located within the Stabroek Block (Matthews et al. 2016). New locations for sound sources have recently been proposed as part of the Liza Phase 2 Development Project (Figure 1). The Phase 2 drill centers (DCs) are located within 2 km of the Phase 1 DCs; the Phase 2 Floating Production, Storage, and Offloading (FPSO) vessel is located approximately 8.5 km east of the Phase 1 FPSO vessel. JASCO was asked to assess the need for re-modeling distances to injury and disturbance thresholds for the Phase 2 sound source locations.

The sound footprints for Phase 1 scenarios were modeled to estimate distances to sound level threshold criteria for marine mammals based on:

- Injury, as defined by Southall et al. (2007), Wood et al. (2012), and Finneran (2015). These sound footprints were calculated as frequency-weighted (M-weighted) sound exposure levels (SEL) for 24 hours of operation.
- Behavioral disturbance, as defined by the U.S. National Marine Fisheries Service (HESS 1999, NMFS 2013). These sound footprints were calculated as unweighted sound pressure level (SPL) thresholds of 120 dB re 1 µPa (non-impulsive sources) and 160 dB re 1 µPa (impulsive sources).

We assume that the same criteria would be used in Phase 2 to assess the effects on marine mammals.

We were advised by EEPGL that the planned Phase 2 infrastructure and work activities are similar to those initially modeled for Phase 1, and have thus assumed that the estimated source levels and scenarios described in the Phase 1 work are valid for Phase 2.

In 2016, we modeled sound propagation with JASCO's Marine Operations Noise Model (MONM) and JASCO's Full Waveform Range-dependent Acoustic Model (FWRAM). These models produce depth-, range-, and azimuth-dependent sound fields associated with environmental parameters (including bathymetry, geoacoustic properties, and underwater sound speed profile) that are specific to the Stabroek Block area. At the time, no site-specific information was available for developing geoacoustic properties or sound speed profiles. Thus, generic profiles for the modeled region were developed based on publicly available data (Rucker 1967, Hamilton 1980, Teague et al. 1990, Carnes 2009, Maxon Consulting Inc. 2014). These profile estimates provided conservative sound propagation results within the modeled area, which extended up to 100 km from the Phase 1 FPSO vessel. Because of the relative proximity of the Phase 2 sound source locations to the Phase 1 sound source locations, we consider the Phase 1 profiles to be appropriate estimates of the environmental parameters for the Phase 2 activities.

The main difference between Phase 1 and Phase 2 locations is that there is a nearby area of slightly deeper water northeast of the Phase 2 FPSO (Figure 1). This bathymetric ridge is, however, too far from the Phase 2 FPSO to influence the maximum distances to injury criteria (less than 300 m for all Phase 1 scenarios).

Therefore, based on the proximity of the Phase 1 and Phase 2 sound source locations, the homogeneous environmental properties over a large area that encompasses both the Phase 1 and Phase 2 Project Development Areas, and the similarity in noise-producing activities for the two Phases, we estimate that model results for the Phase 2 scenarios would present little or no changes in the distances to marine mammal injury thresholds provided for Phase 1. A new assessment of underwater sound levels would be recommended if different criteria to assess the effect on marine life are used, new (more site-specific) geoacoustic information is available, or the nature of the Phase 2 operations differ from Phase 1.

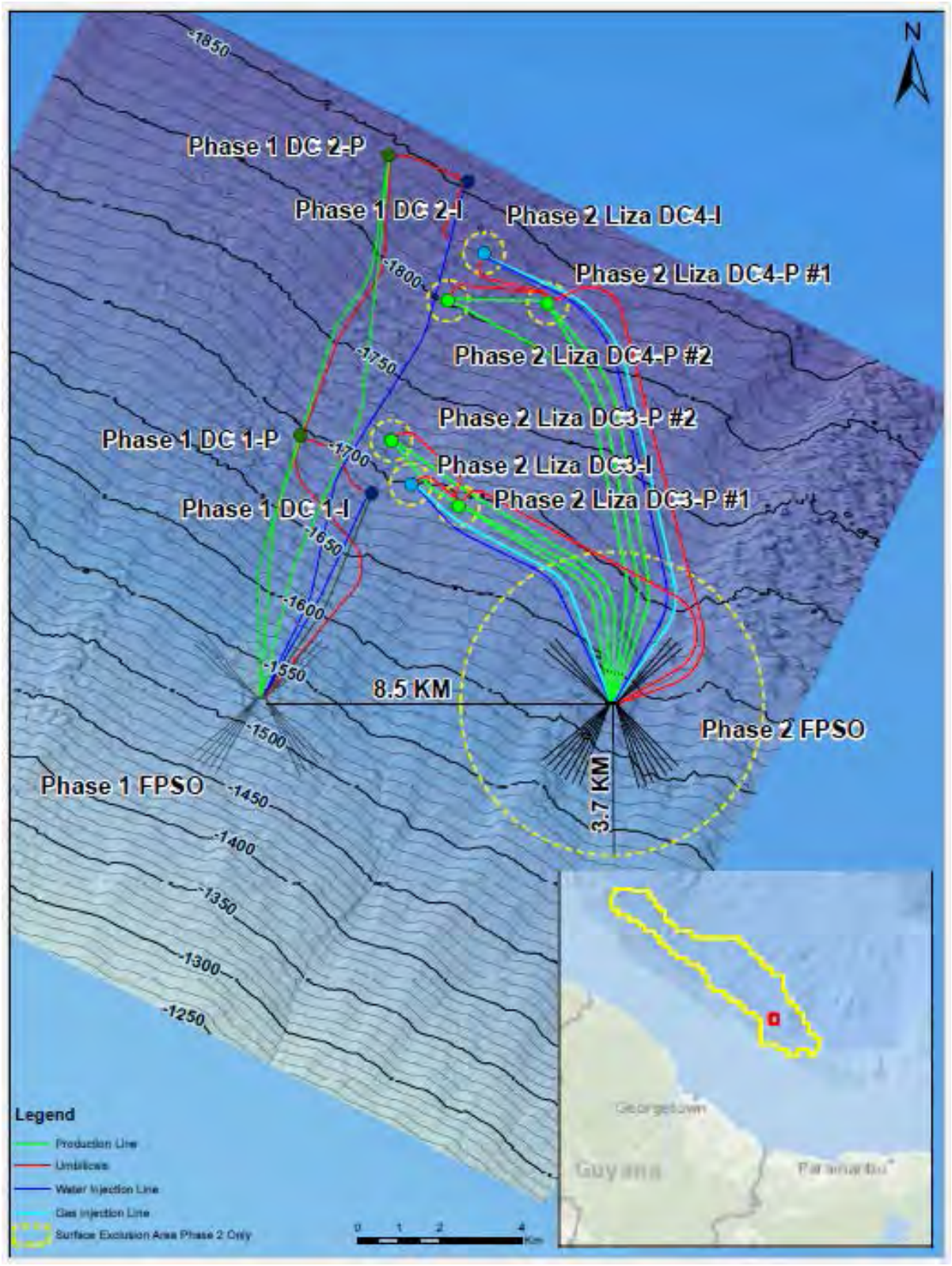


Figure 1. Phase 1 Project layout and proposed Phase 2 Project layout. Figure provided by ERM.

Literature Cited

[HESS] High Energy Seismic Survey. 1999. *High Energy Seismic Survey Review Process and Interim Operational Guidelines for Marine Surveys Offshore Southern California*. Prepared for the California State Lands Commission and the United States Minerals Management Service Pacific Outer Continental Shelf Region by the High Energy Seismic Survey Team, Camarillo, California. 98 pp.

[NMFS] National Marine Fisheries Service. 2013. *Marine Mammals: Interim Sound Threshold Guidance* (webpage). National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. http://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/threshold_guidance.html.

Carnes, M.R. 2009. *Description and Evaluation of GDEM-V 3.0*. Document Number NRL Memorandum Report 7330-09-9165. US Naval Research Laboratory, Stennis Space Center, MS. 21 pp.

Finneran, J.J. 2015. *Auditory weighting functions and TTS/PTS exposure functions for cetaceans and marine carnivores*. San Diego: SSC Pacific.

Hamilton, E.L. 1980. Geoacoustic modeling of the sea floor. *Journal of the Acoustical Society of America* 68(5): 1313-1340.

Matthews, M.-N.R., A. Schlesinger, and I. Gaboury. 2016. *Underwater Sound Associated with Liza Phase 1 Project Activities: Offshore Guyana Stabroek Block*. Document Number 01262. Version 1.0. Technical report by JASCO Applied Sciences for ExxonMobil Exploration Co.

Maxon Consulting Inc. 2014. *Environmental Baseline Study: Guyana Stabroek Block*. Ref. 14024. Prepared by Maxon Consulting, Inc. and TDI Brooks International, Inc. for Esso Exploration and Production Guyana Ltd.

Rucker, J.B. 1967. Paleoecological analysis of cheilostome Bryozoa from Venezuela-British Guiana shelf sediments. *Bulletin of Marine Science* 17(4): 787-839.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammals* 33(4): 411-521.

Teague, W.J., M.J. Carron, and P.J. Hogan. 1990. A comparison between the Generalized Digital Environmental Model and Levitus climatologies. *Journal of Geophysical Research* 95(C5): 7167-7183.

Wood, J., B.L. Southall, and D.J. Tollit. 2012. *PG&E offshore 3 D Seismic Survey Project EIR-Marine Mammal Technical Draft Report*. SMRU Ltd.

Underwater Sound Associated with Liza Phase 1 Project Activities

Offshore Guyana Stabroek Block

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Executive Summary

This underwater sound modeling study predicts underwater sound levels associated with the Liza Phase 1 Development Project (hereinafter referred to as the Project). The Project is designed to develop and produce oil in the ExxonMobil Liza field, located within the Stabroek Block, approximately 190 km offshore central Guyana. The modeled Project activities include drilling development wells, installing and operating a Floating Production Storage and Offloading (FPSO) vessel, and installing Subsea, Umbilical, Riser, and Flowline (SURF) equipment. Sound footprints from representative sound sources, including vessels, a vertical seismic profile (VSP) source, and underwater impact pile driving equipment, were considered. The model results were used to estimate distances to marine mammal injury thresholds, based on best available science.

The underwater sound fields were modeled for water column sound speed profiles representative of April. This time corresponds with lowest surface temperatures, which lead to upward sound refraction and longer-distance sound propagation. The obtained results therefore ensure cautionary estimates of the distances to received sound level thresholds.

Six scenarios were modeled to simulate the following:

1. The operation of a Floating Production Storage and Offloading (FPSO) vessel,
2. The installation of the FPSO vessel, which includes the associated installation and support vessels,
3. The operation of a drill ship and a pipelaying vessel at one of the two drill centers, approximately 13 km north of the FPSO,
4. The operation of a VSP source in the vicinity of the drill centers,
5. Underwater impact pile driving of SURF equipment piles at one of the two drill centers, approximately 13 km north of the FPSO, and
6. Underwater impact pile driving of anchor mooring piles at the FPSO location.

The models produced estimates of the sound fields in M-weighted SEL_{24h} and peak sound pressure levels (PK). The sound fields account for source-specific sound emission characteristics (Section 4.1) and site-specific environmental parameters (Section 4.2). The estimated sound fields are applicable to other locations within the Project area, where site-specific environmental parameters are similar.

For scenarios 1 through 3, the distances to injury thresholds from vessels are small (<10 m). Distances to low- and mid-frequency cetacean injury thresholds for the VSP source were estimated for three sets of acoustic effects criteria. The distances vary from ≤35 m for mid-frequency cetaceans to ≤143 m for low-frequency cetaceans. Distances to the same thresholds for underwater impact pile driving operations are the longer than for the other scenarios. The distances vary from 100 to 762 m for mid-frequency cetaceans and from 1,025 to 1,375 m for low-frequency cetaceans. The sound levels at or above injury thresholds for impact pile driving were found close to the ocean bottom, at depths >1,000 m.

1. Introduction

JASCO Applied Sciences (JASCO) carried out a modeling study for Esso Exploration and Production Guyana Limited (EEPGL) to predict underwater sound levels associated with the Liza Phase 1 Development Project (hereinafter referred to as the Project) located within the Stabroek Block, approximately 190 km offshore central Guyana (Figure 1). The Project activities include installing and operating a Floating Production, Storage, and Offloading (FPSO) vessel, installing and operating Subsea Umbilical, Riser, and Flowline (SURF) equipment, as well as associated development drilling at two drill centers in the Liza field. Each drill center consists of an underwater injection (I) and a production (P) component, tied to the FPSO by the SURF equipment. Installing this Project infrastructure will require the use of multiple vessels, including drill ships, pipelaying vessels, tugs, barges, support, and supply vessels of various sizes. During production operations, the FPSO will be moored. Hydrocarbons produced from the wells will be offloaded onto tankers. This offloading operation may also require the use of tugs, while supply vessels will regularly dock alongside the FPSO.

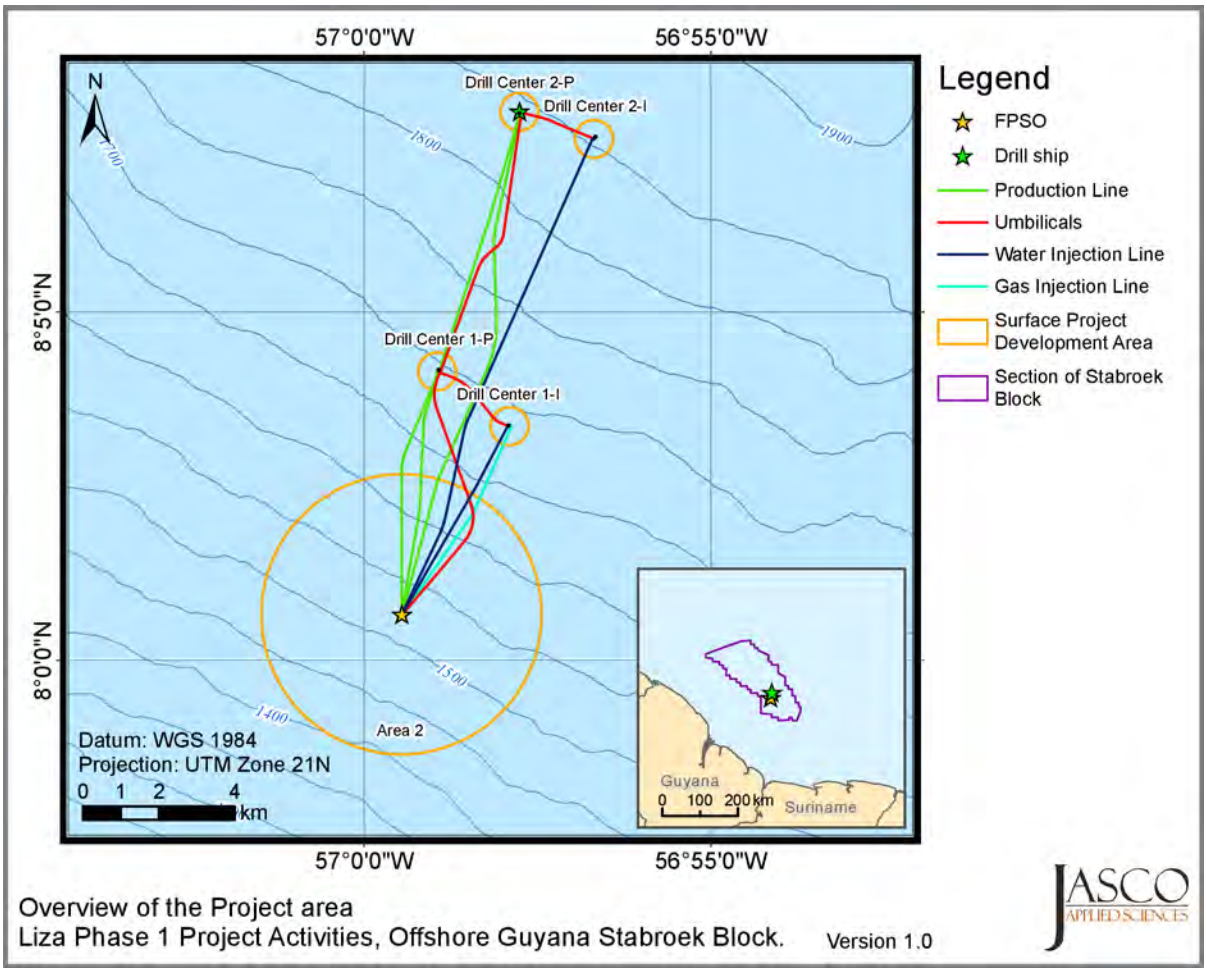


Figure 1. Overview of the Guyana Stabroek project area.

Six scenarios were considered in this modeling study, which include:

1. The operation of an FPSO vessel,
2. The installation of the FPSO vessel, which includes mooring the FPSO, and using several installation and service vessels, and
3. The installation of subsea flowlines and risers and operation of Drill Center 2-P, approximately 13 km north of the FPSO, which includes the operation of a drill ship, a pipelaying vessel, and multiple service vessels,
4. The operation of a VSP source in the vicinity of Drill Centers 2-P and 2-I,
5. The installation of piles for SURF equipment at Drill Center 2-P through underwater impact pile driving, and
6. The installation of anchor mooring piles at the FPSO location through underwater impact pile driving.

The specific vessels, the characteristics of the VSP source, as well as the specifications of the piles and driving hammer are at present unknown. Measurements from surrogate vessels, including the FPSO, drill ship, pipelaying vessel, tugs, and support vessels, were used to derive the acoustic characteristics of the vessels that will likely be used in the operations. The VSP source considered here is a six-element air gun array with a total volume of 1200 in^3. The source pressure signature of this array was modeled with JASCO's Airgun Array Source Model (AASM). This model accounts for individual element volume and position within the array. All modeled piles were 25 m in length, and 5 m in diameter. The modeled impact hammer model is the MENCK 500T, with underwater settings. It was assumed that it will take 5 hours to drive each pile, and that one pile will be driven per 24 hour period. The forcing function transferred from the hammer to the pile was modeled using the GRLWEAP model (GRLWEAP, Pile Dynamics 2010); the sound signature along the pile was modeled using JASCO's pile vibration and near-field sound radiation model (MacGillivray 2014).

Sound propagation was modeled with JASCO's Marine Operations Noise Model (MONM) and JASCO's Full Waveform Range-dependent Acoustic Model (FWRAM). These models produced depth, range, and azimuth dependent sound fields associated with environmental parameters, including bathymetry, that are specific to the Stabroek Block area.

The sound footprint for each scenario was modeled to estimate distances to sound level thresholds based on injurious criteria prescribed by Southall et al. (2007) and Finneran (2015). The sound footprints were calculated as frequency-weighted (M-weighted) sound exposure levels (SEL) for 24 hours of operation.

Section 2 describes the acoustic effect criteria for this study. Definitions of the different metrics associated with the criteria are provided in Appendix A.1. Section 3 discusses the methodology for predicting the source levels and modeling the sound propagation. Section 4 describes the various input parameters pertinent to this study. Section 5 presents the results in two formats: tables of maximum and 95% distances to sound level thresholds and a sound field contour map showing the directivity of the various sound level threshold contours for the VSP source and impact pile driving operations. Section 6 presents an analysis of the results.

1.1. Modeled Scenarios

Various vessels were involved in the first three scenarios, including tugs, supply vessels, and support vessels. At the time of this study, the exact location and description of each vessel were unknown. The modeled scenarios represent an estimate of the general location of each vessel for a 24 hour period; the surrogate vessels provide estimates of the sound emission levels for the proposed vessel fleet. Table 1 and Figures 2–4 list the vessels, their operational state, and their location. Scenario 4 involves a VSP source operating near Drill Center 2-P (Table 1; Figure 4). Scenarios 5 and 6 represent the installation of SURF equipment and FPSO anchor mooring piles using an underwater impact pile driver (Table 1; Figure 5).

Table 1. List of vessels for each modeled scenario. FPSO: Floating Production Storage and Offloading; VSP: Vertical Seismic Profile.

Scenario	Vessel/Source type	Operational state	Location		UTM Coordinates	
			Latitude (°)	Longitude (°)	Easting (m)	Northing (m)
1	FPSO	Moored, not using main engines	8.010982	−56.990920	501000	885512
	Tanker	Idle, held in position by tugs	8.010955	−56.984305	501729	885509
	2 x tugs	Using dynamic positioning	8.010276, 8.011651	−56.987445, −56.987427	501383, 501385	885434, 885586
	Large tug	Using dynamic positioning	8.010955	−56.983479	501820	885509
	Supply vessel	Using dynamic positioning	8.011326	−56.991873	500895	885550
2	FPSO	Using main engine	8.010982	−56.990920	501000	885512
	2 x FPSO supply barges	Using dynamic positioning	8.000010, 8.010665	−56.991447, −56.991719	500942, 500912	884299, 885477
	2 x tugs	Using dynamic positioning	8.010213, 8.000769	−56.991447, −56.991447	500942, 500942	885427, 884383
	FPSO major work vessel	Using dynamic positioning	8.010629	−56.989732	501131	885473
	2 x supply vessels	Using dynamic positioning	8.011326, 7.993162	−56.991873, −56.983788	500895, 501786	885550, 883542
	3 x support vessels	Using dynamic positioning	8.011724, 7.989020, 8.010286	−56.989187, −56.996910, −56.989586	501191, 500340, 501147	885594, 883084, 885435
	Fast supply vessel	Using dynamic positioning	8.010673	−56.969304	503382	885478
	Light construction vessel	Using dynamic positioning	8.011299	−56.989777	501126	885547
3	Drill ship	Drilling and maintenance work	8.131187	−56.962605	504119	898801
	Large crane vessel	Using dynamic positioning	8.130906	−56.963123	504062	898770
	Light construction vessel	Using dynamic positioning	8.131431	−56.963277	504045	898828
	Multiple service vessel	Using dynamic positioning	8.134623	−56.958293	504594	899181
	Pipelaying vessel	Laying pipe	8.117347	−56.964095	503955	897271
	2 x barges	Towed by tugs	8.117428, 8.101734	−56.963841, −56.962799	503983, 504098	897280, 895545
	2 x tugs	Using dynamic positioning	8.117546, 8.102494	−56.963705, −56.962798	503998, 504098	897293, 895629
	2 x supply vessels	Using dynamic positioning	8.130734, 8.117799	−56.963059, −56.964268	504069, 503936	898751, 897321
	3 x support vessels	Using dynamic positioning	8.134479, 8.114625, 8.141861	−56.966644, −56.968507, −56.975277	503674, 503469, 502723	899165, 896970, 899981
	Field intervention vessel	Using dynamic positioning	8.141768	−56.949605	505551	899971
4	VSP source	Up to 40 pulses in 24 hours	8.128535	−56.953837	505085	898508
	VPS support vessel	Using dynamic positioning; deploying the VSP source	8.128535	−56.953837	505085	898508
5	Underwater impact pile driving	Driving SURF equipment piles at Drill Center 2-P	8.131187	−56.962605	504119	898801
6	Underwater impact pile driving	Driving FPSO anchor mooring piles at the FPSO	8.010982	−56.990920	501000	885512

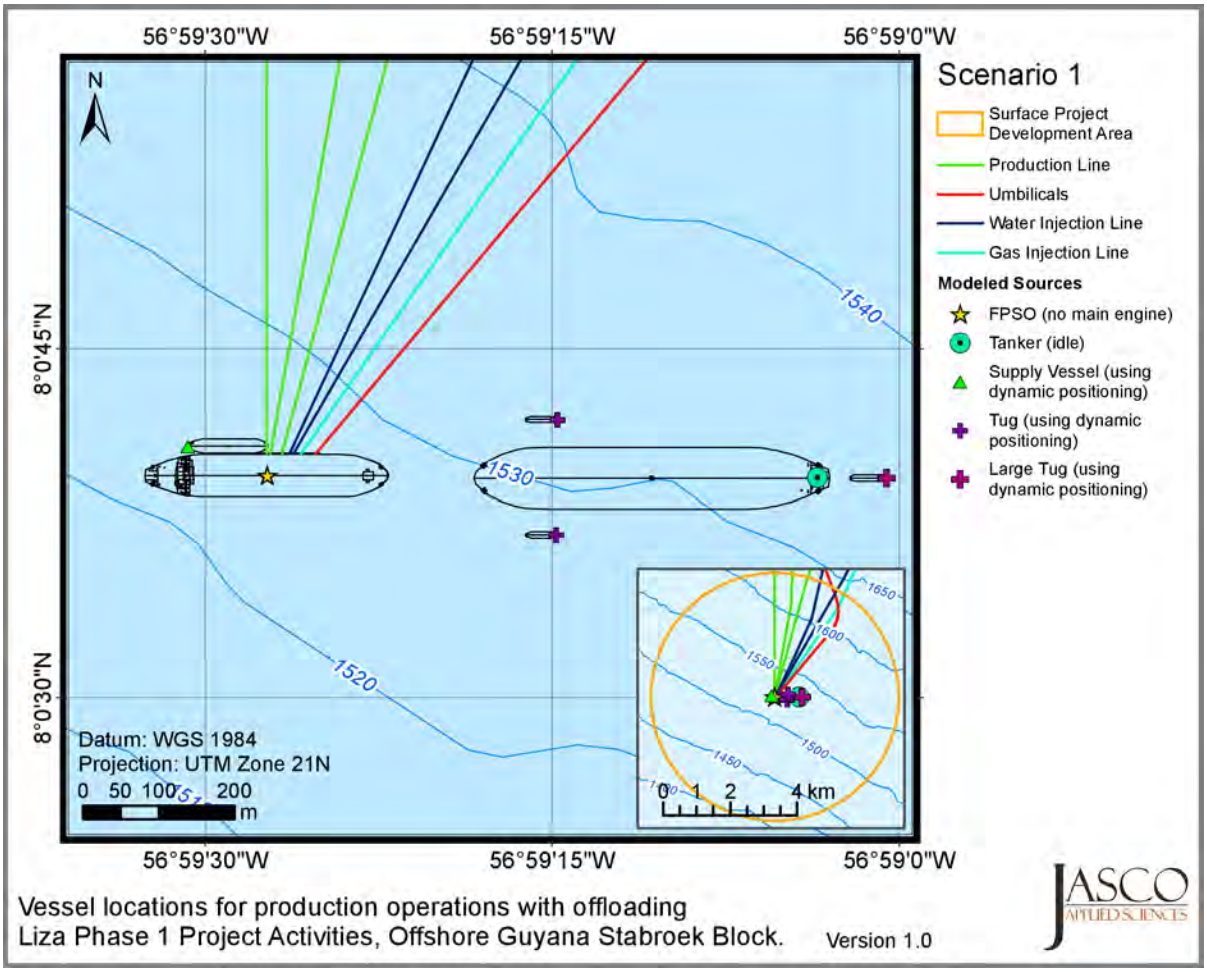


Figure 2. Scenario 1: Location of modeled vessels.

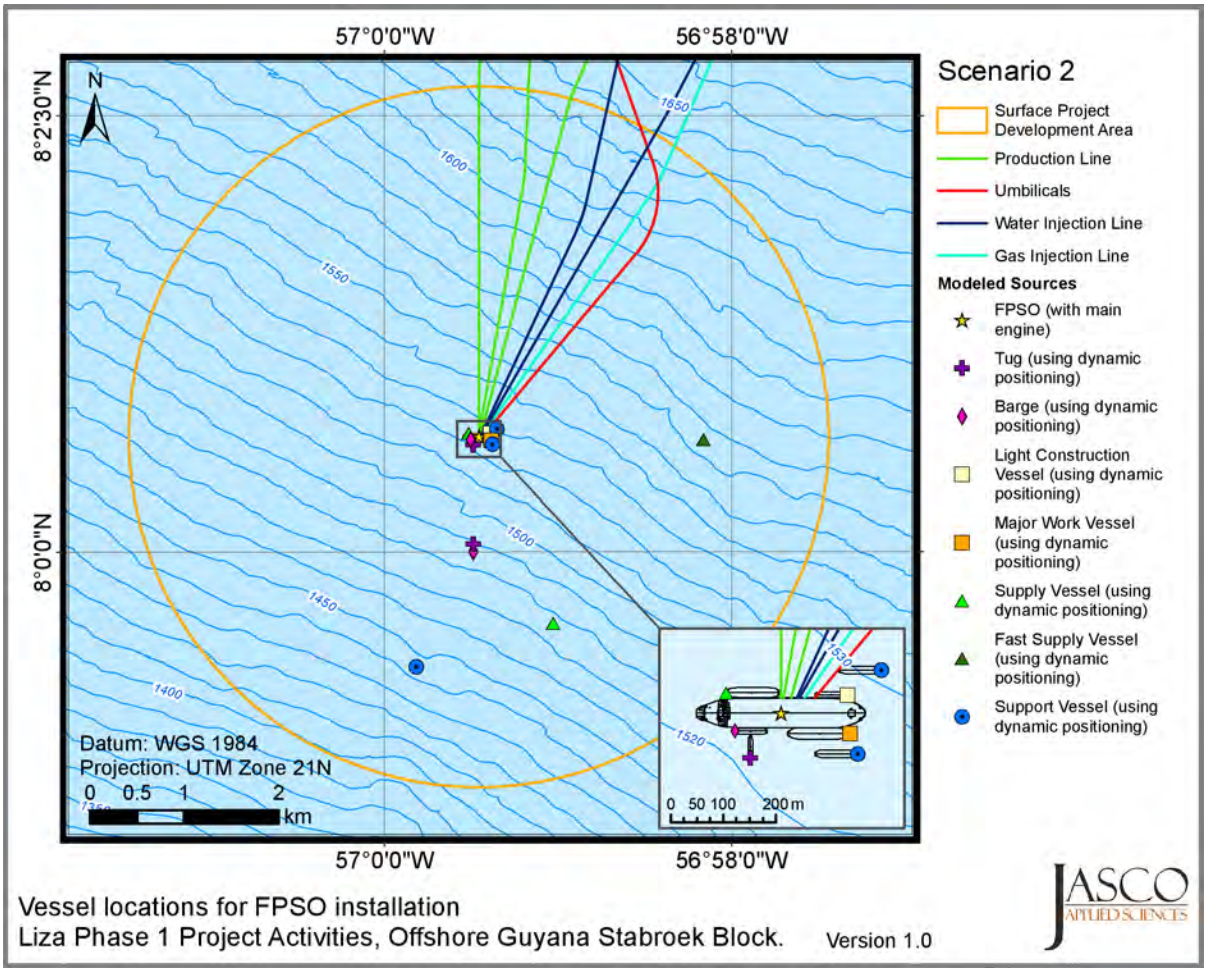


Figure 3. Scenario 2: Location of modeled vessels.

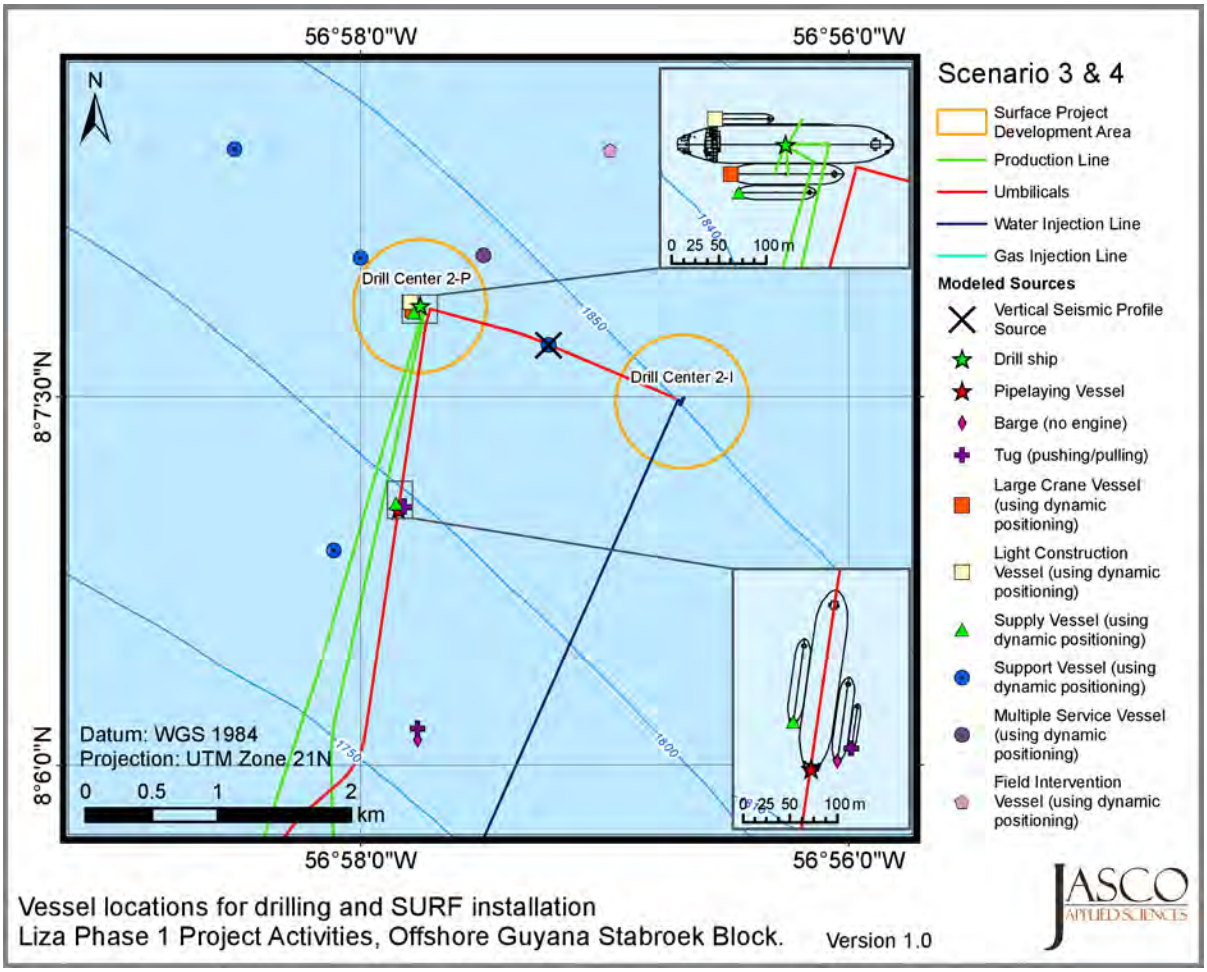


Figure 4. Scenarios 3 and 4: Location of modeled vessels and the VSP source at Drill Center 2.

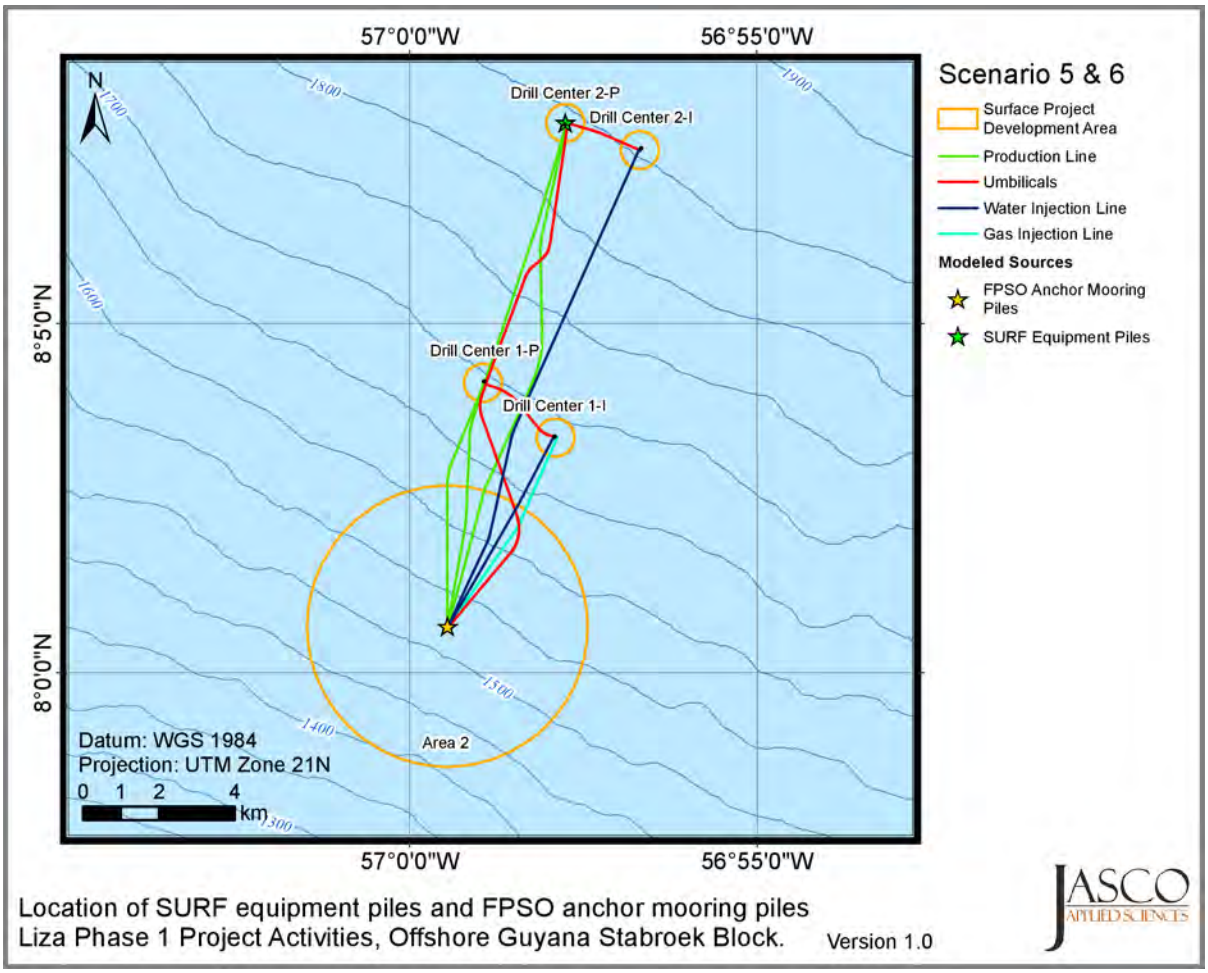


Figure 5. Scenarios 5 and 6: Location of modeled underwater impact pile driving operations at Drill Center 2-P and the FPSO (Area 2).

2. Acoustic Effects Criteria

Underwater sound can affect marine fauna in various ways. The question of which acoustic exposure levels might cause injury to marine mammals is still an active research. Since 2007, several expert groups have investigated SEL and peak pressure-based assessment approaches for injury using methods similar to those applied for humans, and a few key papers have been published on the topic. Those publications are reviewed, and the relative criteria discussed, in Appendix A.2. In the present section we propose specific thresholds used in other recent studies that are the most likely candidates for more widespread use; we caution readers, however, that assessment criteria are likely to evolve in the near future as research is progressing rapidly in this field.

Results of this modeling study are presented in terms M-weighted sound exposure level (SEL; $L_{E,24h}$) and peak pressure level (PK; L_{pk}) thresholds for injury to low- and mid-frequency cetaceans, based on two sets of criteria (Table 2): Southall et al. (2007) and Finneran (2015). These criteria have been chosen to include standard thresholds and thresholds suggested by the best available science, as reviewed and discussed in Appendix A.2. Low-frequency cetaceans, including baleen whales, and mid-frequency cetaceans, including dolphins and small whales, have been observed within or near the Project area. This study therefore focuses only on these marine mammal hearing groups.

Table 2. Marine mammal injury (Permanent Threshold Shift (PTS) onset) thresholds based on Southall et al. (2007), and Finneran (2015). PK and SPL in dB re 1 µPa; weighted SEL (24 hours) in dB re 1 µPa²·s.

Hearing group	Impulsive source				Non-impulsive source		
	Southall et al. (2007)		Finneran (2015)		Southall et al. (2007)		Finneran (2015)
	PK	Weighted SEL_{24h}	PK	Weighted SEL_{24h}	PK	Weighted SEL_{24h}	Weighted SEL_{24h}
Low-frequency cetaceans	230	198	230	192	230	215	207
Mid-frequency cetaceans	230	198	230	187	230	215	199

3. Methods

Underwater acoustic field for the studied vessels were modeled using JASCO's Marine Operations Noise Model (MONM), which is based on source levels derived from measurements of surrogate vessels.

Three complementary acoustic models were used to predict the underwater acoustic field for the studied seismic source. The pressure signatures and directional source levels of the VSP source were predicted with JASCO's Air gun Array Source Model (AASM). The acoustic fields around the array, in terms of M-weighted SEL_{24h}, were modeled with MONM. JASCO's Full Waveform Range-dependent Acoustic Model (FWRAM) was used to determine peak pressure levels as a function of azimuth, depth, and range from the array.

The acoustic source signature for impact pile driving operations was modeled using JASCO's physical model of pile vibration and near-field sound radiation (MacGillivray 2014), in conjunction with the GRLWEAP 2010 wave equation model (GRLWEAP, Pile Dynamics 2010). The acoustic fields, in terms of M-weighted SEL_{24h} and peak pressure levels, were modeled with JASCO's FWRAM.

M-weighting was applied for two hearing groups to weight the importance of received sound levels according to their constituent frequencies.

3.1. Modeling Acoustic Source Levels

3.1.1. Vessels

Several types of vessels were modeled in this study, including an FPSO, a drill ship, a pipelaying vessel, tugs, barges, supply vessels, and support vessels. The vessels characteristics are presented in Section 4.1.1. Underwater sound that radiates from vessels is produced mainly by propeller and thruster cavitation (Ross 1976, §8.6), with a small fraction produced by sound transmitted through the hull, such as sound from engines, gearing, and other mechanical systems (Spence et al. 2007). Sound levels thus tend to be the highest when propulsion systems are used at high power. For example, during dynamic positioning in high currents or winds, or transiting at high speeds. A vessel's sound signature depends on the vessel's size, power output, and propulsion system characteristics (e.g., blade shape and size). Vessels produce broadband acoustic energy with most of the energy emitted below a few kilohertz. Sound from onboard machinery, particularly sound below 200 Hz, dominates the sound spectrum before cavitation begins—normally around 8 to 12 knots on many commercial vessels (Spence et al. 2007).

At the time of this study, the specific vessels engaged in installing and operating at the drill centers were unknown. Generalized source spectra were computed by comparing the expected specifications of the vessels to that of surrogate vessels for which source levels were available. Source levels for the surrogate were derived from measured received levels during various operational states. To account for the differences between the specification of the modeled and surrogate vessels, the spectra of the surrogates were corrected by the power ratings of the modeled and reference vessels:

$$S(f,P) = S_0(f) + 10\log\left(\frac{P}{P_0}\right) \quad (1)$$

where S_0 is the reference spectrum and P_0 is the reference power rating (Ross 1976, §8.6). When needed, surrogate spectra were extrapolated using −2 dB per decade at frequencies below 100 Hz and −1 dB per decade at frequencies above 1000 Hz (Ross 1976, §8.6).

3.1.2. Vertical Seismic Profile Source

The VSP source considered here is a six-element air gun array with a 1200 in^3 total volume. The source characteristics are presented in Section 4.1.2. The source levels and directivity of the VSP array were predicted with JASCO's Air gun Array Source Model (AASM; MacGillivray 2006a). This model is based on the physics of oscillation and radiation of air gun bubbles described by Ziolkowski (1970). The model solves the set of parallel differential equations that govern bubble oscillations. AASM also accounts for nonlinear pressure interactions between air guns, port throttling, bubble damping, and generator-injector (GI) gun behavior that are discussed by Dragoset (1984), Laws et al. (1990), and Landro (1992). AASM includes four empirical parameters that were tuned so model output matches observed air gun behavior. The model parameters fit to a large library of empirical data using a "simulated annealing" global optimization algorithm. These data are measurements of the signatures of Bolt 600/B guns ranging in volume from 5 to 185 in^3 (Racca and Scrimger 1986).

While air gun signatures are highly repeatable at low frequencies, which are used for seismic imaging, at higher frequencies their sound emissions have a large random component that cannot be predicted using a deterministic model. Therefore, AASM uses a stochastic simulation to predict the high-frequency (560−25,000 Hz) sound emissions of individual air guns, using a data-driven multiple-regression model. The multiple-regression model is based on a statistical analysis of a large collection of high quality seismic source signature data recently obtained from the Joint Industry Program (JIP) on Sound and Marine Life (Mattsson and Jenkerson 2008). The stochastic model uses a Monte-Carlo simulation to simulate the random component of the high-frequency spectrum of each element in an array. The mean high-frequency spectra from the stochastic model augment the low-frequency signatures from the physical model, allowing AASM to predict source levels at frequencies up to 25,000 Hz.

AASM produces a set of "notional" signatures for each array element based on:

- Array layout
- Volume, tow depth, and firing pressure of each air gun
- Interactions between different elements in the array

These notional signatures are the pressure waveforms of the individual elements at a standard reference distance of 1 m; they account for the interactions with the other elements in the array. The signatures are summed with the appropriate phase delays to obtain the far-field source signature of the entire array in all directions. This far-field array signature is filtered into 1/3-octave-bands to compute the source levels of the array as a function of frequency band and azimuthal angle in the horizontal plane (at the source depth), after which it is considered to be a directional point source in the far field.

A seismic array consists of many sources and the point-source assumption is invalid in the near field where the array elements add incoherently. The maximum extent of the near field of an array (R_{nf}) is:

$$R_{nf} < \frac{l^2}{4\lambda} \tag{1}$$

where λ is the sound wavelength and l is the longest dimension of the array (Lurton 2002, §5.2.4). For example, an array length of l = 2 m yields a near-field range of 1.5 m at 2 kHz. Beyond this R_{nf} range, the array is assumed to radiate like a directional point source and is treated as such for propagation modeling.

The interactions between individual elements of the array create directionality in the overall acoustic emission. Generally, this directionality is prominent mainly at frequencies in the mid-range between tens of hertz to several hundred hertz. At lower frequencies, with acoustic wavelengths much larger than the separation distances between array elements, the directionality is small. At higher frequencies, the pattern of lobes is too finely spaced to be resolved and the effective directivity is less.

3.1.3. Impact Pile Driving

A physical model of pile vibration and near-field sound radiation is used to calculate source levels of piles. The physical model employed in this study computes the underwater vibration and sound radiation of a pile by solving the theoretical equations of motion for axial and radial vibrations of a cylindrical shell. These equations of motion are solved subject to boundary conditions, which describe the forcing function of the hammer at the top of the pile and the soil resistance at the base of the pile (Figure 6). Damping of the pile vibration due to radiation loading is computed for Mach waves emanating from the pile wall. The equations of motion are discretised using the finite difference (FD) method and are solved on a discrete time and depth mesh.

In order to model the sound emissions of the piles, it was also necessary to model the force of the pile driving hammers. The force at the top of the pile was computed using the GRLWEAP 2010 wave equation model (GRLWEAP, Pile Dynamics 2010), which includes a large database of simulated hammers—both impact and vibratory—based on the manufacturer's specifications. The forcing functions from GRLWEAP were used as inputs to the FD model to compute the resulting pile vibrations.

The sound radiating from the pile itself is simulated using a vertical array of discrete point sources. The point sources are centered on the pile axis. Their amplitudes are derived using an inverse technique, such that their collective particle velocity—calculated using a near-field wave-number integration model—matches the particle velocity in the water at the pile wall. The sound field propagating away from the vertical source array is then calculated using a time-domain acoustic propagation model (e.g., FWRAM; Appendix A.5.3). MacGillivray (2014) describes the theory behind the physical model in more detail.

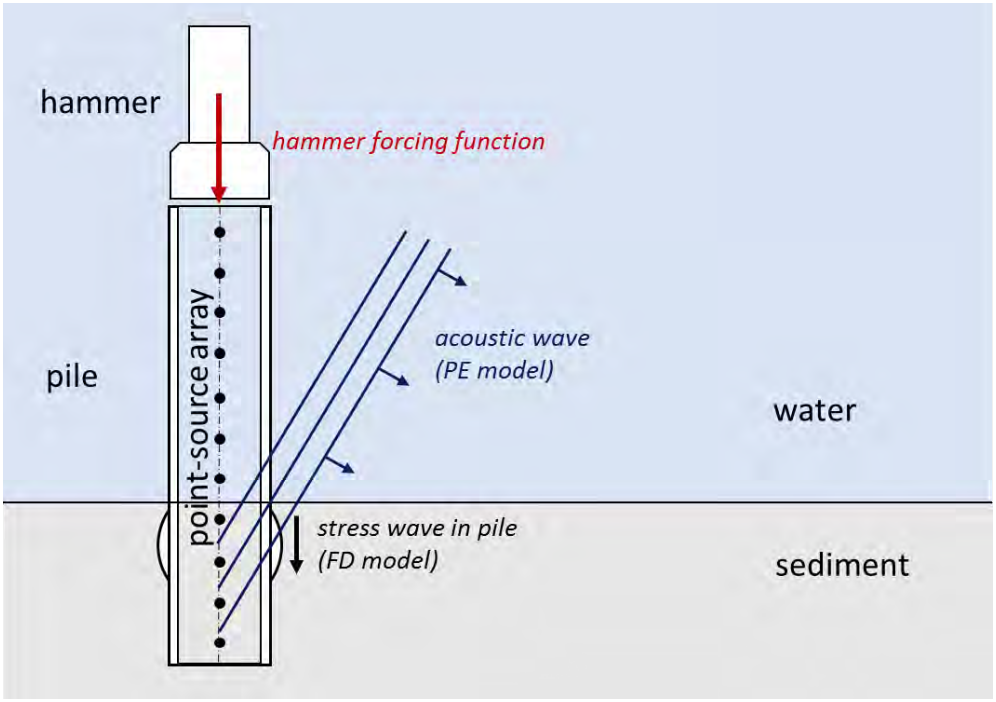


Figure 6. Physical model geometry for impact driving of a cylindrical pile (vertical cross-section). The hammer forcing function is used with the finite difference (FD) model to compute the stress wave vibration in the pile. A vertical array of point sources is used with the parabolic equation (PE) model to compute the acoustic waves that the pile wall radiates.

3.2. Modeling Sound Propagation

Underwater sound propagation (i.e., transmission loss) for the vessels and the VSP source exposure levels was predicted with JASCO's MONM (see Appendix A.5.2). The model computes received SEL (per-pulse SEL for impulsive sources) for directional sources located at a specified depth. It incorporates site-specific environmental properties including a bathymetric grid of the modeled area, in-water sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor. The model computes acoustic fields in three dimensions by modeling transmission loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source.

MONM treats frequency dependence by computing acoustic transmission loss at the center frequencies of 1/3-octave-bands. Sufficiently many 1/3-octave-bands, from 10 Hz to 32 kHz, are modeled to include the majority of acoustic energy emitted by the source. Sound propagation at frequencies from 5 to 32 kHz was modeled by modifying the transmission loss at 5 kHz with the frequency- and range-dependent absorption coefficient for sea water (François and Garrison 1982a). Although mostly insignificant at lower frequencies, absorption coefficients were also applied from 10 Hz to 5 kHz for consistency. The broadband underwater sound field, expressed in terms of M-weighted per-pulse SEL, was computed by filtering and summing the received 1/3-octave-band levels.

JASCO's FWRAM (see Appendix A.5.3) was used to determine peak pressure levels from the VSP source and per-pulse SEL from pile driving operations. FWRAM uses the same computational algorithm as MONM, but computes pressure waveforms via Fourier synthesis of the modeled acoustic transfer function in closely spaced frequency bands. FWRAM employs the array starter method to accurately model sound propagation from a spatially distributed source such as an underwater pile (MacGillivray and Chapman 2012).

The parabolic equation (PE) approximation used in FWRAM (Appendix A.5.3) is valid for sound propagating within a vertical angle range of at least 45° above and below the horizontal plane at the source depth (the exact angle depends on the environment). In the case of underwater impact pile driving, where the pile extends only over a fraction of the water column, the received levels above the pile (propagating at a >45° angle from the horizontal plane) may be underestimated using this model. The main acoustic waves around the pile propagate, however, at an angle of ~17° from the horizontal plane (Reinhall and Dahl 2011). FWRAM therefore provides a valid estimate of the distances to injury thresholds, which occur well within the PE approximation angle.

This approach, combined with the pile driving source model, accurately estimates spectral levels within the 10–800 Hz band where most of the energy from impact pile driving is concentrated. An extrapolation method (Zykov et al. 2016) was used to extend the modeled levels in 1/3-octave-bands up to 25 kHz, by applying a −2 dB per 1/3-octave-band roll-off coefficient to the per-pulse SEL value starting at the 800 Hz band. The acoustic energy levels at these higher frequencies are required to correctly assess the acoustic fields against Finneran (2015) criteria. The broadband underwater sound field, expressed in terms of M-weighted per-pulse SEL, was computed by filtering and summing the received 1/3-octave-band levels.

The injury thresholds evaluated here account for the total acoustic energy a marine mammal is subjected to within a defined period (24 hours in the present case). In the present study, the M-weighted SEL_{24h} were obtained by assuming a stationary scenario. With this simplified approach the acoustic energy (SEL) for 1 sec (for non-impulsive sources) or a single pulse (for impulsive sources) at a particular location was replicated in situ to estimate the cumulative metric. For a given number (N) of source activity seconds or of acoustic pulse events over a 24-hour period, SEL_{24h} was thus computed using the basic formula:

$$\mathrm{SEL}_{24h} = \mathrm{SEL} + 10\log_{10}(N) \,. \qquad (2)$$

By assuming stationary sources, the method provides conservative estimates of the maximum extent of each sound level isopleth. This approach also yields notional values that are not strongly dependent on the environment or on the position of each source, which simplifies comparisons between different source types and acoustic effect criteria.

Although a more complex analysis would be outside the scope of this study, an important consideration that qualifies the cumulative received level estimates is that individuals of most species do not remain stationary throughout the exposure period. Their dose accumulation, therefore, depends on their movement and would likely be lower than for a stationary receiver. A second issue is that animals tend to recover from the sub-injurious effects of sound exposure over time; the paradigm of a strictly dosimetric accumulation is not therefore altogether correct, but the recovery period of most species is unknown.

3.3. Calculating Distances to Acoustic Effect Thresholds

The underwater sound fields predicted by the propagation models were sampled so that the received sound level at each location in the horizontal plane was taken to be the maximum value over all modeled depths for that location. Two distances from the source are reported for each sound level: 1) R_{max}, the maximum range at which the given sound level was encountered in the modeled maximum-over-depth sound field over all azimuths, and 2) $R_{95\%}$, the maximum range at which the given sound level was encountered after the 5% farthest such points were excluded (Figure 7). The $R_{95\%}$ is used because the maximum-over-depth sound field footprint is often non-circular and can include anomalous protrusions along a few azimuths. Regardless of the geometric shape of the maximum-over-depth footprint, $R_{95\%}$ is the predicted range encompassing at least 95% of the area (in the horizontal plane) that would be exposed to sound at or above that level. The difference between R_{max} and $R_{95\%}$ depends on the source directivity and the heterogeneity of the acoustic environment. The $R_{95\%}$ excludes ends of protruding areas or small isolated acoustic foci not representative of the nominal ensonification zone.

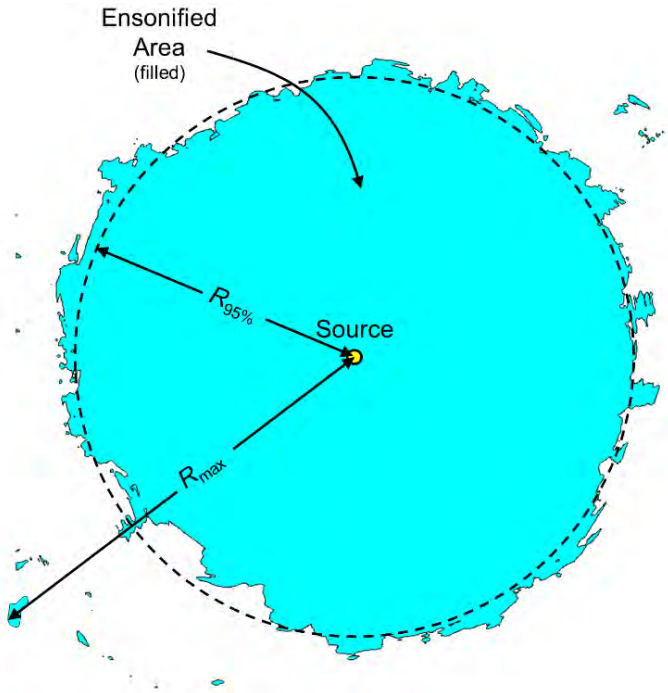


Figure 7. Example of an area ensonified to an arbitrary sound level showing R_{max} and $R_{95\%}$ radii.

4. Model Parameters

4.1. Acoustic Source Parameters

4.1.1. Vessels

A surrogate source vessel was chosen to represent each of the proposed vessels modeled in this study (Table 3). For vessels where the surrogate was significantly different in length, width, draft, or power, the surrogate's spectrum was adjusted based on the ratio of available power between the proposed and surrogate vessel (Section 3.1.1).

In Scenario 1 (Table 1; Figure 2), three tugs held the tanker in position (i.e., the tanker's main engine and propulsion system were idling or off). Thus, the sound levels from the tanker were neglected in the modeled scenario because they will be significantly lower (by at least 10 dB) than sounds from the tugs.

In Scenario 2 (Table 1; Figure 3), sound levels from the fast supply vessel, a small craft approximately 19 m long with a draft of less than 1 m, were also expected to be significantly lower (~150 dB re 1 µPa @ 1 m; Funk et al. 2008 §3.7) than sound levels from the adjacent vessels. This vessel was excluded from the modeled scenario.

The specific characteristics of the Floating Production Storage and Offloading (FPSO) that will be used in this project are unknown at present. The spectra used in Scenarios 1 and 2 were derived from the recordings of six FPSOs during various operational stages (Erbe et al. 2013). In Scenario 1, the FPSO was expected to be moored and operating; its spectrum was modeled using the 5th percentile 1/3-octave-band spectrum derived from all the FPSO source spectra recorded. In Scenario 2, tugs positioned the FPSO during installation and mooring. Such operations were expected to be noisier than in Scenario 1; the FPSO spectrum was modeled using the 95th percentile 1/3-octave-band spectrum derived from all the source spectra recorded.

Since the tugs in each scenario will be engaged in various activities (e.g., transiting at various speed, pulling and pushing vessels, handling cables and anchors), the spectra of the surrogate tug, recorded during transit at half and full speed and during anchor pulling, were averaged to produce a mean 1/3-octave-band spectrum.

The source depth for vessels other than the drill ship was based on the depth at which cavitation from the propulsion system was expected to occur. Gray and Greenley (1980) estimate that the center of the cavitation volume occurs below the propeller blade arc, by an amount equal to ~15% of the propeller diameter. The modeled source depth was estimated by:

$$Z_s = D - 0.85 \times \phi_{prop} \tag{3}$$

where Z_s is the source depth, D is the depth at the bottom of the propeller (often equal to the draft) of the proposed vessel, and $\varnothing_{\text{prop}}$ is the diameter of its propeller.

During drilling operations, sound will be generated at many locations along the drill shaft. For the purpose of this study, the sound was assumed to be concentrated at the top of the drill shaft; the source depth was equal to the operational draft of the drill ship (12 m).

Table 3. Specifications of proposed and surrogate vessels used to estimate source levels.

Vessel type	Proposed vessel								Surrogate vessel							
	Name	Length (m)	Breadth (m)	Draft (m)	Max. power (kW)	Bollard pull (t)	Main propulsion	Propeller diameter (m)	Name	Length (m)	Breadth (m)	Draft (m)	Max. power (kW)	Bollard pull (t)	Main propulsion	Reference
FPSO	Unknown	Unknown	Unknown	Unknown, assumed 10 and 16	Unknown	n/a	Unknown	Unknown, assumed 5.5	Average between	209–340	Unknown	10.8–16	n/a	n/a	n/a	Erbe et al. (2013)
FPSO major work vessel	*Normand Installer*	124	28	7.3	31360	n/a	4 x tunnel thrusters, 1 x retractable azimuth thruster, 2 x controllable pitch propellers in nozzles	4.5	DSV *Fu Lai*	107.1	19.4	Unknown	7400	56	4 x thrusters, 2 x controllable pitch propellers	MacGillivray (2006b)
FPSO supply barge	*Hannah Chouest*	85	18	6	7200	n/a	Unknown	Unknown, assumed 3.2								
Supply vessel																
Support vessel																
Light construction vessel	MEO *Ranger*	64	16	5.4	5000	n/a	2 x tunnel thrusters, 2 x Z-drive propeller	2.7								
Field intervention vessel																
Large crane vessel	*Normand Installer*	124	28	7.3	31360	n/a	4 x tunnel thrusters, 1 x retractable azimuth thruster, 2 x controllable pitch propellers in nozzles	4.5								
Multiple service vessel	*7 Pacific*	134	24	6.75	17300	n/a	3 x stern azimuth thrusters, 1 x retractable bow azimuth thruster, 2 x bow tunnel thrusters	3.2								
Tug	Unknown	Unknown	Unknown	Unknown, assumed 5.5	Unknown	80	Azimuth stern drive	Unknown, assumed 3.2	*Britoil 51*	45	12	5.5	6600	90	2 x fixed pitch nozzeled propellers	Hannay et al. (2004)
Tug (large)	Unknown	Unknown	Unknown	Unknown, assumed 5.4	Unknown	120	Azimuth stern drive	Unknown, assumed 3.2	*Britoil 61*	51	13	5.4	10500	130	2 x controllable pitch nozzeled propellers	Adjusted from *Britoil 51* based on power
Drill ship	*Stenna Carron*	228	42	12	Unknown	n/a	6 x thrusters	n/a	*Stena Forth*	228	41	12	1750	n/a	6 x thrusters	Kyhn et al. (2009)
Pipelaying vessel	*7 Borealis*	182	46	8.5–11.35	45622	n/a	4 x azimuth thrusters, 1 x tunnel thruster	3	*Castoro*	191	35	10	Unknown	n/a	2 x variable pitch propellers, 1 x bow thruster	MacGillivray (2006b)

4.1.2. Vertical Seismic Profile Source

The Schlumberger High-performance Magnum six-gun array (1200 in³ total volume) was modeled as a surrogate VSP source in Scenario 4. The array consists of two vertically-triangular air gun clusters with in-line separations of 2 m. The first cluster has three 150 in³ elements with 0.9 m separation, the second cluster has three 250 in³ elements with a 1.1 m separation. In both clusters, the center air gun is shallower. The elements are fired simultaneously at 2000 psi air pressure. The array was modeled at a 4.5 m depth (the center of the clusters). It is estimated that the VSP source will produce 20–40 pulses within 6–12 hours of operation. Figure 8 illustrates the element distribution in the horizontal (*x*-*y*) plane, and Table 4 shows the array specifications.

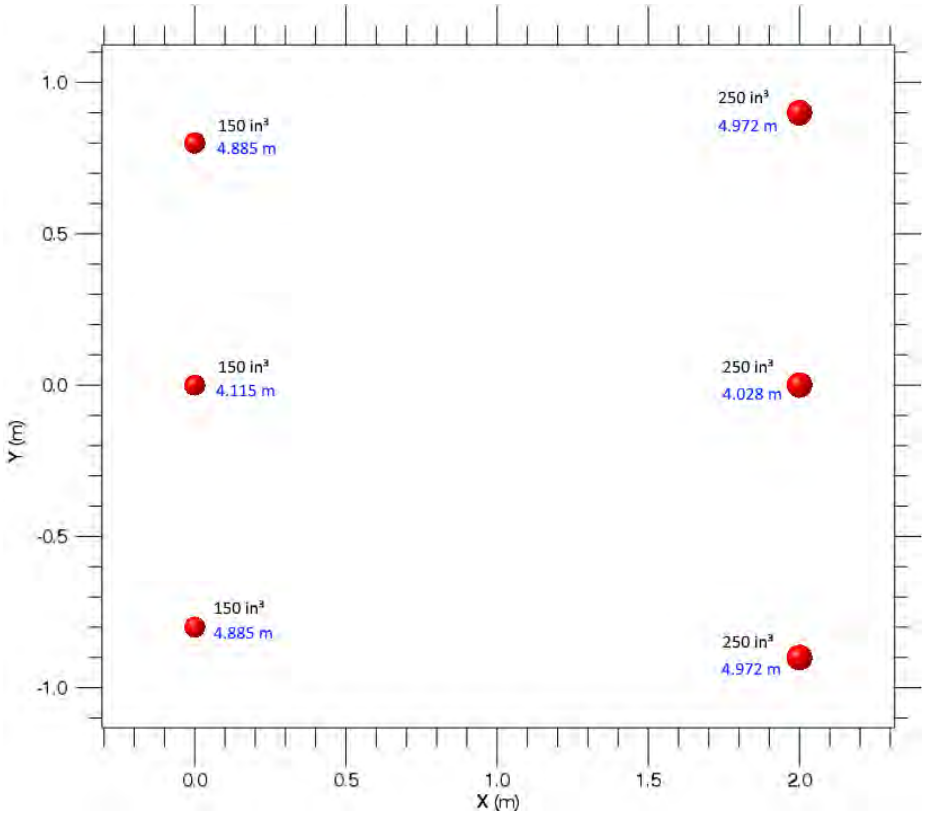


Figure 8. Layout of the High-performance Magnum six-gun array (1200 in³ total volume, 4.5 m depth), composed of 6 elements. Black labels indicate element volume in cubic inches; blue labels indicate the depth of the element relative to the sea surface.

Table 4. Relative positions of the elements within the 1200 in^3 array.

Element	*x* (m)	*y* (m)	*z* (m)	Volume (in^3)
1	0.0	0.000	4.115	150
2	0.0	−0.445	4.885	150
3	0.0	0.445	4.885	150
4	−2.0	0.000	4.028	250
5	−2.0	−0.545	4.972	250
6	−2.0	−0.545	4.972	250

4.1.3. Impact Pile Driving

Impact pile driving of cylindrical steel piles was modeled at two locations (Scenarios 5 and 6; Table 1). At both locations, the water depth was much deeper (1524.4 m and 1842.7 m) than the length of the pile (25 m long; 5 m in diameter). The MENCK 500T underwater hammer was used as the impact pile driver. A generic pile helmet, with a weight 1/5 that of the hammer (Parola 1970), was assumed with the default parameters of the hammer in the GRLWEAP 2010 wave equation model.

Information on the penetration rate per blow was unknown at the time of this study. The maximum number of strikes per minute (38) for the modeled hammer was assumed over a driving period of 5 hours. One driving period was assumed to occur every 24 hours.

4.2. Environmental Parameters

4.2.1. Bathymetry

Bathymetry data, covering an area of approximately 23 × 21 km centered on the modeled sites, was provided by EEPGL. For the long-range modeling (up to 100 km from the FPSO and the drill ship), this grid was extended using data from SRTM15+ (v1.0; Becker et al. 2009, Sandwell et al. 2014) global bathymetry grid, with a resolution of 30 arc-seconds (~460 × 460 m at the studied latitude), to produce a 150 × 150 km region. The data were re-gridded, by minimum curvature gridding, onto a Universal Transverse Mercator (UTM) Zone 21 coordinate projection with a regular grid spacing of 100 × 100 m.

4.2.2. Geoacoustics

The geoacoustic properties of surficial seabed layers depend on the sediment type. As the porosity decreases, the compressional sound speed, sediment bulk density, and compressional attenuation increase. For each modeled location, MONM assumes a single geoacoustic profile of the seafloor for the entire modeled area. The acoustic properties required by MONM are:

- Sediment bulk density,
- Compressional-wave (or P-wave) speed,
- P-wave attenuation in decibels per wavelength,
- Shear-wave (or S-wave) speed, and
- S-wave attenuation, also in decibels per wavelength.

Along the Guyana coast, suspended Amazonian sediments and fluvial mud from various Guyana rivers are transported eastward with the Guiana Current. This large volume of sediment deposition results in a thick (estimated up to 30 m; Rucker 1967) and fairly uniform layer of fine-grained sediment (Maxon

Consulting Inc. 2014). This surficial sediment layer, also characterized by a low concentration of organic carbon (Maxon Consulting Inc. 2014), overlays a mixture of sand and clay ~30–100 m thick (Rucker 1967).

The estimated geoacoustic profile (Table 5) was based on empirical formulas presented by Hamilton (1980). Without information from recent boreholes, a generic geoacoustic profile for silt-clay sediments was used with a 1.3 m/s per meters below the seafloor (mbsf) sound-speed gradient. The density and P-wave attenuation coefficients were taken from Hamilton (1980).

Table 5. Geoacoustic properties of the sub-bottom sediments as a function of depth, in meters below the seafloor (mbsf). Within each depth range, each parameter varies linearly within the stated range.

Depth (mbsf)	Material	Density (g/cm³)	P-wave speed (m/s)	P-wave attenuation (dB/λ)	S-wave speed (m/s)	S-wave attenuation (dB/λ)
0–30	Silt-clay	1.45–1.49	1500–1539	0.17–0.18	200	3.0
30–100	Sand-clay	1.83–2.00	1623–1700	1.21–2.00		
100–500	Sand-clay	2.00	1700–2100	2.00		
>500	Sand-clay	2.00	2100	2.00		

4.2.3. Ocean Sound Speed Profile

The ocean sound speed profiles for the modeled sites were derived from temperature and salinity profiles from the U.S. Naval Oceanographic Office's *Generalized Digital Environmental Model V 3.0* (GDEM; Teague et al. 1990, Carnes 2009). GDEM provides an ocean climatology of temperature and salinity for the world's oceans on a latitude-longitude grid with 0.25° resolution, with a temporal resolution of one month, based on global historical observations from the U.S. Navy's Master Oceanographic Observational Data Set (MOODS). The climatology profiles include 78 fixed depth points to a maximum depth of 6800 m (where the ocean is that deep). The GDEM temperature-salinity profiles were converted to sound speed profiles according to the equations of Coppens (1981):

$$\begin{aligned} c(z,T,S,\phi) &= 1449.05 + 45.7t - 5.21t^2 - 0.23t^3 \\ &\quad + \left(1.333 - 0.126t + 0.009t^2\right)(S-35) + \Delta \\ \Delta &= 16.3Z + 0.18Z^2, \quad Z = \frac{z}{1000}\left[1 - 0.0026\cos(2\phi)\right], \quad t = \frac{T}{10} \end{aligned} \tag{4}$$

where z is water depth (m), T is temperature (°C), S is salinity (psu), and ϕ is latitude (radians).

Mean monthly sound speed profiles were derived from the GDEM profiles at the FPSO and drill ship locations. There are no significant variations in sound speed with geographical location. Monthly variations in sound speed are also minimal, although the profile in April tends to be mostly upward refracting in the top 100 m (Figure 9). This month is therefore expected to promote longest range propagation and was used for all modeled scenarios.

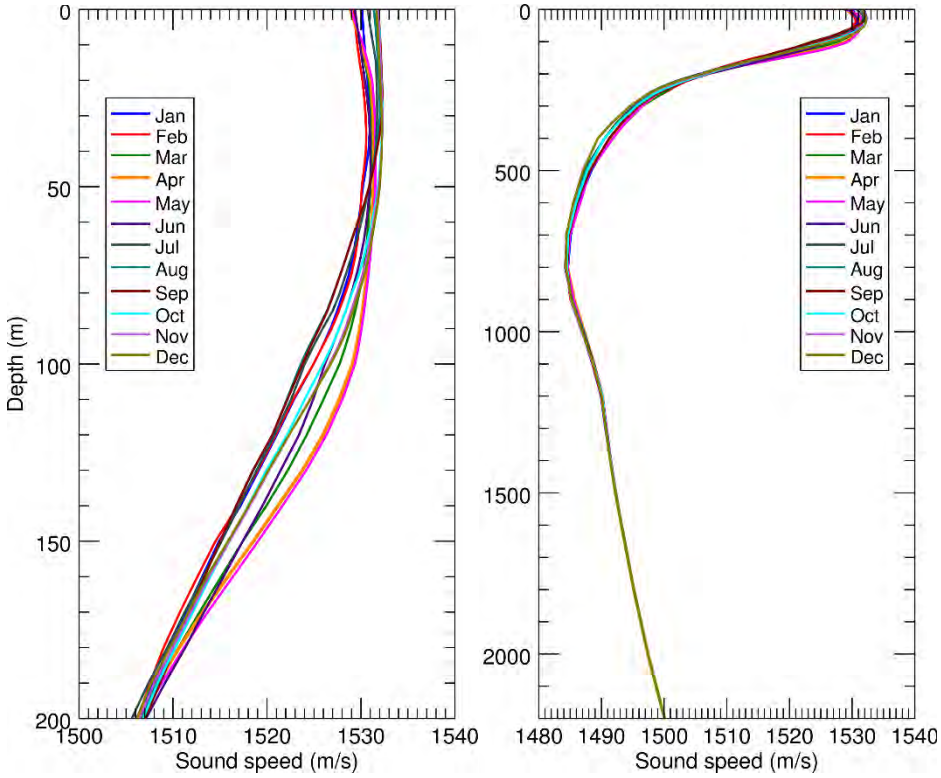


Figure 9. Mean monthly sound speed profiles (left: top 200 m; right: entire water column) at the FPSO location (08° 00' 39.53" N, 056° 59' 27.31" W) derived from data obtained from *GDEM V 3.0* (Teague et al. 1990, Carnes 2009).

4.3. Sound Propagation Modeling Zones

For the purposes of assessing sound levels with MONM, the sound field was modeled up to distances of 2 and 20 km from the FPSO (Scenarios 1 and 2) and the drill ship (Scenario 3), with a horizontal separation of 5 and 20 m between receiver points along the modeled radials. The horizontal angular separation between radials was 2.5°, for a total of N = 144 radial planes. Receiver depths were chosen to span the entire water column over the modeled areas, from 1 to 5000 m, with step sizes increasing with depth.

FWRAM modeled synthetic pulses of the VSP source up to 20 km, along four radials (0, 90, 180, and 270° from the tow direction) to compute peak pressure levels. The horizontal range step was set at 20 m. The tow direction was 293°. The same parameters were used to model sound from pile driving operations, the range step was however adjusted to 2 m up to 200 m from the source, and 25 m thereafter.

5. Results

5.1. Source Levels

5.1.1. Vessels

Figures 10–14 show the estimated 1/3-octave-band source levels for the modeled vessels. The broadband (10 Hz to 32 kHz) source levels vary from 173.4 dB re 1 µPa for the light construction and field intervention vessel to 196.1 dB re 1 µPa for the large tug. Although source levels may vary substantially during different operations, these modeled spectra represent a conservative average over a 24 hour period.

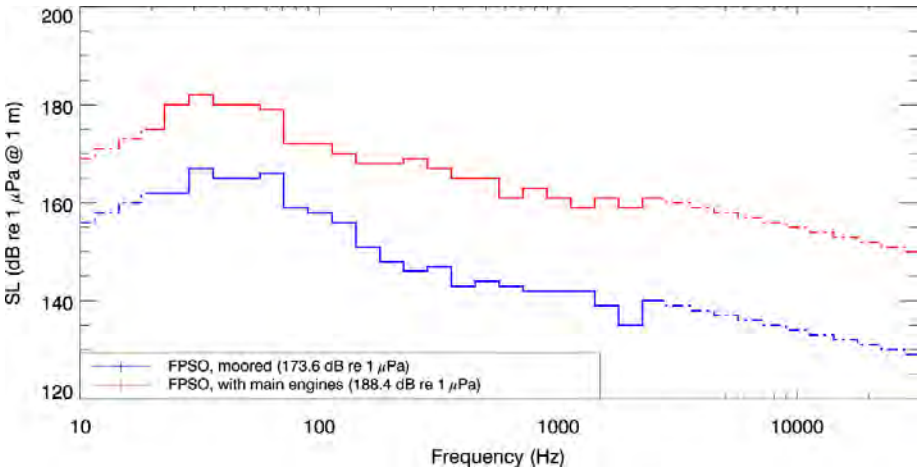


Figure 10. Estimated source level spectra for the FPSO. Dashed lines represent extrapolated levels based on Ross' spectrum (Ross 1976).

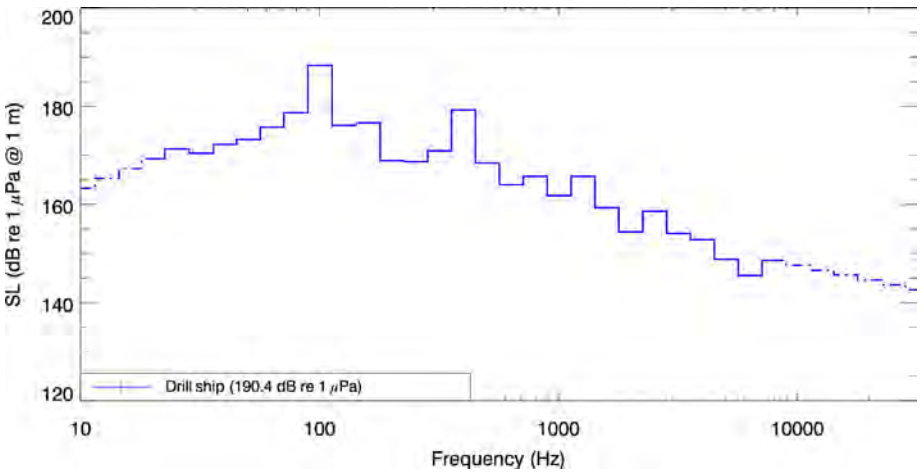


Figure 11. Estimated source level spectrum for the drill ship. Dashed lines represent extrapolated levels based on Ross' spectrum (Ross 1976).

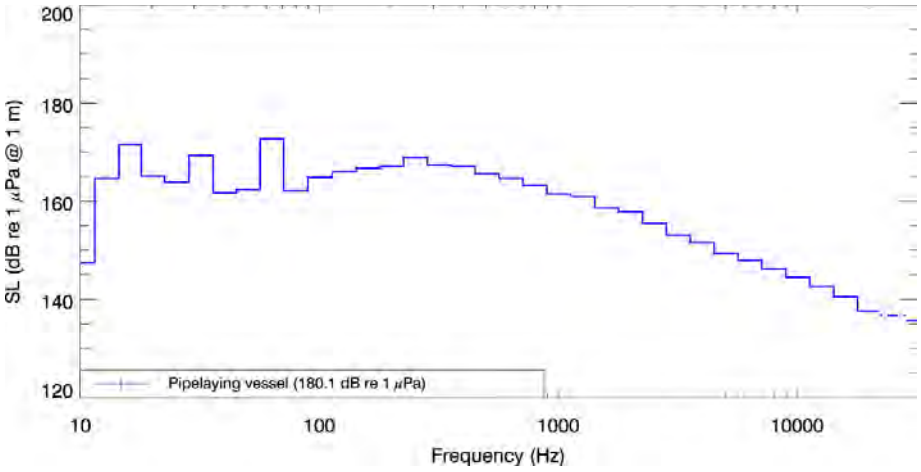


Figure 12. Estimated source level spectrum for the pipelaying vessel. Dashed lines represent extrapolated levels based on Ross' spectrum (Ross 1976).

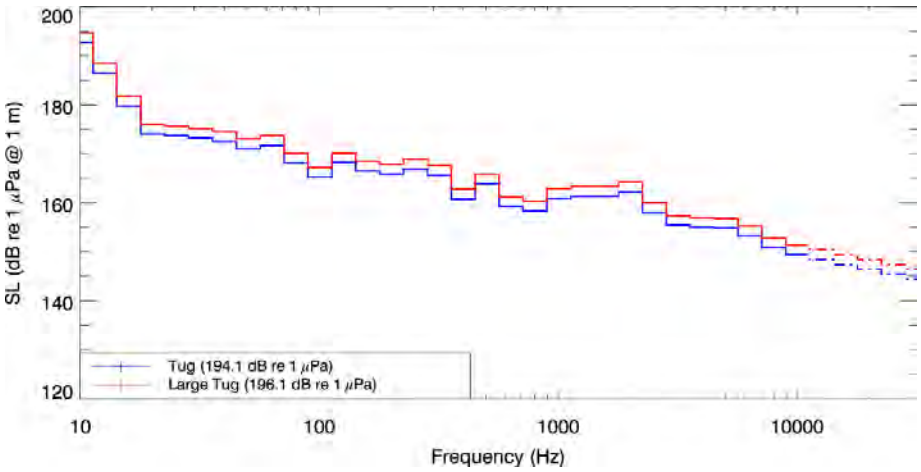


Figure 13. Estimated source level spectra for the tugs. Dashed lines represent extrapolated levels based on Ross' spectrum (Ross 1976).

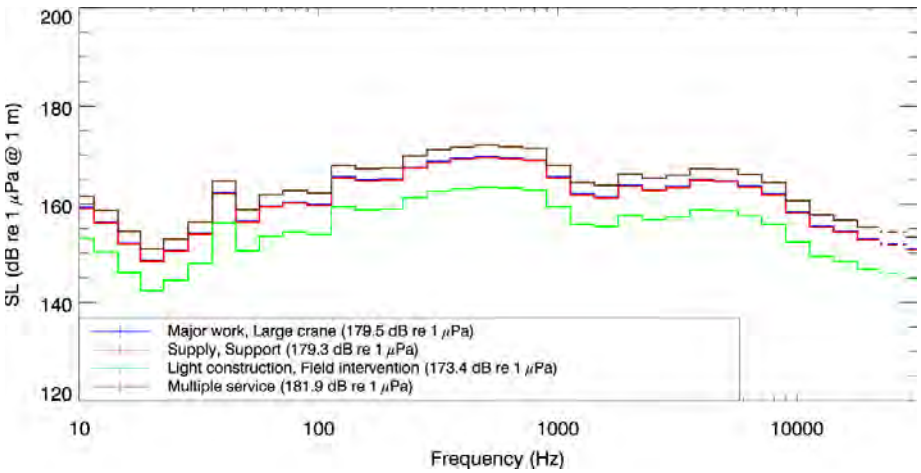


Figure 14. Estimated source level spectra for the various support vessels. Dashed lines represent extrapolated levels based on Ross' spectrum (Ross 1976).

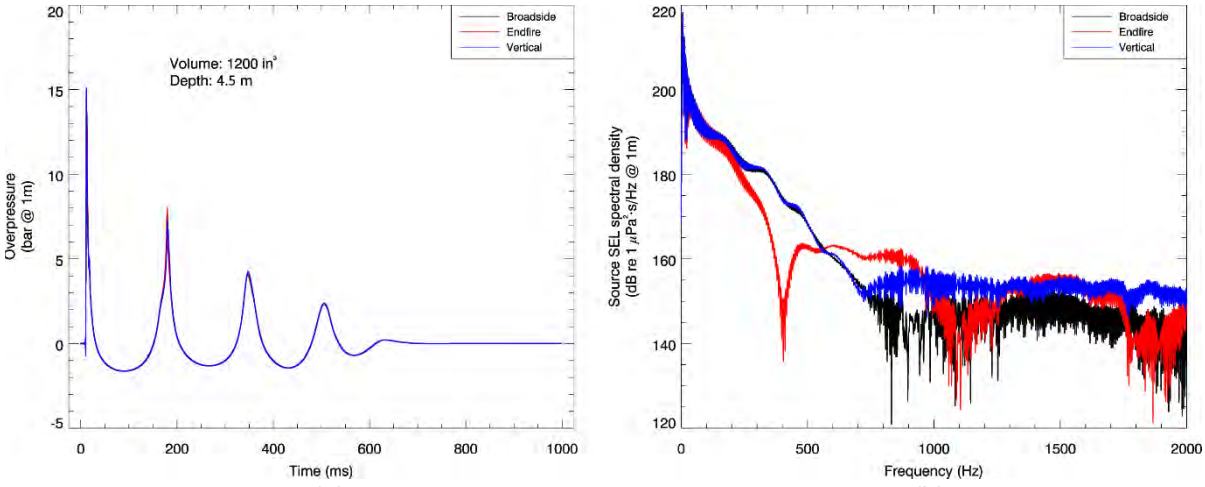
5.1.2. Vertical Seismic Profile Source

The pressure signatures of the individual array elements and the composite 1/3-octave-band source levels of the array, as functions of azimuthal angle (in the horizontal plane), were modeled with AASM (Section 3.1.2). While effects of surface reflected signals on bubble oscillations and inter-bubble interactions are accounted for in the notional pressure signatures of each element by AASM, the surface-reflected signal (i.e., surface ghost) is not shown in the far-field source signature plots below. The acoustic propagation models account for those surface reflections, which are a property of the propagating medium rather than the source.

Figure 15 shows the horizontal overpressure signatures (broadside–perpendicular to the tow direction, and endfire–parallel to the tow direction), the vertical overpressure signature, and corresponding power spectrum levels for the 1200 in^3 array at a 4.5 m tow depth. The signatures consist of a strong primary peak, related to the initial release of high-pressure air, followed by a series of pulses associated with bubble oscillations. Most energy is produced at frequencies below 600 Hz. Frequency-dependent peaks and nulls in the spectrum result from interference among elements in the array, and depend on the volumes and relative locations of the element.

Table 6 shows the broadband SPL and unweighted per-pulse SEL source levels.

Horizontal 1/3-octave-band source levels are shown as a function of band center frequency and azimuth (Figure 16). As discussed in Section 3.1.1, directivity in the sound field is most noticeable at frequencies from ~316 to 2000 Hz.



(a) (b)

Figure 15. Predicted source level details for the 1200 in^3 array. (a) The overpressure signature and (b) the power spectrum in the broadside (perpendicular to tow direction), endfire (directly aft of the array), and downward (vertical) directions.

Table 6. Source level specifications in the horizontal plane for the 1200 in^3 array, for a 4.5 m tow depth.

Direction	Peak pressure level (dB re 1 µPa @ 1 m)	SPL (dB re 1 µPa @ 1 m)	Unweighted per-pulse SEL (dB re 1 µPa²·s @ 1 m)	
			10–2000 Hz	2000–25000 Hz
Broadside (no surface ghost)	243.5	225.7	219.4	172.8
Endfire (no surface ghost)	242.6	225.6	219.3	176.9
Vertical (no surface ghost)	243.6	225.7	219.4	176.4
Vertical (with surface ghost)	243.6	224.3	219.8	179.4

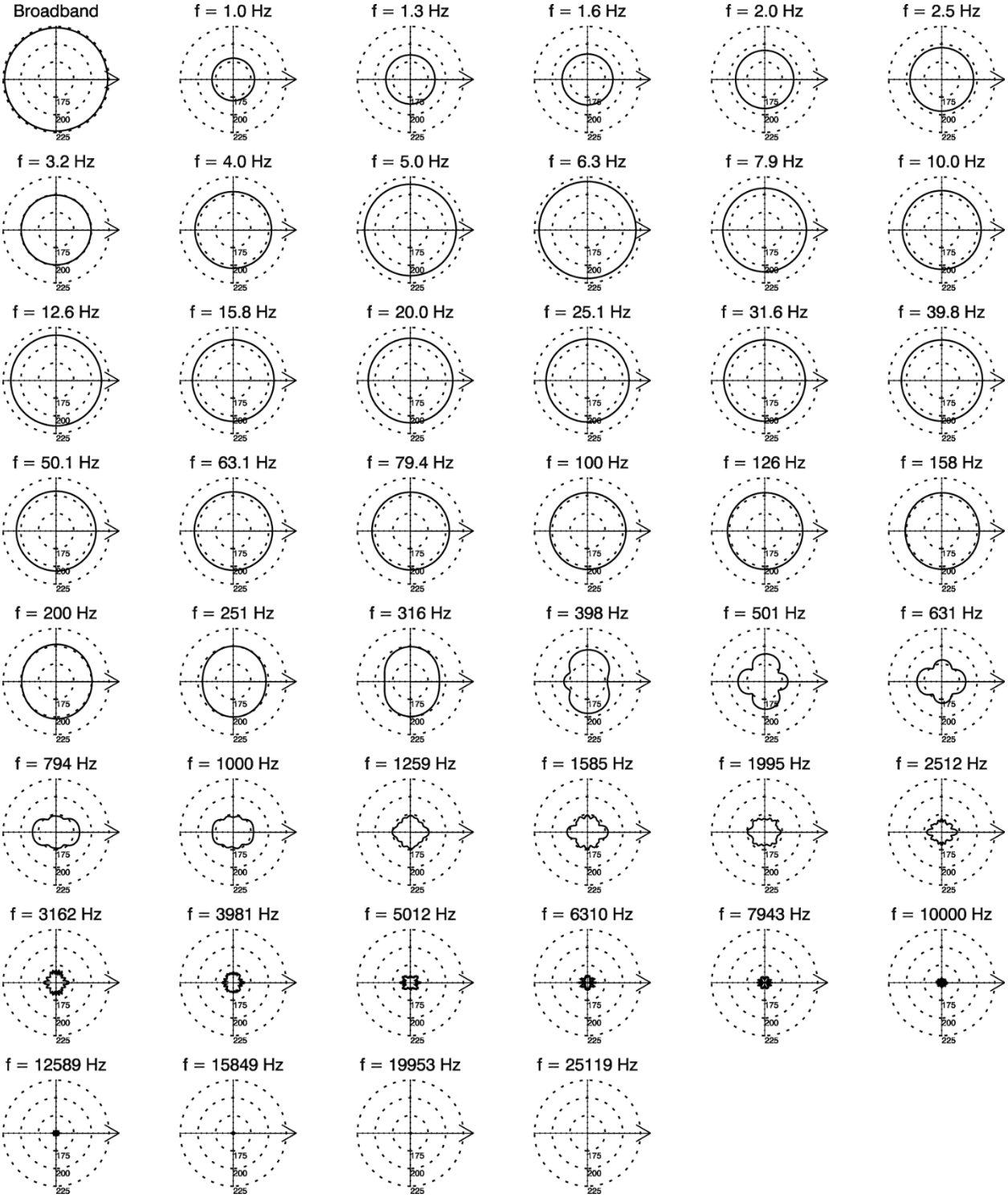


Figure 16. Directionality of the predicted horizontal source levels for the 1200 in^3 array, 10–25,000 Hz.Source levels (in dB re 1 µPa^2·s) are shown as a function of azimuth for the center frequencies of the 1/3-octave-bands modeled; frequencies are shown above the plots. Tow direction is to the right and tow depth is 4.5 m.

5.1.3. Impact Pile Driving

The forcing function at the top of the pile (Figure 17) was modeled using the GRLWEAP 2010 wave equation model. The forcing function consists of a strong primary peak, related to the initial contact of the ram and helmet, followed by a series of pulses associated with the ram-helmet oscillations. JASCO's pile driving source model estimated equivalent source signatures every 2 m along the pile. Figure 18 presents the signature of the monopoles at the top, center, and bottom of the pile. The first peak of these signatures represents the initial pile deformation traveling down the pile; its amplitude decreases and arrival time increases with depth along the pile.

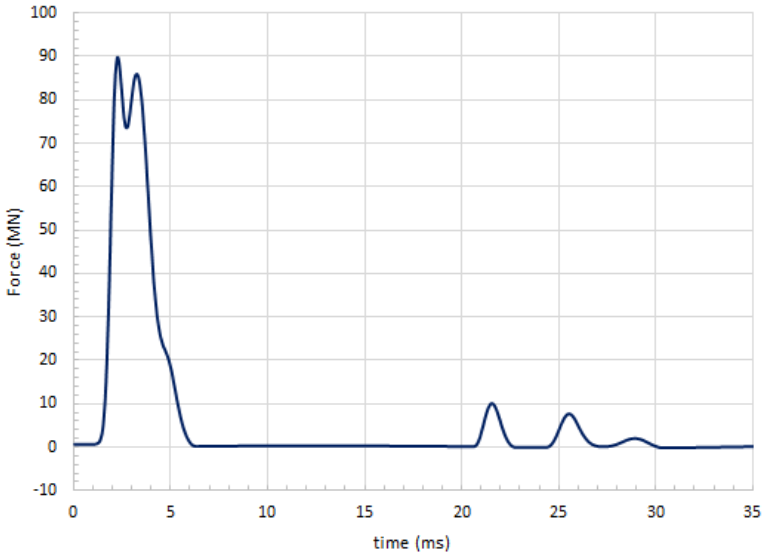


Figure 17. Force at the top of a pile during impact driving of a 25-m long, 5-m wide cylindrical steel pile with the MENCK 500T (underwater) hammer.

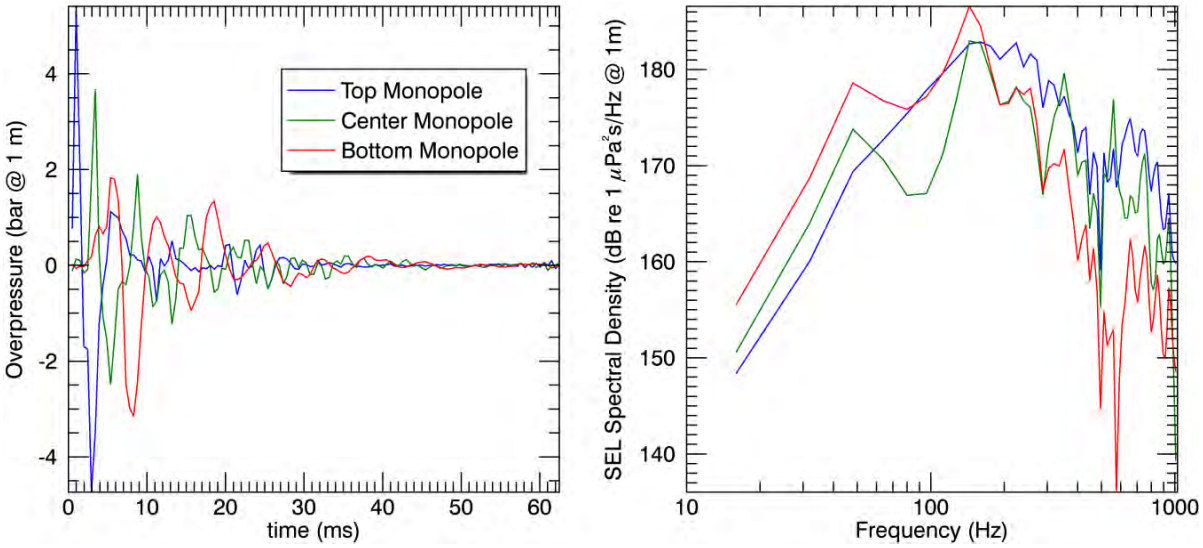


Figure 18. Predicted overpressure signature of three monopoles along the modeled pile: top (in water), center (in water), and bottom (in substrate).

5.2. Sound Fields

5.2.1. Vessels

This section includes the distances to marine mammal injury thresholds resulting from the presence of vessels (Table 7). For the purpose of estimating M-weighted SEL_{24h} in this study, all vessels were assumed stationary, operating over 90% of a 24 hour period. Peak pressure level thresholds for injury criteria were not reached; distances to peak pressure levels are not presented below.

The tabulated values represent the maximum R_{max} and $R_{95\%}$ from any vessels present in a scenario.

Table 7. Scenarios 1–3: Distances (m) to marine mammal injury for non-impulsive sources.

Hearing group	Southall et al. (2007)			Finneran (2015)		
	Threshold (M-weighted SEL_{24h}; dB re 1 µPa²·s)	R_{max} (m)	$R_{95\%}$ (m)	Threshold (M-weighted SEL_{24h}; dB re 1 µPa²·s)	R_{max} (m)	$R_{95\%}$ (m)
Scenario 1						
Low-frequency cetaceans	215	6	6	207	< 5	< 5
Mid-frequency cetaceans	215	< 5	< 5	199	< 5	< 5
Scenario 2						
Low-frequency cetaceans	215	< 5	< 5	207	< 5	< 5
Mid-frequency cetaceans	215	-	-	199	-	-
Scenario 3						
Low-frequency cetaceans	215	9	9	207	6	6
Mid-frequency cetaceans	215	< 5	< 5	199	-	-

5.2.2. Vertical Seismic Profile Source

This section presents the distances to marine mammal injury thresholds for the VSP source in Scenario 4. To estimate distances to marine mammal injury thresholds in M-weighted SEL_{24h}, one operational period was modeled (i.e., it was assumed that the VSP source produces 40 pulses in 24 hours). Distances to peak pressure level thresholds are either not reached or less than distances to M-weighted SEL_{24h} thresholds for injury criteria (Table 8); distances to peak pressure levels are not presented below. In Figure 19, area ensonified at or above injury thresholds are compared; the range to the Mid-frequency cetacean injury threshold based on Finneran (2015) was below the minimum resolvable range.

Table 8. Scenario 4: Distances (m) to marine mammal injury thresholds for the VSP source.

Hearing group	Southall et al. (2007)			Finneran (2015)		
	Threshold (M-weighted SEL_{24h}; dB re 1 µPa²·s)	R_{max} (m)	$R_{95\%}$ (m)	Threshold (M-weighted SEL_{24h}; dB re 1 µPa²·s)	R_{max} (m)	$R_{95\%}$ (m)
Low-frequency cetaceans	198	73	68	192	39	36
Mid-frequency cetaceans	198	35	32	187	-	-

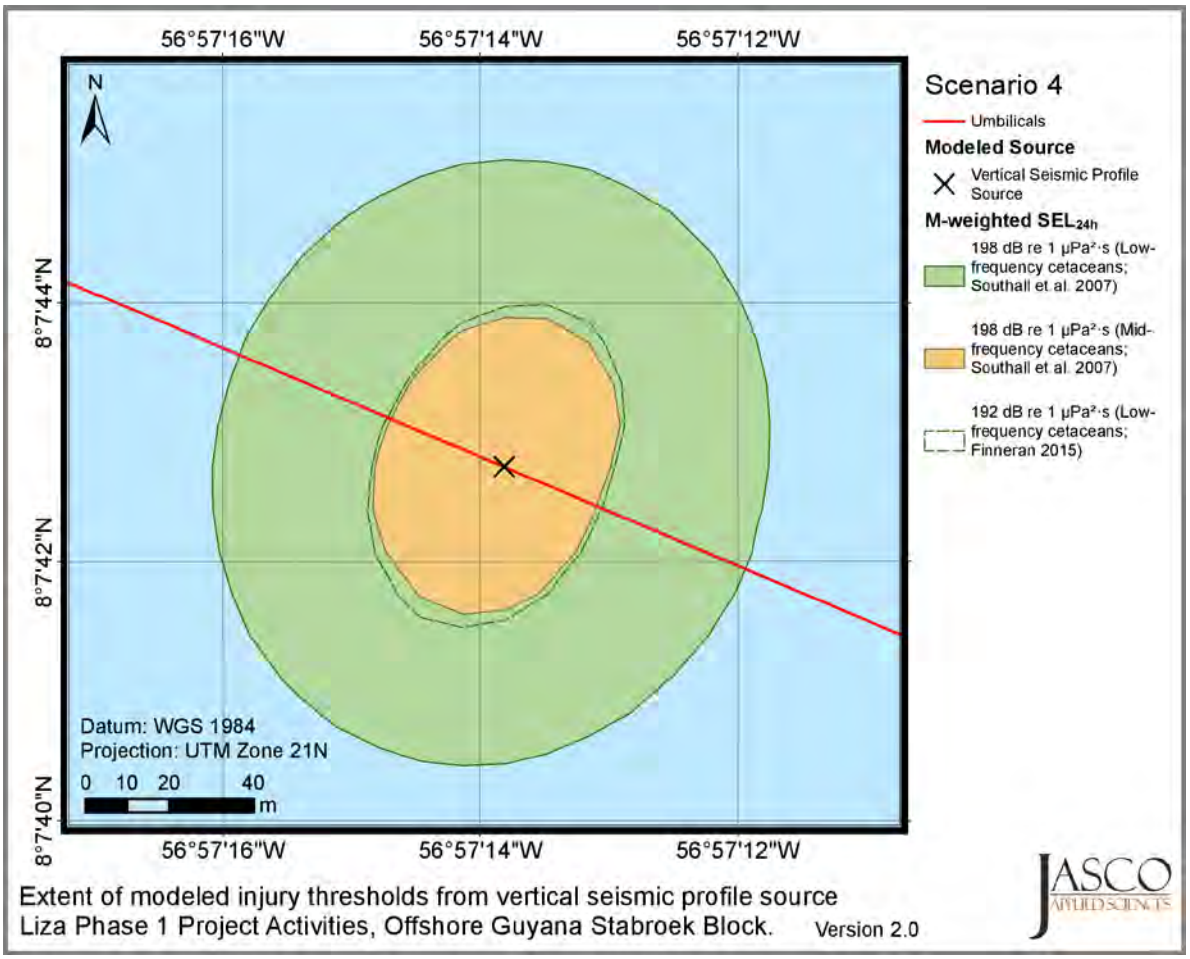


Figure 19. Scenario 4: Sound level contour map showing the extend of the maximum-over-depth M-weighted SEL_{24h} from the VSP source for marine mammal injury thresholds based on Southall et al. (2007) and Finneran (2015).

5.2.3. Impact Pile Driving

This section presents the distances to marine mammal injury thresholds for the underwater pile driving operations in Scenarios 5 and 6. To estimate distances to marine mammal injury thresholds in M-weighted SEL_{24h}, we assumed that one pile was driven for 5 hours, at a rate of 38 strikes per minute, every 24 hours. Distances to peak pressure level thresholds were either not reached or were less than distances to M-weighted SEL_{24h} thresholds for injury criteria; distances to peak pressure levels are not presented.

Tables 9–10, and Figures 20–23, present the distances to marine mammal injury thresholds at Drill Center 2-P and the FPSO, respectively. Figures 21–22 and 24–25 present vertical slices of the corresponding M-weighted SEL_{24h} fields, east of the piles. The parabolic equation (PE) approximation used in FWRAM (Section 3.2) is estimated to be valid for sound propagating up to 45° from the horizontal plane at the source depth. This angle is indicated by the black dash line in each slice.

Table 9. Scenario 5: Distances (m) to marine mammal injury thresholds for the underwater pile driving operations at Drill Center 2-P.

Hearing group	Southall et al. (2007)		Finneran (2015)	
	Threshold (M-weighted SEL_{24h}; dB re 1 µPa²·s)	R_{max} (m)	Threshold (M-weighted SEL_{24h}; dB re 1 µPa²·s)	R_{max} (m)
Low-frequency cetaceans	198	1,300	192	1,025
Mid-frequency cetaceans	198	762	187	136

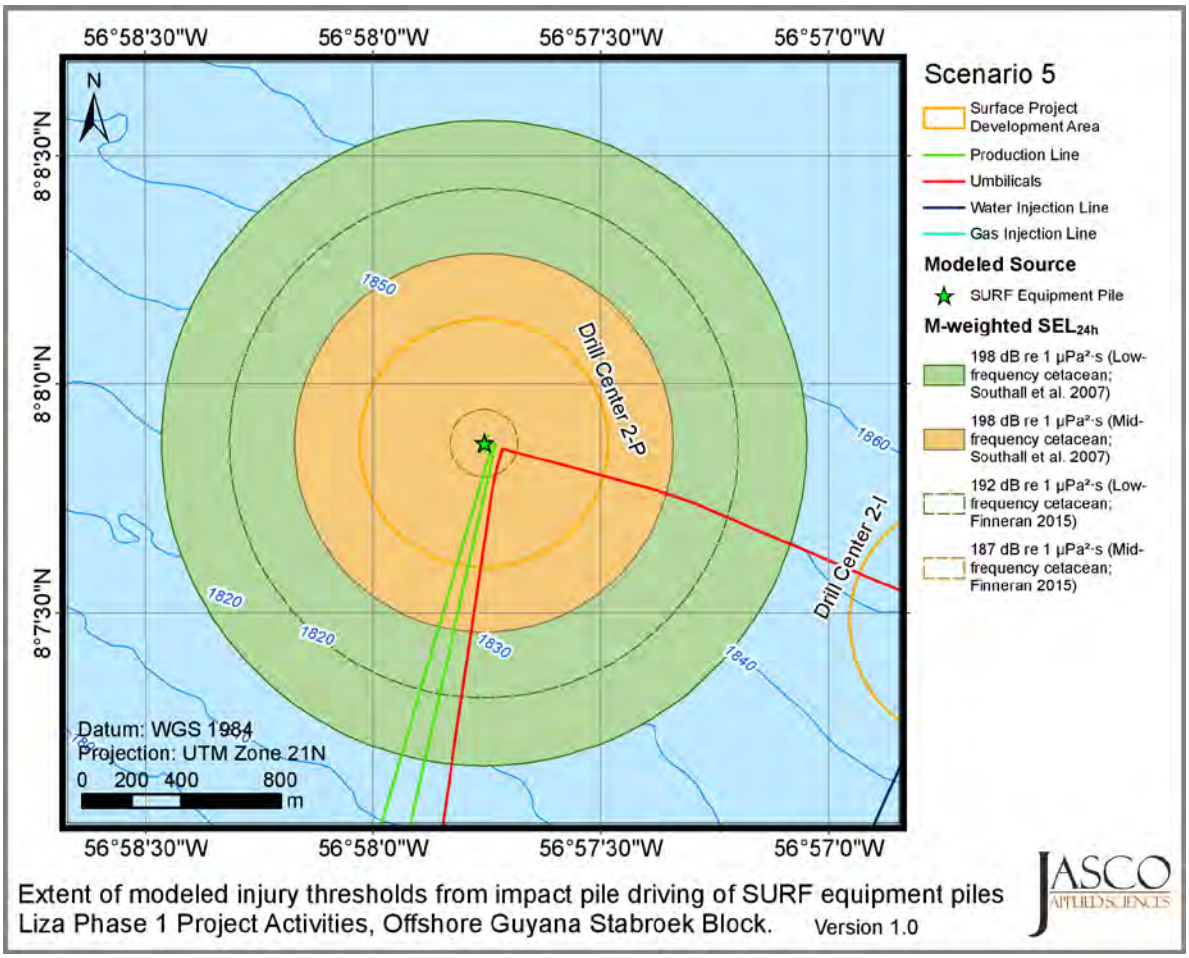


Figure 20. Scenario 5: Sound level contour map showing the extend of the maximum-over-depth M-weighted SEL_{24h} from impact pile driving for marine mammal injury thresholds based on Southall et al. (2007) and Finneran (2015).

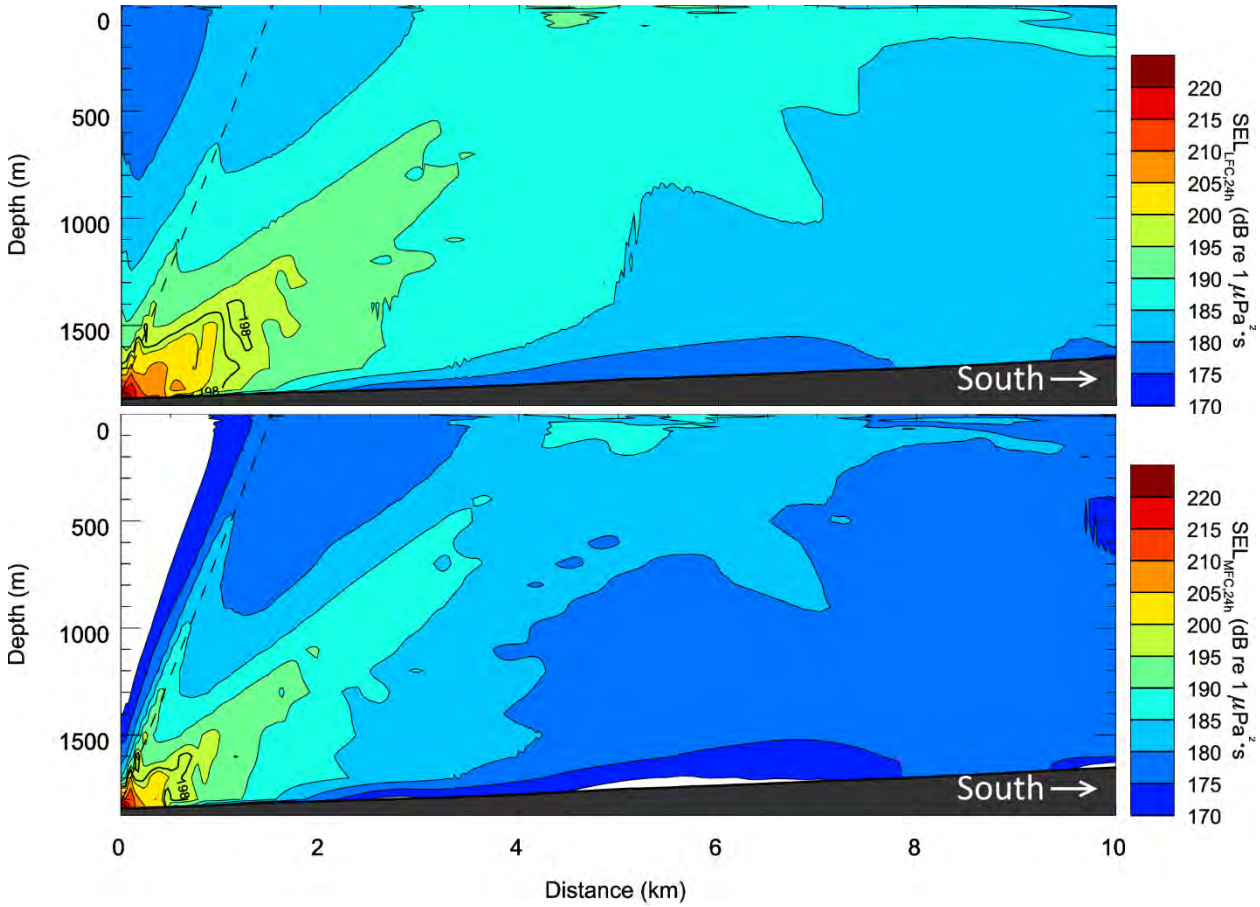


Figure 21. Scenario 5: Estimated M-weighted SEL_{24h} based on Southall et al. (2007), propagating south of the pile at Drill Center 2-P. The thicker black lines indicate sound level isopleths corresponding to the injury thresholds for (top) low- and (bottom) mid-frequency cetaceans. The dash line indicates the limiting angle below which the model is valid; received levels above the source (left of the dash line) are expected to be underestimated. The dark area at the bottom of the plot shows decreasing water depth.

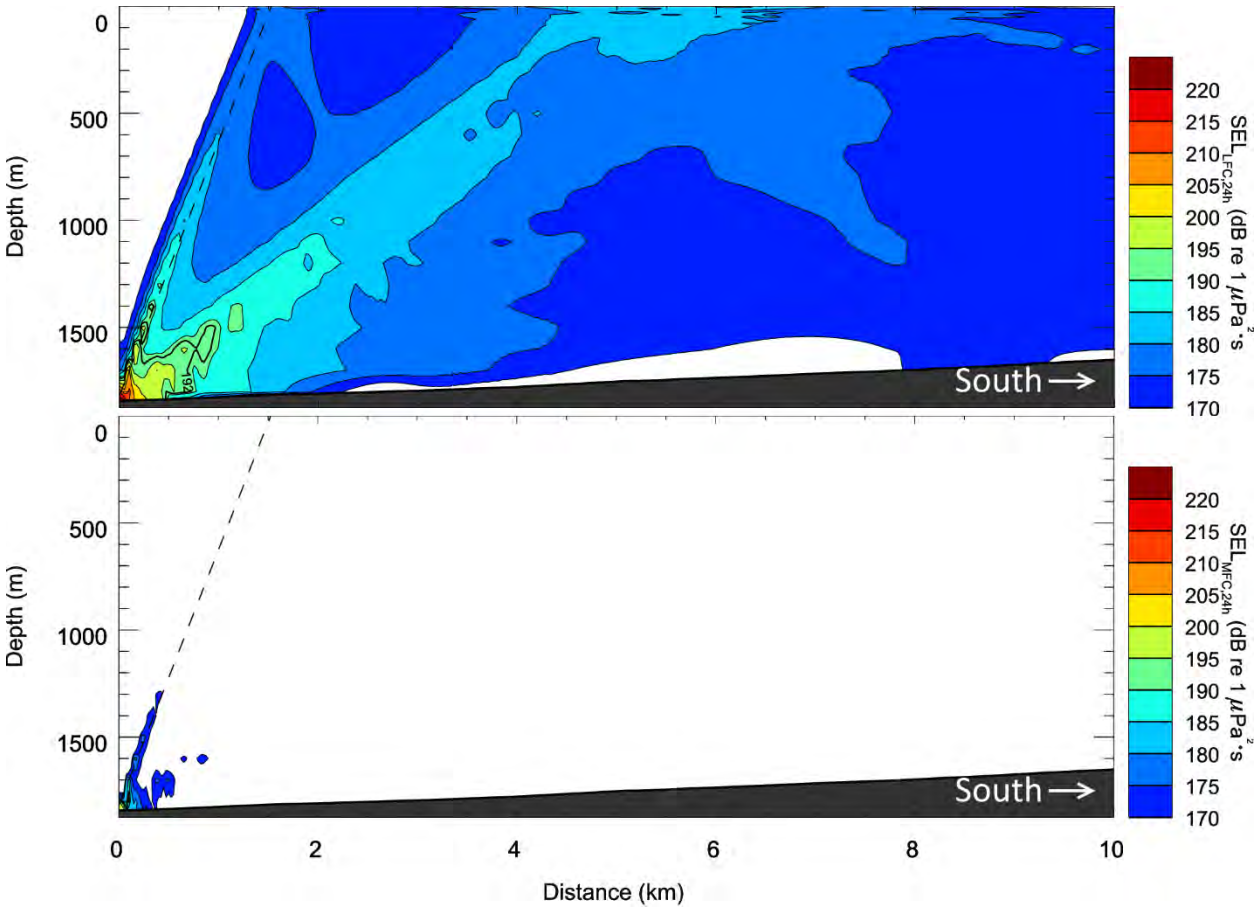


Figure 22. Scenario 5: Estimated M-weighted SEL_{24h} based on Finneran (2015), propagating south of the pile at Drill Center 2-P. The thicker black lines indicate sound level isopleths corresponding to the injury thresholds for (top) low- and (bottom) mid-frequency cetaceans. The dash line indicates the limiting angle below which the model is valid; received levels above the source (left of the dash line) are expected to be underestimated. The dark area at the bottom of the plot shows decreasing water depth.

Table 10. Scenario 6: Distances (m) to marine mammal injury thresholds for the underwater pile driving operations at the FPSO location.

Hearing group	Southall et al. (2007)		Finneran (2015)	
	Threshold (M-weighted SEL_{24h}; dB re 1 µPa²·s)	R_{max} (m)	Threshold (M-weighted SEL_{24h}; dB re 1 µPa²·s)	R_{max} (m)
Low-frequency cetaceans	198	1,375	192	1,075
Mid-frequency cetaceans	198	725	187	100

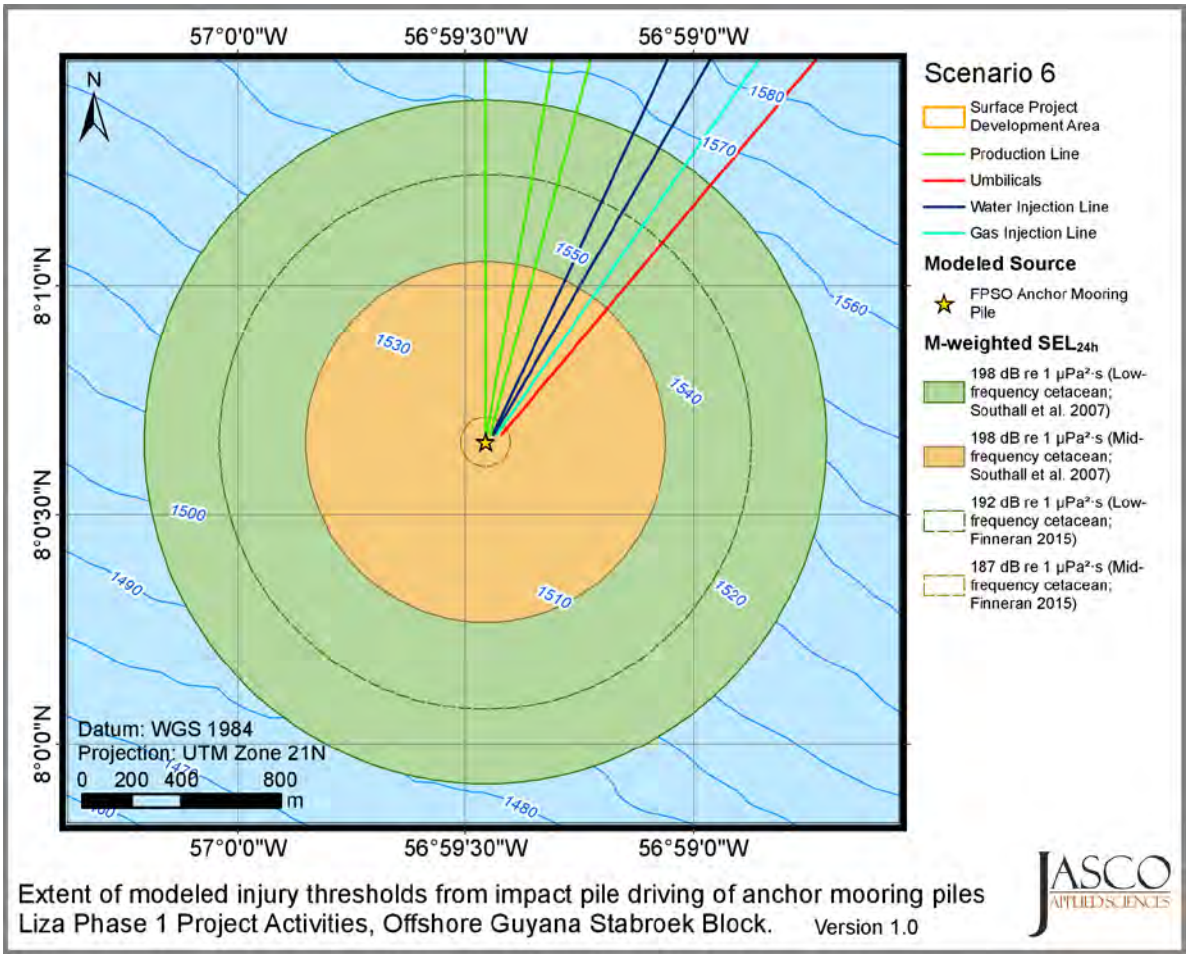


Figure 23. Scenario 6: Sound level contour map showing the extend of the maximum-over-depth M-weighted SEL_{24h} from impact pile driving for marine mammal injury thresholds based on Southall et al. (2007) and Finneran (2015).

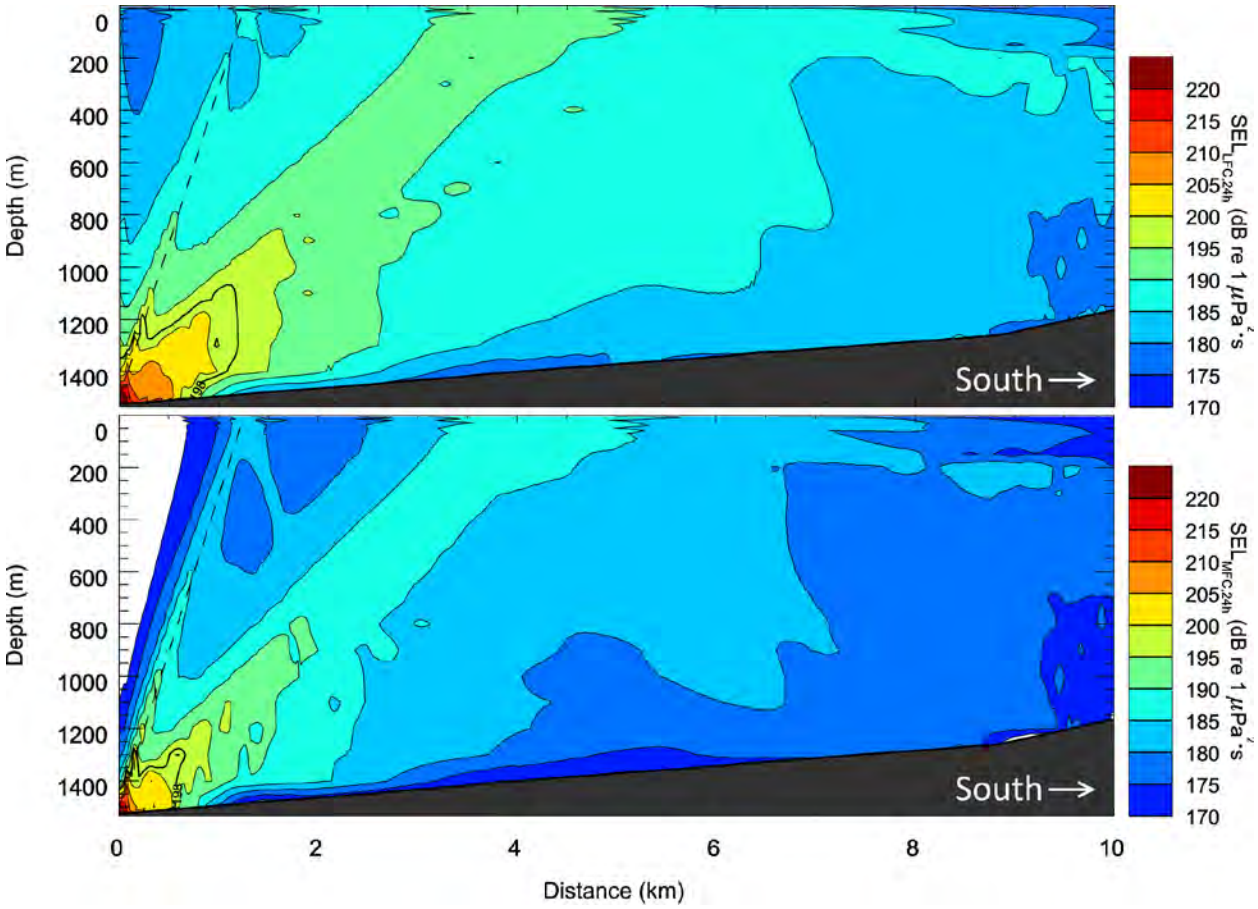


Figure 24. Scenario 6: Estimated M-weighted SEL_{24h} based on Southall et al. (2007), propagating south of the FPSO anchor mooring piles. The thicker black lines indicate sound level isopleths corresponding to the injury thresholds for (top) low- and (bottom) mid-frequency cetaceans. The dash line indicates the limiting angle below which the model is valid; received levels above the source (left of the dash line) are expected to be underestimated. The dark area at the bottom of the plot shows decreasing water depth.

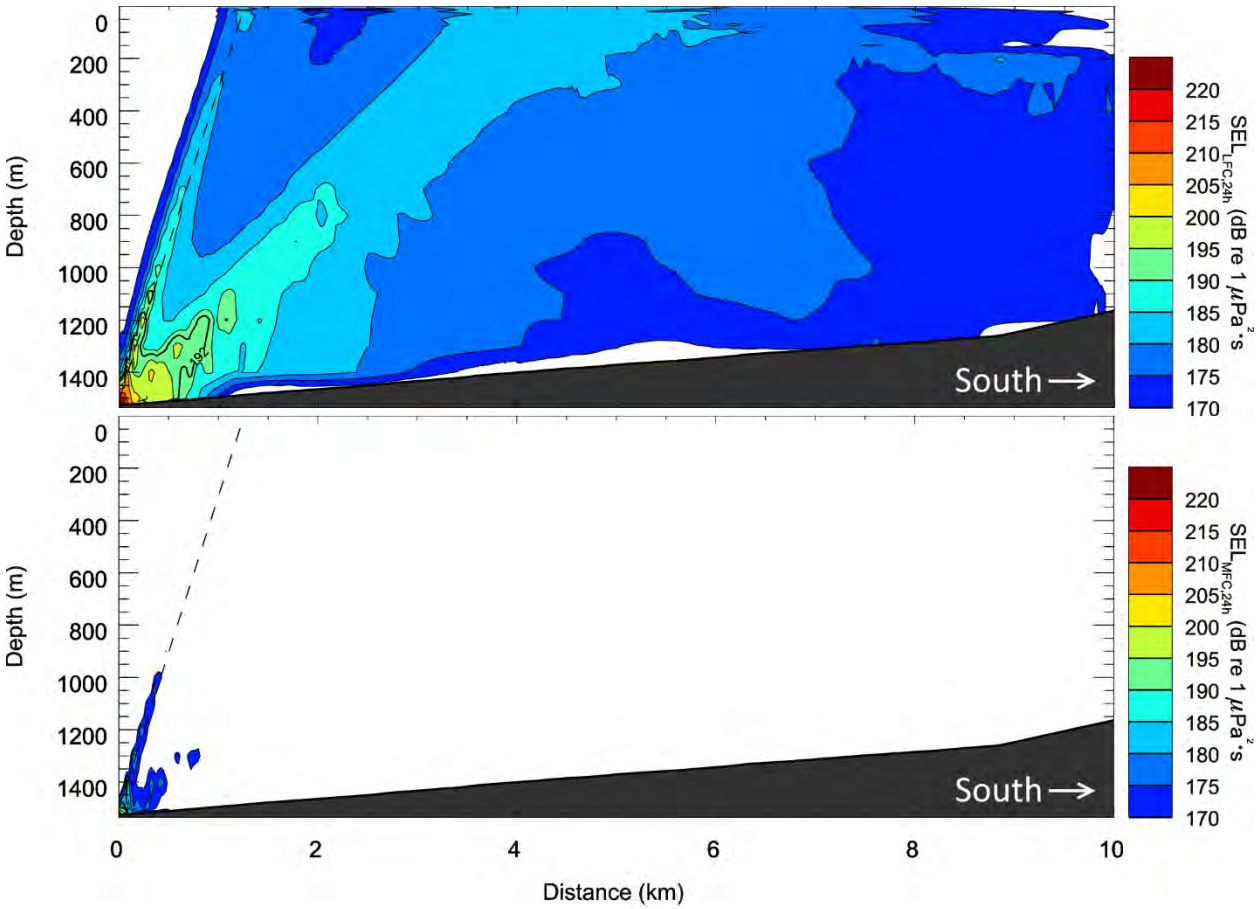


Figure 25. Scenario 6: Estimated M-weighted SEL_{24h} based on Finneran (2015), propagating south of the FPSO anchor mooring piles. The thicker black lines indicate sound level isopleths corresponding to the injury thresholds for (top) low- and (bottom) mid-frequency cetaceans. The dash line indicates the limiting angle below which the model is valid; received levels above the source (left of the dash line) are expected to be underestimated. The dark area at the bottom of the plot shows decreasing water depth.

6. Discussion

The estimated broadband source levels of vessels varied from 173.4 dB re 1 µPa at 1 m for the light construction and field intervention vessels, to 196.1 dB re 1 µPa at 1m for the large tug. Although source levels may vary substantially during operations, the modeled source level spectra of the vessels represent conservative averages over a 24 hour period.

For scenarios 1 through 3, the distances to injury thresholds from vessels were small: <10 m for all species, thus essentially insignificant relative to the size of the vessels. The distances to injury thresholds were similar for Southall et al. (2007) and Finneran (2015) criteria (Table 7). These results assume that the vessels were stationary for 24 hours and the animal was present within the stated distance for the entire accumulation period (24 hours).

The broadband (10–25,000 Hz) per-pulse SEL source level of the VSP source was 219–220 dB re 1 µPa^2·s @ 1 m in all directions (Table 6). Distances (R_{max}) to injury thresholds for mid-frequency cetaceans were 35 m based on Southall et al. (2007) and below the minimum resolvable range based on Finneran (2015); for low-frequency cetaceans they were 73 and 39 m, respectively (Table 8). For this source, the injury thresholds based on Finneran (2015) were generally lower than for Southall et al. (2007) due to the steeper roll-off at low frequencies of the weighting functions for the former. Because most of the energy from the VSP source lies below 600 Hz (Figure 15), Finneran's weighting yields a greater discount than Southall et al. (2007) (see Appendix A.4).

Distances to injury thresholds were longer for impact pile driving than for other operations. Across both modelled sites, for mid-frequency cetaceans the maximum ranges were 762 m based on Southall et al. (2007) and 136 m based on Finneran (2015); for low-frequency cetaceans they were 1,375 m and 1,075 m, respectively (Tables 9–10). The differences in ranges between the two sites were minor. The sound levels at or above injury thresholds were found close to the ocean bottom, at depths >1,000 m. Low-frequency cetacean species present in the area are not expected to dive to those depths and, therefore, should never be exposed to injurious sound levels from pile driving activities. A few species within the mid-frequency hearing group, such as some dolphins, may feed at depths greater than 1,000 m and could therefore be affected by pile driving sound. The amount of time these animals spend below 1,000 m is, however, limited due to their need to resurface to breathe, which reduces the probability of injury.

Glossary

1/3-octave-band
Non-overlapping passbands that are one-third of an octave wide (where an octave is a doubling of frequency). Three adjacent 1/3-octave-bands make up one octave. One-third-octave-bands become wider with increasing frequency. See also octave.

90%-energy time window
The time interval over which the cumulative energy rises from 5% to 95% of the total pulse energy. This interval contains 90% of the total pulse energy. Symbol: T_{90}.

90% root-mean-square sound pressure level (90% SPL)
The root-mean-square sound pressure levels calculated over the 90%-energy time window of a pulse. Used only for pulsed sounds.

Air gun
A device that has a chamber of compressed air, which is "fired" (quickly released) to produce a pulse of acoustic energy.

A-weighting
Frequency-selective weighting for human hearing in air that is derived from the inverse of the idealized 40-phon equal loudness hearing function across frequencies.

absorption
The conversion of acoustic energy into heat, which is captured by insulation.

ambient noise
All-encompassing sound at a given place, usually a composite of sound from many sources near and far (ANSI S1.1-1994 R2004), e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

attenuation
The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium.

auditory weighting function (frequency-weighting function)
Auditory weighting functions account for marine mammal hearing sensitivity. They are applied to sound measurements to emphasize frequencies that an animal hears well and de-emphasize frequencies they hear less well or not at all (Southall et al. 2007, Finneran and Jenkins 2012, NOAA 2013).

azimuth
A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also called bearing.

background noise
Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 R2004). Ambient noise detected, measured, or recorded with a signal is part of the background noise.

bandwidth
The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic sources, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI/ASA S1.13-2005 R2010).

bar
Unit of pressure equal to 100 kPa, which is approximately equal to the atmospheric pressure on Earth at sea level. 1 bar is equal to 10^6 Pa or 10^{11} µPa.

broadband sound level
The total sound pressure level measured over a specified frequency range. If the frequency range is unspecified, it refers to the entire measured frequency range.

broadside direction
Perpendicular to the travel direction of a source. Compare with endfire direction.

cavitation
A rapid formation and collapse of vapor cavities (i.e., bubbles or voids) in water, most often caused by a rapid change in pressure. Fast-spinning vessel propellers typically cause cavitation, which creates a lot of sound.

cetacean
Any animal in the order Cetacea. These are aquatic, mostly marine mammals and include whales, dolphins, and porpoises.

compressional wave
A mechanical vibration wave in which the direction of particle motion is parallel to the direction of propagation. Also called primary wave or P-wave.

continuous sound
A sound whose sound pressure level remains above ambient sound during the observation period (ANSI/ASA S1.13-2005 R2010). A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decibel (dB)
One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power (ANSI S1.1-1994 R2004).

endfire direction
Parallel to the travel direction of a source. See also broadside direction.

ensonified
Exposed to sound.

equal-loudness contour
A curve or curves that show, as a function of frequency, the sound pressure level required to cause a given loudness for a listener having normal hearing, listening to a specified kind of sound in a specified manner (ANSI S1.1-1994 R2004).

far-field
The zone where, to an observer, sound originating from an array of sources (or a spatially-distributed source) appears to radiate from a single point. The distance to the acoustic far-field increases with frequency.

fast-average sound pressure level
The time-averaged sound pressure levels calculated over the duration of a pulse (e.g., 90%-energy time window), using the leaky time integrator from Plomp and Bouman (1959) and a time constant of 125 ms. Used only for pulsed sounds.

fast Fourier transform (FFT)
A computationally efficiently algorithm for computing the discrete Fourier transform.

frequency
The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: *f*. 1 Hz is equal to 1 cycle per second.

geoacoustic
Relating to the acoustic properties of the seabed.

hearing group
Grouping of marine mammal species with similar hearing ranges. Commonly defined hearing groups include low-, mid-, and high-frequency cetaceans, pinnipeds in water, and pinnipeds in air.

hearing threshold
The sound pressure level that is barely audible for a given individual in the absence of significant background noise during a specific percentage of experimental trials.

hertz (Hz)
A unit of frequency defined as one cycle per second.

high-frequency cetacean
The functional hearing group that represents odontocetes specialized for using high frequencies.

intermittent sound
A level of sound that abruptly drops to the background noise level several times during the observation period.

impulsive sound
Sound that is typically brief and intermittent with rapid (within a few seconds) rise time and decay back to ambient levels (NOAA 2013, ANSI S12.7-1986 R2006). For example, seismic sources and impact pile driving.

low-frequency cetacean
The functional hearing group that represents mysticetes (baleen whales).

mid-frequency cetacean
The functional hearing group that represents some odontocetes (dolphins, toothed whales, beaked whales, and bottlenose whales).

M-weighting
The process of band-pass filtering loud sounds to reduce the importance of inaudible or less-audible frequencies for broad classes of marine mammals. “Generalized frequency weightings for various functional hearing groups of marine mammals, allowing for their functional bandwidths and appropriate in characterizing auditory effects of strong sounds” (Southall et al. 2007).

mysticete
Mysticeti, a suborder of cetaceans, use their baleen plates, rather than teeth, to filter food from water. They are not known to echolocate, but use sound for communication. Members of this group include rorquals (Balaenopteridae), right whales (Balaenidae), and the gray whale (*Eschrichtius robustus*).

non-impulsive sound
Sound that is broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically does not have a high peak pressure with rapid rise time (typically only small fluctuations in decibel level)

that impulsive signals have (ANSI/ASA S3.20-1995 R2008). For example, marine vessels, aircraft, machinery, construction, and vibratory pile driving (NIOSH 1998, NOAA 2015).

octave
The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

odontocete
The presence of teeth, rather than baleen, characterizes these whales. Members of the Odontoceti are a suborder of cetaceans, a group comprised of whales, dolphins, and porpoises. The toothed whales' skulls are mostly asymmetric, an adaptation for their echolocation. This group includes sperm whales, killer whales, belugas, narwhals, dolphins, and porpoises.

otariid
A common term used to describe members of the Otariidae, eared seals, commonly called sea lions and fur seals. Otariids are adapted to a semi-aquatic life; they use their large fore flippers for propulsion. Their ears distinguish them from phocids. Otariids are one of the three main groups in the superfamily Pinnipedia; the other two groups are phocids and walrus.

parabolic equation method
A computationally-efficient solution to the acoustic wave equation that is used to model transmission loss. The parabolic equation approximation omits effects of back-scattered sound, simplifying the computation of transmission loss. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

peak sound pressure level (peak SPL)
The maximum instantaneous sound pressure level, in a stated frequency band, within a stated period. Also called zero-to-peak sound pressure level. Unit: decibel (dB).

percentile level, exceedance
The sound level exceeded *n* % of the time during a measurement.

permanent threshold shift (PTS)
A permanent loss of hearing sensitivity caused by excessive acoustic exposure. PTS is considered auditory injury.

phocid
A common term used to describe all members of the family Phocidae. These true/earless seals are more adapted to in-water life than are otariids, which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves. Phocids are one of the three main groups in the superfamily Pinnipedia; the other two groups are otariids and walrus.

pinniped
A common term used to describe all three groups that form the superfamily Pinnipedia: phocids (true seals or earless seals), otariids (eared seals or fur seals and sea lions), and walrus.

point source
A source that radiates sound as if from a single point (ANSI S1.1-1994 R2004).

power spectrum density
The acoustic signal power per unit frequency as measured at a single frequency. Unit: $\mu Pa^2/Hz$, or $\mu Pa^2 \cdot s$.

power spectral density level
The decibel level ($10\log_{10}$) of the power spectrum density, usually presented in 1 Hz bins. Unit: dB re 1 $\mu Pa^2/Hz$.

pressure, acoustic
The deviation from the ambient hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa). Symbol: *p*.

pressure, hydrostatic
The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid. Unit: pascal (Pa).

received level
The sound level measured at a receiver.

Root-mean-square sound pressure level (SPL)
See sound pressure level.

shear wave
A mechanical vibration wave in which the direction of particle motion is perpendicular to the direction of propagation. Also called secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

signature
Pressure signal generated by a source.

sound
A time-varying pressure disturbance generated by mechanical vibration waves travelling through a fluid medium such as air or water.

sound exposure
Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event. Unit: pascal-squared second ($Pa^2 \cdot s$) (ANSI S1.1-1994 R2004).

sound exposure level (SEL)
A cumulative measure related to the sound energy in one or more pulses. Unit: dB re 1 $\mu Pa^2 \cdot s$. SEL is expressed over the summation period (e.g., per-pulse SEL [for seismic sources], single-strike SEL [for pile drivers], 24-hour SEL).

sound field
Region containing sound waves (ANSI S1.1-1994 R2004).

sound pressure level (SPL)
The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R2004).

For sound in water, the reference sound pressure is one micropascal (p_0 = 1 µPa) and the unit for SPL is dB re 1 µPa:

$$\mathrm{SPL} = 10\log_{10}\left(p^2 / p_0^2\right) = 20\log_{10}\left(p / p_0\right)$$

Unless otherwise stated, SPL refers to the root-mean-square sound pressure level. See also 90% sound pressure level and fast-average sound pressure level.

sound speed profile
The speed of sound in the water column as a function of depth below the water surface.

source level (SL)
The sound pressure level measured 1 meter from a theoretical point source that radiates the same total sound power as the actual source. Unit: dB re 1 µPa @ 1 m.

spectrum
An acoustic signal represented in terms of its power (or energy) distribution compared with frequency.

temporary threshold shift (TTS)
Temporary loss of hearing sensitivity caused by excessive acoustic exposure.

transmission loss (TL)
The decibel reduction in sound level between two stated points that results from sound spreading away from an acoustic source subject to the influence of the surrounding environment. Also called propagation loss.

wavelength
Distance over which a wave completes one oscillation cycle. Unit: meter (m). Symbol: λ.

Literature Cited

[MMC] Marine Mammal Commission. 2007. *Marine mammals and noise: A sound approach to research and management*. A Report to Congress from the Marine Mammal Commission. http://www.mmc.gov/reports/workshop/pdf/fullsoundreport.pdf.

[NIOSH] National Institute for Occupational Safety and Health. 1998. *Criteria for a recommended standard: Occupational noise exposure*. Document Number 98-126. U.S. Department of Health and Human Services, NIOSH, Cincinnati, Ohio. 122 pp.

[NMFS] National Marine Fisheries Service. 1998. *Acoustic Criteria Workshop*. Dr. Roger Gentry and Dr. Jeanette Thomas Co-Chairs.

[NMFS] National Marine Fisheries Service. 2013. *Marine Mammals: Interim Sound Threshold Guidance* (webpage). National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. http://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/threshold_guidance.html.

[NMFS] National Marine Fisheries Service. 2016. *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Threshold Levels for Onset Permanent and Temporary Threshold Shifts*. U.S. Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-55. 178 pp. http://www.nmfs.noaa.gov/pr/acoustics/Acoustic%20Guidance%20Files/opr-55_acoustic_guidance_tech_memo.pdf.

[NOAA] National Oceanic and Atmospheric Administration. 2013. *Draft guidance for assessing the effects of anthropogenic sound on marine mammals: Acoustic threshold levels for onset of permanent and temporary threshold shifts*, December 2013, 76 pp. Silver Spring, Maryland: NMFS Office of Protected Resources. http://www.nmfs.noaa.gov/pr/acoustics/draft_acoustic_guidance_2013.pdf.

[NOAA] National Oceanic and Atmospheric Administration. 2015. *Draft guidance for assessing the effects of anthropogenic sound on marine mammal hearing: Underwater acoustic threshold levels for onset of permanent and temporary threshold shifts*, July 2015, 180 pp. Silver Spring, Maryland: NMFS Office of Protected Resources. http://www.nmfs.noaa.gov/pr/acoustics/draft%20acoustic%20guidance%20July%202015.pdf.

[NOAA] National Oceanic and Atmospheric Administration and U.S. Department of Commerce. 2016. *Document Containing Proposed Changes to the NOAA Draft Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Threshold Levels for Onset of Permanent and Temporary Threshold Shifts*. *In*: National Oceanic and Atmospheric Administration and U.S. Department of Commerce. 24 pp. http://www.nmfs.noaa.gov/pr/acoustics/draft_guidance_march_2016_.pdf.

[NOAA] National Oceanic and Atmospheric Administration (U.S.). 1998. Incidental taking of marine mammals; Acoustic harassment. *Federal Register* 63(143): 40103.

[ONR] Office of Naval Research. 1998. *ONR Workshop on the Effect of Anthropogenic Noise in the Marine Environment*. Dr. R. Gisiner Chair.

Aerts, L., M. Blees, S. Blackwell, C. Greene, K. Kim, D. Hannay, and M. Austin. 2008. *Marine mammal monitoring and mitigation during BP Liberty OBC seismic survey in Foggy Island Bay, Beaufort Sea, July-August 2008: 90-day report*. Document Number LGL Report P1011-1. Report by LGL Alaska Research Associates Inc., LGL Ltd., Greeneridge Sciences Inc. and JASCO Applied Sciences for BP Exploration Alaska. 199 pp. http://www.nmfs.noaa.gov/pr/pdfs/permits/bp_liberty_monitoring.pdf.

ANSI S12.7-1986. R2006. *American National Standard Methods for Measurements of Impulsive Noise*. American National Standards Institute, New York.

ANSI S1.1-1994. R2004. *American National Standard Acoustical Terminology*. American National Standards Institute, New York.

ANSI/ASA S1.13-2005. R2010. *American National Standard Measurement of Sound Pressure Levels in Air*. American National Standards Institute and Acoustical Society of America, New York.

ANSI/ASA S3.20-1995. R2008. *American National Standard Bioacoustical Terminology*. American National Standards Institute and Acoustical Society of America, New York.

Arveson, P.T. and D.J. Vendittis. 2000. Radiated noise characteristics of a modern cargo ship. *Journal of the Acoustical Society of America* 107(1): 118-129.

Babushina, Y.S., G.L. Zaslavskii, and L.I. Yurkevich. 1991. Air and underwater hearing characteristics of the northern fur seal: Audiograms, frequency and differential thresholds. *Biophysics* 39: 900-913.

Becker, J.J., D.T. Sandwell, W.H.F. Smith, J. Braud, B. Binder, J. Depner, D. Fabre, J. Factor, S. Ingalls, et al. 2009. Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS. *Marine Geodesy* 32(4): 355-371.

Burdic, W.S. 1984. *Underwater acoustic system analysis*. 1st edition. Prentice Hall, Englewood Cliffs, NJ. 445.

Carnes, M.R. 2009. *Description and Evaluation of GDEM-V 3.0*. Document Number NRL Memorandum Report 7330-09-9165. US Naval Research Laboratory, Stennis Space Center, MS. 21 pp.

Collins, M.D. 1993. A split-step Padé solution for the parabolic equation method. *Journal of the Acoustical Society of America* 93(4): 1736-1742.

Collins, M.D., R.J. Cederberg, D.B. King, and S. Chin-Bing. 1996. Comparison of algorithms for solving parabolic wave equations. *Journal of the Acoustical Society of America* 100(1): 178-182.

Coppens, A.B. 1981. Simple equations for the speed of sound in Neptunian waters. *Journal of the Acoustical Society of America* 69(3): 862-863. http://link.aip.org/link/?JAS/69/862/1.

Dragoset, W.H. 1984. A comprehensive method for evaluating the design of airguns and airgun arrays. *Proceedings, 16th Annual Offshore Technology Conference* Volume 3, May 7-9, 1984. OTC 4747, Houston, Houston. 75–84 pp.

Ellison, W.T. and P.J. Stein. 1999. *SURTASS LFA High Frequency Marine Mammal Monitoring (HF/M3) Sonar: Sustem Description and Test & Evaluation*. Under U.S. Navy Contract N66604-98-D-5725.

Erbe, C., R. McCauley, C. McPherson, and A. Gavrilov. 2013. Underwater noise from offshore oil production vessels. *Journal of the Acoustical Society of America* 133(6): EL465-EL470.

Finneran, J.J. and A.K. Jenkins. 2012. *Criteria and thresholds for U.S. Navy acoustic and explosive effects analysis*. SPAWAR Systems Center Pacific, San Diego, California.

Finneran, J.J. 2015. *Auditory weighting functions and TTS/PTS exposure functions for cetaceans and marine carnivores*. San Diego: SSC Pacific.

Fletcher, J.L. and R.G. Busnel. 1978. *Effects of noise on wildlife*. Academic Press, New York.

François, R.E. and G.R. Garrison. 1982a. Sound absorption based on ocean measurements: Part I: Pure water and magnesium sulfate contributions. *Journal of the Acoustical Society of America* 72(3): 896-907.

François, R.E. and G.R. Garrison. 1982b. Sound absorption based on ocean measurements: Part II: Boric acid contribution and equation for total absorption. *Journal of the Acoustical Society of America* 72(6): 1879-1890.

Funk, D., D. Hannay, D. Ireland, R. Rodrigues, and W. Koski (eds.). 2008. *Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July–November 2007: 90-day report*. LGL Report P969-1. Prepared by LGL Alaska Research Associates Inc., LGL Ltd., and JASCO Research Ltd. for Shell Offshore Inc., National Marine Fisheries Service (US), and US Fish and Wildlife Service. 218 pp.

Gray, L.M. and D.S. Greenley. 1980. Source level model for propeller blade rate radiation for the world's merchant fleet. *J. Acoust. Soc. Am.* 67: 516-522.

Greene, C.R., Jr. and W.J. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. *Journal of the Acoustical Society of America* 83(6): 2246-2254.

Hamilton, E.L. 1980. Geoacoustic modeling of the sea floor. *Journal of the Acoustical Society of America* 68: 1313-1340.

Hannay, D., A. MacGillivray, M. Laurinolli, and R. Racca. 2004. *Sakhalin Energy: Source Level Measurements from 2004 Acoustics Program*. Version 1.5. Technical report prepared for Sakhalin Energy by JASCO Applied Sciences.

Hannay, D. and R. Racca. 2005. *Acoustic Model Validation*. Document Number 0000-S-90-04-T-7006-00-E, Revision 02. Technical report for Sakhalin Energy Investment Company Ltd. by JASCO Research Ltd. 34 pp.

Harris, C.M. 1998. *Handbook of acoustical measurements and noise control*. 3rd edition. Acoustical Society of America, Huntington, NY.

HESS Workshop. 1998. *Mitigation Guidelines for High-Energy Seismic Surveys off Southern California*. A. Knastner Ed., Mediation Institute, Pepperdine University, CA.

Ireland, D.S., R. Rodrigues, D. Funk, W. Koski, and D. Hannay. 2009. *Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July–October 2008: 90-Day Report*. Document Number LGL Report P1049-1. 277 pp.

Kastak, D. and R.J. Schusterman. 1998. Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise, and ecology. *Journal of the Acoustical Society of America* 103: 2216-2228.

Kastelein, R.A., R. van Schie, W.C. Verboom, and D. de Haan. 2005. Underwater hearing sensitivity of a male and a female Steller sea lion (*Eumetopias jubatus*). *Journal of the Acoustical Society of America* 118(3): 1820-1829. http://link.aip.org/link/?JAS/118/1820/1.

Kyhn, L.A., J. Tougaard, F. Jensen, M. Wahlberg, G. Stone, A. Yoshinaga, K. Beedholm, and P.T. Madsen. 2009. Feeding at a high pitch: Source parameters of narrow band, high-frequency clicks from echolocating off-shore hourglass dolphins and coastal Hector's dolphins. *Journal of the Acoustical Society of America* 125(3): 1783-1791.

Landro, M. 1992. Modeling of GI gun signatures. *Geophysical Prospecting* 40: 721–747.

Laws, M., L. Hatton, and M. Haartsen. 1990. Computer modeling of clustered airguns. *First Break* 8: 331–338.

Lurton, X. 2002. *An Introduction to Underwater Acoustics: Principles and Applications*. Springer, Chichester, U.K. 347.

MacGillivray, A. 2014. A model for underwater sound levels generated by marine impact pile driving. *Proceedings of Meetings on Acoustics* 20(1): 045008. http://scitation.aip.org/content/asa/journal/poma/20/1/10.1121/2.0000030.

MacGillivray, A.O. 2006a. *Acoustic Modelling Study of Seismic Airgun Noise in Queen Charlotte Basin*. MSc Thesis. University of Victoria, Victoria, BC. 98 pp.

MacGillivray, A.O. 2006b. *Underwater Acoustic Source Level Measurements of Castoro Otto and Fu Lai*. JASCO Applied Sciences Ltd.

MacGillivray, A.O. and N.R. Chapman. 2012. Modeling underwater sound propagation from an airgun array using the parabolic equation method. *Canadian Acoustics* 40(1): 19-25. http://jcaa.caa-aca.ca/index.php/jcaa/article/view/2502.

Martin, B., K. Broker, M.-N.R. Matthews, J. MacDonnell, and L. Bailey. 2015. *Comparison of measured and modeled air-gun array sound levels in Baffin Bay, West Greenland. OceanNoise 2015*, 11-15 May, Barcelona, Spain.

Mattsson, A. and M. Jenkerson. 2008. *Single Airgun and Cluster Measurement Project*. *Joint Industry Programme (JIP) on Exploration and Production Sound and Marine Life Proramme Review*, October 28-30. International Association of Oil and Gas Producers, Houston, TX.

Maxon Consulting Inc. 2014. *Environmental Baseline Study: Guyana Stabroek Block*. Ref. 14024. Prepared by Maxon Consulting, Inc. and TDI Brooks International, Inc. for Esso Exploration and Production Guyana Ltd.

Moore, P.W.B. and R.J. Schusterman. 1987. Audiometric assessment of northern fur seals, *Callorhinus ursinus*. *Marine Mammal Science* 3: 31-53.

Mulsow, J. and C. Reichmuth. 2007. Electrophysiological assessment of temporal resolution in pinnipeds. *Aquatic Mammals* 33: 122-131.

Mulsow, J., J.J. Finneran, and D.S. Houser. 2011a. California sea lion (*Zalophus californianus*) aerial hearing sensitivity measured using auditory steady-state response and psychophysical methods. *Journal of the Acoustical Society of America* 129: 2298-2306.

Mulsow, J., C. Reichmuth, F.M.D. Gulland, D.A.S. Rosen, and J.J. Finneran. 2011b. Aerial audiograms of several California sea lions (*Zalophus californianus*) and Steller sea lions (*Eumetopias jubatus*) measured using single and multiple simultaneous auditory steady-state response methods. *Journal of Experimental Biology* 214: 1138-1147.

Nedwell, J.R. and A.W. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. *Workshop on Seismics and Marine Mammals*. 23–25th June 1998, London, U.K.

Nedwell, J.R., A.W.H. Turnpenny, J. Lovell, S.J. Parvin, R. Workman, and J.A.L. Spinks. 2007. *A validation of the dB_{ht} as a measure of the behavioural and auditory effects of underwater noise*. Report No. 534R1231 prepared by Subacoustech Ltd. for the UK Department of Business, Enterprise and Regulatory Reform under Project No. RDCZ/011/0004. www.subacoustech.com/information/downloads/reports/534R1231.pdf.

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review* 37(2): 81-115.

O'Neill, C., D. Leary, and A. McCrodan. 2010. Sound Source Verification. (Chapter 3) *In* Blees, M.K., K.G. Hartin, D.S. Ireland, and D. Hannay (eds.). *Marine mammal monitoring and mitigation during open water seismic exploration by Statoil USA E&P Inc. in the Chukchi Sea, August-October 2010: 90-day report*. LGL Report P1119. Prepared by LGL Alaska Research Associates Inc., LGL Ltd., and JASCO Applied Sciences Ltd. for Statoil USA E&P Inc., National Marine Fisheries Service (US), and US Fish and Wildlife Service. 1-34.

Parola, J.F. 1970. *Mechanics of Impact Pile Driving*. Ph.D. Thesis. University of Illinois. 250 pp.

Payne, R. and D. Webb. 1971. Orientation by means of long range acoustic signaling in baleen whales. *Annals of the New York Academy of Sciences* 188: 110-142.

Pile Dynamics, Inc. 2010. GRLWEAP.

Plomp, R. and M.A. Bouman. 1959. Relation between Hearing Threshold and Duration for Tone Pulses. *The Journal of the Acoustical Society of America* 31(6): 749-758. http://scitation.aip.org/content/asa/journal/jasa/31/6/10.1121/1.1907781.

Racca, R., A. Rutenko, K. Bröker, and M. Austin. 2012a. A line in the water - design and enactment of a closed loop, model based sound level boundary estimation strategy for mitigation of behavioural impacts from a seismic survey. *11th European Conference on Underwater Acoustics 2012*. Volume 34(3), Edinburgh, United Kingdom.

Racca, R., A. Rutenko, K. Bröker, and G. Gailey. 2012b. *Model based sound level estimation and in-field adjustment for real-time mitigation of behavioural impacts from a seismic survey and post-event evaluation of sound exposure for individual whales*. *Acoustics 2012 Fremantle: Acoustics, Development and the Environment*, Fremantle, Australia. http://www.acoustics.asn.au/conference_proceedings/AAS2012/papers/p92.pdf.

Racca, R.G. and J.A. Scrimger. 1986. *Underwater Acoustic Source Characteristics of Air and Water Guns*. Document Number DREP Tech. Rep. 06SB 97708-5-7055. Report by JASCO Research Ltd. for Defence Research Establishment Pacific (Canada), Victoria, BC.

Reinhall, P.G. and P.H. Dahl. 2011. *An Investigation of Underwater Sound Propagation from Pile Driving*. Document Number WA-RD 781.1. Prepared for the State of Washington Department of Transportation. 39 pp. http://www.wsdot.wa.gov/research/reports/fullreports/781.1.pdf.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. *Marine Mammals and Noise*. Academic Press, San Diego, California. 576.

Ross, D. 1976. *Mechanics of Underwater Noise*. Pergamon Press, New York. 375 pp.

Rucker, J.B. 1967. Paleoecological analysis of cheilostome Bryozoa from Venezuela-British Guiana shelf sediments. *Bulletin of Marine Science* 17(4): 787-839.

Sandwell, D.T., R.D. Müller, W.H.F. Smith, E. Garcia, and R. Francis. 2014. New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure. *Science* 346(6205): 65-67.

Schusterman, R.J., R.F. Balliet, and J. Nixon. 1972. Underwater audiogram of the California sea lion by the conditioned vocalization technique. *Journal of the Experimental Analysis of Behavior* 17: 339-350.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammals* 33(4): 411-521.

Spence, J., R. Fischer, M. Bahtiarian, L. Boroditsky, N. Jones, and R. Dempsey. 2007. *Review of Existing and Future Potential Treatments for Reducing Underwater Sound from Oil and Gas Industry Activities*. Report Number NCE REPORT 07-001. Report prepared by Noise Control Engineering, Inc., for Joint Industry Programme on E&P Sound and Marine Life.

Teague, W.J., M.J. Carron, and P.J. Hogan. 1990. A comparison between the Generalized Digital Environmental Model and Levitus climatologies. *Journal of Geophysical Research* 95(C5): 7167-7183.

Tyack, P.L. 2008. Implications for marine mammals of large-scale changes in the marine acoustic environment. *Journal of Mammalogy* 89(3): 549-558.

Warner, G., C. Erbe, and D. Hannay. 2010. Underwater Sound Measurements. (Chapter 3) *In* Reiser, C.M., D.W. Funk, R. Rodrigues, and D. Hannay (eds.). *Marine Mammal Monitoring and Mitigation during Open Water Shallow Hazards and Site Clearance Surveys by Shell Offshore Inc. in the Alaskan Chukchi Sea, July-October 2009: 90-Day Report*. LGL Report P1112-1. Report by LGL Alaska Research Associates Inc. and JASCO Applied Sciences for Shell Offshore Inc., National Marine Fisheries Service (US), and US Fish and Wildlife Service. 1-54.

Weilgart, L.S. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology* 85: 1091-1116.

Zhang, Y. and C. Tindle. 1995. Improved equivalent fluid approximations for a low shear speed ocean bottom. *Journal of the Acoustical Society of America* 98(6): 3391-3396. http://scitation.aip.org/content/asa/journal/jasa/98/6/10.1121/1.413789.

Ziolkowski, A. 1970. A method for calculating the output pressure waveform from an airgun. *Geophysical Journal of the Royal Astronomical Society* 21(2): 137-161.

Zykov, M.M., T.J. Deveau, and D. Zeddies. 2016. *Modelling Underwater Sound Associated with Constructing Canaport Energy East Marine Terminal: Impact and Vibratory Pile Driving Noise*. Document Number 01161, Version 3.0. Technical report by JASCO Applied Sciences for Stantec Consulting Ltd.

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Appendix A. Underwater Acoustics

A.1. Acoustic Metrics

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 µPa. Because the perceived loudness of sound, especially impulsive sound such as from seismic sources, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate sound and its effects on marine life. We provide specific definitions of relevant metrics used in the accompanying report. Where possible we follow the ANSI and ISO standard definitions and symbols for sound metrics, but these standards are not always consistent.

The zero-to-peak sound pressure level, or peak sound pressure level (PK; dB re 1 µPa), is the maximum instantaneous sound pressure level in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$L_{p,pk} = 20\log_{10}\left[\frac{\max(|p(t)|)}{p_0}\right]. \quad \text{(A-1)}$$

$L_{p,pk}$ is often included as a criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of a sound event, it is generally a poor indicator of perceived loudness.

The root-mean-square (rms) sound pressure level (SPL; dB re 1 µPa) is the rms pressure level in a stated frequency band over a specified time window (T, s) containing the acoustic event of interest. It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \Big/ p_0^2\right). \quad \text{(A-2)}$$

The SPL represents a nominal effective continuous sound over the duration of an acoustic event, such as the emission of one acoustic pulse, a marine mammal vocalization, the passage of a vessel, or over a fixed duration. Because the window length, T, is the divisor, events with similar sound exposure level (SEL) but more spread out in time have a lower SPL.

The sound exposure level (SEL, dB re 1 µPa^2·s) is a measure related to the acoustic energy contained in one or more acoustic events (N). The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T):

$$L_E = 10\log_{10}\left(\int_T p^2(t)dt \Big/ T_0 p_0^2\right) \quad \text{(A-3)}$$

where T_0 is a reference time interval of 1 s. The SEL continues to increase with time when non-zero pressure signals are present. It therefore can be construed as a dose-type measurement, so the integration time used must be carefully considered in terms of relevance for impact to the exposed recipients.

SEL can be calculated over periods with multiple acoustic events or over a fixed duration. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}}\right). \quad \text{(A-4)}$$

If applied, the frequency weighting of an acoustic event should be specified, as in the case of M-weighted SEL (e.g., $L_{E,LFC,24h}$; Appendix A.3). The use of fast, slow, or impulse exponential-time-averaging or other time-related characteristics should else be specified.

A.1.1. 1/3-Octave Band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into 1/3-octave-bands, which are one-third of an octave wide; each octave represents a doubling in sound frequency. The center frequency of the ith 1/3-octave-band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{i/10} , \tag{A-5}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith 1/3-octave-band are defined as:

$$f_{lo} = 10^{-1/20} f_c(i) \quad \text{and} \quad f_{hi} = 10^{1/20} f_c(i) . \tag{A-6}$$

The 1/3-octave-bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure A-1). The acoustic modeling spans from band 10 ($f_c(10)$ = 10 Hz) to band 45 ($f_c(45)$ = 32 kHz).

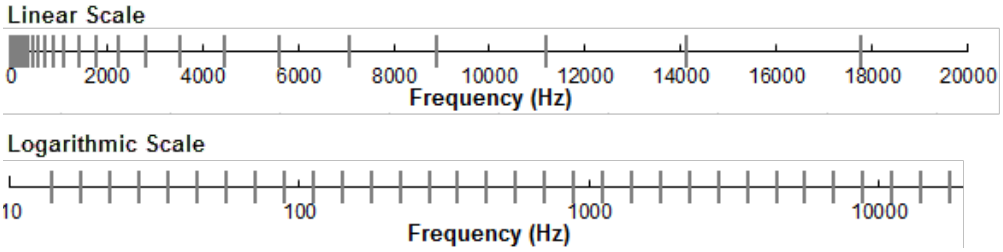


Figure A-1. One-third-octave-bands shown on a linear frequency scale and on a logarithmic scale.

The sound pressure level in the ith 1/3-octave-band $(L_b^{(i)})$ is computed from the power spectrum $S(f)$ between f_{lo} and f_{hi}:

$$L_b^{(i)} = 10 \log_{10} \left(\int_{f_{lo}}^{f_{hi}} S(f) df \right) . \tag{A-7}$$

Summing the sound pressure level of all the 1/3-octave-bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{L_b^{(i)}/10} . \tag{A-8}$$

Figure A-2 shows an example of how the 1/3-octave-band sound pressure levels compare to the power spectrum of an ambient noise signal. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum, especially at higher frequencies. Acoustic

modeling of 1/3-octave-bands require less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

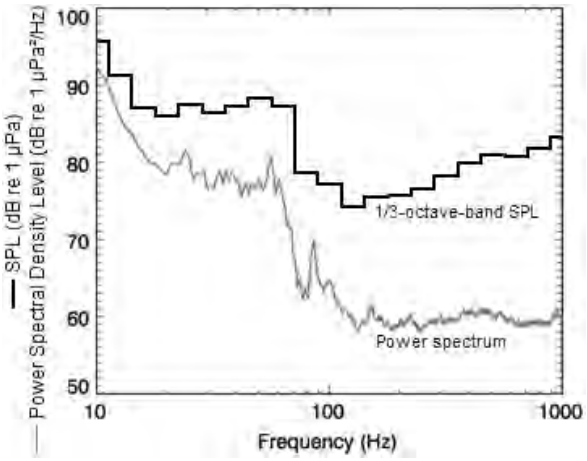


Figure A-2. A power spectrum and the corresponding 1/3-octave-band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

A.2. Sound Sources

A.2.1. Types of Sound

Numerous scientific reviews and workshops over the past 40 years have focused on how anthropogenic sounds can affect marine life (Payne and Webb 1971, Fletcher and Busnel 1978, Richardson et al. 1995, MMC 2007, Nowacek et al. 2007, Southall et al. 2007, Weilgart 2007, Tyack 2008). When assessing potential impacts of anthropogenic sound on marine life, sound sources and their resulting sounds are commonly divided into two main categories: impulsive, which includes single and multiple pulses, and non-impulsive. Impulsive sounds are typically brief and intermittent with a rapid rise time and decay (NOAA 2015). Examples of impulsive sound sources include impact pile driving, seismic sources, and some types of sonar. Non-impulsive sounds can be brief or prolonged, continuous or intermittent, and do not generally have the high peak pressure and rapid rise time that impulsive sounds do (NOAA 2015). Examples of non-impulsive sound sources include vibratory pile driving, vessel propulsion systems, and some types of sonar.

Numerous definitions and mathematical distinctions (e.g., Burdic 1984, Harris 1998) differentiate impulsive and non-impulsive sounds from one another. In practice, however, the distinction between these two sound types is not always apparent. Certain signals, such as those emitted by acoustic deterrents and harassment devices, share properties with both impulsive and non-impulsive sounds. Similarly, while vibratory pile drivers are commonly classified as continuous, it is possible to distinguish the rapid rise times associated with individual strikes of the driver very near the pile (within a few meters). Propagation effects also play a role in the classification of sounds; a sound that is deemed impulsive near the source might be categorized as non-impulsive farther from the source, due to spreading (e.g., Greene and Richardson 1988).

A.2.2. Vessel Sounds

Underwater sound that radiates from vessels is produced mainly by propeller and thruster cavitation, with a smaller fraction of sound produced by sound transmitted through the hull, such as by engines, gearing, and other mechanical systems. Sound levels tend to be the highest when thrusters are used to position the vessel and when the vessel is transiting at high speeds. A vessel's sound signature depends on the vessel's size, power output, propulsion system (e.g., conventional propellers vs. Voith Schneider propulsion), and the design characteristics of the given system (e.g., blade shape and size). A vessel produces broadband acoustic energy with most of the energy emitted below a few kilohertz. Sound from onboard machinery, particularly sound below 200 Hz, dominates the sound spectrum before cavitation begins—normally around 8–12 knots on many commercial vessels (Spence et al. 2007). Sound from vessels typically raises the background sound level by tenfold or more (Arveson and Vendittis 2000).

A.2.3. Vertical Seismic Profile Sources

Seismic air guns generate pulsed acoustic energy by releasing a highly compressed air bubble into the water that expands and then collapses. These sources produce frequencies from several hertz to a few kilohertz, with larger element volumes producing lower frequencies and higher sound levels.

During a vertical seismic profiling, a stationary source array is deployed from either a drill ship or a closely stationed auxiliary vessel. A single element produces an approximately omnidirectional sound field, emitting acoustic energy equally in all directions. For all seismic surveys, source array layouts and firing delays are configured to achieve higher sound energy emission levels in the vertical direction where the pulses from all elements add in-phase. Lower levels of sound energy are emitted in other directions. Source arrays might show significant directionality in the horizontal direction due to the phase delay between pulses because the elements are horizontally separated.

A.2.4. Impact Pile Driving

Impact pile driving consists of infixing piles of various shapes and materials into the ground by striking the top end of the pile with a ram. In its simplest form, pile driving is achieved by a free-falling ram directly striking the pile. After the strike, the ram is raised and the action repeated until a sufficient portion of the pile penetrates the ground. Additional equipment can be used for higher efficiency or to accomplish activities such as driving fully submerged piles. For example, free-falling pile drivers have generally been replaced by more sophisticated mechanisms that control downward and upward movement of the ram. Cushion materials can be installed between the ram and the drive head. Aside from redistributing some of the energy from the hammer impact and protecting the contact surfaces from damage, the cushion also allows some control on the maximum amplitude and duration of the force applied to the pile.

After each strike, the initial radial deformation at the top of the pile wall caused by impact compression rapidly travels downward along the pile, generating in the process a pressure wave in the water column. Because of the properties of the material, the deformation travels down the pile faster than the speed of sound in water, resulting in a radiating pressure wave that resemble a Mach cone with a cone angle of ~17° (Reinhall and Dahl 2011).

A.3. Acoustic Effect Criteria

A.3.1. Marine Mammals

It has been long recognized that marine mammals can be adversely affected by underwater anthropogenic sound. For example, Payne and Webb (1971) suggested that communication distances of fin whales are reduced by shipping sounds. Subsequently, similar concerns arose regarding effects of other underwater sound sources and the possibility that impulsive sources could cause auditory injury. This led to a series of workshops held in the late 1990s, conducted to address acoustic mitigation requirements for seismic surveys and other underwater sound sources (NMFS 1998, ONR 1998, HESS 1998, Nedwell and Turnpenny 1998, Ellison and Stein 1999).

The U.S. National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) considered recommendations from these workshops and adopted a set of interim thresholds for assessing injury and disturbance due to both impulsive and non-impulsive, or continuous sound, types of acoustic sources (e.g., NOAA 1998). We refer to these thresholds as the NMFS SPL criteria. Regulatory agencies in many countries have applied these criteria since the early 2000s, but recent advances in assessment approaches are starting to replace them.

The NMFS SPL criteria for acoustic exposure injury to marine mammals were set according to recommendations for cautionary estimates of sound levels leading to onset of permanent hearing threshold shift (PTS). These criteria prescribe injury thresholds of 190 dB re 1 µPa SPL for pinnipeds and 180 dB re 1 µPa SPL for cetaceans (NMFS 2013). A corresponding injury threshold was not defined for non-impulsive sounds at that time. NMFS indicates that the SPL criteria should be used for all sources including sonars and explosives (NMFS 2013). These injury thresholds are applied to individual acoustic pulses and do not consider the overall duration of the sound or its acoustic frequency distribution.

Criteria that do not take into account exposure duration or acoustic spectra are generally insufficient for assessing hearing injury. Human workplace noise assessments consider the SPL as well as the duration of exposure and sound spectral characteristics. For example, the International Institute of Noise Control Engineering (I-INCE) and the Occupational Safety and Health Administration (OSHA) suggests thresholds in C-weighted peak pressure level and A-weighted time-average sound level (dB(A)[1] L_{eq}). They also suggest exchange rates that increase the allowable thresholds for each halving or doubling of exposure time. This approach assumes that hearing damage depends on the relative loudness perceived by the human ear. It also assumes that the ear might partially recover from past exposures, particularly if there are periods of quiet nested within the overall exposure.

In recognition of shortcomings of the SPL-only based injury criteria, in 2005 NMFS sponsored the Noise Criteria Group to review literature on marine mammal hearing to propose new acoustic exposure criteria (NMFS 2013). Some members of this expert group published a landmark paper (Southall et al. 2007) that suggested assessment methods similar to those applied for humans. The resulting recommendations introduced dual acoustic injury criteria for impulsive sounds that included peak pressure level thresholds and cumulative SEL_{24h} thresholds, where the subscripted *24h* refers to the 24 hour accumulation period for calculating SEL. The peak pressure level criterion is not frequency weighted whereas the SEL_{24h} is frequency weighted according to one of four marine mammal species hearing groups: Low-, Mid- and High-Frequency Cetaceans (LFC, MFC, and HFC respectively) and Pinnipeds in Water (PINN). These weighting functions are referred to as M-weighting filters (analogous to the A-weighting filter for human; Appendix A.4.1). The SEL_{24h} thresholds were obtained by extrapolating measurements of onset levels of Temporary Threshold Shift (TTS) in belugas by the amount of TTS required to produce Permanent Threshold Shift (PTS) in chinchillas. The Southall et al. (2007) recommendations do not specify an exchange rate, which suggests that the thresholds are the same regardless of the duration of exposure (i.e., it infers a 3 dB exchange rate).

[1] The "A" refers to a specific frequency-dependent filter shaped according to a human equal loudness contour.

In 2012, the US Navy recommended a different set of criteria for assessing Navy operations (Finneran and Jenkins 2012). Their analysis incorporated new dolphin equal-loudness contours[2] to update weighting functions and injury thresholds for LFC, MFC, and HFC. They recommended separating the pinniped group into otariids (eared seals) and phocids (earless seals) and assigning adjusted frequency thresholds to the former based on several sensitivity studies (Schusterman et al. 1972, Moore and Schusterman 1987, Babushina et al. 1991, Kastak and Schusterman 1998, Kastelein et al. 2005, Mulsow and Reichmuth 2007, Mulsow et al. 2011a, Mulsow et al. 2011b).

In 2015, the US Navy updated the set of recommended thresholds and frequency-weighting functions based on newly available data Finneran (2015). In general, thresholds at low frequencies were increased from the 2012 recommendations, and thresholds for the low-frequency cetaceans were increased at all frequencies.

As of 2016, an optimal approach is not apparent. There is consensus in the research community that an SEL-based method is preferable either separately or in addition to an SPL-based approach to assess the potential for injuries. In August 2016, after substantial public and expert input into three draft versions and based largely on the above-mentioned literature (NOAA and US Dept of Commerce 2013, 2015, 2016), NMFS finalized technical guidance for assessing the effect of anthropogenic sound on marine mammal hearing (NMFS 2016). The guidance describes injury criteria with new thresholds and frequency weighting functions for five hearing groups described by Finneran and Jenkins (2012).

A.4. Marine Mammals Frequency Weighting

The potential for sound to affect animals depends on how well the animals can hear it. Sounds are less likely to disturb or injure the auditory system of an animal if they are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e., barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency weighting relevant to an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

A.4.1. Southall et al. 2007

Auditory weighting functions for marine mammals—called *M-weighting* functions—were proposed by Southall et al. (2007). Functions were defined for five hearing groups of marine mammals:

- Low-frequency cetaceans (LFCs)—mysticetes (baleen whales)
- Mid-frequency cetaceans (MFCs)—some odontocetes (toothed whales)
- High-frequency cetaceans (HFCs)—odontocetes specialized for using high-frequencies
- Pinnipeds in water—seals, sea lions, and walrus
- Pinnipeds in air

The M-weighting functions have unity gain (0 dB) through the passband and their high and low frequency roll-offs are approximately –12 dB per octave. The amplitude response in the frequency domain of each M-weighting function is defined by:

$$G(f) = -20\log_{10}\left[\left(1+\frac{a^2}{f^2}\right)\left(1+\frac{f^2}{b^2}\right)\right] \qquad \text{(A-9)}$$

[2] An equal-loudness contour is the measured sound pressure level (dB re 1 µPa for underwater sounds) over frequency, for which a listener perceives a constant loudness when exposed to pure tones.

where *G*(f) is the weighting function amplitude (in dB) at the frequency *f* (in Hz), and *a* and *b* are the estimated lower and upper hearing limits, respectively, which control the roll-off and passband of the weighting function. The parameters *a* and *b* are defined uniquely for each hearing group (Table A-1). The auditory weighting functions recommended by Southall et al. (2007) are shown in Figure A-3.

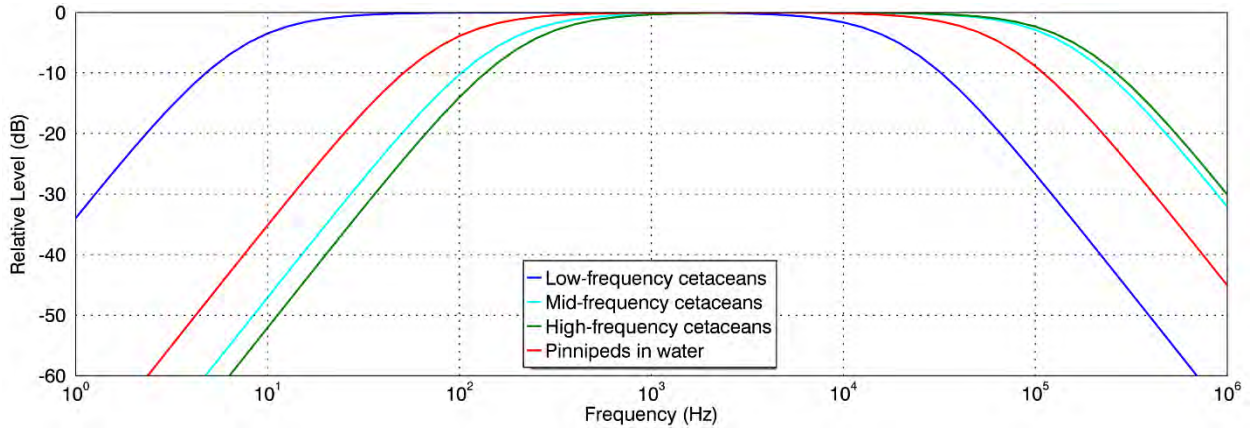


Figure A-3. Auditory weighting functions for functional marine mammal hearing groups as recommended by Southall et al. (2007).

Table A-1. Parameters for the auditory weighting functions recommended by Southall et al. (2007).

Hearing group	Southall et al. (2007)	
	a (Hz)	*b* (Hz)
Low-frequency cetaceans (LFC)	7	22,000
Mid-frequency cetaceans (MFC)	150	160,000
High-frequency cetaceans (HFC)	200	180,000
Pinnipeds in water (Pw)	75	75,000

A.4.2. Finneran 2015

In 2015, a U.S. Navy Technical Report by Finneran (2015) recommended new auditory weighting functions. The overall shape of the auditory weighting functions is similar to human A-weighting functions, which follows the sensitivity of the human ear at low sound levels. The new frequency-weighting function is:

$$G(f) = K + 10\log_{10}\left[\left(\frac{(f/f_{lo})^{2a}}{\left[1+(f/f_{lo})^{2}\right]^{a}\left[1+(f/f_{hi})^{2}\right]^{b}}\right)\right], \quad \text{(A-10)}$$

Although the inclusion of some species changed (e.g., the addition of hourglass (*Lagenorhynchus cruciger*) and Peale's (*Lagenorhynchus australis*) dolphins to the high-frequency functional hearing group), the five recommended functional hearing groups remained those presented in the Finneran and Jenkins (2012). Table A-2 lists the frequency-weighting parameters for each hearing group; Figure A-4 shows the resulting frequency-weighting curves.

Table A-2. Parameters for the auditory weighting functions recommended by Finneran (2015).

Hearing group	*a*	*b*	f_{lo} (Hz)	f_{hi} (kHz)	*K* (dB)
Low-frequency cetaceans	1.5	2	380	13,000	0.43
Mid-frequency cetaceans	1.6	2	7,400	110,000	1.02
High-frequency cetaceans	1.7	2	16,000	150,000	1.63
Phocid pinnipeds in water	2.0	2	770	27,000	0.49
Otariid pinnipeds in water	0.8	2	1,300	37,000	0.38

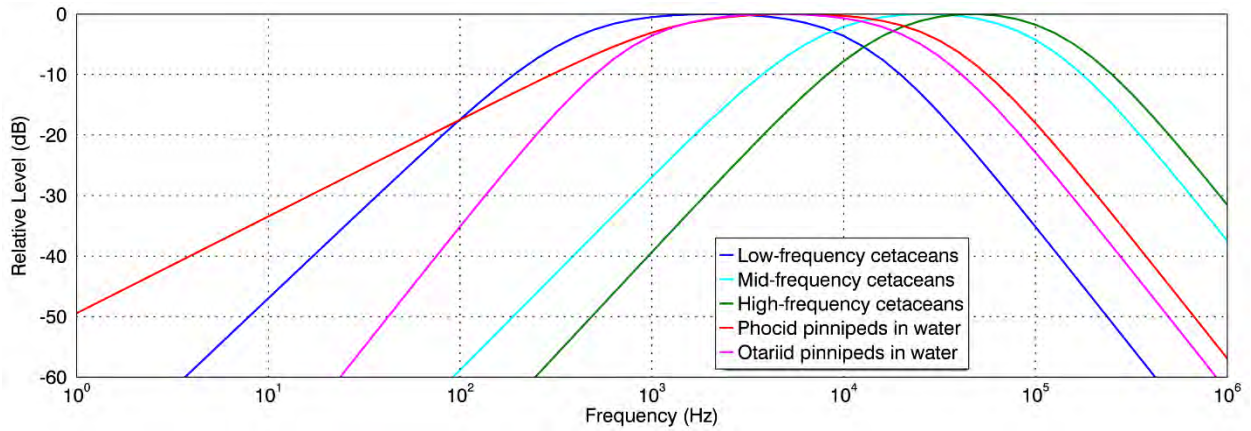


Figure A-4. Auditory weighting functions for functional marine mammal hearing groups as recommended by Finneran (2015).

A.5. Sound Propagation Models

A.5.1. Transmission Loss

The propagation of sound through the environment was modeled by predicting the acoustic transmission loss—a measure, in decibels, of the decrease in sound level between a source and a receiver some distance away. Geometric spreading of acoustic waves is the predominant way by which transmission loss occurs. Transmission loss also happens when the sound is absorbed and scattered by the seawater, and absorbed scattered, and reflected at the water surface and within the seabed. Transmission loss depends on the acoustic properties of the ocean and seabed; its value changes with frequency.

If the acoustic source level (SL), expressed in dB re 1 µPa @ 1 m, and transmission loss (TL), in units of dB, at a given frequency are known, then the received level (RL) at a receiver location can be calculated in dB re 1 µPa @ 1 m by:

$$\mathrm{RL} = \mathrm{SL} - \mathrm{TL}\ . \qquad \text{(A-11)}$$

A.5.2. Acoustic Propagation with MONM

Underwater sound propagation (i.e., transmission loss) at frequencies of 10 Hz to 2 kHz was predicted with JASCO's Marine Operations Noise Model (MONM). MONM computes received per-pulse SEL for directional impulsive sources, and SEL over 1 s for non-impulsive sources, at a specified source depth.

MONM computes acoustic propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the U.S. Naval Research Laboratory's Range-dependent

Acoustic Model (RAM), which has been modified to account for a solid seabed (Zhang and Tindle 1995). The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). MONM accounts for the additional reflection loss at the seabed, which results from partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. MONM incorporates the following site-specific environmental properties: a bathymetric grid of the modeled area, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor.

MONM computes acoustic fields in three dimensions by modeling transmission loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as N×2-D. These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding N = 360°/$\Delta\theta$ number of planes (Figure A-5).

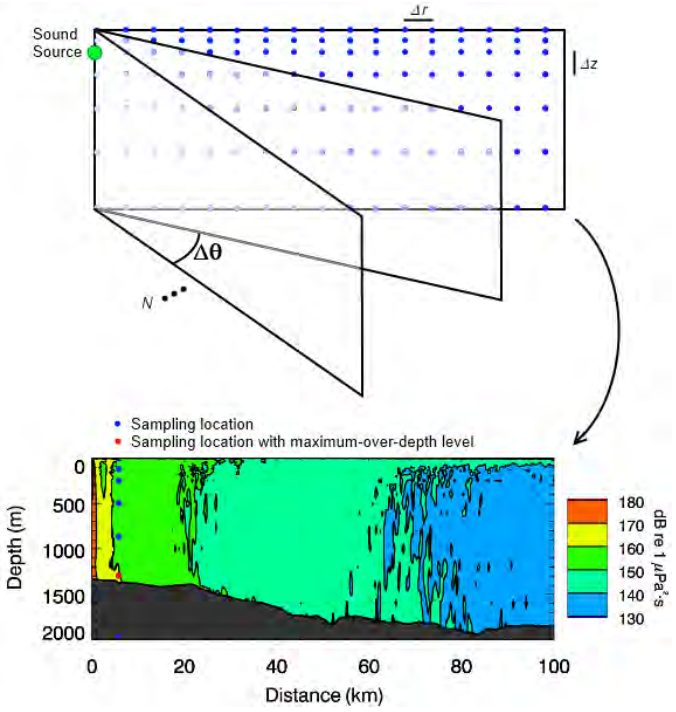


Figure A-5. The N×2-D and maximum-over-depth modeling approach used by MONM.

MONM treats frequency dependence by computing acoustic transmission loss at the center frequencies of 1/3-octave-bands. Sufficiently many 1/3-octave-bands, starting at 10 Hz, are modeled to include the majority of acoustic energy emitted by the source. At each center frequency, the transmission loss is modeled within each of the N vertical planes as a function of depth and range from the source. The 1/3-octave-band received per-pulse SEL are computed by subtracting the band transmission loss values from the directional source level in that frequency band. Composite broadband received SEL are then computed by summing the received 1/3-octave-band levels.

The frequency-dependent transmission loss computed by MONM may be corrected to account for the attenuation of acoustic energy by molecular absorption in seawater. The volumetric sound absorption is quantified by an attenuation coefficient, expressed in units of decibels per kilometer (dB/km). The absorption coefficient depends on the temperature, salinity, and pressure of the water as well as the sound frequency. In general, the absorption coefficient increases with the square of frequency. The absorption of acoustic wave energy has a noticeable effect (>0.05 dB/km) at frequencies above 1 kHz. For example, at 10 kHz the absorption loss over 10 km distance can exceed 10 dB. This coefficient for seawater can be computed according to the formulae of François and Garrison (1982b, b), which

consider the contributions of pure seawater, magnesium sulfate, and boric acid. The formula applies to all oceanic conditions and frequencies from 200 Hz to 1 MHz. For this project, absorption coefficients were computed and applied for all modeled frequencies. Because of the computational expense associated with parabolic equation modeling at frequencies at or above several kHz and the relative importance of absorption at such frequencies, the transmission loss in each frequency band between 6 and 32 kHz was approximated from the transmission loss computed at 5 kHz by applying the correct frequency-dependent absorption coefficient in each band.

The received per-pulse SEL sound field within each vertical radial plane is sampled at various ranges from the source, generally with a fixed radial step size. At each sampling range along the surface, the sound field is sampled at various depths, with the step size between samples increasing with depth below the surface. The step sizes are chosen to provide increased coverage near the depth of the source and at depths of interest in terms of the sound speed profile. For areas with deep water, sampling is not performed at depths beyond those reachable by marine mammals. The received per-pulse SEL at a surface sampling location is taken as the maximum value that occurs over all samples within the water column, i.e., the maximum-over-depth received per-pulse SEL. These maximum-over-depth per-pulse SEL are presented as color contours around the source.

MONM's predictions have been validated against experimental data from several underwater acoustic measurement programs conducted by JASCO (Hannay and Racca 2005, Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010, Racca et al. 2012a, Racca et al. 2012b, Martin et al. 2015).

An inherent variability in measured sound levels is caused by temporal variability in the environment and the variability in the signature of repeated acoustic impulses (sample sound source verification results is presented in Figure A-6). While MONM's predictions correspond to the averaged received levels, cautionary estimates of the threshold radii are obtained by shifting the best fit line (solid line, Figure A-6) upward so that the trend line encompasses 90% of all the data (dashed line, Figure A-6).

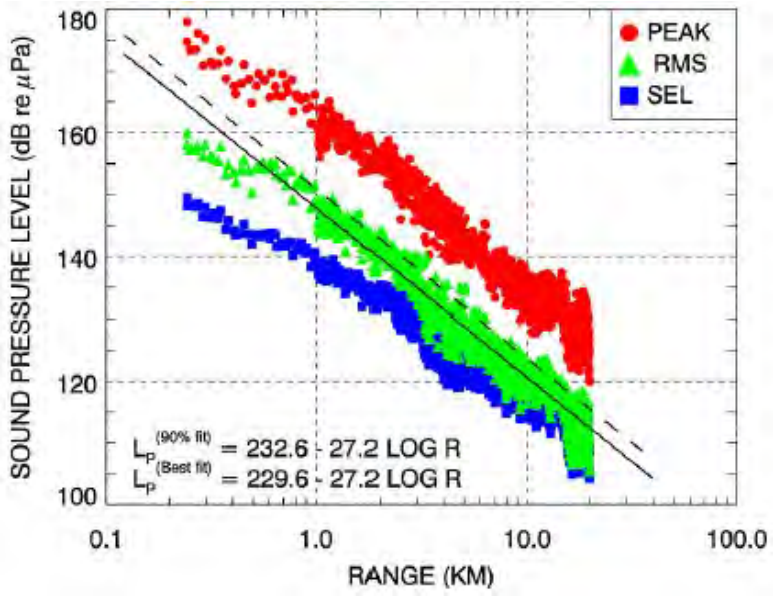


Figure A-6. Peak and SPL and per-pulse SEL versus range from a 20 in^3 air gun array. Solid line is the least squares best fit to SPL. Dashed line is the best fit line increased by 3.0 dB to exceed 90% of all SPL values (90th percentile fit) (Ireland et al. 2009, Figure 10).

Sound source verification results show that this 90th percentile best-fit is, on average, 3 dB higher than the original best fit line for sources in water depths greater than 20 m (Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010). Consequently, a safety factor of 3 dB is

customarily added to the predicted received levels to provide cautionary results reflecting the inherent variability of sound levels in the modeled area.

The transmission loss computed by MONM can be further corrected to account for the attenuation of acoustic energy by molecular absorption in seawater. The volumetric sound absorption is quantified by an attenuation coefficient, expressed in units of decibels per kilometer (dB/km). The absorption coefficient depends on the temperature, salinity, and pressure of the water as well as the sound frequency. In general, the absorption coefficient increases with the square of frequency. The absorption of acoustic wave energy has a noticeable effect (>0.05 dB/km) at frequencies above 1 kHz. At 10 kHz, the absorption loss over a 10 km distance can exceed 10 dB. This coefficient for seawater can be computed according to the formulae of François and Garrison (1982b, 1982a), which consider the contribution of pure seawater, magnesium sulfate, and boric acid. The formulae apply to all oceanic conditions and frequencies from 200 Hz to 1 MHz.

A.5.3. Acoustic Propagation with FWRAM

For impulsive sounds, time-domain representations of the pressure waves generated in the water are required to calculate peak pressure level or to accuratly model sound propagating away from a vertical source array. For this study, synthetic pressure waveforms were computed using FWRAM, which is a time-domain acoustic model based on the same wide-angle parabolic equation (PE) algorithm as MONM. FWRAM computes synthetic pressure waveforms versus range and depth for range-varying marine acoustic environments, and it takes the same environmental inputs as MONM (bathymetry, water sound speed profile, and seabed geoacoustic profile). Unlike MONM, FWRAM computes pressure waveforms via Fourier synthesis of the modeled acoustic transfer function in closely spaced frequency bands. FWRAM employs the array starter method to accurately model sound propagation from a spatially distributed source (MacGillivray and Chapman 2012).

Synthetic pressure waveforms were modeled over the frequency range 10–2048 Hz, inside a 1 s window. The synthetic pressure waveforms were post-processed, after applying a travel time correction, to calculate PK and SEL metrics versus range and depth from the sources.

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APPENDIX G

Appendix 2014 Environmental Baseline Study Report

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ENVIRONMENTAL BASELINE STUDY

GUYANA STABROEK BLOCK

Prepared for

Esso Exploration and Production Guyana Ltd.

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July 2014
Executive Summary Report

ENVIRONMENTAL BASELINE STUDY
GUYANA – STABROEK BLOCK

Executive Summary Report

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July 2014

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ACRONYMS AND ABBREVIATIONS

α	parametric probability
µg	microgram
µg L^{-1}	microgram per liter (parts per billion)
µg g^{-1}	microgram per gram (parts per million)
µm	micron (micrometer)
<	less than
>	greater than
≥	greater than or equal to
≤	less than or equal to
/	divider
%	percent
‰	parts per thousand
°	degrees
±	plus or minus
®	registered trade mark
amu	atomic mass unit
As	arsenic
ASE	accelerated solvent extractor
ASTM	American Society for Testing and Materials
ca.	approximately
C	centigrade
cm	centimeter
CPI	carbon preference index
CTD	conductivity, temperature and depth
CV	coefficient of variation
DRC	dynamic reaction cell
DGPS	Differential Global Positioning System
DO	dissolved oxygen
EBS	Environmental Baseline Study
g	gram
GC-FID	gas chromatography/flame ionization detection
GC-MS	gas chromatography/mass spectrometry
GGMC	Guyana Geology and Mines Commission
Hz	hertz
ICP-MS	inductively-coupled plasma/mass spectrometry (ICP)
ID	identifier
km	kilometer
km^2	square kilometer
L	liter
m	meter
m^2	square meter
MDL	method detection limit
mg	milligram
mg L^{-1}	milligram per liter
mL	milliliter

mm	millimeter
m/z	mass to charge ratio
n	number or count
N	North
na	not applicable
NASA	US National Aeronautics and Space Administration
ng g^{-1}	nanogram per gram (parts per billion)
ng L^{-1}	nanogram per liter (parts per trillion)
p	Pearson's Correlation Coefficient
PAH	polycyclic aromatic hydrocarbons
QA/QC	Quality Assurance/Quality Control
RPD	relative percent difference
RSD	relative standard deviation
RTG	Real Time Gypsy
RV	Research Vessel
s^{-1}	records per second
SHC	saturated and aliphatic hydrocarbons, and selected isoprenoids
SIM	selected ion monitoring
SIO	Scripps Institute of Oceanography
SOP	standard operating procedure
TM	Trade mark
TOC	total organic carbon
TSS	total suspended solids
USA	United States of America
USEPA	United States Environmental Protection Agency
W	west
WGS	World Geodetic System
x	multiplier
z	non-parametric probability

EXECUTIVE SUMMARY

This report presents the background, approach, and results of an environmental baseline study (EBS) conducted in April and May 2014 in the Stabroek Block located approximately 130 to 240 km offshore central Guyana. The report describes the characteristics of physical, chemical, and biological properties of sediment and the water column to document baseline conditions prior to planned petroleum exploration and potential development in Liza and Sorubim, two areas located within Stabroek. Profiling of the water column was conducted to provide general information on water quality and physical structure at the time of the survey and to compare results to available regional information.

Background

The EBS emphasized water and sediment because they are a major repository for introduced environmental substances to the marine environment. Sediments can provide an integrated view of historical and contemporary contaminant inputs and depositional events. Benthic infauna (macrofauna) communities are a useful indicator of environmental health, due to their relative sensitivity to changes in sediment physical and chemical conditions. The study documents current concentrations of hydrocarbons and metals in offshore sediments, as these are the main contaminants potentially introduced from petroleum exploration and development.

EBS Objectives

The primary objective of the study was to define the range of sediment habitat conditions at Liza and Sorubim, and to examine chemical and biological patterns of variability in relation to sediment physical characteristics and water depth. To meet this objective, sediments were collected at 18 sampling stations: ten at Liza and eight at Sorubim.

A second objective was to evaluate water column physical structure (salinity, temperature, density, dissolved oxygen, turbidity), general water quality (suspended solids, total organic carbon), and selected chemical concentrations in near-surface, mixed layer, and near-bottom waters. Water data were collected at seven of the sediment station locations: four at Liza and three at Sorubim, effectively covering the area of interest.

Results

Water Physical Structure and Quality. Water column profiling depicted a steep halocline, reaching a maximum salinity of 37‰ at 100 m depth. Water temperature dropped monotonically from 28^{o} C at the surface to 3^{o} C around 2000 m. The water column was highly stratified, likely limiting nutrient flux into surface waters from below the mixed layer. The permanent (non-seasonal) pycnocline extends down to approximately 200 m, below which density increases slowly with depth. The water column was relatively clear, with light transmittance through the 25 cm path length typically greater than 95%. Dissolved oxygen was consistently high, ranging from roughly 6 mg L-1 near the surface to greater than 8 mg L-1 in near-bottom waters, although concentrations dropped as low as 4 mg L-1 at one station.

Water Chemical Results. Petroleum hydrocarbons (PAH and SHC) and ten pollutant-indicator metals were measured at three depths at each station. Concentrations of all metals, including barium, were well below those considered harmful to aquatic organisms in marine waters. Barium was the only metal detected in all samples, also displaying the highest concentrations in all samples (6.04-9.21 □g L-1). Copper, mercury, and zinc were the only other metals detected, with all mercury concentrations <1 ng L-1 (part-per-trillion). Arsenic, cadmium, chromium, copper, and lead were not detected in any sample at the low part-per-billion level (<4 µg L-1).

Total PAH (for 43 compounds) concentrations were extremely low in all samples (≤50 ng L-1). The majority of detected PAH compounds were naphthalene, and C1- and C2-naphthalenes, suggesting potential ultra-trace level introduction from the analytical laboratory. These compounds are ubiquitous laboratory contaminants, commonly found in floor wax, tubing, and other laboratory equipment. Total SHC concentrations were below detection limits (<12 µg L-1) in all but one sample, with a result of 109 µg L-1.
Sediment Particle Size and Chemistry. EBS samples consisted primarily of fine-grained material (avg. 77.3%) (<0.063 mm diameter), averaging 77.3%, with roughly equal portions of silts and clays. Sand comprised the remaining minor fraction in all samples. Concentrations of total organic carbon (TOC) were very low (<1%) in all samples. In general, the highest organic carbon concentrations were observed in sediments closest to shore, and increased with increasing percentage fine-grained sediments.

All of the ten pollutant-indicator metals had concentrations similar to those reported for clean coastal environments, except for arsenic, which was slightly enriched. Arsenic can become elevated from arsenic oxides, a byproduct of gold-mining, which is an established industry in Guyana. Most metals increased significantly with increasing fine-grained sediment and TOC, but either the opposite or no significant relationship was observed with water depth.

Extremely low concentrations of hydrocarbons were measured in sediments at Liza and Sorubim. Total PAH concentrations ranged from 16.48 to 53.36 ng g-1 dry weight in all samples. Concentrations of total SHC ranged from 2.6 to 14 g g-1. Relative distributions of hydrocarbon compounds indicated biogenic sources opposed to petroleum or combustion-related sources, which typically dominate the offshore hydrocarbon signature from atmospheric fallout. Biogenic hydrocarbon sources most likely consist of terrestrial plant and humic material transported downslope from river inputs. Both total PAH and total SHC exhibited strong, positive correlations with TOC, also indicating biogenic origins of these trace level hydrocarbons. The dominance of naphthalenes and phenanthrenes (2- and 3-ring PAH) was observed in the majority of samples, suggesting plant biogenesis. In particular, low concentrations of phenanthrene have been measured in bark and twigs of Vismia trees, of which the species Vismia guyana and Vismia baccifera are native to Guyana.

Benthic Infauna. Total abundance was low, averaging 116 organisms m-2. This organism density is below the range of typical abundances reported from other continental slopes. The most abundant major taxonomic groups were polychaete worms, mollusks, and crustaceans. Polychaetes were the numerically dominant group at Liza (41%, avg. 47 m-2), while mollusks were dominant at Sorubim (37.5%, avg. 37.5 m-2). The overall prevalence of these three groups is typical for marine sediments. Polychaetes typically comprise about half of the numbers and a third of the macrofaunal species from deep-water marine habitats worldwide. No other individual major taxa were abundant, and collectively comprised less than 14% of total abundance. The observed impoverished macrofauna is likely ascribed to limited organic food sources, indicated by the extremely low organic carbon content in Liza and Sorubim sediment.

A total of 50 distinct families were identified, with approximately half represented by either one or two individuals. This is a relatively high level of diversity considering the low abundance of the macrofauna. Dominant families were typical cosmopolitan inhabitants of shelf and slope sediments worldwide. These included oweniid polychaetes, pericarid crustaceans, and tindariid and nuculanid (bivalve) mollusks. The relatively low percent coefficient of variation (mean=36) between sampling stations indicates that this is a conservative parameter and a potentially effective index for monitoring potential change induced from oil and gas exploration and development.

Conclusions

Offshore sediments collected from Liza and Sorubim areas of Stabroek Block have metal and hydrocarbon concentrations lower than those reported for undeveloped coastal environments, except for arsenic, which may be slightly enriched through mineral deposits. Biological results indicated a low abundance but relatively diverse macrofauna relative to offshore marine habitats of similar water depth and latitude.

Potential impacts to the macrofauna from petroleum development offshore are unlikely to be significant and restricted to the immediate area, and a steep species accumulation curve should be realized as conditions return to normal. However, there is the potential for pollutant transport from drilling and operations into more sensitive areas of nearshore shallow zones from the dominant longshore current.

1 INTRODUCTION AND EBS OBJECTIVES

This executive summary report presents the results of an environmental baseline study (EBS) conducted offshore Guyana by TDI-Brooks International (TDI) and reported by Maxon Consulting on behalf of Esso Exploration and Production Guyana Ltd. Sampling was conducted in April and May 2014 in the Liza and Sorubim areas slated for oil and gas exploration within the Stabroek Block. Analyses of sediment and water samples were conducted by B&B Laboratory and Albion, located in College Station, Texas, USA. Benthic macrofauna samples were analyzed by Lovell Taxonomic Services with oversight from Maxon Consulting (both located in San Diego, California, USA).

This report focuses on general environmental characteristics of marine sediment and oceanic water in the area of planned exploration. The report objective is to provide information that can be used to support environmental decision making through the evaluation of chemical, physical, and biological properties of sediment and the water column within the Liza and Sorubim sites. Emphasis was placed upon sampling and analysis of the sedimentary environment because sediment and their biota are relatively immobile and integrate the effects of depositional processes, including physical disturbances and potential introduction of contaminants (Boesch and Rabalais 1987). The benthic environment can be a depositional area for discharged drilling cuttings and adhered muds, and is recognized as a sensitive and reliable monitoring indicator for measuring potential impacts from exploration drilling. This report presents survey data and summarizes key environmental features in support of EBS objectives.

1.1 Environmental Baseline Study Objectives

Study objectives were formulated for the successful completion and interpretation of EBS data and are listed below. The objectives are directed toward documenting background environmental conditions in the vicinity of potential sites prior to oil and gas exploration drilling.

1. *Provide comprehensive, descriptive, and quantitative documentation of environmental conditions at Liza and Sorubim sites of potential exploration and development.*

The EBS was designed to cover the estimated range of potential impacts to the environment from exploration drilling and potential well development. The location of offshore sites, Liza and Sorubim, and associated sampling stations are shown in **Figures 1-1** and **1-2**, respectively. Sediment station locations were selected to provide the range of existing environmental conditions prior to future planned exploration and development.

2. *Gain information to assess the significance of environmental impacts to offshore Guyana sediment from potential existing sources, such as atmospheric deposition and hydrodynamic transport.*

Trace level hydrocarbon chemical analyses were conducted to distinguish types and potential sources of petroleum related compounds measured in sediments and water. Biological samples were analyzed using a 0.5 millimeter (mm) screen to describe benthic macrofaunal community structure.

3. *Identify potential confounding factors that may interfere with the interpretation of sediment chemical and biological data to aid sampling design and interpretation of future environmental data.*

Correlation analyses were performed to identify statistically significant co-varying environmental parameters (confounding factors) to help interpret key chemical and biological results. Common confounding factors include sediment particle size, water depth, total organic carbon (TOC), and dissolved oxygen, which can influence hydrocarbon, metal, and/or benthic macrofauna results.

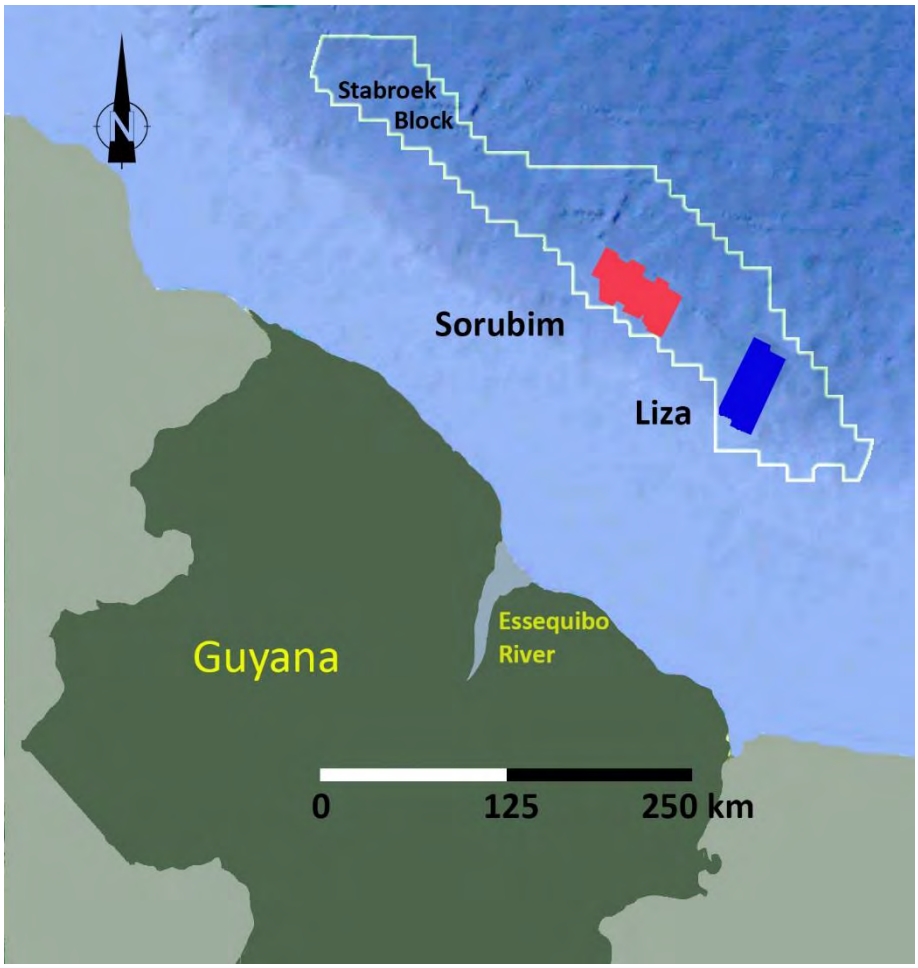


Figure 1-1. Stabroek Block with locations of Liza and Sorubim EBS project areas.

1.2 Sampling Design

Sampling locations (stations), shown in **Figure 1-2**, were selected to encompass the water depth and spatial range of existing conditions over an area of planned exploration drilling. **Table 1-1** presents station names, geographic coordinates, water depths, and types and numbers of samples collected. The sampling areas ranged from approximately 130 to 240 kilometers (km) offshore in water depths of 860 to 2400 meters (m), with Liza slightly shallower than Sorubim (see Table 1-1). Sediment samples were collected at a total of 18 stations (10 at Liza and 8 at Sorubim) using a single 0.25 square meter (m^2) box core.

The physical structure of the water column was electronically profiled at seven stations, four at Sorubim and five at Liza. In addition, three discrete water samples were collected at each station, resulting in a total of 21 discrete water samples. The sampling design supports the following methods of data interpretation to meet the previously stated EBS objectives:

- Describe central tendencies and range of key physical, chemical, and biological data throughout potential areas of oil and gas exploration and development.
- Identify potential confounding factors, such as water depth, sediment grain size, organic carbon content, dissolved solids, and dissolved oxygen that may affect interpretation of important project-related parameters, such as benthic macrofauna abundance/diversity, and concentrations of hydrocarbons and metals in sediment.
- Summarize results for water column key variables to depict existing contaminant concentrations and evaluate potential sources prior to exploration drilling.

Sediment samples were analyzed for benthic macrofauna community structure, grain size, total organic carbon (TOC), petroleum-related hydrocarbons (including polycyclic aromatic hydrocarbons [PAH] and saturated aliphatic hydrocarbons [SHC]), and 12 metals (including barium). Chemical and physical samples were collected from the top 10 cm of sediment. Benthic macrofauna were collected from the top 15 centimeters (cm) of a 0.1 m^2 sample area and retained on a 0.5-mm diameter screen. Discrete water samples were collected near the surface (10 m depth), mid-water, and near-bottom. Samples were analyzed for total organic carbon, total suspended solids, nine metals (including barium), and hydrocarbons (SHC and PAH). Continuous water column profiles were obtained for conductivity/salinity, temperature, density, light transmission (an indicator of water clarity), and dissolved oxygen at each of the seven water stations.

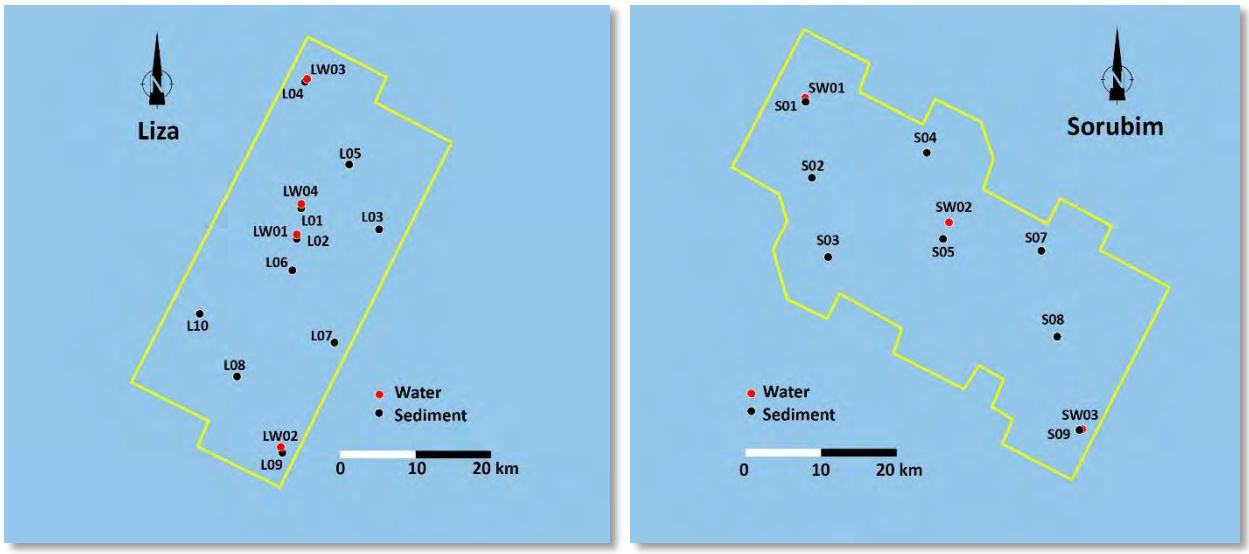


Figure 1-2. Locations of water and sediment sampling stations at Liza and Sorubim.

Table 1-1. Sediment and water station names, locations, and sampling inventory.

Sample ID	Station	Bottom Depth (m)	Latitude[1] (North)	Longitude[1] (West)	Sediment Samples	Water Samples[2]	Water Profiles[3]
Liza							
L-EBC01	L01	1831	8.1109	56.94940	1		
L-EBC02	L02	1741	8.0758	56.95319	1		
L-EBC03	L03	1853	8.0859	56.85493	1		
L-EBC04	L04	2074	8.2560	56.94463	1		
L-EBC05	L05	1931	8.1594	56.89383	1		
L-EBC06	L06	1649	8.0366	56.95963	1		
L-EBC07	L07	1478	7.9527	56.91102	1		
L-EBC08	L08	1106	7.9104	57.02392	1		
L-EBC09	L09	877	7.8214	56.97025	1		
L-EBC10	L10	1328	7.9855	57.06931	1		
L-WAT01	LW01	1216	8.0781	56.95367		1	1
L-WAT02	LW02	1741	7.8273	56.97295		1	1
L-WAT03	LW03	2004	8.2565	56.94205		1	1
L-WAT04	LW04	1772	8.1172	56.94806		1	1
Sorubim							
S-EBC01	S01	2327	8.7627	57.84372	1		
S-EBC02	S02	2171	8.6761	57.82443	1		
S-EBC03	S03	1962	8.5832	57.80321	1		
S-EBC04	S04	2238	8.7077	57.69202	1		
S-EBC05	S05	2038	8.6057	57.66938	1		
S-EBC06	S06	1857	8.4945	57.64313	not collected[4]		
S-EBC07	S07	2204	8.5910	57.55337	1		
S-EBC08	S08	2030	8.4919	57.53158	1		
S-EBC09	S09	1737	8.3840	57.50826	1		
S-WAT01	SW01	2014	8.7736	57.83698		1	1
S-WAT02	SW02	1859	8.6250	57.66557		1	1
S-WAT03	SW03	1491	8.3826	57.50786		1	1

[1]Reported in WGS 84 decimal degrees; [2]Discrete chemistry samples collected at surface, mid-water, and near-bottom depths; [3]Water column profiles of conductivity (salinity), temperature, density, and dissolved oxygen; [4]unable to collect acceptable sediment sample after several attempts.

1.3 Report Organization

This report is organized into two parts, the main report body and Appendices A-C. The main report body is organized into eight sections.

Section 1 – Introduction and EBS Objectives presents the purpose of the environmental baseline survey, the study design and sample inventories for sediment and water, and the site location.

Section 2 – Methods presents field, laboratory, and data analysis procedures. Field methods are presented for navigation and station positioning, and sample collection, processing and transfer to laboratories. Laboratory analytical methods are summarized for chemical, biological and physical samples, including sample preparation, instrumentation, quality control, and reporting. This section includes methods of data analysis, including brief descriptions of statistics used to support interpretation of results.

Section 3 – Water Physical Structure and Discrete Sample Results presents results for seven vertical profiles of conductivity/salinity, water density, temperature, turbidity, and dissolved oxygen. Water structure is discussed in relation to published studies of the region. Summary statistics are presented for discrete water column samples collected at each of three depths for total organic carbon (TOC), total suspended solids (TSS), metals and hydrocarbons.

Section 4 – Sediment Physical and Chemical Results presents results for grain size, total organic carbon, metals and hydrocarbons. Effects of sediment physical characteristics on chemical and biological parameters are emphasized. Statistical results are summarized, presenting central tendencies, range and variation in parameters for each of the two exploration sites. Spatial distributions of key physical and chemical parameters are graphically presented and evaluated.

Section 5 – Biological Characteristics of Sediment discusses patterns of diversity and abundance for benthic macrofauna. Statistical results are presented for central tendencies, range and variation in total abundance, number of distinct taxa, and distributions of selected major family-level taxa for each of the two exploration sites. Statistically significant relationships between key biological parameters and selected sediment physical parameters are reported.

Section 6 – Evaluation of Data Quality for chemical and biological analyses is presented in this section. Study objectives, presented in Section 1, are evaluated with respect to the sampling design and data collected. Laboratory quality control results are assessed for precision and accuracy for key chemical and biological data and the corresponding analytical methods used.

Section 7 - Discussion and Conclusions are presented regarding chemical and biological data for the two combined sites, and the use of these data to assess future potential impacts from oil and gas exploration drilling and development.

Section 8 – References provides full citations for referenced works. Complete results for each sample are presented in the appendices.

2 FIELD AND ANALYITICAL METHODS

Field and laboratory methods describing the collection and analysis of sediment and water data are described in this section. Additionally, statistical and graphical methods used to interpret and present EBS results are discussed.

2.1. Field Methods

Field operations were conducted from the Research Vessel (RV) GYRE, a 55.5-m vessel, outfitted with two hydraulic winches, respectively operating stern and port mounted A-frames. The vessel is equipped with wet and dry laboratories, and storage rooms containing sample freezers and dry storage areas.

A C&C Technologies™ C-Nav 2050 full Differential Global Positioning System (DGPS) and a Winfrog navigation package were used to position and navigate the vessel. C-Nav is based on Real Time Gypsy (RTG) technology developed by the US National Aeronautics and Space Administration (NASA) to achieve position accuracies of ≤0.1m to 2m. Geographical locations of sampling stations were recorded in latitude/longitude decimal degrees (WGS 84 datum). Locations were recorded electronically with station identification and date/time of sample collection and stored on an onboard computer until subsequent transfer to the project database.

Standard operating procedures governing all field operations were reviewed by the scientific team members and included establishing shift assignments, maintaining effective communications, preparing for sampling activities while in transit, recording field data, storing and tracking of samples, and packing and shipping of samples upon cruise completion.

2.1.1 Water Sampling and Profiling

Discrete water samples were collected from the near-surface (5–10 m depth), at the mixed layer (ca. 25-m below surface), and from approximately 5-10 m above the seafloor at each of seven stations. All samples were analyzed for total suspended solids, total organic carbon (TOC), metals, saturated hydrocarbons (SHC), and polycyclic aromatic hydrocarbons (PAH).

Samples were collected using 3- to 5-liter (L) polyvinyl chloride Niskin bottles deployed from a rosette at the targeted depth. Sample bottles were deployed open at both ends, and closed at the targeted depth. Bottles were washed before sampling and between each station with a non-phosphate detergent, then rinsed with de-ionized water and filtered seawater. For hydrocarbon analysis, a 1-L subsample was transferred from the Niskin bottle into a pre-cleaned borosilicate glass jar, containing 1 milliliter (mL) of 50% hydrochloric acid preservative to prevent bacterial degradation of hydrocarbons. For metals, a 500-mL aliquot was collected from the Niskin bottle directly into a pre-cleaned polyethylene jar containing 0.5 mL of 50% hydrochloric acid preservative. All chemistry water samples were refrigerated at 4^{o}celcius (C) while on board ship.

The water column was electronically profiled with the CTD, augmented with additional sensors for dissolved oxygen and percent light transmission (turbidity). Water column data were collected at a rate of 2 records per second (s^{-1}) throughout the water column.

2.1.2 Sediment Sampling

Sediments were sampled with a 50 x 50 centimeter (cm) steel box corer, providing a sediment surface area of 0.25 m^2.

Benthic Macrofauna. A 0.1 m^2 square, stainless steel sleeve was used to subsample the box core. The sleeve was inserted into one corner of the box core to a depth of 15 cm. The entire volume of sediment was collected (including overlying water) from the sleeve and placed into a plastic bucket. The sediment and collected water were transferred within 30 minutes of collection to a flow-through sieve with a 0.5-mm mesh. After sieving, macrofauna samples and retained sediments were transferred to plastic containers and preserved with approximately 50% volume of 10% buffered formalin and rose bengal dye. The preservative was sufficient to cover the entire sample, and exceeded the retained material volume by at least 10%. Rose bengal, which is a vital stain, stained living biological material red, facilitating the efficient removal of biological material during subsequent laboratory sample sorting. If necessary, high-volume samples were stored in more than one sample container, and labeled accordingly. Each sample was inverted several times to ensure thorough mixing of the preservative. Preserved samples were stored in plastic coolers at ambient temperature.

2.2 Analytical Methods

The environmental baseline analytical program was designed to provide high quality, detailed chemical and biological data to meet program objectives. **Table 2-1** lists the physical, chemical and biological tests, corresponding matrices, analytical methods, and processing laboratories.

Table 2-1. Analytical methods, laboratory, and number and type of EBS samples.

Parameter	Sediment Samples	Water Samples	Analytical Method
B&B Laboratories, College Station, Texas, USA			
Total Suspended Solids	-	21	Filtration and gravimetric determination
Total Organic Carbon	18	21	Combustion with infra-red detection
Polycyclic Aromatic Hydrocarbons (PAH)	18	21	GC-MS SIM, USEPA 8270-modified
Saturated Hydrocarbons (SHC)	18	21	GC-FID, USEPA 8015-modified
Albion Laboratory, College Station, Texas, USA			
Metals (except mercury)	18	21	ICP-MS, USEPA Methods 1638 & 200.8
Mercury	18	21	Cold vapor with atomic fluorescence
Lovell Benthic Laboratory, San Pedro, California, USA			
Benthic macrofauna	18	-	0.5mm sieve; identification and enumeration at family level, 4 major taxonomic groups

ICP=inductively coupled plasma spectroscopy detector
ICP-MS= ICP with mass detector
GC-FID = gas chromatography with flame ionization
GC-MS = gas chromatography with mass detector

2.2.1 TSS, TOC, and Sediment Particle Size

Total suspended solids (TSS) in water samples were analyzed using a standard filtration and gravimetric method following USEPA Method 160.3. In summary, a 1-L sample obtained from the Niskin sampler at each depth was volumetrically determined using a graduated cylinder and then passed through a 0.45 micron (µm) filter in the vessel laboratory. The filter was then wrapped in foil, labeled, and stored refrigerated until shipment back to B&B Laboratory for analysis. In the laboratory, the sample was dried in a desiccator and weighed to the nearest 0.01 milligram (mg). Results were reported in mg L^{-1} for each sample.

Total organic carbon (TOC) was analyzed using a persulfate digestion of carbon at 100° C followed with detection of organic carbon using an O.I. Analytical Model 700 TOC Analyzer based on USEPA methods 9060 and 415.1. Water samples were acidified to a pH of <2 and analyzed unfiltered. The reported TOC results are the total of dissolved and particulate organic carbon.

Sediment TOC samples were digested with a 50% by volume phosphoric acid solution. The acid-sediment slurry was oven dried at 105° C, weighed. The resulting moisture-free sample was combusted at 1350° C and TOC was quantified using a Leco CR-412 Total Carbon Analyzer to remove chlorine interferences in marine samples by filtering gases through a magnesium perchlorate, halogen trap column.

Sediment particle size was determined for the four major size classes: gravel, sand, silt, clay using a sieve and hydrometer technique. Sediment samples analyzed for grain size were thoroughly mixed. Approximately 100 to 150 g of each sample was weighed into receiving containers. Ten (10) mL of deflocculent solution (1% solution of sodium hexametaphosphate in deionized water) was added to the jar and shaken until the sample was totally disaggregated. The disaggregated sample was poured through a number 230 sieve into a 1000-mL graduated cylinder. The sieved sample is washed with deionized water. Sediment retained on the number 230 sieve was transferred into a pre-weighed beaker and oven dried (70-90° C) for at least 24 hours. Dried sediment was transferred to a series of stacked sieves, shaken and the contents of each weighed. Sediment passing through the smallest sieve was added to the 1000-mL graduated cylinder and further processed using the hydrometer settling method ASTM D-422. Percent gravel, sand, silt, clay and several graphic sediment parameters were calculated from initial weights and retained fractions.

2.2.2 Metals

Water samples were analyzed for nine metals and sediment samples were analyzed for 12 metals (see Appendices A and B for respective metals).

Water samples (except those analyzed for mercury) were preserved under clean room conditions to a pH of <2 using ultrapure nitric acid. Preserved samples were allowed to equilibrate for at least 24 hours to insure all metals adsorbed to the container walls were re-solubilized. A near-total (≥90%) recoverable digest was then performed on the preserved total recoverable samples. Additional acid was added and the samples were heated for at least two hours at 85° C, and allowed to cool prior to analysis. In addition, all samples were subjected to an additional 48 hour ultraviolet digestion procedure. The ultraviolet procedure insured that all dissolved organic chelates that could interfere with extraction efficiency were decomposed, prior to pre-concentration.

Mercury water samples were preserved under clean room conditions with bromine monochloride (BrCl) and digested (equilibrated) for at least 24 hours prior to analysis. The composite was analyzed under clean room conditions by dual gold amalgam trap cold vapor atomic fluorescence, following USEPA method 1631 revision E.

Sediment samples were analyzed for the same nine metals analyzed in water samples plus aluminum, cadmium, and iron. Except for mercury, sediment metals were analyzed using either standard inductively coupled plasma spectrometry (ICP) with mass detector (ICP-MS) (USEPA method 200.8), or in the case of chromium and iron, ICP-MS modified to use an ammonia gas dynamic reaction cell (DRC)-ICP-MS. Prior to ICP analysis, sediment samples were homogenized, sub-sampled and freeze-dried to a constant weight. The dried sediment was then ground to a fine powder. For USEPA method 200.8, approximately 0.2 g of the dried and powdered sediment samples were subjected to a strong acid leaching digestion at 95° C for 4 hours. Ultra-pure deionized water was then added to the acid leachate to achieve a final volume of approximately 20 mL. The leachate (digestate) was then diluted further to keep the solution concentration within the calibration range of the ICP-MS instrument, and to adjust the acid strength for analysis. Sediment mercury samples also were analyzed using USEPA method 1631 revision E.

2.2.3 Hydrocarbons

Extraction of Hydrocarbons. A sediment aliquot was dried in a convection oven at 40° C, and then thoroughly homogenized using a ceramic mortar and pestle. An additional aliquot of approximately 1 g of wet sediment was removed and dried in an oven at 105° C to a constant weight for percent moisture determination. Samples were extracted using a Dionex ASE200 Accelerated Solvent Extractor (ASE). The dried sample was loaded into 22- or 33-mL stainless steel ASE extraction tubes. The extractions were performed using 100% dicholormethane at 100° C and 2000 psi. The extracted organics dissolved in the solvent were collected in 60-mL glass vials. The extract was concentrated to approximately 10 mL in the collection vials and then transferred to 25-mL Kurdena-Danish concentrator tubes. The sample extract was concentrated to 3 mL in a water bath at 55 to 60° C. Additional cleanup procedures were used for sediments including high-pressure liquid chromatography fractionation followed by silica gel and alumina-column cleanup. Cleanup procedures were performed to remove potentially interfering non-target compounds.

The sample extract was loaded on top of 300 mm x 19 mm glass liquid chromatography columns packed with 10 g of deactivated alumina and 20 g of deactivated silica gel. The columns were loaded in 100% dichloromethane. The dichloromethane was replaced by adding 40 mL of pentane. The extract was carefully added to the top of the chromatography column. The column was flushed at a rate of 1 to 2 mL per minute using 200 mL of 50:50 pentane/dichloromethane and collected into 250-mL flasks. The eluent collected in the 250-mL flask was evaporated to 2 mL using a water bath at 55 to 60° C. The samples were transferred into 2 mL amber vials. The concentrated extract was then analyzed by GC-MS for polycyclic aromatic hydrocarbons (PAHs) or by GC-FID for saturated hydrocarbons and selected isoprenoids.

If the extract was colored it was processed through silica gel/alumina chromatography columns. The sample extract was then loaded on top of 300 mm x 19 mm glass liquid chromatography columns packed with 10 g of deactivated alumina and 20 g of deactivated silica gel. The columns were loaded in 100% dichloromethane. The dichloromethane was replaced by adding 40 mL of pentane. The extract was carefully added to the top of the chromatography column. The column was flushed at a rate of 1 to 2 mL per minute using 200 mL of 50:50 pentane/dichloromethane and collected into 250-mL flasks. The eluent collected in the 250-mL flask was evaporated to 2 mL using a water bath at 55 to 60° C. The samples were transferred into 2-mL amber vials. The concentrated extract was then analyzed by GC-MS with selected ion monitoring (SIM) for polycyclic aromatic hydrocarbons or GC-FID for saturated hydrocarbons.

***Polycyclic aromatic hydrocarbon (PAH) analysis*.** Parent PAHs and their alkylated homologues were analyzed in sample extracts by a HewlettPackard model 5890 GS and model 5972 MS, operated in SIM mode, using a capillary column. A list of analyzed compounds is provided in Appendices A1 and B1 for water and sediment samples. The GC was operated in splitless mode and the capillary column was an Agilent Technologies HP-5MS (60 m x 0.25 mm ID and 0.25 mm film thickness). The carrier gas was helium at a flow rate of 1 mL min^{-1}. The temperature of the injection port was 300^{o} C and transfer line was 290^{o} C. The initial oven temperature was 60^{o} C and the ramp rate was 7^{o} C per minute to a final oven temperature of 310^{o} C, held for 20 minutes. For analyte identification, the extracted ion current profiles of the primary m/z and the confirmatory ion for each analyte must be at a maximum in the same scan or within one scan of each other and the retention time must fall with 5 seconds of the retention time of the authentic standard or alkyl homologue grouping. The pattern of alkylated PAH homologue groupings was established by analysis of reference oil standards. The relative peak heights of the primary mass ion compared to the confirmation or secondary mass ion must fall within 30% of the relative intensities of these masses in a reference mass spectrum.

Saturated hydrocarbons (SHC) analysis. Saturated hydrocarbons are defined as a group of straight- and branched-chained (saturated) as well as cyclic hydrocarbons that are typically found in petroleum related products and crude oil. In sediments, a complete range of these "saturated" hydrocarbons were analyzed that encompass light and heavy fractions of petroleum (e.g., Nc_9-nC_{40}) and selected isoprenoids, including pristine and phytane. A list of analyzed compounds is provided in Appendices A1 and B1 for water and sediment samples. Target analytes were extracted with PAH compounds and analyzed using gas chromatography with flame ionization detection (GC-FID). Measured concentrations were calculated against the surrogate compounds (e.g., tetracosane-d50) added prior to the extraction.

2.2.4 Benthic Macrofauna

Benthic macrofaunal samples were sorted in order to remove the fauna from the sediment and separate them into major taxonomic groups for taxonomic analysis by specialty taxonomists. Sorting was performed under dissecting microscopes with fiber optic lighting. Small volumes of sediment were spread out in sorting trays and systematically inspected. Animals were removed from each sample and separated into vials representing five major sorting groups: polychaetes, crustaceans, mollusks, echinoderms, and miscellaneous phyla. Borosilicate glass vials with poly-seal lids were used for sorted fractions. Each vial was labeled with sample ID and taxonomic group. Labels were written on rag paper using India ink pen. Each tray of sediment was inspected until the sorter was confident that all animals were removed. The sorted sediments were placed into a separate labeled jar and the process continued until the entire sample was sorted.

Prior to sorting, samples collected for identification and enumeration of benthic infauna were sieved again and separated into three size fractions that were examined separately under a dissecting scope: 1) easily suspended material (e.g., light bodied/typically non-shell bearing specimens and detritus; 2) large heavy material (e.g., shell hash, large shell bearing mollusks and large worm tubes); and 3) coarse sediments (i.e., aggregated clay). Easily suspended material was washed under a fume hood into a 2-L beaker. Sample material was thoroughly suspended/agitated with freshwater dispensed from a ½ inch Tygon hose attached to a municipal water line. Suspended material was allowed to settle for a few seconds before decanting supernatant onto an ASTM Standard 35 (500 µm) sieve.

The process was repeated 5 to 10 times, until the wash water was visibly clear. Material retained on the sieve was washed into a labeled 50-mL beaker. Large heavy material retained in the 2-L beaker was washed on an ASTM Standard 10 (2 mm) sieve fitted above an ASTM Standard 35 (500 µm) sieve. Material retained on the 2-mm screen was washed with fresh water dispensed from a spray wand attached to a municipal water line to remove any residual fine materials. Retained coarse material was washed into a labeled 100-mL beaker. Coarse sediment was pre-sieved on the 2-mm sieve and retained on the underlying 500-µm sieve, and washed with freshwater dispensed from a 1-cm diameter Tygon hose and fine spray wand attached to a municipal water line to remove any residual sand and silt. Material retained on the 500-µm sieve was washed into a labeled 500-mL beaker. All material retained on sieves was examined under a fluorescent magnifier to ensure that all organisms had been removed.

The three sieved fractions were consolidated during the picking (sorting) process. Picked specimens were transferred to labeled glass vials containing 70% ethanol. Dissecting and compound microscopes with standard magnifications of 6x-50x and 40x-1000x were used to examine the specimens. Fiber optic lighting was used to illuminate specimens under the dissecting microscope.

Infauna were separated into four major taxonomic groups: polychaeta, mollusca, crustacea, and combined other taxa. Abundances were recorded to the family level, with names reported for the taxonomic categories of annelids, crustaceans, echinoderms, mollusks, and miscellaneous grouped phyla. The number of organisms reported accounted for all organisms in a sample that were alive at the time of collection. Empty mollusk shells or crustacean molts were not counted. Limitations that effect the level of identification are lack of published literature for the area; condition of the specimens (fragmented, poorly preserved); and juvenile, reproductive, or other poorly documented life stage.

Specialty taxonomists used taxonomic literature pertinent to the region from which the samples were collected. Additional literature from other regions or literature of a general nature was used as necessary. When possible, specimens not attributable to a described family were given a unique provisional name and notes on its unique taxonomic characteristics were made to facilitate subsequent identifications. Damaged or juvenile specimens were identified to the family level whenever possible.

Quality control included two forms of oversight. First, all material processed by each of two pickers was reexamined by the taxonomist for each benthic category. Second, instruction and guidance from the lead taxonomist was available and frequently provided to pickers throughout the analysis. To maintain consistent standards resulting taxonomic lists from provided to an alternative taxonomist for verification. Any discrepancies in identification were corrected by the lead taxonomist and standardized in the taxonomic database.

2.2.5 Sample Archival

Sediment not consumed by analyses is stored frozen for up to one year under strict chain-of-custody procedures at B&B Laboratory, College Station, Texas.

Representative organisms from processed macrofauna samples were preserved in 70% ethanol and submitted for archival at Scripps Institute of Oceanography (SIO), Benthic Invertebrate Collection, La Jolla, California (http://collections.ucsd.edu/bi/index.cfm). The SIO Benthic Invertebrate Collection contains over 750,000 specimens, with approximately 20,000 identified to genus level and 14,500 to species level. The collection supports scientific research by providing specimens for study on the taxonomy, evolution, and ecology of benthic invertebrates. Archived specimens are available for examination at SIO and for loan to researchers at academic institutions.

2.3 Quality Control (QC)

Details on the type, quantity, and performance results specific to each method are presented in Section 6 (Evaluation of Data Quality). A complete suite of laboratory QC samples was run with sediment and water chemistry samples to confirm method performance and control. Method-specific required laboratory QA/QC samples included a control blank, duplicate samples, performance validation samples, standard reference materials, and various recovery and check standards, depending on the analysis.

Results that were collected using electronic or remotely deployed instruments were checked for accuracy and precision by the equipment manufacturer (e.g., Seabird Electronics, Winfrog Navigation) or by the scientific team, following guidance from the manufacturer.

2.4 Data Management and Analysis

All data management and analysis tasks were performed using the SAS™ Software System (version 9.4) in batch programming mode. SAS™ is a data management, statistical, and graphical system that is widely used and is the recognized standard by many academic, government and medical/health industries worldwide. Graphical presentations of data were performed using Surfer® (version 10, Golden Software, Inc.) and Grapher (version 9, Golden Software, Inc.) software. Data were translated from Microsoft Excel files to SAS™ data sets, and all analyses were performed within the SAS™ system. Statistical results were output as text, rich text format and Microsoft Excel files. Key parameters used in statistical analyses are shown in **Table 2-2**.

Table 2-2. EBS key parameters used in statistical analyses.

Chemical Parameters	***Benthic Macrofauna***	***Water Quality Parameters***
Barium	Total Abundance	Total Suspended Solids
Cadmium	Polychaeta Abundance	Total Organic Carbon
Chromium	Crustacea Abundance	pH
Copper	Echinodermata Abundance	Dissolved Oxygen
Iron	Family Diversity	Turbidity
Lead	Mollusca Abundance	Salinity
Mercury	Other Grouped Phyla Abundance	Density
Nickel	***Sediment Physical Parameters***	Temperature
Vanadium	Sediment particle size (various)	Depth
Zinc	Total Organic Carbon	
Total PAH	Depth	
Total Resolved SHC		
Total Unresolved SHC		
Total SHC		

2.4.1 Descriptive Statistics

Descriptive statistics were performed for key variables of the physical, chemical, and biological data sets. Summary statistics included computations for sample mean, mean standard deviation, range of values, and where appropriate, frequencies of detectable concentrations. Average results were used in cases where duplicate samples were analyzed by the laboratory. These results were then used to generate statistical results (e.g., central tendencies) for the entire data set. Values equal to one-half of the method detection limit were used for non-detect chemistry results in statistical calculations. Computations were performed on final results that passed data quality objectives.

2.4.2 Correlation Analysis

Correlation analysis provides insight into the relationship between two analysis variables. Pearson Product-Moment correlation coefficients were calculated for pair-wise variables of interest within the data set. The significance of correlations between meaningful pairs of environmental variables (e.g., depth and total abundance) is discussed in Sections 3 through 5, providing results for the correlation coefficient and probability level of statistical significance.

2.4.3 Graphical Presentations of Data

Bar plots showing concentrations of hydrocarbon compounds at selected individual stations were produced in Excel (Microsoft Office, Version 2013). Contour maps were produced by the rectangular grid-based contouring program, Surfer® (Golden Software, Version 10). This program interpolates irregularly spaced data into a regularly spaced grid, and places interpolated data in a grid file. Original data included station coordinates and selected chemical and biological parameters for each station.

2.4.4 Analysis of Hydrocarbon Source

General sources of hydrocarbons were identified by evaluation of selected diagnostic ratios and parameters (Douglas et al. 1996; Steinhauer and Boehm 1992). Indices and parameters used to identify hydrocarbon source are shown in **Table 2-3**. Characteristics based on PAH compounds provide information on the source of hydrocarbon contaminants, whereas SHC-based parameters are used primarily to distinguish between biogenic and petroleum-derived sources. Parameters based on both PAH and SHC compounds were used to discern hydrocarbon sources in offshore Guyana sediment (see Section 4).

Table 2-3. Diagnostic ratios and parameters of SHC and PAH used to identify hydrocarbon source.

Parameter or Ratio	Relevance in Environmental Samples
Saturated Hydrocarbons (SHC)	
Pristane/Phytane	Source of phytane is mainly petroleum, whereas pristane is derived from both biological matter and oil. In "clean" environmental samples, this ratio is > 1.0 and decreases as oil is added.
nC16/(nC15 + nC17)	The ratio of hexadecane (nC16) over pentadecane (nC15) plus heptadecane (nC17). At "background" levels, hydrocarbon nC15 and nC17 can be used as indicators of plankton (algae) hydrocarbon inputs. As plankton productivity increases the ratio decreases.
Carbon Preference Index (CPI)	The total odd-chain hydrocarbons divided by the total even-chain HC. A value of 2-4 indicates input from plants, as oil is added the value decreases, approaching 1.0
Polycyclic Aromatic Hydrocarbons (PAH)	
N/P	The ratio of summed naphthalene alkylated homologues (C1-C4) over summed phenanthrene-anthracene alkylated homologues (C1-C4); this ratio decreases with increased weathering of oil.
Perylene	A biogenic compound formed during early diagenesis in marine and lacustrine sediments; usually associated with terrestrial plants.
Total PAH	The sum of all PAH target analytes including 2- through 6-ring parent PAH and C1 - C4 alkyl substituted PAH. General indicator of petroleum hydrocarbon sources.
Pyrogenic	The sum of combustion PAH compounds (4-, 5-, and 6-ring PAHs): fluoranthene, pyrene, chrysene, B(a)A, B(b)F, B(k)F, B(a)P, D(a,h)A, B(g,h,i)P
Petrogenic	The sum of petrogenic PAH compounds (2-, 3-, and 4 -ring PAHs): naphthalenes, acenaphthene, acenaphthylene, fluorene, phenanthrenes, dibenzothiophenes, chrysenes, and fluoranthenes/pyrenes
Petrogenic/Pyrogenic	Useful to determine relative contributions of pyrogenic and petrogenic hydrocarbons in differentiating sources. The ratio increases as inputs from petroleum increase.

adapted from Steinhauer and Boehm (1992).

3 WATER COLUMN RESULTS

This section presents results for water column profiles and chemical/physical analyses of collected (discrete) water samples. Four profiles and 12 samples (4 stations x 3 depths) were collected at Liza; and three profiles and nine samples (3 stations x 3 depths) were collected at Sorubim.

3.1 Background

Guyana's Atlantic Ocean coastline is approximately 430 kilometers (km) in length, bounded by Suriname on the east and Venezuela on the west. Guyana has a land area of approximately 214,970 km^2, and also shares a border with Brazil on the west and south. The country is situated between 1 and 9 north latitude and between 56 and 62 west longitude. The offshore region, including Liza and Sorubim, located 130 to 240 km offshore and along a combined total of 120 km of coastline, is primarily under the influence of large scale oceanic processes overlying the upper continental slope, and are generally beyond the immediate influence of coastal shore processes of localized runoff, sedimentation, and thermal structuring. Guyana generally has an equatorial climate with year-round rainfall; however, variations in rainfall affect surface water features accordingly, both locally and through runoff from its four major rivers, including the Essequibo River delta (see Figure 1-1, Section 1).

3.2 Water Column Profiles

Depth profiles of salinity, temperature, density, dissolved oxygen, and percent light transmittance (as an indicator of turbidity) are shown in **Figures 3-1** through **3-4** for each of seven water stations. Summary statistics for profiled data collected at the same station depth as discrete samples are presented in **Table 3-1.** Results indicate a consistent water column structure over the survey period and sampling area. A lens of relatively low salinity (~ 33‰) water gives way to a steep halocline, reaching a maximum salinity of 37‰ at 100 m at both sites. Water temperature drops monotonically from 28° C at the surface to 3° C around 2000m. The resulting density profiles indicate a highly stratified water column, which likely limits nutrient flux into surface waters from below the mixed layer. There is a sharp increase (step) in density at the 100m salinity maximum in most profiles. The permanent (non-seasonal) pycnocline extends down to approximately 200m, below which density increases slowly with depth. The water column is relatively clear, with light transmittance through the 25 cm path length typically greater than 95%. A minor accumulation of material appears to rest on the 100 m step in the density profile, where transmittance drops to 92% in several profiles. Dissolved oxygen profiles show high levels (ca. 6 mg L^{-1}) near the surface and even higher levels (>8 mg L^{-1}) below 1000 m. The water column properties are quite reasonable, given the local oceanography. The profiles were collected approximately 175 km offshore of the delta of the Essequibo River, Guyana's largest river. Guyana annual precipitation is very high, averaging between 250–350 cm. The lower salinity surface layer is most likely maintained by river and rainfall input. The wind-driven coastal North Brazil Current and Guyana Current (Lumpkin and Garzoli 2005), resulting from the North Equatorial Current from the east (Tomczak and Godfrey 2003), determine water conditions above the permanent pycnocline. Salinities range from 36 to 37‰ and temperatures range from 22° to 28.5° C

(http://oceancurrents.rsmas.miami.edu/atlantic/guiana.html).

The conditions below the permanent pycnocline are maintained by Antarctic Intermediate Water down to approximately 1000m, and below that by North Atlantic Deep Water (Tomczak and Godfrey 2003). The Antarctic water is characterized as relatively fresh (34.3‰) and cold (2° C). The underlying North Atlantic Deep Water, formed when the salty Gulf Stream is cooled off Labrador, sinks and moves southward. It is more salty (35‰), has high oxygen concentrations (6–8 mg L^{-1}) and is identifiable down to 4000 m. The coincident increase in salinity and dissolved oxygen below 1200m can be seen in nearly every one of the corresponding profiles.

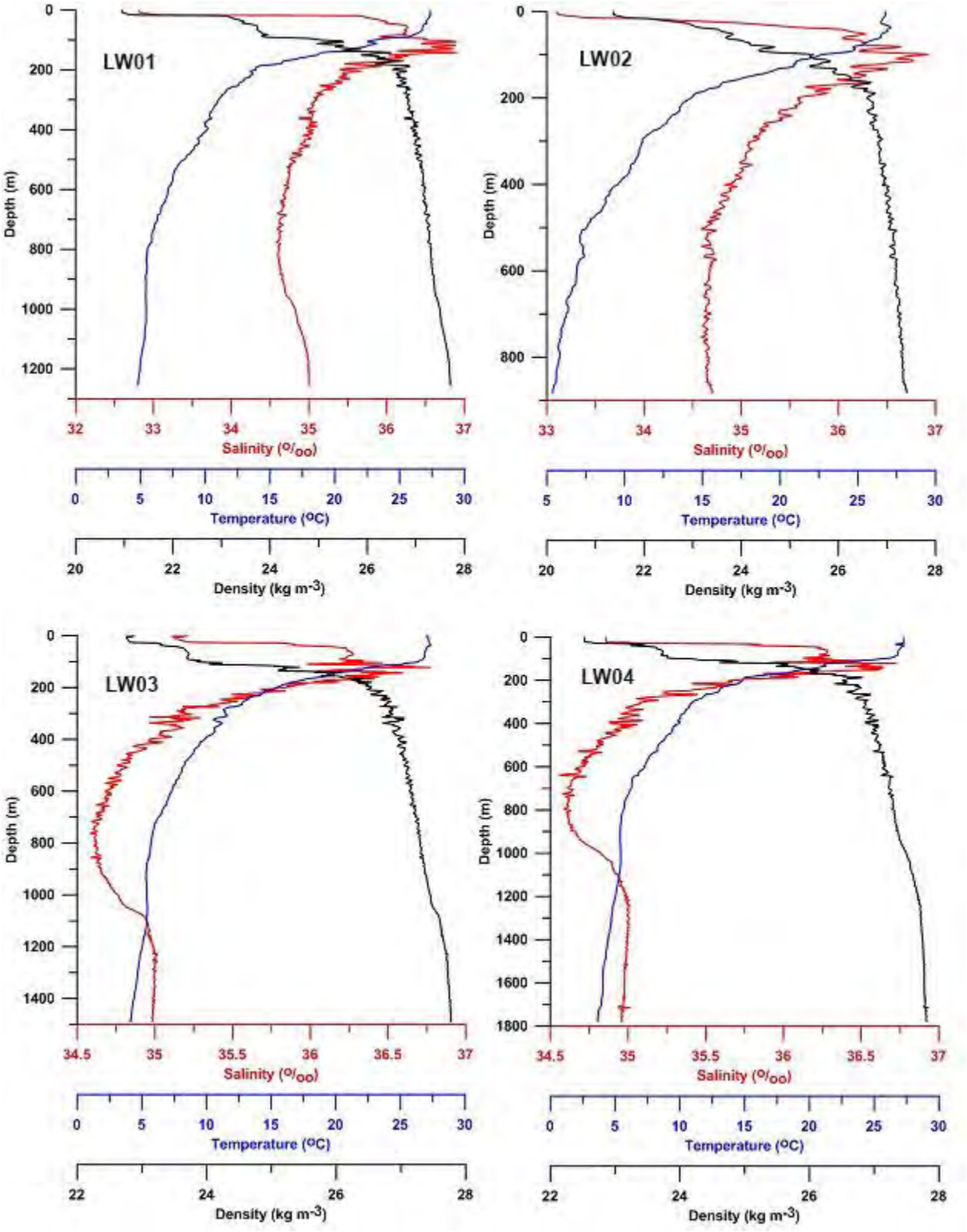


Figure 3-1. Profiles of salinity, temperature, and water density at each of four stations at Liza.

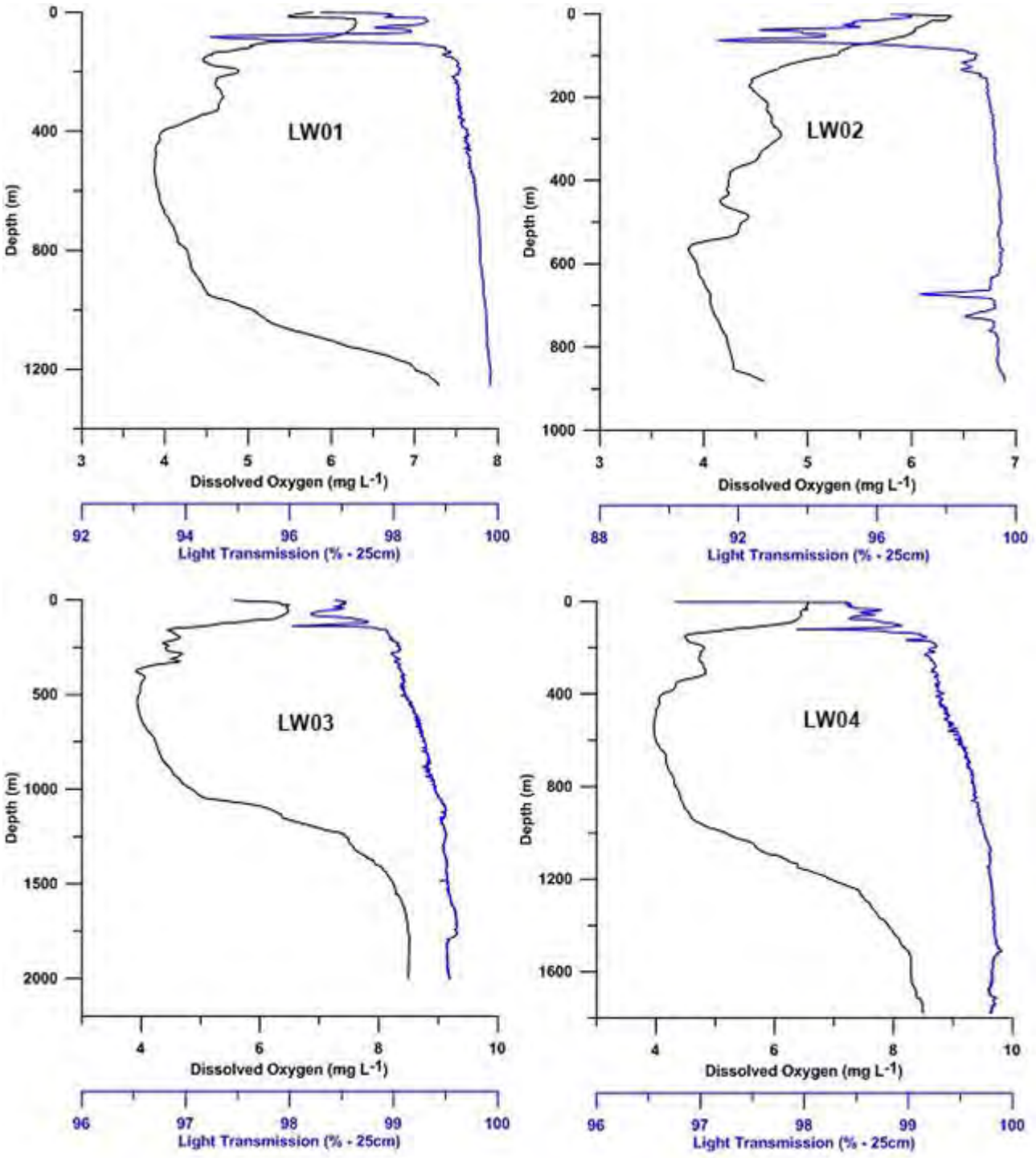


Figure 3-2. Profiles of dissolved oxygen and percent light transmission at each of four stations at Liza.

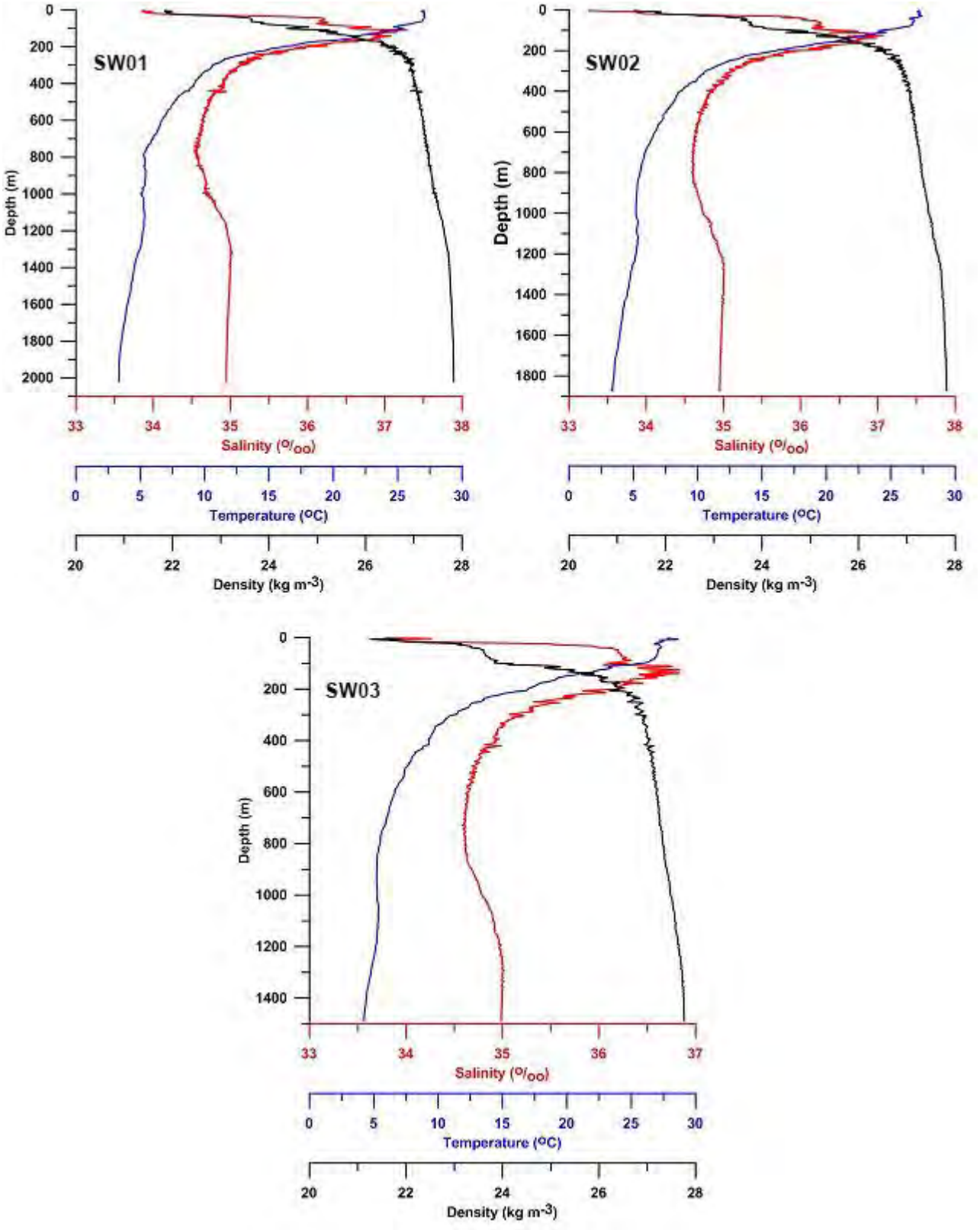


Figure 3-3. Profiles of salinity, temperature, and water density at each of three stations at Sorubim.

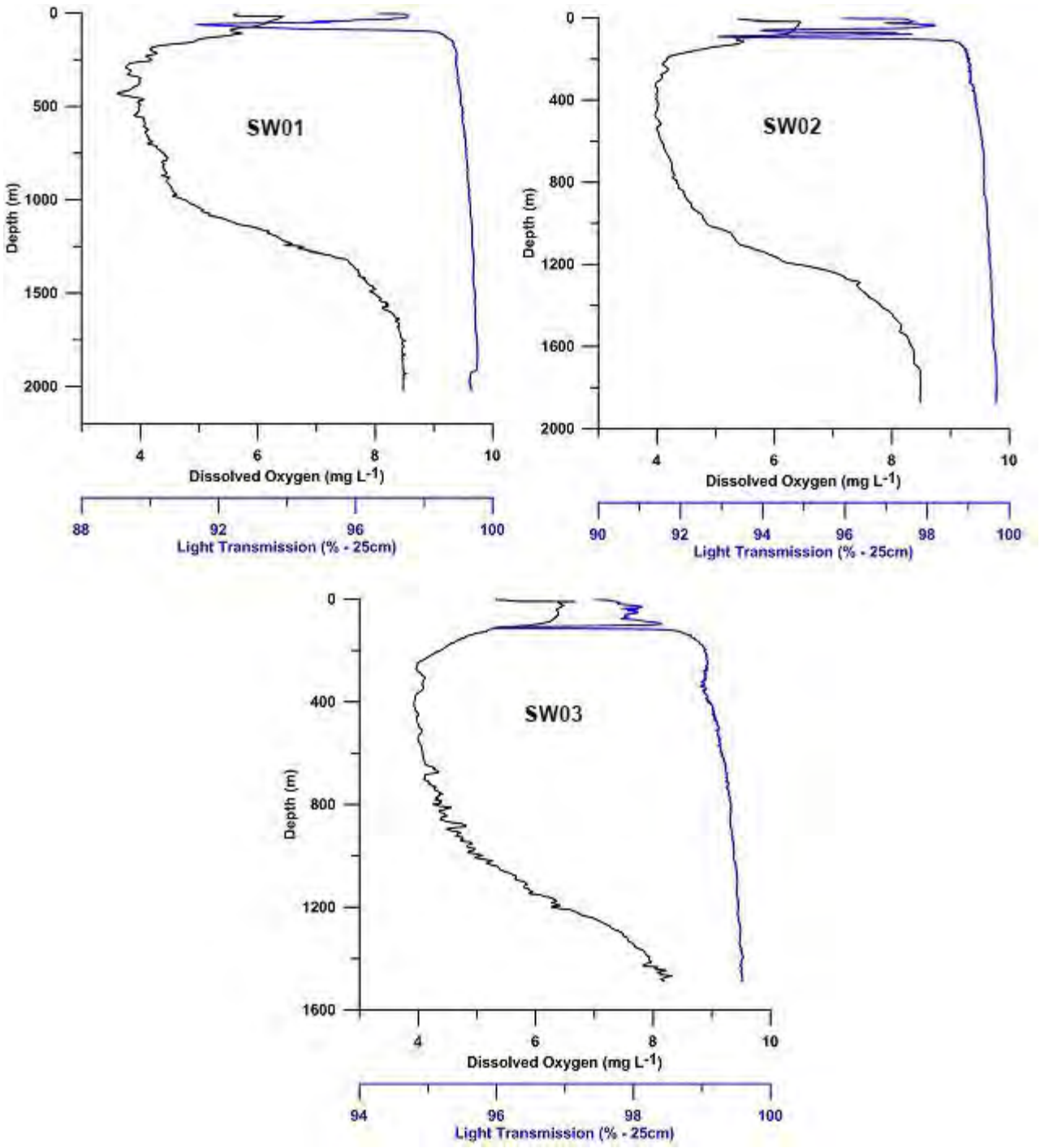


Figure 3-4. Profiles of dissolved oxygen and percent light transmission at each of three stations at Sorubim.

Table 3-1. Summary statistics for water physical structure data.

Parameter	Units	Mean	Standard Deviation	Minimum	Maximum
		Liza (n=12)			
Temperature[1]	°C	19.67	11	3.42	27.36
pH[2]	pH units	8.1	0.13	7.84	8.19
Salinity[1]	‰	34.74	0.79	32.9	35.7
Dissolved Oxygen[1]	mg L^{-1}	5.47	0.76	3.86	8.39
		Sorubim (n=9)			
Temperature[1]	°C	19.37	11.79	3.34	27.47
pH[2]	Unit	8.11	0.1	7.94	8.19
Salinity[1]	‰	34.56	0.63	33.7	35.2
Dissolved Oxygen[1]	mg L^{-1}	5.99	0.67	5.52	8.48

[1]profile results measured at discrete sample water depth; [2]results for discrete samples

3.3 Discrete Water Sample Results

Summary statistics for water physical parameters, metals, and hydrocarbons are shown in **Tables 3-2** through **3-4**.

3.3.1 Total Suspended Solids (TSS) and Total Organic Carbon (TOC)

Total suspended solids can be an important water quality parameter with respect to sediment transport and discharges to the water column from exploration or development drilling. There were no significant trends between depths, with results ranging from very clear (<1 mg L^{-1}) to moderately turbid (8.85 mg L^{-1}) water. Unlike turbidity, there was no clear trend in TSS with water depth. Although the limited number of depth strata sampled may not have been sufficient to detect depth-related trends, it appears to have adequately captured the range of results for the water column. Although collected over a limited time period, these results are assumed to represent seasonal background conditions for the study area. Background concentrations during heavy rain may be significantly higher due to suspended material broadcast from the Essequibo River.

Total organic carbon (particulate + dissolved organic carbon) concentrations provide rough estimations of productivity in ocean water when not confounded by anthropogenic inputs, such as treated sewage, agricultural runoff, or other organic inputs. Results for all samples were low, at ≤1.2 mg L^{-1}, with mean concentrations of 0.42 and 0.46 mg L^{-1}, respectively, for Liza and Sorubim samples. These results are comparable to a concentration of 0.83 mg L^{-1} TOC for an open ocean surface water sample collected from the Gulf of Mexico that was analyzed for quality control purposes. There were no significant differences (α=0.05) in mean TOC concentrations between sample depths at either site.

Table 3-2. Summary results TOC and TSS for Liza and Sorubim discrete water samples.

Parameter (mg L^{-1})	Mean	Standard Deviation	Minimum	Maximum
Liza (n=12)				
Total Organic Carbon (TOC)	0.81	0.26	0.42	1.13
Total Suspended Sediment (TSS)	4.3	1.92	1.4	7.25
Sorubim (n=9)				
Total Organic Carbon (TOC)	0.81	0.24	0.46	1.04
Total Suspended Sediment (TSS)	4.77	2.38	0.35	8.95

3.3.2 Heavy Metals and Other Elements

Except for barium, nearly all results were below laboratory detection limits (**Table 3-3**). Barium was detected in all samples, with concentrations well within the natural range for ocean water (Morel et al. 2006). An ultra-trace method used to analyze mercury produced detectable concentrations of sub-part-per-trillion (<1 ng L^{-1}) in only two samples, both collected at Liza. All reported concentrations were well below those considered harmful to aquatic organisms in marine receiving waters (Buchman 2008).

Table 3-3. Summary results for metals in Liza and Sorubim water samples. Results reported in µg L^{-1}.

Parameter	No. of Detects	Mean	Standard Deviation	Minimum	Maximum
Liza (n=12)					
Arsenic	0	<2	NA	<2	<2
Barium	12	7.5	0.83	6.4	9.21
Cadmium	0	<2	NA	<2	<2
Chromium	0	<5	NA	<5	<5
Copper	1	1.68	0.63	<3	3.68
Lead	0	<0.6	NA	<0.6	<0.6
Mercury	2	0.000124	0.000057	<0.0002	0.000254
Nickel	0	<4	NA	<4	<4
Vanadium	0	<4	NA	<4	<4
Sorubim (n=9)					
Arsenic	0	<2	NA	<2	<2
Barium	9	7.62	0.93	6.04	8.81
Cadmium	0	<2	NA	<2	<2
Chromium	0	<5	NA	<5	<5
Copper	0	<3	NA	<3	<3
Lead	0	<0.6	NA	<0.6	<0.6
Mercury	0	<0.0002	NA	<0.0002	<0.0002
Nickel	0	<4	NA	<4	<4
Vanadium	0	<4	NA	<4	<4
Zinc	1	2.38	1.13	<4	5.38

Note: ½ of the detection limit was used for non-detect results in all statistical calculations; NA=not applicable

3.3.3 Hydrocarbons

Polycyclic aromatic hydrocarbons (PAH) and saturated aliphatic hydrocarbons (SHC) were measured as general indicators of petroleum-related contamination. Although hydrocarbons are fairly hydrophobic, trace concentrations of dissolved and adsorbed (to suspended material) compounds persist in many offshore water bodies throughout the world's oceans, with the highest concentrations typically reported for waters near populated industrial areas with nearby rivers (Kennish 1992).

Most hydrocarbons attain peak concentrations in rivers, and estuarine and coastal environments, as there is a strong tendency to adsorb to suspended particles that settle before being carried offshore. Hydrocarbons enter the ocean environment from various sources including natural oil seeps, spills from vessels and drilling rigs, incorporation of airborne particulate matter and down-slope transport of contaminated sediment. Ultimately, they degrade, are taken up by biota in the water column, or are sequestered in sediment.

Summary results for total PAH and total SHC are shown in **Table 3-4** for Liza and Sorubim water samples. Total PAH concentrations (based on the sum of 43 analytes) were extremely low in all samples (≤50 ng L^{-1}). The only PAH compounds detected were naphthalene, C_1 and C_2 alkylated homologues of naphthalene, fluorene, and phenanthrene. These low molecular weight PAHs are ubiquitous trace-level laboratory contaminants. Naphthalene contamination is often introduced from floor waxes, polyvinyl chloride tubing, and other laboratory equipment. Evidence of ultra-trace naphthalene contamination from the laboratory also is derived from the fact that all samples were affected and similar concentrations were detected in the corresponding method blanks. Fluorene and phenanthrene are ubiquitous PAHs found in all petroleum and its products, and in combusted fuels. Ultra-trace concentrations detected in otherwise uncontaminated samples, such as those collected at Liza and Sorubim, are often introduced from laboratory analytical equipment (i.e., cross-contamination).

Table 3-4. Summary results for hydrocarbons in Liza and Sorubim water samples. Results reported in µg L^{-1}, except where noted.

Analyte	No. of Detects	Mean	Standard Deviation	Minimum	Maximum
Liza (n=12)					
Total PAH (ng L^{-1})	12	31.56	6.44	18.0	43.32
Total SHC	3	36.38	66.42	<13	230
Total Unresolved SHC	3	21.3	27.87	<13	87
Total Resolved SHC	3	20.05	39.1	<13	143
Sorubim (n=9)					
Total PAH (ng L^{-1})	9	40.42	5.27	31.39	47.82
Total SHC	1	17.89	34.17	<13	109
Total Unresolved SHC	1	16.89	31.17	<13	100
Total Resolved SHC	1	6.78	0.83	<13	9

Note: ½ of the detection limit was used for non-detect results in all statistical calculations

4 SEDIMENT PHYSICAL AND CHEMICAL RESULTS

Analytical results, consisting of total organic carbon, particle size, hydrocarbons, and metals are presented for ten Liza and eight Sorubim sediment samples. Results for key chemical parameters were evaluated for spatial distribution at Liza and Sorubim, and for variability in relation to water depth and sediment physical characteristics. Results from diagnostic tools to identify potential hydrocarbon sources also are discussed. All results are reported on a dry weight basis.

4.1 Background

Sediment particle size characteristics are emphasized for their controlling influence upon sedimentary community dynamics, and because they often correlate with biologically meaningful variables such as sediment porosity, compaction, oxygen tension, water content and retention of organic matter. Particle size can be equally important in controlling sediment chemical concentrations due to the increase in adsorptive capacity with finer-grained particles. Because many contaminants co-occur with fine-grained particles, there is a potential for contaminant accumulation in deep-water areas, including the continental slope depths of the Stabroek Block.

Guyana coastal sediment is characterized by very thick deposits of transported Amazon mud and high volumes of fluvial mud from erosion in its coastal waters. These ultra-fined grained sediments move down the shelf edge towards the seaward basins, including the area of Liza and Sorubim. In the study area, sediments also are broadcast offshore by the Essequibo River, which empties southwest of the two exploration sites. Although the Guyana coastline has four major rivers that flow through a region of high terrestrial biodiversity, associated rates of detrital carbon flux to the deep seabed (> 1000m) from coastal and overlying water column sources are low, typical of low-productivity tropical habitats.

4.2 Sediment Grain Size and Total Organic Carbon

Sediment particle size (grain size) was reported for four major classes: gravel, sand, silt, and clay based on the percent composition of each class. Fines are the sum of silt and clay fractions, and represent the proportion of particles with diameters <0.0625 mm. Descriptions and corresponding ranges in size (based on the Wentworth scale, Folk 1980) are summarized in **Table 4-1**.

Particle size characteristics are summarized in **Table 4-2**. The majority of sediment samples are categorized as poorly to moderately sorted fine-grained material, comprised of approximately equal portions of silt and clay. All 18 stations had sediment containing greater than 59% fines, with gravel-sized particles absent from all samples and sand contributing no more than 40% in any sample. Results indicate fairly uniform, primarily fine-grained sediment comprised of a fairly narrow range of class sizes based on the Wentworth scale, typical of offshore depositional areas.

In general, significant relationships between key particle size parameters and sample depth were observed at Liza, but not at Sorubim. At Liza, percent fines (p= -0.85, z = 0.021) and TOC (p = -0.93, z = 0.0001) decreased significantly with water depth, but no such relationships were observed at Sorubim (z > 0.05). These results are likely due to the wider range of water depths at Liza compared with Sorubim, rather than differences in bottom sediment physical conditions. Concentrations of TOC were much lower than those of typical depositional sediments, with results less than 1% at all stations.

The respective distributions of percent fines and TOC at Liza and Sorubim are illustrated in **Figures 4-1** and **4-2**, in which both parameters display trends of higher concentrations in the southwest portion of the site, which is closer to shore.

Table 4-1. Sediment particle size descriptions (adapted from Folk 1980).

Sediment Type	Wentworth Scale (mm diameter)	Description
Gravel	>2 to 64	Very Fine Gravel to Gravel
Sand	>0.0625 to 2	Very Fine Sand to Very Coarse Sand
Silt	>0.0039 to 0.0625	Very Fine Silt to Coarse Silt
Clay	>0.00098 to 0.0039	Medium Clay to Coarse Clay

Table 4-2. Summary results for sediment particle size class and TOC. Results reported as percent (%) dry weight.

Parameter	Mean	Minimum	Maximum	Standard Deviation	Station with Minimum	Station with Maximum
Liza (n=10)						
Gravel	0	0	0	0	NA	NA
Sand	17.83	2.09	40.50	12.81	L10	L05
Silt	39.34	20.42	55.56	11.86	L05	L08
Clay	42.83	32.36	57.96	7.11	L07	L06
Fines	82.17	59.5	97.91	12.81	L05	L10
Graphic Sorting (Phi)	2.78	1.47	3.59	0.69	L10	L05
TOC	0.52	0.3147	0.8685	0.16	L05	L09
Sorubim (n=8)						
Gravel	0	0	0	0	NA	NA
Sand	28.88	14.63	38.92	8.92	S03	S09
Silt	31.97	24.17	37.30	4.78	S02	S08
Clay	39.15	24.74	56.37	11.36	S09	S03
Fines	71.12	61.08	85.37	8.92	S09	S03
Graphic Sorting (Phi)	3.37	2.69	3.77	0.39	S03	S02
TOC	0.37	0.2333	0.4939	0.08	S09	S03

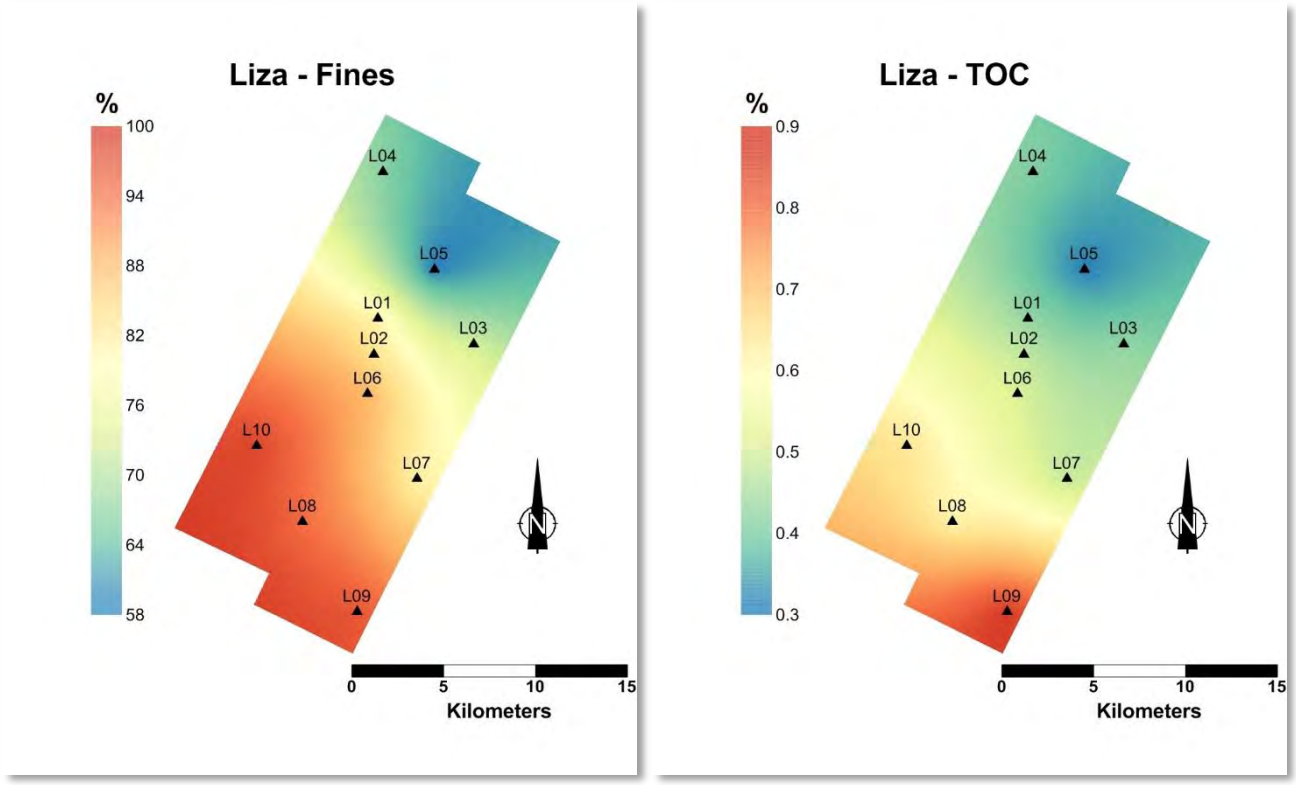


Figure 4-2. Spatial distribution of percent fines (silt + clay) and total organic carbon (TOC) at Liza.

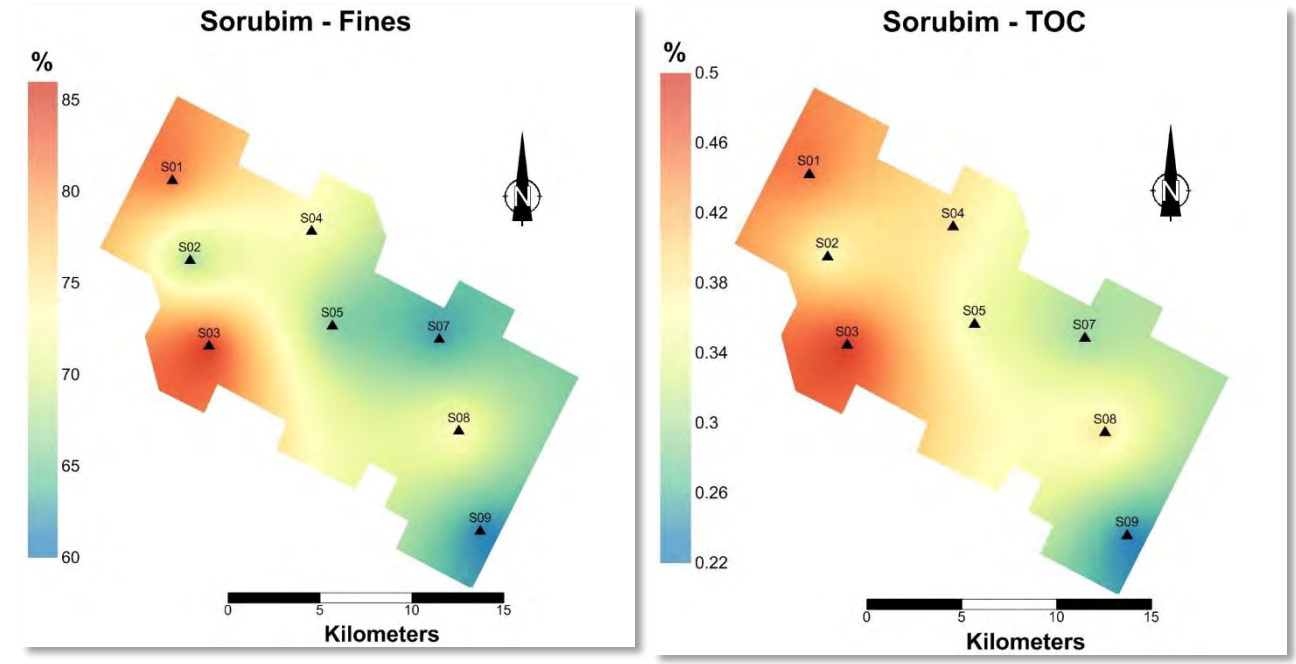


Figure 4-2. Spatial distribution of percent fines (silt + clay) and total organic carbon (TOC) at Sorubim.

4.3 Metals

Twelve metals were measured to determine general patterns of distribution within each site and to assess potential contamination from any nearby pollution sources. Ten metals commonly associated with anthropogenic sources, consisting of arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, vanadium and zinc were analyzed. Two additional metals, aluminum and iron, were analyzed to provide geological source information. Mean metal concentrations and associated statistics for Liza and Sorubim sediments are shown in **Table 4-3**. In general, concentrations of all metals were slightly lower at Sorubim compared with Liza; however, there were no statistically significant differences ($\alpha = 0.05$) between mean concentrations of any metal between the two sites. Concentrations of most metals were similar to or less than mean concentrations reported for the upper continental crust, except for arsenic, which had mean concentrations more than three times higher. Arsenic can become naturally enriched from arsenic-rich igneous and sedimentary rocks, and arsenic-bearing minerals, including arsenopyrite (AsFeS), realgar (AsS) and orpiment (As_2S_3). Elevated arsenic also is a byproduct of gold-mining, a staple of Guyana's economy. The Guyana Geology and Mines Commission (GGMC) oversees the mining industry and has implemented modern mining practices and codes of operation.

Table 4-3. Summary results for sediment metals for Liza and Sorubim. Reported in µg g^{-1} dry weight.

Parameter	Mean	Minimum	Maximum	Standard Deviation	Station with Minimum	Station with Maximum	Mean Background[1]
			Liza (n=10)				
Aluminum	11495	8100	15000	2322	L05	L10	77440
Arsenic	6.06	4.51	11.4	2.07	L01	L09	2.0
Barium	98.92	57.4	159	27.5	L05	L10	668
Cadmium	0.13	0.102	0.165	0.02	L05	L09	0.102
Chromium	14.95	8.57	21.1	4.34	L05	L09	35
Copper	13.11	9.86	16.5	1.84	L05	L10	14.3
Iron	19130	13500	25300	3879	L05	L09	30890
Lead	11.55	8.33	15.6	2.21	L05	L10	17
Mercury	0.042	0.0263	0.0624	0.012	L05	L10	0.056
Nickel	21.44	14.1	32.3	4.9	L05	L10	18.6
Vanadium	23.54	18.1	28.3	3.8	L05	L09	53
Zinc	45.51	26.9	63.7	12.5	L05	L10	52
			Sorubim (n=8)				
Aluminum	8779	7040	11800	1767	S05	S03	77440
Arsenic	6.78	3.86	14.1	3.17	S07	S02	2.0
Barium	76.53	37.8	119	25.8	S09	S01	668
Cadmium	0.13	0.0872	0.15	0.02	S09	S04	0.102
Chromium	12.44	8.38	16.9	2.63	S07	S03	35
Copper	14.53	9.63	19.6	3.12	S09	S01	14.3
Iron	14825	11300	19700	3092	S07	S02	30890
Lead	10.52	8.42	12.3	1.32	S09	S03	17
Mercury	0.034	0.022	0.0457	0.008	S09	S01	0.056
Nickel	18.29	13.8	22.9	2.9	S09	S01	18.6
Vanadium	25.03	17.4	35.8	5.3	S07	S02	53
Zinc	37.14	30.6	46.3	6.4	S07	S03	52

[1]Mean concentration in upper continental crust (Wedepohl 1995)

Pearson correlation coefficients for metals with water depth, percent fines, and/or TOC are shown in **Table 4-4** for Liza and Sorubim sediments. Barium, which can be introduced to the marine environment as barite in drilling muds, increased significantly with percent fines (z<0.001) at both sites. Most metal concentrations increased significantly with increasing TOC and fine-grained sediment (percent fines). Significant changes in these relationships along with increased concentrations of certain metals may be used as an indication of anthropogenic activities. For example, post-exploration changes in the strong positive correlation between percent fines and barium may indicate effects from drilling. In addition to TOC, barium also was strongly correlated with aluminum (p = 0.83, z = 0.003 at Liza; p = 0.82, z = 0.01 at Sorubim), which is apparent in **Figure 4-3**.

Table 4-4. Pearson correlation results (p) for key chemical and selected physical parameters at Liza and Sorubim. Significant correlations (z < 0.05) are shown in **bold.**

Metal	Water Depth	Percent Fines	Percent TOC
	Liza (n = 10)		
Aluminum	**-0.79**	**0.91**	**0.80**
Arsenic	**-0.82**	**0.64**	**0.91**
Barium	-0.57	**0.83**	0.55
Cadmium	-0.61	**0.65**	**0.79**
Chromium	**-0.94**	**0.95**	**0.91**
Copper	-0.17	0.59	0.29
Iron	**-0.84**	**0.94**	**0.90**
Lead	**-0.81**	**0.94**	**0.86**
Mercury	**-0.86**	**0.93**	**0.84**
Nickel	-0.54	**0.82**	0.56
Vanadium	**-0.90**	**0.90**	**0.87**
Zinc	**-0.88**	**0.96**	**0.89**
	Sorubim (n = 8)		
Aluminum	0.29	**0.90**	**0.86**
Arsenic	-0.02	-0.07	0.09
Barium	0.57	**0.93**	**0.93**
Cadmium	0.64	0.68	0.68
Chromium	0.01	**0.87**	**0.83**
Copper	0.69	**0.83**	**0.88**
Iron	-0.02	0.41	0.43
Lead	0.51	**0.71**	**0.83**
Mercury	0.60	**0.93**	**0.96**
Nickel	0.56	**0.92**	**0.93**
Vanadium	-0.09	0.18	0.26
Zinc	0.34	**0.85**	**0.87**

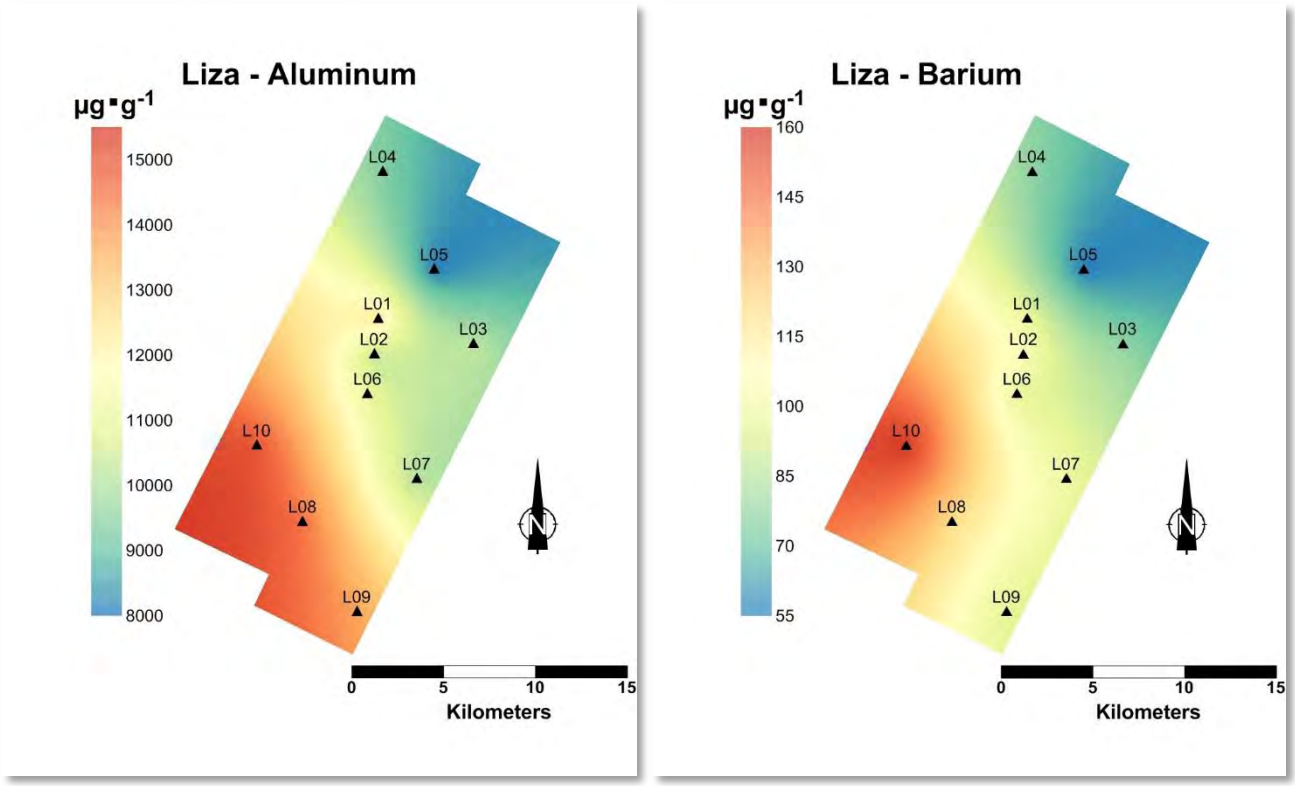


Figure 4-3. Spatial distribution of aluminum and barium in surface sediment at Liza.

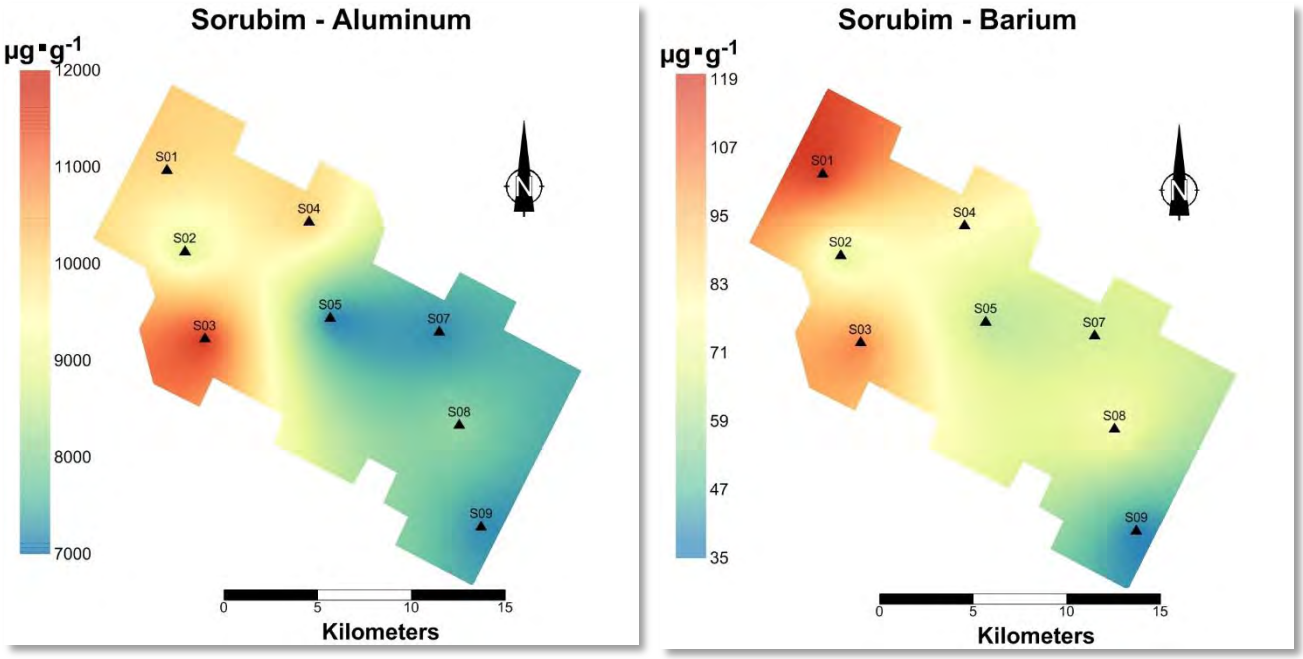


Figure 4-4. Spatial distribution of aluminum and barium in surface sediment at Sorubim.

4.4 Hydrocarbons

Hydrocarbon data describe background conditions as a precursor to future oil and gas development, with the objective of establishing a statistically reliable database for assessment of potential impacts and predictive capacity for projected environmental perturbations. Specifically, the EBS study objectives focus on defining existing chemical concentrations in sediment within the Liza and Sorubim exploration sites. Two classes of organic chemicals consisting of polycyclic aromatic hydrocarbons (PAH) and saturated hydrocarbons (SHC) were emphasized since they are important indicators of age and source of petroleum-related hydrocarbons in sediments. Polycyclic aromatic hydrocarbons analyzed included 20 parent (unalkylated) compounds and 23 alkylated homologues, consisting of two- to six-ring PAH compounds and dibenzothiophenes (sulfur containing compounds). Laboratory data also included results for biphenyl, several hopanes, and several furans, which were not included or interpreted in the EBS. These compounds are rarely addressed in published studies of environmental hydrocarbons, and are not required for the interpretation of hydrocarbon type and potential source in offshore Guyana sediment.

Extremely low concentrations of hydrocarbons were measured in sediments collected at both sites. Total PAH (43 analytes) concentrations ranged from 16.48 to 53.36 ng g^{-1} (nanograms per gram; parts-per-billion) dry weight. Concentrations of total SHC (39 nC_9-nC_{40} analytes, including 7 isoprenoids) also were extremely low, ranging from 1.2 to 14 µg g^{-1} (micrograms per gram; parts-per-million) (mean=9.5 µg g^{-1}), with resolved hydrocarbons comprising the majority of SHC in most samples. There was no significant correlation between total PAH and total SHC (apparent in **Figure 4-5** for Liza), indicating non-petroleum related sources for these extremely low hydrocarbon concentrations.

Hydrocarbon concentrations measured at both sites were lower than those reported for coastal sediments adjacent to relatively unpopulated or non-industrialized regions that receive minor hydrocarbon inputs, such as undeveloped coastal California, the south Baltic Sea, the North Atlantic continental slope and the Gulf of Finland, which all have total aliphatic hydrocarbon (SHC) concentrations ranging from 70 to 500 µg g^{-1} and total PAH concentrations <1 µg g^{-1} (i.e., 1000 ng g^{-1}) (Kennish 1997).

Table 4-5. Summary results for hydrocarbons. Reported in dry weight.

Analyte	Mean	Minimum	Maximum	Standard Deviation	Minimum at Station	Maximum at Station
			Liza (n=10)			
Total PAH (ng g^{-1})	38.61	24.58	53.36	10.99	L05	L08
Total SHC (µg g^{-1})	10.64	8	14	1.92	L06	L05
Total Unresolved SHC (µg g^{-1})	6.97	3	12	2.87	L09	L05
Total Resolved SHC (µg g^{-1})	3.68	2	8.9	2.07	L01	L09
			Sorubim (n=8)			
Total PAH (ng g^{-1})	31.50	16.48	48.05	11.05	S09	S01
Total SHC (µg g^{-1})	8.05	2.6	9.4	2.28	S09	S05
Total Unresolved SHC (µg g^{-1})	5.93	1.2	8.5	2.44	S09	S05
Total Resolved SHC (µg g^{-1})	2.11	0.9	4	1.23	S05	S02

Several key hydrocarbon parameters displayed significant correlations with water depth, grain size parameters, and/or TOC (see **Table 4-6)**; however, results were inconsistent between sites, likely due to the extremely low concentrations measured and the relatively narrow depth range sampled. The positive correlations between total PAH and TOC for both sites is due almost entirely to perylene, a biogenic PAH, which comprised >80% of total PAH concentration in most samples.

Table 4-6. Pearson correlation results (*p*) for key hydrocarbon parameters at Liza and Sorubim. Significant correlations ($z < 0.05$) are shown in **bold.**

Hydrocarbon	Water Depth	Percent Fines	Percent TOC
	Liza (n = 10)		
Total PAH	**-0.86**	**0.82**	**0.71**
Total SHC	0.13	-0.52	-0.14
Total Unresolved SHC	**0.65**	**-0.77**	**-0.71**
Total Resolved SHC	**-0.81**	0.60	**0.88**
	Sorubim (n = 8)		
Total PAH	0.46	**0.89**	**0.93**
Total SHC	**0.78**	0.24	0.46
Total Unresolved SHC	0.48	0.01	0.19
Total Resolved SHC	0.53	0.42	0.47

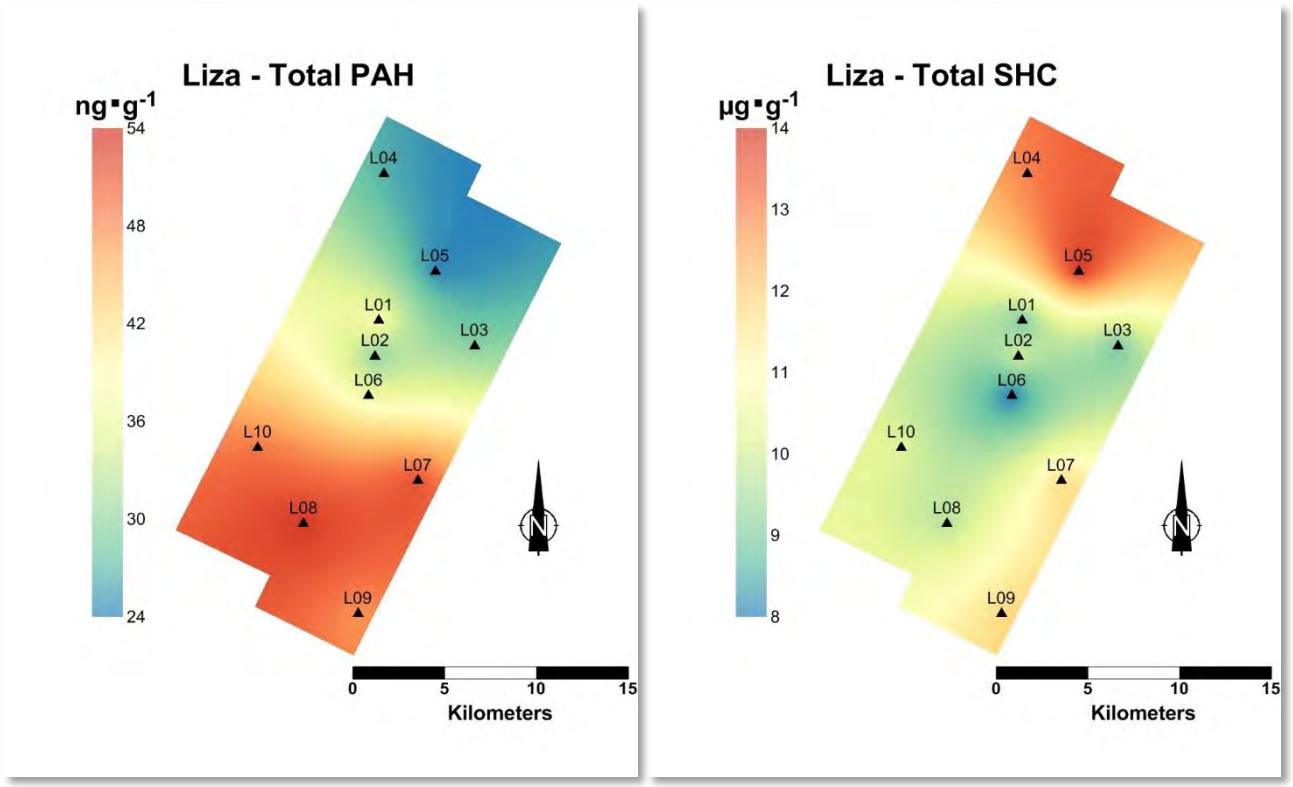


Figure 4-5. Spatial distribution of total PAH and total SHC in surface sediment at Liza.

4.4.1 Hydrocarbon Source

The within sample distribution of individual PAH compounds provides information for a range of hydrocarbon sources, whereas SHC compounds are used primarily to distinguish between biogenic and petroleum-derived sources. Relatively high concentrations of low molecular weight PAH (2-, 3-, and several 4-ring PAH) are typically associated with petrogenic (petroleum-derived) sources. Increased concentrations of high molecular weight PAH (4-, 5- and 6-ring PAH) indicate either pyrogenic (fossil fuel combustion) sources or possibly heavier, more degraded crude oils, depending on their relative distributions. Pyrogenic sources typically display increased concentrations of fluoranthene and pyrene relative to their corresponding alkylated homologues, while heavier crude oils generally display a fuller suite of alkylated compounds that are elevated relative to their parent compounds. The degree of hydrocarbon weathering generally increases as the ratio of naphthalene homologues to phenanthrene/anthracene homologues decreases. Interpretation of values for this ratio (i.e., N/P) and other diagnostic indices used to identify hydrocarbon source and degree of weathering are shown in **Table 2-3** (Section 2); results for diagnostic parameters for the 18 EBS sediment samples are shown in **Table 4-7**.

The distribution of n-alkanes in mature crude oil and distillates typically does not exhibit odd-even carbon preference. Terrestrial plants synthesize n-alkanes almost exclusively with an odd number of carbon atoms in the nC_{25} to nC_{37} range, whereas marine plants synthesize odd-numbered carbon chains in the nC_{15} to nC_{21} range (Hunt 1995). The ratio of pristane to phytane concentrations in sediment also is a useful diagnostic parameter, because phytane is mainly derived from petroleum, whereas both petroleum and biological sources typically contribute pristane to marine sediment. In addition, reduction in concentrations of low molecular weight alkanes (i.e., nC_9 to nC_{20}) and the ratio of heptadecane (nC_{17}) to pristane are commonly related to evaporative and biological weathering of hydrocarbons in sediment.

Table 4-7. Values for key diagnostic parameters indicating hydrocarbon source.

Analyte	Mean	Minimum	Maximum	Standard Deviation	Minimum at Station	Maximum at Station
			Liza (n=10)			
Petrogenic/Pyrogenic	3.36	2.14	4.65	0.97	L04	L07
CPI	1.97	1.47	3.27	0.50	L10	L09
C16/(C15+C17)	0.40	0.24	0.51	0.10	L09	L05
Pristane/Phytane:	1.34	0.67	1.8	0.42	L01	L09
			Sorubim (n=8)			
Petrogenic/Pyrogenic	2.66	1.94	3.37	0.60	S04	S02
CPI	1.99	1.24	3.22	0.59	S07	S02
C16/(C15+C17)	0.36	0.25	0.54	0.09	S08	S09
Pristane/Phytane:	1.05	0.33	2.0	0.51	S03	S01

*see Section 2.3.4 for a description of diagnostic parameters; CPI=carbon preference index

Chromatograms for all 18 sediment samples exhibited a noticeable predominance of odd-carbon-number over even-carbon-number n-alkanes, with a Carbon Preference Index (CPI) value >2 in most samples, indicating primarily biogenic sources of these low concentration hydrocarbons. A strong odd-carbon-number preference in the nC_{25} to nC_{37} range also was observed, indicating that the majority of hydrocarbons in sediment are derived primarily from plant (biogenic) material. Similarly, the low ratio (<1) of nC_{16} over the sum of nC_{15} + nC_{17} for all samples, indicates relatively low inputs of marine algae to these sediments, consistent with the low observed organic carbon content.

Analysis of the aromatic fractions revealed the presence of a full suite of 2-, 3-, 4-, 5- and 6-ring PAH compounds in most samples, with a notable absence of the sulfur-containing benzofurans. In general, sample distributions were dominated by the low molecular weight PAHs, naphthalenes and anthracene-phenanthrenes. High concentrations of perylene relative to other PAH compounds also were observed for all samples. Perylene is a biogenic compound formed during early diagenesis in marine and lacustrine sediments, usually associated with terrestrial plants (Tan and Heit 1981; LaFlamme and Hites 1978), and has been reported as the dominant PAH in clean sediments sampled offshore Brazil. A study by Krauss et al. (2005) indicated that naphthalenes and phenanthrenes (2- and 3-ring PAH) from plant biogenesis provided the majority of PAH measured in sediments and soils in a Brazilian rainforest with low overall PAH concentrations (i.e., <1 µg g^{-1}). In particular, phenanthrene had elevated concentrations (12-60 ng g^{-1}) in bark and twigs of Vismia trees, of which several species (e.g., *Vismia guyana, Vismia baccifera)* are native to Guyana.

The relative absence of combustion-related PAH in all sediment samples, as evidenced in petrogenic/pyrogenic ratios greater than 1 (**Table 4-7**), further indicates that biogenic or natural material, rather than combustion-related compounds, are the primary source of low level hydrocarbons measured in Guyana offshore sediment.

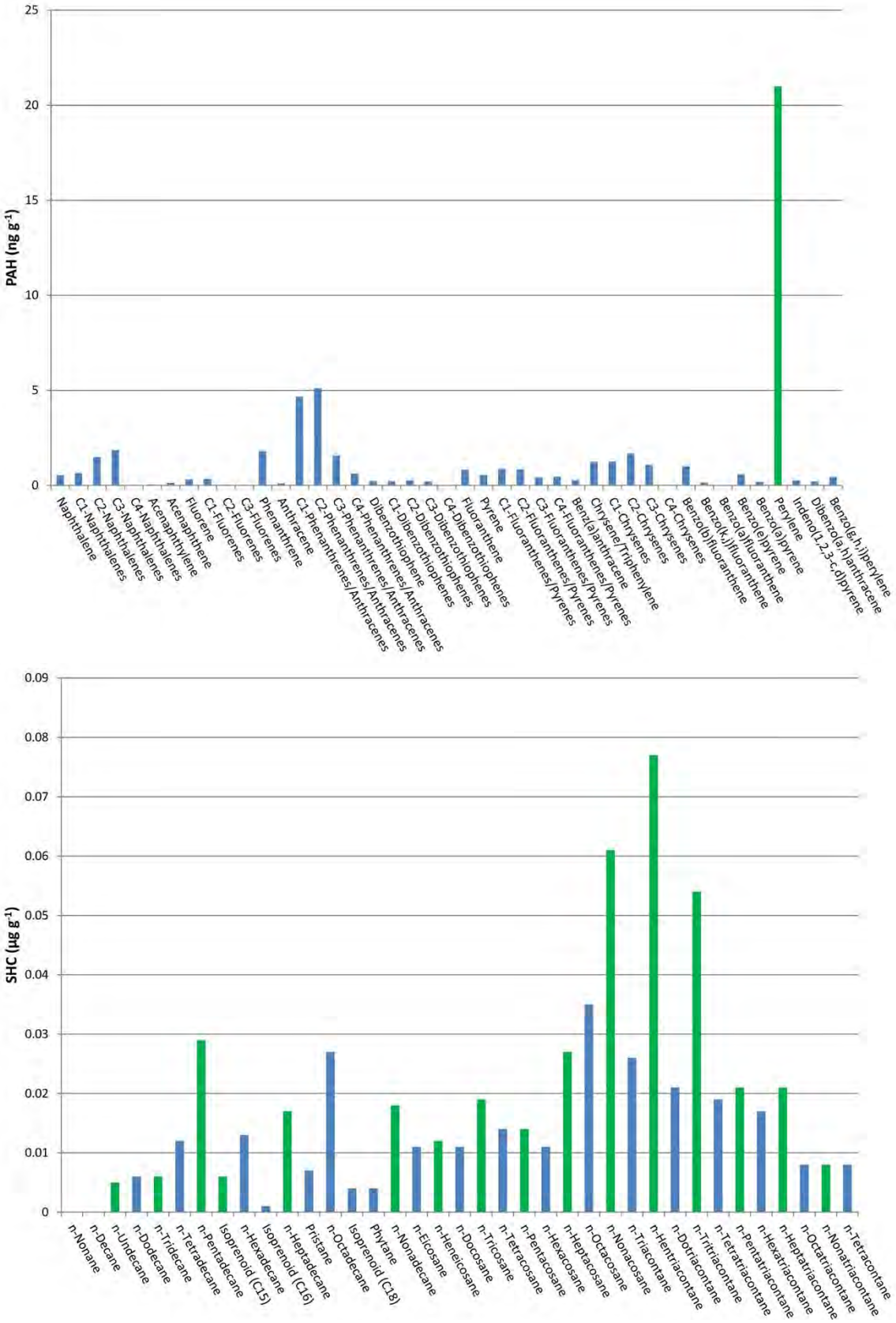


Figure 4-6. Distributions of individual PAH (top) and SHC (bottom) analytes in a representative sediment sample (station L08).

5 BENTHIC MACROFAUNA RESULTS

Benthic macrofauna results are presented for ten Liza and eight Sorubim sediment samples, consisting of patterns of total abundance, abundance of major taxonomic groups, taxonomic diversity, and taxonomic dominance. Presented results include mean values, maxima and minima, and coefficients of variation of data for each of the two sites. Correlations of the biota with depth, sediment grain size and organic content also are examined, spanning the entire range of sediment conditions and depth (877–2327m).

The two sites were sampled at mid- to outer continental slope depths (see Section 1). A stainless steel box corer insert with a sampling surface area of 0.1 m² was used to collect the samples, which were sieved through a 0.5 mm screen and preserved for analysis. Abundance data were respectively transformed and reported as the number of organisms per square meter, which is consistent with conventionally reported benthic literature. Complete field sampling procedures and analytical methods are described in Section 2.

Information on species diversity is constrained by the lack of taxonomic refinement in identification of organisms from deep sediments in general, and particularly from areas such as offshore Guyana (see Levin et al. 2001). Due to the relatively unknown nature of the deep-water biota from this region, taxonomic diversity is discussed in a broader context that is not directly related to the species concept of diversity. Instead, discussion is focused on biological diversity at the family level, which has been shown to be effective in delineating pollution impacts upon the diversity of benthic macrofauna (Ferraro and Cole 1990; Dauvin et al. 2003; Gomez Gesteira et al. 2003).

5.1 Background

The benthic boundary layer serves as a repository for sinking particles containing both organic and inorganic matter, hosting a biologically active and complex trophic food web in continental slope sediments. Benthic infaunal organisms are described as those residing on and in the sediments. They are collected by grab or core sampling, and have conventionally been designated as macrofauna at sizes larger than 0.5 mm (Holme and McIntyre 1971). Most macrofauna live within the upper 10 cm of sediment and are small, averaging only a few milligrams in weight and usually numbering from several hundred to several thousand per m^2 (m^{-2}). Peak values may reach several tens of thousands m^{-2} when a smaller sieve screen (e.g., 0.3mm) is utilized. Many of the increased numbers retained on the smaller screen are isopod and tanaid crustaceans.

The most common invertebrate macrofaunal groups found in marine shelf and continental slope sediments are polychaetous annelid worms, peracarid crustaceans and mollusks (Rex 1981; Grassle et al. 1990; Gage and Tyler 1991). Polychaetes typically comprise about half of the numbers and a third of the macrofaunal species from deep-water marine habitats. Beyond the continental shelf, conventionally defined as exceeding 150 m in depth, macrofaunal biomass and average body size typically decrease with depth, usually ascribed to decreasing food availability and reduced temperature (Rowe et al. 1991; Levin et al. 2000).

Macrofauna communities are known to be strongly influenced by bathymetric gradients in factors such as temperature, dissolved oxygen, and food availability, with depth strongly correlated to shifts of benthic community composition. Relationships of these environmental factors with macrofaunal benthic diversity have been summarized by Levin and Gage (1998) from 40 sites ranging from shelf to abyssal depths of the Atlantic, Pacific and Indian Oceans. Depth, latitude, sediment total organic carbon content (TOC) and bottom water oxygen concentration were determined to be the most significant factors affecting four indices of diversity and community structure, accounting for 52% to 87% of observed variation. Sediment grain size factors were relatively insignificant. When depth and latitude effects were removed, oxygen and organic carbon accounted for 32% to 67% of variation in the four indices.

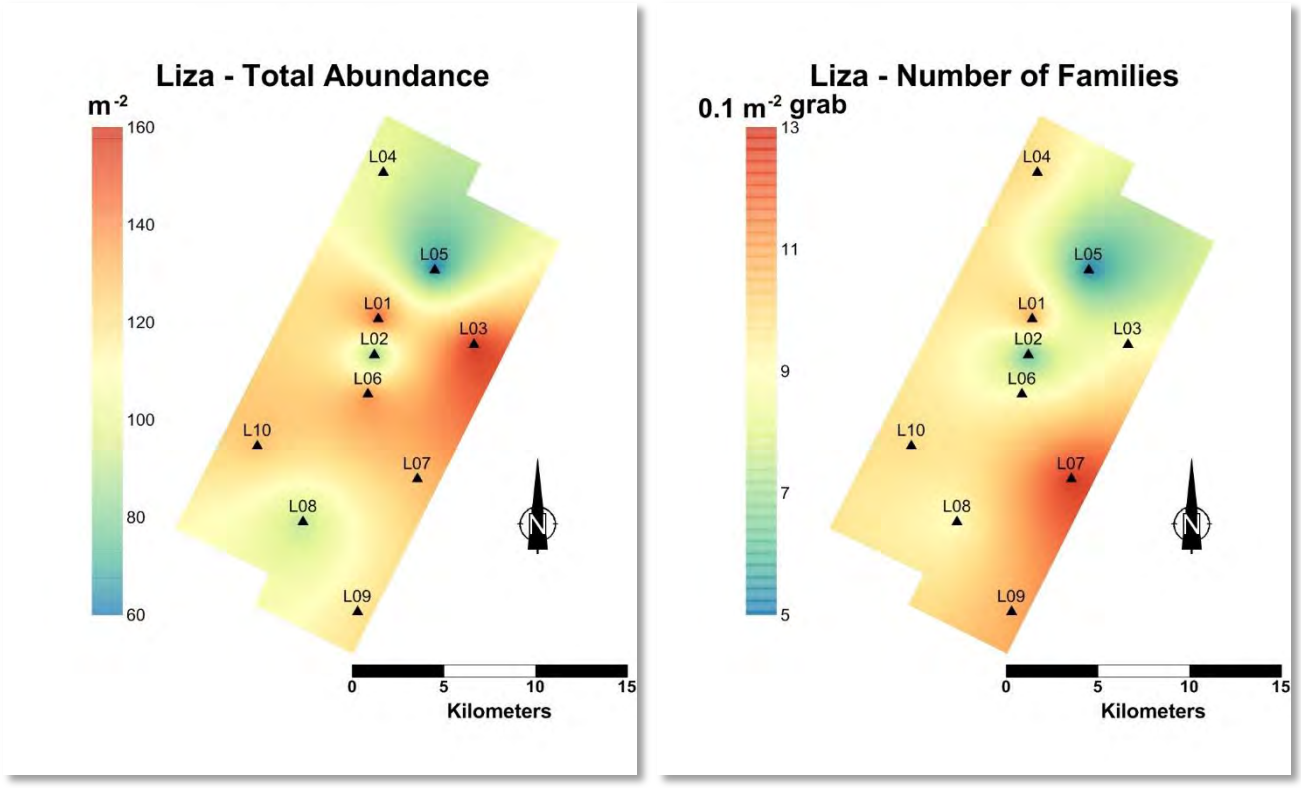


Figure 5-1. Spatial distribution of macrofauna total abundance and family diversity at Liza.

At depths greater than 500 m, seasonal variation in physical parameters (e.g. temperature, salinity) is minimal (Thistle 2003). The absence of significant upwelling phenomena offshore Guyana and little or no seasonal variation in surface productivity in offshore tropical waters suggest that no, or minimal, seasonal variation would be predicted for the benthos in the Liza and Sorubim sampling areas.

Studies of macrofaunal community diversity and abundance have not been conducted on the continental slope offshore Guyana, nor from adjacent areas within several hundred kilometers. This reflects the dearth of information from deep water sites in the southern hemisphere, especially from the western Atlantic Ocean (see Levin and Gooday 2003). From the broader region, studies in the Venezuelan Basin have indicated a macrofaunal abundance of 678 organisms m^{-2} and biomass carbon levels of less than 0.01 grams m^{-2} (Tietjen 1992). Sediments from this region may contain high levels of biogenic carbonate (up to 75%) from Foraminifera tests and may harbor distinctive faunal elements (Briggs 1985).

5.2 Liza – Abundance and Diversity

Ten stations, with a total sampling area of 1.0 m^2, contained 116 organisms, represented by 50 distinct families. General patterns of abundance and diversity, and correlations with sediment parameters and depth follow.

5.2.1 Abundance

Average total macrofaunal abundance was 116 m^{-2}, ranging from 60 to 160 m^{-2}. This population density is at the lower end of macrofaunal densities reported from continental slope sediments around the world (see Rowe et al. 1982; Gage and Tyler 1991). Levels of sediment organic carbon were extremely low in Liza sediments, averaging only 0.52% of sediment dry weight (see Section 4.1). Low sediment TOC suggests limited input of organic food sources sinking to the bottom and does not appear to be sufficient to maintain an abundant macrofauna. Abundance statistics are summarized in **Table 5-1**. Spatial distribution of the abundance of all organisms is illustrated in **Figure 5-1**. Total abundance was not significantly correlated with water depth or sediment physical parameters.

Table 5-1. Summary statistics for benthic macrofauna at Liza (*n*=10). Reported as organisms m^{-2} except where noted.

Parameter	Mean	Standard Deviation	CV	Minimum	Maximum	Station with Minimum	Station with Maximum
Number of Families[1]	9.3	2.4	25.4	5	13	L05	L07
Total Abundance	116	32.4	27.9	60	160	L05	L03
Crustacea	20	14.9	74.5	0	50	L10	L01
Mollusca	29	20.2	69.8	0	60	L05	L03
Polychaeta	47	22.6	48.2	20	90	L04	L01
Other Minor Phyla	11	11	100	0	30	L01	L10

[1]reported as distinct taxa per 0.1 m^2 grab sample; CV=coefficient of variation

The most abundant major taxonomic group was polychaete worms, averaging 47 m^{-2}, comprising 41% of total abundance, followed by mollusks (29 m^{-2}, 25%) and crustaceans (20 m^{-2}, 16%). Collectively they comprised 83% of total macrofaunal numbers. These major taxa are the predominant macrofaunal components of continental slope sediments worldwide. Several other taxonomic groups made up the remaining 18%, including four of the five major classes of echinoderms (brittle stars, starfish, sea-cucumbers, sea urchins), along with nemerteans (ribbon worms), nematodes (round worms), sponges, pycnogonids (sea-spiders) and sipunculids (peanut worms). Dominant families, collectively exceeding 50% of total macrofaunal abundance, are listed in **Table 5-2**.

Table 5-2. Dominant families of macrofauna collectively comprising >50% of total abundance at Liza (*n*=10).

Family	Major Taxon	Percent of total abundance	Frequency of Occurrence (%)
Oweniidae	Polychaete	14.7	70
Tindariidae	Bivalve Mollusk	7.8	40
Apseudidae	Tanaid Crustacean	4.3	50
Arcidae	Bivalve Mollusk	4.3	30
Maldanidae	Polychaete	3.4	30
Golfingiidae	Sipunculid	3.4	30
Phyllodocidae	Polychaete	2.6	30
Chaetopteridae	Polychaete	2.6	20
Ampharetidae	Polychaete	2.6	20
Eusiridae	Amphipod Crustacean	2.6	30
Bairdiidae	Ostracod Crustacean	2.6	20

Polychaete worms were present in all 10 samples and were the numerically dominant taxonomic group, comprising 41% of total abundance (47 m^{-2}), varying by a factor 4.5 between samples.

Predominance of polychaetes is characteristic of continental slope sediments (Knox 1977; Gage and Tyler 1991). Nineteen polychaete families were identified, of which five collectively comprised more than 75% of total polychaete abundance (Oweniidae, 17 m^{-2}; Maldanidae, 4 m^{-2}; Chaetopteridae, 3 m^{-2}; Phyllodocidae, 3 m^{-2}; Ampharetidae, 3 m^{-2}). These families are common and cosmopolitan in distribution from continental slope sediments.

Oweniid polychaetes were the most abundant family of macrofauna, comprising 14.7% of total organisms sampled. These sedentary tube dwelling polychaetes feed on surface deposits and filter suspended particulate matter. Other families such as Capitellidae, Spionidae and Cirratulidae which typify deep sediments with higher organic content (see Pearson and Rosenberg 1978; Bellan 1984) were present, but in lower numbers. Polychaete abundance was not significantly correlated with depth, mean grain size or TOC.

Mollusks were collected at nine of the ten stations. Abundance averaged 29 m^{-2}, comprising 25% of the total macrofauna. Eleven families were collected, of which eight were pelecypods (bivalves). Other molluscan taxa included gastropods (snails), scaphopods (tusk shells) and chaetodermatids. Mollusk abundance was not significantly correlated with depth, TOC or sediment grain size parameters.

Pelecypods had an average abundance of 25 m^{-2}, comprising 86% of mollusk numbers and 22% of total macrofaunal abundance. Tindariids (9 m^{-2}) and Arcids (5 m^{-2}) were the most abundant pelecypod families. Only a single gastropod (snail) was collected (from station L07). Scaphopods of the family Dentaliidae were represented by single specimens from Stations L08 and L10. A single chaetodermatid was collected at station L10.

Crustaceans were present in nine of the ten samples. Abundance averaged 20 m^{-2}, comprising 16% of the total macrofauna. The coefficient of variation between stations (74.5) was the highest of the major taxonomic groups. Crustacean abundance was not significantly correlated with depth, TOC, or sediment grain size parameters.

The most abundant crustaceans were amphipods and tanaidaceans (6 and 5 m^{-2}, respectively). Cumaceans, ostracods, and isopods comprised the remaining crustacean fauna (collectively 5 m^{-2}). Typically, tanaidaceans and isopods are the numerically dominant crustacean groups in slope sediments.

Crustaceans were represented by 10 families, each typically absent from the majority stations or represented by a single individual. Only the tanaidacean family Apseudidae was present at the majority of stations, from which only single individuals were collected. With the exception of three ostracod specimens, all crustaceans (amphipods, isopods, cumaceans, tanaidaceans) were members of the Pericarida super-order, a group of crustaceans that brood their young, generally are of small body size, and are highly successful in deep marine sediments (Sanders 1977; Brandt 1997).

Grouped Minor Phyla, the remaining Liza macrofauna, consisting of a variety of major taxa, collectively comprised 18% of total abundance. Of these, echinoderms (9 m^{-2}) and sipunculids (6 m^{-2}) were most abundant. None of the remaining major taxa exceeded 2 m^{-2} in average abundance.

5.2.2 Diversity and Dominance

The number of families per sample (also referred to as family diversity) can provide an assessment of species habitat suitability. A diversity of families indicates relatively unstressed conditions, with habitat factors that are central to the tolerance ranges of a relatively high number of potential recruits. Low family diversity may reflect environmentally stressed or marginal conditions unsuitable for successful settlement and subsequent growth of recruits. Dominance is defined as the number of species comprising 50% or more of total infaunal abundance. Herein, it is applied to the number of families.

Fifty families of marine organisms were identified from the 10 boxcore samples. Areal (spatial) distribution of family diversity is shown in **Figure 5-1**. The average number of families per grab was 9.3, ranging from 5 to 13, with a CV of 25.4. This is a high number of families given the low total number (n = 116) of organisms retrieved from ten samples. The average number of organisms per family was only 2.3, indicating a low level of dominance by any specific family. This indicates conditions of low physical-chemical stress at the sediment boundary, thereby providing adequate habitat for a diverse biota, but with low flux of detrital food material reaching the bottom to support a larger population.

It is noteworthy that over half of the 50 families were represented by either one or two individuals from the ten samples. This proportion of families represented by few individuals indicates that much more sampling is required to adequately represent the family diversity either locally or regionally (see Grassle and Maciolek 1992).

5.3 Sorubim – Abundance and Diversity

Eight stations from the Sorubim site, with a total sampling area of 0.8 m^2 contained 80 organisms, represented by a 41 families. General patterns of abundance, diversity and their correlations with sediment parameters and depth are discussed below.

5.3.1 Abundance

Average total macrofaunal abundance was 100 m^{-2}. This population density is at the lower end, but within the range, of macrofaunal densities reported from continental slope sediments around the world (see Rowe et al. 1982; Gage and Tyler 1991). Levels of sediment organic carbon were low in sediments, averaging only 0.37% of sediment dry weight (Section 3.3.1), indicating a general limitation of organic food sources reaching bottom sediments to maintain an abundant macrofauna. The only significant correlation (z < 0.05) between abundance and depth, TOC or sediment grain size parameters was a positive correlation between bivalve abundance and percent fines.

Abundance statistics are summarized in **Table 5-3**. Dominant families, collectively exceeding 50% of total macrofaunal abundance, are listed in Table 5-4. Spatial distribution is illustrated in **Figure 5-2**.

Table 5-3. Summary statistics for benthic macrofauna at Sorubim (*n*=8). Reported as organisms m^{-2} except where noted.

Parameter	Mean	Standard Deviation	CV	Minimum	Maximum	Station with Minimum	Station with Maximum
Number of Families[1]	8	3.4	42.8	4	14	S01	S05
Total Abundance	100	40	40	40	150	S01	S03
Crustacea	15	20	133.3	0	50	S01	S05
Mollusca	37.5	29.2	77.7	0	100	S01	S03
Polychaeta	28.8	27	93.8	0	90	S09	S07
Other Minor Phyla	13.8	14.1	102.4	0	40	S01	S08

[1]reported as distinct taxa per 0.1 m^2 grab sample; CV=coefficient of variation

Table 5-4. Dominant families of macrofauna collectively comprising >50% of total abundance at Sorubim (*n*=8).

Family	Major Taxon	Percent of total abundance	Frequency of Occurrence (%)
Tindariidae	Bivalve Mollusk	12.5	37.5
Oweniidae	Polychaete	7.5	20
Nuculidae	Bivalve Mollusk	7.5	27.5
Silicea*	Sponge	3.8	12.5
Chrysopetalidae	Polychaete	3.8	12.5
Spionidae	Polychaete	3.8	25
Cirratulidae	Polychaete	3.8	37.5
Nematoda*	Round Worm	3.8	37.5
Eusiridae	Amphipod Crustacean	2.5	25

*Unidentified family

Mollusks were the most abundant major taxonomic group, averaging 37.5 m^{-2}, comprising 37.5% of total abundance, followed by polychaete worms (28.8 m^{-2}, 29%) and crustaceans (15 m^{-2}, 15%). Collectively they comprised 81% of total macrofaunal numbers. These major taxa are the predominant macrofaunal components of continental slope sediments, worldwide. Several other taxonomic groups made up the remaining 18.5%, including four of the five major classes of echinoderms (brittle stars, starfish, sea-cucumbers, sea urchins), along with hydrozoans, sea-anemones, nemerteans, nematodes and sponges.

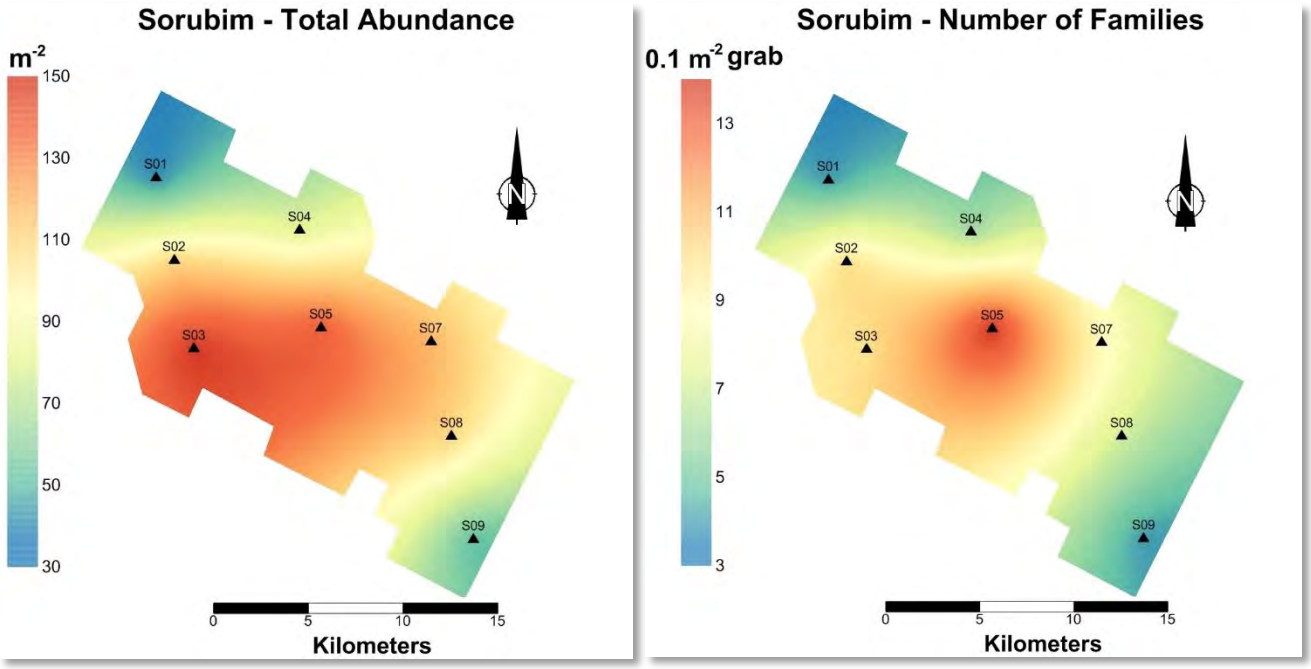


Figure 5-2. Spatial distribution of macrofauna total abundance and family diversity at Sorubim.

Mollusks were collected at seven of the eight sampling stations. Abundance averaged 37.5 m^{-2}, comprising 37.5% of the total macrofauna. Eleven families were collected, of which nine were pelecypods (bivalves). Other molluscan taxa included gastropods (snails) and scaphopods (tusk shells).

Pelecypods had an average abundance of 32.5 m^{-2}, comprising 87% of mollusk numbers and 32.5% of total macrofaunal abundance. Tindariidae (12.5 %) and Nuculidae (7.5 %) were the most abundant pelecypod families (**Table 5-4**). Both of these families are members of the bivalve Order Nuculoida, which contains several families that are dominant members of continental slope macrofaunal communities. Only two gastropods (snails) were collected (from stations S05 and S07). Scaphopods of the family Laevidentaliidae were represented by single specimen from station S03.

Pelecypod abundance exhibited a positive correlation with fine (silt + clay) sediments ($p = 0.837$, $z = 0.019$). Correspondingly, they had a significant negative correlation with the larger sand fraction. Correlations with depth and TOC were insignificant.

Polychaete worms were present in seven of the eight samples, with an average abundance of 28.8 m^{-2}, comprising 29% of total abundance, with a CV of 93.8 between samples. Polychaetes typically represent a higher fraction of total abundance in slope sediments.

Eleven polychaete families were identified, of which oweniids (7.5 m^{-2}) were the most abundant. Other representative families (see **Table 5-4**) are common and cosmopolitan in distribution from continental slope sediments. These sedentary tube dwelling polychaetes feed on surface deposits and filter suspended particulate matter. Other families such as Capitellidae, Spionidae and Cirratulidae which typify deep sediments with higher organic content (see Pearson and Rosenberg 1978; Bellan 1984) were present, but in lower numbers. Polychaete abundance was not significantly correlated with depth, mean grain size or TOC.

Crustaceans were present at four of the eight stations. Abundance averaged 15 m^{-2}, comprising 15% of the total macrofauna. The coefficient of variation between stations (133.5) was the highest of the major taxonomic groups. Crustacean abundance was not significantly correlated with depth, TOC or sediment grain size parameters.

The most abundant crustaceans were amphipods (10 m^{-2}). Tanaidaceans and isopods each averaged 2.5 m^{-2}. They are typically found at higher population densities in slope sediments. Crustaceans were absent from half of the eight stations. Only a single crustacean family (Eusiridae), an amphipod, exceeded 2% of total macrofaunal abundance. All crustaceans were pericarids, which brood their young.

Grouped Minor Phyla; the remaining Sorubim macrofauna, consisting of a variety of major taxa collectively comprised 19% of total abundance. Of these, echinoderms (5 m^{-2}) and sponges (5 m^{-2}) were most abundant.

5.3.2 Diversity and Dominance

Forty-one families of marine organisms were identified from the eight stations. Spatial distribution of family diversity is shown in **Figure 5-2**. The average number of families per grab was 8.0, ranging from 4 to 14, with a CV of 42.8. This is a high number of families given the low total number of organisms (*n* = 80) obtained from the eight samples. The average number of organisms per family was only 1.95, indicating a low level of dominance by any specific family, suggesting conditions of low physical-chemical stress at the sediment boundary. While a diversity of families was present, none had large populations due to an apparent lack of food source as indicated by low TOC values, which averaged less than 0.4% of sediment dry weight.

6 EVALUATION OF DATA QUALITY

This section evaluates the quality of the collected and analyzed data to determine whether relevant program objectives identified in Section 1.1 were met. Specifically, elements of the study design, critical to meeting program objectives (restated below) were evaluated using EBS results (Section 6.1). Sections 6.2 and 6.3 evaluate quality control data for key chemical and biological parameters provided by the laboratories to ensure that data quality objectives, specified in method-specific Standard Operating Procedures (SOPs), were met. Detailed descriptions of analytical methods are presented in Section 2.

6.1 Evaluation of EBS Objectives

Results for key parameters were examined to determine whether the following program objectives (see Section 1) were met.

1. *Provide comprehensive, descriptive, and quantitative documentation of environmental conditions in the area of potential exploration within Liza and Sorubim exploration sites.*

2. *Gain information to assess the significance of environmental impacts to offshore Guyana sediment from potential existing sources such as atmospheric deposition.*

3. *Identify potential confounding factors that may interfere with the interpretation of sediment chemical and biological data to aid sampling design and interpretation of future environmental data.*

To meet the above objectives, sediment and water were sampled in Liza and Sorubim areas of planned petroleum exploration to determine environmental conditions prior to future drilling (see Figure 1-1, Section 1). A total of 18 sediment samples were collected: ten at Liza and eight at Sorubim. Water samples were collected at seven of the sediment stations: four at Liza and three at Sorubim. Samples were collected at three discrete depths (near-surface, at 25m depth, and near-bottom) to capture representative samples from the stratified water column. Water depths ranged from 877m to 2327m for the sampling area, which was located primarily downslope off the central coast of Guyana.

Results for key physical, biological, and chemical parameters (identified in Table 2-2, Section 2) were evaluated to provide estimates of variability and identify physical factors that may impact monitoring results. Potential physical confounding factors, including sediment particle size, water depth, and total organic carbon (TOC), also were measured. These factors are recognized for their strong influence on benthic community structure and sediment chemical characteristics, and can be important in the interpretation of data.

6.1.1 Study Objective 1

Variation within the data set, presented as coefficients of variation (CV), is shown for selected key parameters in **Table 6-1**. Coefficients of variation indicate the relative spread in population data, where the CV = standard deviation ⁄ the population mean x 100. The mean value ± 2 x CV (expressed as percent of mean) provides an approximation of the data envelope containing 95% of the individual data points. With the exception of percent sand at Liza, all key physical and chemical parameters had CV's <50 for sediment samples collected from each site, consistent with physically uniform, uncontaminated sediment. Echinodermata and Amphipoda abundance CV's were relatively high (>100) compared with other macrofauna results, likely due to very low numbers of individuals and patchy distribution. In general, variability is expected to decrease with decreasing distance between stations in future surveys.

Benthic macrofauna community results with CV's >100 are often reported in the literature, typically due to factors such as recruitment, availability of food, predation, environmental contamination, and organic enrichment.

Table 6-1. Coefficients of variation (CV) for mean results reported for selected key parameters for Liza and Sorubim.

Parameter	Liza (*n*=10)	Sorubim (*n*=8)
Sand	71.9	30.9
Silt	30.1	15.0
Clay	16.6	29.0
Fines	15.6	12.5
TOC	30.4	22.6
Depth	24.2	9.0
Aluminum	20.2	20.1
Arsenic	34.2	46.8
Barium	27.8	33.7
Cadmium	19.4	18.3
Chromium	29.0	21.1
Copper	14.0	21.5
Iron	20.3	20.9
Lead	19.1	12.5
Mercury	27.9	21.9
Nickel	23.0	15.9
Vanadium	16.0	21.2
Zinc	27.5	17.3
Total PAH(43)	28.5	35.1
Total SHC	18.0	28.3
Total Unresolved SHC	41.2	41.2
Total Resolved SHC	56.1	58.3
Total Abundance	27.9	40.0
Number of Families	25.4	42.8
Annelida	48.2	93.8
Crustacea	74.5	133.3
Mollusca	69.8	77.7
Other	100.0	102.4
Echinodermata	143.0	151.2
Amphipoda	161.0	141.4
Pelecypoda	76.0	73.1
Polychaeta	48.2	80.0

Low variability in key physical and chemical measurements indicates that post-exploration environmental impacts to study area sediments will be relatively easy to discern from existing conditions. For example, drilling-related discharges to the seafloor, including barium, cuttings (via grain size measurements), or hydrocarbons (e.g., adhered non-aqueous drilling mud), should produce significant differences from background at concentrations of approximately two times higher than EBS concentrations, which are very low based on results from this study. A prospective (a priori) power analysis should be performed prior to designing a post-drilling program to provide information on the number of samples needed to determine a defined difference between mean values for different areas (e.g., well site, reference), which is a standard approach used to quantify changes from drilling-related discharges.

6.1.2 Study Objective 2

Potential confounding factors were evaluated to satisfy Study Objective 2, and to aid sampling design of future studies. Pearson correlations were performed on measured parameters to identify physical characteristics that were significantly correlated with key chemical and biological results, and could therefore, potentially confound interpretation of results. Correlation results for physical parameters with key chemical and macrofauna parameters are presented in Sections 4 and 5, respectively.

Most metals (including barium) and several key hydrocarbon parameters displayed significant correlations with percent fines and TOC (z <0.05) at both sites. These results indicate that sediment grain size and/or TOC should be taken into account in the interpretation of chemical results in future studies.

There were no significant correlations between major macrofauna group abundances with sediment physical parameters or water depth for either site. This is an unusual situation that is likely due to the limited water depth range and consistently low levels of TOC observed at each site.

6.2 Analytical Chemistry Data Quality

Laboratory quality control results were evaluated to ensure that data of sufficient quality were produced to meet program objectives. Quality control objectives for batch analysis (≤20 field samples) are shown in **Table 6-2** for analysis of hydrocarbons and in **Table 6-4** for metals. Quality control results for PAH, SHC and metals data follow.

6.2.1 Hydrocarbons

B&B Analytical Laboratory quality control data packages demonstrated that initial calibration, continuing calibration and procedural blank data for polycyclic aromatic hydrocarbons (PAH) and saturated (aliphatic) hydrocarbons (SHC) met or exceeded data quality objectives listed in **Table 6-2**. Continuing calibration, procedural blanks, duplicate samples, and blank spike/blank spike duplicate pairs were analyzed with every batch of field samples.

PAH. Trace levels of several target compounds (primarily naphthalene, and C_1- and C_2-napthalenes) were detected in the procedural blanks for both sediment and water samples. All concentrations were below five times the corresponding method detection limits, and therefore, met quality control criteria for the method.

Surrogate standards were added to every field sample to monitor extraction efficiency. Surrogate standard recoveries were within the quality control limits specified in **Table 6-3** for all sediment and water samples.

Differences in analyte concentrations (>10x method detection limit) for duplicate samples, as well as concentrations of 100% of matrix spike/matrix spike duplicate analytes and all of the reference standard analytes were within acceptable limits (results not shown).

SHC. Initial calibration, continuing calibration, and procedural blank data for SHC analysis performed by B&B Analytical Laboratory met or exceeded data quality objectives for the method (US EPA 8015-modified). Continuing calibration, procedural blank, duplicate sample, blank spike/blank spike duplicate and standard reference material were analyzed with every batch of field samples. Surrogate standards were added to every field sample to monitor extraction efficiency. Differences in analyte concentrations (>10 x method detection limit) of duplicate samples were within acceptable limits, as were matrix spike and matrix spike duplicate analyte concentrations. Based on these results, SHC analysis satisfied the data quality objectives established for the program. Quality control results for surrogate spike recoveries for 18 sediment and 21 water samples for PAH and SHC are summarized in **Table 6-3**. All surrogate recoveries were within acceptable ranges for each method.

Table 6-2. Summary results for QC surrogate recovery for hydrocarbons (PAH and SHC) in sediment and water. Results reported as percent recoveries (%).

QC Parameter	QC Frequency	Acceptance Criteria	Corrective Action
Instrument Check	1 per analytical run	±15% recovery	Reanalyze or document justification.
Surrogate recovery	2-3 per sample	50-120% recovery	Reanalyze or document justification. Flag impacted data.
Procedural blank	1 per batch of 20 samples	No target analytes > 5X MDL	Reanalyze or document justification. Flag impacted data.
Laboratory Control Sample (Blank Spike)	1 per batch of 20 samples	70-120% recovery	Reanalyze or document justification. Flag impacted data.
Laboratory Sample Duplicate	1 per batch of 20 samples	±30% RPD for 90% of the target analytes that are present at concentrations >10x MDL	Review data to assess impact of matrix. Reanalyze or document justification. Flag impacted data.
Instrument Calibration – Initial Calibration	Initial 5-point prior to sample analysis	±25% RSD single compound average of 15%	Re-calibration or document justification.

MDL=method detection limit; RPD=relative percent difference; RSD=relative standard deviation.

Table 6-3. QC summary results for hydrocarbons (PAH and SHC) analyzed in water and sediment. Results reported as percent (%).

Surrogate	Mean	Minimum	Maximum	Standard Deviation	Acceptable
Sediment PAH (n=18)					
Acenaphthene-d10	86.66	83.67	91.64	2.44	Yes
Chrysene-d12	82.63	79.95	85.15	1.44	Yes
Naphthalene-d8	79.88	74.57	87.36	3.65	Yes
Perylene-d12	62.59	31.71	81.61	14.38	Yes
Phenanthrene-d10	84.30	81.49	87.84	1.67	Yes
Sediment SHC (n=18)					
n-Dodecane-d26	80.56	74.70	89.60	5.50	Yes
n-Eicosane-d42	90.44	83.30	97.20	4.81	Yes
n-Triacontane-d6	94.08	86.40	101.40	5.27	Yes
Water PAH (n=21)					
Naphthalene-d8	83.18	69.32	92.00	6.46	Yes
Acenaphthene-d10	90.41	80.65	105.00	6.64	Yes
Phenanthrene-d10	82.35	66.66	99.00	8.46	Yes
Chrysene-d12	86.74	74.00	94.00	6.01	Yes
Perylene-d12	86.05	74.00	92.00	5.78	Yes
Water SHC (n=21)					
n-Dodecane-d26	56.95	29.90	73.80	11.17	Yes
n-Eicosane-d42	92.11	78.80	98.00	5.51	Yes
n-Triacontane-d6	86.85	71.70	97.10	5.07	Yes

6.2.2 Metals

Quality control criteria and corresponding results for metals analysis are presented in **Tables 6-4** and **6-5,** respectively. Analysis of procedural blanks, matrix spikes, and sample duplicates performed by Albion Environmental Laboratory met all data quality objectives. A procedural blank was analyzed with each batch in order to monitor potential contamination resulting from laboratory reagents and processing procedures. A matrix spike sample (method of additions analysis) was analyzed to provide information on the extent of any signal suppression or enhancement due to the sample matrix. A sample duplicate was analyzed every 10 samples to verify method precision. Based on these results, analysis of metals satisfied the data quality objectives established for the program.

The heated, strong acid leach digestion used to extract metals is NOT a total digestion quantifying all of a given element present in the sediment matrix. The percentage of metal leached into solution for analysis varies by element. For example, for the more refractory metals (e.g., chromium, vanadium), only a relatively small percentage is extracted. For many other elements (including many pollutant metals) that are largely adsorbed onto the sediment particles, a much higher percentage is extracted. A sediment reference material (MESS-3) was used to estimate the percentage of each element leached into solution for analysis. The percentage released is compared to a historical percentage that is typically observed for such a heated strong acid leach. Results for the batch analysis of MESS-3 were within the normal range of historical data, indicating acceptable accuracy for the EBS metals analyzed (historical data not shown).

6-4. Data quality objectives for metals analyzed by ICP with mass detector.

QC Parameter	Acceptance Criteria	Corrective Actions
Mass Calibration	Must not differ by more than 0.1 amu from true value	Perform Instrument Maintenance. Re-calibrate
Resolution Checks	Less than 0.9 amu at full width at 10% peak height	Perform Instrument Maintenance. Re-check
Method Blank	< reporting limit	Notify project manager. Re-extract samples. Evaluate impact to data, discuss with manager, determine if corrective action is necessary
Laboratory Control Sample	80-120% recovery for aqueous and 75-125% recovery for solid	Evaluate impact to data, discuss with manager, determine if corrective action is necessary
Matrix Spike Duplicate (if requested)	75-125% recovery for solid and aqueous; and 20% RPD	Evaluate impact to data, discuss with manager, determine if corrective action is necessary
Initial and Continuing Calibration Verification	90-110% recovery	Perform Instrument Maintenance. Re-analyze affected samples. Notify project manager and justify.
Initial and Continuing Calibration Blank	< reporting limit	Perform Instrument Maintenance. Re-analyze affected samples. Notify project manager and justify.
ICSA and ICSAB Solution	80-120% recovery for spiked analytes	Evaluate impact to data, discuss with manager, determine if corrective action is necessary

amu=atomic mass unit; MDL=method detection limit; RPD=relative percent difference; RSD=relative standard deviation.

6-5. QC summary results for metals analyzed in water and sediment. Results reported as percent (%) unless noted.

QC Sample	Total QC Batch Samples	Minimum	Maximum	Acceptable
Sediment Samples (n=18)				
Matrix Spike Recovery	2	89 (V)	116 (Ba)	Yes
Laboratory Duplicate RPD	2	0.9 (V)	24 (Pb)	Yes
Reference Material Recovery	2	91 (V)	104 (Al, Fe)	Yes
Blank Spike Recovery	2	81 (Pb, Zn)	115 (As)	Yes
Method Blank (µg L^{-1})	2	<0.002 (Hg)	<20 (Al, Fe)	Yes
Water Samples (n=21)				
Matrix Spike Recovery	3	92 (Cd, Cu)	107 (As)	Yes
Reference Material Recovery	3	92 (V)	102 (Zn)	Yes
Blank Spike Recovery	3	95 (Zn)	115 (Ni)	Yes
Method Blank (µg L^{-1})	2	<0.0002 (Hg)	<0.5 (Pb, Zn, Ni, Cr)	Yes
Field Blank (µg L^{-1})	3	<0.0002 (Hg)	<0.5 (Pb, Zn, Ni, Cr)	Yes

6.3 Benthic Infauna

There are three major processes that affect the quality of benthic infaunal data: 1) field collection of samples, 2) laboratory removal and sorting of organisms, and 3) taxonomic identification. Quality control procedures and results used for each of these three major processes follow.

6.3.1 Collection of Benthic Infaunal Sediment Samples

Sample quality was controlled through a process of observation and measurement during the acquisition of sediments destined for infaunal analysis. All 18 EBS sediment samples collected met the following criteria:

1. Sampling device (e.g., 0.1-m^2 box core insert) was not overfilled with sediment
2. Sampling device was fully closed upon sample retrieval
3. Overlying water was not excessively turbid
4. Sampling device contained greater than 15 cm of sediment
5. Sieving/screening device was without tears and punctures for all samples

Infaunal sediment samples collected during the investigation that did not meet the above criteria were rejected and the station was re-sampled. Review of station occupation data taken from the field logs indicated that of the 21 stations sampled, two required more than one grab due to washed out, slumped, or disturbed sediment.

6.3.2 Laboratory Removal and Sorting of Organisms

Ten percent of all samples (i.e., 2 random samples) were re-sorted to provide assurance that >90% of infaunal organisms were removed from sample debris. Resorting was conducted by a quality control technician that did not perform the initial sorting task. The quality control technician sorted through previously processed material following procedures used during the initial removal/sorting process. The total number of newly discovered organisms from the second sorting effort was compared to the total number of organisms obtained from the initial processing task. If the resorted sample contained greater than 10 percent additional organisms, all samples processed by the initial processing technician were completely reprocessed.

Sorting QC results for two randomly selected samples follow. Sample S-EBC02 (station S02) passed, scoring 100%. Sample L-EBC07 (station L07) failed at 90%. An additional QC sample for the initial sorter was randomly chosen from their remaining eight samples. That sample (L-EBC03, station L03) passed, scoring 100%. Final QC results were 95% average sorting efficiency.

6.3.3 Identification and Enumeration of Benthic Macrofauna

Randomly selected 10% of all identifications were reviewed by a second taxonomist. Individual taxa were compared to an extensive in-house reference collection and a voucher collection of identified species was established. Additionally, names of identified species were compared to species reported from other investigations of Caribbean / southwest Atlantic macrofauna, and with the scientific literature for similar latitudes and water depths.

7 DISCUSSION AND CONCLUSIONS

The offshore Guyana EBS area is relatively isolated from coastal activities, and at present is removed from other offshore oil and gas operations. Potential impacts to the marine environment from offshore petroleum development are unlikely to be significant if they are restricted to the immediate development area. However, there is the potential for transport of drilling and operation-related substances into sensitive areas of nearshore shallow zones from the longshore North Brazil Current (NBC) that flows north along the northeastern coast of South America, as it passes Guyana. In addition, the environment may be vulnerable to offshore transport of substances from the Essequibo River, which could project a freshwater lens to Stabroek Block surface waters during periods of heavy flow. Metal and hydrocarbon concentrations in offshore sediments and water are some of the lowest reported worldwide. However, increased industrialization of onshore areas, or localized activities associated with oil and gas exploration and production could contribute to pollutants offshore.

The observed patterns of variance in key physical, chemical, and biological parameters have general implications for environmental monitoring design. Under observed conditions, minor chemical perturbations to the seafloor from drilling operations will be discerned in the local environment within Liza and Sorubim areas of the Stabroek Block. Based upon the current set of data, hydrocarbons (i.e., total PAH and total resolved SHC) are the best indicators of chemical impact. This is due to their potential source from drilling activities as well as their extremely low concentrations and strong positive correlations with fine-grained sediment and organic carbon content.

Benthic macrofauna at Liza and Sorubim are characterized by low abundances combined with high diversity, and low dominance by specific groups. Numerically prevalent groups include polychaete worms, pelecypod molluscs and pericarid crustaceans, as is typical of slope-depth sediments worldwide. The respective average abundances of 116 m^{-2} and 100 m^{-2} are amongst the lowest values reported from continental slope sediments. This result indicates low primary productivity in overlying surface waters, as indicated by corresponding sediment total organic carbon concentrations of approximately 0.5%.

While total abundances were similar between the sites, polychaetes were relatively more abundant at Liza, while mollusks prevailed at Sorubim. Crustaceans were more common and abundant at Liza. The 51 and 41 respective families identified at Liza and Sorubim are typical of continental slope habitats over wide geographic ranges of the world's oceans that are not limited by oxygen depletion, organic loading, or other unique conditions.

The majority of families were represented by no more than two individuals per station, suggesting a low level of group dominance, and indicating that higher sampling density would be required to adequately characterize local or regional diversity.

The results of the Liza and Sorubim site surveys did not indicate the presence of any unique or atypical habitat for the region under consideration. Thus, should any localized potential impact from drilling activities occur, they are unlikely to pose a significant threat to overall population maintenance of the resident biota in the region.

Based upon the current set of data, while abundances of major taxonomic and selected indicator species may be sensitive to drilling-related impacts, taxonomic diversity (e.g., family diversity) would likely provide the best indicator due to its conservative nature (low variability) and responsiveness to environmental perturbations.

Little information concerning temporal variability in macrofauna from this region is available. Therefore, direct comparison of pre- and post-drilling conditions to quantify impacts from exploration activities should be avoided. Instead, inference of drilling-related effects should be based on statistically-based gradient analysis between point sources and references sites that are removed from potential impacts.

8 REFERENCES

Bellan, G. 1984. Indicateurs et indices biologiques dans le domaine marin. Biological Bulletin 15(1): 13-20.

Boesch, D.F. and N.N. Rabelais (Eds.). 1987. Long-term Environmental Effects of Offshore Oil and Gas Development. Elsevier, New York.

Brandt, A. 1997. Biodiversity of peracarid crustaceans (Malacostraca) from the shelf down to the deep Arctic Ocean, Biology & Conservation 6: 1533-1556.

Briggs, K.B. 1985. Deposit feeding by some deep-sea megabenthos from the Venezuela Basin: selective or non-selective. Marine Ecology Progress Series 21: 127-134.

Buchman, M.F. 2008. NOAA Screening Quick Reference Table, NOAA OR&R Report 08-1, Seattle, WA, Office of Response and Restoration Division, National Oceanic and Atmospheric Administration, 34 pages. http://response.restoration.noaa.gov/book_shelf/122_NEW-SQuiRTs.pdf

Dauvin, J.C., J.L. Gomez Gesteira, and M. Salvande Fraga. 2003. Taxonomic Sufficiency: an overview of its use in the monitoring of sublittoral benthic communities. Marine Pollution Bulletin 46(2003): 552-555

Douglas, G.S., A. E. Bence, R.C. Prince, S.J. McMillen, and E. L. Butler. 1996. Environmental stability of selected petroleum hydrocarbon source and weathering ratios. Environmental Science and Technology, Vol. 30, p. 2332-2339.

Ferraro, S.P. and F.A. Cole. 1990. Taxonomic level and sample size sufficient for assessing pollution impacts on the Southern California Bight macrobenthos. Marine Ecology Progress Series 67: 251-262.

Folk, R.L. 1980. The Petrology of Sedimentary Rocks. Hemphill. Publ. Co., Austin, TX, 182 pp.

Gage, J.D. and P.A. Tyler. 1991. Deep Sea Biology. A Natural History of Organisms at the Deep-Sea Floor. Cambridge University Press, 504 pp.

Gomez Gesteira, J.L.., J.C. Dauvin and M. Salvande Fraga. 2003. Taxonomic level for assessing oil spill effects on soft-bottom sublittoral benthic communities. Marine Pollution Bulletin 46 (2003): 562-572.

Grassle, J. F, N.J. Maciolek, and J.A. Blake. 1990. Are deep-sea communities resilient? In: The Earth in Transition: Patterns and Processes of Biotic Impoverishment. G.M. Woodwell (Ed.), Cambridge Univ. Press, New York, pp. 359-384.

Grassle, J.F. and N.J. Maciolek. 1992. Deep-sea species richness: Regional local diversity estimates from quantitative bottom samples. American Naturalist 139 (2): 313-341.

Holme, N.A. and A. McIntyre. 1971. Methods for the study of marine benthos. International Biological Pragramme Handbook No. 16. Blackwell, Oxford. 334 pp.

Hunt, J.M. 1995. Petroleum Geochemistry and Geology, 2ND Ed. WH Freeman and Company. New York. pp. 743. ISBN 0 7167 2441 3.

Kennish, M.J. 1992. Ecology of Estuaries: Anthropogenic Effects. CRC Press, Boca Raton, FL, 494 pp.

Kennish, M.J. 1997. (Ed.) Practical Handbook of Estuarine and Marine Pollution. CRC Press, Boca Raton, FL, 524 pp.

Knox, G.A. 1977. The role of polychaetes in benthic soft-bottom communities. Pp. 547-604, In Essays of Polychaetous Annelids, in Memory of Dr. Olga Hartman. D.T. Reish and K. Fauchald (Eds.). Allan Hancock Foundation, Special Publication, 604 p.

Krauss, M. W. Wilcke, C. Martius, A.G. Bandeira, M.V.B Garcia, and W. Amelung. 2005. Atmospheric versus biological sources of polycyclic aromatic hydrocarbons (PAHs) in a tropical rain forest environment. Environmental Pollution 135(1): 143-154.

LaFlamme, R.E. and R.A. Hites. 1978. The Global Distribution of Polycyclic Aromatic Hydrocarbons in Recent Sediments. Geochim. et Cosmochim. Acta. 42:289-303.

Levin, L.A. and J.D. Gage. 1998. Relationships between oxygen, organic matter and the diversity of bathyal macrofauna. Deep-Sea Research II 45: 129-163.

Levin, L.A., J.D. Gage, C. Martin and P.A. Lamont. 2000. Macrobenthic community structure within and beneath the oxygen minimum zone, NW Arabian Sea. Deep-Sea Research II 47 (2000): 189-226.

Levin, L.A., R.J. Etter, M.A. Rex, A.J. Gooday, C.R. Smith, J. Pineda, C.T. Stuart, R.R. Hessler and D. Pawson. 2001. Environmental influences on regional deep-sea species diversity. Annual Review of Ecology & Systematics 32: 51-93.

Levin, L.A. and A.J. Gooday. 2003. The Deep Atlantic Ocean. Chapter 5 *In*: Ecosystems of the Deep Oceans. P.A. Tyler (Ed.), Elsevier.

Lumpkin, R. and Garzoli, S.L. 2005. Near-surface circulation in the Tropical Atlantic Ocean. Deep-Sea Research I, 52:495–518.

Morel, F.M.M., A.J. Milligan, and M.A. Saito. 2006. Marine bioinorganic chemistry: the role of trace metals in the oceanic cycles of major nutrients. Pp. 113-144, *In*: The Oceans and Marine Geochemistry (Ed. H. Elderfield). Vol 6 *Treatise on Geochemistry* (Eds. H.D. Holland and K.K. Turekian), Elsevier–Pergamon, Oxford.

Pearson, T.R. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review, 16: 229-3111.

Rowe, G.T., P. Polloni and R.L. Haedrich. 1982. The deep-sea macrobenthos on the continental margin of the northwest Atlantic Ocean. Deep-Sea Research 29A: 257-278.

Rowe, G.T., M. Sibuet, J. Deming, A. Khripounoff, J. Tietjen, S. Macko, and R. Theroux. 1991. "Total" sediment biomass and preliminary estimates of organic carbon residence time in deep-sea benthos. Mar. Ecol. Progr. Ser. 79: 99-114.

Rex, M.A. 1981. Community structure in the deep sea benthos. Ann Rev. Ecol. Syst. 12:331-353.

Sanders, H.L. 1977. Evolutionary ecology and the deep-sea benthos, In: Changing Scenes in Natural Sciences, 1776-1976. Academy of Natural Sciences, Special Publication 12, 223-243.

Steinhauer, M.S. and P.D. Boehm. 1992. The composition and distribution of saturated and aromatic hydrocarbons in nearshore sediments, river sediments, and coastal peat of the Alaskan Beaufort Sea: Implications for detecting anthropogenic inputs. Mar. Env. Res. 33: 223-253.

Tan, Y.L. and M. Heit. 1981. Biogenic and abiogenic polynuclear aromatic hydrocarbons in sediments from two remote Adirondack lakes. Geochim. Cosmochim. Acta 45, 2267‐2279.

Thistle, D. 2003. The deep-sea floor; an overview. Ecosystems of the Deep Oceans. Ecosystems of the World, 28. Elsevier, Amsterdam, pp. 5-37.

Tietjen, Abundance and biomass of metazoan meiobenthos in the deep sea. 1992. *In*: G.T. Rowe and V. Pariente (Eds.), Deep-Sea Foof Chains and the Global Carbon Cycle. Kluwer Academic, Dordrecht. pp. 1567-1577.

Tomczak, M. and J. S. Godfrey. 2003. Regional Oceanography, an Introduction. 2nd Ed. Daya Publishing House. Delhi, India - 110 052.

Wedepohl, K.H. 1995. The composition of the continental crust. Geochimica et Cosmochimica Acta. 79(7): 1217-1232.

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APPENDIX H

2016 Environmental Baseline Survey Report

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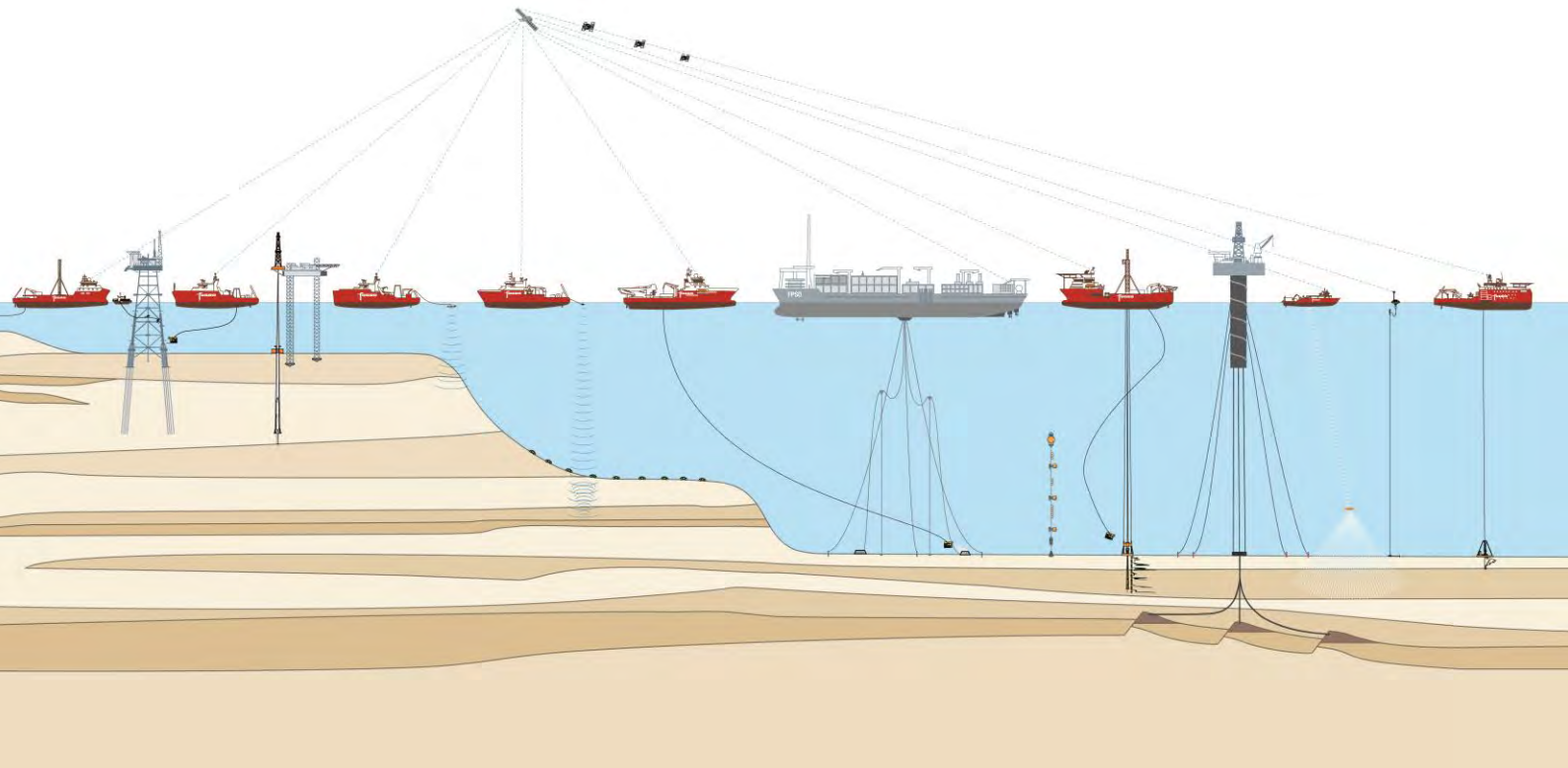
Environmental Baseline Survey Report
Liza Development, Offshore Guyana
4 March to 19 March 2016

Environmental Baseline Survey Report

Fugro Job No. 2415-3066-EBS
Esso Exploration and Production Guyana Limited

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Environmental Baseline Survey Report
Liza Development, Offshore Guyana
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Environmental Baseline Survey Report

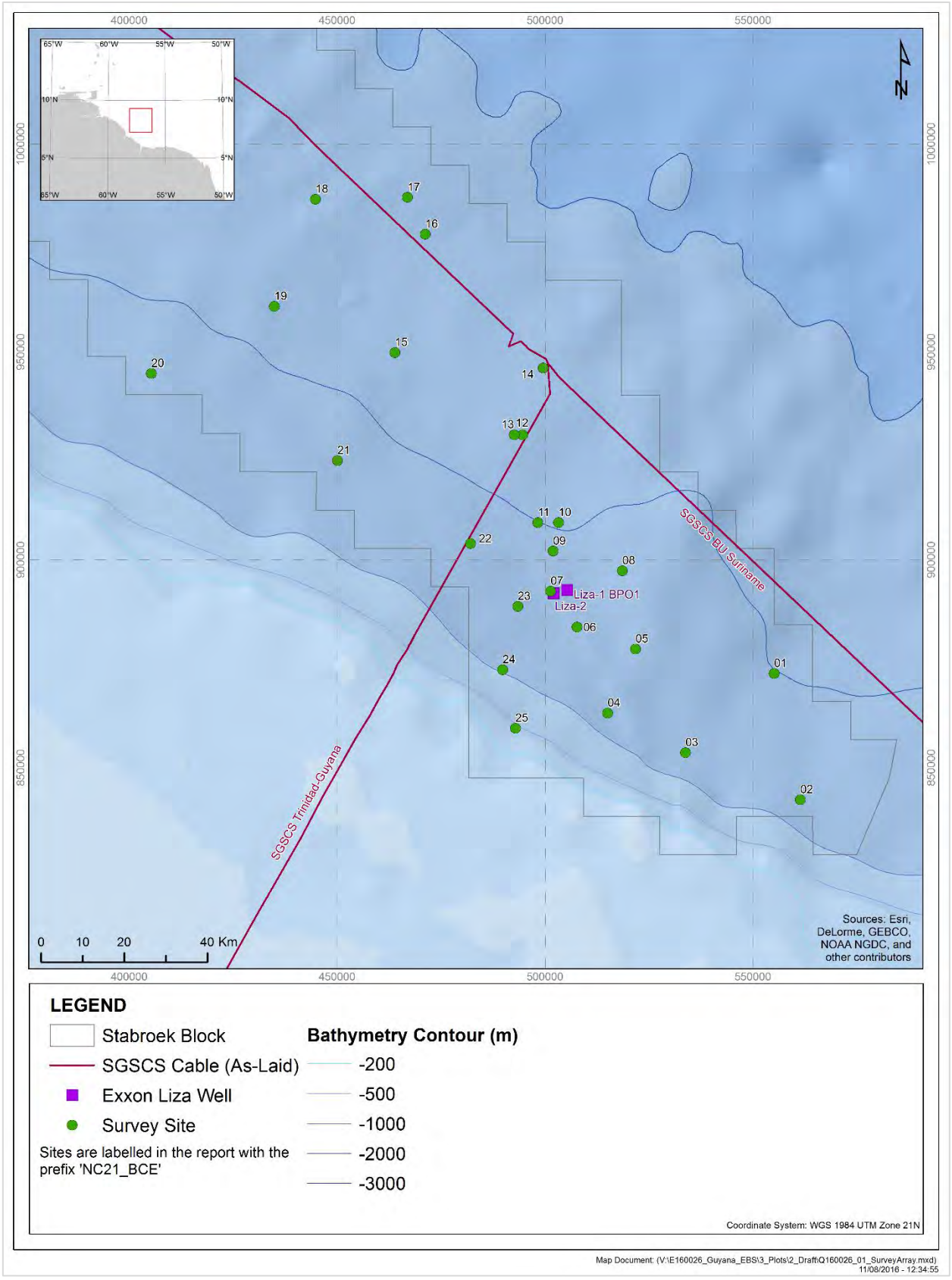
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EXECUTIVE SUMMARY

On the instruction of Esso Exploration and Production Guyana Limited (EEPGL), Fugro GeoServices Incorporated (FGSI) and Fugro EMU Limited (Fugro EMU) performed a detailed integrated site investigation program covering the Liza-1 Deepwater Field within the Stabroek area, offshore of Georgetown, Guyana.

The main objective of the Environmental Baseline Survey (EBS) was to acquire sufficient environmental data so as to describe all habitats recorded within the Stabroek Block and to identify and delineate the extent of any potentially sensitive habitats or species, if present. The results of the survey will act as a basis for comparison with subsequent data from environmental monitoring programs, and highlight potential sensitive areas. The EBS aim was fulfilled through the acquisition of water and seabed sediment samples, which were subsequently analysed with respect to physico-chemical and biological characteristics. Sediment grab sampling was performed at 25 locations to establish the physico-chemical and biological properties of the sediment at pre-determined locations. Water quality was also assessed through in-situ monitoring of water column profiles at 15 locations, which provided information on a range of physico-chemical parameters of the seawater.

Seabed sediments across the survey area comprised predominantly of sandy mud, muddy sand and, to a lesser extent, mud, one station also consisted of slightly gravelly sandy mud. Mud content was high, averaging 60.8% across the survey area. Sand content averaged 39.1% across the survey area, and gravel was absent except at one station (NC21_BCE025). Organic content in the form of Total Organic Carbon was low and no pattern of spatial distribution was identified.

Total hydrocarbon concentrations (THC) were considered to be at low levels across the survey area. Higher levels of THC were associated with finer sediments. Concentrations of THC were below 5 $\mu g g^{-1}$ at all stations and were consistent with background concentrations reported in other studies.

Of the seabed sediment metals analysed in this study, aluminium was dominant, and its concentration consistently higher than that of iron. Mean metal concentrations across the survey area were generally at low levels. Individual metal concentration at each sampling station were also generally below the comparative standards used in this study (NOAA ERL's and Canadian Sediment Quality Guidelines). However, arsenic, nickel, copper and lead all exceeded NOAA ERL values at some of the stations within the survey area (10, 2 and 1 stations respectively for each metal).

Analysis of the photographic data collected by the SPI camera identified one biotope complex as defined by the European Union nature information service habitat classification system (EUNIS, 2015), 'circalittoral sandy mud' (A5.35) with aspects of 'Deep sea mud' (A6.5). No potentially sensitive habitats were identified in the current survey.

Results from the seabed sediment samples showed macrofaunal communities within the survey area to be rich and diverse, with abundances fairly evenly distributed across the taxa recorded. Of the

environmental parameters assessed, there were no strong correlations between any parameter and macrofaunal communities.

Macrofauna were dominated by polychaete worms, followed by crustaceans, whereas molluscs were poorly represented and comprised mainly bivalves. Results of the multivariate analysis identified four clusters of stations and two unclassified stations across the entire survey area.

Results of the water profiles showed a stratified water column, with similar profiles being seen at all stations, however the depth of the thermocline, halocline and oxygen boundary layer increase proportionally with water depth. Values of dissolved oxygen at shallower depths are near oxygen saturation, with oxygen levels decreasing with increasing depth across the survey area.

SUMMARY OF SURVEY RESULTS

Location:

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W				
Location	**Easting [m]**	**Northing [m]**	**Latitude**	**Longitude**
Liza-1	505 213.49	892 693.82	08° 04′ 33.40″ N	056° 57′ 09.65″ W
Liza-2	501 965.60	891 960.90	08° 04′ 09.54″ N	056° 58′ 55.78″ W

Study Area: Environmental surveys were completed over the 640 km2 Liza field development area, located offshore of Georgetown, Guyana.

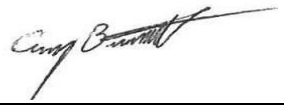
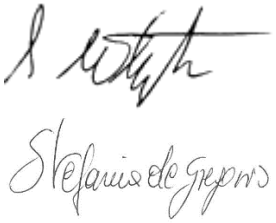
Survey Strategy: Box coring and sediment profile imaging (SPI) were proposed at 25 stations. Conductivity, temperature and depth (CTD) data and water samples were also proposed at 15 of these stations. All box core, CTD and water samples were successfully collected. The SPI camera was required to collect plan view and profile images from each station. Plan view images were successfully collected from nine stations and profile images were successfully collected from 11 stations.

All stations were selected by the client, taking into consideration stations previously sampled for an EBS prepared by Maxon Consulting and TDI Brooks in 2014, planned areas of the block associated with current and future exploration, appraisal and potential development activities, with the desire to further characterize the marine environment within the block.

Bathymetry: Depths in the EBS area ranged from 200 m below lowest astronomical tide (LAT) in the south-west to 2800 m below LAT in the north-west. Depths of the geophysical survey ranged from 105 m to 1875 m.

Seabed Features: Depressions were observed sporadically across the site. The majority of the seabed was found to comprise muddy sands or sandy muds with varying quantities of shell material.

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ABBREVIATIONS

Al	Aluminium
ARPD	Apparent Redox Potential Discontinuity
AUV	Autonomous Underwater Vehicle
BAC	Background Assessment Concentration
BC	Background Concentration
BHQ	Benthic Health Quality
CCC	Criterion Continuous Concentration
CEMP	Coordinated Environmental Monitoring Programme
CMC	Criterion Maximum Concentration
CPI	Carbon Preference Index
CM	Central Meridian
CTD	Conductivity, Temperature and Depth
CV-AFS	Cold Vapour Atomic Fluorescence Spectroscopy
DCM	Dichloromethane
DNA	Deoxyribonucleic acid
DO	Dissolved oxygen
DTI	Department of Trade and Industry
EBS	Environmental Baseline Survey
EPA	United States Environmental Protection Agency
ERL	Effects Range Low
ERM	Effects Range Median
EUNIS	European Nature Information Service
FA/FB	Fauna Sample A/Fauna Sample B
FGSI	Fugro GeoServices Incorporated
FTU	Formazin Turbidity Unit
GC	Gas Chromatography
GC-MS	Gas Chromatography - Mass Spectrometry
GC-FID	Gas Chromatography - Flame Ionisation Detection
H'(log_2)	Shannon-Wiener Diversity Index
GNSS	Global Navigation Satellite System
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy
J'	Pielou's Evenness
JNCC	Joint Nature Conservation Committee
LAT	Lowest Astronomical Tide
LOI	Loss on Ignition
MBES	Multibeam Echosounder
MDS	Multi-dimensional Scaling
Min	Minimum
max	Maximum
mV	Millivolts
N	Total Individuals

nC_{12-20}	Alkanes ranging from carbon numbers 12 to 20
nC_{21-36}	Alkanes ranging from carbon numbers 21 to 36
nC_{12-36}	Alkanes ranging from carbon numbers 12 to 36
ngg^{-1}	Nanograms per gram
nMDS	Non-metric Multidimensional Scaling
NMBAQC	National Marine Biological Analytical Control Scheme
NOAA	United States National Oceanic and Atmospheric Administration
NPD	Naphthalene, Phenanthrene, Anthracene and Dibenziothene
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic
PAH	Polycyclic Aromatic Hydrocarbons
PC	Physico-chemical (grab sub-sample)
PCA	Principal Components Analysis
PSD	Particle Size Distribution
Ph	Phytane
pH	Measure of acidity (Power of Hydrogen)
ppt	Parts per thousand
PRIMER	Plymouth Routines in Multivariate Ecological Research
Pr	Pristane
QA	Quality Assurance
QC	Quality Control
SBP	Sub-bottom Profiler
SBR	Sediment Boundary Roughness
SD	Standard Deviation
SIMPER	Similarity Percentage Index
SPI	Sediment Profile Imaging
SSS	Sidescan sonar
stdev	Standard Deviation
TEL	Total Exposure Limits
THC	Total Hydrocarbon Concentration
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UCM	Unresolved Complex Mixture
UHF	Ultra High Frequency
UKAS	United Kingdom Accreditation Service
UTM	Universal Transverse Mercator
WAS	Wilson Auto-Siever
WGS84	World Geodetic System 1984
λ	Simpson's Dominance Index

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1. INTRODUCTION AND SCOPE OF WORK

On the instruction of Esso Exploration and Production Guyana Limited (EEPGL), Fugro GeoServices Incorporated (FGSI) and Fugro EMU Limited (Fugro EMU) performed a detailed integrated site investigation program covering the Liza Field Development Area within the Stabroek area, offshore of Georgetown, Guyana.

The coordinates for the proposed well locations Liza-1 and Liza-2 are displayed in Table 1.1. The survey involved geophysical autonomous underwater vehicle (AUV) data acquisition, a geohazard/geotechnical survey, and an Environmental Baseline Survey (EBS). Each of these activities was undertaken separately, the EBS was conducted onboard the RV Fugro Americas between 4 March and 19 March 2016.

This report provides details of environmental operations and presents a detailed analysis and interpretation of all data collected.

Table 1.1: Proposed Well Locations

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W				
Location	**Easting [m]**	**Northing [m]**	**Latitude**	**Longitude**
Liza-1	505 213.49	892 693.82	08° 04′ 33.40″ N	056° 57′ 09.65″ W
Liza-2	501 965.60	891 960.90	08º 04′ 09.54″ N	056º 58′ 55.78″ W

1.1 Scope of Work

1.1.1 Geophysical Survey

The geophysical survey was undertaken to provide information on seafloor and near-seafloor geological conditions within the Liza Field Development survey area. Geophysical data are used to identify any potential hazards, constraints and cultural resources that may impact the design and placement of the planned subsea installations and flowlines.

The geophysical data were collected using a high-resolution Autonomous Underwater Vehicle (AUV) including multibeam echo sounder (MBES), sidescan sonar (SSS) and chirp sub-bottom profiler (SBP), and a hull-mounted MBES and SBP.

1.1.2 Environmental Survey

The main objective of the environmental survey was to acquire environmental data in order to describe all the habitats and characteristic species recorded within the study area. The information recorded was used to: identify and delineate the extent of any potentially sensitive habitats and/or species, if present; to describe baseline conditions of the physico-chemical and biological properties of the sediment and water column at key locations selected by the client; and to expand and build on the knowledge gained from sampled stations in the previous EBS prepared by Maxon Consulting and TDI Brooks in 2014, which focused on the Liza and Sorbium Areas. The EBS survey was designed to assess a broader range of the Stabroek Block covering a variety of water depths and

corresponding potential marine habitats, to further characterize these as well as the Liza Area of Interest. This report presents the results of the environmental baseline survey.

1.2 Geodetic Parameters

All coordinates detailed in this report are referenced to the World Geodetic System 1984 (WGS84) datum and Universal Transverse Mercator (UTM) Projection Zone 21 North, Central Meridian (CM 57ºW). Detailed geodetic and projection parameters are provided in Table 1.2.

Table 1.2: Project Geodetic Parameters

Global Positioning System Geodetic Parameters [1]							
Datum:	World Geodetic System 1984 (WGS84)						
Spheroid:	World Geodetic System 1984						
Semi major axis:	a = 6 378 137.000 m						
Reciprocal flattening:	1/f = 298.257 223 563						
Local Geodetic Datum Parameters							
Datum:	World Geodetic System 1984 (WGS84)						
Spheroid:	World Geodetic System 1984						
Semi major axis:	a = 6378137.00000m						
Reciprocal flattening:	1/f = 298.2572236						
Datum Transformation Parameters from WGS84 to WGS84 [2]							
Shift dX:	0.00	m	Rotation rX:	0.00	arc sec	Scale Factor:	-1.200 ppm
Shift dY:	0.00	m	Rotation rY:	0.00	arc sec		
Shift dZ:	0.00	m	Rotation rZ:	0.00	arc sec		
Project Projection Parameters							
Grid Projection:	Universal Transverse Mercator, Northern Hemisphere						
UTM Zone:	21 N						
Central Meridian:	57° 00′ 00″ West						
Latitude of Origin:	00° 00′ 00″ North						
False Easting:	500 000 m						
False Northing:	0 m						
Scale factor on Central Meridian:	0.9996						
Units:	metre						

Notes:
1. Fugro Starfix navigation software always uses WGS84 geodetic parameters as a primary datum for any geodetic calculations
2. This is the right-hand coordinate frame rotation used by the Fugro Starfix navigation software

2. METHODS

The following section provides an overview of survey, analysis, and interpretation methods. Further details of the methods employed can be found in Appendix B.

2.1 Environmental Survey Strategy

Box coring and sediment profile imaging (SPI) were proposed at 25 stations, of which 15 were selected for conductivity temperature and depth (CTD) data and water samples. Collection of water samples was proposed at the surface, below the thermocline and at the bottom of the water column, close to the sediment surface. The coordinates, data to be acquired and rationale for each location are provided in Table 2.1, and displayed spatially in Figure 2.1. Acceptable sampling accuracy was agreed with the client representative to be within 50 m of the target location for box cores and 100 m for CTD/water samples. The survey array for the Stabroek area, including all sampling undertaken, well locations and boundaries, is illustrated in Figure 2.1. At each station water and sediment samples were also collected to support potential environmental DNA analysis that was being planned by the client and will be reported separately.

Table 2.1: Proposed Environmental Survey Stations

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W				
Stations	**Easting [m]**	**Northing [m]**	**Rationale**	**Sample Acquisition**
NC21_16BCE001	555 087.5	872 666.7	Regional/Liza data collection as per client sampling plan	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE002	561 362.9	842 298.1	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE003	533 722.2	853 586.9	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE004	515 005.1	863 106.6	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE005	521 741.0	878 532.9	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE006	507 683.0	883 790.0	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE007	501 316.1	892 438.6	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE008	518 555.0	897 354.7	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE009	501 900.3	902 086.7	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE010	503 234.0	908 943.0	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W				
Stations	**Easting [m]**	**Northing [m]**	**Rationale**	**Sample Acquisition**
NC21_16BCE011	498 234.0	908 950.9	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE012	494 587.2	930 071.3	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE013	492 587.2	930 071.3	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE014	499 542.0	946 110.0	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE015	463 847.9	949 827.0	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE016	471 156.5	978 303.6	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE017	466 847.0	987 164.0	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE018	444 776.4	986 730.1	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE019	434 883.5	960 957.7	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE020	405 291.3	944 807.2	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE021	450 032.4	923 884.0	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE022	482 055.8	903 906.1	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE023	493 428.0	888 781.0	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE024	489 763.6	873 528.2	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE025	492 834.0	859 481.8	Regional/Liza data collection as per client sampling	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples

Notes:
PC = Physico-chemical sample
FA = Fauna sample A
FB = Fauna sample B
DNA = Deoxyribonucleic acid sample

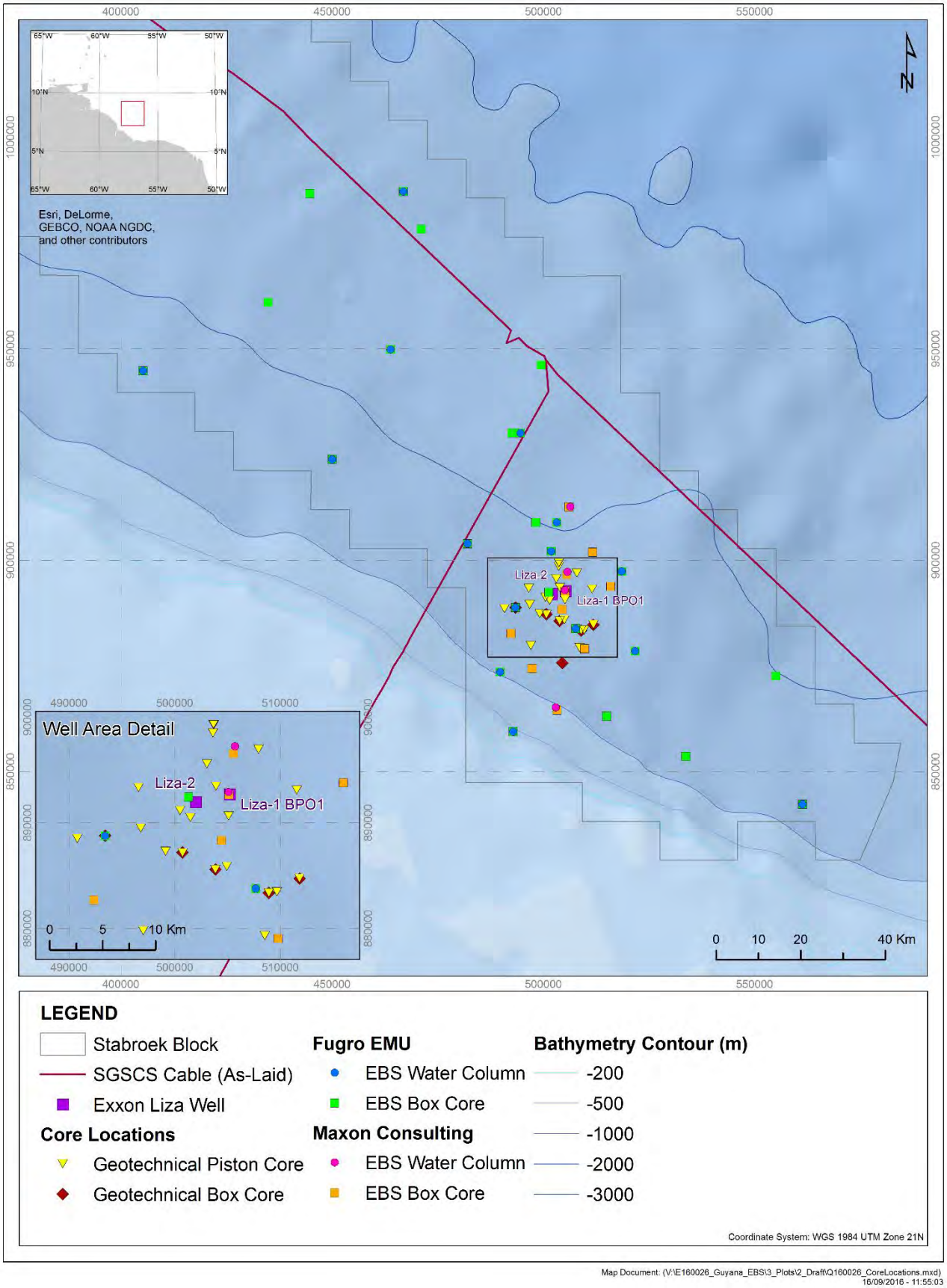


Figure 2.1: Survey array for the Stabroek area (provided by EEPGL)

2.2 Survey Methods

2.2.1 Combined Water Sampling and Profiling

The following procedure describes the deployment and recovery of the Valeport 606+ deepwater CTD and simultaneous deployment and recovery of 5 litre Niskin water samplers. This section also describes the subsequent uploading and processing of water profile data and handling of water samples.

2.2.2 Deployment and Recovery

The CTD and Niskin water samplers were deployed using the following methodology:

- The CTD was set up to record conductivity, temperature, depth, turbidity, pH and dissolved oxygen (DO). Both the pH and DO sensors were calibrated onboard prior to survey operations;
- After calibration the data output from the CTD underwent a visual check to ensure that the readings were accurate and the pH and DO sensors had not drifted after calibration;
- At each station the initial drop had a clump weight, beacon, CTD and six 5 litre Niskin water samplers attached to the lifting wire at intervals coinciding with the bottom three sampling depths;
- The Niskin bottles were armed and a messenger weight suspended under each sampler except the bottom one. The messenger weights were rigged so that once the first Niskin was triggered a domino effect would take place triggering those suspended below;
- The equipment was deployed over the stern using the A-frame;
- Once deployed the CTD was held at the surface for a period of approximately five minutes to allow the profiler to acclimatise to environmental conditions;
- The equipment was then lowered to the desired depth at a rate of 0.5 m s^{-1} to 1.0 m s^{-1}. When at the desired depth deployment stopped and a messenger weight was attached to the lift wire. The weight was then released to trigger the samplers;
- A conservative fall rate was used to determine release time after which a positional fix for the bottom sample was taken by the surveyor;
- The equipment was then recovered to deck with each item of equipment being removed from the wire as it paid in;
- The Niskin samplers were set to sample at three depths the surface (10 m), below the thermocline and 20 m above the seabed.

2.2.3 Water Profile Processing

The CTD was rinsed with clean water immediately after deployment – the plug area was dried after rinsing. Data were uploaded from the unit (.dat format) and translated into a text file (.000 format) with the pressure tare applied. These raw data were backed up to hard drive immediately.

The translated data were copied into Water Profile QA.xls and data quality checked. The following acceptance criteria applied:

- All data must be within expected values for seawater (e.g. pH = 7.8 to 8.5; DO = approximately 100 % at surface and declines with depth);
- Data should be collected for the duration of both the down and up casts;
- Data should be consistent between down and up casts.

Occasional spikes in data (due to sensor interference) are acceptable as is some variation in readings at depths where profiler is stationary (i.e. where Niskin water samplers fitted or samples taken); this occurs due to mixing effects, which the fast response DO meter is particularly susceptible to.

2.2.4 Water Sample Processing

The Niskin water samplers were cleaned after each deployment, after the following subsamples were collected:

- Nutrient samples A and B were collected at each depth and stored in 1 litre plastic bottles at – 20 ºC;
- Heavy metal samples A and B were collected at each depth and stored in 125 ml plastic bottles at between 4 ºC and 6 ºC;
- Two total suspended solid (TSS) sample was collected at each depth and stored in 1 litre plastic bottles at – 20 ºC;
- Samples to be tested for Mercury (A and B) were collected at each depth and stored in 100 ml glass bottles at between 4 ºC and 6 ºC. The samples were preserved in 5 ml 17 % Hydrochloric acid;
- Biodiversity Deoxyribonucleic Acid (DNA) samples A, B and C were filtered through a cleaned peristaltic pump, stored in individual frozen plastic bags, in accordance with the client's sampling plan and Biodiversity DNA Seawater and Sediment Sampling Protocol.

2.3 Seabed Video/Photography

Seabed profile and plan view images were acquired using an AquaFact SPI camera system mounted within a purpose-built camera frame complete with two high resolution stills cameras and flashes, one for taking profile images and one for taking plan view images. Stills were captured to the cameras internal memory card and downloaded upon recovery to verify image quality was sufficient.

Operational procedures for seabed photography were as follows:

- The condition of the SPI camera was checked and confirmed by the Environmental Shift Leader on deck;
- All mechanisms were checked thoroughly prior to deployment;
- Areas of particular interest included:
  - Status of all bolts and ensured that they are tight;

- All weights were checked that they were secure and split rings present by visually and manually inspecting them;
- All cables were inspected for damage/fraying;
- All components were checked to be fitted correctly;
- All plugs were checked to be in deployment position.

- Once confirmed, the environmental shift leader tested the camera once more;
- Two guide ropes were attached, if required, to the SPI camera frame away from potential snags;
- When all personnel were in place (non-seaward side), the person designated for communications informed the bridge as to the status on deck, and informed them that they wished to deploy. This decision was based on many factors including acceptable distance from target;
- Only when the bridge gave clearance deployment commenced;
- The SPI camera frame was slowly raised and held so that the lifting wire took up the weight of the unit. At this point the safety pins were removed from the system;
- With the safety pins removed, the camera frame was slowly raised to clear the bulwark. The frame was not raised more than necessary for manoeuvring it over the side;
- If attached, the guide ropes each side were pulled taut to control the swing;
- When over the side and clear of the vessel, the camera frame was lowered to the water as quickly as possible to minimise the opportunity for swinging and knocking into the ship and damaging ship and equipment;
- On reaching the sea surface, any steadying ropes were retrieved;
- Following confirmation from the Bridge, the frame was lowered to within 10 m of the seabed and stopped;
- Final confirmation of position was sought from the bridge. Once confirmed, the frame was gently lowered to the seabed at a nominal speed of ~20 m/min. (This is important as it ensures the integrity of the surface of the sample);
- The Environmental Shift Leader then confirmed a fix with the Surveyor;
- Once the system was on the seabed a surface shot was taken;
- When in contact with the seabed the system remained undisturbed (slack cable) for 30 seconds. During this time, the central carriage of the frame slowly lowered itself into the sediment, taking an image of the vertical profile sectioned and begun a resetting count;
- After each picture, the system was lifted clear of the seabed (approximately 15 m) and held for 40 seconds before lowering it to the seabed again where it re-entered the sediment for another photograph. A separate fix was taken with each camera penetration.

Camera recovery procedures were as follows:

- The camera frame was recovered through the water column at the maximum winch speed, slowing the rate of recovery down ~25 m prior to the unit breaking the surface;

- Once at the surface, the unit was brought close in to the side of the ship to minimise any pendulum action. The unit was hauled up the side of the ship to a height where ropes could be put around the frame if necessary. Care was taken not to strike the side of the vessel with any force (care of ship/equipment). All this was coordinated by the Communications Deck Officer who liaised with the rope handlers and winch/crane operator as to when the frame was steady and the winch was stopped. The ropes were then safely put around the frame;
- Once secured, the frame was gently raised inboard, maintaining control with the guide ropes at all times;
- The camera frame was lowered onto a clear area of deck and the safety pins replaced. Care was taken to retain some tension on the lifting wire to enable the insertion of the safety pins and to prevent camera damage;
- The frame was tied off to provide stability.

2.4 Sediment Grab Sampling

Seabed samples were acquired using a USNEL 0.25 m^2 box core.

Operational procedures for grab sampling were as follows:

- The USNEL 0.25 m^2 box core was prepared for operations prior to arrival on station. An ultra-short baseline (USBL) beacon was attached to the box core frame. The Bridge communicated to the deck via an ultra-high frequency (UHF) radio when the vessel was steady and on location, and the box core was deployed from the starboard crane and lowered to the seabed using the starboard winch;
- When the engineer operating the winch observed that the box core had reached the seabed (evidenced through a distinct slackening of the wire rope and snatch block), the on-line surveyor was informed (via UHF radio) and a fix was taken;
- On recovery to the deck, the sample was inspected and judged acceptable or otherwise (see below for rejection criteria);
- The sample was subsampled into two 0.1 m^2 fauna and one physico-chemical samples, which were retained for analysis;
- Deck logs were completed for each sample acquired (including no samples) with: date, time, sample number, fix number, sediment type, depth and colour of strata in the sediment (if any) using Munsell colour codes, odour (i.e. H_2S), bioturbation or debris.

Samples were considered unacceptable in the following instances:

- Evidence of sediment washout caused through improperly closed scoop or inspection hatch;
- Sediment sample taken on an angle; where the box was not parallel to the seabed when it fired;
- Disruption of the sample through striking the side of the vessel;

- Sample represented less than 20 % of the grab's capacity (unless deemed acceptable by the client representative);
- Sample is more than 50 m from the target location, unless deemed acceptable by the client representative, particularly in deeper waters;
- Deemed unacceptable by the client representative for any other reason;
- Presence of Hagfish within the sample, as this species of fish produces mucilaginous slime which renders a sample unusable. Other sessile organisms or fish would not lead to discarding a sample unless exhibiting similar characteristics but the use of box cores is not designed to sample highly mobile fauna such as fish.

2.5 Physico-chemical Sample Processing

Sub-samples were taken from the surface of the sample while retained in the box core as follows:

- Hydrocarbon samples were collected using a metal scoop to a nominal depth of 2 cm. Samples collected were HC-A and HC-B. The samples were preserved in glass jars at - 20 ºC;
- Heavy metal samples were collected using a plastic scoop to a nominal depth of 2 cm. Samples collected were HM-A and HM-B. The samples were preserved in polythene bags at – 20 ºC;
- Particle size samples were collected using a plastic scoop to a nominal depth of 5 cm. Samples collected were PSD-A and PSD-B. The samples were preserved in polythene bags at -20 ºC;
- Prior to any subsampling metal scoops was pre-cleaned using acetone;
- Biodiversity DNA samples were collected using a sterile plastic scoop to put approximately 5 g of sediment in three whirlpack bags to collect DNA A, B and C.

2.6 Macrofauna Sample Processing

Macrofauna samples were processed as follows:

- After the sediment had been described and photographed the top 20 cm was transferred into a 0.5 mm mesh sieve along with the remaining supernatant water;
- The sample was then transferred to the Wilson Auto Siever (WAS) for washing;
- Once the sediment had been removed the sample was transferred to containers labelled with the job number, station code, and fauna code (FA or FB depending on replicate) and fixed in 10 % formal saline (a buffered 4% formaldehyde solution in seawater). The sample containers were then sealed, hazard labelled and stored securely on deck.

2.7 Laboratory and Analytical Methods

2.7.1 Particle Size Analysis

Sediment samples were analysed for particle size using wet, dry sieving and laser diffraction techniques (see Appendix B). Data were expressed at 0.5 phi intervals. The phi scale is a logarithmic

scale for expressing grain size, with negative phi numbers for grain sizes greater than 1000 µm and positive phi numbers for grain sizes less than 1000 µm.

Particle size data were interpreted from descriptive terms based on the Folk (The distinction between grain size and mineral composition in sedimentary rock nomenclature, 1954) classification. Aggregated data (based on the Wentworth (A scale of grade and class terms for clastic sediments, 1922) scale) of fines (<63 µm), sand (63 µm to 2 mm) and coarse (>2 mm) fractions, and sorting coefficient were also used to characterise and describe the data. The sorting coefficient, which ranges from 0 (very well sorted) to >4 (extremely poorly sorted) indicates the degree to which the particles are of uniform size.

Sediment particle size distribution statistics for each sample were calculated from the raw data using Gradistat V8 (Blott, 2010). Statistics used in the calculation of grain size parameters and associated descriptive terminology included mean, standard deviation, skewness and kurtosis. Calculation of median and mode provided information on the sediment sample distribution statistics together with a set of percentiles to include D_{10}, D_{50} and D_{90}. Monitoring the percentiles allows assessment of changes in the main particle size, as well as changes at the extremes of the distribution, which could be due to, e.g. the presence of fines, or oversized particles/agglomerates. Details of statistical tests and methods can be found in Appendix B.2.

Correlation analysis between environmental variables was undertaken using the Spearman's correlation coefficient. This correlation analysis, based on ranks, allows characterising of the strength of relationships among a set of variables, without making assumption of linearity between variables (Clarke, Per. Comm., 2014). Correlation analysis provides an effective way of revealing the relationships between multiple variables.

Particle size data were further analysed by multivariate statistical methods. Multivariate analyses were undertaken using the Plymouth Routines in Multivariate Ecological Research (PRIMER) v6.0 statistical package (Clarke and Gorley, 2006). Data for the percentage composition within half phi unit sieve size classes were analysed by hierarchical agglomerative cluster analysis, using the Euclidean distance measure as recommended by Clarke and Gorley (2006). The Principal component analysis (PCA) was undertaken on the major sediment fractions data set (gravel, sand and mud) in order to identify spatial patterns and relationships between variables. The PSD dataset was 4^{th} root transformed to reduce the degree of skewness and bring the dataset as close to normal distribution as possible, which in turn allowed optimum performance of the multivariate analyses, (Clarke, Per. Comm., 2007) Details of statistical analysis are presented in Appendix B.2.

2.7.2 Organic Carbon Content

Organic carbon content of the samples was analysed by measuring total organic carbon (TOC). TOC analysis involves pre-treatment with acid prior to quantitation (by non-dispersive infrared analysis of release CO_2), which liberates inorganic carbonates and thus yields an accurate estimate of organic carbon content. It should also be noted that TOC includes both labile (bio available) and refractory material, and may therefore correlate poorly with perceived biological impact (Loh, 2005).

2.7.3 Hydrocarbon Analysis

Hydrocarbon analysis of sediments was performed by UKAS accredited Fugro EMU laboratories. Samples for hydrocarbon analysis were extracted by ultrasonication with mixed solvents and the resulting extracts cleaned-up using absorption column chromatography. The extracts were analysed for total hydrocarbon content (THC), unresolved complex mixture (UCM), individual and total n-alkanes (nC_{12} to nC_{36}) and the subsequent carbon preference indices (CPIs) using gas chromatography and a flame ionisation detector (GC-FID). Aromatic hydrocarbons were analysed by gas chromatography with mass spectrometry (GC-MS).

The concentration of individual n-alkanes present in the sediments was determined by measuring the response of each component (nC_{12} to nC_{36}) by GC-FID. Standard solutions containing an appropriate range and amount of n-alkanes were run to calibrate the instrument and to acquire response factors for quantification purposes. Individual n-alkanes were quantified using a series of internal standards and summed to give a total n-alkane (nC_{12} to nC_{36}) value for each sediment sample. The total hydrocarbon material present was quantified using response factors calculated from the analysis of mixed oil standard solutions over an appropriate range while the UCM was determined by subtracting the area of all the resolved peaks from the total hydrocarbon area and applying the total hydrocarbon response factor.

The distributions and concentrations of 2 to 6 ring polycyclic aromatic hydrocarbons (PAHs) within the samples were analysed by GC-MS. Standard solutions containing an appropriate range and concentration of aromatic hydrocarbons were run to calibrate the instrument and acquire response factors for quantification purposes. Individual aromatic compounds were quantified using a series of deuterated internal standards to give a total 2 to 6 ring PAH value for the sediment samples. Total hydrocarbon concentration (THC), unresolved complex mixture (UCM) and individual n-alkanes (nC_{12} to nC_{36}) were analysed by gas chromatography with flame ionisation detection (GC-FID).

Full details of all the analytical techniques employed are included in Appendix B.

2.7.4 Heavy and Trace Metals

The majority of heavy and trace metals (arsenic, cadmium, chromium, copper, lead, nickel, vanadium, and zinc) were analysed following total metal digestion using hydrofluoric acid. Samples underwent near total digestions using hydrofluoric and boric acid for aluminium, barium, iron and Strontium. Mercury was determined following nitric acid and hydrogen peroxide digestion.

The samples were treated by a hydrofluoric acid digestion followed by multi-element analysis by inductively coupled plasma-mass spectrometry (ICP-MS). This method was used to analyse arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc. The hydrofluoric acid digest was also used to analyse aluminium, barium and iron by inductively coupled plasma-optical emission spectroscopy (ICP-OES). Analysis of total barium was by fusion of solids followed by acid dissolution and analysis by ICP-MS. Mercury was determined by a microwave assisted aqua-regia digestion, followed by reduction using acidic tin chloride with determination by cold vapour atomic fluorescence spectroscopy (CV-AFS).

Since metals from natural and anthropogenic sources accumulate together, it is necessary to determine what proportion of the sedimentary load is associated with one source or the other. This is because of variable anthropogenic inputs and natural sedimentary load can vary by several orders of magnitude depending on the nature, grain size, distribution and provenance of metal-rich/metal-poor minerals/compounds in the sediment (Loring and Rantala, 1992).

Normalization attempts to compensate for the natural variability of trace metals in sediments so that any anthropogenic metal contribution may be detected and quantified (Loring, 1991). In the current study metal concentrations results were normalised to 5% Al in line with the current OSPAR, (2012) guidelines for the monitoring of contaminants in sediments.

2.7.5 Macrofauna

Macrofauna analysis was completed by Fugro EMU laboratories which are members of the National Marine Biological Analytical Quality Control Scheme (NMBAQC scheme) of quality assurance.

On return to the laboratory, the samples were further washed on a 0.5 mm mesh. The material retained was placed back in the original container and the preservative changed to phenoxytol (2%). The animals were then separated by hand from the remaining sediment by using a combination of stereo microscopes for the fine sediments and in white trays for any coarser material.

Following checks by a biologist on the efficiency of the sorting procedure, the animals were identified and enumerated by specialist taxonomists. Identification was to species level where possible. A few specimens, due to their immaturity, damage incurred during processing or lack of suitable taxonomic literature, could not be identified to species and were identified at higher taxonomic levels as appropriate. After identification, samples were stored in 70% ethanol/1% propylene glycol/29% water.

Abundances were entered on file in a spreadsheet package which stores and sorts entries into taxonomic order and provides output files for numerical analysis, abundances were added to the lowest taxonomic level identified (usually either species or genus). Nomenclature and taxonomic ordering follows that given on the World Register of Marine Species (http://www.marinespecies.org/). Once all the entries had been checked, the resulting quantitative data were subjected to various statistical techniques to investigate community structure. All quantitative analyses were performed on species abundances pooled from the two replicates at each station, thus the sample size was 0.2 m^2 at all stations.

Prior to statistical analysis, the macrofaunal abundance data was rationalised to avoid spurious enhancement of community statistics this involved the removal of all epibenthic taxa (e.g. Ostracods) and juvenile specimens, as they are not considered to be a permanent part of the community. Some indeterminate species were also rationalised at a higher taxonomic level with another taxa in the same genus in order to maintain these data in the dataset e.g. *Streblosoma intestinalis* with *Streblosoma* sp indet and *Gnathia oxyuraea* with *Gnathia* sp indet (female).

Analysis was therefore undertaken on the data set that excluded juveniles, as well as the data set with juveniles included. Comparison between the results of the two analyses revealed a high level of similarity in the clustering of stations into groups, suggesting that the two datasets were essentially revealing the same ecological pattern. Consequently, the following results in the current study are based on the data set with juveniles excluded.

Various univariate and multivariate analyses have been used to integrate and describe the macrofauna data. Ranked abundance/dominance is a simple, but effective way of determining the most prevalent taxa in the samples taking account of potential differences in abundance between samples. This was achieved by summing the rank scores for all samples to give the overall rank dominance for each taxon. A comparison of the ranked dominance and ranked abundance of each taxon shows whether the abundance is spatially even or confined to single sample/station.

Estimates of the total species richness of the community, and thus an estimation of the sampling efficiency were calculated based on the accumulation of species with increasing sampling. Species accumulation plots calculated by the Chao1, Chao2, Jacknife1 and Jacknife2 formulae were calculated in PRIMER v6 (see (Chao, 2005) for further discussion of these indices).

The primary variables, numbers of taxa (S) and abundance (N), have been calculated together with the univariate measures of diversity; evenness (J′), Simpson's dominance (1-λ) and Shannon-Wiener diversity station data (0.1 m^2) using the PRIMER v6 DIVERSE procedure (Clarke and Gorley, 2006). Pielou's evenness (J′) and the Simpson's index of evenness (1-λ) are measures of equitability (i.e. how evenly the individuals are distributed among different species; low evenness indicates that a sample is dominated by one or a few highly abundant species whereas high evenness means that total abundance is spread more evenly among the constituent species. The Shannon-Wiener index (H′) (Shannon and Weaver, 1949) combines both the components of species richness and evenness to calculate a measure of diversity. Further details on the univariate measures analysed are available in Appendix B.2.3.

The macrofauna data were further analysed by multivariate analysis using PRIMER V6. Analysis was based on fourth root transformed data, which was considered appropriate due to the reasonably large range in abundance values between the samples. This transformation reduced the influence of highly abundant taxa which would otherwise have a disproportionate influence on the dataset. Bray-Curtis similarity was used to construct a similarity matrix between both sample data and station summed data. Samples were also summed to aggregated data per station to allow analysis of gross spatial trends. Analytical techniques included hierarchical clustering with SIMPROF, SIMPER and Bio-Env matching. Dendrograms and nMDS ordinations have been used to illustrate the multivariate analyses. Further details of these methods can be found in Appendix B.2.3.

3. RESULTS

3.1 Field Operations

Grab samples were successfully taken at all of the 25 proposed environmental locations with complete suites of samples (2 macrofauna and 2 physico-chemical samples) acquired at all stations.

Water samples and CTD casts were successfully taken at all fifteen proposed locations. Complete suites of samples were acquired at all stations.

SPI camera plan view images were successfully collected at five stations and profile images were successfully collected from eleven stations. Due to technical difficulties, it was decided by the client not to complete SPI sampling.

Table 3.1 details all samples acquired.

Table 3.1: Overview of all Completed Sampling

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	**Easting [m]**	**Northing [m]**	**Depth [m BSL]**	**Type**	**Samples**
NC21_16BCE025B	492 845.9	859 475.8	480	Box Core	2 x Fauna 1 x PC
NC21_16BCE024A	489 768.1	873 529.0	1060	Box Core	2 x Fauna 1 x PC
NC21_16BCE004D	514 969.8	863 122.2	1210	Box Core	2 x Fauna 1 x PC
NC21_16BCE003	533 689.7	853 622.4	1280	Box Core	2 x Fauna 1 x PC
NC21_16BCE002	561 350.3	842 307.2	1250	Box Core	2 x Fauna 1 x PC
NC21_16BCE001	555 100.2	872 654.1	1980	Box Core	2 x Fauna 1 x PC
NC21_16BCE005A	521 742.9	878 560.6	1550	Box Core	2 x Fauna 1 x PC
NC21_16BCE006	507 679.2	883 785.8	1570	Box Core	2 x Fauna 1 x PC
Phases II and III NC21_16BCE023	493 418.5	888 796.6	1510	Box Core	2 x Fauna 1 x PC
NC21_16BCE007	501 296.7	892 444.8	1700	Box Core	2 x Fauna 1 x PC
NC21_16BCE008A	518 560.9	897 371.5	1800	Box Core	2 x Fauna 1 x PC
NC21_16BCE009	501 901.8	902 067.1	1900	Box Core	2 x Fauna 1 x PC
NC21_16BCE010	503 236.3	908 940.4	2040	Box Core	2 x Fauna 1 x PC
NC21_16BCE011	498 238.0	908 974.6	2010	Box Core	2 x Fauna 1 x PC
NC21_16BCE012	494 550.4	930 119.5	2210	Box Core	2 x Fauna 1 x PC
NC21_16BCE013	492 558.1	930 097.7	2200	Box Core	2 x Fauna 1 x PC
NC21_16BCE014B	499 626.4	946 103.9	2550	Box Core	2 x Fauna 1 x PC
NC21_16BCE015	463 898.0	949 829.2	2400	Box Core	2 x Fauna 1 x PC
NC21_16BCE016	471 163.5	978 365.0	2760	Box Core	2 x Fauna 1 x PC
NC21_16BCE017	466 834.0	987 157.9	2760	Box Core	2 x Fauna 1 x PC
NC21_16BCE017D	466 846.3	987 168.7	2760	Box Core	2 x Fauna 1 x PC
NC21_16BCE018B	444 740.8	986 775.1	2680	Box Core	2 x Fauna 1 x PC
NC21_16BCE019A	434 891.5	960 929.8	2240	Box Core	2 x Fauna 1 x PC

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	**Easting [m]**	**Northing [m]**	**Depth [m BSL]**	**Type**	**Samples**
NC21_16BCE020	405 312.8	944 730.9	1500	Box Core	2 x Fauna 1 x PC
NC21_16BCE021	450 066.7	923 881.1	1660	Box Core	2 x Fauna 1 x PC
NC21_16BCE022	482 091.3	903 844.9	1640	Box Core	2 x Fauna 1 x PC
NC21_16WC025_M2	492 841.3	859 484.2	100	Niskin	Water Sample
NC21_16WC025_T1	492 840.5	859 484.9	1	Niskin	Water Sample
NC21_16WC024_B2	489 870.6	873 478.0	922	Niskin	Water Sample
NC21_16WC024_M2	489 799.1	873 513.9	320	Niskin	Water Sample
NC21_16WC024_T1	489 762.4	873 532.2	1	Niskin	Water Sample
NC21_16WC002_B2	561 426.9	842 302.5	1171	Niskin	Water Sample
NC21_16WC002_M2	561 426.9	842 302.5	371	Niskin	Water Sample
NC21_16WC002_T1	561 294.3	842 336.4	1	Niskin	Water Sample
NC21_16WC005_B1	521 886.3	878 433.8	1681	Niskin	Water Sample
NC21_16WC005_M1	521 700.8	878 577.8	400	Niskin	Water Sample
NC21_16WC005_T1	521 655.6	878 595.6	1	Niskin	Water Sample
NC21_16WC005_CTD	521 855.4	878 458.6	1681	Niskin	Water Sample
NC21_16WC006_B1	507 771.2	883 708.2	1550	Niskin	Water Sample
NC21_16WC006_M1	507 771.2	883 708.2	400	Niskin	Water Sample
NC21_16WC006_T1	507 572.4	883 856.5	1	Niskin	Water Sample
NC21_16WC023_B1	493 466.7	888 755.4	1494	Niskin	Water Sample
NC21_16WC023_M1	493 466.7	888 755.4	400	Niskin	Water Sample
NC21_16WC023_M2	493 321.4	888 847.1	100	Niskin	Water Sample
NC21_16WC023_M3	493 319.9	888 849.1	40	Niskin	Water Sample
NC21_16WC023_T1	493 319.6	888 846.5	1	Niskin	Water Sample
NC21_16WC008_B1	518 607.9	897 311.7	1925	Niskin	Water Sample
NC21_16WC008_M1	518 471.1	897 428.0	500	Niskin	Water Sample
NC21_16WC008_T1	518 444.0	897 442.6	1	Niskin	Water Sample
NC21_16WC009_B1	501 947.2	902 090.7	1882	Niskin	Water Sample
NC21_16WC009_M1	501 812.6	902 154.1	350	Niskin	Water Sample
NC21_16WC009_B2	501 949.8	902 103.1	1880	Niskin	Water Sample
NC21_16WC009_B3	501 939.6	902 086.9	1880	Niskin	Water Sample
NC21_16WC009_T1	501 794.6	902 170.5	1	Niskin	Water Sample
NC21_16WC010_B1	503 288.6	908 925.4	2020	Niskin	Water Sample
NC21_16WC010_M1	503 155.2	909 004.0	500	Niskin	Water Sample
NC21_16WC010_T1	503 137.8	909 021.1	1	Niskin	Water Sample
NC21_16WC010_CTD1	503 289.6	908 950.0	2020	Niskin	Water Sample
NC21_16WC010_CTD2	503 351.8	908 856.3	2023	Niskin	Water Sample
NC21_16WC012_B1	494 651.6	930 043.8	2350	Niskin	Water Sample
NC21_16WC012_M1	494 503.0	930 153.8	600	Niskin	Water Sample
NC21_16WC012_T1	494 497.4	930 156.5	1	Niskin	Water Sample

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	**Easting [m]**	**Northing [m]**	**Depth [m BSL]**	**Type**	**Samples**
NC21_16WC015_B1	463 946.6	949 801.0	2390	Niskin	Water Sample
NC21_16WC015_M1	463 800.4	949 883.7	600	Niskin	Water Sample
NC21_16WC015_T1	463 802.9	949 881.0	1	Niskin	Water Sample
NC21_16WC017_B1	466 817.9	987 201.0	2747	Niskin	Water Sample
NC21_16WC017_M1	466 773.3	987 214.3	350	Niskin	Water Sample
NC21_16WC017_T1	466 798.2	987 203.5	1	Niskin	Water Sample
NC21_16WC017_B3	466 792.0	987 207.6	2743	Niskin	Water Sample
NC21_16WC018_B1	444 929.2	986 709.8	2637	Niskin	Water Sample
NC21_16WC018_T1	444 729.0	986 761.8	1	Niskin	Water Sample
NC21_16WC018_M1	444 722.5	986 765.9	350	Niskin	Water Sample
NC21_16WC020_B1	405 447.5	944 832.4	1845	Niskin	Water Sample
NC21_16WC020_T1	405 164.1	944 825.4	1	Niskin	Water Sample
NC21_16WC020_M1	405 212.3	944 808.9	400	Niskin	Water Sample
NC21_16WC021_B1	450 071.3	923 925.7	1740	Niskin	Water Sample
NC21_16WC021_T1	449 902.2	924 019.0	1	Niskin	Water Sample
NC21_16WC021_M1	449 910.3	924 005.3	265	Niskin	Water Sample
NC21_16WC022_B1	482 122.8	903 886.9	1690	Niskin	Water Sample
NC21_16WC022_T1	481 918.7	903 996.1	1	Niskin	Water Sample
NC21_16WC022_M1	481 934.0	903 973.6	300	Niskin	Water Sample
NC21_16WC025_M2	492 841.3	859 484.2	100	Niskin	Water Sample
NC21_16WC025_T1	492 840.5	859 484.9	1	Niskin	Water Sample
NC21_16WC024_B2	489 870.6	873 478.0	922	Niskin	Water Sample
NC21_16WC024_M2	489 799.1	873 513.9	320	Niskin	Water Sample
NC21_16WC024_T1	489 762.4	873 532.2	1	Niskin	Water Sample
NC21_16WC002_B2	561 426.9	842 302.5	1171	Niskin	Water Sample
NC21_16WC002_M2	561 426.9	842 302.5	371	Niskin	Water Sample
NC21_16WC002_T1	561 294.3	842 336.4	1	Niskin	Water Sample
NC21_16WC005_B1	521 886.3	878 433.8	1681	Niskin	Water Sample
NC21_16WC005_M1	521 700.8	878 577.8	400	Niskin	Water Sample
NC21_16WC006_B1	507 771.2	883 708.2	1550	Niskin	Water Sample
NC21_16WC006_M1	507 771.2	883 708.2	400	Niskin	Water Sample
NC21_16WC006_T1	507 572.4	883 856.5	1	Niskin	Water Sample
NC21_16WC023_B1	493 466.7	888 755.4	1494	Niskin	Water Sample
NC21_16WC023_M1	493 466.7	888 755.4	400	Niskin	Water Sample
NC21_16WC023_M2	493 321.4	888 847.1	100	Niskin	Water Sample
NC21_16WC023_M3	493 319.9	888 849.1	40	Niskin	Water Sample
NC21_16WC023_T1	493 319.6	888 846.5	1	Niskin	Water Sample
NC21_16WC008_B1	518 607.9	897 311.7	1925	Niskin	Water Sample
NC21_16WC008_M1	518 471.1	897 428.0	500	Niskin	Water Sample

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	**Easting [m]**	**Northing [m]**	**Depth [m BSL]**	**Type**	**Samples**
NC21_16WC008_T1	518 444.0	897 442.6	1	Niskin	Water Sample
NC21_16WC009_B1	501 947.2	902 090.7	1882	Niskin	Water Sample
NC21_16WC009_M1	501 812.6	902 154.1	350	Niskin	Water Sample
NC21_16WC009_B2	501 949.8	902 103.1	1880	Niskin	Water Sample
NC21_16WC009_B3	501 939.6	902 086.9	1880	Niskin	Water Sample
NC21_16WC009_T1	501 794.6	902 170.5	1	Niskin	Water Sample
NC21_16WC010_B1	503 288.6	908 925.4	2020	Niskin	Water Sample
NC21_16WC010_M1	503 155.2	909 004.0	500	Niskin	Water Sample
NC21_16WC010_T1	503 137.8	909 021.1	1	Niskin	Water Sample
NC21_16WC010_CTD1	503 289.6	908 950.0	2020	Niskin	Water Sample
NC21_16WC010_CTD2	503 351.8	908 856.3	2023	Niskin	Water Sample
NC21_16WC012_B1	494 651.6	930 043.8	2350	Niskin	Water Sample
NC21_16WC012_M1	494 503.0	930 153.8	600	Niskin	Water Sample
NC21_16WC012_T1	494 497.4	930 156.5	1	Niskin	Water Sample
NC21_16WC015_B1	463 946.6	949 801.0	2390	Niskin	Water Sample
NC21_16WC015_M1	463 800.4	949 883.7	600	Niskin	Water Sample
NC21_16WC015_T1	463 802.9	949 881.0	1	Niskin	Water Sample
NC21_16WC017_B1	466 817.9	987 201.0	2747	Niskin	Water Sample
NC21_16WC017_M1	466 773.3	987 214.3	350	Niskin	Water Sample
NC21_16WC017_T1	466 798.2	987 203.5	1	Niskin	Water Sample
NC21_16WC017_B3	466 792.0	987 207.6	2743	Niskin	Water Sample
NC21_16WC018_B1	444 929.2	986 709.8	2637	Niskin	Water Sample
NC21_16WC018_T1	444 729.0	986 761.8	1	Niskin	Water Sample
NC21_16WC018_M1	444 722.5	986 765.9	350	Niskin	Water Sample
NC21_16WC020_B1	405 447.5	944 832.4	1845	Niskin	Water Sample
NC21_16WC020_T1	405 164.1	944 825.4	1	Niskin	Water Sample
NC21_16WC020_M1	405 212.3	944 808.9	400	Niskin	Water Sample
NC21_16WC021_B1	450 071.3	923 925.7	1740	Niskin	Water Sample
NC21_16WC021_T1	449 902.2	924 019.0	1	Niskin	Water Sample
NC21_16WC021_M1	449 910.3	924 005.3	265	Niskin	Water Sample
NC21_16WC022_B1	482 122.8	903 886.9	1690	Niskin	Water Sample
NC21_16WC022_T1	481 918.7	903 996.1	1	Niskin	Water Sample
NC21_16SP025	492 839.9	859 483.1	264	SPI	Still
rep2	492 847.7	859 482.8	264	SPI	Still
rep3	492 844.5	859 480.9	264	SPI	Still
rep4	492 843.1	859 483.4	264	SPI	Still
rep5	492 841.3	859 484.3	264	SPI	Still
NC21_16SP024	489 773.5	873 511.5	938	SPI	Still
rep2	489 770.3	873 513.9	938	SPI	Still

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	**Easting [m]**	**Northing [m]**	**Depth [m BSL]**	**Type**	**Samples**
rep3	489 776.8	873 516.3	938	SPI	Still
rep4	489 768.8	873 515.6	938	SPI	Still
rep5	489 770.4	873 518.9	938	SPI	Still
NC21_16SP004D	515 043.4	863 083.3	1132	SPI	Still
rep2	515 043.6	863 086.5	1132	SPI	Still
rep3	515 047.0	863 086.5	1132	SPI	Still
rep4	515 044.0	863 087.4	1132	SPI	Still
rep5	515 045.1	863 089.5	1132	SPI	Still
NC21_16SP002	561 371.8	842 290.4	1188	SPI	Still
rep2	561 374.2	842 288.1	1188	SPI	Still
rep3	561 374.2	842 290.8	1188	SPI	Still
rep4	561 376.0	842 291.3	1188	SPI	Still
rep5	561 375.8	842 290.2	1188	SPI	Still
NC21_16SP001	555 085.7	872 693.4	1994	SPI	Still
rep2	555 095.1	872 692.7	1994	SPI	Still
rep3	555 100.5	872 692.0	1994	SPI	Still
rep4	555 105.8	872 692.6	1994	SPI	Still
rep5	555 109.3	872 693.0	1994	SPI	Still
NC21_16SP005B	521 746.8	878 545.7	1693	SPI	Still
rep2	521 751.9	878 545.6	1693	SPI	Still
rep3	521 757.7	878 544.3	1693	SPI	Still
rep4	521 759.1	878 549.4	1693	SPI	Still
rep5	521 764.5	878 547.1	1693	SPI	Still
NC21_16SP006	507 699.6	883 767.9	1568	SPI	Still
rep2	507 712.2	883 760.9	1568	SPI	Still
rep3	507 717.0	883 756.8	1568	SPI	Still
rep4	507 723.5	883 751.4	1568	SPI	Still
rep5	507 727.2	883 750.9	1568	SPI	Still
NC21_16SP023	493 425.7	888 741.4	1509	SPI	Still
rep2	493 432.6	888 735.5	1509	SPI	Still
rep3	493 437.1	888 731.5	1509	SPI	Still
rep4	493 440.0	888 726.9	1509	SPI	Still
rep5	493 445.4	888 721.7	1509	SPI	Still
NC21_16SP007	501 306.8	892 424.0	1695	SPI	Still
rep2	501 317.8	892 419.4	1695	SPI	Still
rep3	501 323.4	892 416.0	1695	SPI	Still
rep4	501 328.4	892 413.3	1695	SPI	Still
rep5	501 333.6	892 411.6	1695	SPI	Still
NC21_16SP008	518 582.2	897 363.6	1942	SPI	Still

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	**Easting [m]**	**Northing [m]**	**Depth [m BSL]**	**Type**	**Samples**
rep2	518 592.6	897 358.6	1942	SPI	Still
rep3	518 597.5	897 356.9	1942	SPI	Still
rep4	518 608.0	897 351.6	1942	SPI	Still
rep5	518 616.4	897 345.9	1942	SPI	Still
NC21_16SP009	501 873.2	902 086.7	1887	SPI	Still
rep2	501 890.4	902 084.0	1887	SPI	Still
rep3	501 905.9	902 081.4	1887	SPI	Still
rep4	501 919.9	902 077.9	1887	SPI	Still
rep5	501 927.8	902 076.0	1887	SPI	Still

Notes:
† = Coordinates for first successful grab to target are provided
PC = Physico-chemical sample
BSL = Below sea level

3.2 Bathymetry

The following summary has been adapted from geophysical report (Report No. 2415-3066-FieldGeophys).

The bathymetry for the survey area, overlain with the environmental survey stations is shown in Figure 3.1.

Water depth ranged from 105 m (LAT) in the south-west of the survey area to 1,875 m (LAT) in the northwest for the area covered by the geophysical survey, the environmental survey exceeded the extents of this. The seabed ranged from undulating to hummocky in the Liza field development area and hummocky to rugged in the outer shelf area. Seabed gradient within the survey area generally ranged from < 1° to 4°, though some steeper gradients, 4° to 34° were observed along the flanks of the seafloor hummocks. Two large seafloor depressions show localised depressions between 4° and 20°.

The seabed was interpreted to comprise mainly of soft, fine-grained sediments and some coarser grained sediments present on the upper slopes and outer shelf area. Very small, discrete patches of high MBES backscatter and high SSS reflectivity were observed in the southern half of the survey area. These were interpreted to represent possible de-watering processes and/or shallow eroded beds, exposing the coarser underlying substrate. To the northeast, larger patches of high reflectivity and backscatter were observed, particularly on top of the seabed hummocks. These were interpreted as older, underlying sediment beds, exposed by bottom currents and possibly dewatering processes.

3.2.1 Seabed Features

The following summary has been adapted from geophysical report (Report No 2415-3066-FieldGeophys).

No prominent seafloor features or hazards were observed during the geophysical survey.

Numerous small depressions were observed across the survey site and were generally up to 30 m in diameter and 0.5 m deep. The two largest depressions observed were 48 m diameter and 1 m deep, and 270 m long, 100 m wide and 6 m to 8 m deep. The smaller of the two had coarser sediments in the bottom but the larger depression did not, suggesting seafloor sinking or collapse in the past. On the upper slope, areas of high MBES backscatter were identified as depressions with hardground possibly associated with expulsion of shallow gas. The hardground could represent authigenic carbonates, surficial hydrates and/or deepwater benthic communities.

The seabed hummocks, as mentioned above, were observed throughout the survey area and ranged in length from < 50 m to 800 m long and 20 m to 300 m wide.

One post-drill well (Liza-1) was identified within the survey area. Disturbed soft and coarse sediment surrounding the well was identified as well cuttings and debris. One subsea cable was identified running northwest to southeast through the survey area. The mainly exposed cable was ~25 mm in diameter and ran through the survey area for 25 km.

Seventy-three sonar contacts were identified as small geological or anthropogenic debris. The origin of the majority of debris was believed to be items thrown from vessels in the area.

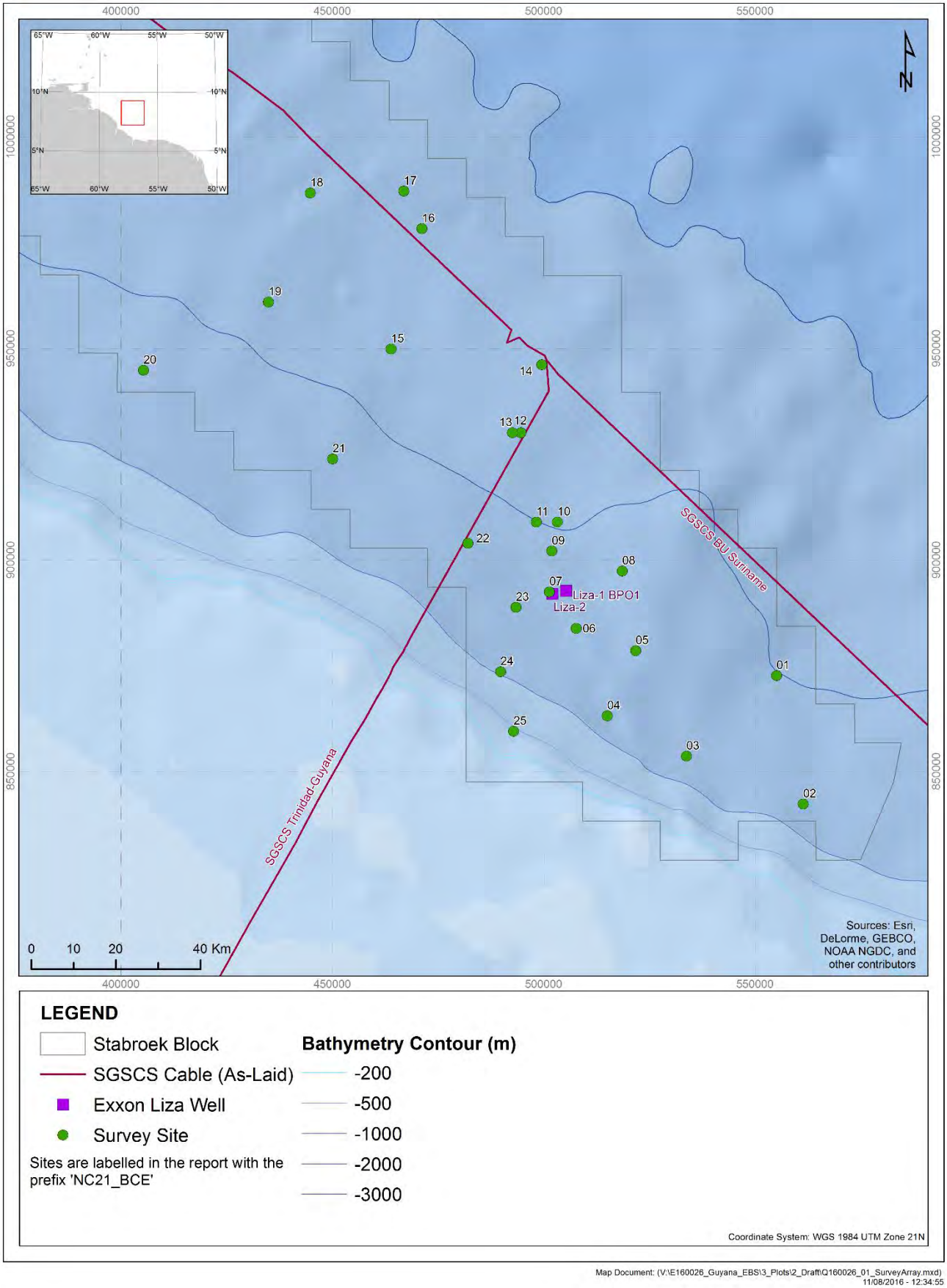


Figure 3.1: Survey area bathymetry and environmental survey stations

3.3 Sediment Particle Size Distribution and Organic Content

3.3.1 Particle Size

Summarised results and sediment descriptions based on Wentworth and Folk Classifications are presented in Table 3.2. The distribution of sediment fractional compositions of samples is illustrated in Figure 3.2, whilst the full particle size analysis results and example grab photographs are provided in Appendix D. Replicate samples (A and B) were obtained at all 25 stations (details of sampling log can be found in Appendix C).

The majority of sediment samples (56%) were classified as sandy mud, according to the BGS Modified Folk Classification, the remaining samples been represented by muddy sand (32%); mud (8%); and slightly gravelly muddy sand (4%). The sediment sorting ranged from poorly sorted to very poorly sorted, the former associated with muddy sediments, the latter typical of slightly more heterogeneous sediments.

Mud was the predominant sediment type, with values ranging from 18.5% (station NC21_BCE019) to 94.6% (station NC21_BCE003), with an average of 60.8% across the survey area.

Levels of sand were also high across much of the survey area, making up over 30% of the sediment at 16 stations. The highest level of sand was recorded at station NC21_BCE019 (81.4%), the lowest sand content was found at station NC21_BCE003 (5.4%), the average sand content across all stations was 39.1%.

Levels of gravel were low across the survey area, with 96% of samples showing values equal, or very close, to zero. The highest level of gravel was recorded at station NC21_BCE025 (2.3%).

Correlation analysis showed that there was no significant relationship between sediment distribution across the survey area and increasing depth, with the highest Spearman's correlation coefficient value being between depth and sand (rho = 0.296), the rho value required for p=0.05 was rho = 0.336 (full results of correlation analysis in Appendix H).

The field log (Appendix C) provided qualitative information on the sample sediment type, with the majority of samples being described as sandy mud and less often muddy sand.

3.3.2 Total Organic Carbon

Organic content, in the form of organic carbon, was generally low across the survey area, with 19 stations showing values below the reporting limit (0.2%) (Table 3.2). The remaining stations showed values of total organic carbon (TOC) of between 0.38% (NC21_BCE025) and 1.10% (NC21_BCE023).

When assessed using Spearmans Rank Coefficient in conjunction with physical variables (depth, gravel, sand and mud content), a significant correlation between TOC and mud content was observed (rho = 0.56, $p < 0.01$), with a corresponding negative correlation with sand content

(rho = -0.56, p< 0.01). TOC was also negatively correlated with depth (rho= -0.70, p< 0.01). The spatial distribution of organic carbon across the survey area is illustrated in Figure 3.3.

3.3.3 In Situ Sediment Parameters

Sediment pH and redox were recorded from samples upon recovery to deck. Sediment pH ranged from 7.17 to 7.92, with an average pH across the survey area of 7.60. Sediment redox in millivolts (mV) ranged from 172 mV to 280 mV with an average of 221 mV. These redox results indicate study sediments across the survey area are anaerobic corresponding to moderately reducing conditions (Delaune and Reddy, 2005).

Table 3.2: Summary of Sediment Particle Size Distribution Data

Station	Sorting	Mean			Mode 1	Mode 2	Mode 3	Fractional Composition				pH	Redox [mV]	TOC [%]
		Phi	µm	Description	Phi	Phi	Phi	Mud [%]	Sand [%]	Gravel [%]	Description [Folk]			
NC21_BCE001	Very poorly sorted	6.03	15.26	Fine silt	7.75	1.25	3.75	74.23	25.77	0.00	Sandy mud	7.58	203	<0.2
NC21_BCE002	Poorly sorted	7.29	6.40	Very fine silt	7.75	0.00	0.00	92.15	7.85	0.00	Mud	7.63	205	0.83
NC21_BCE003	Poorly sorted	7.26	6.54	Very fine silt	7.25	0.00	0.00	94.59	5.41	0.00	Mud	7.66	185	0.61
NC21_BCE004	Very poorly sorted	6.84	8.72	Fine silt	7.25	0.00	0.00	87.31	12.69	0.00	Sandy mud	7.79	198	0.50
NC21_BCE005	Very poorly sorted	6.42	11.71	Fine silt	7.75	3.75	1.75	77.97	22.03	0.00	Sandy mud	7.70	218	<0.2
NC21_BCE006	Very poorly sorted	5.33	24.87	Medium silt	7.75	1.25	0.00	59.14	40.86	0.00	Sandy mud	7.38	218	<0.2
NC21_BCE007	Very poorly sorted	5.01	31.13	Medium silt	1.75	7.75	0.00	55.68	44.28	0.03	Slightly gravelly sandy mud	7.60	233	<0.2
NC21_BCE008	Very poorly sorted	4.19	54.95	Coarse silt	1.75	7.75	0.00	41.50	58.48	0.01	Slightly gravelly muddy sand	7.17	227	<0.2
NC21_BCE009	Very poorly sorted	4.68	38.95	Coarse silt	1.75	7.75	0.00	51.55	48.45	0.00	Sandy mud	7.36	220	<0.2
NC21_BCE010	Very poorly sorted	4.19	54.69	Coarse silt	1.25	8.25	0.00	41.59	58.28	0.13	Slightly gravelly muddy sand	7.68	280	<0.2
NC21_BCE011	Very poorly sorted	4.32	49.97	Coarse silt	1.75	7.75	0.00	44.05	55.93	0.02	Slightly gravelly muddy sand	7.60	219	<0.2
NC21_BCE012	Very poorly sorted	4.45	45.86	Coarse silt	1.25	7.75	3.75	48.39	51.61	0.00	Muddy sand	7.60	236	<0.2
NC21_BCE013	Very poorly sorted	3.92	66.04	Very fine sand	1.25	8.25	0.00	37.58	62.36	0.06	Slightly gravelly muddy sand	7.66	221	<0.2
NC21_BCE014	Very poorly sorted	6.40	11.84	Fine silt	7.75	1.25	0.00	79.55	20.45	0.00	Sandy mud	7.69	190	<0.2
NC21_BCE015	Very poorly sorted	4.00	62.53	Very fine sand	1.25	7.75	0.00	40.34	59.66	0.00	Muddy sand	7.71	221	<0.2
NC21_BCE016	Very poorly sorted	5.84	17.50	Medium silt	7.75	1.25	4.25	69.14	30.86	0.00	Sandy mud	7.87	218	<0.2
NC21_BCE017	Very poorly sorted	6.25	13.18	Fine silt	7.75	1.25	0.00	76.82	23.18	0.00	Sandy mud	7.67	253	<0.2
NC21_BCE018	Very poorly sorted	6.45	11.40	Fine silt	7.75	4.25	1.25	79.26	20.74	0.00	Sandy mud	7.76	225	<0.2
NC21_BCE019	Very poorly sorted	2.50	177.20	Fine sand	1.75	0.00	0.00	18.49	81.45	0.06	Slightly gravelly muddy sand	7.17	267	<0.2
NC21_BCE020	Very poorly sorted	5.15	28.24	Medium silt	7.75	1.25	3.75	59.40	40.47	0.13	Slightly gravelly sandy mud	7.35	235	<0.2

Station	Sorting	Mean			Mode 1	Mode 2	Mode 3	Fractional Composition				pH	Redox [mV]	TOC [%]
		Phi	µm	Description	Phi	Phi	Phi	Mud [%]	Sand [%]	Gravel [%]	Description [Folk]			
NC21_BCE021	Very poorly sorted	3.44	92.38	Very fine sand	1.25	8.25	0.00	27.48	72.50	0.03	Slightly gravelly muddy sand	7.52	243	<0.2
NC21_BCE022	Very poorly sorted	4.95	32.44	Coarse silt	1.75	7.75	0.00	54.76	45.24	0.00	Sandy mud	7.40	231	<0.2
NC21_BCE023	Very poorly sorted	6.85	8.68	Fine silt	7.75	0.00	0.00	86.89	13.11	0.00	Sandy mud	7.57	230	1.10
NC21_BCE024	Very poorly sorted	6.70	9.61	Fine silt	7.25	2.25	0.00	87.19	12.81	0.00	Sandy mud	7.88	178	0.82
NC21_BCE025	very poorly sorted	3.91	66.67	Very fine sand	2.75	1.75	7.75	34.37	63.31	2.33	Slightly gravelly muddy sand	7.92	187	0.38
Mean	Very poorly sorted	5.29	37.87	Medium silt	4.75	4.93	3.75	60.78	39.11	0.11	Slightly gravelly sandy mud	7.60	222	0.32
SD		1.32	37.53		3.08	3.16	2.10	21.97	21.84	0.46		0.20	24	0.25
Min	Very poorly sorted	2.50	6.40	Very fine silt	1.25	1.25	1.25	18.49	5.41	0.00	Mud	7.17	178	<0.2
Max	Poorly sorted	7.29	177.20	Fine sand	7.75	8.25	7.75	94.59	81.45	2.33	Slightly gravelly muddy sand	7.92	280	1.10

Notes:
TOC = Total organic carbon

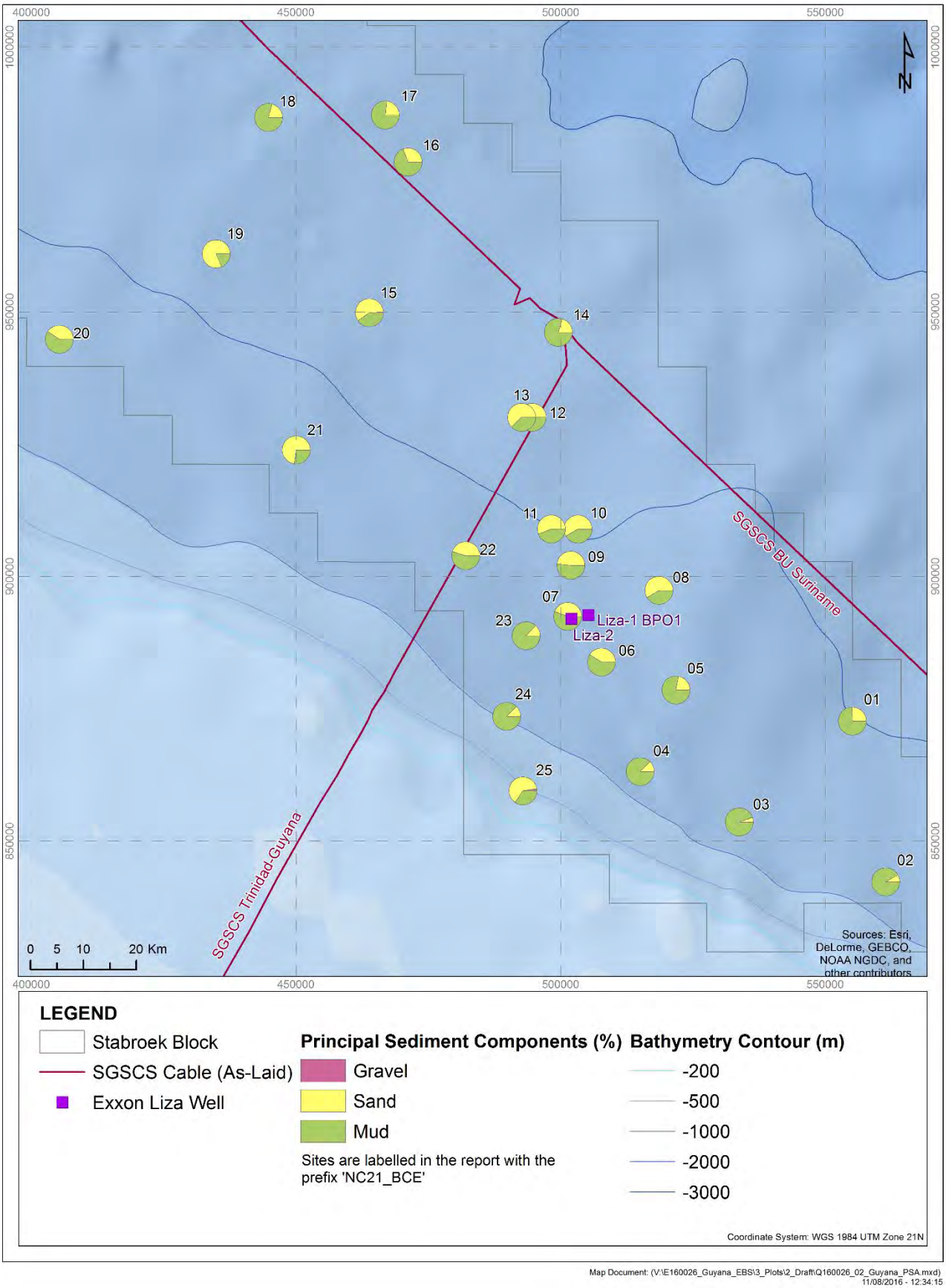


Figure 3.2: Spatial distribution of sediment characteristics

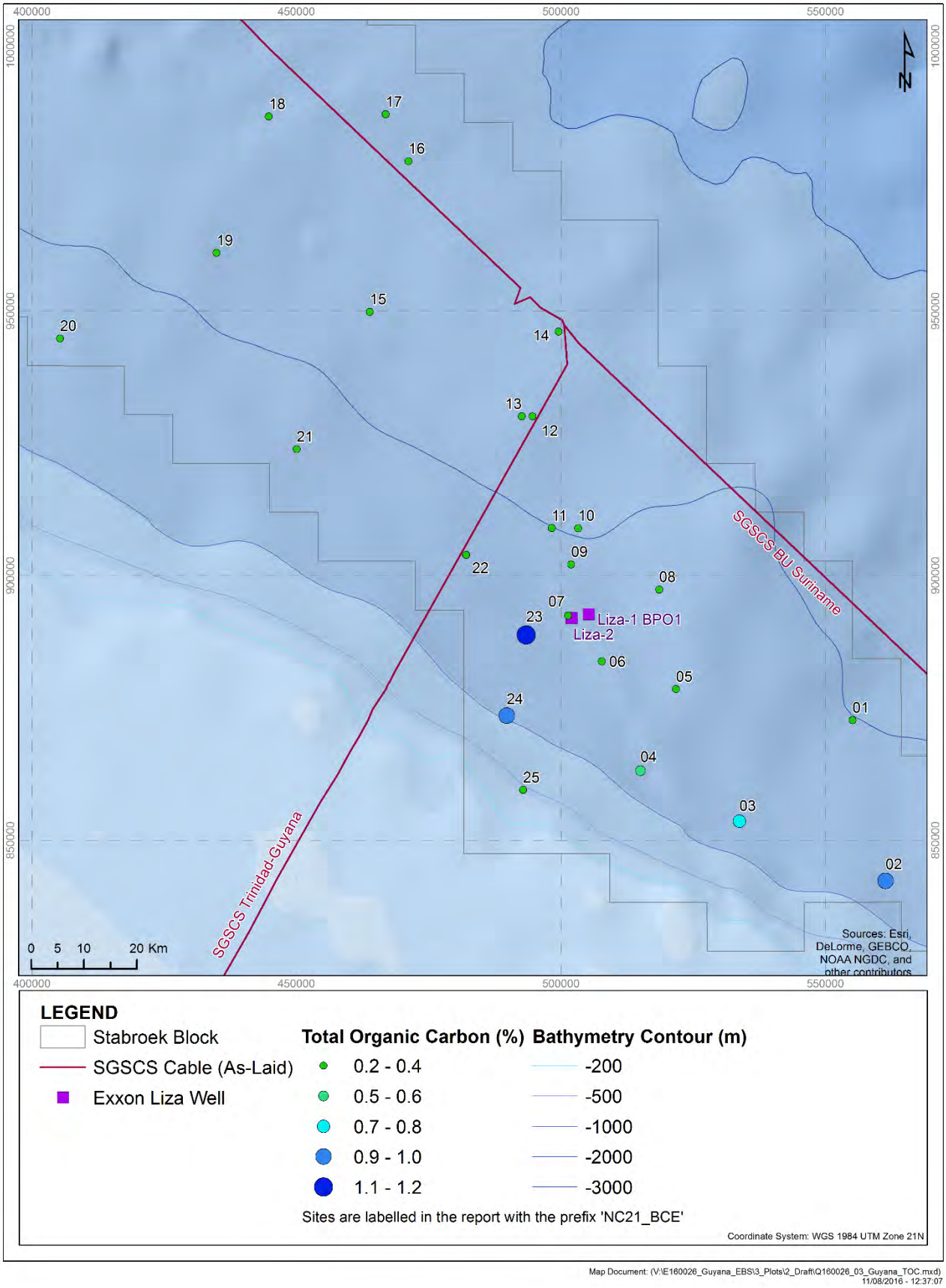


Figure 3.3: Spatial distribution of total organic carbon

3.3.4 Multivariate Analysis

Multivariate analyses were undertaken on the particle size dataset in order to identify spatial patterns in the sediment distribution. Analyses included hierarchical agglomerative clustering employing the Euclidean distance resemblance matrix. Data were 4th root transformed prior to analysis.

3.3.4.1 Hierarchical Agglomerative Clustering Analysis

Results of the hierarchical agglomerative clustering analysis are presented in Figure 3.4 and Figure 3.5. Three main groups of stations were identified by the multivariate analysis (clusters 1, 2, and station NC21_BCE025, which was unassigned), together with two subgroups within cluster 1. The characteristics of each cluster are summarised in Table 3.3. Additionally, the Udden/Wentworth grade scale (Eleftheriou and McIntyre, 2005; Wentworth, 1922) was used to describe the sediment between dominant phi classes within clusters. It is noteworthy that, although some stations are displayed as being statistically different, based on the output of the SIMPROF test, differences were not considered to be of ecological significance based on the analysis of the individual sample's sediment type, which are discussed further in this section.

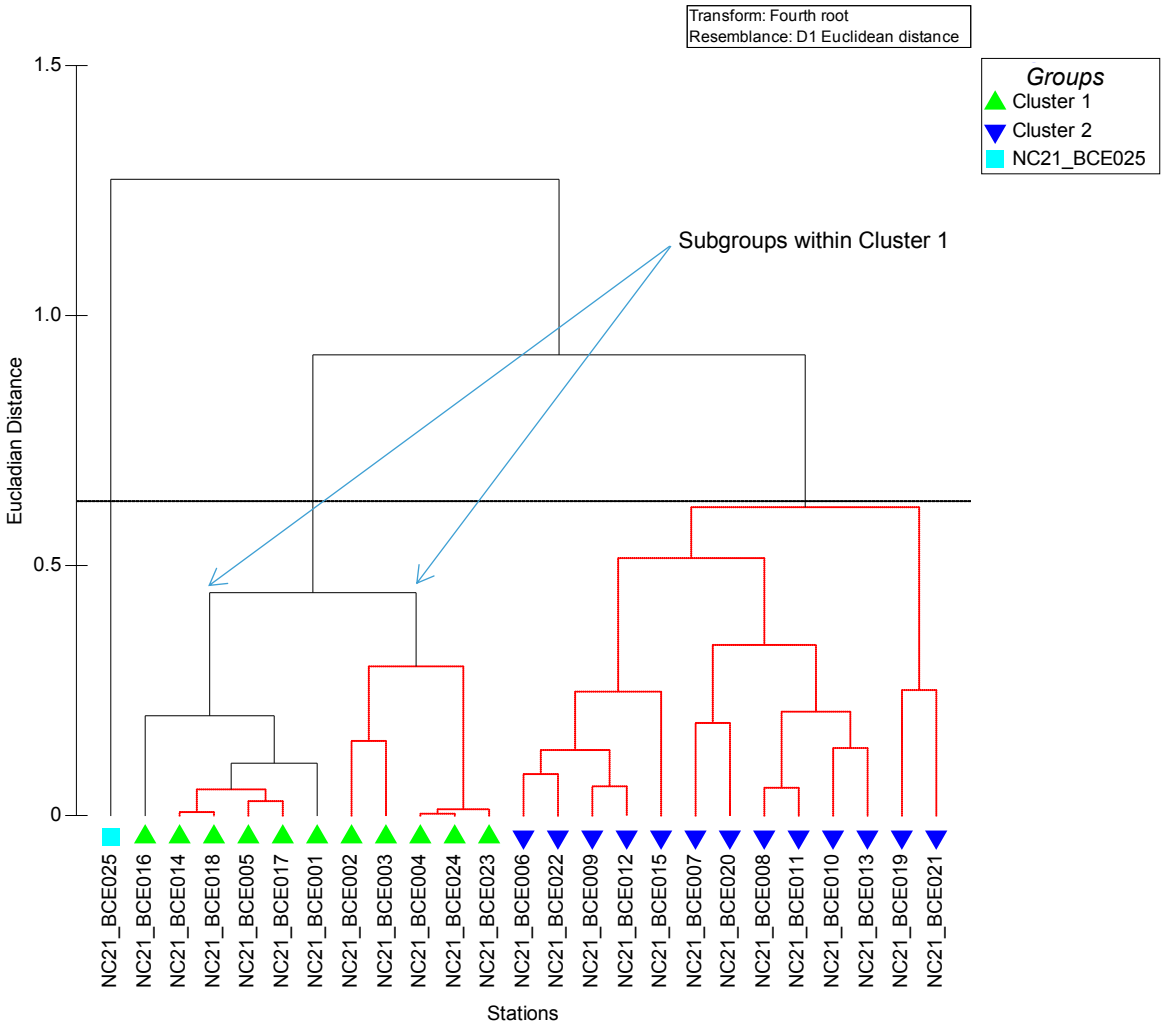


Figure 3.4: Dendrogram of Euclidean distance of sediment particle size

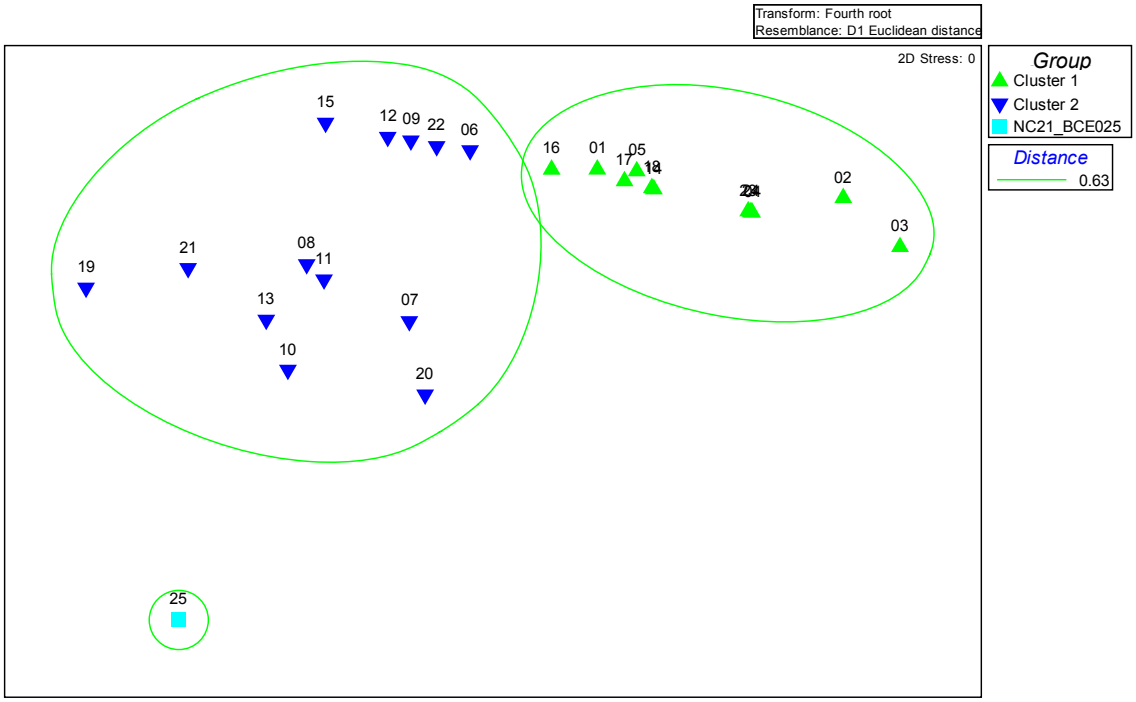


Figure 3.5: MDS of Euclidean distance of sediment particle distribution (note station prefix have been removed to improve clarity of plot)

Table 3.3: Summary Particle Size Distributions for Groups

Group	Samples	Depth [m]	D50 [µm]	Main Sediment Fraction			Description
				Gravel	Sand	Mud	
1 Average square distance 0.07	NC21_BCE001-005, NC21_014, NC21_016-18, NC21_BCE023, NC21_BCE024	1874 ± 693	7.73 ± 1.21	0.00 ± 0.00	7.89 ± 17.72	7.89 ± 82.28	Mud and sandy mud, poorly sorted/very poorly sorted, unimodal, bimodal and trimodal distribution
2 Average square distance 0.12	NC21_BCE006-13, NC21_BCE015, NC21_BCE019-22	1913 ± 292	100.28 ± 71.94	0.04 ± 005	55.35 ± 12.18	44.61 ± 12.18	Muddy sand and sandy mud, poorly sorted/very poorly sorted, unimodal, bimodal and trimodal distribution
NC21_BCE025 Average squared distance N/A	NC21_BCE025	480	122	2.33	63.31	34.37	Slightly gravelly muddy sand, very poorly sorted, trimodal distribution

Notes:
Values refer to mean ± standard deviation within each groups
Description is based on Folk [BGS modified]
BSL = Below sea level

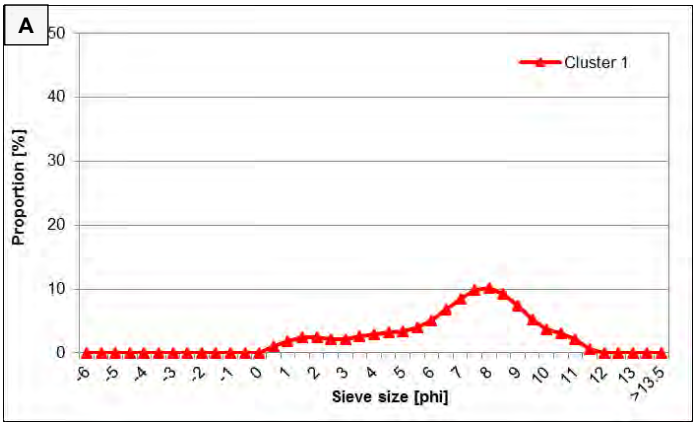
Cluster 1 comprised of eleven samples from stations to the north and south of the survey array. It was characterised by sandy mud, except stations NC21_BCE002 and NC21_BCE003, which were classified as mud. The sediment was poorly or very poorly sorted, the 8 phi sediment particle size (very fine silt) was primarily responsible for the separation of this group of stations (Table 3.4). Stations within this group showed, on average, bimodal distribution, peaking at 1.5 phi sediment particle size (medium sand), and 8.0 phi sediment particle size (very fine silt.).

Cluster 2 comprised thirteen stations located in the middle of the survey array, it was characterised by muddy sand and occasionally sandy mud. The 1.5 phi sediment particle size (medium sand) was primarily responsible for the separation of this group of stations (Table 3.4). Stations within this group showed, on average, bimodal distribution, peaking at the 8.0 phi sediment particle (very fine silt), and at the 1.5 phi sediment particle size (medium sand).

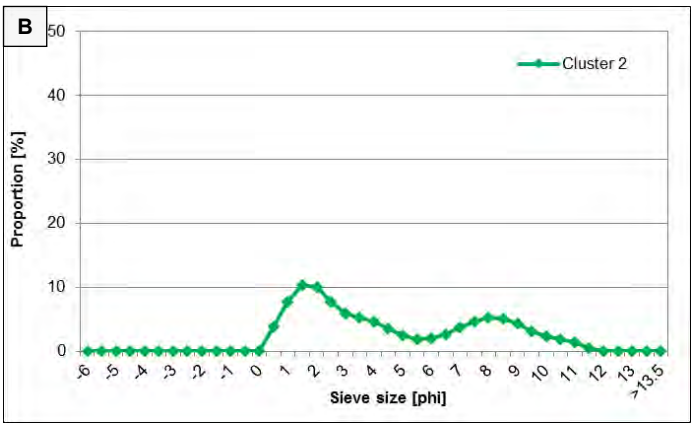
NC21_BEC025 was not linked to either cluster 1 or 2. It was characterised as slightly gravelly muddy sand, very poorly sorted and dominated by the 3.0 phi sediment particle size (fine sand) fraction. The primary separating factor of this station was likely due to it been the only station with a relatively high, compared to other stations, gravel/pebble component between -2.0 phi and -1.0 phi (pebble to very coarse sand) (Table 3.4). This station bore a trimodal distribution with peaks at sediment particle sizes of -2.0 phi (pebble to granule, 3.0 phi (fine sand) and 8phi (very fine silt).

An overall spatial distribution pattern was identified within the survey area, with stations to the north and south of the survey area been composed of predominantly sandy mud sediments, whilst stations in the centre were composed primarily of muddy sands. The shallowest station, NC21_BCE25 was the only station with a notable gravel content.

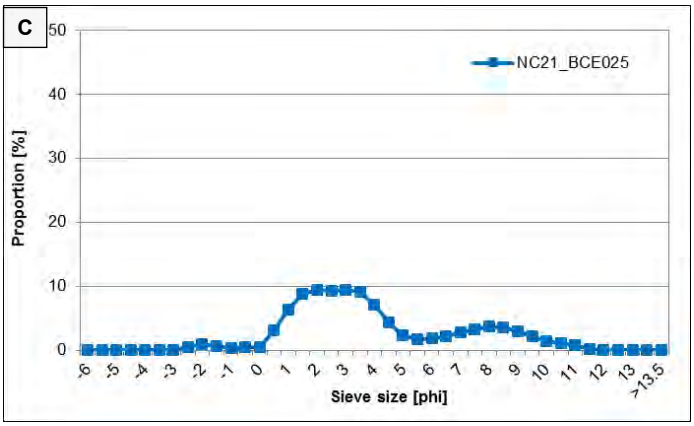
Table 3.4: Average Particle Size Distribution within Multivariate Groups of Stations













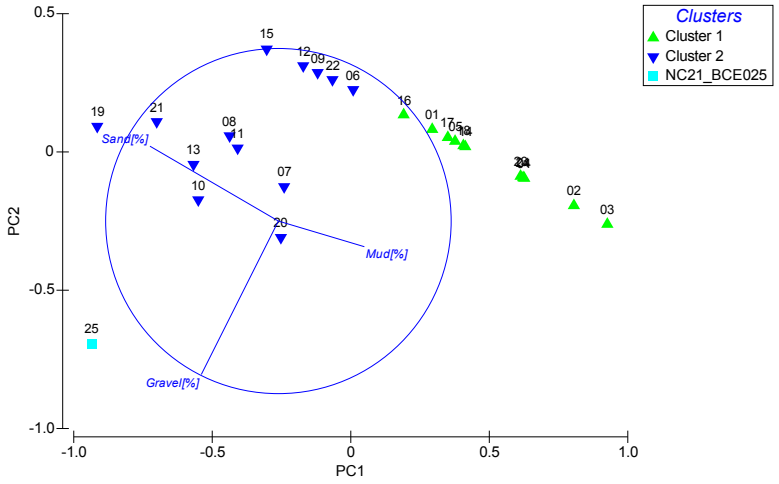
Graph A: Particle size distribution (Cluster 1)
Photo A: Station NC21_BCE001 (Cluster 1 representative sample)
Graph B: Particle size distribution (Cluster 2)
Photo B: Station NC21_BCE015 (Cluster 2 representative sample)
Graph C: Particle size (Station NC21_BCE025)
Photo C: Station NC21_BCE025

3.3.4.2 Principal Component Analysis

The principal component analysis (PCA) was undertaken on the major sediment fractions (gravel, sand and mud), in order to illustrate the overall spatial distribution of sediment types within the survey area and relationships with other variables.

Results are presented in Figure 3.6. Percentage sand made up the majority of the principal component one (PC1), whilst percentage gravel made up the majority of component two (PC2) and percentage mud made up the majority of component three (PC3). PC1 caused 83% of the total variation between stations, indicating that percentage sand explained the majority of variation in sediment composition across the survey area (Figure 3.7).

The sediment sorting coefficient reflected the heterogeneity of sediments, with all sediment been poorly to very poorly sorted (Figure 3.6). When overlain with the percentages of mud, sand and gravel (Figure 3.7 A, B and C, respectively), gravel composition is highlighted as a separating factor for station NC21_BCE025, as for cluster analysis, whilst the definition of sandy muds against muddy sands in Clusters 1 and 2, respectively, was less clear but notable in differences in the sand and mud content.



PC	% Variation
1	83.0
2	15.1
3	1.9

Coefficients in the linear combinations of variables making up PC's

Variable	PC1	PC2	PC3
% Mud	0.498	-0.149	0.855
% Sand	-0.744	0.434	0.508
% Gravel	-0.446	-0.889	0.105

Data 4th root transformed

Figure 3.6: Two-dimensional representation of the principal components analysis of sediment composition

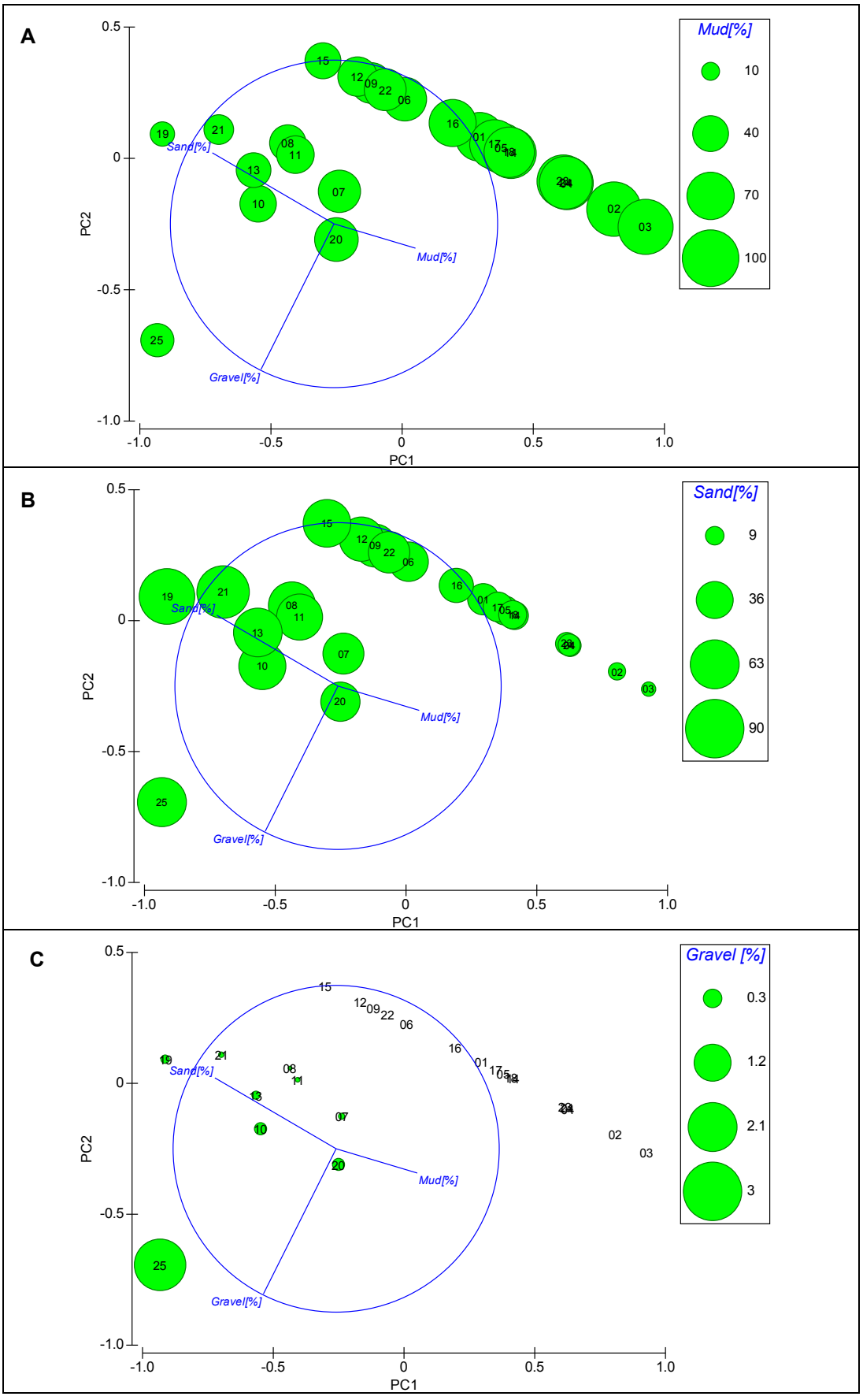


Figure 3.7: Two-dimensional representation of the PCA of sediment composition. Data with superimposed circles proportional in diameter to % mud (A); sand (B); gravel(C)

3.4 SPI Results

The following results have been extracted from the SPI survey report (Aquafact, 2016). The full report can be found in Appendix E. Triplicate SPI photographs were obtained from 11 out of a total of 12 EBS stations attempted for SPI. Plan view images of the seafloor were collected from five stations. Sediment and water samples, as well as in situ CTD profiles were also collated at all 25 EBS stations originally planned.

Seafloor sediment predominantly consisted of soft, oxidised mud and clays, with a smaller sand fraction and shell debris dominated by foraminiferans and to a lesser extent gastropods (Scaphopoda). Most areas were overlaid by a flocculent layer of detrital material, particularly the deeper stations near the edge of the continental slope where mud and clay accumulation was highest. Although the majority of the site was dominated by mud and clay, the shallowest station (SP025), located near the start of the continental slope, was dominated by muddy sand.

Prism penetration was high, usually more than 10 cm, a reflection of the depositional nature of the area dominated by soft mud and clay (< 63 µm; <4 phi) transported from the Essequibo and Demerara Rivers that discharge large quantities of kaolinite and other soft sediments into the sea. Mud clasts were also common on the seafloor surface in most stations. Sediment boundary roughness (SBR) was relatively low, an indication of the relatively flat nature of the seafloor, particularly in the depositional, deeper areas along the continental slope. Changes in SBR were the result of the bioturbating activity of decapods and other invertebrates and the presence of clay casts that accumulated in some stations. Apparent redox potential discontinuity (ARPD) is the depth below the seabed from which processes transition from oxidising to reducing processes, it is measured by looking at the gradient of colour change from the top of the SPI image. ARPD were relatively deep in most areas, with a deep layer of oxygenated, ferric clays in most stations. Considering the overall impoverished community and low faunal richness, it is considered that oxygenation is the result of physicochemical processes and, to a lesser extent, biological activity.

Faunal diversity and richness observed from the SPI was poor overall, the seafloor dominated by tube building polychaetes and, occasionally, by burrowing decapods (e.g. squat lobster), It is worth noting that species diversity and richness determined from stills can differ significantly to that derived from macrofaunal data as it is very hard to identify organisms to species level from SPI stills. Additionally, overall area of benthos sampled by a single SPI still is significantly smaller than that derived from a grab sample, this means that macrofaunal samples could show the community as more diverse and rich than SPI analysis.

The faunal community was transitional, successional stages I to II and III, from the initial colonising stages to intermediate stages dominated by shallow dwelling polychaetes and amphipods. Benthic health quality (BHQ) scores were largely influenced by the presence of deep ARPDs (high scores resulting from deep, i.e. > 5 cm ARPD depths) due to the sedimentology of the site and physicochemical processes. Although in temperate areas high BHQs are correlated with the presence of a well-developed, ‘climax’ infaunal community this was not the case in the study area.

Notwithstanding the limitations of SPI to provide a full and detailed description of the composition of infaunal assemblages, the images collected indicate that the ambient conditions at the stations sampled

along the continental slope are nonetheless typical of deep sea muds and clays colonised by a naturally species poor infaunal community.

3.5 Sediment Hydrocarbons

Results of hydrocarbon analyses are summarised in Table 3.5 and Table 3.6 and the distribution of total hydrocarbon concentrations (THC) illustrated in Figure 3.8, with full results presented in Appendix F. Full results of the correlation analysis between hydrocarbons and other abiotic and biotic variables are presented in Appendix H.

Total Hydrocarbon (THC) concentrations ranged from 1.5 μgg^{-1} at stations NC21_BCE008, NC21_BCE013 and NC21_BCE019 located through the centre of the survey array, to 4.8 μgg^{-1} at station NC21_BCE003 on the southern edge of Stabroek area. The average concentration of THC across the survey area was 2.8 μgg^{-1} (Table 3.6).

THC concentrations showed relatively strong positive correlation with all tested metals except copper and arsenic. In addition, THC strongly correlated with the percentage of mud in the sediment (rho = 0.843, $p<0.01$). There were also strong positive correlations between THC and TOC (rho = 0.605, $p<0.01$).

The concentrations of n-alkanes (C_{12-36}) were between 0.12 μgg^{-1} (station NC21_BCE019) and 0.50 μgg^{-1} (station NC21_BCE003), with an average of 0.27 μgg^{-1} across the survey area. Levels of the short chain n-alkane (C_{12-20}) were consistently lower than those of the long chain n-alkanes (nC_{21-36}). The highest concentrations of short chain n-alkane (C_{12-20}) and long chain n-alkanes (nC_{21-36}) were recorded at station NC21_BCE002 and station NC21_BCE003 respectively. Concentrations of n-alkane were strongly positively correlated with all metals tested (rho = 0.50598 to 0.6145, $p< 0.01$) except Copper and Mercury, and correlated to a lesser degree with Arsenic and Mercury in addition, the concentration of n-alkanes (C_{12-36}) strongly correlated with percentage of mud (rho = 0.80, $p<0.01$).

The Unresolved Complex Mixture (UCM) concentrations were between 0.9 μgg^{-1} at stations NC21_BCE013 (representing 60% of THC) and 2.8 μgg^{-1} at station NC21_BCE003 (representing 58% of THC). The average across the survey area was 1.8 μgg^{-1}, which represented 64% of the THC concentration. Concentrations of UCM using Spearmans Rank Coefficient was strongly positively correlated with all metals (rho = 0.52519 to 0.67785, $p< 0.01$) except copper, and less positively correlated with Copper, Selenium and Arsenic. In addition, the concentration of n-alkanes (C_{12-36}) strongly correlates with percentage of mud (rho = 0.833, $p<0.01$).

Table 3.5: Summary of Hydrocarbon Results [µgg^{-1} dry weight]

Concentrations Expressed as µgg^{-1} Dry Sediment													
Station Identification	Sample Type	GC											GC-MS
		THC	UCM	n-alkanes			CPI					Pr/Ph Ratio	2 - 6 Ring PAH
				nC_{12-20}	nC_{21-36}	nC_{12-36}	nC_{12-20}	nC_{21-36}	nC_{12-36}	Pristane	Phytane		
NC21_BCE001	SED	3.5	2.5	0.07	0.26	0.33	1.23	2.43	2.07	0.002	0.002	1.43	0.048
NC21_BCE002	SED	4.2	2.2	0.13	0.36	0.49	1.24	2.66	2.14	0.004	0.003	1.47	0.088
NC21_BCE003	SED	4.8	2.8	0.12	0.38	0.50	1.20	2.57	2.10	0.003	0.002	1.98	0.078
NC21_BCE004	SED	3.8	2.0	0.10	0.34	0.44	1.28	2.93	2.37	0.003	0.002	1.79	0.076
NC21_BCE005	SED	2.8	2.0	0.05	0.16	0.21	1.21	2.28	1.96	0.002	0.001	1.35	0.035
NC21_BCE006	SED	2.6	1.5	0.06	0.17	0.22	1.38	2.78	2.27	0.002	0.001	1.49	0.239
NC21_BCE007	SED	2.2	1.3	0.05	0.18	0.23	1.22	2.99	2.39	0.003	0.001	2.27	0.028
NC21_BCE008	SED	1.5	0.9	0.03	0.11	0.14	1.19	2.94	2.36	0.001	0.001	1.37	0.020
NC21_BCE009	SED	2.4	1.5	0.07	0.17	0.24	2.41	2.83	2.70	0.001	0.001	1.08	0.035
NC21_BCE010	SED	2.7	1.8	0.04	0.18	0.22	1.15	2.41	2.11	0.002	0.001	1.31	0.027
NC21_BCE011	SED	2.0	1.3	0.03	0.12	0.15	1.29	2.80	2.32	0.002	0.003	0.66	0.022
NC21_BCE012	SED	1.9	1.2	0.04	0.13	0.17	1.19	2.84	2.30	0.013	0.012	1.05	0.025
NC21_BCE013	SED	1.5	0.9	0.03	0.12	0.15	1.22	2.79	2.27	0.001	0.001	1.65	0.019
NC21_BCE014	SED	3.1	2.0	0.07	0.34	0.41	1.20	2.76	2.37	0.002	0.002	1.12	0.048
NC21_BCE015	SED	2.8	1.9	0.05	0.23	0.28	1.15	2.64	2.23	0.002	0.002	0.81	0.036
NC21_BCE016	SED	2.1	1.4	0.04	0.16	0.20	1.27	2.78	2.34	0.001	0.001	1.27	0.023
NC21_BCE017	SED	3.2	2.2	0.07	0.30	0.37	1.27	2.55	2.21	0.002	0.001	1.53	0.048
NC21_BCE018	SED	3.6	2.6	0.07	0.27	0.34	1.10	2.78	2.23	0.002	0.002	1.49	0.045
NC21_BCE019	SED	1.5	1.0	0.02	0.10	0.12	1.27	2.25	2.02	0.001	0.005	0.18	0.016
NC21_BCE020	SED	2.5	1.8	0.05	0.17	0.22	1.39	2.33	2.04	0.002	0.001	1.75	0.031
NC21_BCE021	SED	1.7	1.1	0.03	0.13	0.17	1.29	2.53	2.18	0.001	0.011	0.13	0.022
NC21_BCE022	SED	2.5	1.7	0.05	0.20	0.25	1.18	2.09	1.86	0.002	0.002	1.06	0.036
NC21_BCE023	SED	3.2	2.2	0.07	0.19	0.26	1.19	2.15	1.83	0.003	0.002	1.35	0.049

Concentrations Expressed as µgg^{-1} Dry Sediment													
Station Identification	Sample Type	GC											GC-MS
		THC	UCM	n-alkanes			CPI					Pr/Ph Ratio	2 - 6 Ring PAH
				nC_{12-20}	nC_{21-36}	nC_{12-36}	nC_{12-20}	nC_{21-36}	nC_{12-36}	Pristane	Phytane		
NC21_BCE024	SED	4.4	2.7	0.10	0.33	0.43	1.38	2.49	2.16	0.004	0.002	1.68	0.077
NC21_BCE025	SED	2.5	1.4	0.03	0.19	0.22	1.34	2.93	2.60	0.001	0.001	0.70	0.023
Current Survey													
Mean	SED	2.8	1.8	0.06	0.21	0.27	1.29	2.62	2.22	0.002	0.003	1.28	0.05
SD	SED	0.9	0.6	0.03	0.09	0.11	0.24	0.26	0.20	0.002	0.003	0.50	0.04
Min	SED	1.5	0.9	0.02	0.10	0.12	1.10	2.09	1.83	0.001	0.001	0.13	0.02
Max	SED	4.8	2.8	0.13	0.38	0.50	2.41	2.99	2.70	0.013	0.012	2.27	0.24

Notes:
GC = Gas chromatography
GC-MS = Gas chromatography – Mass Spectrometry
THC = Total hydrocarbons
UCM = Unresolved complex mixture
CPI = Carbon preference index (the ratio of odd number carbon chain n-alkanes to even numbered chain n-alkanes)
Pr/Ph = ratio of pristane to phytane
2 to 6 ring PAH = Total 2 to 6 ring polycyclic aromatic hydrocarbons (including alkyl homologues) - see PAH table for full details of compounds quantified).

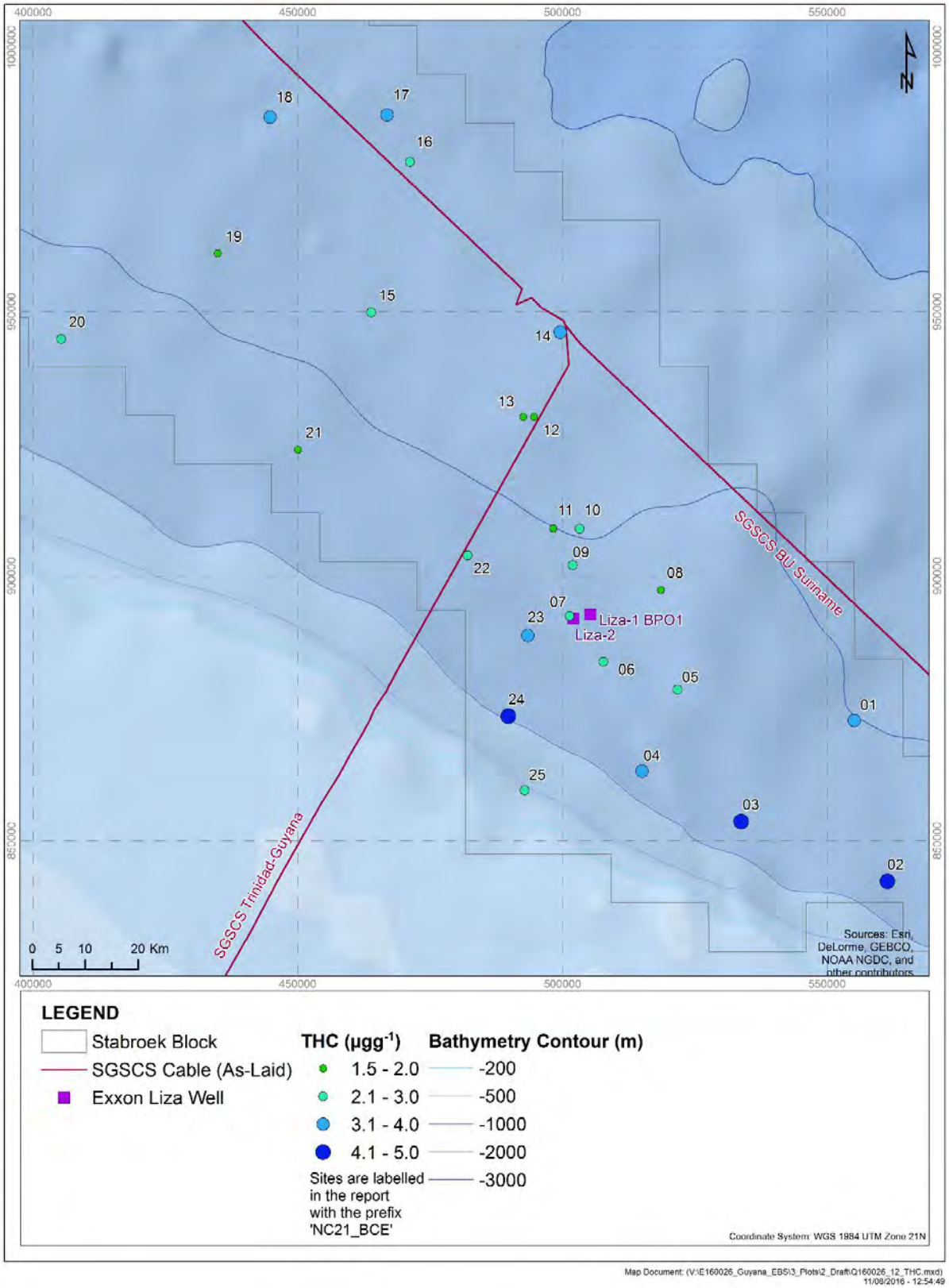


Figure 3.8: Spatial distribution of total hydrocarbon (THC) concentrations [ugg^{-1}]

Table 3.6:Polycyclic Aromatic Hydrocarbons (PAH) Concentrations [ngg^{-1}]

Analyte	Station												
	NC21_ BCE001	NC21_ BCE002	NC21_ BCE003	NC21_ BCE004	NC21_ BCE005	NC21_ BCE006	NC21_ BCE007	NC21_ BCE008	NC21_ BCE009	NC21_ BCE010	NC21_ BCE011	NC21_ BCE012	NC21_ BCE013
Naphthalene	0.3	0.7	0.7	0.6	0.3	1.7	0.3	0.3	0.3	0.3	0.2	0.3	0.4
Acenaphthylene	0.1	0.1	0.1	0.1	0.1	0.9	0.1	0.1	0.1	0.1	0.1	< 0.1	0.1
Acenaphthene	0.1	0.2	0.2	0.1	0.1	4.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Fluorene	0.2	0.3	0.3	0.3	0.1	7.8	0.2	0.1	0.2	0.1	0.1	0.1	0.2
Phenanthrene	1.0	1.4	1.4	1.3	0.8	35.8	0.7	0.5	1.0	0.5	0.5	0.5	0.5
Anthracene	0.1	0.1	0.2	0.1	0.1	9.3	0.1	0.1	0.2	0.1	< 0.1	< 0.1	0.1
Fluoranthene	0.8	1.0	1.0	1.0	0.6	31.9	0.5	0.4	1.0	0.4	0.4	0.4	0.4
Pyrene	0.4	0.7	0.7	0.6	0.3	20.1	0.3	0.2	0.6	0.2	0.2	0.3	0.2
Benz(a)anthracene	0.2	0.3	0.3	0.3	0.1	10.9	0.1	0.1	0.3	0.1	0.1	0.1	0.1
Chrysene	0.8	1.0	0.9	0.9	0.5	8.8	0.4	0.3	0.7	0.4	0.3	0.3	0.3
Benzo(b)fluoranthene	1.1	1.2	1.3	1.0	0.7	6.3	0.5	0.4	0.7	0.4	0.4	0.4	0.4
Benzo(k)fluoranthene	0.2	0.2	0.2	0.1	0.1	3.5	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Benzo(a)pyrene	0.1	0.2	0.2	0.2	0.1	7.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Indeno(1.2.3.cd)pyrene	0.3	0.3	0.3	0.2	0.2	3.7	0.1	0.1	0.3	0.2	0.1	0.1	0.1
Dibenz(a.h)anthracene	0.1	0.1	0.1	0.1	0.1	1.2	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1
Benzo(g.h.i)perylene	0.5	0.6	0.6	0.5	0.3	3.8	0.2	0.2	0.3	0.2	0.2	0.2	0.2
Total EPA 16	**6.3**	**8.4**	**8.5**	**7.4**	**4.5**	**157**	**3.8**	**3.1**	**6.3**	**3.3**	**2.9**	**3.0**	**3.3**

Table 3.6: Polycyclic Aromatic Hydrocarbons (PAH) Concentrations [ngg^{-1}] Continued

Analyte	EBS Station											
	NC21_ BCE014	NC21_ BCE015	NC21_ BCE016	NC21_ BCE017	NC21_ BCE018	NC21_ BCE019	NC21_ BCE020	NC21_ BCE021	NC21_ BCE022	NC21_ BCE023	NC21_ BCE024	NC21_ BCE025
Naphthalene	0.4	0.3	0.3	0.5	0.4	0.2	0.3	0.2	0.3	0.4	0.4	0.2
Acenaphthylene	0.1	0.1	< 0.1	0.1	0.1	< 0.1	< 0.1	< 0.1	0.1	0.1	0.1	< 0.1
Acenaphthene	0.1	0.1	0.1	0.1	0.1	< 0.1	0.1	< 0.1	0.1	0.1	0.1	< 0.1
Fluorene	0.2	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.2	0.2	0.1
Phenanthrene	1.0	0.7	0.6	1.0	1.0	0.3	0.7	0.5	0.9	1.1	1.2	0.3
Anthracene	0.1	0.1	< 0.1	0.1	0.1	< 0.1	< 0.1	< 0.1	0.1	0.1	0.1	< 0.1
Fluoranthene	0.7	0.7	0.4	0.9	0.9	0.3	0.5	0.4	0.9	0.8	1.0	0.2
Pyrene	0.4	0.4	0.2	0.5	0.5	0.2	0.3	0.2	0.5	0.4	0.7	0.2
Benz(a)anthracene	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.4	0.1
Chrysene	0.8	0.7	0.4	0.7	0.8	0.3	0.4	0.3	0.6	0.7	0.9	0.2
Benzo(b)fluoranthene	1.1	1.0	0.6	1.2	1.1	0.5	0.7	0.5	0.8	0.9	1.4	0.3
Benzo(k)fluoranthene	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.1
Benzo(a)pyrene	0.1	0.1	0.1	0.1	0.2	0.1	0.1	< 0.1	0.2	0.1	0.2	0.1
Indeno(1.2.3.cd)pyrene	0.3	0.3	0.1	0.3	0.3	0.2	0.2	0.1	0.3	0.2	0.4	0.1
Dibenz(a.h)anthracene	0.1	0.1	< 0.1	0.1	0.1	< 0.1	0.1	< 0.1	0.1	0.1	0.1	< 0.1
Benzo(g.h.i)perylene	0.5	0.4	0.2	0.5	0.4	0.2	0.3	0.1	0.4	0.3	0.7	0.2
Total EPA 16	**6.3**	**5.5**	**3.3**	**6.7**	**6.6**	**2.6**	**4.1**	**2.6**	**5.8**	**5.9**	**8.1**	**2.1**

3.5.1 Carbon Preference Index (CPI)

The Carbon Preference Index (CPI) is a measure of homologous odd over even n-alkanes in a specified range of carbon number and is routinely used as a source indicator in marine sediments.

Values of the CPI for short chain n-alkanes (C_{12-20}) ranged from 1.10 at station NC21_BCE018 to 2.41 at station NC21_BCE009, with the mean value of 1.29.

Values of the CPI for long chain n-alkanes (C_{21-36}) ranged from 2.09 at station NC21_BCE022 to 2.99 at station NC21_BCE007, with the mean value of 2.62.

The CPI for the entire range of n-alkanes (nC_{12-36}) ranged from 1.83 at station NC21_BCE023 to 2.70 at station NC21_BCE009.

3.5.2 Pristane and Phytane

The minimum concentration for pristane of 0.001 μgg^{-1} occurred at seven stations; NC21_BCE008, NC21_BCE009, NC21_BCE013, NC21_BCE016, NC21_BCE018, NC21_BCE021 and NC21_BCE025. The maximum concentration of 0.004 μgg^{-1} was recorded at stations NC21_BCE002 and NC21_BCE024. The average value across the survey area was 0.002 μgg^{-1}. The minimum concentration for phytane of 0.001 μgg^{-1} was recorded at the many of the stations (11 of 25), while the maximum value of 0.012 μgg^{-1} was recorded at station NC21_BCE012.

Pristine/phytane ratios ranged from 0.013 at station NC21_BCE021 to 2.27 at station NC21_BCE007.

3.5.3 Individual n-Alkanes

Concentrations of the individual n-alkanes are presented in Table 3.7.

The long chain n-alkane nC_{31} accounted for the highest mean concentration across the survey area (47.2 ngg^{-1}), followed by the long chain nC_{29} (36.01 ngg^{-1}) and the long chain nC_{33} (22.3 ngg^{-1}). Highest concentrations of n-alkane nC_{31} were recorded at stations NC21_BCE002, NC21_003 and NC21_BCE004. The same stations exhibited similarly elevated levels of nC_{29} and nC_{33}. The remaining long chain n-alkanes showed average concentrations of between 3.2 ngg^{-1} and 16.9 ngg^{-1}. Of the short chain n-alkanes, nC_{17} occurred in highest concentrations (mean 11.2 ngg^{-1}), with the highest concentrations occurring at stations NC21_BCE002 and NC21_BCE003 (22.6 ngg^{-1} and 20.8 ngg^{-1} respectively). The remaining short chain n-alkanes showed average concentrations of between 2.4 ngg^{-1} and 8.0 ngg^{-1}.

All n-alkanes showed a significant correlation with environmental parameters, positively correlating with mud and TOC and negatively correlating with sand (rho = 0.54272 to 0.8977, $p<0.01$ and rho = -0.51615 to -0.89777, $p<0.01$, respectively) (Appendix H).

Table 3.7: Individual Aliphatic Concentrations [ngg^{-1} dry weight]

n-Alkane	Station													
	NC21_BCE001	NC21_BCE002	NC21_BCE003	NC21_BCE004	NC21_BCE005	NC21_BCE006	NC21_BCE007	NC21_BCE008	NC21_BCE009	NC21_BCE010	NC21_BCE011	NC21_BCE012	NC21_BCE013	NC21_BCE014
nC_{12}	4.0	5.8	9.1	3.9	2.1	2.9	2.2	1.3	1.9	2.0	1.4	1.8	1.8	2.3
nC_{13}	6.9	12.0	14.6	9.6	3.2	5.4	5.6	3.6	4.8	4.0	3.4	4.4	4.8	4.0
nC_{14}	6.8	9.0	9.5	7.7	4.2	3.8	3.7	2.5	3.0	2.6	2.2	2.8	2.9	4.8
nC_{15}	9.8	17.3	14.8	14.8	6.7	8.4	6.4	3.6	5.3	4.0	4.0	4.7	4.0	9.8
nC_{16}	5.2	11.8	9.7	9.2	4.4	3.7	5.0	2.9	4.6	3.6	3.1	3.3	2.8	5.7
nC_{17}	12.1	22.6	20.8	19.0	7.9	8.2	9.1	5.1	31.2	5.8	6.4	6.2	5.5	12.9
nC_{18}	7.8	16.0	13.7	12.8	5.4	9.3	6.3	3.5	5.9	4.7	4.1	4.3	4.2	8.7
nC_{19}	10.5	18.8	16.0	14.7	8.2	12.3	6.6	4.0	7.7	5.7	5.1	4.4	4.5	10.7
nC_{20}	8.1	14.4	12.8	11.7	5.4	5.2	5.6	3.4	5.0	4.1	3.8	4.2	3.8	9.6
nC_{21}	8.2	13.1	14.0	11.9	5.4	11.3	5.0	2.1	5.2	3.9	3.1	3.9	3.1	10.4
nC_{22}	7.2	12.5	12.0	10.1	5.0	4.7	5.0	2.7	4.7	3.6	3.8	4.0	3.4	8.5
nC_{23}	9.7	16.9	15.0	14.2	6.9	6.5	6.7	4.0	5.9	5.3	4.5	4.7	4.3	13.1
nC_{24}	7.8	13.0	11.8	11.0	5.0	5.2	5.4	3.3	5.7	4.5	5.2	3.8	3.4	9.6
nC_{25}	11.4	18.5	17.0	15.8	7.5	7.0	8.1	4.9	7.4	6.6	5.3	6.1	5.3	14.4
nC_{26}	9.7	16.4	14.1	11.9	6.0	6.2	6.1	4.1	6.0	5.5	4.1	5.0	4.2	12.7
nC_{27}	21.4	29.7	29.5	25.5	12.6	12.7	14.9	9.5	13.9	12.6	9.7	11.0	10.2	28.9
nC_{28}	10.2	19.4	18.9	16.5	7.0	7.0	8.0	4.9	7.3	7.0	4.9	5.9	5.0	14.0
nC_{29}	44.6	57.7	61.0	61.6	28.2	27.1	32.7	18.9	29.3	27.0	20.2	22.2	20.5	60.6
nC_{30}	12.1	13.1	16.9	12.2	6.9	8.0	7.4	4.3	7.4	9.5	4.5	5.4	5.0	17.4
nC_{31}	55.0	79.9	83.7	78.7	34.2	36.0	44.1	26.4	40.8	40.9	28.5	31.9	28.9	78.8
nC_{32}	9.4	16.9	18.5	17.1	6.9	8.1	7.7	5.3	7.7	12.2	5.3	5.6	5.8	10.3
nC_{33}	23.9	40.0	40.6	38.6	15.4	16.9	19.7	12.7	18.9	23.2	13.9	14.0	13.4	35.3
nC_{34}	14.6	5.1	7.3	4.1	10.6	3.0	2.8	1.4	2.8	6.6	1.6	1.9	1.9	13.6
nC_{35}	7.6	9.4	10.7	8.5	3.9	3.8	4.0	2.8	3.7	7.7	3.5	3.6	2.7	9.7
nC_{36}	4.0	3.4	6.2	4.1	2.8	1.4	3.0	1.6	2.6	3.9	2.4	2.6	3.1	4.8

Table 3.7: Individual Aliphatic Concentrations [ngg-1 dry weight] Continued

n-Alkane	Station											Mean
	NC21_BCE015	NC21_BCE016	NC21_BCE017	NC21_BCE018	NC21_BCE019	NC21_BCE020	NC21_BCE021	NC21_BCE022	NC21_BCE023	NC21_BCE024	NC21_BCE025	
nC_{12}	1.9	1.5	1.9	2.3	0.8	0.9	1.2	1.7	2.5	3.0	0.8	2.4
nC_{13}	3.5	3.0	4.4	4.7	1.8	2.5	2.9	3.8	4.5	5.8	1.7	5.0
nC_{14}	3.8	3.1	4.7	5.0	1.7	3.1	2.7	3.6	5.0	6.0	2.0	4.3
nC_{15}	6.4	6.6	11.3	10.2	3.4	5.2	5.0	6.2	9.4	16.5	5.7	8.0
nC_{16}	4.4	3.5	6.1	5.8	1.6	4.3	2.6	4.7	6.3	7.8	1.9	5.0
nC_{17}	9.5	6.8	12.4	13.0	3.6	9.4	6.9	8.7	12.3	19.2	5.2	11.2
nC_{18}	6.8	4.6	9.0	13.3	2.6	6.4	4.0	6.2	8.4	11.4	4.0	7.3
nC_{19}	8.1	5.6	10.3	9.9	2.9	12.6	4.8	7.5	10.5	14.5	4.9	8.8
nC_{20}	7.0	4.6	8.6	8.1	2.5	6.7	4.7	5.9	8.5	12.3	4.3	6.8
nC_{21}	6.6	5.0	8.8	8.8	2.6	5.9	4.1	5.6	7.5	11.7	1.6	6.8
nC_{22}	5.9	4.5	7.7	7.2	2.3	4.5	3.9	5.1	7.0	10.0	3.3	5.9
nC_{23}	8.3	5.9	10.8	10.3	2.9	6.4	5.5	6.9	8.9	13.4	6.3	8.1
nC_{24}	6.4	5.9	11.4	8.2	2.9	5.0	4.4	6.0	6.7	9.9	4.4	6.6
nC_{25}	9.9	7.1	13.0	12.2	4.0	7.7	6.0	9.1	9.1	15.4	11.0	9.6
nC_{26}	7.3	5.5	10.6	10.1	3.6	6.0	6.0	6.8	7.5	11.0	6.2	7.7
nC_{27}	18.7	13.6	24.5	23.3	7.0	14.4	10.2	15.4	15.0	22.5	14.6	16.9
nC_{28}	9.7	6.8	12.5	11.1	4.1	7.0	6.2	8.4	8.3	13.5	6.6	9.2
nC_{29}	38.1	27.2	50.3	47.7	15.2	26.5	22.9	31.8	30.7	58.5	39.8	36.0
nC_{30}	13.0	7.6	16.7	12.5	6.1	9.2	6.4	13.3	13.1	12.3	11.9	10.1
nC_{31}	51.8	36.0	66.0	62.1	20.2	34.9	29.8	40.3	37.2	66.1	46.9	47.2
nC_{32}	6.9	4.5	9.0	7.4	3.7	7.2	4.1	9.3	7.1	14.8	8.9	8.8
nC_{33}	24.3	15.9	31.5	24.8	11.1	16.0	12.9	20.2	17.6	36.3	19.3	22.3
nC_{34}	9.1	4.9	12.6	9.8	5.1	9.0	5.1	12.9	8.8	15.9	6.8	7.1
nC_{35}	7.8	4.5	10.5	6.2	4.1	4.1	4.1	5.2	5.6	12.2	5.0	6.0
nC_{36}	4.4	1.7	4.2	4.0	2.1	1.9	1.7	2.6	2.5	7.3	1.1	3.2

3.5.4 Gas Chromatography Traces

A visual comparison of the GC-FID profiles can provide information regarding the presence and type of hydrocarbons present in marine sediment samples. An example of a GC trace is provided in (Figure 3.9) with all GC traces provided in Appendix F.1. It is characterised by a small 'hump' of unresolved material occurring late in the chromatogram window and a low level of resolved n alkanes that are dominated by the heavier waxy compounds i.e. those from nC_{25}. Peaks A-D were derived from known standards included for the analysis.

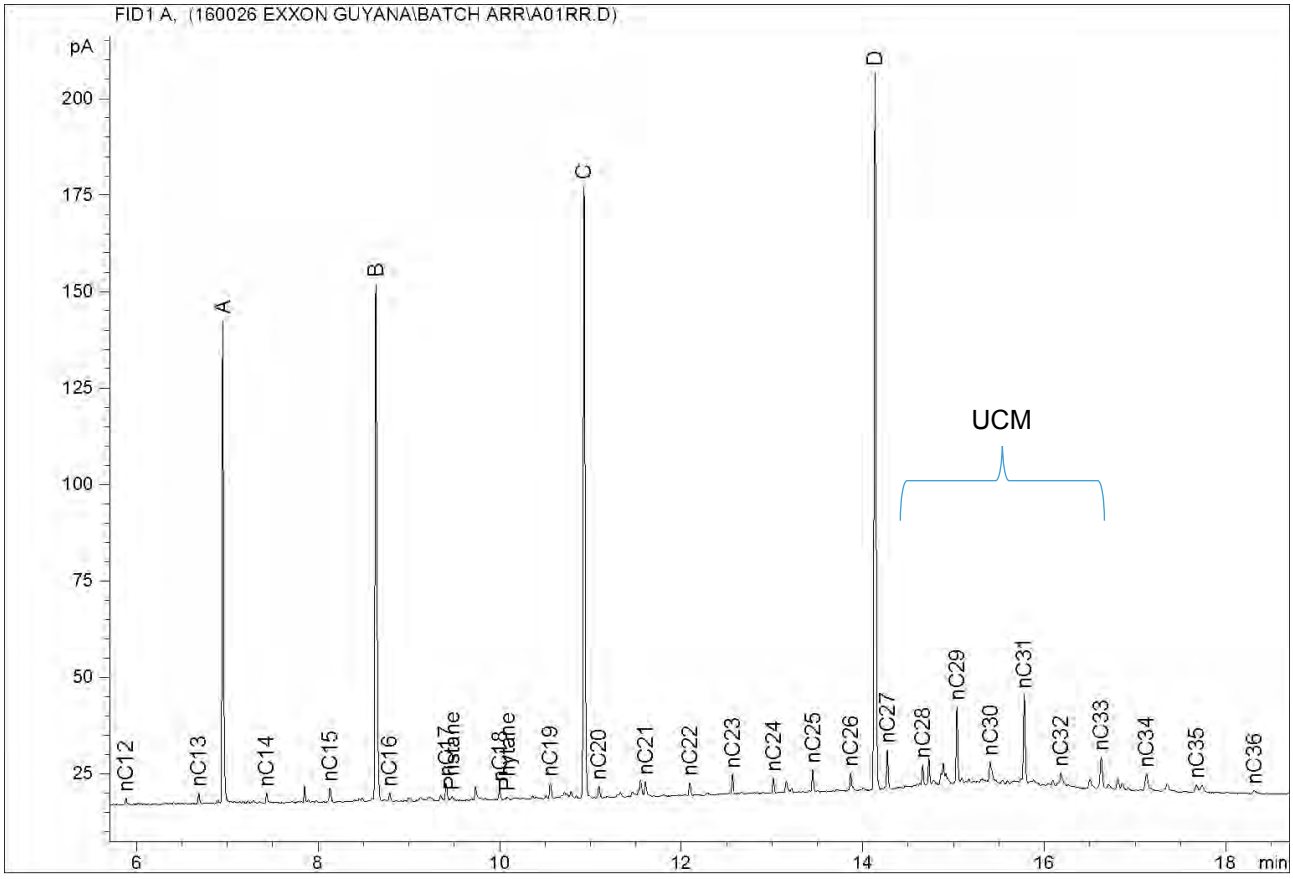


Figure 3.9: Example of gas chromatographic profile- station NC21_BCE025

3.5.5 Polycyclic Aromatic Hydrocarbons

3.5.5.1 Total PAH

Results of the polycyclic aromatic hydrocarbons (PAHs) are summarised in Table 3.8 and shown spatially in Figure 3.8. Total 2 to 6 ring PAH concentrations ranged from 16 ngg^{-1} at station NC21_BCE019 to 239 ngg^{-1} at station NC21_BCE006, with an average across the survey area of 48 ngg^{-1}. The 2 to 3 ring PAHs (total NPD) were all lower than the station 4 to 6 ring PAH concentrations, the former ranging from 6 ngg^{-1} at station NC 21_BCE019 to 82 ngg^{-1} at station NC21_BCE006. Concentrations of 4 to 6 ring PAHs showed a similar spatial distribution of concentrations, with the lowest (10 ngg^{-1}) and highest (157 ngg^{-1}) values recorded for stations NC 21_BCE019 and NC21_BCE006 respectively. The results of the current survey observed higher maximum levels of all PAH's than the previous survey, while the minimum levels observed were similar in each.

Table 3.8: Summary of PAH Results [ngg^{-1} dry weight]

Station	Total PAH (Sum of 2-6 Rings)	Sum of NPD	Sum of 4-6 Ring	NPD/4-6 Ring Ratio
NC21_BCE001	48	16	32	0.50
NC21_BCE002	88	27	61	0.44
NC21_BCE003	78	27	51	0.53

Station	Total PAH (Sum of 2-6 Rings)	Sum of NPD	Sum of 4-6 Ring	NPD/4-6 Ring Ratio
NC21_BCE004	76	25	51	0.49
NC21_BCE005	35	13	22	0.59
NC21_BCE006	239	82	157	0.52
NC21_BCE007	28	11	17	0.65
NC21_BCE008	20	7	13	0.54
NC21_BCE009	35	13	22	0.59
NC21_BCE010	27	10	17	0.59
NC21_BCE011	22	9	13	0.69
NC21_BCE012	25	9	16	0.56
NC21_BCE013	19	7	12	0.58
NC21_BCE014	48	15	33	0.45
NC21_BCE015	36	11	25	0.44
NC21_BCE016	23	9	14	0.64
NC21_BCE017	48	15	33	0.45
NC21_BCE018	45	14	31	0.45
NC21_BCE019	16	6	10	0.60
NC21_BCE020	31	14	17	0.82
NC21_BCE021	22	8	14	0.57
NC21_BCE022	36	13	23	0.57
NC21_BCE023	49	18	31	0.58
NC21_BCE024	77	21	56	0.38
NC21_BCE025	23	6	17	0.35
Current Survey from 25 stations				
Mean	**48**	**16**	**32**	**0.54**
SD	**45**	**15**	**30**	**0.10**
Min	**16**	**6**	**10**	**0.35**
Max	**239**	**82**	**157**	**0.82**
2014 Survey (Maxon Consulting and TDI Brooks, 2014) from 12 stations				
Mean	**35.44**	**14.56**	**61.05**	**0.24**
SD	**10.97**	**5.25**	**21.35**	**0.05**
Min	**16.49**	**7.47**	**25.50**	**0.14**
Max	**53.36**	**21.48**	**86.63**	**0.32**

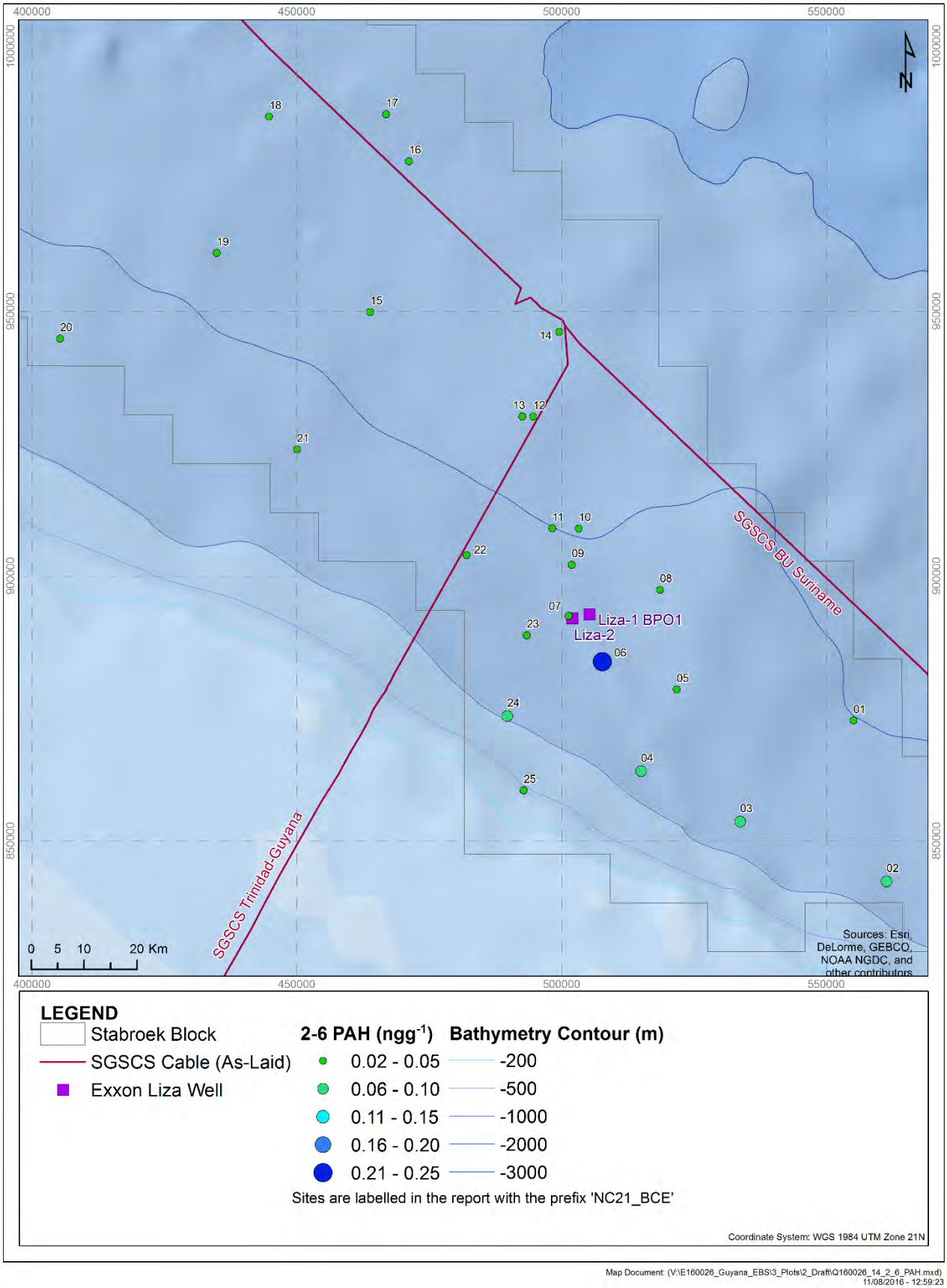


Figure 3.10: Spatial distribution of 2 to 6 ring PAH concentrations.

3.5.5.2 Parent/Alkyl Distribution

Information on the source(s) of PAH in sediment may be obtained from a study of their alkyl homologue distributions (i.e., the degree of methyl, ethyl, substitution of the parent compounds). The distribution of parent 2 to 6 ring PAH compounds also reflects whether the source is petrogenic or pyrolytic. The individual PAHs concentrations are presented in Table 3.9, with examples of parent alkyl distribution shown in Figure 3.11 and Figure 3.12 using a three-dimensional plot which shows the PAH concentrations in terms of parent compound and alkyl homologue distribution of the aromatic material in the sediments analysed. The predominantly pyrogenic nature of the aromatic material present in these sediments is further exemplified by these plots. The PAH parent/alkyl distribution at all stations is presented in Appendix F.2.

Samples showed a predominance of 4 to 6 rings PAHs (Figure 3.11 and Figure 3.12), with a general predominance of 4 to 6 rings PAH parent compound over its alkylated derivatives. The 2 to 3 rings (NPD) PAHs were present in lower concentrations than the 4 to 6 ring PAH's, total concentration of each 2 to 3 ring PAH were made up of a large contribution of alkylated derivatives relative to their parent compounds.

Of the NPD, the naphthalene parent compound was below the detection limit at 21 stations, with the remaining four stations showing values at the detection limit (Table 3.9). Its alkylated derivatives were as high as 5 ngg^{-1} at station NC 21_BCE006 and this station showed the highest total naphthalene concentration across the survey area. A similar distributional pattern was observed with respect to phenanthrene/anthracene with station NC21_BCE006 exhibiting the highest total concentration. The observed naphthalene parent compound was lower than its alkylated derivatives whereas with phenanthrene/anthracene parent compound constituted the highest concentration. Dibenzothiophene concentrations were below the detection limit at all sampling stations but station NC21_BCE006, where all alkyl derivatives were recorded just above at the detection limit (Table 3.9).

PAHs concentrations showed positive correlation with environmental variables, exhibiting a strong positive correlation with percentage mud (rho=0.83, p=0.01, and a lesser correlation with TOC (rho=0.53, p=0.05). A significant positive correlation was found between PAH concentrations and aluminium, barium, iron, lead, selenium and zinc (rho=0.53-0.64, p=0.01), with weaker positive correlations between arsenic, cadmium and chromium (rho=0.36-0.46, p=0.05).

Table 3.9: Individual PAH Concentrations [ngg^{-1} dry weight]

PAH	Station												
	NC21_BCE001	NC21_BCE002	NC21_BCE003	NC21_BCE004	NC21_BCE005	NC21_BCE006	NC21_BCE007	NC21_BCE008	NC21_BCE009	NC21_BCE010	NC21_BCE011	NC21_BCE012	NC21_BCE013
Naphthalene (128)	< 1	1	1	1	< 1	2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C1 128	1	2	2	2	1	4	1	1	1	1	1	1	1
C2 128	2	3	3	3	1	5	1	1	2	1	1	1	1
C3 128	2	3	4	3	2	3	2	1	2	1	1	1	1
C4 128	1	2	2	2	1	2	1	1	1	1	1	1	1
TOTAL 128	**6**	**11**	**12**	**11**	**5**	**16**	**5**	**4**	**6**	**4**	**4**	**4**	**4**
Phenanthrene/ Anthracene (178)	1	1	1	1	1	45	1	< 1	1	1	1	1	< 1
C1 178	2	3	3	3	2	10	1	1	2	1	1	1	1
C2 178	4	6	6	5	3	6	2	1	2	2	2	1	1
C3 178	3	5	4	4	2	3	2	1	2	2	1	2	1
TOTAL 178	10	15	14	13	8	64	6	3	7	6	5	5	3
Dibenzothiophene (DBT)	< 1	< 1	< 1	< 1	< 1	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C1 184	< 1	< 1	< 1	< 1	< 1	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C2 184	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C3 184	< 1	1	1	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TOTAL 184	**< 1**	**1**	**1**	**1**	**< 1**	**2**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**
Fluoranthene/Pyrene (202)	1	2	2	2	1	52	1	< 1	2	< 1	< 1	< 1	< 1
C1 202	1	1	1	1	1	9	< 1	< 1	1	< 1	< 1	< 1	< 1
C2 202	1	1	1	1	1	3	1	< 1	1	1	< 1	< 1	< 1
C3 202	1	2	2	2	1	2	1	1	1	1	< 1	1	< 1
TOTAL 202	**4**	**6**	**6**	**6**	**4**	**66**	**3**	**1**	**5**	**2**	**< 1**	**1**	**< 1**
Benzanthracenes/ Benzphenanthrenes (228)	2	3	2	2	1	24	1	1	2	1	1	1	1
C1 228	2	3	2	2	1	6	1	1	1	1	1	1	1
C2 228	2	4	3	3	2	3	1	1	2	2	2	2	1
TOTAL 228	**6**	**10**	**7**	**7**	**4**	**33**	**3**	**3**	**5**	**4**	**4**	**4**	**3**
m/z 252	15	34	29	29	11	37	8	6	9	7	6	7	6
C1 252	2	3	3	3	1	5	1	1	1	1	1	1	1
C2 252	2	3	2	2	1	2	1	1	1	1	1	1	1
TOTAL 252	**19**	**40**	**34**	**34**	**13**	**44**	**10**	**8**	**11**	**9**	**8**	**9**	**8**
m/z 276	2	3	2	2	1	11	1	1	1	1	1	1	1
C1 276	< 1	1	1	1	< 1	2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C2 276	1	1	1	1	< 1	1	< 1	< 1	< 1	1	< 1	1	< 1
TOTAL 276	**3**	**5**	**4**	**4**	**1**	**14**	**1**	**1**	**1**	**2**	**1**	**2**	**1**

Table 3.9: Individual PAH Concentrations [ngg-1 dry weight] Continued

n-Alkane	Station (continued)												Mean	SD
	NC21_BCE014	NC21_BCE015	NC21_BCE016	NC21_BCE017	NC21_BCE018	NC21_BCE019	NC21_BCE020	NC21_BCE021	NC21_BCE022	NC21_BCE023	NC21_BCE024	NC21_BCE025		
Naphthalene (128)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	1
C1 128	1	1	1	2	1	1	2	1	1	1	1	1	1	1
C2 128	2	1	1	2	2	1	1	1	1	2	2	1	2	1
C3 128	2	1	1	2	2	1	2	1	2	2	3	1	2	1
C4 128	1	1	1	1	1	< 1	1	1	1	2	2	< 1	1	1
TOTAL 128	**6**	**4**	**4**	**7**	**6**	**3**	**6**	**4**	**5**	**7**	**8**	**3**	**6**	**3**
Phenanthrene/ Anthracene (178)	1	1	1	1	1	< 1	1	1	1	1	1	< 1	3	10
C1 178	2	2	1	2	2	1	2	1	2	3	3	1	2	2
C2 178	3	2	2	3	3	1	3	1	3	4	5	1	3	2
C3 178	3	2	1	2	2	1	2	1	2	3	3	1	2	1
TOTAL 178	**9**	**7**	**5**	**8**	**8**	**3**	**8**	**4**	**8**	**11**	**12**	**3**	**10**	**12**
Dibenzothiophene (DBT)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	-
C1 184	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	-
C2 184	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	-	-
C3 184	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1	1	0
TOTAL 184	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**1**	**< 1**	**1**	**0**
Fluoranthene/Pyrene (202)	1	1	< 1	1	2	< 1	1	<1	2	1	2	< 1	5	13
C1 202	1	1	< 1	1	1	< 1	< 1	< 1	1	1	1	< 1	2	2
C2 202	1	< 1	< 1	1	1	< 1	< 1	< 1	< 1	1	1	< 1	1	1
C3 202	1	1	< 1	1	1	< 1	< 1	< 1	1	1	1	< 1	1	0
TOTAL 202	**4**	**3**	**< 1**	**4**	**5**	**< 1**	**1**	**< 1**	**4**	**4**	**5**	**< 1**	**7**	**14**
Benzanthracenes/ Benzphenanthrenes (228)	2	2	1	2	2	1	1	1	2	2	2	1	2	5
C1 228	2	1	1	2	2	< 1	1	1	1	2	3	1	2	1
C2 228	2	1	1	2	2	1	1	1	2	2	3	2	2	1
TOTAL 228	**6**	**4**	**3**	**6**	**6**	**2**	**3**	**3**	**5**	**6**	**8**	**4**	**6**	**6**
m/z 252	15	12	8	16	14	5	10	7	11	15	33	10	14	10
C1 252	2	2	1	2	2	1	1	1	1	2	3	1	2	1
C2 252	2	1	1	2	2	1	1	1	1	2	3	1	1	1
TOTAL 252	**19**	**15**	**10**	**20**	**18**	**7**	**12**	**9**	**13**	**19**	**39**	**12**	**18**	**11**
m/z 276	2	2	1	2	1	1	1	1	1	1	2	1	2	2
C1 276	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1	1	0
C2 276	1	1	< 1	1	1	< 1	< 1	1	< 1	1	1	< 1	1	0
TOTAL 276	**4**	**3**	**1**	**3**	**2**	**1**	**1**	**2**	**1**	**2**	**4**	**1**	**3**	**3**

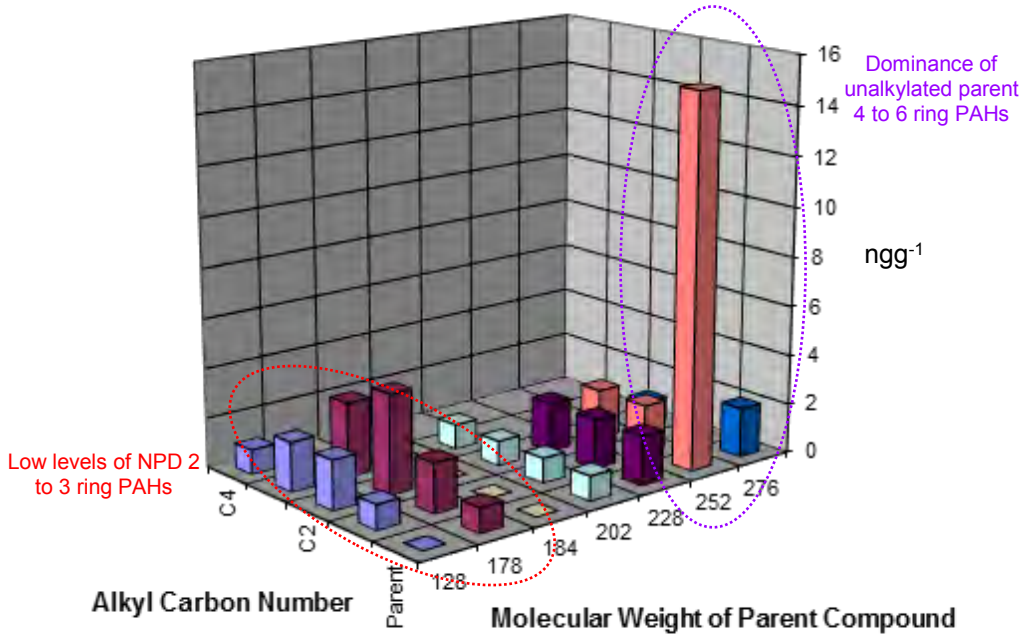


Figure 3.11: Example of parent/alkyl distribution - station NC21_BCE001

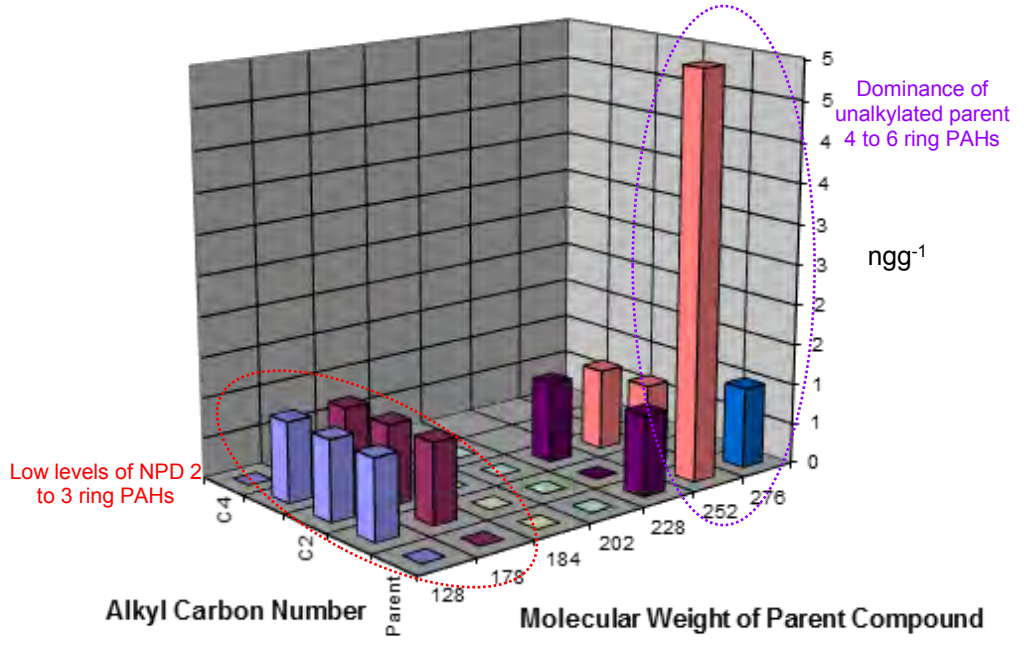


Figure 3.12: Example of parent/alkyl distribution - station NC21_BCE019

3.5.5.3 USEPA Specified PAHs

Results of the 16 PAHs recommended as priority pollutants, and referred to as the EPA 16, are summarised in Table 3.10, and assessed against the NOAA Effect Range Low (ERL) values and NOAA Effects Range Median (ERM), also reported in Table 3.10. The ERL represents the threshold below which there is a low probability of PAH presence impacting benthic fauna. The ERM is the threshold above which there is a higher probability of impacts to benthic fauna being observed. Concentrations for each of the 16 PAH were much lower than the equivalent NOAA ERL and NOAA ERM.

Table 3.10: USEPA Specified PAH Concentrations [ngg^{-1} dry weight]

PAH	Station										NOAA ERL	NOAA ERM
	NC21_BCE001	NC21_BCE002	NC21_BCE003	NC21_BCE004	NC21_BCE005	NC21_BCE006	NC21_BCE007	NC21_BCE008	NC21_BCE009	NC21_BCE010		
Naphthalene	0.3	0.7	0.7	0.6	0.3	1.7	0.3	0.3	0.3	0.3	160	2100
Acenaphthylene	0.1	0.1	0.1	0.1	0.1	0.9	0.1	0.1	0.1	0.1	44	640
Acenaphthene	0.1	0.2	0.2	0.1	0.1	4.3	0.1	0.1	0.1	0.1	16	500
Fluorene	0.2	0.3	0.3	0.3	0.1	7.8	0.2	0.1	0.2	0.1	19	540
Phenanthrene	1.0	1.4	1.4	1.3	0.8	35.8	0.7	0.5	1.0	0.5	240	1500
Anthracene	0.1	0.1	0.2	0.1	0.1	9.3	0.1	0.1	0.2	0.1	85	1100
Fluoranthene	0.8	1.0	1.0	1.0	0.6	31.9	0.5	0.4	1.0	0.4	600	5100
Pyrene	0.4	0.7	0.7	0.6	0.3	20.1	0.3	0.2	0.6	0.2	665	2600
Benzo(a)anthracene	0.2	0.3	0.3	0.3	0.1	10.9	0.1	0.1	0.3	0.1	261	1600
Chrysene	0.8	1.0	0.9	0.9	0.5	8.8	0.4	0.3	0.7	0.4	384	2800
Benzo(b)fluoranthene	1.1	1.2	1.3	1.0	0.7	6.3	0.5	0.4	0.7	0.4	-	-
Benzo(k)fluoranthene	0.2	0.2	0.2	0.1	0.1	3.5	0.1	0.1	0.2	0.1	-	-
Benzo(a)pyrene	0.1	0.2	0.2	0.2	0.1	7.1	0.1	0.1	0.2	0.1	430	1600
Indeno(123cd)pyrene	0.3	0.3	0.3	0.2	0.2	3.7	0.1	0.1	0.3	0.2	-	-
Benzo(ghi)perylene	0.5	0.6	0.6	0.5	0.3	3.8	0.2	0.2	0.3	0.2	-	-
Dibenzo(ah)anthracene	0.1	0.1	0.1	0.1	0.1	1.2	<0.1	<0.1	0.1	<0.1	63	260
Total EPA 16	**6.3**	**8.4**	**8.5**	**7.4**	**4.5**	**157**	**3.8**	**3.1**	**6.3**	**3.3**	-	-

Table 3.10: USEPA Specified PAH Concentrations [ngg-1 dry weight] Continued

PAH	Station										NOAA ERL	NOAA ERM
	NC21_BCE011	NC21_BCE012	NC21_BCE013	NC21_BCE014	NC21_BCE015	NC21_BCE016	NC21_BCE017	NC21_BCE018	NC21_BCE019	NC21_BCE020		
Naphthalene	0.2	0.3	0.4	0.4	0.3	0.3	0.5	0.4	0.2	0.3	160	2100
Acenaphthylene	0.1	< 0.1	0.1	0.1	0.1	< 0.1	0.1	0.1	< 0.1	< 0.1	44	640
Acenaphthene	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	< 0.1	0.1	16	500
Fluorene	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.2	19	540
Phenanthrene	0.5	0.5	0.5	1.0	0.7	0.6	1.0	1.0	0.3	0.7	240	1500
Anthracene	< 0.1	< 0.1	0.1	0.1	0.1	< 0.1	0.1	0.1	< 0.1	< 0.1	85	1100
Fluoranthene	0.4	0.4	0.4	0.7	0.7	0.4	0.9	0.9	0.3	0.5	600	5100
Pyrene	0.2	0.3	0.2	0.4	0.4	0.2	0.5	0.5	0.2	0.3	665	2600
Benzo(a)anthracene	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.1	261	1600
Chrysene	0.3	0.3	0.3	0.8	0.7	0.4	0.7	0.8	0.3	0.4	384	2800
Benzo(b)fluoranthene	0.4	0.4	0.4	1.1	1.0	0.6	1.2	1.1	0.5	0.7	-	-
Benzo(k)fluoranthene	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.1	-	-
Benzo(a)pyrene	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	430	1600
Indeno(123cd)pyrene	0.1	0.1	0.1	0.3	0.3	0.1	0.3	0.3	0.2	0.2	-	-
Benzo(ghi)perylene	0.2	0.2	0.2	0.5	0.4	0.2	0.5	0.4	0.2	0.3	-	-
Dibenzo(ah)anthracene	< 0.1	< 0.1	<0.1	0.1	0.1	< 0.1	0.1	0.1	< 0.1	0.1	63	260
Total EPA 16	**2.9**	**3**	**3.3**	**6.3**	**5.5**	**3.3**	**6.7**	**6.6**	**2.6**	**4.1**	**-**	-

Table 3.10: USEPA Specified PAH Concentrations [ngg-1 dry weight] Continued

PAH	Station					Mean	SD	NOAA ERL	NOAA ERM
	NC21_BCE021	NC21_BCE022	NC21_BCE023	NC21_BCE024	NC21_BCE025				
Naphthalene	0.2	0.3	0.4	0.4	0.2	0.4	0.3	160	2100
Acenaphthylene	< 0.1	0.1	0.1	0.1	< 0.1	-	-	44	640
Acenaphthene	< 0.1	0.1	0.1	0.1	< 0.1	-	-	16	500
Fluorene	0.1	0.1	0.2	0.2	0.1	0.5	1.5	19	540
Phenanthrene	0.5	0.9	1.1	1.2	0.3	2.2	7.0	240	1500
Anthracene	< 0.1	0.1	0.1	0.1	< 0.1	-	-	85	1100
Fluoranthene	0.4	0.9	0.8	1.0	0.2	1.9	6.3	600	5100
Pyrene	0.2	0.5	0.4	0.7	0.2	1.2	3.9	665	2600
Benzo(a)anthracene	0.1	0.2	0.2	0.4	0.1	0.6	2.1	261	1600
Chrysene	0.3	0.6	0.7	0.9	0.2	0.9	1.7	384	2800
Benzo(b)fluoranthene	0.5	0.8	0.9	1.4	0.3	1.0	1.2	-	-
Benzo(k)fluoranthene	0.1	0.2	0.2	0.2	0.1	0.3	0.7	-	-
Benzo(a)pyrene	< 0.1	0.2	0.1	0.2	0.1	0.4	1.4	430	1600
Indeno(123cd)pyrene	0.1	0.3	0.2	0.4	0.1	0.4	0.7	-	-
Benzo(ghi)perylene	0.1	0.4	0.3	0.7	0.2	0.5	0.7	-	-
Dibenzo(ah)anthracene	< 0.1	0.1	0.1	0.1	< 0.1	0.2	0.3	63	260
Total EPA 16	**2.6**	**5.8**	**5.9**	**8.1**	**2.1**	**11.1**	**30.5**	**-**	-

3.6 Sediment Heavy and Trace Metals

The current OSPAR Coordinated Environmental Monitoring Programme (CEMP) environmental focus around heavy metals is on cadmium, mercury and lead (OSPAR, 2014). Cadmium and lead both occur naturally the marine environment; however, they are toxic and liable to bio-accumulate so there is a concern for both the overall health of the environment and for human consumption of seafood. Mercury is an extremely rare element in the earth's crust but does occur naturally in young geologically active areas (volcanic regions). It is extremely toxic to humans and biota and can be transformed, once in the environment, into more toxic organometallic compounds (OSPAR, 2009).

3.6.1 Sediment Heavy Metals

The concentrations of hydrofluoric acid extractable metals measured in the surface sediments are listed in Table 3.11, along with background/regional data, where available, including NOAA ERL and ERM values.

Heavy metal concentrations were normalised to 5% aluminium and correlating to iron. Normalisation is a method used to decrease the variability in metal concentrations occurring from changes in the proportions of fine material (<63 µm) and allows comparison of metals levels across different regions. Normalised data for heavy metals to aluminium are displayed in Table 3.12 and correlations to iron are presented in Figure 3.13.

Cadmium (Cd) levels in the sediments ranged from 0.073 $\mu g g^{-1}$ at station NC21_BCE019 to 0.255 $\mu g g^{-1}$ at station NC21_BCE002 (mean 0.120 $\mu g g^{-1}$). Nickel (Ni) levels for the sample stations ranged from 10.8 $\mu g g^{-1}$ at station NC21_BCE019 to 51.5 $\mu g g^{-1}$ at station NC21_BCE003 (mean 27.0 $\mu g g^{-1}$). Mercury (Hg) levels ranged from 0.0161 $\mu g g^{-1}$ at station NC21_BCE025 to 0.0420 $\mu g g^{-1}$ at station NC21_BCE003 (mean 0.0285 $\mu g g^{-1}$).

Chromium (Cr) concentrations in the sediments ranged from 14.5 $\mu g g^{-1}$ at station NC21_BCE019 to 53.4 $\mu g g^{-1}$ at station NC21_BCE025 (mean 36.1 $\mu g g^{-1}$). Copper (Cu) levels ranged from 6.88 $\mu g g^{-1}$ at station NC21_BCE025 to 30.5 $\mu g g^{-1}$ at station NC21_BCE017 (mean 20.2 $\mu g g^{-1}$). Lead (Pb) levels ranged from 9.85 $\mu g g^{-1}$ at station NC21_BCE019 to 27.5 $\mu g g^{-1}$ at station NC21_BCE025 (mean 15.5 $\mu g g^{-1}$). Finally, zinc levels ranged from 32.5 $\mu g g^{-1}$ at station NC21_BCE019 to 101 $\mu g g^{-1}$ at station NC21_BCE024 (mean 69.7 $\mu g g^{-1}$).

Barium (Ba) levels ranged from 43.7$\mu g g^{-1}$ (station NC21_BCE019) to 272 $\mu g g^{-1}$ (station NC21_BCE003), mean 175 $\mu g g^{-1}$. The spatial distribution of barium levels is shown in Figure 3.14. Barium showed a very strong positive correlation with mud content (rho = 0.751, p=0.01) and strong correlations with hydrocarbon variables (THC, n-alkanes, UCM and total 2 to 6 ring PAHs), metals (aluminium, cadmium, chromium, copper, iron, nickel, lead, zinc and mercury) and selenium.

The spatial distribution of arsenic concentrations across the survey area is shown in Figure 3.15. Arsenic concentrations ranged from 6.09 $\mu g g^{-1}$ at station NC21_BCE012 to 97.10 $\mu g g^{-1}$ at station NC21_BCE025, the mean concentration was 11.59 $\mu g g^{-1}$.

The maximum reported values observed in the 2016 survey were consistently higher than those from the 2014 survey, likewise the mean and minimum values reported were generally higher in 2016 than 2014. It is important to note that all 2014 stations were in different locations within the survey area and a different extraction method had been used to process the sediment samples. As such care must be used when comparing the two datasets. The results obtained will be assessed further in relation to CEMP data in Section 4.

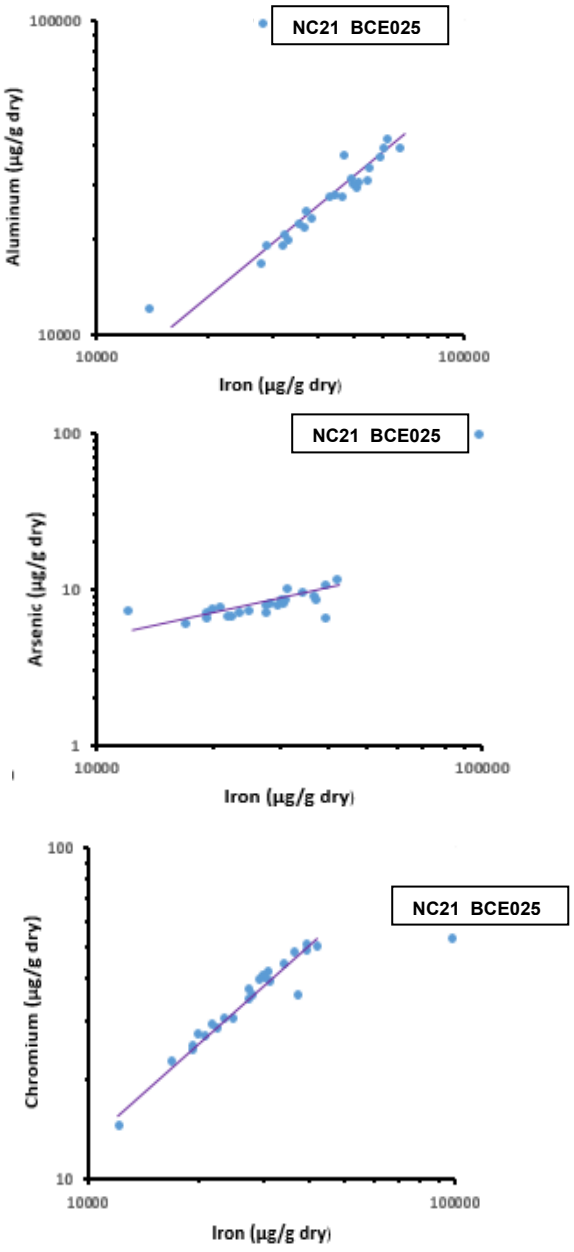


Figure 3.13: Results plotting the correlation of sedimentary metals to iron

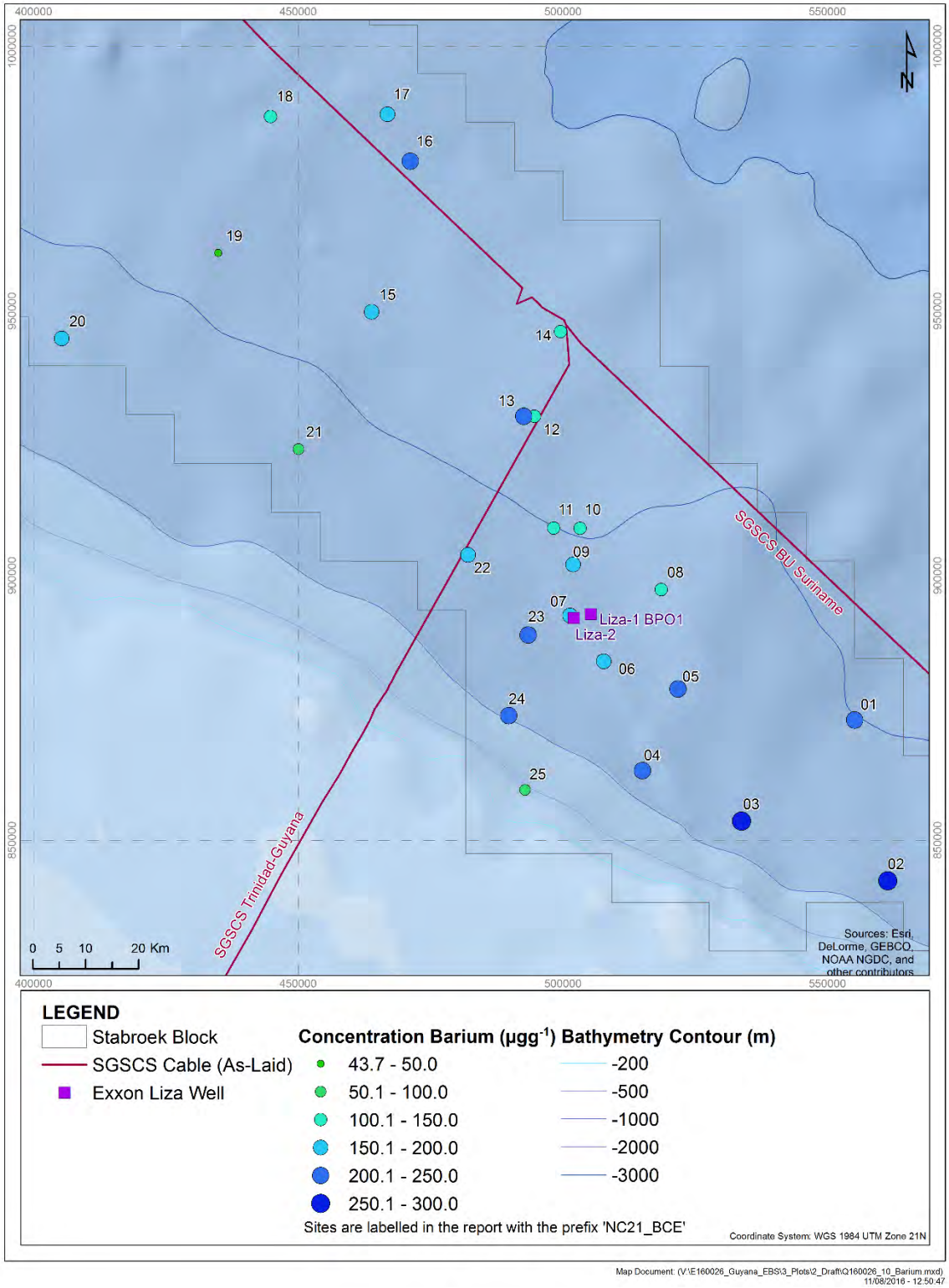


Figure 3.14: Spatial distribution of barium concentrations [ugg^{-1}]

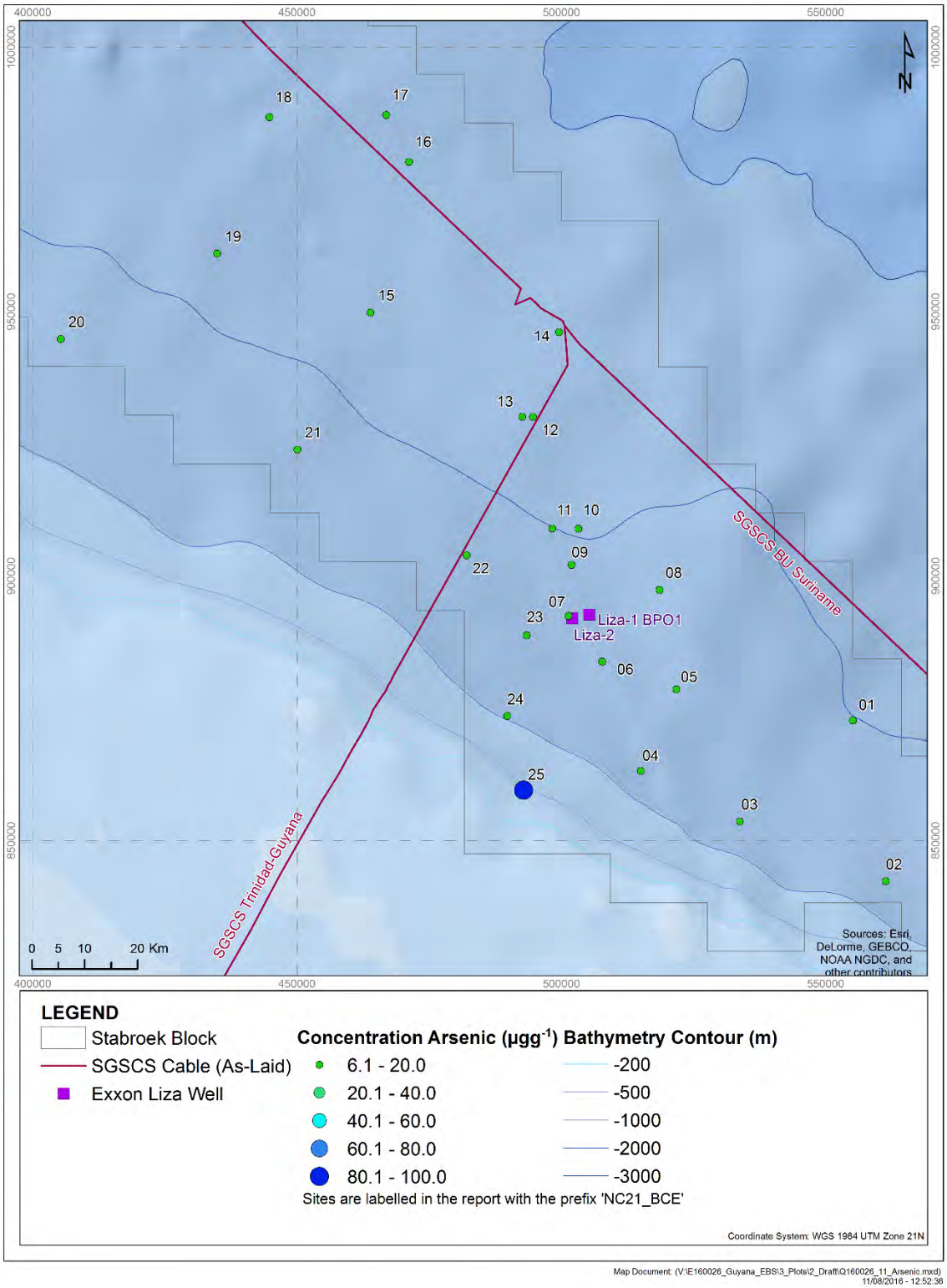


Figure 3.15: Spatial distribution of arsenic concentrations [ugg^{-1}]

Table 3.11: Heavy and Trace Metal Concentrations [µgg^{-1} dry weight]

Station	Al	As	Ba	Cd	Cr	Cu	Fe	Hg	Se	Pb	Ni	Zn
NC21_BCE001	54500	8.60	215	0.122	42.1	20.9	30800	0.0324	0.243	16.8	29.1	76.6
NC21_BCE002	66600	6.62	268	0.255	51.0	18.9	39200	0.0357	0.749	20.3	32.1	89.3
NC21_BCE003	62100	11.40	272	0.167	50.6	26.6	41900	0.0420	0.360	21.1	51.5	101.0
NC21_BCE004	59300	9.09	241	0.120	48.1	18.7	36600	0.0339	0.284	19.1	37.3	96.2
NC21_BCE005	55000	9.67	246	0.123	44.4	21.9	34100	0.0331	0.191	17.7	35.7	86.5
NC21_BCE006	44700	8.23	190	0.103	35.9	24	28000	0.0308	0.197	16.2	26.7	75.4
NC21_BCE007	42800	7.01	186	0.108	34.7	17	27400	0.0276	0.219	13.9	24.5	65.1
NC21_BCE008	32000	6.48	126	0.108	25.3	15.2	19200	0.0214	0.175	12.0	19.0	48.0
NC21_BCE009	38600	7.16	165	0.107	30.5	19.5	23400	0.0240	0.184	14.1	23.9	60.3
NC21_BCE010	32400	7.69	125	0.111	26.9	23.4	20900	0.0251	0.173	13.0	21.5	56.7
NC21_BCE011	36900	6.79	144	0.116	29.3	20.6	21800	0.0253	0.144	11.9	21.7	54.9
NC21_BCE012	27900	6.09	106	0.111	22.7	17	16900	0.0217	0.144	10.5	19.3	43.5
NC21_BCE013	51000	7.99	208	0.121	40.1	27.5	29300	0.0359	0.154	14.6	28.7	75.9
NC21_BCE014	33100	7.54	121	0.128	27.3	20.1	20000	0.0248	0.181	11.7	20.4	50.7
NC21_BCE015	46400	7.91	181	0.125	37.4	25.3	27400	0.0274	0.128	13.1	26.6	69.4
NC21_BCE016	51700	8.04	202	0.137	40.3	29.4	30400	0.0352	0.194	16.2	29.8	78.7
NC21_BCE017	50100	8.64	199	0.133	40.9	30.5	30000	0.0339	0.152	15.8	30.9	81.8
NC21_BCE018	35700	6.80	148	0.097	28.4	18	22400	0.0226	0.147	13.3	22.9	56.4
NC21_BCE019	13900	7.25	43.7	0.073	14.5	11.5	12100	0.0167	0.100	9.85	10.8	32.5
NC21_BCE020	47000	8.53	190	0.103	36.0	19	37200	0.0271	0.154	14.3	25.3	67.6
NC21_BCE021	29000	7.10	96.6	0.085	24.5	12.7	19200	0.0199	0.120	11.6	17.2	47.0
NC21_BCE022	37300	7.23	159	0.088	30.5	17	24800	0.0250	0.150	14.4	25.8	66.7
NC21_BCE023	49300	10.10	225	0.131	39.7	22.7	31300	0.0401	0.263	18.5	35.1	84.5
NC21_BCE024	60100	10.70	243	0.124	48.9	19.5	39400	0.0349	0.473	20.5	39.0	101.0
NC21_BCE025	28400	97.10	62.4	0.103	53.4	6.88	98100	0.0161	0.332	27.5	21.3	77.7
Min	**13900**	**6.09**	**44**	**0.073**	**14.5**	**6.9**	**12100**	**0.0161**	**0.120**	**9.9**	**10.8**	**32.5**
Mean	**43432**	**11.59**	**175**	**0.120**	**36.1**	**20.2**	**30472**	**0.0285**	**0.230**	**15.5**	**27.0**	**69.7**
Max	**66600**	**97.1**	**272**	**0.255**	**53.4**	**30.5**	**98100**	**0.0420**	**0.749**	**27.5**	**51.5**	**101**
SD	**12861**	**17.86**	**61**	**0.034**	**10.1**	**5.5**	**16051**	**0.0070**	**0.139**	**4.0**	**8.4**	**18.3**
2014 Survey (Maxon Consulting and TDI Brooks, 2014)												
Min	**7040**	**3.86**	**37.8**	**0.087**	**8.38**	**9.63**	**11300**	**0.022**	**13.8**	**-**	**8.33**	**26.9**
Mean	**10288**	**6.38**	**89.0**	**0.125**	**13.83**	**13.74**	**17217**	**0.039**	**20.0**	**-**	**11.09**	**41.8**
Max	**15000**	**14.10**	**159.0**	**0.165**	**21.10**	**19.60**	**25300**	**0.062**	**32.3**	**-**	**15.60**	**63.7**
SD	**2464**	**2.56**	**28.4**	**0.023**	**3.80**	**2.52**	**4092**	**0.011**	**4.3**	**-**	**1.89**	**10.9**
NOAA Effects Range Low - (Buchman, 2008)												
ERL	**-**	**8.2**	**-**	**1.2**	**81.0**	**34.0**	**-**	**0.15**	**-**	**46.7**	**20.9**	**150.0**
ERM	**-**	**70.0**		**9.6**	**370.0**	**270.0**	**-**	**0.71**	**-**	**218**	**51.6**	**410.0**

Notes:
ERL = effects range low
ERM = Effects range median
SD = Standard deviation

Table 3.12: Heavy and Trace Metal Concentrations Normalised to 5% Al [µgg^{-1} dry weight]

Station	Al	As	Ba	Cd	Cr	Cu	Fe	Hg	Se	Pb	Ni	Zn
NC21_BCE001	50000	7.89	197	0.112	38.6	19.2	32009	0.0297	0.223	15.4	26.7	70.3
NC21_BCE002	50000	4.97	201	0.191	38.3	14.2	29526	0.0268	0.562	15.2	24.1	67.0
NC21_BCE003	50000	9.18	219	0.134	40.7	21.4	30211	0.0338	0.290	17.0	41.5	81.3
NC21_BCE004	50000	7.66	203	0.101	40.6	15.8	30287	0.0286	0.239	16.1	31.5	81.1
NC21_BCE005	50000	8.79	224	0.112	40.4	19.9	28725	0.0301	0.174	16.1	32.5	78.6
NC21_BCE006	50000	9.21	213	0.115	40.2	26.8	32253	0.0345	0.220	18.1	29.9	84.3
NC21_BCE007	50000	8.19	217	0.126	40.5	19.9	29400	0.0322	0.256	16.2	28.6	76.1
NC21_BCE008	50000	10.13	197	0.169	39.5	23.8	29539	0.0334	0.273	18.8	29.7	75.0
NC21_BCE009	50000	9.27	214	0.139	39.5	25.3	29940	0.0311	0.238	18.3	31.0	78.1
NC21_BCE010	50000	11.87	193	0.171	41.5	36.1	30000	0.0387	0.267	20.1	33.2	87.5
NC21_BCE011	50000	9.20	195	0.157	39.7	27.9	28257	0.0343	0.195	16.1	29.4	74.4
NC21_BCE012	50000	10.91	190	0.199	40.7	30.5	29429	0.0389	0.258	18.8	34.6	78.0
NC21_BCE013	50000	7.83	204	0.119	39.3	27.0	32779	0.0352	0.151	14.3	28.1	74.4
NC21_BCE014	50000	11.39	183	0.193	41.2	30.4	30311	0.0375	0.273	17.7	30.8	76.6
NC21_BCE015	50000	8.52	195	0.135	40.3	27.3	33244	0.0295	0.138	14.1	28.7	74.8
NC21_BCE016	50000	7.78	195	0.132	39.0	28.4	33103	0.0340	0.188	15.7	28.8	76.1
NC21_BCE017	50000	8.62	199	0.133	40.8	30.4	172711	0.0338	0.152	15.8	30.8	81.6
NC21_BCE018	50000	9.52	207	0.136	39.8	25.2	30860	0.0317	0.206	18.6	32.1	79.0
NC21_BCE019	50000	26.08	157	0.263	52.2	41.4	39574	0.0601	0.360	35.4	38.8	116.9
NC21_BCE020	50000	9.07	202	0.110	38.3	20.2	33736	0.0288	0.164	15.2	26.9	71.9
NC21_BCE021	50000	12.24	166.6	0.147	42.2	21.9	31744	0.0343	0.207	20.0	29.7	81.0
NC21_BCE022	50000	9.69	213	0.118	40.9	22.8	31000	0.0335	0.201	19.3	34.6	89.4
NC21_BCE023	50000	10.24	228	0.133	40.3	23.0	43525	0.0407	0.267	18.8	35.6	85.7
NC21_BCE024	50000	8.90	202	0.103	40.7	16.2	31373	0.0290	0.394	17.1	32.4	84.0
NC21_BCE025	50000	170.95	109.9	0.181	94.0	12.1	31320	0.0283	0.585	48.4	37.5	136.8
Min	**50000**	**4.97**	**110**	**0.101**	**38.3**	**12.1**	**28257**	**0.027**	**0.138**	**14.1**	**24.1**	**67.0**
Mean	**50000**	**16.32**	**197**	**0.145**	**42.8**	**24.3**	**37394**	**0.034**	**0.255**	**19.1**	**31.5**	**82.4**
Max	**50000**	**170.95**	**228**	**0.263**	**94.0**	**41.4**	**172711**	**0.060**	**0.585**	**48.4**	**41.5**	**136.8**
SD	**0**	**32.43**	**24**	**0.038**	**11.0**	**6.7**	**28387**	**0.007**	**0.113**	**7.3**	**4.0**	**14.7**
2014 Survey (Maxon Consulting and TDI Brooks, 2014)												
Min	**7040**	**3.86**	**37.8**	**0.087**	**8.38**	**9.63**	**11300**	**0.022**	**13.8**	**-**	**8.33**	**26.9**
Mean	**10288**	**6.38**	**89.0**	**0.125**	**13.83**	**13.74**	**17217**	**0.039**	**20.0**	**-**	**11.09**	**41.8**
Max	**15000**	**14.10**	**159.0**	**0.165**	**21.10**	**19.60**	**25300**	**0.062**	**32.3**	**-**	**15.60**	**63.7**
SD	**2464**	**2.56**	**28.4**	**0.023**	**3.80**	**2.52**	**4092**	**0.011**	**4.3**	**-**	**1.89**	**10.9**
OSPAR (2007/2008 CEMP Assessment: Trends and concentrations of selected hazardous substances in sediments and trends in TBT-specific biological effects, 2008) – BC/BAC												
BC		**15**		**0.20**	**60.0**	**20.0**		**0.05**		**30**	**25**	**90.0**
BAC		**25**		**0.31**	**81.0**	**27.0**		**0.07**		**36**	**38**	**122.0**

Notes:
BC = Background concentrations
BAC = Background assessment concentrations

3.7 Seabed Habitats and Epifauna

The following summary describes the identified habitats, and biotopes where possible, within the survey area, focussing on potentially sensitive habitats and species, if present. The 'Biotopes/Ecosystems Nomenclature, Habitats of South America' (Institute of Terrestrial Ecology, 1996) has been used to broadly classify the observed seabed habitats. Due to a lack of more detailed habitat guidelines and background literature for South American marine habitats, the EUNIS habitat classification (European) has also been used. The European classification system remains in agreement for the overarching descriptors of habitats. However, it's species data is significantly different and so in depth classifications (i.e. biotope complexes) cannot be applied.

The results of the seabed photography sediment and faunal data review showed the survey area to be primarily comprised of one broad habitat, namely 'Western Atlantic abyssal benthic communities' (11.2122). This habitat encompasses benthic communities of abyssal plains and abyssal hills of Atlantic waters of South America north of about 42 °S, characteristic of the Western Atlantic province of the Atlantic abyssal region. The equivalent EUNIS habitat was 'Sublittoral sediment' (A5), encompassing sediments from boulders and cobbles, through pebbles and shingles, coarse sands, sands, fine sands, muds and mixed sediments (Davies et al., 2004). Each sediment type hosts characteristic biological communities, which together define biotopes.

The 'Biotopes/Ecosystems Nomenclature, Habitats of South America' habitat classification does not have more detailed biotope descriptions available than 'Western Atlantic abyssal benthic communities' habitat (11.2122). However, within the EUNIS habitat 'Sublittoral sediment', one biotope complex/biotope was identified, which was 'Circalittoral Sandy mud (A5.35) with aspects of 'Deep sea mud' (A6.5), and details of which are presented in following section. Example photographs of the biotope encountered in the survey area are shown in Plate 3.1.

3.7.1 Potentially Sensitive Habitats

No potentially sensitive habitats or species were observed throughout the Stabroek area, however, there are limited sensitive species or habitat guidelines available and as such these have been extrapolated from other guidelines (JNCC and OSPAR. It is important to note that while this has been informed by faunal and sediment data at all stations, supporting still images are only available for eleven stations (profile) and five sites (plan view).

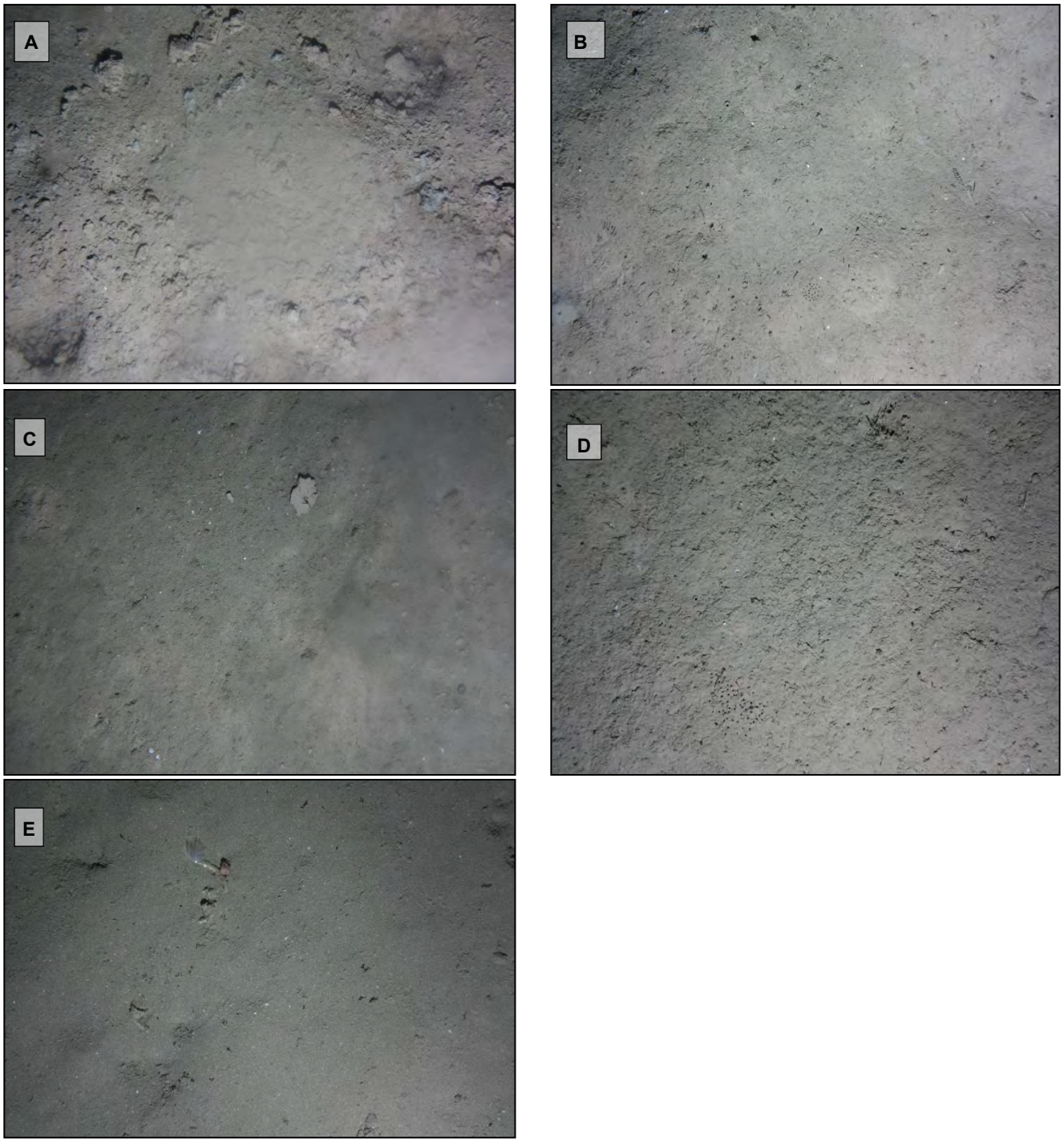


Photo A: Station NC21_BCE002; *Mud*, *tube building polychaetes and amphipods, mud shrimp burrows, Scaphopoda (tusk shells), gastropods, foraminiferans*
Photo B: Station NC21_BCE004; *Sandy Mud*, *tube building polychaetes and amphipods, mud shrimp burrows, foraminiferans. Unidentified hydroid*
Photo C: Station NC21_BCE005 *Sandy Mud*, *tube building polychaetes and amphipods,foraminiferans, Scaphopoda*
Photo D: Station NC21_BCE024 *Sandy Mud*, *tube building polychaetes and amphipods, foraminiferans*
Photo E: Station NC21_BCE025; *Muddy Sand*, *Sabellids and other tube building polychaetes, mud shrimp burrows,*

Plate 3.1: Example seabed photographs

3.8 Macrofauna

Two 0.1 m^2 macrofaunal grab samples (FA and FB) were acquired at each of the 25 stations. All A replicate samples were analysed (25 samples), with individuals of macrofaunal taxa (≥1 mm) identified, enumerated and expressed as abundance per station (0.1m^2).

Prior to statistical analysis been undertaken, the data were subjected to rationalisation, specifically a number of taxa of indeterminate identity, and therefore already possibly identified, were either removed from the data set (e.g. were damaged), or merged into higher taxa to avoid spurious enhancement of the species list. Meiofauna and protozoan species were also removed from the data set. Juveniles were assessed for their influence on the faunal species pattern prior to been removed from the species list (details in Section 2.7.5).

Following the rationalisation process, the benthic fauna across the survey area comprised a total of 165 macrofaunal taxa, represented by 506 individuals. These excluded: the juveniles (17 species and 42 individuals); meiofauna (four species and 118 individuals, represented mainly by Nematoda); and damaged organisms (nine taxa and 25 individuals).

Juveniles represented just over 8% of the total faunal abundance, with individual taxon's abundance ranging from 1 to 11 individuals across the survey area. Juvenile abundance was low compared to that of the overall faunal abundance and was therefore not further considered for analyses. The full macrofaunal dataset, and details of the rationalisation process, are provided in Appendix G.

3.8.1 General Description of Phyletic Composition

The phyletic composition of the infaunal communities is summarised in Table 3.13 and graphically represented in Figure 3.16.

Annelida were dominant in terms of species abundance and composition, accounting for 42.7% and 40.0% of the total species abundance and composition, respectively, across the survey area. The crustaceans accounted for the second highest species composition, 38.2%, followed by the molluscs (12.7%) and other taxa (9.1%), with the Echiura hosting the lowest number of species across the survey area, representing 0.6% of the total species composition. Crustacea also hosted the second highest abundance (39.1%), then the molluscs (8.7%), whereas the other taxa had similar abundances, represented 9.5% of the total abundance.

Amongst the annelids, members of the genus *Spiophanes* were the most abundant species, accounting for 32 individuals across the survey area, followed by members of the genus *Myriochele*, the family Ampharetidae and the genus *Monticellina* with abundances of 26, 16, and 11 individuals respectively. *Spiophanes* was the most frequently recorded Annelid taxon across the survey area, occurring in 44% of samples (Table 3.13 and Table 3.14). Of the other dominant polychaetes, *Myriochele* occurred in 36% of the samples, Ampharetidae and *Monticellina* in 24% of samples (Table 3.14).

Amongst the crustaceans, the amphipod family Ampeliscidae was dominant in terms of abundance, accounting for 15.2% (25 individuals) of the crustaceans' abundance and occurring in 48% of samples. Of the other crustaceans recorded, Tanaidacea of the genus *Glabroapseudes*, Isopods from the family

Desmosomatidae and the species *Leptanthura affinis* and amphipods from the genus Harpinia (designated as species A for identification purposes) were the next four most abundant crustacean species, with abundances of 11, 10, 10 and 10 individuals respectively. The isopods *Leptanthura affinis*, Desmosomatidae and *Macrostylis* sp. were the next most frequently occurring, each been recorded in 24% of stations.

Of the molluscs, the bivalves of the genus *Ennucula* and the species *Pristigloma alba* were the most abundant molluscan species, accounting for six and five individuals across the survey area, and occurring in 16% and 20% of the stations, respectively.

The holothurian of genus *Synaptidae* was by far the most abundant of the echinoderms, accounting for 3 individuals across 12% of stations. Echinoderms were generally only present in very low numbers at low frequency throughout the survey area.

Finally, amongst the other taxa, Nemertea were the most abundant and frequently occurring fauna. However, numbers in all groups were low.

Table 3.13: Abundance of Major Taxonomic Groups

Group	Number of Taxa	Taxa [%]	Abundance	Abundance [%]
Annelida	66	40.0	216	42.7
Crustacea	63	38.2	198	39.1
Molusca	21	12.7	44	8.7
Nemertea	7	4.2	31	6.1
Cnidaria	2	1.2	8	1.6
Echinodermata	5	3.0	8	1.6
Echiura	1	0.6	1	0.2
Total	**165**	**100**	**506**	**100**

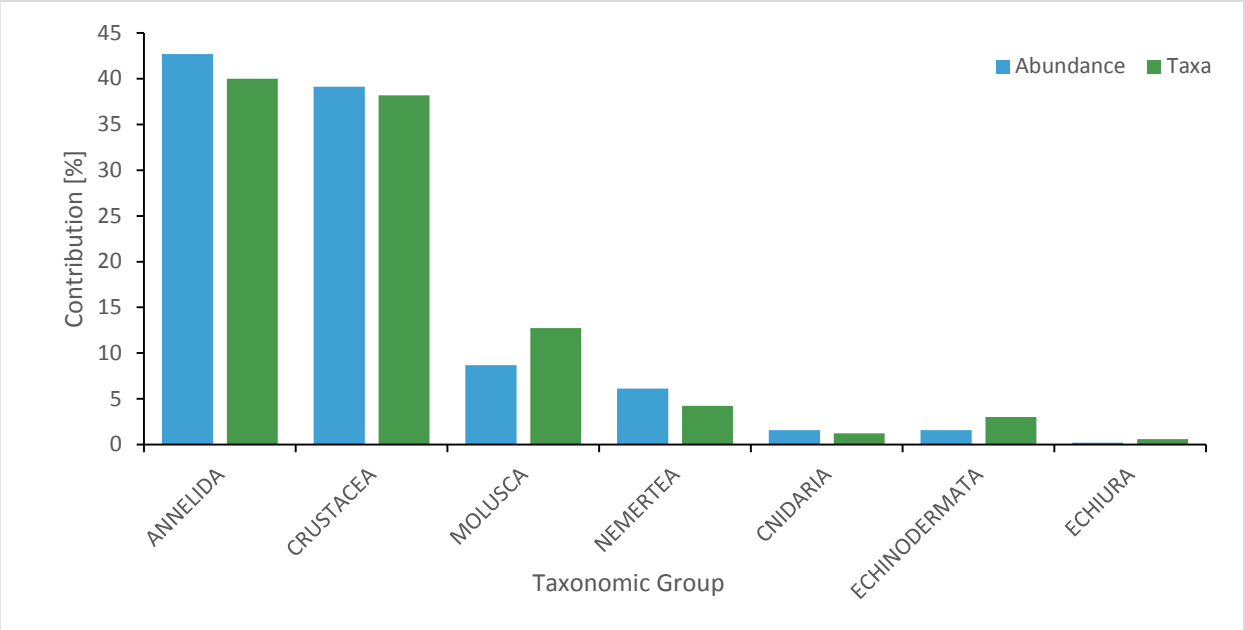


Figure 3.16: Abundance of major taxonomic groups

3.8.2 Ranked Abundance and Dominance

A list of the top ten most abundant taxa recorded within the survey area is presented (Table 3.14), together with their frequency of occurrence. Mean abundances are expressed per station (0.1 m^2). The rank dominance is a single measure which allows identification of the species which are dominant in terms of abundance and frequency of occurrence. It is derived by ranking the taxa recorded within the survey area in terms of abundance and frequency, which are then combined to give the overall rank dominance for each species.

Frequency of occurrence was relatively low for all taxa with no taxa appearing in more than 48% of samples. As a result, five of the most abundant taxa were also amongst the top ten ranked dominant taxa, with Spiophanes, Myriochele and Ampilescidae, ranked first second and third respectively for abundance and first, third and second respectively for ranked dominance. *Monticellina* sp., *Aspidosiphon zinni* and *Leptanthura affinis* were in the ten most abundant taxa but not amongst the top ten ranked dominant, as their frequency of occurrence were 24% (*Monticellina* spand *Leptanthura affinis*) and 12% (*Aspidosiphon zinni*), equating to a presence at six and three of 25 stations respectively.

Table 3.14: Dominant Taxa and Dominance Rank for Stations [0.1m^2]

Taxon	Rank Abundance	Mean Abundance	Frequency [%]	Rank Dominance
Spiophanes (dam.)	1	1.28	44	1
Myriochele	2	1.04	36	3
Ampeliscidae	3	1.00	48	2
Ampharetidae (dam.)	4	0.64	24	4
Glabroapseudes	5	0.44	12	9
Monticellina	5	0.44	24	11
Desmosomatidae	7	0.40	24	5
Harpinia sp. A	7	0.40	28	10
Leptanthura affinis	7	0.40	24	12
Aspidosiphon zinni	10	0.36	12	32

3.8.3 Species Accumulation and Richness Estimation

The species accumulation plot displayed in Figure 3.17 was generated using untransformed station data (0.1 m^2) in PRIMER. The observed numbers of taxa obtained through repeated sampling (Sobs) were cumulatively plotted, as were richness estimates from repeated sampling as calculated by the Chao1, Chao2, Jacknife1 and Jacknife2 formulae. All of the displayed curves were smoothed by random permutations of the data points.

The observed species accumulation curve appeared to be rising and yet to have reached its asymptote, suggesting that, though most of the taxa in the survey areas were likely sampled, more species/taxa would likely be recorded through further sampling. The richness estimators suggests that the survey area has been moderately described, with estimates for the total macrofaunal diversity of the area ranging from 258 taxa (Chao 2) to 289 taxa (Jacknife 2), compared to the 165 taxa recorded (Sobs). These estimates suggested that between 64.0% and 57.1% of the area's total faunal diversity had been detected by the sampling undertaken. As such, the data is deemed sufficient to characterise the macrofaunal communities within the survey area. Additional analysis of eDNA samples collected during this survey may help further improve biodiversity characterisation of macrofaunal communities.

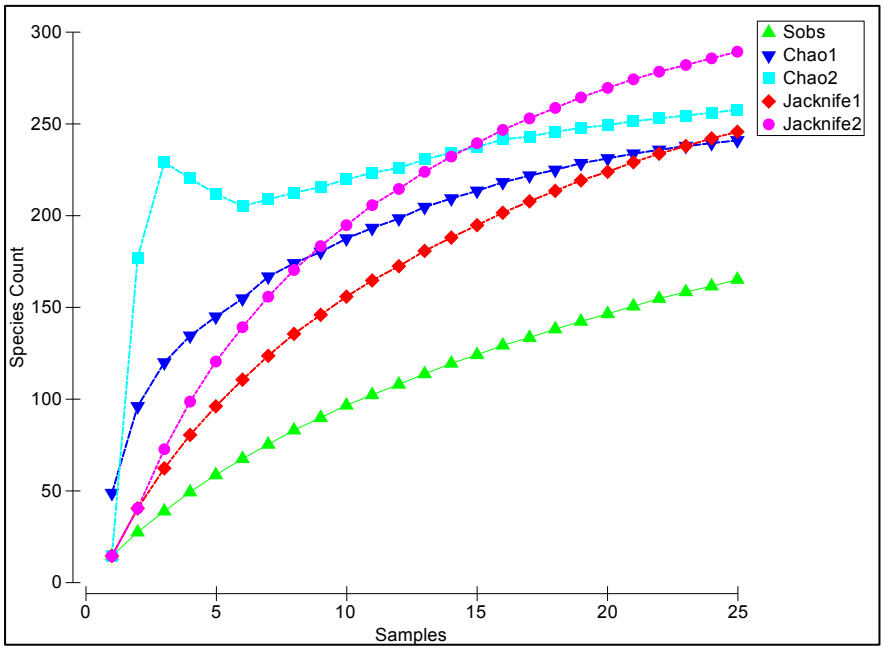


Figure 3.17: Species accumulation plot

3.8.4 Primary Variables and Diversity

The primary variables, numbers of taxa (S) and abundance (N), were calculated together with the univariate measures, including, equitability (Pielou's Index *J'*) and (Simpson's Index *1-λ*) and diversity (Shannon-Wiener's Index *H'*Log2) per station data (0.1 m^2). This analysis was performed using PRIMER v6 and the role of these indices within the analyses is provided in Appendix B.2. Primary variables and diversity indices station data are presented in Table 3.15.

The spatial distributions of the primary variables across the survey area are presented in Figure 3.18 and Figure 3.19.

Visual inspection of the data suggested that the distribution of number of taxa may be influenced by the mud content and/or the depth (Figure 3.18). There seemed to be a general decrease in species, and to a lesser degree abundance (Figure 3.19), from the south to the north of the survey area, such that, as depth and mud content increased, the number of species decreased. A weak negative correlation was observed between depth and number of taxa and abundance (rho = -0.41673 and -0.4176, $p<0.05$, respectively). However, no statistically significant correlation was observed between mud, sand, gravel and number of taxa and abundance.

Table 3.15: Primary Variables and Diversity Indices by Sample [0.1 m^2]

Station	Taxa [S]	Abundance [N]*	Margalef's Index [d]	Pielou's Index [j']	Shannon-Wiener Index [H']	Simpson's Index [1-λ]	No. of Juveniles
NC21_BCE001	27	35	7.31	0.97	3.21	0.98	22
NC21_BCE002	19	20	6.01	0.99	2.93	0.99	4
NC21_BCE003	14	20	4.34	0.97	2.55	0.96	0
NC21_BCE004	24	28	6.90	0.98	3.12	0.99	2
NC21_BCE005	12	14	4.17	0.98	2.44	0.98	0
NC21_BCE006	21	35	5.63	0.94	2.85	0.96	19
NC21_BCE007	25	37	6.65	0.91	2.93	0.94	14
NC21_BCE008	18	27	5.16	0.95	2.74	0.96	11
NC21_BCE009	3	7	1.03	0.72	0.80	0.52	2
NC21_BCE010	14	26	3.99	0.94	2.47	0.94	7
NC21_BCE011	15	31	4.08	0.90	2.42	0.92	9
NC21_BCE012	12	21	3.61	0.85	2.12	0.86	18
NC21_BCE013	8	9	3.19	0.98	2.04	0.97	3
NC21_BCE014	11	12	4.02	0.99	2.37	0.98	13
NC21_BCE015	15	16	5.05	0.99	2.69	0.99	6
NC21_BCE016	6	7	2.57	0.98	1.75	0.95	6
NC21_BCE017	8	9	3.19	0.98	2.04	0.97	5
NC21_BCE018	7	7	3.08	1.00	1.95	1.00	0
NC21_BCE019	10	12	3.62	0.98	2.25	0.97	0
NC21_BCE020	6	7	2.57	0.98	1.75	0.95	4
NC21_BCE021	14	20	4.34	0.95	2.51	0.95	10
NC21_BCE022	24	29	6.83	0.98	3.13	0.99	6
NC21_BCE023	12	17	3.88	0.95	2.36	0.95	2
NC21_BCE024	28	44	7.13	0.94	3.14	0.97	13
NC21_BCE025	9	16	2.89	0.90	1.98	0.88	11
Min	**3**	**7**	**1.03**	**0.72**	**0.80**	**0.52**	**0**
Mean	**14**	**20**	**4.74**	**0.95**	**2.42**	**0.94**	**7**
Max	**28**	**44**	**7.31**	**1.00**	**3.21**	**1.00**	**22**
SD	**7**	**11**	**1.65**	**0.06**	**0.56**	**0.09**	**6**

Note:
* = abundance of juveniles (not included in total abundance N).

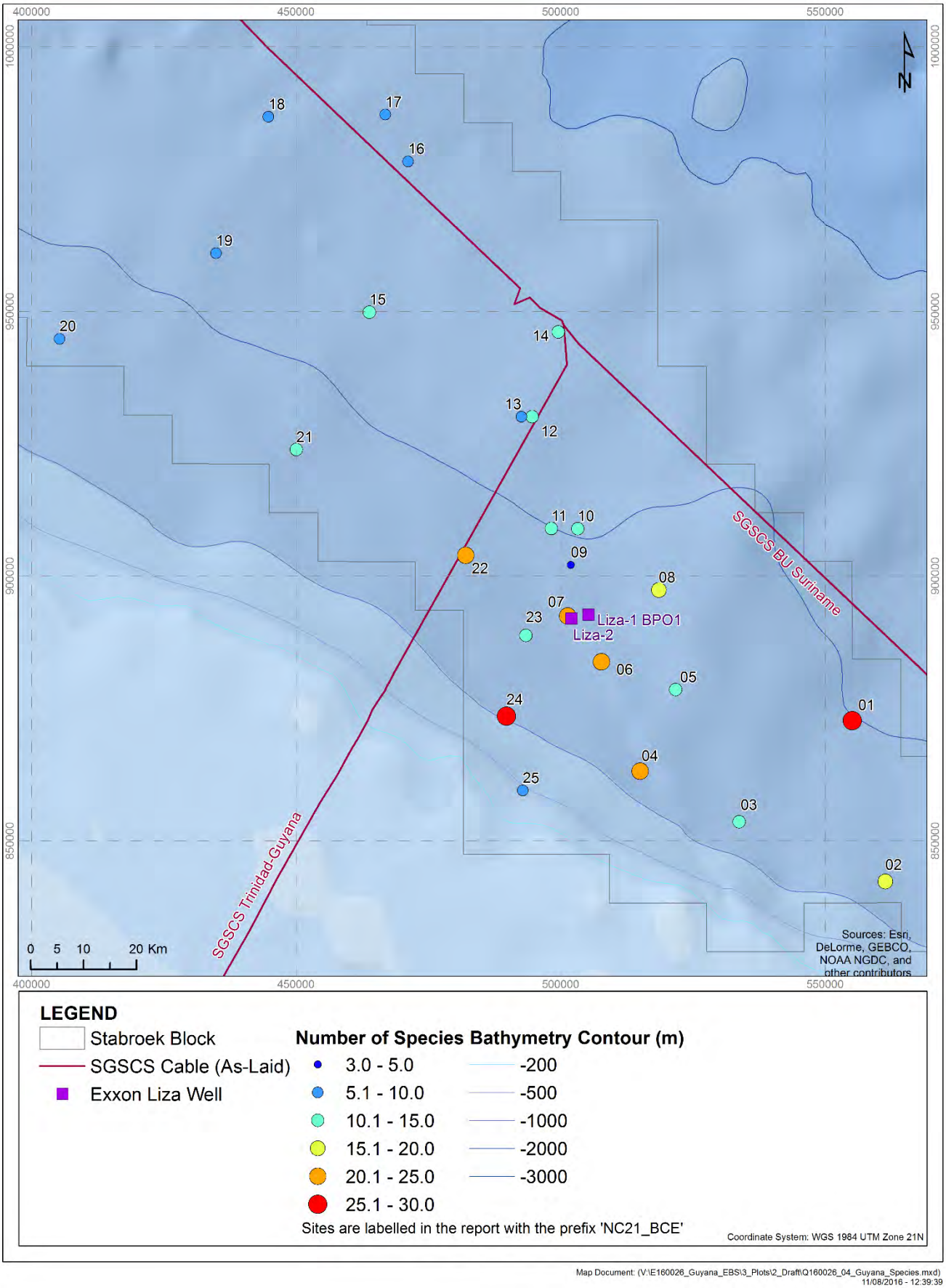


Figure 3.18: Spatial distribution of number of taxa (S) [0.1 m^2]

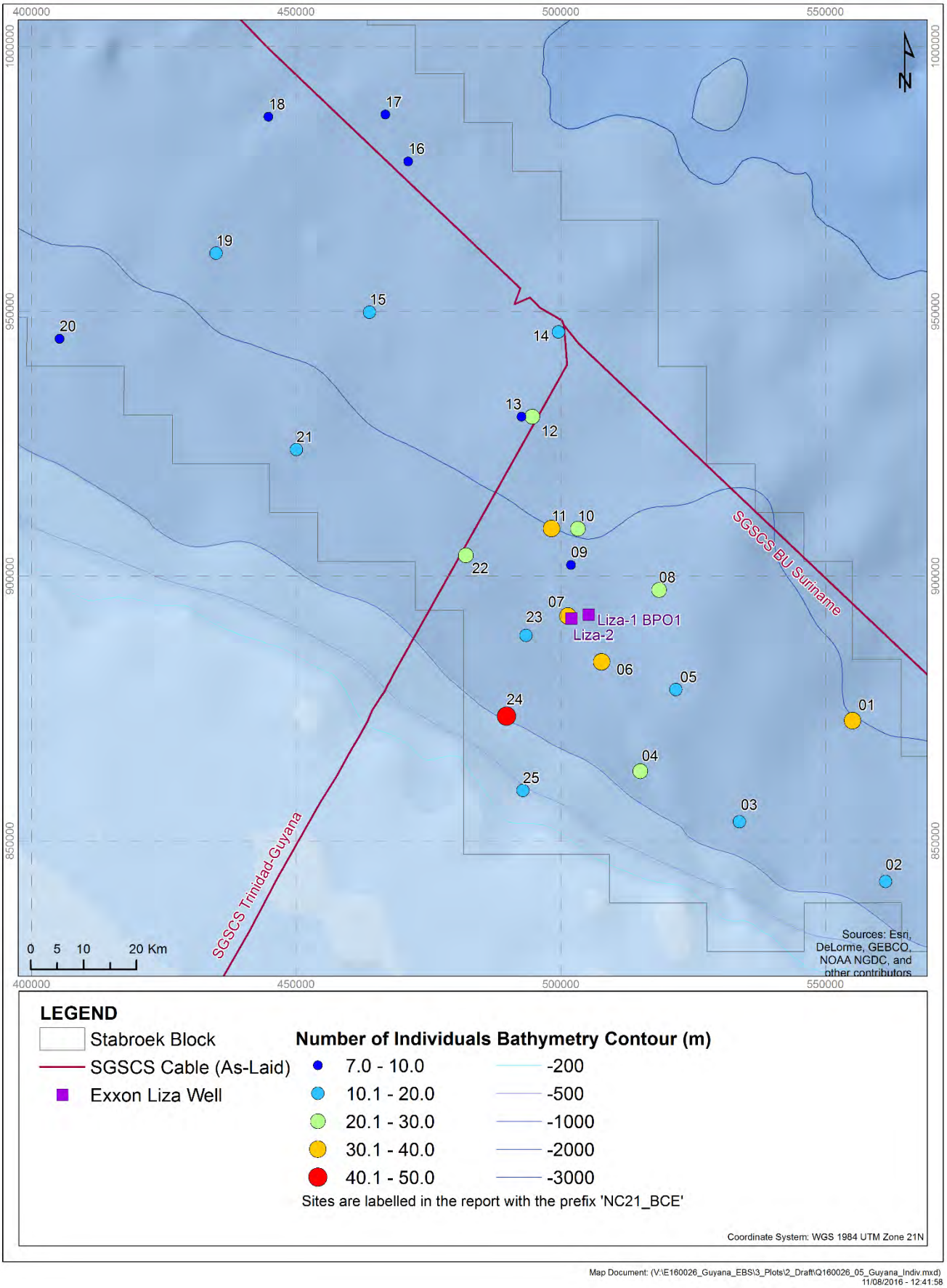


Figure 3.19: Spatial distribution of number of individuals (N) [0.1 m^2]

3.8.5 Multivariate Analysis

Prior to multivariate analysis the faunal data set was transformed. A 4th root transformation provided the best assessment of the faunal communities, allowing assessment of the underlying fauna, whilst placing the right weight to the intermediate and dominant taxa.

Distribution patterns of macrofauna within the survey area were assessed employing the hierarchical clustering analysis, the results of which are presented in Figure 3.20 and Figure 3.21. As shown, four groups of stations were identified and two unclassified stations, separating at a 12% similarity level. The characteristics of each group of stations were assessed by means of the SIMPER analysis, the results of which are summarised in Table 3.16. Mean abundances presented in Table 3.16 refer to untransformed data; species within each group are ranked in decreasing order of mean abundance.

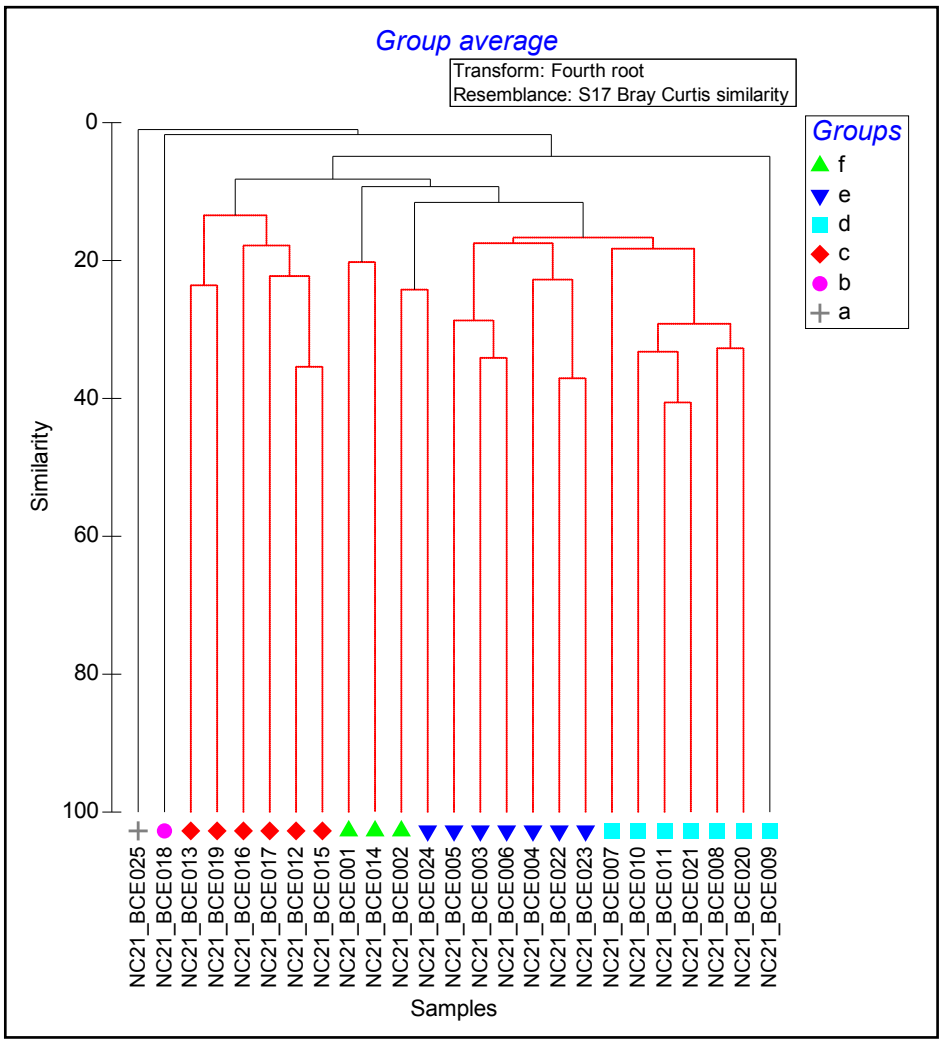


Figure 3.20: Dendrogram by Bray-Curtis similarity for fourth root transformed station data

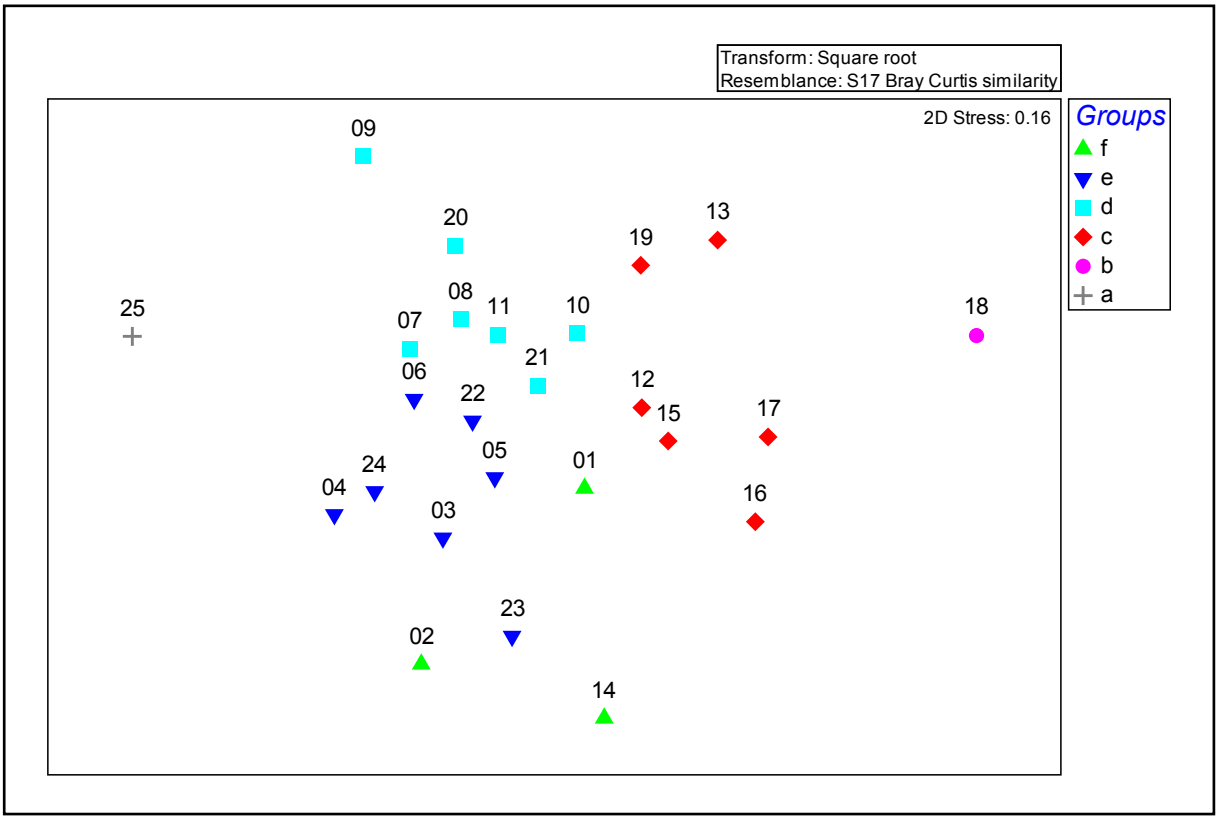


Figure 3.21: nMDS ordination by Bray Curtis similarity for fourth root transformed station data

Table 3.16: Summary of Within Group Similarity Following SIMPER Analysis

Group	Station	Sediment Features	Depth [m]
Group A Single replicate sample	NC21_BCE025	Slightly gravelly muddy sand	480
Group B Single replicate sample	NC21_BCE018	Sandy mud	2680
Group C Average similarity 17.62%	NC21_BCE012 NC21_BCE013 NC21_BCE015 NC21_BCE016 NC21_BCE017 NC21_BCE019	Muddy sand Muddy sand Muddy sand Muddy sand Muddy sand Muddy sand	2210 2200 2400 2760 2780 2240
Group D Average similarity: 22.45%	NC21_BCE001 NC21_BCE002 NC21_BCE014	Sandy mud Mud Sandy mud	1980 1250 2550
Group E Average similarity: 21.13%	NC21_BCE003 NC21_BCE004 NC21_BCE005 NC21_BCE006 NC21_BCE022 NC21_BCE023 NC21_BCE024	Mud Sandy mud Sandy mud Sandy mud Sandy mud Sandy mud Sandy mud	1280 1210 1550 1570 1640 1510 1060
Group F Average similarity 15.33%	NC21_BCE007 NC21_BCE008 NC21_BCE009 NC21_BCE010 NC21_BCE011 NC21_BCE020 NC21_BCE021	Sandy mud Sandy mud Sandy mud Sandy mud Sandy mud Sandy mud Sandy mud	1700 1800 1900 2040 2010 1500 1660

Group C comprised six stations. Characterising species included the polychaete worm genus *Notoproctus* sp., which was primarily responsible for the separation of this group of stations. The group hosted the lowest mean number of species and the lowest mean abundance of all groups (note this does not include unclassified stations). It was characterised by stations with a sediment type of muddy sand, and less frequently sandy mud. All sites were poorly sorted or very poorly sorted, with the mean percentage of sand (51.5%), and mean percentage mud of 48.5%.

Group D comprised of three stations. Characterising species included the polychaete worm *Myrochele* sp., which was primarily responsible for the separation of this group of stations. The group hosted the joint highest mean number of species and joint second highest number of individuals, with samples within the group exhibiting the highest degree of similarity. It was characterised by mud and sandy mud sediments, poorly sorted or very poorly sorted, with the highest percentage of mud at 92.1% and an average across stations of 82.0%.

Group E comprised samples from seven stations. The characterising faunal group was amphipods from the family Ampeliscidae. This group had the joint highest faunal diversity, and the overall highest faunal abundance, with stations within the group showing a low degree of similarity. It was also characterised by mud at one station and sandy mud at the rest. Sediments were poorly sorted or very poorly sorted. Average mud content was 78.3% and average sand content was 21.7%.

Group F comprised the remaining seven stations, characterising species included the isopod *Hydroniscus* sp. A, which was primarily responsible for the separation of this group of stations. Of these seven stations, three were sandy mud and four were muddy sand, all were poorly or very poorly sorted. The highest percentage of mud was 59.4% with a mean of 45.9%. The highest percentage of sand was 72.5%, with a mean of 54.1%.

Overall, there was little similarity in the species compositions between and within groups, with the low intra sample variability indicating patchy benthic communities within the survey area. The patchy benthic communities observed could be due to natural variation and/or disturbance, or anthropogenic disturbance. A weak pattern was observed between macrofauna composition and changes in depth and sediment composition (increasing mud fraction). However, this pattern was not statistically significant.

The multivariate analysis highlighted that, spatial patterns of faunal distribution across the survey area were associated with depth, with the smallest cluster by number of species and individuals identified (group C) found at the deepest station. The other communities identified differed on the basis of the depth and sediment heterogeneity, with predominantly muddy, typically well sorted sediments hosting more species and individuals (Groups D and E). With increasing percentage of finer sediment, and associated sorting coefficient, the faunal richness and abundance generally increased (Group D and E). Transitional areas exhibited elements of both communities (Group F).

The two unclassified stations occurred at the shallowest (A) and second deepest (B) stations. Station NC21_BCE025 (A) was characterised as the shallowest station and also the only station with any notable gravel content (2.3%). Station NC21_BCE018 (B) was the second deepest of all stations and only seven species and seven taxa were sampled.

3.8.5.1 Relationships between Physical and Biological Variables

Relationships between environmental and biological variables were assessed by means of the BEST analysis from the PRIMER suite, in order to identify which of the physical and chemical variables best explained the observed pattern of macrofaunal distribution across the survey area.

Results showed that depth was the single variable that best explained the observed pattern of faunal distribution (rho = 0.561). The combination of variables that returned the highest value of correlation coefficient included: depth, CPInC12-20 and arsenic (rho = 0.611). No other variable, either alone or in combination, returned higher value than these. Results of the global test showed that these relationships were significant (sample statistic rho = 0.611, significance level = 0.1%).

3.9 Water Samples

3.9.1 Water Profiling

Results of the water column profiles indicated well mixed layers of water across the entire survey area, as indicated by the vertical line on the plots, an example of which is presented in Figure 3.22. The full set of results generated with OceanV3 is presented in Appendix I.

Results showed a stratified water column, with a defined thermocline, halocline and oxygen boundary, below which these parameters notably dropped. All other parameters monitored returned similar values throughout the water column. Spatial variations of the parameters were driven by depth, with boundary layers been deeper in deeper water.

Surface water temperature was fairly uniform across the survey area, with a mean sea surface temperature (SST) of 27.8°C. Temperature at the bottom of the CTD profiles varied between 2.7 °C at station NC21_16WC017 (the deepest site) and 11.2°C at NC21_16WC025 (the shallowest site).

Salinity range was very small, with surface values per station of between 37.05 ppt (NC21_16WC008) and 36.60 ppt (NC21_16WC025). Below the halocline salinity values dropped to between 33.63 ppt (NC21_16WC008) and 35.30 ppt (NC21_16WC025).

Mean values per station of pH were between 8.18 (NC21_16WC025) and 8.47 (NC21_16WC015). Turbidity was very low, with mean values per station equal or less to 2.9 (FTU).

A summary of the water physical parameters, as measured by the water column profiles is presented in Table 3.17.

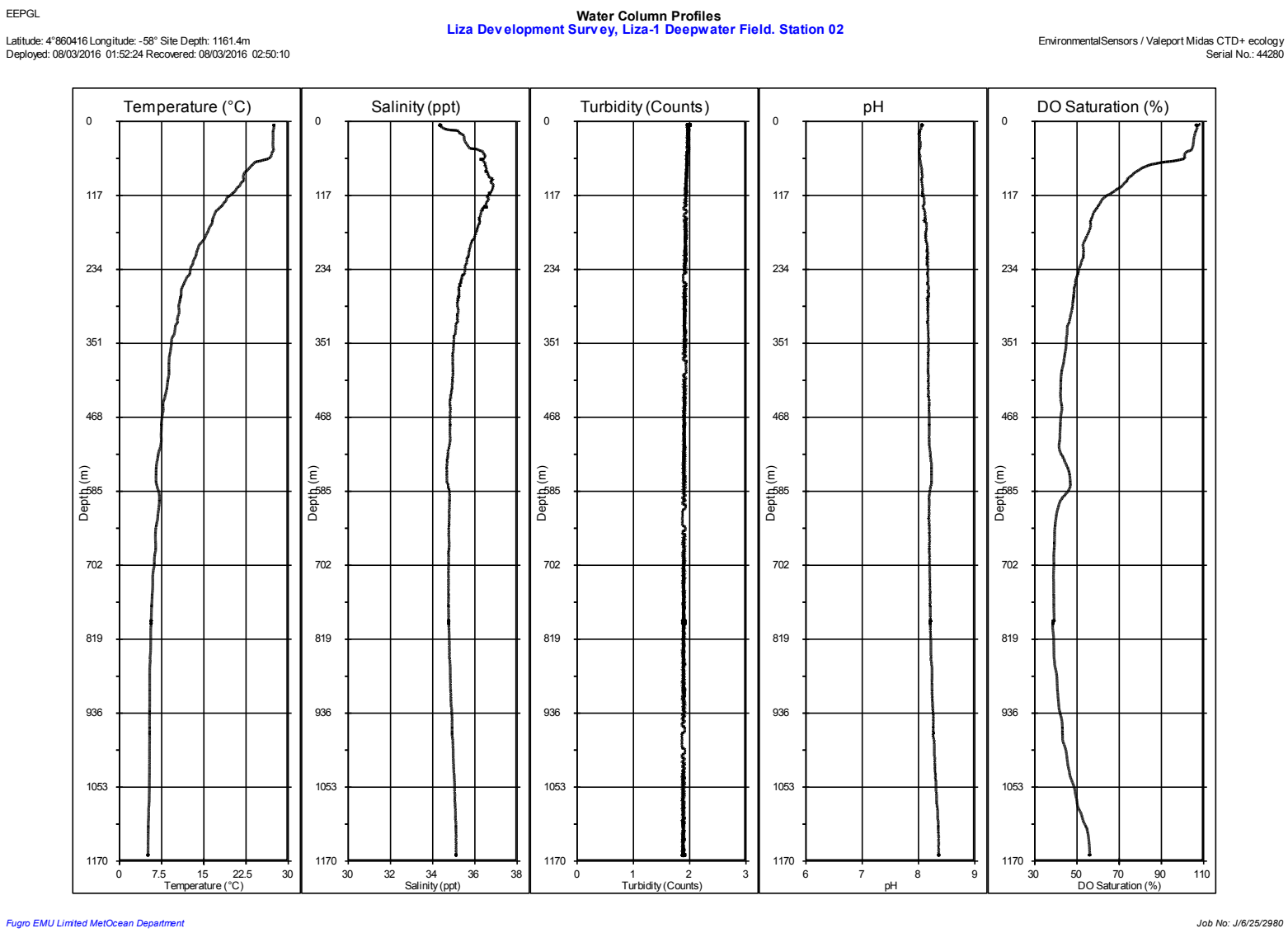


Figure 3.22: Water column profile at sampling station NC21_16WC002

Table 3.17: Summary of Water Physical Parameters Recorded by Water Column Profiles

Station	Statistics	Depth [m]	Temperature [°C]	Salinity [ppt]	DO Saturation [%]	pH	Turbidity [FTU counts]
NC21_16WC002	Min	-	5.07	34.31	38.44	7.99	1.85
	Mean	**-**	10.15	34.93	54.88	8.21	1.91
	Max	1161.87	27.46	36.90	108.34	8.36	2.04
	StDev	-	8.04	0.46	23.28	0.09	0.04
NC21_16WC005	Min	-	3.77	34.50	35.49	7.96	2.31
	Mean	**-**	10.67	34.99	62.66	8.21	2.37
	Max	1666.71	27.58	36.69	101.55	8.44	2.56
	StDev	-	9.25	0.40	21.70	0.12	0.04
NC21_16WC006	Min	-	3.95	33.99	36.14	7.88	1.70
	Mean	**-**	9.27	34.99	58.04	8.12	2.11
	Max	1532.63	27.61	36.61	101.23	8.28	2.97
	StDev	-	7.86	0.49	18.68	0.13	0.25
NC21_16WC008	Min	-	3.44	33.63	35.03	7.85	2.31
	Mean	**-**	8.56	34.96	56.78	8.15	2.35
	Max	1907.46	27.90	37.05	103.12	8.39	2.50
	StDev	-	7.64	0.54	17.64	0.14	0.03
NC21_16WC009	Min	-	3.49	33.34	34.34	-	2.39
	Mean	**-**	7.42	34.98	48.88	**-**	2.44
	Max	1888.06	27.88	36.85	95.54	-	2.58
	StDev	-	5.90	0.49	11.64	-	0.01
NC21_16WC010	Min	-	3.55	33.67	34.07	7.86	2.35
	Mean	**-**	4.87	35.07	57.66	8.26	2.43
	Max	2000.91	27.95	36.96	92.22	8.33	2.49
	StDev	-	3.28	0.24	7.92	0.09	0.02
NC21_16WC012	Min	-	3.19	33.89	34.36	7.89	2.44
	Mean	**-**	7.53	35.00	53.74	8.18	2.52
	Max	2318.35	27.77	36.94	92.68	8.31	2.60
	StDev	-	7.38	0.47	14.62	0.13	0.03
NC21_16WC015	Min	-	3.26	33.91	34.56	8.01	2.56
	Mean	**-**	7.39	35.02	54.08	8.34	2.60
	Max	2363.25	27.99	37.04	93.53	8.47	2.94
	StDev	-	7.37	0.46	14.35	0.15	0.04
NC21_16WC017	Min	-	2.68	34.66	37.89	8.01	2.73
	Mean	**-**	6.61	35.10	55.98	8.30	2.90
	Max	2714.41	28.03	36.91	94.31	8.46	3.00
	StDev	-	7.39	0.37	13.59	0.13	0.08
NC21_16WC018	Min	-	2.77	34.69	36.64	7.99	2.56
	Mean	**-**	7.76	35.13	59.04	8.13	2.66
	Max	2605.08	27.95	37.03	101.51	8.22	2.74
	StDev	-	8.04	0.36	17.31	0.07	0.04
NC21_16WC020	Min	-	3.68	34.64	36.41	7.91	2.81
	Mean	**-**	8.28	35.08	57.83	8.15	2.82
	Max	1832.73	28.05	36.78	99.67	8.29	3.06
	StDev	-	7.49	0.38	16.31	0.12	0.02
NC21_16WC021	Min	-	3.76	34.69	36.69	7.98	2.65
	Mean	**-**	9.62	35.14	59.15	8.12	2.70
	Max	1721.71	28.00	36.88	102.00	8.29	2.76
	StDev	-	8.35	0.40	19.73	0.10	0.02
NC21_16WC022	Min	-	3.62	34.66	39.64	7.91	2.74
	Mean	**-**	4.44	35.01	61.06	8.19	2.83
	Max	1702.74	28.18	37.09	110.41	8.23	3.14
	StDev	-	6.09	0.49	14.68	0.11	0.07

Station	Statistics	Depth [m]	Temperature [°C]	Salinity [ppt]	DO Saturation [%]	pH	Turbidity [FTU counts]
NC21_16WC023	Min	-	4.25	34.19	36.93	7.91	2.20
	Mean	**-**	9.64	35.01	59.66	8.13	2.25
	Max	1474.59	27.51	36.60	102.40	8.34	2.29
	StDev	-	7.78	0.46	18.52	0.13	0.02
NC21_16WC024	Min	-	5.39	34.75	38.60	8.04	1.86
	Mean	**-**	16.11	35.36	69.16	8.15	1.92
	Max	911.79	27.50	36.72	107.16	8.28	1.98
	StDev	-	9.88	0.55	30.55	0.09	0.03
NC21_16WC025	Min	-	11.23	35.30	48.42	8.02	1.90
	Mean	-	22.59	35.93	86.10	8.07	1.94
	Max	248.04	27.45	36.60	105.65	8.18	1.99
	StDev	-	6.42	0.40	24.06	0.06	0.01

3.9.2 Water Total Organic Carbon (TOC)

TOC concentrations are presented in Table 3.18 and showed only slight stratification, with generally marginally lower values for TOC from deeper samples. In surface seawater samples, TOC ranged from 0.9 mgl^{-1} at station NC21_16WC012 to 3.9 mgl^{-1} (station NC21_16WC005). In mid depth samples, TOC ranged from 0.8 mgl^{-1} at station NC21_16WC020 to 4.0 mgl^{-1} (station NC21_16WC002). In the bottom depth samples, TOC concentrations ranged from 0.9 mgl^{-1} at station NC21_16WC025 to 2.4 mgl^{-1} (at stations NC21_16WC005, NC21_16WC006 and NC21_16WC015).

Table 3.18: Summary of Water Total Organic Carbon

Station	Total Organic Carbon [mgl^{-1}]		
	Surface	Mid	Bottom
NC21_16WC002	1.5	4.0	1.6
NC21_16WC005	3.9	2.9	2.4
NC21_16WC006	2.5	2.1	2.4
NC21_16WC008	2.7	2.2	2.0
NC21_16WC009	2.4	1.5	2.0
NC21_16WC010	2.4	1.8	1.9
NC21_16WC012	0.9	1.3	1.1
NC21_16WC015	3.4	1.7	2.4
NC21_16WC017	3.1	1.8	2.2
NC21_16WC018	1.3	1.0	1.5
NC21_16WC020	2.0	0.8	1.0
NC21_16WC021	3.0	1.9	1.7
NC21_16WC022	2.2	2.3	1.7
NC21_16WC023	2.3	1.8	1.6
NC21_16WC024	1.2	1.8	2.1
NC21_16WC025	2.2	1.0	0.9
Min	**0.9**	**0.8**	**0.9**
Max	**3.9**	**4.0**	**2.4**
Mean	**2.3**	**1.9**	**1.8**
SD	**0.8**	**0.8**	**0.5**

3.9.3 Total Suspended Solids (TSS)

Total suspended solids (TSS) concentrations are presented in Table 3.19 and showed only slight stratification, with generally lower values for TSS from deeper samples. In surface seawater samples, TSS ranged from 2.4 mgl^{-1} at stations NC21_16WC009, NC21_16WC015 and NC21_16WC018 to 18.3 mgl^{-1} (station NC21_16WC021). In mid depth samples, concentrations ranged from below the detection limit at four stations to 6.5 mgl^{-1} (station NC21_16WC021). In the bottom depth sample, TSS concentrations ranged below the detection limit at five stations to 7.7 mgl^{-1} (station NC21_16WC002).

Table 3.19: Summary of Water Total Suspended Solids

Station	Total Suspended Solids [mgl^{-1}]		
	Surface	Mid	Bottom
NC21_16WC002	6.5	4.1	7.7
NC21_16WC005	7.6	2.3	4.2
NC21_16WC006	4.0	2.9	2.2
NC21_16WC008	7.7	2.1	< 2.0
NC21_16WC009	2.4	< 2.0	2.1
NC21_16WC010	6.7	2.8	2.4
NC21_16WC012	5.4	2.1	< 2.0
NC21_16WC015	2.4	< 2.0	3.2
NC21_16WC017	4.4	3.7	3.3
NC21_16WC018	2.4	2.2	< 2.0
NC21_16WC020	5.5	< 2.0	< 2.0
NC21_16WC021	18.3	6.5	3.2
NC21_16WC022	6.2	2.0	< 2.0
NC21_16WC023	13.3	< 2.0	4.0
NC21_16WC024	9.7	2.8	2.9
NC21_16WC025	4.2	3.7	2.7
Min	**2.4**	**2.0**	**2.1**
Max	**18.3**	**6.5**	**7.7**
Mean	**6.7**	**3.1**	**3.4**
SD	**4.2**	**1.3**	**1.6**

3.9.4 Water Hydrocarbons

3.9.4.1 Total Hydrocarbons and n-Alkanes

Total hydrocarbon analysis results are presented in Table 3.20. Concentrations were generally similar at each depth within a station, with the two exceptions of the bottom samples from NC21_16WC005 and NC21_16WC023. Concentrations ranged from 8.3 μgl^{-1}, in the bottom water sample at station NC21_16WC012, to 35.9 µgl-1, in the bottom water sample at reference station NC21_16WC023.

Table 3.20. Total Hydrocarbon in water samples

Station	Total Hydrocarbon (THC) µg/l Water		
	Top	Middle	Bottom
NC21_16WC002	16.4	17.7	10.8
NC21_16WC005	15.1	9.2	32.9
NC21_16WC006	11.5	13.8	27.7
NC21_16WC008	11.4	10.4	11.2
NC21_16WC009	10.0	9.4	9.1
NC21_16WC010	20.5	9.2	11.1
NC21_16WC012	13.1	14.1	8.3
NC21_16WC015	15.2	13.5	13.7
NC21_16WC017	17.4	19.3	13.6
NC21_16WC018	11.5	13.7	13.5
NC21_16WC020	18.8	12.3	15.0
NC21_16WC021	17.5	13.6	14.5
NC21_16WC022	15.8	12.5	13.3
NC21_16WC023	22.0	16.6	35.9
NC21_16WC024	22.1	18.8	26.1
NC21_16WC025	33.1	26.4	20.5
Min	**10.0**	**9.2**	**8.3**
Max	**33.1**	**26.4**	**35.9**
Mean	**17.0**	**14.4**	**17.3**
SD	**5.7**	**4.5**	**8.7**

Result for the other components of hydrocarbons analysis for the water samples at all stations are presented in Table 3.21.

The ratio of Pristane/Phytane (Table 3.21) was above 1 for the majority of the samples (77%) and < 1 in bottom water samples at stations NC21_WC010, NC21_WC012, NC21_WC015, NC21_WC021 and NC21_WC023. The ratio of Pristane/Phytane was < 1 in mid water samples at stations NC21_WC010, NC21_WC020, NC21_WC021, NC21_WC023 and NC21_WC025, the only surface sample where the ratio of Pristane/Phytane was < 1 was at station NC21_WC025.

Total concentrations for individual n-alkanes analysis at each site were generally low across the survey area. The values ranged between 0.37 $\mu g l^{-1}$, recorded in the bottom water sample at station NC21_WC015, and 16.3 $\mu g l^{-1}$, recorded in the bottom waters sample at station NC21_WC005. The results of individual alkanes are presented in Table 3.22.

Table 3.21: Summary of the Organic Compounds Concentrations in the Water Samples

Concentrations Expressed as µg/l Water											
Station	GC-MS										
	UCM	n-alkanes			CPI			Pristane	Phytane	Pr/Ph Ratio	2 - 6 Ring PAH
		nC_{12-20}	nC_{21-36}	nC_{12-36}	nC_{12-20}	nC_{21-36}	nC_{12-36}				
NC21_WC002 Bottom	2.9	0.28	2.68	2.97	1.20	0.92	0.95	0.012	0.010	1.14	0.064
NC21_WC002 Mid	3.6	0.28	6.49	6.78	1.29	0.92	0.93	0.012	0.010	1.24	0.075
NC21_WC002 Surface	6.3	0.33	3.89	4.22	1.49	0.91	0.95	0.012	0.007	1.77	0.072
NC21_WC005 Bottom	5.5	0.40	15.9	16.3	1.34	0.91	0.92	0.022	0.008	2.67	0.080
NC21_WC005 Mid	4.5	0.26	0.27	0.53	1.29	0.96	1.11	0.015	0.013	1.21	0.067
NC21_WC005 Surface	7.6	0.31	2.40	2.71	1.22	0.92	0.95	0.021	0.009	2.33	0.064
NC21_WC006 Bottom	7.2	0.41	8.90	9.3	1.0	0.98	0.98	0.017	0.016	1.02	0.106
NC21_WC006 Mid	4.0	0.35	4.16	4.52	1.51	0.95	0.98	0.017	0.008	1.98	0.069
NC21_WC006 Surface	5.3	0.38	0.46	0.85	1.49	0.98	1.18	0.019	0.013	1.46	0.080
NC21_WC008 Bottom	5.9	0.30	0.70	1.00	1.40	0.96	1.08	0.014	0.007	2.02	0.067
NC21_WC008 Mid	5.6	0.20	0.20	0.40	1.37	0.96	1.15	0.016	0.005	3.01	0.069
NC21_WC008 Surface	5.8	0.24	1.18	1.42	1.47	0.90	0.97	0.011	0.008	1.39	0.064
NC21_WC009 Bottom	4.7	0.24	0.17	0.41	1.22	0.98	1.12	0.012	0.007	1.78	0.066
NC21_WC009 Mid	4.7	0.22	0.25	0.48	0.93	1.15	1.04	0.019	0.015	1.26	0.065
NC21_WC009 Surface	5.1	0.27	0.43	0.70	1.13	0.95	1.02	0.017	0.015	1.15	0.061
NC21_WC010 Bottom	6.6	0.23	0.19	0.42	0.87	1.11	0.97	0.014	0.022	0.64	0.064
NC21_WC010 Mid	4.1	0.33	0.27	0.60	0.84	0.90	0.87	0.025	0.025	0.99	0.065
NC21_WC010 Surface	12.2	0.32	1.98	2.30	1.04	0.92	0.94	0.028	0.023	1.23	0.089
NC21_WC012 Bottom	3.7	0.27	0.13	0.41	0.86	1.04	0.91	0.013	0.018	0.75	0.059
NC21_WC012 Mid	7.9	0.31	0.71	1.02	0.98	0.94	0.95	0.021	0.016	1.28	0.074
NC21_WC012 Surface	6.7	0.33	0.54	0.86	1.17	0.95	1.03	0.024	0.016	1.51	0.076
NC21_WC015 Bottom	8.6	0.27	0.10	0.37	0.90	0.88	0.89	0.022	0.025	0.86	0.076
NC21_WC015 Mid	8.5	0.35	0.26	0.61	0.87	0.95	0.90	0.021	0.021	1.00	0.084
NC21_WC015 Surface	8.0	0.32	1.98	2.31	1.18	0.88	0.92	0.016	0.022	0.72	0.066
NC21_WC017 Bottom	8.3	0.32	0.27	0.58	0.89	0.93	0.91	0.023	0.015	1.50	0.072
NC21_WC017 Mid	3.7	0.29	7.72	8.01	0.81	0.91	0.91	0.024	0.023	1.08	0.075
NC21_WC017 Surface	10.1	0.24	2.04	2.27	0.79	0.96	0.94	0.016	0.012	1.35	0.084
NC21_WC018 Bottom	9.6	0.16	0.36	0.52	0.85	0.92	0.90	0.009	0.009	1.00	0.076
NC21_WC018 Mid	9.7	0.20	0.22	0.43	0.77	0.84	0.81	0.010	0.007	1.34	0.094
NC21_WC018 Surface	6.2	0.25	0.36	0.61	0.91	0.88	0.89	0.012	0.014	0.89	0.109
NC21_WC020 Bottom	10.1	0.34	0.37	0.72	0.83	0.93	0.88	0.019	0.013	1.48	0.113
NC21_WC020 Mid	8.4	0.25	0.20	0.46	0.91	1.01	0.96	0.012	0.014	0.87	0.091
NC21_WC020 Surface	11.4	0.28	2.44	2.72	1.21	0.91	0.93	0.024	0.016	1.48	0.096
NC21_WC021 Bottom	10.2	0.22	0.48	0.70	0.84	0.95	0.91	0.011	0.014	0.80	0.077
NC21_WC021 Mid	8.8	0.20	0.36	0.56	0.72	0.90	0.83	0.017	0.021	0.84	0.082
NC21_WC021 Surface	12.6	0.24	0.30	0.55	0.78	1.02	0.90	0.011	0.011	1.02	0.087
NC21_WC022 Bottom	9.8	0.18	0.26	0.44	0.78	0.99	0.90	0.017	0.007	2.44	0.067
NC21_WC022 Mid	8.0	0.26	0.21	0.47	0.82	0.63	0.73	0.015	0.010	1.52	0.080
NC21_WC022 Surface	11.6	0.15	0.43	0.58	0.67	1.07	0.95	0.012	0.009	1.34	0.051
NC21_WC023 (100m)	11.9	0.15	9.27	9.41	0.49	0.90	0.89	0.010	0.008	1.22	0.073
NC21_WC023 (40m)	12.0	0.38	0.50	0.88	0.81	0.96	0.89	0.011	0.010	1.08	0.072
NC21_WC023 Bottom	26.8	0.36	0.83	1.19	0.60	0.96	0.84	0.025	0.026	0.96	0.111
NC21_WC023 Mid	11.7	0.13	0.72	0.85	0.50	0.96	0.87	0.007	0.007	0.88	0.058
NC21_WC023 Surface	13.2	0.18	2.29	2.46	0.51	0.95	0.91	0.013	0.010	1.21	0.062

Concentrations Expressed as µg/l Water											
Station	GC-MS										
	UCM	n-alkanes			CPI			Pristane	Phytane	Pr/Ph Ratio	2 - 6 Ring PAH
		nC_{12-20}	nC_{21-36}	nC_{12-36}	nC_{12-20}	nC_{21-36}	nC_{12-36}				
NC21_WC024 Bottom	28.3	0.26	0.52	0.77	0.73	0.94	0.87	0.019	0.017	1.15	0.065
NC21_WC024 Mid	14.0	0.16	0.57	0.73	0.49	0.98	0.85	0.017	0.010	1.78	0.054
NC21_WC024 Surface	14.1	0.21	1.37	1.58	0.48	0.93	0.86	0.012	0.010	1.19	0.062
NC21_WC025 Bottom	13.8	0.19	0.98	1.17	0.46	0.94	0.85	0.012	0.010	1.16	0.063

Notes:
UCM = Unresolved complex mixture
CPI = Carbon preference index (the ratio of odd number carbon chain n-alkanes to even numbered chain n-alkanes)
Pr/Ph = ratio of pristane to phytane
2 - 6 ring PAH = Total 2 - 6 ring polycyclic aromatic hydrocarbons (including alkyl homologues - see PAH table for full details of compounds quantified)

Table 3.22: Individual n-Alkanes Average Concentrations at Each Site [ngl^{-1} of Water]

Alkanes	NC21_WC002 Bottom	NC21_WC002 Mid	NC21_WC002 Surface	NC21_WC005 Bottom	NC21_WC005 Mid	NC21_WC005 Surface	NC21_WC006 Bottom	NC21_WC006 Mid	NC21_WC006 Surface	NC21_WC008 Bottom	NC21_WC008 Mid	NC21_WC008 Surface
nC_{12}	31.7	23.6	27.4	27.5	21.0	24.5	32.1	29.0	23.9	22.9	16.8	20.3
nC_{13}	95.4	84.0	91.1	123	86.6	94.2	135	96.8	96.3	81.4	60.6	61.3
nC_{14}	46.7	45.8	49.9	71.0	48.2	56.2	67.1	54.6	55.9	46.9	34.2	37.0
nC_{15}	29.3	33.5	61.8	64.9	22.0	38.1	15.7	80.1	76.9	56.1	28.4	53.3
nC_{16}	13.0	15.5	15.3	22.7	15.4	20.7	26.2	17.3	19.8	15.3	14.9	13.3
nC_{17}	13.0	22.3	23.8	26.9	22.8	20.3	29.5	19.3	26.4	19.9	13.8	11.6
nC_{18}	19.6	23.6	20.0	29.1	15.6	22.0	41.2	18.4	29.5	21.3	12.6	13.1
nC_{19}	17.2	18.6	18.5	15.4	16.6	18.2	24.2	16.7	30.6	16.2	15.6	14.2
nC_{20}	18.5	14.5	18.1	21.7	14.8	16.9	36.1	22.1	24.9	17.9	7.8	11.8
nC_{21}	11.0	12.5	6.2	10.5	3.2	7.5	11.9	10.2	9.0	3.0	6.6	7.7
nC_{22}	4.7	6.3	9.4	9.1	5.5	8.7	8.4	4.2	8.4	4.6	8.0	4.1
nC_{23}	8.6	6.1	7.4	12.9	5.9	10.5	10.8	5.5	5.1	5.7	2.8	5.0
nC_{24}	11.5	9.9	9.4	16.9	5.0	18.6	21.9	9.4	8.4	6.5	6.7	6.6
nC_{25}	8.9	11.6	11.6	22.7	8.4	22.2	48.6	16.4	7.5	6.0	8.1	7.5
nC_{26}	12.3	26.8	19.5	57.8	10.8	29.0	118	33.0	10.7	6.4	6.7	8.4
nC_{27}	25.5	54.6	35.8	109	18.6	51.8	252	84.6	11.2	14.3	12.4	13.8
nC_{28}	55.0	126	81.6	242	21.4	74.1	456	160	12.3	18.9	11.6	21.2
nC_{29}	109	264	156	545	23.5	119	708	265	20.9	24.3	11.8	42.7
nC_{30}	190	455	276	1050	25.4	169	972	369	25.4	47.4	15.7	70.4
nC_{31}	308	746	446	1800	29.3	236	1310	506	39.0	83.9	15.1	111
nC_{32}	395	954	569	2340	34.7	302	1390	577	55.0	96.5	19.9	154
nC_{33}	437	1050	630	2660	26.7	355	1290	610	67.9	114	18.3	187
nC_{34}	423	1020	600	2570	22.9	373	1020	565	66.5	104	17.0	203
nC_{35}	379	959	563	2430	14.3	346	775	526	69.4	94.3	20.8	183
nC_{36}	304	793	473	2030	9.8	275	522	420	48.1	74.3	14.2	154
Total (µg/l)	**2.97**	**6.78**	**4.22**	**16.3**	**0.528**	**2.71**	**9.31**	**4.52**	**0.849**	**1.00**	**0.400**	**1.42**

Table 3.22: Individual n-Alkanes Average Concentrations at Each Site [ngl-1 of Water] Continued

Alkanes	NC21_WC009 Bottom	NC21_WC009 Mid	NC21_WC009 Surface	NC21_WC010 Bottom	NC21_WC010 Mid	NC21_WC010 Surface	NC21_WC012 Bottom	NC21_WC012 Mid	NC21_WC012 Surface	NC21_WC015 Bottom	NC21_WC015 Mid	NC21_WC015 Surface
nC_{12}	15.5	20.7	23.2	21.7	33.1	29.6	30.6	27.0	27.6	24.9	32.3	24.8
nC_{13}	61.9	49.5	53.3	52.2	73.7	64.4	61.8	65.9	69.6	57.4	70.7	57.4
nC_{14}	39.5	39.1	41.4	39.0	53.3	50.2	49.4	45.5	47.8	43.7	53.8	40.1
nC_{15}	38.6	19.7	48.6	18.3	25.0	47.1	26.1	28.8	57.8	22.5	34.3	64.8
nC_{16}	13.5	13.7	20.4	17.3	28.2	23.3	20.6	28.6	20.9	25.0	29.1	20.4
nC_{17}	14.0	19.4	22.9	19.5	26.8	28.3	20.6	25.0	25.7	25.0	31.4	25.1
nC_{18}	17.9	22.3	27.7	26.9	38.3	37.7	30.8	36.8	32.7	33.0	39.4	35.3
nC_{19}	17.6	18.6	18.7	17.6	24.9	26.2	17.1	32.2	22.9	24.9	28.1	28.6
nC_{20}	22.1	19.1	14.2	18.9	26.4	18.3	15.1	16.9	21.4	17.8	34.3	28.1
nC_{21}	9.2	10.2	5.3	11.2	12.3	23.4	9.9	10.2	9.8	11.3	12.3	14.1
nC_{22}	7.9	7.8	4.6	6.9	8.6	18.2	8.0	8.4	11.3	7.5	8.6	16.6
nC_{23}	6.5	9.0	7.6	5.0	8.0	16.6	7.3	9.5	11.2	6.0	8.2	30.4
nC_{24}	11.7	9.9	12.1	12.1	26.9	18.9	7.8	23.2	23.3	22.9	14.5	56.5
nC_{25}	10.3	14.7	12.8	11.2	11.0	13.5	9.1	32.4	13.8	4.8	10.8	65.5
nC_{26}	13.8	18.2	18.2	10.2	13.8	15.6	6.9	43.8	14.0	4.0	15.8	68.3
nC_{27}	17.6	19.6	22.6	15.0	18.8	17.2	9.6	47.6	20.9	5.6	20.4	74.2
nC_{28}	14.1	20.5	26.2	11.6	17.5	28.3	11.6	52.9	21.4	6.6	19.8	74.7
nC_{29}	11.4	23.0	35.9	13.4	23.7	60.7	9.9	57.3	25.4	3.9	19.3	100
nC_{30}	9.5	15.8	42.2	15.6	22.1	126	9.7	61.8	35.1	3.6	19.2	151
nC_{31}	11.8	18.5	49.4	17.0	25.3	220	8.0	73.8	51.1	6.3	19.5	204
nC_{32}	8.3	21.9	54.1	15.4	24.6	274	9.3	76.8	62.7	3.7	20.6	272
nC_{33}	7.4	22.0	51.9	14.2	21.1	313	7.6	69.4	68.3	4.2	25.1	245
nC_{34}	7.7	14.7	41.8	9.8	20.6	304	7.0	65.0	61.6	1.9	18.8	222
nC_{35}	10.0	19.2	25.7	14.0	10.2	284	6.2	46.2	61.7	3.4	10.5	196
nC_{36}	12.4	9.9	22.7	9.3	10.1	245	5.0	36.2	46.3	1.2	15.8	195
Total (µg/l)	**0.410**	**0.477**	**0.703**	**0.423**	**0.604**	**2.30**	**0.405**	**1.02**	**0.864**	**0.371**	**0.613**	**2.31**

Table 3.22: Individual n-Alkanes Average Concentrations at Each Site [ngl-1 of Water] Continued

Alkanes	NC21_WC017 Bottom	NC21_WC017 Mid	NC21_WC017 Surface	NC21_WC018 Bottom	NC21_WC018 Mid	NC21_WC018 Surface	NC21_WC020 Bottom	NC21_WC020 Mid	NC21_WC020 Surface	NC21_WC021 Bottom	NC21_WC021 Mid	NC21_WC021 Surface
nC_{12}	29.6	28.8	27.0	17.2	23.0	26.1	44.8	27.4	27.7	21.3	18.0	22.6
nC_{13}	62.9	56.7	53.6	38.6	42.1	49.4	83.5	60.9	49.7	46.8	37.5	51.7
nC_{14}	50.7	46.5	41.6	29.7	30.4	41.8	61.8	47.1	32.4	43.6	34.7	43.3
nC_{15}	23.3	25.5	10.1	10.5	13.9	11.7	27.3	25.4	62.6	22.8	11.6	17.5
nC_{16}	21.2	28.6	17.3	13.0	17.1	20.6	23.2	15.8	17.5	15.0	15.4	16.5
nC_{17}	26.2	24.8	24.3	11.5	14.0	41.0	25.0	17.0	21.0	14.5	14.6	17.7
nC_{18}	37.6	34.8	26.4	16.6	24.9	24.8	36.1	24.7	27.1	24.1	25.6	29.4
nC_{19}	37.3	24.5	15.6	15.0	18.6	18.1	19.7	17.7	20.2	18.1	19.5	20.6
nC_{20}	28.7	23.2	19.2	12.0	20.0	18.9	21.7	17.4	22.1	17.2	21.2	25.6
nC_{21}	8.8	11.1	13.4	7.1	10.1	9.2	10.8	13.3	9.6	8.5	15.3	10.1
nC_{22}	9.1	7.4	8.7	6.4	9.3	6.3	9.3	11.6	9.6	10.0	15.0	8.9
nC_{23}	6.5	8.8	10.1	6.2	7.4	5.7	9.2	6.4	10.9	13.5	14.4	13.7
nC_{24}	8.2	9.5	31.9	19.1	14.0	12.2	25.9	16.5	24.4	21.4	24.5	15.9
nC_{25}	7.4	10.4	27.2	13.1	7.4	10.8	9.2	10.1	11.9	19.7	18.8	16.1
nC_{26}	7.3	14.2	45.5	17.7	10.4	8.7	11.3	14.2	16.9	21.9	20.5	14.1
nC_{27}	11.3	31.2	69.0	20.4	12.9	12.4	17.9	15.5	23.0	28.1	21.0	17.3
nC_{28}	13.5	71.0	105	27.0	13.8	10.2	24.8	11.2	41.5	35.7	27.6	18.8
nC_{29}	14.7	212	150	30.5	18.4	13.3	24.8	12.7	84.8	38.9	22.4	17.9
nC_{30}	14.3	485	205	32.9	18.2	18.7	36.2	16.2	178	43.1	19.9	18.5
nC_{31}	23.3	884	267	39.4	18.9	27.8	39.8	15.7	283	44.4	27.5	26.2
nC_{32}	25.4	1140	293	37.5	20.4	35.7	41.8	11.5	351	54.6	26.0	27.1
nC_{33}	24.2	1290	280	31.8	14.3	49.3	43.2	17.5	391	51.8	26.7	31.1
nC_{34}	33.4	1250	228	26.3	18.3	52.2	29.2	16.0	366	36.3	25.0	24.3
nC_{35}	32.1	1230	183	22.5	12.6	39.6	25.3	11.3	345	26.9	24.7	21.0
nC_{36}	26.9	1060	121	19.4	16.4	46.1	15.6	3.7	292	21.2	30.9	23.6
Total (µg/l)	**0.584**	**8.01**	**2.27**	**0.521**	**0.427**	**0.610**	**0.72**	**0.457**	**2.72**	**0.70**	**0.558**	**0.550**

Table 3.22: Individual n-Alkanes Average Concentrations at Each Site [ngl-1 of Water] Continued

Alkanes	NC21_WC022 Bottom	NC21_WC022 Mid	NC21_WC022 Surface	NC21_WC023 Bottom	NC21_WC023 Mid	NC21_WC023 Surface	NC21_WC024 Bottom	NC21_WC024 Mid	NC21_WC024 Surface	NC21_WC025 Bottom	NC21_WC025 Mid	NC21_WC025 Surface
nC_{12}	18.6	27.1	3.7	15.3	1.7	7.4	4.5	14.9	14.6	9.2	4.5	8.9
nC_{13}	40.8	55.3	7.1	14.1	1.1	5.4	8.4	4.0	19.9	7.3	4.0	10.9
nC_{14}	31.6	46.2	20.4	55.3	35.6	38.0	57.7	33.5	54.6	50.5	28.9	44.3
nC_{15}	11.7	21.0	14.7	24.1	8.7	9.4	25.6	9.9	10.2	10.7	17.2	17.2
nC_{16}	14.8	22.8	16.5	35.7	11.4	15.5	22.4	15.0	14.1	23.9	17.4	12.9
nC_{17}	12.5	19.3	20.0	43.0	16.0	21.3	46.5	21.6	20.6	25.6	15.9	15.3
nC_{18}	16.4	31.4	18.3	73.0	18.6	33.6	33.8	18.0	31.9	21.4	24.5	26.1
nC_{19}	13.2	21.4	18.9	54.7	17.7	23.2	28.4	16.6	17.2	14.9	22.3	13.9
nC_{20}	19.1	16.0	30.9	45.8	19.2	22.3	29.7	24.2	26.6	22.1	12.5	20.5
nC_{21}	10.3	10.8	14.9	14.5	9.4	12.2	16.0	13.1	11.0	5.4	10.6	11.0
nC_{22}	6.6	9.1	8.2	7.6	7.2	11.1	12.4	7.2	13.2	8.0	6.6	12.2
nC_{23}	8.9	7.4	20.8	18.9	7.7	13.1	5.5	8.1	7.1	18.6	6.9	17.6
nC_{24}	11.1	55.7	32.3	10.2	9.3	19.3	8.6	11.6	7.1	16.1	15.1	32.4
nC_{25}	8.0	5.6	52.0	10.7	10.7	24.5	5.1	16.8	9.9	14.1	28.2	46.7
nC_{26}	13.4	7.8	49.8	10.0	16.9	35.6	6.9	20.6	14.4	14.1	43.3	92.1
nC_{27}	12.1	10.5	46.8	11.7	26.3	67.2	8.0	27.1	24.4	19.3	76.8	188
nC_{28}	19.8	10.5	41.4	21.9	45.1	103	22.6	41.5	46.2	27.8	166	390
nC_{29}	20.9	13.0	32.8	38.8	61.8	154	34.0	46.9	79.6	46.3	288	706
nC_{30}	25.2	13.2	25.3	60.4	73.5	211	46.3	58.3	122	64.2	421	1040
nC_{31}	26.4	12.6	22.1	92.9	94.1	295	64.0	65.7	174	91.7	577	1430
nC_{32}	25.9	13.9	17.8	113	98.3	354	69.3	74.7	190	118	629	1580
nC_{33}	21.2	10.9	14.2	126	94.6	334	70.1	69.1	198	147	619	1560
nC_{34}	20.5	11.1	15.9	113	73.7	271	61.0	49.2	188	143	553	1370
nC_{35}	23.2	11.1	16.5	95.5	49.2	214	48.1	35.1	157	135	470	1190
nC_{36}	10.0	8.0	14.3	88.4	45.2	170	39.4	25.7	127	115	376	931
Total (µg/l)	**0.442**	**0.472**	**0.576**	**1.20**	**0.853**	**2.46**	**0.774**	**0.729**	**1.58**	**1.17**	**4.43**	**10.8**

3.9.4.2 Gas Chromatography Traces

The gas chromatography trace for all depths sample showed very low concentrations of n-alkanes and a very low level of UCM in the range of nC_{27} to nC_{35} at all stations (Table 3.22). The gas chromatography trace for the surface water sample at station NC21_16WC025 is provided as an example in Figure 3.23. Chromatograms for all samples are presented in Appendix J.1. Peaks A-D were derived from known standards included for the analysis.

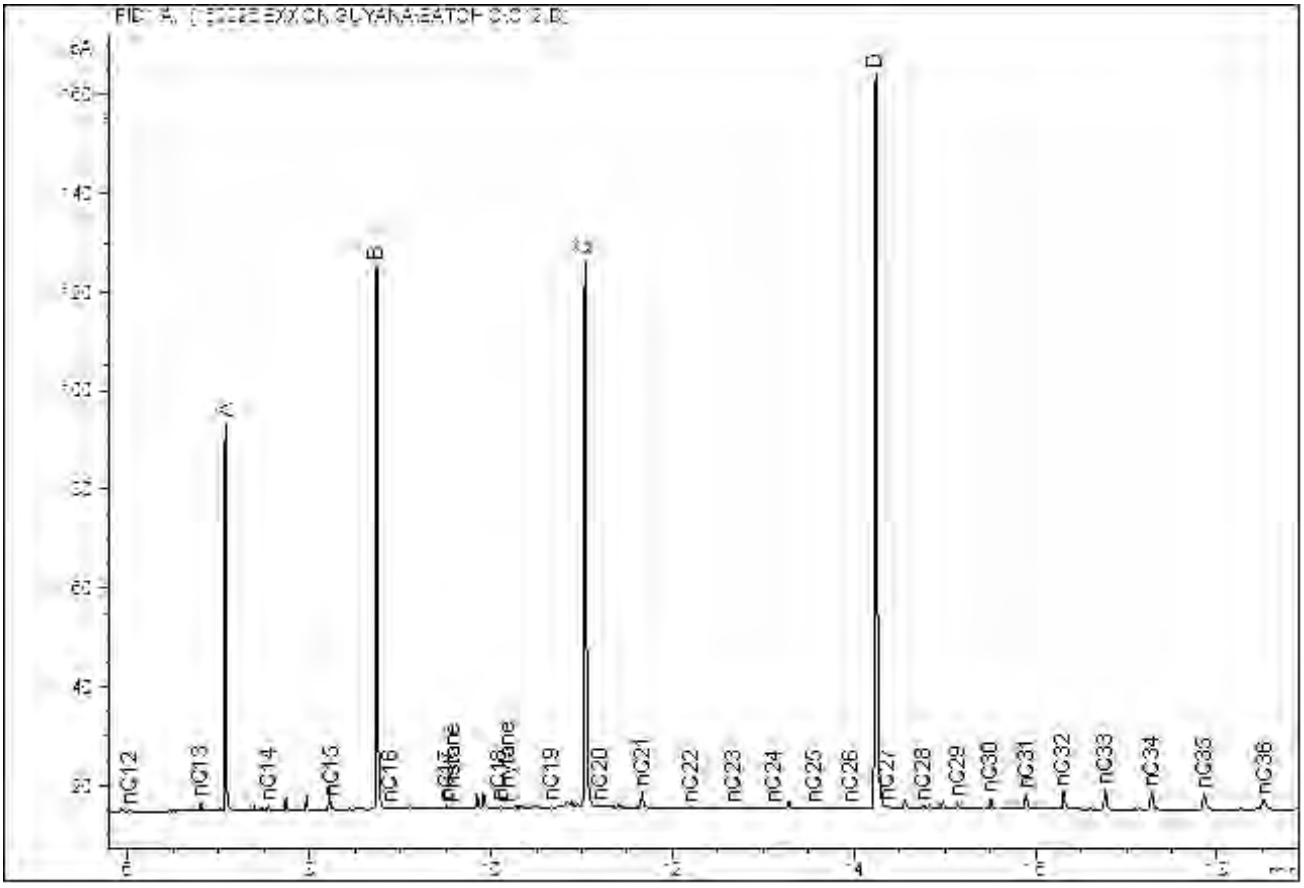


Figure 3.23: Water hydrocarbon analysis – gas chromatography trace (NC21_WC008 surface mid water sample)

3.9.4.3 Polycyclic Aromatic Hydrocarbons

The concentrations of all 16 PAHs in the water samples at the sixteen water sampling stations are presented in Table 3.23. The total concentrations ranged from 6.0 ngl^{-1}, in the mid water sample at station NC21_WC023, to 20.6 ngl^{-1}, in the middle water sample at station NC21_WC018. The full suite of parent/alkyl distribution across the survey area is presented in Appendix J.2.

Table 3.23: Concentrations of all 16 PAHs (ng/l Water)

PAH	NC21_WC002 Bottom	NC21_WC002 Mid	NC21_WC002 Surface	NC21_WC005 Bottom	NC21_WC005 Mid	NC21_WC005 Surface	NC21_WC006 Bottom	NC21_WC006 Mid	NC21_WC006 Surface	NC21_WC008 Bottom	NC21_WC008 Mid	NC21_WC008 Surface	Benchmark (ng/L)
Naphthalene	2.5	2.7	3.1	3.7	2.3	2.9	6.3	4.1	3.9	3.0	2.8	2.8	193 500
Acenaphthylene	0.3	0.2	0.3	0.3	0.3	0.2	0.5	0.3	0.3	0.3	0.3	0.3	306 900
Acenaphthene	0.7	0.8	1.0	1.2	0.8	0.9	1.3	0.9	1.1	1.1	0.7	0.6	55 850
Fluorene	0.8	1.0	1.0	1.3	0.8	1.0	1.6	1.0	1.2	1.1	0.7	0.8	39 300
Phenanthrene	1.0	1.0	1.1	1.3	0.9	1.0	1.2	1.0	1.1	1.2	0.8	0.8	19 130
Anthracene	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	20 730
Fluoranthene	0.4	0.3	0.3	0.3	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.2	7 109
Pyrene	0.4	0.4	0.4	0.3	0.4	0.3	0.5	0.2	0.3	0.3	0.3	0.2	10 110
Benzo(a)anthracene	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	2 227
Chrysene	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.4	0.1	0.2	0.1	2 042
Benzo(b)fluoranthene	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.2	0.1	979
Benzo(k)fluoranthene	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.3	0.1	0.1	0.1	981
Benzo(a)pyrene	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.1	957
Indeno(123cd)pyrene	0.4	0.3	0.2	0.2	0.2	0.1	0.2	0.1	0.3	0.2	0.2	0.2	275
Benzo(ghi)perylene	0.3	0.2	0.1	0.2	0.2	0.1	0.2	0.1	0.3	0.1	0.1	0.1	439
Dibenzo(ah)anthracene	0.5	0.3	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.2	282
Tot EPA 16	**8.4**	**7.9**	**8.5**	**9.7**	**7.2**	**7.4**	**13.0**	**8.6**	**10.8**	**8.3**	**7.1**	**6.8**	**-**

Table 3.23: Concentrations of all 16 PAHs (ng/l Water) Continued

PAH	NC21_WC009 Bottom	NC21_WC009 Mid	NC21_WC009 Surface	NC21_WC010 Bottom	NC21_WC010 Mid	NC21_WC010 Surface	NC21_WC012 Bottom	NC21_WC012 Mid	NC21_WC012 Surface	NC21_WC015 Bottom	NC21_WC015 Mid	NC21_WC015 Surface	Benchmark (ng/L)
Naphthalene	3.0	3.3	2.7	3.5	3.8	6.0	4.3	3.1	4.5	5.5	4.2	3.9	193 500
Acenaphthylene	0.2	0.3	0.3	0.6	0.3	0.3	0.4	0.2	0.2	0.5	0.2	0.2	306 900
Acenaphthene	0.6	1.2	1.3	1.4	1.5	2.4	1.5	1.2	1.4	1.6	1.6	1.5	55 850
Fluorene	0.7	1.4	1.5	1.5	1.9	2.7	1.6	1.4	1.5	1.9	1.9	1.9	39 300
Phenanthrene	0.8	1.2	1.2	1.1	1.3	2.4	1.2	1.2	1.3	1.1	1.4	1.5	19 130
Anthracene	0.1	0.2	0.1	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.1	0.1	20 730
Fluoranthene	0.2	0.3	0.3	0.3	0.2	0.4	0.2	0.3	0.2	0.3	0.2	0.3	7 109
Pyrene	0.4	0.4	0.4	0.2	0.3	0.4	0.2	0.3	0.3	0.2	0.3	0.5	10 110
Benzo(a)anthracene	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	2 227
Chrysene	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	2 042
Benzo(b)fluoranthene	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	979
Benzo(k)fluoranthene	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	981
Benzo(a)pyrene	<0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	<0.1	0.1	0.1	957
Indeno(123cd)pyrene	0.2	0.4	0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.2	0.1	275
Benzo(ghi)perylene	0.1	0.3	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.1	439
Dibenzo(ah)anthracene	0.1	0.4	0.2	0.2	0.1	0.2	0.1	0.3	0.2	0.1	0.2	0.1	282
Tot EPA 16	**6.9**	**10.4**	**8.8**	**9.9**	**10.3**	**15.9**	**10.3**	**9.4**	**10.8**	**12.0**	**11.0**	**10.7**	**-**

Table 3.23: Concentrations of all 16 PAHs (ng/l Water) Continued

PAH	NC21_WC017 Bottom	NC21_WC017 Mid	NC21_WC017 Surface	NC21_WC018 Bottom	NC21_WC018 Mid	NC21_WC018 Surface	NC21_WC020 Bottom	NC21_WC020 Mid	NC21_WC020 Surface	NC21_WC021 Bottom	NC21_WC021 Mid	NC21_WC021 Surface	Benchmark (ng/L)
Naphthalene	4.3	3.8	3.8	2.9	3.8	5.7	3.8	2.9	3.6	3.3	4.9	3.9	193 500
Acenaphthylene	0.4	0.2	0.8	0.5	0.3	0.4	0.4	0.3	0.2	0.3	0.3	0.2	306 900
Acenaphthene	1.7	1.5	1.0	0.6	0.6	4.4	1.2	1.0	0.9	0.7	0.8	0.7	55 850
Fluorene	2.1	2.0	1.3	0.9	0.8	3.7	1.3	0.9	1.1	0.9	1.1	0.9	39 300
Phenanthrene	1.3	1.4	1.6	0.9	1.0	3.4	1.3	1.0	1.3	0.8	1.0	1.0	19 130
Anthracene	0.1	0.1	0.3	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.1	20 730
Fluoranthene	0.2	0.2	0.4	0.3	0.3	0.6	0.5	0.3	0.2	0.3	0.3	0.3	7 109
Pyrene	0.2	0.3	0.8	0.3	0.3	0.5	0.5	0.3	0.3	0.3	0.3	0.3	10 110
Benzo(a)anthracene	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.2	2 227
Chrysene	0.1	0.1	0.3	0.1	0.3	0.3	0.3	0.2	0.2	0.2	0.1	0.2	2 042
Benzo(b)fluoranthene	0.1	0.1	0.3	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.1	0.2	979
Benzo(k)fluoranthene	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.3	981
Benzo(a)pyrene	0.1	0.1	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.1	0.1	0.2	957
Indeno(123cd)pyrene	0.1	0.2	0.6	0.3	0.4	0.3	0.5	0.3	0.4	0.2	0.1	0.4	275
Benzo(ghi)perylene	0.1	0.1	0.4	0.3	0.3	0.2	0.3	0.3	0.3	0.1	0.1	0.3	439
Dibenzo(ah)anthracene	0.2	0.1	0.7	0.3	0.4	0.2	0.5	0.4	0.4	0.2	0.2	0.4	282
Tot EPA 16	**11.2**	**10.4**	**13.0**	**8.2**	**9.5**	**20.6**	**11.8**	**8.7**	**9.9**	**7.9**	**9.8**	**9.6**	**-**

Table 3.23: Concentrations of all 16 PAHs (ng/l Water) Continued

PAH	NC21_WC022 Bottom	NC21_WC022 Mid	NC21_WC022 Surface	NC21_WC023 Bottom	NC21_WC023 Mid	NC21_WC023 Surface	NC21_WC024 Bottom	NC21_WC024 Mid	NC21_WC024 Surface	NC21_WC025 Bottom	NC21_WC025 Mid	NC21_WC025 Surface	Benchmark (ng/L)
Naphthalene	2.8	3.5	2.8	7.0	2.6	3.2	4.7	2.5	3.3	3.7	3.5	6.6	193 500
Acenaphthylene	0.2	0.3	0.2	0.4	0.2	0.3	0.1	0.2	0.1	0.2	0.2	0.2	306 900
Acenaphthene	0.5	0.7	0.3	1.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	55 850
Fluorene	0.6	0.9	0.6	2.3	0.7	0.8	0.9	0.7	0.9	0.9	0.8	1.1	39 300
Phenanthrene	0.7	0.9	0.5	1.1	0.6	0.9	0.7	0.8	0.8	0.8	0.8	1.0	19 130
Anthracene	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	<0.1	0.1	20 730
Fluoranthene	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	7 109
Pyrene	0.2	0.2	0.3	0.4	0.3	0.5	0.2	0.3	0.2	0.3	0.3	0.3	10 110
Benzo(a)anthracene	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	<0.1	<0.1	2 227
Chrysene	0.2	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	2 042
Benzo(b)fluoranthene	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	979
Benzo(k)fluoranthene	0.1	0.1	0.2	0.1	0.1	<0.1	0.1	0.1	0.1	0.1	0.1	<0.1	981
Benzo(a)pyrene	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	957
Indeno(123cd)pyrene	0.2	0.2	0.4	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	275
Benzo(ghi)perylene	0.2	0.1	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	439
Dibenzo(ah)anthracene	0.2	0.2	0.5	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	282
Tot EPA 16	**6.6**	**7.8**	**7.2**	**14.0**	**6.0**	**7.4**	**8.2**	**6.2**	**7.0**	**7.5**	**7.0**	**10.7**	**-**

Among the 16 PAHs, PAHs with short-chain compounds (NPD) had high proportional concentrations, ranging between 39 % to 69 % of the total PAHs. This was due to the high concentrations of naphtalene at all sites. 4 to 6 ring PAH's showed higher concentrations across the survey stations (Table 3.24).

Table 3.24: Individual PAH Concentrations [per Station ngl^{-1}]

Analyte	NC21_WC002 Bottom	NC21_WC002 Mid	NC21_WC002 Surface	NC21_WC005 Bottom	NC21_WC005 Mid	NC21_WC005 Surface	NC21_WC006 Bottom	NC21_WC006 Mid	NC21_WC006 Surface	NC21_WC008 Bottom	NC21_WC008 Mid	NC21_WC008 Surface
Naphthalene (128)	2	3	3	4	2	3	6	4	4	3	3	3
C1 128	4	5	5	7	5	5	11	5	5	4	4	5
C2 128	5	7	8	7	7	5	23	6	7	5	7	5
C3 128	4	5	5	7	4	6	9	5	11	5	5	5
C4 128	2	3	2	3	2	3	6	2	3	3	2	2
TOTAL 128	**17**	**23**	**23**	**28**	**20**	**22**	**55**	**22**	**30**	**20**	**21**	**20**
Phenanthrene/ anthracene (178)	1	1	1	1	1	1	1	1	1	1	1	1
C1 178	1	1	1	1	1	1	1	1	1	1	1	1
C2 178	2	2	2	2	2	2	2	2	2	2	1	2
C3 178	3	3	3	3	2	2	3	2	3	2	2	2
TOTAL 178	**7**	**7**	**7**	**7**	**6**	**6**	**7**	**6**	**7**	**6**	**5**	**6**
Dibenzothiophene (DBT)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C1 184	1	< 1	1	1	1	1	1	< 1	1	1	1	1
C2 184	1	1	1	1	1	1	1	1	1	1	1	1
C3 184	4	4	4	4	4	4	5	4	4	4	3	3
TOTAL 184	**6**	**5**	**6**	**6**	**6**	**6**	**7**	**5**	**6**	**6**	**5**	**5**
Fluoranthene/ pyrene (202)	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1	< 1	< 1	< 1	< 1
C1 202	1	1	1	1	1	1	1	< 1	1	1	1	1
C2 202	1	1	1	1	1	1	1	1	1	1	1	1
C3 202	2	2	2	2	1	2	2	2	2	2	2	2
TOTAL 202	**4**	**4**	**4**	**4**	**3**	**4**	**5**	**3**	**4**	**4**	**4**	**4**
Benzanthracenes/ benzphenanthrenes (228)	1	1	1	1	1	1	1	1	1	1	1	1
C1 228	1	1	1	1	2	1	1	1	1	1	1	1
C2 228	7	10	8	8	9	6	7	9	7	7	9	6
TOTAL 228	**9**	**12**	**10**	**10**	**12**	**8**	**9**	**11**	**9**	**9**	**11**	**8**
m/z 252	3	5	3	6	3	3	3	3	4	3	3	3
C1 252	5	6	6	6	5	5	6	6	5	6	5	5
C2 252	7	6	6	6	6	5	7	6	6	5	6	5
TOTAL 252	**15**	**17**	**15**	**18**	**14**	**13**	**16**	**15**	**15**	**14**	**14**	**13**
m/z 276	2	2	2	2	2	2	2	2	3	2	3	2
C1 276	1	2	1	2	1	1	2	1	2	2	1	2
C2 276	3	3	4	3	3	2	3	4	4	4	5	4
TOTAL 276	**6**	**7**	**7**	**7**	**6**	**5**	**7**	**7**	**9**	**8**	**9**	**8**
NPD	30	35	36	41	32	34	69	33	43	32	31	31
% NPD	47	47	50	51	48	53	65	48	54	48	45	48
Total 2-6 ring PAH	**64**	**75**	**72**	**80**	**67**	**64**	**106**	**69**	**80**	**67**	**69**	**64**

Table 3.24: Individual PAH Concentrations [per Station ngl-1] Continued

Analyte	NC21_WC009 Bottom	NC21_WC009 Mid	NC21_WC009 Surface	NC21_WC010 Bottom	NC21_WC010 Mid	NC21_WC010 Surface	NC21_WC012 Bottom	NC21_WC012 Mid	NC21_WC012 Surface	NC21_WC015 Bottom	NC21_WC015 Mid	NC21_WC015 Surface
Naphthalene (128)	3	3	3	4	4	6	4	3	4	6	4	4
C1 128	5	4	4	6	5	7	6	4	5	7	5	6
C2 128	7	4	4	4	4	7	5	5	5	6	5	5
C3 128	4	4	4	5	6	8	5	6	7	6	6	5
C4 128	2	2	3	3	3	4	3	4	4	4	4	3
TOTAL 128	**21**	**17**	**18**	**22**	**22**	**32**	**23**	**22**	**25**	**29**	**24**	**23**
Phenanthrene/ anthracene (178)	1	1	1	1	1	2	1	1	1	1	1	1
C1 178	1	1	1	1	1	2	1	1	1	2	1	1
C2 178	2	2	1	2	2	2	1	2	2	2	2	2
C3 178	2	2	2	2	2	3	2	3	2	2	2	2
TOTAL 178	**6**	**6**	**5**	**6**	**6**	**9**	**5**	**7**	**6**	**7**	**6**	**6**
Dibenzothiophene (DBT)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C1 184	1	1	1	1	1	1	1	1	1	1	1	1
C2 184	1	1	1	1	1	1	1	1	1	1	1	1
C3 184	4	3	3	3	3	3	3	3	4	3	3	4
TOTAL 184	**6**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**6**	**5**	**5**	**6**
Fluoranthene/ pyrene (202)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C1 202	1	1	1	1	1	1	1	1	1	1	1	< 1
C2 202	1	1	1	1	1	1	1	1	1	1	1	1
C3 202	1	2	2	2	2	2	1	2	2	1	2	2
TOTAL 202	**3**	**4**	**4**	**4**	**4**	**4**	**3**	**4**	**4**	**3**	**4**	**3**
Benzanthracenes/ benzphenanthrenes (228)	1	1	1	1	1	1	1	1	1	1	1	1
C1 228	1	1	1	1	1	1	1	1	1	1	1	1
C2 228	8	8	8	7	7	7	6	7	9	9	8	9
TOTAL 228	**10**	**10**	**10**	**9**	**9**	**9**	**8**	**9**	**11**	**11**	**10**	**11**
m/z 252	2	3	2	2	2	4	2	4	3	3	5	2
C1 252	4	4	5	5	5	8	4	6	6	5	8	4
C2 252	6	7	4	4	4	7	3	6	5	5	8	4
TOTAL 252	**12**	**14**	**11**	**11**	**11**	**19**	**9**	**16**	**14**	**13**	**21**	**10**
m/z 276	2	3	2	2	2	3	2	3	3	2	4	2
C1 276	2	2	2	2	2	3	1	2	2	2	3	1
C2 276	4	4	4	3	4	5	3	6	5	4	7	4
TOTAL 276	**8**	**9**	**8**	**7**	**8**	**11**	**6**	**11**	**10**	**8**	**14**	**7**
NPD	33	28	28	33	33	46	33	34	37	41	35	35
% NPD	50	43	46	52	51	52	56	46	49	54	42	53
Total 2-6 ring PAH	**66**	**65**	**61**	**64**	**65**	**89**	**59**	**74**	**76**	**76**	**84**	**66**

Table 3.24: Individual PAH Concentrations [per Station ngl-1] Continued

Analyte	NC21_WC017 Bottom	NC21_WC017 Mid	NC21_WC017 Surface	NC21_WC018 Bottom	NC21_WC018 Mid	NC21_WC018 Surface	NC21_WC020 Bottom	NC21_WC020 Mid	NC21_WC020 Surface	NC21_WC021 Bottom	NC21_WC021 Mid	NC21_WC021 Surface
Naphthalene (128)	4	4	4	3	4	6	4	3	4	3	5	4
C1 128	6	5	7	7	6	11	8	6	7	6	8	6
C2 128	5	5	7	5	5	9	6	5	5	4	5	5
C3 128	5	5	7	5	7	11	8	5	7	6	8	8
C4 128	4	3	3	3	3	4	4	3	3	2	4	3
TOTAL 128	**24**	**22**	**28**	**23**	**25**	**41**	**30**	**22**	**26**	**21**	**30**	**26**
Phenanthrene/ anthracene (178)	1	1	2	1	1	3	1	1	1	1	1	1
C1 178	2	1	2	1	1	2	2	1	1	1	1	1
C2 178	2	2	2	2	2	3	3	2	3	2	2	2
C3 178	2	2	3	3	2	3	3	2	3	3	3	4
TOTAL 178	**7**	**6**	**9**	**7**	**6**	**11**	**9**	**6**	**8**	**7**	**7**	**8**
Dibenzothiophene (DBT)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C1 184	1	1	1	1	1	1	1	1	1	1	1	1
C2 184	1	1	1	1	2	1	2	3	2	2	2	1
C3 184	3	4	3	3	3	3	4	4	4	3	3	3
TOTAL 184	**5**	**6**	**5**	**5**	**6**	**5**	**7**	**8**	**7**	**6**	**6**	**5**
Fluoranthene/ pyrene (202)	< 1	< 1	1	< 1	< 1	2	1	< 1	< 1	< 1	< 1	< 1
C1 202	1	1	1	1	1	1	1	1	1	1	1	1
C2 202	1	1	1	1	1	1	1	1	1	1	1	1
C3 202	2	2	1	2	1	2	2	1	2	2	2	1
TOTAL 202	**4**	**4**	**4**	**4**	**3**	**6**	**5**	**3**	**4**	**4**	**4**	**3**
Benzanthracenes/ benzphenanthrenes (228)	1	1	1	1	1	1	1	1	1	1	1	1
C1 228	1	1	2	2	3	3	4	3	4	2	2	3
C2 228	7	9	8	7	8	11	9	8	9	9	9	9
TOTAL 228	**9**	**11**	**11**	**10**	**12**	**15**	**14**	**12**	**14**	**12**	**12**	**13**
m/z 252	3	5	4	3	5	4	6	5	5	3	3	4
C1 252	6	6	5	5	9	6	8	8	8	7	5	6
C2 252	5	6	8	8	11	9	12	11	9	6	6	9
TOTAL 252	**14**	**17**	**17**	**16**	**25**	**19**	**26**	**24**	**22**	**16**	**14**	**19**
m/z 276	2	2	3	3	4	3	6	4	4	3	2	3
C1 276	2	2	2	2	4	3	5	4	4	3	2	3
C2 276	5	5	5	6	9	6	11	8	7	5	5	7
TOTAL 276	**9**	**9**	**10**	**11**	**17**	**12**	**22**	**16**	**15**	**11**	**9**	**13**
NPD	36	34	42	35	37	57	46	36	41	34	43	39
% NPD	50	45	50	46	39	52	41	40	43	44	52	45
Total 2-6 ring PAH	**72**	**75**	**84**	**76**	**94**	**109**	**113**	**91**	**96**	**77**	**82**	**87**

Table 3.24: Individual PAH Concentrations [per Station ngl-1] Continued

Analyte	NC21_WC017 Bottom	NC21_WC017 Mid	NC21_WC017 Surface	NC21_WC018 Bottom	NC21_WC018 Mid	NC21_WC018 Surface	NC21_WC020 Bottom	NC21_WC020 Mid	NC21_WC020 Surface	NC21_WC021 Bottom	NC21_WC021 Mid	NC21_WC021 Surface
Naphthalene (128)	3	3	3	7	3	3	5	2	3	4	3	7
C1 128	5	7	6	13	5	6	6	5	6	6	5	11
C2 128	4	5	2	22	4	5	6	5	4	5	5	9
C3 128	5	6	4	10	4	4	5	4	4	5	4	6
C4 128	2	2	2	7	2	2	3	2	2	3	2	4
TOTAL 128	**19**	**23**	**17**	**59**	**18**	**20**	**25**	**18**	**19**	**23**	**19**	**37**
Phenanthrene/ anthracene (178)	1	1	< 1	1	1	1	1	1	1	1	1	1
C1 178	1	1	1	2	1	1	1	1	1	1	1	1
C2 178	2	2	1	3	2	2	2	2	2	2	2	3
C3 178	3	2	1	3	2	2	2	2	2	2	2	2
TOTAL 178	**7**	**6**	**3**	**9**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**7**
Dibenzothiophene (DBT)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C1 184	1	1	< 1	1	1	1	1	1	1	1	1	1
C2 184	1	2	1	3	2	2	1	1	2	1	2	1
C3 184	3	3	2	5	3	3	4	4	3	4	4	4
TOTAL 184	**5**	**6**	**3**	**9**	**6**	**6**	**6**	**6**	**6**	**6**	**7**	**6**
Fluoranthene/ pyrene (202)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
C1 202	1	1	< 1	1	1	1	1	< 1	1	1	1	1
C2 202	1	1	< 1	1	1	1	1	1	1	1	1	1
C3 202	1	1	1	2	1	1	1	1	1	1	1	1
TOTAL 202	**3**	**3**	**1**	**4**	**3**	**3**	**3**	**2**	**3**	**3**	**3**	**3**
Benzanthracenes/ benzphenanthrenes (228)	1	1	1	1	1	1	1	1	1	1	1	1
C1 228	2	3	1	1	1	1	1	1	1	1	1	1
C2 228	7	8	5	5	5	5	5	4	5	5	5	5
TOTAL 228	**10**	**12**	**7**	**7**	**7**	**7**	**7**	**6**	**7**	**7**	**7**	**7**
m/z 252	3	3	3	3	2	3	2	2	3	3	3	3
C1 252	4	7	4	5	4	5	5	4	5	4	5	5
C2 252	7	8	5	6	5	5	4	4	5	5	5	4
TOTAL 252	**14**	**18**	**12**	**14**	**11**	**13**	**11**	**10**	**13**	**12**	**13**	**12**
m/z 276	3	3	3	3	2	2	2	2	2	2	2	1
C1 276	2	3	1	2	1	1	1	1	1	1	1	1
C2 276	4	6	4	4	4	4	4	3	5	3	4	2
TOTAL 276	**9**	**12**	**8**	**9**	**7**	**7**	**7**	**6**	**8**	**6**	**7**	**4**
NPD	31	35	23	77	30	32	37	30	31	35	32	50
% NPD	46	44	45	69	52	52	57	56	50	56	52	66
Total 2-6 ring PAH	**67**	**80**	**51**	**111**	**58**	**62**	**65**	**54**	**62**	**63**	**62**	**76**

Notes:
NPD = Total of all naphthalenes, phenanthrenes and dibenzothiophenes

3.9.5 Water Heavy and Trace Metals

Heavy metals are natural constituents of the aquatic environment and are generally found in very low concentrations. Current environmental interest in metals in seawater is mainly focussed on arsenic, cadmium, copper, mercury and zinc with environmental quality standards derived for these parameters (EPA, 2015). The concentrations of heavy metals in the seawater water are presented in water samples are presented in Table 3.25.

Concentrations of barium, iron, mercury and vanadium were below detection limits at all stations and depths (Table 3.25).

Concentrations of cadmium were below detection limits in 56% of the water samples collected, primarily in samples collected from the surface or the bottom of the water column. Where cadmium samples were above detection limits all values were still near the detection limit, ranging from 0.03 μgl^{-1} at the bottom sample of station NC21_16WC012 to 0.064 μgl^{-1} at the midwater sample for station NC21_WC002.

Concentrations of chromium were below detection limits at the surface, while they were only seen at mid water at two stations (NC21_16WC017 and NC21_16WC017 and in the bottom sample at one station (NC21_16WC017), at each of these locations the concentrations were still only just above the detection limit of <0.5 μgl^{-1}.

Copper concentrations in the surface seawater samples ranged from below the limit of detection (0.2 μgl^{-1}) at eight stations to 0.801 μgl^{-1} at station NC21_16WC002 (mean 0.361 μgl^{-1}). Mid depth seawater copper concentrations ranged from below the limit of detection at fourteen stations to 0.286 μgl^{-1} at station NC21_16WC002 (mean 0.237 μgl^{-1}). Copper concentrations in the bottom depth seawater samples ranged from below the limit of detection at nine stations to 0.985 μgl^{-1} (NC21_16WC023), with an average concentration of 0.405 μgl^{-1}.

Lead concentrations in the surface seawater samples ranged from below the limit of detection (0.04 μgl^{-1}) at eight stations to 0.345 μgl^{-1} at station NC21 16WC010 (mean 0.135 μgl^{-1}). Mid depth seawater lead concentrations ranged from below the limit of detection at nine stations to 0.186 μgl^{-1} at station NC21 16WC006 (mean 0.0.085 μgl^{-1}). In the bottom depth samples, lead concentrations ranged from below the limit of detection at six stations to 0.625 μgl^{-1} at station NC21_16WC023 (mean 0.0.163 μgl^{-1}).

Zinc concentrations in the surface seawater samples ranged from 1.15 μgl^{-1} at station NC21 16WC008 to 18.40 μgl^{-1} at station NC21 16WC006 (mean 5.68 μgl^{-1}). Mid depth seawater zinc concentrations ranged from 0.448 μgl^{-1} at station NC21_16WC008 to 23.1 μgl^{-1} at station NC21_16WC002 (mean 5.393 μgl^{-1}). In the bottom depth samples, zinc concentrations ranged from 0.867 μgl^{-1} at station NC21_16WC012 to 26.40 μgl^{-1} at station NC21_16WC023 (mean 8.75 μgl^{-1}).

Surface seawater arsenic concentrations ranged from below the limit of detection at one station (1 μgl^{-1}) to 1.41 μgl^{-1} at station NC21_16WC002 (mean 1.253 μgl^{-1}). Mid depth seawater arsenic concentrations ranged from 1.12 μgl^{-1} at station NC21 16WCO22 to 1.75 μgl^{-1} at station

NC21_16WC002 (mean 1.49 μgl^{-1}). In the bottom depth samples, arsenic concentrations ranged from 1.38 μgl^{-1} at station NC21_16WC024 to 1.77 μgl^{-1} at station NC21_16WC002 (mean 1.51 μgl^{-1}).

Table 3.25: Summary of Water Sample Heavy Metal Analysis

Concentrations Expressed as μgl^{-1}										
Station	**Depth**	**Cadmium**	**Copper**	**Lead**	**Zinc**	**Barium**	**Iron**	**Mercury**	**Chromium**	**Arsenic**
NC21_16WC002	Bottom	0.043	< 0.2	< 0.04	5.11	< 100	< 100	< 0.01	< 0.5	1.77
	Mid	0.064	0.286	0.084	23.10	< 100	< 100	< 0.01	< 0.5	1.75
	Surface	< 0.03	0.807	< 0.04	3.40	< 100	< 100	< 0.01	< 0.5	1.41
NC21_16WC005	Bottom	0.034	0.41	0.406	20.10	< 100	< 100	< 0.01	< 0.5	1.59
	Mid	0.04	< 0.2	< 0.04	1.61	< 100	< 100	< 0.01	< 0.5	1.59
	Surface	< 0.03	0.211	0.207	18.00	< 100	< 100	< 0.01	< 0.5	1.24
NC21_16WC006	Bottom	< 0.03	0.502	0.191	11.80	< 100	< 100	< 0.01	< 0.5	1.43
	Mid	0.044	< 0.2	0.186	5.82	< 100	< 100	< 0.01	< 0.5	1.7
	Surface	< 0.03	0.338	0.254	18.40	< 100	< 100	< 0.01	< 0.5	1.3
NC21_16WC008	Bottom	< 0.03	0.245	0.218	5.84	< 100	< 100	< 0.01	< 0.5	1.57
	Mid	0.043	< 0.2	< 0.04	0.45	< 100	< 100	< 0.01	< 0.5	1.61
	Surface	< 0.03	0.53	0.065	7.18	< 100	< 100	< 0.01	< 0.5	1.28
NC21_16WC009	Bottom	0.034	< 0.2	< 0.04	< 0.4	< 100	< 100	< 0.01	< 0.5	1.58
	Mid	0.038	< 0.2	< 0.04	2.47	< 100	< 100	< 0.01	< 0.5	1.47
	Surface	< 0.03	< 0.2	< 0.04	1.15	< 100	< 100	< 0.01	< 0.5	1.26
NC21_16WC010	Bottom	< 0.03	< 0.2	0.046	4.02	< 100	< 100	< 0.01	< 0.5	1.52
	Mid	0.059	< 0.2	< 0.04	1.11	< 100	< 100	< 0.01	< 0.5	1.69
	Surface	< 0.03	< 0.2	0.343	9.52	< 100	< 100	< 0.01	< 0.5	<1
NC21_16WC012	Bottom	0.03	< 0.2	< 0.04	0.87	< 100	< 100	< 0.01	< 0.5	1.45
	Mid	0.054	< 0.2	< 0.04	0.45	< 100	< 100	< 0.01	< 0.5	1.47
	Surface	< 0.03	< 0.2	< 0.04	2.57	< 100	< 100	< 0.01	< 0.5	1.02
NC21_16WC015	Bottom	0.03	< 0.2	< 0.04	1.63	< 100	< 100	< 0.01	< 0.5	1.6
	Mid	< 0.03	< 0.2	0.122	6.04	< 100	< 100	< 0.01	< 0.5	1.62
	Surface	0.06	< 0.2	< 0.04	2.39	< 100	< 100	< 0.01	< 0.5	1.28
NC21_16WC017	Bottom	0.038	0.215	0.102	8.74	< 100	< 100	< 0.01	0.673	1.51
	Mid	0.033	< 0.2	0.06	2.84	< 100	< 100	< 0.01	0.778	1.59
	Surface	< 0.03	< 0.2	< 0.04	2.87	< 100	< 100	< 0.01	< 0.5	1.37
NC21_16WC018	Bottom	< 0.03	< 0.2	< 0.04	14.20	< 100	< 100	< 0.01	< 0.5	1.44
	Mid	0.039	< 0.2	< 0.04	2.13	< 100	< 100	< 0.01	0.523	1.44
	Surface	< 0.03	< 0.2	0.069	3.11	< 100	< 100	< 0.01	< 0.5	1.27
NC21_16WC020	Bottom	< 0.03	< 0.2	0.041	2.49	< 100	< 100	< 0.01	< 0.5	1.56
	Mid	0.046	< 0.2	0.08	5.28	< 100	< 100	< 0.01	< 0.5	1.64
	Surface	< 0.03	0.38	0.112	5.12	< 100	< 100	< 0.01	< 0.5	1.2
NC21_16WC021	Bottom	< 0.03	< 0.2	< 0.04	2.87	< 100	< 100	< 0.01	< 0.5	1.39
	Mid	< 0.03	< 0.2	0.041	3.55	< 100	< 100	< 0.01	< 0.5	1.3
	Surface	< 0.03	< 0.2	0.041	1.97	< 100	< 100	< 0.01	< 0.5	1.36

Concentrations Expressed as µgl^{-1}										
Station	**Depth**	**Cadmium**	**Copper**	**Lead**	**Zinc**	**Barium**	**Iron**	**Mercury**	**Chromium**	**Arsenic**
NC21_16WC022	Bottom	< 0.03	0.264	0.043	2.26	< 100	< 100	< 0.01	< 0.5	1.49
	Mid	0.034	< 0.2	< 0.04	0.63	< 100	< 100	< 0.01	< 0.5	1.12
	Surface	< 0.03	< 0.2	< 0.04	1.34	< 100	< 100	< 0.01	< 0.5	1.28
NC21_16WC023	Bottom	0.052	0.985	0.625	26.40	< 100	< 100	< 0.01	< 0.5	1.49
	Mid	0.041	< 0.2	< 0.04	3.98	< 100	< 100	< 0.01	< 0.5	1.73
	Surface	< 0.03	0.223	< 0.04	1.88	< 100	< 100	< 0.01	< 0.5	1.21
NC21_16WC023 40m	40m	< 0.03	< 0.2	0.156	4.47	< 100	< 100	< 0.01	< 0.5	<1
NC21_16WC023 100m	100m	< 0.03	< 0.2	0.104	11.90	< 100	< 100	< 0.01	< 0.5	1.32
NC21_16WC024	Bottom	0.058	< 0.2	0.059	3.22	< 100	< 100	< 0.01	< 0.5	1.38
	Mid	0.036	0.212	< 0.04	4.43	< 100	< 100	< 0.01	< 0.5	1.26
	Surface	< 0.03	0.286	< 0.04	4.48	< 100	< 100	< 0.01	< 0.5	1.36
NC21_WC025	Bottom	< 0.03	< 0.2	0.089	22.80	< 100	< 100	< 0.01	0.649	1.46
	Mid	< 0.03	< 0.2	0.068	6.59	< 100	< 100	< 0.01	< 0.5	1.26
	Surface	< 0.03	0.261	0.085	12.00	< 100	< 100	< 0.01	< 0.5	1.19
MIN		**0.030**	**0.211**	**0.041**	**0.45**	**-**	**-**	**-**	**0.523**	**1.02**
MEAN		**0.043**	**0.385**	**0.144**	**6.42**	**-**	**-**	**-**	**0.656**	**1.43**
MAX		**0.064**	**0.985**	**0.625**	**26.40**	**-**	**-**	**-**	**0.778**	**1.77**
ST DEV		**0.010**	**0.225**	**0.134**	**6.59**	**-**	**-**	**-**	**0.105**	**0.18**
US EPA Saltwater Quality Standards (EPA, 2015)										
CMC		40	4.8	210	90	-	-	1.8	-	69
CCC		8.8	3.1	8.1	81	-	-	0.94	-	36

Notes:
Blank cells indicate that the value could not be calculated
Concentrations exceeding the US EPA CMC
CMC = criterion maximum concentration
CCC = criterion continuous concentration

4. DISCUSSION

Sediment descriptions consisted of a range of sediment types, from slightly gravelly muddy sand at the shallowest site to poorly sorted sandy mud or mud, with sandy mud being the predominant sediment type across the survey area. A pattern of sediment distribution was identified, with the shallowest station (< 500 m) consisting of slightly gravelly muddy sand. Stations in waters deeper than 500 m but shallower than 2500 m varied between mud, muddy sand and sandy mud, characterised by varying proportions of sand and mud. Stations at sites > 2500 m consisted entirely of sandy mud and were characterised by a high proportion of mud and a smaller fraction of sand. Samples from shallower stations showed a degree of heterogeneity encompassing notable percentages of coarser sediment, specifically sand, particularly the stations located in the south of the survey array. Multivariate analysis of the particle size data broadly supported this pattern. The shallowest station, NC21_16BCE025 remained ungrouped, whilst the other stations were split between two clusters. The two clusters did not appear to support the pattern, as Cluster 1 contained the shallowest stations bar NC21_16BCE025 but also the deepest station, possibly due to insufficient sampling from each depth, or a degree of heterogeneity across the Stabroek area.

Samples from most stations showed a degree of disturbance, as indicated by the bimodal and trimodal distribution (Hein, 2007) of all samples from all but three stations. Such disturbance is likely to be associated with the local hydrodynamic conditions of the area (e.g. seabed bottom current velocity), as well as local sediment mineral composition and/or biological activity (Holmes et al., 2004).

TOC concentrations were found to be higher at stations with a greater proportion of fine sediments. A significant positive correlation was calculated between TOC and the proportion of mud, with a corresponding significant negative correlation with the proportion of sand. These indicated that sediment composition was directly related to the concentration of organic material found at each station. This would be expected since fine particles provide a greater surface area for the adsorption of organic matter (Keil et al, 1994).

Total hydrocarbon concentrations (THC) were considered to be at low levels across the survey area with a pattern of higher levels of THC associated with finer sediments and a higher mean phi. It has been suggested that typical THC levels (i.e. ‘background’) in sediments remote from anthropogenic activities range from 0.2 μgg^{-1} to 5 μgg^{-1}, with values in some areas being as high as 15 μgg^{-1} (NSTF, 1993). Concentrations of THC were below 5 μgg^{-1} at all stations and, as such, not sufficiently high to be considered contaminated to any notable degree.

The ratio of odd to even carbon numbered normal alkanes is termed the CPI, and was calculated over various chain length ranges. Elevated ratios (i.e. those >1.00) over the nC_{21-36} carbon range are due to the domination of odd-chain length n-alkanes and typically observed/associated with inputs from terrestrial run-off (leaf waxes, etc). High CPI ratios (>1.0) were found for the entire range of n-alkanes (nC_{12-36}) at all stations and indicated a dominance of biogenic alkanes rather than those derived from petrogenic sources. This could be expected given the volume of land runoff from the

Essequibo and Demerara rivers and therefore the potential influence of the nearby landmass on the immediate marine environment (Miller et al., 2003).

An examination of the concentrations of individual n-alkanes and GC traces indicated the presence of very low levels of UCM (possibly as a result of low long term background levels of hydrocarbons, however there is currently no existing evidence to support this), and odd carbon number dominated sequences represented by small peaks at longer chain lengths (nC_{21-36}) suggesting terrestrially derived organic plant matter. More specifically a presence of elevated peaks of nC_{31}, then nC_{29}, followed by nC_{33} is indicative of the n-alkane pattern of terrestrial grasses and the soil under grassland (Zech et al., 2009).

Concentrations of total 2 to 6 ring PAH varied across the survey area. The 2 to 3 ring PAHs and alkylated PAHs dominate in crude oils (National Research Council, 1985), and, as such, their presence may be indicative of contamination associated with offshore oil and gas production and/or diesel contamination from shipping activities (DTI, 2001). PAHs from combustion sources are characterised by a lesser degree of alkylation than PAHs from petroleum, as high temperature processes (incomplete combustion or pyrolysis) favour less alkylation (National Research Council, 1985). In addition, combustion sources contain relatively low quantities of 2 to 3 ring aromatic families (e.g. naphthalenes), while being dominated by 4 to 6 ring PAHs, (e.g. pyrene and benzofluoranthenes) (Boitsov et al., 2009). NPD levels at station NC21_BCE006 are higher than those at other stations, which could be resulting from drilling operations at the Liza 1 well, however these elevated levels are not evident at stations NC21_BCE007 and NC21_BCE0023, both of which are closer to the well.

Throughout the Liza development EBS survey all stations were dominated by 4 to 6 ring PAHs with very low degrees of alkylation, indicating predominantly pyrolytic rather than petrogenic sources of input into the marine environment. However, high concentrations of the parent compounds in the mass to charge ratio (m/z) 252 were recorded across all stations. This pattern was attributed to the PAH perylene, which is linked to plant pigments from terrestrial runoff and is not indicative of either petrogenic or pyrolytic sources (Irwin, 1997).

Metals concentrations in sediments were generally low and variations in observed levels appear to reflect a common background source with the exception of one station (NC21_BCE025) where elevated concentrations appear to be due to an additional anthropogenic source. These metals could be, in part, introduced from contaminated terrestrial runoff from Guyana's' mining industry and the two main riverine inputs to the Guyana basin (TDI Brooks, 2014). Arsenic is a known by-product of gold mining, which is a key industry in Guyana. Concentrations of arsenic, lead and chromium exceeded the conservative NOAA ERL threshold values at 10, 2 and 1 stations, respectively but did not exceed the NOAA ERM screening values with the exception of arsenic at BCE025. If NOAA ERM values are exceeded, there is a higher probability that sediment quality will be impaired and impact the benthic community. However, such impacts are not obvious based on the analysis of macrobenthos collected at this site. All metals were present at low or undetectable concentrations in the water column and below USEPA marine water quality criteria.

Analysis of the photographic data collected by the SPI camera identified one biotope complex as defined by the European Union nature information service habitat classification system (EUNIS, 2015), 'circalittoral sandy mud' (A5.35) with aspects of 'Deep sea mud' (A6.5). Due to the limited snapshot nature of photographs taken by the system, benthic epifauna was scarcely observed. Where visible, the seabed observed on the SPI plan view images was inhabited by tube building polychaetes (possibly Sabellidae and Terebellidae) and burrowing shrimp. Seafloor features of biogenic origin, e.g. tubes, burrows, feeding pits, faecal casts and mounds were recorded in some stations using a combination of plan view and profile images. No potentially sensitive habitats were identified in the current survey.

The infaunal community recorded for the current survey was dominated by polychaetes (40% of taxa). The most abundant taxa overall were polychaetes from the genus *Spiophanes* and *Myriochele,* and amphipods of the family Ampilescidae.

Spiophanes only occurred in 44% of samples, while *Myriochele* occurred in 36% of samples and Ampilescidae occurred in 48% of samples. No taxa occurred in more than 48% of the samples taken, suggesting that there was notable variability in the benthic communities within the region.

Univariate analysis supported the suggestion that there was notable variability in the benthic community within the region. Primary variables (number of taxa and abundance of individuals) appeared to vary greatly between stations indicating variation in benthic community structure. Univariate measures of evenness (J' and 1-λ) varied between stations but the distribution of individuals amongst the different taxa tended towards evenness at all stations with station NC21_BCE018 being perfectly even (same number of species and individual taxa were present).

The diversity measure (H'), varied greatly between stations. Higher diversity was found at stations with greater evenness, whilst lower diversity was found at stations with greater dominance. Overall, diversity was relatively high across the survey area, with over ten species identified at 17 of the 25 grab sample stations. A weak negative correlation was observed between depth and number of taxa and abundance.

Multivariate analysis of the macrofauna data divided the stations into four groups of similar community composition, and two unclassified stations. It produced results suggesting that community structure was influenced by sediment type to some degree and depth. Within cluster similarity was low (<20%) for all clusters indicating that there was variation within the cluster groupings.

All cluster communities were significantly different from each other, with the top five characterising taxa from each cluster having no species in common except Ampilescidae, which was the third and first most characterising taxon of cluster groups D and E respectively. These differences in community structure may be linked to changes in sediment composition and water depth, as each group appears to comprise of similar sediment descriptions and depth ranges. However, the analyses showed no significant correlation between these abiotic factors and number of taxa or number of individuals. Multivariate analysis of the macrofauna community with PSD data showed no

correlation between grain size and macrofauna assemblages. As such, it is difficult to deduce whether there is a dominant influencing factor on the faunal communities.

Water profiling at the sixteen water sampling stations identified a generally stratified water column, with similarly shaped profiles at each station, with depth of thermocline, halocline and oxygen boundary increasing with water depth.

At all sixteen water profiling stations temperature, salinity and dissolved oxygen displayed a strong thermocline, halocline and oxygen boundary. Surface temperature at all stations were reasonably similar, however, lowest profile temperature decreased proportionally to water depth. Turbidity within the water column remained reasonably constant throughout the entire length of all water profiles, this is because the survey area is located offshore in deep water with little influence of direct fluvial (riverine) input. At all water sampling stations, the pH increased slowly with increasing depth and all profiles were very similar between stations.

TOC and TSS were generally low at all stations, with TOC increasing slightly overall with depth and TSS generally decreasing with depth.

Total hydrocarbon concentrations and polycyclic aromatic hydrocarbon (PAH) concentrations in seawater samples were generally considered to be at low levels across the survey area, with little variation between samples. All levels were found to be below the USEPA water quality guidelines published in Burgess *et al.* 2013. Gas chromatography traces exhibited only small spikes in individual long-chain n-alkanes at the water sampling stations at all stations. These long-chain n-alkanes are widely distributed in the plant kingdom (Douglas and Eglinton, 1966; Eglinton et al., 1962) and their presence may be indicative of an input to the water column through runoff from adjacent landmasses.

Heavy and trace metal concentrations were low in all water samples, being close to or below their respective detection limits in all cases and did not vary substantially between stations or with depth. Concentrations of all metals were below their respective US EPA Saltwater Quality Standards thresholds, where these were available.

5. REFERENCES

AQUAFACT, 2016. *Sediment Profile Imaging (SPI) Survey. Liza Site, Stabroek Licensed. Block Offshore Guyana*

BLOTT, S., 2010. *GRADISTAT: A Grain Size Distribution and Statistics Packages for the Analysis of Unconslidated Sediment by Sieving or Laser Granulometer.* Berkshire: Kenneth Pye Associates Ltd.

BLUMER, M. and SNYDER, W.D., 1965. Isoprenoid hydrocarbons in recent sediments: presence of pristane and probably phytane. *Science, **150***, pp.1588-1589.

BOITSOV, S., JENSEN, H.K.B. and KLUNGSØYR, J., 2009. Natural background and anthropogenic inputs of polycyclic aromatic hydrocarbons (PAH) in sediments of South-Western Barents Sea. *Marine Environmental Research*, **68**, (5), pp. 236-245.

BRAY, R.J., and CURTIS, J.T., 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs, **27***, pp. 325-349.

BUCHMAN, M.F., 2008. *NOAA Screening Quick reference Tables, NOAA OR&R Report 08-1 .* Seattle, WA: Office of Responce and Restoration Division, National Oceanic and Atmospheric Administration.

BURGESS, R.M., BERRY, W.J., MOUNT, D.R. and DITORO, D.M., 2013. Mechanistic Sediment Quality Guidelines Based on Contaminant Bioavailability; Equilibrium Partitioning Sediment Benchmarks, *Environmental Toxicology and Chemistry*, **32**, No. 1, pp. 102–114.

CHAO, A., 2005. Species richness estimation. In N. Balakrishnan, C. B. Read, and B. Vidakovic (Eds.), *Encyclopedia of Statistical Sciences.* New York: Wiley.

CLARKE, R.C. and GORLEY, R.N., 2006. *PRIMER v6: User Manual/Tutorial.* Plymouth: PRIMER-E.

DELAUNE, R.D. and REDDY, K.R., 2005. Redox Potential. *Encyclopedia of Soils in the Environment*. D. Hillel (ed). Academic Press. pp.366-371.

DTI., 1993. *Conditions for the Discharge of Oil Contaminated Cuttings Resulting from Offshore Drilling.* London: Department of Trade and Industry, Oil and Gas Division.

ELEFTHERIOU, A. and MCINTYRE A., 2005. *Methods for the Study of Marine Benthos.* Third Edition. ISBN 0-632-05488-3

EUNIS, 2012. *EUNIS Habitat Classification 2012 - a Revision of the Habitat Classification Descriptions,* Paris: European Topic Centre on Nature Protection and Biodiversity.

EUNIS, 2016. EUNIS Habitat Classification. [Online] Available at: *http://eunis.eea.europa.eu/habitats-code-browser.jsp*

FOLK, R.L., 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. *Journal of Geology*, **65**, (4), pp. 344-359.

INSTITUTE OF TERRESTRIAL ECOLOGY/INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE, 1996. Biotopes/Ecosystems Nomenclature. Habitats of South America [online].

Available at: *http://cb.naturalsciences.be/ants/pdf_free/PHYSIS-HabitatsSouthAmerica.pdf* [accessed September 2016].

LORING, D.H., 1991. Normalization of Heavy-Metal Data from Estuarine and Coastal Sediments. ICES *Journal of Marine Science: Journal du Conseil*, **48**, (1), pp.101-115.

LORING, D.H. and RANTALA, R.T.T., 1992. Manual for the geochemical analyses of marine sediments and suspended particulate matter. Earth-science reviews, 32(4), pp.235-283.

MCDOUGALL, J., 2000. The Significance of Hydrocarbons in the Surficial Sediments from Atlantic Margin Regions. In *Atlantic Margin Environmental Surveys of the seafloor 1996 and 1998.* Aberdeen: Atlantic Frontier Environmental Network.

NELSON-SMITH, A., 1972. *Oil Pollution and Marine Ecology.* London: Elek Science.

N.R.C., 1985. *Oil in the sea.* National Research Council of the National Academy of Sciences. National Academy Press, Washington,

OSPAR, 2004. *Guidelines for Monitoring the Environmental Impact of Offshore Oil and Gas Activities.* Reykjavik: OSPAR: Reference 2004-11e.

OSPAR, 2008. *2007/2008 CEMP Assessment: Trends and concentrations of selected hazardous substances in sediments and trends in TBT-specific biological effects.* Reykjavik: OSPAR Commission.

OSPAR, 2009a. CEMP Assessment Report: 2008/2009 Assessment of Trends and Concentrations of Selected Hazardous Substances in Sediments and Biota. Monitoring Assessment Series 2009. *http://qsr2010.ospar.org/media/assessments/p00390_2009_CEMP_assessment_report.pdf.*

OSPAR, 2009b. *Agreement on CEMP Assessment Criteria for the QSR 2010 Agreement number: 2009-2.*

OSPAR 2009c. Background Document on CEMP assessment criteria for the QSR 2010 OSPAR Commission Monitoring and Assessment Series, Publication Number: 461/2009. Available from: *http://qsr2010.ospar.org/media/assessments/p00390_supplements/p00461_Background_Doc_CEMP_Assessmt_Criteria_Haz_Subs.pdf.*

OSPAR, 2012 *Status Report on the OSPAR Network of Marine Protected Areas OSPAR Commission London.* Publication No. 618/2013

OSPAR, 2014. *Levels and Trends in Marine Contaminants and Their Biological Effects – CEMP Assessment Report 2013.* Monitoring and Assessment Series. OSPAR Commission London. Publication No. 631/2014.

PIELOU, E.C., 1969. *An Introduction to Mathematical Ecology.* New York: Wiley.

SHANNON, C.E. and WEAVER, W., 1949. *The Mathematical Theory of Communication.* Urbana: University of Illinois Press.

SIMPSON, E.H., 1949. Measurement of diversity. *Nature,* **163**, pp. 688.

UKOOA., 2001. *An Analysis of UK Offshore Oil and Gas Environmental Surveys 1975 – 1995.* Aberdeen: Heriot-Watt University, UKOOA.

USEPA (UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 2016. National Recommended Water Quality Criteria – Aquatic Life Criteria Table. Available from: *https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table,* Accessed 08 August 2016

WENTWORTH, C.K., 1922. A scale of grade and class terms for clastic sediments. *Journal of Geology, **30***, pp. 377-392.

WONG, M.K., and WILLIAMS, P.J., 1980. A Study of Three Extraction Methods for Hydrocarbons in Marine Sediment. *Marine Chemistry,* **9**, (3), pp. 183-190.

YOUNGBLOOD, W.W., and BLUMER, M., 1975. Olycyclic Aromatic Hydrocarbons in the Environment: Homologous Series in Soils and Recent Marine Sediments. *Geochimica et Cosmochimica Acta,* **39**, (9), pp. 1303-1314.

APPENDIX I

2017 Environmental Baseline Survey Report

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Final Water Quality Assessment Report for Exxon Guyana Phase 1

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FINAL WATER QUALITY ASSESSMENT REPORT FOR EXXON GUYANA PHASE 1









Prepared by:

January 2018

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FINAL WATER QUALITY REPORT FOR EXXON GUYANA PROJECT: PHASE 1 OFFSHORE GUYANA

Prepared for

ESSO EXPLORATION & PRODUCTION GUYANA LTD
99 New Market Street,
North Cummingsburg Georgetown,
Guyana

Prepared by:

Environmental Sciences Ltd
141 Riverside Drive, San Fernando,
Trinidad & Tobago, W.I.

January 2018

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1 INTRODUCTION

1.1 Background

Esso Exploration and Production Guyana Limited (EEPGL) has a Production Sharing Contract with the Government of Guyana which covers 26,800 km^2 in the Stabroek Block, offshore Guyana. In 2014, EEPGL applied for Governmental approvals for the development and execution of a Strategic Environmental Assessment (SEA) for a two-well drilling program within the Block. These approvals were granted in January 2015, and EEPGL subsequently undertook more than 2 years of exploration and assessment activities, within one of 2 specific areas of interest, the Liza Field.

The first exploration well, Liza-1, was successfully drilled during the first half of 2015, and in May of that year, EEPGL announced a significant discovery of high-quality oil-bearing sands with the Liza-1 well, approximately 190 km offshore Guyana. This discovery has given renewed impetus to the planning and development of the offshore area for oil and gas commercialisation, and, to this end, from 2014 to present, EEPGL has conducted several geotechnical, seismic and environmental baseline surveys within and adjacent to the Block. Included in the latter is a comprehensive metocean service program, within which RPS Group has been contracted by EEPGL for the retrieval, servicing and redeployment of metocean buoys placed within the Liza Field, and along the continental slope and shelf areas offshore Guyana. The metocean survey is geared towards the retrieval of long-term met-ocean data for application in environmental and other modelling work in preparation for additional project to be executed by EEPGL within the study area.

EEPGL requested under the contract with RPS for metocean survey service #4, targeted to be completed in September – October 2017, additional scope of services, including water quality assessment within the study area, for which ESL was sub-contracted by RPS in approximately July 2017.

1.2 Project Summary

ESL was sub-contracted by RPS to conduct additional environmental studies related to: (i) water column profiling (in-situ/probe); (ii) sampling of water for chemical analyses; and (iii) collection of DNA samples from water. Additional details pertaining to the scope of work are provided in Section 2.2 below.

1.3 Regulatory Setting

The scope of ESL's water sampling exercise is covered by the metocean survey environmental permit, issued to EEPGL by the Environmental Protection Agency of the Government of Guyana, for the execution of this work.

2 PROJECT OBJECTIVES & SCOPE

2.1 Study Objective

The objective of this study is to provide a description of the water quality within the study area for this Project (deepwater, slope and shelf areas), based on the review of in-situ and lab data related to the specific parameters specified, for the period October 2017.

2.2 Summary of Scope of Work

A total of 12 stations were identified by EEPGL, for the assessment of water quality. ESL's scope of work included the following:

1. Water column profiling (*in-situ*/probe) for 6 parameters at each of the 12 stations as identified by EEGPL, resulting in a water column profile for each parameter at each station. This gave 6 water column parameter profiles at each station, resulting in a total of 72 water column parameter profiles;
2. Sampling of water for chemical analyses at 3 levels of the water column (top, middle and bottom) at 12 stations, with duplicate sampling conducted in each instance, resulting in a total of 72 samples; and
3. Collection of DNA samples from water at 9 of the 12 stations. At each station, DNA samples were obtained in triplicate, at the top, middle and bottom of the water column, resulting in a total of 81 samples.

ESL was responsible for:

- Sample planning and execution upon the ESL-commissioned vessel during the pre-determined survey period (September-October 2017);
- Sample handling, storage, transportation and chain of custody to the relevant labs;
- Analysis and QA/QC of chemical parameters at ESL's lab facility;
- Management of ESL's laboratory analytical sub-contractors (IAG and ALS laboratories);
- Processing and QA/QC of in-situ/probe data and generation of depth profiles for each parameter; and
- Data management, analysis and reporting.

ESL's deliverables will include an electronic submission of the draft water quality assessment report, which will not include the results of the DNA genomic testing at the 9 identified stations, as that is the subject of a separate report by another sub-contractor.

The final submission will include an electronic submission in MS Word and pdf formats and will also include 1 printed copy.

2.3 Decision Statement

The procedures outlined by EEGPL for the execution of the additional scope of water sampling were adhered to, and sampling was completed within the required timeframe. All samples were processed within the required holding times and the report generation was well within the specified timeline. The overall objective of the study was met; the water quality within the sampled area was found to be of good quality for the sampling period October 2017.

3 PROJECT ORGANISATION & COMMUNICATIONS

The following Sections provide details of the services and capabilities of ESL, the ESL Field Team who were responsible for the water sampling exercise and contact data.

3.1 Names, Role and Contact Information for All Key Staff

Table 1 below presents information of the ESL sampling team members, their designation and roles, as well as contact data.

Table 1: Key Staff Information for the Exxon Guyana Offshore Project, Water Sampling (September – October 2017)

Name	Company	Designation	Role	Contact Information
Devon Ramoo	ESL	Senior Field Technician	Coordinate and execute water sampling exercise, CTD data collection and DNA sampling of the water column	(868) 739 1300
Mitra Rampersad	ESL	Field Technician	Assist in the execution of water sampling exercise, CTD data collection and DNA sampling of the water column	(868) 772 4999
Jason Apping	ESL	Field Technician	Assist in the execution of water sampling exercise, CTD data collection and DNA sampling of the water column	(868) 396 8676

3.2 Subcontractor Information

3.2.1 Company Profile

Environmental Sciences Limited (ESL) is a locally incorporated company launched in August 2003. The Company's main office is currently located at #141 Riverside Drive, San Fernando, Trinidad, West Indies.

The company's core resource base comprises of qualified and experienced professionals as well as international partners and consultants that provide support for environmental research, marine, coastal and land based projects.

Environmental Sciences Limited (ESL) retains expertise from the local and foreign industries familiar with upstream and downstream practices, engineering and scientific industrial specifications, in addition to a thorough understanding of the current legislation, in particular, the area of relevant environmental legislation for marine and land impact assessments, risk assessments and social assessments.

Environmental Sciences Limited is currently partners with leading companies who specialize in specific oceanography, numerical sediment transport, scour modelling studies and high level preparation of impact assessments. ESL also provides oil spill trajectory modelling through its affiliation with Tetra Tech. Tetra Tech is a leader in the field of coastal and marine modelling, Oil Spill Trajectory and prediction, sediment transport and effluent plume modelling. The company has also worked with IRC, ABS and DNV on various projects.

ESL also utilises the services of a high level risk assessment company for various levels of risk assessments (hazards identification, qualitative and quantitative QRA risk assessment) for specific projects.

ESL's core business stream includes the provision of technical and environmental studies and assessment solutions, engineering, design and project management services for the upstream and downstream industries as well as port and jetty development.

ESL's Environmental Management System (EMS) has been developed to provide quality policies and procedures. The company provides full time resources to maximize our quality system and update our EMS including ISO/IEC 17025 accreditation (see Appendix 1 for relevant certificates).

ESL takes pride in having local staff, which gives the company a better understanding of the areas within Trinidad and Tobago and the Caribbean. This local content is a valuable resource specific to the local diversity and variety of projects the company engages in.

3.2.2 ESL's Scope of Work

Environmental Sciences Limited (ESL) was subcontracted to conduct the water sampling exercise at 12 locations within the designated study area (see Figure 1 in Section 4.2 below). The project area is located approximately 23 km northeast off Guyana's coastline with water depths in the range 14 – 2,006 m. Water samples were retrieved during the period September 30 – October 5, 2017 in duplicate at each station at the top, mid and bottom levels of the water column. Section 2.2 above provides greater detail of the sampling exercise whilst Section 4.5.2 below provides the detailed water sampling methodology employed.

3.2.3 Contact Information

Environmental Sciences Limited (ESL) of Trinidad & Tobago, West Indies may be contacted via the understated telephone numbers and/or email addresses:

Telephone Nos.: (868) 657 – 9024
(868) 657 – 1560

Email address: jerome.als@environsciences.net
elka.bachan@environsciences.net
admin.assistant@environsciences.net

3.3 QC Journey Management for ESL Field Team

Exxonmobil Exploration Company | Generic Specifications

Geophysical Operations - Shallow Seabed Group | Initial Environmental Survey Acquisition and Analytical Methods

QC Journey Management Form

ExxonMobil Project: ~~Exxon~~ Phase 1 Water Quality Project.	Location: Guyana Marine offshore.
Estimated Duration Of Project: 35-45 days	Field Crew Name & Contact Information: Dean Ramoo (1-868-739-1300)
ExxonMobil Field Supervisor: Nil	Alternate Contacts: +870 773 991495
Consulting Company: ESL	Consultant Name – Position: Sr Field Tech (Marine) Mobile Tel: 1-868-739-1300 Email: dean.ramoo@environsciences.net
24/7 Emergency Contact Numbers: 1: 761-7084 - Allan Ramoo (Father) 2: 3:	Consultant Project Manager and Phone No: Ellen Ballan 1868657-1560 / 9024.
International Medical and Travel Insurance Information: Insurer: N/K Class: Policy Number:	Visa Validity: N/A Last Drug & Alcohol Test: 20/4/17. Offshore Survival/HUET Validity: 14/8/18 Physical Exam Validity: 20/2/2019
Insurance Company: N/K. Tel: Fax/Email:	Passport – Country and Validity: Trinidad + Tobago 16/02/2026 Visa – Issuer and Validity: N/A TWIC - Issuer & Validity: N/A.
Travel Itinerary: (or attach copy) Depart from Trinidad on the MV sea service on 9/9/17 Return to Trinidad from Guyana by air on 24/11/17	
Travel Coordinator – Contact Details: Shenelle Duncan (1-868-657-1560/9024) Check-in on arrival – Contact Details:	

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Exxonmobil Exploration Company | Generic Specifications

Geophysical Operations - Shallow Seabed Group | Initial Environmental Survey Acquisition and Analytical Methods

QC Journey Management Form

ExxonMobil Project: Exxon Phase 1 water Quality Project	Location: Guyana marine offshore
Estimated Duration Of Project: 35-45 days	Field Crew Name & Contact Information: Mitra Ramprasad (1-868-772-4999)
ExxonMobil Field Supervisor: Nil	Alternate Contacts: +870 773 991495
Consulting Company: ESL	Consultant Name – Position: Rel Tech (Marine) Mobile Tel: (1-868-772-4999) Email: mitra.ramprasad@enviosciences.net
24/7 Emergency Contact Numbers: 1: 788-0178 (mother - Tara Ramprasad) 2: 3:	Consultant Project Manager and Phone No: Ellen Bacon 1868 657 1560 /9024
International Medical and Travel Insurance Information: Insurer: N/A Class: Policy Number:	Visa Validity: N/A Last Drug & Alcohol Test: 20/4/17 Offshore Survival/HUET Validity: 1/1/21 Physical Exam Validity: 27/1/18
Insurance Company: Tel: N/A Fax/Email:	Passport – Country and Validity: Trinidad & Tobago 14/03/2016 Visa – Issuer and Validity: N/A TWIC - Issuer & Validity: N/A
Travel Itinerary: (or attach copy)	Depart from Trinidad on the MV Sea Serene on 9/9/17 Return to Trinidad from Guyana on MV Sea Serene on 23/11/17
Travel Coordinator – Contact Details: Shenelle Duncan (1868-657 1560 /9024) Check-in on arrival – Contact Details:	

Exxonmobil Exploration Company | Generic Specifications

Geophysical Operations - Shallow Seabed Group | Initial Environmental Survey Acquisition and Analytical Methods

QC Journey Management Form

ExxonMobil Project: Exxon Phase 1 Water Quality Project	Location: Guyana marine offshore
Estimated Duration Of Project: 35-45 days	Field Crew Name & Contact Information: Jason Apping 1868 396 8676
ExxonMobil Field Supervisor: N.I	Alternate Contacts: + 870 773991 495
Consulting Company: ESL	Consultant Name – Position: Field Tech (marine) Mobile Tel: 1868 396 8676 Email: jason.apping@gmail.com
24/7 Emergency Contact Numbers: 1: 320-1525 – Tamara Apping (wife) 2: 3:	Consultant Project Manager and Phone No: Ellen Bachan 1868 657-1560/ 9024
International Medical and Travel Insurance Information: Insurer: Class: N/A Policy Number:	Visa Validity: N/A Last Drug & Alcohol Test: 20/4/17 Offshore Survival/HUET Validity: 21/8/20 Physical Exam Validity: 27/1/18
Insurance Company: Tel: N/A Fax/Email:	Passport – Country and Validity: Trinidad + Tobago 23/03/2027 Visa – Issuer and Validity: N/A TWIC - Issuer & Validity: N/A
Travel Itinerary: (or attach copy) Depart from Trinidad on the M/V Sea Service on 9/9/17 Return to Trinidad from Guyana by air around 21st Nov 2017	
Travel Coordinator – Contact Details: Shurelle Duncan (1868 657 1560/ 9024) Check-in on arrival – Contact Details:	

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3.4 Special Training / Safety Certifications



Falck

Certificate

The Competent Authorities of
Falck Nutec Trinidad and Tobago Limited
Approved Training Centre
At Centre of Excellence, Macoya Road, Tunapuna, Trinidad
Hereby Certify that

Devon Ramoo

Has Attended and Successfully completed

Tropical Further Offshore Emergency Training (TFOET)

CERTIFIED COURSE (CODE 5614)

Start Date:	**15.08.2014**
End Date:	**15.08.2014**
Expiry Date:	**14.08.2018**

Certificate Number:

74245614150814401715

Stuart Aikenhead
Managing Director



Certificate

Falck Safety Services Limited

Mitra M. Rampersad

Participant

Has attended and been successfully assessed against the Learning Outcomes of

Tropical Further Offshore Emergency Training (TFOET)

OPITO APPROVED COURSE (CODE 5614)

7424561409011763414 2

Certificate Number

09.01.2017 - 09.01.2017

Course Training Dates

08.01.2021

Expiry Date

Managing Director: Wendy Zilla

Falck Safety Services



Certificate

Falck Safety Services Limited

Jason Apping

Participant

Has attended and been successfully assessed against the Learning Outcomes of

Tropical Further Offshore Emergency Training (TFOET)

OPITO APPROVED COURSE (CODE 5614)

7424561422081645928 8

Certificate Number

22.08.2016 - 22.08.2016

Course Training Dates

21.08.2020

Expiry Date

Managing Director: Wendy Zilla

Falck Safety Services

Dr. Victor Coombs

B.A. (U.M.B.) M.B.B.S (U.W.I) MSc C.H.D.C (LOND.)
D.P.H. (U.K.) D.I.H (RCP.RCS) A.F.O.M. (RCP) Cert. Av. Med (RCP) E.M.B.A (U.W.I)
MSc. Emerg. Med (U.W.I)

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Tel: 222-8021

14 Endeavour Road
Chaguanas,
Trinidad, W.I
Tel: 671-4859

E-Mail:gmesh1@carib-link.net

DATE: 2017/02/21

OFFSHORE MEDICAL CERTIFICATE
In accordance with Oil and Gas UK Medical Guidelines.

Name: DEVON RAMDOO Date-of-Birth: 09 FEB 1984

Company Name: ENVIRONMENTAL SCIENCES LIMITED

Occupation: MARINE TECHNICIAN

This individual has been examined in accordance with **OIL & GAS UK MEDICAL GUIDELINES,** and in my opinion is **FIT/~~UNFIT~~** for work offshore.

In the event of limited certification, state here the specific restrictions applying and the date of next review.

Restrictions: _____

_____

_____

Next review date: _____

Examining Physician Name (Print): **DR. VICTOR COOMBS.**

DR. VICTOR COOMBS
Consultant in Occupational & Environmental Health
UKOOA PIN #OGUK/2010/1603
123, Riverside Dr., San Fernando
Tel: 1-868 653 4055

PIN NO: **OGUK/2010/1603**

Date of Examination: 2017/02/21

Date of Expiry: 2019/02/20

Signed: _____

Dr. Victor Coombs

B.A. (U.M.B.) M.B.B.S (U.W.I) MSc C.H.D.C (LOND.)
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Tel: 671-4859

E-Mail:gmesh1@carib-link.net

DATE: 16/01/28

OFFSHORE MEDICAL CERTIFICATE
In accordance with Oil and Gas UK Medical Guidelines.

Name: MITRA RAMPERSAD Date-of-Birth: 28/11/1987

Company Name: ENVIRONMENTAL SCIENCES LIMITED

Occupation: FIELD OPERATIONS/SALES COORDINATOR

This individual has been examined in accordance with **OIL & GAS UK MEDICAL GUIDELINES,** and in my opinion is **FIT/UNFIT** for work offshore.

In the event of limited certification, state here the specific restrictions applying and the date of next review.

Restrictions: _____

_____

_____

Next review date: _____

Examining Physician Name (Print): **DR. VICTOR COOMBS.**

PIN NO: **OGUK/2010/1603**

Date of Examination: 16/01/28

Date of Expiry: 2018-01-27

Signed: _____

DR.VICTOR COOMBS
Consultant In Occupational & Environmental Health.
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Trinidad, W.I
Tel: 671-4859

E-Mail:gmesh1@carib-link.net

DATE:

OFFSHORE MEDICAL CERTIFICATE
In accordance with Oil and Gas UK Medical Guidelines.

Name: JASON APPING Date-of-Birth: 18/03/1980

Company Name: ENVIRONMENTAL SCIENCES LIMITED

Occupation: FIELD TECH

This individual has been examined in accordance with **OIL & GAS UK MEDICAL GUIDELINES,** and in my opinion is **FIT/UNFIT** for work offshore.

In the event of limited certification, state here the specific restrictions applying and the date of next review.

Restrictions: _____

Next review date: _____

Examining Physician Name (Print): **DR. VICTOR COOMBS.**

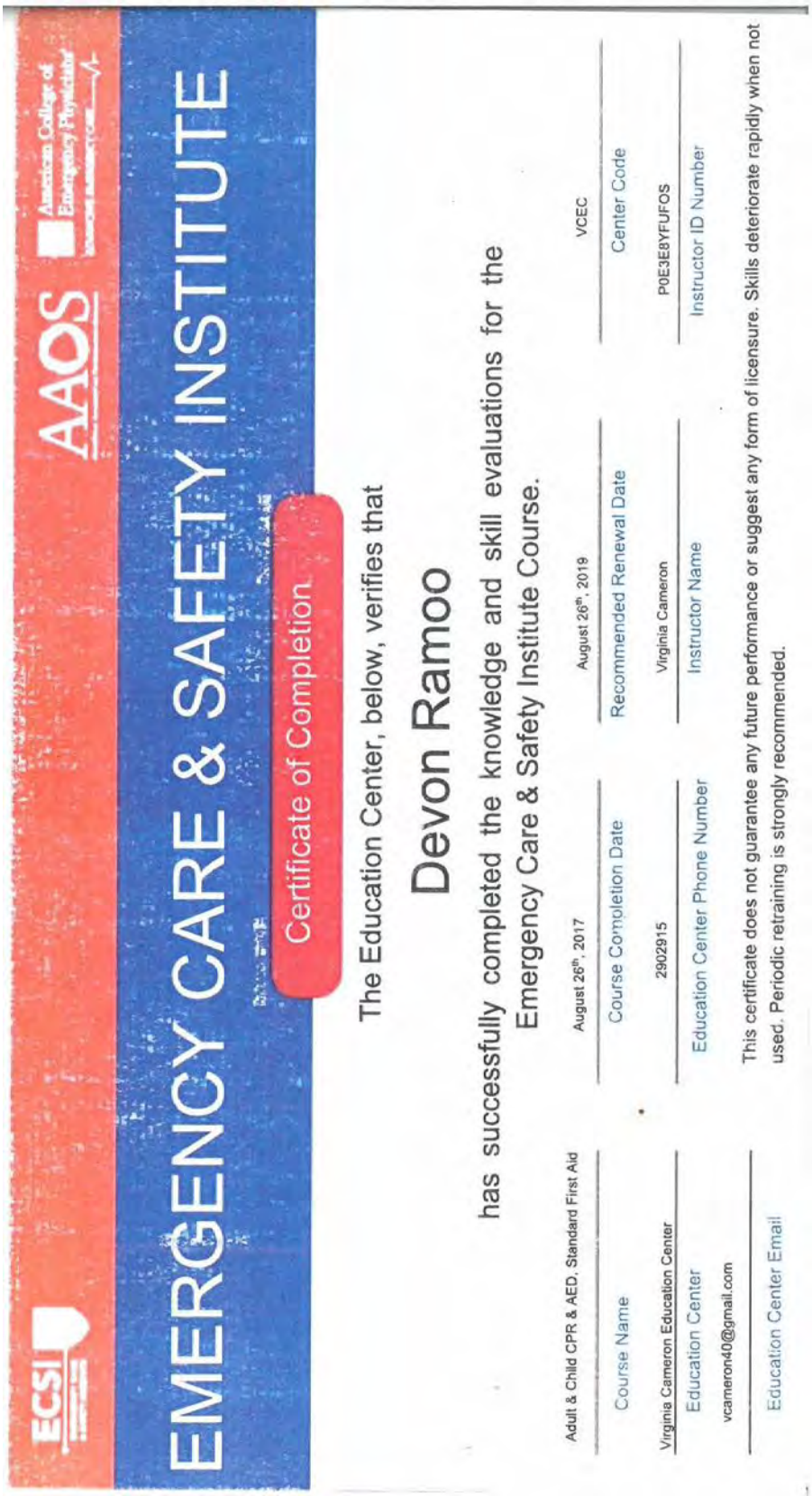
PIN NO: **OGUK/2010/1603**

Date of Examination: 16/01/28

Date of Expiry: 18-01-27

Signed: _____

DR.VICTOR COOMBS
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Cert.Av. Med., MSc. Emerg. Med.
Tel: 868-653-4055



ECSI

AAOS

American College of Emergency Physicians

EMERGENCY CARE & SAFETY INSTITUTE

Certificate of Completion

The Education Center, below, verifies that

Devon Ramoo

has successfully completed the knowledge and skill evaluations for the Emergency Care & Safety Institute Course.

Adult & Child CPR & AED, Standard First Aid	August 26th, 2017	August 26th, 2019	VCEC
Course Name	Course Completion Date	Recommended Renewal Date	Center Code
Virginia Cameron Education Center	2902915	Virginia Cameron	P0E3E8YFUFOS
Education Center vcameron40@gmail.com	Education Center Phone Number	Instructor Name	Instructor ID Number
Education Center Email	This certificate does not guarantee any future performance or suggest any form of licensure. Skills deteriorate rapidly when not used. Periodic retraining is strongly recommended.		



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Certificate of Completion

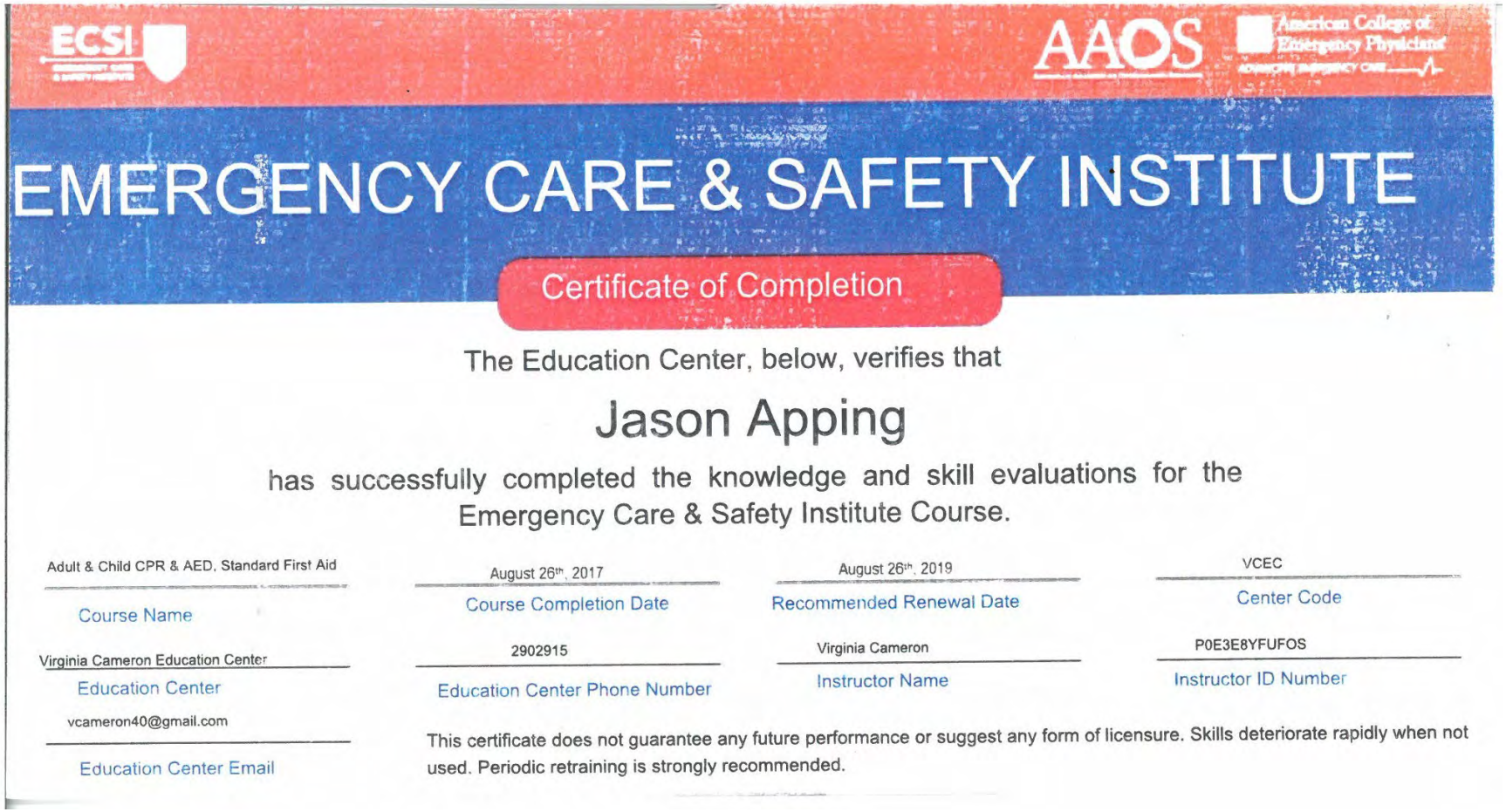
The Education Center, below, verifies that

Mitra Rampersad

has successfully completed the knowledge and skill evaluations for the Emergency Care & Safety Institute Course.

Adult & Child CPR & AED, Standard First Aid	August 26th, 2017	August 26th, 2019	VCEC
Course Name	Course Completion Date	Recommended Renewal Date	Center Code
Virginia Cameron Education Center	2902915	Virginia Cameron	P0E3E8YFUFOS
Education Center	Education Center Phone Number	Instructor Name	Instructor ID Number
vcameron40@gmail.com			
Education Center Email			

This certificate does not guarantee any future performance or suggest any form of licensure. Skills deteriorate rapidly when not used. Periodic retraining is strongly recommended.



ECSI

AAOS

American College of Emergency Physicians

EMERGENCY CARE & SAFETY INSTITUTE

Certificate of Completion

The Education Center, below, verifies that

Jason Apping

has successfully completed the knowledge and skill evaluations for the Emergency Care & Safety Institute Course.

Adult & Child CPR & AED, Standard First Aid	August 26th, 2017	August 26th, 2019	VCEC
Course Name	Course Completion Date	Recommended Renewal Date	Center Code
Virginia Cameron Education Center	2902915	Virginia Cameron	P0E3E8YFUFOS
Education Center	Education Center Phone Number	Instructor Name	Instructor ID Number
vcameron40@gmail.com			
Education Center Email			

This certificate does not guarantee any future performance or suggest any form of licensure. Skills deteriorate rapidly when not used. Periodic retraining is strongly recommended.

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4 FIELD PROGRAM

This Section presents the various aspects related to the field work undertaken by the ESL Field Team during the water sampling exercise for the period September 30 – October 5, 2017. The subsections below present the HSE approvals, sampling logs, equipment list, packing and shipping instructions, as well as sample disposal.

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4.1 Job Safety Analysis (JSA) for Water Sampling

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JOB SAFETY ANALYSIS

Location/System	Offshore Guyana	**Date**	September-November 2017	**JSA # 17-20**	**Site Visited:** Yes	**Team Lead:** Devon Ramoo **Company:** ESL
Job/Task Description	**Water Sampling and CTD Probe Work**					
Name of Vessel	**Sea Service**					
Prepared by: Jared Bisnath (IISEAdvisor/Field&Marine Tech.)						
Has consideration been given to weather conditions YES ~~NO~~	Are written job procedures discussed YES ~~NO~~		Are there SIMOPS YES~~NO~~		Emergency Response Plan Made & Discussed YES ~~NO~~	

Hazard Effect (HE) x Probability (P) =Risk(R) *R Signifies residual risk after control measures in place

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY/ DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
Journey to sample points and Deploying and retrieving sampling equipment (CTD Probe, Niskin, Winch). The winch system uses rope.	Collisions with vessels and installations	Injury &/or Drowning of personnel on board vessel; Loss of Vessel & Equipment	3	2	6	High	Vessel Captain certified and competent. Vessel inspected and approved before use -vessel in good working condition. Double check sample coordinates against the coordinates of pipeline locations. Call channel 16 on radio to acquire emergency assistance for towing to safe point. Use Satellite phone if needed (ESL: +870773907924). Use satellite phone to get assistance. Anchor and secure vessel until help arrives. SOPEP Spill kits for on deck spill response; Follow the ERP.	3	1	3	Medium	Team Lead
	Winch system failure	Crushed limbs, abrasions, fire, loss of equipment, amputations	3	2	6	High	Winch certified for use. Adequate supervision Winch and cables visually inspected before taken to work site and before use. Workers competent to use winch Adequate power supply Proper certified cable used for winch system Fire extinguisher on board with current inspection certificate	3	1	3	Medium	Team Lead

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SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
							Clearly identified Work Area					
	Leaks from machinery	Slippery conditions, falls, broken limbs, environmental damage.	2	2	4	Medium	Inspect equipment intermittently for leaks. PM Program Use drip trays where needed. If possible, tie absorbent pads to leak points. Universal absorbent pads used for cleaning up spills must be stored in a proper container. On reaching land, these are taken to an approved disposal company such as Envirocare for disposal. Do not wash the deck of the boat until spills are cleaned.	2	1	2	Low	Team Lead
	VesselFailure (engine, rudderfailure, etc)	Collisions, robberies, dehydration,	3	2	6	High	Use satellite phone to get assistance (ESL:). Call channel 16 on radio to acquire emergency assistance for towing to safe point. Anchor and secure vessel until help arrives. Follow procedure in ERP.	3	1	3	Medium	Team Lead
	Incompetent workers	Personal injury, injury to other works, damage to property	2	2	4	Medium	Workers trained and competent to retrieve samples (Follow SOP). Exercise adequate care when sampling. Use required PPE.	1	1	1	Low	Team Lead
	Cable	Cuts, entanglement.	2	2	4	Medium	Inspect cables before use. Be mindful of hand placement when winch is in operation.	2	1	2	Low	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
		amputation, struck by					Use of PPE. Cordoned off work area					
	Falling objects	Head injuries, Broken bones, death	3	2	6	High	Establish lifting plan before testing winch. Never stand, walk or work under a load. Use of PPE (safety hat, etc.) Cordoned off work area	3	1	3	Medium	Team Lead
	Struck by objects	Head injuries, broken bones, soft tissue injury death.	3	2	6	High	Pay attention to activities. Do not walk into areas where loads are being lifted and transferred. Use of PPE (safety hat, etc.) Cordoned off work area	3	1	3	Medium	Team Lead
	Man overboard	Head injuries, broken limbs, drowning	3	2	6	High	All team members adequately trained in safety procedures for working on floating structures and near/over open water and on boats. Ensure that approved life jackets or work vests are worn at all times. Fall arrest systems are used where fall prevention mechanisms (e.g. railings) are not in place: The area will be properly highlighted and cordoned off via tiger-striped painting indicating requirements of special approved and certified fall arrest PPE. Persons within this area must wear at all times; Full body harness which will be connected to retractable lanyards and Work Vests. The Lanyard will not allow for persons to reach over the edge of the boat and will be attached to certified anchor points.	3	1	3	Medium	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
							Only persons designated by the Team Leader as necessary for work within this area will be allowed access. Follow ERP.: man overboard procedure					
	Inclement weather	Damage to boat, drowning, lightning strikes (burns, damage to equipment, death)	2	2	4	Medium	Listen to weather advisory. Monitor changes in weather. Abandon work in extreme weather. Follow procedure in ERP.: inclement weather procedure	2	1	2	Low	Team Lead
	Poor manual handling techniques	Muscle sprains and strains, falls, cuts, crushed appendages	2	2	4	Medium	Use mechanical means where practical Establish lifting plan, adequate supervision, adequate training, use of proper manual handling techniques, establish clear lines of communication, adequate manpower, use of PPE	1	1	1	Low	Team Lead
	Rotating parts and pinch points e.g. the winch & grab	Amputations, cuts, soft tissue damage	2	2	4	Medium	Workers must use care around equipment and avoid distractions Be aware of the placement of hands and feet around all moving parts of equipment. Proper emergency shutdown controls and proper guards installed on machinery.	1	1	1	Low	Team Lead
	Poor lighting conditions	Personnel injury	2	2	4	Medium	Ensure that there are adequate lighting on deck at all times.	1	1	1	Low	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
	Threats to the environment	Environmental damage	2	2	4	Medium	Ensure that all chemicals are properly contained. Spill containment and proper disposal of any oily waste Maceration of food and freezing of food waste. Garbage such as food, cups, paper etc, stored in a refrigerated compartment. On reaching land, the garbage is then taken to an approved facility such as SWMCOL. Untreated sewage will be stored on board the vessel in an approved tank. On land, sewage will be pumped out of the tank and onto an approved truck for disposal at a sewage treatment facility. Minimize disturbance to the ocean floor – on reaching sample points, ensure that sample coordinates are accurate to avoid taking additional grabs which further disturb the seabed.	1	1	1	Low	Team Lead
	Piracy	Injury to Personnel, Loss of Life, Loss of Equipment / Vessel					Refer to ARSingh Security Plan/Procedure					Team Lead/Vessel Master
Journey between sampling points.	Same as journey to sample points. Follow the same safety procedures.											

SAFETY EQUIPMENT REQUIRED:

Safety hard hat	Y	Safety Glasses	Y	Face Shield	N	Hearing Protection	Y	Goggles	N	Cotton Gloves	N	Fire Blanket	N	Lock Out	N
Safety Harness	Y	Barricades	N	Vessel Entry permit	N	Fire resistant clothing	Y	Rubber gloves	Y	Chemical Resistant gloves	Y	Tag out	Y	Fire extinguishers	Y
Rope off area	N	Hot work permit	N	Fire watch	N	Scaffolding	N	Gas detectors	N	Lifting precaution	Y	Dust mask	N	Respirator	N
Safety Footwear	Y														

HAZARD CHECKLIST:

Falls from heights	N	Falling objects	Y	Collision	Y	Access/Egress	Y	Moving Machinery	Y	Liquid or Gas under Pressure	Y
Noise	Y	Chemical exposure	Y	Illumination	Y	Flammable Materials	Y	Flaring / hydrocarbon gas release	N	Electricity	N
Oil/ Chemical	Y	Competence of personnel	Y	Confine Space	N	Corrosive Material	N	Manual Handling	Y	Naked Flames	N

Was toolbox meeting held: Yes No?

NAMES OF JOB CREW:	DEVON PARSON	CLIFTON ASH	MARK BRUCE	CARLOS ESTREADA	MITRA PACHECO	JASON APPING	NIGEL GILL	CHRIS MALMQVIST			
SIGNATURES OF JOB CREW:											
APPROVED BY:											

EMERGENCY CONTACT LIST

Emergency Numbers

TRINIDAD	
Ambulance	**811**
Police	**999**
Coast Guard	**634-4440**
Air Guard **Air Guard Operations**	**669-3877/4787** **669-7067**
GUYANA	
Ambulance	
Police	
Coast Guard	
Air Guard **Air Guard Operations**	
ESL Main Office	**657-1560**
ESL – Jerome Als (Managing Director)	**684-5209**
ESL – Nicholas Als **(Operations Manager)**	**312-0917**
ESL – Elka Bachan (Project Manager)	**389- 2673**
ESL Company Doctor – Dr. Moonan	**652-3664**
ARSingh Contact - Nicholas Kowlessar	**732-4599**

Radio Contact

Channel 16 **Call Sign - HP6228**

Vessel Contacts

ESL Sat	**+870773993548**
Sea Service **VSat** **Email**	**+870773212982**

Exxon Contact

Scott Moser	832 624 3662 Tel 832 683 0286 Cell j.scott.moser@exxonmobil.com e-mail

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Risk Ranking

Table 1: Hazard Effects and Rating

Hazard Effect	HE Rating
Major	3
Medium	2
Minimum	1

Table 2: Probability and Rating

Probability	P Rating
Highly Possible	3
Possible	2
Unlikely	1

Table 3: Risk Ranking Matrix

RISK MATRIX				
	Probability Rating			
HE Rating		1	2	3
	1	1	2	3
	2	2	4	6
	3	3	6	9

KEY

	Low Risk
	Medium Risk
	High Risk

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TOOL BOX MEETING FORM

Date:

Conducted By:

Location:

Topics Discussed

Attendees

NAME IN BLOCK LETTERS	SIGNATURE

4.2 Sampling Plan Design

The sampling plan for this study is shown in Figure 1 below. The plan was designed to ensure that water samples would be obtained throughout the project area; at the shelf and deepwater locations. Twelve stations were selected within the study area. The UTM coordinates for these sampling stations (WGS ’84 datum, Zone 20N) are presented in Figure 1 below.

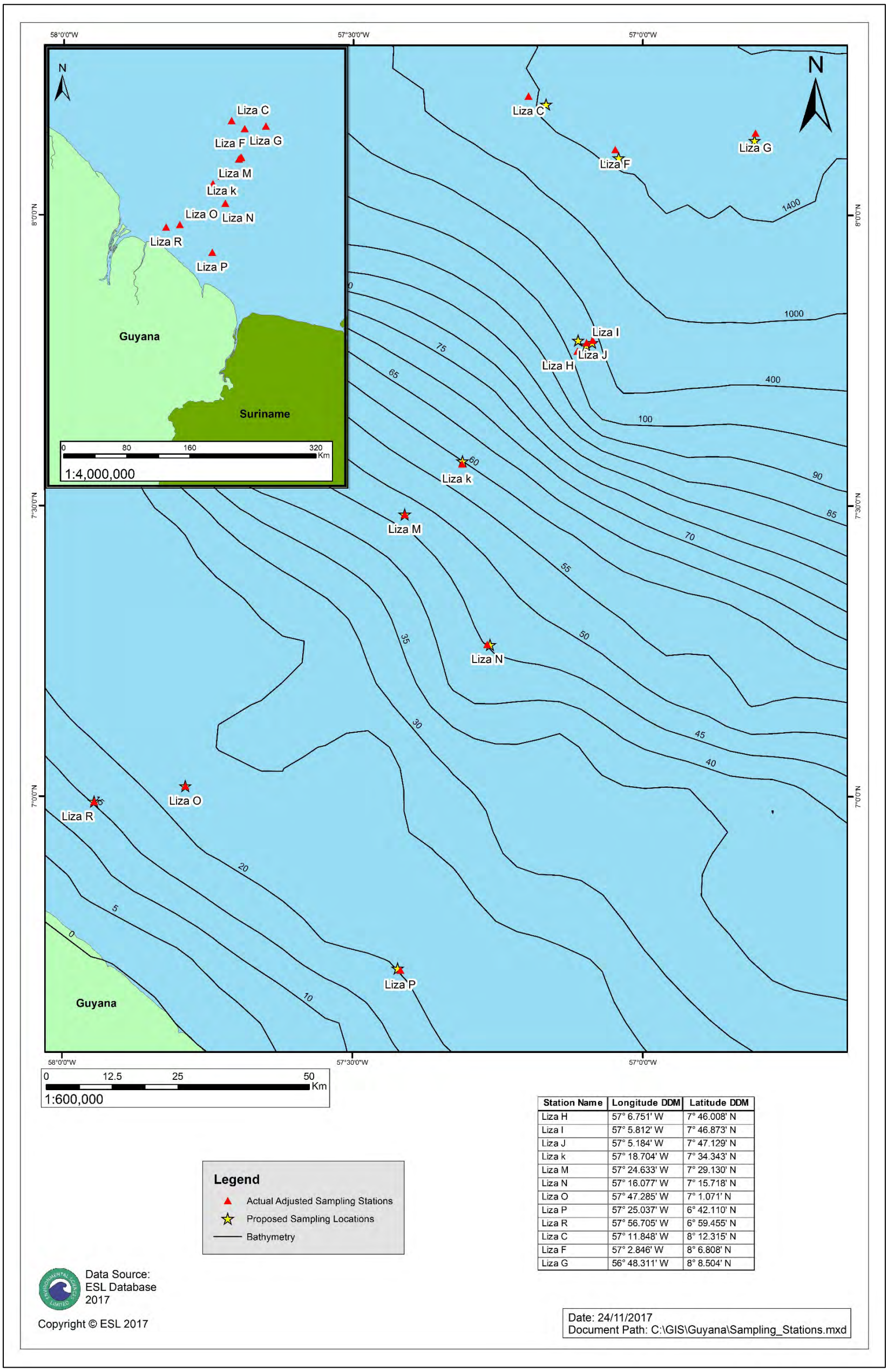
The development of the sampling plan map took into account the following, in order to inform the spread of the stations:

1. The location of 12 Metocean buoy locations in the project area was considered for a representative study area design

2. The SOW requirement at the same aforementioned 12 locations for the CTD and water quality assessment at top, mid and bottom depths (in duplicate); a total of 72 water quality stations and 12 CTD data collection locations

3. Localised bathymetry within and around the project area was considered to check for major seabed structures, and it was found that the area was fairly shallow, moderately deeper at the shelf and extended into the deepwater zone.

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Station Name	Longitude DDM	Latitude DDM
Liza H	57° 6.751' W	7° 46.008' N
Liza I	57° 5.812' W	7° 46.873' N
Liza J	57° 5.184' W	7° 47.129' N
Liza k	57° 18.704' W	7° 34.343' N
Liza M	57° 24.633' W	7° 29.130' N
Liza N	57° 16.077' W	7° 15.718' N
Liza O	57° 47.285' W	7° 1.071' N
Liza P	57° 25.037' W	6° 42.110' N
Liza R	57° 56.705' W	6° 59.455' N
Liza C	57° 11.848' W	8° 12.315' N
Liza F	57° 2.846' W	8° 6.808' N
Liza G	56° 48.311' W	8° 8.504' N

Figure 1: Water and CTD Sample Locations for Exxon Guyana, Offshore Project, Phase 1 (September – October 2017)

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4.3 Field Documentation

This Section presents the records taken during the sampling event and the Chain-of-Custodies (COCs) until samples were delivered to the ESL, IAG and ALS Environmental laboratories.

4.3.1 Station Logs

Table 2 below presents the names of the12 locations sampled during Phase 1, the date of sampling and their corresponding water depth in metres. The coordinates of each location sampled is presented in the Degree, Minutes, Second (DMS) format.

Table 2: Log of Sample Stations for Phase 1 Water Sampling (September – October 2017)

Station Name	Date Sampled	Depth (m)	Coordinates	
			Latitude	Longitude
Liza C	04/10/2017	1704.5	8° 12' 18.90"N	57° 11 '50.89"W
Liza F	04/10/2017	1713.4	8° 6' 48.48"N	57° 2' 50.77"W
Liza G	05/10/2017	2005	8° 8' 30.21"N	56° 48'18.67"W
Liza H	30/09/2017	133.3	7° 47' 0.48"N	57° 6' 42.84"W
Liza I	01/10/2017	156.8	7° 46' 50.94"N	57° 5' 48.78"W
Liza J	01/10/2017	214.4	7° 47' 7.74"N	57° 5' 11.04"W
Liza K	01/10/2017	63.7	7° 34' 26.52"N	57° 18' 30.90"W
Liza M	01/10/2017	53.3	7° 29' 7.80"N	57° 24' 37.98"W
Liza N	01/10/2017	47.9	7° 15' 43.08"N	57° 16' 4.62"W
Liza O	02/10/2017	25.8	7° 1' 13.92"N	57° 47' 3.54"W
Liza P	02/10/2017	22.8	6° 42' 11.40"N	57° 25' 9.24"W
Liza R	02/10/2017	13.1	6° 59' 27.28"N	57° 56' 42.33"W

4.3.2 Chain-of-Custody

Chain of custody (COC) forms are used to track samples from the point of sampling, during transit and final delivery of samples to the preferred laboratories. Appendix 2 provides the COCs for ESL, IAG and ALS Environmental laboratories.

4.4 Detailed List of Field Equipment/Supplies

Water quality sampling and CTD data collection within the project area necessitated a variety of equipment and supplies. These are presented in Table 3 below, whilst Appendix 3 provides the relevant calibration certificates.

Table 3: Summary of Sampling Equipment/Supplies

Item	Name of Equipment	Quantity
1	Generator	2
2	SeaBird CTD	1
3	Electric Winch	1
4	Niskin Water Samplers	5
5	Dyneema Synthetic rope	1
6	Plastic Sample bottles	350
7	Glass Sample bottles	175

4.5 Water Sample Survey, Offshore Guyana (September – October 2017)

Prior to water sampling by the ESL Field Team, the Sea Service was fitted with the necessary equipment during vessel mobilisation in Trinidad as discussed in Section 4.5.1 below.

4.5.1 Vessel Mobilisation

The vessel (Sea Service) was outfitted with a specialised A-Frame for sediment sampling. Differential GPS and navigation software were also added to the vessel so that navigation to monitoring points would be more efficient and accurate.

After securing sampling equipment on the vessel, function tests were conducted on all GPS and sampling equipment below:

- DGPS System (with GPS antenna and differential signal receiver)
- HYPACK Software (computer-based navigation software to receive input from the DGPS system
- A-frame and hydraulic winch
- Electric winch
- SeaBird CTD Profiler
- Niskin water samplers and
- Generator (x2)

The Vessel departed to Guyana after all function tests were passed.

4.5.2 Water Sampling Methodology

Water sampling was conducted at each of the 12 stations identified in Figure 1 above with the aid of a Niskin Non-Metallic Water Sampler and SeaBird CTD, during the period September 30th – October 5th, 2017. The CTD was first deployed to reach the seafloor to ascertain the thermocline. Thereafter 2 clean 15L Niskin samplers were attached and deployed using the mechanical winch. On reaching the desired depth, it was then triggered using a messenger device that closed the sampler, thereby collecting the duplicated water (one sample per Niskin) at the bottom of the water column, 1 m above the end of the weighted line. The CTD was then removed and the data downloaded; the purpose of this was to determine the location of the thermocline, which in turn determined the location of the 'middle' water sample. Sampling at the top of the water column, the sampler was triggered within 1 m below the surface.

Each sample was retrieved from the water sampler using the winch. Water samples to be analysed for nutrient and metal parameters in the laboratory were filled into 1L plastic containers, whilst samples for saturated hydrocarbons, cyanides and TOC (500 ml) were filled into glass bottles. Similarly, bottles used to collect water samples for metals analysis were pre-treated with nitric acid, whilst the bottles used to collect water samples for TOC, COD and ammonia were pre-treated with sulphuric acid. Additionally, bottles for cyanide were pre-treated with sodium hydroxide, whilst saturated hydrocarbons were prepared with hydrochloric acid. All bottles were labelled appropriately (see Appendix 4) and subsequently refrigerated at 4°C for transport.

In-situ sampling was also conducted at the 12 water stations referenced above, as shown in Figure 1 above, during the period September 30th – October 5th, 2017. This was conducted with the use of SBE 19 plus SeaBird CTD profiler, which was deployed into the water column at a steady rate from the surface to the sea floor, and recorded data continuously once sensors were exposed to water. When

completed, each probe was retrieved from the water, and data were checked to ensure values were obtained for the applicable parameters.

The CTD profiler was equipped with built-in sensors to measure conductivity, temperature and depth directly, and were also equipped with optional (additional) sensors for the measurement of pH, dissolved oxygen and turbidity. Salinity was calculated by the software component, based on the values recorded for conductivity.

All sampling utilised standardised and scientifically robust methods as outlined in '*Standard Methods for the Examination of Water and Wastewater 22nd Ed*.' and USEPA (Rice *et al.* 2012). To assist in reliability, analytical accuracy and valid interpretation of data, a program of quality control measures was implemented in sample collection and handling / preservation.

Water Monitoring Quality Assurance and Quality Control (QA/QC) Analysis

The Quality Assurance and Quality Control (QA/QC) analysis was entrained in the water sampling methodology, which was designed to provide routine and consistent checks, to ensure data integrity, accuracy and completeness. QA/QC activities include general methods such as accuracy checks on data sampling and acquisition and the use of approved standardised procedures. QA/QC procedures executed by ESL's technical team include the following:

- Sampling was conducted by trained and experienced technicians
- The Seabird CTD was deployed first to determine the location of the thermocline
- The Niskin sampler used has a messenger device that closes at the desired depth, ensuring that a representative sample of the respective water depth is obtained without contamination
- The sample containers were acid washed prior to sampling to prevent contamination. This was done for all types of sampling containers/bottles
- Proper labeling of the sample bottles at all stations were conducted which include the date, sample station number and an indication of the level at which the water was collected, i.e. top, middle or bottom
- To minimise the potential for volatilisation or biodegradation between sampling and analysis, samples were kept at 4°C
- Standard analysis methodologies were utilised
- A Chain of Custody was issued by the field technicians to the ESL, as well as the IAG and ALS Environmental lab personnel upon receipt of samples.

4.5.3 Vessel Demobilisation

After docking, samples were removed and dispatched to the ESL, IAG and ALS Environmental laboratories for the respective analyses (see Section 4.5.2, Table 6 below).

4.6 Field Instrument Use and Calibration

A detailed equipment list is provided in Section 4.4 above (see Table 3). Of the 7 types of equipment used during the water sampling survey, only the SBE 19+ Seabird CTD Profiler required calibration. Calibration certificates for 5 sensors (pH, temperature, dissolved oxygen, conductivity, pressure and turbidity) are provided in Appendix 3. Depth was determined from the pressure readings.

4.7 Sampling Equipment Decontamination Methods

Niskin water samplers that are fitted with a messenger that triggers the collection of the water samples at the desired depths were utilised during this sampling exercise. Upon retrieval of the samplers, the water was transferred to the respective pre-treated bottles for storage via a tap located at the bottom of the Niskin water sampler (see Figure 2 below).



Figure 2: Niskin Water Sampler

Prior to the redeployment, the water samplers were decontaminated by washing with DNase and deionised water. This ensured that subsequent samples were not tainted in any way.

4.8 Sample Handling Instructions (processing, preservatives)

The ESL field team were responsible for the collection, preservation and handling of water samples from the point of sample retrieval to the delivery of samples. The team followed the SMEWW 1060C for Sample Storage and Preservation.

The preservation included the addition of either sodium hydroxide, hydrochloric acid or nitric acid to the samples for the different parameters to be analysed (see Table 5 below in Section 5.1 below). To attain the pH required for the preservation of the water samples, ESL's field team used a dropper and gradually added the required acid (see Table 5 below) whilst simultaneously checking the pH of the sample to attain the pH needed per sample.

4.9 Packing Instructions (important for laboratory samples)

Upon retrieval and collection of the water samples into their respective pre-treated bottles, they were subsequently packaged and storage at the recommended temperature and environmental conditions during the sampling exercise and transit, until delivery to the different laboratories.

The Packing Instructions employed is as follows:

1. Insert large plastic bag in cooler, and place about 1'' of padding along the bottom of the bag.
2. Insert cold sample bottles (standing up) and individually wrapped in bubble wrap, in the bag.
3. Place Ziploc bags filled with ice on top of the sample containers, and along the sides if there is enough space.
4. Place an additional layer of padding at the top of the samples.
5. Pull ends of plastic bag up, squeeze air out of bag, twist and knot the plastic bag.
6. Place an additional layer of padding at the top of the plastic bag.
7. Place chain of custody forms inside a Ziploc bag and tape the bag to the inside of the lip of the cooler.
8. Close the cooler and seal with packaging tape, wrapping the tape vertically around the cooler.
9. Tape the address of the recipient to the outside of the cooler

4.10 Shipping Instructions (custom broker for international shipments)

Shipping Instructions:

1. Prepare the Toxic Substances Control Act (TSCA) form (in triplicate), Commercial Invoice and soil permit (if applicable) for preferred courier.
2. Complete the airway bill for preferred courier.
3. Call local courier and make an appointment for the collection of the samples.

All shipping airway bills are provided in Appendix 5.

4.11 Sample disposal

After the completion of analysis, samples are retained for a period of 6 months from the date of submission of report to the client. Upon the expiration of this time period, the date of disposal is logged into the Sample Log Book prior to disposal. Samples are disposed of by washing down the sink unless they are considered toxic, in which case they are disposed of at ESL's remediation site.

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5 CHEMISTRY ANALYTICAL (LABORATORY) PROGRAM

Chemical analysis of the 72 water samples retrieved with the designated project area, were conducted by ESL and partner laboratories, International Analytical Group (IAG) and ALS Environmental (ALS). Table 4 below shows the 3 laboratories that conducted the analysis and the parameters that were done by each. The respective laboratory certificates of accreditation are provided in Appendix 1.

Table 4: Summary of the Water Quality Parameters analysed Offshore Guyana, (September – October 2017)

Name of Laboratory	Type of data	Equipment	Parameter Analysed
ESL	In-situ	SeaBird CTD	pH
			Temperature
			Specific conductivity
			Salinity
			Dissolved oxygen
			Turbidity
	Analytical	Laboratory	Total dissolved solids
			Total suspended solids
			Chemical oxygen demand
			Ammonia
			Total Metals (arsenic, barium, cadmium, chromium, copper, iron, mercury, nickel, zinc)
IAG	Analytical	Laboratory	Total organic carbon
			Total cyanide
ALS	Analytical	Laboratory	Saturated hydrocarbons

5.1 Analytical Methods for Chemical Analysis

Table 5 below summarises the analytical methods used for water quality analysis, the detection limits, the preservation and storage techniques, holding times as well as the quality assurance/quality control measures executed during the actual analysis.

Table 5: Summary of Analytical Test Methods for Parameter Analyses

PARAMETER	TEST PROCEDURE	Detection Limit	QC Acceptance Limit	HOLDING TIME	PRESERVATION REQUIREMENTS	QA/QC DETAILS REQUIRED
Temperature °C	SMEWW 2550 B	N/A	N/A	In -Situ	N/A	N/A
Depth (m)	-	N/A	N/A	In -Situ	N/A	N/A
Conductivity	SMEWW 2510 A	N/A	N/A	In -Situ	N/A	N/A
Salinity (psu)	SMEWW 2520 A	N/A	N/A	In -Situ	N/A	N/A
Dissolved Oxygen (mg/L)	SMEWW 4500-O G	N/A	N/A	In -Situ	N/A	N/A
Turbidity (NTU)	SMEWW 2130 A	N/A	N/A	In -Situ	N/A	N/A
pH	SMEWW 4500-pH A, B	N/A	N/A	In -Situ	N/A	N/A
Total Dissolved Solids (mg/L)	SMEWW 52540 C	2.00	90 %- 110%	28 days	Cool, 4°C	Duplicate, blank
Total Suspended Solids (mg/L)	SMEWW 2540 B	0.20	90 %- 110%	7 days	Cool, 4°C	Duplicate, blank
Chemical Oxygen Demand (mg/L)	SMEWW 5220 C	30	90 %- 110%	28 days	Cool, 4°C, H_2SO_4 to pH<2	Duplicate, blank, check standard
Ammonia (mg/L)	SMEWW 4500-NH_3	0.01	90 %- 110%	28 days	Cool, 4°C, H_2SO_4 to pH<2	Duplicate, blank, check standard
Cyanide (mg/L)	SMEWW 4500 CN^- C & F	0.005	90 %- 110%	14 days	Cool, 4°C in dark. NaOH to pH>12	Duplicate, blank, check standard
Total Chromium (mg/L)	SMEWW 3030E & 3111A & B	0.23	90 %- 110%	6 months	Cool, 4°C, HNO_3 to pH<2	Duplicate, blank, check standard, spike
Nickel (mg/L)	SMEWW 3030E & 3111A & B	0.33	90 %- 110%	6 months	Cool, 4°C, HNO_3 to pH<2	Duplicate, blank, check standard, spike
Copper (mg/L)	SMEWW 3030E & 3111A & B	0.19	90 %- 110%	6 months	Cool, 4°C, HNO_3 to pH<2	Duplicate, blank, check standard, spike
Iron (mg/L)	SMEWW 3030E & 3111A & B	0.20	90 %- 110%	6 months	Cool, 4°C, HNO_3 to pH<2	Duplicate, blank, check standard, spike

PARAMETER	TEST PROCEDURE	Detection Limit	QC Acceptance Limit	HOLDING TIME	PRESERVATION REQUIREMENTS	QA/QC DETAILS REQUIRED
Zinc (mg/L)	SMEWW 3030E & 3111A & B	0.18	90 %- 110%	6 months	Cool, 4°C, HNO_3 to pH<2	Duplicate, blank, check standard, spike
Arsenic (mg/L)	SMEWW 3030E & 31114 & B	0.01	90 %- 110%	6 months	Cool, 4°C, HNO_3 to pH<2	Duplicate, blank, check standard, spike
Barium (mg/L)	SMEWW 3111A D	0.01	90 %- 110%	6 months	Cool, 4°C, HNO_3 to pH<2	Duplicate, blank, check standard, spike
Cadmium (mg/L)	SMEWW 3030E & 3111A & B	0.06	90 %- 110%	6 months	Cool, 4°C, HNO_3 to pH<2	Duplicate, blank, check standard, spike
Mercury (mg/L)	SMEWW 3030E & 31112 & B	0.00	90 %- 110%	28 days	Cool, 4°C, HNO_3 to pH<2	Duplicate, blank, check standard, spike
Saturated Hydrocarbons (µg/L)	USEPA 8015 C	200 - 320	90 %- 110%	14 days	Cool, 4°C, HCL to pH<2	Duplicate, blank, check standard, spike
Total Organic Carbon (mg/L)	MSA Walkley Black	1.00	90 %- 110%	28 days	Cool, 4°C, H_2SO_4 to pH<2	Duplicate, blank, check standard, spike

5.2 Analyte Listing

Table 6 below presents the complete list of water analytes[1] and their respective detection limits for the Exxon Guyana, Offshore Project – Phase 1.

Table 6: Summary of Analytes and their Reporting Limits

Name of Laboratory	Analyte	Detection Limits
ESL	Total dissolved solids	2.00 mg/L
	Total suspended solids	0.20 mg/L
	Chemical oxygen demand	30.0 mg/L
	Ammonia	0.01 mg/L
	Total arsenic	0.005 mg/L
	Total barium	0.01 mg/L
	Total cadmium	0.06 mg/L
	Total chromium	0.23 mg/L
	Total copper	0.19 mg/L
	Total iron	0.20 mg/L
	Total mercury	0.002 mg/L
	Total nickel	0.33 mg/L
	Total zinc	0.18 mg/L
IAG	Total organic carbon	1.0 mg/L
	Total cyanide	0.005 mg/L
ALS Environmental	n-Nonane	200- 320 ppb
	n-Decane	200- 320 ppb
	n-Undecane	200- 320 ppb
	n-Dodecane	200- 320 ppb
	n-Tridecane	200- 320 ppb
	2,6,10-Trimethyldodecane	200- 320 ppb
	n-Tetradecane	200- 320 ppb
	2,6,10-Trimethyltridecane	200- 320 ppb
	n-Pentadecane	200- 320 ppb
	n-Hexadecane	200- 320 ppb
	Norpristane	200- 320 ppb
	n-Heptadecane	200- 320 ppb
	Pristane	200- 320 ppb
	n-Octadecane	200- 320 ppb
	Phytane	200- 320 ppb
	n-Nonadecane	200- 320 ppb
	n-Eicosane	200- 320 ppb

[1] BOD and Faecal coliforms were not sampled and analysed due to their short holding times, as agreed with Elka.

Name of Laboratory	Analyte	Detection Limits
	n-Heneicosane	200- 320 ppb
	n-Docosane	200- 320 ppb
	n-Tricosane	200- 320 ppb
	n-Tetracosane	200- 320 ppb
	n-Pentacosane	200- 320 ppb
	n-Hexacosane	200- 320 ppb
	n-Heptacosane	200- 320 ppb
	n-Octacosane	200- 320 ppb
	n-Nonacosane	200- 320 ppb
	n-Triacontane	200- 320 ppb
	n-Hentriacontane	200- 320 ppb
	n-Dotriacontane	200- 320 ppb
	n-Tritriacontane	200- 320 ppb
	n-Tetratriacontane	200- 320 ppb
	n-Pentatriacontane	200- 320 ppb
	n-Hexatriacontane	200- 320 ppb
	n-Heptatriacontane	200- 320 ppb
	n-Octatriacontane	200- 320 ppb
	n-Nonatriacontane	200- 320 ppb
	n-Tetracontane	200- 320 ppb

6 RESULTS & DISUCSSION

6.1 Data Analysis, Management & Reporting

This Section presents the results and discussion of the water sampling conducted within the shelf, slope and deepwater stations within the study area. A total of 12 stations were sampled, at the top, middle and bottom of the water column, with duplicate sampling employed. This gave a total of 72 samples for chemical analysis. In-situ monitoring of water quality was also conducted across the length of the water column at all 12 stations.

The results were obtained in raw format: as unprocessed in-situ (probe) data, and as analytical results formulated into worksheets. In the case of the former, the data was imported in the MS Excel and QA/QC'ed to ensure that duplicated data were removed from the depth-profiles. These duplicate data are a normal occurrence in raw probe data and is typically generated by continuous and uncontrollable vertical movements of the probe whilst recording during deployment (owing to variable deployment speed as a result of varying current speed and direction).

For the lab reporting, the analytical worksheet values were QA/QC'ed internally and inputted into an MS Word format which served as the ESL Lab Report. QA/QC'ed reports generated by ALS and IAG were used to obtain the results for the sub-contracted parameters, and these values were integrated into ESL's lab report.

Both sets of data were submitted to ESL's Technical Team who was responsible for generating the formulated results and discussion presented in Sections 6.2 and 6.3 below. With respect to the probe data, the processed data were used to generate depth profiles for each parameter at each station, and these profiles are presented in Appendix 6 of Chapter 9 below. Typical and variant depth profiles are presented in Sections 6.2.2 to 6.2.6 below, with a focused discussion on the changes to the parameters with depth across the study area. Indications of the conformity of these parameters to the expected norm based on published environmental studies is also provided for context.

With respect to the chemical analysis, the results presented in ESL's lab report was imported into MS Excel. Each parameter was analysed using statistical calculations of the range, average and standard deviations in 3 ways, per replicate: (i) across all data values combined; (ii) by water column position (i.e. disaggregated by top, middle and bottom of the water column); (iii) and by location of the station (i.e. disaggregated by depth: shelf, slope and deep).

For each parameter, the summary data are presented in a tabular format, and, where applicable and suitable, the data are also presented in a graphical format.

The discussion focuses on the changes in the level of the parameter with depth across the water column (from top to bottom) and with distance from the shore (14 – 2,006 m). A concluding statement is provided at the end of this section. All citations are listed according to the Chicago Style Manual in Chapter 8 (References & Bibliography). Reference is also made throughout the discussion to relevant appendices, which are contained in Chapter 9 of this report (Supporting Documentation).

6.2 *In-situ Parameters*

Section 6.2.1 below presents a tabular summary of the *in-situ* parameter data obtained at the 12 stations within the study area and the sub-sequent sections describe the findings of the data analysis for each parameter. Typical depth profiles are presented for each parameter, and all depth-profiles are presented in Appendix 6 of Chapter 9.

6.2.1 *In-Situ* Parameter Data Summary Table (October 2017)

Table 7 below includes the range the range recorded for each parameter across the water column and the calculated average (with standard deviation) across the water column. The raw data from which these calculations were made, is presented in Appendix 7 of Chapter 9.

Table 7: Data Summary Table for the *In-Situ* Parameters (October 2017)

Station Location	Station Name	Depth (m)	*In-Situ* Parameter									
			Temperature (˚C)		Salinity (psu)		Specific Conductivity (µS/cm)		DO (mg/l)		Turbidity (NTU)	
			Range	Average ± SD	Range	Average ± SD	Range	Average ± SD	Range	Average ± SD	Range	Average ± SD
Shelf	Liza K	64	23.56 – 28.56	26.77 ± 1.65	36.06 – 36.79	36.26 ± 0.14	54,455.98 - 55,438.77	54,752.17 ± 219.39	6.33 - 6.86	6.51 ± 0.18	0.89 - 2.58	1.16 ± 0.27
	Liza M	54	24.64 – 28.95	27.55 ± 1.39	36.05 – 36.70	36.23 ± 0.13	54,458.76 - 55,318.07	54,700.73 ± 183.37	6.29 - 6.74	6.43 ± 0.15	0.97 - 2.71	1.16 ± 0.28
	Liza N	48	25.02 – 29.13	27.47 ± 1.55	35.97 – 36.71	36.21 ± 0.15	54,349.55 - 55,327.91	54,676.07 ± 213.37	6.27 - 6.70	6.44 ± 0.16	1.59 - 4.21	1.81 ± 0.47
	Liza O	26	28.23 – 29.86	29.40 ± 0.32	35.53 – 36.73	35.98 ± 0.21	53,755.68 - 55,354.40	54,366.34 ± 287.45	6.21 - 6.34	6.25 ± 0.03	1.47 - 17.21	2.11 ± 2.48
	Liza P	23	26.92 – 28.87	28.79 ± 0.25	35.72 – 36.85	35.95 ± 0.13	53,999.74 - 55,511.47	54,320.94 ± 178.79	6.30 - 6.50	6.31 ± 0.02	1.40 - 3.55	1.89 ± 0.63
	Liza R	14	28.48 – 29.78	29.49 ± 0.28	31.92 – 35.98	33.48 ± 1.53	48,873.58 - 54,354.04	50,981.36 ± 2,068.48	6.26 - 6.45	6.32 ± 0.05	1.63 - 22.23	7.08 ± 6.10
Slope	Liza H	134	19.60 – 29.82	25.13 ± 3.13	35.14 – 36.63	36.23 ± 0.28	53,226.47 - 55,385.97	54,776.34 ± 456.80	6.23 - 7.37	6.68 ± 0.36	1.09 - 3.41	1.21 ± 0.16
	Liza I	157	17.67 – 28.34	23.92 ± 3.73	35.40 – 36.68	36.26 ± 0.30	53,902.09 - 55,419.88	54,869.75 ± 485.29	6.36 - 7.69	6.86 ± 0.44	1.26 - 3.38	1.42 ± 0.21
	Liza J	215	15.49 – 28.31	21.56 ± 4.38	33.57 – 36.68	36.20 ± 0.36	51, 113.91 - 55,439.93	54,911.41 ± 556.23	6.37 - 8.05	7.16 ± 0.55	1.52 - 2.96	1.59 ± 0.13
Deep	Liza C	1,705	3.85 – 29.52	8.36 ± 6.56	34.45 – 36.82	34.99 ± 0.48	52,302.63 - 57,426.73	55,796.08 ± 1,102.60	6.28 - 10.42	9.52 ± 1.13	0.83 - 6.45	0.91 ± 0.12
	Liza F	1,714	3.81 – 29.35	8.07 ± 6.17	34.48 – 36.82	35.01 ± 0.48	52,338.95 - 57,455.49	55,865.45 ± 1,033.50	6.30 - 10.43	9.57 ± 1.08	0.94 - 3.28	1.07 ± 0.08
	Liza G	2,006	3.32 – 29.34	7.63 ± 6.52	34.38 – 36.60	34.99 ± 0.45	52,200.96 - 57,863.77	56,115.87 ± 1,206.79	6.28 - 10.56	9.68 ± 1.14	1.67 - 4.12	1.78 ± 0.09

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6.2.2 pH

The results and detailed discussion of pH levels at the 12 water stations within Liza Field measured during Phase 1 of the Guyana Offshore Project will be provided in an addendum to this report.

6.2.3 Temperature

Water depth was found to influence the form of temperature profiles across the study area. A total of 4 profile variants were recorded. The shallowest stations sampled within the shelf area (Station O, P and R; 14 – 26 m) displayed a very well mixed water column, as evidenced with the limited change in temperature with depth (Figure 3 below). The marginally deeper stations on the shelf (Stations K, M and N; 48 – 64 m) were also found to be very well mixed within 30 m of the water surface, after which the temperature gradually decreased to between 23 – 25°C), an overall change of approximately 3 – 4°C from the surface; Table 7 above). These stations are represented by the typical profile in Figure 4 below, and, represent, overall, well mixed conditions at these stations in October 2017 (secondary dry season, which lasts from late July to early November).

This form was also manifested in the slope stations (Stations H, I & J; 134 – 215 m), with well mixed water occurring within 60 m of the water surface, and the gradual linear decrease in temperature to near bottom, at temperatures ranging from 15 – 19°C, with an overall temperature difference of 11 – 12°C, from surface to bottom (Figure 5 below). As with the shelf stations, these profiles indicate well mixed profiles for the slope stations sampled in October 2017.

The final profile variant pertained to the deepwater stations (Stations C, F & G; 1,705 – 2,006 m), and reveal water column stratification in the form of a thermocline (Figure 6 below). For these stations, the water column was well mixed within 200 m of the surface, followed by a rapid change in the temperature of seawater with depth (thermocline). The thickness of the thermocline for these stations in October 2017 was approximately 800 m thick, with marginal changes in temperature occurring beyond the 1,000 m mark to bottom depths. Overall, the temperature gradient from surface to bottom was found to be approximately 26°C (see Table 7 above). The thermocline is therefore considered to be a transition zone between the surface mixed layer and deeper, colder water. The surface layer tends to be of a higher but stable temperature owing to the effect of insolation, wind and warm air, whilst the deeper, colder waters are steady in temperature owing to the absence of these factors (NOAA 2012). The thermocline is a typical feature of deeper marine waters, given that deep ocean waters are not well mixed (Bergman 2011; NOAA 2012).

When seawater temperature levels were averaged across the water column at each station), it was found that the average seawater temperature level decreased with distance from the shore (Figure 7). All profiles exhibited surface seawater temperatures within the range 28.31 – 29.86°C, which is typical of the marine environment, where, in tropical latitudes, surface seawater temperatures can range from 27 – 30°C (Gordon 2004; marinebio.org; n.d.).

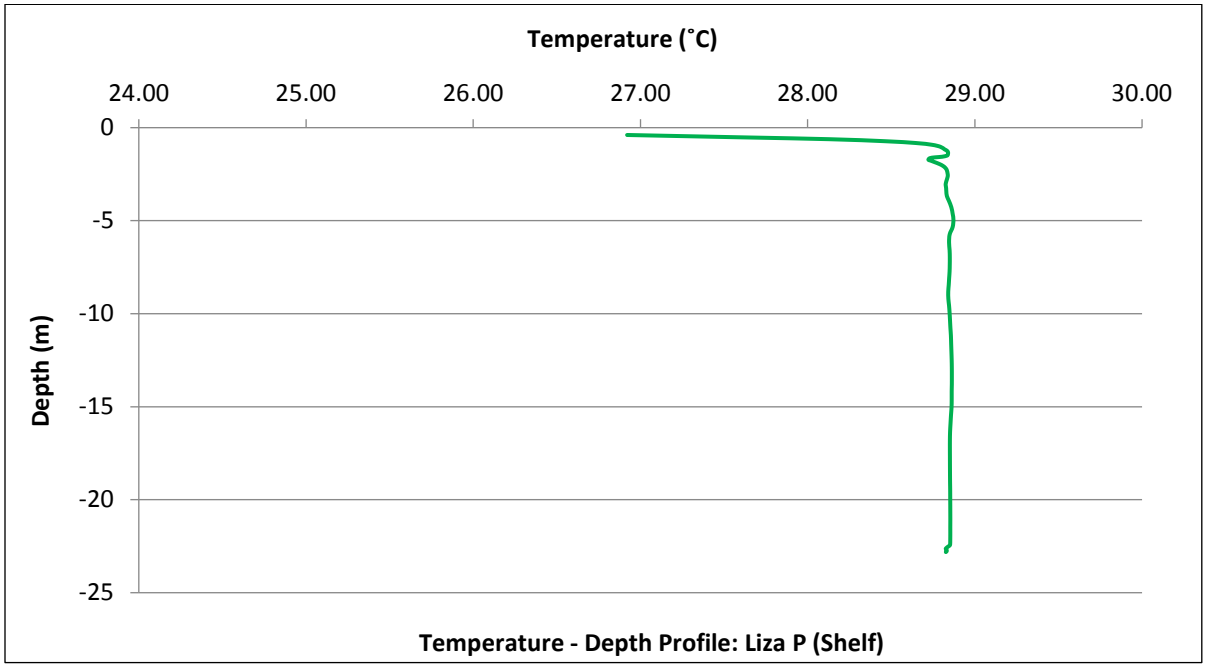


Figure 3: Typical Temperature-Depth Profile for the Shallowest Shelf Stations (Stations O, P & R; 14 – 26 m; October 2017)

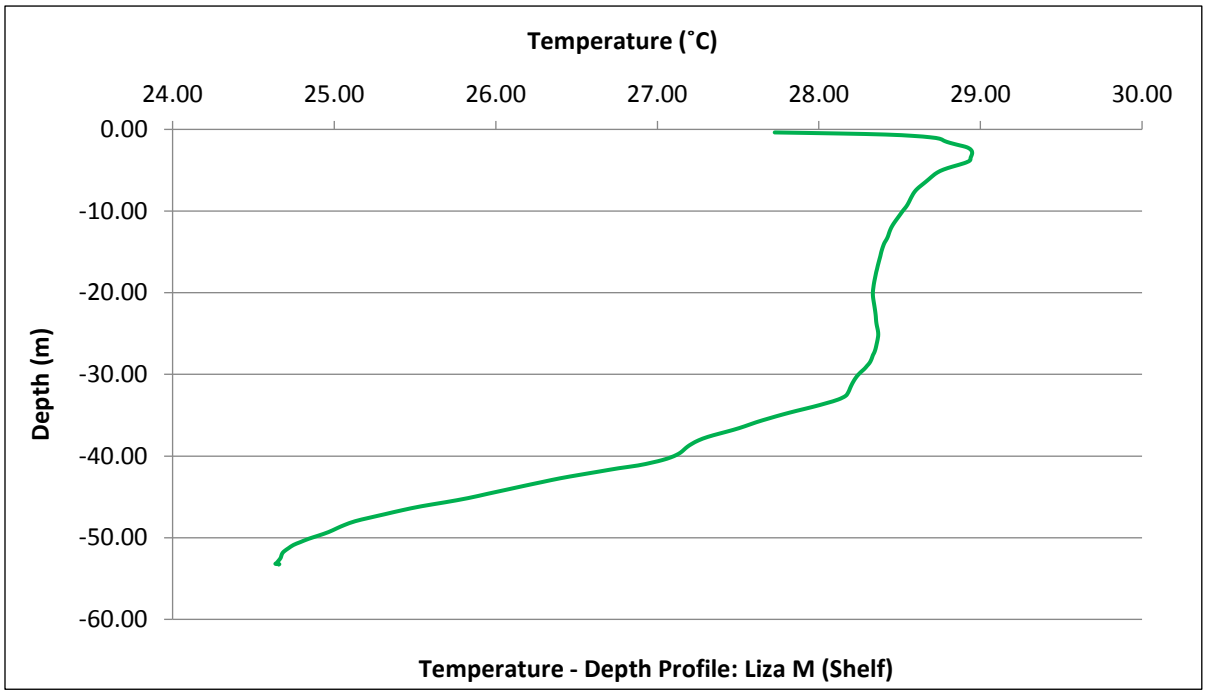


Figure 4: Typical Temperature-Depth Profile for the Shelf Stations K, M and N (48 – 64 m; October 2017)

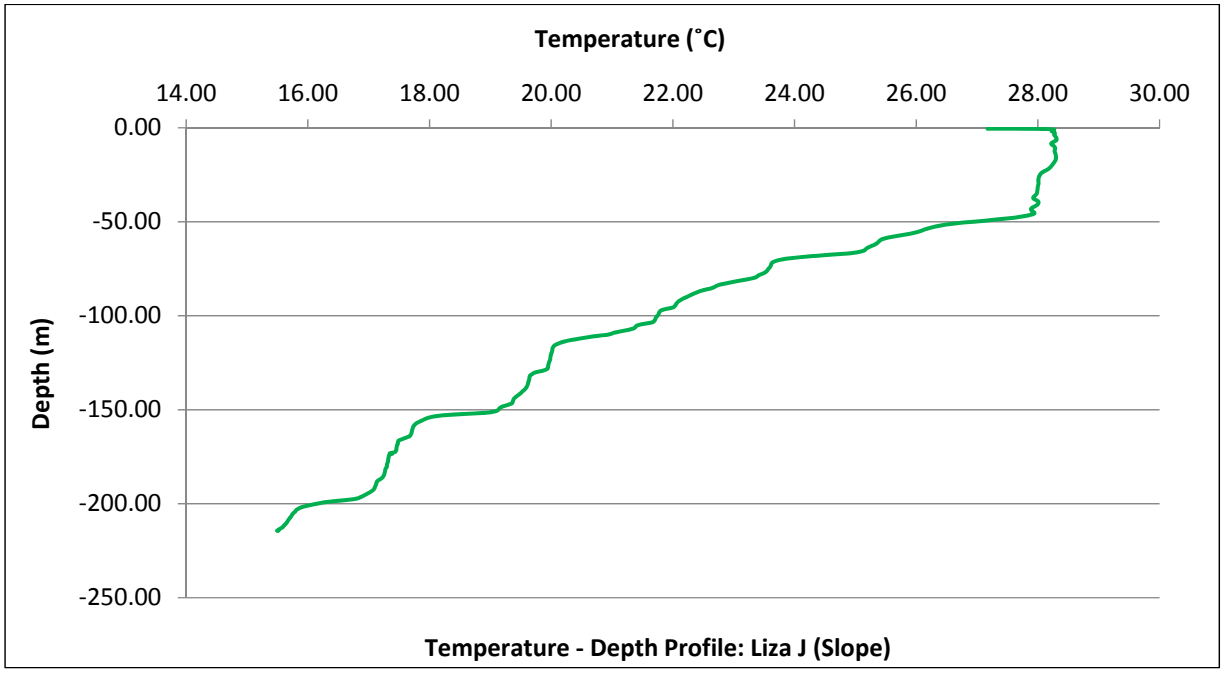


Figure 5: Typical Temperature-Depth Profile for the Slope Stations H, I & J (134 – 215 m; October 2017)

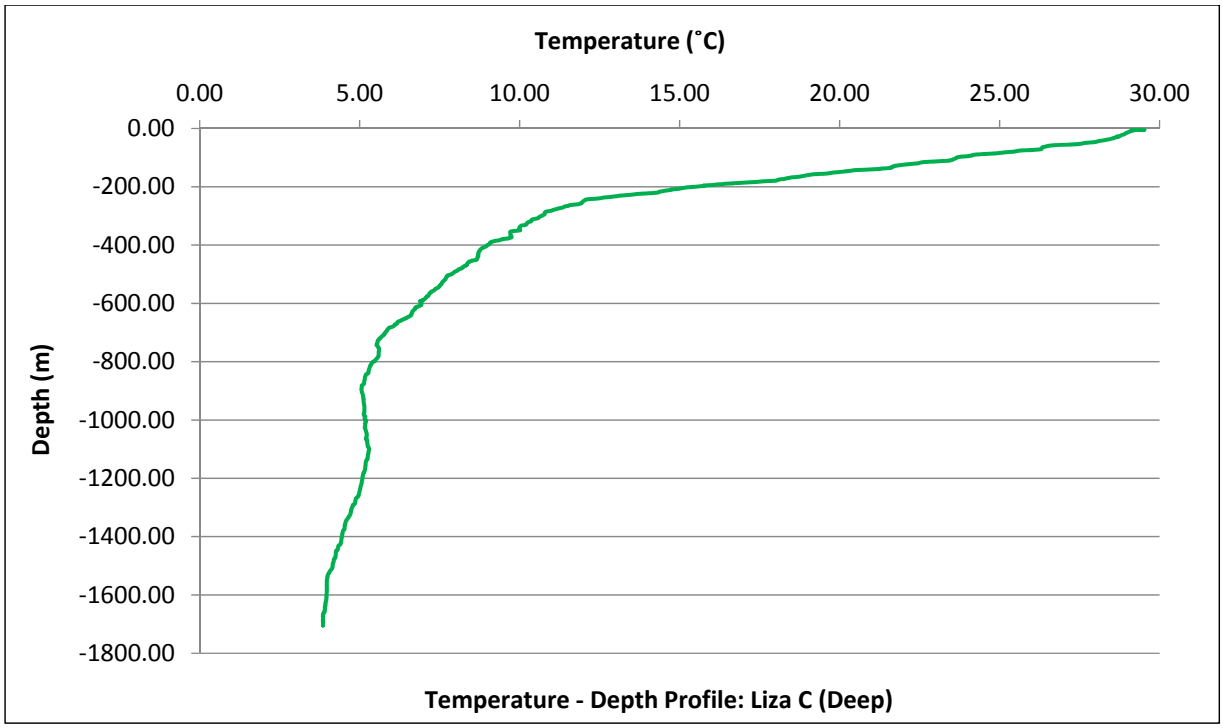


Figure 6: Typical Temperature-Depth Profile for the Slope Stations C, F & G (1,705 – 2,006 m; October 2017)

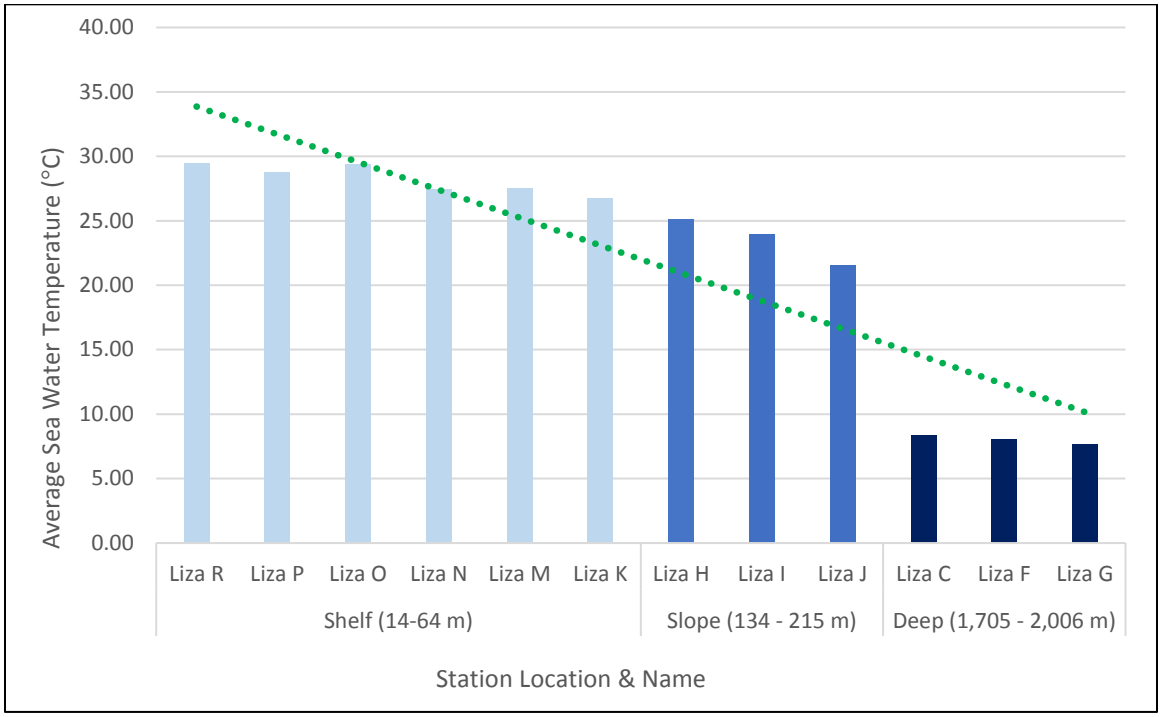


Figure 7: Average Seawater Temperature (°C) Levels Across the Sampled Area (October 2017)

6.2.4 Salinity & Specific Conductivity

Salinity-depth profiles were similar across all shelf and slope stations (see Table 7 above), with minor variations in form, but where in general, there was no evidence of a halocline, owing to the absence of a density gradient, i.e. well mixed conditions throughout the water column. Typical profiles are shown in Figure 8 and Figure 9 respectively, below. For these profiles, salinity was seen to increase marginally with depth. The same was observed for specific conductivity-depth profiles for the shelf and slope stations, and the salinity and specific conductivity profiles tended to be similar.

The salinity profiles at the deepwater stations did demonstrate the presence of a halocline, with marginally less dense water at the surface, in comparison to the slope and shelf stations (see Table 7 above and Figure 10 below). The halocline, a vertical zone in the water column in which salinity changes rapidly with depth, is located below the well-mixed, uniformly saline surface water layer. This feature is common in deeper marine waters, and typically arises as a result of the interplay of various environmental factors, such as sea water temperature change with depth (as a result of insolation and evaporation), as well as with the influx of fresh water sources, leading to water density stratification (Gordon 2004).

For the deepwater stations, the halocline began approximately at the 200 m mark, and extended roughly down to the 1,000 m depth (i.e. the halocline was approximately 800 m thick). Beyond this depth, there were minimal changes in salinity with depth, down to the bottom layer, thus giving a relatively uniform bottom layer (1,000 m down to as deep as nearly 2,006 m at Liza G, the deepest station). In each deepwater profile, a slight 'bulge' was also observed in the middle of the water column (500 – 1,000 m depth), where salinity was found to be marginally lower than the deepest waters (see Figure 10 below). As noted with the shelf and slope stations, specific conductivity profiles were similar to those of salinity (Figure 11 below).

Overall, there was a marginal difference in salinities across all stations, with most stations ranging between 34 – 36 ppt[2]. The average level of salinity was also very similar with distance from the shore (see Figure 12 below). The recorded values for salinity (see Table 7 above) compared very well to those quoted in various studies, which indicate that ocean salinity may be, on average, 34.7 to 35 ppt (NIO; n.d.; marinebio.org; n.d.; and Gordon 2004), whilst ranging from 28 – 41 ppt (marinebio.org; n.d.). Surface salinities may be slightly lower as compared to the halocline owing to the influence of fresh water, which is less dense. Regional oceanographic factors (such as the outflows of large South American mainland

[2] *It should be noted that there is a minimal numerical difference in values quoted in psu and ppt (of the order of 0.01).*

rivers and the influence of the NBC retroflection) may have an impact on the quantity of fresh/salt water interface at the sea surface, and hence the degree of surface salinity (Gyory *et al*.; n.d.).

Changes in specific conductivity and salinity tend to be similar, since the ions measured to give salinity readings are a subset of those which give conductivity measurements. This was reflected in all profiles for the October 2017 dataset. For the deepwater stations, specific conductivity was observed to decrease rapidly within the zone identified as the halocline above and was relatively constant with depth after the 1,000 m mark. The 'bulge' in salinity observed at the middle of the water column was not reflected in the specific conductivity profile, but this may generally be the result of more limited changes in specific conductivity with depth (see Figure 11 below). Overall, the average level of specific conductivity was found to increase with distance offshore (Figure 13 below).

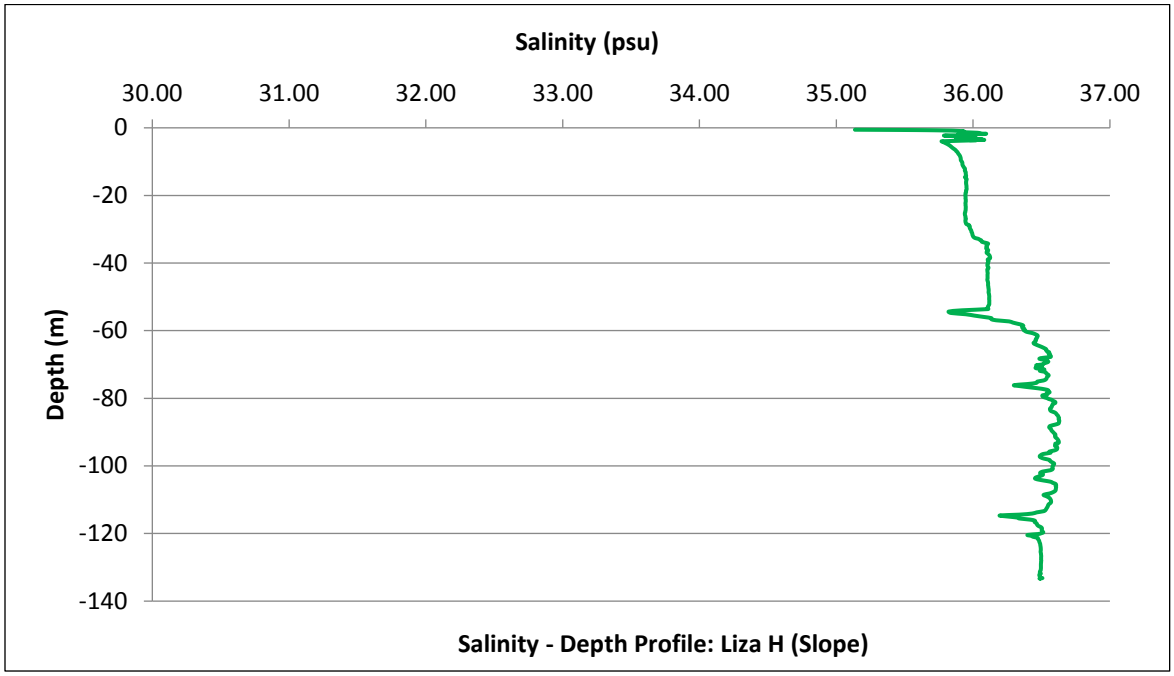


Figure 8: Typical Salinity-Depth Profile for the Shelf & Slope Stations (14 – 215 m; October 2017)

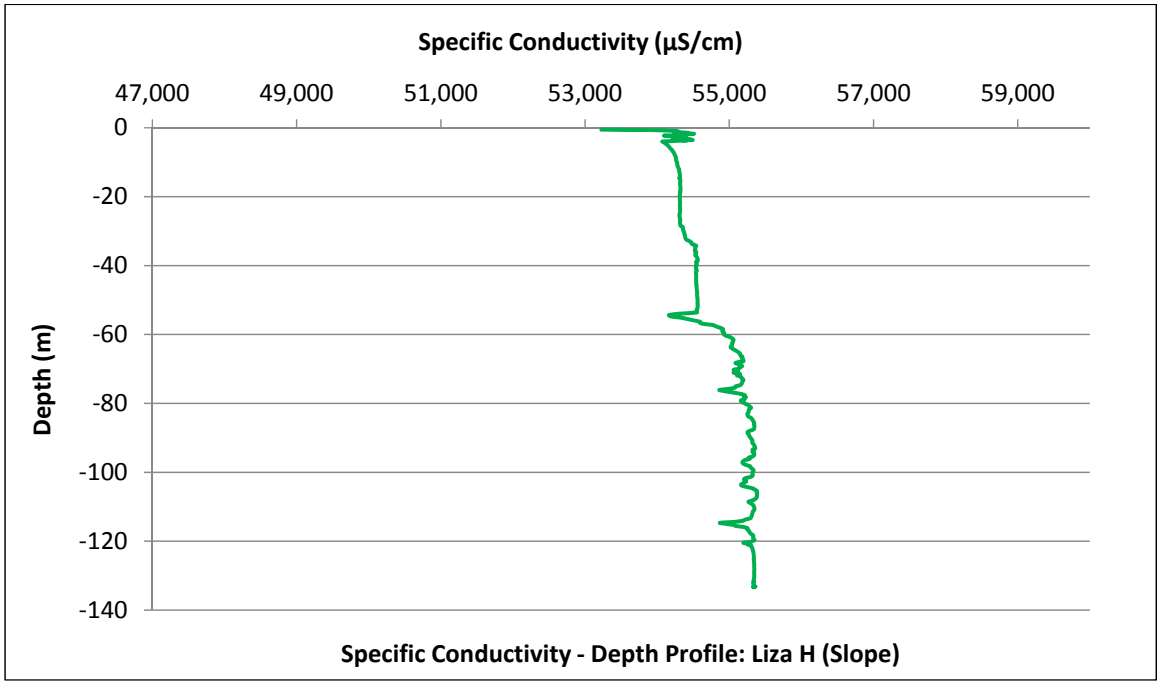


Figure 9: Typical Specific Conductivity-Depth Profile for the Shelf & Slope Stations (14 – 215 m; October 2017)

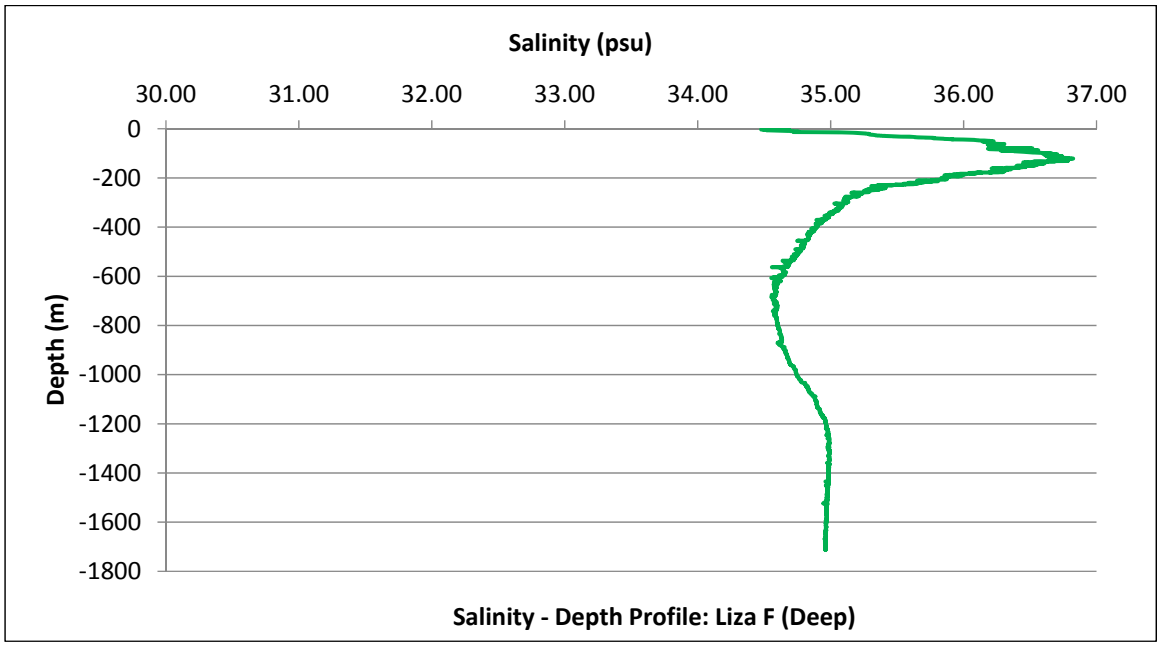


Figure 10: Typical Salinity-Depth Profile for the Deepwater Stations (1,705 – 2,006 m; October 2017)

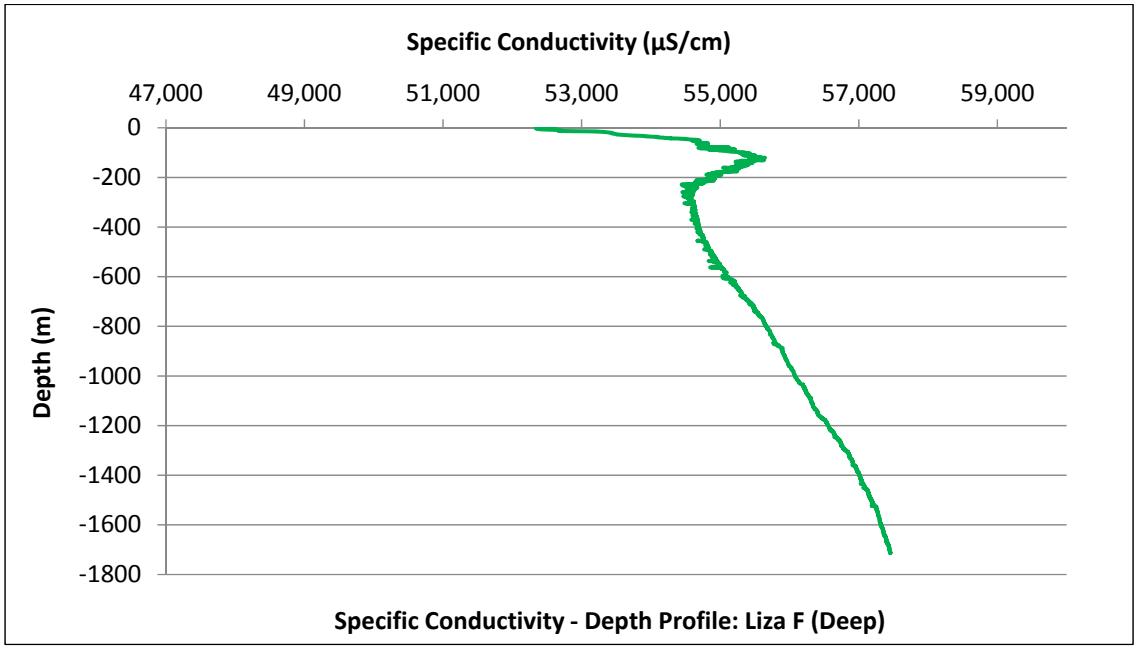


Figure 11: Typical Specific Conductivity-Depth Profile for the Deepwater Stations (1,705 – 2,006 m; October 2017)

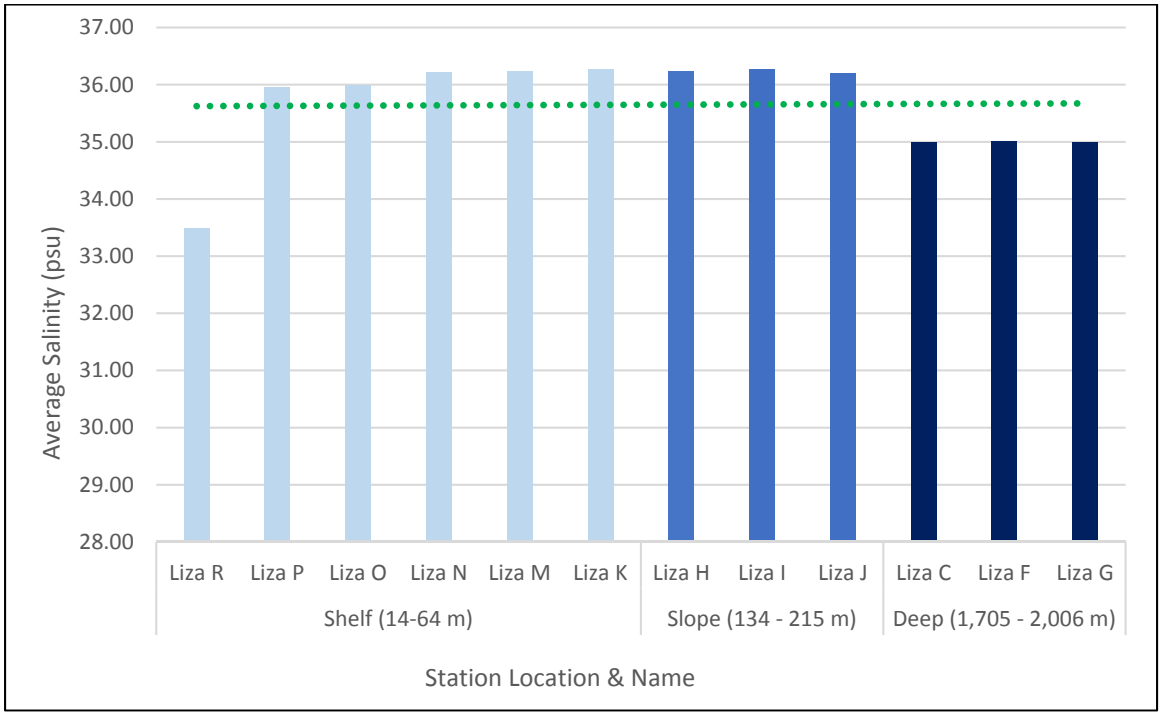


Figure 12: Average Salinity (psu) Levels Across the Sampled Area (October 2017)

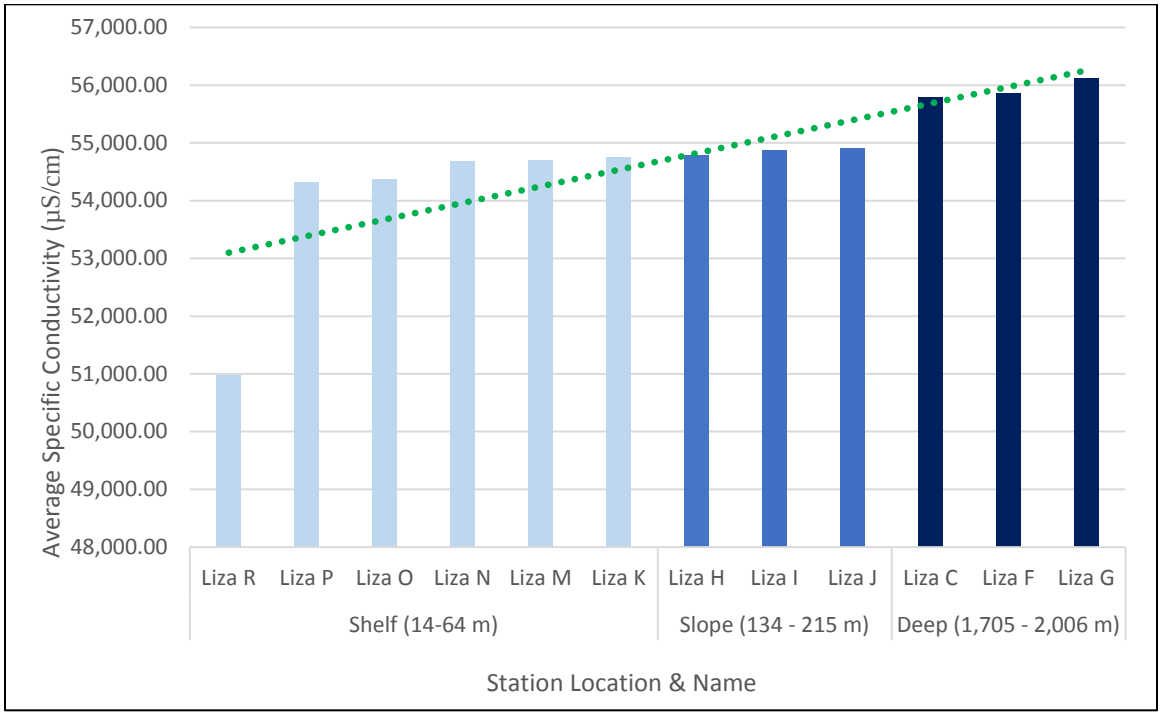


Figure 13: Average Specific Conductivity (µS/cm) Levels Across the Sampled Area (October 2017)

6.2.5 DO

As with temperature, depth was found to influence the form of DO profiles across the study area, and a total of 3 variants were found. DO was found to be very similar and did not change with depth at all shelf stations. Values ranged from 6.21 – 6.86 mg/l (see Table 7 above), and the very low standard deviation values corroborated the limited variability within the datasets. A typical DO-depth profile for the shelf stations is presented in Figure 14 below.

For the slope stations (Liza H, I and J; 134 – 215 m), DO values did not change with depth up to the 40 – 50 m mark, but after this point, began to increase marginally with depth (see Figure 15 below). This corresponds with the decrease in temperature at the 40 – 50 m mark (see Section 6.2.3 and Figure 5 above). This was as expected (Kemker 2013), given that more oxygen can be dissolved in colder waters (Kemker 2013). Conversely, DO may also be lower in surface waters due to higher rates of respiration (Kemker 2013).

This general trend was also observed for the deepwater stations, but in this case, the effect of greater depths (1,705 – 2,006 m), and consequently, colder water temperatures (see Section 6.2.3 and Figure 6 above), meant that DO increased at a greater rate throughout the thermocline. After the thermocline (1,000 m), DO changed very little with depth (Figure 16 below). The overall effect, particularly within the slope and deepwater stations, is that DO increased to varying degrees with the decrease in temperature with depth (Figure 17 below).

At the slope stations, DO levels ranged from 6.23 – 8.05 mg/l, and at the deepwater stations, 6.28 – 10.56 mg/l. These latter datasets were therefore more variable than those for the shelf stations. Overall, however, all values exceeded the minimum of 5 mg/l (Kemker 2013), which is indicative of the healthy environment for aquatic organisms (see Figure 17 below). Values recorded were generally in keeping with reported values in environmental studies (e.g. Kemker 2013), which quoted values of up to 9 mg/l, with possible super-saturation of water with oxygen (11 – 20%), based on varying environmental conditions.

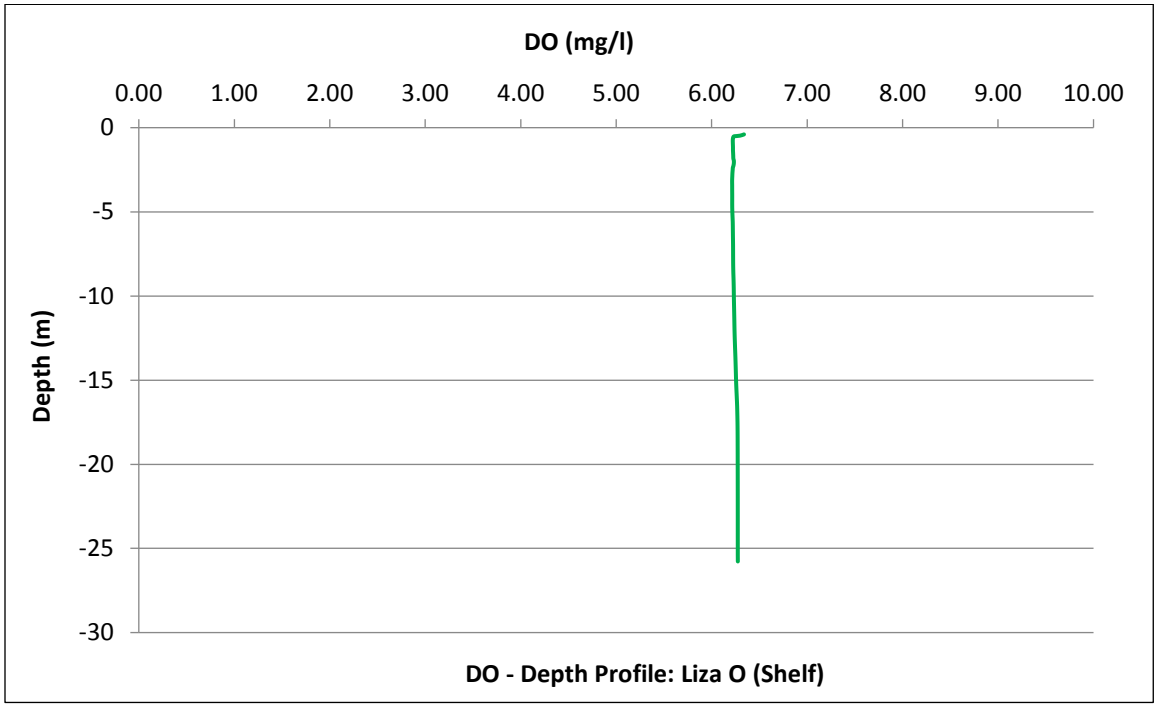


Figure 14: Typical DO-Depth Profile for the Shelf Stations (14 – 64 m; October 2017)

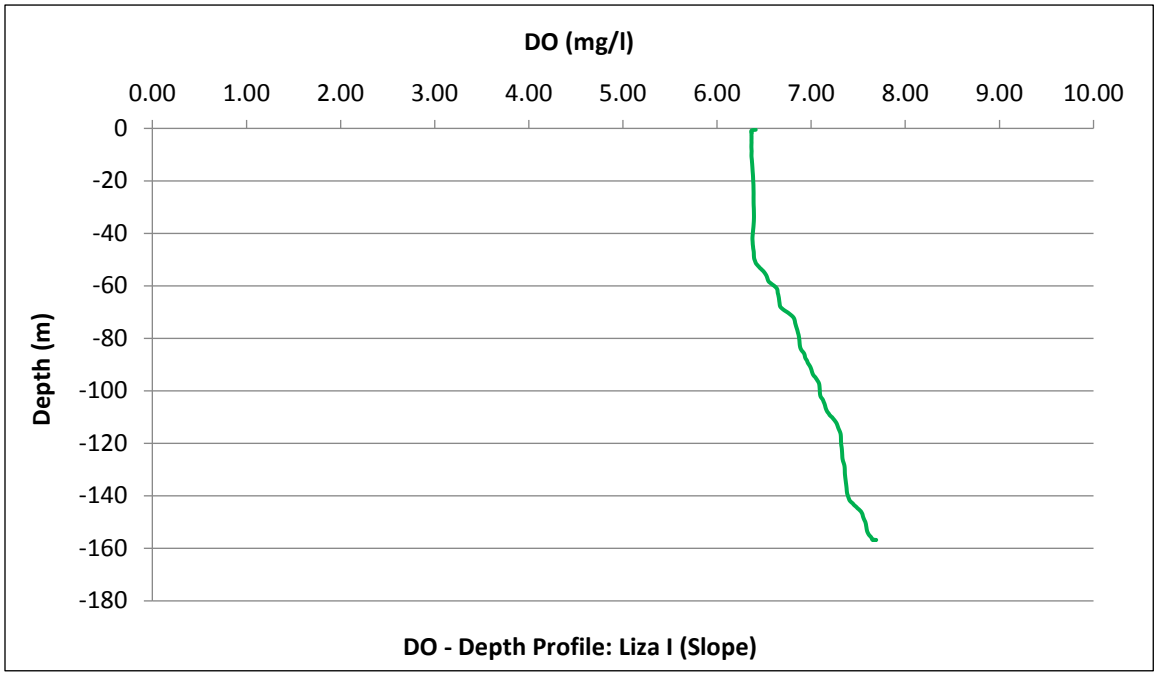


Figure 15: Typical DO-Depth Profile for the Slope Stations (134 – 215 m; October 2017)

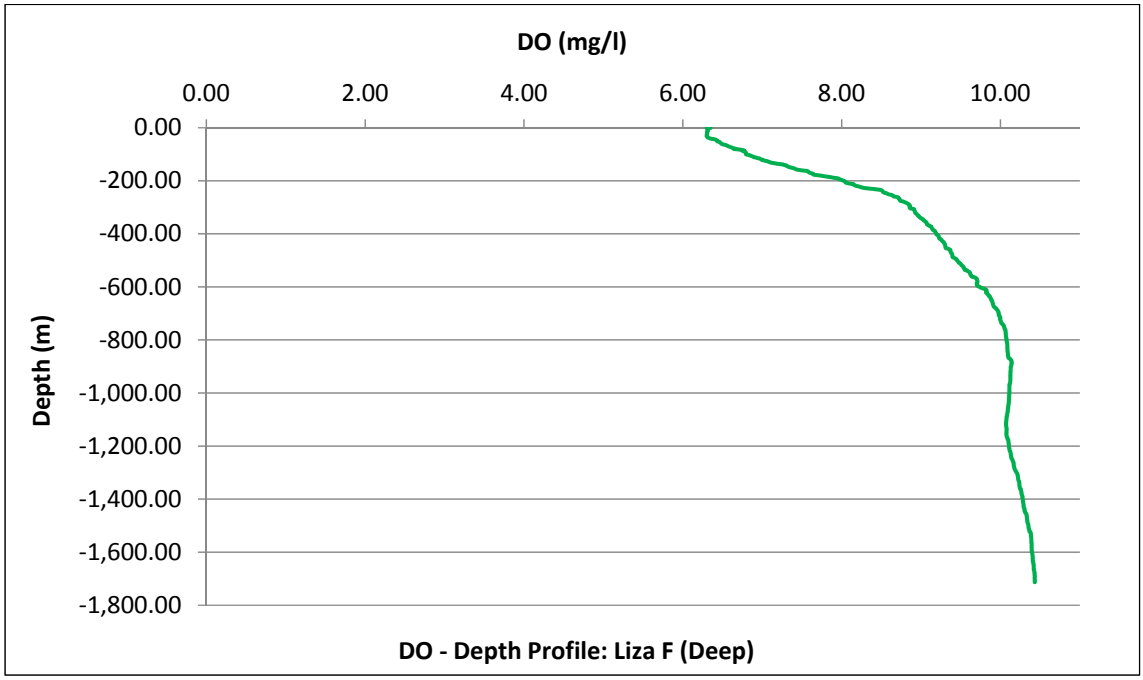


Figure 16: Typical DO-Depth Profile for the Deepwater Stations (1,705 – 2,006 m; October 2017)

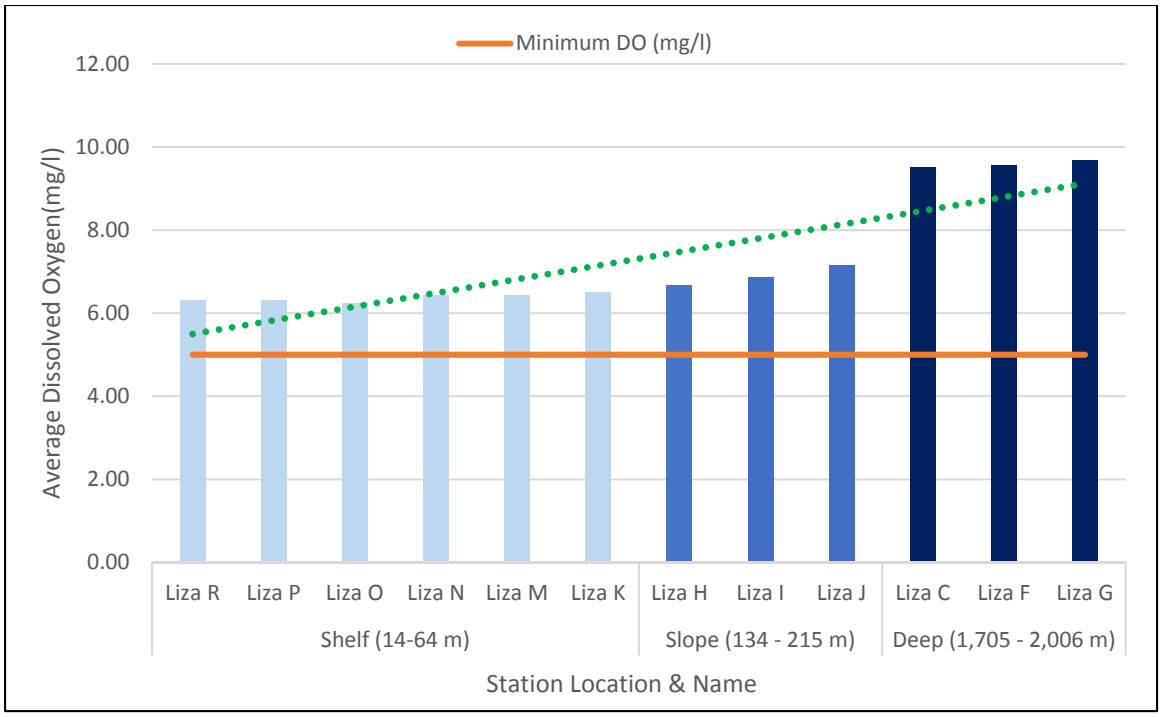


Figure 17: Average DO (mg/l) Levels Across the Sampled Area (October 2017)

6.2.6 Turbidity

Turbidity-depth profiles were also consistent across all stations (Figure 18 below), with the exception of the shallowest station, Liza R at the 14 m depth (Figure 19 below). At all stations except Liza R, turbidity was marginally higher at the surface of the water column (2.58 – 17.21 NTU) and then decreased to values ranging from 0.83 – 1.67 NTU, with very minimal change in the values with depth, regardless of the depth of the station. At Liza R, however, the levels of turbidity ranged from 1.63 NTU at the surface to 22.23 NTU at the bottom, showing a trend of increasing turbidity with depth. The possible explanations for this may be that there was a localised increase in sediment load within the water column at this station, possibly related to some disturbance at the sea floor at the time of sampling. In general, the average level of turbidity (taking Station Liz R into account), was found to decrease with depth (Figure 20 below).

Marginally higher surface turbidity values (Figure 21 below) may be as a result of suspended solids present from regional riverine input. The marine waters off the coast of Guyana are subject to high ambient suspended sediment concentrations dominated by material derived from the Amazon River system (Warne *et al.* 2002). Turbidity levels (at the surface and throughout the water column) may be relatively low at the time of sampling however, given that the NBC retroflection would be in operation at the time of sampling, meaning that the Guiana Current and the Amazon-derived sediment associated with it) would be carried away from the Guiana Coast and the Caribbean towards Africa (Bishof *et al.* 2003).

The NBC retroflection is also known to coincide with the period of peak flow of the Amazon River (May to July; Warne *et al.* 2002), which has the potential to impact upon the marine water quality of Guyana. The levels detected in in October 2017 would be markedly lower than at the time of the year when the Amazon waters influence the Caribbean (January to June), when the NBC retroflection is absent (Artigas *et al.* 2003). The effects of these regional rivers have been observed across the Guiana Coast and as far as Barbados (Steven and Brooks 1972).

It should also be noted, that the level of TSS recorded at Station Liza R was also higher in comparison to the levels at the other stations, and so corroborate this finding (see Section 6.3.2 below).

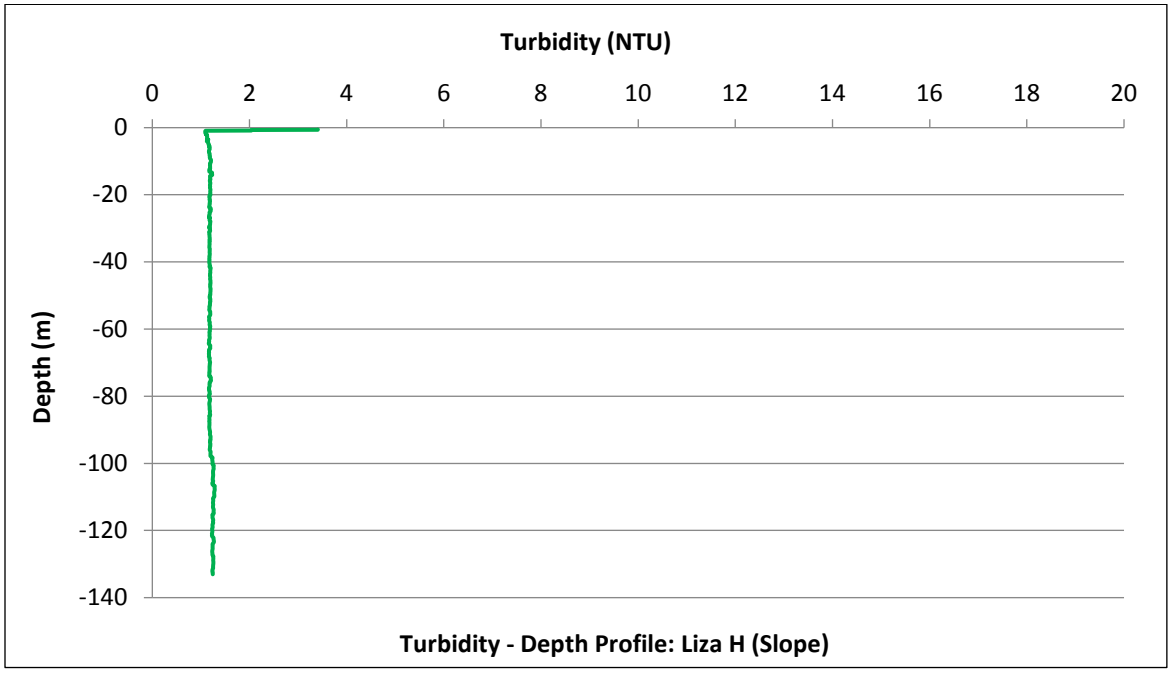


Figure 18: Typical Turbidity-Depth Profile for the Shelf, Slope & Deepwater Stations (23 – 2,006 m; October 2017)

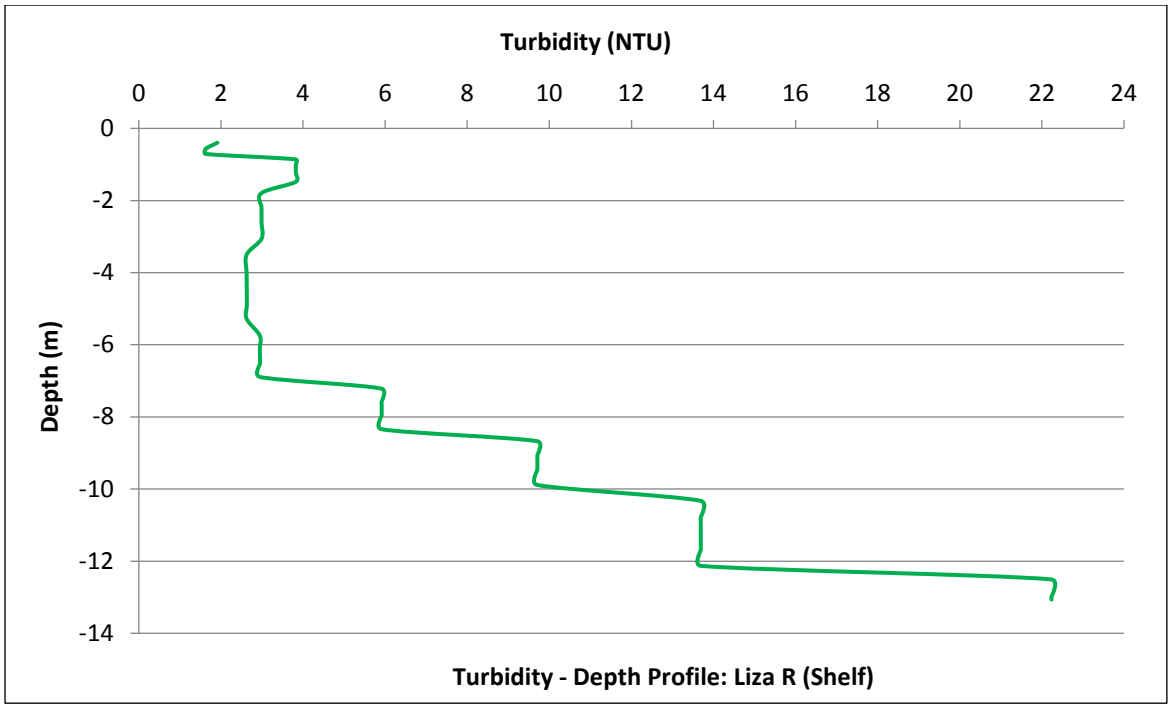


Figure 19: Turbidity-Depth Profile at Station Liza R (14 m; October 2017)

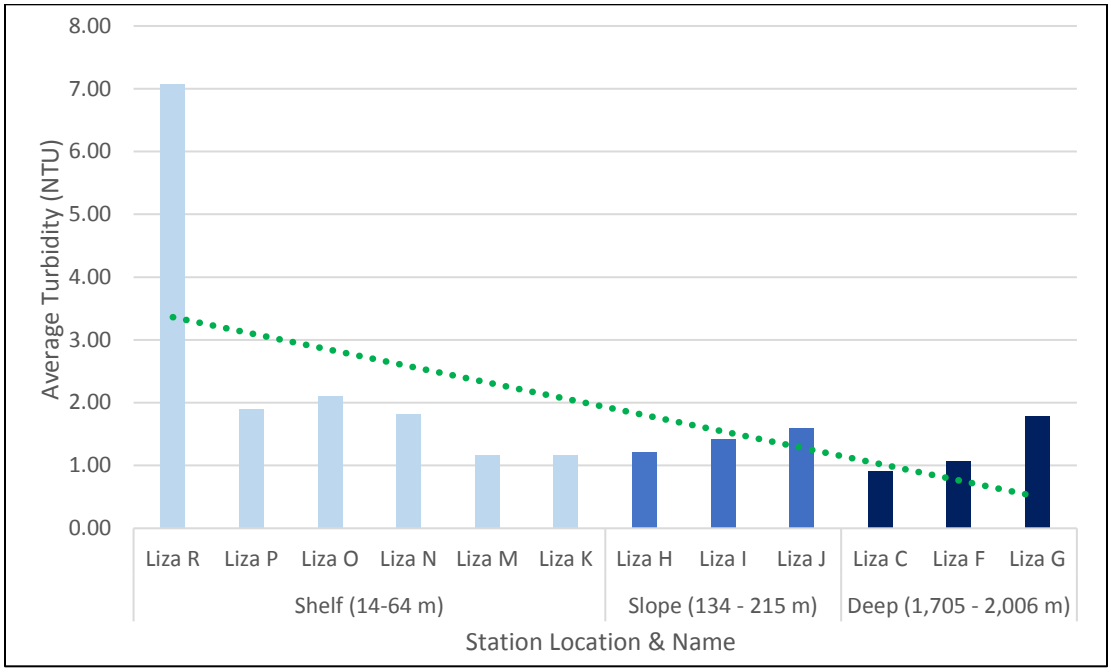


Figure 20: Average Turbidity Levels throughout the Area Sampled (14 – 2,006 m; October 2017)

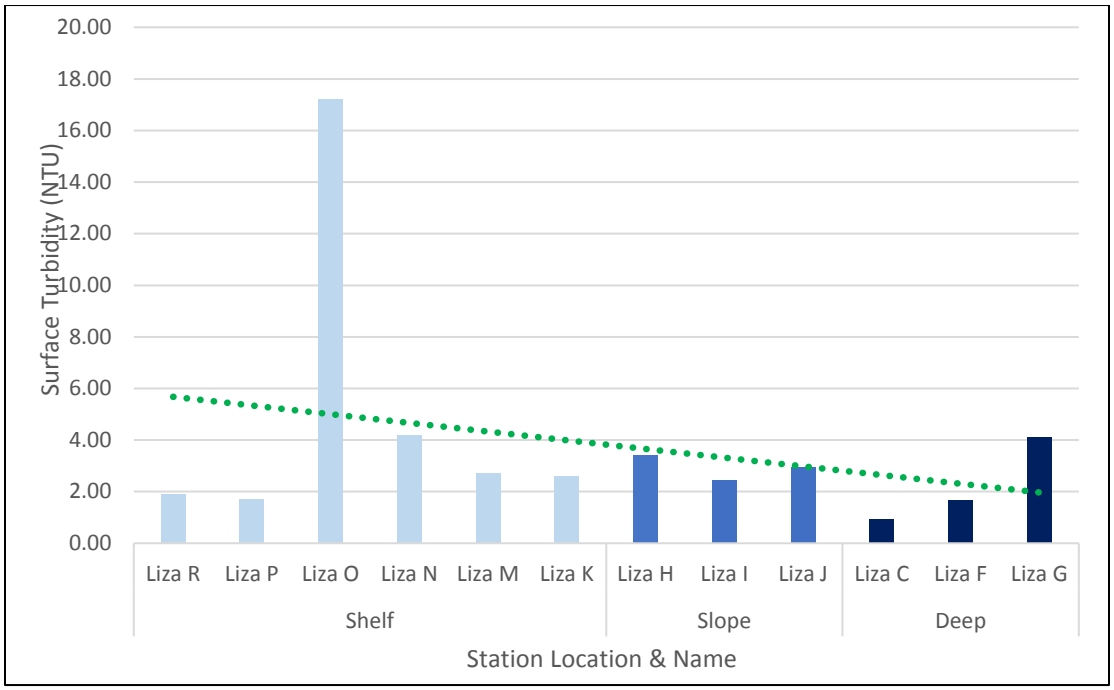


Figure 21: Surface Turbidity Levels throughout the Area Sampled (14 – 2,006 m; October 2017)

6.3 Water Chemistry

Total cyanide and the total forms of the metals, arsenic, cadmium, copper, chromium, iron, nickel, zinc, mercury and barium were below the detectable limit (BDL) at all stations sampled, at all levels of the water column, for both replicates taken in October 2017. Saturated hydrocarbons were detected at the slope and shelf stations (various levels of the water column) but not at the deepwater stations. Ammonia was detected only at 5 of the 6 shelf stations. The parameters TDS, TSS, TOC and COD were detected at all stations, at all levels of the water column (for both replicates) in October 2017, the exception being at the bottom of the water column at Liza O, for COD.

6.3.1 Total Dissolved Solids (TDS)

Table 8 below presents the calculated ranges and averages (with standard deviation) for the TDS dataset, when considering: all samples combined; by water column position (i.e. disaggregated by top, middle and bottom of the water column); and by location of the station (i.e. disaggregated by depth: shelf, slope and deep). Figure 22 shows the levels of TDS (Rep 1)[3] across the area sampled. Overall, values ranged from 30,000 – 39,000 mg/l, with an average value of 33,417 ± 3,065 mg/l, with marginally higher values being recorded at shelf Stations Liza M and R (the shallowest station) and slope Station Liza J.

When the data were disaggregated by water column level (see Table 8 above and Figure 23 below), it was found that the average TDS levels were highest the top of the water column and lowest at the middle. When disaggregated by station location (depth), it was found that the average level of TDS decreased with distance from the shore (Figure 24 below).

[3] *For TDS, the analytical results were rounded to whole number integers of the magnitude of 10^5, and so values are identical for replicates 1 and 2. See Appendix 8 of Chapter 9 for actual values by station.*

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Table 8: Statistical Summary for TDS in Water (All Stations; Both Replicates; October 2017)

Treatment of Data		Replicate 1		Replicate 2	
		Range	Average ± SD	Range	Average ± SD
Across All Samples		30,000 – 39,000	33,417 ± 3,065	30,000 – 39,000	33,417 ± 3,065
By Water Column Position	**Top**	30,000 – 39,000	33,500 ± 3,205	30,000 – 39,000	33,500 ± 3,205
	Middle	30,000 – 37,000	33,333 ± 3,025	30,000 – 37,000	33,333 ± 3,025
	Bottom	30,000 – 39,000	33,417 ± 3,232	30,000 – 39,000	33,417 ± 3,232
By Station Location / Depth	**Shelf (14-64 m)**	30,000 – 39,000	34,333 ± 3,3325.50	30,000 – 39,000	34,333 ± 3,3325.50
	Slope (134 – 215 m)	30,000 – 37,000	33,889 ± 2,976.80	30,000 – 37,000	33,889 ± 2,976.80
	Deep (1,705 – 2,006 m)	30,000 – 32,000	31,111 ± 781.74	30,000 – 32,000	31,111 ± 781.74



Figure 22: Distribution of TDS Levels (mg/l) across the Area Sampled (October 2017)

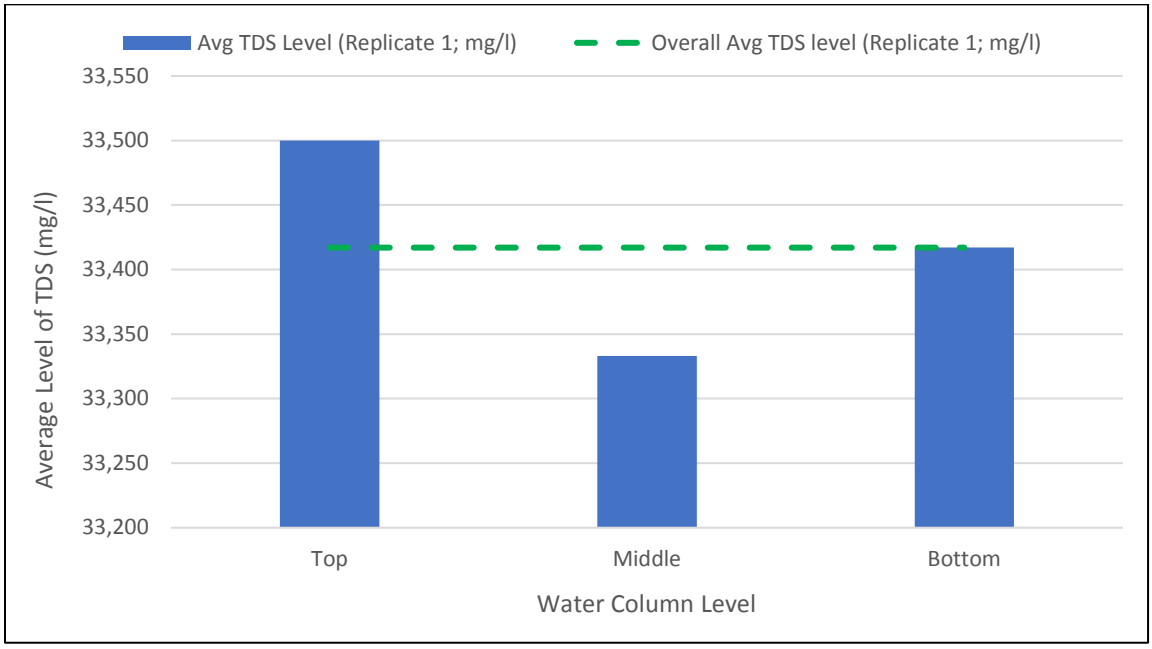


Figure 23: Comparison of the Average Levels of TDS by Water Column Level (October 2017)

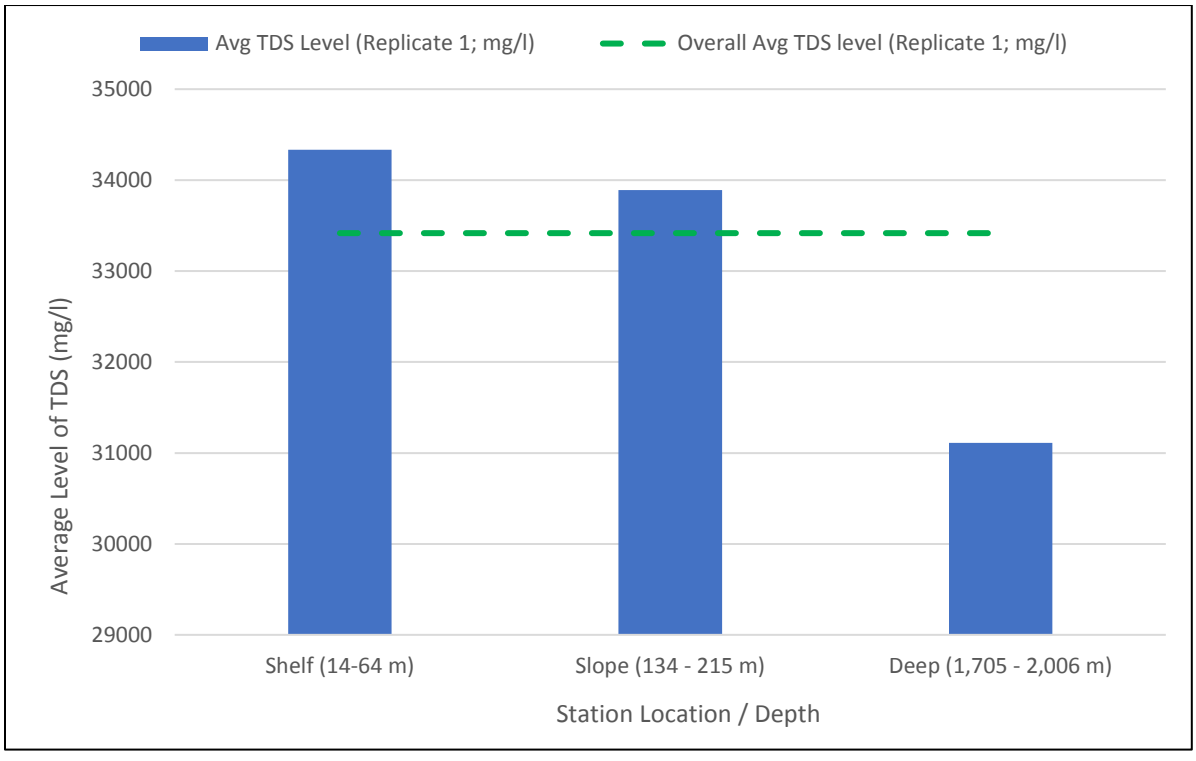


Figure 24: Comparison of the Average Levels of TDS by Station Location / Depth (October 2017)

6.3.2 Total Suspended Solids (TSS)

Table 9 below presents the calculated ranges and averages (with standard deviation) for the TSS dataset, when considering: all samples combined; by water column position (i.e. disaggregated by top, middle and bottom of the water column); and by location of the station (i.e. disaggregated by depth: shelf, slope and deep). Figure 25 shows the levels of TSS (Replicates 1 and 2) across the area sampled. Overall, the replicate data were very similar to each other, and values ranged from 3 – 33 mg/l for both replicates. Average values of 8 ± 6 mg/l and 8 ± 7 mg/l were recorded for Replicates 1 and 2, respectively (see Table 9 below). In both datasets, the standard deviation was very high, indicating high variability amongst the values within the datasets. This variability is evident in Figure 25 below, in which Stations Liza R (the shallowest station, located on the shelf) and Station Liza H (slope) are anomalous, and therefore appeared to skew the dataset. In the case of Liza R, this corroborates the *in-situ* turbidity readings (see Section 6.2.6 above). Conversely, the same cannot be said for Liza H; the turbidity-depth profile for Station H (see Figure 18 in Section 6.2.6 above) showed low turbidity similar to all other stations whilst the TSS values at this station were high relative to the other stations.

When the data were disaggregated by water column level, it was found that, for both replicates, the average TSS levels at the middle were lower than those at the top and the bottom, and the reason for this is that the anomalously higher values occurred in the top and bottom of the water column (see water column level ranges presented in see Table 9 below and Figure 26 below).

When disaggregated by station location (depth), it was found that, for both replicates, the average levels of TSS were higher at the shelf stations, as opposed to at the slope and deepwater stations, and decreased with distance from the shore. The influence of the relatively higher levels of TSS at Station Liza R is also evident here. Conversely, though the levels of TSS were also relatively higher at Station Liza H, the average value (for slope stations) was depressed (and so, lower than that for the shelf) because of the limited variability amongst the other detected values (see Table 9 below and Figure 27 below).

Kemker (2014) cites levels of TSS less than 20 mg/l as indicative of clear waters, suggesting that these recorded values for October 2017 were low, except at Liza R and Liza H (at the bottom and top, respectively).

Table 9: Statistical Summary for TSS in Water (All Stations; Both Replicates; October 2017)

Treatment of Data		Replicate 1		Replicate 2	
		Range	Average ± SD	Range	Average ± SD
Across All Samples		3 – 33	8 ± 6.00	3 – 33	8 ± 7.00
By Water Column Position	**Top**	3.40 – 33	8.93 ± 8.14	3.2 – 33	8.95 ± 8.14
	Middle	2.80 – 10.20	5.87 ± 2.80	2.8 – 11	5.87 ± 2.80
	Bottom	3.20 - 23	8.20 ± 5.03	3 – 32	8.92 ± 7.52
By Station Location / Depth	**Shelf (14-64 m)**	2.80 - 23	8.79 ± 4.40	2.8 – 32	10.06 ± 6.27
	Slope (134 – 215 m)	2.80 - 33	7.38 ± 9.69	2.8 - 33	7.38 ± 2.77
	Deep (1,705 – 2,006 m)	3.40 – 10.20	6.62 ± 2.57	3.2 - 11	6.69 ± 2.77

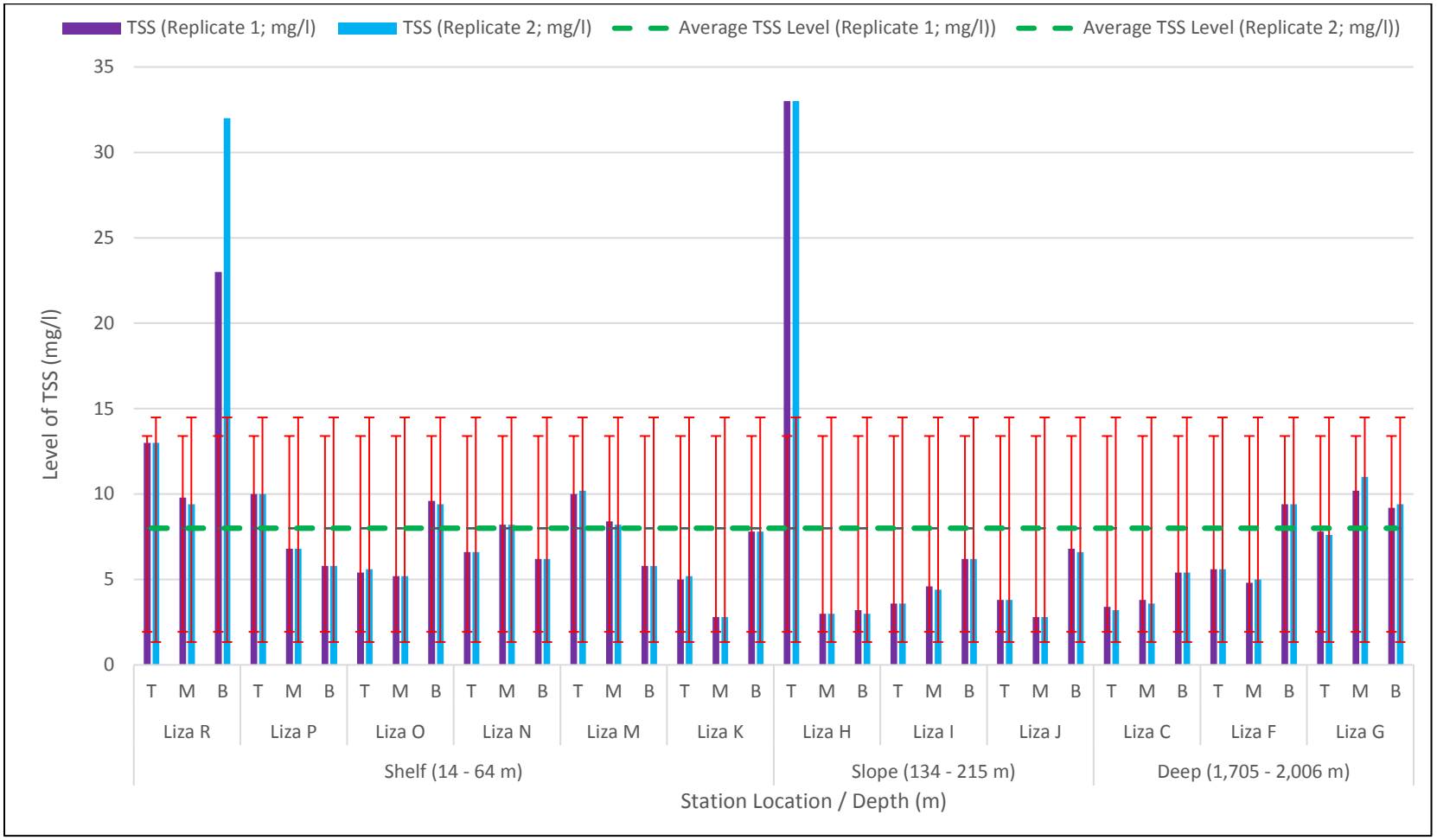


Figure 25: Distribution of TSS Levels (mg/l) across the Area Sampled (Both Replicates; October 2017)

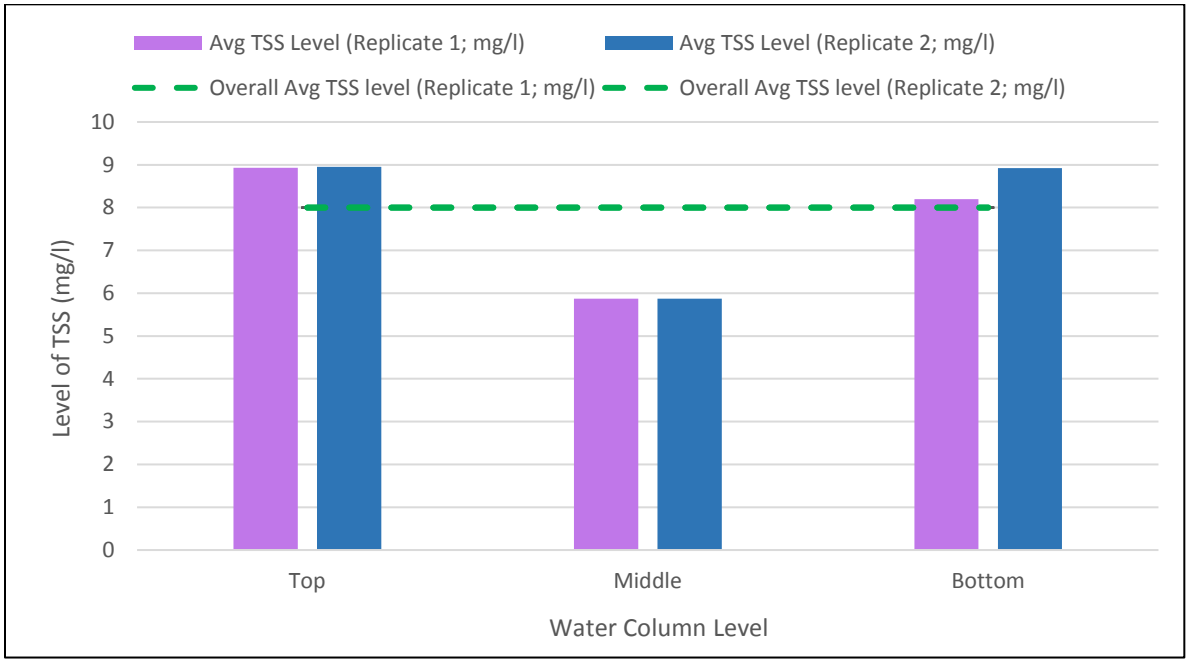


Figure 26: Comparison of the Average Levels of TSS by Water Column Level (October 2017)

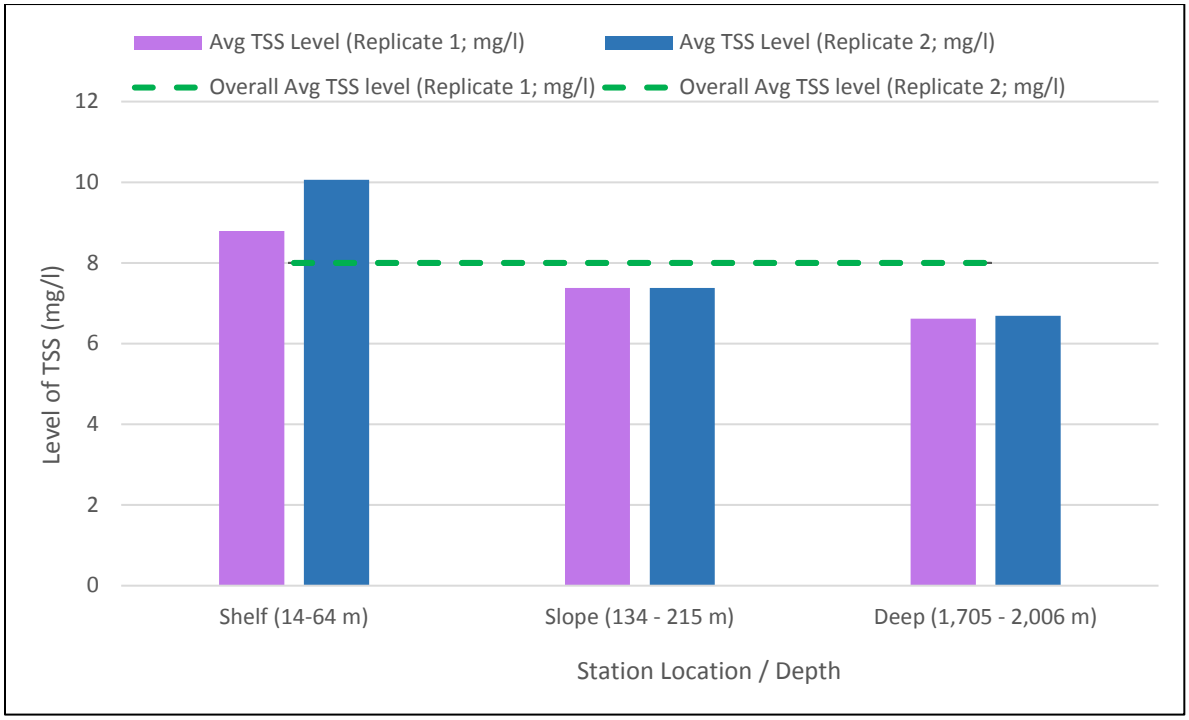


Figure 27: Comparison of the Average Levels of TSS by Station Location / Depth (October 2017)

6.3.3 Total Organic Carbon (TOC)

Table 10 below presents the calculated ranges and averages (with standard deviation) for the TOC dataset, when considering: all samples combined; by water column position (i.e. disaggregated by top, middle and bottom of the water column); and by location of the station (i.e. disaggregated by depth: shelf, slope and deep). Figure 28 below shows the levels of TOC (Replicates 1 and 2) across the area sampled. In each case, the data displayed very low variability, and both datasets were very similar, with the average value for Replicate 2 being marginally higher than that of Replicate 1 (see Table 10 below).

When the data were disaggregated by water column level, it was found that, for both replicates, average TOC levels tended to decrease with depth (Figure 29 below). When disaggregated by station location (depth), it was found that, for Replicate 1, the average TOC level was highest at the slope stations, whilst for Replicate 2, it was highest at the shelf stations (Figure 30 below). It must, however, be noted, that the datasets displayed very low variability and the actual recorded differences are very small, for both replicates.

Table 10: Statistical Summary for TOC (mg/l) in Water (All Stations; Both Replicates; October 2017)

Treatment of Data		Replicate 1		Replicate 2	
		Range	Average ± SD	Range	Average ± SD
Across All Samples		1.00 - 2.20	1.49 ± 0.2539	1.10 - 2.00	1.54 ± 0.2524
By Water Column Position	**Top**	1.30 – 2.20	1.61 ± 0.2811	1.30 – 2.00	1.62 ± 0.2588
	Middle	1.10 – 1.80	1.48 ± 0.2443	1.10 – 1.90	1.58 ± 0.2329
	Bottom	1.00 – 1.70	1.38 ± 0.1913	1.10 – 2.00	1.43 ± 0.2462
By Station Location / Depth	**Shelf (14-64 m)**	1.20 – 2.20	1.63 ± 0.2477	1.40 – 2.00	1.63 ± 0.2164
	Slope (134 – 215 m)	1.30 – 1.90	1.59 ± 0.2179	1.20 – 2.00	1.59 ± 0.2479
	Deep (1,705 – 2,006 m)	1.00 – 1.50	1.27 ± 0.1732	1.10 – 1.80	1.33 ± 0.2236

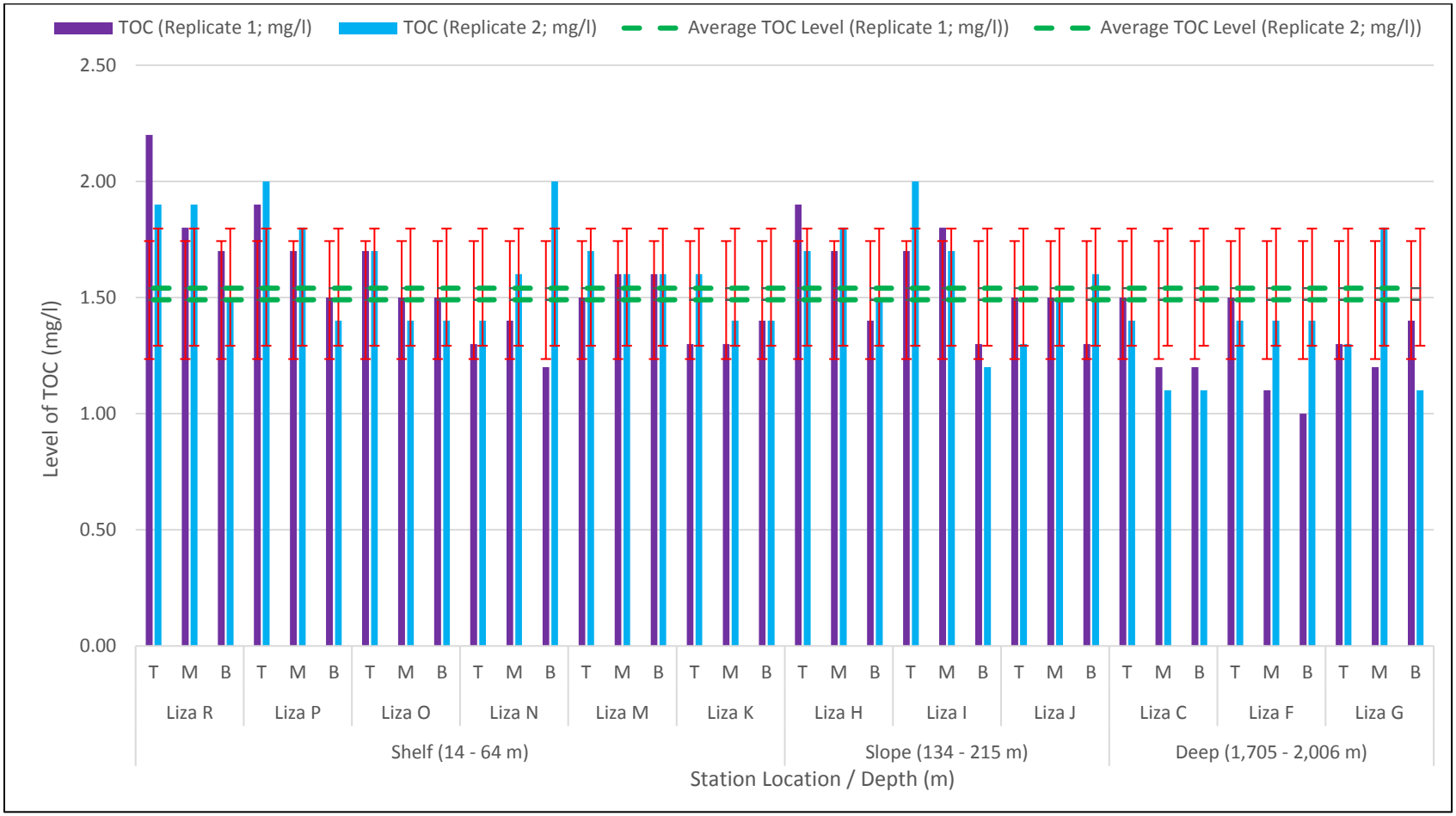


Figure 28: Distribution of TOC Levels (mg/l) across the Area Sampled (Both Replicates; October 2017)

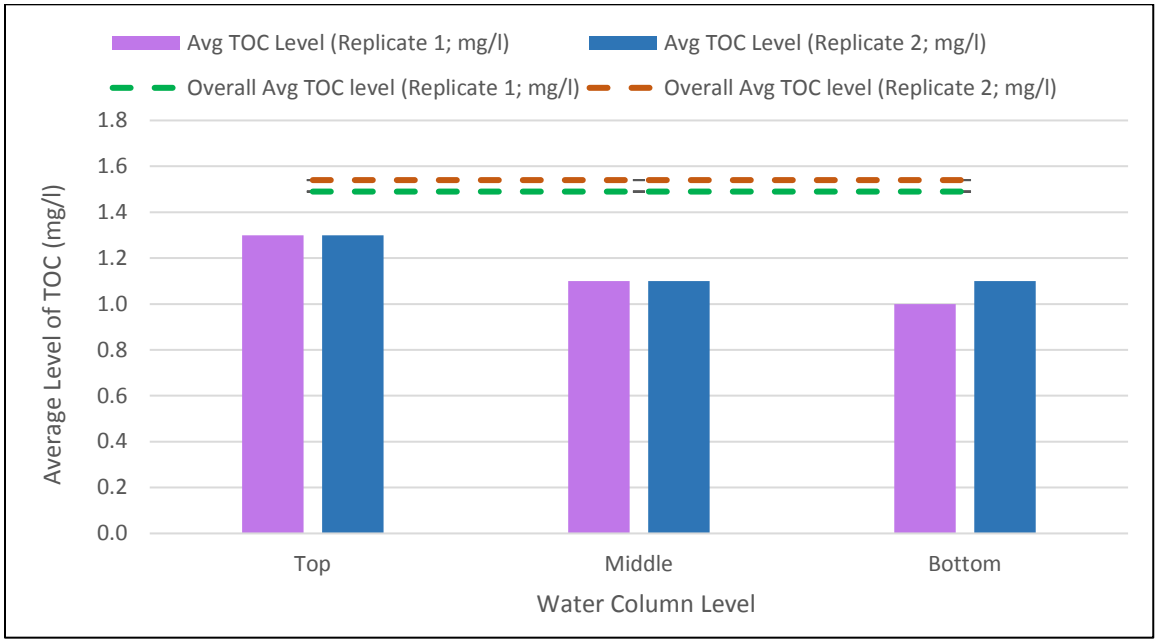


Figure 29: Comparison of the Average Levels of TOC by Water Column Level (October 2017)

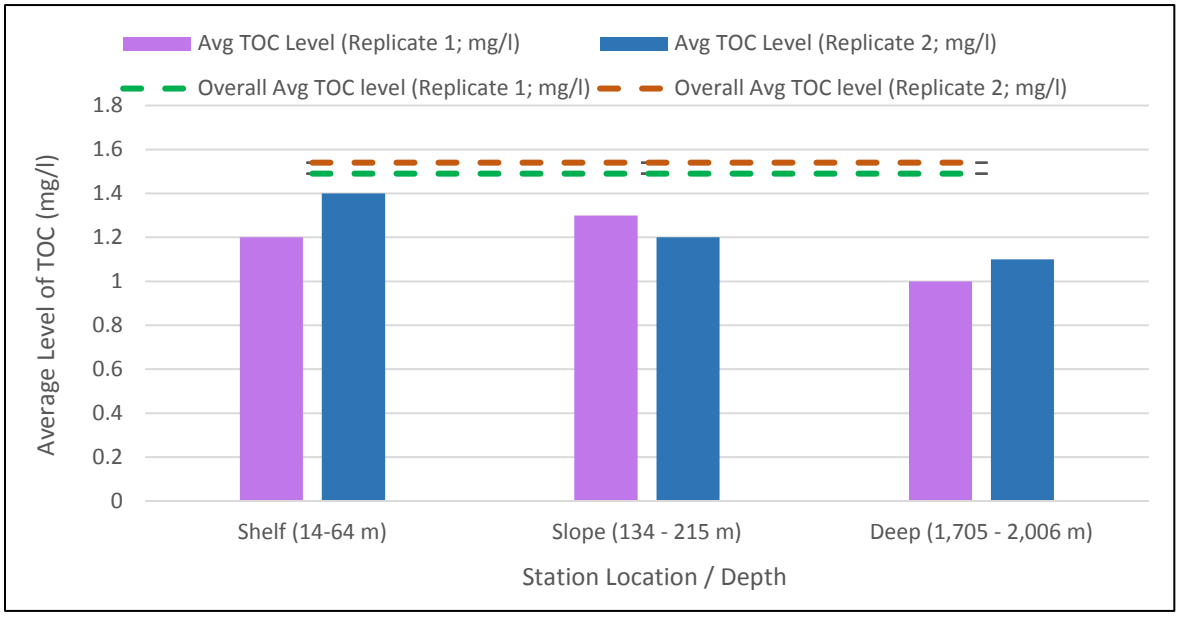


Figure 30: Comparison of the Average Levels of TOC by Station Location / Depth (October 2017)

6.3.4 Chemical Oxygen Demand (COD)

Table 11 below presents the calculated ranges and averages (with standard deviation) for the COD dataset, when considering: all samples combined; by water column position (i.e. disaggregated by top, middle and bottom of the water column); and by location of the station (i.e. disaggregated by depth: shelf, slope and deep). Figure 31 below shows the levels of COD (Replicates 1 and 2) across the area sampled. For Replicates 1 and 2, values ranged from BDL – 180 mg/l, but there was only one location at which COD was undetected. This occurred at the bottom of the water column at shelf Station Liza O, and excluding this, the minimum value was 30 mg/l (both replicates). The average value of COD for Replicate 1 (excluding the station at which BDL was recorded) was 93.43 ± 40.22 mg/l, and for Replicate 2, it was marginally higher, at 94.29 ± 14.32 mg/l. Figure 31 below shows that the recorded COD values for both replicates were very similar to each other, but indicates the high variability within each dataset; this is corroborated by the relatively high standard deviation values for the combined dataset (see Table 11 below).

When the data were disaggregated by water column level, it was found that, for both replicates, average COD levels tended to decrease with depth (Figure 32 below), with the average values at the top being 1.4 and 1.5 times higher than the average bottom values (Replicates 1 and 2, respectively).

When disaggregated by station location (depth), it was found that, for both replicates, the average COD level was lowest at the shelf stations (closest to the shore), but were largely similar at the slope and deepwater stations (Figure 33 below). In this case, the average values at the slope and deepwater stations were 1.4 times as high as the average for the shelf stations.

Table 11: Statistical Summary for COD (mg/l) in Water (All Stations; Both Replicates; October 2017)

Treatment of Data		Replicate 1		Replicate 2	
		Range	Average ± SD	Range	Average ± SD
Across All Samples		BDL – 180	93.43 ± 40.22	BDL – 170	94.29 ± 41.32
By Water Column Position	**Top**	60 – 180	109.17 ± 34.23	60 – 170	113.33 ± 37.50
	Middle	30 – 170	87.50 ± 46.15	30 – 170	87.50 ± 45.75
	Bottom	BDL – 160	75.83 ± 42.95	BDL – 160	74.17 ± 41.22
By Station Location / Depth	**Shelf (14-64 m)**	BDL - 160	77.78 ± 40.37	BDL – 160	76.11 ± 40.61
	Slope (134 – 215 m)	60 – 180	107.78 ± 36.32	50 – 170	108.89 ± 40.76
	Deep (1,705 – 2,006 m)	30 – 170	100 ± 48.48	40 – 170	105.56 ± 45.58

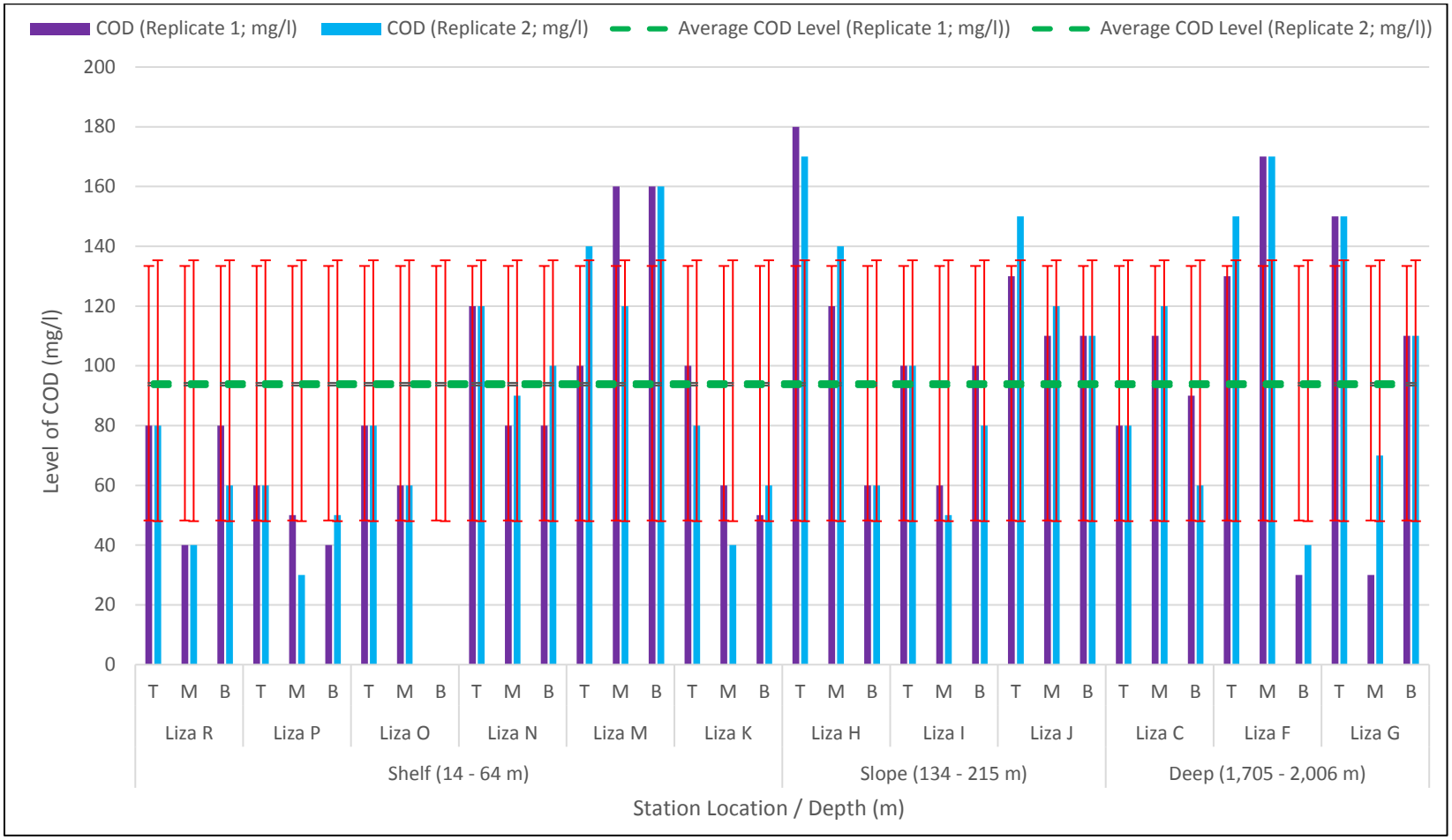


Figure 31: Distribution of COD Levels (mg/l) across the Area Sampled (Both Replicates; October 2017)

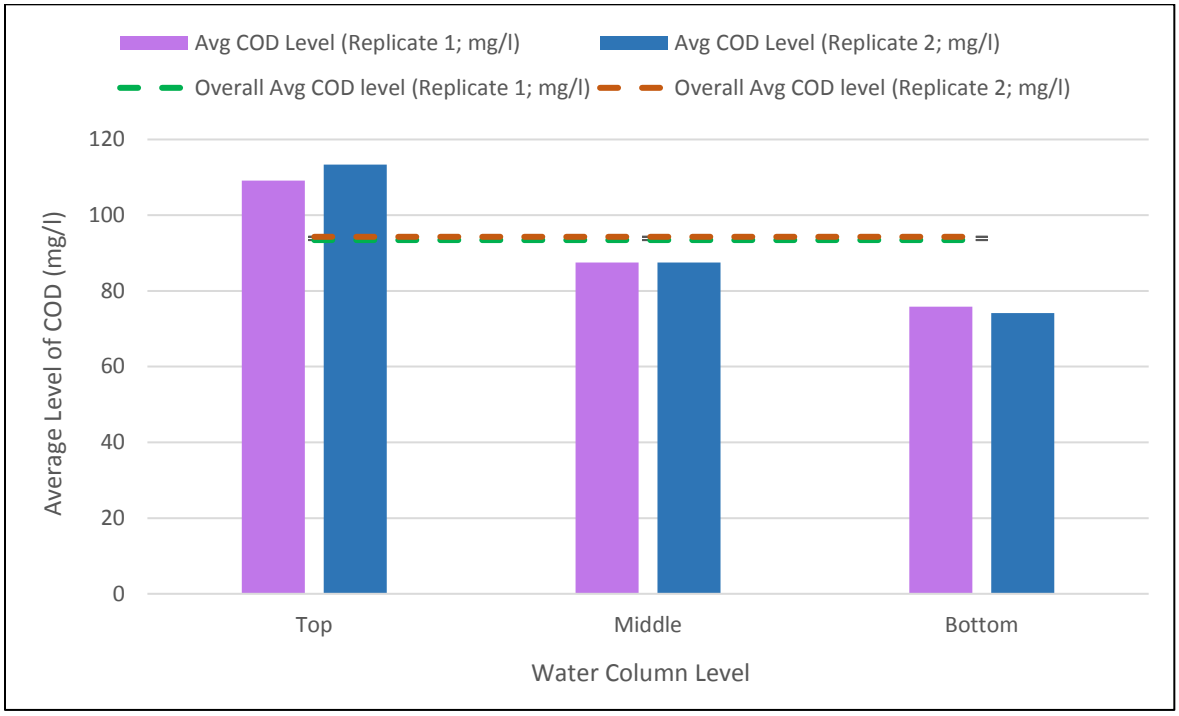


Figure 32: Comparison of the Average Levels of COD by Water Column Level (October 2017)

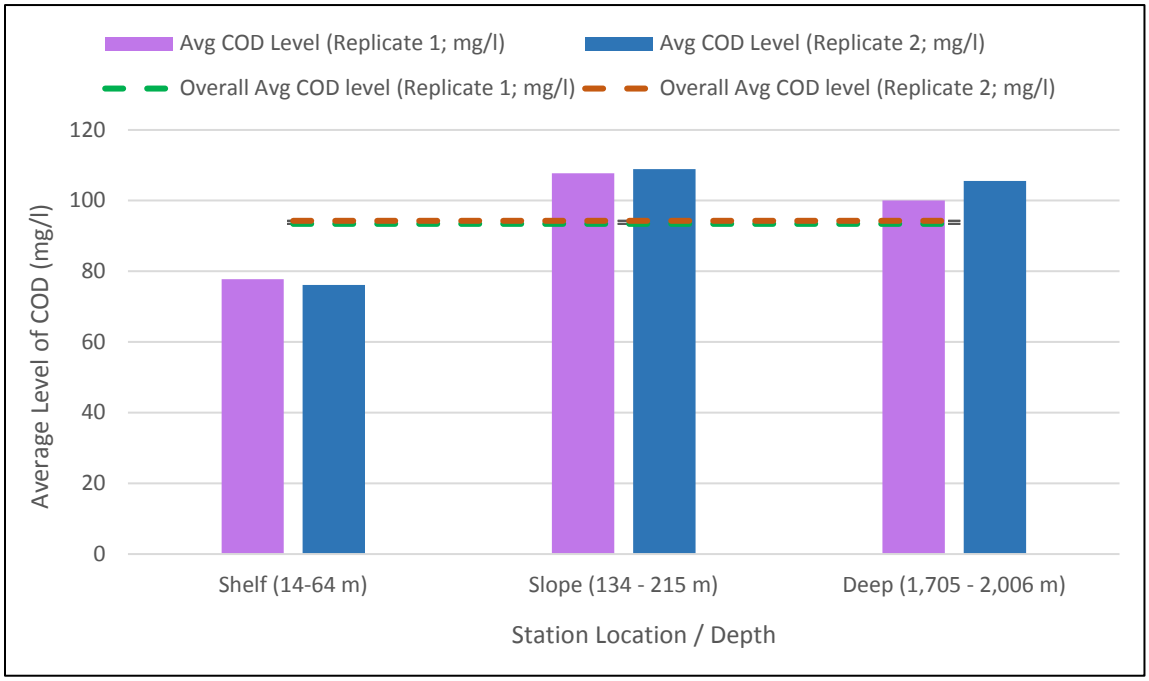


Figure 33: Comparison of the Average Levels of COD by Station Location / Depth (October 2017)

6.3.5 Saturated Hydrocarbons

As indicated in Section 6.3 above, saturated hydrocarbons were detected at all the slope and shelf stations (at various levels of the water column) but not at the deepwater stations. Table 12 presents the detected values for this parameter. From the table, it can be observed that saturated hydrocarbons were detected in one replicate but not in the other, for 9 out of the 13 samples listed. For these analytical tests, the detection limit ranged from 200 – 320 µg/l (varying by batch during sample analysis using Gas Chromatography-Mass Spectrometry or GC-MS equipment), and, in each instance, the replicate values at each station were not significantly greater than the detection limit. In addition, analytical values derived from measurements close to the detection limit were not subject to the same accuracy and precision criteria as results derived from measurements higher on the calibration range for the method.

Where detected, levels of saturated hydrocarbons ranged from 210 – 580 µg/l (replicated combined, with an average value of 362.35 ± 98.27 µg/l; Table 13 below). The data revealed that the average level of saturated hydrocarbons was highest at the middle of the water column, and higher at the slope stations, as opposed to shelf stations (see Table 13 below).

Table 12: Detected Levels of Saturated Hydrocarbons (µg/l; October 2017)

Depth (m)	Station Location	Station Name	Water Column Position	Saturated Hydrocarbons	
				Replicate 1	Replicate 2
14	Shelf	Liza R	Bottom	BDL	580
23		Liza P	Top	250	250
26		Liza O	Top	210	BDL
48		Liza N	Middle	BDL	240
54		Liza M	Bottom	BDL	320
64		Liza K	Bottom	BDL	320
134	Slope	Liza H	Top	390	350
134			Middle	450	460
157		Liza I	Top	340	BDL
157			Middle	410	BDL
215		Liza J	Top	BDL	350

Depth (m)	Station Location	Station Name	Water Column Position	Saturated Hydrocarbons	
				Replicate 1	Replicate 2
215			Middle	410	490
215			Bottom	340	BDL

Table 13: Statistical Summary for Saturated Hydrocarbons (µg/l) in Water (Where Detected; Replicates Combined; October 2017)

Treatment of Data (Replicates Combined)		Range (µg/l)	Average ± SD (µg/l)
Across All Samples		210 - 580	362.35 ± 98.27
By Water Column Position	**Top**	210 – 390	305.71 ± 67.78
	Middle	240 – 490	410 ± 88.77
	Bottom	320 - 580	390 ± 127.02
By Station Location / Depth	**Shelf (14 – 64 m)**	210 - 580	310 ± 125.96
	Slope (134 – 215 m)	340 – 490	399 ± 54.46

6.3.6 Ammonia

Ammonia values ranged from BDL – 0.02 mg/l. It was not detected at any level of the water column at any of the slope and deepwater stations, nor was it detected at the deepest shelf station, Liza K (64 m). Table 14 below shows that detected values were restricted to shelf stations M, N, O, P and R, within 14 – 54 m of the shore, and at varying levels of the water column. Where detected, ammonia ranged from 0.01 – 0.02 mg/l, with an overall average of 0.0127 ± 0.0047 mg/l (both replicates combined). Thus, the values are very similar, and this is corroborated by the very low standard deviation, suggesting very marginal variation within the dataset. It was also detected at the bottom and middle of the water column, with only one occurrence at the top (Station Liza O).

From Table 14 below, it can be observed that ammonia was detected in one replicate but not in the other, for 5 out of the 8 samples listed. For these analytical tests, the detection limit was 0.01 mg/l (see Appendix 8 in Chapter 9), and, in each instance, the replicate values at each station were not significantly greater than the detection limit. In addition, analytical values derived from measurements close to

the detection limit were not subject to the same accuracy and precision criteria as results derived from measurements higher on the calibration range for the method.

Table 14: Detected Levels of Ammonia (mg/l; October 2017)

Depth (m)	Station Location	Station Name	Water Column Position	Ammonia (mg/l)	
				Replicate 1	Replicate 2
14	Shelf	Liza R	Middle	0.01	0.02
			Bottom	0.01	BDL
23		Liza P	Bottom	0.02	0.01
26		Liza O	Top	BDL	0.01
			Bottom	0.01	0.01
48		Liza N	Middle	0.01	BDL
			Bottom	BDL	0.02
54		Liza M	Middle	BDL	0.01

6.4 Conclusion

An examination of the depth profiles for the various *in-situ* parameters (temperature, salinity, specific conductivity, DO and turbidity) revealed differences based on station location: depth profiles for temperature and salinity in particular revealed the presence of a thermocline and halocline at the deepwater stations (1,705 – 2,006 m), but well mixed conditions at the shelf (14 – 26 m) and slope stations (134 – 215 m). The changes in the levels of all 6 parameters were consistent with changes quoted in various environmental studies. Thus, the parameters behaved as expected in the marine environment.

Total cyanide and all metals were BDL at all levels of the water column at all stations; saturated hydrocarbons were detected at a few shelf locations and at all slope locations, whilst TOC and COD were detected in all 72 samples, along with TDS and TSS, the values for the latter of which conformed to the findings for the *in-situ* turbidity readings at shelf Station Liza R (but not Liza H). Ammonia was only detected (at various levels of the water column, within 14 – 54 m of the shore, being BDL at all slope and deepwater stations, as well as at the deepest shelf station, Liza K (26 m).

TDS, TSS, TOC and COD were generally found to decrease from the top to the bottom of the water column. TDS, TSS and TOC were also noted to decrease with distance from the shore, whilst COD was observed to increase with distance from the shore.

In general, the parameter results obtained from the water sampled in October 2017 appear to indicate sound water quality, given the relatively low levels of the parameters assessed above. The detection of TOC and COD indicate there were organic and/or inorganic carbon present in the water sampled in October 2017, the source is unknown.

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7 QUALITY ASSURANCE/QUALITY CONTROL

Chemical analysis of the water samples was executed with QA/QC checks and balances inherent in the test methods utilised or the various parameters as described in Section 4.5.2 above.

Additionally, the following checks were conducted in order to determine the accuracy and/or precision of the standard test methods:

- TSS and TDS – One duplicate sample was run for every twenty samples. Values for the duplicates must agree within 5% of their average
- HACH Analytes (COD, Ammonia) – A commercially available check standard of known concentration was analysed for every twenty samples. The measured concentration must be within 90% - 110% of the known (target) value.
- Cyanide – Method blank, Laboratory Control Sample (LCS) and Matrix Spike/Matrix Spike Duplicate (MS/MSD).
- Total Metals (Cr, Ni, Cu, Cd, Fe, Zn, As, Hg, Ba) – Matrix spikes (laboratory-prepared) and check standards within the range of calibration were conducted for one in every ten samples. Expected recovery for matrix spikes is 80 - 120% of the expected value, while check standard recoveries should be within 90 - 110% of the target value. Additionally, the check standards were entered into control charts to check for system bias and accuracy.
- Saturated Hydrocarbons – A primary surrogate (Dodecane-d26) and secondary surrogate (Triacontane-d62) were analysed with each sample. Acceptable recovery is considered to be between 40 - 150%. Four sets of Laboratory Control Samples/Duplicate Laboratory Control Samples (LCS/DLCS) were run with the samples, with acceptable recovery range set at 50 - 125%. Four method blank samples were also run.
- TOC - Method blank, Laboratory Control Sample (LCS) and Matrix Spike/Matrix Spike Duplicate (MS/MSD).

Checks of data calculations and transcription into the report were performed by a separate person from those performing tests and writing the report. All samples and analyses were completed as planned.

Quality control criteria were met for all analytes in this project.

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8 REFERENCES

Allen, H.E. n.d. Are all metals in the soil & water bioavailable? Eurometaux (European Association of Metals). http://www.eurometaux.org/MetalsToday/MetalsFAQs/Metalsbioavailablesoilwater.aspx Accessed March 20th, 2017

Artigas, L.F., P. Vendeville, M. Leopold, D. Guiral & J.F. Ternon, 2003. Marine biodiversity in French Guiana: estuarine, coastal, and shelf ecosystems under the influence of Amazonian waters. Guyana 67, 302-326.

Barber, S.J. n.d. The Spatial Variability of Total & Bioavailable Metal Concentrations in the Sediments of Mitchell Lake. Department of Earth and Environmental Science, Environmental Geochemistry Laboratory, University of Texas at San Antonio. 12 pp.

Bergman, J. 2011. Temperature of Ocean Water. Windows to the Universe. http://www.windows2universe.org/earth/Water/temp.html Accessed March 17th, 2017

Bernhard, J.M. 1988. Postmortem vital staining in benthic foraminifera: duration and importance in population and distributional studies, J. Foram. Res. 18, 143-146

Bischof, B, A.J. Mariano and E.H. Ryan. 2003. "The North Brazil Current" in Ocean Surface Currents. http://oceancurrents.rsmas.miami.edu/atlantic/north-brazil.html. Accessed March 19th, 2017

Burone, L., P. Muniz, A.M. Pires-Vanini and M. Rodrigues. 2003. Spatial distribution of organic matter in the surface sediments of Ubatuba Bay (Southeastern – Brazil). Annals of the Brazilian Academy of Sciences (2003) 75(1): 77-90.

Clarke, K.R, Gorley, R.N. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E: Plymouth

Condie. S.A. 1991: Separation and recirculation of the North Brazil Current. Journal of Marine Research, 49, 1-19.

Conrad C. F. and C.J. Chisholm-Brause. 2004. Spatial survey of trace metal contaminants in the sediments of the Elizabeth River, Virginia. Marine Pollution Bulletin 49(4): 319–324.

European Commission (EC) and BIO Intelligence. 2007. How do Changes in Ocean Temperature Affect Marine Ecosystems. Science for Environmental Policy: European Commission DG Alert News Service. http://ec.europa.eu/environment/integration/research/newsalert/pdf/52na2.pdf
Accessed September 18th, 2017.

Eutechinst. 2012. Conductivity/Total Dissolved Solids/Salinity
http://www.eutechinst.com/brochures/annual_catalogue/2012_catalogue_con_tds_salt.pdf
Accessed October 18th, 2017

Franson, M.A.H., A.D. Eaton, L.S. Clesceri and A.E. Greenberg. 2005. Standard Methods for the Examination of Water and Wastewater. Prepared and published by the American Public Health Association, American Waterworks Association and Water Environment Federation. Published by the American Public Health Association. Washington D.C.

Fauchland, K., and Jumars, P.A. 1979. The diet of worms: a study of polychaete feeding guilds, 17, 193-284

Gao, X., Y. Yang and C. Wanga. 2012. Geochemistry of organic carbon and nitrogen in surface sediments of coastal Bohai Bay inferred from their ratios and stable isotopic signatures. Marine Pollution Bulletin 64 (2012): 1148-1155. 9 pp.

Gordon, A.L. 2004. The Climate System: Ocean Stratification.
http://eesc.columbia.edu/courses/ees/climate/lectures/o_strat.html
Accessed February 18th, 2016

Gyory, J., A.J. Mariano and E.H. Ryan. nd. "The Caribbean Current." Ocean Surface Currents.
http://oceancurrents.rsmas.miami.edu/caribbean/caribbean.html.
Accessed November 27th, 2017

HACH. 2010. Water Analysis Handbook. Fifth Edition. HACH Company, P.O. Box 389 Loveland, Colorado, 80539-0389

Kemker, C. 2014. “Turbidity, Total Suspended Solids and Water Clarity.” Fundamentals of Environmental Measurements. Fondriest Environmental, Inc. 13 Jun. 2014.
http://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/ >
Accessed February 25th, 2017

Kemker, C. 2013. "Dissolved Oxygen." Fundamentals of Environmental Measurements. Fondriest Environmental, Inc. http://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/ >.
Accessed February 18th, 2016

Koldewijn, B.W., 1958. Sediments of the Paria-Trinidad-shelf. Fys.-Geog. Lab. Pub., Amsterdam University, v. 1, p. 109.
Accessed July 6th, 2017

Köster. M. and L. Meyer-Reil. 2001. Characterization of carbon and microbial biomass pools in shallow water coastal sediments of the southern Baltic Sea (Nordrügensche Bodden). Marine Ecology Progress Series. Vol. 214: 25–41, 2001. 17 pp.

Lazar, L., M.T. Gomoiu, L. Boicenco and D. Vasiliu. 2012. Total Organic Carbon (TOC) of the Surface Layer Sediments covering the Seafloor of the Romanian Black Sea Coast. Geo-Eco-Marine 18/12. pp: 121 – 132.

Marinebio.org. n.d. The Ocean and Temperature.
http://marinebio.org/oceans/temperature/
Accessed February 18th, 2015

Miller, A.L. and L.H., Keeney, D.R. (Eds.). 1992. Methods of Soil Analysis. Part 2. Chemical and microbiological properties. Agronomy Monograph, second ed., vol. 9, American Society of Agronomy, Madison, WI, pp. 199-224.

Muller-Karger, F.E., McCain, C.R. and Richardson, P.L. (1988). The Dispersal of the Amazon's Water. Nature 333: 56-59 pp.

The National Institute of Oceanography (NIO), India, n.d. Seawater.
http://www.nio.org/index/option/com_nomenu/task/show/tid/2/id/140
Accessed September 12th, 2012.

National Oceanographic and Atmospheric Administration. 2012. Thermocline.
http://www.erh.noaa.gov/cle/marine/marine_education/thermocline.php
Accessed February 19th, 2015

Ogden, J. C and E. H. Gladfelter, eds. 1982.Coral reefs, seagrass beds and mangroves: Their interaction in the coastal zones of the Caribbean. Report of a workshop held at the West Indies Laboratory, St. Croix, U.S. Virgin Islands May 1982. UNESCO IOCARIBE.

Omer, W.M.M. 2010. Ocean acidification in the Arabian Sea and the Red Sea: A thesis submitted in partial fulfilment for the degree of Master of Science. Faculty of Mathematics and Natural Sciences, Geophysical Institute, Chemical Oceanography. June 2010. University of Bergen. 67 pp.

OzCoasts (Geoscience Australia). 2012. Dissolved oxygen.
http://www.ozcoasts.gov.au/indicators/dissolved_oxygen.jsp
Accessed September 6th, 2017.

OzCOasts Geoscience Australia. 2012. What is Turbidity.
http://www.ozcoasts.gov.au/indicators/turbidity.jsp
Accessed September 6th, 2017.

Paller M.H. and A.S. Knox. 2013. Bioavailability of Metals in Contaminated Sediments. Proceedings of the 16th International Conference on Heavy Metals in the Environment, E3S Web of Conferences 1, 02001 (2013)

Prieto-Portar, L.A. 2007. Geotechnical_Manual_Lab.
http://www.learningace.com/doc/3095955/e65b0811b1ce11cac0e94f526bcb0a7d/geotechnical_manual_lab
Accessed July 8th, 2017

Puyate Y.T. and A. Rim-Rukeh, 2008. Variability with depth of some physic-chemical and biological parameters at Atlantic Ocean water in part of the coastal area of Nigeria. Journal of Applied Science Environmental Management Vol 12(1) 87-91.
http://www.bioline.org.br/pdf?ja08013
Accessed September 6th, 2017.

Rampersad, J., C. Ikon, N.I. Khandaker and S. Schleifer, 2008. Mineralogy of the coastal sand obtained from the twin island republic of Trinidad & Tobago. Geological Society of America, v. 40, no. 6, p. 181.

Rice, E.W., R.B. Baird, A.D. Eaton and L.S. Clesceri. 2012. Standard Methods for the Examination of Water and Wastewater, 22nd Edition. Prepared and published by the American Public Health Association, American Waterworks Association and Water Environment Federation and the American Public Health Association. Washington D.C.

Roemmich, D. 1981: Circulation in the Caribbean Sea: A well-resolved inverse problem. Journal of Geophysical Research, 86, 7993-8005. In: Gyory, J., A.J. Mariano and E.H. Ryan. n.d. "The Caribbean Current." Ocean Surface Currents.
http://oceancurrents.rsmas.miami.edu/caribbean/caribbean.html.
Accessed January 31st, 2012

Seiter, K., C. Hensen, J. Schroter and M. Zabel. 2004. Organic Carbon Content in surface Sediments – Defining Regional Provinces. Deep Sea Research Part 1: Oceanographic Research Papers Volume 51 Issue 12: 2001 – 2026.

Steven, D.M. and Brooks, A.L. (1972). Identification of Amazon River Water at Barbados, W. Indies, by salinity and silicate measurements. Marine Biology 14: 345-348 pp.

Totah, N. 2011. Calculating Percentage Recovery & Percentage Yield. In: Appendix for CHE 276 Organic Chemistry. 2 pp.

United States Environmental Protection Agency. 1999. Method 1664, Revision A: N-Hexane Extractable Material (HEM; Oil and Grease) and Silica Gel Treated N-Hexane Extractable Material (SGTHEM; Non-polar Material) by Extraction and Gravimetry. Office of Water, Washington, DC 20460. EPA-821-R-98-002, PB99-121949. 27 pp.

United States Environmental Protection Agency. 1998. Method 9071B, n-Hexane Extractable Material (Hem) for Sludge, Sediment, and Solid Samples. In Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Office of Resource Conservation and Recovery, Washington, DC 20460. Revision 2. EPA–RCRA–2012–0072.

United States Environmental Protection Agency. 1996a. Method SW846 6010B Inductively Coupled Plasma-Atomic Emission Spectrometry. In Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Office of Resource Conservation and Recovery, Washington, DC 20460. Revision 3. EPA–RCRA–2012–0072.

United States Environmental Protection Agency. 1996b. Method SW846 8260B Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS). In Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Office of Resource Conservation and Recovery, Washington, DC 20460. Revision 2. EPA–RCRA–2012–0072.

United States Environmental Protection Agency. 1996c. Method SW846 8270C Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS). In Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Office of Resource Conservation and Recovery, Washington, DC 20460. Revision 2. EPA–RCRA–2012–0072.

USEPA Region III BTAG Marine Sediment Screening Benchmarks. 2004. http://www.epa.gov/reg3hwmd/risk/eco/btag/sbv/marine/screenbench.htm Accessed June 2nd, 2014

USEPA. 1976. Quality Criteria for Water (Red Book). Office of Water and Hazardous Materials. July 1976. Washington, D.C. 534 pp.

Walker, D.A., A.E. Linton and C.T. Schafer. 1974. Sudan Black B: a superior stain to Rose Bengal for distinguishing living from non-living foraminifera, J. Foram. Res., 4, 205-215

Warne. A.G., R.H. Meade, W.A. White, E.H. Guevara, J. Gibeaut, R.C. Smyth, A. Aslan and T. Tremblay. 2002. Regional controls on geomorphology, hydrology, and ecosystem integrity in the Orinoco Delta, Venezuela. Geomorphology 44 (2002) 273–307. 35 pp.

Waterwatch Australia, 2005. Monitoring Water Quality. Methods (continued) Electrical conductivity.
http://www.waterwatch.org.au/publications/module4/electrical.html
Accessed November 21st, 2017.

9 APPENDICES

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Appendix 1 - Laboratory Accreditation Certificates

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TT LABS
TRINIDAD AND TOBAGO
laboratory Accreditation Service

CERTIFICATE OF ACCREDITATION

ENVIRONMENTAL SCIENCES LTD

Testing Laboratory No.: LAS-004

is an accredited Laboratory which fulfils the requirements of ISO/IEC 17025 and has demonstrated competence to carry out tests as per a defined scope for:

CHEMICAL TESTING

as per attached schedule

While this certificate remains valid, the Accredited Laboratory named above is authorized to issue TTLABS-endorsed certificates.

Karlene Carolyn Lewis

Manager, TTLABS

"Recognized as the official national laboratory accreditation body by the Ministry of Trade and Industry of the Republic of Trinidad and Tobago"

Initial Accreditation date: 12th December 2011

This certificate issued on: 2nd January 2015

"This laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17025:2005. This accreditation demonstrated technical competence for a defined scope and the operation of a laboratory quality management system. (refer to joint ISO-ILAC-IAF Communiqué dated 18 June 2005)"

TT TABS
TRINIDAD AND TOBAGO
laboratory Accreditation Service

SCHEDULE OF ACCREDITATION

Testing Laboratory Number: **LAS-004**

Permanent Address of Laboratory:	**Management Signatories:**
Environmental Sciences Limited 141 Riverside Drive San Fernando Trinidad and Tobago. W.I. **Postal Address** 141 Riverside Drive San Fernando Trinidad and Tobago. W.I. Tel : 868-657-9024 Fax : 868-653-2571 e-mail: shivanna.lee@envirosciences.net	Jerome Als **Technical Signatories:** Shivanna Mahabir-Lee **Nominated Representative:** Renica Pariag **Certificate of Accreditation** Issue No. : 2 Date of issue : 2nd Jan 2015

Materials/Products Tested	Types of Tests/Properties Measured, Range of Measurement	Standard Specifications, Equipment/Techniques Used
CHEMICAL Metals in Water and Wastewater	1) Flame Atomic Absorption Spectrophotometry for: • Cadmium • Chromium • Copper • Lead • Iron • Zinc • Nickel **Units: µg/L**	Reference – Standard Methods for Evaluation of Water and Wastewater (SMEWW) 3111 A - Metals by flame atomic absorption spectrometry SMEWW 3111 B – Direct air-acetylene flame method **Method No. QMT 001**

Date of accreditation: 12th December, 2011

Manager, TTLABS

LAS-004_Sched_1 Page 1 of 1







State of Florida
Department of Health, Bureau of Public Health Laboratories
This is to certify that

E81010

TESTAMERICA PENSACOLA
3355 MCLEMORE DRIVE
PENSACOLA, FL 32514

has complied with Florida Administrative Code 64E-1,
for the examination of environmental samples in the following categories

DRINKING WATER - MICROBIOLOGY, DRINKING WATER - PRIMARY INORGANIC CONTAMINANTS, DRINKING WATER - SECONDARY INORGANIC CONTAMINANTS, DRINKING WATER - SYNTHETIC ORGANIC CONTAMINANTS, NON-POTABLE WATER - EXTRACTABLE ORGANICS, NON-POTABLE WATER - GENERAL CHEMISTRY, NON-POTABLE WATER - METALS, NON-POTABLE WATER - MICROBIOLOGY, NON-POTABLE WATER - PESTICIDES-HERBICIDES-PCB'S, NON-POTABLE WATER - VOLATILE ORGANICS, SOLID AND CHEMICAL MATERIALS - EXTRACTABLE ORGANICS, SOLID AND CHEMICAL MATERIALS - GENERAL CHEMISTRY, SOLID AND CHEMICAL MATERIALS - METALS, SOLID AND CHEMICAL MATERIALS - PESTICIDES-HERBICIDES-PCB'S, SOLID AND CHEMICAL MATERIALS - VOLATILE ORGANICS, BIOLOGICAL TISSUE - EXTRACTABLE ORGANICS, BIOLOGICAL TISSUE - METALS, BIOLOGICAL TISSUE - PESTICIDES-HERBICIDES-PCB'S

Continued certification is contingent upon successful on-going compliance with the NELAC Standards and FAC Rule 64E-1 regulations. Specific methods and analytes certified are cited on the Laboratory Scope of Accreditation for this laboratory and are on file at the Bureau of Public Health Laboratories, P. O. Box 210, Jacksonville, Florida 32231. Clients and customers are urged to verify with this agency the laboratory's certification status in Florida for particular methods and analytes.

Date Issued: July 01, 2017 Expiration Date: June 30, 2018



Susanne Crowe

Susanne Crowe, MHA
Acting Chief, Bureau of Public Health Laboratories
DH Form 1697, 7/04
NON-TRANSFERABLE E81010-46-07/01/2017
Supersedes all previously issued certificates

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OREGON

Environmental Laboratory Accreditation Program

ALS Environmental, Kelso

WA100010

1317 South 13th Ave.

Kelso, WA 98626

NELAP Recognized

IS GRANTED APPROVAL BY ORELAP UNDER THE 2009 TNI STANDARDS, TO PERFORM ANALYSES ON ENVIRONMENTAL SAMPLES IN MATRICES AS LISTED BELOW :

Air	*Drinking Water*	*Non Potable Water*	*Solids and Chem. Waste*	*Tissue*
	Chemistry	Chemistry	Chemistry	Chemistry
	Microbiology	Microbiology		

AND AS RECORDED IN THE LIST OF APPROVED ANALYTES, METHODS, ANALYTICAL TECHNIQUES, AND FIELDS OF TESTING ISSUED CONCURRENTLY WITH THIS CERTIFICATE AND REVISED AS NECESSARY.

ACCREDITED STATUS DEPENDS ON SUCCESSFUL ONGOING PARTICIPATION IN THE PROGRAM AND CONTINUED COMPLIANCE WITH THE STANDARDS.

CUSTOMERS ARE URGED TO VERIFY THE LABORATORY'S CURRENT ACCREDITATION STATUS IN OREGON.

Scott Hoatson
Oregon State Public Health Laboratory
Interim ORELAP Program Manager
3150 NW. 229th Ave, Suite 100
Hillsboro, OR 97124

EFFECTIVE DATE : 02/11/2017

EXPIRATION DATE : 02/10/2018

Certificate No : WA100010 - 016

OREGON

Environmental Laboratory Accreditation Program

ORELAP Fields of Accreditation

ORELAP ID: WA100010

ALS Environmental, Kelso
1317 South 13th Ave.
Kelso, WA 98626

EPA CODE: WA01276
Certificate: WA100010 - 016

Issue Date: 2/11/2017 Expiration Date: 2/10/2018

As of 2/11/2017 this list supersedes all previous lists for this certificate number.

MATRIX	Reference	Code	Analyte	Code	Description
Biological Tissue	ALS Kelso LCP-PFC 4			60001505	ALS Kelso - Perfluorinated Compounds by HPLC-MS-MS
		6911	Perfluorobutane Sulfonate (PFBS)		
		9562	Perfluorodecane Sulfonate (PFDS)		
		6905	Perfluorodecanoic acid (PFDA)		
		6903	Perfluorododecanoic (PFDDA)		
		6908	Perfluoroheptanoic acid (PFHA)		
		6910	Perfluorohexane Sulfonate (PFHS)		
		6913	Perfluorohexanoic acid (PFHXA)		
		6906	Perfluorononanoic acid (PFNA)		
		6912	Perfluorooctanoic acid		
		6909	Perfluorooctanoic Sulfonate (PFOS)		
		6914	Perfluoropentanoic acid (PFPEA)		
		6904	Perfluoroundecanoic acid (PFUDA)		
	CAS SOC-Butyl 10			60035009	Butyltin by GC/Flame Photometric Detector
		1201	Butyltin trichloride		
		1202	Dibutyltin dichloride		
		1209	Tetrabutyltin		
		1203	Tributyltin chloride		
	EPA 1630			10122608	Methyl Mercury by Purge & Trap Cold Vapor Atomic Fluorescence Spectrometry
		1205	Methyl Mercury		
	EPA 1631E			10237204	Mercury in Water by Oxidation, Purge & Trap, and Cold Vapor Atomic Fluorescence
		1095	Mercury		
	EPA 1632A			10123407	Arsenic in Water by Gaseous Hydride Atomic Absorption
		1010	Arsenic		
		1012	Arsenite (As+3)		
		6138	Dimethylarsinic acid (DMA)		
		1207	Monomethylarsonic acid (MMA)		
	EPA 3540C			10140202	Soxhlet Extraction
		8031	Extraction/Preparation		
	EPA 3541			10140406	Automated Soxhlet Extraction
		8031	Extraction/Preparation		
	EPA 3630C			10146802	Silica gel cleanup
		8031	Extraction/Preparation		

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Biological Tissue	EPA 3640A			10147203	Gel Preparation Cleanup
		8031	Extraction/Preparation		
	EPA 365.3			10070607	Phosphorous - Colorimetric, two reagent.
		1908	Total Phosphate		
	EPA 3660B			10148400	Sulfur cleanup
		8031	Extraction/Preparation		
	EPA 3665A			10148808	Sulfuric Acid / permanganate Cleanup
		8031	Extraction/Preparation		
	EPA 5035A			10284807	Closed-System Purge-and-Trap and Extraction for Volatile Organics in Soil and Waste Samples
		8031	Extraction/Preparation		
	EPA 6010C			10155803	ICP - AES
		1000	Aluminum		
		1005	Antimony		
		1010	Arsenic		
		1015	Barium		
		1020	Beryllium		
		1025	Boron		
		1030	Cadmium		
		1040	Chromium		
		1050	Cobalt		
		1055	Copper		
		1070	Iron		
		1075	Lead		
		1090	Manganese		
		1100	Molybdenum		
		1105	Nickel		
		1140	Selenium		
		1150	Silver		
		1175	Tin		
		1185	Vanadium		
		1190	Zinc		
	EPA 6020A			10156408	Inductively Coupled Plasma-Mass Spectrometry
		1000	Aluminum		
		1005	Antimony		
		1010	Arsenic		
		1015	Barium		
		1020	Beryllium		
		1030	Cadmium		
		1040	Chromium		

Department of Agriculture, Laboratory Division
Department of Environmental Quality, Laboratory Division
Oregon Health Authority, Public Health Division

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Environmental Laboratory Accreditation Program

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Biological Tissue	EPA 6020A				
		1050	Cobalt		
		1055	Copper		
		1070	Iron		
		1075	Lead		
		1090	Manganese		
		1100	Molybdenum		
		1105	Nickel		
		1140	Selenium		
		1150	Silver		
		1165	Thallium		
		1185	Vanadium		
		1190	Zinc		
	EPA 7196A			10162400	Chromium Hexavalent colorimetric
		1045	Chromium VI		
	EPA 7471B			10166402	Mercury by Cold Vapor Atomic Absorption
		1095	Mercury		
	EPA 7742			10169207	Selenium by Borohydride Reduction and Atomic Absorption
		1140	Selenium		
	EPA 8081B			10178800	Organochlorine Pesticides by GC/ECD
		8580	2,4'-DDD		
		8585	2,4'-DDE		
		8590	2,4'-DDT		
		7355	4,4'-DDD		
		7360	4,4'-DDE		
		7365	4,4'-DDT		
		7005	Alachlor		
		7025	Aldrin		
		7110	alpha-BHC (alpha-Hexachlorocyclohexane)		
		7240	alpha-Chlordane		
		7115	beta-BHC (beta-Hexachlorocyclohexane)		
		7250	Chlordane (tech.)		
		7300	Chlorpyrifos		
		7925	cis-Nonachlor		
		7105	delta-BHC		
		7470	Dieldrin		
		7510	Endosulfan I		
		7515	Endosulfan II		
		7520	Endosulfan sulfate		
		7540	Endrin		
		7530	Endrin aldehyde		

Department of Agriculture, Laboratory Division
Department of Environmental Quality, Laboratory Division
Oregon Health Authority, Public Health Division

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OREGON

Environmental Laboratory Accreditation Program

ORELAP Fields of Accreditation

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Kelso, WA 98626

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Issue Date: 2/11/2017 Expiration Date: 2/10/2018

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Biological Tissue	EPA 8081B	7535	Endrin ketone		
		7120	gamma-BHC (Lindane, gamma-Hexachlorocyclohexane)		
		7245	gamma-Chlordane		
		7685	Heptachlor		
		7690	Heptachlor epoxide		
		6275	Hexachlorobenzene		
		4835	Hexachlorobutadiene		
		7725	Isodrin		
		7810	Methoxychlor		
		7870	Mirex		
		3890	Oxychlordane		
		8250	Toxaphene (Chlorinated camphene)		
	EPA 8082A			10179201	Polychlorinated Biphenyls (PCBs) by GC/ECD
		9095	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl (BZ-206)		
		9090	2,2',3,3',4,4',5,5'-Octachlorobiphenyl (BZ-194)		
		9103	2,2',3,3',4,4',5,6-Octachlorobiphenyl (BZ-195)		
		9065	2,2',3,3',4,4',5-Heptachlorobiphenyl (BZ-170)		
		9020	2,2',3,3',4,4'-Hexachlorobiphenyl (BZ-128)		
		9112	2,2',3,3',4,5',6,6'-Octachlorobiphenyl (BZ-201)		
		9116	2,2',3,3',4,5,6'-Heptachlorobiphenyl (BZ-174)		
		9114	2,2',3,3',4,5',6'-Heptachlorobiphenyl (BZ-177)		
		9120	2,2',3,3',4,6'-Hexachlorobiphenyl (BZ-132)		
		9133	2,2',3,4,4',5,5',6-Octachlorobiphenyl (BZ-203)		
		9134	2,2',3,4,4',5,5'-Heptachlorobiphenyl (BZ-180)		
		9075	2,2',3,4,4',5',6-Heptachlorobiphenyl (BZ-183)		
		9025	2,2',3,4,4',5'-Hexachlorobiphenyl (BZ-138)		
		9139	2,2',3,4,4',6,6'-Heptachlorobiphenyl (BZ-184)		
		9080	2,2',3,4',5,5',6-Heptachlorobiphenyl (BZ-187)		
		9030	2,2',3,4,5,5'-Hexachlorobiphenyl (BZ-141)		
		9151	2,2',3,4',5',6-Hexachlorobiphenyl (BZ-149)		

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Biological Tissue	EPA 8082A	8975	2,2',3,4,5'-Pentachlorobiphenyl (BZ-87)
		9155	2,2',3,4',5-Pentachlorobiphenyl (BZ-90)
		9154	2,2',3,4',5'-Pentachlorobiphenyl (BZ-97)
		9035	2,2',3,5,5',6-Hexachlorobiphenyl (BZ-151)
		9166	2,2',3,5',6-Pentachlorobiphenyl (BZ-95)
		8945	2,2',3,5'-Tetrachlorobiphenyl (BZ-44)
		9040	2,2',4,4',5,5'-Hexachlorobiphenyl (BZ-153)
		9174	2,2',4,4',5,6'-Hexachlorobiphenyl (BZ-154)
		9175	2,2',4,4',5-Pentachlorobiphenyl (BZ-99)
		8980	2,2',4,5,5'-Pentachlorobiphenyl (BZ-101)
		8950	2,2',4,5'-Tetrachlorobiphenyl (BZ-49)
		8955	2,2',5,5'-Tetrachlorobiphenyl (BZ-52)
		8930	2,2',5-Trichlorobiphenyl (BZ-18)
		9085	2,3,3',4,4',5,5'-Heptachlorobiphenyl (BZ-189)
		9050	2,3,3',4,4',5-Hexachlorobiphenyl (BZ-156)
		9045	2,3,3',4,4',5'-Hexachlorobiphenyl (BZ-157)
		9193	2,3,3',4,4',6-Hexachlorobiphenyl (BZ-158)
		8985	2,3,3',4,4'-Pentachlorobiphenyl (BZ-105)
		8990	2,3,3',4',6-Pentachlorobiphenyl (BZ-110)
		9207	2,3,3',4'-Tetrachlorobiphenyl (BZ-56)
		9055	2,3',4,4',5,5'-Hexachlorobiphenyl (BZ-167)
		9218	2,3',4,4',5',6-Hexachlorobiphenyl (BZ-168)
		9005	2,3,4,4',5-Pentachlorobiphenyl (BZ-114)
		8995	2,3',4,4',5-Pentachlorobiphenyl (BZ-118)
		9000	2,3',4,4',5'-Pentachlorobiphenyl (BZ-123)
		9220	2,3',4,4',6-Pentachlorobiphenyl (BZ-119)
		9221	2,3,4,4'-Tetrachlorobiphenyl (BZ-60)
		8960	2,3',4,4'-Tetrachlorobiphenyl (BZ-66)
		9230	2,3',4',5-Tetrachlorobiphenyl (BZ-70)
		9239	2,3',4'-Trichlorobiphenyl (BZ-33)
		8920	2,3-Dichlorobiphenyl (BZ-5)
		9250	2,4,4',5-Tetrachlorobiphenyl (BZ-74)

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		8940	2,4',5-Trichlorobiphenyl (BZ-31)		
		8915	2-Chlorobiphenyl (BZ-1)		
		9060	3,3',4,4',5,5'-Hexachlorobiphenyl (BZ-169)		
		9015	3,3',4,4',5-Pentachlorobiphenyl (BZ-126)		
		8965	3,3',4,4'-Tetrachlorobiphenyl (BZ-77)		
		8970	3,4,4',5-Tetrachlorobiphenyl (BZ-81)		
		9266	3,4,4'-Trichlorobiphenyl (BZ-37)		
		8880	Aroclor-1016 (PCB-1016)		
		8885	Aroclor-1221 (PCB-1221)		
		8890	Aroclor-1232 (PCB-1232)		
		8895	Aroclor-1242 (PCB-1242)		
		8900	Aroclor-1248 (PCB-1248)		
		8905	Aroclor-1254 (PCB-1254)		
		8910	Aroclor-1260 (PCB-1260)		
		8912	Aroclor-1262 (PCB-1262)		
		8913	Aroclor-1268 (PCB-1268)		
		9105	Decachlorobiphenyl (BZ-209)		
	EPA 8270D SIM			10242509	Semivolatile Organic compounds by GC/MS Selective Ion Monitoring
		5155	1,2,4-Trichlorobenzene		
		4610	1,2-Dichlorobenzene		
		6221	1,2-Diphenylhydrazine		
		4615	1,3-Dichlorobenzene		
		4620	1,4-Dichlorobenzene		
		6380	1-Methylnaphthalene		
		9501	1-Methylphenanthrene		
		6852	2,3,5-Trimethylnaphthalene		
		6835	2,4,5-Trichlorophenol		
		6840	2,4,6-Trichlorophenol		
		6000	2,4-Dichlorophenol		
		6130	2,4-Dimethylphenol		
		6175	2,4-Dinitrophenol		
		6185	2,4-Dinitrotoluene (2,4-DNT)		
		6188	2,6-Dimethylnaphthalene		
		6190	2,6-Dinitrotoluene (2,6-DNT)		
		5795	2-Chloronaphthalene		
		5800	2-Chlorophenol		
		6360	2-Methyl-4,6-dinitrophenol (4,6-Dinitro-2-methylphenol)		
		6385	2-Methylnaphthalene		
		6400	2-Methylphenol (o-Cresol)		
		6460	2-Nitroaniline		

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Biological Tissue	EPA 8270D SIM	6490	2-Nitrophenol
		6412	3 & 4 Methylphenol
		5660	4-Bromophenyl phenyl ether (BDE-3)
		5700	4-Chloro-3-methylphenol
		5825	4-Chlorophenyl phenylether
		6410	4-Methylphenol (p-Cresol)
		6470	4-Nitroaniline
		6500	4-Nitrophenol
		5500	Acenaphthene
		5505	Acenaphthylene
		5555	Anthracene
		5575	Benzo(a)anthracene
		5580	Benzo(a)pyrene
		5605	Benzo(e)pyrene
		5590	Benzo(g,h,i)perylene
		9309	Benzo(j)fluoranthene
		5600	Benzo(k)fluoranthene
		5585	Benzo[b]fluoranthene
		5630	Benzyl alcohol
		5640	Biphenyl
		5760	bis(2-Chloroethoxy)methane
		5765	bis(2-Chloroethyl) ether
		5780	bis(2-Chloroisopropyl) ether
		5670	Butyl benzyl phthalate
		5680	Carbazole
		5855	Chrysene
		6065	Di(2-ethylhexyl) phthalate (bis(2-Ethylhexyl)phthalate, DEHP)
		5895	Dibenz(a,h) anthracene
		5905	Dibenzofuran
		6070	Diethyl phthalate
		6135	Dimethyl phthalate
		5925	Di-n-butyl phthalate
		6200	Di-n-octyl phthalate
		6265	Fluoranthene
		6270	Fluorene
		6275	Hexachlorobenzene
		4835	Hexachlorobutadiene
		4840	Hexachloroethane
		6315	Indeno(1,2,3-cd) pyrene
		6320	Isophorone
		5005	Naphthalene
		5015	Nitrobenzene
		6525	n-Nitrosodiethylamine

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Biological Tissue	EPA 8270D SIM	6545	n-Nitrosodi-n-propylamine		
		6535	n-Nitrosodiphenylamine		
		6605	Pentachlorophenol		
		6608	Perylene		
		6615	Phenanthrene		
		6625	Phenol		
		6665	Pyrene		
	EPA 8330B			10308006	Nitroaromatics, Nitramines and Nitrate Esters by High Performance Liquid Chromatography (HPLC)
		6885	1,3,5-Trinitrobenzene (1,3,5-TNB)		
		6160	1,3-Dinitrobenzene (1,3-DNB)		
		9651	2,4,6-Trinitrotoluene (2,4,6-TNT)		
		6185	2,4-Dinitrotoluene (2,4-DNT)		
		6190	2,6-Dinitrotoluene (2,6-DNT)		
		9303	2-Amino-4,6-dinitrotoluene (2-am-dnt)		
		9507	2-Nitrotoluene		
		6150	3,5-Dinitroaniline		
		9510	3-Nitrotoluene		
		9306	4-Amino-2,6-dinitrotoluene (4-am-dnt)		
		9513	4-Nitrotoluene		
		6415	Methyl-2,4,6-trinitrophenylnitramine (tetryl)		
		5015	Nitrobenzene		
		6485	Nitroglycerin		
		9522	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)		
		9558	Pentaerythritoltetranitrate (PETN)		
		9432	RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine)		
Drinking Water	ALS Kelso LCP-PFC 4			60001505	ALS Kelso - Perfluorinated Compounds by HPLC-MS-MS
		6457	6:2 Fluorotelomersulfonate (6:2FTS)		
		6461	8:2 Fluorotelomersulfonate (8:2FTS)		
		9395	N-Ethylperfluorooctanesulfonamide (EtFOSA)		
		9431	N-Ethylperfluorooctanesulfonamidoethanol (EtFOSE)		
		9433	N-Methylperfluorooctanesulfonamide (MeFOSA)		
		9434	N-Methylperfluorooctanesulfonamidoethanol (MeFOSA)		
		6911	Perfluorobutane Sulfonate (PFBS)		
		6915	Perfluorobutyric acid (PFBA)		

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Drinking Water	ALS Kelso LCP-PFC 4	9562	Perfluorodecane Sulfonate (PFDS)		
		6905	Perfluorodecanoic acid (PFDA)		
		6903	Perfluorododecanoic (PFDDA)		
		9470	Perfluoroheptanesulfonic acid (PFHpS)		
		6908	Perfluoroheptanoic acid (PFHA)		
		6910	Perfluorohexane Sulfonate (PFHS)		
		6913	Perfluorohexanoic acid (PFHXA)		
		6906	Perfluorononanoic acid (PFNA)		
		6917	Perfluorooctane Sulfonamide (PFOSA)		
		6912	Perfluorooctanoic acid		
		6909	Perfluorooctanoic Sulfonate (PFOS)		
		6914	Perfluoropentanoic acid (PFPEA)		
		6902	Perfluorotetradecanoic acid (PFTDA)		
		9563	Perfluorotridecanoic (PFTRIA)		
		6904	Perfluoroundecanoic acid (PFUDA)		
	EPA 180.1			10011402	Turbidity - Nephelometric
		2055	Turbidity		
	EPA 200.7 4.4			10013806	ICP - metals
		1000	Aluminum		
		1005	Antimony		
		1015	Barium		
		1020	Beryllium		
		1025	Boron		
		1030	Cadmium		
		1035	Calcium		
		1040	Chromium		
		1055	Copper		
		1760	Hardness (calc.)		
		1070	Iron		
		1085	Magnesium		
		1090	Manganese		
		1100	Molybdenum		
		1105	Nickel		
		1125	Potassium		
		1990	Silica as SiO2		
		1150	Silver		
		1155	Sodium		
		1185	Vanadium		
		1190	Zinc		
	EPA 200.8 5.4			10014605	Metals by ICP-MS
		1000	Aluminum		
		1005	Antimony		

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Drinking Water	EPA 200.8 5.4	1010	Arsenic		
		1015	Barium		
		1020	Beryllium		
		1030	Cadmium		
		1040	Chromium		
		1055	Copper		
		1075	Lead		
		1090	Manganese		
		1105	Nickel		
		1140	Selenium		
		1150	Silver		
		1165	Thallium		
	EPA 245.1 3			10036609	Mercury by Cold Vapor Atomic Absorption
		1095	Mercury		
	EPA 300.0 2.1			10053200	Methods for the Determination of Inorganic Substances in Environmental Samples
		1575	Chloride		
		1730	Fluoride		
		1810	Nitrate as N		
		1820	Nitrate-nitrite		
		1840	Nitrite as N		
		2000	Sulfate		
	EPA 300.1			10053608	Ion chromatography - anions.
		1535	Bromate		
		1540	Bromide		
		1570	Chlorate		
		1595	Chlorite		
	EPA 314.0			10055400	Perchlorate in Drinking Water by Ion Chromatography
		1895	Perchlorate		
	EPA 335.4			10061208	Methods for the Determination of Inorganic Substances in Environmental Samples
		1645	Total cyanide		
	EPA 353.2 2			10067604	Nitrate/Nitrite Nitrogen - Automated, Cadmium
		1810	Nitrate as N		
		1840	Nitrite as N		
		1825	Total nitrate+nitrite		
	EPA 504.1			10082607	EDB/DBCP/TCP micro-extraction, GC/ECD
		5180	1,2,3-Trichloropropane		
		4570	1,2-Dibromo-3-chloropropane (DBCP)		

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Drinking Water	EPA 504.1	4585	1,2-Dibromoethane (EDB, Ethylene dibromide)		
	EPA 524.2 4.1			10088809	Volatile Organic Compounds GC/MS Capillary Column
		5105	1,1,1,2-Tetrachloroethane		
		5160	1,1,1-Trichloroethane		
		5110	1,1,2,2-Tetrachloroethane		
		5165	1,1,2-Trichloroethane		
		4630	1,1-Dichloroethane		
		4640	1,1-Dichloroethylene		
		4670	1,1-Dichloropropene		
		5150	1,2,3-Trichlorobenzene		
		5180	1,2,3-Trichloropropane		
		5155	1,2,4-Trichlorobenzene		
		5210	1,2,4-Trimethylbenzene		
		4570	1,2-Dibromo-3-chloropropane (DBCP)		
		4610	1,2-Dichlorobenzene		
		4635	1,2-Dichloroethane (Ethylene dichloride)		
		4655	1,2-Dichloropropane		
		5215	1,3,5-Trimethylbenzene		
		4615	1,3-Dichlorobenzene		
		4660	1,3-Dichloropropane		
		4620	1,4-Dichlorobenzene		
		4665	2,2-Dichloropropane		
		4535	2-Chlorotoluene		
		4540	4-Chlorotoluene		
		4910	4-Isopropyltoluene (p-Cymene)		
		4375	Benzene		
		4385	Bromobenzene		
		4390	Bromochloromethane		
		4395	Bromodichloromethane		
		4397	Bromoethane (Ethyl Bromide)		
		4400	Bromoform		
		4455	Carbon tetrachloride		
		4475	Chlorobenzene		
		4575	Chlorodibromomethane		
		4485	Chloroethane (Ethyl chloride)		
		4505	Chloroform		
		4645	cis-1,2-Dichloroethylene		
		4680	cis-1,3-Dichloropropene		
		4595	Dibromomethane (Methylene bromide)		
		4625	Dichlorodifluoromethane (Freon-12)		
		4765	Ethylbenzene		

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Drinking Water	EPA 524.2 4.1	4835	Hexachlorobutadiene		
		4900	Isopropylbenzene (Cumene)		
		5240	m+p-xylene		
		4950	Methyl bromide (Bromomethane)		
		4960	Methyl chloride (Chloromethane)		
		5000	Methyl tert-butyl ether (MTBE)		
		4975	Methylene chloride (Dichloromethane)		
		5005	Naphthalene		
		4435	n-Butylbenzene		
		5090	n-Propylbenzene		
		5250	o-Xylene		
		4440	sec-Butylbenzene		
		5100	Styrene		
		4445	tert-Butylbenzene		
		5115	Tetrachloroethylene (Perchloroethylene)		
		5140	Toluene		
		5205	Total trihalomethanes		
		4700	trans-1,2-Dichloroethylene		
		4685	trans-1,3-Dichloropropylene		
		5170	Trichloroethene (Trichloroethylene)		
		5175	Trichlorofluoromethane (Fluorotrichloromethane, Freon 11)		
		5235	Vinyl chloride		
		5260	Xylene (total)		
	EPA 537 1.1			10091675	Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS
		6911	Perfluorobutane Sulfonate (PFBS)		
		6908	Perfluoroheptanoic acid (PFHA)		
		6910	Perfluorohexane Sulfonate (PFHS)		
		6906	Perfluorononanoic acid (PFNA)		
		6912	Perfluorooctanoic acid		
		6909	Perfluorooctanoic Sulfonate (PFOS)		
	EPA 552.2 1			10095804	Haloacetic Acid/Dalapon, Liquid/Liquid Extraction, Derivitization and GC/ECD
		9312	Bromoacetic acid		
		9315	Bromochloroacetic acid		
		9336	Chloroacetic acid		
		9357	Dibromoacetic acid		
		9360	Dichloroacetic acid		
		9414	Total haloacetic acids		
		9642	Trichloroacetic acid		
	SM 2120 B 20th ED			20224004	Color by Visual Comparison
		1605	Color		

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Drinking Water	SM 2320 B 20th ED	1505	Alkalinity as CaCO3	20045209	Alkalinity by Titration
	SM 2340 B 20th ED	1750	Hardness	20046202	Hardness by calculation
	SM 2510 B 20th ED	1610	Conductivity	20048208	Conductivity by Probe
	SM 2540 C 20th ED	1955	Residue-filterable (TDS)	20050004	Total Dissolved Solids
	SM 4500-Cl F 20th ED	1945	Residual free chlorine	20080506	Residual Chlorine by DPD Ferrous Titration
	SM 4500-F⁻ C 20th ED	1730	Fluoride	20102005	Fluoride by Ion Selective Electrode
	SM 4500-H+ B 20th ED	1900	pH	20104807	pH by Probe
	SM 4500-P E 20th ED	1870	Orthophosphate as P	20123802	Phosphorus by Ascorbic Acid Reduction
	SM 5310 C 20th ED	2040	Total organic carbon	20138403	Total Organic Carbon by Persulfate-Ultraviolet Oxidation Method
	SM 9215 B (PCA) 20th ED	2555	Heterotrophic plate count	20181208	Heterotrophic Plate Count Pour Plate (plate count agar): Heterotrophic Bacteria
	SM 9223 B (Colilert®) 20th ED	2525 2500	Escherichia coli Total coliforms	20212208	Chromogenic/Fluorogenic Qualitative (Colilert®): Total Coliform and E. coli
	SM 9223 B (Colilert®-18) 21st ED	2525 2500	Escherichia coli Total coliforms	20214408	Chromogenic/Fluorogenic Qualitative (Colilert®-18): Total Coliform and E. coli
	SM 9223 B (Colilert®-18) 20th ED	2525 2500	Escherichia coli Total coliforms	20214204	Chromogenic/Fluorogenic Qualitative (Colilert®-18): Total Coliform and E. coli
	SM 9223 B (Colilert-18® Multiple-tube) 20th ED	2530	Fecal coliforms	20229407	Chromogenic/Fluorogenic Quantitative: Total Coliform and E. coli
Non-Potable Water	ALS Kelso LCP-Acryl 1	4330	Acrylamide	60001712	ALS Kelso - Acrylamide by HPLC/MS/MS

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Non-Potable Water	ALS Kelso LCP-PFC 4		60001505	ALS Kelso - Perfluorinated Compounds by HPLC-MS-MS
	6457	6:2 Fluorotelomersulfonate (6:2FTS)		
	6461	8:2 Fluorotelomersulfonate (8:2FTS)		
	9395	N-Ethylperfluorooctanesulfonamide (EtFOSA)		
	9431	N-Ethylperfluorooctanesulfonamidoethanol (EtFOSE)		
	9433	N-Methylperfluorooctanesulfonamide (MeFOSA)		
	9434	N-Methylperfluorooctanesulfonamidoethanol (MeFOSA)		
	6911	Perfluorobutane Sulfonate (PFBS)		
	6915	Perfluorobutyric acid (PFBA)		
	9562	Perfluorodecane Sulfonate (PFDS)		
	6905	Perfluorodecanoic acid (PFDA)		
	6903	Perfluorododecanoic (PFDDA)		
	9470	Perfluoroheptanesulfonic acid (PFHpS)		
	6908	Perfluoroheptanoic acid (PFHA)		
	6910	Perfluorohexane Sulfonate (PFHS)		
	6913	Perfluorohexanoic acid (PFHXA)		
	6906	Perfluorononanoic acid (PFNA)		
	6917	Perfluorooctane Sulfonamide (PFOSA)		
	6912	Perfluorooctanoic acid		
	6909	Perfluorooctanoic Sulfonate (PFOS)		
	6914	Perfluoropentanoic acid (PFPEA)		
	6902	Perfluorotetradecanoic acid (PFTDA)		
	9563	Perfluorotridecanoic (PFTRIA)		
	6904	Perfluoroundecanoic acid (PFUDA)		
	ALS Kelso SOC-8151M 11		60001754	ALS Kelso - Chlorinated Pesticides by GC/ECD
	6730	2,3,4,5-Tetrachlorophenol		
	6740	2,3,5,6-Tetrachlorophenol		
	6835	2,4,5-Trichlorophenol		
	6840	2,4,6-Trichlorophenol		
	6818	3,4,5-Trichlorophenol		
	5997	3,4-Dichlorophenol		
	6397	3,5-Dichlorophenol		
	6605	Pentachlorophenol		
	ASTM D1426-08B		30007397	Ammonia by Titration
	1515	Ammonia as N		
	ASTM D1426-98B		30023406	Ammonia by Titration
	1515	Ammonia as N		

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Non-Potable Water	ASTM D3590-02(06)A	1795	Kjeldahl nitrogen - total	30016819	Total Kjeldahl Nitrogen in Water
	ASTM D3590-89B	1795	Kjeldahl nitrogen - total	30016809	Total Kjeldahl Nitrogen in Water
	ASTM D4129 05	2040	Total organic carbon	30018907	Total and Organic Carbon in Water by High Temperature Oxidation and by Coulometric Detection
	Brooks Rand SOP BR-0002 (1631) method ID# 1225	4930	Methanol	60002804	Selected HAPS in Condensates by GC/FID
	CAS PestMS2 (1699 modified) 2	8580	2,4'-DDD	60035101	Chlorinated Pesticides by GC/MS/MS
		8585	2,4'-DDE		
		8590	2,4'-DDT		
		7355	4,4'-DDD		
		7360	4,4'-DDE		
		7365	4,4'-DDT		
		7025	Aldrin		
		7110	alpha-BHC (alpha-Hexachlorocyclohexane)		
		7240	alpha-Chlordane		
		7115	beta-BHC (beta-Hexachlorocyclohexane)		
		7300	Chlorpyrifos		
		7925	cis-Nonachlor		
		7105	delta-BHC		
		7470	Dieldrin		
		7510	Endosulfan I		
		7515	Endosulfan II		
		7520	Endosulfan sulfate		
		7540	Endrin		
		7530	Endrin aldehyde		
		7535	Endrin ketone		
		7120	gamma-BHC (Lindane, gamma-HexachlorocyclohexanE)		
		7245	gamma-Chlordane		
		7685	Heptachlor		
		7690	Heptachlor epoxide		
		6275	Hexachlorobenzene		
		7725	Isodrin		
		7810	Methoxychlor		
		7870	Mirex		
		5553	Octachlorostyrene		

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Non-Potable Water	CAS PestMS2 (1699 modified) 2	3890	Oxychlordane		
		7910	trans-Nonachlor		
	CAS SOC-Butyl 10			60035009	Butyltin by GC/Flame Photometric Detector
		1201	Butyltin trichloride		
		1202	Dibutyltin dichloride		
		1209	Tetrabutyltin		
		1203	Tributyltin chloride		
	Enterolert®			60030208	Chromogenic/Fluorogenic Quantitative (Enterolert®): Enterococci
		2520	Enterococci		
	EPA 1020A			10117007	Ignitability Setaflash Closed-cup Method
		1780	Ignitability		
	EPA 160.4			10256801	Total Volatile Solids, ignition @ 550 C.
		4075	Vol. residue, density, water & solids content of coatings		
	EPA 1630			10122608	Methyl Mercury by Purge & Trap Cold Vapor Atomic Fluorescence Spectrometry
		1205	Methyl Mercury		
	EPA 1631E			10237204	Mercury in Water by Oxidation, Purge & Trap, and Cold Vapor Atomic Fluorescence
		1095	Mercury		
	EPA 1632A			10123407	Arsenic in Water by Gaseous Hydride Atomic Absorption
		1010	Arsenic		
		1012	Arsenite (As+3)		
		6138	Dimethylarsinic acid (DMA)		
		1207	Monomethylarsonic acid (MMA)		
	EPA 1650C			10125005	Adsorbable Organic Halides by Adsorption and Coulometric Titration
		4345	Adsorbable organic halogens (AOX)		
	EPA 1653A			10125403	Chlorinated Phenolics by "In Situ" Acetylation and GC/MS
		6735	2,3,4,6-Tetrachlorophenol		
		6835	2,4,5-Trichlorophenol		
		6840	2,4,6-Trichlorophenol		
		6805	3,4,5-Trichlorocatechol		
		6815	3,4,5-Trichloroguaiacol		
		6810	3,4,6-Trichlorocatechol		
		6820	3,4,6-Trichloroguaiacol		
		6825	4,5,6-Trichloroguaiacol		
		6605	Pentachlorophenol		
		6720	Tetrachlorocatechol		

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Non-Potable Water	EPA 1653A	6725	Tetrachloroguaiacol		
		6875	Trichlorosyringol		
	EPA 1664A (HEM)			10127807	N-Hexane Extractable Material (Oil and Grease) by Extraction and Gravimetry
		1803	n-Hexane Extractable Material (O&G)		
		1860	Oil & Grease		
	EPA 1694 1.0			10132908	Pharmaceuticals and Personal Care Products by HPLC/MS/MS
		6769	17a-estradiol		
		6771	17a-ethynylestradiol		
		6773	17ß-estradiol		
		4307	Acetominophen		
		7052	Androstenedione		
		7065	Atrazine		
		9301	Bisphenol A		
		5675	Caffeine		
		7194	Carbamazepine		
		7375	DEET		
		7086	Diazepam		
		7087	Diclofenac		
		6075	Diethylstilbestrol		
		7253	Estriol		
		7254	Estrone		
		7257	Fluoxetine		
		7258	Gemfibrozil		
		7219	Hydrocodone		
		7259	Ibuprofen		
		7719	Iopromide		
		7313	Meprobamate		
		7316	Methadone		
		7269	Naproxen		
		7317	Oxybenzone		
		7318	Pentoxifylline		
		7284	Progesterone		
		9585	Salicylic acid		
		7297	Sulfamethoxazole		
		7301	Testosterone		
		7304	Triclosan		
		7307	Trimethoprim		
	EPA 180.1			10011402	Turbidity - Nephelometric
		2055	Turbidity		
	EPA 200.7 4.4			10013806	ICP - metals
		1000	Aluminum		

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Non-Potable Water	EPA 200.7 4.4	1005	Antimony		
		1010	Arsenic		
		1015	Barium		
		1020	Beryllium		
		1025	Boron		
		1030	Cadmium		
		1035	Calcium		
		1040	Chromium		
		1050	Cobalt		
		1055	Copper		
		1760	Hardness (calc.)		
		1070	Iron		
		1075	Lead		
		1085	Magnesium		
		1090	Manganese		
		1100	Molybdenum		
		1105	Nickel		
		1125	Potassium		
		1140	Selenium		
		1990	Silica as SiO2		
		1150	Silver		
		1155	Sodium		
		1160	Strontium		
		1175	Tin		
		1180	Titanium		
		1185	Vanadium		
		1190	Zinc		
	EPA 200.8 5.4			10014605	Metals by ICP-MS
		1000	Aluminum		
		1005	Antimony		
		1010	Arsenic		
		1015	Barium		
		1020	Beryllium		
		1030	Cadmium		
		1040	Chromium		
		1050	Cobalt		
		1055	Copper		
		1070	Iron		
		1075	Lead		
		1090	Manganese		
		1100	Molybdenum		
		1105	Nickel		
		1140	Selenium		

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EPA 200.8 5.4				
	1150	Silver		
	1165	Thallium		
	3035	Uranium		
	1185	Vanadium		
	1190	Zinc		
EPA 245.1 3			10036609	Mercury by Cold Vapor Atomic Absorption
	1095	Mercury		
EPA 300.0 2.1			10053200	Methods for the Determination of Inorganic Substances in Environmental Samples
	1540	Bromide		
	1575	Chloride		
	1730	Fluoride		
	1810	Nitrate as N		
	1820	Nitrate-nitrite		
	1840	Nitrite as N		
	2000	Sulfate		
EPA 3005A			10133207	Acid Digestion of waters for Total Recoverable or Dissolved Metals
	8031	Extraction/Preparation		
EPA 3010A			10133605	Acid Digestion of Aqueous samples and Extracts for Total Metals
	8031	Extraction/Preparation		
EPA 3020A			10134404	Acid Digestion of Aqueous samples and Extracts for Total Metals for Analysis by GFAA
	8031	Extraction/Preparation		
EPA 314.0			10055400	Perchlorate in Drinking Water by Ion Chromatography
	1895	Perchlorate		
EPA 330.4			10059004	Residual Chlorine - DPD-FAS Titration
	1940	Total residual chlorine		
EPA 335.4			10061208	Methods for the Determination of Inorganic Substances in Environmental Samples
	1645	Total cyanide		
EPA 3510C			10138202	Separatory Funnel Liquid-liquid extraction
	8031	Extraction/Preparation		
EPA 3511			10279808	Organic Compounds in Water by Microextraction
	8031	Extraction/Preparation		
EPA 3520C			10139001	Continuous Liquid-liquid extraction
	8031	Extraction/Preparation		

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EPA 353.2 2			10067604	Nitrate/Nitrite Nitrogen - Automated, Cadmium
	1810	Nitrate as N		
	1820	Nitrate-nitrite		
	1840	Nitrite as N		
	1825	Total nitrate+nitrite		
EPA 3535A			10139409	Solid-Phase Extraction (SPE)
	8031	Extraction/Preparation		
EPA 3610B			10144602	Alumina Cleanup
	8031	Extraction/Preparation		
EPA 3620C			10146006	Florisil Cleanup
	8031	Extraction/Preparation		
EPA 3630C			10146802	Silica gel cleanup
	8031	Extraction/Preparation		
EPA 3640A			10147203	Gel Preparation Cleanup
	8031	Extraction/Preparation		
EPA 365.3			10070607	Phosphorous - Colorimetric, two reagent.
	1870	Orthophosphate as P		
	1908	Total Phosphate		
EPA 3660B			10148400	Sulfur cleanup
	8031	Extraction/Preparation		
EPA 3665A			10148808	Sulfuric Acid / permanganate Cleanup
	8031	Extraction/Preparation		
EPA 420.1			10079206	Phenolics - Spectrophotometric, manual.
	1905	Total phenolics		
EPA 5030B			10153409	Purge and trap for aqueous samples
	8031	Extraction/Preparation		
EPA 6010C			10155803	ICP - AES
	1000	Aluminum		
	1005	Antimony		
	1010	Arsenic		
	1015	Barium		
	1020	Beryllium		
	1025	Boron		
	1030	Cadmium		
	1035	Calcium		
	1040	Chromium		
	1050	Cobalt		
	1055	Copper		

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Non-Potable Water	EPA 6010C	1070	Iron		
		1075	Lead		
		1085	Magnesium		
		1090	Manganese		
		1100	Molybdenum		
		1105	Nickel		
		1125	Potassium		
		1140	Selenium		
		1150	Silver		
		1155	Sodium		
		1160	Strontium		
		1165	Thallium		
		1175	Tin		
		1180	Titanium		
		1185	Vanadium		
		1190	Zinc		
	EPA 6020A			10156408	Inductively Coupled Plasma-Mass Spectrometry
		1000	Aluminum		
		1005	Antimony		
		1010	Arsenic		
		1015	Barium		
		1020	Beryllium		
		1030	Cadmium		
		1040	Chromium		
		1050	Cobalt		
		1055	Copper		
		1070	Iron		
		1075	Lead		
		1090	Manganese		
		1100	Molybdenum		
		1105	Nickel		
		1140	Selenium		
		1150	Silver		
		1160	Strontium		
		1165	Thallium		
		3035	Uranium		
		1185	Vanadium		
		1190	Zinc		
	EPA 608			10103603	Organochlorine Pesticides & PCBs by GC/ECD
		7355	4,4'-DDD		
		7360	4,4'-DDE		
		7365	4,4'-DDT		

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Non-Potable Water	EPA 608	7025	Aldrin		
		7110	alpha-BHC (alpha-Hexachlorocyclohexane)		
		8880	Aroclor-1016 (PCB-1016)		
		8885	Aroclor-1221 (PCB-1221)		
		8890	Aroclor-1232 (PCB-1232)		
		8895	Aroclor-1242 (PCB-1242)		
		8900	Aroclor-1248 (PCB-1248)		
		8905	Aroclor-1254 (PCB-1254)		
		8910	Aroclor-1260 (PCB-1260)		
		7115	beta-BHC (beta-Hexachlorocyclohexane)		
		7250	Chlordane (tech.)		
		7105	delta-BHC		
		7470	Dieldrin		
		7510	Endosulfan I		
		7515	Endosulfan II		
		7520	Endosulfan sulfate		
		7540	Endrin		
		7530	Endrin aldehyde		
		7120	gamma-BHC (Lindane, gamma-HexachlorocyclohexanE)		
		7685	Heptachlor		
		7690	Heptachlor epoxide		
		7810	Methoxychlor		
		8250	Toxaphene (Chlorinated camphene)		
	EPA 624			10107207	Volatile Organic Compounds by purge and trap GC/MS
		5160	1,1,1-Trichloroethane		
		5110	1,1,2,2-Tetrachloroethane		
		5165	1,1,2-Trichloroethane		
		4630	1,1-Dichloroethane		
		4640	1,1-Dichloroethylene		
		5155	1,2,4-Trichlorobenzene		
		4610	1,2-Dichlorobenzene		
		4635	1,2-Dichloroethane (Ethylene dichloride)		
		4655	1,2-Dichloropropane		
		4615	1,3-Dichlorobenzene		
		4620	1,4-Dichlorobenzene		
		4500	2-Chloroethyl vinyl ether		
		4995	4-Methyl-2-pentanone (MIBK)		
		4325	Acrolein (Propenal)		
		4340	Acrylonitrile		
		4375	Benzene		
		4395	Bromodichloromethane		

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Non-Potable Water	EPA 624	4400	Bromoform		
		4455	Carbon tetrachloride		
		4475	Chlorobenzene		
		4575	Chlorodibromomethane		
		4485	Chloroethane (Ethyl chloride)		
		4505	Chloroform		
		4680	cis-1,3-Dichloropropene		
		4625	Dichlorodifluoromethane (Freon-12)		
		4765	Ethylbenzene		
		4950	Methyl bromide (Bromomethane)		
		4960	Methyl chloride (Chloromethane)		
		4975	Methylene chloride (Dichloromethane)		
		5100	Styrene		
		5115	Tetrachloroethylene (Perchloroethylene)		
		5140	Toluene		
		4700	trans-1,2-Dichloroethylene		
		4685	trans-1,3-Dichloropropylene		
		5170	Trichloroethene (Trichloroethylene)		
		5175	Trichlorofluoromethane (Fluorotrichloromethane, Freon 11)		
		5235	Vinyl chloride		
		5260	Xylene (total)		
	EPA 625			10300002	Base/Neutrals and Acids by GC/MS
		5155	1,2,4-Trichlorobenzene		
		4610	1,2-Dichlorobenzene		
		6221	1,2-Diphenylhydrazine		
		4615	1,3-Dichlorobenzene		
		4620	1,4-Dichlorobenzene		
		6840	2,4,6-Trichlorophenol		
		6000	2,4-Dichlorophenol		
		6130	2,4-Dimethylphenol		
		6175	2,4-Dinitrophenol		
		6185	2,4-Dinitrotoluene (2,4-DNT)		
		6190	2,6-Dinitrotoluene (2,6-DNT)		
		5795	2-Chloronaphthalene		
		5800	2-Chlorophenol		
		6360	2-Methyl-4,6-dinitrophenol (4,6-Dinitro-2-methylphenol)		
		6490	2-Nitrophenol		
		5945	3,3'-Dichlorobenzidine		
		5660	4-Bromophenyl phenyl ether (BDE-3)		
		5700	4-Chloro-3-methylphenol		
		5825	4-Chlorophenyl phenylether		
		6500	4-Nitrophenol		

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Non-Potable Water	EPA 625	5500	Acenaphthene		
		5505	Acenaphthylene		
		5555	Anthracene		
		5595	Benzidine		
		5575	Benzo(a)anthracene		
		5580	Benzo(a)pyrene		
		5590	Benzo(g,h,i)perylene		
		5600	Benzo(k)fluoranthene		
		5585	Benzo[b]fluoranthene		
		5760	bis(2-Chloroethoxy)methane		
		5765	bis(2-Chloroethyl) ether		
		5780	bis(2-Chloroisopropyl) ether		
		5670	Butyl benzyl phthalate		
		5855	Chrysene		
		6065	Di(2-ethylhexyl) phthalate (bis(2-Ethylhexyl)phthalate, DEHP)		
		5895	Dibenz(a,h) anthracene		
		6070	Diethyl phthalate		
		6135	Dimethyl phthalate		
		5925	Di-n-butyl phthalate		
		6200	Di-n-octyl phthalate		
		6265	Fluoranthene		
		6270	Fluorene		
		6275	Hexachlorobenzene		
		4835	Hexachlorobutadiene		
		6285	Hexachlorocyclopentadiene		
		4840	Hexachloroethane		
		6315	Indeno(1,2,3-cd) pyrene		
		6320	Isophorone		
		5005	Naphthalene		
		5015	Nitrobenzene		
		6530	n-Nitrosodimethylamine		
		6545	n-Nitrosodi-n-propylamine		
		6535	n-Nitrosodiphenylamine		
		6605	Pentachlorophenol		
		6615	Phenanthrene		
		6625	Phenol		
		6665	Pyrene		
	EPA 6850			10304606	Perchlorate in Water, Soils and Solid Wastes Using High Performance Liquid Chromatography/Electrospray Ionization/Mass Spectrometry
		1895	Perchlorate		

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EPA 7010			10157809	Metals by Graphite Furnace Atomic Absorption
	1010	Arsenic		
	1040	Chromium		
	1075	Lead		
	1140	Selenium		
	1165	Thallium		
EPA 7062			10159407	Antimony and Arsenic by Borohydride Reduction and Atomic Absorption
	1010	Arsenic		
EPA 7196A			10162400	Chromium Hexavalent colorimetric
	1045	Chromium VI		
EPA 7470A			10165807	Mercury in Liquid Waste by Cold Vapor Atomic Absorption
	1095	Mercury		
EPA 7742			10169207	Selenium by Borohydride Reduction and Atomic Absorption
	1140	Selenium		
EPA 8015C			10173805	Non-halogenated organics using GC/FID
	9369	Diesel range organics (DRO)		
	4785	Ethylene glycol		
	9408	Gasoline range organics (GRO)		
EPA 8081B			10178800	Organochlorine Pesticides by GC/ECD
	8580	2,4'-DDD		
	8585	2,4'-DDE		
	8590	2,4'-DDT		
	7355	4,4'-DDD		
	7360	4,4'-DDE		
	7365	4,4'-DDT		
	7005	Alachlor		
	7025	Aldrin		
	7110	alpha-BHC (alpha-Hexachlorocyclohexane)		
	7240	alpha-Chlordane		
	7115	beta-BHC (beta-Hexachlorocyclohexane)		
	7250	Chlordane (tech.)		
	7300	Chlorpyrifos		
	7925	cis-Nonachlor		
	7105	delta-BHC		
	7470	Dieldrin		
	7510	Endosulfan I		
	7515	Endosulfan II		
	7520	Endosulfan sulfate		

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		7530	Endrin aldehyde		
		7535	Endrin ketone		
		7120	gamma-BHC (Lindane, gamma-Hexachlorocyclohexane)		
		7245	gamma-Chlordane		
		7685	Heptachlor		
		7690	Heptachlor epoxide		
		6275	Hexachlorobenzene		
		4835	Hexachlorobutadiene		
		4840	Hexachloroethane		
		7725	Isodrin		
		7810	Methoxychlor		
		7870	Mirex		
		3890	Oxychlordane		
		8250	Toxaphene (Chlorinated camphene)		
		7910	trans-Nonachlor		
	EPA 8082A			10179201	Polychlorinated Biphenyls (PCBs) by GC/ECD
		9095	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl (BZ-206)		
		9090	2,2',3,3',4,4',5,5'-Octachlorobiphenyl (BZ-194)		
		9103	2,2',3,3',4,4',5,6-Octachlorobiphenyl (BZ-195)		
		9065	2,2',3,3',4,4',5-Heptachlorobiphenyl (BZ-170)		
		9020	2,2',3,3',4,4'-Hexachlorobiphenyl (BZ-128)		
		9112	2,2',3,3',4,5',6,6'-Octachlorobiphenyl (BZ-201)		
		9116	2,2',3,3',4,5,6'-Heptachlorobiphenyl (BZ-174)		
		9114	2,2',3,3',4,5',6'-Heptachlorobiphenyl (BZ-177)		
		9120	2,2',3,3',4,6'-Hexachlorobiphenyl (BZ-132)		
		9133	2,2',3,4,4',5,5',6-Octachlorobiphenyl (BZ-203)		
		9134	2,2',3,4,4',5,5'-Heptachlorobiphenyl (BZ-180)		
		9075	2,2',3,4,4',5',6-Heptachlorobiphenyl (BZ-183)		
		9025	2,2',3,4,4',5'-Hexachlorobiphenyl (BZ-138)		
		9139	2,2',3,4,4',6,6'-Heptachlorobiphenyl (BZ-184)		
		9080	2,2',3,4',5,5',6-Heptachlorobiphenyl (BZ-187)		

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Non-Potable Water	EPA 8082A	9030	2,2',3,4,5,5'-Hexachlorobiphenyl (BZ-141)
		9151	2,2',3,4',5',6-Hexachlorobiphenyl (BZ-149)
		8975	2,2',3,4,5'-Pentachlorobiphenyl (BZ-87)
		9155	2,2',3,4',5-Pentachlorobiphenyl (BZ-90)
		9154	2,2',3,4',5'-Pentachlorobiphenyl (BZ-97)
		9035	2,2',3,5,5',6-Hexachlorobiphenyl (BZ-151)
		9166	2,2',3,5',6-Pentachlorobiphenyl (BZ-95)
		8945	2,2',3,5'-Tetrachlorobiphenyl (BZ-44)
		9040	2,2',4,4',5,5'-Hexachlorobiphenyl (BZ-153)
		9174	2,2',4,4',5,6'-Hexachlorobiphenyl (BZ-154)
		9175	2,2',4,4',5-Pentachlorobiphenyl (BZ-99)
		8980	2,2',4,5,5'-Pentachlorobiphenyl (BZ-101)
		8950	2,2',4,5'-Tetrachlorobiphenyl (BZ-49)
		8955	2,2',5,5'-Tetrachlorobiphenyl (BZ-52)
		8930	2,2',5-Trichlorobiphenyl (BZ-18)
		9085	2,3,3',4,4',5,5'-Heptachlorobiphenyl (BZ-189)
		9050	2,3,3',4,4',5-Hexachlorobiphenyl (BZ-156)
		9045	2,3,3',4,4',5'-Hexachlorobiphenyl (BZ-157)
		9193	2,3,3',4,4',6-Hexachlorobiphenyl (BZ-158)
		8985	2,3,3',4,4'-Pentachlorobiphenyl (BZ-105)
		8990	2,3,3',4',6-Pentachlorobiphenyl (BZ-110)
		9207	2,3,3',4'-Tetrachlorobiphenyl (BZ-56)
		9055	2,3',4,4',5,5'-Hexachlorobiphenyl (BZ-167)
		9217	2,3,4,4',5,6-Hexachlorobiphenyl (BZ-166)
		9218	2,3',4,4',5',6-Hexachlorobiphenyl (BZ-168)
		9005	2,3,4,4',5-Pentachlorobiphenyl (BZ-114)
		8995	2,3',4,4',5-Pentachlorobiphenyl (BZ-118)
		9000	2,3',4,4',5'-Pentachlorobiphenyl (BZ-123)
		9220	2,3',4,4',6-Pentachlorobiphenyl (BZ-119)
		9221	2,3,4,4'-Tetrachlorobiphenyl (BZ-60)

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		9230	2,3',4',5-Tetrachlorobiphenyl (BZ-70)		
		9239	2,3',4'-Trichlorobiphenyl (BZ-33)		
		8920	2,3-Dichlorobiphenyl (BZ-5)		
		9250	2,4,4',5-Tetrachlorobiphenyl (BZ-74)		
		9252	2,4,4'-Trichlorobiphenyl (BZ-28)		
		8940	2,4',5-Trichlorobiphenyl (BZ-31)		
		9256	2,4'-Dichlorobiphenyl (BZ-8)		
		8915	2-Chlorobiphenyl (BZ-1)		
		9060	3,3',4,4',5,5'-Hexachlorobiphenyl (BZ-169)		
		9015	3,3',4,4',5-Pentachlorobiphenyl (BZ-126)		
		8965	3,3',4,4'-Tetrachlorobiphenyl (BZ-77)		
		8970	3,4,4',5-Tetrachlorobiphenyl (BZ-81)		
		9266	3,4,4'-Trichlorobiphenyl (BZ-37)		
		8880	Aroclor-1016 (PCB-1016)		
		8885	Aroclor-1221 (PCB-1221)		
		8890	Aroclor-1232 (PCB-1232)		
		8895	Aroclor-1242 (PCB-1242)		
		8900	Aroclor-1248 (PCB-1248)		
		8905	Aroclor-1254 (PCB-1254)		
		8910	Aroclor-1260 (PCB-1260)		
		8912	Aroclor-1262 (PCB-1262)		
		8913	Aroclor-1268 (PCB-1268)		
		9105	Decachlorobiphenyl (BZ-209)		
	EPA 8141B			10182204	Organophosphorous Pesticides by GC/NPD
		7075	Azinphos-methyl (Guthion)		
		7125	Bolstar (Sulprofos)		
		7300	Chlorpyrifos		
		7315	Coumaphos		
		7395	Demeton-o		
		7385	Demeton-s		
		7410	Diazinon		
		8610	Dichlorovos (DDVP, Dichlorvos)		
		7475	Dimethoate		
		8625	Disulfoton		
		7550	EPN		
		7570	Ethoprop		
		7600	Fensulfothion		
		7605	Fenthion		
		7770	Malathion		
		7785	Merphos		

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		7850	Mevinphos		
		7955	Parathion, ethyl		
		7985	Phorate		
		8110	Ronnel		
		8155	Sulfotepp		
		8200	Tetrachlorvinphos (Stirophos, Gardona) Z-isomer		
		8245	Tokuthion (Prothiophos)		
		8275	Trichloronate		
	EPA 8151A			10183207	Chlorinated Herbicides by GC/ECD
		8655	2,4,5-T		
		8545	2,4-D		
		8560	2,4-DB		
		8555	Dalapon		
		8595	Dicamba		
		8605	Dichloroprop (Dichlorprop)		
		8620	Dinoseb (2-sec-butyl-4,6-dinitrophenol, DNBP)		
		7775	MCPA		
		7780	MCPP		
		8650	Silvex (2,4,5-TP)		
	EPA 8260C			10307003	Volatile Organics: GC/MS (capillary column)
		5105	1,1,1,2-Tetrachloroethane		
		5185	1,1,1-Trichloro-2,2,2-trifluoroethane		
		5160	1,1,1-Trichloroethane		
		5110	1,1,2,2-Tetrachloroethane		
		5195	1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)		
		5165	1,1,2-Trichloroethane		
		5167	1,1,2-Trichlorofluoroethane		
		4630	1,1-Dichloroethane		
		4640	1,1-Dichloroethylene		
		4670	1,1-Dichloropropene		
		5150	1,2,3-Trichlorobenzene		
		5180	1,2,3-Trichloropropane		
		5155	1,2,4-Trichlorobenzene		
		5210	1,2,4-Trimethylbenzene		
		4570	1,2-Dibromo-3-chloropropane (DBCP)		
		4585	1,2-Dibromoethane (EDB, Ethylene dibromide)		
		4610	1,2-Dichlorobenzene		
		4635	1,2-Dichloroethane (Ethylene dichloride)		
		4655	1,2-Dichloropropane		

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Non-Potable Water	EPA 8260C	6800	1,3,5-Trichlorobenzene
		5215	1,3,5-Trimethylbenzene
		4615	1,3-Dichlorobenzene
		4660	1,3-Dichloropropane
		4620	1,4-Dichlorobenzene
		4735	1,4-Dioxane (1,4- Diethyleneoxide)
		4510	1-Chlorohexane
		4665	2,2-Dichloropropane
		4410	2-Butanone (Methyl ethyl ketone, MEK)
		4500	2-Chloroethyl vinyl ether
		4535	2-Chlorotoluene
		4860	2-Hexanone (MBK)
		5020	2-Nitropropane
		4536	4-Bromofluorobenzene
		4540	4-Chlorotoluene
		4910	4-Isopropyltoluene (p-Cymene)
		4995	4-Methyl-2-pentanone (MIBK)
		4305	Acetamide
		4315	Acetone
		4320	Acetonitrile
		4325	Acrolein (Propenal)
		4330	Acrylamide
		4340	Acrylonitrile
		4355	Allyl chloride (3-Chloropropene)
		4375	Benzene
		4385	Bromobenzene
		4390	Bromochloromethane
		4395	Bromodichloromethane
		4400	Bromoform
		4450	Carbon disulfide
		4455	Carbon tetrachloride
		4475	Chlorobenzene
		4575	Chlorodibromomethane
		4485	Chloroethane (Ethyl chloride)
		4505	Chloroform
		4525	Chloroprene (2-Chloro-1,3-butadiene)
		4705	cis & trans-1,2-Dichloroethene
		4645	cis-1,2-Dichloroethylene
		4680	cis-1,3-Dichloropropene
		4595	Dibromomethane (Methylene bromide)
		4625	Dichlorodifluoromethane (Freon-12)
		4725	Diethyl ether
		4755	Ethyl acetate

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Non-Potable Water	EPA 8260C	4810	Ethyl methacrylate		
		4765	Ethylbenzene		
		4835	Hexachlorobutadiene		
		4870	Iodomethane (Methyl iodide)		
		4875	Isobutyl alcohol (2-Methyl-1-propanol)		
		4900	Isopropylbenzene (Cumene)		
		5240	m+p-xylene		
		4925	Methacrylonitrile		
		4950	Methyl bromide (Bromomethane)		
		4960	Methyl chloride (Chloromethane)		
		5000	Methyl tert-butyl ether (MTBE)		
		4975	Methylene chloride (Dichloromethane)		
		5245	m-Xylene		
		5005	Naphthalene		
		4435	n-Butylbenzene		
		5090	n-Propylbenzene		
		5250	o-Xylene		
		4440	sec-Butylbenzene		
		5100	Styrene		
		4370	T-amylmethylether (TAME)		
		4445	tert-Butylbenzene		
		5115	Tetrachloroethylene (Perchloroethylene)		
		5140	Toluene		
		4700	trans-1,2-Dichloroethylene		
		4685	trans-1,3-Dichloropropylene		
		4605	trans-1,4-Dichloro-2-butene		
		5170	Trichloroethene (Trichloroethylene)		
		5175	Trichlorofluoromethane (Fluorotrichloromethane, Freon 11)		
		5225	Vinyl acetate		
		5235	Vinyl chloride		
		5260	Xylene (total)		
	EPA 8270D			10186002	Semivolatile Organic compounds by GC/MS
		6715	1,2,4,5-Tetrachlorobenzene		
		5155	1,2,4-Trichlorobenzene		
		4610	1,2-Dichlorobenzene		
		6221	1,2-Diphenylhydrazine		
		6885	1,3,5-Trinitrobenzene (1,3,5-TNB)		
		4615	1,3-Dichlorobenzene		
		4620	1,4-Dichlorobenzene		
		6420	1,4-Naphthoquinone		
		6630	1,4-Phenylenediamine		
		5790	1-Chloronaphthalene		

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Non-Potable Water	EPA 8270D	6380	1-Methylnaphthalene
		6425	1-Naphthylamine
		6735	2,3,4,6-Tetrachlorophenol
		6835	2,4,5-Trichlorophenol
		6840	2,4,6-Trichlorophenol
		6000	2,4-Dichlorophenol
		6130	2,4-Dimethylphenol
		6175	2,4-Dinitrophenol
		6185	2,4-Dinitrotoluene (2,4-DNT)
		6005	2,6-Dichlorophenol
		6190	2,6-Dinitrotoluene (2,6-DNT)
		5735	2-Chloroaniline
		5795	2-Chloronaphthalene
		5800	2-Chlorophenol
		6360	2-Methyl-4,6-dinitrophenol (4,6-Dinitro-2-methylphenol)
		5145	2-Methylaniline (o-Toluidine)
		6385	2-Methylnaphthalene
		6400	2-Methylphenol (o-Cresol)
		6430	2-Naphthylamine
		6460	2-Nitroaniline
		6490	2-Nitrophenol
		5050	2-Picoline (2-Methylpyridine)
		6412	3 & 4 Methylphenol
		5945	3,3'-Dichlorobenzidine
		6120	3,3'-Dimethylbenzidine
		6355	3-Methylcholanthrene
		6405	3-Methylphenol (m-Cresol)
		6465	3-Nitroaniline
		5540	4-Aminobiphenyl
		5660	4-Bromophenyl phenyl ether (BDE-3)
		5700	4-Chloro-3-methylphenol
		5745	4-Chloroaniline
		5825	4-Chlorophenyl phenylether
		6410	4-Methylphenol (p-Cresol)
		6470	4-Nitroaniline
		6500	4-Nitrophenol
		6125	a-a-Dimethylphenethylamine
		5500	Acenaphthene
		5505	Acenaphthylene
		5510	Acetophenone
		5545	Aniline
		5555	Anthracene
		5560	Aramite

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Non-Potable Water	EPA 8270D	7065	Atrazine
		5562	Azobenzene
		5570	Benzaldehyde
		5575	Benzo(a)anthracene
		5580	Benzo(a)pyrene
		5590	Benzo(g,h,i)perylene
		9309	Benzo(j)fluoranthene
		5600	Benzo(k)fluoranthene
		5585	Benzo[b]fluoranthene
		5610	Benzoic acid
		5630	Benzyl alcohol
		5640	Biphenyl
		5760	bis(2-Chloroethoxy)methane
		5765	bis(2-Chloroethyl) ether
		5780	bis(2-Chloroisopropyl) ether
		5670	Butyl benzyl phthalate
		7180	Caprolactam
		5680	Carbazole
		7260	Chlorobenzilate
		5855	Chrysene
		6065	Di(2-ethylhexyl) phthalate (bis(2-Ethylhexyl)phthalate, DEHP)
		7405	Diallate
		7410	Diazinon
		5895	Dibenz(a,h) anthracene
		5905	Dibenzofuran
		6070	Diethyl phthalate
		7475	Dimethoate
		6135	Dimethyl phthalate
		5925	Di-n-butyl phthalate
		6200	Di-n-octyl phthalate
		7580	Famphur
		6265	Fluoranthene
		6270	Fluorene
		6275	Hexachlorobenzene
		4835	Hexachlorobutadiene
		6285	Hexachlorocyclopentadiene
		4840	Hexachloroethane
		6290	Hexachlorophene
		6315	Indeno(1,2,3-cd) pyrene
		7725	Isodrin
		6320	Isophorone
		7740	Kepone
		6345	Methapyrilene

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Non-Potable Water	EPA 8270D	7825	Methyl parathion (Parathion, methyl)		
		5005	Naphthalene		
		5015	Nitrobenzene		
		6525	n-Nitrosodiethylamine		
		6530	n-Nitrosodimethylamine		
		6545	n-Nitrosodi-n-propylamine		
		6535	n-Nitrosodiphenylamine		
		6555	n-Nitrosomorpholine		
		6560	n-Nitrosopiperidine		
		6565	n-Nitrosopyrrolidine		
		7955	Parathion, ethyl		
		6590	Pentachlorobenzene		
		6600	Pentachloronitrobenzene		
		6605	Pentachlorophenol		
		6615	Phenanthrene		
		6625	Phenol		
		6650	Pronamide (Kerb)		
		6665	Pyrene		
		5095	Pyridine		
		6685	Safrole		
		8235	Thionazin (Zinophos)		
	EPA 8270D SIM			10242509	Semivolatile Organic compounds by GC/MS Selective Ion Monitoring
		4735	1,4-Dioxane (1,4- Diethyleneoxide)		
		6380	1-Methylnaphthalene		
		9501	1-Methylphenanthrene		
		6852	2,3,5-Trimethylnaphthalene		
		6188	2,6-Dimethylnaphthalene		
		6385	2-Methylnaphthalene		
		5500	Acenaphthene		
		5505	Acenaphthylene		
		5555	Anthracene		
		5575	Benzo(a)anthracene		
		5580	Benzo(a)pyrene		
		5605	Benzo(e)pyrene		
		5590	Benzo(g,h,i)perylene		
		9309	Benzo(j)fluoranthene		
		5600	Benzo(k)fluoranthene		
		5585	Benzo[b]fluoranthene		
		5640	Biphenyl		
		5680	Carbazole		
		5855	Chrysene		
		5895	Dibenz(a,h) anthracene		
		5905	Dibenzofuran		

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Non-Potable Water	EPA 8270D SIM	5910	Dibenzothiophene		
		6265	Fluoranthene		
		6270	Fluorene		
		6315	Indeno(1,2,3-cd) pyrene		
		5005	Naphthalene		
		6605	Pentachlorophenol		
		6608	Perylene		
		6615	Phenanthrene		
		6665	Pyrene		
	EPA 8315A			10188008	Determination of Carbonyl Compounds by HPLC/UV-VIS
		4815	Formaldehyde		
	EPA 8321B			10189205	Solvent Extractable non-volatile compounds by HPLC/TS/MS
		7010	Aldicarb (Temik)		
		7040	Aminocarb		
		7080	Barban		
		7130	Bromacil		
		7195	Carbaryl (Sevin)		
		7205	Carbofuran (Furaden)		
		7275	Chloropropham		
		7505	Diuron		
		7610	Fenuron		
		7630	Fluometuron		
		7765	Linuron (Lorox)		
		7800	Methiocarb (Mesurol)		
		7805	Methomyl (Lannate)		
		7855	Mexacarbate		
		7885	Monuron		
		7915	Neburon		
		7940	Oxamyl		
		8075	Propham		
		8080	Propoxur (Baygon)		
		8120	Siduron		
	EPA 8330B			10308006	Nitroaromatics, Nitramines and Nitrate Esters by High Performance Liquid Chromatography (HPLC)
		6885	1,3,5-Trinitrobenzene (1,3,5-TNB)		
		6160	1,3-Dinitrobenzene (1,3-DNB)		
		9651	2,4,6-Trinitrotoluene (2,4,6-TNT)		
		6185	2,4-Dinitrotoluene (2,4-DNT)		
		6190	2,6-Dinitrotoluene (2,6-DNT)		
		9303	2-Amino-4,6-dinitrotoluene (2-am-dnt)		
		9507	2-Nitrotoluene		
		6150	3,5-Dinitroaniline		

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EPA 8330B	9510	3-Nitrotoluene		
	9306	4-Amino-2,6-dinitrotoluene (4-am-dnt)		
	9513	4-Nitrotoluene		
	6415	Methyl-2,4,6-trinitrophenylnitramine (tetryl)		
	5015	Nitrobenzene		
	6485	Nitroglycerin		
	9522	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)		
	9558	Pentaerythritoltetranitrate (PETN)		
	9432	RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine)		
EPA 9012B			10243206	Total and Amenable Cyanide (automated colorimetric with off-line distillation)
	1510	Amenable cyanide		
	1645	Total cyanide		
EPA 9020B			10194408	Total Organic Halides
	2045	Total organic halides (TOX)		
EPA 9040C			10244403	pH Electrometric Measurement
	1900	pH		
EPA 9060A			10244801	Total Organic Carbon
	2040	Total organic carbon		
NCASI 94.03 0			60031507	Methanol in Process Liquids and Wastewaters
	4930	Methanol		
NWTPH-Dx			90018409	Oregon DEQ TPH Diesel Range
	9369	Diesel range organics (DRO)		
	9506	Residual Range Organics (RRO)		
NWTPH-Gx			90018603	Oregon DEQ TPH Gasoline Range Organics by GC/FID-PID Purge & Trap
	9408	Gasoline range organics (GRO)		
NWTPH-HCID			90013200	Oregon DEQ Total Petroleum Hydrocarbon ID
	2050	Total Petroleum Hydrocarbons (TPH)		
SM 2120 B 20th ED			20224004	Color by Visual Comparison
	1605	Color		
SM 2310 B 20th ED			20044206	Acidity by Titration
	1500	Acidity, as CaCO3		
SM 2320 B 20th ED			20045209	Alkalinity by Titration
	1505	Alkalinity as CaCO3		
SM 2340 B 20th ED			20046202	Hardness by calculation
	1750	Hardness		

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Non-Potable Water	SM 2340 C 20th ED	1750	Hardness	20047205	Hardness by EDTA Titration
	SM 2510 B-97 1997	1610	Conductivity	20048606	Conductivity by Probe
	SM 2540 B 20th ED	1950	Residue-total	20049007	Total Solids
	SM 2540 C 20th ED	1955	Residue-filterable (TDS)	20050004	Total Dissolved Solids
	SM 2540 D 20th ED	1960	Residue-nonfilterable (TSS)	20050800	Total Suspended Solids
	SM 2540 D-2011	1960	Residue-nonfilterable (TSS)	20051212	Total Suspended Solids Dried at 103 - 105 C
	SM 2540 D-97 1997	1960	Residue-nonfilterable (TSS)	20051201	Total Suspended Solids Dried at 103 - 105C
	SM 2540 F 20th ED	1965	Residue-settleable	20051803	Settleable Solids
	SM 4500-Cl C 20th ED	1575	Chloride	20078802	Chloride by Iodometric Method II
	SM 4500-Cl F 20th ED	1945	Residual free chlorine	20080506	Residual Chlorine by DPD Ferrous Titration
	SM 4500-CN E 20th ED	1635 1645	Cyanide Total cyanide	20092404	Cyanide by Colorimetric Determination
	SM 4500-CN G 20th ED	1510	Amenable cyanide	20093203	Cyanide Amenable to Chlorination after Distillation
	SM 4500-CN^- E-97 online	1635	Cyanide	20096406	Cyanide by Colorimetric Method
	SM 4500-F^- C 20th ED	1730	Fluoride	20102005	Fluoride by Ion Selective Electrode
	SM 4500-H+ B 20th ED	1900	pH	20104807	pH by Probe
	SM 4500-NH3 E 20th ED	1515	Ammonia as N	20109802	Ammonia by Selective Ion Probe
	SM 4500-NH3 G 20th ED	1515	Ammonia as N	20111006	Ammonia by Automated Phenate

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SM 4500-O G 20th ED			20121204	Dissolved Oxygen by Membrane Electrode Method
	1880	Oxygen, dissolved		
SM 4500-S2 F-2011			20126663	Sulfide by Iodometric Method
	2005	Sulfide		
SM 4500-S2¯ D 20th ED			20125400	Sulfide by Methylene Blue Method
	2005	Sulfide		
SM 4500-S2¯ D-97 online			20125808	Sulfide by Methylene Blue Method
	2005	Sulfide		
SM 4500-S2¯ F 20th ED			20126209	Sulfide by Iodometric Titration
	2005	Sulfide		
SM 4500-SO3¯ B 20th ED			20130205	Sulfite by Iodometric Method
	2015	Sulfite-SO3		
SM 5210 B 20th ED			20134809	Biochemical Oxygen Demand, 5-Day (BOD5)
	1530	Biochemical oxygen demand		
SM 5220 C 20th ED			20135608	Chemical Oxygen Demand by Closed Reflux and Titration
	1565	Chemical oxygen demand		
SM 5310 C 20th ED			20138403	Total Organic Carbon by Persulfate-Ultraviolet Oxidation Method
	2040	Total organic carbon		
SM 5540 C 20th ED			20144609	Surfactants as MBAS
	2025	Surfactants - MBAS		
SM 5550 B 20th ED			20145306	Tannin and Lignin
	9597	Tannin & Lignin		
SM 9215 B (PCA) 20th ED			20181208	Heterotrophic Plate Count Pour Plate (plate count agar): Heterotrophic Bacteria
	2555	Heterotrophic plate count		
SM 9221 B (LTB) + C MPN 20th ED			20186805	Multiple Tube Fermentation Quantitative (LTB): Total Coliform
	2500	Total coliforms		
SM 9221 E (EC) 20th ED			20226806	Multiple Tube Fermentation Quantitative (EC): Fecal Coliform
	2530	Fecal coliforms		
SM 9222 D (m-FC) 20th ED			20209603	Membrane Filtration Quantitative (m-FC): Fecal Coliform
	2530	Fecal coliforms		
SM 9223 B (Colilert®) 20th ED			20212208	Chromogenic/Fluorogenic Qualitative (Colilert®): Total Coliform and E. coli
	2525	Escherichia coli		
	2500	Total coliforms		

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Non-Potable Water	SM 9223 B (Colilert®-18 Quanti-Tray®) 20th ED			20213201	Chromogenic/Fluorogenic Quantitative (Colilert®-18): Total Coliform and E. coli
		2525	Escherichia coli		
		2500	Total coliforms		
	SM 9223 B (Colilert®-18) 21st ED			20214408	Chromogenic/Fluorogenic Qualitative (Colilert®-18): Total Coliform and E. coli
		2525	Escherichia coli		
		2500	Total coliforms		
	SM 9223 B (Colilert®-18) 20th ED			20214204	Chromogenic/Fluorogenic Qualitative (Colilert®-18): Total Coliform and E. coli
		2525	Escherichia coli		
		2500	Total coliforms		
	WI(95) DRO			90019457	Wisconsin DNR - Modified Method for Determination of Diesel Range Organics by GC-FID
		9369	Diesel range organics (DRO)		
	WI(95) GRO			90019468	Wisconsin DNR - Modified Method for Determining Gasoline Range Organics GC-FID
		9408	Gasoline range organics (GRO)		
Solids					
	ALS Kelso LCP-Acryl 1			60001712	ALS Kelso - Acrylamide by HPLC/MS/MS
		4330	Acrylamide		
	ALS Kelso LCP-PFC 4			60001505	ALS Kelso - Perfluorinated Compounds by HPLC-MS-MS
		6911	Perfluorobutane Sulfonate (PFBS)		
		9562	Perfluorodecane Sulfonate (PFDS)		
		6905	Perfluorodecanoic acid (PFDA)		
		6903	Perfluorododecanoic (PFDDA)		
		6908	Perfluoroheptanoic acid (PFHA)		
		6910	Perfluorohexane Sulfonate (PFHS)		
		6913	Perfluorohexanoic acid (PFHXA)		
		6906	Perfluorononanoic acid (PFNA)		
		6912	Perfluorooctanoic acid		
		6909	Perfluorooctanoic Sulfonate (PFOS)		
		6914	Perfluoropentanoic acid (PFPEA)		
		6904	Perfluoroundecanoic acid (PFUDA)		
	ALS Kelso SOC-8151M 11			60001754	ALS Kelso - Chlorinated Pesticides by GC/ECD
		6730	2,3,4,5-Tetrachlorophenol		
		6740	2,3,5,6-Tetrachlorophenol		
		6835	2,4,5-Trichlorophenol		
		6840	2,4,6-Trichlorophenol		
		6818	3,4,5-Trichlorophenol		
		5997	3,4-Dichlorophenol		

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Solids	ALS Kelso SOC-8151M 11	6397	3,5-Dichlorophenol		
		6605	Pentachlorophenol		
	ASTM D1426-08B			30007397	Ammonia by Titration
		1515	Ammonia as N		
	ASTM D3590-02(06)A			30016819	Total Kjeldahl Nitrogen in Water
		1795	Kjeldahl nitrogen - total		
	ASTM D4129 05			30018907	Total and Organic Carbon in Water by High Temperature Oxidation and by Coulometric Detection
		2040	Total organic carbon		
	ASTM D422-63			30030854	Partical Size Distribution (Grain sizing)
		6118	Distribution of particle sizes		
	CAS PestMS2 (1699 modified) 2			60035101	Chlorinated Pesticides by GC/MS/MS
		8580	2,4'-DDD		
		8585	2,4'-DDE		
		8590	2,4'-DDT		
		7355	4,4'-DDD		
		7360	4,4'-DDE		
		7365	4,4'-DDT		
		7025	Aldrin		
		7110	alpha-BHC (alpha-Hexachlorocyclohexane)		
		7240	alpha-Chlordane		
		7115	beta-BHC (beta-Hexachlorocyclohexane)		
		7300	Chlorpyrifos		
		7925	cis-Nonachlor		
		7105	delta-BHC		
		7470	Dieldrin		
		7510	Endosulfan I		
		7515	Endosulfan II		
		7520	Endosulfan sulfate		
		7540	Endrin		
		7530	Endrin aldehyde		
		7535	Endrin ketone		
		7120	gamma-BHC (Lindane, gamma-Hexachlorocyclohexane)		
		7245	gamma-Chlordane		
		7685	Heptachlor		
		7690	Heptachlor epoxide		
		6275	Hexachlorobenzene		
		7725	Isodrin		
		7810	Methoxychlor		

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Solids	CAS PestMS2 (1699 modified) 2	7870	Mirex		
		5553	Octachlorostyrene		
		3890	Oxychlordane		
		7910	trans-Nonachlor		
	CAS SOC-Butyl 10			60035009	Butyltin by GC/Flame Photometric Detector
		1201	Butyltin trichloride		
		1202	Dibutyltin dichloride		
		1209	Tetrabutyltin		
		1203	Tributyltin chloride		
	EPA 1020A			10117007	Ignitability Setaflash Closed-cup Method
		1780	Ignitability		
	EPA 1110A			10235208	Corrosivity Toward Steel
		1615	Corrosivity		
	EPA 1311			10118806	Toxicity Characteristic Leaching Procedure
		8031	Extraction/Preparation		
	EPA 1312			10119003	Synthetic Precipitation Leaching Procedure
		8031	Extraction/Preparation		
	EPA 160.3			10009800	Total Solids, dried @ 103-105 C.
		1950	Residue-total		
	EPA 1630			10122608	Methyl Mercury by Purge & Trap Cold Vapor Atomic Fluorescence Spectrometry
		1205	Methyl Mercury		
	EPA 1631E			10237204	Mercury in Water by Oxidation, Purge & Trap, and Cold Vapor Atomic Fluorescence
		1095	Mercury		
	EPA 1664A (HEM)			10127807	N-Hexane Extractable Material (Oil and Grease) by Extraction and Gravimetry
		1803	n-Hexane Extractable Material (O&G)		
		1860	Oil & Grease		
	EPA 300.0 2.1			10053200	Methods for the Determination of Inorganic Substances in Environmental Samples
		1575	Chloride		
		1730	Fluoride		
		2000	Sulfate		
	EPA 3050B			10135601	Acid Digestion of Sediments, Sludges, and soils
		8031	Extraction/Preparation		
	EPA 314.0			10055400	Perchlorate in Drinking Water by Ion Chromatography
		1895	Perchlorate		

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Solids	EPA 350.1 2		10063602	Ammonia Nitrogen - Colorimetric, Auto Phenate
		1515 Ammonia as N		
	EPA 353.2 2		10067604	Nitrate/Nitrite Nitrogen - Automated, Cadmium
		1810 Nitrate as N		
		1840 Nitrite as N		
		1825 Total nitrate+nitrite		
	EPA 3540C		10140202	Soxhlet Extraction
		8031 Extraction/Preparation		
	EPA 3541		10140406	Automated Soxhlet Extraction
		8031 Extraction/Preparation		
	EPA 3546		10141205	Microwave Extraction
		8031 Extraction/Preparation		
	EPA 3550C		10142004	Ultrasonic Extraction
		8031 Extraction/Preparation		
	EPA 3580A		10143007	Waste Dilution
		8031 Extraction/Preparation		
	EPA 3620C		10146006	Florisil Cleanup
		8031 Extraction/Preparation		
	EPA 3630C		10146802	Silica gel cleanup
		8031 Extraction/Preparation		
	EPA 3640A		10147203	Gel Preparation Cleanup
		8031 Extraction/Preparation		
	EPA 365.3		10070607	Phosphorous - Colorimetric, two reagent.
		1870 Orthophosphate as P		
		1908 Total Phosphate		
	EPA 3660B		10148400	Sulfur cleanup
		8031 Extraction/Preparation		
	EPA 3665A		10148808	Sulfuric Acid / permanganate Cleanup
		8031 Extraction/Preparation		
	EPA 5030B		10153409	Purge and trap for aqueous samples
		8031 Extraction/Preparation		
	EPA 5035A		10284807	Closed-System Purge-and-Trap and Extraction for Volatile Organics in Soil and Waste Samples
		8031 Extraction/Preparation		
	EPA 6010C		10155803	ICP - AES
		1000 Aluminum		

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Solids	EPA 6010C	1005	Antimony	
		1010	Arsenic	
		1015	Barium	
		1020	Beryllium	
		1025	Boron	
		1030	Cadmium	
		1035	Calcium	
		1040	Chromium	
		1050	Cobalt	
		1055	Copper	
		1070	Iron	
		1075	Lead	
		1085	Magnesium	
		1090	Manganese	
		1100	Molybdenum	
		1105	Nickel	
		1125	Potassium	
		1140	Selenium	
		1150	Silver	
		1155	Sodium	
		1160	Strontium	
		1165	Thallium	
		1175	Tin	
		1180	Titanium	
		1185	Vanadium	
		1190	Zinc	
	EPA 6020A			10156408 Inductively Coupled Plasma-Mass Spectrometry
		1000	Aluminum	
		1005	Antimony	
		1010	Arsenic	
		1015	Barium	
		1020	Beryllium	
		1030	Cadmium	
		1040	Chromium	
		1050	Cobalt	
		1055	Copper	
		1070	Iron	
		1075	Lead	
		1090	Manganese	
		1100	Molybdenum	
		1105	Nickel	
		1140	Selenium	
		1150	Silver	

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Solids	EPA 6020A	1160	Strontium		
		1165	Thallium		
		1185	Vanadium		
		1190	Zinc		
	EPA 6850			10304606	Perchlorate in Water, Soils and Solid Wastes Using High Performance Liquid Chromatography/Electrospray Ionization/Mass Spectrometry
		1895	Perchlorate		
	EPA 7062			10159407	Antimony and Arsenic by Borohydride Reduction and Atomic Absorption
		1010	Arsenic		
	EPA 7196A			10162400	Chromium Hexavalent colorimetric
		1045	Chromium VI		
	EPA 7471B			10166402	Mercury by Cold Vapor Atomic Absorption
		1095	Mercury		
	EPA 7742			10169207	Selenium by Borohydride Reduction and Atomic Absorption
		1140	Selenium		
	EPA 8015C			10173805	Non-halogenated organics using GC/FID
		9369	Diesel range organics (DRO)		
		4785	Ethylene glycol		
		9408	Gasoline range organics (GRO)		
	EPA 8081B			10178800	Organochlorine Pesticides by GC/ECD
		8580	2,4'-DDD		
		8585	2,4'-DDE		
		8590	2,4'-DDT		
		7355	4,4'-DDD		
		7360	4,4'-DDE		
		7365	4,4'-DDT		
		7005	Alachlor		
		7025	Aldrin		
		7110	alpha-BHC (alpha-Hexachlorocyclohexane)		
		7240	alpha-Chlordane		
		7115	beta-BHC (beta-Hexachlorocyclohexane)		
		7250	Chlordane (tech.)		
		7300	Chlorpyrifos		
		7925	cis-Nonachlor		
		7105	delta-BHC		
		7470	Dieldrin		
		7510	Endosulfan I		

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Solids	EPA 8081B	7515	Endosulfan II		
		7520	Endosulfan sulfate		
		7540	Endrin		
		7530	Endrin aldehyde		
		7535	Endrin ketone		
		7120	gamma-BHC (Lindane, gamma-Hexachlorocyclohexane)		
		7245	gamma-Chlordane		
		7685	Heptachlor		
		7690	Heptachlor epoxide		
		6275	Hexachlorobenzene		
		4835	Hexachlorobutadiene		
		4840	Hexachloroethane		
		7725	Isodrin		
		7810	Methoxychlor		
		7870	Mirex		
		3890	Oxychlordane		
		8250	Toxaphene (Chlorinated camphene)		
		7910	trans-Nonachlor		
	EPA 8082A			10179201	Polychlorinated Biphenyls (PCBs) by GC/ECD
		9095	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl (BZ-206)		
		9090	2,2',3,3',4,4',5,5'-Octachlorobiphenyl (BZ-194)		
		9103	2,2',3,3',4,4',5,6-Octachlorobiphenyl (BZ-195)		
		9065	2,2',3,3',4,4',5-Heptachlorobiphenyl (BZ-170)		
		9020	2,2',3,3',4,4'-Hexachlorobiphenyl (BZ-128)		
		9112	2,2',3,3',4,5',6,6'-Octachlorobiphenyl (BZ-201)		
		9116	2,2',3,3',4,5,6'-Heptachlorobiphenyl (BZ-174)		
		9114	2,2',3,3',4,5',6'-Heptachlorobiphenyl (BZ-177)		
		9120	2,2',3,3',4,6'-Hexachlorobiphenyl (BZ-132)		
		9133	2,2',3,4,4',5,5',6-Octachlorobiphenyl (BZ-203)		
		9134	2,2',3,4,4',5,5'-Heptachlorobiphenyl (BZ-180)		
		9075	2,2',3,4,4',5',6-Heptachlorobiphenyl (BZ-183)		
		9025	2,2',3,4,4',5'-Hexachlorobiphenyl (BZ-138)		

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Solids	EPA 8082A	9139	2,2',3,4,4',6,6'-Heptachlorobiphenyl (BZ-184)
		9080	2,2',3,4',5,5',6-Heptachlorobiphenyl (BZ-187)
		9030	2,2',3,4,5,5'-Hexachlorobiphenyl (BZ-141)
		9151	2,2',3,4',5',6-Hexachlorobiphenyl (BZ-149)
		8975	2,2',3,4,5'-Pentachlorobiphenyl (BZ-87)
		9155	2,2',3,4',5-Pentachlorobiphenyl (BZ-90)
		9154	2,2',3,4',5'-Pentachlorobiphenyl (BZ-97)
		9035	2,2',3,5,5',6-Hexachlorobiphenyl (BZ-151)
		9166	2,2',3,5',6-Pentachlorobiphenyl (BZ-95)
		8945	2,2',3,5'-Tetrachlorobiphenyl (BZ-44)
		9040	2,2',4,4',5,5'-Hexachlorobiphenyl (BZ-153)
		9174	2,2',4,4',5,6'-Hexachlorobiphenyl (BZ-154)
		9175	2,2',4,4',5-Pentachlorobiphenyl (BZ-99)
		8980	2,2',4,5,5'-Pentachlorobiphenyl (BZ-101)
		8950	2,2',4,5'-Tetrachlorobiphenyl (BZ-49)
		8955	2,2',5,5'-Tetrachlorobiphenyl (BZ-52)
		8930	2,2',5-Trichlorobiphenyl (BZ-18)
		9085	2,3,3',4,4',5,5'-Heptachlorobiphenyl (BZ-189)
		9050	2,3,3',4,4',5-Hexachlorobiphenyl (BZ-156)
		9193	2,3,3',4,4',6-Hexachlorobiphenyl (BZ-158)
		8985	2,3,3',4,4'-Pentachlorobiphenyl (BZ-105)
		8990	2,3,3',4',6-Pentachlorobiphenyl (BZ-110)
		9207	2,3,3',4'-Tetrachlorobiphenyl (BZ-56)
		9055	2,3',4,4',5,5'-Hexachlorobiphenyl (BZ-167)
		9218	2,3',4,4',5',6-Hexachlorobiphenyl (BZ-168)
		9005	2,3,4,4',5-Pentachlorobiphenyl (BZ-114)
		8995	2,3',4,4',5-Pentachlorobiphenyl (BZ-118)
		9000	2,3',4,4',5'-Pentachlorobiphenyl (BZ-123)
		9220	2,3',4,4',6-Pentachlorobiphenyl (BZ-119)
		9221	2,3,4,4'-Tetrachlorobiphenyl (BZ-60)

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Solids	EPA 8082A	8960	2,3',4,4'-Tetrachlorobiphenyl (BZ-66)		
		9230	2,3',4',5-Tetrachlorobiphenyl (BZ-70)		
		9239	2,3',4'-Trichlorobiphenyl (BZ-33)		
		8920	2,3-Dichlorobiphenyl (BZ-5)		
		9250	2,4,4',5-Tetrachlorobiphenyl (BZ-74)		
		9252	2,4,4'-Trichlorobiphenyl (BZ-28)		
		8940	2,4',5-Trichlorobiphenyl (BZ-31)		
		9256	2,4'-Dichlorobiphenyl (BZ-8)		
		8915	2-Chlorobiphenyl (BZ-1)		
		9060	3,3',4,4',5,5'-Hexachlorobiphenyl (BZ-169)		
		9015	3,3',4,4',5-Pentachlorobiphenyl (BZ-126)		
		8965	3,3',4,4'-Tetrachlorobiphenyl (BZ-77)		
		8970	3,4,4',5-Tetrachlorobiphenyl (BZ-81)		
		9266	3,4,4'-Trichlorobiphenyl (BZ-37)		
		8880	Aroclor-1016 (PCB-1016)		
		8885	Aroclor-1221 (PCB-1221)		
		8890	Aroclor-1232 (PCB-1232)		
		8895	Aroclor-1242 (PCB-1242)		
		8900	Aroclor-1248 (PCB-1248)		
		8905	Aroclor-1254 (PCB-1254)		
		8910	Aroclor-1260 (PCB-1260)		
		8912	Aroclor-1262 (PCB-1262)		
		8913	Aroclor-1268 (PCB-1268)		
		9105	Decachlorobiphenyl (BZ-209)		
	EPA 8141B			10182204	Organophosphorous Pesticides by GC/NPD
		7075	Azinphos-methyl (Guthion)		
		7125	Bolstar (Sulprofos)		
		7300	Chlorpyrifos		
		7315	Coumaphos		
		7395	Demeton-o		
		7385	Demeton-s		
		7410	Diazinon		
		8610	Dichlorovos (DDVP, Dichlorvos)		
		7475	Dimethoate		
		8625	Disulfoton		
		7550	EPN		
		7570	Ethoprop		
		7600	Fensulfothion		
		7605	Fenthion		
		7770	Malathion		
		7785	Merphos		

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		7850	Mevinphos		
		7955	Parathion, ethyl		
		7985	Phorate		
		8110	Ronnel		
		8155	Sulfotepp		
		8200	Tetrachlorvinphos (Stirophos, Gardona) Z-isomer		
		8245	Tokuthion (Prothiophos)		
		8275	Trichloronate		
	EPA 8151A			10183207	Chlorinated Herbicides by GC/ECD
		8655	2,4,5-T		
		8545	2,4-D		
		8560	2,4-DB		
		8555	Dalapon		
		8595	Dicamba		
		8605	Dichloroprop (Dichlorprop)		
		8620	Dinoseb (2-sec-butyl-4,6-dinitrophenol, DNBP)		
		7775	MCPA		
		7780	MCPP		
		8650	Silvex (2,4,5-TP)		
	EPA 8260C			10307003	Volatile Organics: GC/MS (capillary column)
		5105	1,1,1,2-Tetrachloroethane		
		5185	1,1,1-Trichloro-2,2,2-trifluoroethane		
		5160	1,1,1-Trichloroethane		
		5110	1,1,2,2-Tetrachloroethane		
		5195	1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)		
		5165	1,1,2-Trichloroethane		
		5167	1,1,2-Trichlorofluoroethane		
		4630	1,1-Dichloroethane		
		4640	1,1-Dichloroethylene		
		4670	1,1-Dichloropropene		
		5150	1,2,3-Trichlorobenzene		
		5180	1,2,3-Trichloropropane		
		5155	1,2,4-Trichlorobenzene		
		5210	1,2,4-Trimethylbenzene		
		4570	1,2-Dibromo-3-chloropropane (DBCP)		
		4585	1,2-Dibromoethane (EDB, Ethylene dibromide)		
		4610	1,2-Dichlorobenzene		
		4635	1,2-Dichloroethane (Ethylene dichloride)		
		4655	1,2-Dichloropropane		

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Solids	EPA 8260C	6800	1,3,5-Trichlorobenzene
		5215	1,3,5-Trimethylbenzene
		4615	1,3-Dichlorobenzene
		4660	1,3-Dichloropropane
		4620	1,4-Dichlorobenzene
		4735	1,4-Dioxane (1,4- Diethyleneoxide)
		4510	1-Chlorohexane
		4665	2,2-Dichloropropane
		4410	2-Butanone (Methyl ethyl ketone, MEK)
		4500	2-Chloroethyl vinyl ether
		4535	2-Chlorotoluene
		4860	2-Hexanone (MBK)
		5020	2-Nitropropane
		4536	4-Bromofluorobenzene
		4540	4-Chlorotoluene
		4910	4-Isopropyltoluene (p-Cymene)
		4995	4-Methyl-2-pentanone (MIBK)
		4305	Acetamide
		4315	Acetone
		4320	Acetonitrile
		4325	Acrolein (Propenal)
		4330	Acrylamide
		4340	Acrylonitrile
		4355	Allyl chloride (3-Chloropropene)
		4375	Benzene
		4385	Bromobenzene
		4390	Bromochloromethane
		4395	Bromodichloromethane
		4400	Bromoform
		4450	Carbon disulfide
		4455	Carbon tetrachloride
		4475	Chlorobenzene
		4575	Chlorodibromomethane
		4485	Chloroethane (Ethyl chloride)
		4505	Chloroform
		4525	Chloroprene (2-Chloro-1,3-butadiene)
		4705	cis & trans-1,2-Dichloroethene
		4645	cis-1,2-Dichloroethylene
		4680	cis-1,3-Dichloropropene
		4595	Dibromomethane (Methylene bromide)
		4625	Dichlorodifluoromethane (Freon-12)
		4725	Diethyl ether
		4755	Ethyl acetate

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Solids	EPA 8260C	4810	Ethyl methacrylate	
		4765	Ethylbenzene	
		4835	Hexachlorobutadiene	
		4870	Iodomethane (Methyl iodide)	
		4875	Isobutyl alcohol (2-Methyl-1-propanol)	
		4900	Isopropylbenzene (Cumene)	
		5240	m+p-xylene	
		4925	Methacrylonitrile	
		4950	Methyl bromide (Bromomethane)	
		4960	Methyl chloride (Chloromethane)	
		5000	Methyl tert-butyl ether (MTBE)	
		4975	Methylene chloride (Dichloromethane)	
		5245	m-Xylene	
		5005	Naphthalene	
		4435	n-Butylbenzene	
		5090	n-Propylbenzene	
		5250	o-Xylene	
		4440	sec-Butylbenzene	
		5100	Styrene	
		4370	T-amylmethylether (TAME)	
		4445	tert-Butylbenzene	
		5115	Tetrachloroethylene (Perchloroethylene)	
		5140	Toluene	
		4700	trans-1,2-Dichloroethylene	
		4685	trans-1,3-Dichloropropylene	
		4605	trans-1,4-Dichloro-2-butene	
		5170	Trichloroethene (Trichloroethylene)	
		5175	Trichlorofluoromethane (Fluorotrichloromethane, Freon 11)	
		5225	Vinyl acetate	
		5235	Vinyl chloride	
		5260	Xylene (total)	
	EPA 8270D		10186002	Semivolatile Organic compounds by GC/MS
		6715	1,2,4,5-Tetrachlorobenzene	
		5155	1,2,4-Trichlorobenzene	
		4610	1,2-Dichlorobenzene	
		6221	1,2-Diphenylhydrazine	
		6885	1,3,5-Trinitrobenzene (1,3,5-TNB)	
		4615	1,3-Dichlorobenzene	
		4620	1,4-Dichlorobenzene	
		6420	1,4-Naphthoquinone	
		6630	1,4-Phenylenediamine	
		5790	1-Chloronaphthalene	

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Solids	EPA 8270D	6380	1-Methylnaphthalene
		6425	1-Naphthylamine
		6735	2,3,4,6-Tetrachlorophenol
		6835	2,4,5-Trichlorophenol
		6840	2,4,6-Trichlorophenol
		6000	2,4-Dichlorophenol
		6130	2,4-Dimethylphenol
		6175	2,4-Dinitrophenol
		6185	2,4-Dinitrotoluene (2,4-DNT)
		6005	2,6-Dichlorophenol
		6190	2,6-Dinitrotoluene (2,6-DNT)
		5735	2-Chloroaniline
		5795	2-Chloronaphthalene
		5800	2-Chlorophenol
		6360	2-Methyl-4,6-dinitrophenol (4,6-Dinitro-2-methylphenol)
		5145	2-Methylaniline (o-Toluidine)
		6385	2-Methylnaphthalene
		6400	2-Methylphenol (o-Cresol)
		6430	2-Naphthylamine
		6460	2-Nitroaniline
		6490	2-Nitrophenol
		5050	2-Picoline (2-Methylpyridine)
		6412	3 & 4 Methylphenol
		5945	3,3'-Dichlorobenzidine
		6120	3,3'-Dimethylbenzidine
		6355	3-Methylcholanthrene
		6405	3-Methylphenol (m-Cresol)
		6465	3-Nitroaniline
		5540	4-Aminobiphenyl
		5660	4-Bromophenyl phenyl ether (BDE-3)
		5700	4-Chloro-3-methylphenol
		5745	4-Chloroaniline
		5825	4-Chlorophenyl phenylether
		6410	4-Methylphenol (p-Cresol)
		6470	4-Nitroaniline
		6500	4-Nitrophenol
		6125	a-a-Dimethylphenethylamine
		5500	Acenaphthene
		5505	Acenaphthylene
		5510	Acetophenone
		5545	Aniline
		5555	Anthracene
		5560	Aramite

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Solids	EPA 8270D	7065	Atrazine
		5562	Azobenzene
		5570	Benzaldehyde
		5575	Benzo(a)anthracene
		5580	Benzo(a)pyrene
		5590	Benzo(g,h,i)perylene
		9309	Benzo(j)fluoranthene
		5600	Benzo(k)fluoranthene
		5585	Benzo[b]fluoranthene
		5610	Benzoic acid
		5630	Benzyl alcohol
		5640	Biphenyl
		5760	bis(2-Chloroethoxy)methane
		5765	bis(2-Chloroethyl) ether
		5780	bis(2-Chloroisopropyl) ether
		5670	Butyl benzyl phthalate
		7180	Caprolactam
		5680	Carbazole
		7260	Chlorobenzilate
		5855	Chrysene
		6065	Di(2-ethylhexyl) phthalate (bis(2-Ethylhexyl)phthalate, DEHP)
		7405	Diallate
		7410	Diazinon
		5895	Dibenz(a,h) anthracene
		5905	Dibenzofuran
		6070	Diethyl phthalate
		7475	Dimethoate
		6135	Dimethyl phthalate
		5925	Di-n-butyl phthalate
		6200	Di-n-octyl phthalate
		7580	Famphur
		6265	Fluoranthene
		6270	Fluorene
		6275	Hexachlorobenzene
		4835	Hexachlorobutadiene
		6285	Hexachlorocyclopentadiene
		4840	Hexachloroethane
		6290	Hexachlorophene
		6315	Indeno(1,2,3-cd) pyrene
		7725	Isodrin
		6320	Isophorone
		7740	Kepone
		6345	Methapyrilene

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Solids	EPA 8270D	7825	Methyl parathion (Parathion, methyl)		
		5005	Naphthalene		
		5015	Nitrobenzene		
		6525	n-Nitrosodiethylamine		
		6530	n-Nitrosodimethylamine		
		6545	n-Nitrosodi-n-propylamine		
		6535	n-Nitrosodiphenylamine		
		6555	n-Nitrosomorpholine		
		6560	n-Nitrosopiperidine		
		6565	n-Nitrosopyrrolidine		
		7955	Parathion, ethyl		
		6590	Pentachlorobenzene		
		6600	Pentachloronitrobenzene		
		6605	Pentachlorophenol		
		6615	Phenanthrene		
		6625	Phenol		
		6650	Pronamide (Kerb)		
		6665	Pyrene		
		5095	Pyridine		
		6685	Safrole		
		8235	Thionazin (Zinophos)		
	EPA 8270D SIM			10242509	Semivolatile Organic compounds by GC/MS Selective Ion Monitoring
		4735	1,4-Dioxane (1,4- Diethyleneoxide)		
		6380	1-Methylnaphthalene		
		6852	2,3,5-Trimethylnaphthalene		
		6188	2,6-Dimethylnaphthalene		
		6385	2-Methylnaphthalene		
		5500	Acenaphthene		
		5505	Acenaphthylene		
		5555	Anthracene		
		5575	Benzo(a)anthracene		
		5580	Benzo(a)pyrene		
		5605	Benzo(e)pyrene		
		5590	Benzo(g,h,i)perylene		
		9309	Benzo(j)fluoranthene		
		5600	Benzo(k)fluoranthene		
		5585	Benzo[b]fluoranthene		
		5640	Biphenyl		
		5680	Carbazole		
		5855	Chrysene		
		5895	Dibenz(a,h) anthracene		
		5905	Dibenzofuran		
		5910	Dibenzothiophene		

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Solids	EPA 8270D SIM	6265	Fluoranthene		
		6270	Fluorene		
		6315	Indeno(1,2,3-cd) pyrene		
		5005	Naphthalene		
		6605	Pentachlorophenol		
		6608	Perylene		
		6615	Phenanthrene		
		6665	Pyrene		
	EPA 8321B			10189205	Solvent Extractable non-volatile compounds by HPLC/TS/MS
		7710	3-Hydroxycarbofuran		
		7010	Aldicarb (Temik)		
		7015	Aldicarb sulfone		
		7020	Aldicarb sulfoxide		
		7195	Carbaryl (Sevin)		
		7205	Carbofuran (Furaden)		
		7800	Methiocarb (Mesurol)		
		7805	Methomyl (Lannate)		
		7940	Oxamyl		
		8080	Propoxur (Baygon)		
	EPA 8330B			10308006	Nitroaromatics, Nitramines and Nitrate Esters by High Performance Liquid Chromatography (HPLC)
		6885	1,3,5-Trinitrobenzene (1,3,5-TNB)		
		6160	1,3-Dinitrobenzene (1,3-DNB)		
		9651	2,4,6-Trinitrotoluene (2,4,6-TNT)		
		6185	2,4-Dinitrotoluene (2,4-DNT)		
		6190	2,6-Dinitrotoluene (2,6-DNT)		
		9303	2-Amino-4,6-dinitrotoluene (2-am-dnt)		
		9507	2-Nitrotoluene		
		6150	3,5-Dinitroaniline		
		9510	3-Nitrotoluene		
		9306	4-Amino-2,6-dinitrotoluene (4-am-dnt)		
		9513	4-Nitrotoluene		
		6415	Methyl-2,4,6-trinitrophenylnitramine (tetryl)		
		5015	Nitrobenzene		
		6485	Nitroglycerin		
		9522	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)		
		9558	Pentaerythritoltetranitrate (PETN)		
		9432	RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine)		

Solids	EPA 9012B			10243206	Total and Amenable Cyanide (automated colorimetric with off-line distillation)
		1510	Amenable cyanide		
		1645	Total cyanide		
	EPA 9013A			10908802	Cyanide Extraction Procedure for Solids and Oils
		8031	Extraction/Preparation		
	EPA 9020B			10194408	Total Organic Halides
		2045	Total organic halides (TOX)		
	EPA 9030B			10196605	Acid-Soluble and Acid-Insoluble sulfides: Distillation
		2005	Sulfide		
	EPA 9034			10196006	Titrimetric Procedure for Acid-Soluble and Acid-Insoluble Sulfides
		2005	Sulfide		
	EPA 9045D			10244607	Soil and Waste pH
		1900	pH		
	EPA 9056A			10199607	Determination of Inorganic Anions by Ion Chromatography
		1575	Chloride		
		1730	Fluoride		
		1805	Nitrate		
		1835	Nitrite		
		2000	Sulfate		
	EPA 9071A			10201408	Oil and Grease Extraction Method for sludge and sediment samples	
		1660	Oil & Grease		
	NWTPH-Dx			90018409	Oregon DEQ TPH Diesel Range
		9369	Diesel range organics (DRO)		
		9505	Residual Range Organics (RRO)		
	NWTPH-Gx			90018603	Oregon DEQ TPH Gasoline Range Organics by GC/FID-PID Purge & Trap
		9408	Gasoline range organics (GRO)		
	NWTPH-HCID			90013200	Oregon DEQ Total Petroleum Hydrocarbon ID
		2050	Total Petroleum Hydrocarbons (TPH)		
	PLUMB 1981			60006259	Extraction/Preparation
		6118	Distribution of particle sizes		
		8031	Extraction/Preparation		
	WI(95) DRO			90019457	Wisconsin DNR - Modified Method for Determination of Diesel Range Organics by GC-FID
		9369	Diesel range organics (DRO)		

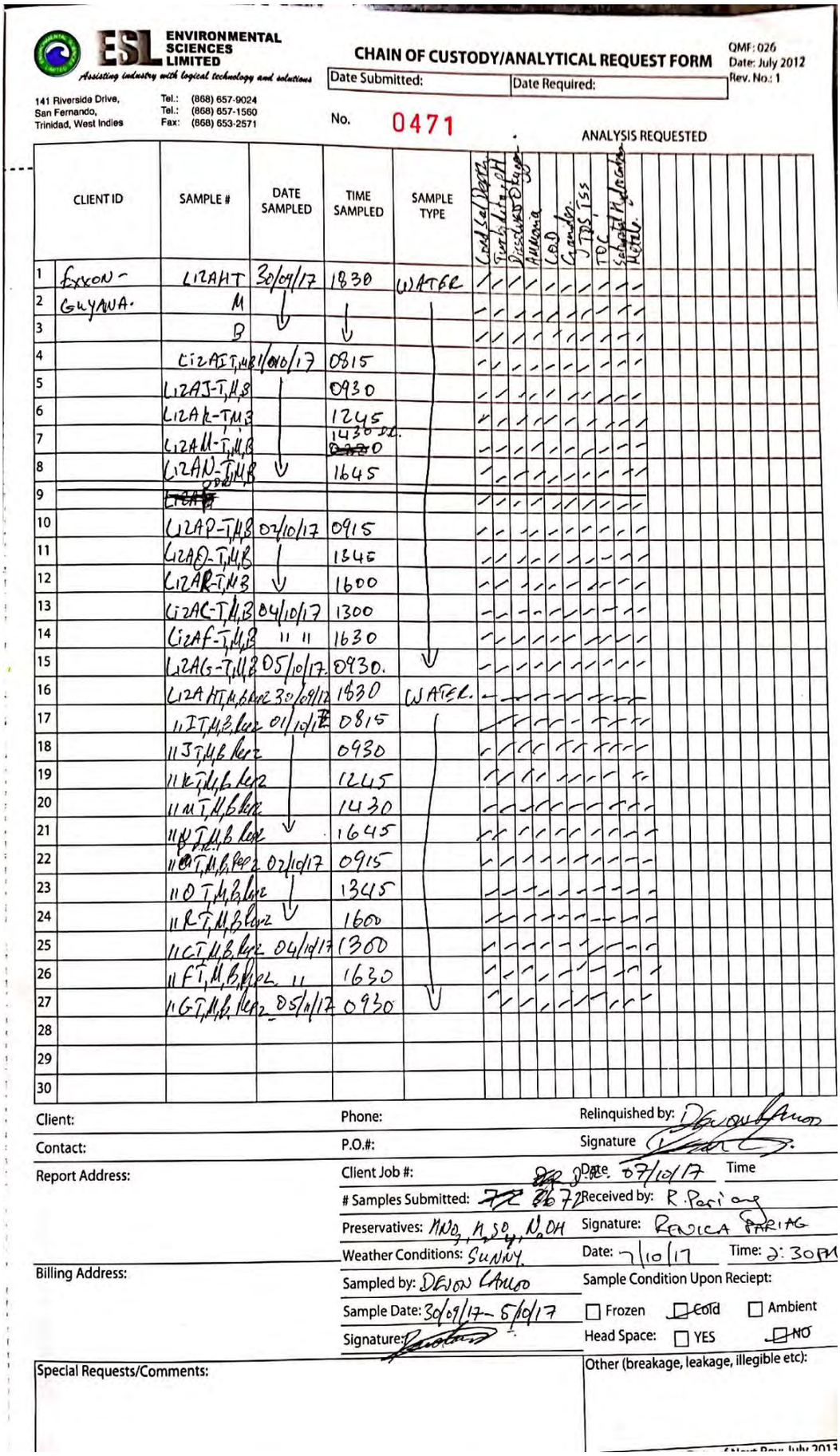
Department of Agriculture, Laboratory Division
Department of Environmental Quality, Laboratory Division
Oregon Health Authority, Public Health Division

55 of 55

Appendix 2 - Chain-of-Custodies (COCs)

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ESL Chain-of-Custody



ENVIRONMENTAL SCIENCES LIMITED
Assisting industry with logical technology and solutions

141 Riverside Drive, San Fernando, Trinidad, West Indies
Tel.: (868) 657-9024
Tel.: (868) 657-1560
Fax: (868) 653-2571

CHAIN OF CUSTODY/ANALYTICAL REQUEST FORM

QMF: 026
Date: July 2012
Rev. No.: 1

Date Submitted: | Date Required:

No. 0471

ANALYSIS REQUESTED

	CLIENT ID	SAMPLE #	DATE SAMPLED	TIME SAMPLED	SAMPLE TYPE
1	EXXON -	L12AHT	30/09/17	1830	WATER
2	GUYANA.	M	↓	↓	
3		B			
4		L12AI T,M,B	1/10/17	0815	
5		L12AJ-T,M,B		0930	
6		L12AK-T,M,B		1245	
7		L12AM-T,M,B		1430 D.L.	
8		L12AN-T,M,B	↓	1645	
9		~~L12AO~~			
10		L12AP-T,M,B	04/10/17	0915	
11		L12AQ-T,M,B		1345	
12		L12AR-T,M,B	↓	1600	
13		L12AC-T,M,B	04/10/17	1300	
14		L12AF-T,M,B	" "	1630	
15		L12AG-T,M,B	05/10/17	0930.	↓
16		L12A HT,M,B Rep2	30/09/17	1830	WATER.
17		" I T,M,B, Rep2	01/10/17	0815	
18		" J T,M,B Rep2		0930	
19		" K T,M,B, Rep2		1245	
20		" M T,M,B Rep2		1430	
21		" N T,M,B Rep2	↓	1645	
22		" ~~O~~ T,M,B, Rep2	02/10/17	0915	
23		" O T,M,B, Rep2		1345	
24		" R T,M,B, Rep2	↓	1600	
25		" C T,M,B, Rep2	04/10/17	1300	
26		" F T,M,B, Rep2	" "	1630	
27		" G T,M,B, Rep2	05/10/17	0930	↓
28					
29					
30					

Client:
Contact:
Report Address:

Billing Address:

Phone:
P.O.#:
Client Job #:
Samples Submitted: ~~72~~ ~~67~~ 72
Preservatives: HNO_3, H_2SO_4, NaOH
Weather Conditions: SUNNY.
Sampled by: DEVON CALLOO
Sample Date: 30/09/17 - 5/10/17
Signature:

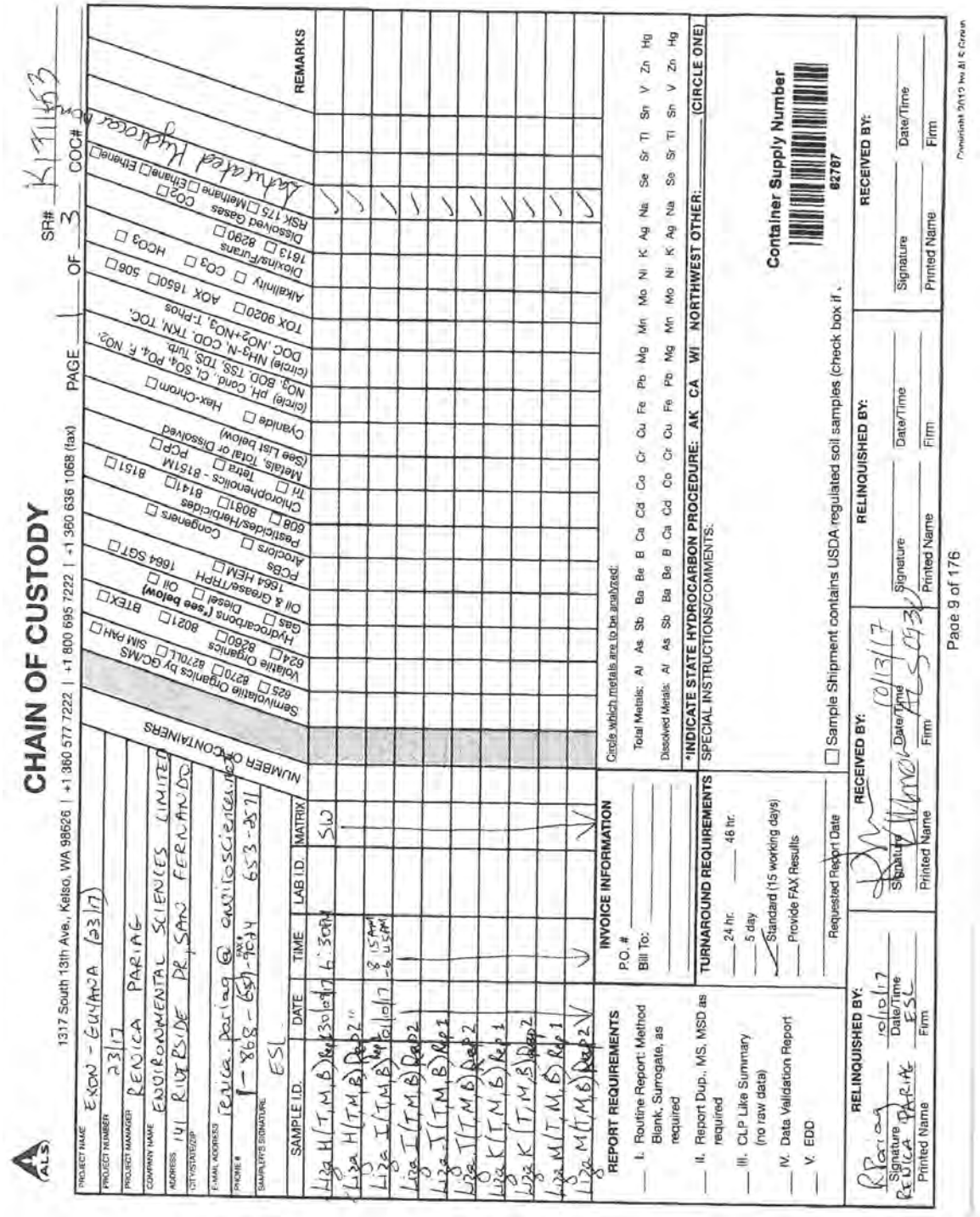
Relinquished by: DEVON CALLOO
Signature
Date: 07/10/17 Time
Received by: R. Pariag
Signature: REVICA PARIAG
Date: 7/10/17 Time: 2:30PM
Sample Condition Upon Reciept:
☐ Frozen ☐ ~~Cold~~ ☐ Ambient
Head Space: ☐ YES ☐ ~~NO~~

Special Requests/Comments:

Other (breakage, leakage, illegible etc):

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ALS Environmental Chain-of-Custody



CHAIN OF CUSTODY

ALS — 1317 South 13th Ave., Kelso, WA 98626 | +1 360 577 7222 | +1 800 695 7222 | +1 360 636 1068 (fax)

PAGE 2 OF 3 — SR# 613453 — COC#

PROJECT NAME: Exxon - Guyana
PROJECT NUMBER: 2317
PROJECT MANAGER: Renica Parag
COMPANY NAME: Environmental Sciences Limited
ADDRESS: 41 Riverside Dr, San Fernando
CITY/STATE/ZIP:
E-MAIL ADDRESS: renica.parag@environsciences.net
PHONE #: 1-868-657-9054 FAX: 653-2571
SAMPLER'S SIGNATURE: ESL

NUMBER OF CONTAINERS

SAMPLE I.D.	DATE	TIME	LAB I.D.	MATRIX	REMARKS
Liza N(T,M,B)Rep1	10/7/17	2:30PM		SO	
Liza N(T,M,B)Rep2	"	"			
Liza P(T,M,B)Rep1	10/7/17	9:15AM			
Liza P(T,M,B)Rep2	"	"			
Liza O(T,M,B)Rep1	1:45PM				
Liza O(T,M,B)Rep2	"				
Liza R(T,M,B)Rep1	4:00PM				
Liza R(T,M,B)Rep2	"				
Liza C(T,M,B)Rep1	10/8/17	11:00AM			
Liza C(T,M,B)Rep2	"	"			

Semivolatile Organics by GC/MS: 625 ☐ 8270 ☐ 8270LL ☐ SIM PAH ☐
Volatile Organics: 624 ☐ 8260 ☐ 8021 ☐ BTEX ☐
Hydrocarbons (see below): Gas ☐ Diesel ☐ Oil ☐
Oil & Grease/TRPH: 1664 HEM ☐ 1664 SGT ☐
PCBs: Aroclors ☐ Congeners ☐
Pesticides/Herbicides: 608 ☐ 8081 ☐ 8141 ☐ 8151 ☐
Chlorophenolics - 8151M: Total ☐ PCP ☐
Metals, Total or Dissolved (See List below): Tot ☐
Cyanide ☐ Hex-Chrom ☐
(circle) pH, Cond., Cl, SO4, PO4, F, NO2, NO3, BOD, TSS, TDS, Turb.
(circle) NH3-N, COD, TKN, TOC, DOC, NO2+NO3, T-Phos
TOX 9020 ☐ AOX 1650 ☐ 506 ☐
Alkalinity ☐ CO3 ☐ HCO3 ☐
Dioxins/Furans 1613 ☐ 8290 ☐
Dissolved Gases RSK 175 ☐ Methane ☐ Ethane ☐ Ethene ☐ CO2 ☐
Scheduled Hydrocarbons

Circle which metals are to be analyzed:
Total Metals: Al As Sb Ba Be B Ca Cd Co Cr Cu Fe Pb Mg Mn Mo Ni K Ag Na Se Sr Tl Sn V Zn Hg
Dissolved Metals: Al As Sb Ba Be B Ca Cd Co Cr Cu Fe Pb Mg Mn Mo Ni K Ag Na Se Sr Tl Sn V Zn Hg

INVOICE INFORMATION
P.O. #
Bill To:

***INDICATE STATE HYDROCARBON PROCEDURE:** AK CA WI NORTHWEST OTHER: _____ (CIRCLE ONE)
SPECIAL INSTRUCTIONS/COMMENTS:

REPORT REQUIREMENTS
I. Routine Report: Method Blank, Surrogate, as required
II. Report Dup., MS, MSD as required
III. CLP Like Summary (no raw data)
IV. Data Validation Report
V. EDD
Requested Report Date

TURNAROUND REQUIREMENTS
24 hr. ___ 48 hr.
5 day
Standard (15 working days)
Provide FAX Results

☐ Sample Shipment contains USDA regulated soil samples (check box if applicable)

Container Supply Number
82767

RELINQUISHED BY:	RECEIVED BY:	RELINQUISHED BY:	RECEIVED BY:
Signature: RParag	Signature:	Signature:	Signature:
Date/Time: 10/10/17	Date/Time: 10/13/17 0934	Date/Time:	Date/Time:
Printed Name: Renica Parag	Printed Name:	Printed Name:	Printed Name:
Firm: ESL	Firm:	Firm:	Firm:

Page 10 of 176

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CHAIN OF CUSTODY

ALS — 1317 South 13th Ave., Kelso, WA 98626 | +1 360 577 7222 | +1 800 695 7222 | +1 360 636 1068 (fax)

SR# K1711693 — PAGE 3 OF 3 — COC#

PROJECT NAME: Exxon - Guyana 23|17
PROJECT NUMBER: 23|17
PROJECT MANAGER: Renica Pareng
COMPANY NAME: Environmental Sciences Limited
ADDRESS: 141 Riverside Dr. San Fernando
CITY/STATE/ZIP:
E-MAIL ADDRESS: renica.pareng@ealtdcaribbean.net
PHONE #: 1-868-657-9054 FAX: 653-2571
SAMPLER'S SIGNATURE: ESL

NUMBER OF CONTAINERS

SAMPLE I.D.	DATE	TIME	LAB I.D.	MATRIX
Liz-E(T,M,B) Rep 2	04/10/17	4:00PM		SW
Liz-F(T,M,B) Rep 2	"			
Liz-G(T,M,B) Rep 2	05/10/17	9:30AM		
Liz-G(T,M,B) Rep 2	"			

Semivolatile Organics by GC/MS: 625 ☐ 8270 ☐ 8270LL ☐ SIM PAH ☐
Volatile Organics: 624 ☐ 8260 ☐ 8021 ☐ BTEX ☐
Hydrocarbons (see below): Gas ☐ Diesel ☐ Oil ☐
Oil & Grease/TRPH: 1664 HEM ☐ 1664 SGT ☐
PCBs: Aroclors ☐
Pesticides/Herbicides: Congeners ☐
8081 ☐ 8151 ☐
Chlorophenolics - 8151M: PCP ☐
Metals, Total or Dissolved (See List below): Terra ☐ Tri ☐
Cyanide ☐ Hex-Chrom ☐
(circle) pH, Cond., Cl, SO4, PO4, F, NO2, NO3, BOD, TSS, TDS, Turb.
(circle) NH3-N, COD, TKN, TOC, DOC, NO2+NO3, T-Phos
TOX 9020 ☐ AOX 1650 ☐ 506 ☐
Alkalinity ☐ CO3 ☐ HCO3 ☐
Dioxins/Furans 1613 ☐ 8290 ☐
Dissolved Gases RSK 175 ☐ Methane ☐ Ethane ☐ Ethene ☐ CO2 ☐
Sediment Hydrometer
REMARKS

Circle which metals are to be analyzed:
Total Metals: Al As Sb Ba Be B Ca Cd Co Cr Cu Fe Pb Mg Mn Mo Ni K Ag Na Se Sr Tl Sn V Zn Hg
Dissolved Metals: Al As Sb Ba Be B Ca Cd Co Cr Cu Fe Pb Mg Mn Mo Ni K Ag Na Se Sr Tl Sn V Zn Hg

REPORT REQUIREMENTS
— I. Routine Report: Method Blank, Surrogate, as required
— II. Report Dup., MS, MSD as required
— III. CLP Like Summary (no raw data)
— IV. Data Validation Report
— V. EDD
Requested Report Date

INVOICE INFORMATION
P.O. #
Bill To:

TURNAROUND REQUIREMENTS
— 24 hr. — 48 hr.
— 5 day
✓ Standard (15 working days)
— Provide FAX Results

***INDICATE STATE HYDROCARBON PROCEDURE: AK CA WI NORTHWEST OTHER: (CIRCLE ONE)**
SPECIAL INSTRUCTIONS/COMMENTS:

☐ Sample Shipment contains USDA regulated soil samples (check box if ap.

Container Supply Number
82787

RELINQUISHED BY:
Signature: R Pareng
Printed Name: Renica Pareng
Date/Time: 10/10/17
Firm:

RECEIVED BY:
Signature:
Printed Name:
Date/Time: 10/13/17 1132
Firm:

RELINQUISHED BY:
Signature:
Printed Name:
Date/Time:
Firm:

RECEIVED BY:
Signature:
Printed Name:
Date/Time:
Firm:

Paoe 11 of 176

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PC #2

Cooler Receipt and Preservation Form

lient Environmental Science Ltd Service Request K17 11153

eceived: 10/13/17 Opened: 10/13/17 By: tbm Unloaded: 10/13/17 By: PK

Samples were received via? (USPS) Fed Ex UPS DHL PDX Courier Hand Delivered

Samples were received in: (circle) (Cooler) Box Envelope Other _____ NA

Were custody seals on coolers? NA Y (N) If yes, how many and where? _____

If present, were custody seals intact? Y (N) If present, were they signed and dated? Y N

Raw Cooler Temp	Corrected Cooler Temp	Raw Temp Blank	Corrected Temp Blank	Corr. Factor	Thermometer ID	Cooler/COC ID NA	Tracking Number NA	Filed
17.7	–	17.7	–	0	391		974241089856 801375347	86
16.9	16.8	16.8	16.7	-0.1	382		" " "	82
17.8	18.0	18.0	18.2	+0.2	378		" " "	84
17.6	17.8	17.0	17.2	+0.2	351		" " "	83

4. Packing material: (Inserts) Baggies (Bubble Wrap) Gel Packs (Wet Ice) Dry Ice Sleeves melted wet ice
5. Were custody papers properly filled out (ink, signed, etc.)? NA (Y) N
6. Were samples received in good condition (temperature, unbroken)? *Indicate in the table below.* NA (Y) N
   If applicable, tissue samples were received: *Frozen Partially Thawed Thawed*
7. Were all sample labels complete (i.e analysis, preservation, etc.)? NA (Y) N
8. Did all sample labels and tags agree with custody papers? *Indicate major discrepancies in the table on page 2.* NA (Y) N
9. Were appropriate bottles/containers and volumes received for the tests indicated? NA (Y) N
10. Were the pH-preserved bottles (*see SMO GEN SOP*) received at the appropriate pH? *Indicate in the table below* (NA) Y N
11. Were VOA vials received without headspace? *Indicate in the table below.* (NA) Y N
12. Was C12/Res negative? (NA) Y N

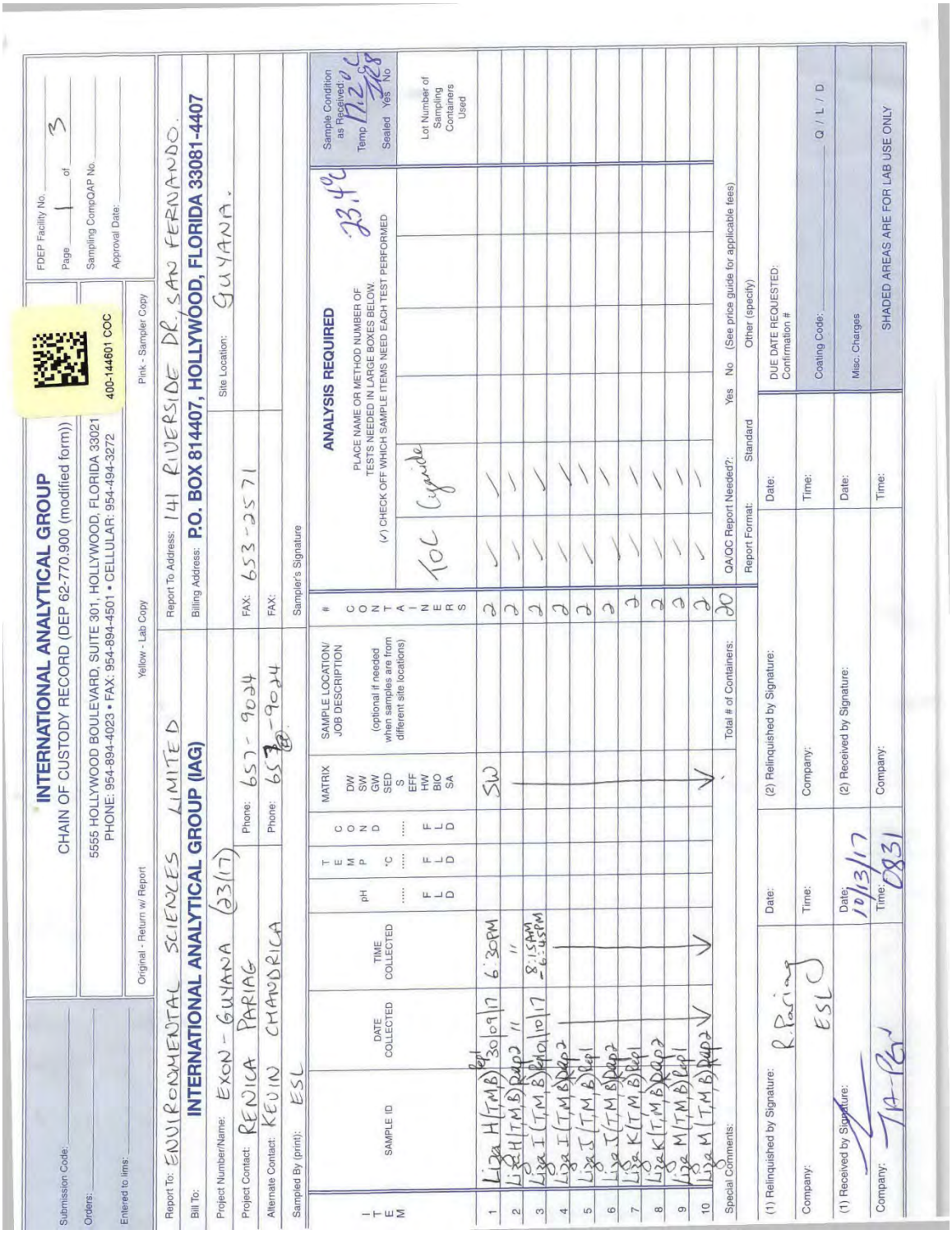
Sample ID on Bottle	Sample ID on COC	Identified by:

Sample ID	Bottle Count Bottle Type	Out of Temp	Head-space	Broke	pH	Reagent	Volume added	Reagent Lot Number	Initials	Time
All Samples		X								

Notes, Discrepancies, & Resolutions: _____

7/25/16 *Page ____ of ____*

IAG Chain-of-Custody



INTERNATIONAL ANALYTICAL GROUP
CHAIN OF CUSTODY RECORD (DEP 62-770.900 (modified form))

5555 HOLLYWOOD BOULEVARD, SUITE 301, HOLLYWOOD, FLORIDA 33021
PHONE: 954-894-4023 • FAX: 954-894-4501 • CELLULAR: 954-494-3272

400-144601 COC

Original - Return w/ Report | Yellow - Lab Copy | Pink - Sampler Copy

Submission Code:
Orders:
Entered to Iims:

FDEP Facility No.
Page 1 of 3
Sampling CompQAP No.
Approval Date:

Report To: ENVIRONMENTAL SCIENCES LIMITED
Report To Address: 141 RIVERSIDE DR, SAN FERNANDO.
Bill To: INTERNATIONAL ANALYTICAL GROUP (IAG)
Billing Address: P.O. BOX 814407, HOLLYWOOD, FLORIDA 33081-4407
Project Number/Name: EXXON - GUYANA (23/17)
Site Location: GUYANA.
Project Contact: RENICA PARIAG
Phone: 657-9024
FAX: 653-2571
Alternate Contact: KEVIN CHANDRICA
Phone: 657-9024
FAX:
Sampled By (print): ESL
Sampler's Signature

ITEM	SAMPLE ID	DATE COLLECTED	TIME COLLECTED	pH FLD	°C FLD	TEMP FLD	COND FLD	MATRIX DW GW SW SED S EFF HW BIO SA	SAMPLE LOCATION/ JOB DESCRIPTION (optional if needed when samples are from different site locations)	# CONTAINERS	ANALYSIS REQUIRED PLACE NAME OR METHOD NUMBER OF TESTS NEEDED IN LARGE BOXES BELOW. (√) CHECK OFF WHICH SAMPLE ITEMS NEED EACH TEST PERFORMED	Sample Condition as Received: Temp 23.4°C Sealed Yes No	Lot Number of Sampling Containers Used
											TOC Liquide		
1	Liza H(T,M,B)Rep1	30/09/17	6:30PM					SW		2	√		
2	Liza H(T,M,B)Rep2	"	"							2	√		
3	Liza I(T,M,B)Rep1	01/10/17	8:15AM - 6:45PM							2	√		
4	Liza I(T,M,B)Rep2									2	√		
5	Liza J(T,M,B)Rep1									2	√		
6	Liza J(T,M,B)Rep2									2	√		
7	Liza K(T,M,B)Rep1									2	√		
8	Liza K(T,M,B)Rep2									2	√		
9	Liza M(T,M,B)Rep1									2	√		
10	Liza M(T,M,B)Rep2	√	√					√		2	√		

Special Comments: Total # of Containers: 20

QA/QC Report Needed?: Yes No (See price guide for applicable fees)
Report Format: Standard Other (specify)
DUE DATE REQUESTED:
Confirmation #
Coating Code: Q / L / D
Misc. Charges
SHADED AREAS ARE FOR LAB USE ONLY

(1) Relinquished by Signature: R. Pariag Date: Time: (2) Relinquished by Signature: Date: Time:
Company: ESL Company:
(1) Received by Signature: Date: 10/13/17 (2) Received by Signature: Date:
Company: Time: 0831 Company: Time:

Submission Code:
Orders:
Entered to lims:

INTERNATIONAL ANALYTICAL GROUP
CHAIN OF CUSTODY RECORD (DEP 62-770.900 (modified form))

5555 HOLLYWOOD BOULEVARD, SUITE 301, HOLLYWOOD, FLORIDA 33021
PHONE: 954-894-4023 • FAX: 954-894-4501 • CELLULAR: 954-494-3272

Original - Return w/ Report | Yellow - Lab Copy | Pink - Sampler Copy

FDEP Facility No.
Page 2 of 3
Sampling CompQAP No.
Approval Date:

Report To: ENVIRONMENTAL SCIENCES LIMITED
Report To Address: 141 RIVERSIDE DR. SAN FERNANDO.
Bill To: INTERNATIONAL ANALYTICAL GROUP (IAG)
Billing Address: P.O. BOX 814407, HOLLYWOOD, FLORIDA 33081-4407
Project Number/Name: EXON GUYANA (23/17).
Site Location: GUYANA.
Project Contact: RENICA PARIAG
Phone: 657-9034
FAX: 653-2571
Alternate Contact: KEVIN CHANDRICA
Phone: " "
FAX:
Sampled By (print): ESL
Sampler's Signature

ITEM	SAMPLE ID	DATE COLLECTED	TIME COLLECTED	pH FLD	TEMP °C FLD	COND FLD	MATRIX (DW SW GW SED S EFF HW BIO SA)	SAMPLE LOCATION/ JOB DESCRIPTION (optional if needed when samples are from different site locations)	# CONTAINERS	ANALYSIS REQUIRED: TOC	ANALYSIS REQUIRED: Cyanide	Lot Number of Sampling Containers Used
1	Liza N (T,M,B) Rep1	01/10/17	2:30PM				SW		2	✓	✓	
2	Liza N (T,M,B) Rep2	"	"						2	✓	✓	
3	Liza P (T,M,B) Rep1	01/10/17	9:15AM						2	✓	✓	
4	Liza P (T,M,B) Rep2		"						2	✓	✓	
5	Liza O (T,M,B) Rep1		1:45PM						2	✓	✓	
6	Liza O (T,M,B) Rep2		"						2	✓	✓	
7	Liza R (T,M,B) Rep1		4:00PM						2	✓	✓	
8	Liza R (T,M,B) Rep2		"						2	✓	✓	
9	Liza C (T,M,B) Rep1	01/10/17	1:00PM						2	✓	✓	
10	Liza C (T,M,B) Rep2		"				↓		2	✓	✓	

Special Comments:
Total # of Containers: 20

Sample Condition as Received: Temp ____ C; Sealed Yes No

QA/QC Report Needed?: Yes No (See price guide for applicable fees)
Report Format: Standard Other (specify)

(1) Relinquished by Signature: R. Pariag	Date:	(2) Relinquished by Signature:	Date:
Company: ESL	Time:	Company:	Time:
(1) Received by Signature:	Date: 10/13/17	(2) Received by Signature:	Date:
Company: M-PGN	Time: 831	Company:	Time:

DUE DATE REQUESTED:
Confirmation #
Coating Code: ____ Q / L / D
Misc. Charges
SHADED AREAS ARE FOR LAB USE ONLY

Submission Code:
Orders:
Entered to lims:

INTERNATIONAL ANALYTICAL GROUP
CHAIN OF CUSTODY RECORD (DEP 62-770.900 (modified form))

5555 HOLLYWOOD BOULEVARD, SUITE 301, HOLLYWOOD, FLORIDA 33021
PHONE: 954-894-4023 • FAX: 954-894-4501 • CELLULAR: 954-494-3272

Original - Return w/ Report | Yellow - Lab Copy | Pink - Sampler Copy

FDEP Facility No.:
Page 3 of 3
Sampling CompQAP No.:
Approval Date:

Report To: ENVIRONMENTAL SCIENCES LIMITED
Report To Address: 141
Bill To: **INTERNATIONAL ANALYTICAL GROUP (IAG)**
Billing Address: **P.O. BOX 814407, HOLLYWOOD, FLORIDA 33081-4407**
Project Number/Name: EXON - GUYANA (23/17)
Site Location:
Project Contact: RENICA PARIAG
Phone: 657-9074
FAX:
Alternate Contact: KEVIN CHANDRICA
Phone: 〃
FAX:
Sampled By (print): ESL
Sampler's Signature:

ITEM	SAMPLE ID	DATE COLLECTED	TIME COLLECTED	pH FLD	TEMP °C FLD	COND FLD	MATRIX (DW SW GW SED S EFF HW BIO SA)	SAMPLE LOCATION/ JOB DESCRIPTION (optional if needed when samples are from different site locations)	# CONTAINERS	ANALYSIS REQUIRED: TOC	ANALYSIS REQUIRED: Cyanide	Lot Number of Sampling Containers Used
1	Liza F(T,M,B) Rep1	04/10/17	4:00PM				SW		2	✓	✓	
2	Liza F(T,M,B)Rep2	〃	〃						2	✓	✓	
3	Liza G(T,M,B)Rep1	05/10/17	9:30AM						2	✓	✓	
4	Liza G(T,M,B)Rep2	〃	〃				↓		2	✓	✓	
5												
6												
7												
8												
9												
10												

Sample Condition as Received: Temp ____ C; Sealed Yes No

Special Comments:
Total # of Containers: 8
QA/QC Report Needed?: Yes No (See price guide for applicable fees)
Report Format: Standard Other (specify)

(1) Relinquished by Signature: R. Pariag	Date:	(2) Relinquished by Signature:	Date:
Company: ESL	Time:	Company:	Time:
(1) Received by Signature:	Date: 10/13/17	(2) Received by Signature:	Date:
Company: TA-PEN	Time: 0931	Company:	Time:

DUE DATE REQUESTED:
Confirmation #
Coating Code: Q / L / D
Misc. Charges
SHADED AREAS ARE FOR LAB USE ONLY

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Appendix 3 – Calibration Certificates

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SEA-BIRD ELECTRONICS, INC.
13431 NE 20th St. Bellevue, Washington 98005 USA
Phone: (425) 643-9866 Fax: (425) 643-9954 www.seabird.com

Temperature Calibration Report

Customer:	SEATRONICS INC		
Job Number:	88989	**Date of Report:**	3/15/2016
Model Number	SBE 19Plus	**Serial Number:**	19P55870-6614

Temperature sensors are normally calibrated 'as received', without adjustments, allowing a determination sensor drift. If the calibration identifies a problem, then a second calibration is performed after work is completed. The 'as received' calibration is not performed if the sensor is damaged or non-functional, or by customer request.

An 'as received' calibration certificate is provided, listing coefficients to convert sensor frequency to temperature. Users must choose whether the 'as received' calibration or the previous calibration better represents the sensor condition during deployment. In SEASOFT enter the chosen coefficients. The coefficient 'offset' allows a small correction for drift between calibrations (consult the SEASOFT manual). Calibration coefficients obtained after a repair apply only to subsequent data.

'AS RECEIVED CALIBRATION' ☑ Performed ☐ Not Performed

Date: 3/15/2016 Drift since last cal: +0.00113 Degrees Celsius/year

Comments:

'CALIBRATION AFTER REPAIR' ☐ Performed ☑ Not Performed

Date: Drift since Last cal: Degrees Celsius/year

Comments:

Sea-Bird Electronics, Inc.
13431 NE 20th Street, Bellevue, WA 98005-2010 USA
Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 1846
CALIBRATION DATE: 29-Mar-16

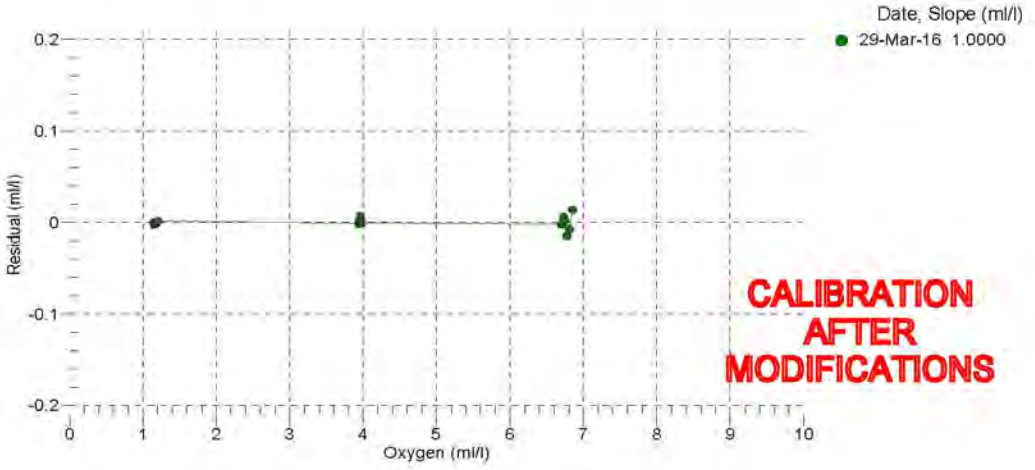
SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.5946
Voffset = -0.4988
Tau20 = 1.54
A = -4.3312e-003
B = 1.3449e-004
C = -2.2582e-006
E nominal = 0.036

NOMINAL DYNAMIC COEFFICIENTS
D1 = 1.92634e-4
D2 = -4.64803e-2
H1 = -3.300000e-2
H2 = 5.00000e+3
H3 = 1.45000e+3

BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.15	6.00	0.00	0.726	1.16	-0.00
1.16	2.00	0.00	0.701	1.15	-0.00
1.16	12.00	0.00	0.768	1.16	0.00
1.19	20.00	0.00	0.829	1.19	-0.00
1.20	26.00	0.00	0.877	1.20	0.00
1.20	30.00	0.00	0.909	1.20	0.00
3.94	2.00	0.00	1.169	3.94	-0.00
3.95	12.00	0.00	1.412	3.95	0.00
3.95	6.00	0.00	1.278	3.95	0.00
3.97	26.00	0.00	1.752	3.97	0.01
3.97	20.00	0.00	1.604	3.97	-0.00
3.98	30.00	0.00	1.859	3.98	-0.00
6.70	2.00	0.00	1.673	6.70	-0.00
6.73	6.00	0.00	1.829	6.74	0.01
6.75	12.00	0.00	2.061	6.75	0.00
6.78	20.00	0.00	2.382	6.76	-0.01
6.81	30.00	0.00	2.824	6.80	-0.01
6.85	26.00	0.00	2.665	6.86	0.01

V = instrument output (volts); T = temperature (°C), S = salinity (PSU), K = temperature (°K)
Oxsol(T,S) = oxygen saturation (ml/l); P = pressure (dbar)
Oxygen (ml/l) = Soc * (V + Voffset) * (1.0 + A * T + B * T^2 + C * T^2) * Oxsol(T,S) * exp(E * P / K)
Residual (ml/l) = instrument oxygen - bath oxygen



Sea-Bird Electronics, Inc.
13431 NE 20th Street, Bellevue, WA 98005-2010 USA
Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 6614
CALIBRATION DATE: 14-Mar-16

SBE 19plus V2 PRESSURE CALIBRATION DATA
5076 psia S/N 3140496

COEFFICIENTS:

PA0 =	3.609881e-001	PTCA0 =	5.247964e+005
PA1 =	1.565788e-002	PTCA1 =	3.204348e+000
PA2 =	-6.210196e-010	PTCA2 =	-1.007961e-001
PTEMPA0 =	-6.410535e+001	PTCB0 =	2.515100e+001
PTEMPA1 =	5.199986e+001	PTCB1 =	-0.000000e+000
PTEMPA2 =	-2.581041e-001	PTCB2 =	0.000000e+000

PRESSURE SPAN CALIBRATION

PRESSURE (PSIA)	INSTRUMENT OUTPUT (counts)	THERMISTOR OUTPUT (volts)	COMPUTED PRESSURE (PSIA)	RESIDUAL (%FSR)
14.49	525726.9	1.6	14.57	0.00
1026.37	590507.6	1.6	1026.22	-0.00
2038.59	655651.2	1.7	2038.28	-0.01
3050.62	721158.7	1.7	3050.68	-0.00
4062.97	787008.7	1.7	4063.00	0.00
5075.24	853195.4	1.7	5075.08	-0.00
4063.00	787023.4	1.7	4063.23	0.00
3050.86	721183.3	1.7	3051.07	0.00
2038.59	655660.5	1.7	2038.74	0.00
1026.45	590521.9	1.7	1026.45	-0.00
14.50	525729.2	1.7	14.55	0.00

THERMAL CORRECTION

TEMP (°C)	THERMISTOR OUTPUT (volts)	INSTRUMENT OUTPUT (counts)
32.50	1.88	525733.98
29.00	1.81	525745.31
24.00	1.71	525756.14
18.50	1.60	525761.39
15.00	1.53	525761.60
4.50	1.33	525748.39
1.00	1.26	525739.91

TEMPERATURE (°C)	SPAN (mV)
-5.00	35.15
35.00	25.15

y = thermistor output (counts)

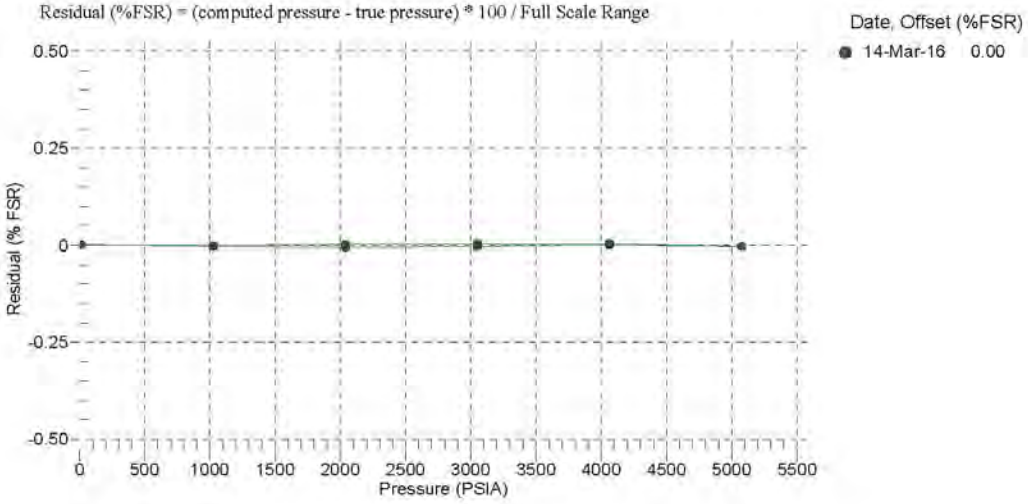
$t = PTEMPA0 + PTEMPA1 * y + PTEMPA2 * y^2$

$x = \text{instrument output} - PTCA0 - PTCA1 * t - PTCA2 * t^2$

$n = x * PTCB0 / (PTCB0 + PTCB1 * t + PTCB2 * t^2)$

$\text{pressure (PSIA)} = PA0 + PA1 * n + PA2 * n^2$

Residual (%FSR) = (computed pressure - true pressure) * 100 / Full Scale Range



Sea-Bird Electronics, Inc.
13431 NE 20th Street, Bellevue, WA 98005-2010 USA
Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

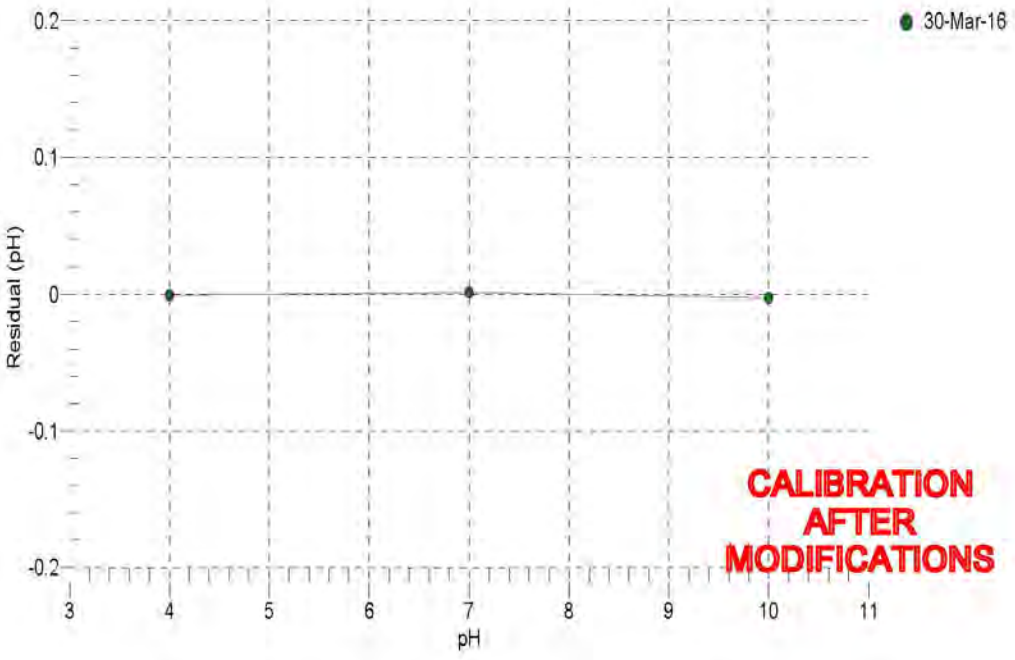
SENSOR SERIAL NUMBER: 0921
CALIBRATION DATE: 30-Mar-16

SBE 18 pH CALIBRATION DATA

pH COEFFICIENTS:
pHslope = 4.5910
pHoffset = 2.5497

pH BUFFER	TEMPERATURE (°C)	INSTRUMENT OUTPUT (volts)	COMPUTED pH	RESIDUAL (pH)
4.0	22.7	1.741	3.999	-0.001
7.0	22.7	2.550	7.001	0.001
10.0	22.9	3.358	9.997	-0.003

Vout = Instrument pH sensor output in volts
pH = 7.0 + (Vout - pHoffset) / (pHslope * °K * 1.98416E-4)
Residual (pH) = instrument pH - buffer pH



SEA-BIRD ELECTRONICS, INC.
13431 NE 20th Street Bellevue, Washington 98005 USA
Phone: (425) 643-9866 Fax: (425) 643-9954 www.seabird.com

Conductivity Calibration Report

Customer:	SEATRONICS INC		
Job Number:	88989	**Date of Report:**	3/15/2016
Model Number	SBE 19Plus	**Serial Number:**	19P55870-6614

Conductivity sensors are normally calibrated 'as received', without cleaning or adjustments, allowing a determination of sensor drift. If the calibration identifies a problem or indicates cell cleaning is necessary, then a second calibration is performed after work is completed. The 'as received' calibration is not performed if the sensor is damaged or non-functional, or by customer request.

An 'as received' calibration certificate is provided, listing the coefficients used to convert sensor frequency to conductivity. Users must choose whether the 'as received' calibration or the previous calibration better represents the sensor condition during deployment. In SEASOFT enter the chosen coefficients. The coefficient 'slope' allows small corrections for drift between calibrations (consult the SEASOFT manual). Calibration coefficients obtained after a repair or cleaning apply only to subsequent data.

'AS RECEIVED CALIBRATION' ☑ Performed ☐ Not Performed

Date: 3/15/2016 Drift since last cal: 0.0000 PSU/month*

Comments:

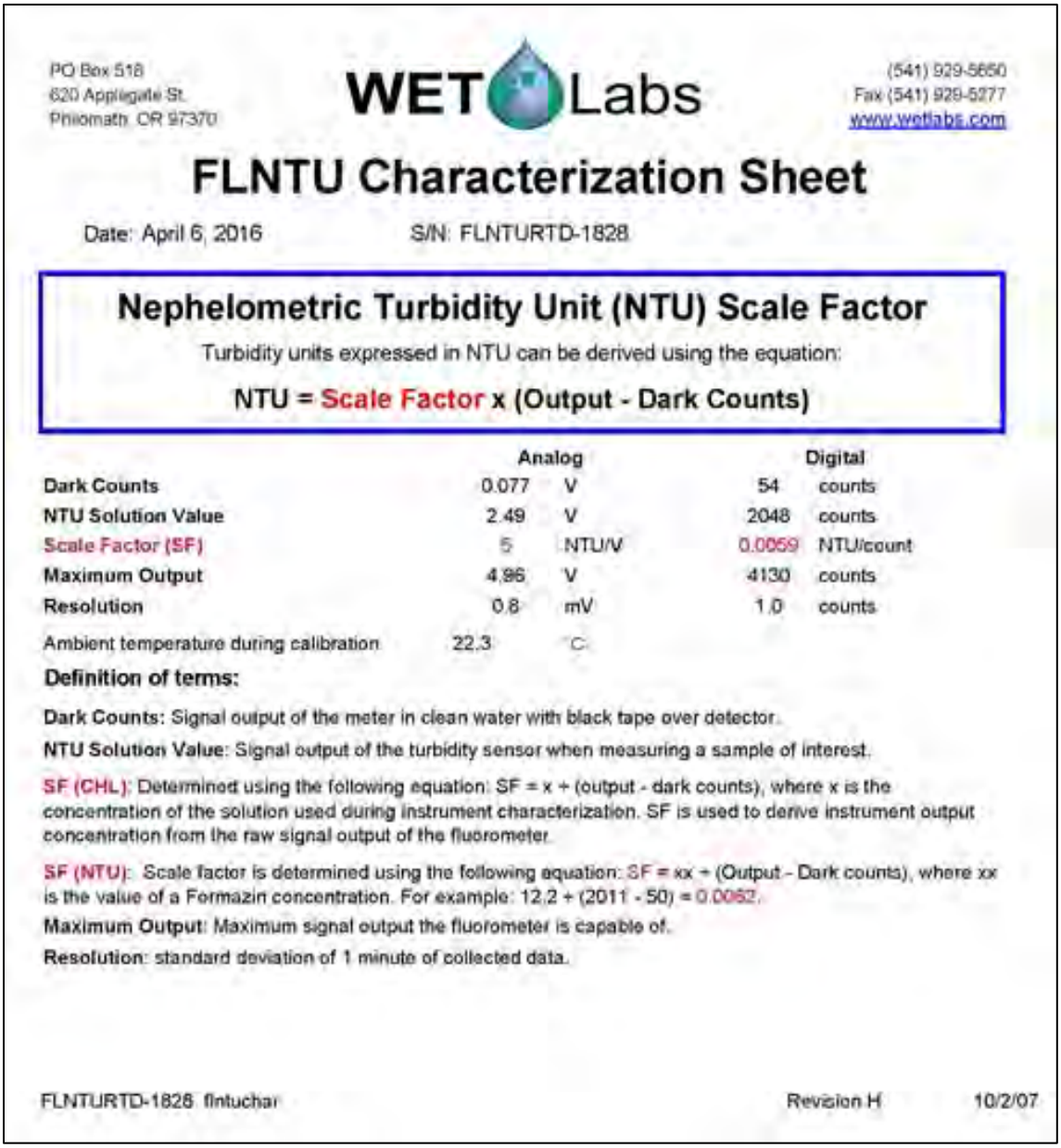
'CALIBRATION AFTER CLEANING & REPLATINIZING' ☐ Performed ☑ Not Performed

Date: Drift since Last cal: PSU/month*

Comments:

**Measured at 3.0 S/m*

Cell cleaning and electrode replatinizing tend to 'reset' the conductivity sensor to its original condition. Lack of drift in post-cleaning-calibration indicates geometric stability of the cell and electrical stability of the sensor circuit.



PO Box 518
620 Applegate St.
Philomath, OR 97370

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

WET Labs

FLNTU Characterization Sheet

Date: April 6, 2016 S/N: FLNTURTD-1828

Nephelometric Turbidity Unit (NTU) Scale Factor

Turbidity units expressed in NTU can be derived using the equation:

NTU = Scale Factor x (Output - Dark Counts)

	Analog		Digital	
Dark Counts	0.077	V	54	counts
NTU Solution Value	2.49	V	2048	counts
Scale Factor (SF)	5	NTU/V	0.0059	NTU/count
Maximum Output	4.96	V	4130	counts
Resolution	0.8	mV	1.0	counts
Ambient temperature during calibration	22.3	C		

Definition of terms:

Dark Counts: Signal output of the meter in clean water with black tape over detector.

NTU Solution Value: Signal output of the turbidity sensor when measuring a sample of interest.

SF (CHL): Determined using the following equation: SF = x ÷ (output - dark counts), where x is the concentration of the solution used during instrument characterization. SF is used to derive instrument output concentration from the raw signal output of the fluorometer.

SF (NTU): Scale factor is determined using the following equation: SF = xx ÷ (Output - Dark counts), where xx is the value of a Formazin concentration. For example: 12.2 ÷ (2011 - 50) = 0.0062.

Maximum Output: Maximum signal output the fluorometer is capable of.

Resolution: standard deviation of 1 minute of collected data.

FLNTURTD-1828 flntuchar Revision H 10/2/07

Appendix 4 - Sample Label

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Figure 1 below is an example of a sample label used during the execution of the CTD and water sampling exercise within the Project area off the northeast coast of Guyana.

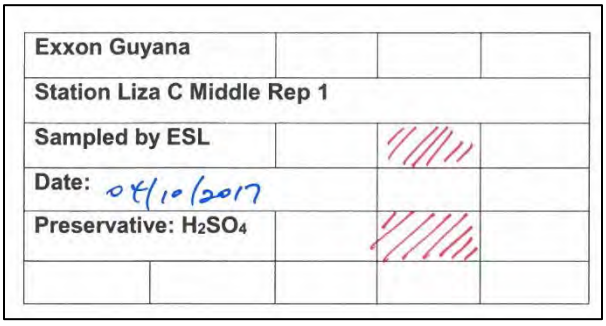


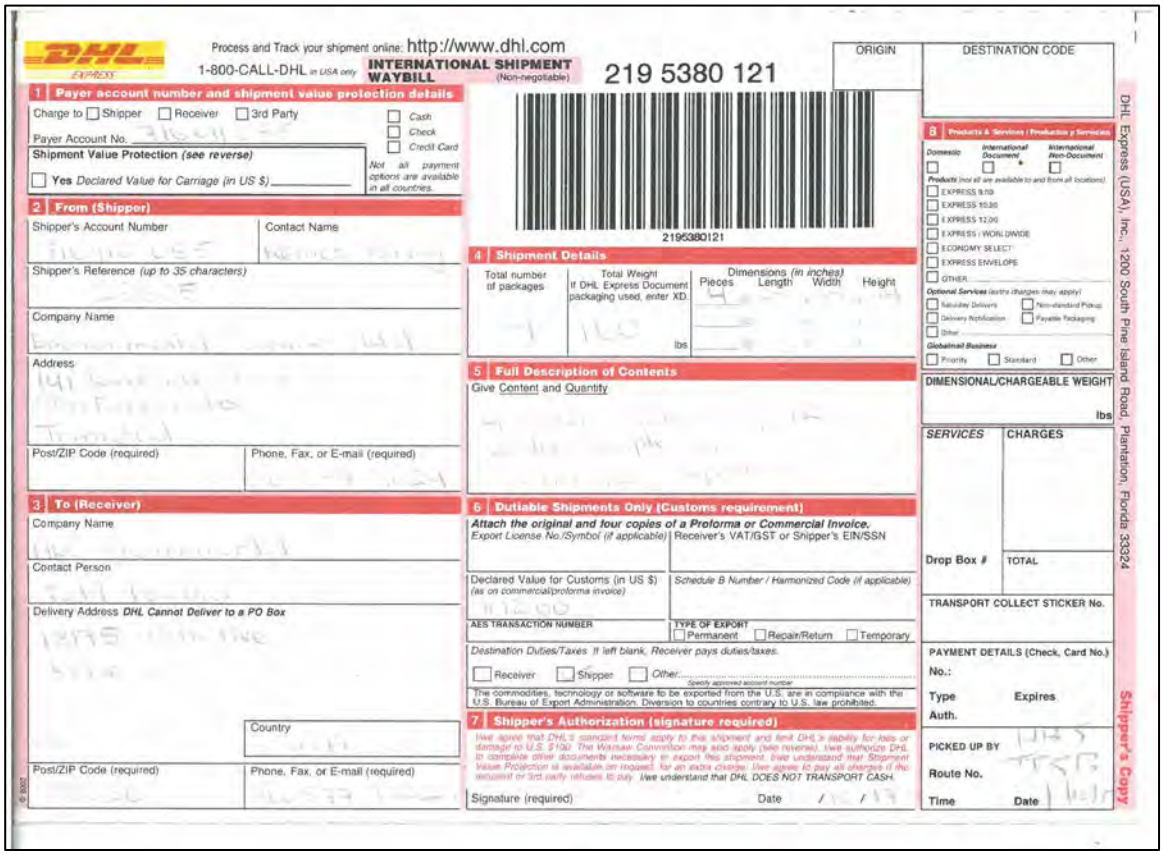
Figure 1: Example of Sample Label

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Appendix 5 - Shipping Documentation

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ALS Environmental Airway Bill



Process and Track your shipment online: http://www.dhl.com
1-800-CALL-DHL in USA only
INTERNATIONAL SHIPMENT WAYBILL (Non-negotiable)
219 5380 121
ORIGIN
DESTINATION CODE

1 Payer account number and shipment value protection details
Charge to ☐ Shipper ☐ Receiver ☐ 3rd Party
Payer Account No.
Shipment Value Protection (see reverse)
☐ Yes Declared Value for Carriage (in US $)
☐ Cash ☐ Check ☐ Credit Card
Not all payment options are available in all countries.

2 From (Shipper)
Shipper's Account Number
Contact Name
Shipper's Reference (up to 35 characters)
Company Name
Address
Post/ZIP Code (required)
Phone, Fax, or E-mail (required)

3 To (Receiver)
Company Name
Contact Person
Delivery Address DHL Cannot Deliver to a PO Box
Country
Post/ZIP Code (required)
Phone, Fax, or E-mail (required)

4 Shipment Details
Total number of packages
Total Weight If DHL Express Document packaging used, enter XD.
lbs
Dimensions (in inches) Pieces Length Width Height

5 Full Description of Contents
Give Content and Quantity

6 Dutiable Shipments Only (Customs requirement)
Attach the original and four copies of a Proforma or Commercial Invoice.
Export License No./Symbol (if applicable)
Receiver's VAT/GST or Shipper's EIN/SSN
Declared Value for Customs (in US $) (as on commercial/proforma invoice)
Schedule B Number / Harmonized Code (if applicable)
AES TRANSACTION NUMBER
TYPE OF EXPORT ☐ Permanent ☐ Repair/Return ☐ Temporary
Destination Duties/Taxes If left blank, Receiver pays duties/taxes.
☐ Receiver ☐ Shipper ☐ Other:
The commodities, technology or software to be exported from the U.S. are in compliance with the U.S. Bureau of Export Administration. Diversion to countries contrary to U.S. law prohibited.

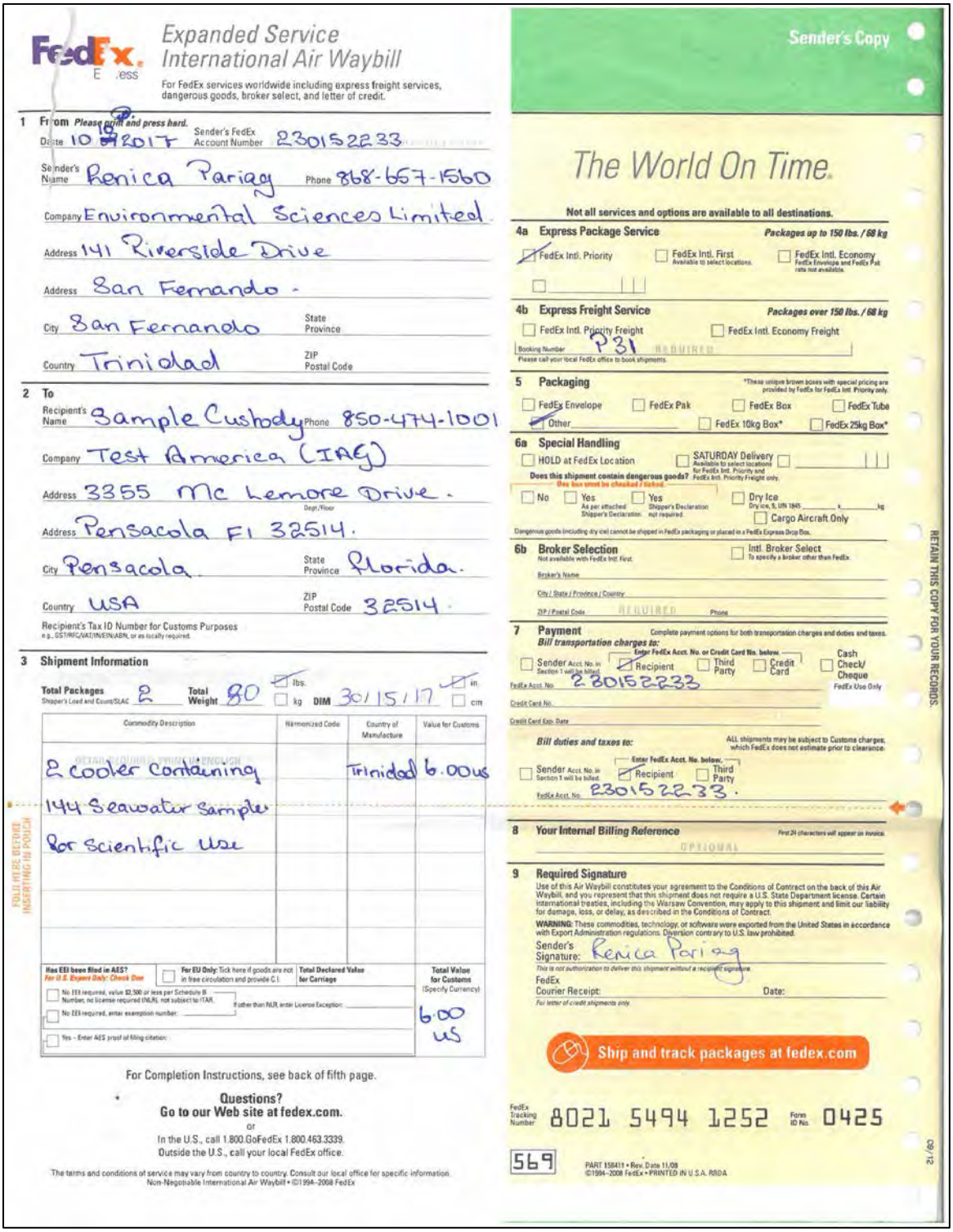
7 Shipper's Authorization (signature required)
I/we agree that DHL's standard terms apply to this shipment and limit DHL's liability for loss or damage to U.S. $100. The Warsaw Convention may also apply (see reverse). I/we authorize DHL to complete other documents necessary to export this shipment. I/we understand that Shipment Value Protection is available on request, for an extra charge. I/we agree to pay all charges if the recipient or 3rd party refuses to pay. I/we understand that DHL DOES NOT TRANSPORT CASH.
Signature (required)
Date / /

8 Products & Services (Production p Services)
Domestic | International Document | International Non-Document
Products (not all are available to and from all locations)
☐ EXPRESS 9:00
☐ EXPRESS 10:30
☐ EXPRESS 12:00
☐ EXPRESS WORLDWIDE
☐ ECONOMY SELECT
☐ EXPRESS ENVELOPE
☐ OTHER
Optional Services (extra charges may apply)
☐ Saturday Delivery ☐ Non-standard Pickup
☐ Delivery Notification ☐ Payable Packaging
☐ Other
Global Mail Business
☐ Priority ☐ Standard ☐ Other

DIMENSIONAL/CHARGEABLE WEIGHT
lbs
SERVICES | CHARGES
Drop Box # | TOTAL
TRANSPORT COLLECT STICKER No.
PAYMENT DETAILS (Check, Card No.)
No.:
Type Expires
Auth.
PICKED UP BY
Route No.
Time Date

DHL Express (USA), Inc., 1200 South Pine Island Road, Plantation, Florida 33324
Shipper's Copy

IAG Airway Bill



FedEx Express

Expanded Service
International Air Waybill

For FedEx services worldwide including express freight services, dangerous goods, broker select, and letter of credit.

1 From Please print and press hard.
Date 10/8/2017 Sender's FedEx Account Number 230152233
Sender's Name Renica Pariag Phone 868-657-1560
Company Environmental Sciences Limited
Address 141 Riverside Drive
Address San Fernando
City San Fernando State/Province
Country Trinidad ZIP/Postal Code

2 To
Recipient's Name Sample Custody Phone 850-474-1001
Company Test America (IAG)
Address 3355 Mc Lemore Drive
Address Pensacola FL 32514
City Pensacola State/Province Florida
Country USA ZIP/Postal Code 32514
Recipient's Tax ID Number for Customs Purposes

3 Shipment Information
Total Packages 2 Total Weight 80 lbs / kg DIM 30/15/17 in / cm

Commodity Description	Harmonized Code	Country of Manufacture	Value for Customs
2 cooler containing 144 Seawater samples for Scientific use		Trinidad	6.00 US

Has EEI been filed in AES? For U.S. Exports Only: Check One
No EEI required, value $2,500 or less per Schedule B Number, no license required (NLR), not subject to ITAR.
No EEI required, enter exemption number:
Yes - Enter AES proof of filing citation:
For EU Only: Tick here if goods are not in free circulation and provide C.I.
Total Declared Value for Carriage
Total Value for Customs (Specify Currency) 6.00 US

For Completion Instructions, see back of fifth page.

Questions?
Go to our Web site at fedex.com.
Or
In the U.S., call 1.800.GoFedEx 1.800.463.3339.
Outside the U.S., call your local FedEx office.

The terms and conditions of service may vary from country to country. Consult our local office for specific information.
Non-Negotiable International Air Waybill • ©1994–2008 FedEx

FOLD HERE BEFORE INSERTING IN POUCH

Sender's Copy

The World On Time.

Not all services and options are available to all destinations.

4a Express Package Service — Packages up to 150 lbs. / 68 kg
☑ FedEx Intl. Priority ☐ FedEx Intl. First (Available to select locations.) ☐ FedEx Intl. Economy (FedEx Envelope and FedEx Pak rate not available.)

4b Express Freight Service — Packages over 150 lbs. / 68 kg
☐ FedEx Intl. Priority Freight ☐ FedEx Intl. Economy Freight
Booking Number P31 REQUIRED
Please call your local FedEx office to book shipments.

5 Packaging — *These unique brown boxes with special pricing are provided by FedEx for FedEx Intl. Priority only.
☐ FedEx Envelope ☐ FedEx Pak ☐ FedEx Box ☐ FedEx Tube
☑ Other ☐ FedEx 10kg Box* ☐ FedEx 25kg Box*

6a Special Handling
☐ HOLD at FedEx Location ☐ SATURDAY Delivery (Available to select locations for FedEx Intl. Priority and FedEx Intl. Priority Freight only.)
Does this shipment contain dangerous goods? One box must be checked / ticked.
☐ No ☐ Yes (As per attached Shipper's Declaration) ☐ Yes (Shipper's Declaration not required) ☐ Dry Ice (Dry ice, 9, UN 1845 ____ x ____ kg) ☐ Cargo Aircraft Only
Dangerous goods (including dry ice) cannot be shipped in FedEx packaging or placed in a FedEx Express Drop Box.

6b Broker Selection (Not available with FedEx Intl. First.) ☐ Intl. Broker Select (To specify a broker other than FedEx.)
Broker's Name
City / State / Province / Country
ZIP / Postal Code REQUIRED Phone

7 Payment — Complete payment options for both transportation charges and duties and taxes.
Bill transportation charges to: Enter FedEx Acct. No. or Credit Card No. below.
☐ Sender (Acct. No. in Section 1 will be billed) ☑ Recipient ☐ Third Party ☐ Credit Card ☐ Cash/Check/Cheque
FedEx Acct. No. 230152233 FedEx Use Only
Credit Card No.
Credit Card Exp. Date

Bill duties and taxes to: ALL shipments may be subject to Customs charges, which FedEx does not estimate prior to clearance.
Enter FedEx Acct. No. below.
☐ Sender (Acct. No. in Section 1 will be billed) ☑ Recipient ☐ Third Party
FedEx Acct. No. 230152233

8 Your Internal Billing Reference — First 24 characters will appear on invoice.
OPTIONAL

9 Required Signature
Use of this Air Waybill constitutes your agreement to the Conditions of Contract on the back of this Air Waybill, and you represent that this shipment does not require a U.S. State Department license. Certain international treaties, including the Warsaw Convention, may apply to this shipment and limit our liability for damage, loss, or delay, as described in the Conditions of Contract.
WARNING: These commodities, technology, or software were exported from the United States in accordance with Export Administration regulations. Diversion contrary to U.S. law prohibited.
Sender's Signature: Renica Pariag
This is not authorization to deliver this shipment without a recipient signature.
FedEx Courier Receipt: Date:
For letter of credit shipments only.

Ship and track packages at fedex.com

FedEx Tracking Number 8021 5494 1252 Form ID No. 0425

569

PART 158411 • Rev. Date 11/08
©1994–2008 FedEx • PRINTED IN U.S.A. RRDA

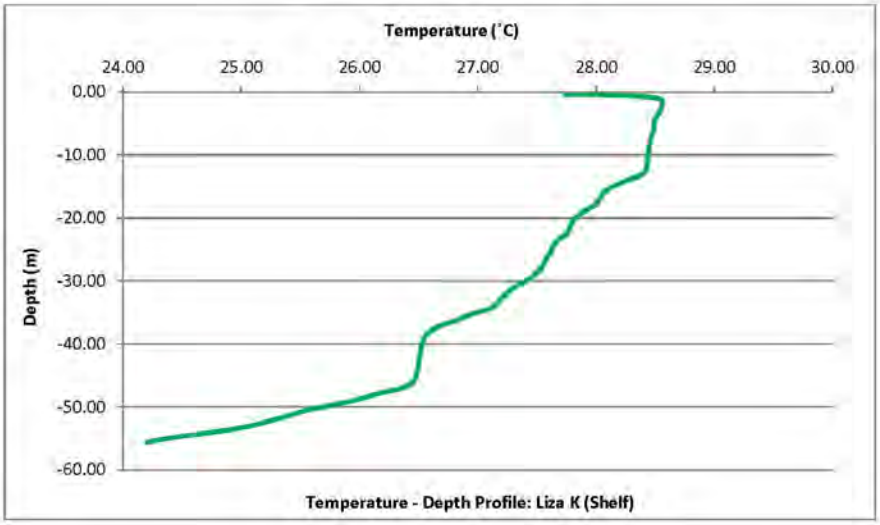
RETAIN THIS COPY FOR YOUR RECORDS.

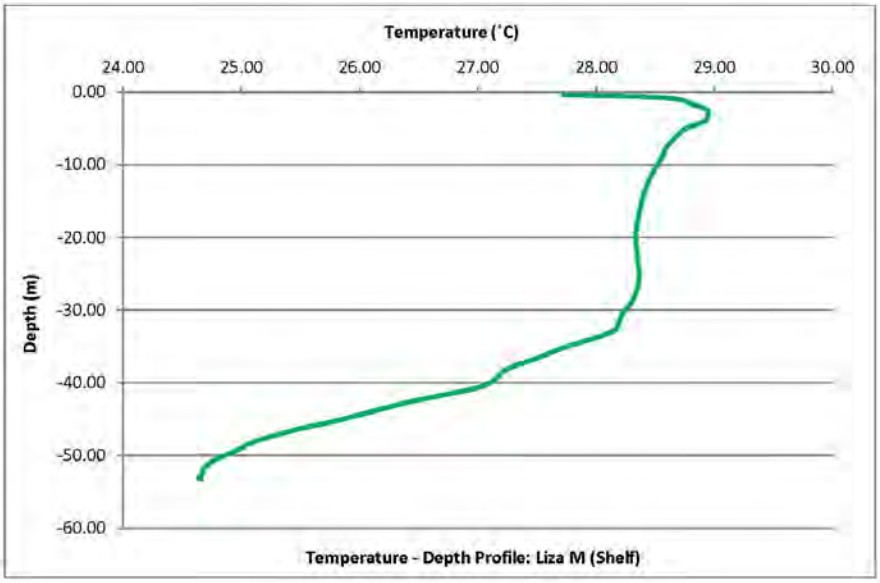
09/12

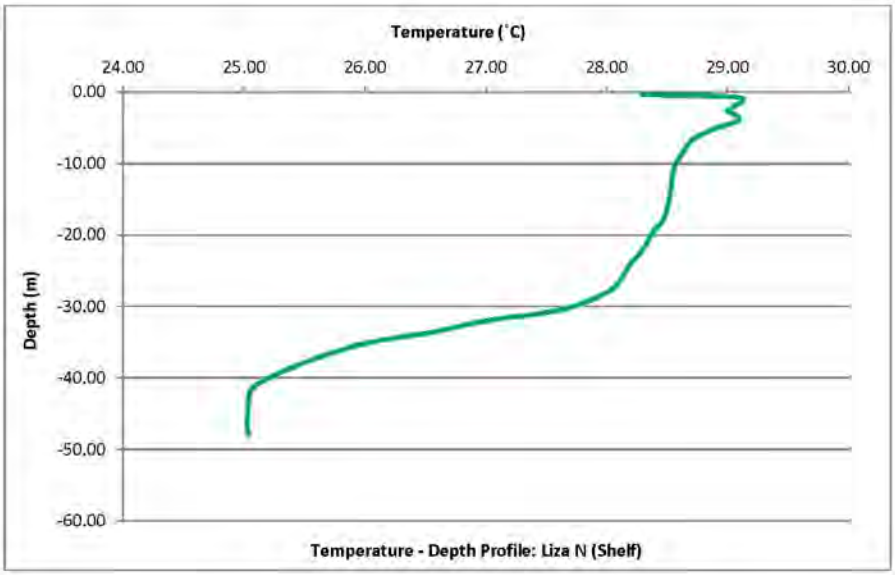
Appendix 6 - Insitu Profiles

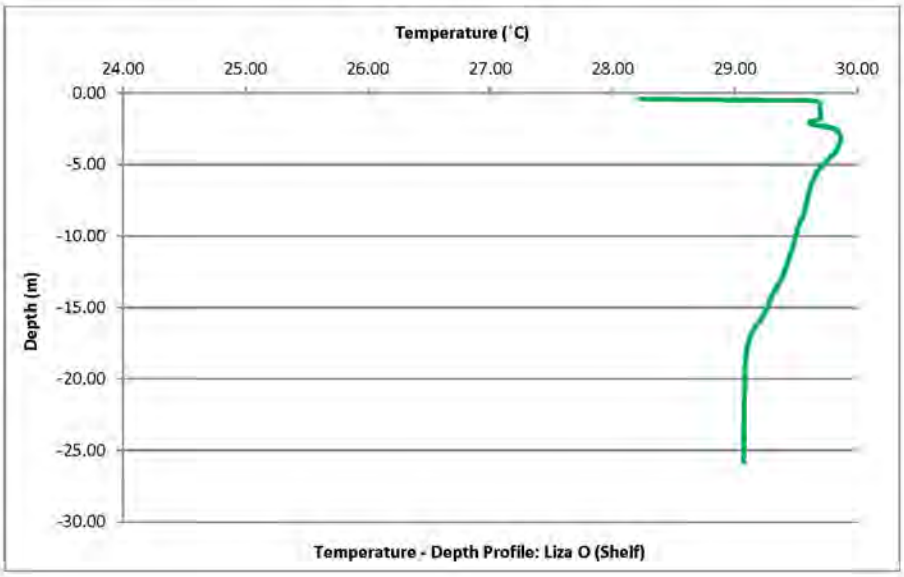
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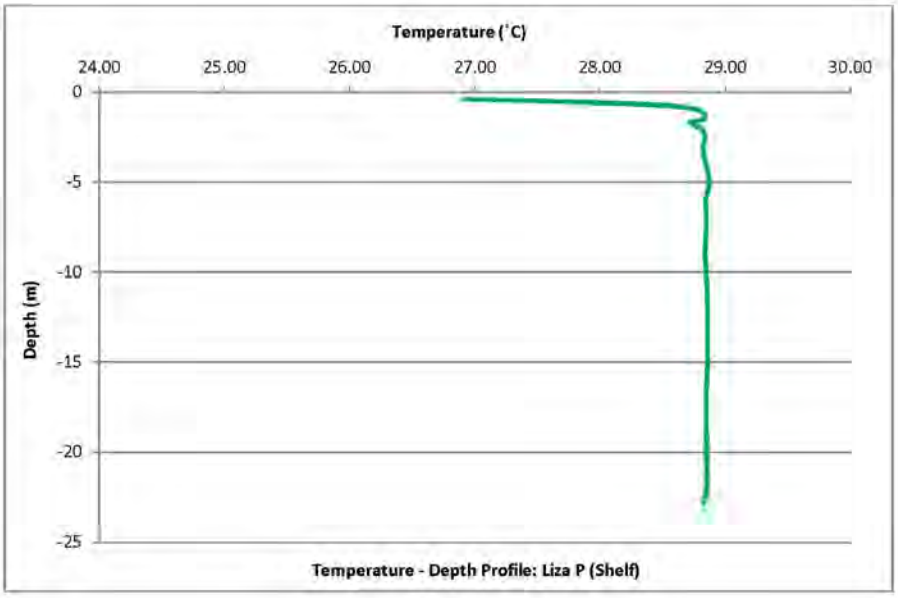
Temperature-Depth Profiles

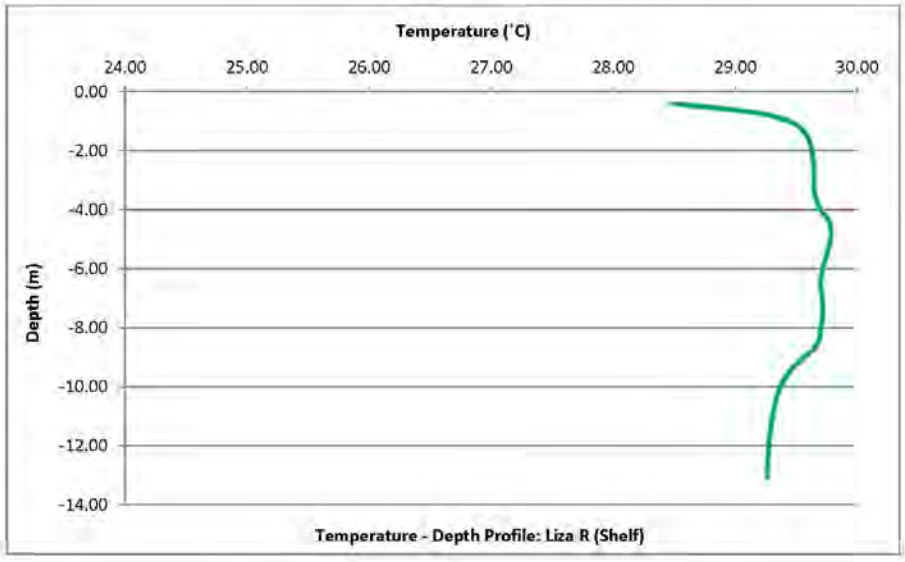


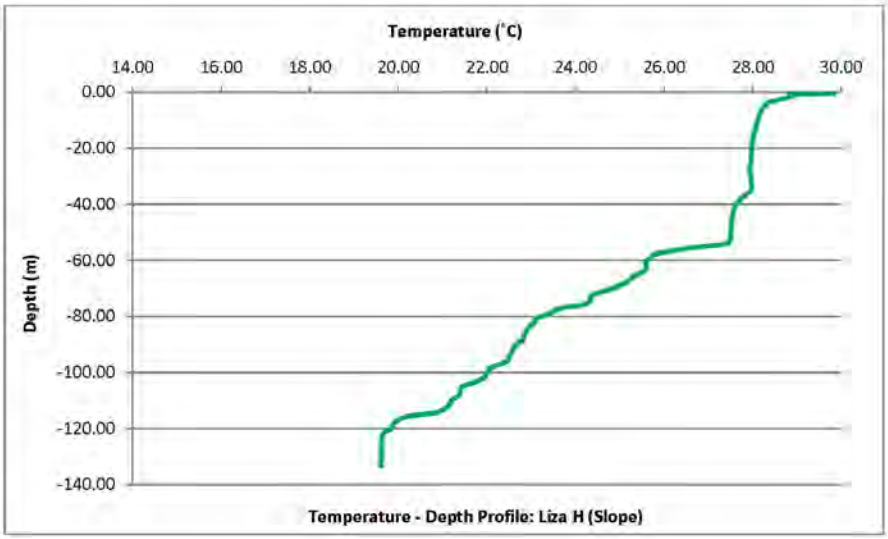


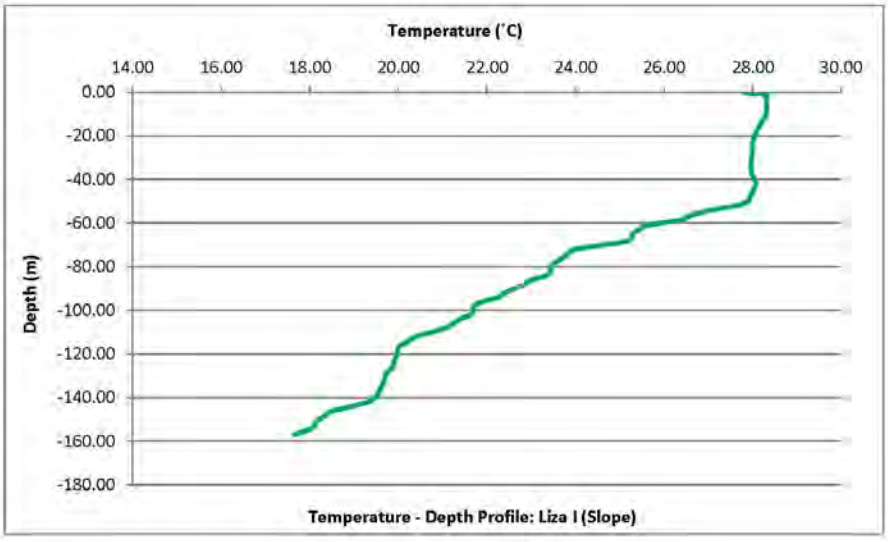

Temperature (˚C)
24.00
25.00
26.00
27.00
28.00
29.00
30.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
Depth (m)
Temperature - Depth Profile: Liza N (Shelf)

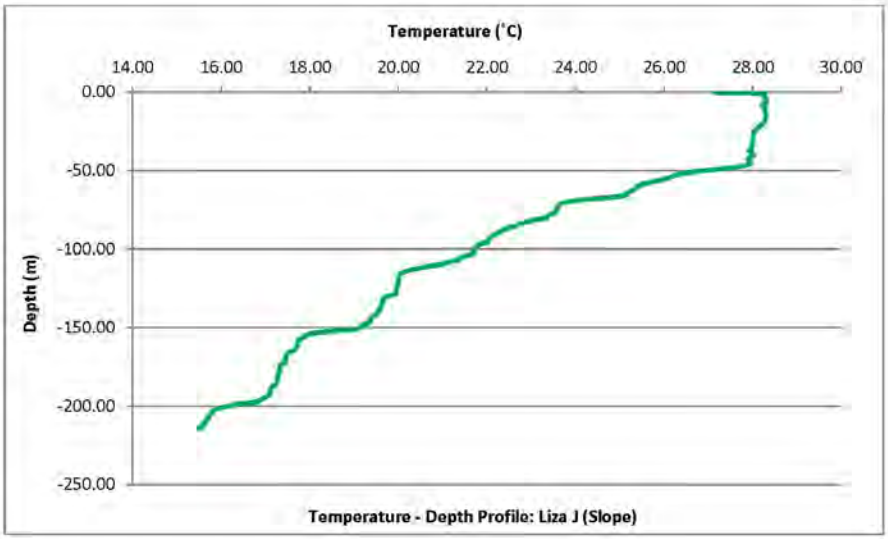

Temperature (˚C)
24.00
25.00
26.00
27.00
28.00
29.00
30.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
Depth (m)
Temperature - Depth Profile: Liza O (Shelf)

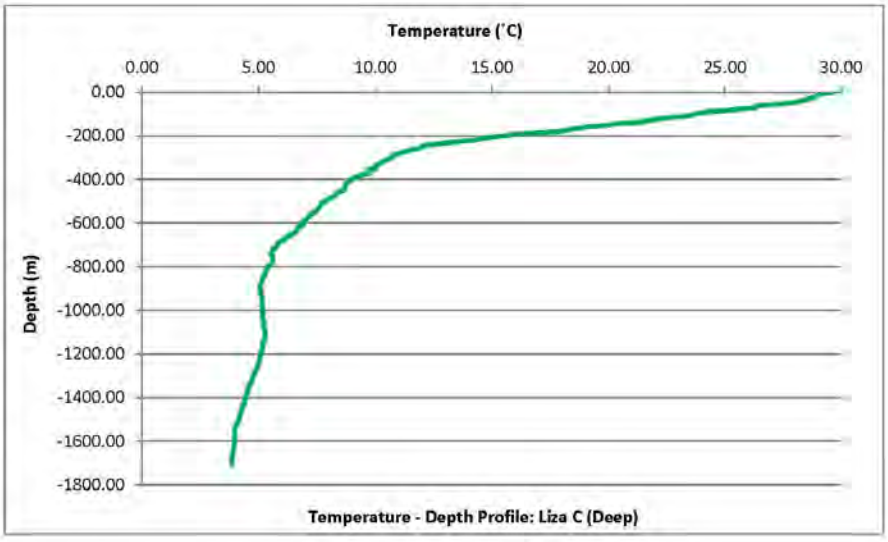

Temperature (°C)
24.00
25.00
26.00
27.00
28.00
29.00
30.00
0
-5
-10
-15
-20
-25
Depth (m)
Temperature - Depth Profile: Liza P (Shelf)

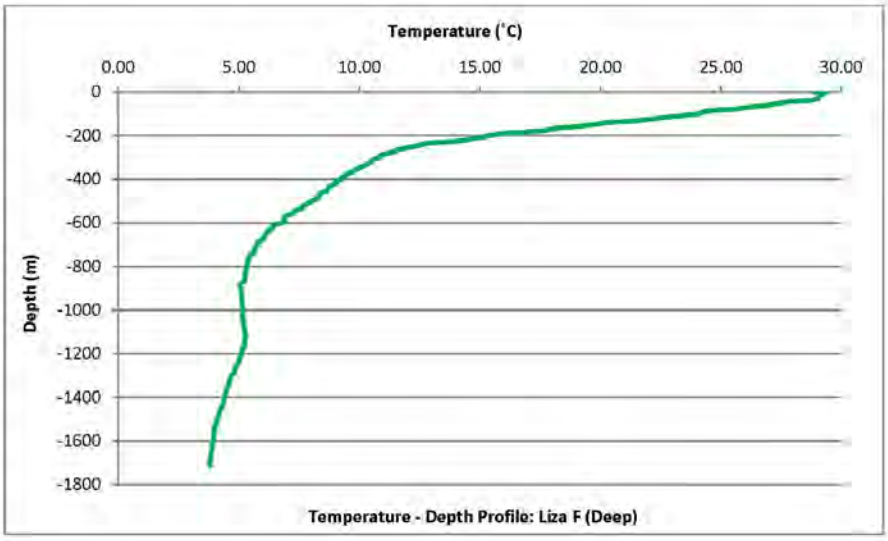

Temperature (°C)
24.00
25.00
26.00
27.00
28.00
29.00
30.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
Depth (m)
Temperature - Depth Profile: Liza R (Shelf)

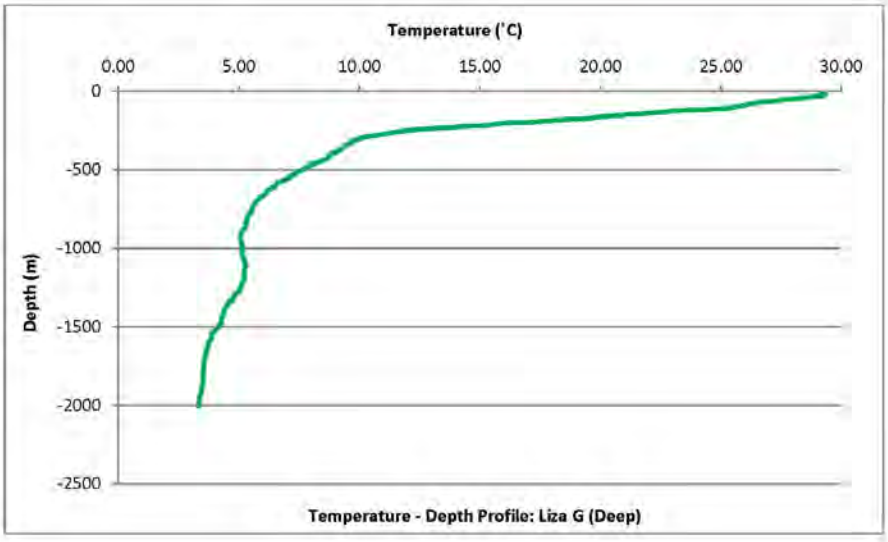

Temperature (˚C)
14.00
16.00
18.00
20.00
22.00
24.00
26.00
28.00
30.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
Depth (m)
Temperature - Depth Profile: Liza H (Slope)


Temperature (˚C)
14.00
16.00
18.00
20.00
22.00
24.00
26.00
28.00
30.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
Depth (m)
Temperature - Depth Profile: Liza I (Slope)

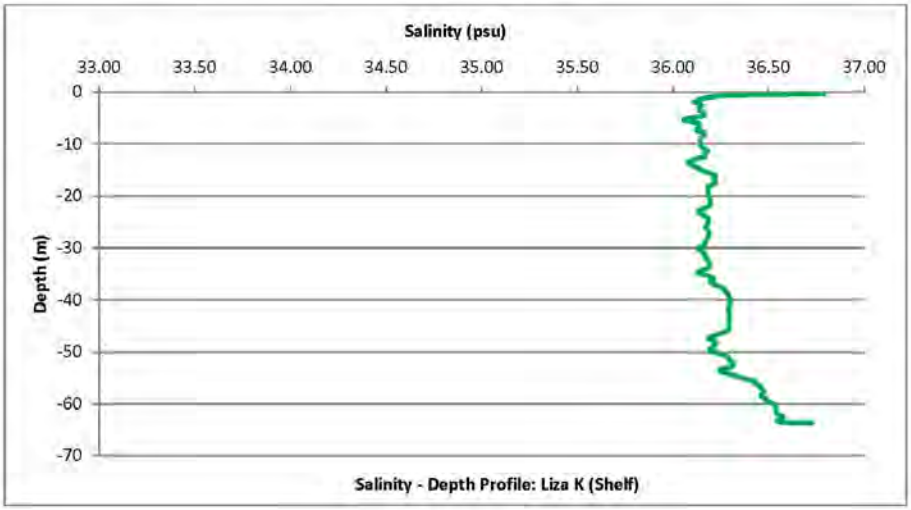

Temperature (˚C)
14.00
16.00
18.00
20.00
22.00
24.00
26.00
28.00
30.00
0.00
-50.00
-100.00
-150.00
-200.00
-250.00
Depth (m)
Temperature - Depth Profile: Liza J (Slope)

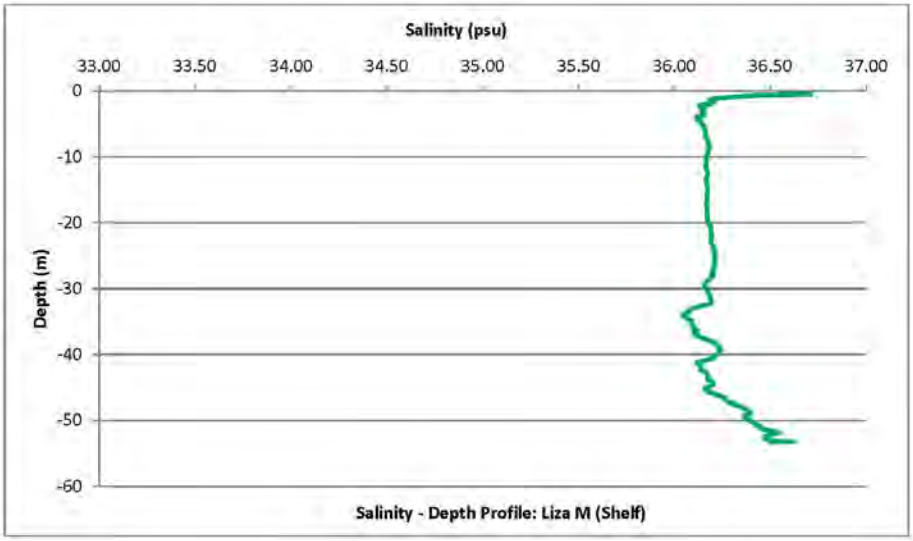

Temperature (˚C)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
0.00
-200.00
-400.00
-600.00
-800.00
-1000.00
-1200.00
-1400.00
-1600.00
-1800.00
Depth (m)
Temperature - Depth Profile: Liza C (Deep)

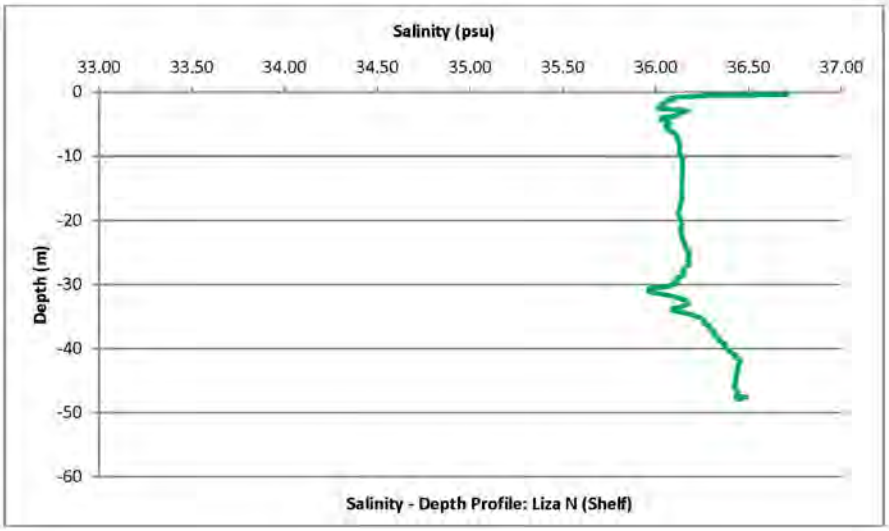

Temperature (˚C)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
Depth (m)
Temperature - Depth Profile: Liza F (Deep)

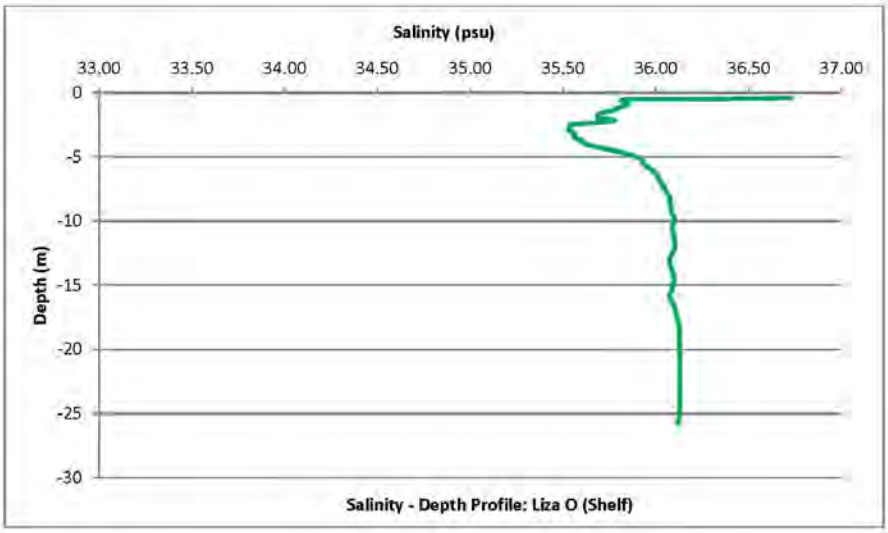

Temperature (˚C)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
0
-500
-1000
-1500
-2000
-2500
Depth (m)
Temperature - Depth Profile: Liza G (Deep)

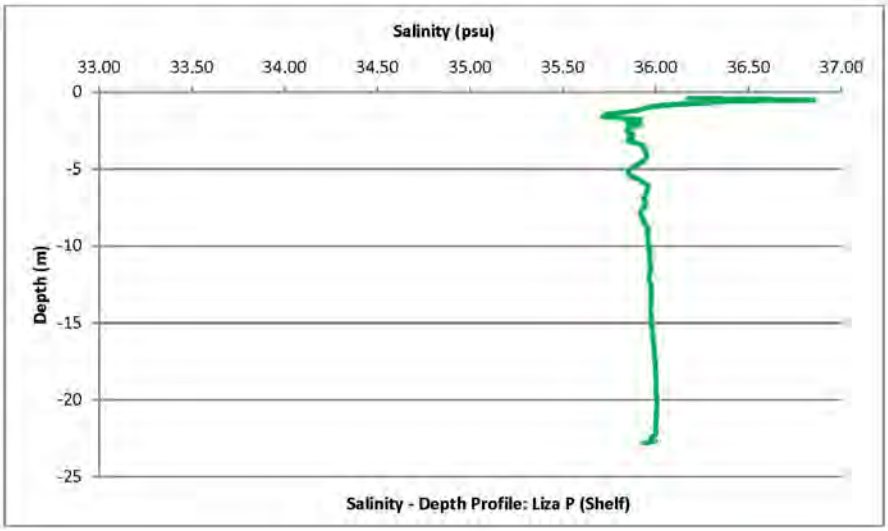
Salinity-Depth Profiles

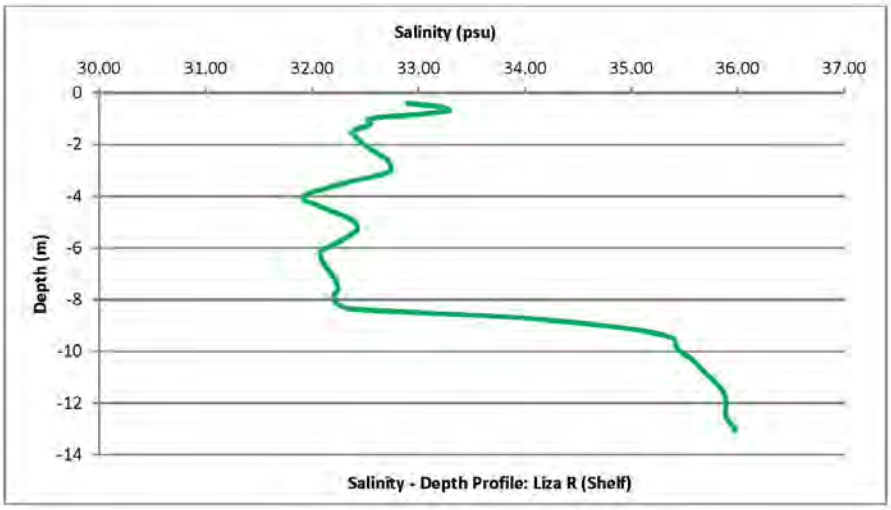




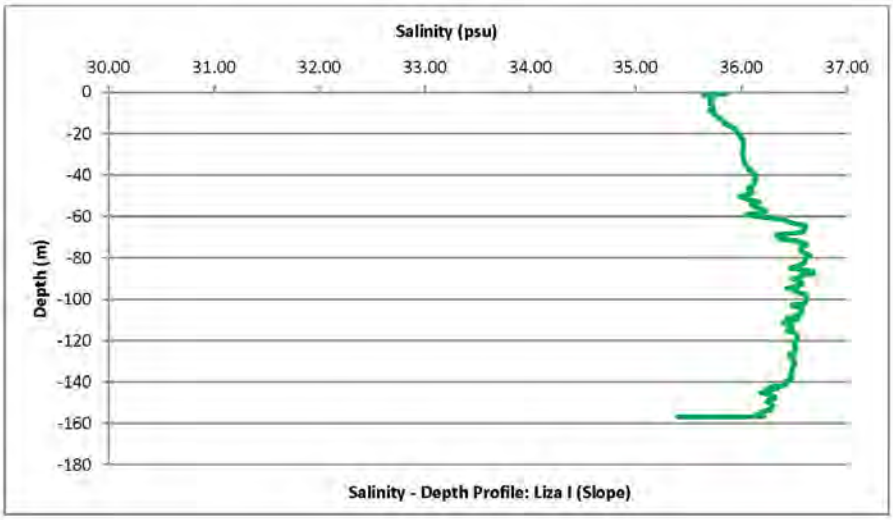

Salinity (psu)
33.00
33.50
34.00
34.50
35.00
35.50
36.00
36.50
37.00
0
-10
-20
-30
-40
-50
-60
Depth (m)
Salinity - Depth Profile: Liza N (Shelf)

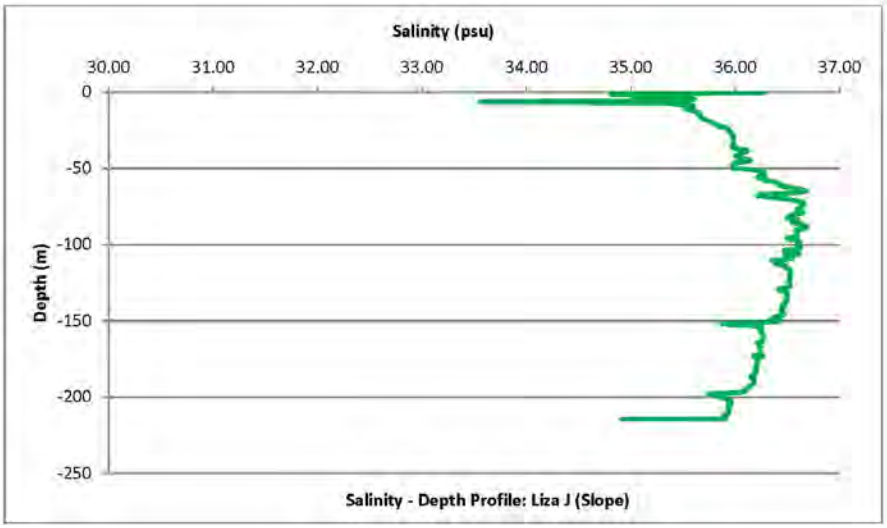

Salinity (psu)
33.00
33.50
34.00
34.50
35.00
35.50
36.00
36.50
37.00
0
-5
-10
-15
-20
-25
-30
Depth (m)
Salinity - Depth Profile: Liza O (Shelf)

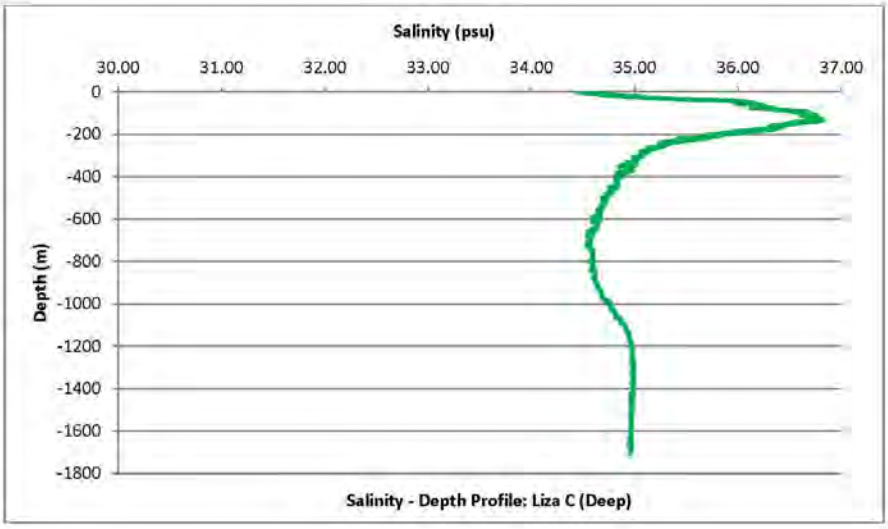

Salinity (psu)
33.00
33.50
34.00
34.50
35.00
35.50
36.00
36.50
37.00
0
-5
-10
-15
-20
-25
Depth (m)
Salinity - Depth Profile: Liza P (Shelf)

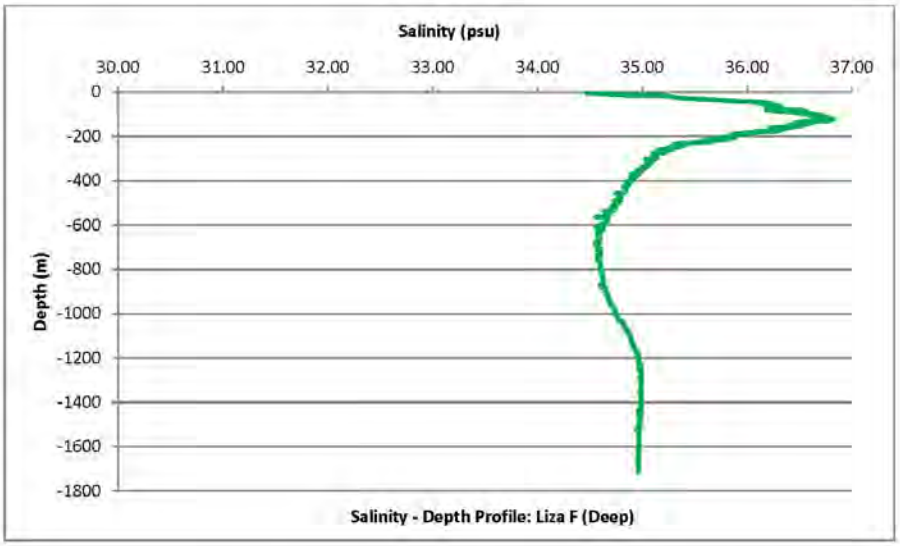

Salinity (psu)
30.00
31.00
32.00
33.00
34.00
35.00
36.00
37.00
0
-2
-4
-6
-8
-10
-12
-14
Depth (m)
Salinity - Depth Profile: Liza R (Shelf)

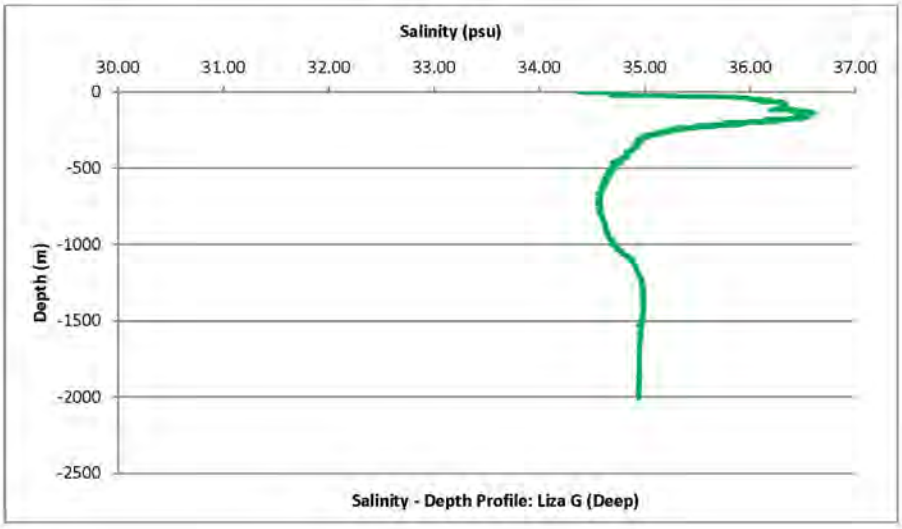

Salinity (psu)
30.00
31.00
32.00
33.00
34.00
35.00
36.00
37.00
0
-20
-40
-60
-80
-100
-120
-140
Depth (m)
Salinity - Depth Profile: Liza H (Slope)


Salinity (psu)
30.00
31.00
32.00
33.00
34.00
35.00
36.00
37.00
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
Depth (m)
Salinity - Depth Profile: Liza I (Slope)

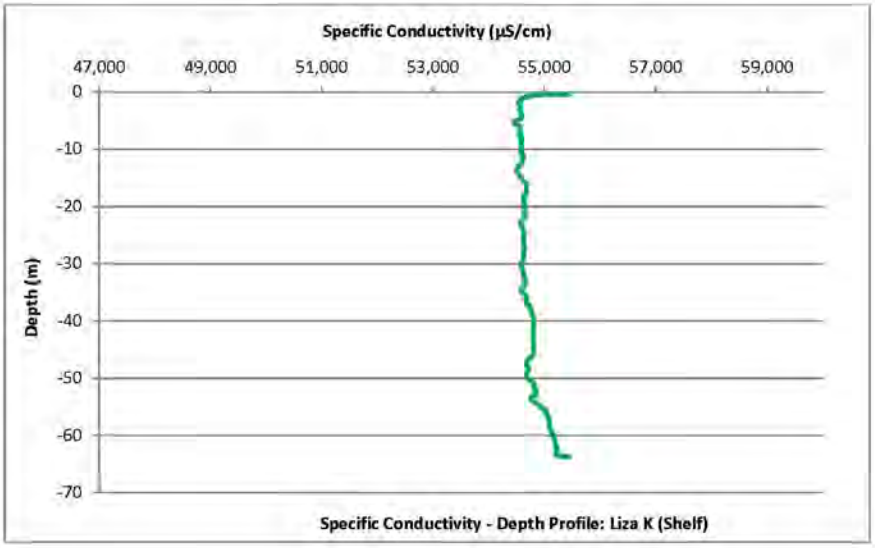

Salinity (psu)
30.00
31.00
32.00
33.00
34.00
35.00
36.00
37.00
0
-50
-100
-150
-200
-250
Depth (m)
Salinity - Depth Profile: Liza J (Slope)

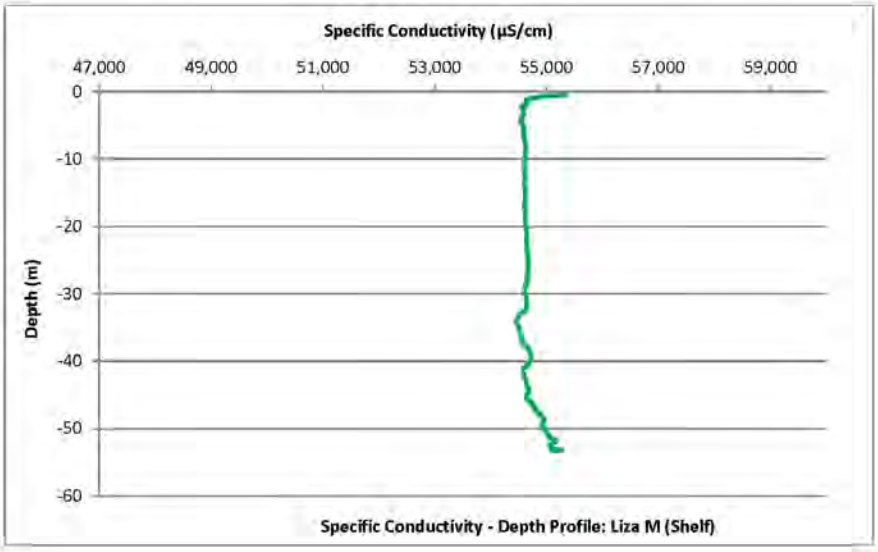

Salinity (psu)
30.00
31.00
32.00
33.00
34.00
35.00
36.00
37.00
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
Depth (m)
Salinity - Depth Profile: Liza C (Deep)

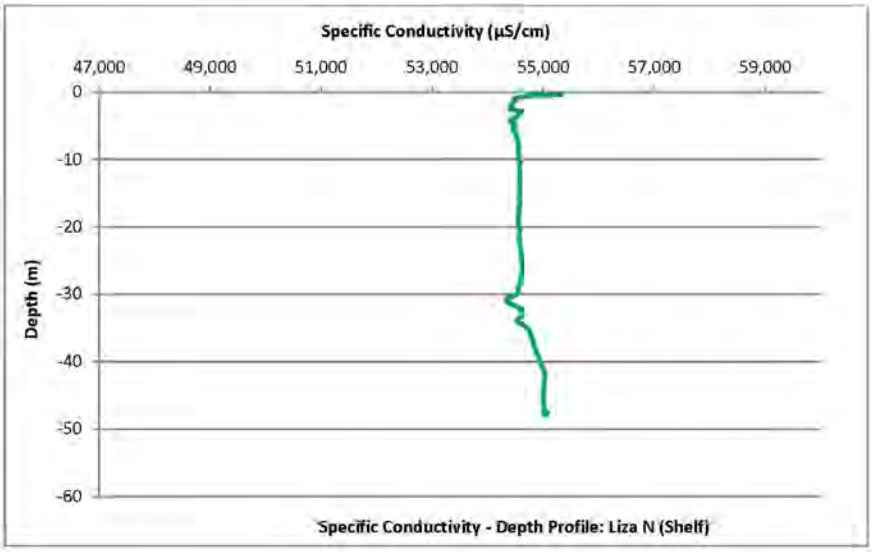

Salinity (psu)
30.00
31.00
32.00
33.00
34.00
35.00
36.00
37.00
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
Depth (m)
Salinity - Depth Profile: Liza F (Deep)

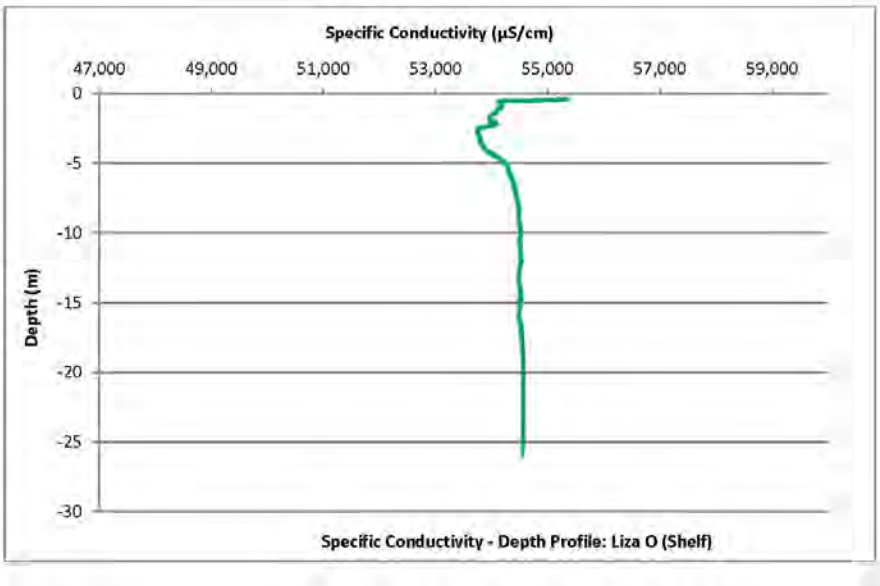

Salinity (psu)
30.00
31.00
32.00
33.00
34.00
35.00
36.00
37.00
0
-500
-1000
-1500
-2000
-2500
Depth (m)
Salinity - Depth Profile: Liza G (Deep)

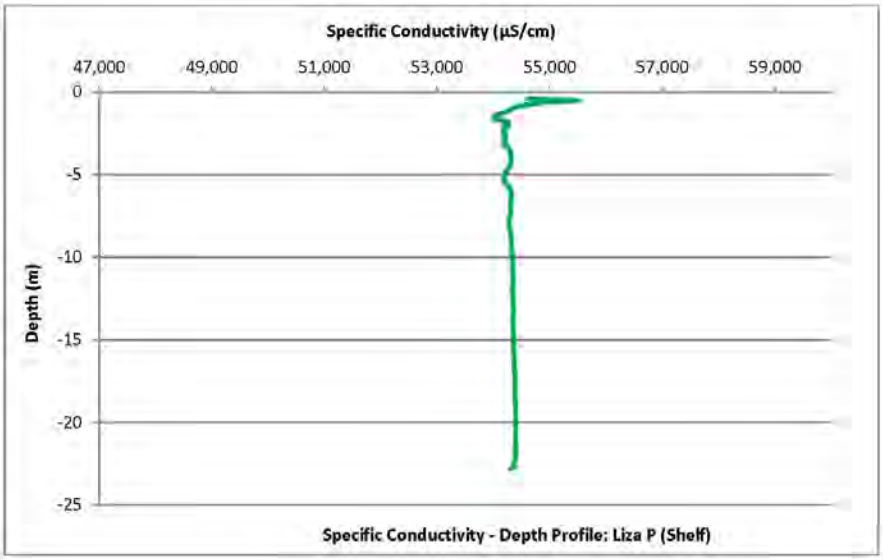
Specific Conductivity-Depth Profiles

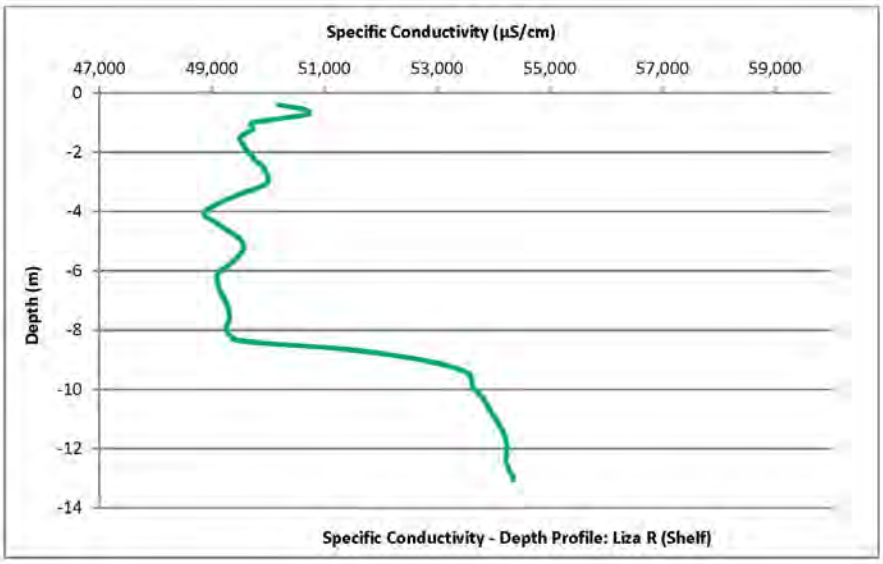


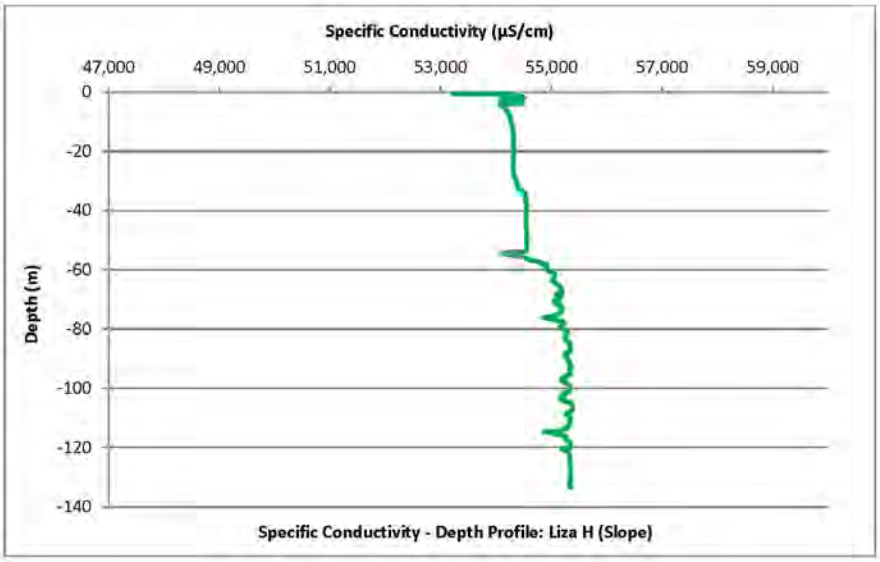


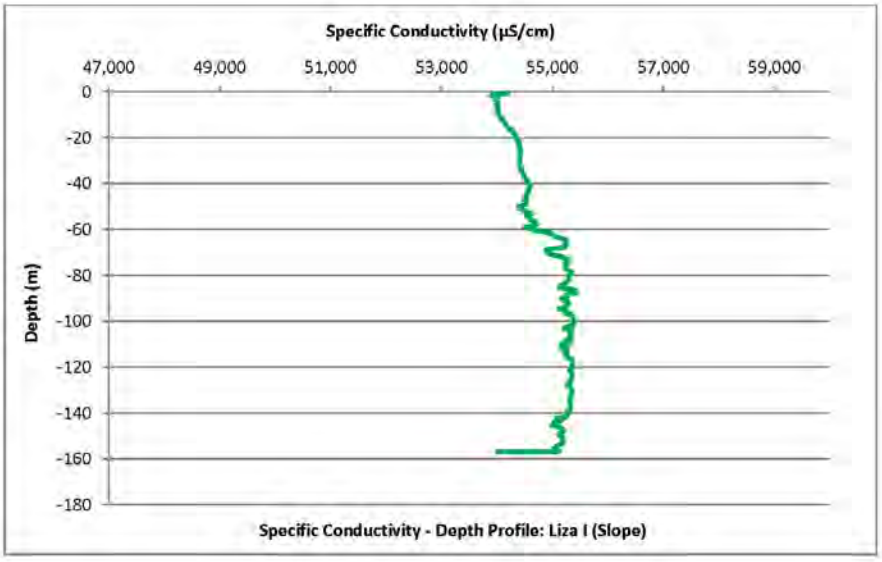

Specific Conductivity (µS/cm)
47,000
49,000
51,000
53,000
55,000
57,000
59,000
0
-10
-20
-30
-40
-50
-60
Depth (m)
Specific Conductivity - Depth Profile: Liza N (Shelf)

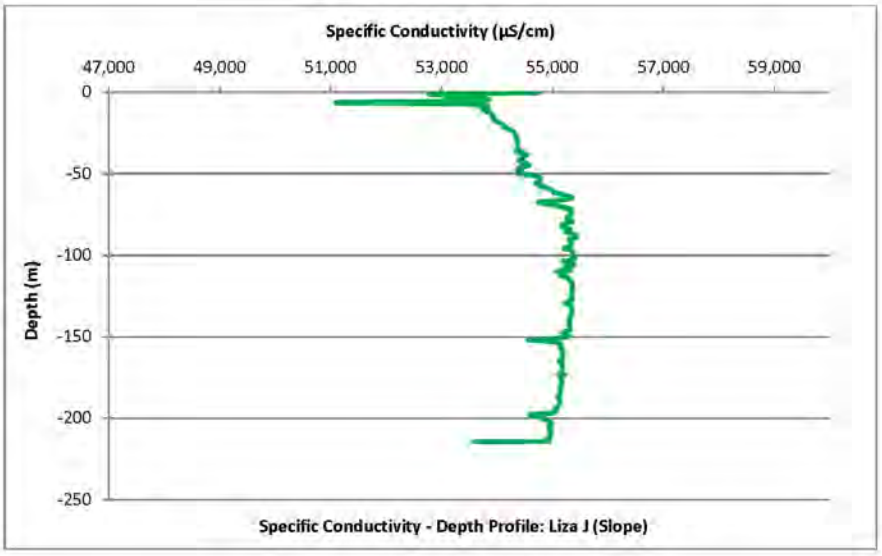

Specific Conductivity (µS/cm)
47,000
49,000
51,000
53,000
55,000
57,000
59,000
0
-5
-10
-15
-20
-25
-30
Depth (m)
Specific Conductivity - Depth Profile: Liza O (Shelf)

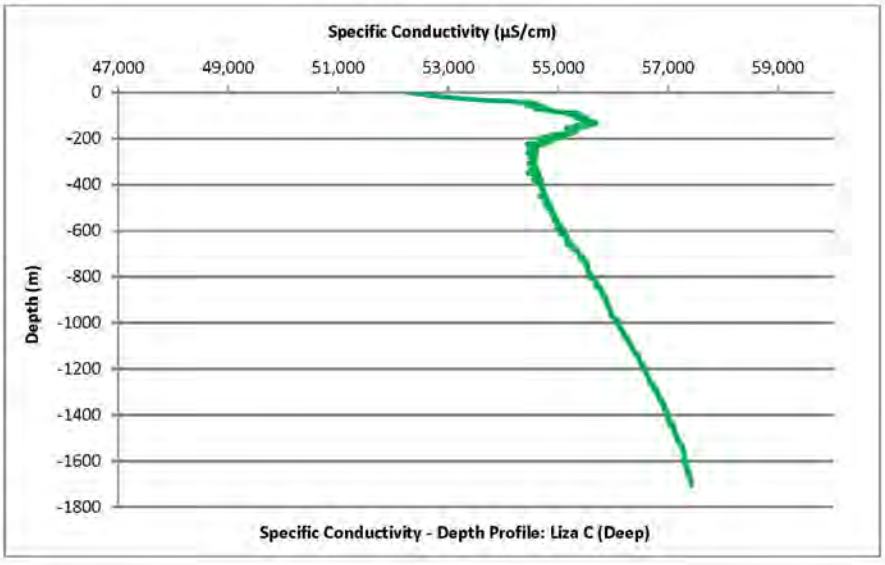

Specific Conductivity (µS/cm)
47,000
49,000
51,000
53,000
55,000
57,000
59,000
0
-5
-10
-15
-20
-25
Depth (m)
Specific Conductivity - Depth Profile: Liza P (Shelf)

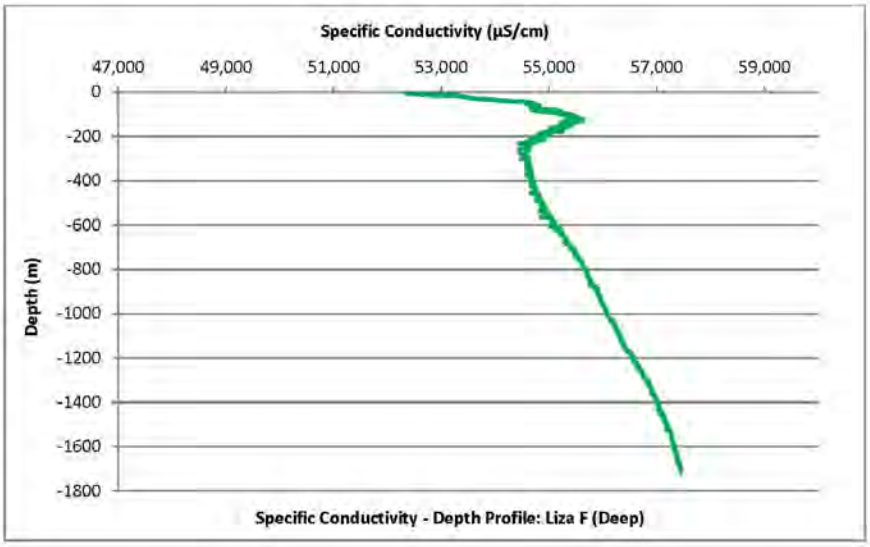

Specific Conductivity (µS/cm)
47,000
49,000
51,000
53,000
55,000
57,000
59,000
0
-2
-4
-6
-8
-10
-12
-14
Depth (m)
Specific Conductivity - Depth Profile: Liza R (Shelf)

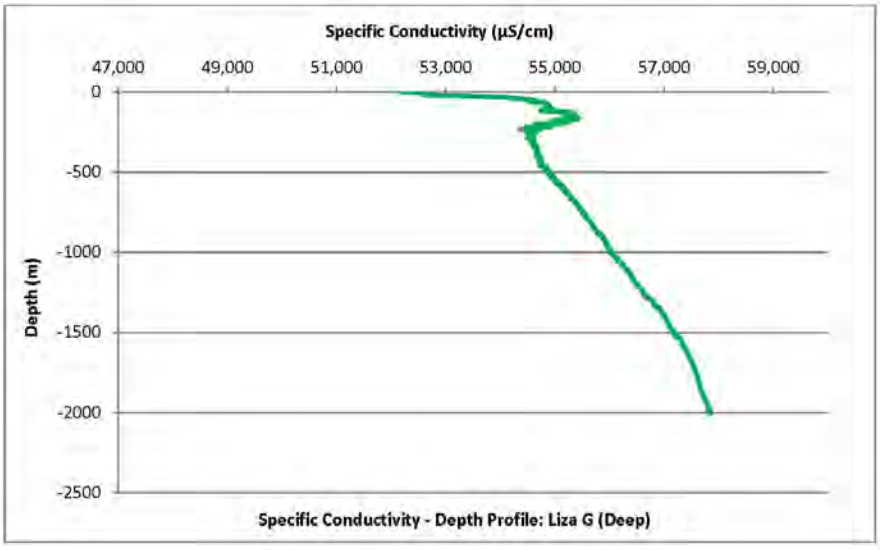

Specific Conductivity (µS/cm)
47,000
49,000
51,000
53,000
55,000
57,000
59,000
0
-20
-40
-60
-80
-100
-120
-140
Depth (m)
Specific Conductivity - Depth Profile: Liza H (Slope)


Specific Conductivity (µS/cm)
47,000
49,000
51,000
53,000
55,000
57,000
59,000
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
Depth (m)
Specific Conductivity - Depth Profile: Liza I (Slope)

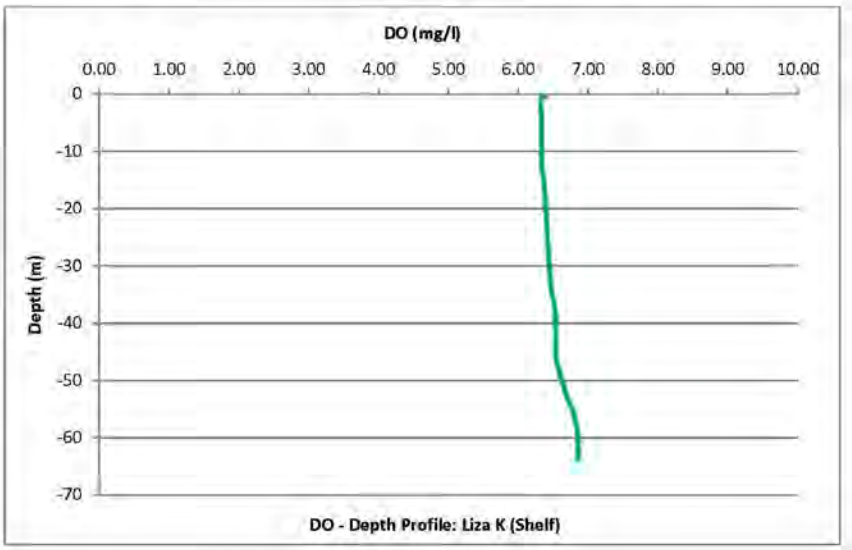

Specific Conductivity (µS/cm)
47,000
49,000
51,000
53,000
55,000
57,000
59,000
0
-50
-100
-150
-200
-250
Depth (m)
Specific Conductivity - Depth Profile: Liza J (Slope)

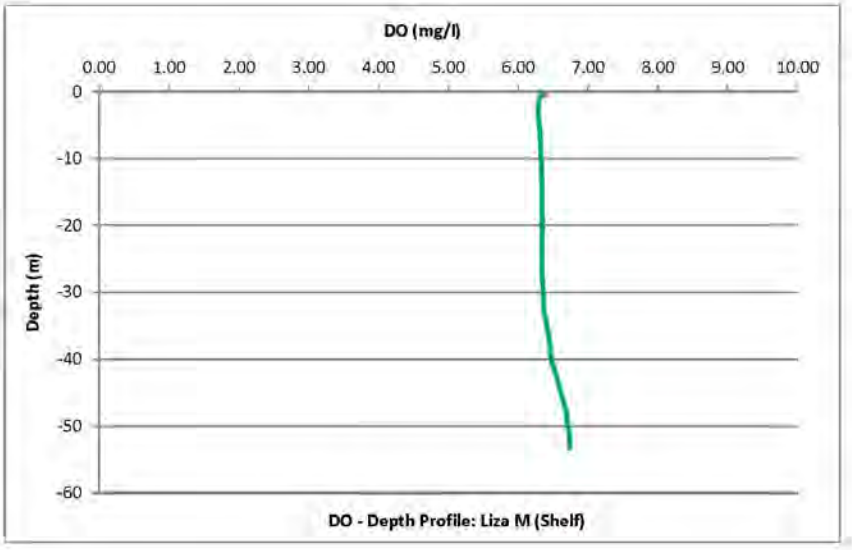

Specific Conductivity (µS/cm)
47,000
49,000
51,000
53,000
55,000
57,000
59,000
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
Depth (m)
Specific Conductivity - Depth Profile: Liza C (Deep)

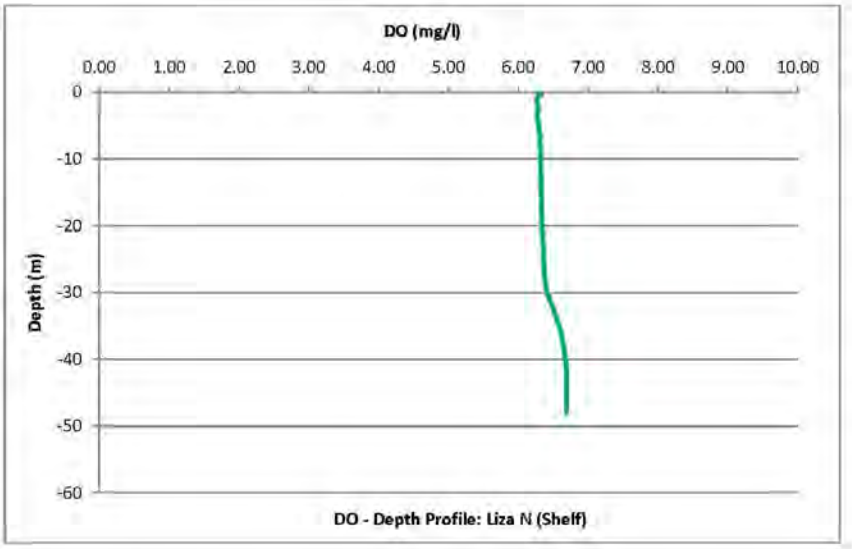

Specific Conductivity (µS/cm)
47,000
49,000
51,000
53,000
55,000
57,000
59,000
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
Depth (m)
Specific Conductivity - Depth Profile: Liza F (Deep)

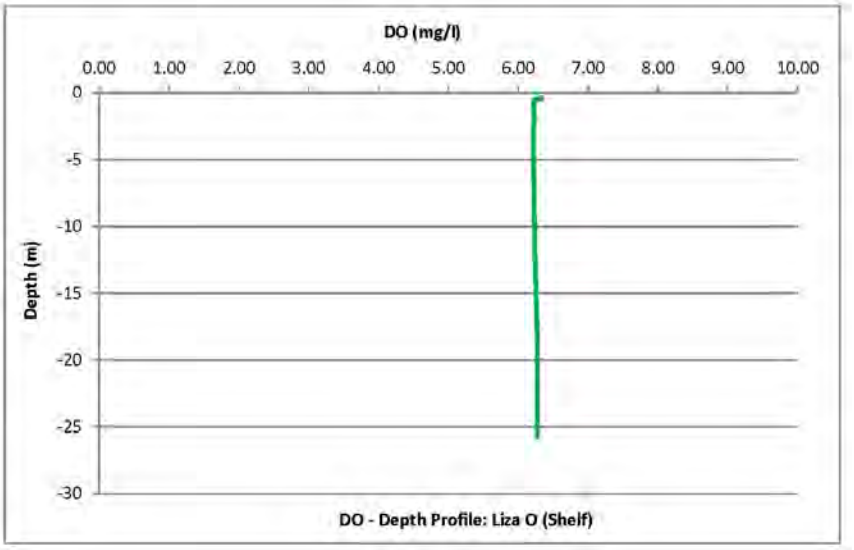

Specific Conductivity (µS/cm)
47,000
49,000
51,000
53,000
55,000
57,000
59,000
0
-500
-1000
-1500
-2000
-2500
Depth (m)
Specific Conductivity - Depth Profile: Liza G (Deep)

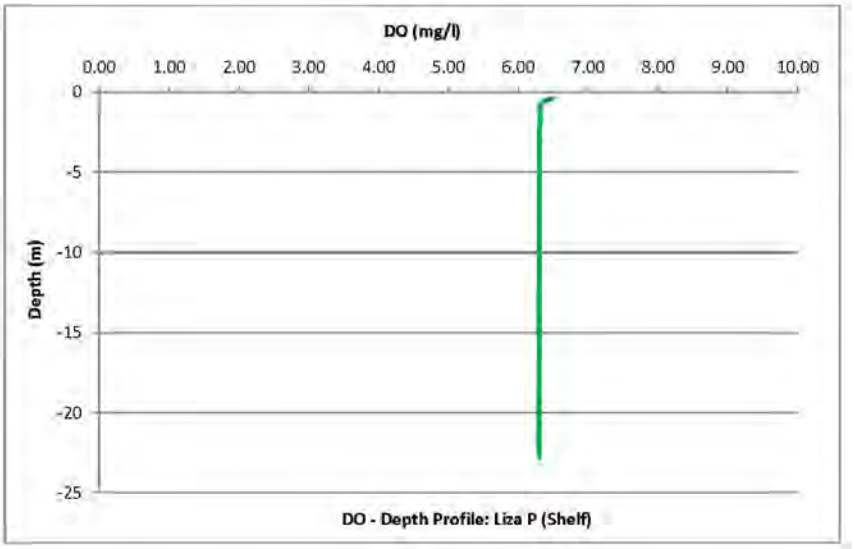
DO-Depth Profiles

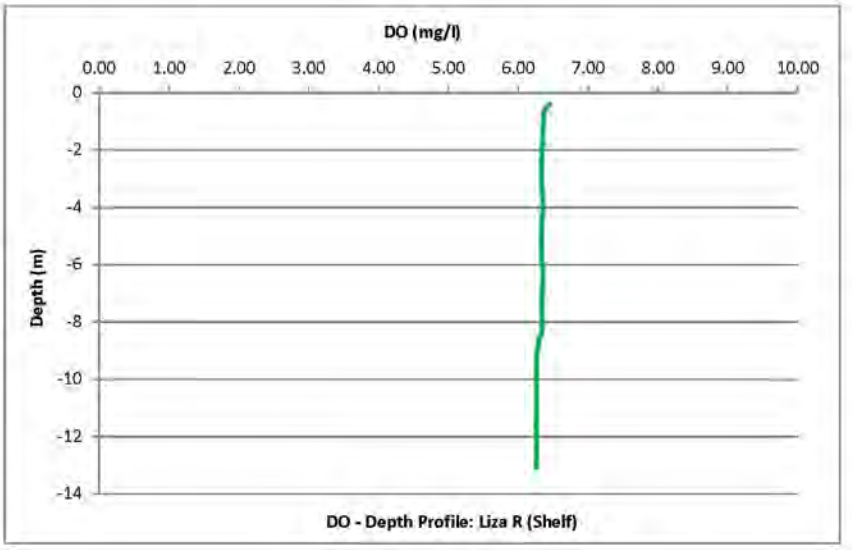


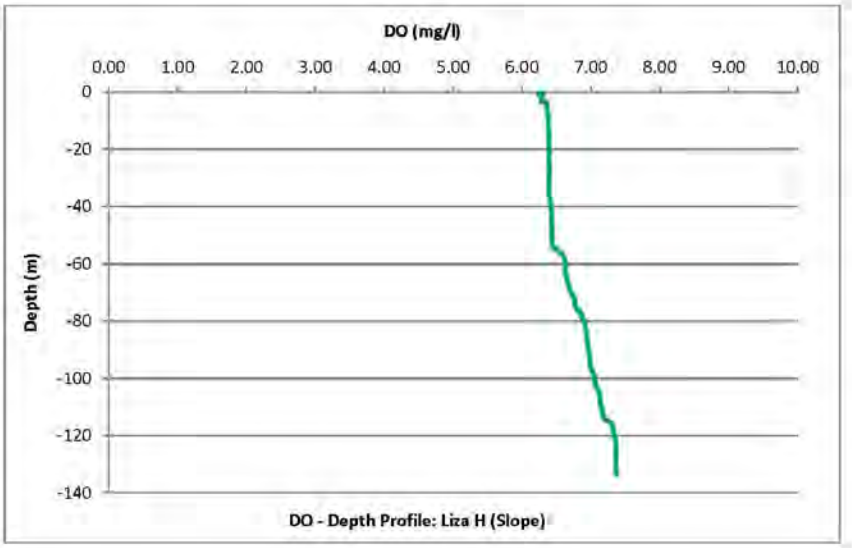


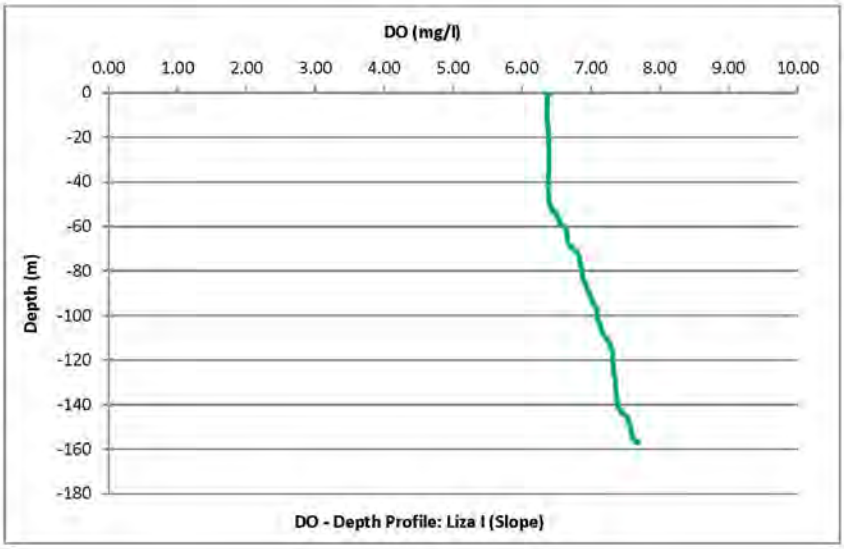

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3.00
4.00
5.00
6.00
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0
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Depth (m)
DO - Depth Profile: Liza N (Shelf)

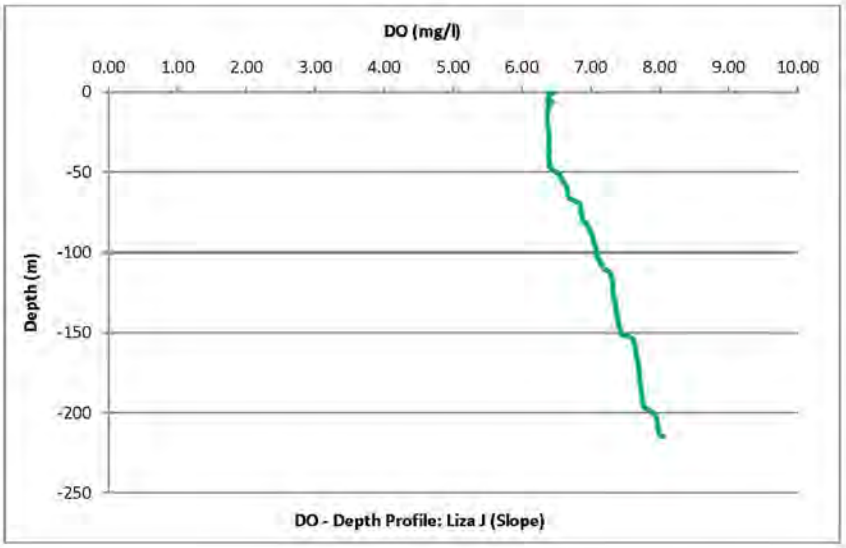

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Depth (m)
DO - Depth Profile: Liza O (Shelf)

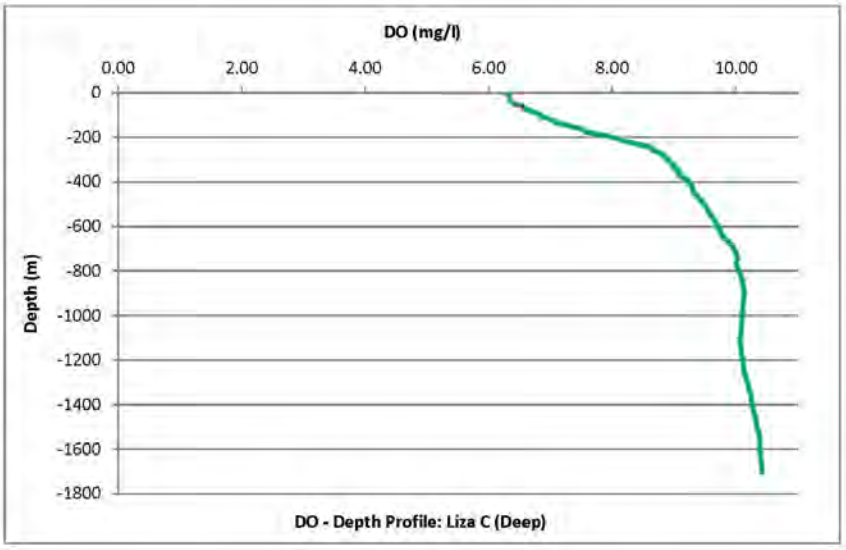

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Depth (m)
DO - Depth Profile: Liza P (Shelf)

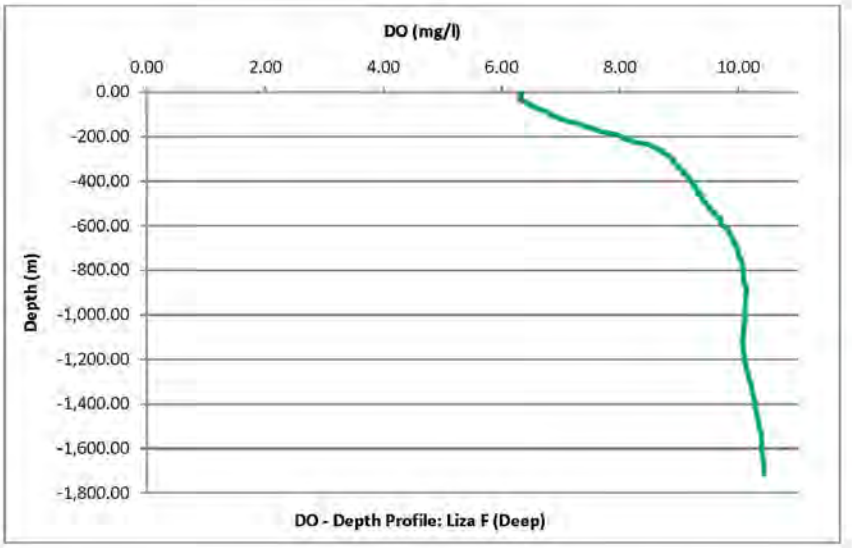

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Depth (m)
DO - Depth Profile: Liza R (Shelf)

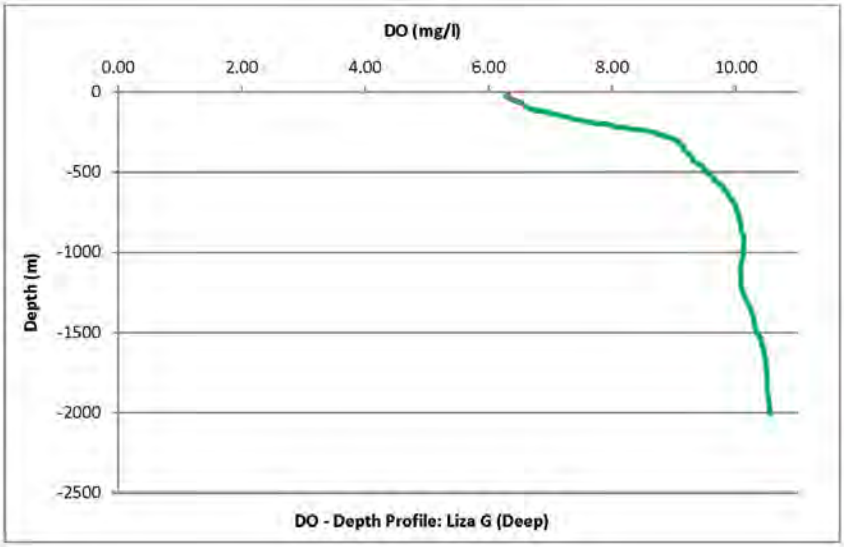

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8.00
9.00
10.00
0
-20
-40
-60
-80
-100
-120
-140
Depth (m)
DO - Depth Profile: Liza H (Slope)


DO (mg/l)
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1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
0
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-180
Depth (m)
DO - Depth Profile: Liza I (Slope)

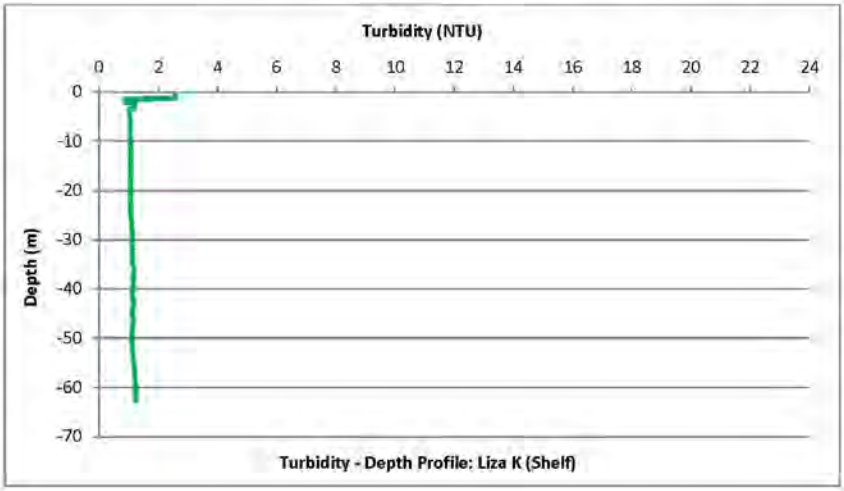

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3.00
4.00
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6.00
7.00
8.00
9.00
10.00
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-200
-250
Depth (m)
DO - Depth Profile: Liza J (Slope)

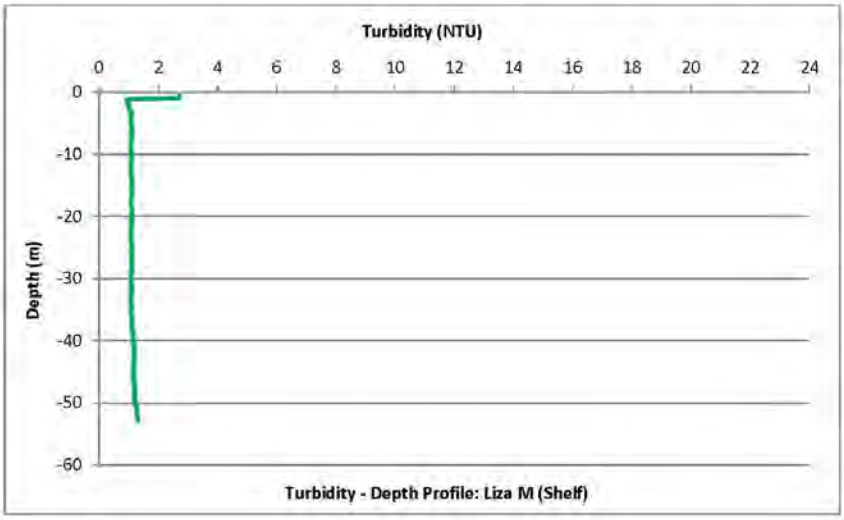

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-1400
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-1800
Depth (m)
DO - Depth Profile: Liza C (Deep)

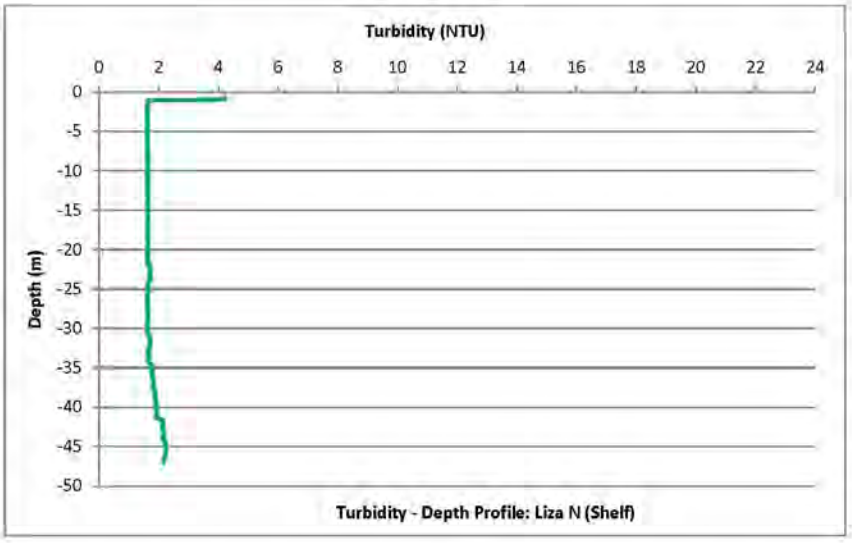

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-1,400.00
-1,600.00
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Depth (m)
DO - Depth Profile: Liza F (Deep)

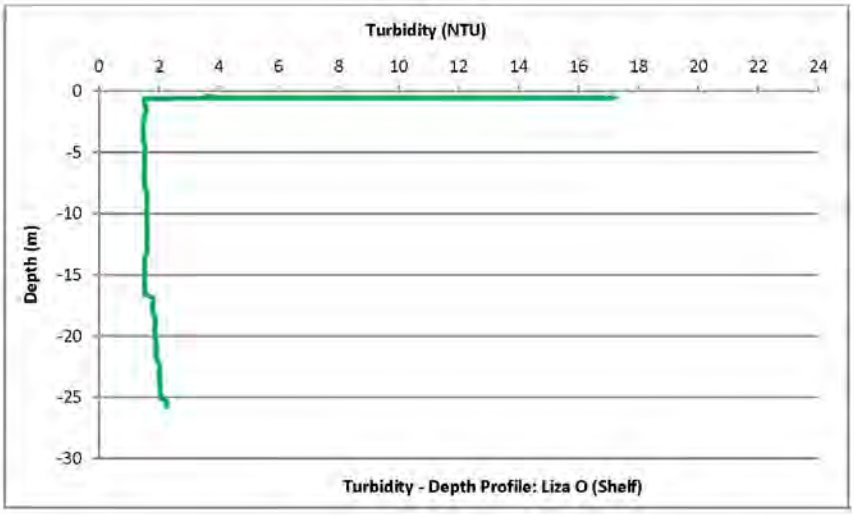

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10.00
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-1000
-1500
-2000
-2500
Depth (m)
DO - Depth Profile: Liza G (Deep)

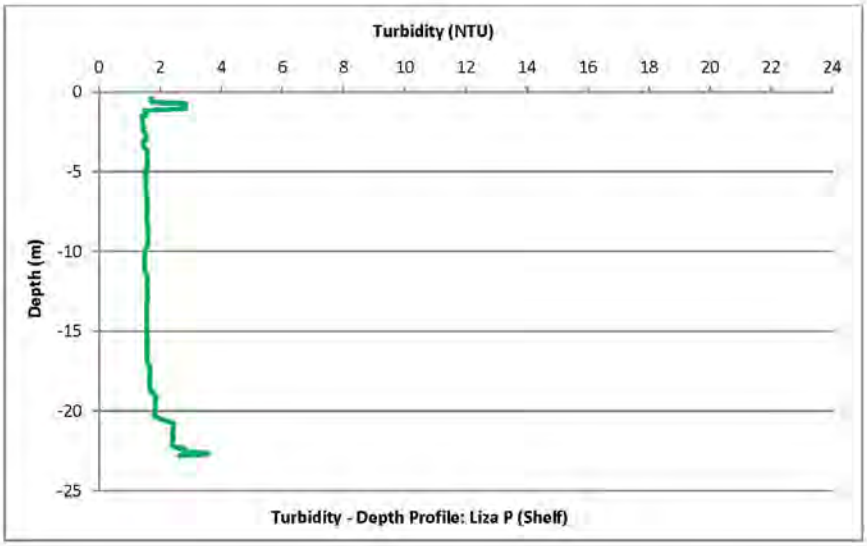
Turbidity-Depth Profiles

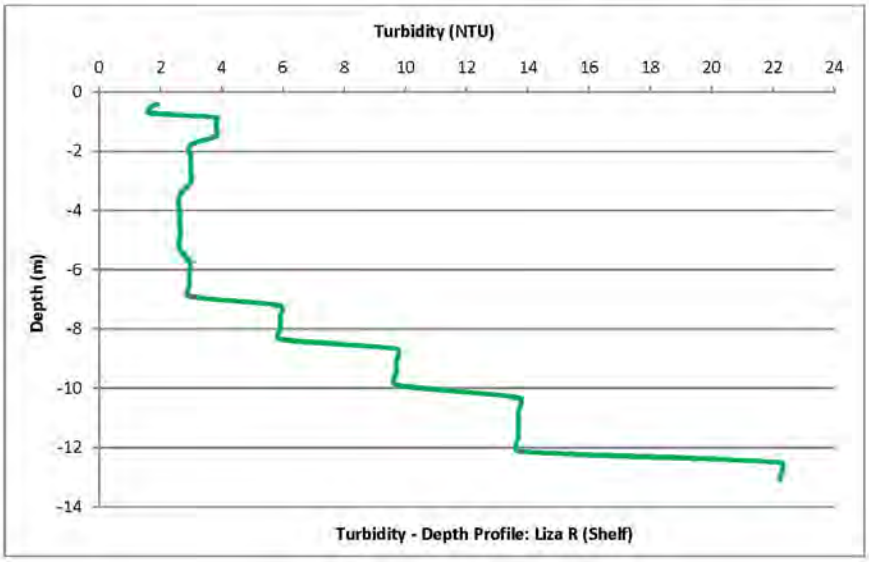


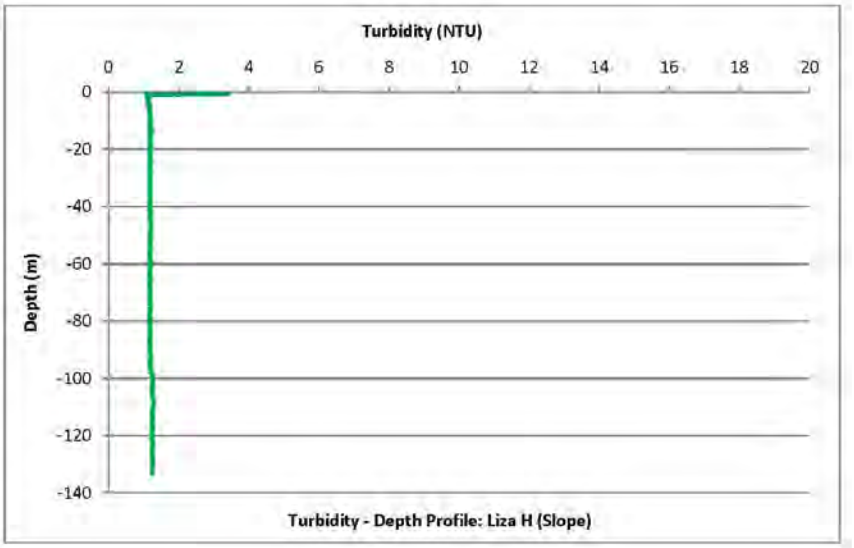


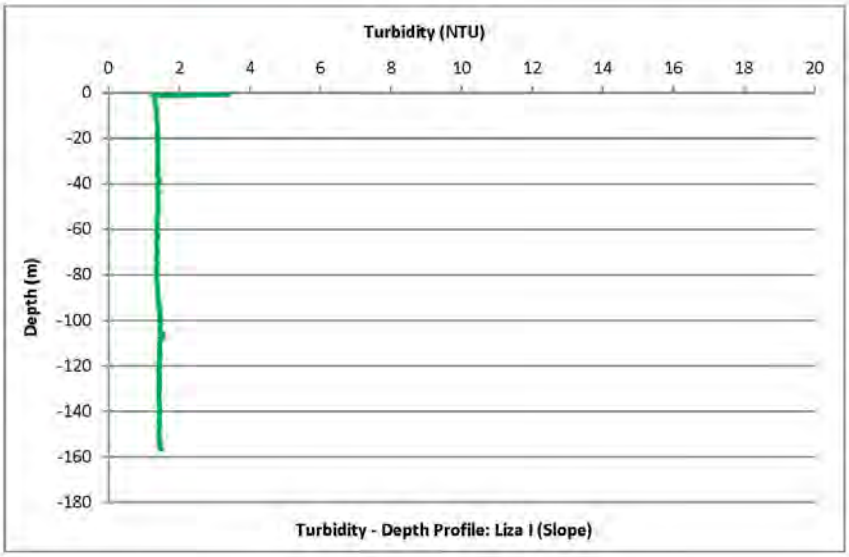

Turbidity (NTU)
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0 -5 -10 -15 -20 -25 -30 -35 -40 -45 -50
Depth (m)
Turbidity - Depth Profile: Liza N (Shelf)

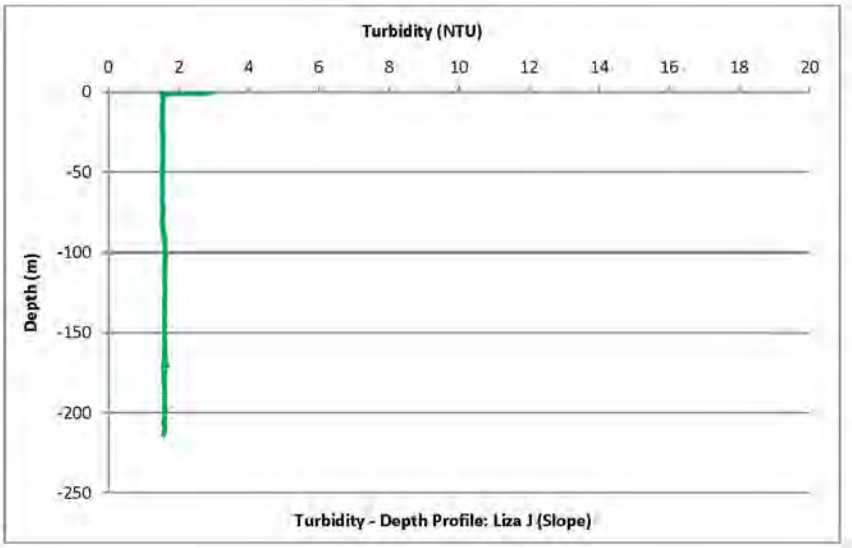

Turbidity (NTU)
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0 -5 -10 -15 -20 -25 -30
Depth (m)
Turbidity - Depth Profile: Liza O (Shelf)

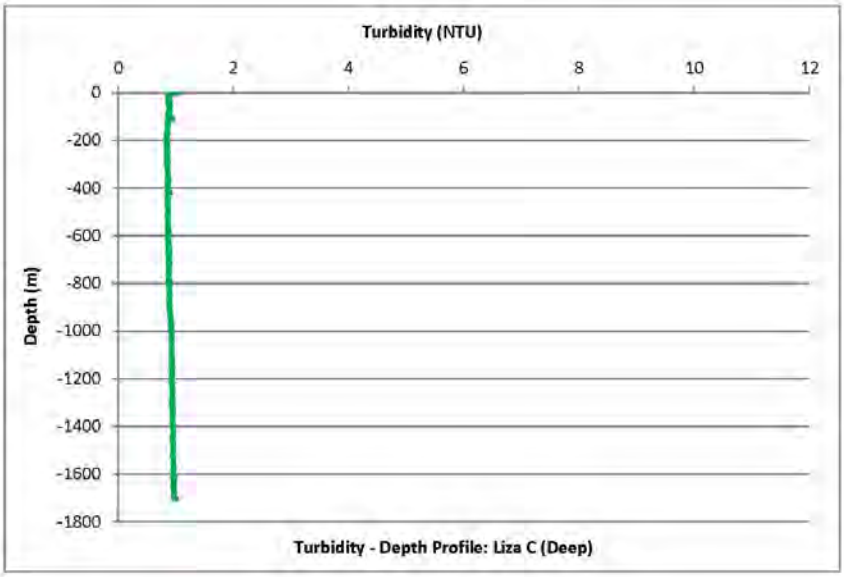

Turbidity (NTU)
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0
-5
-10
-15
-20
-25
Depth (m)
Turbidity - Depth Profile: Liza P (Shelf)

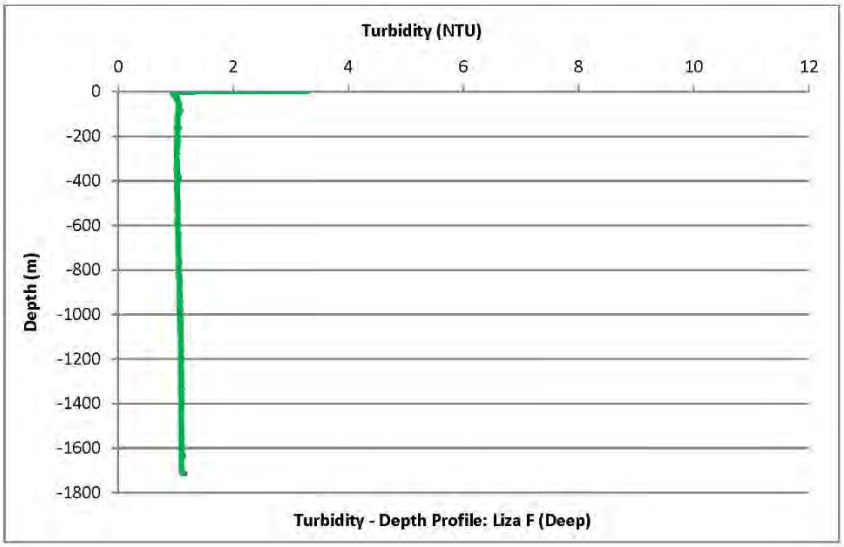

Turbidity (NTU)
0 2 4 6 8 10 12 14 16 18 20 22 24
0
-2
-4
-6
-8
-10
-12
-14
Depth (m)
Turbidity - Depth Profile: Liza R (Shelf)

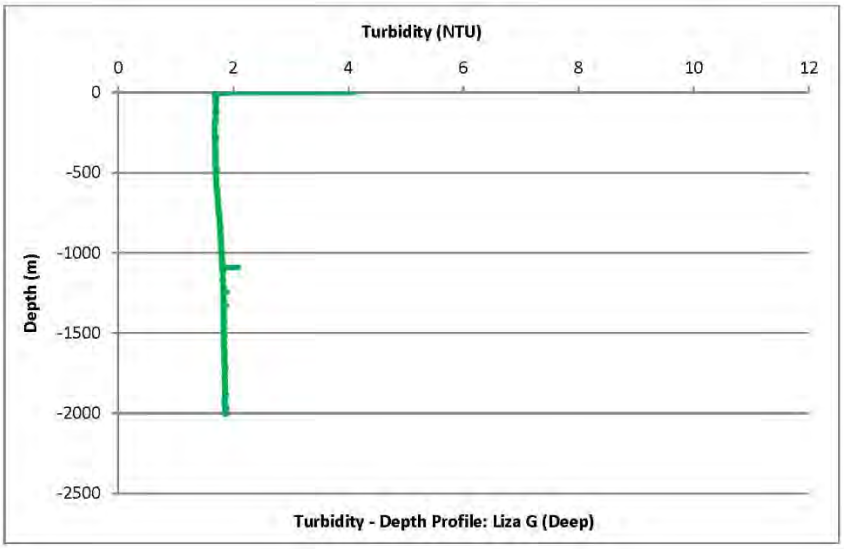

Turbidity (NTU)
0
2
4
6
8
10
12
14
16
18
20
0
-20
-40
-60
-80
-100
-120
-140
Depth (m)
Turbidity - Depth Profile: Liza H (Slope)


Turbidity (NTU)
0
2
4
6
8
10
12
14
16
18
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
Depth (m)
Turbidity - Depth Profile: Liza I (Slope)


Turbidity (NTU)
0
2
4
6
8
10
12
14
16
18
20
0
-50
-100
-150
-200
-250
Depth (m)
Turbidity - Depth Profile: Liza J (Slope)


Turbidity (NTU)
0
2
4
6
8
10
12
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
Depth (m)
Turbidity - Depth Profile: Liza C (Deep)


Turbidity (NTU)
0
2
4
6
8
10
12
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
Depth (m)
Turbidity - Depth Profile: Liza F (Deep)


Turbidity (NTU)
0
2
4
6
8
10
12
0
-500
-1000
-1500
-2000
-2500
Depth (m)
Turbidity - Depth Profile: Liza G (Deep)

Appendix 7 – Raw CTD Data

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Appendix 8 – Analytical Laboratory Report-Water Quality

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ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive, San Fernando, Trinidad, West Indies.
Tel.: (868) 657-9024, (868) 657-1560 Fax: (868) 653-2571 Email: jerome.als@envirosciences.net

Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

ANALYSIS REPORT

Client:	Exxon
Project No:	23/17
Report No:	1
Sample Received:	October 7th, 2017
Dates of Analysis:	October 9th, 2017- November 13th, 2017
Date of Report:	November 20th, 2017
Sample Type:	Water

Results shown in this test report apply to the specific samples tested only
Page 1 of 14

ENVIRONMENTAL SCIENCES LIMITED
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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

ESL Sample No.	Client Sample ID
23/17- C Top, Rep 1	LIZA C Top, Rep 1
23/17- C Mid, Rep 1	LIZA C Middle, Rep 1
23/17- C Bott, Rep 1	LIZA C Bottom, Rep 1
23/17- F Top, Rep 1	LIZA F Top, Rep 1
23/17- F Mid, Rep 1	LIZA F Middle, Rep 1
23/17- F Bott, Rep 1	LIZA F Bottom, Rep 1
23/17- G Top, Rep 1	LIZA G Top, Rep 1
23/17- G Mid, Rep 1	LIZA G Middle, Rep 1
23/17- G Bott, Rep 1	LIZA G Bottom, Rep 1
23/17- H Top, Rep 1	LIZA H Top, Rep 1
23/17- H Mid, Rep 1	LIZA H Middle, Rep 1
23/17- H Bott, Rep 1	LIZA H Bottom, Rep 1
23/17- I Top, Rep 1	LIZA I Top, Rep 1
23/17- I Mid, Rep 1	LIZA I Middle, Rep 1
23/17- I Bott, Rep 1	LIZA I Bottom, Rep 1
23/17- J Top, Rep 1	LIZA J Top, Rep 1
23/17- J Mid, Rep 1	LIZA J Middle, Rep 1
23/17- J Bott, Rep 1	LIZA J Bottom, Rep 1

Results shown in this test report apply to the specific samples tested only
Page 2 of 14

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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

23/17- K Top, Rep 1	LIZA K Top, Rep 1
23/17- K Mid, Rep 1	LIZA K Middle, Rep 1
23/17- K Bott, Rep1	LIZA K Bottom, Rep 1
23/17- M Top, Rep 1	LIZA M Top, Rep 1
23/17- M Mid, Rep 1	LIZA M Middle, Rep 1
23/17- M Bott, Rep 1	LIZA M Bottom, Rep 1
23/17- N Top, Rep 1	LIZA N Top, Rep 1
23/17- N Mid, Rep 1	LIZA N Middle, Rep 1
23/17- N Bott, Rep 1	LIZA N Bottom, Rep 1
23/17- O Top, Rep 1	LIZA O Top, Rep 1
23/17- O Mid, Rep 1	LIZA O Middle, Rep 1
23/17- O Bott, Rep 1	LIZA O Bottom, Rep 1
23/17- P Top, Rep 1	LIZA P Top, Rep 1
23/17- P Mid, Rep 1	LIZA P Middle, Rep 1
23/17- P Bott, Rep 1	LIZA P Bottom, Rep 1
23/17- R Top, Rep 1	LIZA R Top, Rep 1
23/17- R Mid, Rep 1	LIZA R Middle, Rep 1
23/17- R Bott, Rep 1	LIZA R Bottom, Rep 1

Results shown in this test report apply to the specific samples tested only
Page 3 of 14

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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

23/17- C Top, Rep 2	LIZA C Top, Rep 2
23/17- C Mid, Rep 2	LIZA C Middle, Rep 2
23/17- C Bott, Rep	LIZA C Bottom, Rep 2
23/17- F Top, Rep 2	LIZA F Top, Rep 2
23/17- F Mid, Rep	LIZA F Middle, Rep 2
23/17- F Bott, Rep	LIZA F Bottom, Rep 2
23/17- G Top, Rep 2	LIZA G Top, Rep 2
23/17- G Mid, Rep	LIZA G Middle, Rep 2
23/17- G Bott, Rep	LIZA G Bottom, Rep 2
23/17- H Top, Rep 2	LIZA H Top, Rep 2
23/17- H Mid, Rep	LIZA H Middle, Rep 2
23/17- H Bott, Rep	LIZA H Bottom, Rep 2
23/17- I Top, Rep 2	LIZA I Top, Rep 2
23/17- I Mid, Rep 2	LIZA I Middle, Rep 2
23/17- I Bott, Rep	LIZA I Bottom, Rep 2
23/17- J Top, Rep 2	LIZA J Top, Rep 2
23/17- J Mid, Rep	LIZA J Middle, Rep 2
23/17- J Bott, Rep	LIZA J Bottom, Rep 2
23/17- K Top, Rep 2	LIZA K Top, Rep 2
23/17- K Mid, Rep	LIZA K Middle, Rep 2
23/17- K Bott, Rep	LIZA K Bottom, Rep 2

Results shown in this test report apply to the specific samples tested only
Page 4 of 14

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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

23/17- M Top, Rep 2	LIZA M Top, Rep 2
23/17- M Mid, Rep	LIZA M Middle, Rep 2
23/17- M Bott, Rep	LIZA M Bottom, Rep 2
23/17- N Top, Rep 2	LIZA N Top, Rep 2
23/17- N Mid, Rep	LIZA N Middle, Rep 2
23/17- N Bott, Rep	LIZA N Bottom, Rep 2
23/17- O Top, Rep 2	LIZA O Top, Rep 2
23/17- O Mid, Rep	LIZA O Middle, Rep 2
23/17- O Bott, Rep	LIZA O Bottom, Rep 2
23/17- P Top, Rep 2	LIZA P Top, Rep 2
23/17- P Mid, Rep	LIZA P Middle, Rep 2
23/17- P Bott, Rep	LIZA P Bottom, Rep 2
23/17- R Top, Rep 2	LIZA R Top, Rep 2
23/17- R Mid, Rep	LIZA R Middle, Rep 2
23/17- R Bott, Rep 2	LIZA R Bottom, Rep 2

Results shown in this test report apply to the specific samples tested only
Page 5 of 14

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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

Introduction

Seventy-Two (72) water samples were taken by ESL's field team between 30/09/2017 and 05/10/2017 and submitted to ESL's laboratory on October 7th, 2017 in good condition. The samples were analysed for Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), Nitrogen Ammonia, Total Cyanides, Total Organic Carbon (TOC), Saturated Hydrocarbons and Total Metals (Arsenic, Cadmium, Copper, Chromium, Iron, Nickel, Zinc, Barium and Mercury).

The samples were preserved and submitted in properly labelled containers as recommended by SMEWW Method 1060.

Methodology

All methodologies are derived from guidelines and methods from the Standard Methods for the Examination of Water and Wastewater 22nd Ed and US EPA Methods.

Parameter	Standard Test Method	Dates of Analysis
Total Dissolved Solids (TDS)	SMEWW 2540 A-C	06/10/17
Total Suspended Solids (TSS)	SMEWW 2540 A-D	05/10/17
Chemical Oxygen Demand (COD)	SMEWW 5220 C	09/10/17
Ammonia	SMEWW 4500-NH3 A, B	10/10/17
Total Cyanide	SMEWW 4500 CN`,C & F	16/10/17 - 31/10/17
Saturated Hydrocarbons	SMEWW 8015 M, EPA 3510C	02/11/17 - 06/11/17
Total Organic Carbons	MCAWW 415.1	20/10/17 - 23/10/17
Total Arsenic	SMEWW 3114 A& B	14/11/17
Total Cadmium	SMEWW 3111 A& B	09/11/17 - 13/11/17
Total Copper	SMEWW 3111 A& B	10/11/17
Total Chromium	SMEWW 3111 A& B	10/11/17
Total Iron	SMEWW 3111 A& B	13/11/17
Total Nickel	SMEWW 3111 A& B	09/11/17 - 13/11/17
Total Zinc	SMEWW 3111 A& B	09/11/17 - 13/11/17
Total Mercury	SMEWW 3112 A& B	09/11/17 - 13/11/17
Total Barium	SMEWW 3111 A & B	13/11/17

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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

Results

ESL Sample No.	Client Sample ID	TDS ppm	TSS ppm	COD ppm	NH_3-N ppm	**CN^- ppm	*S/Hydro-Carbons ppb	**TOC ppm
23/17- C Top, Rep 1	LIZA C Top, Rep 1	31,000	3.4	80	BDL	BDL	BDL	1.5
23/17- C Mid, Rep 1	LIZA C Middle, Rep 1	30,000	3.8	110	BDL	BDL	BDL	1.2
23/17- C Bott. Rep 1	LIZA C Bottom, Rep	30,000	5.4	90	BDL	BDL	BDL	1.2
23/17- F Top, Rep 1	LIZA F Top, Rep 1	31,000	5.6	130	BDL	BDL	BDL	1.5
23/17- F Mid, Rep 1	LIZA F Middle, Rep 1	31,000	4.8	170	BDL	BDL	BDL	1.1
23/17- F Bott. Rep 1	LIZA F Bottom, Rep 1	31,000	9.4	30	BDL	BDL	BDL	1.0
23/17- G Top, Rep 1	LIZA G Top, Rep 1	32,000	7.8	150	BDL	BDL	BDL	1.3
23/17- G Mid, Rep 1	LIZA G Middle, Rep 1	32,000	10.2	30	BDL	BDL	BDL	1.2
23/17- G Bott. Rep 1	LIZA G Bottom, Rep 1	32,000	9.2	110	BDL	BDL	BDL	1.4
23/17- H Top, Rep 1	LIZA H Top, Rep 1	35,000	33	180	BDL	BDL	390	1.9
23/17- H Mid, Rep 1	LIZA H Middle, Rep 1	35,000	3.0	120	BDL	BDL	450	1.7
23/17- H Bott. Rep 1	LIZA H Bottom, Rep 1	33,000	3.2	60	BDL	BDL	BDL	1.4
23/17-I Top, Rep 1	LIZA I Top, Rep 1	30,000	3.6	100	BDL	BDL	340	1.7
23/17- I Mid, Rep 1	LIZA I Middle, Rep 1	31,000	4.6	60	BDL	BDL	410	1.8
23/17- I Bott. Rep 1	LIZA I Bottom, Rep 1	30,000	6.2	100	BDL	BDL	BDL	1.3
23/17- J Top, Rep 1	LIZA J Top, Rep 1	37,000	3.8	130	BDL	BDL	BDL	1.5
23/17- J Mid, Rep 1	LIZA J Middle, Rep 1	37,000	2.8	110	BDL	BDL	410	1.5
23/17- J Bott. Rep 1	LIZA J Bottom, Rep 1	37,000	6.8	110	BDL	BDL	340	1.3
23/17- K Top, Rep 1	LIZA K Top, Rep 1	31,000	5.0	100	BDL	BDL	BDL	1.3
23/17- K Mid, Rep 1	LIZA K Middle, Rep 1	30,000	2.8	60	BDL	BDL	BDL	1.3

Results shown in this test report apply to the specific samples tested only
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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

ESL Sample No.	Client Sample ID	TDS ppm	TSS ppm	COD ppm	NH_3-N ppm	**CN^- ppm	*S/Hydro-Carbons ppb	**TOC ppm
23/17- K Bott. Rep 1	LIZA K Bottom, Rep 1	31,000	7.8	50	BDL	BDL	BDL	1.4
23/17- M Top, Rep 1	LIZA M Top, Rep 1	39,000	10	100	BDL	BDL	BDL	1.5
23/17- M Mid, Rep 1	LIZA M Middle, Rep 1	38,000	8.4	160	BDL	BDL	BDL	1.6
23/17- M Bott. Rep 1	LIZA M Bottom, Rep 1	39,000	5.8	160	BDL	BDL	BDL	1.6
23/17- N Top, Rep 1	LIZA N Top, Rep 1	30,000	6.6	120	BDL	BDL	BDL	1.3
23/17- N Mid, Rep 1	LIZA N Middle, Rep 1	31,000	8.2	80	0.01	BDL	BDL	1.4
23/17- N Bott. Rep 1	LIZA N Bottom, Rep 1	31,000	6.2	80	BDL	BDL	BDL	1.2
23/17- O Top, Rep 1	LIZA O Top, Rep 1	35,000	5.4	80	BDL	BDL	210	1.7
23/17- O Mid, Rep 1	LIZA O Middle, Rep 1	36,000	5.2	60	BDL	BDL	BDL	1.5
23/17- O Bott. Rep 1	LIZA O Bottom, Rep 1	36,000	9.6	BDL	0.01	BDL	BDL	1.5
23/17- P Top, Rep 1	LIZA P Top, Rep 1	33,000	10	60	BDL	BDL	250	1.9
23/17- P Mid, Rep 1	LIZA P Middle, Rep 1	32,000	6.8	50	BDL	BDL	BDL	1.7
23/17- P Bott. Rep 1	LIZA P Bottom, Rep 1	33,000	5.8	40	0.02	BDL	BDL	1.5
23/17- R Top Rep 1	LIZA R Top, Rep 1	38,000	13	80	BDL	BDL	BDL	2.2
23/17- R Mid Rep 1	LIZA R Middle, Rep 1	37,000	9.8	40	0.01	BDL	BDL	1.8
23/17- R Bott. Rep 1	LIZA R Bottom, Rep 1	38,000	23	80	0.01	BDL	BDL	1.7
23/17- C Top Rep 2	LIZA C Top, Rep 2	31,000	3.2	80	BDL	BDL	BDL	1.4
23/7- C Mid Rep 2	LIZA C Middle, Rep 2	30,000	3.6	120	BDL	BDL	BDL	1.1
23/17- C Bott. Rep 2	LIZA C Bottom, Rep 2	30,000	5.4	60	BDL	BDL	BDL	1.1
23/17- F Top Rep 2	LIZA F Top, Rep 2	31,000	5.6	150	BDL	BDL	BDL	1.4

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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

ESL Sample No.	Client Sample ID	TDS ppm	TSS ppm	COD ppm	NH_3-N ppm	**CN^- ppm	*S/Hydro-Carbons ppb	**TOC ppm
23/17- F Mid Rep 2	LIZA F Middle, Rep 2	31,000	5.0	170	BDL	BDL	BDL	1.4
23/17- F Bott. Rep 2	LIZA F Bottom, Rep 2	31,000	9.4	40	BDL	BDL	BDL	1.4
23/17- G Top Rep 2	LIZA G Top, Rep 2	32,000	7.6	150	BDL	BDL	BDL	1.3
23/17- G Mid Rep 2	LIZA G Middle, Rep 2	32,000	11	70	BDL	BDL	BDL	1.8
23/17- G Bott. Rep 2	LIZA G Bottom, Rep 2	32,000	9.4	110	BDL	BDL	BDL	1.1
23/17- H Top Rep 2	LIZA H Top, Rep 2	35,000	33	170	BDL	BDL	350	1.7
23/17- H Mid Rep 2	LIZA H Middle, Rep 2	35,000	3.0	140	BDL	BDL	460	1.8
23/17- H Bott. Rep 2	LIZA H Bottom, Rep 2	33,000	3.0	60	BDL	BDL	BDL	1.5
23/17- I Top Rep 2	LIZA I Top, Rep 2	30,000	3.6	100	BDL	BDL	BDL	2.0
23/17- I Mid Rep 2	LIZA I Middle, Rep 2	31,000	4.4	50	BDL	BDL	BDL	1.7
23/17- I Bott. Rep 2	LIZA I Bottom, Rep 2	30,000	6.2	80	BDL	BDL	BDL	1.2
23/17- J Top Rep 2	LIZA J Top, Rep 2	37,000	3.8	150	BDL	BDL	350	1.3
23/17- J Mid Rep 2	LIZA J Middle, Rep 2	37,000	2.8	120	BDL	BDL	490	1.5
23/17- J Bott. Rep 2	LIZA J Bottom, Rep 2	37,000	6.6	110	BDL	BDL	BDL	1.6
23/17- K Top Rep 2	LIZA K Top, Rep 2	31,000	5.2	80	BDL	BDL	BDL	1.6
23/17- K Mid Rep 2	LIZA K Middle, Rep 2	30,000	2.8	40	BDL	BDL	BDL	1.4
23/17- K Bott. Rep 2	LIZA K Bottom, Rep 2	31,000	7.8	60	BDL	BDL	320	1.4
23/17- M Top Rep 2	LIZA M Top, Rep 2	39,000	10.2	140	BDL	BDL	BDL	1.7
23/17- M Mid Rep 2	LIZA M Middle, Rep 2	38,000	8.2	120	0.01	BDL	BDL	1.6
23/17- M Bott. Rep 2	LIZA M Bottom, Rep 2	39,000	5.8	160	BDL	BDL	320	1.6

Results shown in this test report apply to the specific samples tested only
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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

ESL Sample No.	Client Sample ID	TDS ppm	TSS ppm	COD ppm	NH_3-N ppm	**CN^- ppm	*S/Hydro-Carbons ppb	**TOC ppm
23/17- N Top Rep 2	LIZA N Top, Rep 2	30,000	6.6	120	BDL	BDL	BDL	1.4
23/17- N Mid Rep 2	LIZA N Middle, Rep 2	31,000	8.2	90	BDL	BDL	240	1.6
23/17- N Bott. Rep 2	LIZA N Bottom, Rep 2	31,000	6.2	100	0.02	BDL	BDL	2.0
23/17- O Top, Rep 2	LIZA O Top, Rep 2	35,000	5.6	80	0.01	BDL	BDL	1.7
23/17- O Mid, Rep 2	LIZA O Middle, Rep 2	36,000	5.2	60	BDL	BDL	BDL	1.4
23/17- O Bott. Rep 2	LIZA O Bottom, Rep 2	36,000	9.4	BDL	0.01	BDL	BDL	1.4
23/17- P Top, Rep 2	LIZA P Top, Rep 2	33,000	10	60	BDL	BDL	250	2.0
23/17- P Mid, Rep 2	LIZA P Middle, Rep 2	32,000	6.8	30	BDL	BDL	BDL	1.8
23/17- P Bott. Rep 2	LIZA P Bottom, Rep 2	33,000	5.8	50	0.01	BDL	BDL	1.4
23/17- R Top, Rep 2	LIZA R Top, Rep 2	38,000	13	80	BDL	BDL	BDL	1.9
23/17- R Mid, Rep 2	LIZA R Middle, Rep 2	37,000	9.4	40	0.02	BDL	BDL	1.9
23/17- R Bott. Rep 2	LIZA R Bottom, Rep 2	38,000	32	60	BDL	BDL	580	1.5

ppm = mg/L
BDL = Below Detection Limit
*- Subcontracted to ALS Environmental
** - Subcontracted to International Analytical Group

Results shown in this test report apply to the specific samples tested only
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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

ESL Sample No.	Client Sample ID	As ppm	Cd ppm	Cu ppm	Cr ppm	Fe ppm	Ni ppm	Zn ppm	Hg ppm	Ba ppm
23/17- C Top, Rep 1	LIZA C Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- C Mid, Rep 1	LIZA C Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- C Bott. Rep 1	LIZA C Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- F Top, Rep 1	LIZA F Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- F Mid, Rep 1	LIZA F Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- F Bott. Rep 1	LIZA F Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- G Top, Rep 1	LIZA G Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- G Mid, Rep 1	LIZA G Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- G Bott. Rep 1	LIZA G Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- H Top, Rep 1	LIZA H Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- H Mid, Rep 1	LIZA H Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- H Bott. Rep 1	LIZA H Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17-I Top, Rep 1	LIZA I Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- I Mid, Rep 1	LIZA I Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- I Bott. Rep 1	LIZA I Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- J Top, Rep 1	LIZA J Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- J Mid, Rep 1	LIZA J Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- J Bott. Rep 1	LIZA J Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- K Top, Rep 1	LIZA K Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- K Mid, Rep 1	LIZA K Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- K Bott. Rep 1	LIZA K Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- M Top, Rep 1	LIZA M Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- M Mid, Rep 1	LIZA M Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- M Bott. Rep 1	LIZA M Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- N Top, Rep 1	LIZA N Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- N Mid, Rep 1	LIZA N Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- N Bott. Rep 1	LIZA N Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- O Top, Rep 1	LIZA O Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- O Mid, Rep 1	LIZA O Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- O Bott. Rep 1	LIZA O Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- P Top, Rep 1	LIZA P Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- P Mid, Rep 1	LIZA P Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- P Bott. Rep 1	LIZA P Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- R Top, Rep 1	LIZA R Top, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- R Mid, Rep 1	LIZA R Middle, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- R Bott. Rep 1	LIZA R Bottom, Rep 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- C Top Rep 2	LIZA C Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/7- C Mid Rep 2	LIZA C Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- C Bott. Rep 2	LIZA C Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- F Top Rep 2	LIZA F Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- F Mid Rep 2	LIZA F Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- F Bott. Rep 2	LIZA F Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

ESL Sample No.	Client Sample ID	As ppm	Cd ppm	Cu ppm	Cr ppm	Fe ppm	Ni ppm	Zn ppm	Hg ppm	Ba ppm
23/17- G Top Rep 2	LIZA G Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- G Mid Rep 2	LIZA G Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- G Bott. Rep 2	LIZA G Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- H Top Rep 2	LIZA H Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- H Mid Rep 2	LIZA H Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- H Bott. Rep 2	LIZA H Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- I Top Rep 2	LIZA I Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- I Mid Rep 2	LIZA I Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- I Bott. Rep 2	LIZA I Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- J Top Rep 2	LIZA J Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- J Mid Rep 2	LIZA J Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- J Bott. Rep 2	LIZA J Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- K Top Rep 2	LIZA K Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- K Mid Rep 2	LIZA K Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- K Bott. Rep 2	LIZA K Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- M Top Rep 2	LIZA M Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- M Mid Rep 2	LIZA M Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- M Bott. Rep 2	LIZA M Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- N Top Rep 2	LIZA N Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- N Mid Rep 2	LIZA N Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- N Bott. Rep 2	LIZA N Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- O Top, Rep 2	LIZA O Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- O Mid, Rep 2	LIZA O Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- O Bott. Rep 2	LIZA O Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- P Top, Rep 2	LIZA P Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- P Mid, Rep 2	LIZA P Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- P Bott. Rep 2	LIZA P Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- R Top, Rep 2	LIZA R Top, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- R Mid, Rep 2	LIZA R Middle, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
23/17- R Bott. Rep 2	LIZA R Bottom, Rep 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Uncertainty of Measurement		--	±7.1 %	±9.4 %	±7.8 %	±8.2 %	±7.4 %	±6.8 %	--	--

ppm = mg/L
BDL = Below Detection Limit

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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

Detection Limits:

Parameters	Detection Limit in water (mg/L)
TSS	0.20
TDS	2.0
COD	30
NH_3	0.01
Total As	0.005
Total Ni	0.33
Total Cyanide	0.0050
Total Cr	0.23
Total Fe	0.20
Total Cd	0.06
Total Cu	0.19
Total Zn	0.18
Total Ba	0.01
Total Hg	0.002
Saturated Hydrocarbons (ppb)	200 – 320
TOC	1.0

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Project Code: 23/17 Client Name: Exxon Report Date: November 20th, 2017

References:

Rice, E.W., R.B. Baird, A.D. Eaton and L.S. Clesceri. 2012. Standard Methods for the Examination of Water and Wastewater, 22nd Edition. Prepared and published by the American Public Health Association, American Waterworks Association and Water Environment Federation and the American Public Health Association. Washington D.C.

United States Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Office of Research and Development, Method 1664, Revision A: N-Hexane Extractable Material (HEM; Oil and Grease) and Silica Gel Treated N-Hexane Extractable Material (SGT-HEM; Non-polar Material) by Extraction and Gravimetry, EPA-821-R-98-002, February 1999.

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Results shown in this test report apply to the specific samples tested only
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Final Environmental Baseline Assessment of Sediment Quality along the Continental Shelf Guyana—Phase 2

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FINAL ENVIRONMENTAL BASELINE ASSESSMENT OF SEDIMENT QUALITY ALONG THE CONTINENTAL SHELF GUYANA—PHASE 2









Prepared by:

April 2018

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FINAL ENVIRONMENTAL BASELINE SEDIMENT QUALITY REPORT FOR EXXON GUYANA PROJECT: PHASE 2 OFFSHORE GUYANA

Prepared for

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April 2018

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EXECUTIVE SUMMARY

Introduction

As part of the ongoing development of the Stabroek Block, offshore Guyana, Esso Exploration and Production Guyana Limited (EEPGL) requested under the contract with RPS for metocean survey service #4, targeted to be completed in September – October 2017, additional scope of services, including sediment quality assessment within the study area, for which Environmental Sciences Limited (ESL) was sub-contracted by RPS in July 2017. This report pertains to the environmental baseline assessment of sediment quality and benthic macrofauna at 10 stations located along the Continental Shelf of Guyana.

ESL's scope of work for this Project entailed the following: sample planning and execution (October 2017, and December 2017 for saturated hydrocarbon only); sample handling, storage, transportation and chain of custody to the relevant labs; analysis and QA/QC of particle size, chemical parameters and benthic macrofauna at ESL's lab facility; management of ESL's laboratory analytical sub-contractor (IAG) and benthic taxonomy sub-contractor (OEL); and data management, analysis and reporting.

Methodology

For the environmental baseline assessment of sediment quality and benthic macrofauna along the Continental Shelf of Guyana, a total of 10 stations were sampled, as presented in the sample plan map (Figure 1 of the Main Report). The 10 stations were located north of the Guyana coastline within water depths of 18 – 98 m along the continental shelf.

The development of the sample plan took into account the location of the 10 existing metocean stations consisting of 4 subsurface oceanographic moorings with one wave buoy and 6 trawl resistant bottom mounted monitoring systems, the client's requirement of one sediment sample and triplicate benthic samples at each station, as well as the water depths along the shelf. This resulted in a total of 10 sediment samples and 30 benthic samples for the environmental baseline assessment.

Sampling occurred during the periods of October 26th – 27th, and December 27th – 29th (saturated hydrocarbons only), 2017, upon the Sea Service vessel, with the use of a van Veen grab (0.1 m^2) for sediment quality (including grain size) and benthic assessment. Equipment were deployed via an A-frame and winch system. The full suite of sediment parameters is presented in Table 3 of the Main Report. Analysis included particle size distribution, organics, total and bioavailable metals, moisture content and redox potential. The benthic macrofaunal communities were assessed by grab analysis.

All sampling utilised standardised and scientifically robust methods as outlined in '*EPA-823-B-01-002: Methods for collections, storage and manipulation of sediments for chemical analyses: Technical Manual' (USEPA 2001)*. To assist in reliability, analytical accuracy and valid interpretation of data, a program of quality control measures was implemented in sample collection, handling / preservation and laboratory procedures.

Chemical analysis of the sediment samples was performed by both ESL and Test America (IAG). Grain size analysis was conducted by ESL using the methods outlined in '*Standard Test Method for Particle-Size Analysis of Soils, ASTM D 422* (ASTM 2007). All other parameters were executed by IAG using the *SW846 "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates*.

Sediment quality data and macrobenthic taxonomic abundance data were inputted into MS Excel® for statistical analysis; the latter was also processed in PRIMER for univariate and multivariate analyses. Where applicable, sediment total metals' concentrations reported in this study were compared to the USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Levels (USEPA 2006), as well as the Effects Range median (ERM) values (Buchman 2008).

Results & Discussion

Sediment grain size results from October 2017 indicated that the predominant fractions at the 10 shelf stations varied significantly, and revealed a range of soil classifications, including clay to a mix of clay, sand and loam. The clay fraction generally tended to decrease with distance from the shore and, when the % size fraction of clay was compared to the level of TOC (%), a correlation was found between the two which is typical and expected given the studies cited in the Section 6.3 of the main report.

PAHs and total and bioavailable forms of the metals, cadmium, selenium and mercury were below the detectable limit (BDL) at all 10 shelf stations sampled in October 2017. The bioavailable forms of the metals, copper, chromium, iron, nickel, lead, zinc, barium, aluminium and arsenic were BDL at all stations, despite being detected in the total form at every station. The only exception to the latter was total copper, which was detected at 8 of the 10 stations sampled. In the case of aluminium and arsenic, the bioavailable form was detected at one or two stations in October 2017.

Redox potential readings were positive and therefore appeared to indicate oxic conditions within the sediment (meaning that oxygen is present to carry out oxidation processes as a result of organic matter present in the sediment samples at the time of sampling). Where applicable, sediment total metals' concentrations reported in this study were compared to the USEPA Mid-Atlantic Risk Assessment

Marine Sediment Screening Levels (USEPA 2006) as a preliminary and conservative sediment quality screening threshold. In cases where the USEPA benchmark was exceeded, total metal concentration was then compared to the Effects Range median (ERM) values (Buchman 2008) as a measure of possible toxic effects to benthos. The majority of the total metals did not exceed the USEPA Mid-Atlantic Risk Assessment Screening Benchmarks: total copper (18.7 mg/kg); total chromium (52.30 mg/kg); total nickel (15.9 mg/kg); total lead (30.20 mg/kg); and total zinc (124.00 mg/kg). The only parameter which exceeded its USEPA Benchmark was total arsenic (7.24 mg/kg). This value was exceeded at 8 of the 10 stations sampled, and in the case of the highest detected values, at Stations 15 and 24, the values were 6 and 3 times higher (respectively) than the Benchmark. However, though the USEPA Benchmark was exceeded at 8 stations, all 10 values were well below its ERM value of 70 mg/kg and thus is unlikely to cause impacts to the benthos. Based on the reported concentrations iron in these sediments, 3 of the stations with elevated levels of total arsenic may be attributed to anthropogenic contamination (e.g. mining activities) while the other 5 stations were found to be consistent with background levels monitored in 2016. There are no USEPA Benchmarks for bioavailable metals, nor total forms of iron, aluminium and barium; nor the other parameters tested from sediment sampled in October 2017.

When considering the changes in the levels of the various parameters across the 10 stations, the majority of the parameters were found to be higher at Stations 22, 21 and 24 with lower levels at the other stations: sediment moisture (out of water) and the total forms of the metals, copper, chromium, iron, nickel, aluminium, lead, zinc and barium. Conversely, total arsenic was highest at Station 15, whilst both redox potential and TOC varied across the study area.

In general, the sediment sampled in October 2017 appeared to be of good quality, given: the low levels of TOC in comparison to those found in nutrient-rich waters; the presence of moisture within the sediment; the presence of oxygen to drive redox reactions; the absence of bioavailable levels of most sediment metals; and the lack of exceedance of the USEPA Benchmarks and their ERM values for nearly all total metals.

Eighty seven percent of the saturated hydrocarbons analytes were absent along the shelf, with only 2 of the 5 detected hydrocarbons recorded at all 10 stations. Where detected, saturated hydrocarbons ranged from 0.14 – 10.0 mg/kg, with n-Dotriacontane consistent across the 10 stations, whilst n-Hexatriacontane decreased with distance from the shoreline.

Results of the Baseline Assessment Survey (October 2017) benthic macrofaunal analysis indicated that the benthic macrofaunal community along the continental shelf was diverse in species composition and abundance at the time of sampling. A total of 4,101 specimens belonging to 133 taxa (family) were found within 30 samples, with an average of 136.7± 223.09 specimens per grab and 20.4 ± 9.05

taxa per grab. Station 24 had the highest number of specimens (1,353) and Station 15, the lowest (45).

An arthropod belonging to the family Chevaliidae was the most abundant organism, accounting for 54.79% (2,247) of all specimens detected. Analysis in PRIMER utilising dendrograms and MDS plots showed that there was low similarity in faunal distributions among stations, with abiotic factors such as depth and grain size indicating no significant effects on biotic data. This study documents the natural variability in chemistry, biota and taxonomic diversity that occurs in sediments along the Guyana Continental Shelf during the period sampled.

1 INTRODUCTION

1.1 Background

Esso Exploration and Production Guyana Limited (EEPGL) has a Production Sharing Contract with the Government of Guyana which covers 26,800 km^2 in the Stabroek Block, offshore Guyana. In 2014, EEPGL applied for Governmental approvals for the development and execution of a Strategic Environmental Assessment (SEA) for a two-well drilling program within the Block. These approvals were granted in January 2015, and EEPGL subsequently undertook more than 2 years of exploration and assessment activities, within one of 2 specific areas of interest, the Liza Field.

The first exploration well, Liza-1, was successfully drilled during the first half of 2015, and in May of that year, EEPGL announced a significant discovery of high-quality oil-bearing sands with the Liza-1 well, approximately 190 km offshore Guyana. This discovery has given renewed impetus to the planning and development of the offshore area for oil and gas commercialisation, and, to this end, from 2014 to present, EEPGL has conducted several geotechnical, seismic and environmental baseline surveys within and adjacent to the Block. Included in the latter is a comprehensive metocean service program, within which RPS Group has been contracted by EEPGL for the retrieval, servicing and redeployment of metocean buoys placed within the Liza Field, and along the continental slope and shelf areas offshore Guyana. The metocean survey is geared towards the retrieval of long-term met-ocean data for application in environmental and other modelling work in preparation for additional projects to be executed by EEPGL within the study area.

EEPGL requested under the contract with RPS for metocean survey service #4, targeted to be completed in September – October 2017, additional scope of services, including sediment quality assessment (including benthic macrofauna) within the study area, for which ESL was sub-contracted by RPS in approximately July 2017. Resampling for saturated hydrocarbon analysis only was done in December 27th – 29th, 2017 due to the expiration of samples prior to analysis.

1.2 Project Summary

ESL was sub-contracted by RPS to conduct an environmental baseline assessment of sediment quality at 10 stations located along the Continental Shelf area, inclusive of particle size distribution (sediment grain size), sediment chemical analyses, and benthic macrofauna, which is the subject of this report. Additional details pertaining to the scope of work are provided in Section 2.2 below.

1.3 Regulatory Setting

The scope of ESL's baseline sediment sampling exercise is covered by the metocean survey environmental permit, issued to EEPGL by the Environmental Protection Agency of the Government of Guyana, for the execution of this work.

2 PROJECT OBJECTIVES & SCOPE

2.1 Study Objective

The objective of this study is to provide a description of the baseline conditions related to sediment quality and benthic macrofauna at the 10 shelf stations sampled within the study area for this Project, based on the results of lab data related to the parameters specified, for the period October 26th – 27th, 2017 and December 27th – 29th, 2017 (saturated hydrocarbons only).

2.2 Summary of Scope of Work

A total of 10 stations were identified by EEPGL, for the baseline assessment of sediment quality and benthic macrofauna. ESL's scope of work included the sampling of sediment for particle size distribution (sediment grain size), chemical analyses and benthic macrofauna at the surface of the seafloor, at 10 stations located along the Continental Shelf, resulting in a total of 10 samples (grain size and sediment chemistry) and 30 samples (benthic macrofauna).

ESL was responsible for:

- Sample planning and execution upon the ESL-commissioned vessel during the pre-determined survey period (October 2017);
- Sample handling, storage, transportation and chain of custody to the relevant labs;
- Analysis and QA/QC of grain size, chemical parameters and benthic macrofaunal samples at ESL's lab facility;
- Management of ESL's laboratory analytical sub-contractor (IAG) and benthic taxonomy sub-contractor Ocean Ecology Limited (OEL); and
- Data management, analysis and reporting.

ESL's deliverables will include an electronic submission of the draft environmental baseline sediment quality assessment report. The final submission will include an electronic submission in MS Word and pdf formats and will also include 1 printed copy.

2.3 Decision Statement

The procedures outlined by EEGPL for the execution of the additional scope of sediment and benthic sampling were adhered to, and sampling was completed within the required timeframe. All samples were processed within the required holding times and the report generation was well within the specified timeline. The

overall objective of the study was met; the sediment quality within the sampled area was found to be of good quality for the sampling period October 26th – 27th, 2017 and December 27th – 29th, 2017 (saturated hydrocarbons).

Benthic macrofaunal analysis indicated that the benthic macrofaunal community along the continental shelf was diverse in species composition and abundance at the time of sampling with abiotic factors such as depth and grain size indicating no significant effects on biotic data.

3 PROJECT ORGANISATION & COMMUNICATIONS

The following Sections provide details of the services and capabilities of ESL, the ESL Field Team who were responsible for the sediment and benthic sampling exercise along the continental shelf.

3.1 Names, Role and Contact Information for All Key Staff

Appendix 1A presents information of the ESL sampling team members, their designation and roles, as well as contact data.

3.2 Subcontractor Information

3.2.1 Company Profile

Environmental Sciences Limited (ESL) is a locally incorporated company launched in August 2003. The Company's main office is currently located at #141 Riverside Drive, San Fernando, Trinidad, West Indies.

The company's core resource base comprises of qualified and experienced professionals as well as international partners and consultants that provide support for environmental research, marine, coastal and land based projects.

ESL retains expertise from the local and foreign industries familiar with upstream and downstream practices, engineering and scientific industrial specifications, in addition to a thorough understanding of the current legislation, in particular, the area of relevant environmental legislation for marine and land impact assessments, risk assessments and social assessments.

ESL is currently partners with leading companies who specialize in specific oceanography, numerical sediment transport, scour modelling studies and high-level preparation of impact assessments. ESL also provides oil spill trajectory modelling through its affiliation with Tetra Tech. Tetra Tech is a leader in the field of coastal and marine modelling, Oil Spill Trajectory and prediction, sediment transport and effluent plume modelling. The company has also worked with RPS, IRC, ABS and DNV on various projects.

ESL also utilises the services of a high-level risk assessment company for various levels of risk assessments (hazards identification, qualitative and quantitative QRA risk assessment) for specific projects.

ESL's core business stream includes the provision of technical and environmental studies and assessment solutions, engineering, design and project management services for the upstream and downstream industries as well as port and jetty development.

ESL's Environmental Management System (EMS) has been developed to provide quality policies and procedures. The company provides full time resources to maximize our quality system and update our EMS including ISO/IEC 17025 accreditation (see Appendix 2 for relevant certificates).

ESL takes pride in having local staff, which gives the company a better understanding of the areas within Trinidad and Tobago and the Caribbean. This local content is a valuable resource specific to the local diversity and variety of projects the company engages in.

3.2.2 ESL's Scope of Work

ESL was subcontracted to conduct the sediment and benthic sampling exercise at 10 locations within the designated study area (see Figure 1 in Section 4.2 below). The project area is located approximately 23 km northeast off Guyana's coastline with water depths in the range 18 – 98 m. Sediment samples were retrieved during the period October 26th – 27th, 2017 with one in quadruplicate at each station; one for sediment chemistry and triplicate for benthic assessment. Due to the expiration of the saturated hydrocarbon samples shelf life, resampling occurred from December 27th – 29th, 2017. Section 4.5.2 above provides greater detail of the sampling exercise whilst Section 4.5.2 and Section 4.5.3 below provides the detailed sediment and benthic sampling methodology employed.

3.2.3 Contact Information

ESL of Trinidad & Tobago, West Indies may be contacted via the understated telephone numbers and/or email addresses:

Telephone Nos.: (868) 657 – 9024
(868) 657 – 1560

Email address: jerome.als@environsciences.net
elka.bachan@environsciences.net
admin.assistant@environsciences.net

3.3 QC Journey Management for ESL Field Team

Appendix 1B provides the journey management forms that were used to document the transit, crew members and other related information during the execution of this Project.

3.4 Special Training / Safety Certifications

Appendix 1C provides the offshore training, medical approvals and safety training certificates for the members of the ESL Field Team.

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4 FIELD PROGRAM

This Section presents the various aspects related to the field work undertaken by the ESL Field Team during the sediment and benthic sampling exercise for the period October 26th – 27th, 2017 and December 27th – 29th, 2017 (saturated hydrocarbons). The subsections below present the HSE approvals, sampling logs, equipment list, packing and shipping instructions, as well as sample disposal.

4.1 Job Safety Analysis (JSA) for Sediment & Benthic Sampling

Appendix 3 provides the applicable JSAs that were employed and adhered to during the execution of this Project.

4.2 Sampling Plan Design

The sampling plan for this study is shown in Figure 1 below. The plan was designed to ensure that sediment and benthic samples were obtained throughout the project area. Ten stations were selected within the study area. The UTM coordinates for these sampling stations (WGS ’84 datum, Zone 20N) are presented in Figure 1 below.

The development of the sampling plan map took into account the following, in order to inform the spread of the stations:

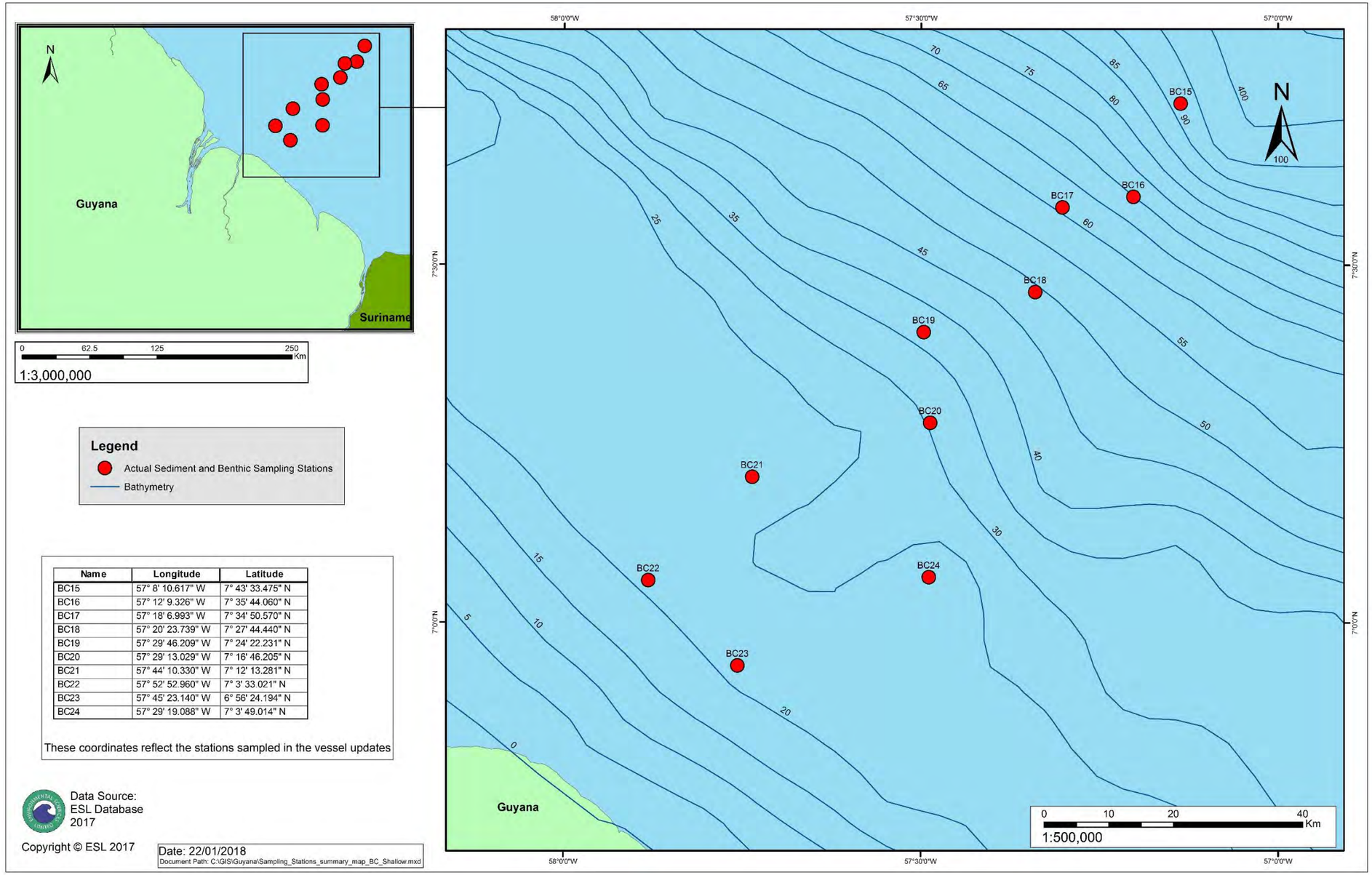
1. The location of 10 existing Metocean stations in the project area was considered for a representative study area design

2. The client’s requirement at the same 10 locations for the one sediment sample for chemical analysis; a total of 10 sediment samples. Additional sediment samples per station for benthic analysis (in triplicate); a total of 30 samples[1]

3. Localised bathymetry within and around the project area was considered to check for major seabed structures, and it was found that the area was fairly shallow, moderately deeper at the shelf and extended into the deepwater zone.

[1] *Triplicate benthic samples per location was agreed to by Esso and ESL instead of in-situ water data*

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Name	Longitude	Latitude
BC15	57° 8' 10.617" W	7° 43' 33.475" N
BC16	57° 12' 9.326" W	7° 35' 44.060" N
BC17	57° 18' 6.993" W	7° 34' 50.570" N
BC18	57° 20' 23.739" W	7° 27' 44.440" N
BC19	57° 29' 46.209" W	7° 24' 22.231" N
BC20	57° 29' 13.029" W	7° 16' 46.205" N
BC21	57° 44' 10.330" W	7° 12' 13.281" N
BC22	57° 52' 52.960" W	7° 3' 33.021" N
BC23	57° 45' 23.140" W	6° 56' 24.194" N
BC24	57° 29' 19.088" W	7° 3' 49.014" N

These coordinates reflect the stations sampled in the vessel updates

Data Source:
ESL Database
2017

Copyright © ESL 2017

Date: 22/01/2018
Document Path: C:\GIS\Guyana\Sampling_Stations_summary_map_BC_Shallow.mxd

Figure 1: Sediment and Benthic Sample Locations for Exxon Guyana, Offshore Project, Phase 2 (October 2017)

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4.3 Field Documentation

This Section presents the records taken during the sampling event and the Chain-of-Custodies (COCs) until samples were delivered to the ESL and partner laboratory International Analytical Group (IAG).

4.3.1 Station Logs

Table 1 below presents the names of the10 locations sampled during Phase 2, the date of sampling and their corresponding water depth in metres. The coordinates of each location sampled is presented in the Degree, Minutes, Second (DMS) format.

Table 1: Log of Sample Stations for Phase 2 Sediment and Benthic Sampling (October 2017)

Station Number	Date sampled	Depth (m)	Coordinate	
			Latitude	Longitude
BC15	26/10/2017	98	7° 43' 33.475" N	57° 8' 10.617" W
BC16	26/10/2017	67	7° 35' 44.060" N	57° 12' 9.326" W
BC17	26/10/2017	60	7° 34' 50.570" N	57° 18' 6.993" W
BC18	26/10/2017	50	7° 27' 44.440" N	57° 20' 23.739" W
BC19	26/10/2017	42	7° 24' 22.231" N	57° 29' 46.209" W
BC20	26/10/2017	31	7° 16' 46.205" N	57° 29' 13.029" W
BC21	27/10/2017	25	7° 12' 13.281" N	57° 44' 10.330" W
BC22	27/10/2017	18	7° 3' 33.021" N	57° 52' 52.960" W
BC23	27/10/2017	19.5	6° 56' 24.194" N	57° 45' 23.140" W
BC24	27/10/2017	26	7° 3' 49.014" N	57° 29' 19.088" W

4.3.2 Chain-of-Custody

Chain of custody (COC) forms are used to track samples from the point of sampling, during transit and final delivery of samples to the preferred laboratories. Appendix 4 provides the COCs for ESL and IAG Environmental laboratories.

4.4 Detailed List of Field Equipment/Supplies

Sediment and benthic sampling within the project area necessitated a variety of equipment and supplies. These are presented in Table 2 below, whilst Appendix 5 provides the relevant User's guide/calibration certificate.

Table 2: Sampling Equipment/Supplies

Item	Name of Equipment	Quantity
1	Generator	2
2	Van Veen Grab	1
3	Electric Winch	1
4	Dyneema Synthetic Rope	1
5	Ziploc Bags	40
6	PINPOINT® Redox Monitor	1

4.5 Sediment and Benthic Sample Survey, Offshore Guyana (October 2017)

Prior to sediment and benthic sampling by the ESL Field Team, the Sea Service was fitted with the necessary equipment during vessel mobilisation in Trinidad as discussed in Section 4.4 above and Section 4.5.1 below.

4.5.1 Vessel Mobilisation

The vessel (Sea Service) was outfitted with the van Veen grab for sediment and benthic sampling. Differential GPS and navigation software were also added to the vessel so that navigation to monitoring points would be more efficient and accurate.

After securing sampling equipment on the vessel, function tests were conducted on all GPS and sampling equipment below:

- DGPS System (with GPS antenna and differential signal receiver)
- HYPACK Software (computer-based navigation software to receive input from the DGPS system
- A-frame and hydraulic winch
- Electric winch
- Redox Monitor
- Van Veen grab (0.1 m^2) and
- Generator (x2)

The Vessel departed to Guyana after all function tests were passed.

4.5.2 Sediment Sampling Methodology

Sediment sampling was conducted at each of the 10 stations identified in Figure 1 above with the aid of a van Veen (0.1 m^2) Grab, during the period October 26th – 27th, 2017. Noteworthy, is that due to the expiration of samples for saturated hydrocarbon analysis, resampling for this parameter was done in December 27th - 29th, 2017 (see Appendix 10). At each station, the grab was attached to ESL's winch system and lowered in the open position. When it came to rest on the seabed, the release of tension on the bridle enabled the triggering bar to drop. Once tension was applied again to the bridle, the jaws were drawn together, and a sample was taken. The winch was then used to return the grab to the surface and the sediment sample was then removed from the grab.

Each sample (for chemistry and grain size analysis) was placed in separate gallon-sized Ziploc bags, labelled and double-bagged (see Appendix 6). All samples were then stored at 4°C until delivery to IAG and ESL for analysis.

All sampling utilised standardised and scientifically robust methods as outlined in '*EPA-823-B-01-002: Methods for collections, storage and manipulation of sediments for chemical analyses: Technical Manual' (USEPA 2001)*. To assist in reliability, analytical accuracy and valid interpretation of data, a program of quality control measures was implemented in sample collection, handling / preservation and laboratory procedures.

Sediment Monitoring Quality Assurance and Quality Control (QA/QC) Analysis

The Quality Assurance and Quality Control (QA/QC) analysis was entrained in the sediment sampling methodology, which was designed to provide routine and consistent checks, to ensure data integrity, accuracy and completeness. QA/QC activities included general methods such as accuracy checks on data sampling

and acquisition and the use of approved standardised procedures. QA/QC procedures executed by ESL's technical team include the following:

- Sampling was conducted by trained and experienced technicians
- The van Veen grab (0.1 m^2) was used, that closes on impact so that the representative sample at the location was not washed away when moving through the water column during retrieval
- Proper labeling of the sterilised sample containers at all stations were conducted which include the date and sample station number
- To minimise the potential for volatilisation or biodegradation between sampling and analysis, samples were kept at 4°C
- Standard analysis methodologies were utilised
- A Chain of Custody was issued by the Field Technicians to the ESL, as well as IAG lab personnel upon delivery of the samples to the laboratory
- The ESL laboratory is also an accredited one which fulfils the requirements for ISO/IEC 17025:2005.

4.5.3 Benthic Sampling Methodology

Grabs for benthic macrofaunal analysis were retrieved in the same manner and during the same period as described in Section 4.5.2 above. Samples were taken in triplicate at each of the 10 locations, resulting in a total of 30 samples. In each case, checks on the grab were made to ensure the grab was acceptable (the criteria for which is presented in ESL's Benthic Methodology in Appendix 7).

At each station (and once acceptable), each replicate was washed on the vessel with sea water through a series of sieves (4 mm, 1 mm and 0.5 mm) set up on a sieve table possessing a 'sink and drainpipe' design. Washing in this manner allowed initial separation of the sample, whereby the larger, excess sediment particles were removed, and material collected on the 0.5 mm sieve at the bottom of the sieve table set-up was retained and washed gently into a sample container. The sample was then fixed with 10% Formalin buffered with sodium borate, labelled appropriately and stored on-deck until delivery to ESL's laboratory. Rose Bengal was not utilised (see Appendix 7).

At the ESL laboratory, each sample was washed thoroughly and repeatedly to remove excess Formalin. The sample, through elutriation, was further separated into lighter and denser fractions using the 0.5 mm sieve, and these were sorted using microscopes in the Benthic Laboratory. Organisms which were deemed to be alive at the time of sampling were removed and placed into labelled glass vials. Identification was then carried out per vial, using taxonomic keys and ESL's reference library (collection of specimen organisms). Results were recorded in hard copy and MS Excel® for statistical analysis. Appendix 7 presents a more

detailed description of the methodology employed for washing, sorting and identification of species. Samples were then retained in storage for a maximum period of 6 months after which they are disposed of at an approved site.

4.5.4 Particle Size Distribution

The classification of soils for environmental purposes requires that the distribution of grain sizes in a given soil mass be known. The samples were retrieved in a similar manner and during the same period as stated in Section 4.5.2 above. The <63 µm Sieve Analysis Method was utilised by ESL to determine the particle size distribution of the sediment samples taken at the 10 locations along the continental shelf of Guyana (see Figure 1 above). The sediment samples were passed through an array of sieves with different mesh sizes (#5, 10, 35, 60, 120, 230) which were stacked upon each other in increasing number sizes. The sieves are made of woven wires with square openings which decrease in size as the sieve number increases; this allows the grains to be sorted by size. Thereafter, sediment type was then classified into sands and gravels based on the dominant fraction and particle size. Appendix 7 provides the detailed Size Analysis Method used.

4.5.5 Vessel Demobilisation

After docking, samples were removed and dispatched to the ESL and IAG Environmental laboratories for the respective analyses (see Section 5.1.2, Table 5 below).

4.6 Field Instrument Use and Calibration

A detailed equipment list is provided in Section 4.4 above (see Table 2). Of the 5 types of equipment used during the sediment and benthic sampling survey, only the PINPOINT® Redox Monitor required calibration. The User's guide for calibration of the monitor is provided in Appendix 5.

4.7 Sampling Equipment Decontamination Methods

A Van Veen grab fitted with a tension enabled bridle that triggers the collection of the sediment samples was utilised during this sampling exercise (Figure 2 below). Upon retrieval of the grab, the sediment was transferred to the respective Ziploc bags for storage and transportation.



Figure 2: Van Veen Grab

Prior to the redeployment, the grab was rinsed with water. This ensured that subsequent samples were not tainted in any way.

4.8 Sample Handling Instructions (processing, preservatives)

The ESL field team were responsible for the collection, preservation and handling of sediment and benthic samples from the point of sample retrieval to the delivery of samples. The team followed the USEPA 2001 methods for collection, storage and manipulation of sediments for chemical and toxicological analyses. No preservation was required for the sediment samples taken for chemical analysis (see Table 4 below). Benthic samples however, were treated with 10% Formalin which is descried in Section 4.5.3 above and the Benthic Methodology provided in Appendix 7.

4.9 Packing Instructions (important for laboratory samples)

Upon retrieval and collection of the sediment and benthic samples into their respective Ziploc bags, they were subsequently packaged and stored at the recommended temperature and environmental conditions during the sampling exercise and transit, until delivery to the different laboratories.

The Packing Instructions employed is as follows:

1. Insert large plastic bag in cooler, and place about 1'' of padding along the bottom of the bag.
2. Insert cold sediment samples in the bag.
3. Place Ziploc bags filled with ice on top of the samples and along the sides if there is enough space.
4. Place an additional layer of padding at the top of the samples.
5. Pull ends of plastic bag up, squeeze air out of bag, twist and knot the plastic bag.
6. Place an additional layer of padding at the top of the plastic bag.
7. Place chain of custody forms inside a Ziploc bag and tape the bag to the inside of the lip of the cooler.
8. Close the cooler and seal with packaging tape, wrapping the tape vertically around the cooler.
9. Tape the address of the recipient to the outside of the cooler.

4.10 Shipping Instructions (customs broker for international shipments)

Shipping Instructions:

1. Prepare the Toxic Substances Control Act (TSCA) form (in triplicate), Commercial Invoice and soil permit (if applicable) for preferred courier.
2. Complete the airway bill for preferred courier.
3. Call local courier and make an appointment for the collection of the samples.

The above procedure was adhered to for all samples so at to assure courier that the samples were safe for shipment. All shipping airway bills are provided in Appendix 8.

4.11 Sample disposal

After the completion of analysis, samples are retained for a period of 6 months from the date of submission of report to the client. Upon the expiration of this time period, the date of disposal is logged into the Sample Log Book prior to disposal. Samples are disposed of by washing down the sink unless they are considered toxic, in which case they are disposed of at an approved site.

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5 CHEMISTRY ANALYTICAL (LABORATORY) PROGRAM

Chemical analysis of the 10 water samples retrieved with the designated project area, were conducted by ESL and IAG. Table 3 below shows the 2 laboratories that conducted the analysis and the parameters that were done by each. The respective laboratory certificates of accreditation are provided in Appendix 2.

Table 3: Summary of the Sediment Quality Parameters analysed Offshore Guyana, (October 2017)

Name of Laboratory	Type of data	Parameter Analysed
IAG	Sediment Quality - Chemistry	Total & Bioavailable Cadmium
		Total & Bioavailable Copper
		Total & Bioavailable Chromium
		Total & Bioavailable Iron
		Total & Bioavailable Nickel
		Total & Bioavailable Lead
		Total & Bioavailable Selenium
		Total & Bioavailable Zinc
		Total & Bioavailable Mercury
		Total & Bioavailable Arsenic
		Total & Bioavailable Barium
		Total & Bioavailable Aluminium
		Total Organic Carbon
		% Moisture
		Redox Potential
		PAHs
		Saturated Hydrocarbons
ESL	Sediment Quality	Grain size
		Benthic Macrofauna

5.1 Sediment Quality

The sub-section below presents the analytical methods, list of analytes assessed and their respective detection limits for sediment quality and particle size distribution.

5.1.1 Analytical Methods for Sediment

Table 4 below summarises the analytical methods used for sediment quality analysis, the preservation and storage techniques, holding times as well as the quality assurance/quality control measures executed during the actual analysis. Appendix 10 also provides the analytical methods employed for each parameter analysed herein, as well as the detailed results.

Both the total and bioavailable forms of the understated metals were analysed. Whilst total metals refer to the various forms (pore water, weakly adsorbed, associated with carbonate, associated with iron/manganese oxide, complexed by organics, associated with sulphide, in mineral lattice) of a metal in the environment, only a portion of the total quantity of chemical present is potentially available for uptake by organisms. This concept is referred to as the biological availability (bioavailability) of a chemical. Different sample preparation and extraction methods are used to analyse total and bioavailable metals, respectively.

Samples for total metal analysis were prepared and extracted using USEPA 3050B Acid Digestion of sediments, sludge and soils Rev 2. which entailed digestion of the samples using repeated additions of concentrated nitric acid and hydrogen peroxide. Bioavailable metal analysis adapted a method which involved a dry weight sample of 10g that was shaken with 2M nitric, 0.05M EDTA with 0.1M $CaCl_2$ for one hour before analysis (Alibrahim 2016). Total and bioavailable concentration of all metals (except mercury) were analysed using USEPA 846 6010B. Total and bioavailable mercury was analysed using USEPA 846 7470A.

Table 4: Summary of Analytical Test Methods for Sediment Chemical Analyses

PARAMETER	TEST PROCEDURE	STORAGE AND HOLDING TIME	Detection Limits	QC Acceptance Limit	QA/QC DETAILS REQUIRED	LAB ANALYZING
Total Chromium (mg/kg)	SW 846 6010B	Store at 4^0C for up to 6 months	1.2 -2.5	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Cadmium (mg/kg)	SW 846 6010B		0.59 - 1.2	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Nickel (mg/kg)	SW 846 6010B		0.59 - 1.2	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Copper (mg/kg)	SW 846 6010B		1.2 - 2.5	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Iron (mg/kg)	SW 846 6010B		12 -25	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Zinc (mg/kg)	SW 846 6010B		2.4 - 4.9	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Arsenic (mg/kg)	SW 846 6010B		0.59 - 1.2	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Barium (mg/kg)	SW 846 6010B		1.2 - 2.5	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Mercury (mg/kg)	SW 846 7471A		0.017 - 0.031	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Lead (mg/kg)	SW 846 6010B		0.59 - 1.2	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Selenium (mg/kg)	SW846 6010B		1.2 -2.5	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Total Aluminium (mg/kg)	SW 846 6010B		12 -25	85% - 115%	Duplicate, check standard, blank	IAG-Test America

PARAMETER	TEST PROCEDURE	STORAGE AND HOLDING TIME	Detection Limits	QC Acceptance Limit	QA/QC DETAILS REQUIRED	LAB ANALYZING
Bioavailable Arsenic (mg/kg)	SW 846 6010B		0.59 - 1.2	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Zinc (mg/kg)	SW 846 6010B		2.4 - 4.9	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Mercury (mg/kg)	SW 846 7471A		0.017 - 0.031	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Chromium (mg/kg)	SW 846 6010B		1.2 - 2.5	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Cadmium (mg/kg)	SW 846 6010B		0.59 - 1.2	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Copper (mg/kg)	SW 846 6010B		1.2 - 2.5	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Lead (mg/kg)	SW 846 6010B		0.59 - 1.2	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Nickel (mg/kg)	SW 846 6010B		0.59 - 1.2	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Barium (mg/kg)	SW 846 6010B		1.2 - 2.5	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Selenium mg/kg	SW 846 6010B		1.2 - 2.5	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Iron (mg/kg)	SW 846 6010B		12 -25	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Bioavailable Aluminium (mg/kg)	SW 846 6010B		12 -25	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Saturated Hydrocarbons	USEPA 8015 C	Store at 4^0C for up to 28 days	N/A	85% - 115%	Duplicate, blank, check standard, spike	ALS Environmental

PARAMETER	TEST PROCEDURE	STORAGE AND HOLDING TIME	Detection Limits	QC Acceptance Limit	QA/QC DETAILS REQUIRED	LAB ANALYZING
Percent Moisture %	ASTM D2216 - 10	Store at 4^0C for up to 28 days	0.01	85% - 115%	Duplicate, Blank, Standard	IAG-Test America
Poly Aromatic Hydrocarbons (mg/kg)	SW856 8270C	Store at 4^0C for up to 28 days	0.42 - 0.83	85% - 115%	Duplicate, check standard, blank	IAG-Test America
Full Particle Size Distribution	<63µm Sieve Analysis Method	Store at 4^0C for up to 6 months	N/A	85% - 115%	N/A	ESL
TOC (mg/kg)	MSA Walkley Black	Store at 4^0C for up to 28 days	0.1	85% - 115%	Duplicate, check standard, blank	IAG-Test America

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5.1.2 Sediment Chemistry Analyte Listing

Table 5 below presents the complete list of sediment analytes and their respective detection limits for the Esso Guyana, Offshore Project – Phase 2.

Table 5: Summary of Analytes and their Detection Limits

Name of Laboratory	Analyte	Detection Limits (mg/kg)
IAG	Total Cadmium	0.59 – 1.20
	Total Copper	1.20 – 2.50
	Total Chromium	1.20 – 2.50
	Total Iron	12.00 – 25.00
	Total Nickel	0.59 – 1.20
	Total Lead	0.59 – 1.20
	Total Selenium	1.20 – 2.50
	Total Zinc	2.40 – 4.90
	Total Mercury	0.017 – 0.031
	Total Arsenic	0.59 – 1.20
	Total Barium	1.20 – 2.50
	Total Aluminium	12.00 – 25.00
	Bioavailable Cadmium	0.59 – 1.20
	Bioavailable Copper	1.20 – 2.50
	Bioavailable Chromium	1.20 – 2.50
	Bioavailable Iron	12.00 – 25.00
	Bioavailable Nickel	0.59 – 1.20
	Bioavailable Lead	0.59 – 1.20
	Bioavailable Selenium	1.20 – 2.50
	Bioavailable Zinc	2.40 – 4.90
	Bioavailable Mercury	0.017 – 0.031
	Bioavailable Arsenic	0.59 – 1.20
	Bioavailable Barium	1.20 – 2.50
	Bioavailable Aluminium	12.00 – 25.00
	Total Organic Carbon	0.10
	% Moisture	0.01
	Pinpoint® Redox Potential	-2,000 - +2,000 mV
	Total PAHs	0.42 – 0.83
	Saturated Hydrocarbons	NA
ESL	Grain Size	NA

NA – Not applicable

5.1.3 Particle Size Distribution

Sediment samples were classified based on the fraction % of sand, silt and clay particles with the dominant fraction having a major influence on the overall soil type. The D-Plot software was used to generate the graphs and soil type triangles presented in the Grain Size lab report (see Appendix 9).

5.2 Benthic Macrofauna Assessment

Table 6 below provides a summary of ESL's Benthic methodology employed during the EBS along the Continental Shelf, offshore Guyana.

Table 6: Summary of Methods for ESL Post Drill Survey

Aspect	ESL Sampling Event (October 2017)
Sampling Objective	To determine community structure and identify dominant taxa
No. of Stations Sampled	10 Stations along the Continental Shelf outside Liza Area of Interest
No. of Replicates	3
Type of Grab	Van Veen grab (0.1 m^2)
Size of Sieve	0.5 mm^2
Method of Preservation	10% Formalin buffered with sodium borate
Rose Bengal used	No
Washing Procedure	Thoroughly washed, collected in sieve and placed in container
Other Information	Benthic specimens retrieved were then identified to the Lowest Practical Identification Level (LPIL)* (see Appendix 11)

Subsequent to the methodology outlined above, benthic macrofaunal taxonomic and abundance data were compiled in MS Excel® and PRIMER, for univariate and multivariate analyses, with the latter taking abiotic environmental factors into account.

6 RESULTS & DISCUSSION

6.1 Data Analysis, Management & Reporting

This Section presents the results and discussion of the sediment sampling conducted along the Continental Shelf within the study area. A total of 10 stations were obtained, giving a total of 10 samples for grain size analysis and chemical analyses and 30 for benthic macrofauna.

For sediment grain size and chemical analyses, the results were obtained in raw format, as analytical results formulated into worksheets. The analytical worksheet values and graphics were QA/QC'ed internally and inputted into an MS Word format which served as ESL's Grain Size Analysis and Analytical Lab Reports (Appendices 7 and 8, respectively). In the case of the latter, QA/QC'ed reports generated by IAG were used to obtain the results for the sub-contracted parameters, and these values were integrated into ESL's lab report.

For benthic macrofauna, the specimens were identified to the genus and species level, and taxonomic data inclusive of abundance data was collated into an MS Excel spreadsheet for further analyses in MS Excel and the statistical analysis program, PRIMER. These results were then formulated into a benthic assessment report which is presented in Section 6.4 below.

The afore-mentioned lab reports were submitted to ESL's Technical Team who was responsible for generating the formulated results and discussion presented in Sections 6.2 and 6.3 below. Analytical results presented in ESL's reports were imported into MS Excel. Each parameter was analysed using statistical calculations of the range, average and standard deviations in 2 ways: (i) considering all values across the shelf area; and (ii) with distance from the shoreline (where deeper water depths correlate to increasing distance from the shore).

The summary data are presented in a tabular format, and, where applicable and suitable, the data are also presented in a graphical format. Given that this is an environmental baseline assessment, the discussion serves to present the baseline conditions within the sediment sampled across the study area in October 2017, and so, there is limited comparative analysis. In fact, the only comparison which is made is that of the levels of total metals to their respective USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Benchmarks (USEPA 2006), to give an indication of the levels of these parameters at which there may be potential adverse effect on various components of the environment (USEPA 2006).

A concluding statement is provided at the end of this section. All citations are listed according to the Chicago Style Manual in Chapter 8 (References & Bibliography).

Reference is also made throughout the discussion to relevant appendices, which are contained in Chapter 9 of this report (Supporting Documentation).

6.2 Sediment Grain Size

Table 7 below presents the findings of the grain size analysis conducted on the 10 shelf sediment samples retrieved in October 2017. Figure 3 is a graphical representation of these results. The data revealed that the predominant fraction at stations varied, leading to a range of soil classifications, including clay to a mix of clay, sand and loam (see Table 7 below). Clay was found to be the predominant fraction in 5 of the 10 stations, whilst sand was predominant at 3 stations, and silt at 2.

Table 8 below shows high standard deviations for all fractions, indicating high variability within the dataset (see Figure 3 below). The figure also shows that the clay fraction generally tended to decrease with distance from the shore (the exception being the high clay content in sediment sampled at Station 16 in 67 m depth). Likewise, the sand fraction tended to increase with distance from the shore, and the silt fraction was highest within the depth range 25 – 42 m (see Figure 3 below).

Table 7: Sediment Grain Size Results at the Shelf Stations (October 2017)

Depth (m)	Station No.	Sand Fraction (%)	Clay Fraction (%)	Silt Fraction (%)	Predominant Fraction	USDA Soil Classification
98	**15**	62.15	29.03	8.82	Sand	Sandy Clay Loam
67	**16**	7.14	92.38	0.48	Clay	Clay
60	**17**	68.47	17.89	13.64	Sand	Sandy Loam
50	**18**	63.49	17.72	18.79	Sand	Sandy Loam
42	**19**	24.97	41.39	33.64	Clay	Clay
31	**20**	16.92	31.36	51.72	Silt	Silty Clay Loam
25	**21**	21.11	30.58	48.31	Silt	Clay Loam
18	**22**	0.61	91.74	7.65	Clay	Clay
20	**23**	0.36	99.52	0.12	Clay	Clay
26	**24**	34.66	39.62	25.72	Clay	Clay Loam

Table 8: Comparison of Average Fractions (with Standard Deviation) across the Shelf Stations (October 2017)

Statistic	Sand Fraction (%)	Clay Fraction (%)	Silt Fraction (%)
Average	29.99	49.12	20.89
Standard Deviation	± 26.241	± 32.321	± 18.602

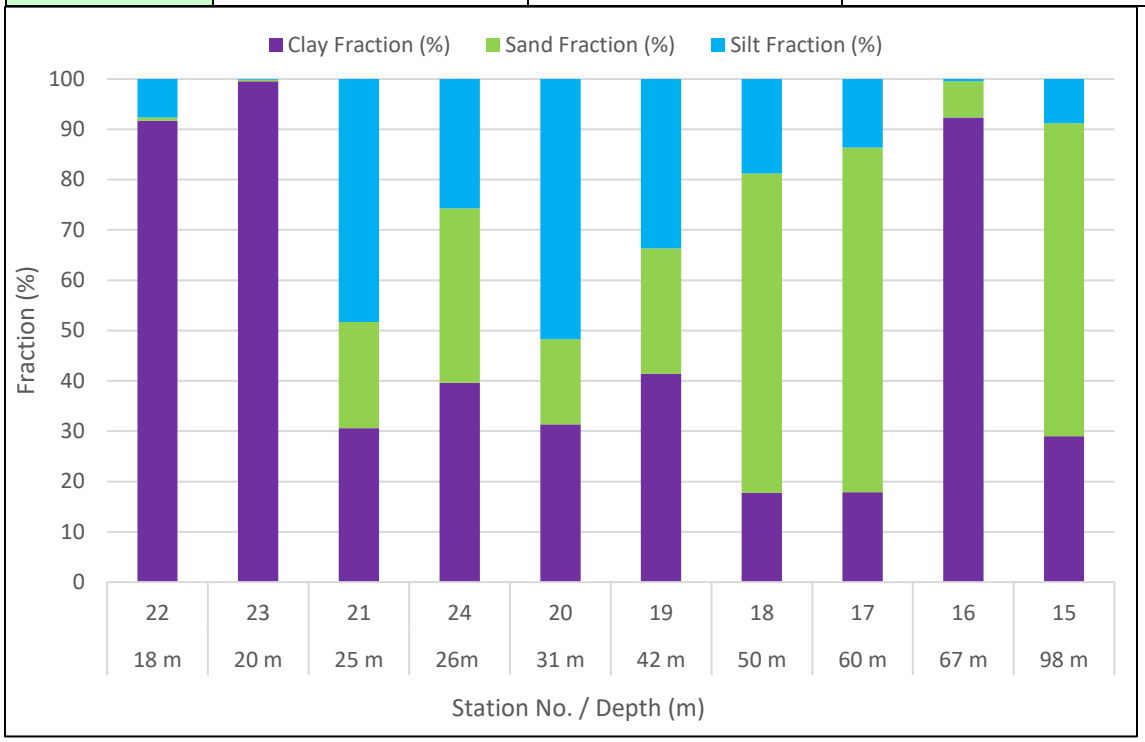


Figure 3: Comparison of Sediment Fractions (%) across the 10 Shelf Stations (October 2017)

6.3 Sediment Chemistry

Table 9 presents a summary of the range and average (with standard deviation) of the parameters tested in the sediment samples retrieved at the 10 shelf stations (18 – 98 m water depth) during October 26th – 27th, 2017 (see Appendix 10 for detailed results). PAHs and total and bioavailable forms of the metals, cadmium, selenium and mercury were below the detectable limit (BDL) at all stations sampled. The bioavailable forms of the metals; copper, chromium, iron, nickel, lead, zinc, barium, aluminium and arsenic were BDL at all stations, despite being detected in the total form. In the case of the latter 2 (aluminium and arsenic), the bioavailable form was detected at one or two stations. As a result of the foregoing, it was not possible to calculate the average value of the above-mentioned parameters.

Table 9: Range & Average Values for Shelf Sediment Stations (October 2017; Baseline)

Parameter (mg/kg)*	Range	Average ± Standard Deviation	USEPA Benchmark (mg/kg)	ERM value (mg/kg)
PAHs	BDL	-	-	-
TOC (%)	BDL – 0.65	0.33 ± 0.202	-	-
Moisture (%)	22.10 – 38.60	27.36 ± 5.912	-	-
Redox Potential (mV)	178.00 – 256.00	210.90 ± 23.187	-	-
Total Cadmium	BDL	-	0.68	9.60
Bioavailable Cadmium	BDL	-	-	-
Total Copper	BDL – 6.70	3.08 ± 2.130	18.70	270.00
Bioavailable Copper	BDL	-	-	-
Total Chromium	7.70 – 24.00	14.51 ± 4.969	52.30	370.00
Bioavailable Chromium	BDL	-	-	-
Total Iron	8,900.00 – 35,000.00	20,720.00 ± 9,577.265	-	-
Bioavailable Iron	BDL	-	-	-
Total Nickel	8.85 – 15.00	8.58 ± 4.072	15.90	51.60
Bioavailable Nickel	BDL	-	-	-
Total Selenium	BDL	-	-	-
Bioavailable Selenium	BDL	-	-	-
Total Aluminium	2,900.00 - 13,000.00	6,510.00 ± 3,613.693	-	-
Bioavailable Aluminium	BDL – 20.00	-	-	-
Total Lead	3.80 – 14.00	7.83 ± 3.994	30.20	218.00
Bioavailable Lead	BDL	-	-	-
Total Zinc	11.00 – 55.00	29.30 ± 15.959	124.00	410.00
Bioavailable Zinc	BDL	-	-	-
Total Mercury	BDL	-	0.13	0.71
Bioavailable Mercury	BDL	-	-	-

Parameter (mg/kg)*	Range	Average ± Standard Deviation	USEPA Benchmark (mg/kg)	ERM value (mg/kg)
Total Arsenic	3.20 – 50.00	15.00 ± 14.141	12.50	70.00
Bioavailable Arsenic	BDL – 1.30	-	-	-
Total Barium	3.50 – 16.00	7.48 ± 4.736	-	-
Bioavailable Barium	BDL	-	-	-
Saturated Hydrocarbons	BDL – 10.00	-	-	-

** The unit of measure is mg/kg unless otherwise specified in the table.*
- Value not calculable for Average / Standard deviation

TOC was detected at 9 of the 10 shelf stations, being BDL at Station 18 (50 m depth). Where detected, it ranged from 0.11 – 0.65%, with an average value of 0.33 ± 0.202%, the standard deviation indicating considerable variability within the dataset (Figure 4 below). There was no apparent trend with TOC levels and distance from shoreline and or depth as the highest TOC levels were detected at the stations closest (Station 22) and furthest (Station 15) to the shoreline. This is most likely attributable to the high standard deviation within the TOC dataset shown in Figure 4 below.

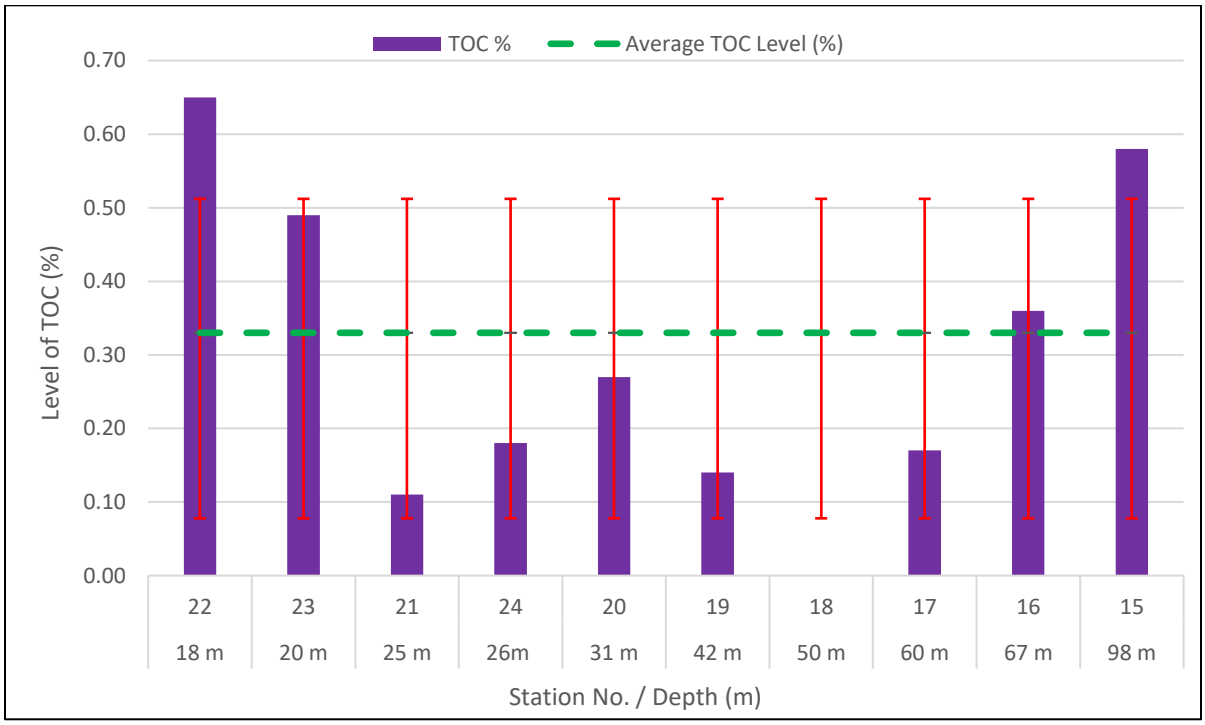


Figure 4: Changes in the Levels of TOC (%) with Distance from the Shore (October 2017)

Numerous sources also indicate that there is a correlation between the level of sediment TOC and the size of the predominant sediment fraction. Specifically, it has been found that TOC increases with fine sedimentary fractions, specifically clay (Lazar *et al*. 2012; Seiter *et al.* 2004; Koster and Meyer-Reil 2001; Burone *et al.* 2003; Gao *et al.* 2012). This may be explained by fine particles' ability to prevent oxygen diffusion in sediments, thereby preserving organic matter and organic particle adsorption onto the surface of clays (Lazar *et al.* 2012). Another factor to take into account is the higher sediment surface to volume ratio of finer sediments, which means that there is a greater surface area to which organic particles can adhere. Figure 5 below shows that the for the October 2017 dataset, the levels of

TOC and the % size of the clay fraction behaved in a similar manner, corroborating the findings of the various studies quoted above.

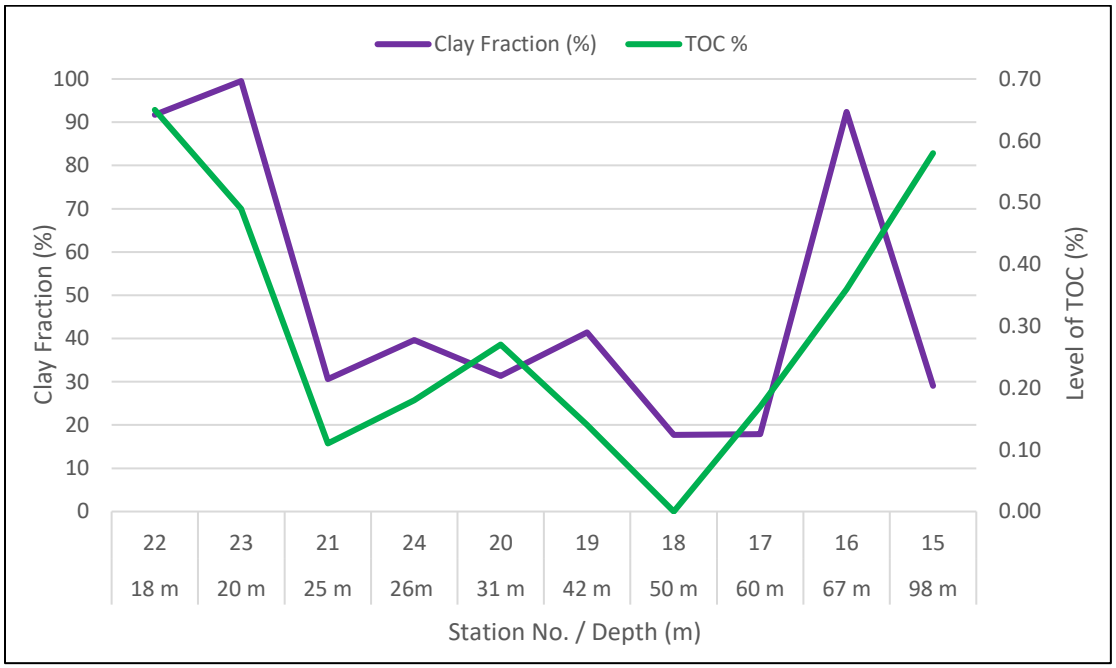


Figure 5: Comparison of the Levels of TOC (%) and Size of the Clay Fraction (%) with Distance from the Shore (October 2017)

Levels of sediment moisture ranged from 22.10 – 38.60%, with an average value of 27.36 ± 5.912% (Figure 6 below); there was limited variability within the dataset, with the highest value occurring at Station 23, 20 m from the shoreline and the lowest at Station 16, 67 m from the shoreline (see Table 9 above). As such, there was no significant relationship between sediment moisture and depth.

The water content of marine sediments is an important fundamental physical property, which is highly variable, whose volume is dependent on particle size and type, as well as the physico-chemistry of the sediment. Temporal and spatial changes may occur in sediment porosity and hence water content, due to activities or processes impacting sediment over the long or short term. The level of organic content also influences water content (Bennett *et al.* 1990).

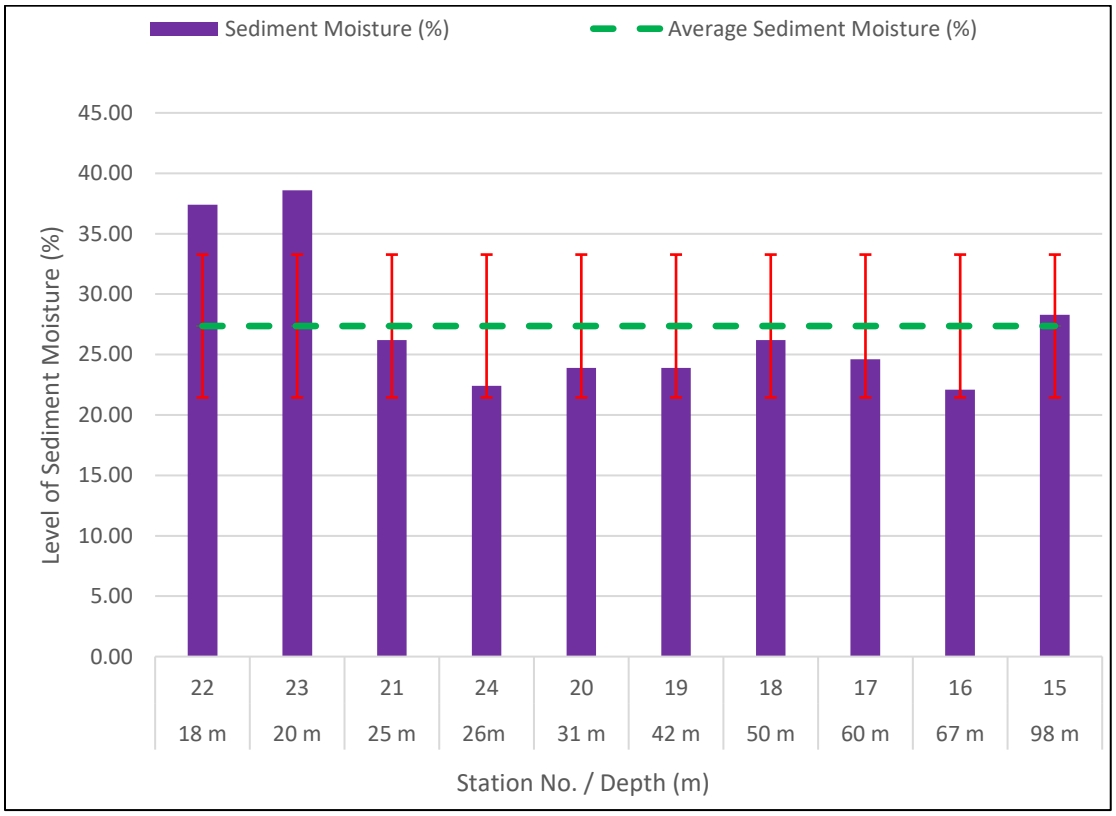


Figure 6: Changes in the Levels of Sediment Moisture (%) with Distance from the Shore (October 2017)

Total copper was detected at 8 of the 10 shelf stations in October 2017; it was BDL at Stations 16 and 18, in approximately 67 m and 50 m water depths, respectively. Where detected, values ranged from 1.30 – 6.70 mg/kg, with an average value of 3.08 ± 2.130 mg/kg, the high standard deviation value indicating the variability in the dataset (see Table 9 above). The highest values were detected at Stations 22 and 23, whilst lower values occurred at the other 6 stations (Figure 7 below). As indicated previously, bioavailable copper was undetected at the shelf stations sampled in October 2017. The values of total copper detected did not exceed the USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Benchmark of 18.7 mg/kg (USEPA 2006) nor its ERM value of 270 mg/kg.

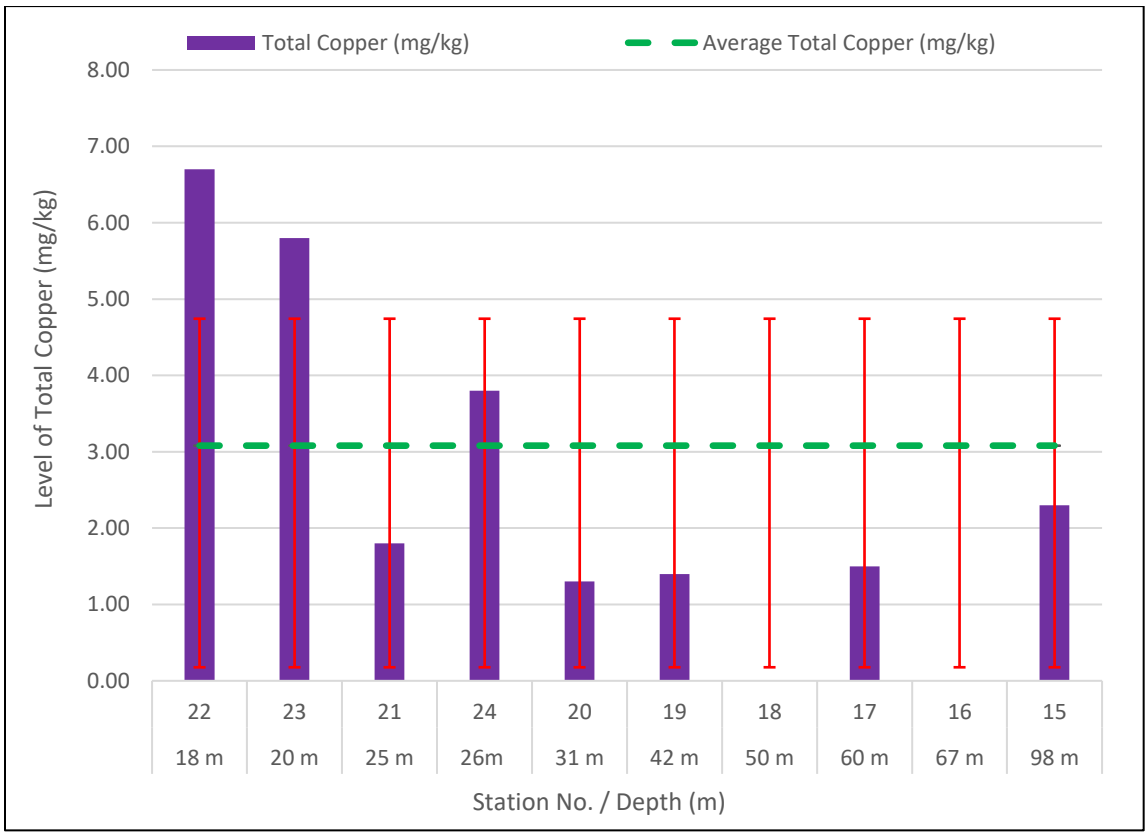


Figure 7: Changes in the Levels of Total Copper (mg/kg) with Distance from the Shore (October 2017)

Total chromium was detected at all 10 shelf stations sampled in October 2017, and ranged from 7.7 – 24.0 mg/kg, with an average value of 14.51 ± 4.969 mg/kg (see Table 9 above). The highest value was recorded at Station 15, which is located furthest from the shore, at a depth of approximately 98 m. Levels of total chromium varied with depth, with the majority of stations recording below average values (Figure 8 below). The values of total chromium detected did not exceed the its USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Benchmark of 52.30 mg/kg (USEPA 2006) or its ERM value of 370 mg/kg, further the bioavailable form was BDL at all 10 shelf stations in October 2017.

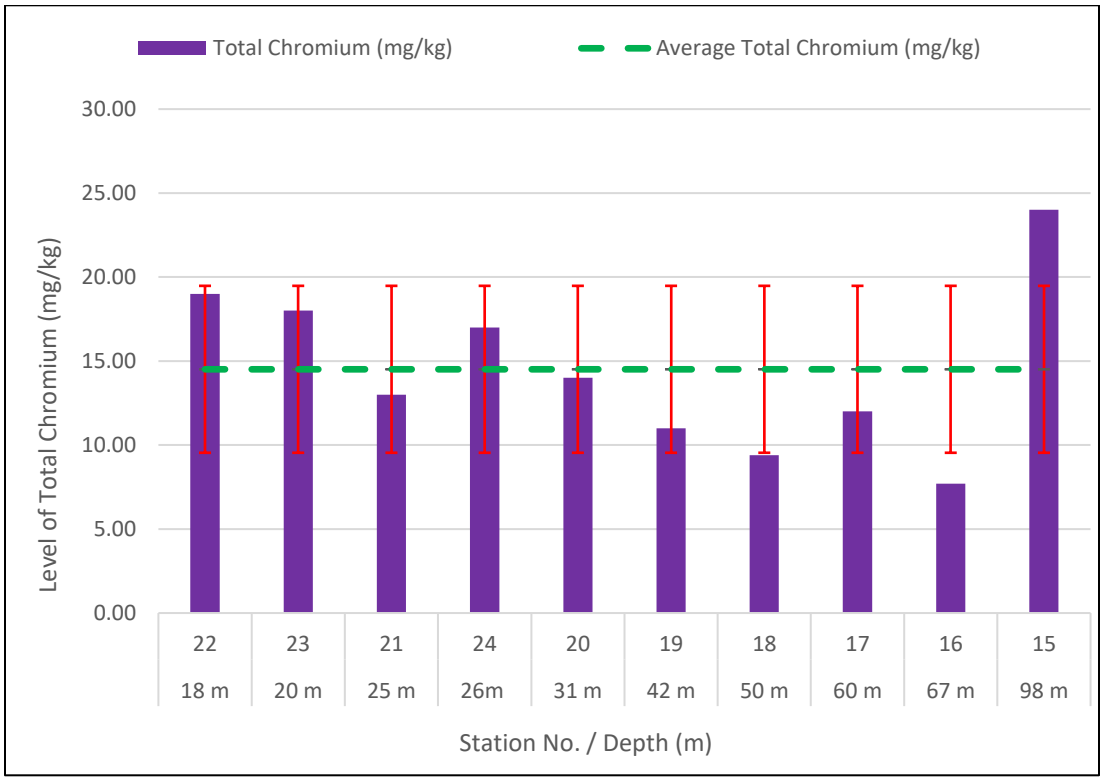


Figure 8: Changes in the Levels of Total Chromium (mg/kg) with Distance from the Shore (October 2017)

Total iron was detected at all 10 shelf stations sampled in October 2017, and ranged from 8,900.00 – 35,000.00 mg/kg, with an average value of 20,720.00 ± 9,577.26 mg/kg (see Table 9 above). Similar to total chromium, the highest value was recorded at Station 15. A closer look at total iron levels revealed that a strong positive correlation existed with that of total chromium, which may be due to similar geochemical properties, such as size and valency with respect to sorption potential (Péter *et al.* 2014). Figure 9 below also shows that the levels of total iron were lower than the average value at 5 of the 10 stations analysed. As mentioned prior, iron did not occur in the bioavailable form at any of the shelf stations sampled in October 2017. There is no USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Benchmark (USEPA 2006) or ERM value for total iron and so this precluded further comparisons.

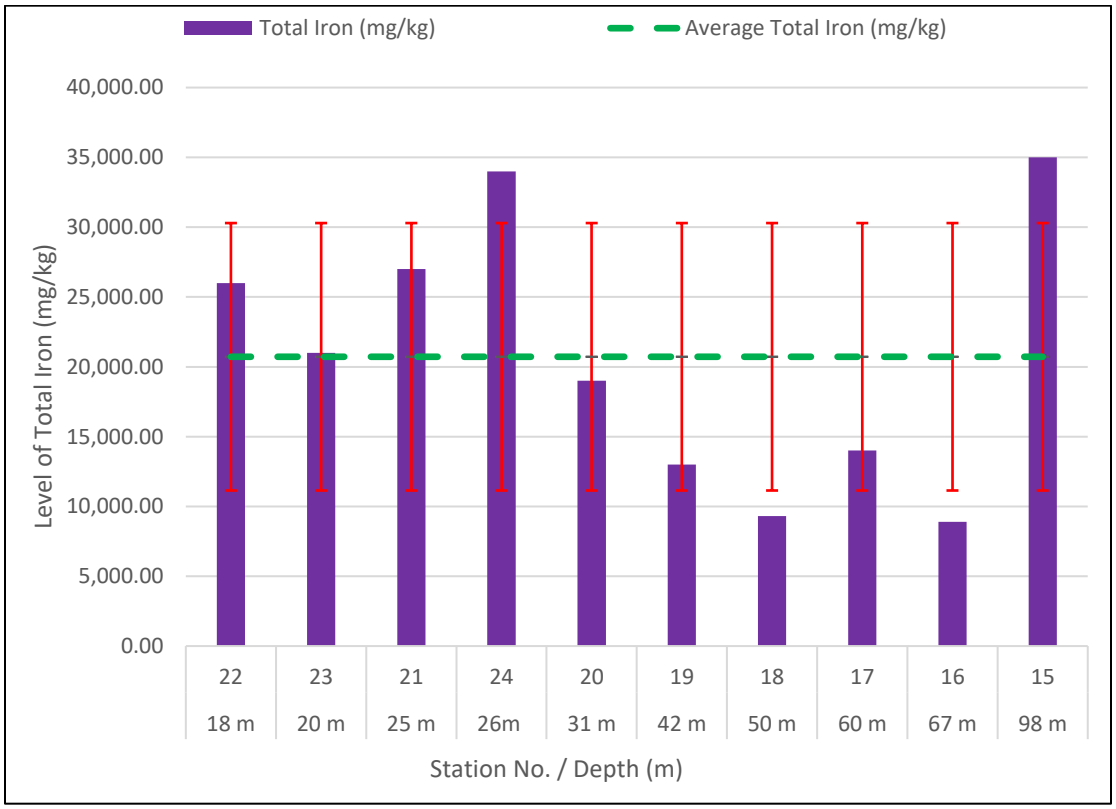


Figure 9: Changes in the Levels of Total Iron (mg/kg) with Distance from the Shore (October 2017)

Total nickel was detected at all shelf stations sampled in October 2017. Values ranged from 3.80 - 15.00 mg/kg, with an average value of 8.58 ± 4.072 mg/kg, the standard deviation value indicating high variability in the dataset (see Table 9 above). Figure 10 shows that total nickel was higher at Stations 22, 21 and 24) as compared to the majority of stations that recorded values below the average value. The bioavailable form was not detected at any stations sampled in October 2017. None of the values of the total form exceeded the USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Benchmark (15.9 mg/kg; see Figure 10 below) or its ERM value of 51.6 mg/kg for total nickel.

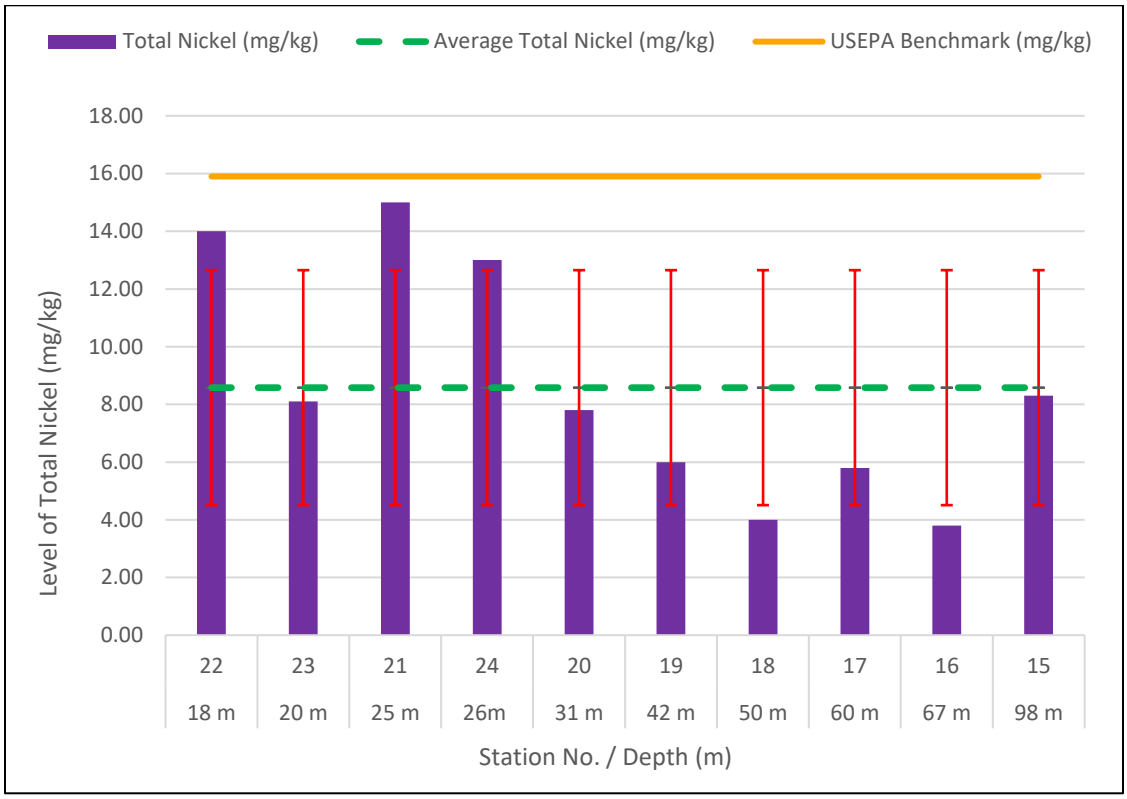


Figure 10: Changes in the Levels of Total Nickel (mg/kg) with Distance from the Shore (October 2017)

Total aluminium was detected at all shelf stations sampled in October 2017. Values ranged from 2,900.00 - 13,000.00 mg/kg, with an average value of 6,510.00 ± 3,613.693 mg/kg, the standard deviation value indicating high variability in the dataset (see Table 9 above). Figure 11 shows that total aluminium was higher as the same stations as that of total nickel (Stations 22, 21 and 24), whilst the other 7 stations were observed to be lower than the average total aluminium value of 2017.

The bioavailable form was detected at 2 stations sampled in October 2017, Stations 22 and 24, at levels of 14.00 mg/kg and 20.00 mg/kg, respectively (both occurrences of which were in water depths (18 m and 26 m, respectively). There is no USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Benchmark or an ERM value for total aluminium (USEPA 2006), and so this precluded further comparisons.

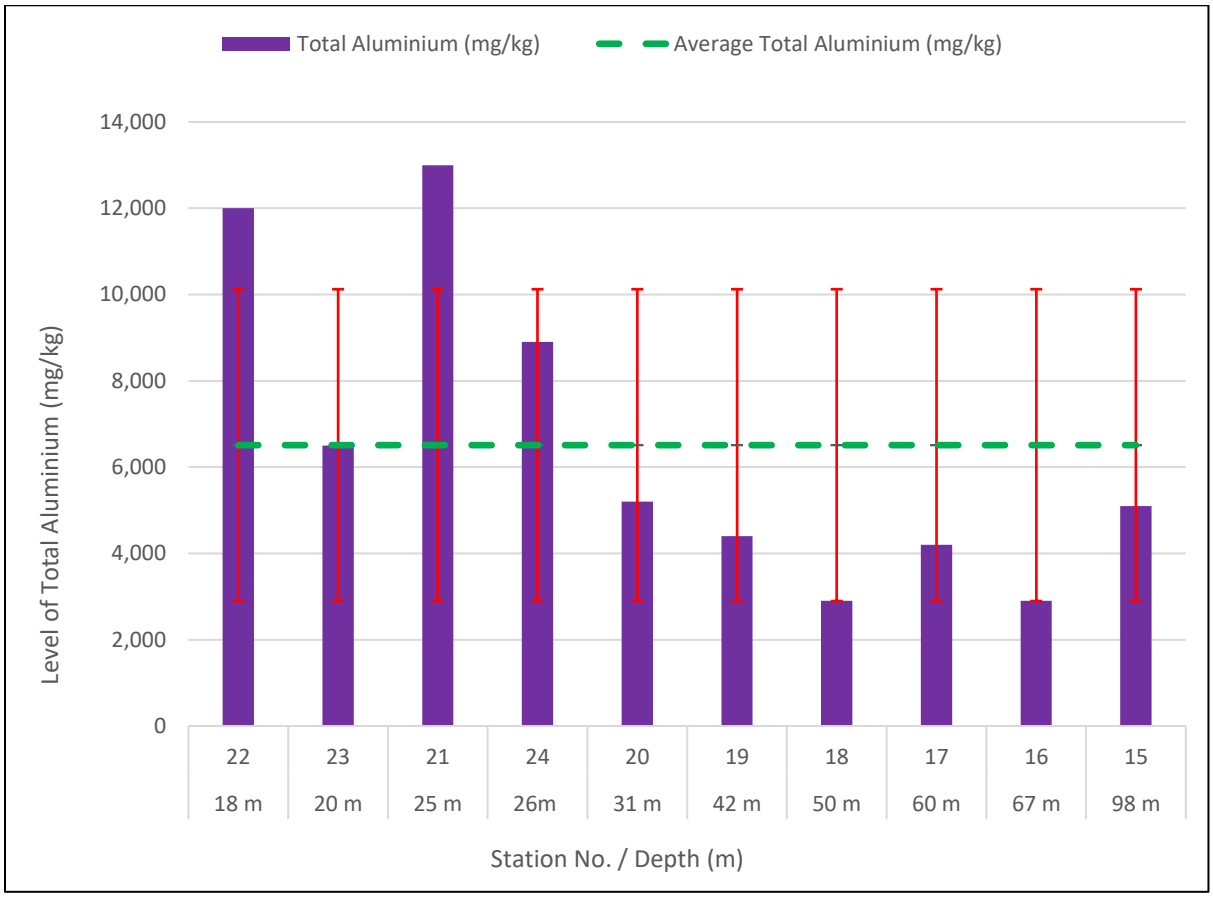


Figure 11: Changes in the Levels of Total Aluminium (mg/kg) with Distance from the Shore (October 2017)

Total lead was detected at all shelf stations sampled in October 2017. Values ranged from 3.80 – 14.00 mg/kg, with an average value of 7.83 ± 3.994 mg/kg (see Table 9 above). The levels of this parameter behaved almost identically to those of total nickel and total aluminium; values were higher at Stations 22, 21 and 24, as compared to the other 7 stations analysed with a high standard deviation indicating variability within the dataset (Figure 12 below). A strong positive linear correlation was observed between total lead and total aluminium. The bioavailable form was not detected at any of the stations, nor did the values of the total form exceed the USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Benchmark (30.2 mg/kg) or its ERM value (218 mg/kg) for total lead.

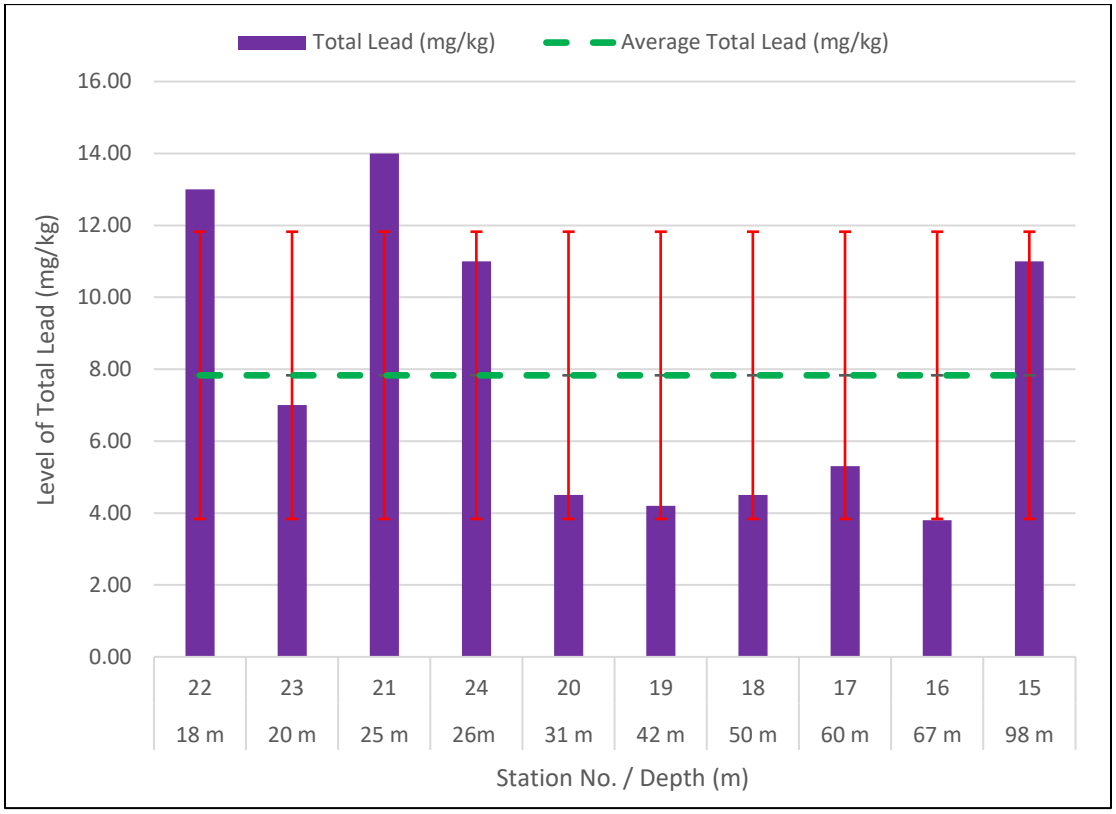


Figure 12: Changes in the Levels of Total Lead (mg/kg) with Distance from the Shore (October 2017)

Total zinc was detected at all 10 shelf stations sampled in October 2017, with values ranging from 11.00 – 55.00 mg/kg, and an average value of 29.30 ± 15.959 mg/kg (see Table 9 above). The variability of the dataset is shown by the high standard deviation (Figure 13 below). The figure also shows that the levels of total zinc were higher at Stations 22, 21 and 24 and lower at the other 7 stations, with a significant variation in the values (see Figure 13 below). As with the majority of the metals tested, the bioavailable form was not detected at any of the stations. The values of the total form also did not exceed neither the USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Benchmark (124.0 mg/kg) nor its ERM value (410 mg/kg) for total zinc.

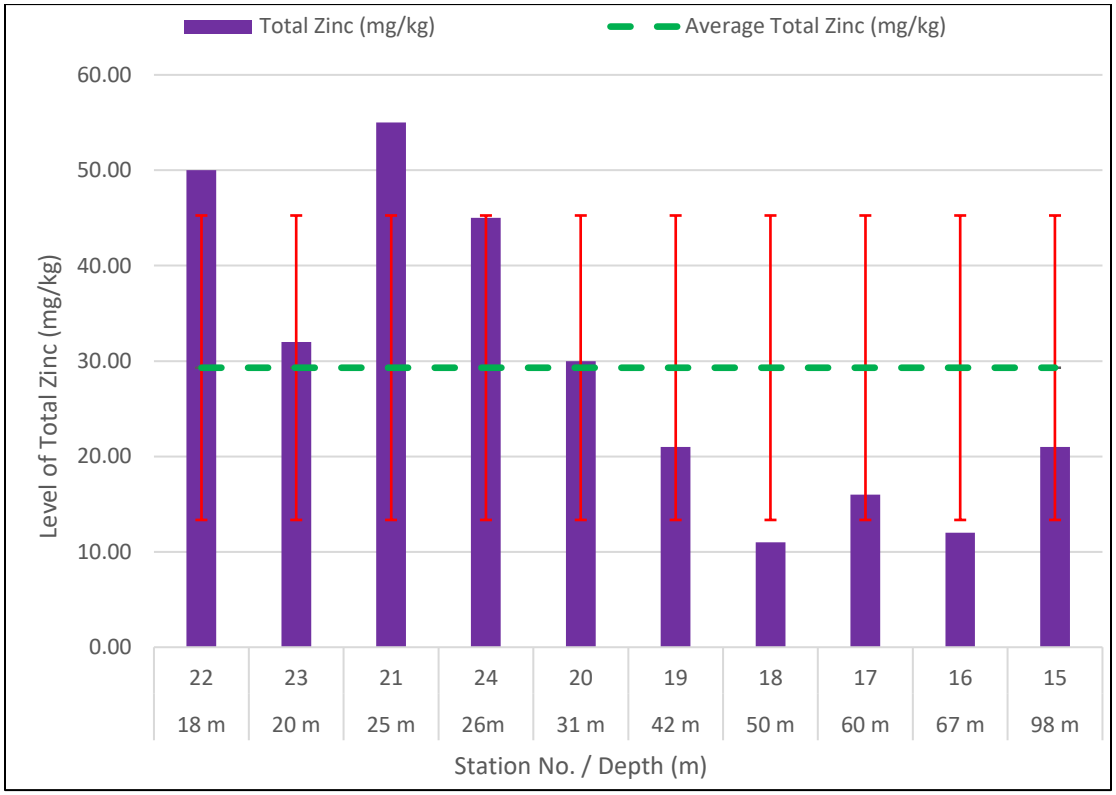


Figure 13: Changes in the Levels of Total Zinc (mg/kg) with Distance from the Shore (October 2017)

Total arsenic was detected at all 10 shelf stations sampled in October 2017, with values ranging from 3.20 – 50.00 mg/kg, and an average value of 15.00 ± 14.141 mg/kg (see Table 9 above). The dataset was highly variable, as shown by the standard deviation value (Figure 14 below). The highest value of total arsenic occurred at Station 15. This value and another detected at Station 24 (29.90 mg/kg) drove the variability observed of total arsenic, with significantly lower values at the other 8 stations. The higher values detected at Stations 15 and 24 were 6 and 3 times higher (respectively) than the USEPA Benchmark (see Figure 14 below).

When the earlier 2016 background survey of total arsenic and iron were taken into consideration (EEPGL 2016), it was observed that all the values, except that of Station 25 showed a strong positive correlation (Figure 15 below). Station 25 was an obvious outlier indicating possible anthropogenic contamination. A comparison of the 2017 arsenic/iron correlation to that of 2016 further revealed that 7 of the 10 detected values of 2017 were consistent with the background levels recorded in 2016. Thus, the observed variation in total arsenic concentrations at most stations reflect natural background concentrations associated with variation in sediment geochemistry. In contrast, 3 stations (Stations 15, 17 and 24) had higher arsenic to iron ratios (denoted by dashed line in Figure 5). These results are indicative of localised contamination consistent with Station 25 of the 2016 EBS study.

Bioavailable arsenic was detected at only one of the 10 stations, Station 21 (25 m water depth), at a value of 1.30 mg/kg. This corresponded to one of the 8 stations that exceeded the USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Benchmark of 7.24 mg/kg for total arsenic. Given the low probability of detection of bioavailable arsenic (12.5%) and the fact that it is considerably lower than the ERM value for its total form (70 mg/kg), the levels of bioavailable arsenic are not expected to cause adverse impacts to benthos.

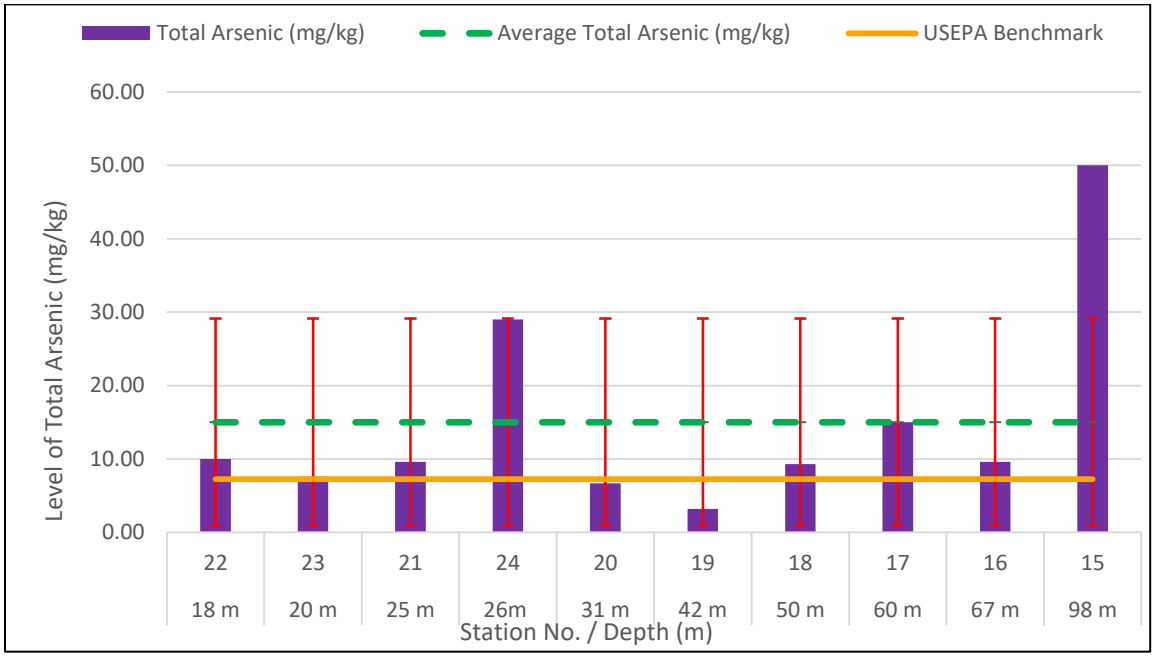


Figure 14: Changes in the Levels of Total Arsenic (mg/kg) with Distance from the Shore (October 2017)

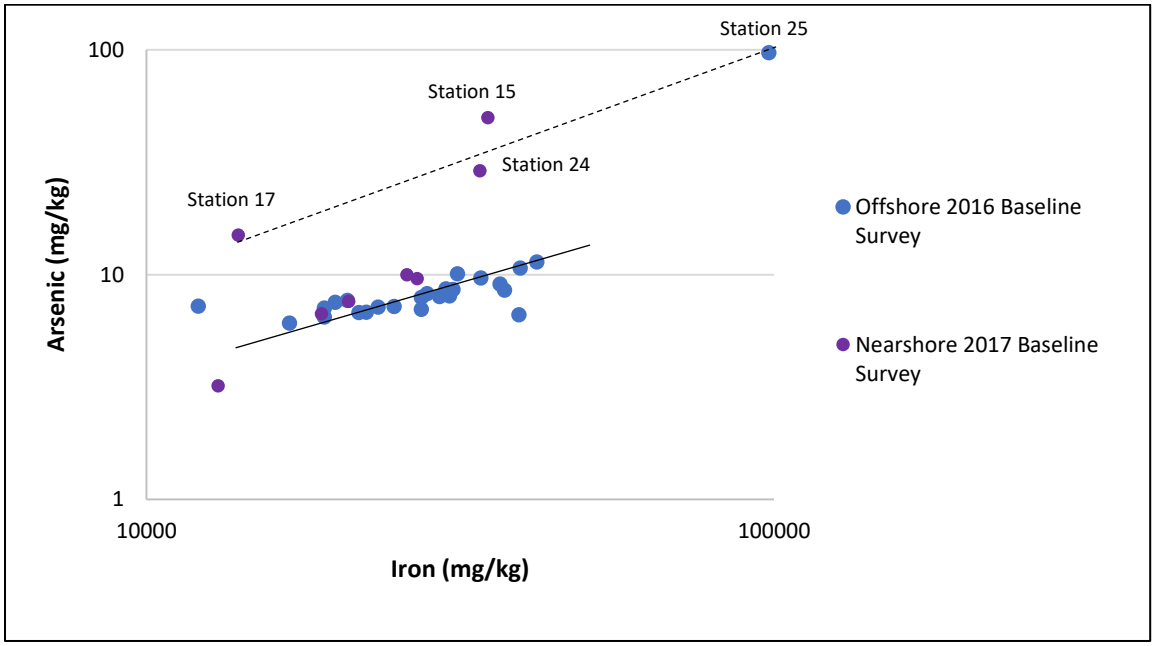


Figure 15: Comparison of Total Arsenic Levels; 2017 EBS to 2016 Background Levels; Solid line indicates stations that reflect natural variability in reported concentrations while dashed line denotes stations that appear to reflect additional anthropogenic contamination sources.

Total barium was detected at all 10 shelf stations sampled in October 2017. Values ranged from 3.50 – 16.00 mg/kg, with an average value of 7.48 ± 4.736 mg/kg (see Table 9 above). The relatively high standard deviation highlights the variability within the dataset, which is shown in Figure 16 below. The data revealed that total barium tended to be higher at Stations 22 and 21, at which the overall average was exceeded, and at each station, the value deviated from the mean by more than one standard deviation. As a consequence, it was observed that total barium levels at the other 8 stations were significantly lower (see Figure 16 below). Bioavailable levels were BDL at all stations sampled, and there are no USEPA Mid-Atlantic Risk Assessment Marine Sediment Screening Benchmark or ERM value for total barium (USEPA 2006), and so this precluded comparison.

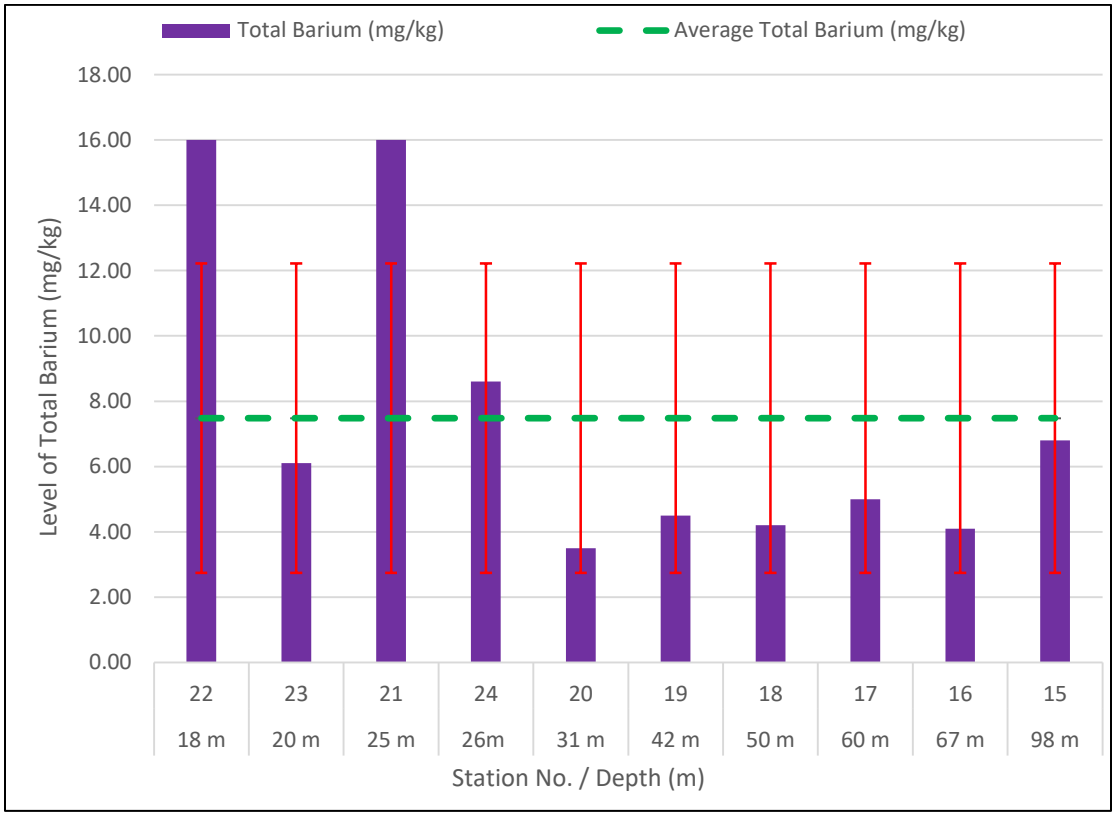


Figure 16: Changes in the Levels of Total Barium (mg/kg) with Distance from the Shore (October 2017)

The redox potential of the shelf sediment sampled in October 2017 ranged from 178.00 – 256.00 mV, with an average value of 210.90 ± 23.187 mV (see Table 9 above). The dataset showed low variability amongst the values (Figure 17 below), as evidenced by the standard deviation value. Overall, there was only a marginal increase in redox potential across the stations, from Station 22 to Station 15(see Figure 17 below).

The oxidation-reduction (redox) state of sediment is the result of the combined effect of biological and chemical processes of reversible and/or irreversible nature (Bågander, 1978). Redox reactions control organic-matter oxidation and element cycling in aquatic ecosystems (Schlesinger and Bernhardt 2013). Redox conditions in surface sediments depend on the degree of organic enrichment (Zobell 1946). Organic enrichment of sediments usually leads to reduced conditions which equate to "poor" sediment quality (i.e. low dissolved oxygen and elevated ammonia or sulphide concentrations), wherein natural benthic communities undergo substantial changes (ECASA 2004). Negative redox potential values are therefore associated with anoxic conditions, in which the degradation of the organic matter is performed by anaerobic bacteria (ECASA 2004). Since the values detected in October 2017 were positive, it can be inferred that these values indicate oxic conditions within the sediment at the time of sampling.

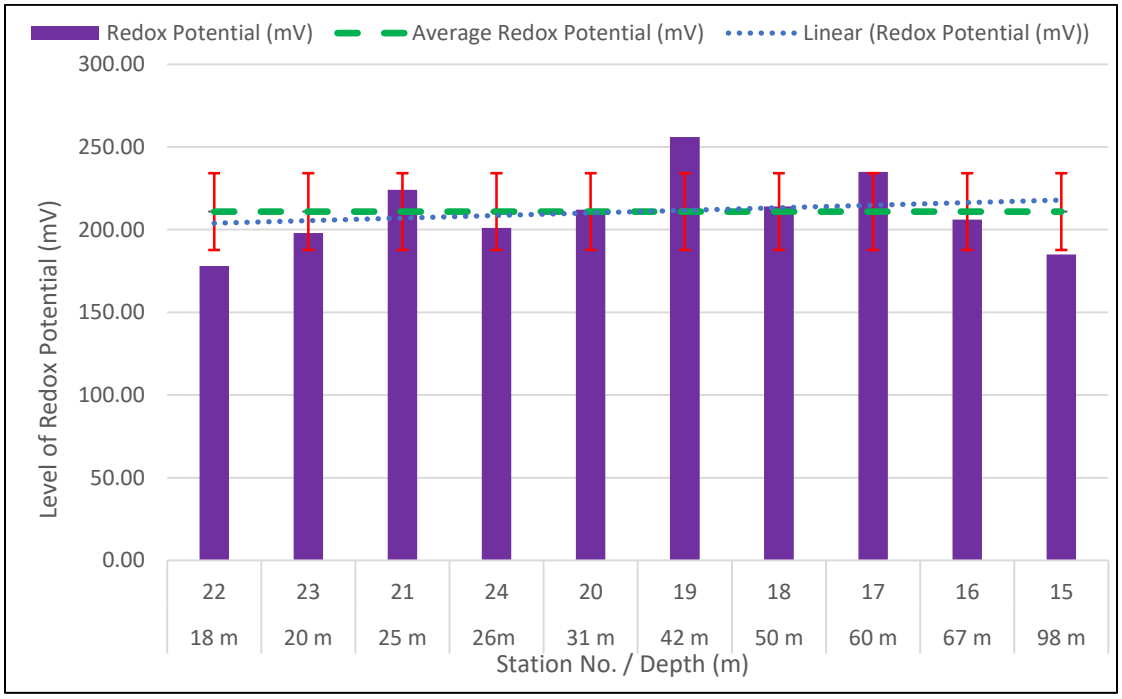


Figure 17: Changes in Redox Potential (mV) with Distance from the Shore (October 2017)

Sediment samples taken at 10 locations were analysed for the full suite of saturated hydrocarbons which constituted a total of 39 individual analytes. Five of the 39 analytes were detected at one or more stations, whilst the remaining 34 analytes were BDL at all 10 stations. Analyte n-Octadecane was detected at one station (Station 19; 0.14 mg/kg), whereas n-Triacontane and total extractable hydrocarbons were both detected at 3 stations each. n-Triacontane was detected at Stations 15, 21 & 24 ranging from 0.17 – 0.31 mg/kg, whilst total extractable hydrocarbons were recorded at Stations 19, 20 & 21 with values in the range of 4.90 – 10.0 mg/kg.

Analyte n-Dotriacontane and n-Hexatriacontane were detected at all 10 stations along the shelf. n-Dotriacontane ranged from 0.17 – 0.26 mg/kg with an average of 0.21 ± 0.0245 mg/kg, whilst n-Hexatriacontane ranged from 0.14 – 0.28 mg/kg with a corresponding average value of 0.20 ± 0.046 mg/kg. All values occurred within one standard deviation of the mean values with the exception of 2 and 3 stations for n-Dotriacontane and n-Hexatriacontane, respectively. Figure 18 below shows that the levels of n-Dotriacontane was highest at Station 19 and lowest at Station 21. Additionally, the values were relatively consistent across the 10 stations regardless of the distance from the shoreline. On the contrary, n-Hexatriacontane was highest at Station 22 (closest to the shoreline) and lowest at Station 20. Levels of n-Hexatriacontane showed 2 instances of a decrease with distance from the shoreline: Station 22 to 20 (18 – 31 m) and Station 19 – 17 (42 – 60 m).

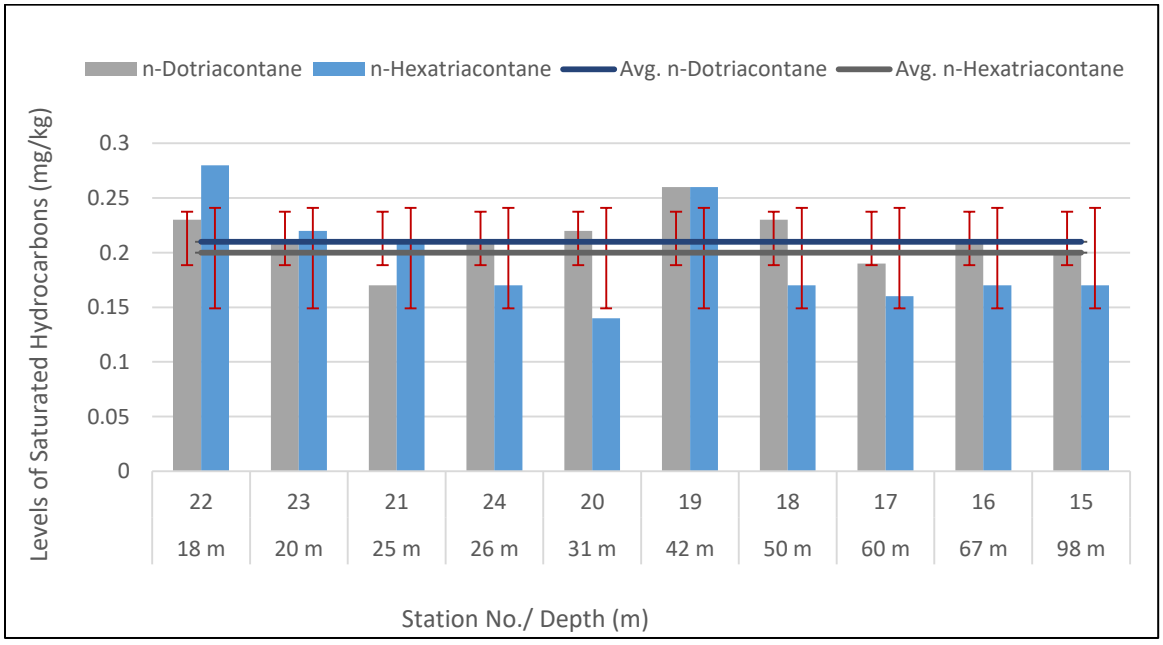


Figure 18: Changes on the Levels of Saturated Hydrocarbons (mg/kg) from the Shore (December 2017)

6.4 Benthic Macrofauna

6.4.1 Introduction

The term '*benthic*' refers to anything associated with or occurring on the bottom of a body of water. The animals and plants that live on or in the bottom are known as the '*benthos'*. Benthic habitats can best be defined as bottom environments with distinct physical, geochemical, and biological characteristics. Benthos is mostly composed of molluscs (gastropods and bivalves), arthropods such as crustaceans, and marine worms (e.g. polychaetes), some of which inhabit both soft-bottom and hard-bottom marine environments. Benthos also includes fauna such as corals (soft and hard) and marine flora such as seagrass beds and macroalgae. For the purposes of this report, soft-bottom dwelling and feeding macroinvertebrates (such as polychaetes, bivalves and gastropods) detected along the Continental Shelf, Guyana, are described. The results below characterise the benthos as part of the environmental baseline shelf assessment of sediment quality.

Marine benthic ecosystems are invaluable from an ecological standpoint; they form complex interactions between various physical parameters (e.g. depth, dissolved oxygen and pH) and biological components of the seabed and the sea. These include predator and prey interactions and fluxes of nutrients and sediments. For example, there may be key inter-relationships between faunas and their habitats. Such interactions may include:

- Physical interactions
- Interactions involving nutrients, Dissolved Organic Matter (DOM) and Particulate Organic Matter (POM) and
- Animal migrations (Ogden and Gladfelter 1982)

Many marine benthic fauna are also considered important because they are bio-indicators of marine ecosystem health. The most susceptible benthic taxa are sessile and sedentary organisms (e.g. corals, sponges, burrowing worms, bivalves, hydroids and bryozoans) because they are unable to avoid impacts from activities which directly affect the seabed (such as the deposition of the cuttings pile associated with drilling activities), leading to the smothering and burial of organisms.

6.4.2 Methodology

The methodology employed for the October 2017 baseline macrobenthic survey is described in Table 10 below. Macrobenthic samples were retrieved in triplicate at each of 10 stations, resulting in a total of 30 samples. The method of grab retrieval was the same as that outlined in ESL's adapted Benthic Methodology (see Appendix 7). In each case, when the grab was retrieved by the winch, checks were made to ensure that the grab was acceptable (see Appendix 7). If deemed acceptable, the sample was collected in a basin and then transferred to the sieve setup (4 mm, 1 mm and 0.5 mm). The sample was then washed gently to remove excess sediment and fixed with 10% formalin buffered with sodium borate, and stored for return to shore. Samples were then washed and sorted at ESL's laboratory, and organisms were identified to the lowest practical identification level (LPIL). ESL's benthic methodology is adapted from Franson *et al.* (2005) Standard Test Method 10500 and is provided in Appendix 7. Appendix 7 also provides ESL's justification for the non-use of Rose Bengal for the processing of benthic samples, as a result of consultations with UK-based international EIA Specialist, Dr. Lynne Barratt and benthic and aquatic specialists Drs. Phil and Anne Smith of the UK-based Aquatonics Limited.

Table 10: Summary of Methods for ESL's Baseline Assessment Survey along the Continental Shelf, Guyana (October 2017)

Aspect	ESL's Baseline Assessment Survey (October 2017)
Sampling Objective	To determine community structure and identify dominant taxa along the Continental Shelf
No. of Stations Sampled	10 stations along Continental Shelf
No. of Replicates	3
Type of Grab	van Veen Grab (0.1 m^2)
Size of Sieve	0.5 mm
Method of Preservation	10% Formalin buffered with sodium borate
Rose Bengal used	No
Washing Procedure	Thoroughly washed, collected in sieve and placed in container
Other Information	Benthic specimens retrieved were then identified to the LPIL*

A summary of the October 2017 baseline assessment survey along the Continental Shelf is presented in Table 11 below, with the complete list referenced in Appendix 11. The high standard deviation values derived in the table above indicate that the number of specimens and taxa recorded per grab and per station were highly variable, with values being spread over a large range.

Table 11: Summary of October 2017 Baseline Assessment Survey

Summary of Baseline Assessment	Result (Baseline; October 2017)
Total # of stations	10
Total # of grabs	3
Total # of specimens	4,101
Total # of taxa (family)	133
Average # of specimens per grab	136.7± 223.09
Range of # of specimens per grab	8 to 932
Average # of taxa (family) per grab	20.4 ± 9.05
Range of # of taxa (family) per grab	4 – 42
Average# of specimens per station	410.1 ± 427.77
Range of # of specimens per station	45 – 1,353
Average # of taxa per station	41.6 ± 12.19
Range of # of taxa per station	20 – 60
Station with highest # of specimens	Station 24 (1,353)
Station with lowest # of specimens	Station 15 (45)
Station with highest # of taxa	Station 18 (60)
Station with lowest # of taxa	Station 15 (20)
Most abundant organism	Chevaliidae (54.79%)
Second most abundant organism	Spionidae (5.04%)

Figure 19 below shows the number of specimens recorded per station, including replicates, in October 2017, from the shallowest (Station 22; 18 m) to deepest Station 15; 98 m) stations along the continental shelf. Stations 24 (26 m), and Station 19 (42 m) recorded the highest and 2nd highest numbers of specimens, respectively. Figure 19 indicates no clear relationship between depth and the number of specimens recorded by station.

This microbenthic assessment attempted to identify organisms to LPIL, however, the analysis of data (including number of taxa, number of specimens and biotic and abiotic assessments within PRIMER) considered taxa at the family level. Figure 20 shows the number of taxa recorded per station, including replicates, from the shallowest to deepest stations along the Continental Shelf. Station 18 (50 m), recorded the highest number of taxa, see Table 11 above). Figure 20 illustrates that there appears to be an increase in the number of taxa with depth from 18 m – 50 m, followed by a decrease in the number of taxa from 50 – 90 m. At the deepest station, Station 15 (98 m), the lowest number of specimens and taxa were recorded. Station depths of 26 m to 60 m, i.e. Stations 24, 20, 19, 18 and 17 indicate the range at which there was the highest number of specimens and taxa.

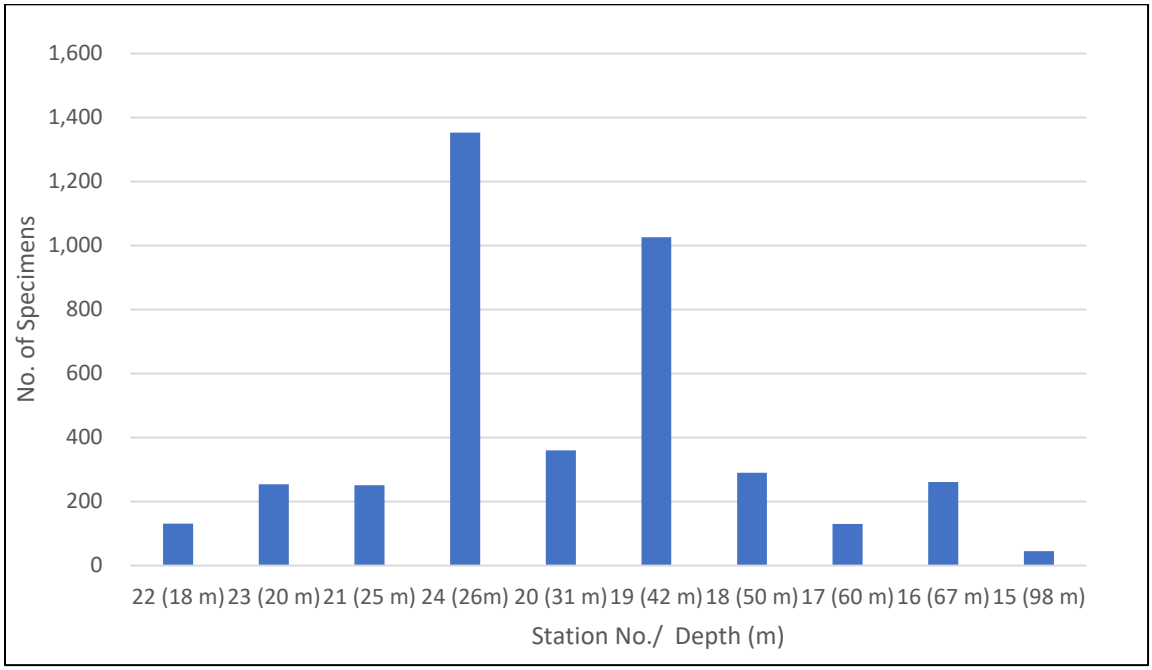


Figure 19: Number of Specimens Recorded (Replicates combined) from Shallowest to Deepest Station Depth for the Baseline Assessment Survey (October 2017)

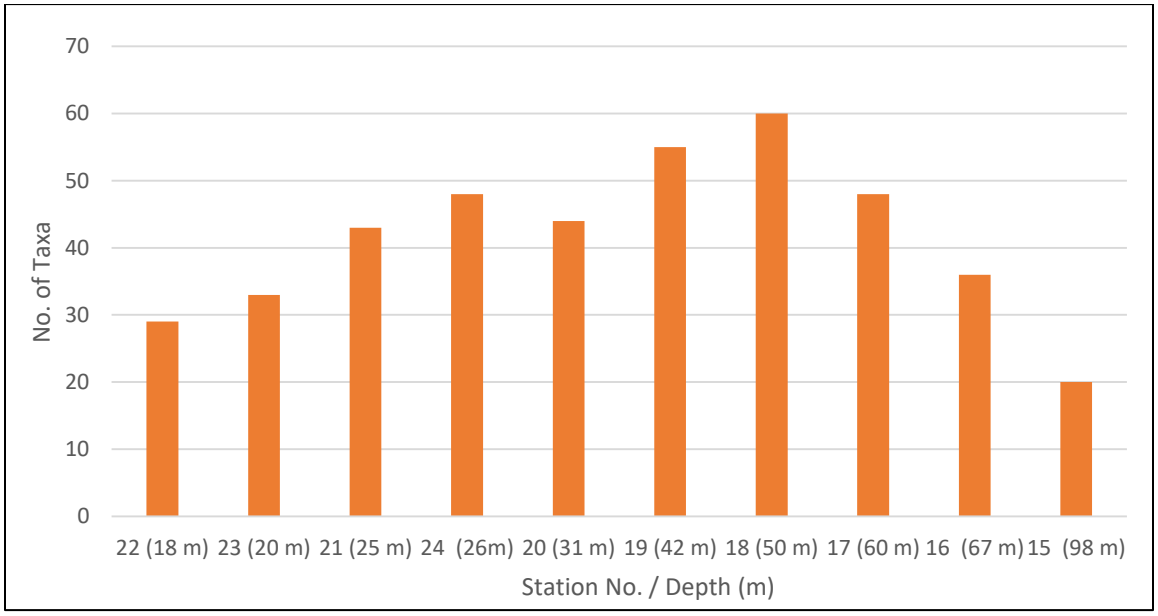


Figure 20: Number of Taxa Recorded (Replicates combined) from Shallowest to Deepest Station Depth for the Baseline Assessment Survey (October 2017)

Phyla distributions based on number of specimens as well as taxa recorded are presented in Table 12 below. A total of 11 phyla were identified. Arthropods accounted for the highest percentage of all specimens and taxa, while annelids accounted for the second highest percentage of specimens and taxa. Mollusca and Echinodermata followed annelids in their taxonomic distribution. All other phyla had fewer specimens and limited distribution.

Table 12: Phyla Distributions based on Number of Specimens and Number of Taxa Recorded for Baseline Assessment Survey October 2017

Phylum	% Specimens	% Taxa
Arthropoda	63.5	43.61
Annelida	33.11	27.82
Mollusca	1.07	12.79
Echinodermata	0.76	4.52
Cnidaria	0.37	3.76
Sipuncula	0.37	2.26
Bryozoa	0.05	1.50
Chordata	0.05	1.50
Brachiopoda	0.63	0.76
Hemichordata	0.05	0.76
Porifera	0.05	0.76

Chevaliidae, an arthropod, shown in Figure 21(a) was the most abundant species, accounting for 54.79% (2,247 out of 4,101) of all specimens found. Spionidae, an annelid, shown in Figure 21(b) was the second most abundant taxon, accounting for 5.05% (207 out of 4,101) of all specimens found. Station 24 (67m in depth), recorded the highest number of Chevaliidae and Spionidae respectively, 1,065 and 29. Photographs of the actual samples are provide in Appendix 11.

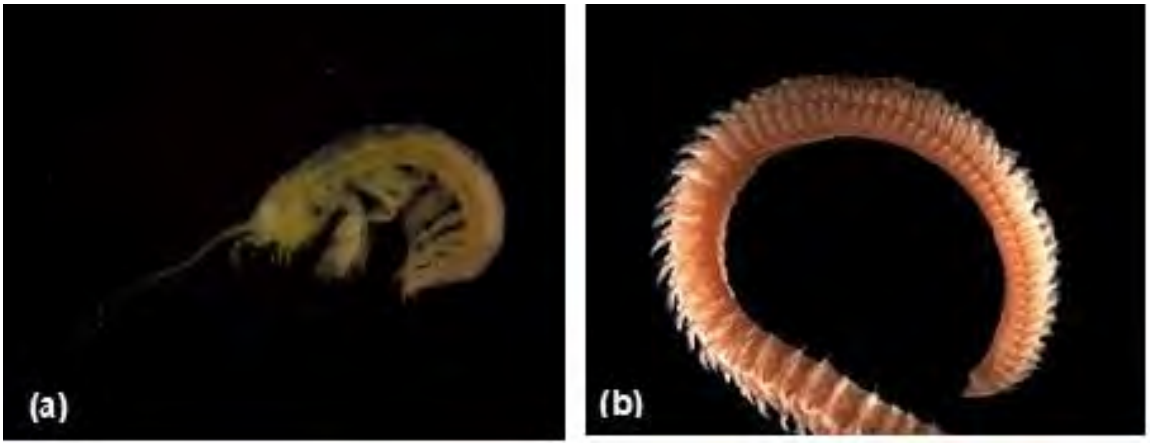


Figure 21: Most Abundant Taxa Recorded during Baseline Assessment Survey (October 2017) (a) Chevaliidae Specimen (b) Spionidae Specimen

Using PRIMER for baseline data analysis, one of the most common diversity indices, the Shannon-Weiner Index (SWI), used to characterize species abundance and evenness, was calculated (using log base e), the results of which are displayed in Table 13 below. The average SWI was found to be 2.36 ± 0.74.

Table 13: Shannon Weiner Indices for October 2017 Survey (All Replicates Combined)

Station	15	16	17	18	19	20	21	22	23	24
SWI	2.75	1.77	3.29	2.46	1.16	2.94	2.83	2.66	2.56	1.16

A cluster analysis was performed using the Bray-Curtis similarity coefficient to identify stations considered to be most similar based on species composition (Figure 22). The resulting dendrogram shows stations 19 (42 m) and 24 (26 m) to be similar, with a value of 60.14%. The dendrogram also shows that the 2 shallowest stations, Station 22 (18 m) and Station 23 (20 m), demonstrated the highest percentage similarity, at a value 61.72% This means that Stations 22 and 23 were only 60% similar, based on species composition. This relatively low similarity was corroborated by the MDS (multi dimensional scaling) plot generated based on species composition as presented in Figure 23 below. MDS plots are used to explain similarities or dissimilarities between data objects with most similar objects clustered together. This plot displays the spatial relationship between the species composition at the station sampled based on similarity values. As a result, the X and Y axes are arbitrary, and it is the relation of the data points to one another which is used for analysis.

When considering the % similarity between Stations 22 and 23 with that of Stations 21 and 24 (see Figure 22 below), also located in relatively shallower waters, the % similarity values were low. Figure 22 also shows that the % similarity between Stations 19 and 24 was similar to that between Stations 22 and 23 (60%). Station 19 is located in relatively deeper water compared to Stations 21, 22, 23 and 24. This suggests that depth was not a significant factor in species composition. An MDS analysis was then conducted using depth as a factor against species composition at the family level (Figure 24 below). No significant clustering was observed among stations with respect to depth, and so it can be inferred that there was no relationship between species composition and depth at the time of sampling.

An MDS analysis was also conducted to determine if there was clustering amongst stations based on the factor of sediment grain size (Figure 25 below). This analysis revealed that there was no significant clustering of stations based on sediment grain size, and so this did not appear to be a factor influencing species composition at the various stations in October 2017.

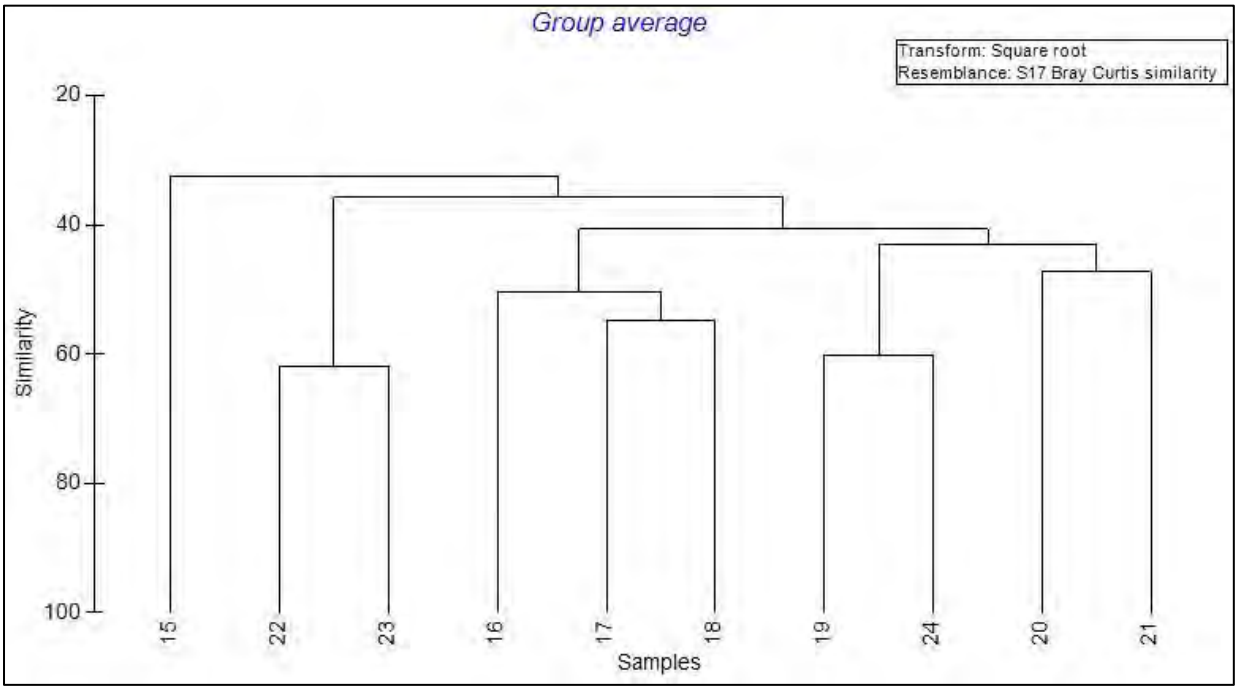


Figure 22: Dendrogram Plot for October 2017 Baseline Assessment Survey Results

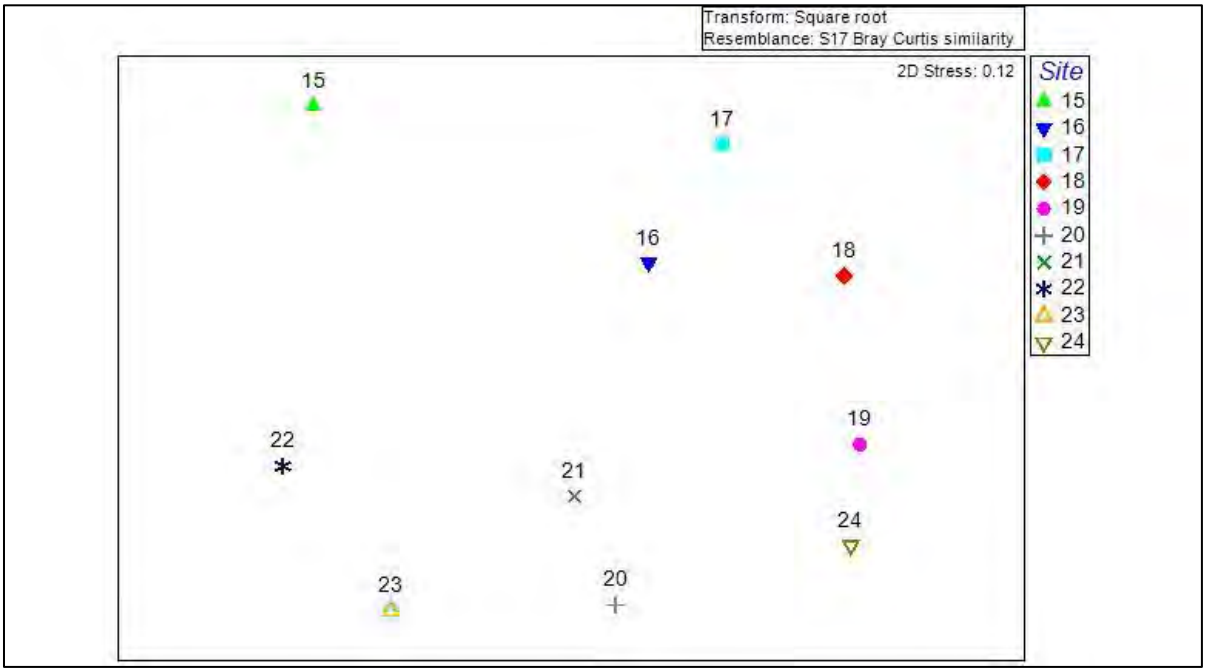


Figure 23: MDS Plot for the October 2017 Survey (Replicates Combined)

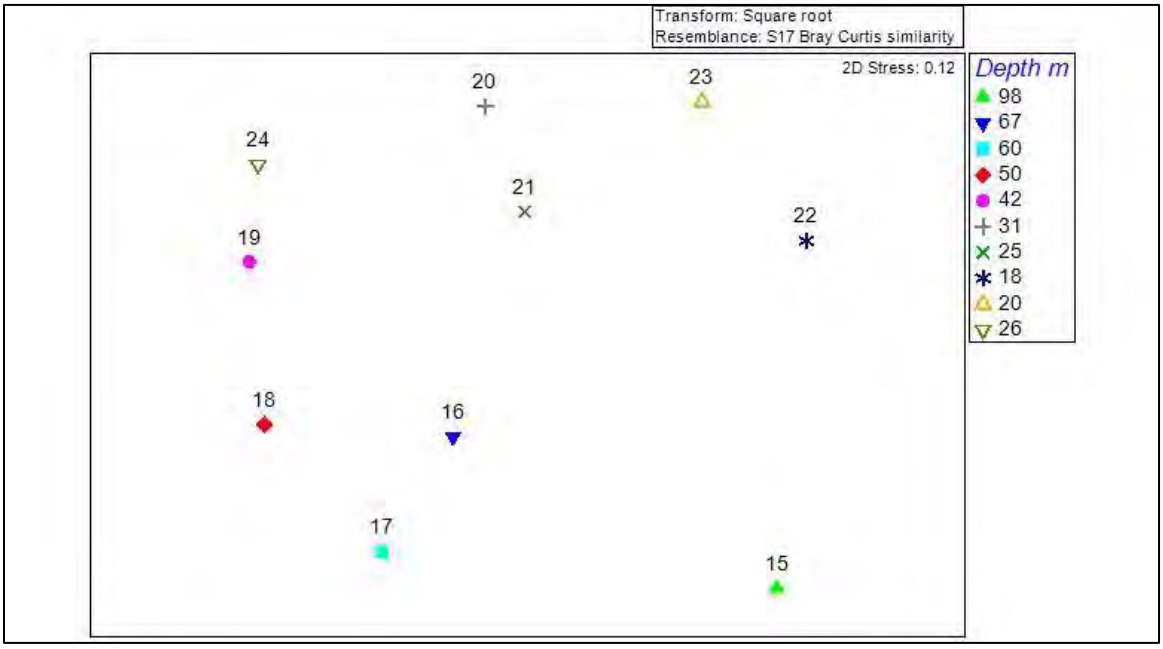


Figure 24: MDS Plot based on the factor of Depth for the October 2017 Baseline Survey (Replicates Combined)

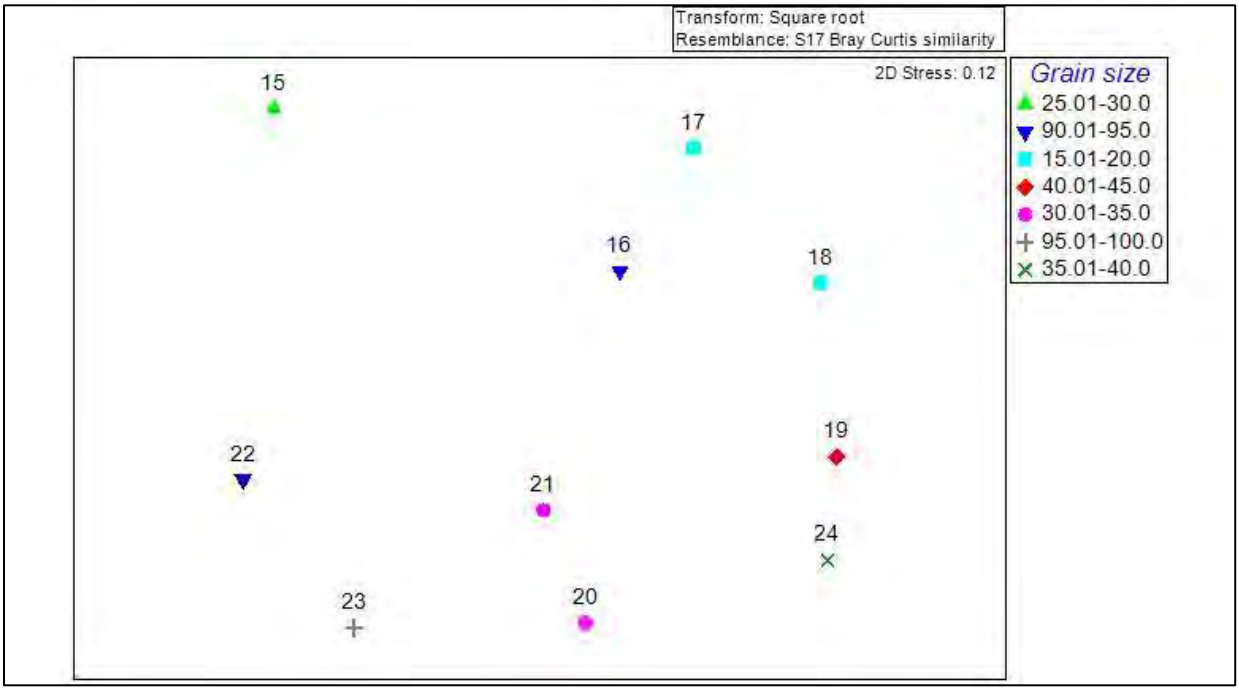


Figure 25: MDS Plot of Predominant Grain Size Fraction for the October 2017 Survey (Replicates Combined)

The Draftsman Plot is a method used for examining correlations between variables in multivariate data. A Draftsman plot consists of a simple array of two-variable scatter diagrams, the purpose of which is to determine which two variables are well correlated within the same dataset. The value of this test lies in its ability to eliminate any single parameter from further analyses (such as BEST; see further below), since running multivariate analyses with many parameters can be time-consuming and, in the case of correlated variables, produce the same result. For this study, the results showed that the highest correlation was found to be between nickel and aluminium in sediment, with a correlation value of 0.798. These results suggest that, as nickel in sediment increased, aluminium in sediment also increased, at the time of sampling. For BEST analysis, either parameter may be eliminated; however, it was decided to keep both parameters in the BEST analysis, since the correlation was not an absolute, strong, positive one (correlation value = 1).

The BEST (Bio-Env) Analysis sought to find the best match between multivariate sample patterns of an assemblage and that from the environmental variables associated with those samples, i.e. which abiotic parameter(s) 'explains' biotic data. When biotic and abiotic data (sediment quality) were combined to determine the most significant variables, the abiotic factor which formed the highest correlation with the biotic data was found to be chromium in sediment, with a correlation value of 0.587. Despite a moderate positive relationship between the

levels of total chromium in sediment and the biotic composition it must be noted that that such correlations do not prove a causal link (ABS 2013). Further, given the low observed total chromium concentrations in study sediments, no rationale can be provided to help explain this observed relationship.

In conclusion, no significant trends in faunal distributions were observed along the Continental Shelf, by species composition (based on familial analysis), nor by the factors of depth and sediment grain size for data obtained during October 2017. There were no apparent relationships to link observed changes in the benthos to abiotic data. This study documents the natural variability in chemistry, benthos and taxonomic diversity along the Guyana Continental Shelf during the period sampled.

6.5 Conclusion

In general, the sediment sampled in October and December 2017appeared to be of good quality, given: the low levels of TOC in comparison to those found in nutrient-rich waters; the presence of moisture within the sediment; the presence of oxygen to drive redox reactions in biological and chemical processed; the absence of bioavailable levels of most sediment metals; and the lack of exceedance of the USEPA Benchmarks and ERM values for nearly all total metals. The only point of concern raised by the results is the 3 potentially contaminated sites for total arsenic and the fact that levels exceeded the USEPA Benchmark but not its' ERM value at 8 of the 10 stations. However, a 12.5 % probability detection of its bioavailable form was found to be of little concern as the consequential impacts to the benthos would be minimal.

Saturated hydrocarbons were absent for the majority of analytes with only 2 detected at all 10 stations. Where detected, the values were low and decreased with distance from the shoreline for only one analyte.

Distribution of benthic macrofauna varied across the Continental shelf when species composition, depth and grain size were considered. Also, there was no apparent correlation between biotic and abiotic factors.

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7 QUALITY ASSURANCE/QUALITY CONTROL

Chemical analysis of the sediment samples was executed with QA/QC checks and balances inherent in the test methods utilised or the various parameters as described in Section 4.5.2 above.

Additionally, the following checks were conducted in order to determine the accuracy and/or precision of the standard test methods:

- Total Metals (Cr, Ni, Cu, Cd, Fe, Zn, As, Al, Pb, Se Hg, Ba) – Method blank, Laboratory Control Sample (LCS) and Matrix Spike/Matrix Spike Duplicate (MS/MSD).
- Bioavailable Metals (Cr, Ni, Cu, Cd, Fe, Zn, As, Al, Pb, Se Hg, Ba) – Method blank, Laboratory Control Sample (LCS) and Matrix Spike/Matrix Spike Duplicate (MS/MSD).
- TOC - Method blank, Laboratory Control Sample (LCS) and Matrix Spike/Matrix Spike Duplicate (MS/MSD).
- PAH - Method blank, Laboratory Control Sample (LCS) and Matrix Spike/Matrix Spike Duplicate (MS/MSD).
- % Moisture - Duplicate for every 20 samples.
- A primary surrogate (o-Terphenyl) was analysed with each sample. Acceptable recovery is considered to be between 50% and 150%. Three sets of Laboratory Control Samples/Duplicate Laboratory Control Samples (LCS/DLCS) were run with the samples, with acceptable recovery range set at 50 to 120%. Three method blank samples were also run.

Checks of data calculations and transcription into the report were performed by a separate person from those performing tests and writing the report. All samples and analyses were completed as planned.

Quality control criteria were met for all analytes in this project.

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8 REFERENCES

Alibrahim ZO (2016) Assessment of bioavailability of some potential toxic metals in mining-affected soils using EDTA extraction and principle component analysis (PCA) approach, Derbyshire, UK. Interdiscip J Chem, 2016, doi: 10.15761/IJC.1000110

Allen, H.E. n.d. Are all metals in the soil & water bioavailable? Eurometaux (European Association of Metals).
http://www.eurometaux.org/MetalsToday/MetalsFAQs/Metalsbioavailablesoilwater.aspx
Accessed March 20th, 2017

Australian Bureau of Statistics. 2013. 1500.0 - A guide for using statistics for evidence based policy. Literacy Stats: Using ABS Statistics: Telling the right story.
http://www.abs.gov.au/websitedbs/a3121120.nsf/home/statistical+language+-+correlation+and+causation
Accessed April 9th, 2018

Anderson, G. 2004. Marine Science: Seawater Composition.
http://www.marinebio.net/marinescience/02ocean/swcomposition.htm
Accessed May 16th, 2017

Artigas, L.F., P. Vendeville, M. Leopold, D. Guiral & J.F. Ternon, 2003. Marine biodiversity in French Guiana: estuarine, coastal, and shelf ecosystems under the influence of Amazonian waters. Guyana 67, 302-326.

ASTM D 422 - Standard Test Method for Particle-Size Analysis of Soils

Bågander, L.E. 1978. An evaluation of the use of redox measurements for characterizing recent sediments. Estuarine and coastal Marine Science, 6: 127-134.

Barber, S.J. nd. The Spatial Variability of Total & Bioavailable Metal Concentrations in the Sediments of Mitchell Lake. Department of Earth and Environmental Science, Environmental Geochemistry Laboratory, University of Texas at San Antonio. 12 pp.

Bennett, R.H., H. Lee and M.H. Hulbert. 1990. Water in Marine Sediments. Naval Oceanographic and Atmospheric Research Laboratory, Seafloor Geosciences Division, Stennis Space Center, MS.

Bernhard, J.M. 1988. Postmortem vital staining in benthic foraminifera: duration and importance in population and distributional studies, J. Foram. Res. 18, 143-146

Bischof, B, A.J. Mariano and E.H. Ryan. 2003. "The North Brazil Current" in Ocean Surface Currents.
http://oceancurrents.rsmas.miami.edu/atlantic/north-brazil.html.
Accessed March 19th, 2017

Burone, L., P. Muniz, A.M. Pires-Vanini and M. Rodrigues. 2003. Spatial distribution of organic matter in the surface sediments of Ubatuba Bay (Southeastern – Brazil). Annals of the Brazilian Academy of Sciences (2003) 75(1): 77-90.

Buchman M.F, 2008. NOAA Screening Quick Reference Tables, NOAA ORR Report 08-1, "Office of Response and Restoration Division, National Oceanic and Atmospheric Administration," Seattle.

Clarke, K.R, Gorley, R.N. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E: Plymouth

Condie. S.A. 1991: Separation and recirculation of the North Brazil Current. Journal of Marine Research, 49, 1-19.

Conrad C. F. and C.J. Chisholm-Brause. 2004. Spatial survey of trace metal contaminants in the sediments of the Elizabeth River, Virginia. Marine Pollution Bulletin 49(4): 319–324.

Ecosystem Approach to Sustainable Aquaculture (ECASA). 2004. ECASA Toolbox: Sediment Redox Potential, Eh.
http://www.ecasatoolbox.org.uk/the-toolbox/eia-country/book-of-protocols/sediment-redox-potential-eh.html
Accessed December 18th, 2017.

EEPGL 2016. Environmental Baseline Survey Report, Liza Development, Offshore Guyana. Prepared by FUGRO EMU LIMITED for ESSO Exploration and Production Guyana Limited.

Franson, M.A.H., A.D. Eaton, L.S. Clesceri and A.E. Greenberg. 2005. Standard Methods for the Examination of Water and Wastewater. Prepared and published by the American Public Health Association, American Waterworks Association and Water Environment Federation. Published by the American Public Health Association. Washington D.C.

Fauchland, K., and Jumars, P.A. 1979. The diet of worms: a study of polychaete feeding guilds, 17, 193-284

Gao, X., Y. Yang and C. Wanga. 2012. Geochemistry of organic carbon and nitrogen in surface sediments of coastal Bohai Bay inferred from their ratios and stable isotopic signatures. Marine Pollution Bulletin 64 (2012): 1148-1155. 9 pp.

Gordon, A.L. 2004. The Climate System: Ocean Stratification. http://eesc.columbia.edu/courses/ees/climate/lectures/o_strat.html Accessed February 18th, 2016

Koldewijn, B.W., 1958. Sediments of the Paria-Trinidad-shelf. Fys.-Geog. Lab. Pub., Amsterdam University, v. 1, p. 109. Accessed July 6th, 2017

Köster. M. and L. Meyer-Reil. 2001. Characterization of carbon and microbial biomass pools in shallow water coastal sediments of the southern Baltic Sea (Nordrügensche Bodden). Marine Ecology Progress Series. Vol. 214: 25–41, 2001. 17 pp.

Miller, A.L. and L.H., Keeney, D.R. (Eds.). 1992. Methods of Soil Analysis. Part 2. Chemical and microbiological properties. Agronomy Monograph, second ed., vol. 9, American Society of Agronomy, Madison, WI, pp. 199-224.

Muller-Karger, F.E., McCain, C.R. and Richardson, P.L. (1988). The Dispersal of the Amazon's Water. Nature 333: 56-59 pp.

Ogden, J. C and E. H. Gladfelter, eds. 1982.Coral reefs, seagrass beds and mangroves: Their interaction in the coastal zones of the Caribbean. Report of a workshop held at the West Indies Laboratory, St. Croix, U.S. Virgin Islands May 1982. UNESCO IOCARIBE.

Open University. 1989. Seawater: its composition, properties and behaviour. Open University, Pergamon Press.

OzCoasts (Geoscience Australia). 2012. pH of coastal waterways http://www.ozcoasts.gov.au/indicators/ph_coastal_waterways.jsp Accessed September 6th, 2017.

Paller M.H. and A.S. Knox. 2013. Bioavailability of Metals in Contaminated Sediments. Proceedings of the 16th International Conference on Heavy Metals in the Environment, E3S Web of Conferences 1, 02001 (2013)

Péter Sipos, Chung Choi, Tibor Németh, Zoltán Szalai & Teréz Póka (2014) Relationship between iron and trace metal fractionation in soils, Chemical Speciation & Bioavailability, 26:1, 21-30, DOI: 10.3184/095422914X13887685052506
Accessed: April 9th, 2018.

Prieto-Portar, L.A. 2007. Geotechnical_Manual_Lab.
http://www.learningace.com/doc/3095955/e65b0811b1ce11cac0e94f526bcb0a7d/geotechnical_manual_lab
Accessed July 8th, 2017

Puyate Y.T. and A. Rim-Rukeh, 2008. Variability with depth of some physic-chemical and biological parameters at Atlantic Ocean water in part of the coastal area of Nigeria. Journal of Applied Science Environmental Management Vol 12(1) 87-91.
http://www.bioline.org.br/pdf?ja08013
Accessed September 6th, 2017.

Rampersad, J., C. Ikon, N.I. Khandaker and S. Schleifer, 2008. Mineralogy of the coastal sand obtained from the twin island republic of Trinidad & Tobago. Geological Society of America, v. 40, no. 6, p. 181.

Rice, E.W., R.B. Baird, A.D. Eaton and L.S. Clesceri. 2012. Standard Methods for the Examination of Water and Wastewater, 22nd Edition. Prepared and published by the American Public Health Association, American Waterworks Association and Water Environment Federation and the American Public Health Association. Washington D.C.

Schlesinger, W.H. and E. Bernhardt. 2013. Biogeochemistry: An Analysis of Global Change 3rd. ed. Academic Press. 688 pp.

Seiter, K., C. Hensen, J. Schroter and M. Zabel. 2004. Organic Carbon Content in surface Sediments – Defining Regional Provinces. Deep Sea Research Part 1: Oceanographic Research Papers Volume 51 Issue 12: 2001 – 2026.

SW846 "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

USEPA Region III BTAG Marine Sediment Screening Benchmarks. 2006.
http://www.epa.gov/reg3hwmd/risk/eco/btag/sbv/marine/screenbench.htm
Accessed June 2nd, 2017

USEPA. 2001. Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual. EPA 823-B-01-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Walker, D.A., A.E. Linton and C.T. Schafer. 1974. Sudan Black B: a superior stain to Rose Bengal for distinguishing living from non-living foraminifera, J.Foram. Res., 4, 205-215

Warne. A.G., R.H. Meade, W.A. White, E.H. Guevara, J. Gibeaut, R.C. Smyth, A. Aslan and T. Tremblay. 2002. Regional controls on geomorphology, hydrology, and ecosystem integrity in the Orinoco Delta, Venezuela. Geomorphology 44 (2002) 273–307. 35 pp.

Zobell, C. E. 1946. Studies on redox potential of marine sediments. Bulletin of the American Association of Petroleum Geologists 30, 477-511.

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9 APPENDICES

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Appendix 1 – ESL Field Team Details

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Appendix 1A - ESL Field Team Details

Table 1 below presents information of the ESL sampling team members, their designation and roles, as well as contact data.

Table 14: Key Staff Information for the EEPGL Guyana Offshore Project, Sediment Sampling (October 2017)

Name	Company	Designation	Role	Contact Information
Devon Ramoo	ESL	Senior Field Technician	Coordinate and execute sediment & benthic sampling exercise	(868) 739 1300
Mitra Rampersad	ESL	Field Technician	Assist in the execution of sediment & benthic sampling exercise	(868) 772 4999
Jason Apping	ESL	Field Technician	Assist in the execution of sediment & benthic sampling exercise	(868) 396 8676

Appendix 1B – ESL QC Journey Management Forms

Exxonmobil Exploration Company | Generic Specifications

Geophysical Operations - Shallow Seabed Group | **Initial Environmental Survey Acquisition and Analytical Methods**

QC Journey Management Form

ExxonMobil Project: Exxon Phase 2 – sediment, ROV & Drop camera Survey	Location: Guyana Marine Offshore
Estimated Duration Of Project: 42 days	Field Crew Name & Contact Information: Devon Ramoo (1-868-739-1300)
ExxonMobil Field Supervisor: Nil	Alternate Contacts: +870 773 991495
Consulting Company: ESL	Consultant Name – Position: Sr Field Tech (Marine) Mobile Tel: 1-868-739-1300 Email: devon.ramoo@enviroscience.net
24/7 Emergency Contact Numbers: 1: 761-7054 – Allen Ramoo (Father) 2: 3:	Consultant Project Manager and Phone No: Ella Dacham 1868 657-1560/9024
International Medical and Travel Insurance Information: Insurer: Class: N/A Policy Number:	Visa Validity: N/A Last Drug & Alcohol Test: 20/4/17 Offshore Survival/HUET Validity: 14/8/15 Physical Exam Validity: 20/2/19
Insurance Company: Tel: N/A Fax/Email:	Passport – Country and Validity: Trinidad + Tobago 16/02/2026 Visa – Issuer and Validity: N/A TWIC - Issuer & Validity: N/A
Travel Itinerary: (or attach copy) Depart from Trinidad on the MV Sea Service on 14/10/17 Return to Trinidad from Guyana by air on 21/11/17	
Travel Coordinator – Contact Details: Shanelle Duncan (1868-657 1560/9024) Check-in on arrival – Contact Details:	

Exxonmobil Exploration Company | Generic Specifications

Geophysical Operations - Shallow Seabed Group | **Initial Environmental Survey Acquisition and Analytical Methods**

QC Journey Management Form

ExxonMobil Project: ~~Exxon Phase 2~~ Sediment, ROV & Drop Camera Survey	Location: Guyana Marine Offshore
Estimated Duration Of Project: 42 days	Field Crew Name & Contact Information: Mitra Rampersad (1-868-772-4999)
ExxonMobil Field Supervisor: Nil	Alternate Contacts: +870 773 991 495
Consulting Company: ESL	Consultant Name – Position: Field Tech (Marine) Mobile Tel: (1-868-772-4999) Email: mitra.rampersad@enviosciences.net
24/7 Emergency Contact Numbers: 1: 788-0178 (Mother-Tara Rampersad) 2: 3:	Consultant Project Manager and Phone No: Elka Barbados 1868 657 1560/9024
International Medical and Travel Insurance Information: Insurer: Class: N/A Policy Number:	Visa Validity: N/A Last Drug & Alcohol Test: 20/4/17 Offshore Survival/HUET Validity: 8/1/21 Physical Exam Validity: 27/1/18
Insurance Company: Tel: N/A Fax/Email:	Passport – Country and Validity: Trinidad & Tobago 4/03/2018 Visa – Issuer and Validity: N/A TWIC - Issuer & Validity: N/A
Travel Itinerary: (or attach copy) Depart from Trinidad on MV Sea Service on 14/10/17 Return to Trinidad on MV Sea Service on 23/11/17	
Travel Coordinator – Contact Details: Shenelle Duncan (1868-657 1560/9024) Check-in on arrival – Contact Details:	

Exxonmobil Exploration Company | Generic Specifications

Geophysical Operations - Shallow Seabed Group | **Initial Environmental Survey Acquisition and Analytical Methods**

QC Journey Management Form

ExxonMobil Project: Exxon Phase 2 – Sediment, ROV & drop camera survey	Location: Guyana marine offshore
Estimated Duration Of Project: 4+ days	Field Crew Name & Contact Information: Jason Apping 1868 396 6676
ExxonMobil Field Supervisor: Nil	Alternate Contacts: + 870 773991 495
Consulting Company: ESL	Consultant Name – Position: Field Tech (marine) Mobile Tel: 1868 396 5674 Email: jason.apping@gmail.com
24/7 Emergency Contact Numbers: 1: 320-1525 – Tamara Apping (wife) 2: 3:	Consultant Project Manager and Phone No: Ella Bachan 1868 657-1560 / 9024
International Medical and Travel Insurance Information: Insurer: Class: N/A Policy Number:	Visa Validity: N/A Last Drug & Alcohol Test: 20/4/17 Offshore Survival/HUET Validity: 21/8/20 Physical Exam Validity: 27/1/18
Insurance Company: Tel: N/A Fax/Email:	Passport – Country and Validity: Trinidad + Tobago 23/03/2027 Visa – Issuer and Validity: N/A TWIC - Issuer & Validity: N/A
Travel Itinerary: (or attach copy)	Depart from Trinidad on the MV Sea Service on 14/10/17 Return to Trinidad from Guyana via air on 21/11/17
Travel Coordinator – Contact Details: Check-in on arrival – Contact Details:	Shanelle Duncan (1868 6571560/9024)

Appendix 1C – ESL Training & Safety Certificates

Falck

Certificate

The Competent Authorities of
Falck Nutec Trinidad and Tobago Limited
Approved Training Centre
At Centre of Excellence, Macoya Road, Tunapuna, Trinidad
Hereby Certify that

Devon Ramoo

Has Attended and Successfully completed

Tropical Further Offshore Emergency Training (TFOET)

CERTIFIED COURSE (CODE 5614)

Start Date:	**15.08.2014**
End Date:	**15.08.2014**
Expiry Date:	**14.08.2018**

Certificate Number:

74245614150814401715

Stuart Aikenhead
Managing Director

Certificate

Falck Safety Services Limited

Mitra M. Rampersad

Participant

Has attended and been successfully assessed against the Learning Outcomes of

Tropical Further Offshore Emergency Training (TFOET)

OPITO APPROVED COURSE (CODE 5614)

74245614090117634142

Certificate Number

09.01.2017 - 09.01.2017

Course Training Dates

08.01.2021

Expiry Date

Managing Director: Wendy Zilla

Falck Safety Services

Certificate

Falck Safety Services Limited

Jason Apping

Participant

Has attended and been successfully assessed against the Learning Outcomes of

Tropical Further Offshore Emergency Training (TFOET)

OPITO APPROVED COURSE (CODE 5614)

7424561422081645928 8

Certificate Number

22.08.2016 - 22.08.2016

Course Training Dates

21.08.2020

Expiry Date

Managing Director: Wendy Zilla

Falck Safety Services

Dr. Victor Coombs

B.A. (U.M.B.) M.B.B.S (U.W.I) MSc C.H.D.C (LOND.)
D.P.H. (U.K.) D.I.H (RCP.RCS) A.F.O.M. (RCP) Cert. Av. Med (RCP) E.M.B.A (U.W.I)
MSc. Emerg. Med (U.W.I)

CONSULTANT IN OCCUPATIONAL AND ENVIRONMENTAL HEALTH.

123 Riverside Drive,
San Fernando,
Trinidad, W.I
Tel: 653-4055

7, White Street.
Woodbrook
Port-of-Spain
Tel: 222-8021

14 Endeavour Road
Chaguanas,
Trinidad, W.I
Tel: 671-4859

E-Mail:gmesh1@carib-link.net

DATE: 2017/02/21

OFFSHORE MEDICAL CERTIFICATE
In accordance with Oil and Gas UK Medical Guidelines.

Name: DEVON RAMOO Date-of-Birth: 09 FEB 1984

Company Name: ENVIRONMENTAL SCIENCES LIMITED

Occupation: MARINE TECHNICIAN

This individual has been examined in accordance with **OIL & GAS UK MEDICAL GUIDELINES,** and in my opinion is **FIT/~~UNFIT~~** for work offshore.

In the event of limited certification, state here the specific restrictions applying and the date of next review.

Restrictions: _____

_____

_____

Next review date: _____

Examining Physician Name (Print): **DR. VICTOR COOMBS.**

PIN NO: **OGUK/2010/1603**

Date of Examination: 2017/02/21

Date of Expiry: 2019/02/20

Signed: _____

DR. VICTOR COOMBS
Consultant in Occupational & Environmental Health
UKOOA PIN #OGUK/2010/1603
123, Riverside Dr., San Fernando
Tel: 1 868 653 4055

Dr. Victor Coombs

B.A. (U.M.B.) M.B.B.S (U.W.I) MSc C.H.D.C (LOND.)
D.P.H. (U.K.) D.I.H (RCP.RCS) A.F.O.M. (RCP) Cert. Av. Med (RCP) E.M.B.A (U.W.I)
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Port-of-Spain
Tel: 222-8021

14 Endeavour Road
Chaguanas,
Trinidad, W.I
Tel: 671-4859

E-Mail:gmesh1@carib-link.net

DATE: 16/01/28

OFFSHORE MEDICAL CERTIFICATE
In accordance with Oil and Gas UK Medical Guidelines.

Name: MITRA RAMPERSAD Date-of-Birth: 28/11/1987

Company Name: ENVIRONMENTAL SCIENCES LIMITED

Occupation: FIELD OPERATIONS/SALES COORDINATOR

This individual has been examined in accordance with **OIL & GAS UK MEDICAL GUIDELINES,** and in my opinion is **FIT/~~UNFIT~~** for work offshore.

In the event of limited certification, state here the specific restrictions applying and the date of next review.

Restrictions: _____

Next review date: _____

Examining Physician Name (Print): **DR. VICTOR COOMBS.**

PIN NO: **OGUK/2010/1603**

Date of Examination: 16/01/28

Date of Expiry: 2018-01-27

Signed: _____

DR.VICTOR COOMBS
Consultant in Occupational & Environmental Health.
UKOOA PIN # OGUK/2010/1603
B.A., M.B.B.S., MSc. C.H.D.C., D.P.H., D.I.P., A.F.O.M., E.M.B.A., Cert.Av. Med., MSc. Emerg. Med.
Tel: 868-653-4055

Dr. Victor Coombs

B.A. (U.M.B.) M.B.B.S (U.W.I) MSc C.H.D.C (LOND.)
D.P.H. (U.K.) D.I.H (RCP.RCS) A.F.O.M. (RCP) Cert. Av. Med (RCP) E.M.B.A (U.W.I)
MSc. Emerg. Med (U.W.I)

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Port-of-Spain
Tel: 222-8021

14 Endeavour Road
Chaguanas,
Trinidad, W.I
Tel: 671-4859

E-Mail:gmesh1@carib-link.net

DATE:

OFFSHORE MEDICAL CERTIFICATE
In accordance with Oil and Gas UK Medical Guidelines.

Name: JASON APPING Date-of-Birth: 18/03/1980

Company Name: ENVIRONMENTAL SCIENCES LIMITED

Occupation: FIELD TECH

This individual has been examined in accordance with **OIL & GAS UK MEDICAL GUIDELINES,** and in my opinion is **FIT/UNFIT** for work offshore.

In the event of limited certification, state here the specific restrictions applying and the date of next review.

Restrictions: _____

Next review date: _____

Examining Physician Name (Print): **DR. VICTOR COOMBS.**

PIN NO: **OGUK/2010/1603**

Date of Examination: 16/01/28

Date of Expiry: 18.01.27

Signed: _____

DR.VICTOR COOMBS
Consultant in Occupational &
Environmental Health.
UKOOA PIN # OGUK / 2010 / 1603
B.A., M.B.B.S., MSc. C.H.D.C., D.P.H.,
D.I.P., A.F.O.M., E.M.B.A.,
Cert.Av. Med., MSc. Emerg. Med.
Tel: 868-653-4055



ECSI

AAOS

American College of Emergency Physicians

EMERGENCY CARE & SAFETY INSTITUTE

Certificate of Completion

The Education Center, below, verifies that

Devon Ramoo

has successfully completed the knowledge and skill evaluations for the Emergency Care & Safety Institute Course.

Adult & Child CPR & AED, Standard First Aid	August 26th, 2017	August 26th, 2019	VCEC
Course Name	Course Completion Date	Recommended Renewal Date	Center Code
Virginia Cameron Education Center	2902915	Virginia Cameron	P0E3E8YFUFOS
Education Center	Education Center Phone Number	Instructor Name	Instructor ID Number
vcameron40@gmail.com			
Education Center Email			

This certificate does not guarantee any future performance or suggest any form of licensure. Skills deteriorate rapidly when not used. Periodic retraining is strongly recommended.



ECSI

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American College of Emergency Physicians

EMERGENCY CARE & SAFETY INSTITUTE

Certificate of Completion

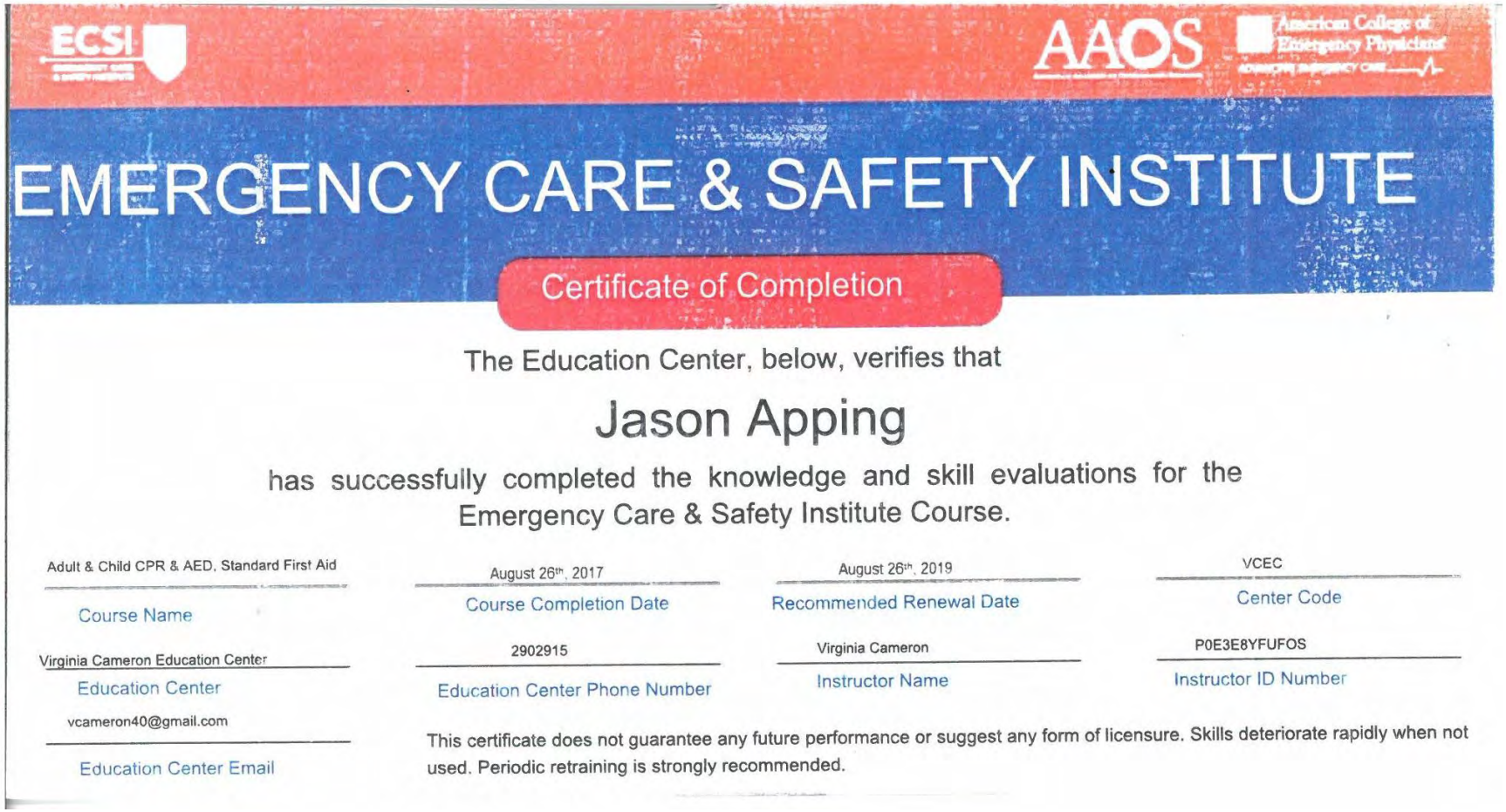
The Education Center, below, verifies that

Mitra Rampersad

has successfully completed the knowledge and skill evaluations for the Emergency Care & Safety Institute Course.

Adult & Child CPR & AED, Standard First Aid	August 26th, 2017	August 26th, 2019	VCEC
Course Name	Course Completion Date	Recommended Renewal Date	Center Code
Virginia Cameron Education Center	2902915	Virginia Cameron	P0E3E8YFUFOS
Education Center	Education Center Phone Number	Instructor Name	Instructor ID Number
vcameron40@gmail.com			
Education Center Email			

This certificate does not guarantee any future performance or suggest any form of licensure. Skills deteriorate rapidly when not used. Periodic retraining is strongly recommended.



ECSI

AAOS

American College of Emergency Physicians

EMERGENCY CARE & SAFETY INSTITUTE

Certificate of Completion

The Education Center, below, verifies that

Jason Apping

has successfully completed the knowledge and skill evaluations for the Emergency Care & Safety Institute Course.

Adult & Child CPR & AED, Standard First Aid	August 26th, 2017	August 26th, 2019	VCEC
Course Name	Course Completion Date	Recommended Renewal Date	Center Code
Virginia Cameron Education Center	2902915	Virginia Cameron	P0E3E8YFUFOS
Education Center	Education Center Phone Number	Instructor Name	Instructor ID Number
vcameron40@gmail.com			
Education Center Email			

This certificate does not guarantee any future performance or suggest any form of licensure. Skills deteriorate rapidly when not used. Periodic retraining is strongly recommended.

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Appendix 2 - Laboratory Accreditation Certificates

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TT TABS
TRINIDAD AND TOBAGO
laboratory
Accreditation
Service

CERTIFICATE OF ACCREDITATION

ENVIRONMENTAL SCIENCES LTD

Testing Laboratory No.: LAS-004

is an accredited Laboratory which fulfils the requirements of ISO/IEC 17025 and has demonstrated competence to carry out tests as per a defined scope for:

CHEMICAL TESTING

as per attached schedule

While this certificate remains valid, the Accredited Laboratory named above is authorized to issue TTLABS-endorsed certificates.

Karlene Carolyn Lewis

Manager, TTLABS

"Recognized as the official national laboratory accreditation body by the Ministry of Trade and Industry of the Republic of Trinidad and Tobago"

Initial Accreditation date: 12th December 2011

This certificate issued on: 2nd January 2015

"This laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17025:2005. This accreditation demonstrated technical competence for a defined scope and the operation of a laboratory quality management system. (refer to joint ISO-ILAC-IAF Communiqué dated 18 June 2005)"

TT LABS
TRINIDAD AND TOBAGO
laboratory Accreditation Service

SCHEDULE OF ACCREDITATION

Testing Laboratory Number: **LAS-004**

Permanent Address of Laboratory: **Environmental Sciences Limited** 141 Riverside Drive San Fernando Trinidad and Tobago. W.I. **Postal Address** 141 Riverside Drive San Fernando Trinidad and Tobago. W.I. Tel : 868-657-9024 Fax : 868-653-2571 e-mail: shivanna.lee@envirosciences.net	**Management Signatories:** Jerome Als **Technical Signatories:** Shivanna Mahabir-Lee **Nominated Representative:** Renica Pariag **Certificate of Accreditation** Issue No. : 2 Date of issue : 2nd Jan 2015

Materials/Products Tested	Types of Tests/Properties Measured, Range of Measurement	Standard Specifications, Equipment/Techniques Used
CHEMICAL Metals in Water and Wastewater	1) Flame Atomic Absorption Spectrophotometry for: • Cadmium • Chromium • Copper • Lead • Iron • Zinc • Nickel **Units: µg/L**	Reference – Standard Methods for Evaluation of Water and Wastewater (SMEWW) 3111 A - Metals by flame atomic absorption spectrometry SMEWW 3111 B – Direct air-acetylene flame method **Method No. QMT 001**

Date of accreditation: 12th December, 2011

Manager, TTLABS



Florida HEALTH



State of Florida
Department of Health, Bureau of Public Health Laboratories
This is to certify that

E81010

TESTAMERICA PENSACOLA
3355 MCLEMORE DRIVE
PENSACOLA, FL 32514

has complied with Florida Administrative Code 64E-1,
for the examination of environmental samples in the following categories

DRINKING WATER - MICROBIOLOGY, DRINKING WATER - PRIMARY INORGANIC CONTAMINANTS, DRINKING WATER - SECONDARY INORGANIC CONTAMINANTS, DRINKING WATER - SYNTHETIC ORGANIC CONTAMINANTS, NON-POTABLE WATER - EXTRACTABLE ORGANICS, NON-POTABLE WATER - GENERAL CHEMISTRY, NON-POTABLE WATER - METALS, NON-POTABLE WATER - MICROBIOLOGY, NON-POTABLE WATER - PESTICIDES-HERBICIDES-PCB'S, NON-POTABLE WATER - VOLATILE ORGANICS, SOLID AND CHEMICAL MATERIALS - EXTRACTABLE ORGANICS, SOLID AND CHEMICAL MATERIALS - GENERAL CHEMISTRY, SOLID AND CHEMICAL MATERIALS - METALS, SOLID AND CHEMICAL MATERIALS - PESTICIDES-HERBICIDES-PCB'S, SOLID AND CHEMICAL MATERIALS - VOLATILE ORGANICS, BIOLOGICAL TISSUE - EXTRACTABLE ORGANICS, BIOLOGICAL TISSUE - METALS, BIOLOGICAL TISSUE - PESTICIDES-HERBICIDES-PCB'S

Continued certification is contingent upon successful on-going compliance with the NELAC Standards and FAC Rule 64E-1 regulations. Specific methods and analytes certified are cited on the Laboratory Scope of Accreditation for this laboratory and are on file at the Bureau of Public Health Laboratories, P. O. Box 210, Jacksonville, Florida 32231. Clients and customers are urged to verify with this agency the laboratory's certification status in Florida for particular methods and analytes.

Date Issued: July 01, 2017 Expiration Date: June 30, 2018



Susanne Crowe

Susanne Crowe, MHA
Acting Chief, Bureau of Public Health Laboratories
DH Form 1697, 7/04
NON-TRANSFERABLE E81010-46-07/01/2017
Supersedes all previously issued certificates

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Appendix 3 – Job Safety Analysis (JSAs)

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JSA #17-19: Mobilisation & Demobilisation

ENVIRONMENTAL SCIENCES LIMITED

JOB SAFETY ANALYSIS

Location/System	Trinidad/Guyana	**Date**	September-November 2017	**JSA # 17-19**	**Site Visited:** Yes	**Team Lead:** Devon Ramoo **Company:** ESL
Job/Task Description	**Mobilization and Demobilization**					
Name of Vessel	**Sea Service**					
Prepared by: Jared Bisnath (HSE Advisor/ Field & Marine Tech.)						
Has consideration been given to weather conditions YES ~~NO~~	Are written job procedures discussed YES ~~NO~~		Are there SIMOPS YES ~~NO~~		Emergency Response Plan Implemented	

Hazard Effect (HE) x Probability (P) =Risk(R) *R Signifies residual risk after control measures in place

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
Inspection of equipment (Winch and sampling equipment)	Poor manual handling technique	Muscle sprains and strains, falls, cuts, crushed appendages	2	2	4	Medium	Use Mechanical Means of Lifting where applicable; Establish lifting plan, adequate supervision, adequate training, use of proper manual handling techniques, establish clear lines of communication, adequate manpower, use of PPE	2	1	2	Low	Team Lead
	Sharp edges, pinch points, rotating parts on equipment	Abrasions, cuts, amputations. entanglement	2	2	4	Medium	Establish plan before beginning inspection, establish position of hands and feet in relation to equipment and moving parts. Use of PPE. Equipment safeguards. Emergency shutdown of rotating equipment.	2	1	2	Low	Team Lead
	Faulty equipment	Cuts, abrasions, burns	2	2	4	Medium	Winch certified. Inspect before use.	2	1	2	Low	Team Lead
	Cable	Cuts, entanglement, amputation	2	2	4	Medium	Inspect cables before use. Certified Cables Be mindful of hand placement when winch is operating. Use of PPE.	2	1	2	Low	Team Lead
	Falling objects	Head injuries, Broken bones, death	3	2	6	High	Establish lifting plan before testing winch. Never stand, walk or work under a load. Use of PPE (safety hat, etc.)	3	1	3	Medium	Team Lead

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SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
	Struck by objects	Head injuries, broken bones, soft tissue injury,death.	3	2	6	High	Pay attention to activities. Do not walk into areas where loads are being lifted and transferred. Cordon off work areas – Hard and/or Soft Barriers	3	1	3	Medium	Team Lead
	Poor communication						VHF Communications Toolbox Meetings					
Mobilizing of tools and equipment unto vehicle at ESL Storage Area	Poor housekeeping	Slip, trip and falls	2	2	4	Medium	Assess work area before any work begins. Ensure that all walkways are clear of clutter, sharp objects, protruding items, grease, etc.	1	1	1	Low	Team Lead
	Uneven surfaces	Slip, trip and falls. Cuts and bruises.	2	2	4	Medium	Establish proper transport pathway before moving begins and communicate to all workers.	1	1	1	Low	Team Lead
	Poor manual handling techniques	Muscle sprains and strains, falls, cuts, crushed appendages	2	2	4	Medium	Use Mechanical Means of Lifting where applicable; Establish lifting plan, adequate supervision, adequate training, use of proper manual handling techniques, establish clear lines of communication, adequate manpower, use of PPE	1	1	1	Low	Team Lead
	Sharp edges, bulky loads	Cuts and bruises, strains, property damage, crushed appendages	2	2	4	Medium	Assess available manpower and assign tasks accordingly. Use of PPE – leather faced gloves to ensure proper grip on equipment.	1	1	1	Low	Team Lead
	Other employees	Injury to other employees	2	2	4	Medium	Inform all employees of intended activity. Cordon off area if necessary.	1	1	1	Low	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
		entering work space – cuts, falls, soft tissue damage, etc										
Journey from ESL Storage to Vessel Location	Overloading of vehicle	Property damage, vehicle failure, accidents, Injuries to Public Road Users	3	2	6	High	Ensure that the vehicle's rated capacity is not exceeded. Use seatbelts at all times. Utilize defensive driving techniques.	3	1	3	Medium	Team Lead
	Poor road conditions/distractions	Collision, equipment damage.	3	2	6	High	Be aware of the road conditions, pay attention to road signs. Adhere to all speed limit signs. Abstain from using cell phone whilst driving. Utilize defensive driving techniques. Employ Journey Management Plan as well as Fatigue Management Plan	3	1	3	Medium	Team Lead
	Vehicle failure	Collision, robberies Property damage and loss of property.	3	2	6	High	ESL vehicles inspected weekly and all defects recorded and reported for repair. Always refer to emergency contacts for assistance when in difficulty. Be alert and aware of your surroundings. Secure personal belongings properly.	3	1	3	Medium	Team Lead
	Other drivers on the road and pedestrians	Collisions, damage to vehicles	3	2	6	High	ESL driver must have a valid driver's license. Obey speed limit and all traffic signs. Workers must adhere to ESL's strict substance abuse	3	1	3	Medium	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
							policy. Maintain at least a three second following distance. Use seatbelts at all times. Drivers are trained for Defensive Driving. Do not react to provocation from other drivers and pedestrians. Stop at red traffic lights. Look out for flashing amber lights at school crossing zones. Give way to pedestrians.					
	Inclement weather	Collisions, damage to equipment	3	2	6	High	Pay attention to weather conditions and weather advisory. Reduce speed in rainy weather. Use hazard lights to increase ability of other drivers to see vehicle. Abandon work in extreme conditions. Follow procedure in ERP	3	1	3	Medium	Team Lead
	Flying objects	Impairment of other drivers' vision Collisions	3	2	6	High	Secure all items, especially light items that can be easily picked up by the wind.	3	1	3	Medium	Team Lead
Mobilizing tools and equipment from vehicle unto the vessel	Poor manual handling technique	Muscle sprains and strains, falls, cuts, crushed appendages	2	2	4	Medium	Establish lifting plan, adequate supervision, adequate training, use of proper manual handling techniques, establish clear lines of communication, adequate manpower, use of PPE. Certified Crane & Rigging Equipment	2	1	2	Low	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
							Certified Crane Operator and Banksman.					
	Wet and slippery surfaces	Slip, trip, and falls, broken limbs	2	2	4	Medium	Exercise caution. Be mindful of proper feet placement. Use sides of boat for support. Use proper footwear – Steel-toed non-slip boots.	2	1	2	Low	Team Lead
	Man overboard	Head injuries, broken limbs, drowning	3	2	6	High	All team members adequately trained in safety procedures for working on floating structures and near/over open water and on boats. Ensure that approved life jackets or work vests are worn at all times. Follow procedure in ERP.	3	1	3	Medium	Team Lead
	Objects at Height	Dropped objects causing head and other injuries	2	2	4	Medium	Ensure crane operator is certified. Inspect lifting equipment before use. Ensure equipment has current certification with records of inspection and maintenance. Establish lifting plan.	2	1	2	Low	Team Lead
	Inclement weather	Damage to boat, drowning, lightning strikes (burns, damage to equipment, death)	2	2	4	Medium	Listen to weather advisory. Monitor changes in weather. Abandon work in extreme weather. Follow procedure in ERP.	2	1	2	Low	Team Lead
Assembling of sampling	Poor manual handling techniques	Muscle sprains and strains, falls,	2	2	4	Medium	Practice proper manual handling techniques at all times. Adhere to SOPs. Use suitable PPE.	1	1	1	Low	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
equipment		cuts, crushed appendages										
	Poor condition of equipment	Personnel injury, property damage	2	2	4	Medium	Inspect equipment prior to use. Ensure maintenance records are current.	1	1	1	Low	Team Lead
	Pinch points	Hand injuries	2	2	4	Medium	Hand protection must be worn at all times. Be aware of finger placements.	1	1	1	Low	Team Lead
	Welding	Arc eye, burns, electric shock, welded particles, fire	2	2	4	Medium	Certified welder and certified equipment. Specified welding PPE: full face welding mask, welding gloves, fire retardant long sleeve coveralls, steel toe shoes. Follow ALL hot work permit requirements. E.g.: Fire Watch. Fire extinguisher/fire-fighting equipment. Gas Testing & Monitoring	1	1	1	Low	Team Lead
	Incompetent personnel	Damage to equipment, bodily injury	2	2	4	Medium	All persons must be trained and certified in their respective field of work, only authorized personnel to assemble and disassemble equipment.	1	1	1	Low	Team Lead
	Poor lighting conditions	Personnel injury	2	2	4	Medium	Ensure that there is adequate lighting on deck at all times.	2	1	2	Low	Team Lead
Mobilizing tools and equipment from vessel onto vehicle	Same as mobilizing tools and equipment from vehicle onto vessel. Follow the same safety procedures.											

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
Journey from vessel boarding location to ESL Compound	Same hazards associated with Journey from ESL to Vessel boarding location. Follow the same safety procedures.											

SAFETY EQUIPMENT REQUIRED:

Safety hard hat	Y	Safety Glasses	Y	Face Shield	Y	Hearing Protection	Y	Goggles	Y	Cotton Gloves	Y	Fire Blanket	Y	Lock Out	Y
Safety Harness	Y	Barricades	N	Vessel Entry permit	Y	Fire resistant clothing	Y	Rubber gloves	Y	Chemical Resistant gloves	N	Tag out	N	Fire extinguishers	Y
Rope off area	N	Hot work permit	Y	Fire watch	Y	Scaffolding	N	Gas detectors	Y	Lifting precaution	Y	Dust mask	N	Respirator	Y
Safety Footwear	Y														

HAZARD CHECKLIST:

Falls from heights	Y	Falling objects	Y	Collision	Y	Access/Egress	Y	Moving Machinery	Y	Liquid or Gas under Pressure	Y
Noise	Y	Chemical exposure	Y	Illumination	Y	Flammable Materials	Y	Flaring / hydrocarbon gas release	N	Electricity	N
Oil/ Chemical	N	Competence of personnel	Y	Confine Space	N	Corrosive Material	N	Manual Handling	Y	Naked Flames	Y

Was toolbox meeting held: Yes No?

NAMES OF JOB CREW:	DEVON RAMOTAR	JASON APPING	LAYNE WILLIAMS	Sudesh Hosein	MITRA RAMPERSAD					
SIGNATURES OF JOB CREW:				S.H						
APPROVED BY:										

EMERGENCY CONTACT LIST

Emergency Numbers

TRINIDAD	
Ambulance	**811**
Police	**999**
Coast Guard	**634-4440**
Air Guard **Air Guard Operations**	**669-3877/4787** **669-7067**
GUYANA	
Ambulance	
Police	
Coast Guard	
Air Guard **Air Guard Operations**	
ESL Main Office	**657-1560**
ESL – Jerome Als (Managing Director)	**684-5209**
ESL – Nicholas Als **(Operations Manager)**	**312-0917**
ESL – Elka Bachan (Project Manager)	**389- 2673**
ESL Company Doctor – Dr. Moonan	**652-3664**
ARSingh Contact - Nicholas Kowlessar	**732-4599**

Radio Contact

Channel 16 **Call Sign - HP6228**

Vessel Contacts

ESL Sat	**+870773993548**
Sea Service **VSat** **Email**	**+870773212982**

Exxon Contact

Scott Moser	832 624 3662 Tel 832 683 0286 Cell j.scott.moser@exxonmobil.com e-mail

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Risk Ranking

Table 1: Hazard Effects and Rating

Hazard Effect	HE Rating
Major	3
Medium	2
Minimum	1

Table 2: Probability and Rating

Probability	P Rating
Highly Possible	3
Possible	2
Unlikely	1

Table 3: Risk Ranking Matrix

RISK MATRIX				
HE Rating	Probability Rating			
		1	2	3
	1	1	2	3
	2	2	4	6
	3	3	6	9

KEY

	Low Risk
	Medium Risk
	High Risk

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TOOL BOX MEETING FORM

Date:

Conducted By:

Location:

Topics Discussed

Attendees

NAME IN BLOCK LETTERS	SIGNATURE

JSA #17-22: Sediment & Benthic Sampling

ENVIRONMENTAL SCIENCES LIMITED

JOB SAFETY ANALYSIS

Location/System	Offshore Guyana	**Date**	September-November 2017	**JSA # 17-22**	**Site Visited:** Yes	**Team Lead:** Devon Ramoo **Company:** ESL
Job/Task Description	**Sediment and Benthic Sampling**					
Name of Vessel	**Sea Service**					
Prepared by: Jared Bisnath (HSE Advisor/Field & Marine Tech.)						
Has consideration been given to weather conditions YES ~~NO~~	Are written job procedures discussed YES ~~NO~~		Are there SIMOPS YES~~NO~~		Emergency Response Plan Made & Discussed YES ~~NO~~	

Hazard Effect (HE) x Probability (P) =Risk(R) *R Signifies residual risk after control measures in place

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
Journey to sample points and Deploying and retrieving sampling equipment (Grab, winch). The winch system uses cable.	Collisions with vessels and installations	Injury &/or Drowning of personnel on board vessel; Loss of Vessel & Equipment	3	2	6	High	Vessel Captain competent. Vessel inspected and approved before use -vessel in good working condition. Double check sample coordinates against the coordinates of pipeline locations. Call channel 16 on radio to acquire emergency assistance for towing to safe point. Use Satellite phone if needed (ESL: ++870773907924). Use company satellite phone to get assistance. Anchor and secure vessel until help arrives. Spill kits for on deck spill response Follow the ERP.	3	1	3	Medium	Team Lead
	Winch system failure	Crushed limbs, abrasions, fire, loss of equipment, amputations	3	2	6	High	Winch certified for use. Adequate supervision Winch and cables visually inspected before taken to work site and before use. Workers competent to use winch Adequate power supply Proper certified cable used for winch system Fire extinguisher on board with current inspection certificate	3	1	3	Medium	Team Lead

Page **1** of **11**

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
							Clearly identified Work Area.					
	Leaks from machinery	Slippery conditions, falls, broken limbs, environmental damage.	2	2	4	Medium	Inspect equipment intermittently for leaks. PM Program Use drip trays where needed. If possible, tie absorbent pads to leak points. Universal absorbent pads used for cleaning up spills must be stored in a proper container. On reaching land, these are taken to an approved disposal company such as Envirocare for disposal. Do not wash the deck of the boat until spills are cleaned.	2	1	2	Low	Team Lead
	Vessel Failure (engine, rudder failure, etc)	Collisions, robberies, dehydration,	3	2	6	High	Use company satellite phone to get assistance (ESL: ++870773993548). Call channel 16 on radio to acquire emergency assistance for towing to safe point. Anchor and secure vessel until help arrives. Follow procedure in ERP.	3	1	3	Medium	Team Lead
	Incompetent workers	Personal injury, injury to other works, damage to property	2	2	4	Medium	Workers competent to retrieve samples. Exercise adequate care when sampling. Use required PPE.	1	1	1	Low	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
	Cable	Cuts, entanglement, amputation, struck by	2	2	4	Medium	Inspect cables before use. Be mindful of hand placement when winch is in operation. Use of PPE. Cordoned off work area	2	1	2	Low	Team Lead
	Falling objects	Head injuries, Broken bones, death	3	2	6	High	Establish lifting plan before testing winch. Never stand, walk or work under a load. Use of PPE (safety hat, etc.) Cordoned off work area	3	1	3	Medium	Team Lead
	Struck by objects	Head injuries, broken bones, soft tissue injury death.	3	2	6	High	Pay attention to activities. Do not walk into areas where loads are being lifted and transferred. Use of PPE (safety hat, etc.) Cordoned off work area	3	1	3	Medium	Team Lead
	Man overboard	Head injuries, broken limbs, drowning	3	2	6	High	All team members adequately trained in safety procedures for working on floating structures and near/over open water and on boats. Ensure that approved life jackets or work vests are worn at all times. Fall arrest systems are used where fall prevention mechanisms (e.g. railings) are not in place: The area will be properly highlighted and cordoned off via tiger-striped painting indicating requirements of special approved and certified fall arrest PPE. Persons within this area must wear at all times; Full body harness which will be	3	1	3	Medium	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
							connected to retractable lanyards and Work Vests. The Lanyard will not allow for persons to reach over the edge of the boat and will be attached to certified anchor points. Only persons designated by the Team Leader as necessary for work within this area will be allowed access. Follow ERP: man overboard procedure					
	Inclement weather	Damage to boat, drowning, lightning strikes (burns, damage to equipment, death)	2	2	4	Medium	Listen to weather advisory. Monitor changes in weather. Abandon work in extreme weather. Follow procedure in ERP.: inclement weather procedure	2	1	2	Low	Team Lead
	Poor manual handling techniques	Muscle sprains and strains, falls, cuts, crushed appendages	2	2	4	Medium	Use mechanical means where practical Establish lifting plan, adequate supervision, adequate training, use of proper manual handling techniques, establish clear lines of communication, adequate manpower, use of PPE	1	1	1	Low	Team Lead
	Vessel mooring	Collision with offshore field support vessel, Personnel injury, property damage	2	2	4	Medium	Vessel Captain competent. Vessel inspected and approved before use -vessel in good working condition. Communication with CPP Control Room and offshore field support vessel in requesting use of mooring point.	1	1	1	Low	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
	Rotating parts and pinch points e.g. the winch & grab	Amputations, cuts, soft tissue damage	2	2	4	Medium	Workers must use care around equipment and avoid distractions Be aware of the placement of hands and feet around all moving parts of equipment. Proper emergency shutdown controls and proper guards installed on machinery.	1	1	1	Low	Team Lead
	Poor lighting conditions	Personnel injury	2	2	4	Medium	Ensure that there is adequate lighting on deck at all times.	1	1	1	Low	Team Lead
	Threats to the environment	Environmental damage	2	2	4	Medium	Ensure that all chemicals are properly contained. Spill containment and proper disposal of any oily waste Maceration of food and freezing of food waste. Garbage such as food, cups, paper etc, stored in a refrigerated compartment. On reaching land, the garbage is then taken to an approved facility such as SWMCOL. Untreated sewage will be stored on board the vessel in an approved tank. On land, sewage will be pumped out of the tank and onto an approved truck for disposal at a sewage treatment facility. Minimize disturbance to the ocean floor – on reaching sample points, ensure that sample coordinates are accurate to avoid taking additional grabs which further disturb the seabed. In cases where the grab sample shows evidence of a sensitive habitat such as coral, abandon grab sampling in	1	1	1	Low	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
							the area.					
	Piracy	Injury to Personnel, Loss of Life, Loss of Equipment / Vessel					Refer to ARSingh Security Plan/Procedure					Team Lead/Vessel Master
	Grab Retrieval	Pinch Points, Crush Points, Broken Bones, Property Damage	3	2	6	High	Restrict access to grab retrieval area. Personnel limit to retrieval area. Only competent and experienced workers allowed handling grab. Clear line of communication among personnel operating winch, hydraulic power pack and handling grab. The grab will remain in the water for tag lines to be applied and for grab to stabilize before bringing it onto the deck. Ensure area is clear of mud or any other slip potential. Minimize trip potentials. Exercise care with foot placement.	3	1	3	Medium	Team Lead
Journey between sampling points.	Same as journey to sample points. Follow the same safety procedures.											

SAFETY EQUIPMENT REQUIRED:

Safety hard hat	Y	Safety Glasses	Y	Face Shield	N	Hearing Protection	Y	Goggles	N	Cotton Gloves	N	Fire Blanket	N	Lock Out	N
Safety Harness	Y	Barricades	N	Vessel Entry permit	N	Fire resistant clothing	Y	Rubber gloves	Y	Chemical Resistant gloves	N	Tag out	Y	Fire extinguishers	Y
Rope off area	N	Hot work permit	N	Fire watch	N	Scaffolding	N	Gas detectors	N	Lifting precaution	Y	Dust mask	N	Respirator	N
Safety Footwear	Y														

HAZARD CHECKLIST:

Falls from heights	N	Falling objects	Y	Collision	Y	Access/Egress	Y	Moving Machinery	Y	Liquid or Gas under Pressure	Y
Noise	Y	Chemical exposure	Y	Illumination	Y	Flammable Materials	Y	Flaring / hydrocarbon gas release	N	Electricity	N
Oil/ Chemical	Y	Competence of personnel	Y	Confine Space	N	Corrosive Material	N	Manual Handling	Y	Naked Flames	N

Was toolbox meeting held: Yes No?

NAMES OF JOB CREW:	DEVON FASEN RAMLOO	APPING	MARK BRUCE	CARLOS ESTRADA	MITRA RAMKISSOO	CLIFTON-ASH	KENRICK LEWIS					
SIGNATURES OF JOB CREW:												
APPROVED BY:												

EMERGENCY CONTACT LIST

Emergency Numbers

TRINIDAD	
Ambulance	**811**
Police	**999**
Coast Guard	**634-4440**
Air Guard **Air Guard Operations**	**669-3877/4787** **669-7067**
GUYANA	
Ambulance	
Police	
Coast Guard	
Air Guard **Air Guard Operations**	
ESL Main Office	**657-1560**
ESL – Jerome Als (Managing Director)	**684-5209**
ESL – Nicholas Als **(Operations Manager)**	**312-0917**
ESL – Elka Bachan (Project Manager)	**389- 2673**
ESL Company Doctor – Dr. Moonan	**652-3664**
ARSingh Contact - Nicholas Kowlessar	**732-4599**

Radio Contact

Channel 16 **Call Sign - HP6228**

Vessel Contacts

ESL Sat	**+870773993548**
Sea Service **VSat** **Email**	**+870773212982**

Exxon Contact

Scott Moser	832 624 3662 Tel 832 683 0286 Cell j.scott.moser@exxonmobil.com e-mail

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Risk Ranking

Table 1: Hazard Effects and Rating

Hazard Effect	HE Rating
Major	3
Medium	2
Minimum	1

Table 2: Probability and Rating

Probability	P Rating
Highly Possible	3
Possible	2
Unlikely	1

Table 3: Risk Ranking Matrix

RISK MATRIX				
	Probability Rating			
HE Rating		1	2	3
	1	1	2	3
	2	2	4	6
	3	3	6	9

KEY

	Low Risk
	Medium Risk
	High Risk

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TOOL BOX MEETING FORM

Date:

Conducted By:

Location:

Topics Discussed

Attendees

NAME IN BLOCK LETTERS	SIGNATURE

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JSA #17-23: Benthic & Washing Preservation

ENVIRONMENTAL SCIENCES LIMITED

JOB SAFETY ANALYSIS

Location/System	Offshore Guyana	**Date**	September-November 2017	**JSA # 17-23**	**Site Visited:** Yes	**Team Lead:** Devon Ramoo **Company: ESL**
Job/Task Description	**Benthic Washing and Preservation**					
Name of Vessel	**Sea Service**					
Prepared by: Jared Bisnath (HSEAdvisor/Field&Marine Tech.)						
Has consideration been given to weather conditions YES ~~NO~~	Are written job procedures discussed YES ~~NO~~		Are there SIMOPS YES~~NO~~		Emergency Response Plan Made & Discussed YES ~~NO~~	

Hazard Effect (HE) x Probability (P) =Risk(R) *R Signifies residual risk after control measures in place

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
Inspection of Equipment	Faulty equipment	Cuts, abrasions.	2	2	4	Medium	Equipment inspected before use.	2	1	2	Low	Team Lead
Washing and Fixation of Benthic samples	Contact with sharp fragments in sediment	Cuts, infection	2	2	4	Medium	Exercise adequate care when washing samples Use appropriate gloves First aid kit on board with disinfectant and antibiotic cream. MSDSs available. Eye wash solution available	1	1	1	Low	Team Lead
	Contact with contaminated sediment	Skin disorders	2	2	4	Medium	Wear proper skin protection when coming into contact sediment. Ensure proper personal clean-up upon completion of sample handling.	1	1	1	Low	Team Lead
	Contact with/ inhalation of formalin/ accidental ingestion	Burns, blisters, permanent scaring, eye irritation, burns to the eye. Inhalation – Decrease in lung function	3	2	6	High	Read the Material Safety Data Sheets (MSDS) provided. Use appropriate protective equipment (i.e., Gloves and safety goggles). Fill jar with water before adding formalin to reduce risk of eye injury in the event that formalin was splashed. Use secondary containment when preserving samples to contain spills. Ensure ample ventilation. Use respirator where appropriate. Ensure proper personal clean-up upon completion of sample	3	1	3	Medium	Team Lead

Page 1 of 9

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
		Formaldehyde is also a known carcinogen Ingestion – formalin is also toxic to the body					handling. Ensure that all formalin containers are properly labeled so it is not mistaken for other liquids. Do not eat, smoke or drink around preservation activities.					
	Spills	Damage to crew members, damage to equipment, environmental damage	3	2	6	High	Always use secondary containment when storing or using chemicals. Clean up spills immediately as outlined in ERP. Universal spill kits on board. Universal absorbent pads used for cleaning up spills must be stored in a proper container. On reaching land, these are taken to an approved disposal company such as Envirocare for disposal. Do not wash deck unless spills are cleaned.	3	1	3	Medium	Team Lead
	Formaldehyde – level 3 flammability	Fire	3	2	6	High	Use secondary containment in storage area and during preservation. Avoid spillages. Clean up spills as they occur. Follow procedure as outlined in ERP. Do not smoke in preservation areas. Store Formalin away from heat, combustible material and ignition sources.	3	1	3	Medium	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
							Protect containers from physical damage. Fire extinguishers and fire detection devices on board.					
	Poor lighting conditions	Personnel injury	2	2	4	Medium	Ensure that there are adequate lighting on deck at all times.	1	1	1	Low	Team Lead
	Contaminated Gloves	Personal injury such as burns, eye injuries, accidental ingestion. Contamination of surfaces with chemicals.	2	2	4	Medium	Work gloves must be removed before entering cabin, kitchen washroom areas, etc. All gloves used during preservation must be stored in a separate container (chemical resistant). On reaching land, all used gloves are taken to an approved facility such as Envirocare for incineration. Ensure proper personal clean-up upon completion of sample handling.	1	1	1	Low	Team Lead
	Accidental ingestion and Cross Contamination	Burns, blisters, deep injuries to the digestive tract	3	2	6	High	Do not eat, drink, or smoke in work areas. First aid kits and MSDS available. Wash hands thoroughly after handling this material. Maintain good housekeeping. Keep all chemicals in appropriately labeled containers and store away from food and drinks.	3	1	3	Medium	Team Lead
Placement of sediment samples in bags and containers	Contact with contaminated sediment	Skin irritation, Eye irritation Eye injuries	2	2	4	Medium	Workers competent to retrieve samples. Use of proper PPE – coverall, safety glasses, boots, and gloves. Advertise care when placing samples in bags and containers.	1	1	1	Low	Team Lead

SEQUENCE OF BASIC JOB STEPS	HAZARDS IDENTIFIED USE CHECKLIST AS A GUIDE TO BE SPECIFIC	HAZARD EFFECT (TYPE OF INJURY / DAMAGE OR ENVIRONMENTAL EFFECT)	HE	P	R	RISK LEVEL	CORRECTIVE MEASURES / RECOMMENDATIONS	HE *	P *	R*	RISK LEVEL	PERSON RESPONSIBLE
							Wash hands thoroughly after collecting samples. Remove any wet clothing after work.					
	Poor lighting conditions	Personnel injury	2	2	4	Medium	Ensure that there is adequate lighting on deck at all times, otherwise, no activities at night.	1	1	1	Low	Team Lead
	Contact with sharp fragments in sediment	Cuts, infection	2	2	4	Medium	Advertise adequate care when washing samples Use appropriate gloves First aid kit on board with disinfectant and antibiotic cream.	1	1	1	Low	Team Lead

SAFETY EQUIPMENT REQUIRED:

Safety hard hat	Y	Safety Glasses	Y	Face Shield	N	Hearing Protection	N	Goggles	N	Cotton Gloves	N	Fire Blanket	N	Lock Out	N
Safety Harness	N	Barricades	N	Vessel Entry permit	N	Fire resistant clothing	Y	Rubber gloves	N	Chemical Resistant gloves	Y	Tag out	N	Fire extinguishers	Y
Rope off area	N	Hot work permit	N	Fire watch	N	Scaffolding	N	Gas detectors	N	Lifting precaution	Y	Dust mask	N	Respirator	Y
Safety Footwear	Y														

HAZARD CHECKLIST:

Falls from heights	N	Falling objects	N	Collision	N	Access/Egress	N	Moving Machinery	N	Liquid or Gas under Pressure	N
Noise	N	Chemical exposure	Y	Illumination	Y	Flammable Materials	Y	Flaring / hydrocarbon gas release	N	Electricity	N
Oil/ Chemical	Y	Competence of personnel	Y	Confine Space	N	Corrosive Material	Y	Manual Handling	Y	Naked Flames	N

Was toolbox meeting held: Yes No?

NAMES OF JOB CREW:	DEVON RAMLOG	MARA RAMLESHO	JASON APPING								
SIGNATURES OF JOB CREW:											

APPROVED BY:

EMERGENCY CONTACT LIST

Emergency Numbers

TRINIDAD	
Ambulance	**811**
Police	**999**
Coast Guard	**634-4440**
Air Guard **Air Guard Operations**	**669-3877/4787** **669-7067**
GUYANA	
Ambulance	
Police	
Coast Guard	
Air Guard **Air Guard Operations**	
ESL Main Office	**657-1560**
ESL – Jerome Als (Managing Director)	**684-5209**
ESL – Nicholas Als **(Operations Manager)**	**312-0917**
ESL – Elka Bachan (Project Manager)	**389- 2673**
ESL Company Doctor – Dr. Moonan	**652-3664**
ARSingh Contact - Nicholas Kowlessar	**732-4599**

Radio Contact

Channel 16 **Call Sign - HP6228**

Vessel Contacts

ESL Sat	**+870773993548**
Sea Service **VSat** **Email**	**+870773212982**

Exxon Contact

Scott Moser	832 624 3662 Tel 832 683 0286 Cell j.scott.moser@exxonmobil.com e-mail

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Risk Ranking

Table 1: Hazard Effects and Rating

Hazard Effect	HE Rating
Major	3
Medium	2
Minimum	1

Table 2: Probability and Rating

Probability	P Rating
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RISK MATRIX				
	Probability Rating			
HE Rating		1	2	3
	1	1	2	3
	2	2	4	6
	3	3	6	9

KEY

	Low Risk
	Medium Risk
	High Risk

ENVIRONMENTAL SCIENCES LIMITED

TOOL BOX MEETING FORM

Date:

Conducted By:

Location:

Topics Discussed

Attendees

NAME IN BLOCK LETTERS	SIGNATURE

Appendix 4 - Chain-of-Custodies (COCs)

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ESL Chain-of-Custody

ENVIRONMENTAL SCIENCES LIMITED
Assisting industry with logical technology and solutions

141 Riverside Drive, San Fernando, Trinidad, West Indies
Tel.: (868) 657-9024
Tel.: (868) 657-1560
Fax: (868) 653-2571

CHAIN OF CUSTODY/ANALYTICAL REQUEST FORM

QMF: 026
Date: July 2012
Rev. No.: 1

Date Submitted: 24/11/17 Date Required:

No. 0472

ANALYSIS REQUESTED

	CLIENT ID	SAMPLE #	DATE SAMPLED	TIME SAMPLED	SAMPLE TYPE
1	Exxon-Guyana	Bc 01	22/10/17.	8:00AM - 8:00PM	Sediment
2	Metocean Project	Bc 02	20/10/17		
3	25/17.	Bc 03	21/10/17		
4		Bc 04	" "		
5		Bc 05	20/10/17		
6		Bc 06	" "		
7		Bc 07	21/10/17.		
8		Bc 08	22/10/17		
9		Bc 09	" "		
10		Bc 10	23/10/17		
11		Bc 11	" "		
12		Bc 12	" "		
13		Bc 13	24/10/17.		
14		Bc 14	25/10/17		
15		Bc 15	26/10/17		
16		Bc 16			
17		Bc 17			
18		Bc 18			
19		Bc 19			
20		Bc 20	↓		
21		Bc 21	27/10/17		
22		Bc 22			
23		Bc 23			
24		Bc 24	↓	↓	
25					
26					
27					
28					
29					
30					

Client: EXXON
Contact: KARI EHMLING
Report Address: EXXON HOUSTON
Billing Address: Same as above

Phone: –
P.O.#: –
Client Job #: –
Samples Submitted: 48 (Dup).
Preservatives: N/A
Weather Conditions: –
Sampled by: DEVON RAMDEO
Sample Date: 20-27/10/17
Signature:

Relinquished by:
Signature:
Date 24/11/17. Time
Received by: R. Pariag.
Signature: 24/11/17 R. Pariag.
Date: 24/11/17 Time: 3:30PM.

Sample Condition Upon Reciept:
☐ Frozen ☒ Cold ☐ Ambient
Head Space: ☐ YES ☐ NO

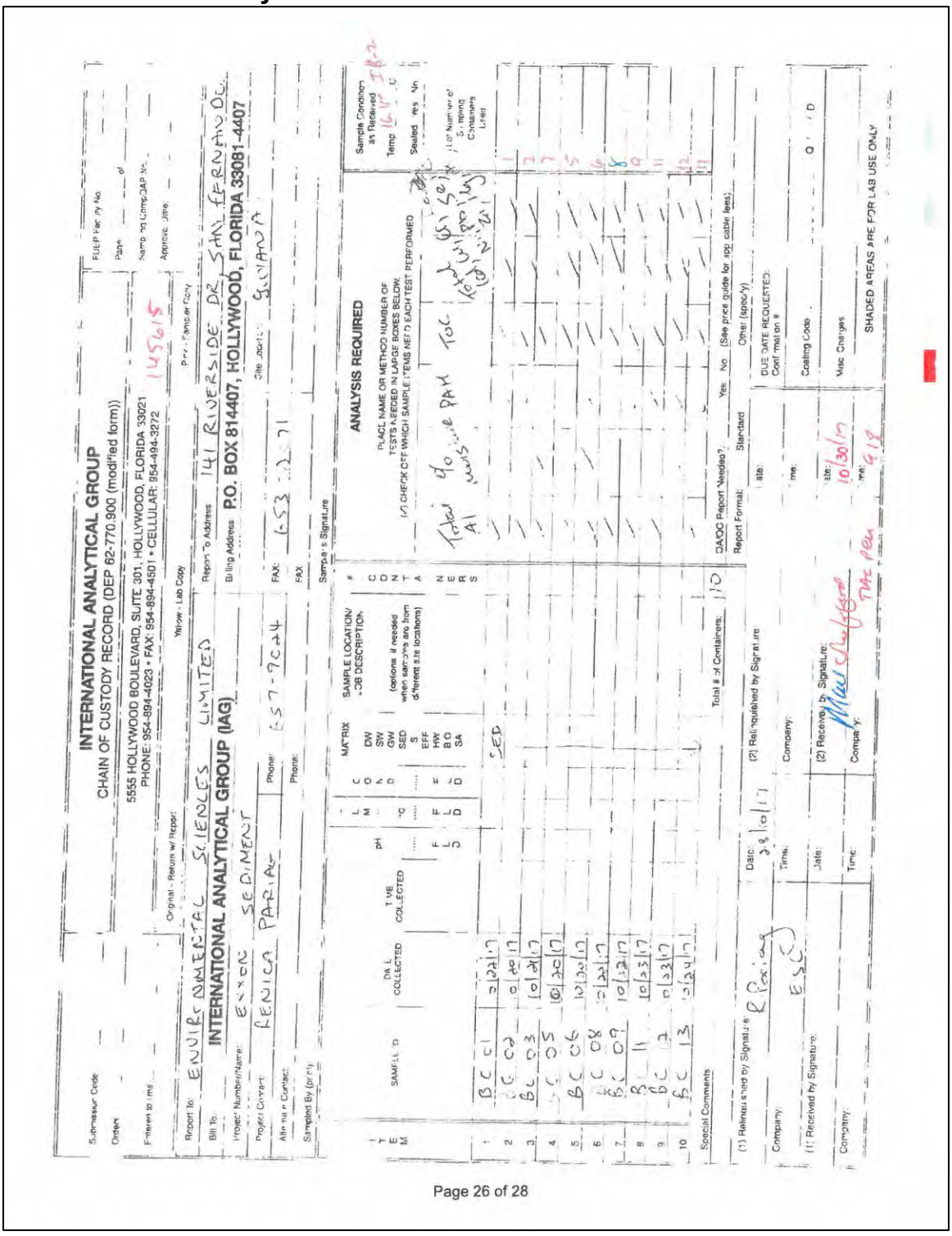
Special Requests/Comments:

Other (breakage, leakage, illegible etc):
N/A.

Compiled by: R.P. Checked by: S.M.L. Approved by: J.A. Date of Next Rev: July 2013

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IAG Chain-of-Custody



INTERNATIONAL ANALYTICAL GROUP
CHAIN OF CUSTODY RECORD (DEP 62-770.900 (modified form))

5555 HOLLYWOOD BOULEVARD, SUITE 301, HOLLYWOOD, FLORIDA 33021
PHONE: 954-894-4023 • FAX: 954-894-4501 • CELLULAR: 954-494-3272

Original - Return w/ Report
Yellow - Lab Copy
Pink - Sampler Copy

Report To: ENVIRONMENTAL SCIENCES LIMITED
Bill To: INTERNATIONAL ANALYTICAL GROUP (IAG)
Billing Address: P.O. BOX 814407, HOLLYWOOD, FLORIDA 33081-4407
Project Number/Name: ESSO SEDIMENT
Project Contact: JESSICA PARLAC Phone: 657-9624 FAX: 653-2171
Alternate Contact: Phone: FAX:
Sampled By (print): Sampler's Signature:

ANALYSIS REQUIRED
PLACE NAME OR METHOD NUMBER OF TESTS NEEDED IN LARGE BOXES BELOW.
(*) CHECK OFF WHICH SAMPLE ITEMS NEED EACH TEST PERFORMED

ITEM	SAMPLE ID	DATE COLLECTED	TIME COLLECTED	pH	MATRIX	# CONTAINERS	SAMPLE LOCATION / JOB DESCRIPTION (options if needed when samples are from different site locations)
1	BC 01	10/21/17			SED		
2	BC 02	10/20/17					
3	BC 03	10/21/17					
4	BC 05	10/20/17					
5	BC 06	10/21/17					
6	BC 08	10/21/17					
7	BC 09	10/23/17					
8	BC 11	10/23/17					
9	BC 3	10/23/17					
10	BC 13	10/24/17					

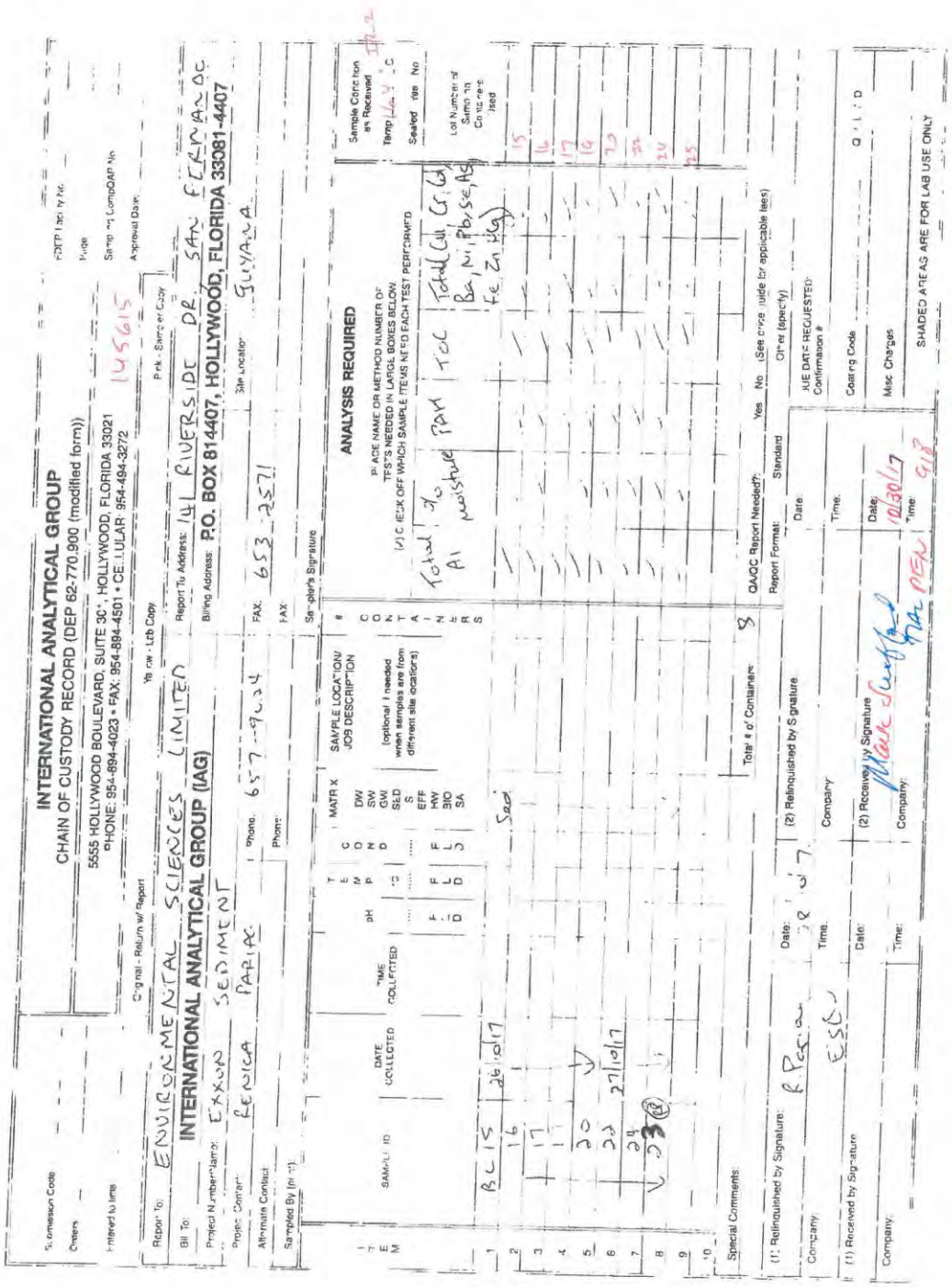
Special Comments:
Total # of Containers: 10

Sample Condition as Received: Temp 16.4 °C Sealed Yes No
(#) Number of Shipping Containers Used

(1) Relinquished by Signature: Date: 10/25/17 (2) Relinquished by Signature:
Company: ESC Time: Company:
(1) Received by Signature: Date: (2) Received by Signature: Date: 10/30/17
Company: Time: Company: Time:

QAQC Report Needed? Yes No (See price guide for applicable fees)
Report Format: Standard Other (specify)
DUE DATE REQUESTED: Confirmation #
Coating Code
Misc Charges
SHADED AREAS ARE FOR LAB USE ONLY

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INTERNATIONAL ANALYTICAL GROUP
CHAIN OF CUSTODY RECORD (DEP 62-770.900 (modified form))

5555 HOLLYWOOD BOULEVARD, SUITE 36*, HOLLYWOOD, FLORIDA 33021
PHONE: 954-894-4023 • FAX: 954-894-4501 • CELLULAR: 954-494-3272

Original - Return w/ Report — Yellow - Lab Copy — Pink - Shipper Copy

Report To: ENVIRONMENTAL SCIENCES LIMITED — Report To Address: 14L RIVERSIDE DR. SAN FERNANDO CA
Bill To: INTERNATIONAL ANALYTICAL GROUP (IAG) — Billing Address: P.O. BOX 814407, HOLLYWOOD, FLORIDA 33081-4407
Project Number/Name: EXXON SEDIMENT — Site Location: GUYANA
Proj. Contact: RENICA PARIAG — Phone: 653-9734 — FAX: 653-3571
Alternate Contact — Phone: — FAX:
Sampled By (print): — Sampler's Signature

ITEM	SAMPLE ID	DATE COLLECTED	TIME COLLECTED	pH	MATRIX: COMP, GRAB, DW, SW, GW, S&D, S, EFF, HW, BIO, SA	SAMPLE LOCATION / JOB DESCRIPTION (optional if needed when samples are from different site locations)	# CONTAINERS	ANALYSIS REQUIRED: PLACE NAME OR METHOD NUMBER OF TEST'S NEEDED IN LARGE BOXES BELOW. USE DESK OPP WHICH SAMPLE ITEMS NEED EACH TEST PERFORMED	Sample Condition as Received: Temp; Sealed Yes No	Lot Number of Sample Containers Used
1	BC15	26/10/17			SED			Total Cd, Cr, Cu, Ba, Ni, Pb, Se, Ag, Fe, Zn (Icp)		15
2	16							Al moisture		16
3	17									17
4	30									18
5	33	27/10/17								33
6	34									34
7	V 33 (2)	V								35
8										
9										
10										

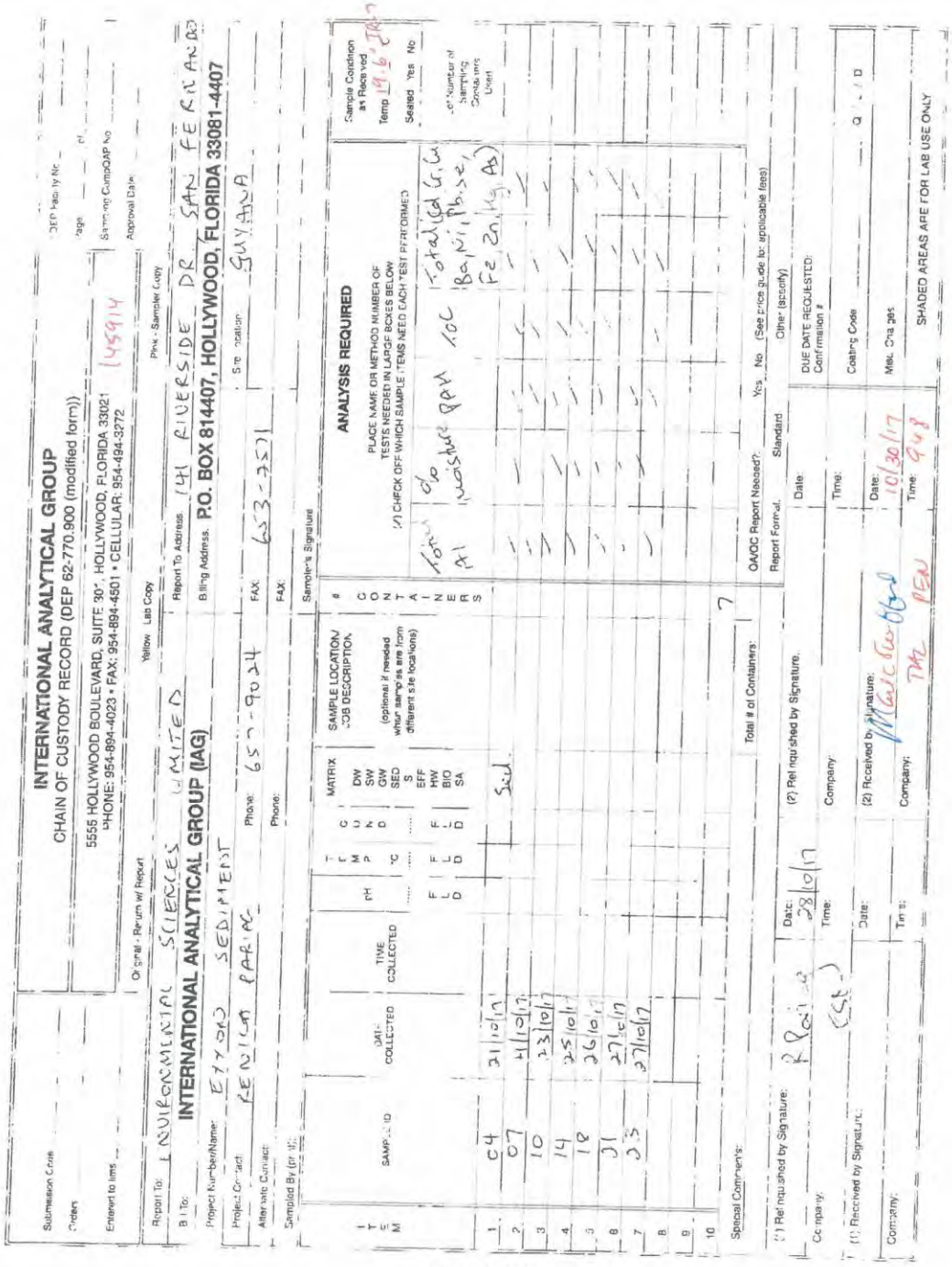
Special Comments: — Total # of Containers: 8 — QA/QC Report Needed?: Yes No (See price guide for applicable fees) — Standard

(1) Relinquished by Signature: R Pascoe — Date: 28/10/17 — Time: — Company: ESSO — (2) Relinquished by Signature — Date: — Time: — Company: — Report Format: — Other (specify) — DATE REQUESTED: — Confirmation #

(1) Received by Signature — Date: — Time: — Company: — (2) Received by Signature: Mark Surety — Date: 30/10/17 — Time: 9:18 — Company: ESL — Misc Charges — Cooling Code

SHADED AREAS ARE FOR LAB USE ONLY

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INTERNATIONAL ANALYTICAL GROUP
CHAIN OF CUSTODY RECORD (DEP 62-770.900 (modified form))

5555 HOLLYWOOD BOULEVARD, SUITE 307, HOLLYWOOD, FLORIDA 33021
PHONE: 954-894-4023 • FAX: 954-894-4501 • CELLULAR: 954-494-3272

Original - Return w/ Report — Yellow - Lab Copy — Pink - Sampler Copy

Report To: E. ROUBICHAUD, SCIENCES, INC — Report To Address: 141 RIVERSIDE DR. SAN FERNANDO
Bill To: INTERNATIONAL ANALYTICAL GROUP (IAG) — Billing Address: P.O. BOX 814407, HOLLYWOOD, FLORIDA 33081-4407
Project Number/Name: E17-010 SEDIMENT — Site Location: GUYANA
Project Contact: RENUKA PARMAR — Phone: 653-9024 — FAX: 653-3531
Alternate Contact: — Phone: — FAX:
Sampled By (print): — Sampler's Signature:

ITEM	SAMPLE ID	DATE COLLECTED	TIME COLLECTED	pH	TEMP	FIELD	GUNDO	MATRIX: DW SW GW SED S EFF HW BIO SA	SAMPLE LOCATION/ JOB DESCRIPTION (optional if needed when samples are from different site locations)	# CONTAINERS
1	04	31/10/17						Sed		
2	07	1/11/17								
3	10	23/10/17								
4	14	25/10/17								
5	18	26/10/17								
6	31	27/10/17								
7	33	27/10/17								
8										
9										
10										

Special Comments: — Total # of Containers: 7

ANALYSIS REQUIRED
PLACE NAME OR METHOD NUMBER OF TESTS NEEDED IN LARGE BOXES BELOW
(*) CHECK OFF WHICH SAMPLE ITEMS NEED EACH TEST PERFORMED

Sample Condition as Received — Temp 19.6 °C — Sealed Yes No — # of Sampling Containers Used

QA/QC Report Needed? Yes No (See price guide for applicable fees) — Report Format: Standard Other (specify)

(1) Relinquished by Signature: — Date: 28/10/17 — Time: — Company: — (2) Relinquished by Signature: — Date: — Time: — Company:

(1) Received by Signature: — Date: — Time: — Company: — (2) Received by Signature: — Date: 10/30/17 — Time: 9:48

DUE DATE REQUESTED: — Confirmation # — Coating Code — Q . . D — Misc. Charges

SHADED AREAS ARE FOR LAB USE ONLY

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Appendix 5 – PINPOINT® Redox Monitor User's Guide

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PINPOINT ®
REDOX/ORP Monitor
(Oxidation Reduction Potential)

User's Guide

American Marine is proud to introduce ***PINPOINT*** **REDOX/ORP Monitor®**, the only truly accurate and affordable continuous monitoring ORP (REDOX) system. Every ***PINPOINT*** **REDOX/ORP Electrode** features a 10-foot high suppression cable, BNC Connector as well as a 99.9% platinum sensor tip. A ***PINPOINT*** **AC Adapter Kit** is recommended for aquarium use since ORP values are most important when continuously monitored. Standard 9-volt battery can be used and should be replaced when visually indicated on the display as "LOBAT".

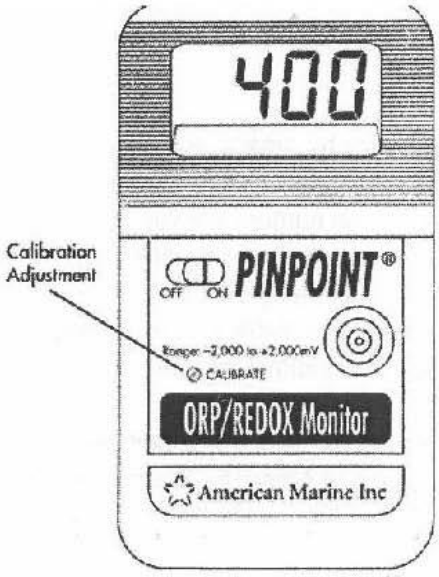
NOTE: The REDOX/ORP Monitor unit is NOT waterproof and must be operated on a dry surface. Liquid contact on the printed circuit board will cause corrosion and void warranty.

• **Set-up**

Unwrap the protective plastic packaging from the ***PINPOINT*** **REDOX/ORP Monitor** unit. Remove the battery cover on the back of the monitor and install a new 9-volt battery or the ***PINPOINT AC Adapter Kit***. Use the pop-up stand on back and place meter on a flat, dry surface. Carefully loosen and remove the plastic storage container installed on the end of the electrode. SAVE the plastic storage container for future use. Attach the BNC Connector from the electrode onto the BNC input of the ORP Monitor. Turn the connector ¼ turn clockwise to lock the connector. Activate the unit by setting the power switch to the ON position. Your ***PINPOINT*** **REDOX/ORP Monitor** is now ready for calibration.

•**Calibration**

The ***PINPOINT*** **REDOX/ORP Electrode** is widely considered to be a superior grade and should be precisely calibrated to the ***PINPOINT*** **ORP/REDOX Meter** before use. Place the tip of the red electrode into the **REDOX 400 Calibration Fluid** and wait a minute or so for the measurement to settle in. Adjust the calibration screw on the front of the monitor to read 400mV. Calibration should be checked frequently for maximum precision. Do not reuse the calibration fluid. ***PINPOINT*** **REDOX 400 Calibration Fluid** also performs a thorough chemical cleaning of the platinum tip and the reference junctions during the calibration process.



Also available:

- ***PINPOINT*** **pH Monitor**
- ***PINPOINT*** **Wireless Thermometer**
- ***PINPOINT*** **Conductivity Monitor**
- ***PINPOINT*** **pH, ORP, Oxygen Electrodes**
- **High Precision pH Calibrating Fluids #4.00, #7.00, 10.00**
- ***PINPOINT*** **II Dissolved Oxygen Monitor**
- 4 meter Oxygen Probe Extension Cable
- ***PINPOINT*** **Salinity Monitor**
- ***110VAC Adapter Kit*** for most ***PINPOINT*** models
- ***PINPOINT*** **pH Controller**
- ***PINPOINT*** **ORP (REDOX) Controller**
- ***PINPOINT*** **Calcium Monitor**

Appendix 6 - Sample Label

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Figure 1 below is an example of a sample label used during the execution of the sediment and benthic sampling exercise within the Project area off the northeast coast of Guyana.



Figure 1: Example of Sample Label

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Appendix 7 – Sampling Methodologies

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GRAIN SIZE
SIEVE ANALYSIS METHOD

INTRODUCTION

The classification of soils for environmental purposes requires that the distribution of grain sizes in a given soil mass be known. Using sieve analysis, one can determine the grain size distribution of soils and classify the soil into sands and gravels. Sieves are made of woven wires with square openings which decrease in size as the sieve number increases; this allows the grains to be sorted by size.

REQUIRED EQUIPMENT

1. Sieves: # 5, 10, 35, 60, 120, 230 and bottom pan
2. An analytical balance sensitive up to 0.1 g
3. Tap with running water
4. #1 Filter paper
5. Plastic funnels
6. Oven.

PROCEDURE

1. Samples are oven dried at 115˚C to remove any weight contributed by water

2. Fold filter paper and then wash with tap water and dry at 115˚C

3. Determine the mass of the dry sample accurately to 0.1 g (W). Usually, a sample weight of about 75 to 100 grams is adequate unless some analytical need suggests otherwise

4. Prepare a stack of sieves. A sieve with larger openings is placed above a sieve with smaller openings. The sieve at the bottom should be No.230. A bottom pan should be placed under sieve No.230. As mentioned before, the sieves that are generally used in a stack are, from top to bottom, No.s 5, 10, 35, 40, 60, 120, and 230

5. Wash the sample through the sieves using tap water

6. Record the weight of a dried filter paper accurately to 0.1 g (W), and assign the sample ID and the top sieve number

7. Wash contents of the top sieve into the weighed and labelled filter paper and allow water to drain

8. Repeat procedures 6 and 7 for each of the remaining sieve in the stack and also the bottom pan

9. Oven dry each filter paper at 115˚C being careful not to allow any of the aggregate to be lost

10. Weigh each filter paper after it has been cooled and record its weight

11. The difference of dried filter paper from the dried filter paper with the respective aggregate for each sieve number is calculated to give the weight of aggregate retained in each sieve

12. Values are entered into “D-Plot” software to produce a USDA soil triangle plot which indicates the classification of the sample.

DATA

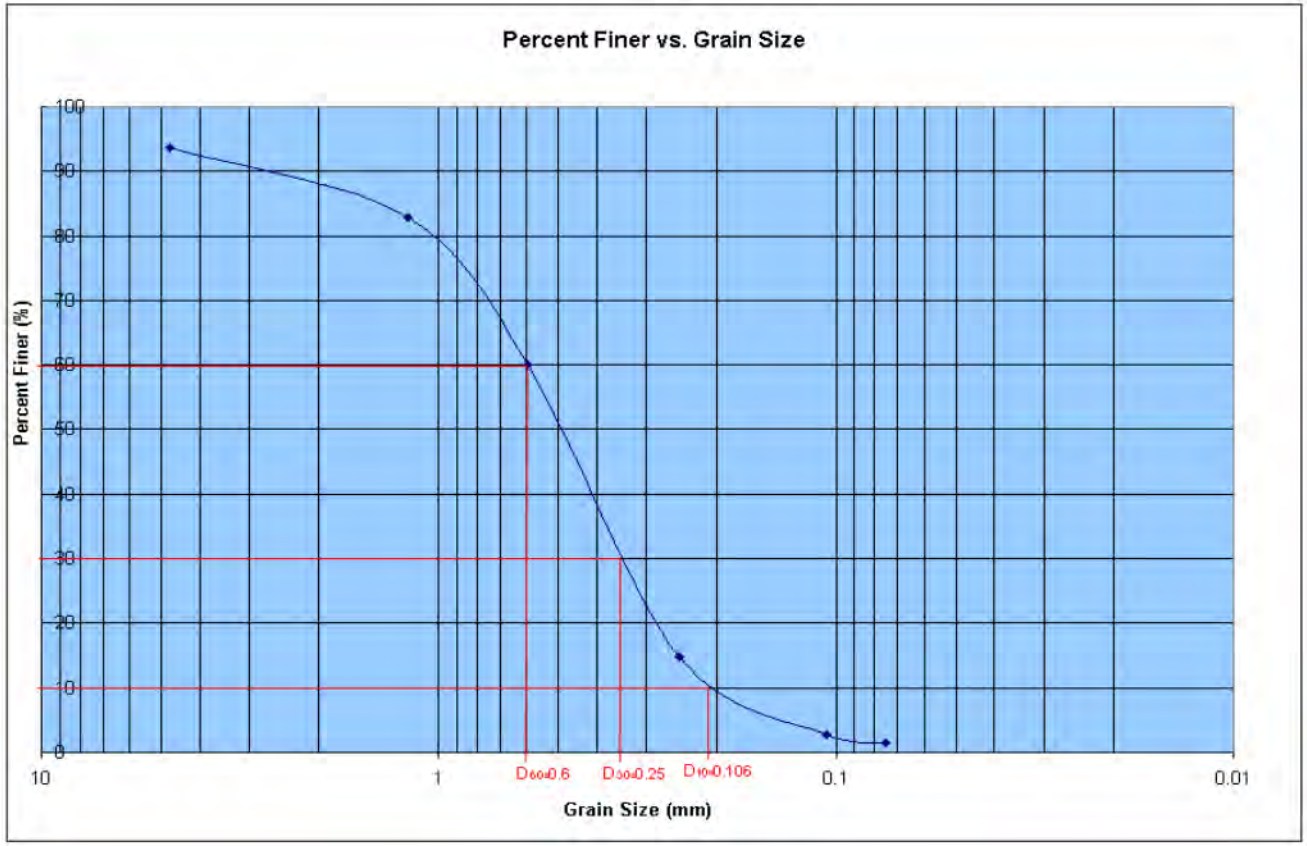
Table 1: Example of Grain Size Analysis Data

Sieve Number	Sieve Opening (in)	Sieve Opening (mm)	Wt. of Filter Paper (g)	Weight of Filter Paper with aggregate (g)	Weight of soil retained on each sieve (g)	% weight of soil retained on each sieve R_n	Cumulative % retained ΣR_n	% Finer $100-\Sigma R_n$
5	0.157	4.0	2.30	34.04	31.74	6.35	6.35	93.65
10	0.093	2.0	2.37	56.45	54.08	10.82	17.17	82.83
35	0.020	0.5	2.31	116.28	113.97	22.80	39.97	60.03
60	0.010	0.25	2.34	228.73	226.39	45.29	85.26	14.74
120	0.005	0.125	2.36	61.93	59.57	11.92	97.18	2.82
230	0.002	0.062	2.30	9.24	6.94	1.39	98.57	1.43
Pan	N.A.	<0.062	2.39	9.53	7.14	1.43	100.0	0.0
					= 499.83 = W_1	$\sum$ = 100.0		

Soil sample type: Granular with some fines

Weight (W) of oven-dry sample: W = 500.03 grams

Weight loss during Sieve analysis: 0.20 grams = 0.04%



D_{10} = 0.11
D_{30} = 0.25
D_{60} = 0.60
Cu = D_{60}/D_{10} = (0.60)/(0.11) = 5.5
Cc = $(D_{30})^2/(D_{60}xD_{10})$ = $(0.25)^2/(0.6*0.11)$ = 0.95

CALCULATIONS

1. *Weight of soil retained on each sieve*
   (g) = Wt. Filter paper w/aggregate – Wt. of Filter paper (g)

2. Percent weight of soil retained on each sieve, R_n (%)
R_n (%) = [Weight of soil retained/ Wt. of oven dry sample] x 100 (%)
Cumulative percent of soil retained on the nth sieve, R_n (%)
R_n (%) = Σ R(n^{th}) (%)

3. *Cumulative percent of soil passing through the nth sieve (% finer), 100 -R_n*
   100 - R_n = percent finer = 100 - Ó R(nth) (%)

4. Weight loss of soil during sieve analysis
(g) = [(Wt. of sample - mass of soil retained) / Wt. of sample] x 100
= (W – W_1) / (W) x 100 (%) **(O.K. if less than 2%)**

5. The grain size distribution obtained from the sieve analysis is plotted in a semi-logarithmic graph paper with grain size plotted on the log scale and percent finer plotted on the natural scale.

NOTES

- If soil retained on No.230 sieve is washed, the dry unit weight determined after washing (Step 10) should be used to calculate percent finer (than No. 230 sieve). The weight lost due to washing should be added to the weight of the soil retained on the pan
- From the grain size distribution curve, grain sizes such as D_{10}, D_{50}, D_{60}, etc. can be obtained. The D refers to the grain size, or apparent diameter, of the soil particles and the subscript (10, 85, 60) denotes the percent that is smaller. For example, D_{10} = 0.104 mm from the distribution curve means that 10 percent of the sample grains are smaller than 0.104 mm. The diameter, D_{10}, is also referred to as effective size. The effective size is used for several empirical correlations, such as coefficient permeability. The coefficient of gradation, Cc, is a parameter which indicates the range of distribution of grain sizes in a given soil specimen. If Cc is relatively large, it indicates a well-graded soil. If Cc is nearly equal to one, it means that the soil grains are of approximately equal size, and the soil may be referred to as a poorly graded soil
- The following formula is used to calculate Cc:
  $Cu = (D_{60} / D_{10})$
  $Cc = (D_{30})^2 / (D_{60} x D_{10})$

The parameter Cc is also referred to as the coefficient of curvature. For sand, if Cu is greater than 6 and Cc is between 1 and 3, it is considered well graded.

However, for a gravel to be well-graded, Cu should be greater than 4 and Cc must be between 1 and 3.

- Measure of dispersion include:
    - ***Median***
        - The diameter at which 50% of the particles are coarser and 50% of the particles are finer i.e. D_{50}
        - The diameter at which the cumulative curve intersects the 50% line
    - ***Mean***
        - The average particle size i.e. Ófn/100
    - ***Standard Deviation***
        - A measure of the degree of sorting
    - ***Skewness***
        - The degree of asymmetry of a frequency or cumulative curve
    - ***Kurtosis***
        - The degree of peakedness or departure from the "normal" frequency or cumulative curve
        - Leptokurtic curves are excessively peaked (center is better sorted than ends)
        - Platykurtic curves are flat-peaked (ends are better sorted than center)
        - Mesokurtic curves are "normal" (a normal bell shaped curve).

REFERENCES

L. A. Prieto-Portar. 2007. *Geotechnical_Manual_Lab*. http://www.learningace.com/doc/3095955/e65b0811b1ce11cac0e94f526bcb0a7d/geotechnical_manual_lab

DPLOT: a grain size distribution and statistics package for the analysis of unconsolidated sediments.

ENVIRONMENTAL SCIENCES LIMITED

METHODOLOGY FOR BENTHIC SAMPLING, SORTING AND IDENTIFICATION

Introduction

This document presents ESL's detailed methodology employed in offshore benthic sampling. This methodology is adapted from the 10500 Benthic Macroinvertebrates Standard Method (Franson *et al.* 2005) and from the methodology used during several Projects undertaken jointly between ESL and the UK-based ABPMer for benthic assessments in areas along the east and west coasts of Trinidad. This methodology requires that only organisms found to be alive at the time of sampling be subjected to identification and verification. Therefore, one of the adaptations of the methodology includes the identification of living tissue by visual means. For example, gastropods are considered to be alive at the time of sampling if living tissue is noted within the shell cavity; bivalves are treated similarly (closed bivalves are opened using a scalpel blade and tissue within examined); polychaetes and arthropods are counted if the head is present. ESL's benthic methodology described hereunder has recently been re-evaluated and audited by UK-based international EIA Specialist, Dr. Lynne Barratt and benthic and aquatic specialists Dr. Phil Smith and Dr. Anne Smith of the UK-based Aquatonics Limited.

The 10500 Benthic Macroinvertebrates Standard Method (Franson *et al.* 2005) was deemed a valuable starting point for deriving the adapted ESL methodology for benthic assessment, as it indicates the type of equipment to be used (such as different types of grabs, based on varying conditions/requirements). Though this Standard Method is applicable to wastewaters, its relevant sections offer applicability to marine areas. These sections are summarised below, and each gives an indication of how the Standard Method is applicable to marine areas:

- 10500 A – Introduction
- 10500 B – Sample Collection
- 10500 C – Sample Processing and Analysis
- 10500 D – Data Evaluation and Presentation

Section A of the 10500 method outlines the definition of benthic macrofauna, indicates the varying habitats (streams, lakes, estuaries and marine environments) in which they can occur, and outlines the analysis that can be conducted with the dataset. It should be noted that waste water effluent stations can occur in different habitats as outlined above and that the use of this Standard Method is not limited to marine environments.

Section B of the Standard Method provides general considerations for sample collection, particularly in the assessment of wastewater discharge. The Standard Method however, notes that the sample methodology will depend on the environment being sampled and the specific needs of the survey.

Section C of the Standard Method outlines the sample processing and analysis techniques. There was general adherence to this section of the method within ESL's benthic sampling methodology.

Section D of the Standard Method highlighted the basic approaches for data evaluation and presentation. Since the focus of the study included baseline assessment of the benthic habitat, the community structure was characterised.

It should also be noted that ESL's adapted methodology for offshore benthic sampling does not include the use of the proteinaceous dye, Rose Bengal. The non-utilisation of Rose Bengal is based upon the technical training received by the benthic staff which emphasises the non-use of Rose Bengal due to its ability to stain living as well as dead organisms where protoplasm has not yet completely decayed (Walker *et al*. 1974; Bernhard 1988), which may result in the overestimation of abundance of organisms within the sample. In addition, experiments conducted by ESL under the tutelage of benthic expert, Dr. Phil Smith, revealed that staining of organisms as a result of the use of Rose Bengal for sorting adversely affects the ability of benthic personnel to accurately identify polychaetes and other benthic organisms. In identification of many marine organisms, subtle differences in colour can be used to help distinguish between similar species.

Review of available literature regarding the use and non-use of Rose Bengal in the benthic sorting process revealed that it remains up to the particular researcher as to whether Rose Bengal forms part of the Standard Operating Procedure (SOP) or not. ESL has decided not to use Rose Bengal as part of its SOP. This is done to ensure that there is no skewing of data from overestimation of abundances due to falsely staining dead material as live (Bernhard 1988; Walker *et al.* 1974).

The following is a detailed description of the benthic methodology employed by ESL:

1. Collection of Benthic Sample

In order to ensure that sampling is accurate, efficient and representative, the following steps must be adhered to:

a) The 'Box Corer' (0.25 m^2) is utilised for all benthic environments which range from stony and hardy to soft and sandy environments. The 'Ponar grab' (0.05 m^2) is used for benthic environments which are stony and difficult to obtain samples, whereas the 'van Veen grab' (0.1 m^2) is chosen for sampling benthic environments which are soft and/or sandy

b) The Box Corer is connected to the ship via a steel cable, coupled to a winch and pulley system and is suspended over the side of the vessel by a steel arm

c) The grab is then primed by manually lifting the both weighted arms and attaching them via a metal clip

d) The grab is then lowered (with minimal swinging) into the marine environment, using the winch, until it touches the benthos. Excessive swinging can cause the sampler to trigger prematurely upon deployment. Lowering of the sampler can be fast until it reaches within a few metres from the bottom. From this point to the point of entry into the sediment, the lowering speed should be less than 1 ft/s. When it touches the benthos, the arms of the grab fall and penetrate the surface of the ocean floor, thus retrieving a benthic sample

e) The grab containing the benthic sample is then lifted onto the vessel by the winch system and the arms of the device are opened, thereby allowing the sample to fall into a basin. Note that the retrieval speed should be maintained to avoid jerking of the sampler and subsequent disturbance of the sediment. The sampler should also be retrieved with minimal swinging to avoid disturbance to the sediment sample

   Note also that the benthic sample is only accepted if it meets the following criteria:
   - Sediment is not extruded from the upper face of the sampler such that organisms may have been lost

- Overlying water is present, indicating minimal leakage
- The sediment surface is relatively flat, indicating minimal disturbance or winnowing
- The following penetration depths (i.e. the maximum depth of sediment sampled) are achieved:
  - 4 – 5 cm for medium to coarse sand
  - 6 – 7 cm for fine sand
  - ≥ 10 cm for muddy sediment

f) The sample is then placed into a container and labelled with the Project Name, Date, Station Number and Replicate Number

g) The buckets are then safely stored, to be returned to shore for further washing, sorting and identification of the samples therein.

2. Washing of Benthic Sample

This stage involves the washing and initial separation of the sample upon collection. The procedure is as follows:

a) The sample is emptied onto the erected sieve table possessing a 'sink and drainpipe' design. At the base of the pipe lies a stopper followed by a series of sieves (4 mm, 1 mm and 0.5 mm)

b) The sample is washed through the apparatus and the coarse material and fine material separated by the various sized sieves

c) The smaller particles are washed further down and are collected in the 0.5 mm sieve placed at the bottom of the sieve table

d) Then the hose is used to push the particles to one side of the sieve whereby the particles are transferred into a labelled container, with any excess water being drained off

e) The washed sample is then placed into a container labelled with the Project Name, the Date, Station number and Grab number

f) Using gloves and goggles, a volume (equal to that of the sample) of 10% Formalin is added to each of the containers and allowed to stand for a minimum of two days to allow for adequate fixation. If Formalin is to be handled indoor a respirator is required

g) The buckets are then safely stored, to be returned to shore for further washing, sorting and identification.

2.1 Onshore Washing

a) Upon returning to shore, each sample is washed individually and subsequently sorted

b) In an outdoor environment, using gloves, one bucket is taken and the cover is carefully removed so as to avoid spillage of the Formalin. **Considerable care is to be taken in handling the Formalin as inhalation can pose a severe health risk**

c) The 0.5 mm sieve is then placed into the sink and the contents (lighter fraction) emptied into the sieve with the use of the hose. This will allow the sediment to be collected so as to avoid loss of sample

d) The collected sample is then thoroughly washed several times to remove any excess Formalin

e) The hose is used to move the sediment to one side of the sieve for complete transfer back to the container

f) At this stage begins the initial separation of the sample into lighter and denser fractions using elutriation, whereby water is used to suspend the lighter particles which are transferred into the 0.5 mm sieve placed in the sink, thus leaving behind the denser, coarser particles

g) This process is repeated until most of the lighter fraction has been removed

h) The lighter fraction is then transferred into a container labelled with the Project Name, Date, Station number, Grab number and Lighter fraction

i) The 0.5 mm sieve is then returned to the sink and the denser material previously collected on the 1.0 mm sieve is then thoroughly washed through the two sieves so that any remaining lighter particles are collected once again on the 0.5 mm sieve and transferred to the labelled container

j) The remaining denser material collected is then transferred to a separate container labelled with the Project Name, Date, Station number, Grab number and Denser fraction

k) With the sample now separated into the lighter and denser fractions, they are returned to the lab for sorting to begin immediately

l) Steps (a) to (k) are repeated for each sample taken, until all samples have been washed and sorted.

Points to Note:

- If 3 persons are doing the sorting, each individual should be given a replicate to sort. This would be useful in highlighting errors in the analysis.

- The time taken to sort the benthic samples should be recorded per replicate, for each individual who is sorting. This would allow for an estimation of efficiency of each individual.

3. Sorting of the Benthic Sample

At this stage of the process, the samples are examined for extraction of the organisms, for later identification:

a) The 2 labelled containers, one containing the lighter fraction and the other containing the denser fraction are brought into the lab and properly stored

b) Using a clean, dry, plastic inverted Petri dish, a ruler and scalpel, parallel lines of 1 cm intervals were scored onto the base of the Petri dish

c) Using the lighter fraction first, a spatula is used to transfer a small quantity of the sample to the clean Petri dish

d) A small amount of water is then added to the Petri dish to disperse the material ensuring that only a single layer of material exists for easy detection of organisms

e) The Petri dish is then placed under a dissecting microscope, in the presence of adequate lighting (additional external sources) and the microscope allowed to focus on the first line drawn on the base of the Petri dish

f) This line is used as a guide, by moving the Petri dish from left to right traversing each line, to look for specimens above and below the line, until the entire surface has been examined

g) Note that only living specimens are extracted and that if the head of an organism is present (for example polychaetes) then it will also be counted. In the case of gastropods, the shell must be opened to determine if the organism is present (this is usually done with the aid of a very sharp scalpel blade)

h) Found specimens are removed using watchmaker's forceps into an accurately labelled vial containing alcohol located at the side of the microscope. It is important to note here that alcohol and water are immiscible, therefore a separate vial containing water is typically placed nearby so that the forceps can be rinsed before returning to the Petri dish of alcohol

i) The remaining material (within the scored Petri dish) is returned to the initial container within which the sample was stored

j) The scored Petri dish is thoroughly washed after each sample

k) Steps (a) to (h) are repeated until the entire sample (both light and dense fractions) is reviewed and all specimens are removed.

4. Identification of the Benthic Sample

After the samples have been sorted, the next step of the process is identification of the organisms collected. This is executed by the following:

a) The contents of the vial are transferred into a new, clean Petri dish, using a squeeze bottle containing alcohol to ensure that no organisms remain in the vial

b) The Petri dish is then placed under a dissecting microscope for initial identification of the organisms. External light sources are also employed to assist in this process

c) Taxonomic keys are utilised in conjunction with any other supplementary material to aid in identification of the organisms present

d) As each new specimen is identified, it should be placed in a vial labelled with the name of the lowest taxonomic level to which it can be identified

e) When a specimen is identified a picture is taken using the camera of the dissecting microscope and is saved under the file name: Species Name, Project Acronym_ Dry or Wet Season, Year. It should be noted that only one picture is taken for each new specimen identified

f) The abundance of each type of organism is manually recorded as each new organism is added to the respective vial

g) For those microscopic organisms which are unable to be identified with the use of the dissecting microscope, they are placed on a slide with one to two drops of glycerol and covered with a cover slip, using the back end of the forceps to gently fix the cover slip in place

h) Using the light microscope and the lowest magnification the slide is placed on the microscope stage and observed

i) Taxonomic keys are also used to aid in identification of the organism to the lowest taxonomic level possible

j) Steps (a) to (i) are repeated for all vials and the total abundance together with the name of the organism (most instances to Family level) is recorded in an Excel Spreadsheet with an appropriate title (For Example; Project Acronym Benthic Sample Dry or Wet Season, Year) as well as in the hard cover benthic notebook (for hard copy record-keeping)

k) All vials are stored in labelled boxes until the project has been fully completed.

5. Quality Assurance/Quality Control

a) Training of Laboratory personnel

At ESL, great emphasis is placed on the hiring process and inhouse training as quality results can only be obtained by a laboratory that employs highly trained and educated personnel.

Sorting Personnel

- New sorting personnel undergo extensive on-the-job training by experienced sorters and taxonomists. Until proficiency is gained, all new personnel have every sample checked for any organisms that may have been missed (i.e., not removed from the sample during initial sorting). This quality assurance is done through spot checks of aliquots of each sample immediately after sorting and through adherence to established quality control programs (see below). Proficiency is judged satisfactory when less than 5% of the total organisms have been missed from each sample. The Laboratory Manager has final responsibility for ensuring proper training of all new personnel, as well as continued high quality performance by the sorting laboratory.

Taxonomists

- All taxonomists working at ESL have at least a B.S. degree in Environmental Management. All taxonomists receive in-house training from aquatic specialist Dr. Phil Smith of the UK-based Aquatonics Limited. Further training on deepwater benthos was provided by Specialists Isabelle Williams (Marine Invertebrate Zoologist with > 40 years' experience) and Dr. Pamela Neubert (Marine Invertebrate Zoologist with > 20 years' experience) from AECOM

- Experienced taxonomists require little training. Emphasis is placed on ensuring correct and consistent identification. This is done by verification of all identified specimens by the more experienced taxonomists in the laboratory

- Taxonomic trainees are given intensive on-the-job training in a particular group of organisms (e.g. Polychaeta, Mollusca, etc.). Trainees are taught morphology, biology, terminology, and

ecology of their particular taxonomic group. In addition, they are taught laboratory techniques and general taxonomic and systematic theory. Verification of all identifications by the more experienced taxonomists in the laboratory is mandatory and strictly adhered to. In addition, the trainees are subjected to the same quality control standards as the most experienced taxonomists.

b) Sorting

- Samples are randomly selected and reworked during a QC period. If the number of organisms found in the reworked sample is less than 95% accuracy, a QC failure is noted in the logbook, and an additional sample is QC'd. If this is also a failure, then all samples previously sorted by that person since the last QC period are resorted. A QC period may be designated weekly or at the end of a specific project, depending upon the number of samples involved

- At the conclusion of the sorting phase of each project, a Quality Control Results form is completed. This tally forms the basis for a section summarising the QC results of the sorting effort within the Laboratory QC Report.

c) Identification and Enumeration

- Quality control at the identification and enumeration levels of sample processing relies upon: 1) quality training; 2) the specimen reference library; 3) in-house verifications of identifications during sample processing; 4) in-house examinations of sample data sheets for questionable identification and enumeration data; 5) in-house support for scientific research and publications; 6) close communication with recognised outside experts, including verification of identifications; and 7) constant update of our taxonomic libraries. In addition, during the QC period, 10% of the samples worked by a given taxonomist will be re-identified. No one reworks his or her own samples. If QC failures are found, all samples worked by that taxonomist since the last QC check are re-identified.

Points to Note:

- After identification has been completed, a hard copy list of all organisms identified is generated and recorded in the Benthic Log Book

- In addition, all identified organisms are recorded in a Microsoft Excel spreadsheet, from which it is exported into PRIMER software for statistical analyses to be conducted

- Furthermore, when a new species has been identified which has not been observed before, a few specimens are placed in a labelled vial with the name (LPIL) and placed in the benthic reference library. A corresponding picture of the specimen is also taken and saved in the folder Project Acronym_ Dry or Wet Season, Year

- Additionally, the abundance is to be recorded as the sum of the number of specimens placed in the benthic reference library plus the number remaining in the vial collected from the samples

- QA/QC – Photographs of benthic specimens are sent to the Benthic Specialists of Ocean Ecology Limited (OEL) for verification.

References:

Bernhard, J.M. 1988. *Postmortem vital staining in benthic foraminifera: duration and importance in population and distributional studies, J. Foram. Res. 18, 143-146*

Clarke, K.R and R.N. Gorley. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E: Plymouth

Franson, M.A.H., A.D. Eaton, L.S. Clesceri and A.E. Greenberg. 2005. *Standard Methods for the Examination of Water and Wastewater. Prepared and published by the American Public Health Association*, American Waterworks Association and Water Environment Federation. Published by the American Public Health Association. Washington D.C.

Fauchland, K. and P.A. Jumars. 1979. *The diet of worms: a study of polychaete feeding guilds*, 17, 193-284

Ogden, J. C and E. H. Gladfelter, eds. 1982. *Coral reefs, seagrass beds and mangroves: Their interaction in the coastal zones of the Caribbean*. Report of a workshop held at the West Indies Laboratory, St. Croix, U.S. Virgin Islands May 1982. UNESCO IOCARIBE.

Walker, D.A., A.E. Linton and C.T. Schafer. 1974. *Sudan Black B: a superior stain to Rose Bengal for distinguishing living from non-living foraminifera*, J. Foram. Res., 4, 205-215.

Appendix 8 - Shipping Documentation

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IAG Airway Bill

FedEx Express — International Air Waybill

For FedEx services worldwide including express freight services, dangerous goods, broker select, and letter of credit.

From *Please print and press hard.*

Date 10/30/2017 Sender's FedEx Account Number 230152233

Sender's Name Environmental Sciences Ltd. Phone 592-225 3501/2

Company c/o John Fernandes Ltd

Address 53-55 Water Street

Address —

City Georgetown State Province —

Country Guyana ZIP Postal Code —

To

Recipient's Name SAMPLE CUSTODY Phone 850-474-1001

Company TEST AMERICA (IAG)

Address 3355 MC LEMORE DRIVE Dept./Floor

Address PENSACOLA FL 32514

City PENSACOLA State Province FLORIDA

Country USA ZIP Postal Code 32514.

Recipient's Tax ID Number for Customs Purposes
e.g., GST/RFC/VAT/IN/EIN/ABN, or as locally required

Shipment Information

Total Packages (Shipper's Load and Count/SLAC) 1 Total Weight ☐ lbs. ☐ kg DIM 22 / 13 / 15 ☑ in ☐ cm

Commodity Description	Harmonized Code	Country of Manufacture	Value for Customs
COOLER With 24 SEDIMENT SAMPLES for Scientific USE.		Guyana	6.00 USD

Has EEI been filed in AES? (For U.S. Export Only: Check One)
☐ No EEI required, value $2,500 or less per Schedule B Number, no license required (NLR), not subject to ITAR
☐ No EEI required, enter exemption number
☐ Yes – Enter AES proof of filing citation

☐ For EU Only: Tick here if goods are not in free circulation and provide C.I.

Total Declared Value for Carriage

Total Value for Customs (Specify Currency) 6.00 USD.

For Completion Instructions, see back of fifth page.

Questions?
Go to our Web site at fedex.com.
or
In the U.S., call 1.800.GoFedEx 1.800.463.3339
Outside the U.S., call your local FedEx office.

The terms and conditions of service may vary from country to country. Consult our local office for specific information.
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The World On Time.

Not all services and options are available to all destinations.

4a Express Package Service *Packages up to 150 lbs. / 68 kg*
☑ FedEx Intl. Priority ☐ FedEx Intl. First (Available to select locations) ☐ FedEx Intl. Economy (FedEx Envelope and FedEx Pak rate not available)

4b Express Freight Service *Packages over 150 lbs. / 68 kg*
☐ FedEx Intl. Priority Freight ☐ FedEx Intl. Economy Freight
Booking Number
Please call your local FedEx office to book shipments.

5 Packaging *These unique brown boxes with special pricing are provided by FedEx for FedEx Intl. Priority only.
☐ FedEx Envelope ☐ FedEx Pak ☐ FedEx Box ☐ FedEx Tube
☑ Other ☐ FedEx 10kg Box* ☐ FedEx 25kg Box*

6a Special Handling
☐ HOLD at FedEx Location ☐ SATURDAY Delivery (Available to select locations for FedEx Intl. Priority and FedEx Intl. Priority Freight only)
Does this shipment contain dangerous goods? (One box must be checked / ticked)
☐ No ☐ Yes (As per attached Shipper's Declaration) ☐ Yes (Shipper's Declaration not required) ☐ Dry Ice (Dry ice, 9, UN 1845 ____ x ____ kg) ☐ Cargo Aircraft Only
Dangerous goods (including dry ice) cannot be shipped in FedEx packaging or placed in a FedEx Express Drop Box.

6b Broker Selection (Not available with FedEx Intl. First) ☐ Intl. Broker Select (To specify a broker other than FedEx.)
Broker's Name
City / State / Province / Country
ZIP / Postal Code Phone

7 Payment Complete payment options for both transportation charges and duties and taxes.
Bill transportation charges to: (Enter FedEx Acct. No. or Credit Card No. below.)
☐ Sender (Acct. No. in Section 1 will be billed) ☐ Recipient ☐ Third Party ☐ Credit Card ☐ Cash / Check / Cheque
FedEx Acct. No. 230152233 (FedEx Use Only)
Credit Card No.
Credit Card Exp. Date

Bill duties and taxes to: (Enter FedEx Acct. No. below.) ALL shipments may be subject to Customs charges, which FedEx does not estimate prior to clearance.
☐ Sender (Acct. No. in Section 1 will be billed) ☑ Recipient ☐ Third Party
FedEx Acct. No. 230152233

8 Your Internal Billing Reference (First 24 characters will appear on invoice.) OPTIONAL

9 Required Signature
Use of this Air Waybill constitutes your agreement to the Conditions of Contract on the back of this Air Waybill, and you represent that this shipment does not require a U.S. State Department license. Certain international treaties, including the Warsaw Convention, may apply to this shipment and limit our liability for damage, loss, or delay, as described in the Conditions of Contract.
WARNING: These commodities, technology, or software were exported from the United States in accordance with Export Administration regulations. Diversion contrary to U.S. law prohibited.
Sender's Signature: Alicia Maxwell
This is not authorization to deliver this shipment without a recipient signature.
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Appendix 9 – Grain Size Lab Report

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Tel.: (868) 657-9024, (868) 657-1560 Fax: (868) 653-2571 Email: jerome.als@envirosciences.net

GRAIN SIZE ANALYSIS REPORT

CLIENT	:	Exxon
CLIENT ADDRESS	:	ESSO Exploration & Production Guyana LTD, Guyana.
PROJECT NO.	:	25/17
REPORT NO.	:	1
DATE RECEIVED	:	24/11/17
DATE OF REPORT	:	01/12/17
DESCRIPTION OF SAMPLE	:	Sediment

ESL SAMPLE NO./ CLIENT SAMPLE ID :

25/17- 15S	BC15 Exxon Station 15 Sediment
25/17- 16S	BC16 Exxon Station 16 Sediment
25/17- 17S	BC17 Exxon Station 17 Sediment
25/17- 18S	BC18 Exxon Station 18 Sediment
25/17- 19S	BC19 Exxon Station 19 Sediment
25/17- 20S	BC20 Exxon Station 20 Sediment
25/17- 21S	BC21 Exxon Station 21 Sediment
25/17- 22S	BC22 Exxon Station 22 Sediment
25/17- 23S	BC23 Exxon Station 23 Sediment
25/17- 24S	BC24 Exxon Station 24 Sediment

Introduction

Twenty four (24) sediment samples were submitted by the client for sieve analysis. The samples were received on the 24th of November, 2017 in good condition.

Methodology

The methodology was derived from The Standard Test Method for Particle-Size Analysis of Soils, ASTM D 422.

Results

Note that the predominant fraction with the highest percentage in each sediment sample is highlighted.

Grain Size Analysis Summary Table

Station Number	U.S.D.A Soil Classification	Predominant Fraction	Percent Sand	Percent Clay	Percent Silt	Size of Predominant Fraction (mm)
15S	Sandy Clay Loam	Sand	62.15	29.03	8.82	2.0 – 0.05
16S	Clay	Clay	7.14	92.38	0.48	< 0.002
17S	Sandy Loam	Sand	68.47	17.89	13.64	2.0 – 0.05
18S	Sandy Loam	Sand	63.49	17.72	18.79	2.0 – 0.05
19S	Clay	Clay	24.97	41.39	33.64	< 0.002
20S	Silty Clay Loam	Silt	16.92	31.36	51.72	0.05 – 0.002

Station Number	U.S.D.A Soil Classification	Predominant Fraction	Percent Sand	Percent Clay	Percent Silt	Size of Predominant Fraction (mm)
21S	Clay Loam	Silt	21.11	30.58	48.31	0.05 – 0.002
22S	Clay	Clay	0.61	91.74	7.65	< 0.002
23S	Clay	Clay	0.36	99.52	0.12	< 0.002
24S	Clay Loam	Clay	34.66	39.62	25.72	<0.002

Reference

ASTM D422-63(2007)e2, Standard Test Method for Particle-Size Analysis of Soils (Withdrawn 2016), ASTM International, West Conshohocken, PA, 2007, www.astm.org

Analyzed by: _____
Alessandra Rajkumar
Analytical Chemist

Reviewed by: _____
Elka Bachan
Project Manager

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Client/Project: ESSO

Date: 01/12/17

Location: Station BC #15

Visual Classification: Sandy Clay Loam

1	2	3	4	5
Sieve Size (mm)	Soil Retained (g)	% retained Col 2 *100 / Wt (Rn)	Cumulative % retained ΣR_n	% Finer 100- ΣR_n
4	0.00	0.00	0.00	100.00
2	0.00	0.00	0.00	100.00
0.5	7.19	31.30	31.30	68.70
0.25	4.07	17.71	49.01	50.99
0.125	3.02	13.15	62.15	37.85
0.062	2.03	8.82	70.97	29.03
<0.062	6.67	29.03	100.00	0.00
	Σ 22.98(Wt_1)			

Initial mass of dry soil (Wt): 22.98g

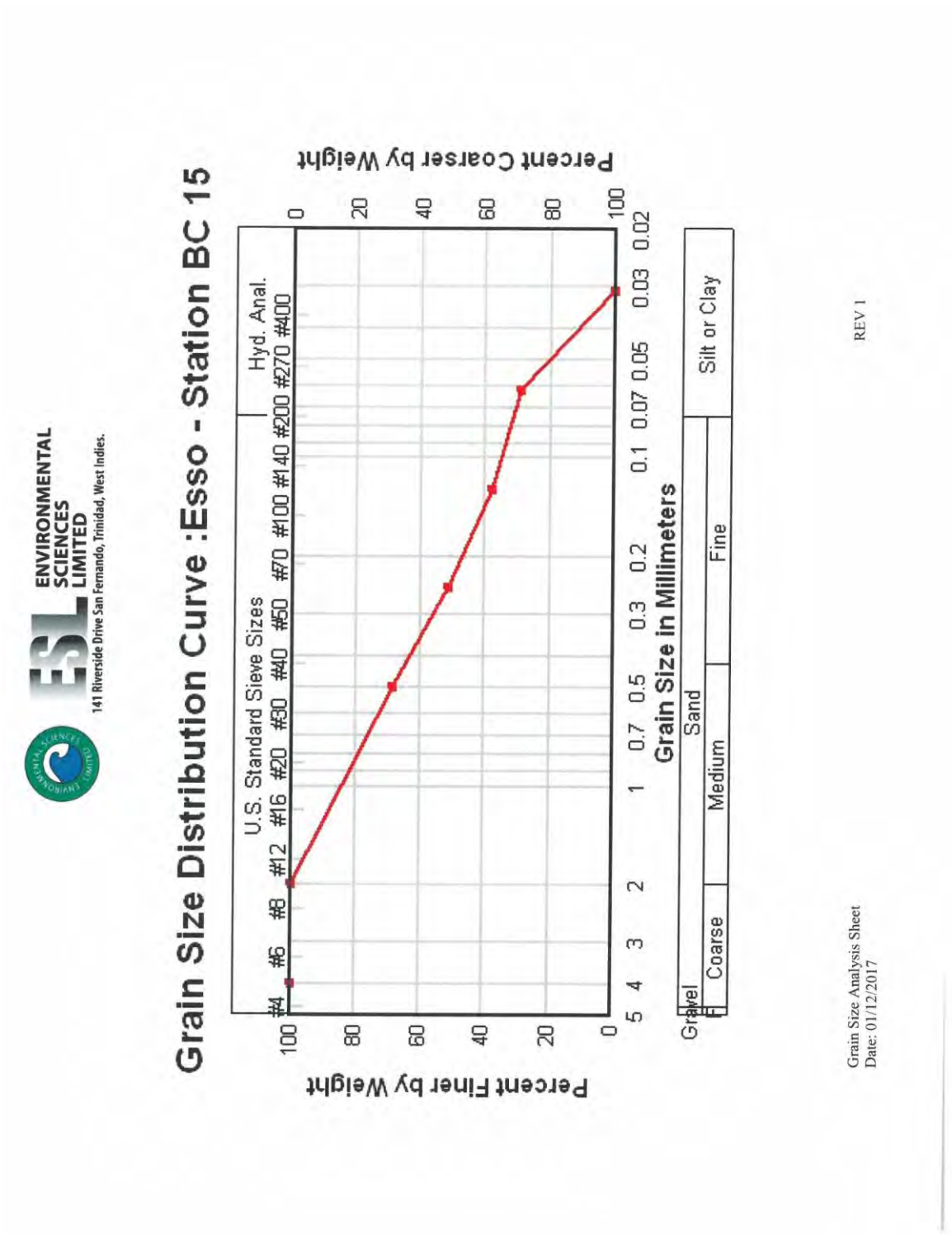
Soil Loss: 0.0%

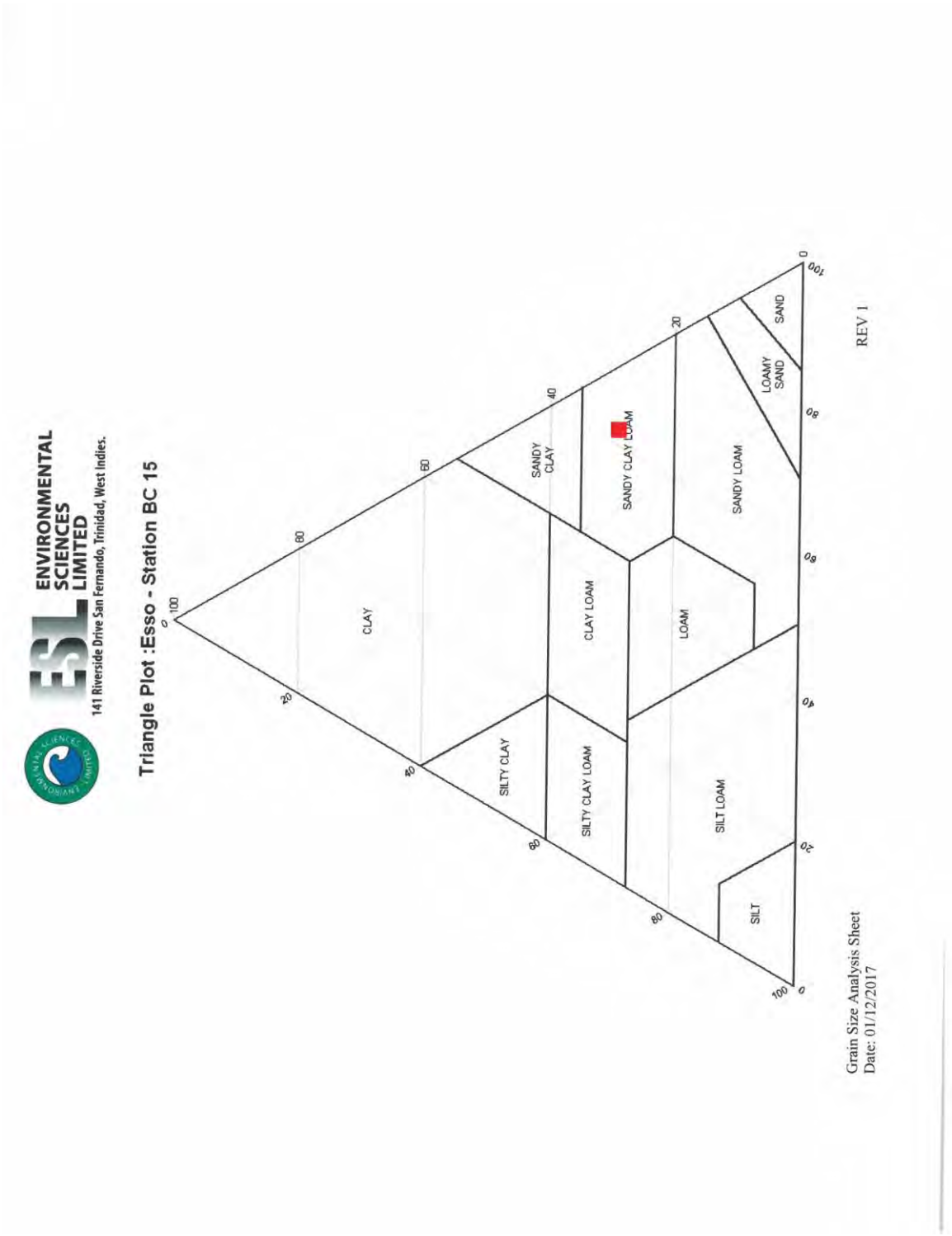
USDA Classification: Sandy Clay Loam

Analyzed by: _____ **Date:** 01/12/17

Grain Size Analysis Sheet
Date: 01/12/2017

REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Grain Size Distribution Curve :Esso - Station BC 15
Percent Finer by Weight
Percent Coarser by Weight
U.S. Standard Sieve Sizes
#4 #6 #8 #12 #16 #20 #30 #40 #50 #70 #100 #140 #200 #270 #400
Hyd. Anal.
Grain Size in Millimeters
Gravel
Sand
Coarse
Medium
Fine
Silt or Clay
REV 1
Grain Size Analysis Sheet
Date: 01/12/2017


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Triangle Plot :Esso - Station BC 15
CLAY
SILTY CLAY
SANDY CLAY
SILTY CLAY LOAM
CLAY LOAM
SANDY CLAY LOAM
LOAM
SILT LOAM
SANDY LOAM
SILT
LOAMY SAND
SAND
REV 1
Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

BC- Station #15

REV 1

Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Client/Project: ESSO

Date: 01/12/17

Location: Station BC #16

Visual Classification: Clay

1	2	3	4	5
Sieve Size (mm)	Soil Retained (g)	% retained $\frac{\text{Col 2}}{\text{Wt}} * 100$ (Rn)	Cumulative % retained ΣR_n	% Finer $100 - \Sigma R_n$
4	0.00	0.00	0.00	100.00
2	0.17	0.63	0.63	99.37
0.5	0.36	1.34	1.97	98.03
0.25	0.93	3.46	5.43	94.57
0.125	0.46	1.71	7.14	92.86
0.062	0.13	0.48	7.62	92.38
<0.062	24.84	92.38	100.00	0.00
	Σ 26.89(Wt_1)			

Initial mass of dry soil (Wt): 26.89g

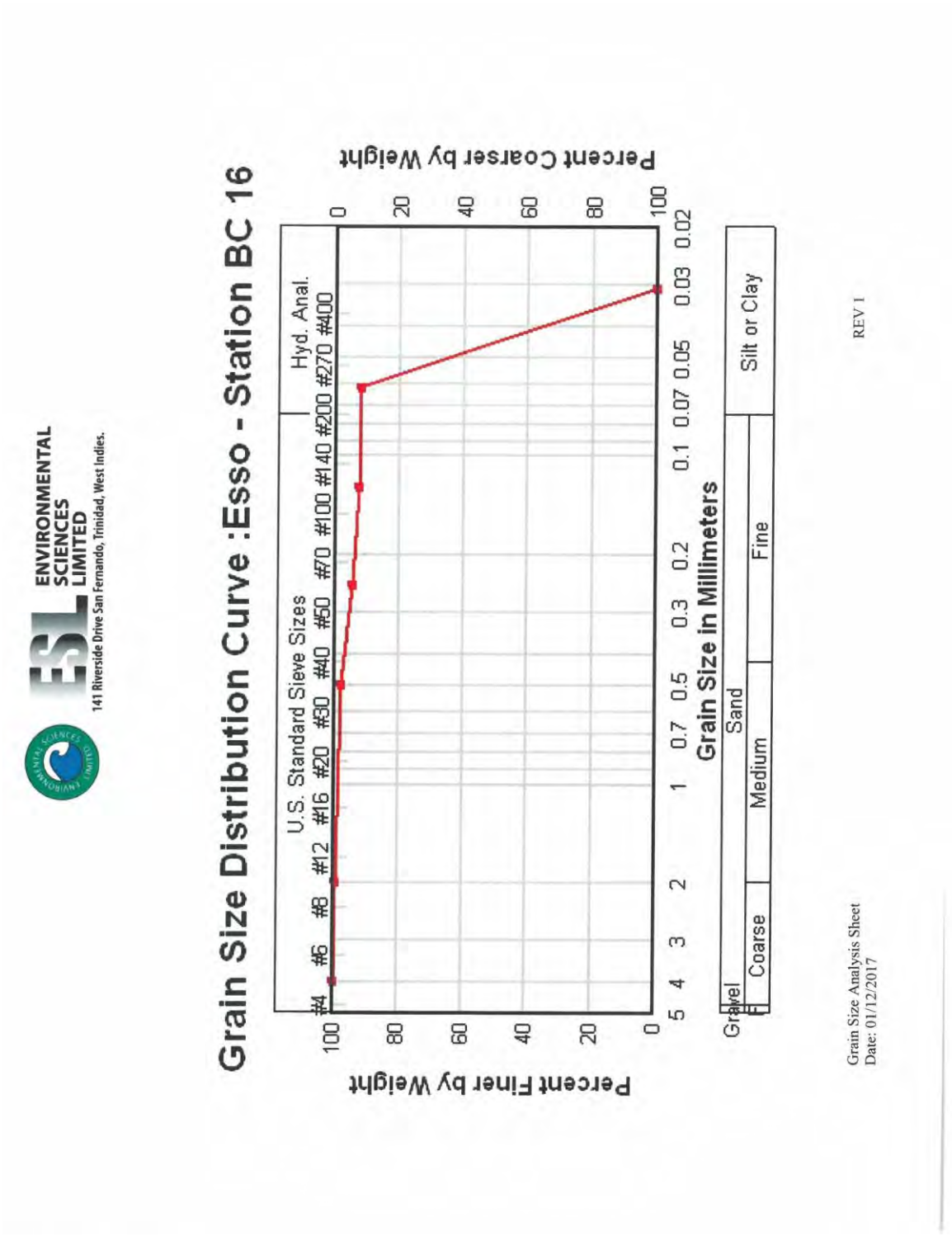
Soil Loss: 0.0%

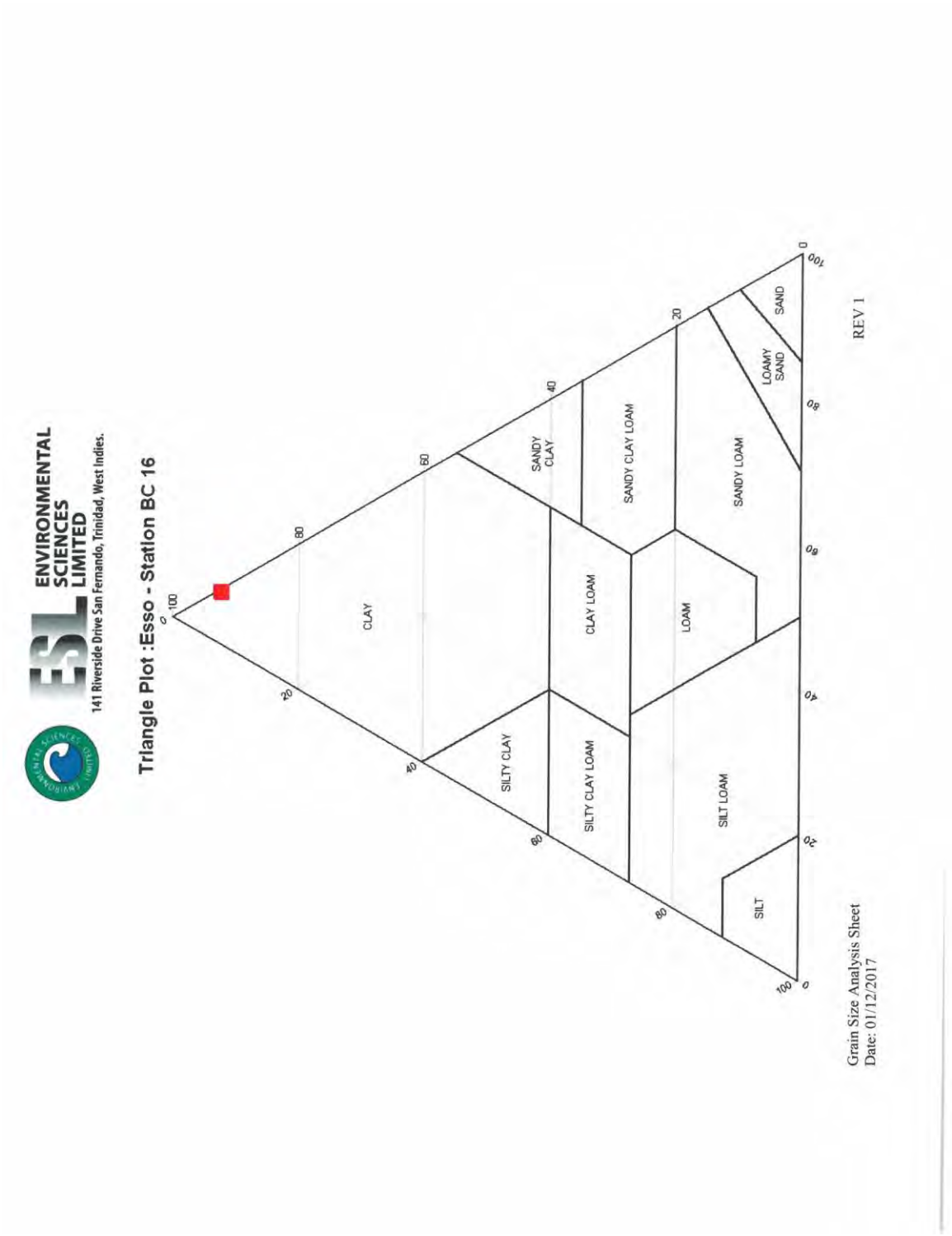
USDA Classification: Clay

Analyzed by: _____ **Date:** 01/12/17

Grain Size Analysis Sheet
Date: 01/12/2017

REV 1


ESL ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Grain Size Distribution Curve :Esso - Station BC 16
Percent Finer by Weight
Percent Coarser by Weight
U.S. Standard Sieve Sizes
Hyd. Anal.
#4 #6 #8 #12 #16 #20 #30 #40 #50 #70 #100 #140 #200 #270 #400
100 80 60 40 20 0
0 20 40 60 80 100
5 4 3 2 1 0.7 0.5 0.3 0.2 0.1 0.07 0.05 0.03 0.02
Grain Size in Millimeters
Gravel
Sand
Coarse
Medium
Fine
Silt or Clay
Grain Size Analysis Sheet
Date: 01/12/2017
REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Triangle Plot :Esso - Station BC 16
CLAY
SILTY CLAY
SANDY CLAY
CLAY LOAM
SILTY CLAY LOAM
SANDY CLAY LOAM
LOAM
SILT LOAM
SANDY LOAM
LOAMY SAND
SAND
SILT
REV 1
Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

BC- Station #16

REV 1

Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Client/Project: ESSO
Date: 01/12/17
Location: Station BC #17
Visual Classification: Sandy Loam

1	2	3	4	5
Sieve Size (mm)	Soil Retained (g)	% retained Col 2 *100 / Wt (Rn)	Cumulative % retained ΣR_n	% Finer $100 - \Sigma R_n$
4	0.00	0.00	0.00	100.00
2	0.96	4.36	4.36	95.64
0.5	3.80	17.36	21.72	78.28
0.25	2.84	12.96	34.68	65.32
0.125	7.39	33.78	68.47	31.53
0.062	2.99	13.64	82.11	17.89
<0.062	3.914	17.89	100.00	0.00
	Σ 21.88(Wt_1)			

Initial mass of dry soil (Wt): 21.88g

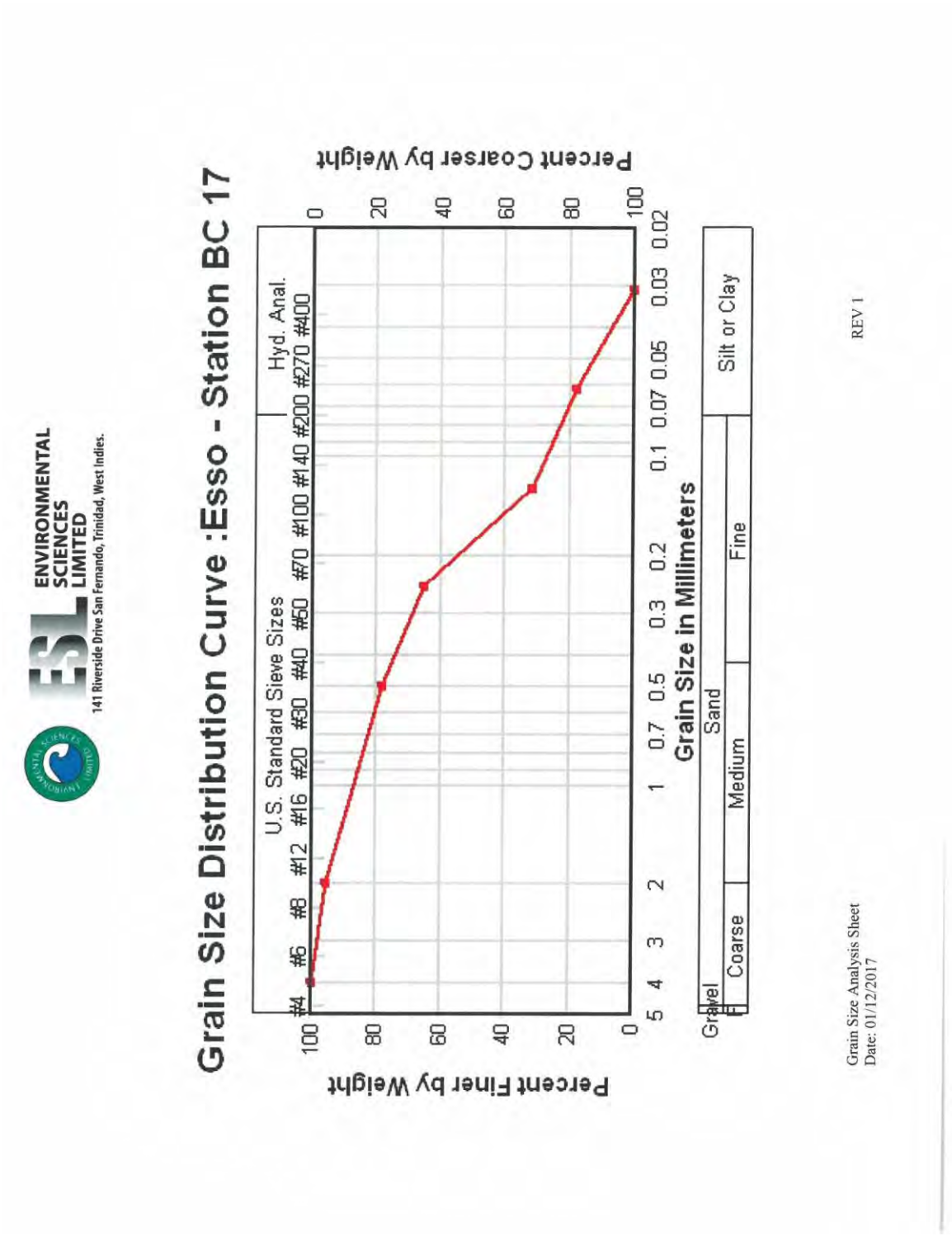
Soil Loss: 0.0%

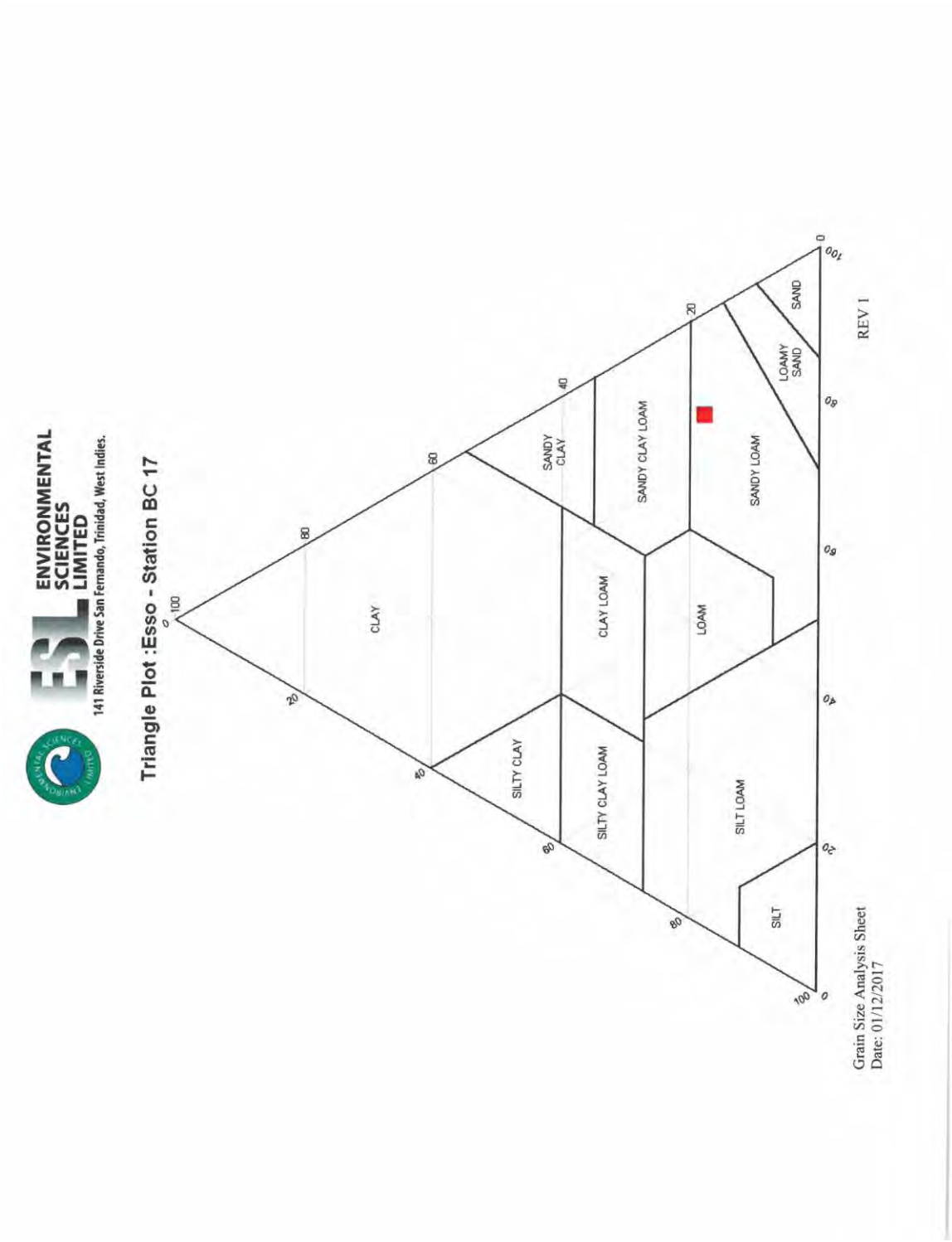
USDA Classification: Sandy Loam

Analyzed by: _____ **Date:** 01/12/17

Grain Size Analysis Sheet
Date: 01/12/2017

REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Grain Size Distribution Curve :Esso - Station BC 17
Percent Finer by Weight
Percent Coarser by Weight
U.S. Standard Sieve Sizes
#4 #6 #8 #12 #16 #20 #30 #40 #50 #70 #100 #140 #200 Hyd. Anal. #270 #400
Grain Size in Millimeters
5 4 3 2 1 0.7 0.5 0.3 0.2 0.1 0.07 0.05 0.03 0.02
Gravel
Sand
Coarse
Medium
Fine
Silt or Clay
Grain Size Analysis Sheet
Date: 01/12/2017
REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Triangle Plot :Esso - Station BC 17
CLAY
SILTY CLAY
SANDY CLAY
CLAY LOAM
SILTY CLAY LOAM
SANDY CLAY LOAM
LOAM
SILT LOAM
SANDY LOAM
LOAMY SAND
SAND
SILT
REV 1
Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

BC- Station #17

REV 1

Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Client/Project: ESSO

Date: 01/12/17

Location: Station BC #18

Visual Classification: Sandy Loam

1	2	3	4	5
Sieve Size (mm)	Soil Retained (g)	% retained Col 2 *100 / Wt (Rn)	Cumulative % retained ΣR_n	% Finer 100- ΣR_n
4	0.68	2.93	2.93	97.07
2	2.16	9.31	12.24	87.76
0.5	5.27	22.72	34.96	65.04
0.25	3.04	13.10	48.06	51.94
0.125	3.58	15.43	63.49	36.51
0.062	4.36	18.79	82.28	17.72
<0.062	4.11	17.72	100.00	0.00
	Σ 23.20(Wt_1)			

Initial mass of dry soil (Wt): 23.20g

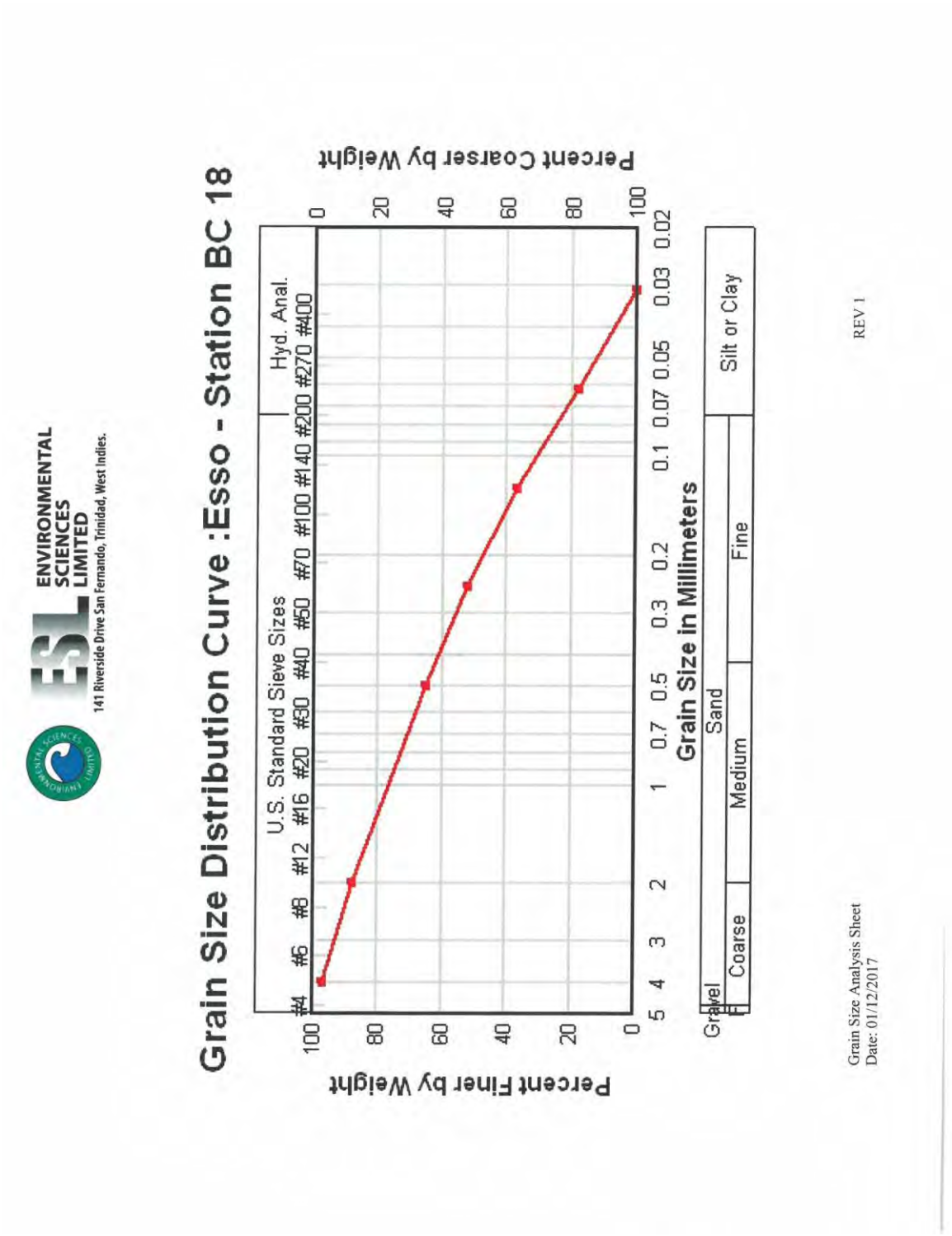
Soil Loss: 0.0%

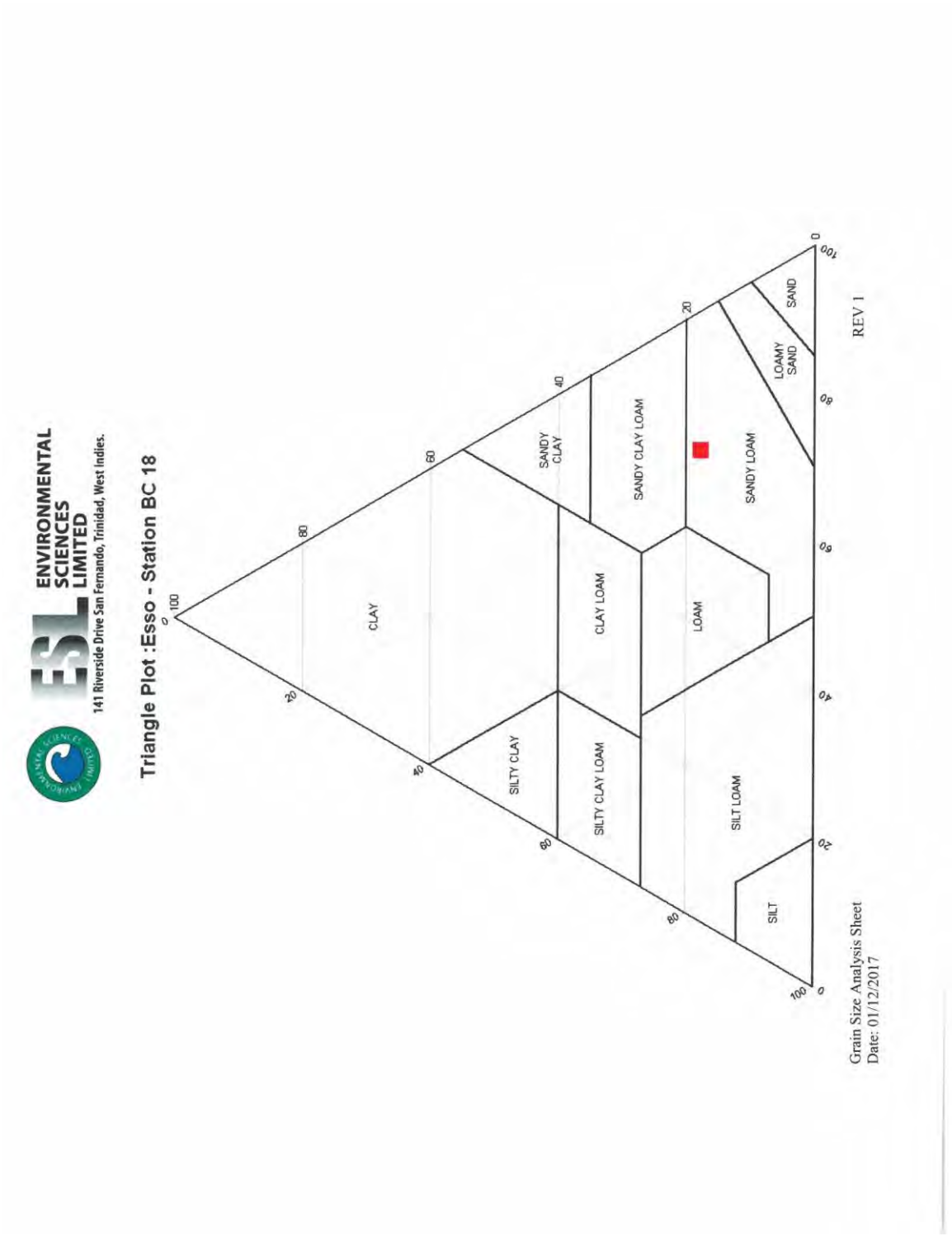
USDA Classification: Sandy Loam

Analyzed by: _____ **Date:** 01/12/17

Grain Size Analysis Sheet
Date: 01/12/2017

REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Grain Size Distribution Curve :Esso - Station BC 18
Percent Finer by Weight
Percent Coarser by Weight
U.S. Standard Sieve Sizes
Hyd. Anal.
#4 #6 #8 #12 #16 #20 #30 #40 #50 #70 #100 #140 #200 #270 #400
100 80 60 40 20 0
5 4 3 2 1 0.7 0.5 0.3 0.2 0.1 0.07 0.05 0.03 0.02
Grain Size in Millimeters
Gravel
Sand
Coarse
Medium
Fine
Silt or Clay
REV 1
Grain Size Analysis Sheet
Date: 01/12/2017


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Triangle Plot :Esso - Station BC 18
CLAY
SILTY CLAY
SANDY CLAY
CLAY LOAM
SILTY CLAY LOAM
SANDY CLAY LOAM
LOAM
SILT LOAM
SANDY LOAM
LOAMY SAND
SAND
SILT
REV 1
Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

BC- Station #18

REV 1

Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Client/Project: ESSO

Date: 01/12/17

Location: Station BC #19

Visual Classification: Clay

1	2	3	4	5
Sieve Size (mm)	Soil Retained (g)	% retained Col 2 *100 / Wt (Rn)	Cumulative % retained ΣR_n	% Finer $100-\Sigma R_n$
4	0.00	0.00	0.00	100.00
2	0.40	1.96	1.96	98.04
0.5	1.46	7.24	9.20	90.80
0.25	1.19	5.92	15.12	84.88
0.125	1.99	9.85	24.97	75.03
0.062	6.78	33.64	58.61	41.39
<0.062	8.344	41.39	100.00	0.00
	Σ 20.16(Wt_1)			

Initial mass of dry soil (Wt): 20.16g

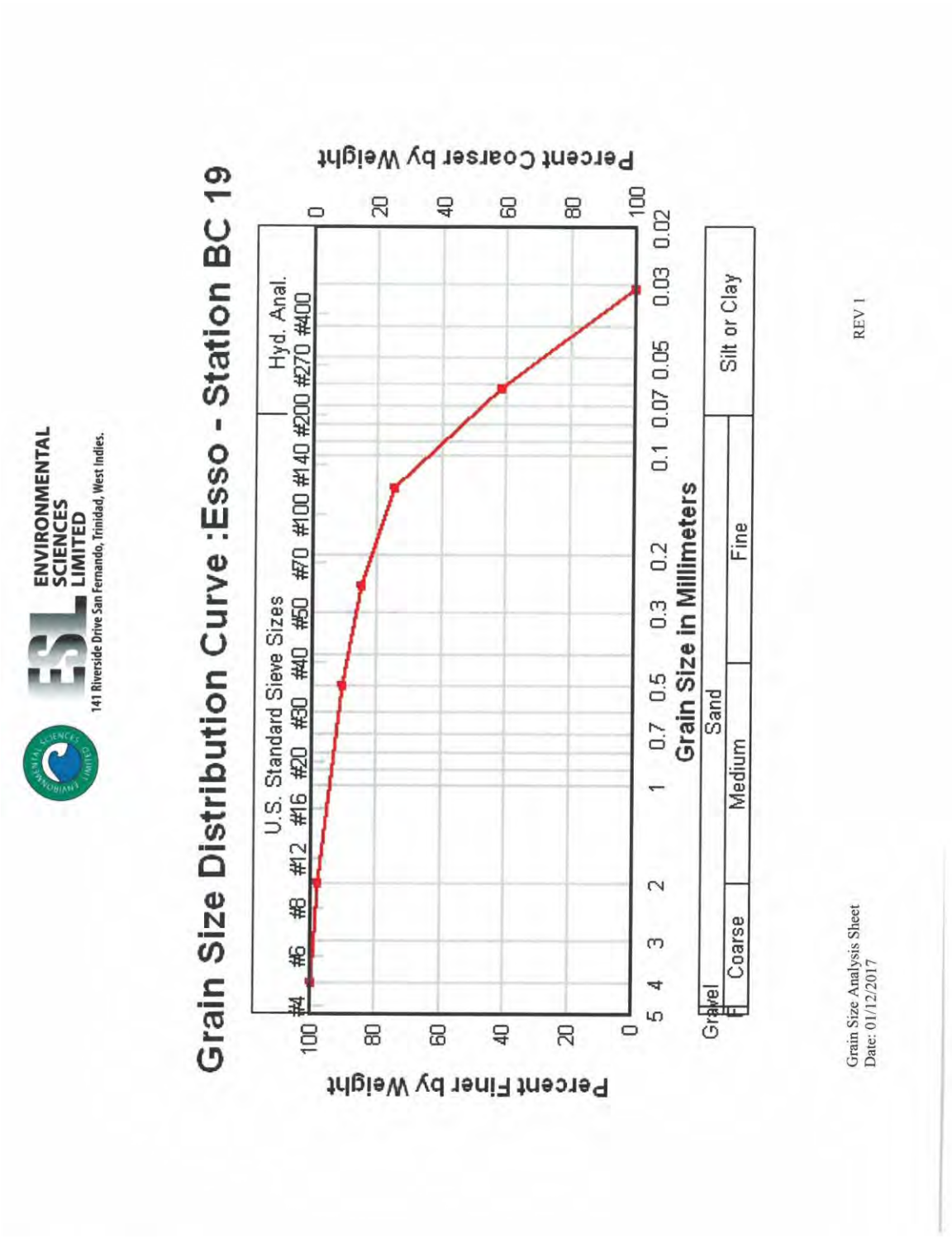
Soil Loss: 0.0%

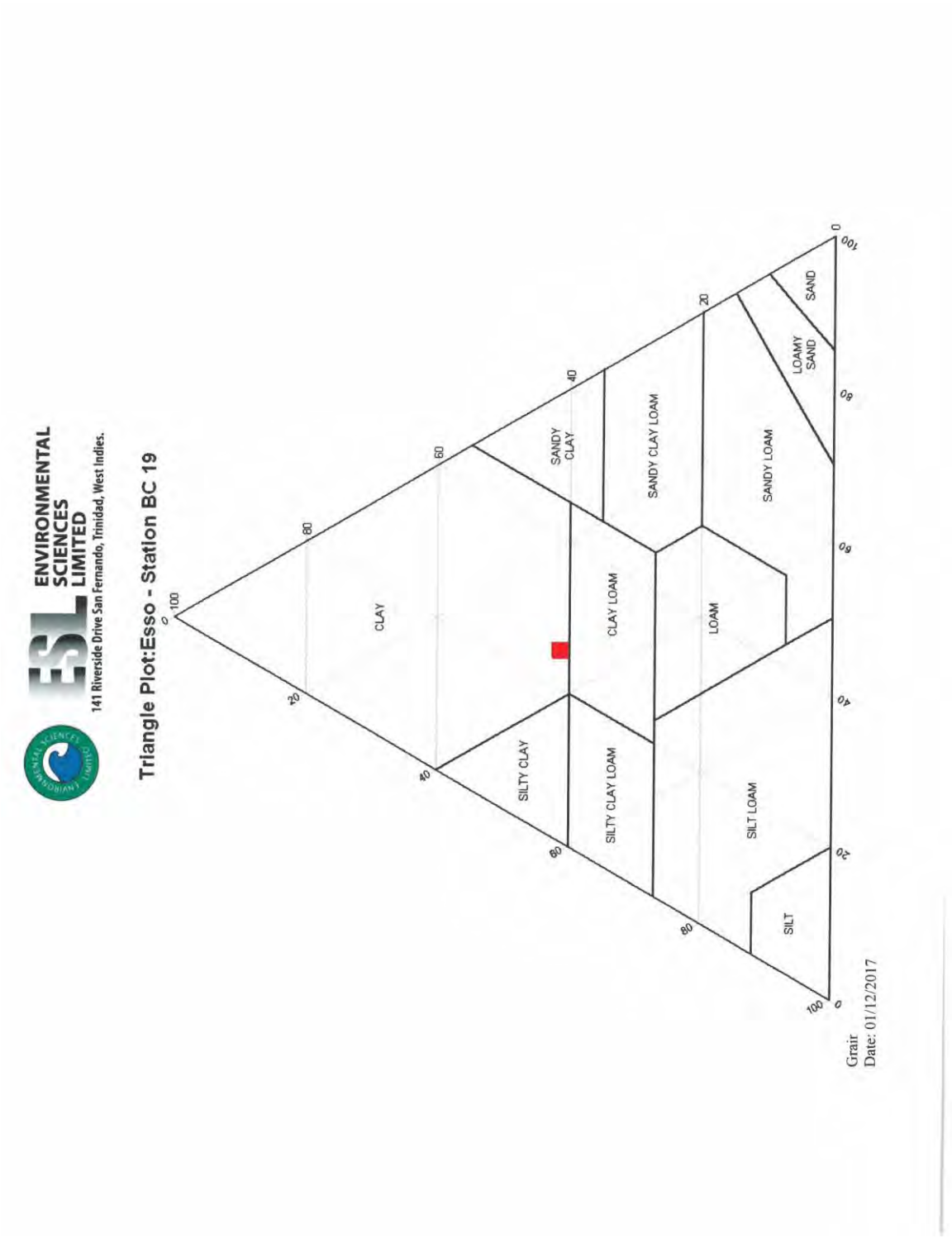
USDA Classification: Clay

Analyzed by: _____ **Date:** 01/12/17

Grain Size Analysis Sheet
Date: 01/12/2017

REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Grain Size Distribution Curve :Esso - Station BC 19
U.S. Standard Sieve Sizes
#4 #6 #8 #12 #16 #20 #30 #40 #50 #70 #100 #140 #200
Hyd. Anal.
#270 #400
Percent Finer by Weight
Percent Coarser by Weight
100 80 60 40 20 0
5 4 3 2 1 0.7 0.5 0.3 0.2 0.1 0.07 0.05 0.03 0.02
Grain Size in Millimeters
Gravel
Sand
Coarse
Medium
Fine
Silt or Clay
Grain Size Analysis Sheet
Date: 01/12/2017
REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Triangle Plot:Esso - Station BC 19
CLAY
SANDY CLAY
SANDY CLAY LOAM
SANDY LOAM
LOAMY SAND
SAND
SILTY CLAY
SILTY CLAY LOAM
CLAY LOAM
LOAM
SILT LOAM
SILT
Grair
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

BC- Station #19

REV 1

Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Client/Project: ESSO

Date: 01/12/17

Location: Station BC #20

Visual Classification: Silty Clay Loam

1	2	3	4	5
Sieve Size (mm)	Soil Retained (g)	% retained $\frac{\text{Col 2} * 100}{\text{Wt}}$ (Rn)	Cumulative % retained ΣR_n	% Finer $100 - \Sigma R_n$
4	0.00	0.00	0.00	100.00
2	0.12	0.55	0.55	99.45
0.5	0.51	2.47	3.03	96.97
0.25	0.41	1.99	5.02	94.98
0.125	2.47	11.90	16.92	83.08
0.062	10.75	51.72	68.64	31.36
<0.062	6.517	31.36	100.00	0.00
	Σ 20.78(Wt_1)			

Initial mass of dry soil (Wt): 20.78g

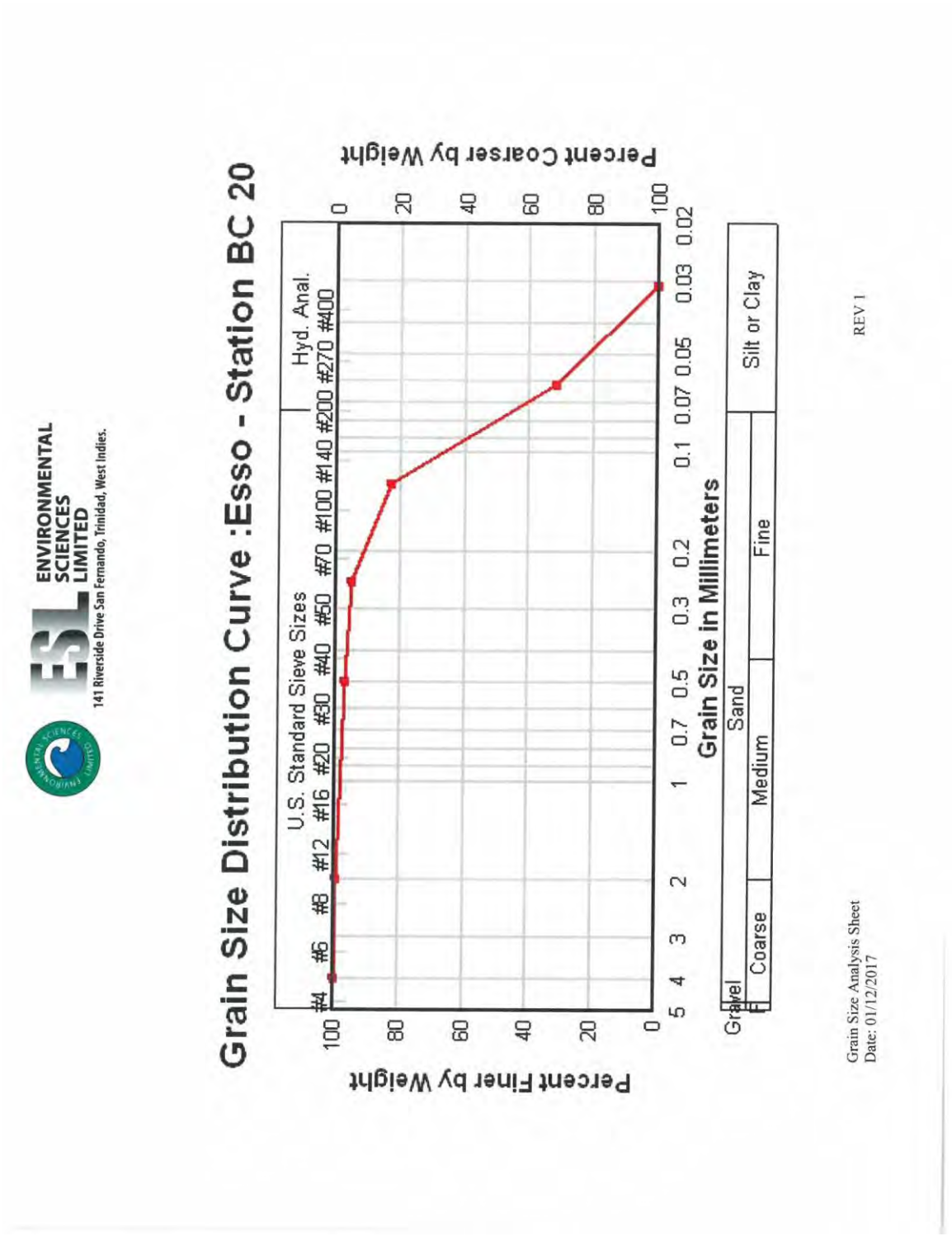
Soil Loss: 0.0%

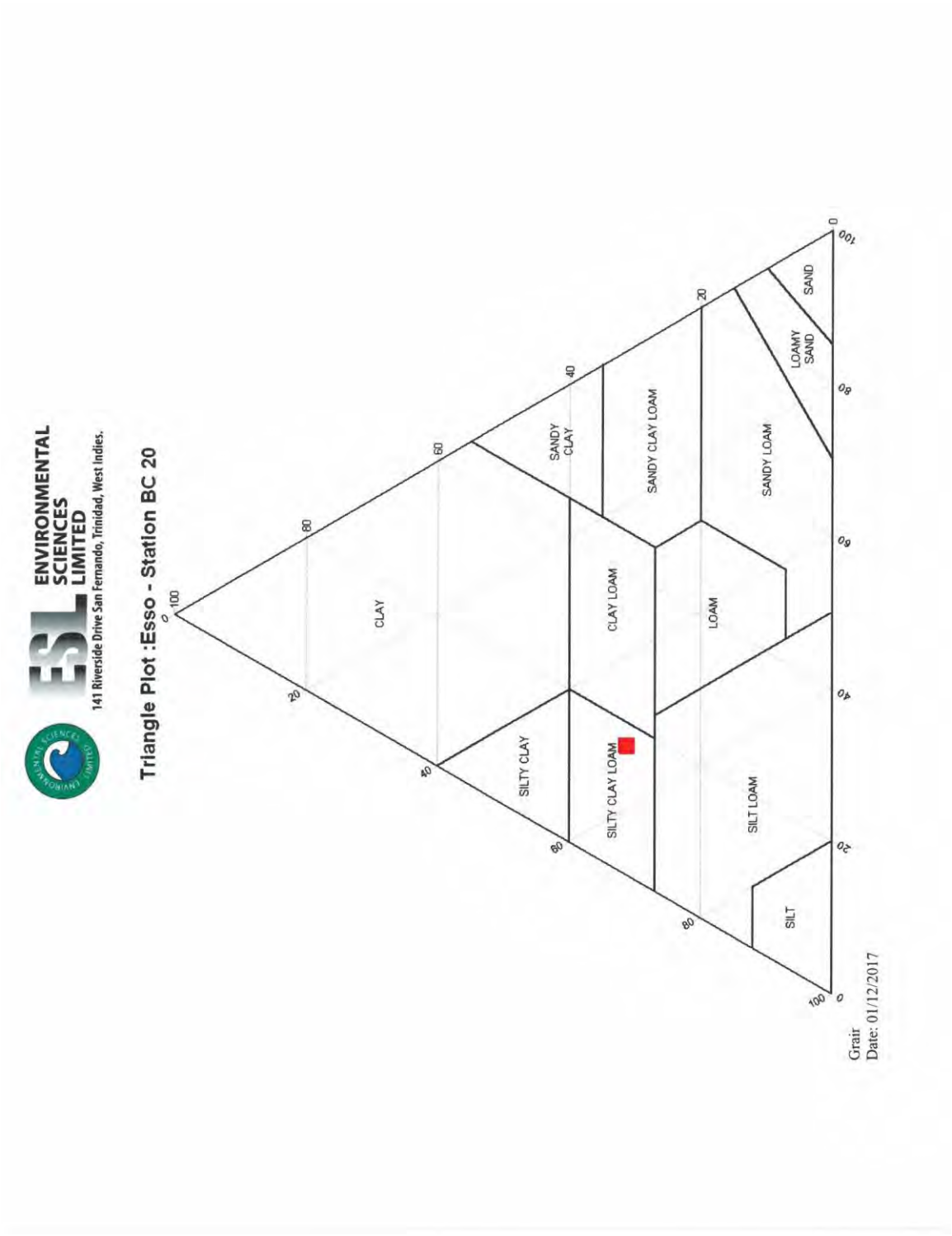
USDA Classification: Silty Clay Loam

Analyzed by: _____ **Date:** 01/12/17

Grain Size Analysis Sheet
Date: 01/12/2017

REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Grain Size Distribution Curve :Esso - Station BC 20
Percent Finer by Weight
Percent Coarser by Weight
U.S. Standard Sieve Sizes
#4 #6 #8 #12 #16 #20 #30 #40 #50 #70 #100 #140 #200
Hyd. Anal.
#270 #400
5 4 3 2 1 0.7 0.5 0.3 0.2 0.1 0.07 0.05 0.03 0.02
Grain Size in Millimeters
Gravel
Sand
Silt or Clay
Coarse
Medium
Fine
Grain Size Analysis Sheet
Date: 01/12/2017
REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Triangle Plot :Esso - Station BC 20
CLAY
SILTY CLAY
SANDY CLAY
SILTY CLAY LOAM
CLAY LOAM
SANDY CLAY LOAM
LOAM
SILT LOAM
SANDY LOAM
SILT
LOAMY SAND
SAND
Grair
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

BC- Station #20

REV 1

Grain Size Analysis Sheet
Date: 01/12/2017

ESL ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Client/Project: ESSO
Date: 01/12/17
Location: Station BC #21
Visual Classification: Clay Loam

1	2	3	4	5
Sieve Size (mm)	Soil Retained (g)	% retained $\frac{\text{Col 2}}{\text{Wt}} * 100$ (Rn)	Cumulative % retained ΣR_n	% Finer $100 - \Sigma R_n$
4	0.00	0.00	0.00	100.00
2	0.43	2.13	2.13	97.87
0.5	1.26	6.20	8.33	91.67
0.25	0.96	4.73	13.06	86.94
0.125	1.63	8.05	21.11	78.89
0.062	9.80	48.31	69.42	30.58
<0.062	6.201	30.58	100.00	0.00
	Σ 20.28(Wt_t)			

Initial mass of dry soil (Wt): 20.28g

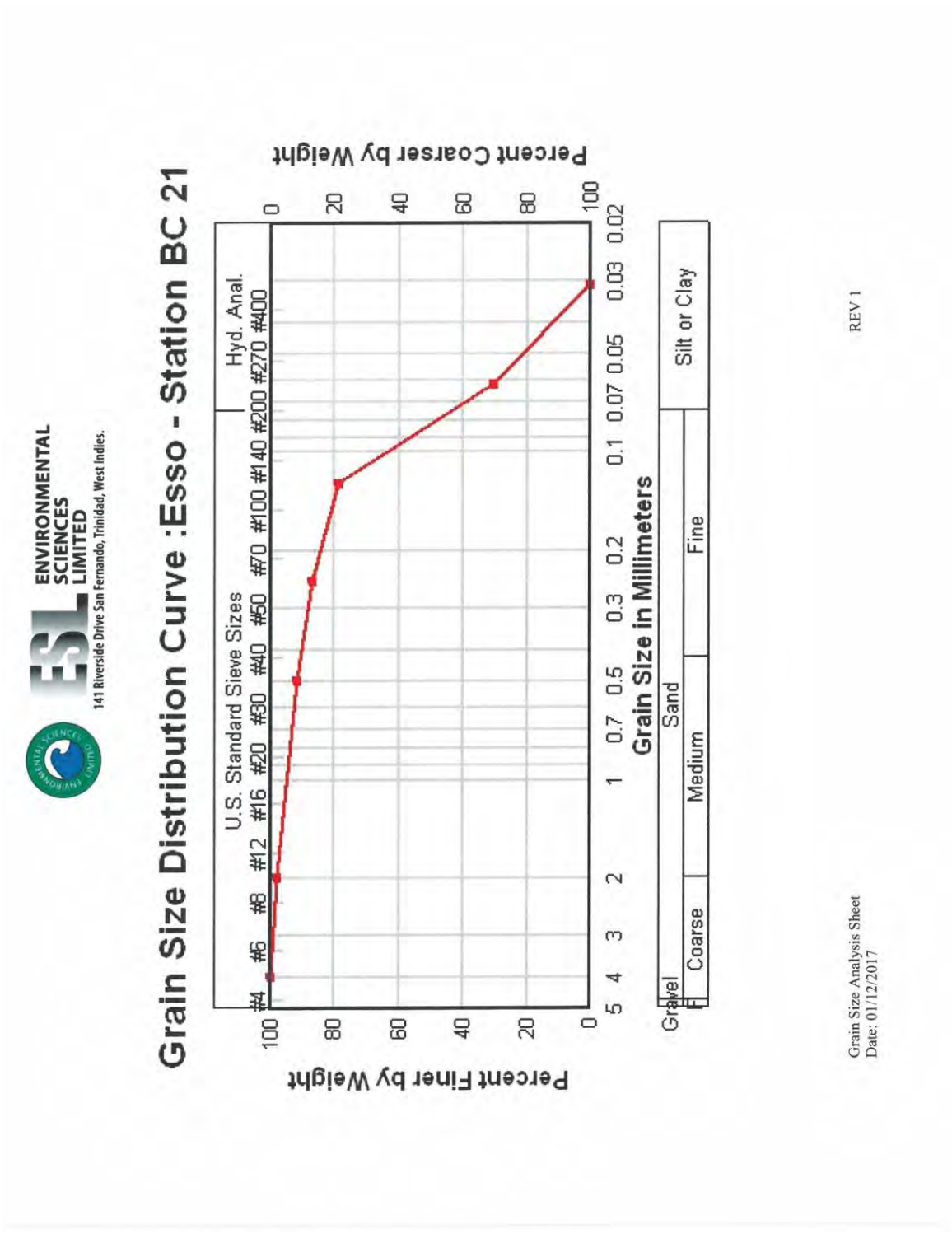
Soil Loss: 0.0%

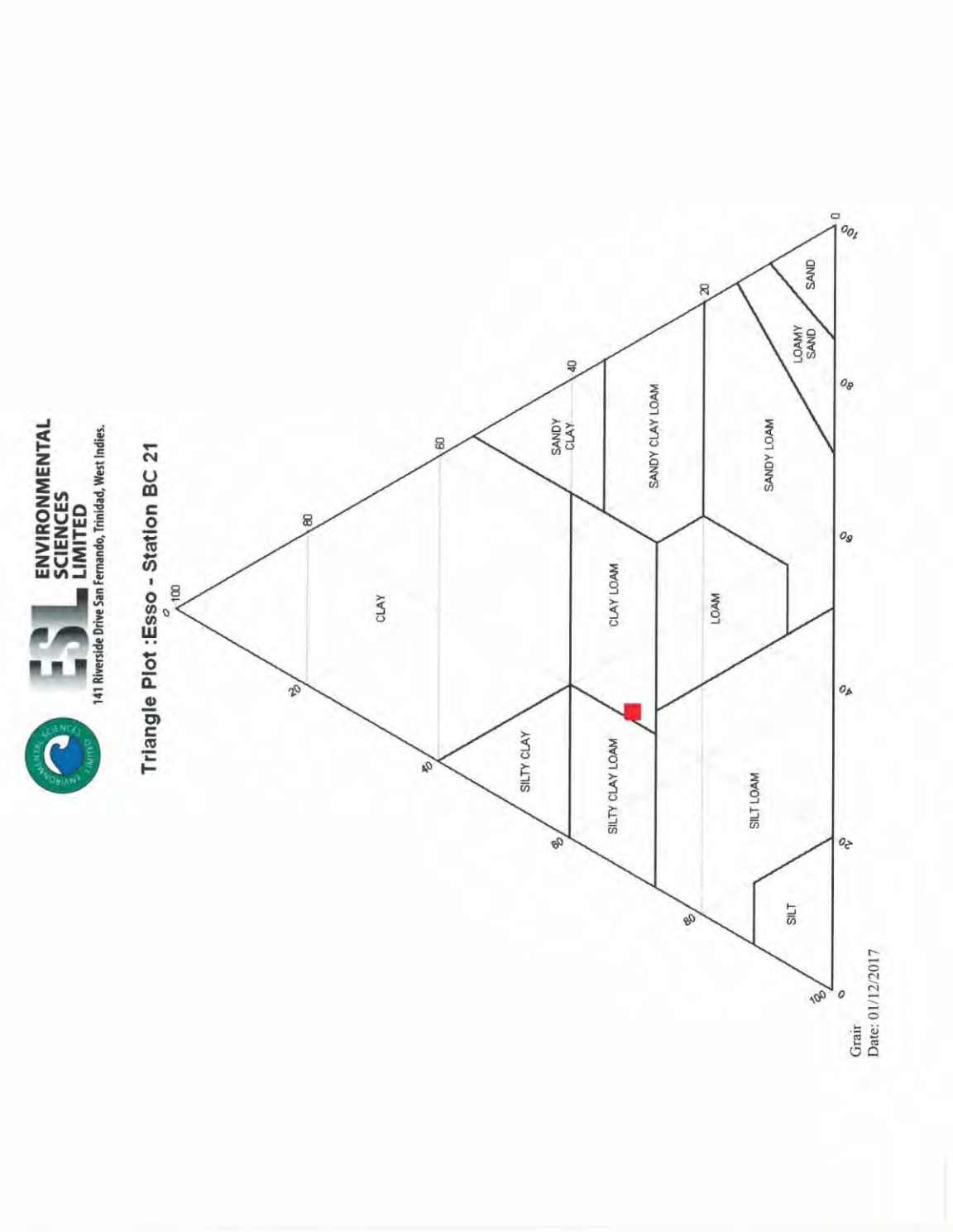
USDA Classification: Clay Loam

Analyzed by: _____ **Date:** 01/12/17

Grain Size Analysis Sheet
Date: 01/12/2017

REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Grain Size Distribution Curve :Esso - Station BC 21
U.S. Standard Sieve Sizes
#4 #6 #8 #12 #16 #20 #30 #40 #50 #70 #100 #140 #200 #270 #400
Hyd. Anal.
Percent Finer by Weight
Percent Coarser by Weight
Grain Size in Millimeters
Gravel
Sand
Coarse
Medium
Fine
Silt or Clay
Grain Size Analysis Sheet
Date: 01/12/2017
REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Triangle Plot :Esso - Station BC 21
CLAY
SILTY CLAY
SANDY CLAY
SILTY CLAY LOAM
CLAY LOAM
SANDY CLAY LOAM
LOAM
SILT LOAM
SANDY LOAM
LOAMY SAND
SAND
SILT
Grair
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

BC- Station #21

REV 1

Grain Size Analysis Sheet
Date: 01/12/2017

ESL ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Client/Project: ESSO

Date: 01/12/17

Location: Station BC #22

Visual Classification: Clay

1	2	3	4	5
Sieve Size (mm)	Soil Retained (g)	% retained $\frac{\text{Col 2}}{\text{Wt}} * 100$ (Rn)	Cumulative % retained ΣR_n	% Finer $100 - \Sigma R_n$
4	0.00	0.00	0.00	100.00
2	0.00	0.00	0.00	100.00
0.5	0.01	0.07	0.07	99.93
0.25	0.01	0.06	0.13	99.87
0.125	0.07	0.49	0.61	99.39
0.062	1.10	7.65	8.26	91.74
<0.062	13.174	91.74	100.00	0.00
	Σ 14.36(Wt_1)			

Initial mass of dry soil (Wt): 14.36g

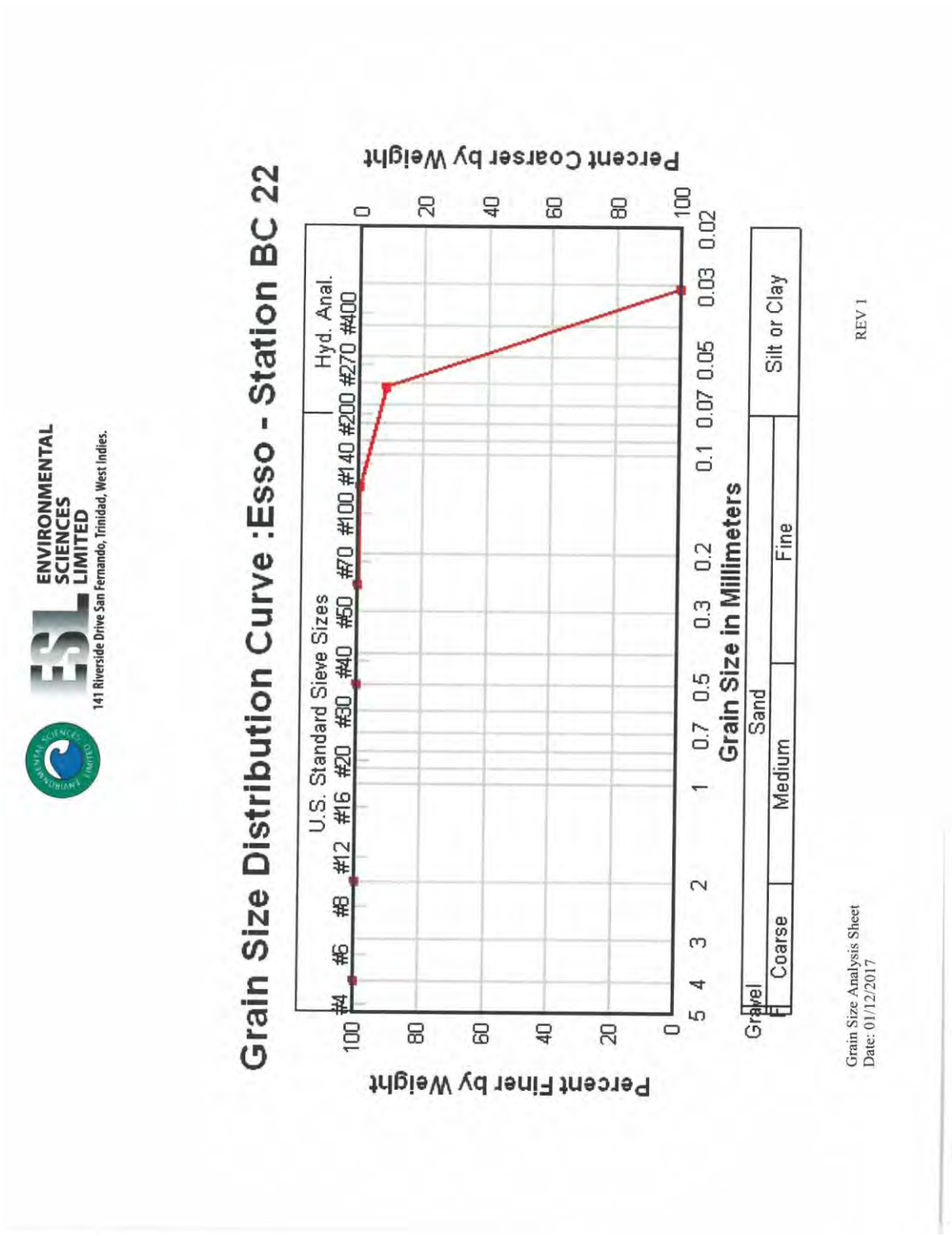
Soil Loss: 0.0%

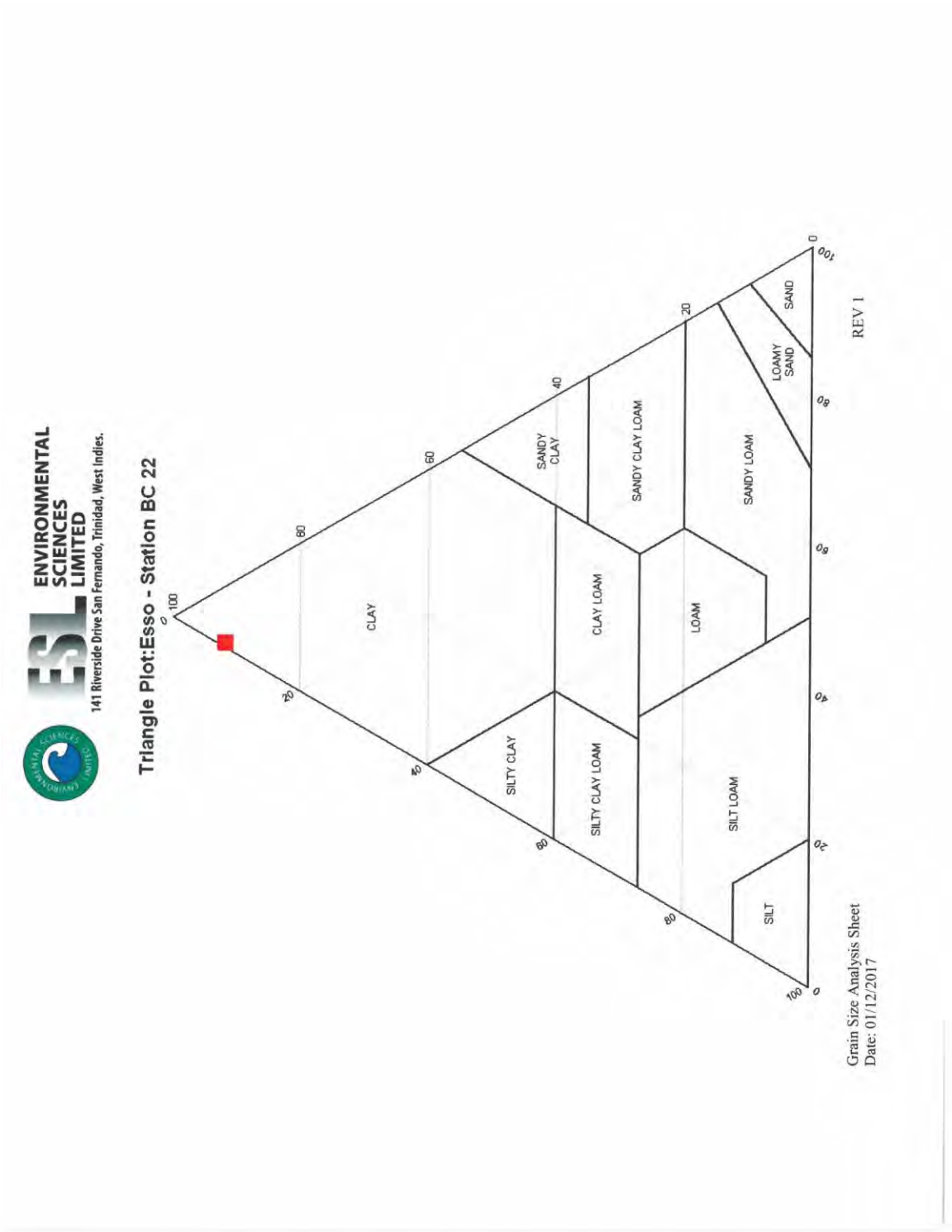
USDA Classification: Clay

Analyzed by: _____ **Date:** 01/12/17

Grain Size Analysis Sheet
Date: 01/12/2017

REV 1


ESL ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Grain Size Distribution Curve :Esso - Station BC 22
Percent Finer by Weight
Percent Coarser by Weight
U.S. Standard Sieve Sizes
Hyd. Anal.
#4 #6 #8 #12 #16 #20 #30 #40 #50 #70 #100 #140 #200 #270 #400
5 4 3 2 1 0.7 0.5 0.3 0.2 0.1 0.07 0.05 0.03 0.02
Grain Size in Millimeters
Gravel
Sand
Coarse
Medium
Fine
Silt or Clay
REV 1
Grain Size Analysis Sheet
Date: 01/12/2017


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Triangle Plot:Esso - Station BC 22
CLAY
SILTY CLAY
SANDY CLAY
CLAY LOAM
SILTY CLAY LOAM
SANDY CLAY LOAM
LOAM
SILT LOAM
SANDY LOAM
LOAMY SAND
SILT
SAND
REV 1
Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

BC- Station #22

REV 1

Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Client/Project: ESSO

Date: 01/12/17

Location: Station BC #23

Visual Classification: Clay

1	2	3	4	5
Sieve Size (mm)	Soil Retained (g)	% retained Col 2 *100 / Wt (Rn)	Cumulative % retained ΣR_n	% Finer 100- ΣR_n
4	0.00	0.00	0.00	100.00
2	0.00	0.00	0.00	100.00
0.5	0.02	0.12	0.12	99.88
0.25	0.02	0.12	0.24	99.76
0.125	0.02	0.12	0.36	99.64
0.062	0.02	0.12	0.48	99.52
<0.062	17.2	99.52	100.00	0.00
	Σ 17.28(Wt_1)			

Initial mass of dry soil (Wt): 17.28g

Soil Loss: 0.0%

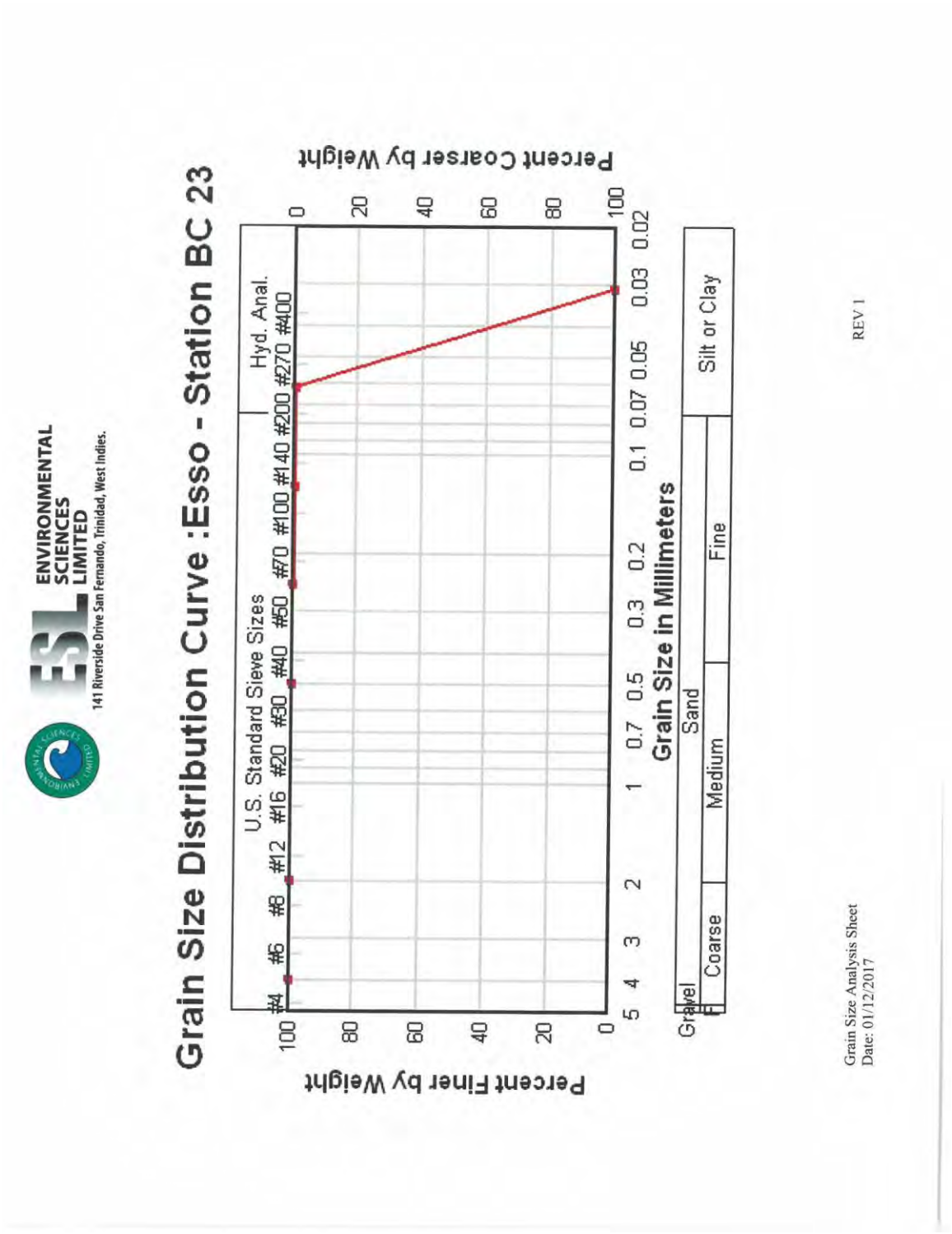
USDA Classification: Clay

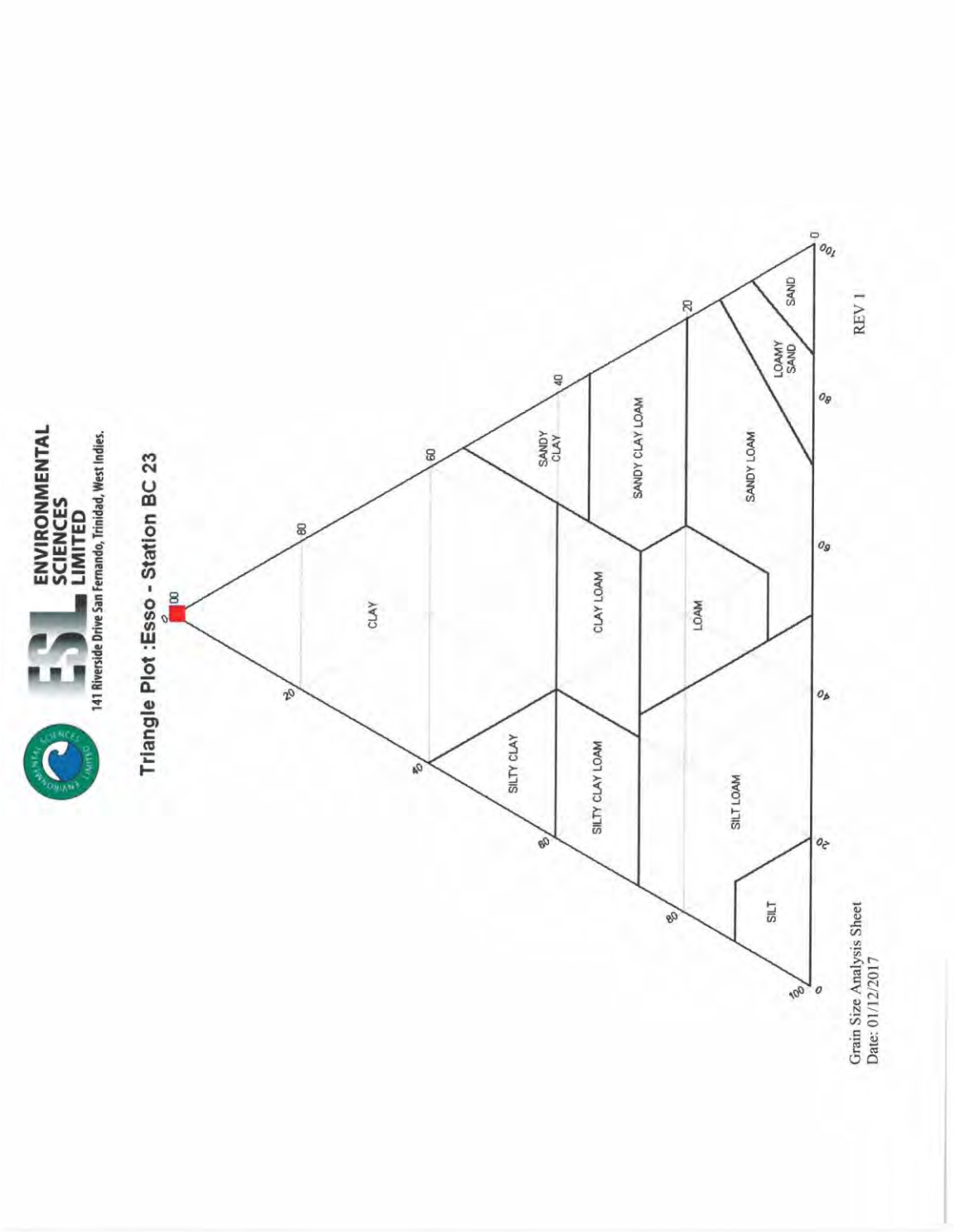
Analyzed by: _____

Date: 01/12/17

Grain Size Analysis Sheet
Date: 01/12/2017

REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Grain Size Distribution Curve :Esso - Station BC 23
U.S. Standard Sieve Sizes
#4 #5 #8 #12 #16 #20 #30 #40 #50 #70 #100 #140 #200
Hyd. Anal.
#270 #400
Percent Finer by Weight
Percent Coarser by Weight
100 80 60 40 20 0
5 4 3 2 1 0.7 0.5 0.3 0.2 0.1 0.07 0.05 0.03 0.02
Grain Size in Millimeters
Gravel
Sand
Coarse
Medium
Fine
Silt or Clay
Grain Size Analysis Sheet
Date: 01/12/2017
REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Triangle Plot :Esso - Station BC 23
CLAY
SANDY CLAY
SANDY CLAY LOAM
SANDY LOAM
LOAMY SAND
SAND
CLAY LOAM
LOAM
SILTY CLAY
SILTY CLAY LOAM
SILT LOAM
SILT
REV 1
Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

BC- Station #23

REV 1

Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Client/Project: ESSO

Date: 01/12/17

Location: Station BC #24

Visual Classification: Clay Loam

1	2	3	4	5
Sieve Size (mm)	Soil Retained (g)	% retained Col 2 *100 / Wt (Rn)	Cumulative % retained ΣR_n	% Finer $100-\Sigma R_n$
4	0.46	2.08	2.08	97.92
2	1.06	4.78	6.86	93.14
0.5	1.93	8.71	15.57	84.43
0.25	1.27	5.73	21.30	78.70
0.125	2.96	13.36	34.66	65.34
0.062	5.70	25.72	60.38	39.62
<0.062	8.78	39.62	100.00	0.00
	Σ 22.16(Wt_1)			

Initial mass of dry soil (Wt): 22.16g

Soil Loss: 0.0%

USDA Classification: Clay Loam

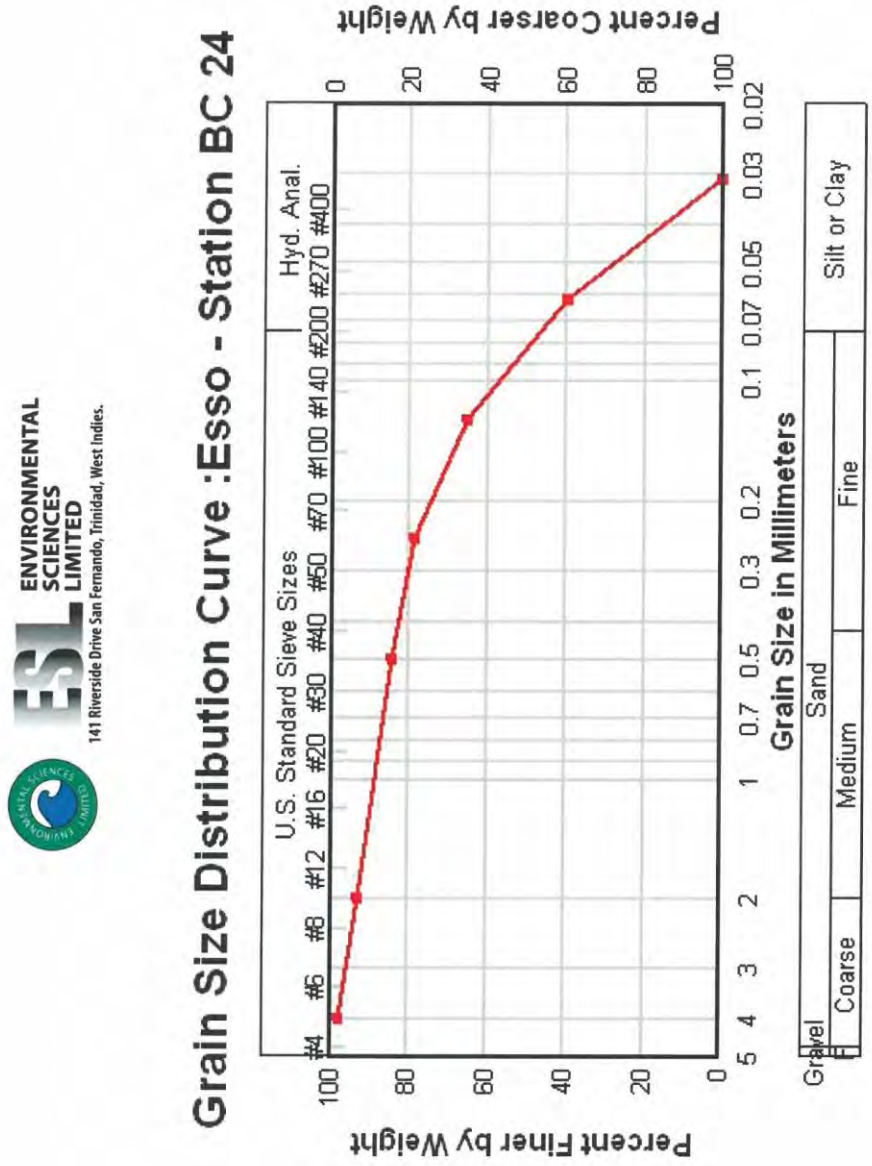
Analyzed by: _____ **Date:** 01/12/17

Grain Size Analysis Sheet
Date: 01/12/2017

REV 1

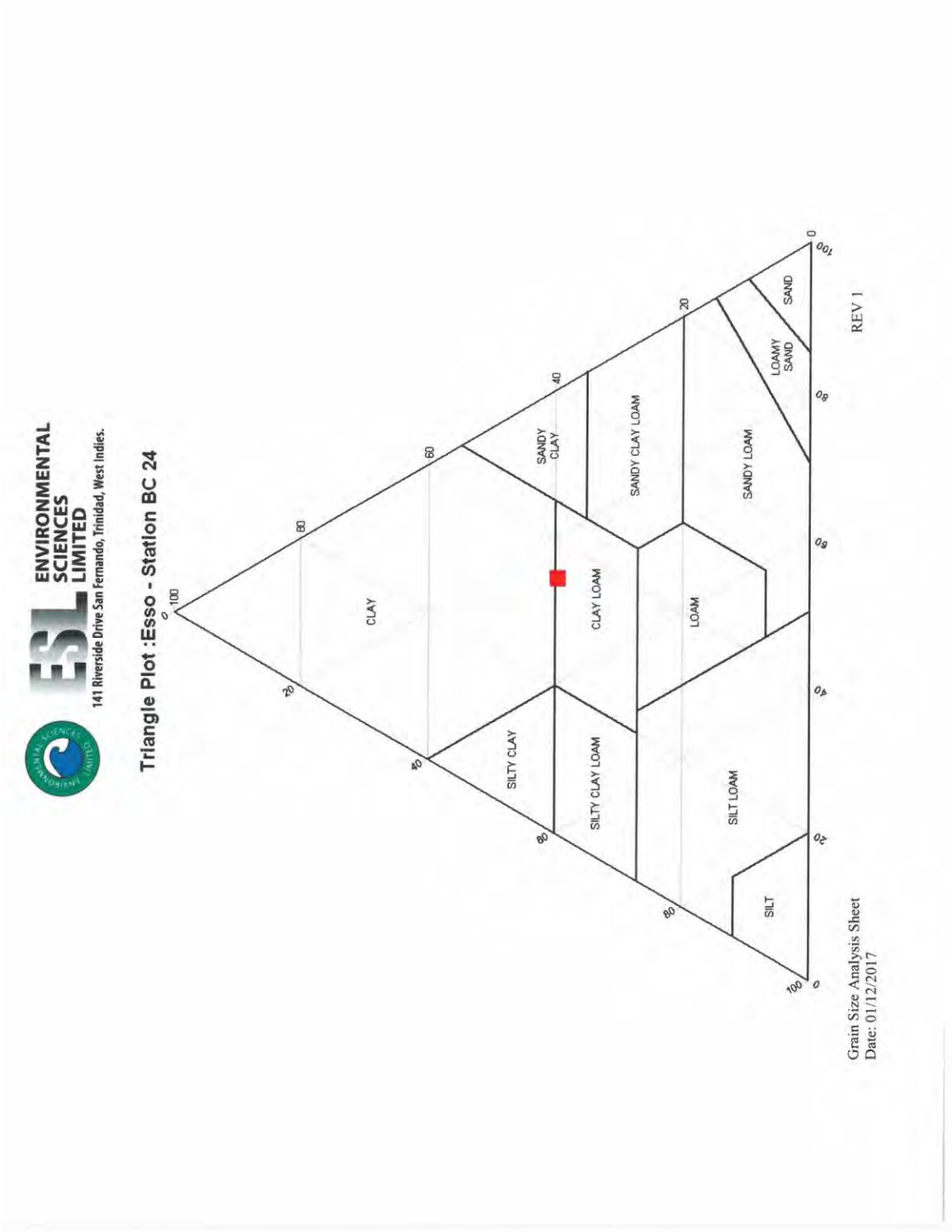
ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

Grain Size Distribution Curve :Esso - Station BC 24



Grain Size Analysis Sheet
Date: 01/12/2017

REV 1


ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.
Triangle Plot :Esso - Station BC 24
CLAY
SILTY CLAY
SANDY CLAY
CLAY LOAM
SILTY CLAY LOAM
SANDY CLAY LOAM
LOAM
SILT LOAM
SANDY LOAM
LOAMY SAND
SAND
SILT
REV 1
Grain Size Analysis Sheet
Date: 01/12/2017

ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive San Fernando, Trinidad, West Indies.

BC- Station #24

REV 1

Grain Size Analysis Sheet
Date: 01/12/2017

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Appendix 10 – Analytical Laboratory Report-Sediment Quality

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ENVIRONMENTAL SCIENCES LIMITED
141 Riverside Drive, San Fernando, Trinidad, West Indies.
Tel.: (868) 657-9024, (868) 657-1560 Fax: (868) 653-2571 Email: jerome.als@envirosciences.net

Project Code: 25/17 Client Name: Exxon Report Date: December 11th, 2017

ANALYSIS REPORT

Client:	Exxon
Client Address :	Exxon Houston
Project Reference:	3105 Exxon Out of Scope Sediment & Sampling-Guyana (Phase 2)
Project No:	25/17 - Rev 1
Report No:	1- EBS for Shelf Stations
Date Received:	November 7th, 2017
Dates of Analysis:	November 9th, 2017- December 4th, 2017
Date of Report:	December 11th, 2017
Sample Type:	Sediment

Results shown in this test report apply to the specific samples tested only
*Test subcontracted to IAG
Page 1 of 7

ENVIRONMENTAL SCIENCES LIMITED
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Project Code: 25/17 Client Name: Exxon Report Date: December 11th, 2017

ESL Sample No.	Client Sample ID
25/17-15S	BC15 Exxon Station 15 Sediment
25/17-16S	BC16 Exxon Station 16 Sediment
25/17-17S	BC17 Exxon Station 17 Sediment
25/17-18S	BC18 Exxon Station 18 Sediment
25/17-19S	BC19 Exxon Station 19 Sediment
25/17-20S	BC20 Exxon Station 20 Sediment
25/17-21S	BC21 Exxon Station 21 Sediment
25/17-22S	BC22 Exxon Station 22 Sediment
25/17-23S	BC23 Exxon Station 23 Sediment
25/17-24S	BC24 Exxon Station 24 Sediment

Introduction

Ten sediment samples were taken by ESL's Field Technicians between October 26th, 2017 and October 27th, 2017 and submitted to ESL's Laboratory for analysis. All samples were preserved and submitted in properly labelled containers as recommended by EPA Method 823-B-01-002. Samples were received at ESL's laboratory on November 7th in good condition.

Sediment samples were analysed for Poly Aromatic Hydrocarbons, Saturated Hydrocarbons, % Moisture, Total Organic Carbon and Total and Bioavailable Metals (Cadmium, Copper, Chromium, Iron, Nickel, Selenium, Aluminium, Lead, Zinc, Mercury, Arsenic and Barium). All sediment analyses were subcontracted to IAG. Sediment results are reported on a dry weight basis.

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Project Code: 25/17 Client Name: Exxon Report Date: December 11th, 2017

Test Methodology

All methodologies are derived from guidelines and methods from the Standard Methods for the Examination of Water and Wastewater 22nd Ed and US EPA methods.

Parameter	Test Method and Description	Date of Analysis
Total Mercury	SW 846 7471A	11/11/2017 – 15/11/2017
Bioavailable Mercury	SW 846 7470A	01/12/2017
Total Metals (Aluminium, Arsenic, Nickel, Lead, Chromium, Cadmium, Copper, Iron, Selenium, Zinc, Barium)	SW 846 6010B	11/11/2017 – 15/11/2017
Bioavailable Metals (Aluminium, Arsenic, Nickel, Lead, Chromium, Cadmium, Copper, Selenium, Iron, Zinc, Barium)	SW 846 6010B	04/12/2017
% Moisture	EPA Moisture method	09/11/2017 - 15/11/2017
PAH's	SW 846 8270C	09/11/2017 - 15/11/2017
TOC	Walkley Black method	14/11/2017

Results shown in this test report apply to the specific samples tested only
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Project Code: 25/17 Client Name: Exxon Report Date: December 11th, 2017

Results:

Sediment:

ESL Sample No.	Client Sample ID	Total Fe* ppm	Total Cu* ppm	Total Al* ppm	Total Zn* ppm	Total Cd* ppm	Total Cr* ppm	Total Pb* ppm	Total Ni* ppm
25/17-15S	Exxon Sediment 15	35,000	2.3	5,100	21	BDL	24	11	8.3
25/17-16S	Exxon Sediment 16	8,900	BDL	2,900	12	BDL	7.7	3.8	3.8
25/17-17S	Exxon Sediment 17	14,000	1.5	4,200	16	BDL	12	5.3	5.8
25/17-18S	Exxon Sediment 18	9,300	BDL	2,900	11	BDL	9.4	4.5	4.0
25/17-19S	Exxon Sediment 19	13,000	1.4	4,400	21	BDL	11	4.2	6.0
25/17-20S	Exxon Sediment 20	19,000	1.3	5,200	30	BDL	14	4.5	7.8
25/17-21S	Exxon Sediment 21	21,000	1.8	6,500	32	BDL	13	7.0	8.1
25/17-22S	Exxon Sediment 22	27,000	6.7	13,000	55	BDL	19	14	15
25/17-23S	Exxon Sediment 23	26,000	5.8	12,000	50	BDL	18	13	14
25/17-24S	Exxon Sediment 24	34,000	3.8	8,900	45	BDL	17	11	13

ppm = mg/kg
BDL= below detection limit
*Test Subcontracted to IAG

ESL Sample No.	Client Sample ID	Total Se* ppm	Total Hg* ppm	Total As* ppm	Total Ba* ppm	PAH* ppm	% Moisture* %	TOC* %
25/17-15S	Exxon Sediment 15	BDL	BDL	50	6.8	BDL	28.3	0.58
25/17-16S	Exxon Sediment 16	BDL	BDL	9.6	4.1	BDL	22.1	0.36
25/17-17S	Exxon Sediment 17	BDL	BDL	15	5.0	BDL	24.6	0.17
25/17-18S	Exxon Sediment 18	BDL	BDL	9.3	4.2	BDL	26.2	BDL
25/17-19S	Exxon Sediment 19	BDL	BDL	3.2	4.5	BDL	23.9	0.14
25/17-20S	Exxon Sediment 20	BDL	BDL	6.7	3.5	BDL	23.9	0.27
25/17-21S	Exxon Sediment 21	BDL	BDL	7.6	6.1	BDL	26.2	0.11
25/17-22S	Exxon Sediment 22	BDL	BDL	9.6	16	BDL	37.4	0.65
25/17-23S	Exxon Sediment 23	BDL	BDL	10	16	BDL	38.6	0.49
25/17-24S	Exxon Sediment 24	BDL	BDL	29	8.6	BDL	22.4	0.18

ppm = mg/kg
BDL= below detection limit
*Test Subcontracted to IAG

Results shown in this test report apply to the specific samples tested only
*Test subcontracted to IAG
Page 4 of 7

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Project Code: 25/17 Client Name: Exxon Report Date: December 11th, 2017

ESL Sample No.	Client Sample ID	Bio Fe* ppm	Bio Cu* ppm	Bio Zn* ppm	Bio Cd* ppm	Bio Cr* ppm	Bio Pb* ppm	Bio Ni* ppm
25/17-15S	Exxon Sediment 15	BDL	BDL	BDL	BDL	BDL	BDL	BDL
25/17-16S	Exxon Sediment 16	BDL	BDL	BDL	BDL	BDL	BDL	BDL
25/17-17S	Exxon Sediment 17	BDL	BDL	BDL	BDL	BDL	BDL	BDL
25/17-18S	Exxon Sediment 18	BDL	BDL	BDL	BDL	BDL	BDL	BDL
25/17-19S	Exxon Sediment 19	BDL	BDL	BDL	BDL	BDL	BDL	BDL
25/17-20S	Exxon Sediment 20	BDL	BDL	BDL	BDL	BDL	BDL	BDL
25/17-21S	Exxon Sediment 21	BDL	BDL	BDL	BDL	BDL	BDL	BDL
25/17-22S	Exxon Sediment 22	BDL	BDL	BDL	BDL	BDL	BDL	BDL
25/17-23S	Exxon Sediment 23	BDL	BDL	BDL	BDL	BDL	BDL	BDL
25/17-24S	Exxon Sediment 24	BDL	BDL	BDL	BDL	BDL	BDL	BDL

ppm = mg/kg
BDL= below detection limit
*Test Subcontracted to IAG

ESL Sample No.	Client Sample ID	Bio Se* ppm	Bio Hg* ppm	Bio As* ppm	Bio Ba* ppm	Bio Al* ppm
25/17-15S	Exxon Sediment 15	BDL	BDL	BDL	BDL	BDL
25/17-16S	Exxon Sediment 16	BDL	BDL	BDL	BDL	BDL
25/17-17S	Exxon Sediment 17	BDL	BDL	BDL	BDL	BDL
25/17-18S	Exxon Sediment 18	BDL	BDL	BDL	BDL	BDL
25/17-19S	Exxon Sediment 19	BDL	BDL	BDL	BDL	BDL
25/17-20S	Exxon Sediment 20	BDL	BDL	BDL	BDL	BDL
25/17-21S	Exxon Sediment 21	BDL	BDL	BDL	BDL	BDL
25/17-22S	Exxon Sediment 22	BDL	BDL	1.3	BDL	BDL
25/17-23S	Exxon Sediment 23	BDL	BDL	BDL	BDL	14
25/17-24S	Exxon Sediment 24	BDL	BDL	BDL	BDL	20

ppm = mg/kg
BDL= below detection limit
*Test Subcontracted to IAG

Results shown in this test report apply to the specific samples tested only
*Test subcontracted to IAG
Page 5 of 7

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Project Code: 25/17 Client Name: Exxon Report Date: December 11th, 2017

Detection Limits:

Parameters	Detection Limit in sediment (mg/kg)
Total As Bio As	0.59 - 1.2 0.50
Total Ba Bio Ba	1.2 - 2.5 1.0
Total Ni Bio Ni	0.59 - 1.2 0.50
Total Pb Bio Pb	0.59 - 1.2 0.50
Total Cr Bio Cr	1.2 - 2.5 1.0
Total Fe Bio As	12 – 25 10
Total Cd Bio Cd	0.59 - 1.2 0.50
Total Cu Bio Cu	1.2 – 2.5 1.0
Total Zn Bio Zn	2.4 - 4.9 2.0
Total Al Bio Al	12 – 25 10
Total Hg Bio Hg	0.017 - 0.031 0.0020
Total Se Bio Se	1.2 - 2.5 1.0
Percent Moisture	0.01
TOC	0.10
PAH	0.42 – 0.83

Results shown in this test report apply to the specific samples tested only
*Test subcontracted to IAG
Page 6 of 7

ENVIRONMENTAL SCIENCES LIMITED
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Project Code: 25/17 Client Name: Exxon Report Date: December 11th, 2017

References:

SW846='Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Third Edition, November 1986 And Its Updates.

Renica Pariag
Laboratory Manager

Kevin Chandrica
Analytical Chemist

Reviewed By: S Mahabir-Lee
Shivanna Mahabir-Lee
HSEQ Consultant

Results shown in this test report apply to the specific samples tested only
*Test subcontracted to IAG
Page 7 of 7

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Project Code: 03/18 RN2 Client Name: Exxon Report Date: January 31st, 2018

ANALYSIS REPORT

Client:	Exxon
Client Address :	Exxon Houston
Project Reference:	3105 Exxon Sediment Sampling - Guyana (Phase 3)
Project No:	03/18
Report No:	2- EBS for Shelf Stations
Date Received:	January 19th, 2018
Dates of Analysis:	January 23rd, 2018 - January 24th, 2018
Date of Report:	January 31st, 2018
Sample Type:	Sediment

Results shown in this test report apply to the specific samples tested only
Page 1 of 8

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Project Code: 03/18 RN2 Client Name: Exxon Report Date: January 31st, 2018

ESL Sample No.	Client Sample ID
03/18-15S	BC15 Exxon Station 15 Sediment
03/18-16S	BC16 Exxon Station 16 Sediment
03/18-17S	BC17 Exxon Station 17 Sediment
03/18-18S	BC18 Exxon Station 18 Sediment
03/18-19S	BC19 Exxon Station 19 Sediment
03/18-20S	BC20 Exxon Station 20 Sediment
03/18-21S	BC21 Exxon Station 21 Sediment
03/18-22S	BC22 Exxon Station 22 Sediment
03/18-23S	BC23 Exxon Station 23 Sediment
03/18-24S	BC24 Exxon Station 24 Sediment

Introduction

Ten sediment samples were taken by ESL's Field Technicians between December 27th, 2017 and December 29th, 2017 and submitted to ESL's affiliate laboratory for analysis. All samples were frozen and submitted in properly labelled containers as recommended by EPA Method 823-B-01-002. Samples were received at ESL's affiliate laboratory on January 19th, 2018 in good condition.

Sediment samples were analysed for Saturated Hydrocarbons.

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Project Code: 03/18 RN2 Client Name: Exxon Report Date: January 31st, 2018

Test Methodology

All methodologies are derived from guidelines and methods from SW846- "Test Methods for Evaluating Solid Waste, Physical /Chemical Methods," Third Edition, November 1986 and its Updates.

Parameter	Test Method and Description	Date of Analysis
Saturated Hydrocarbons	SW 846-8015D- Organics by GC-FID	23/01/2018 - 24/01/2018

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Project Code: 03/18 RN2 Client Name: Exxon Report Date: January 31st, 2018

Results:

Sediment:

Saturated Hydrocarbons-Analyte	03/18-15 Station 15	03/18-16 Station 16	03/18-17 Station 17	03/18-18 Station 18	03/18-19 Station 19	03/18-20 Station 20	03/18-21 Station 21	03/18-22 Station 22	03/18-23 Station 23	03/18-24 Station 24
n-Tridecane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Pentadecane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Nonadecane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Heneicosane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Pentacosane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Heptacosane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Nonacosane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Hentriacontane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Tritriacontane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Pentatriacontane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Heptatriacontane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Octatriacontane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Nonatriacontane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Tetracontane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Dodecane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Dotriacontane	0.20	0.21	0.19	0.23	0.26	0.22	0.17	0.23	0.21	0.21
n-Heptadecane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Hexadecane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Eicosane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Decane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Docosane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Hexacosane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Hexatriacontane	0.17	0.17	0.16	0.17	0.26	0.14	0.21	0.28	0.22	0.17

Results shown in this test report apply to the specific samples tested only
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Project Code: 03/18 RN2 Client Name: Exxon Report Date: January 31st, 2018

Saturated Hydrocarbons-Analyte	03/18-15 Station 15	03/18-16 Station 16	03/18-17 Station 17	03/18-18 Station 18	03/18-19 Station 19	03/18-20 Station 20	03/18-21 Station 21	03/18-22 Station 22	03/18-23 Station 23	03/18-24 Station 24
n-Nonane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Octacosane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Octadecane	BDL	BDL	BDL	BDL	0.14	BDL	BDL	BDL	BDL	BDL
n-Octane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Tetraconsane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Tetradecane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Phytane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pristane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Tetratriacontane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Triacontane	0.17	BDL	BDL	BDL	BDL	BDL	0.31	BDL	BDL	0.19
n-Tricosane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
n-Undecane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Total Extractable Hydrocarbons	BDL	BDL	BDL	BDL	10	6.4	4.9	BDL	BDL	BDL
2,6,10-Trimethyldodecane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2,6,10 Trimethyltridecane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Norpristane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Results shown are in ppm or mg/kg
BDL= below detection limit
Tests Subcontracted to IAG

Results shown in this test report apply to the specific samples tested only

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Project Code: 03/18 RN2 Client Name: Exxon Report Date: January 31st, 2018

Detection Limits:

Saturated Hydrocarbons Analyte	03/18-15 Station 15	03/18-16 Station 16	03/18-17 Station 17	03/18-18 Station 18	03/18-19 Station 19	03/18-20 Station 20	03/18-21 Station 21	03/18-22 Station 22	03/18-23 Station 23	03/18-24 Station 24
n-Tridecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Pentadecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Nonadecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Heneicosane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Pentacosane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Heptacosane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Nonacosane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Hentriacontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Tritriacontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Pentatriacontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Heptatriacontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Octatriacontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Nonatriacontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Tetracontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Dodecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
N-Dotriacontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Heptadecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Hexadecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Eicosane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Decane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Docosane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Hexacosane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Hexatriacontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Nonane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Octacosane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Octadecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Octane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Tetraconsane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Tetradecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13

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Page 6 of 8

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Project Code: 03/18 RN2 Client Name: Exxon Report Date: January 31st, 2018

Saturated Hydrocarbons Analyte	03/18-15 Station 15	03/18-16 Station 16	03/18-17 Station 17	03/18-18 Station 18	03/18-19 Station 19	03/18-20 Station 20	03/18-21 Station 21	03/18-22 Station 22	03/18-23 Station 23	03/18-24 Station 24
Phytane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
Pristane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Tetratriacontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Triacontane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Tricosane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
n-Undecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
Total Extractable Hydrocarbons	4.2	4.0	3.9	4.1	4.4	4.2	4.1	4.5	4.2	4.2
2,6,10-Trimethyldodecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
2,6,10 Trimethyltridecane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13
Norpristane	0.13	0.12	0.12	0.13	0.14	0.13	0.13	0.14	0.13	0.13

Detection Limits shown in ppm or mg/kg

Results shown in this test report apply to the specific samples tested only
Page 7 of 8

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Project Code: 03/18 RN2 Client Name: Exxon Report Date: January 31st, 2018

References:

SW846='Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Third Edition, November 1986 And Its Updates.

EPA=US Environmental Protection Agency

Renica Pariag
Laboratory Manager

Reviewed By: S. Mahabir-Lee
Shivanna Mahabir-Lee
Quality Coordinator

Results shown in this test report apply to the specific samples tested only
Page 8 of 8

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Appendix 11 – Benthic Species List (ESL, October 2017)

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Benthic Macrofauna Species List for Environmental Baseline Assessment along the Continental Shelf, Guyana (ESL; October 2017)

Phylum	Class	Order	Family (Taxa)
Annelida	Polychaeta	**	Capitellidae
		**	Chaetopteridae
		**	Maldanidae
		**	Opheliidae
		**	Orbiniidae
		**	Paraonidae
		**	Scalibregmatidae
		Amphinomida	Amphinomidae
		Eunicida	Dorvilleidae
			Eunicidae
			Lumbrineridae
			Oenonidae
			Onuphidae
		Phyllodocida	Acoetidae
			Eulepethidae
			Glyceridae
			Goniadidae
			Hesionidae
			Nephtyidae
			Nereididae
			Pholoidae
			Phyllodocidae
			Pilargidae
			Polynoidae
			Sigalionidae
			Syllidae
		Sabellida	Oweniidae
			Sabellidae
			Serpulidae
		Spionida	Magelonidae
			Poecilochaetidae
			Spionidae
			Trochochaetidae
		Terebellida	Ampharetidae

Phylum	Class	Order	Family (Taxa)
			Cirratulidae
			Terebellidae
			Trichobranchidae
Arthropoda	Hexanauplia	Calanoida	Calanoida *
	Malacostraca	Amphipoda	Ampeliscidae
			Aoridae
			Caprellidae
			Chevaliidae
			Corophiidae
			Isaeidae
			Ischyroceridae
			Lysianassidae
			Oedicerotidae
			Photidae
			Phoxocephalidae
			Platyischnopidae
			Synopiidae
			Unknown Amphipod
		Cumacea	Bodotriidae
			Diastylidae
			Nannastacidae
			Unknown Cumacea
		Decapoda	Axiidea*
			Brachyura*
			Paguroidea*
			Alpheidae
			Anomura*
			Callianassidae
			Caridea*
			Crangonidae
			Decapoda*
			Diogenidae
			Micheleidae
			Palaemonidae
			Panopeidae
			Pasiphaeidae
			Pilumnidae
			Pinnotheridae

Phylum	Class	Order	Family (Taxa)
			Porcellanidae
			Processidae
			Pseudorhombilidae
			Sergestidae
		Euphausiacea	Euphausiidae
		Isopoda	Anthuridae
			Anthuroidea*
			Cirolanidae
			Hyssuridae
			Leptanthuridae
			Serolidae
		Leptostraca	Nebaliidae
		Mysida	Mysida*
		Tanaidacea	Apseudidae
			Apseudomorpha*
			Kalliapseudidae
			Leptocheliidae
			Metapseudidae
			Parapseudidae
			Tanaellidae
			Tanaidomorpha *
	Ostracoda	Myodocopida	Myodocopida
	Pycnogonida	Pantopoda	Phoxichilidiidae
Brachiopoda	Lingulata	Lingulida	Lingulidae
Bryozoa	Gymnolaemata	Cheilostomatida	Celleporidae
			Scrupariidae
Chordata	Actinopterygii	Ophidiiformes	Bythitidae
	Leptocardii	**	Branchiostomatidae
Cnidaria	Anthozoa	Actiniaria	Edwardsiidae
		Spirularia	Cerianthidae
		Zoantharia	Zoantheria*
	Hydrozoa	Leptothecata	Lafoeidae
			Sertulariidae
Echinodermata	Holothuroidea	**	Holothuroidea
		Apodida	Synaptidae
	Ophiuroidea	Ophiurida	Amphiuridae
			Ophiocomidae
			Ophiuridae

Phylum	Class	Order	Family (Taxa)
			Ophiuroidae*
Hemichordata	**	**	Hemichordata
Mollusca		**	Mactridae
		**	Ungulinidae
			Cardiidae
			Semelidae
			Tellinidae
		Limida	Limidae
		Lucinida	Lucinidae
			Thyasiridae
		Myida	Corbulidae
		Nuculida	Nuculidae
		Ostreida	Pteriidae
		Pectinida	Pectinidae
		Venerida	Arcticidae
	Caudofoveata	Chaetodermatida	Limifossoridae
	Gastropoda	Littorinimorpha	Naticidae
		Neogastropoda	Muricidae
			Olividae
Porifera	**	**	Porifera
Sipuncula	Phascolosomatidea	Aspidosiphonida	Aspidosiphonidae
	Sipunculidea	Golfingiida	Golfingiidae
			Phascolionidae

Benthic Macrofauna Species List per station replicate for Environmental Baseline Assessment along the Continental Shelf, Guyana (ESL; October 2017)

Family	Station																													
	15.1	15.2	15.3	16.1	16.2	16.3	17.1	17.2	17.3	18.1	18.2	18.3	19.1	19.2	19.3	20.1	20.2	20.3	21.1	21.2	21.3	22.1	22.2	22.3	23.1	23.2	23.3	24.1	24.2	24.3	Abundance of specimen
Amphinomidae						1					1													1	1						4
Dorvilleidae										1							1														2
Eunicidae	4	1	1			6					1			1			13		5	14		2							6	5	59
Lumbrineridae	3		3			2	2			2	1		1		1	4		8	12	3								1	1	1	45
Oenonidae								1			1																				2
Onuphidae	2	1	2		2			3		2	2		3	9	3		4	1	38		17	9	7	7	6	7	7	6	23	41	202
Acoetidae									2						2												1				5
Eulepethidae								2																							2
Glyceridae					1	1	1			1				3	2			2			1	3		1	1						17
Goniadidae					1		1	1			4		1	2	1	1	3	5	2		2					3		1	1	1	30
Hesionidae											1			3																	4
Nephtyidae					1			1					4	2	3	6	5	4	1		6					2			2	4	41
Nereididae																10	7	8	1	1		7	3	4	10	11	10		4		76
Pholoidae								1																							1
Phyllodocidae								1		1	4	1	1	1	3	1	1	1	1		1		1		1	1	1	2		1	24
Pilargidae						2		1			1				1		3					1									9
Polynoidae						1		3														1									5
Sigalionidae						1		1			1	1						1													5
Syllidae	3		1		2	1	3	3		1	3			1					2								1	7	8	36
Oweniidae										1	12			1				1	6	3		1		1			2	2		1	31
Sabellidae					1						2			6	13	1	2			1										26
Serpulidae											1							4													5
Magelonidae	1	1				4		4			1		1			6	2	8					1	4	13	4	2		1	1	54
Poecilochaetidae								2																							2
Spionidae					6	2		2	1	1	7		3	7	6	23	22	49	16		3	3	2	7	5	7	6	1	5	23	207
Trochochaetidae																											1				1
Ampharetidae	1	1			8	5	1	1	1		2					2	2	14	4	1		7	9	11	11	18	21			1	121
Cirratulidae	1							1			2	1		4	6	1	1	3			1						1			3	25
Terebellidae						1		2			3		1	2								2				1			1		13
Trichobranchidae								1										1													2
Capitellidae	1				2	1	1	1	2		1	1		4	7	1	5	30		1	2	1							3	5	69
Chaetopteridae								2																							2

Family	Station																													
	15.1	15.2	15.3	16.1	16.2	16.3	17.1	17.2	17.3	18.1	18.2	18.3	19.1	19.2	19.3	20.1	20.2	20.3	21.1	21.2	21.3	22.1	22.2	22.3	23.1	23.2	23.3	24.1	24.2	24.3	Abundance of specimen
Maldanidae	1				1														29	13	7			1	1	1	3	5	12	4	78
Opheliidae	1		1				1	1		1	2			8	9		11	7	1		1	1	1	1	5	3	11	4			70
Orbiniidae					2		1				1		6	2	3	1	6	6	3	1	1			1	1				1		36
Paraonidae			2		1		1				7			1	1	3	1	8	1	1			1	1		2			9	6	46
Calanoida																					1										1
Ampeliscidae	1		3	1	6	1	2	1		1			1	3	6	3		5	2		2	1		10	24	9	16	5	1	2	106
Aoridae														1																	1
Caprellidae						1					2		1		1													6	1		12
Chevaliidae			1	69	18	81	9	22		25	74	54	7	807	13	1				1									277	788	2247
Corophiidae		1									1			1																	3
Isaeidae													2																		2
Ischyroceridae								1																							1
Lysianassidae		1			1	1													1												4
Oedicerotidae						2		1								1		1													5
Photidae	1				1	4								2							1						2				11
Phoxocephalidae	1										3			1																	5
Platyischnopidae																		2			1							1		2	6
Synopiidae									1		1																				2
Bodotriidae					1						2			2							1							1		1	8
Diastylidae															2			2								1			1		6
Nannastacidae											1																				1
Alpheidae												1																		1	2
Callianassidae				1	4	4	1		1	2		2	1						4	1					2		1			4	28
Crangonidae																													4		4
Diogenidae														2																4	6
Micheleidae																														1	1
Palaemonidae																							1								1
Panopeidae																												1			1
Pasiphaeidae								1						1		2	1														5
Pilumnidae																														1	1
Pinnotheridae																						3		1		2	3				9
Porcellanidae														1																	1
Processidae														1		1	1														3
Pseudorhombilidae																							2	2			2				6
Sergestidae																							1	1							2

Family	Station																													
	15.1	15.2	15.3	16.1	16.2	16.3	17.1	17.2	17.3	18.1	18.2	18.3	19.1	19.2	19.3	20.1	20.2	20.3	21.1	21.2	21.3	22.1	22.2	22.3	23.1	23.2	23.3	24.1	24.2	24.3	Abundance of specimen
Euphausiidae					1																										1
Anthuridae								2			2			3				1													8
Cirolanidae												1																			1
Hyssuridae				1																											1
Leptanthuridae											1																				1
Serolidae									1																						1
Nebaliidae												1																			1
Apseudidae										1									1												2
Kalliapseudidae																	1														1
Leptocheliidae											4			1																	5
Metapseudidae								1			1																			2	4
Parapseudidae								5			3			3																	11
Tanaellidae							2			3																					5
Phoxichilidiidae										1																					1
Lingulidae													1	3	2			2	3		4							3	7	1	26
Celleporidae																				1											1
Scrupariidae																				1											1
Bythitidae													1																		1
Branchiostomatidae																												1			1
Edwardsiidae							1							1	1																3
Cerianthidae											1			1														1			3
Lafoeidae																			1												1
Sertulariidae																														1	1
Synaptidae																						1									1
Amphiuridae							1	3		2	1			1		1	3	1	2												15
Ophiocomidae								1				1																			2
Ophiuridae						1	1					3					3				2										10
Ophiuroidae					1						1																				2
Semelidae						1																									1
Tellinidae																	2	1							1						4
Limidae															1																1
Lucinidae							1																	1	1		3				6
Thyasiridae																											1				1
Corbulidae	1							4							1												2			1	9
Nuculidae																		1													1

Family	Station																													
	15.1	15.2	15.3	16.1	16.2	16.3	17.1	17.2	17.3	18.1	18.2	18.3	19.1	19.2	19.3	20.1	20.2	20.3	21.1	21.2	21.3	22.1	22.2	22.3	23.1	23.2	23.3	24.1	24.2	24.3	Abundance of specimen
Pteriidae													2																		2
Pectinidae																					2										2
Arcticidae																1															1
Mactridae																			1							1					2
Ungulinidae														1		2		2	1											1	7
Limifossoridae								1																							1
Naticidae																							1								1
Muricidae											1																				1
Olividae							1																								1
Aspidosiphonidae		1										1		1						1			1	1							6
Golfingiidae	1	1													1							1									4
Phascolionidae					3					1							1														5
unknown amphipod													2																1		3
unknown cumacea																			1												1
anomura																					2										2
axiidea								11			8			1		3		2													25
brachyura																			1						1				1		3
caridea																														1	1
decapoda																														1	1
paguroidea														1																	1
anthuroidea																														15	15
Mysida														2																	2
Porifera					1						1																				2
tanaidomorpha							1			1																			8		10
Myodocopida												2							1		1										4
Scalibregmatidae											1																				1
apseudomorpha												2																			2
Hemichordata																	2														2
Cardiidae																	1												2		3
zoantheria																			1	6											7
Holothuroidea																									1						1

Pictures of Benthic Samples 15 - 24 for Environmental Baseline Assessment along the Continental Shelf, Guyana (ESL; October 2017)





Station 15



Station 16


Exxon-Guyana
STN BC17 Rep2.
26/10/17.
STN BC17 Rep2.
26/10/17.
completed
Bc17
Rep2

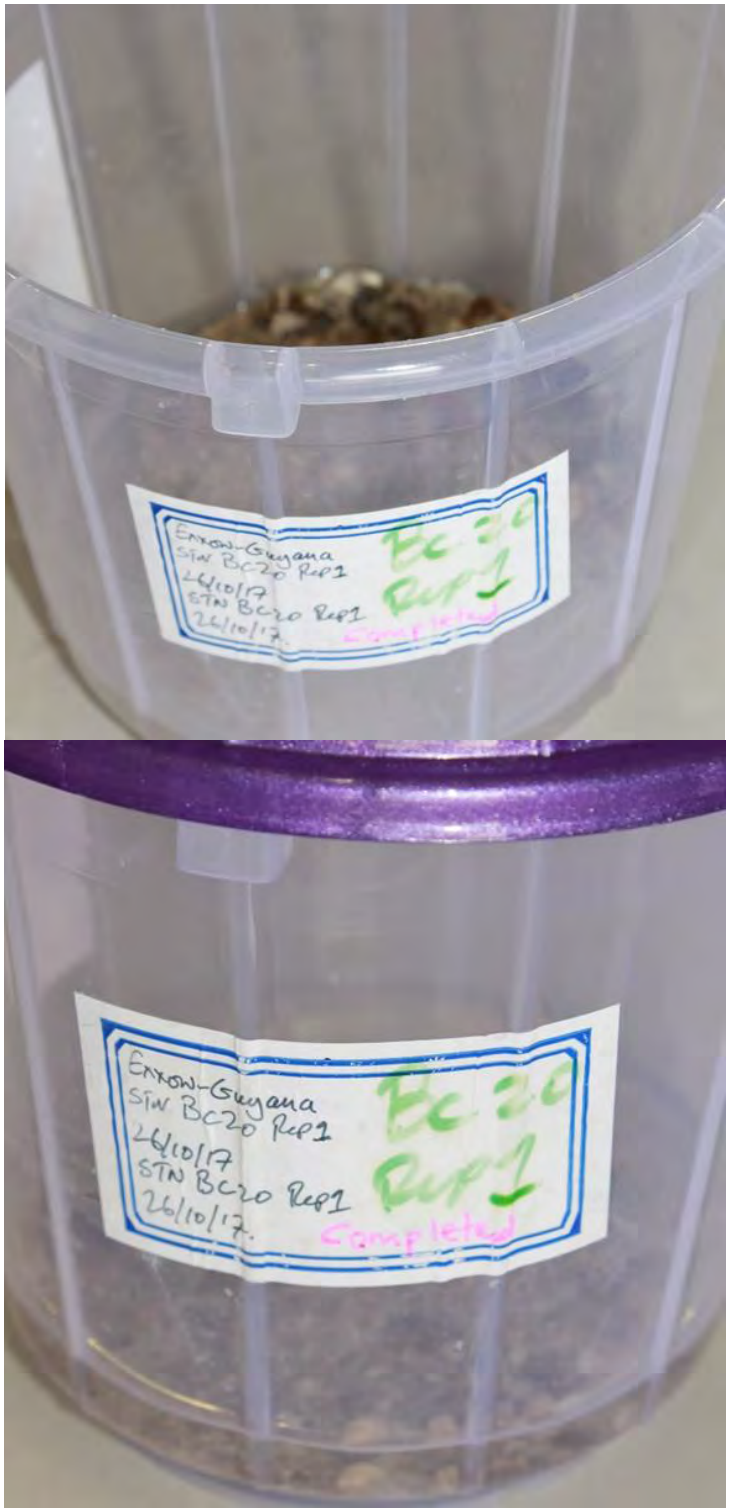
Station 17


Exxon-Guyana
STN BC18 Rep1
26/10/17
STN BC18 Rep1
26/10/17
BC18
Rep1
Food Storage

Station 18


Exxon-Guyana
STN BC 19 Rep2
26/10/17
STN BC19 Rep2
26/10/17.
BC 19
Rep 2

Station 19


Exxon-Guyana
STN BC20 Rep1
24/10/17
STN BC20 Rep1
26/10/17.
Completed

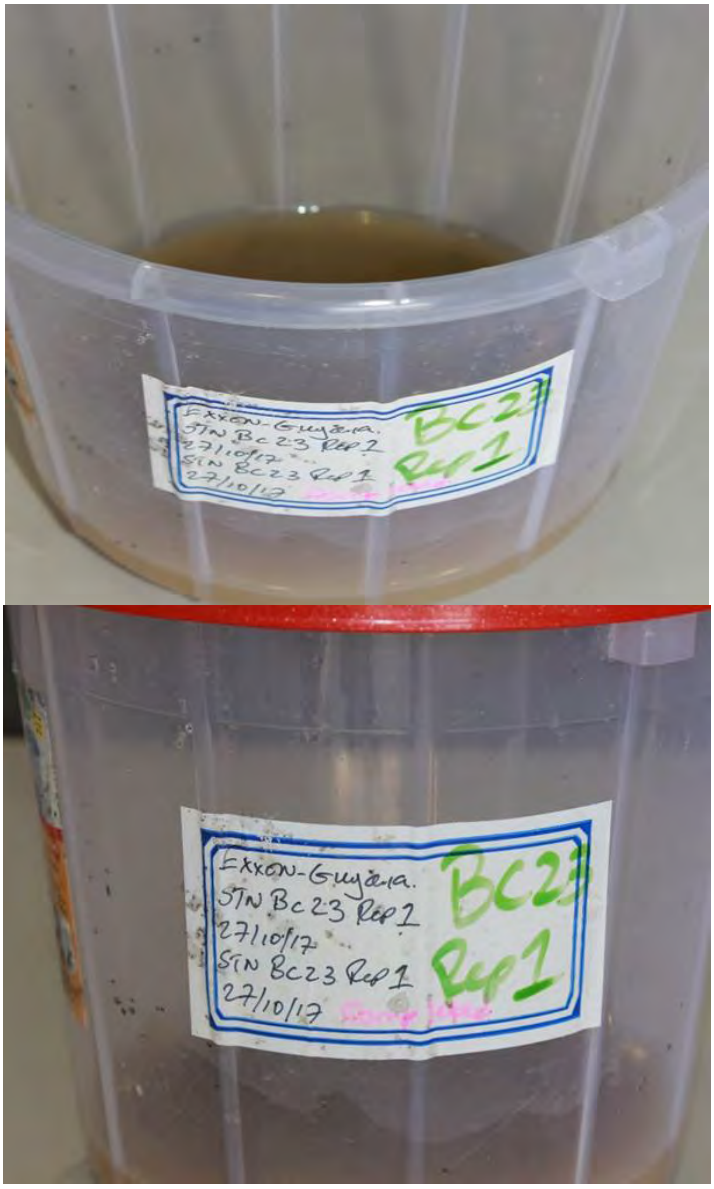
Station 20



Station 21



Station 22


EXXON-Guyana.
STN Bc23 Rep1
27/10/17
STN Bc23 Rep1
27/10/17
BC23
Rep1

Station 23

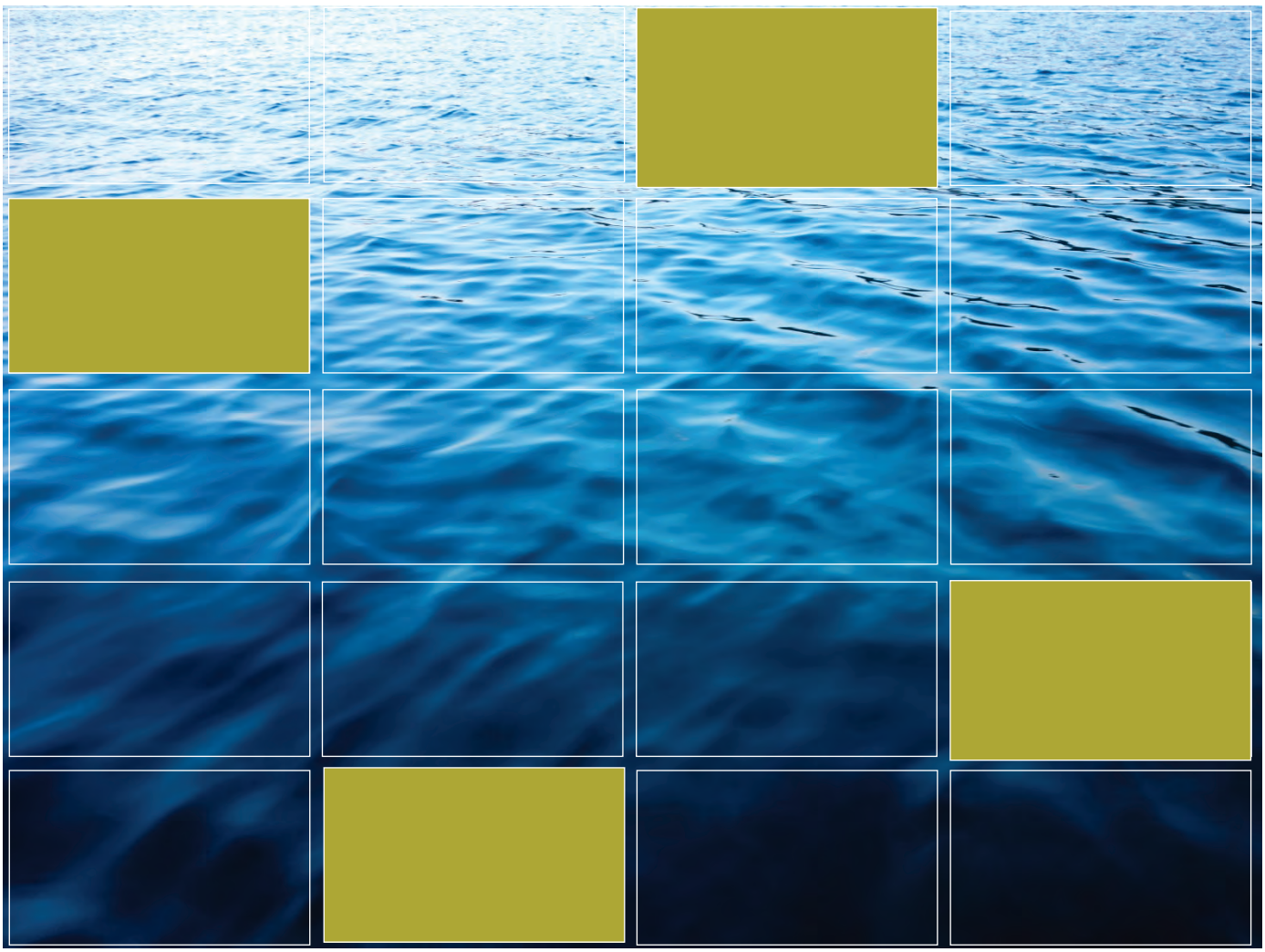


Station 24

APPENDIX J

Water Quality Modeling Report

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Water Quality Modeling Report
Liza Phase 2 Development Project

May 2018

The business of sustainability

ERM

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List of Acronyms

°C	degrees Celsius
bbl	barrel
BPD	barrels per day
cm	centimeter
cm/s	centimeters per second
CORMIX	Cornell Mixing Zone Expert System
EEPGL	Esso Exploration and Production Guyana Limited
EPA	Guyana Environmental Protection Agency
ERM	Environmental Resources Management
FPSO	Floating Production, Storage, and Offloading (vessel)
g/m²	grams per square meter
GEBCO	General Bathymetric Chart of the Oceans
GEMSS	Generalized Environmental Modelling System for Surfacewaters
GIFT	Generalized Integrated Fate and Transport
GLLVHT	Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport
HYCOM	HYbrid Coordinate Ocean Model
kBPD	thousand barrels per day
km	kilometer
km²	square kilometers
m/s	meters per second
m²	square meters
MARPOL 73/78	International Convention for the Prevention of Pollution by Ships, 1973, as modified by the Protocol of 1978
mg/L	milligrams per liter
mm	millimeter
NA	not applicable
NADF	non-aqueous drilling fluid
ppg	pounds per gallon
ppm	parts per million
SRU	Sulfate Removal Unit
SURF	Subsea Umbilicals, Risers, and Flowlines
TSS	total suspended solids
USEPA	U.S. Environmental Protection Agency
WBM	water-based mud

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1.0 INTRODUCTION

1.1 Purpose

In support of an Environmental Impact Assessment (EIA) for its proposed Liza Phase 2 Development Project ("Project"), Esso Exploration and Production Guyana Limited (EEPGL) commissioned Environmental Resources Management (ERM) to perform modelling of discharges into the marine environment related to planned drilling and oil production in the Stabroek Petroleum Prospecting License Area offshore Guyana ("Stabroek Block"; Figure 1-1). These models included simulations of drill cuttings and mud deposition, and discharges of cooling water, sulfate removal and potable water process brines, produced water, and hydrotest fluid. Additionally, modeling was performed for a potential unplanned event comprising the hypothetical release of untreated black water from the Project's proposed floating production, storage and offloading vessel (FPSO).

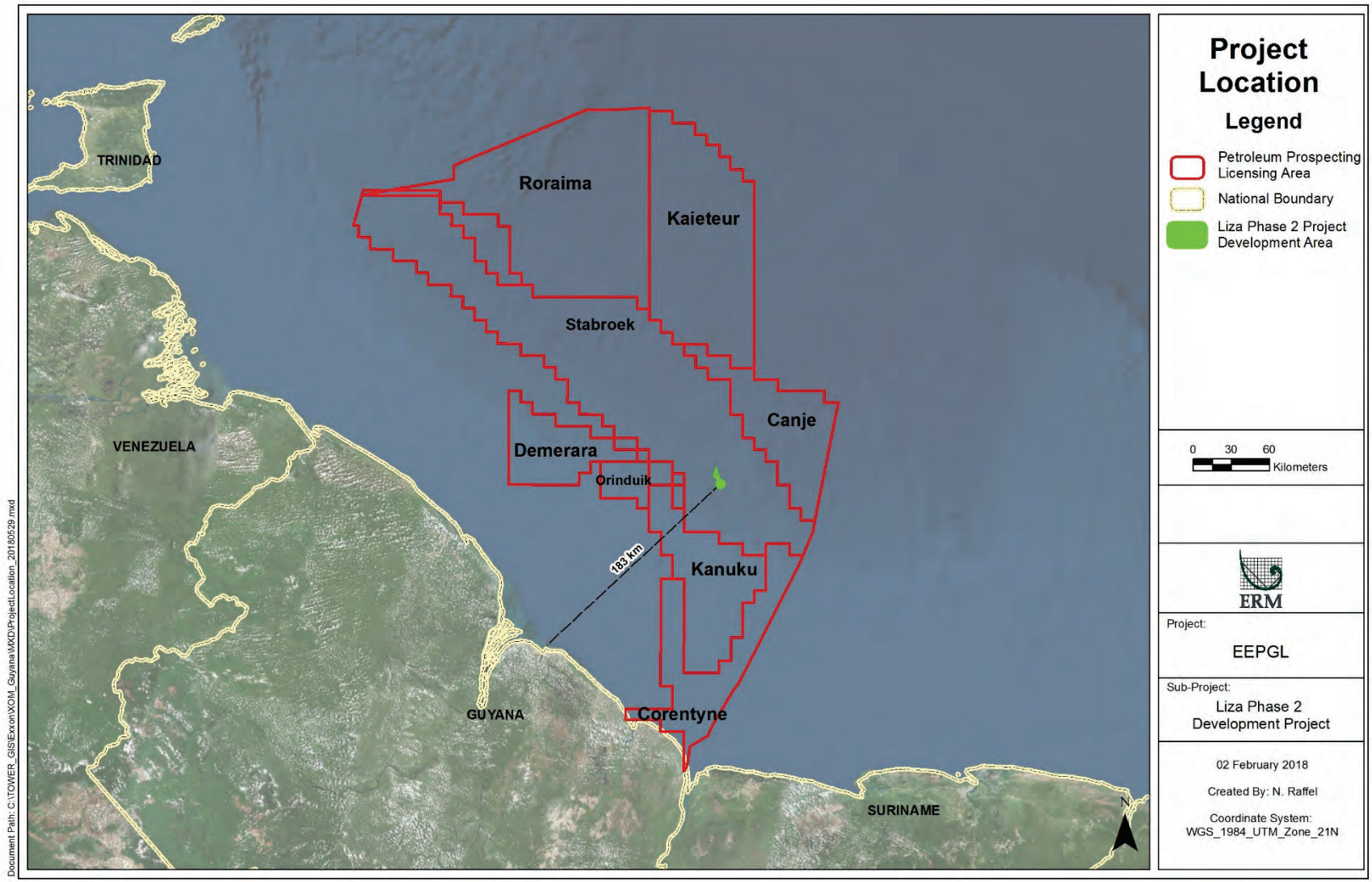
1.2 Scope of Work and Report Organization

This technical report describes the modeling study performed to facilitate assessment of the potential impacts from planned offshore releases and one unplanned offshore release. Section 2 describes modeling performed for planned discharges related to drilling operations and Section 3 describes modeling performed for planned discharges related to production operations, as well as modeling performed for an unplanned release of untreated wastewater (black water) from the Project FPSO. Because the planned activities of the Project will overlap with the planned activities of the Liza Phase 1 Development Project, Section 4 describes modeling performed for the combined (cumulative) activities of these development projects.

Computational models were used to estimate the fate and transport of Project-related discharges. Input data for the modeling were selected based on review of available Project design information, review of oceanographic data from the Project Development Area (PDA) vicinity, and use of conservative assumptions where data were not available.

A separate report describing modeling conducted for unplanned oil spill scenarios is provided as an attachment to the Oil Spill Response Plan prepared in support of EEPGL's offshore activities in Guyana.

Figure 1-1 Stabroek Petroleum Prospecting License Area



2.0 DRILL CUTTINGS AND MUD DEPOSITION MODELING

2.1 Approach

In this study, the discharge of drill cuttings is evaluated. It is assumed that there will be a direct discharge (i.e., near the seabed) of cuttings with water-based drilling fluids during drilling of the riserless open hole section at each well and, for all other well sections, a discharge near the sea surface of cuttings with a small fraction of adhered residual base oil from material removed in the lower well sections after treatment on the FPSO.

Modelling was performed to predict the following as a result of cuttings discharge:

- The total suspended solids (TSS) concentrations in the water column;
- The seabed accumulation (thickness) of the adhered muds and drill cuttings over an area of seafloor (the footprint); and
- The mass of hydrocarbons settled upon the seafloor.

2.1.1 Simulation Design

Released material will pass vertically through the water column because cuttings and muds are denser than the receiving water. Released material will also migrate horizontally due to advection by local and regional currents. The dispersion of cuttings and muds is fundamentally a three-dimensional phenomenon requiring three-dimensional hydrodynamic fate and transport modelling.

Wells will be drilled from four main drill centers, planned as pairs of drill centers at each of two locations (Figure 2-1). A well at each of the drill centers (one production well drill and one injection well) was modeled.

Coordinates of the drill center locations and the depths of water at these locations are presented in Table 2-1.

Figure 2-1 Locations of Planned Phase 2 Drill Centers

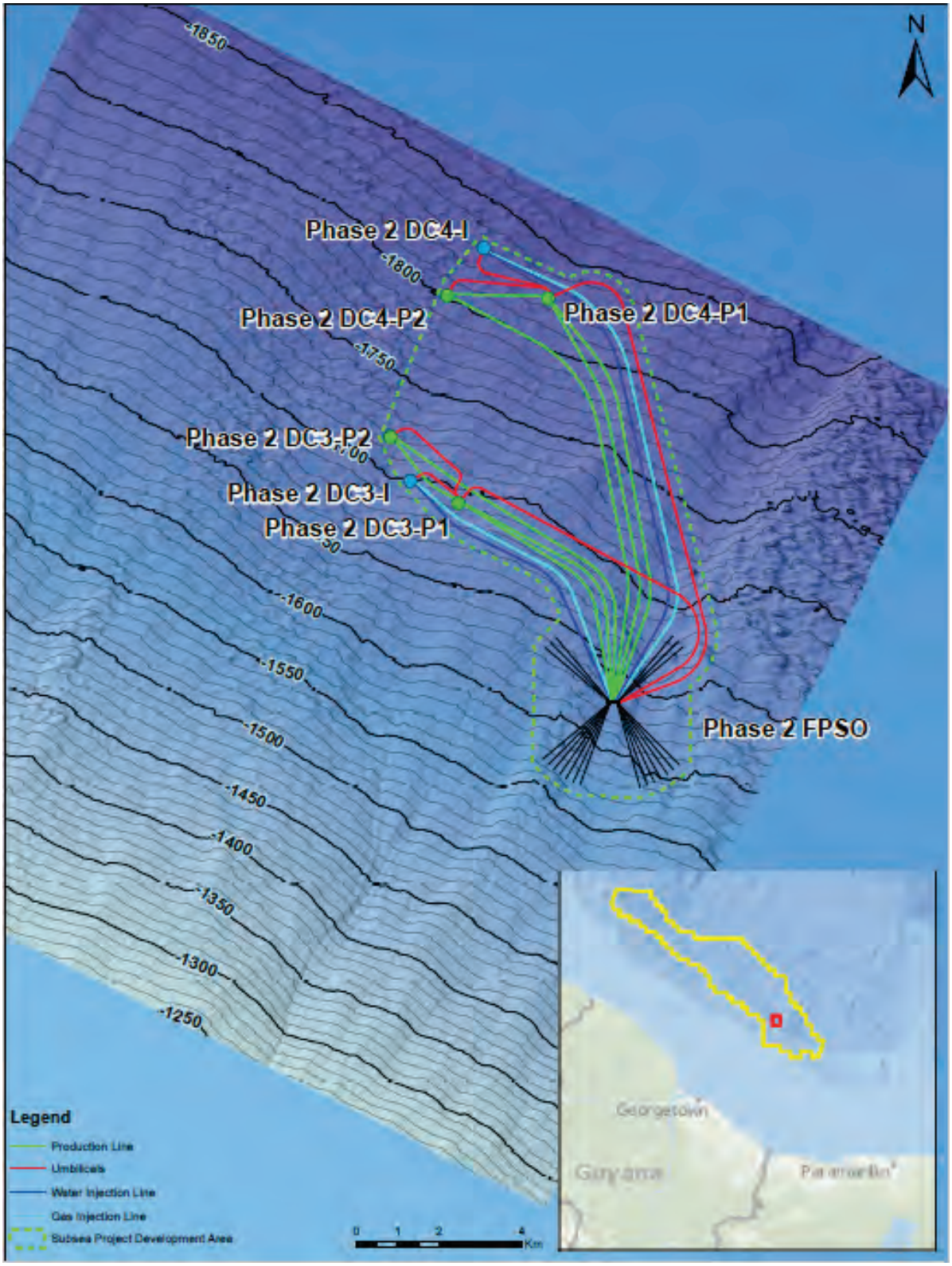


Table 2-1 Drill Center Locations and Water Depths

Drill Center	Longitude (degrees)	Latitude (degrees)	X coordinate in UTM 21N (meters)	Y coordinate in UTM 21N (meters)	Water Depth (meters)
DC3-I	56° 56′ 45.88″	8° 03′ 06.40″	505,941	890,022	1,692
DC3-P1	56° 57′ 32.69″	8° 03′ 44.32″	504,509	891,187	1,680
DC4-I	56° 55′ 40.98″	8° 06′ 20.85″	507,927	895,994	1,845
DC4-P1	56° 56′ 09.76″	8° 07′ 21.15″	507,046	897,846	1,830

At each of these drill centers, the top hole (Section 1) and conductor (Section 2) will be jetted and drilled with water-based muds (WBM) to a depth of 1,219 meters below the mud line. The subsequent three sections (with hole diameters sizes 17.5 inches and 12.25 inches followed by a hole 8.5 inches by 9.875 inches) will be drilled with non-aqueous drilling fluid (NADF) until a total depth is reached at approximately 6,816.2-meters below the mud line. Details of these sections are presented in Table 2-2.

The discharge pipe from the drill platform will release treated cuttings at a depth of 11 meters below mean sea level.

Table 2-2 Well Profile

Section	Diameter (inches)	Well Interval (meters)
Section 1 – Structural (Top Hole, Jet)	36	87
Section 2 – Conductor	26	1,132
Section 3 – Surface	17 ½	1,751
Section 4 – Production	12 ¼	3,292
Section 5 - Open	8 ½ x 9 7/8	554

Three model grids were used: a particle grid, a depositional grid, and a concentration grid.

The movement of the discharged cuttings and muds using Lagrangian particles was computed within the particle grid (Figure 2-2). This particle grid is a square approximately 55 kilometers on each side, with each cell approximately 50 meters by 50 meters. Each grid cell contains an interpolated depth value derived from the bathymetry data described in Section 2.1.3.1. Particles are free to move horizontally and vertically within this grid's domain, independently of the grid, except for movement past the grid boundaries representing the seafloor (as defined by the bathymetry) and shorelines.

For computation of the deposition on the seafloor, the model used a smaller, more finely-spaced two-dimensional (2-D) depositional grid, with each grid centered on a drill center. The depositional grid is a square approximately 20 kilometer on each side. Cell sizes vary in size from 25 meters by 25 meters near the center to 50 meters by 50

meters at the edge of the grid. Figure 2-3 shows the (more tightly spaced) portion of the depositional grid in the vicinity of the FPSO.

The concentration grid, used for computation of TSS concentrations in the water column, is three-dimensional, with the same horizontal dimensions as the depositional grid. Vertically, the cells are 10 meters thick at the surface and bottom regions, where the maximum suspended solids are predicted to occur. The cell thicknesses expand in size towards the middle of the water column region.

A summary of the dimensions of these grids is presented in Table 2-3.

Figure 2-2 Particle Grid

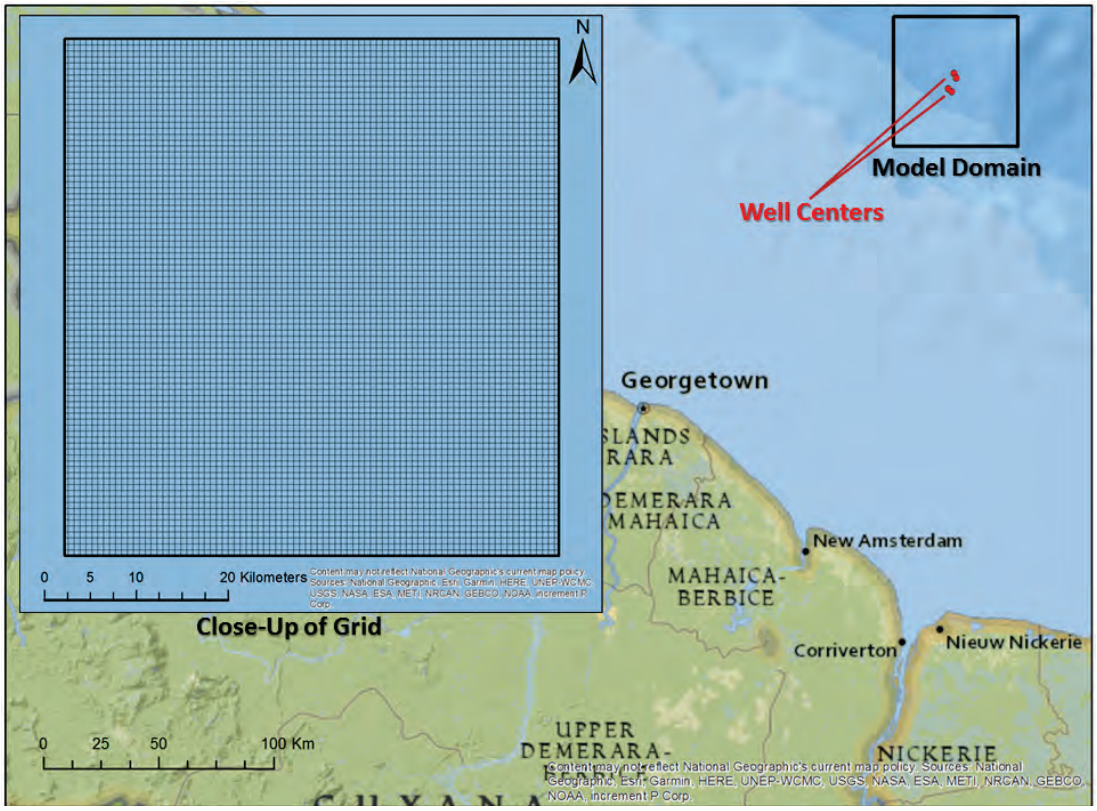


Figure 2-3 Depositional and Concentration Grid

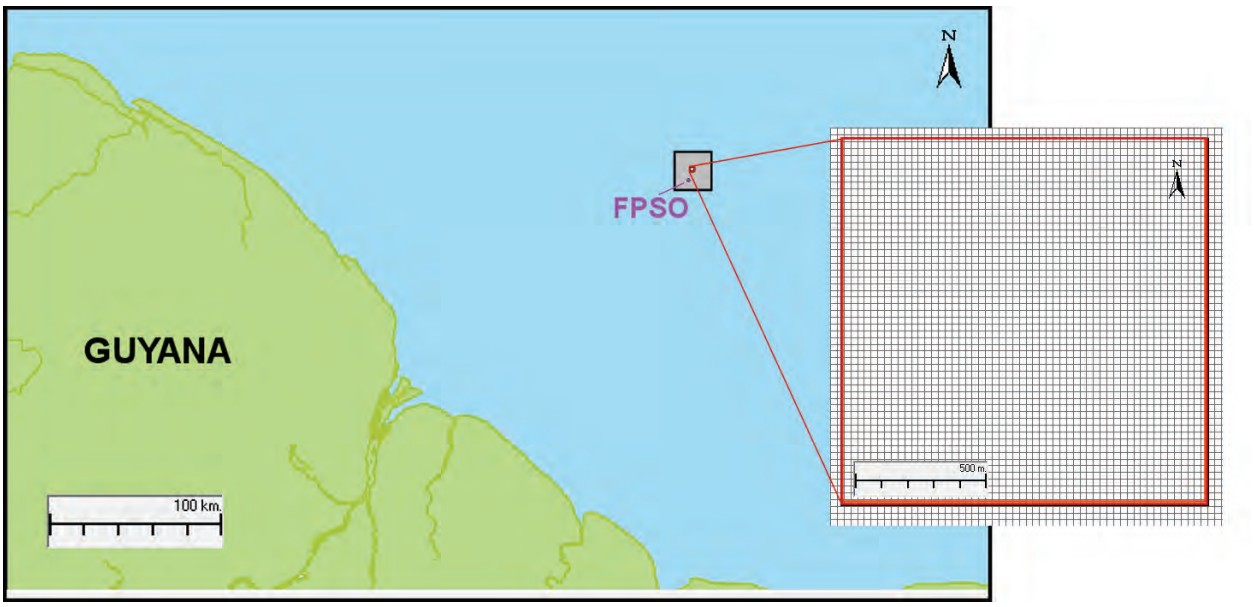


Table 2-3 Grid Dimensions

Grid	Horizontal Dimensions (meters)	Vertical Dimensions
Particle grid	50 x 50	NA
Depositional grid	Variable – smallest 25 x 25 at center	NA
Concentration grid	Variable – smallest 25 x 25 at center	Variable – smallest 10 meters at top and bottom

NA = not applicable

2.1.2 Drill Cuttings and Mud Deposition Software

The modelling was performed using the software package GEMSS® (Generalized Environmental Modelling System for Surfacewaters) and its drill cuttings and muds discharge module, GIFT (Generalized Integrated Fate and Transport) (Kolluru and Spaulding 1993; Kolluru, et al. 1998; Fichera and Kolluru 2007; Fichera et al. 2013; Prakash and Kolluru 2014). GIFT can simulate the fate of dissolved and particulate material discharged from a range of sources, including drill cuttings and muds and produced water. This three-dimensional particle-based model uses Lagrangian algorithms in conjunction with currents, specified mass load rates, release times and locations, particle sizes, settling velocities, and shear stress values. The modelling methodology is based on a deterministic mode of simulation. In deterministic, single event simulations, the starting date and current speed and direction at each time step are chosen from a database of properties in the selected periods.

Drill cuttings and muds were modeled as particles. Movement in the vertical direction resulted in the settling and deposition of cuttings on the seabed. The combined action of erosion and deposition, based on particle size distribution and the intensity of release, results in the predicted net accumulation of drill cuttings on the seabed.

Modelling data inputs included:

- Drill section sizes and schedule;
- Drilling mud types;
- Cuttings and mud grain size distribution;
- Mud and cuttings densities; and
- Mud and cuttings release rates, durations, and discharge depths.

2.1.3 Environmental Data

Model inputs were assembled and formatted for use with GIFT. The environmental data used by the model included bathymetry, ocean current, water temperature and salinity data. Spatially and temporally varying oceanic data were collected to characterize the area in which the discharges will occur and determine appropriate simulation periods to represent the range of potential results (see Section 6.4.2, Existing Conditions – Water Quality).

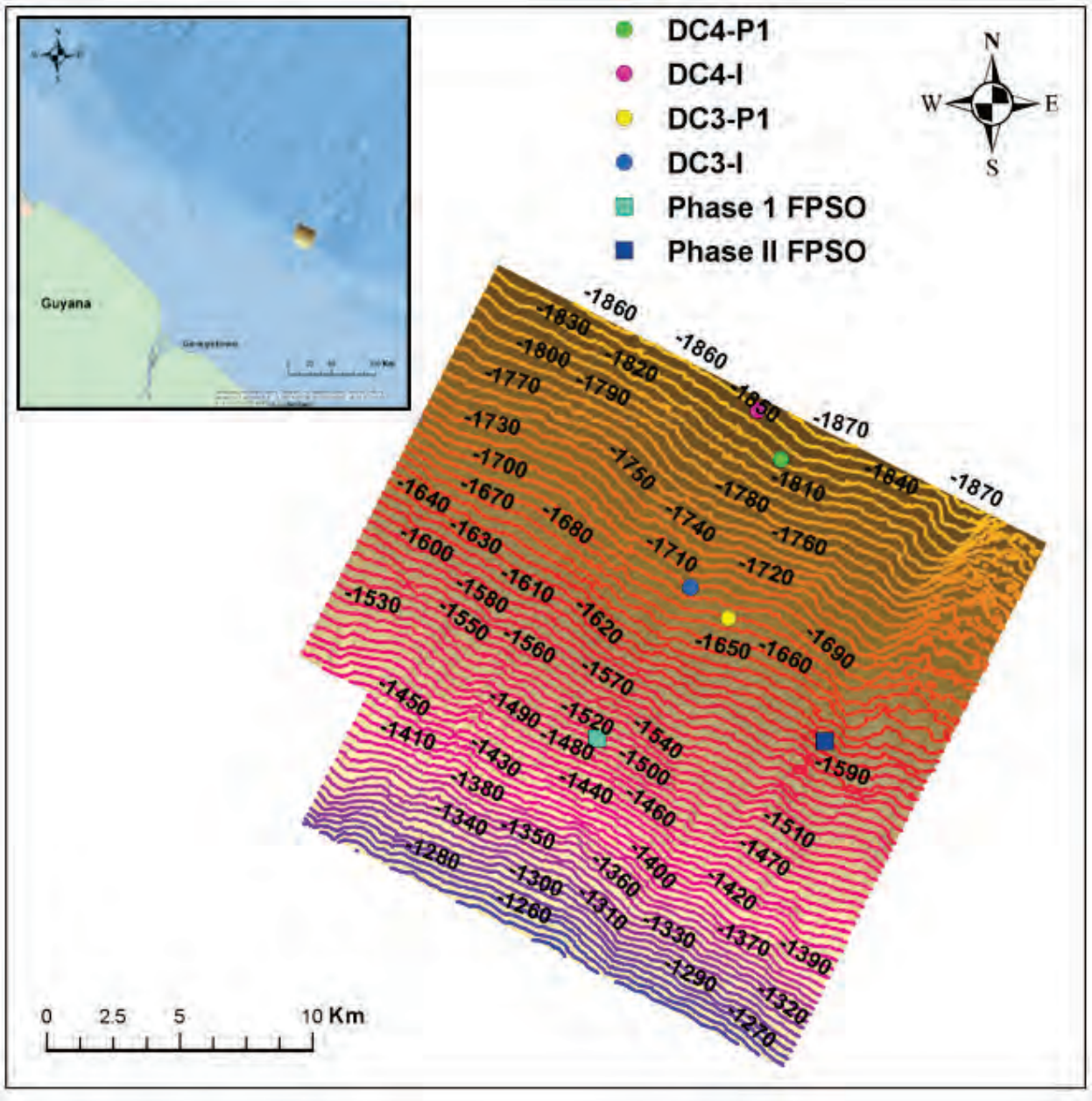
2.1.3.1 Bathymetry

The primary spatial dataset is the bathymetry data, used to describe the depth and shape of the seafloor. Bathymetry data are used to develop the shape and depth of the lower boundary of the modelling grids. Two datasets were used. The primary source of bathymetry was the 2016 bathymetric survey performed by Fugro (Fugro 2016). This dataset was provided as a set of depth contour lines covering a region approximately 23 kilometers by 22 kilometers within the Stabroek Block (Figure 2-4).

The bathymetry data provided by Fugro were supplemented by data from the General Bathymetric Chart of the Oceans (GEBCO), a publicly-available source (BODC 2014). Data from this source provided bathymetry values beyond the extent of the Fugro data, toward the north. The database used for this study is the GEBCO_08 Grid which has a 30 arc-second resolution. GEBCO bathymetry offshore Guyana is shown in Figure 2-5.

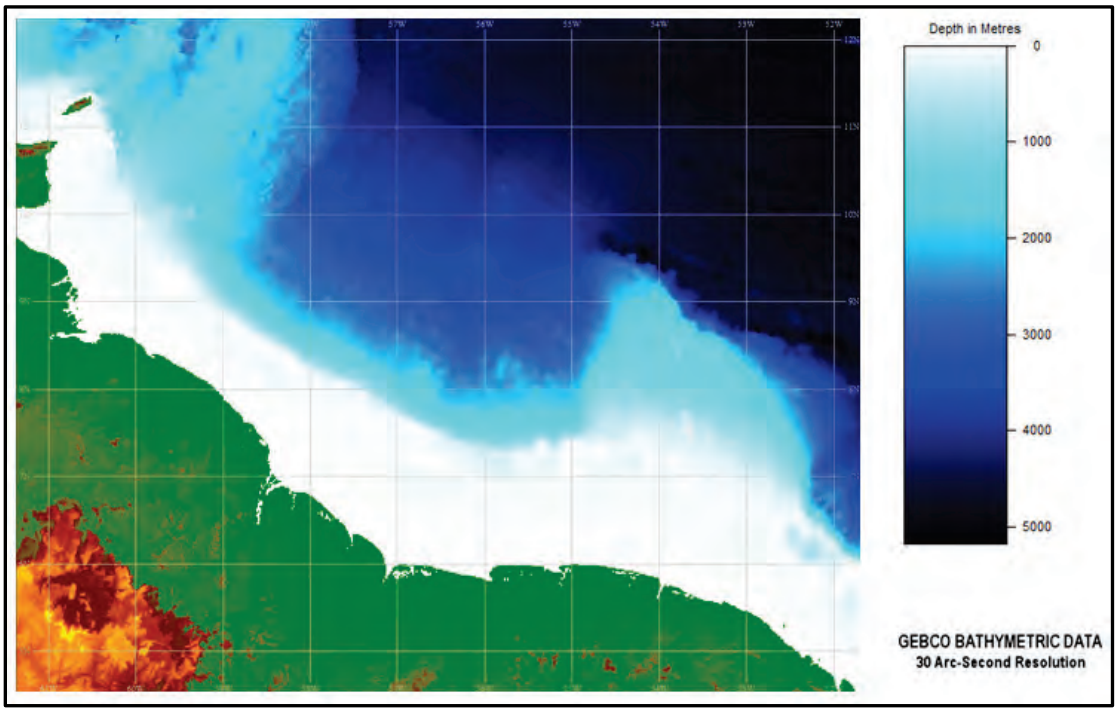
A polyline shapefile of the Guyana coastline was used as a boundary in the model domain between land and water. The coastlines were obtained from Esri's World Boundaries and Places Alternate product.

Figure 2-4 Bathymetry Data



Source: Fugro 2016

Figure 2-5 GEBCO Bathymetry Data Offshore Guyana



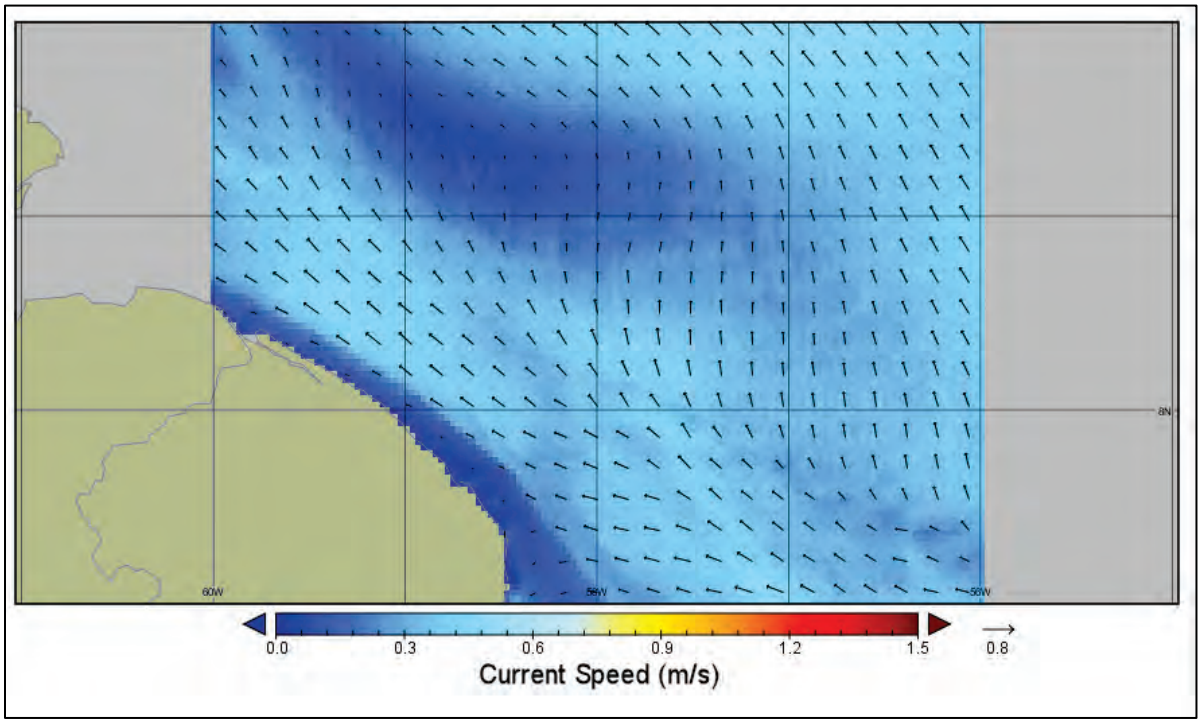
2.1.3.2 *Time Varying Data: Ocean Current, Temperature and Salinity Data*

The time-varying data used for the drill cuttings deposition modelling included ocean current speed and direction, water temperature, and salinity. Deposition modelling requires time-varying currents on a three-dimensional grid. Hourly depth-varying and spatially-varying currents were obtained from ExxonMobil Upstream Research Company using the SAT-OCEAN model combined with currents from the HYbrid Coordinate Ocean Model (HYCOM) global ocean circulation hindcast model (hycom.org). Currents were obtained every three hours from 2005 through 2014. The model extended from 56° W to 58° W longitude and 7°N to 11°N latitude over 128 by 128 grid cells and 22 depth bins at 0, 5, 10, 20, 30, 40, 50, 75, 100, 125, 150, 200, 300, 400, 500, 1000, 1500, 2000, 2500, 3000, 3500, and 4000-meter depths. Depth-varying temperature and salinity values were obtained directly from HYCOM model output.

Monthly-averaged, depth-averaged current speeds were computed across the 2005 to 2014 period of record. Through a statistical analysis of these current speeds at the well locations, the months with the minimum and maximum average current speeds were determined. Modelling was performed assuming drill cuttings deposition occurs starting on the first day of these two months: March 2006 (maximum speed) and August 2013 (minimum speed). Simulations performed during these two months will provide the extremes of the full range of depositional patterns (i.e., from a larger and thinner footprint when the current speeds are highest to a smaller and thicker footprint when the current speeds are lowest).

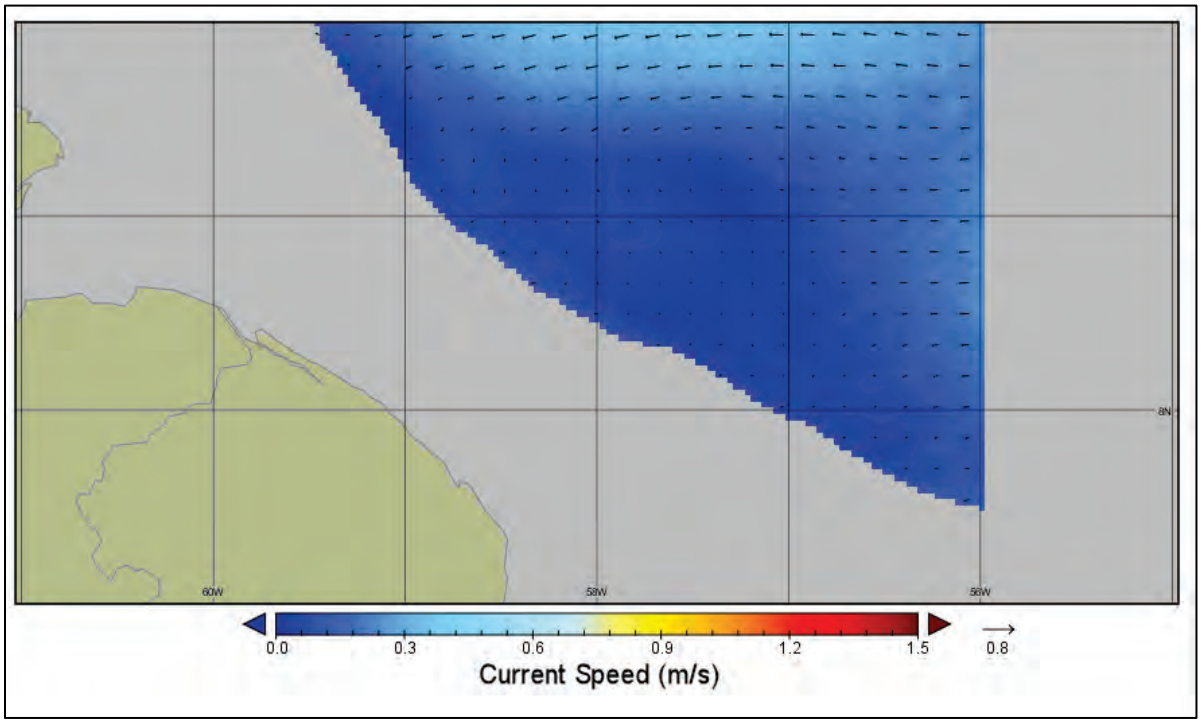
Example current vector plots for March 2006 and August 2013 are shown below in Figure 2-6 and Figure 2-8 (showing current speeds and directions at the sea surface) and in Figure 2-7 and Figure 2-9 (showing current speeds and directions at a depth of 1,000 meters).

Figure 2-6 Example Current Vector Diagram, 1 March 2006 (Surface)



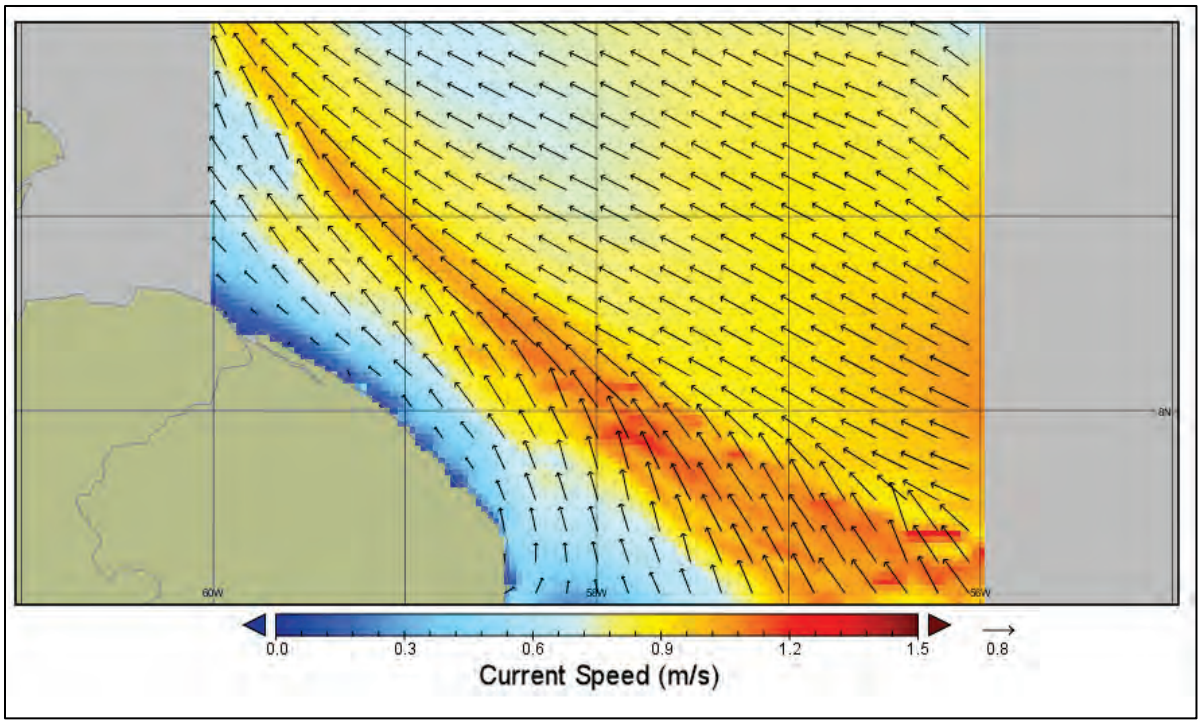
m/s = meters per second

Figure 2-7 Example Current Vector Diagram, 1 March 2006 (1,000-meter Depth)



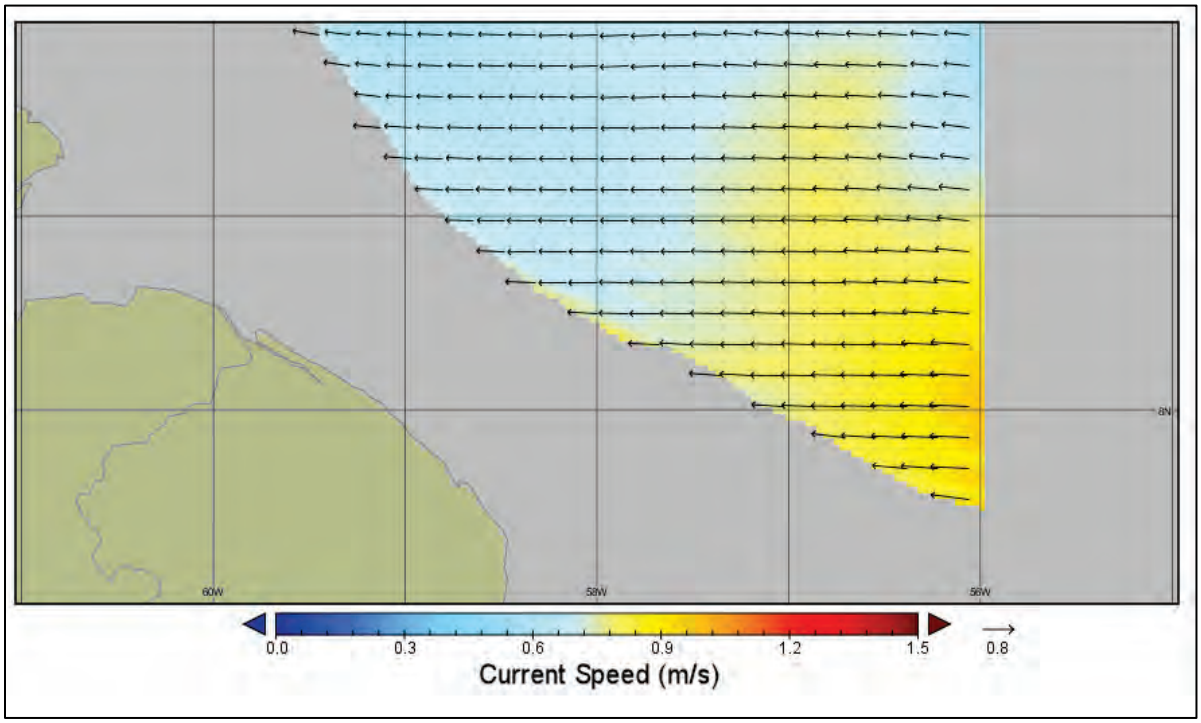
m/s = meters per second

Figure 2-8 Example Current Vector Diagram, 1 August 2013 (Surface)



m/s = meters per second

Figure 2-9 Example Current Vector Diagram, 1 August 2013 (1,000-meter Depth)



m/s = meters per second

2.1.3.3 *Drill cuttings and mud volumes and properties*

Estimated quantities of drill cuttings and fluids to be discharged during drilling are provided in Table 2-4. The estimated times to drill each section were provided by EEPGL. For the top hole sections, only WBM are expected to be used. The volume of WBM discharged in Sections 1 and 2 are 5-times and 8-times the volume of the drill cuttings, respectively. In the subsequent sections, the cuttings with a small percentage of adhered non-aqueous muds will be discharged at a depth of 11 meters below sea level. No non-aqueous drilling muds will be directly discharged (i.e., before treatment). Solids control and cuttings drying equipment will be installed on the drill ships to process and reduce the percentage of NABF retained on cuttings, such that NABF retained on discharged cuttings will not exceed 6.9 percent (by mass) on average. Accordingly, the modeling assumed an NABF content of 6.9 percent by mass for all discharged cuttings.

Table 2-4 Discharge Description

Hole Diameter (inches)	Volume of Cuttings Discharged (bbl)	Volume of Drilling Fluid to be Discharged (bbl)	Type of Drilling Fluid	Estimated Drilling Duration (days)
36	359	1,797	WBM	0.5
26	2,830	22,636	WBM	1.5
17 ½	1,709	284	NADF	3
12 ¼	1,574	262	NADF	6
8 ½ x 9 7/8	159	26	NADF	4
TOTAL	6,632	25,006	-	15

bbl = barrel

Though the actual drilling of the well may take longer to complete, the model simulation of the discharges to the sea was run for 23 days, assuming only 15 days of continuous drilling time for the entire well (inclusive of an assumed one-day pause between well sections) and providing another eight days for settling after cessation of discharges. This provided for a conservative estimate of predicted TSS concentrations.

2.1.3.4 *Cuttings and Mud Properties*

The grain size properties of the drill cuttings and muds were provided by EEPGL. The distribution of particle sizes and associated fall velocities used in this study are listed in for cuttings discharged from Section 1 and 2, in Table 2-6 for WBM and in Table 2-7 for treated cuttings with NADF discharged from Sections 3 through 5. Cuttings density was assumed to be 2.6 kilograms per liter. The WBM density was assumed to be 11 pounds per gallon (ppg). The density of NADF was reported by EEPGL to range between 9 and 13.2 ppg; 9 ppg was used for a conservative assumption since it would result in slower settling and a larger footprint of deposition.

Table 2-5 Properties of Cuttings for Well Sections 1 and 2 (Water-Based Fluid)

Estimated Diameter (cm)	Mass Fraction (Wt %)	Fall Velocity (cm/s)
0.00005	2	0.00003
0.0001	3	0.0001
0.0002	5	0.0003
0.0006	10	0.0046
0.0007	10	0.0695
0.0059	20	0.4460
0.0363	20	1.8300
0.1350	10	6.9300
0.3730	10	14.3000
0.6680	5	19.8000
0.9510	3	23.4000
1.2200	2	26.1000

cm = centimeter; cm/s = centimeters per second

Table 2-6 WBM Grain-Size Distribution

Estimated Diameter (cm)	Mass Fraction (Wt %)	Fall Velocity (cm/s)
0.0005	7	0.0027
0.0007	8	0.0061
0.0011	5	0.0148
0.0015	10	0.0300
0.0018	13.3	0.0434
0.0020	13.3	0.0511
0.0007	19.2	0.0640
0.0008	19.2	0.0823
0.0058	4	0.4270
0.0250	1	1.1200

cm = centimeter; cm/s = centimeters per second

Table 2-7 Properties of Treated Cuttings for Well Sections 3-5 (with Adhered NADF)

Estimated Diameter (cm)	Mass Fraction (Wt %)	Fall Velocity (cm/s)
0.001	43	0.02
0.01	1.01	0.20
0.04	4.99	2.00
0.16	5.55	8.00
0.36	7.99	14.00
0.62	10.99	19.00
0.83	13.01	21.99
1.00	6.81	23.99
1.32	3.69	26.99
1.89	2.47	30.97
*	0.49	124.97

cm = centimeter; cm/s = centimeters per second

* Fall velocity outside the range of available correlations; size computed internally by GIFT model[1]

2.2 Scenarios

Modelling was performed for eight scenarios: for a well at each of four drill centers (DC3-I, DC3-P1, DC4-I and DC4-P1), for the minimum and maximum of the monthly-averaged, depth-averaged current speeds (Table 2-8). The water depth at the four drill centers varied between 1,680 meters at DC3-P1 and 1,845 meters at DC4-I. The same drilling and mud discharge schedule described in Table 2-4 was assumed at all wells.

[1] Fall velocities were based on experiments. These velocities were directly used in the GIFT model to estimate settlement. Estimated diameter sizes are only for reference and do not affect GIFT computations.

Table 2-8 Drill Cuttings and Fluid Deposition Scenarios

Drill Center	Scenario Name	Ambient Current Scenario	Water Depth (meters)
DC3-I	1a	Minimum Monthly Avg.	1,692
	1b	Maximum Monthly Avg.	
DC3-P1	2a	Minimum Monthly Avg.	1,680
	2b	Maximum Monthly Avg.	
DC4-I	3a	Minimum Monthly Avg.	1,845
	3b	Maximum Monthly Avg.	
DC4-P1	4a	Minimum Monthly Avg.	1,830
	4b	Maximum Monthly Avg.	

These scenarios provide predicted cuttings depositional thickness on the seabed on a two-dimensional basis, TSS concentrations in the water column on a three-dimensional basis, and mass of deposited hydrocarbons on a 2-dimensional basis.

2.2.1 Cuttings Depositional Thickness

Burial by drilling muds and cuttings may cause physical impacts upon benthic communities on the seabed. The potential severity of burial impacts depends on the sensitivity of the benthic organism, the thickness of deposition, the amount of oxygen depleting material, and the duration of the burial. Thickness thresholds vary by species and sediment impermeability. A suggested threshold deposition rate of 5 centimeters per month is recommended based on publications by Ellis and Heim (1985) and MarLIN (2011). Smaller threshold values as low as 1 millimeter have been reported (e.g., Smit et al. 2006); however, they are associated with instantaneous burials on benthic species, not gradual smothering effects. Accordingly, for the purpose of modeling, results are presented in terms of the lateral extent of deposition exceeding 5 centimeters in thickness.

2.2.2 Total Suspended Solids

Increases in TSS concentrations in the water column will occur due to discharges of drill cuttings and mud. The highest concentration increases will occur at the point of discharge (i.e., at the seafloor for top sections of the well and near the surface for subsequent sections of the well), and will decrease over time and distance as the TSS plume dissipates and settles. Larger particles will settle out more quickly than finer particles, such that smaller particles may stay suspended longer and travel further than larger particles. As such, elevated TSS concentrations may form in regions where tiny suspended particles linger in a cloud and mix with particles from subsequent discharges.

Impacts on marine organisms related to elevated TSS may occur if light penetration in photic zones is impeded significantly for long periods of time (reducing the ability of plants and phytoplankton to photosynthesize). Increases in TSS may also decrease water clarity and clog fish gills. A commonly used guidance value for TSS effluent

discharges in the marine environment recommended by MARPOL 73/78[2] is 35 milligrams per liter (mg/L) (IMO 2006). Accordingly, for the purpose of modeling, results are presented in terms of the lateral area with TSS concentrations exceeding 35 mg/L.

2.3 Mass of Oil Deposition

Cuttings containing NADF will be treated through the FPSO on-board systems (shakers and dryers). The non-aqueous base fluid portion of the NADF that remains will be reduced to no more than 6.9 percent base fluid retention on cuttings (average, by mass). These hydrocarbons, once settled to the seafloor, can degrade over time, and may enter the pore water within the sediments or become dissolved in the water column, depending on each specific hydrocarbon's tendency to remain partitioned to the solids.

2.4 Results

The results of the modelling are illustrated in the following sections as contour plots. The plots presented indicate the location of the drill cuttings release point. Results are presented for each of the following parameters:

- Cuttings deposition thickness at the end of the simulation;
- Maximum TSS concentration in the water column at any time in the simulation (at the surface and at the bottom, representing the surface and seabed discharges, respectively); and
- Mass of hydrocarbons per unit area deposited on the seafloor.

As discussed above, the following threshold criteria were applied for the purpose of reporting results:

- Criterion 1 – Cuttings deposition rate less than 5 centimeters per month ; and
- Criterion 2 - Recommended TSS concentrations no greater than 35 mg/L.

There are no available criteria applicable for the mass of hydrocarbons deposited on the seafloor.

2.4.1 Cuttings Depositional Thickness

When the first two sections are jetted and drilled before the riser is installed, cuttings and WBMs are discharged directly to the seabed, resulting in a mound of material deposited around the well.

The material discharged at the seabed is deposited in the area directly adjacent to the well head and results in the thickest layers of deposited material. For DC4-I and DC4-P1, results indicate a footprint of cuttings with the majority of the depositional thickness greater than 1 millimeter concentrated in a 0.5-kilometer radius from the drill centers.

[2] International Convention for the Prevention of Pollution by Ships, 1973, as modified by the Protocol of 1978

For DC3-I and DC3-P1, higher thicknesses are also concentrated around the drill center, but discontinuous patches of depositional thicknesses greater than 1 millimeter are present within a 5-kilometer radius of the drill centers. In all scenarios, a small region close to the well exceeded the depositional thickness threshold value of 50 millimeters (5 centimeters). Releases from near the seafloor at DC4 were predicted to travel a shorter distance, and therefore result in a smaller depositional footprint near DC4 than at DC3, because the bulk of the deposition results from near-seafloor releases and modeled currents near the seafloor at DC4 were slower than the modeled currents near the seafloor at DC3.

The lateral extent of thicknesses exceeding this value ranged from roughly a 28-meter to 62-meter radius around the drill center. The maximum thickness predicted was 983 millimeters (Scenario 2a: DC3-P1 minimum currents), but slope failure (i.e., collapse of the depositional mound) and resuspension of the particles are likely to reduce the height of this thickness of deposited materials over time.

Figures 2-10 through 2-17 present the predicted distribution of depositional thicknesses at the time when the maximum thickness is accumulated on the ocean floor during the 23 day simulation period. The model simulates releases over 15 days, and then continues to track settling for another 8 after cessation of discharges. Additionally, the model includes a re-suspension function to simulate the natural process of re-suspension. The results presented reflect the maximum deposited thickness for each location at any one time over the 23 day simulation (which would not happen at the same time at all locations). Usually, the maximum thickness and the largest area above 1 millimeter thickness occur soon after the first two sections are drilled, where drill cuttings and mud are discharged near the ocean floor. Maximum thickness and the area above 1 millimeter thickness may reduce with time due to the resuspension of deposited materials as a result of ocean currents.

The maximum depositional thicknesses predicted by the model ranged from 98.3 centimeters in Scenario 2a (at Well DC3-P1 with minimum currents) to 16.2 centimeters in Scenario 3a (at Well DC4-I with minimum currents).

In Scenario 2a, the maximum thickness of 98.3 centimeters was located in the immediate vicinity of the drill center. Parsing the data, jetting and top hole drilling contributed most of the deposited thickness (98.0 centimeters of the ultimate thickness of 98.3 centimeters). At the end of the simulation period (23 days), the majority of the depositions within the model domain were 1 centimeter thick or less (99.82 percent of the deposited area[3]).

[3] Region where any incremental deposition occurs regardless of the magnitude

In Scenario 3a, the maximum thickness of 16.2 centimeters was also located in the immediate vicinity of the drill center. Parsing the data, jetting and top hole drilling contributed all of the deposited thickness (16.2 centimeters of the ultimate thickness of 16.2 centimeters). At the end of the simulation period (23 days), the majority of the depositions within the model domain were 1-centimeter thick or less (99.5 percent of the deposited area).

Table 2-9 Summary of Results – Cuttings Depositional Thickness

Scenario	Maximum Depositional Thickness (cm)	Area (m^2) with Thickness > 5 cm threshold
1a DC3-I Min Currents	58.5	5,961
1b DC3-I Max Currents	20.5	3,210
2a DC3-P1 Min Currents	98.3	7,386
2b DC3-P1 Max Currents	25.2	6,347
3a DC4-I Min Currents	16.2	1,468
3b DC4-I Max Currents	17.3	1,759
4a DC4-P1 Min Currents	20.8	1,483
4b DC4-P1 Max Currents	19.1	1,773

m^2 = square meters; cm = centimeter

Figure 2-10 Maximum Depositional Thickness—Scenario 1a DC3-I Minimum Currents

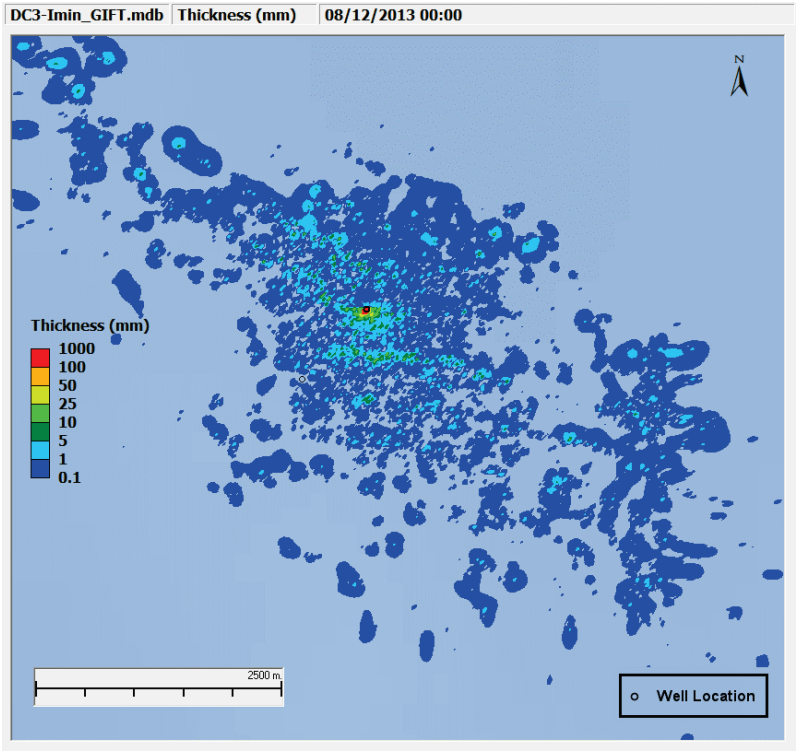


Figure 2-11 Maximum Depositional Thickness—Scenario 1b DC3-I Maximum Currents

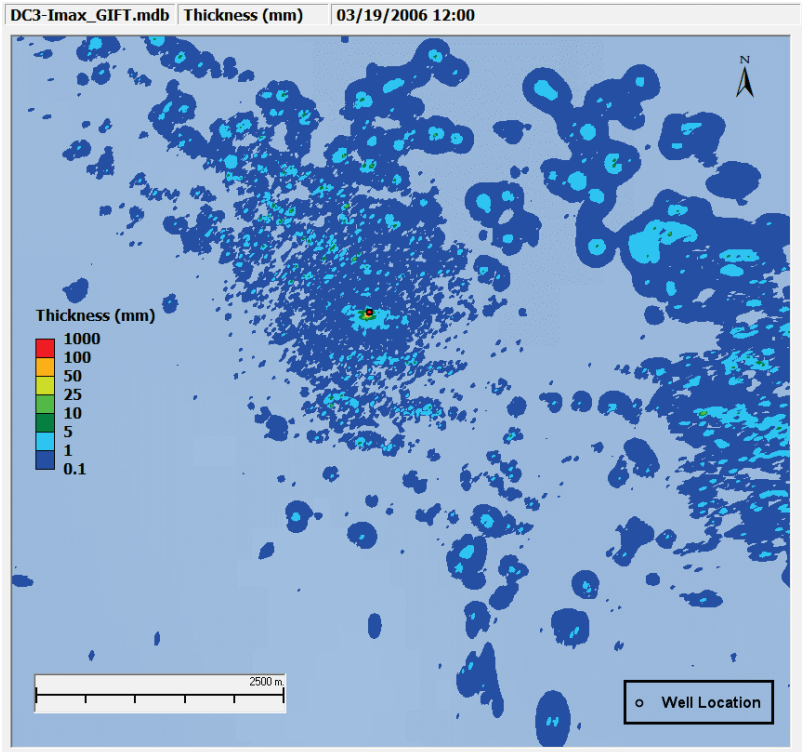


Figure 2-12 Maximum Depositional Thickness—Scenario 2a DC3-P1 Minimum Currents

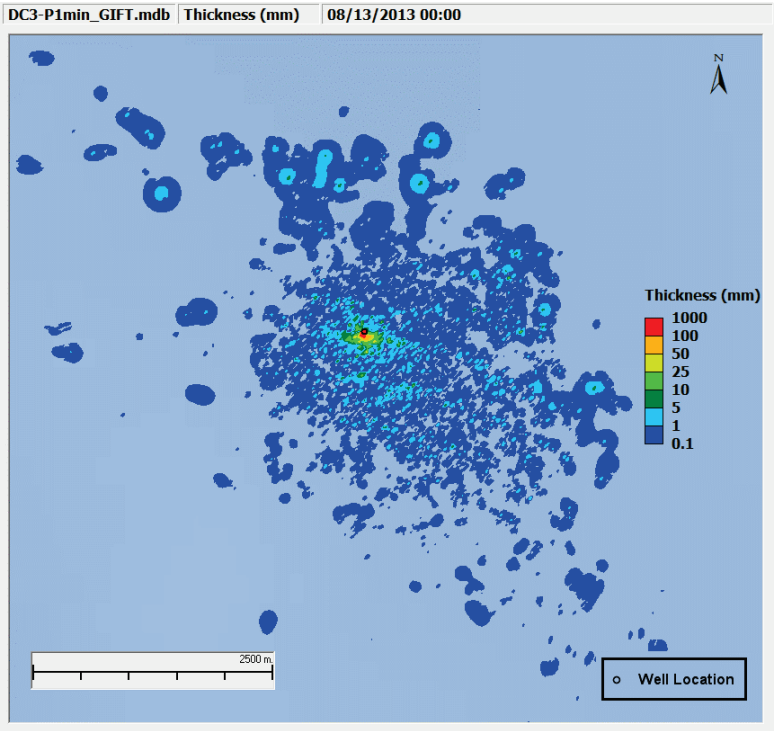


Figure 2-13 Maximum Depositional Thickness—Scenario 2b DC3-P1 Maximum Currents

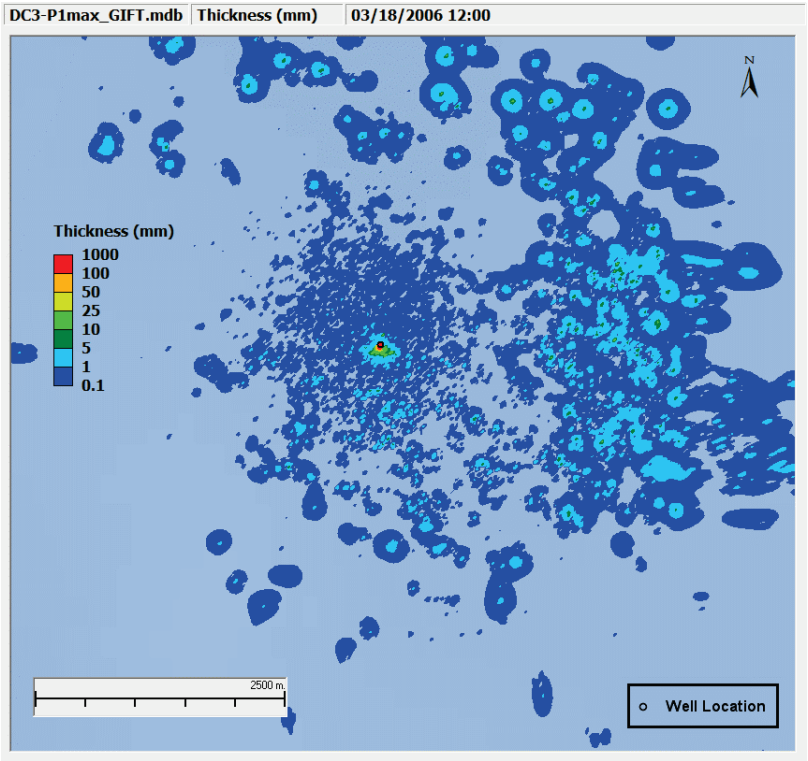


Figure 2-14 Maximum Depositional Thickness—Scenario 3a DC4-I Minimum Currents

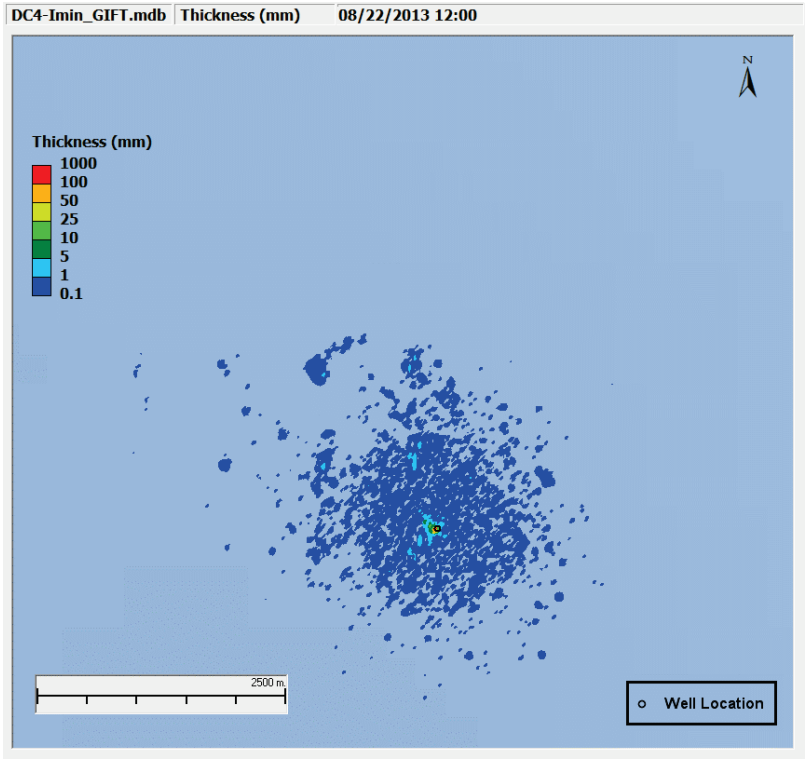


Figure 2-15 Maximum Depositional Thickness—Scenario 3b DC4-I Maximum Currents

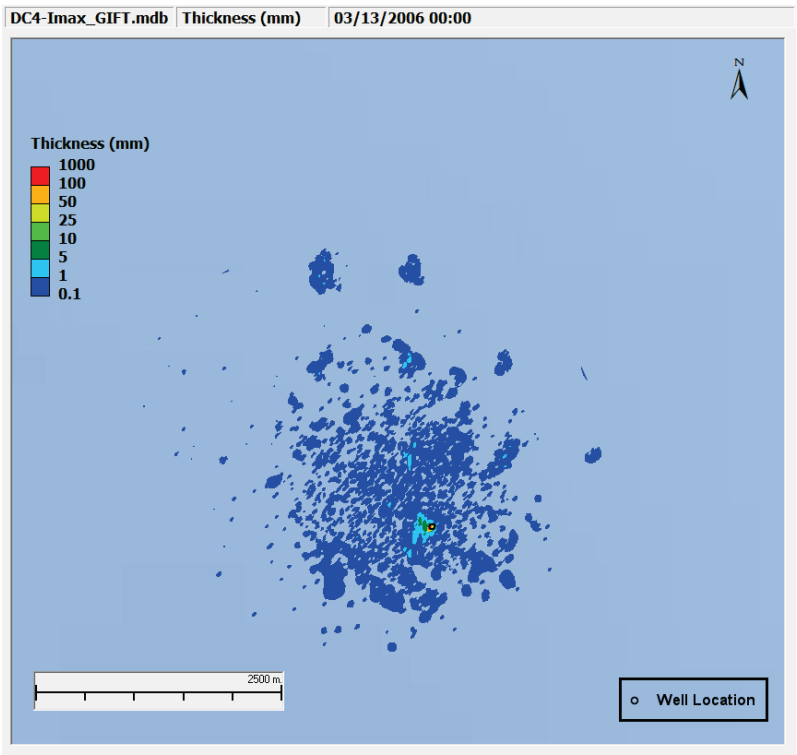


Figure 2-16 Maximum Depositional Thickness—Scenario 4a DC4-P1 Minimum Currents

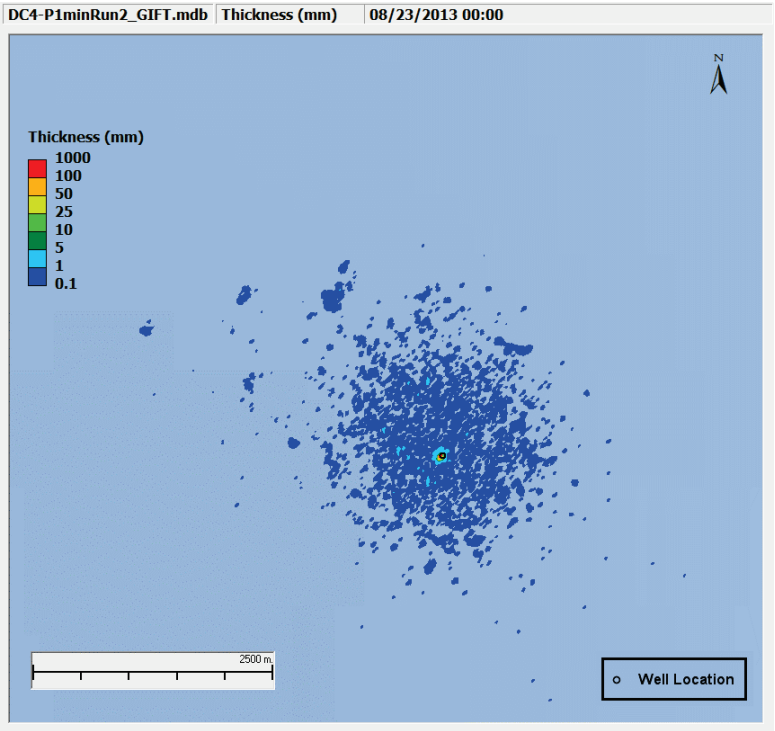
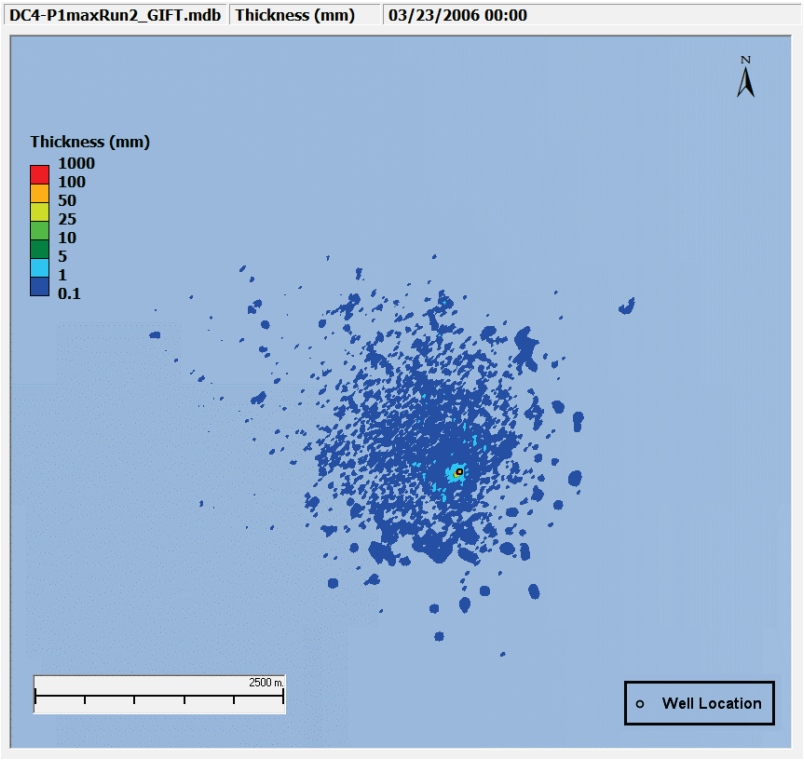


Figure 2-17 Maximum Depositional Thickness—Scenario 4b DC4-P1 Maximum Currents



2.4.2 Total Suspended Solids

Figures 2-18 through 2-33 present the predicted TSS concentrations added above ambient levels at the time when the maximum Project-generated TSS concentration occurs. A separate "maximum" event was captured for near-surface concentrations (correlating with near-surface discharge) and near-seabed concentrations (correlating with direct discharge at the seabed).

The maximum TSS concentration added above ambient as a result of surface discharges ranged from 3.1 mg/L in Scenario 3b (at DC4-I with maximum currents) to 14.1 mg/L in Scenario 1b (at Well DC3-I with maximum currents). The 35 mg/L threshold is not predicted to be exceeded for any of the near-surface discharges, where inhibition of photosynthesis (a factor relevant to the 35 mg/L threshold) would be a concern.

The TSS concentration added above ambient as a result of near seafloor discharges ranged from 5,783 mg/L in Scenario 2a (at Well DC3-P1 with minimum currents) to 41,055 mg/L in Scenario 4a (at Well DC4-P1 with minimum currents). At the sea floor, a maximum lateral extent of approximately 0.325 square kilometers (km^2) is predicted to exhibit concentrations that exceed the 35 mg/L threshold, during drilling of the first two well sections. These maxima occur near the sea floor and are well below the photic zone (the zone where photosynthesis inhibition could impact some organisms).

Note that in the following figures, the estimated maximum TSS concentrations may be slightly offset from the discharge location as the simulation's floating small particles suspended in the water column may concentrate together at various locations. Larger particles do not remain suspended but quickly settle to the seafloor. Table 2-10 summarizes the maximum predicted surface and bottom TSS concentrations modeled and the lateral areas with TSS concentrations exceeding the 35 mg/L threshold under minimum and maximum current conditions at each drill center.

Table 2-10 Total Suspended Solids Summary

Scenario	Maximum TSS (mg/L)		Area (km^2) with TSS > 35 mg/L threshold	
	Surface	Bottom	Surface	Bottom
1a DC3-I Min Currents	7.2	12,591	0	0.080
1b DC3-I Max Currents	14.1	9,801	0	0.282
2a DC3-P1 Min Currents	6.3	5,783	0	0.069
2b DC3-P1 Max Currents	6.9	7,269	0	0.208
3a DC4-I Min Currents	6.0	39,613	0	0.405
3b DC4-I Max Currents	3.1	19,857	0	0.521

Scenario	Maximum TSS (mg/L)		Area (km²) with TSS > 35 mg/L threshold	
	Surface	Bottom	Surface	Bottom
4a DC4-P1 Min Currents	8.1	41,055	0	0.325
4b DC4-P1 Max Currents	10.4	15,690	0	0.475

Figure 2-18 Maximum TSS Concentrations at the Surface—Scenario 1a DC3-I Minimum Currents

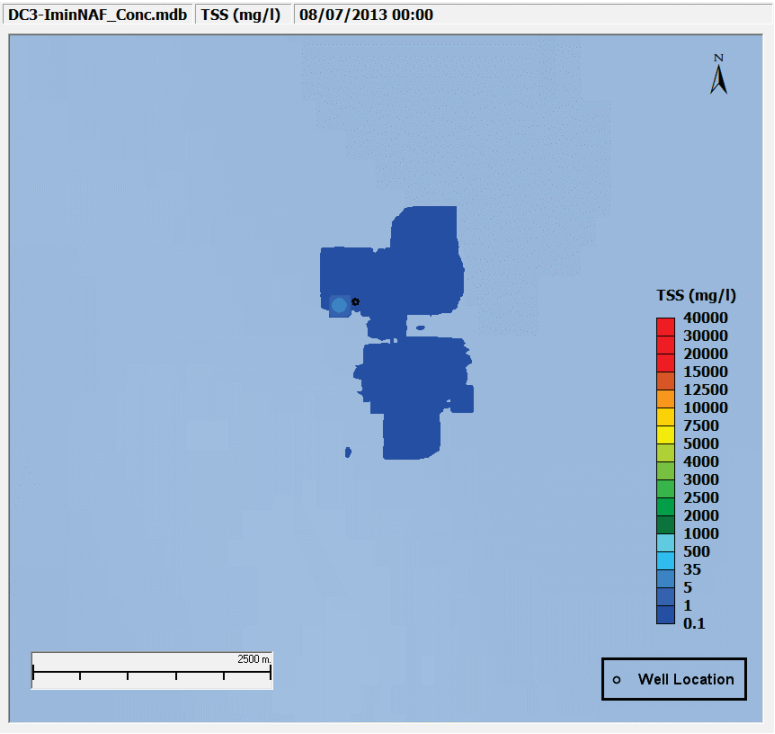


Figure 2-19 Maximum TSS Concentrations at the Bottom—Scenario 1a DC3-I Minimum Currents

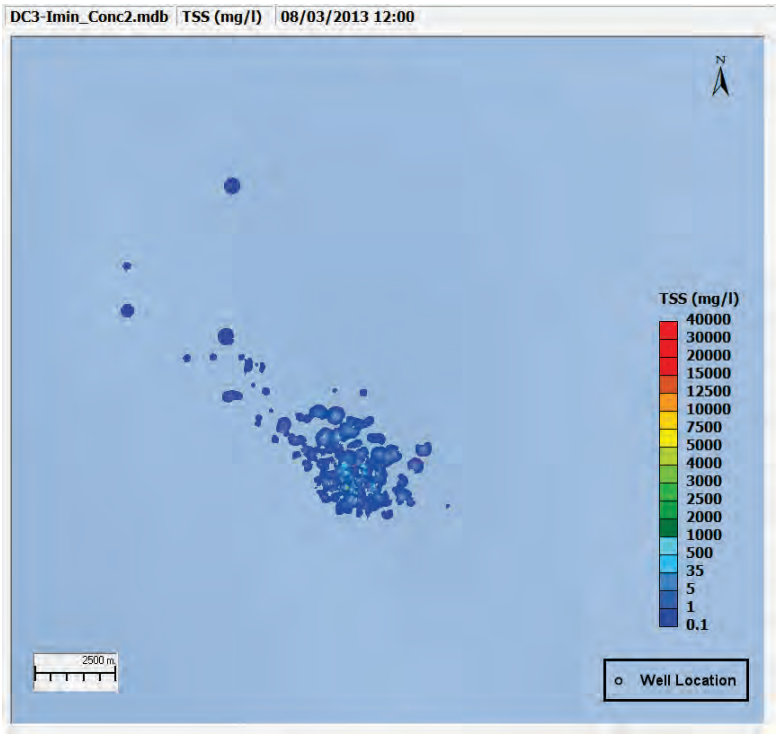


Figure 2-20 Maximum TSS Concentrations at the Surface—Scenario 1b DC3-I Maximum Currents

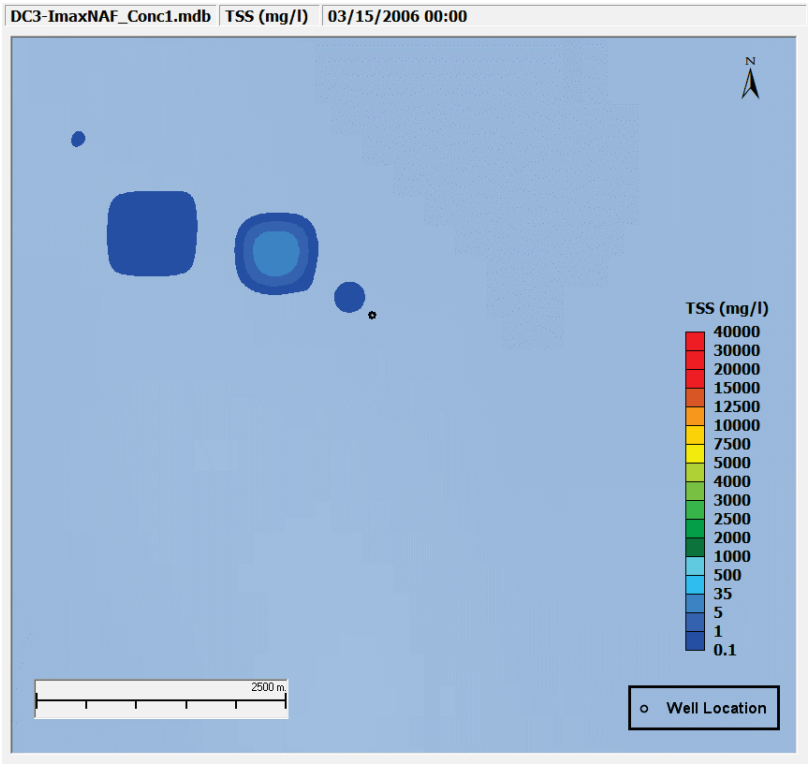


Figure 2-21 Maximum TSS Concentrations at the Bottom—Scenario 1b DC3-I Maximum Currents

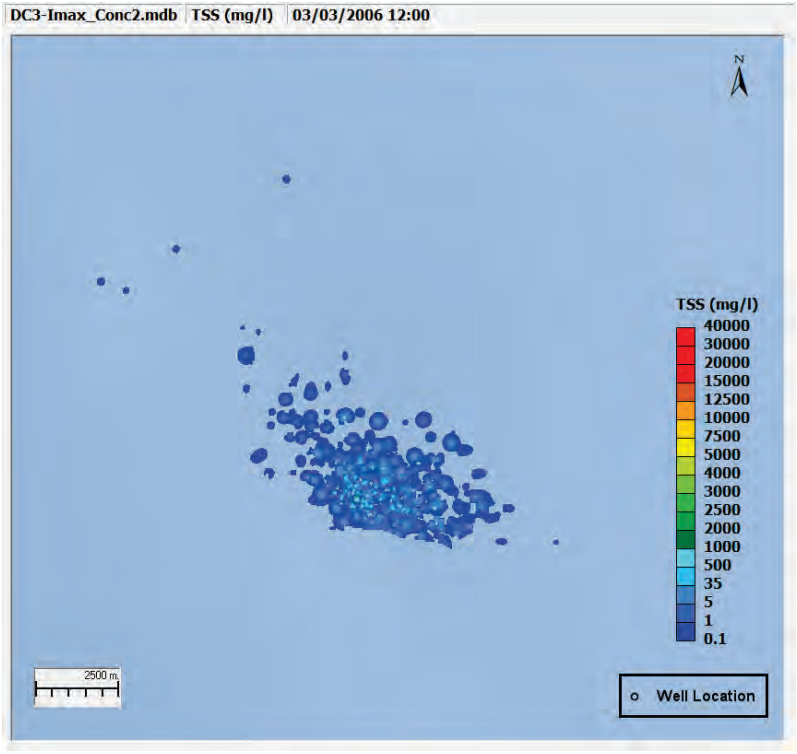


Figure 2-22 Maximum TSS Concentrations at the Surface—Scenario 2a DC3-P1 Minimum Currents

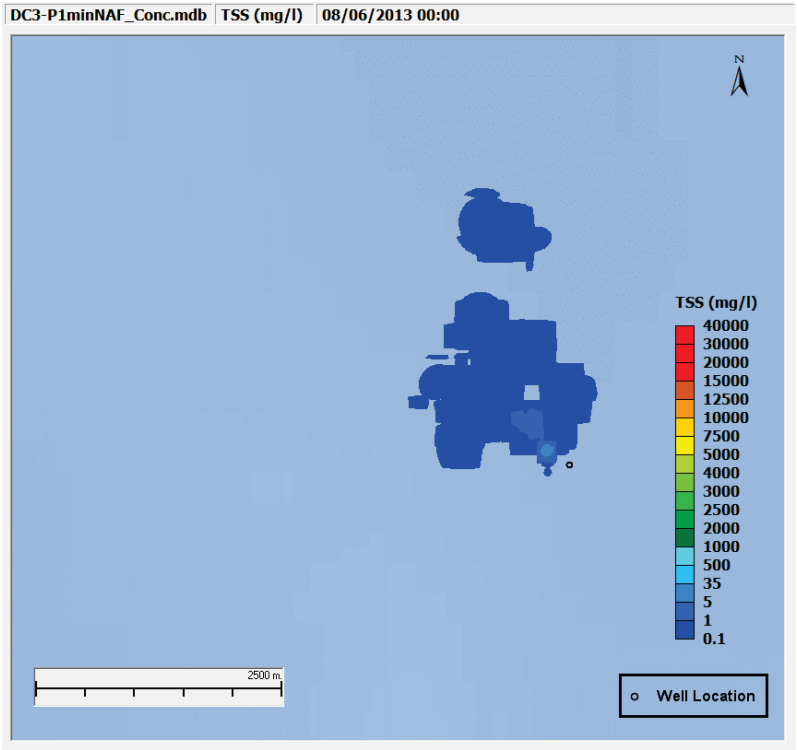


Figure 2-23 Maximum TSS Concentrations at the Bottom—Scenario 2a DC3-P1 Minimum Currents

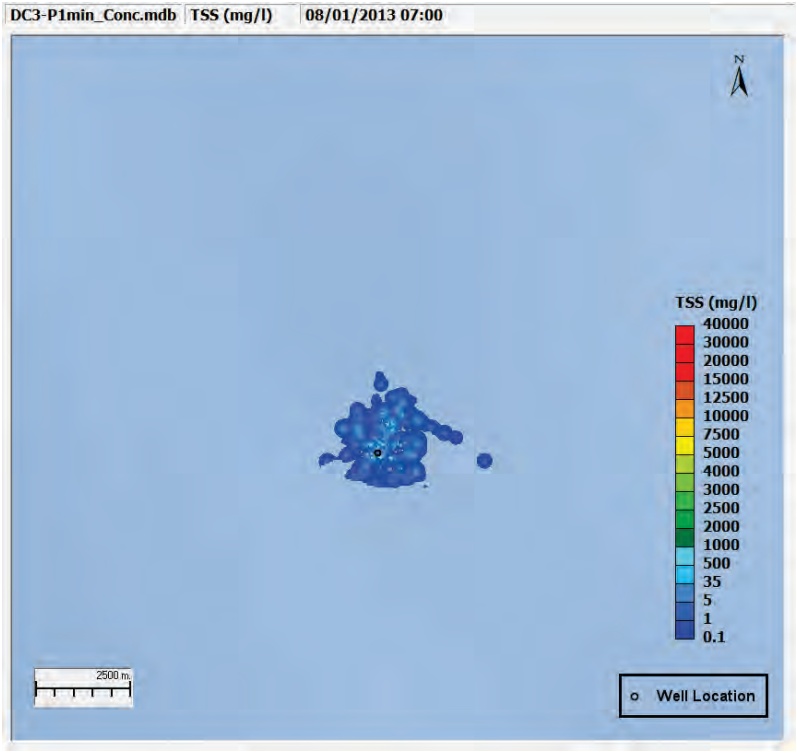


Figure 2-24 Maximum TSS Concentrations at the Surface—Scenario 2b DC3-P1 Maximum Currents

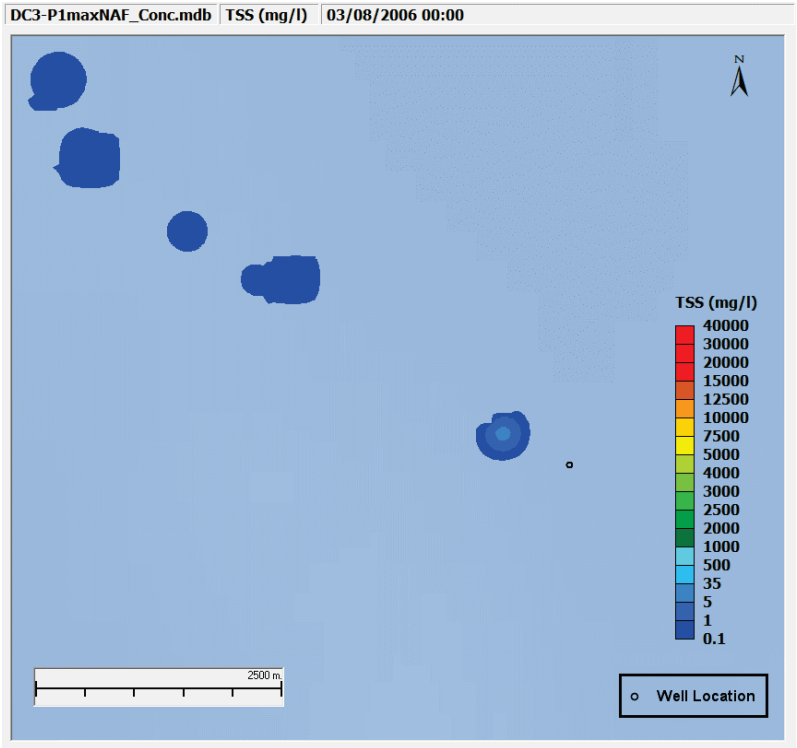


Figure 2-25 Maximum TSS Concentrations at the Bottom—Scenario 2b DC3-P1 Maximum Currents

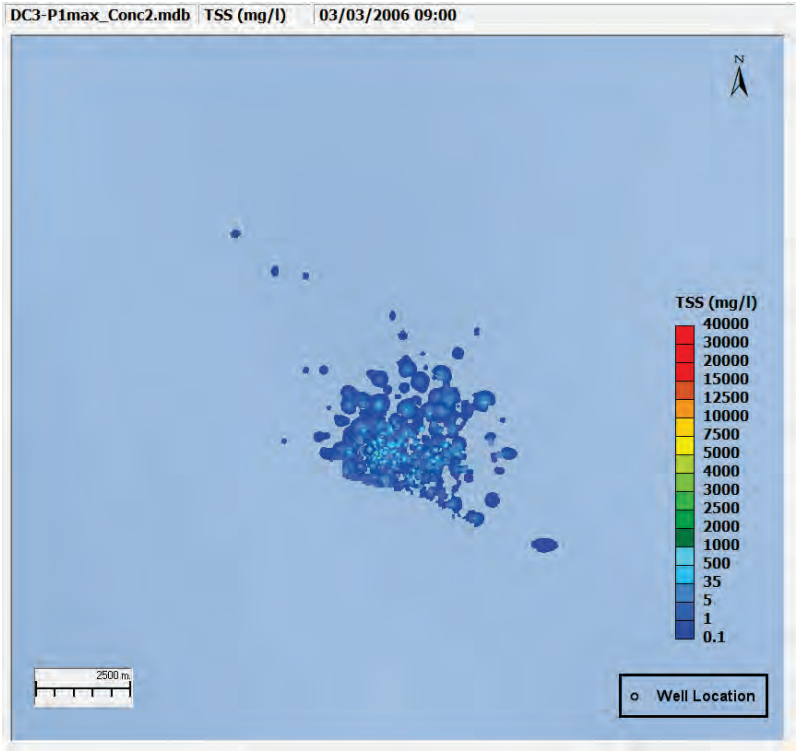


Figure 2-26 Maximum TSS Concentrations at the Surface—Scenario 3a DC4-I Minimum Currents

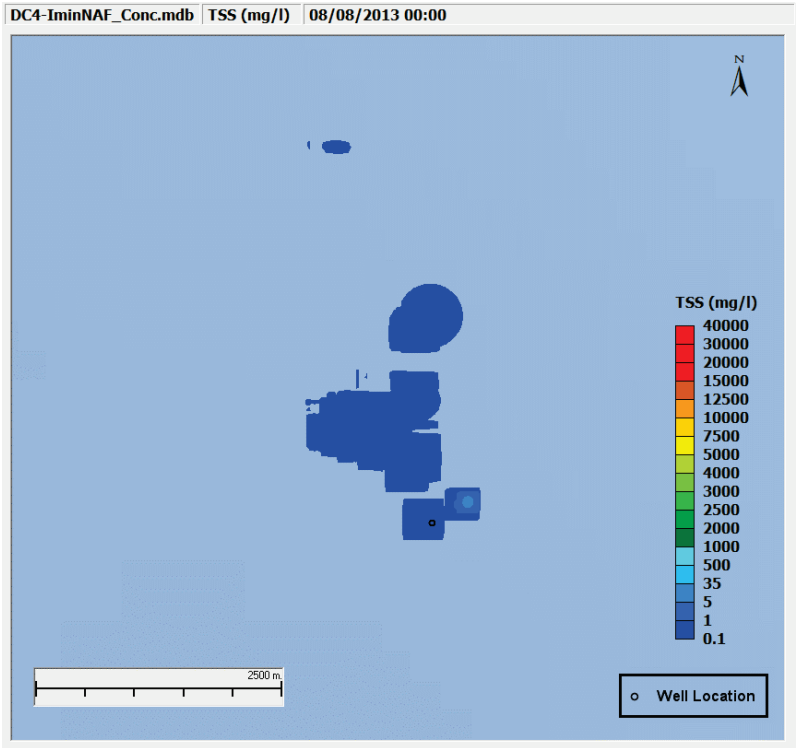


Figure 2-27 Maximum TSS Concentrations at the Bottom—Scenario 3a DC4-I Minimum Currents

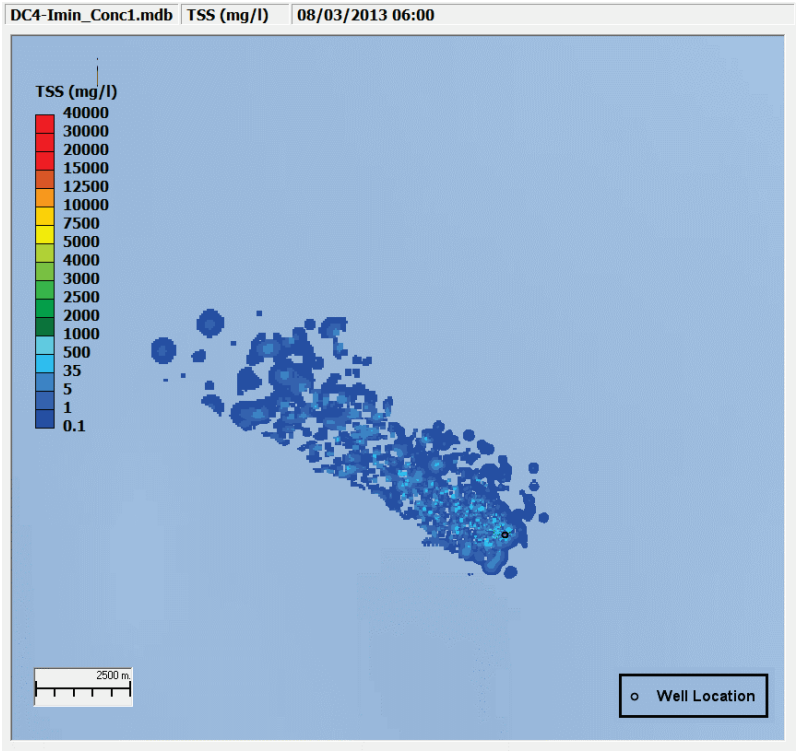


Figure 2-28 Maximum TSS Concentrations at the Surface—Scenario 3b DC4-I Maximum Currents

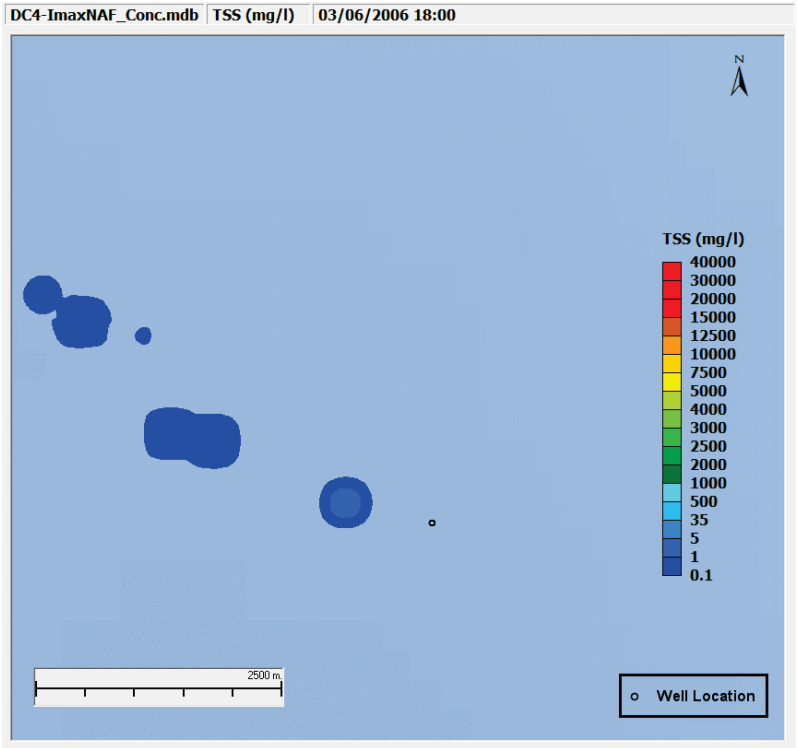


Figure 2-29 Maximum TSS Concentrations at the Bottom—Scenario 3b DC4-I Maximum Currents

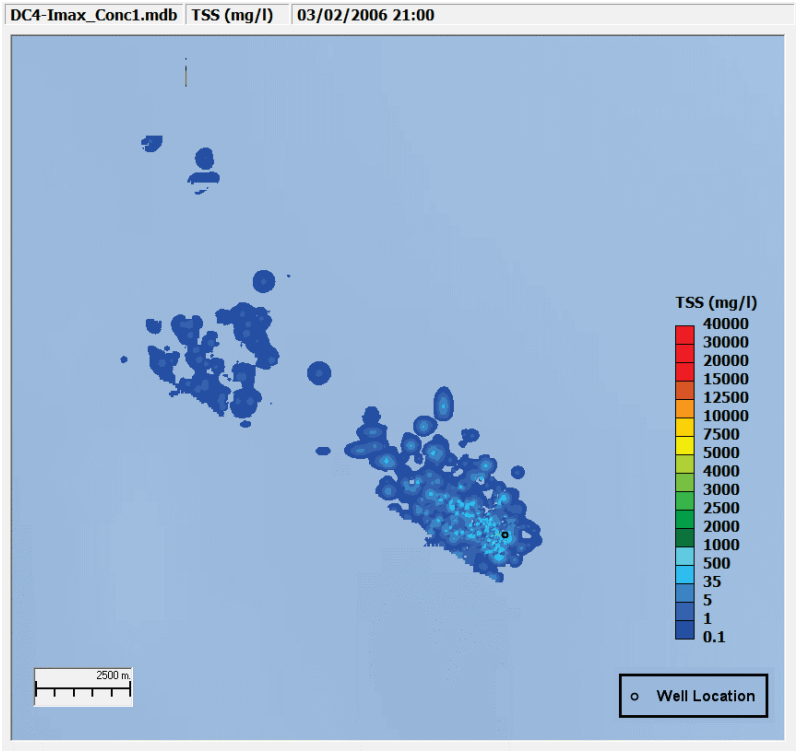


Figure 2-30 Maximum TSS Concentrations at the Surface—Scenario 4a DC4-P1 Minimum Currents

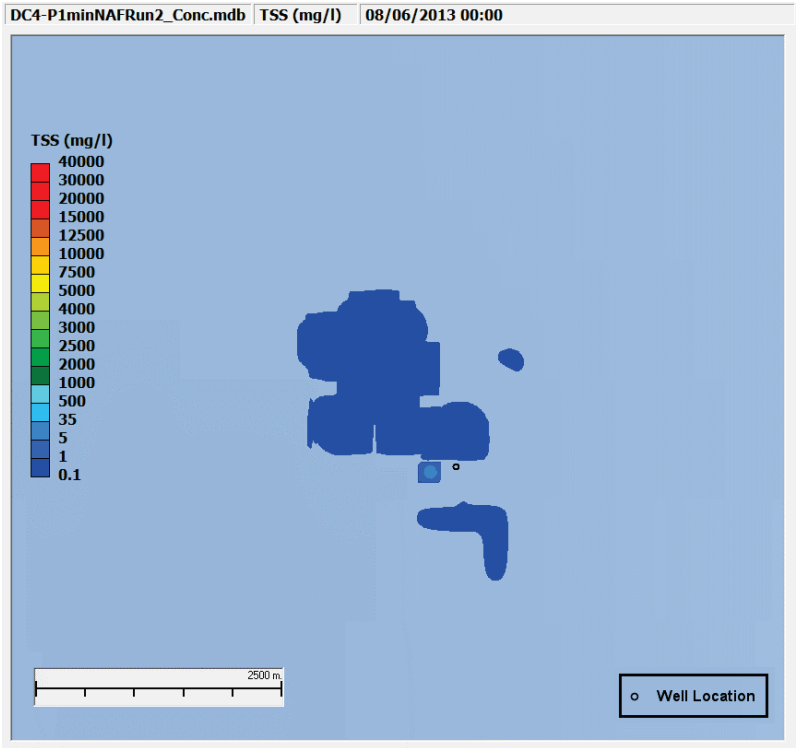


Figure 2-31 Maximum TSS Concentrations at the Bottom—Scenario 4a DC4-P1 Minimum Currents

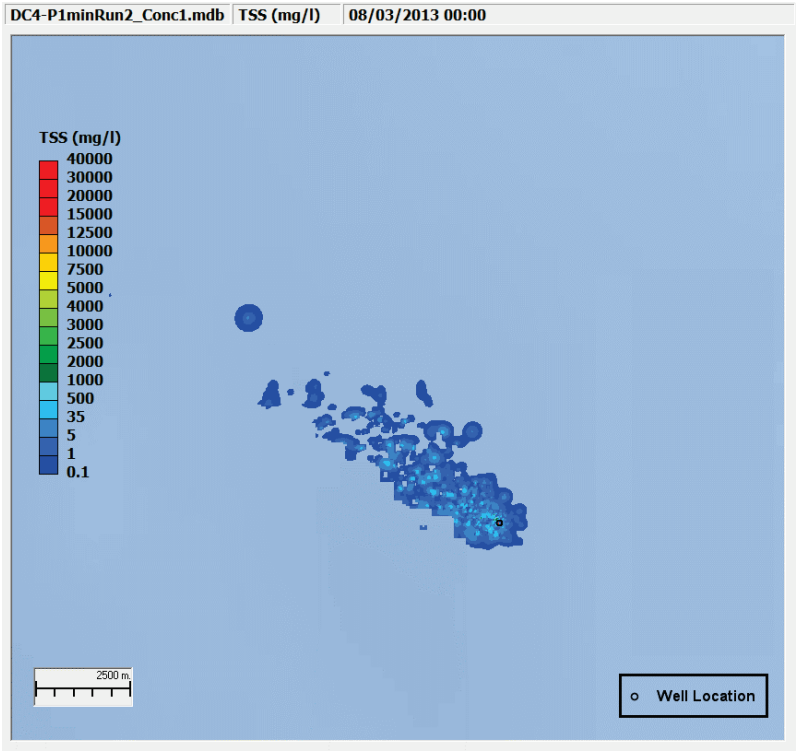


Figure 2-32 Maximum TSS Concentrations at the Surface—Scenario 4b DC4-P1 Maximum Currents

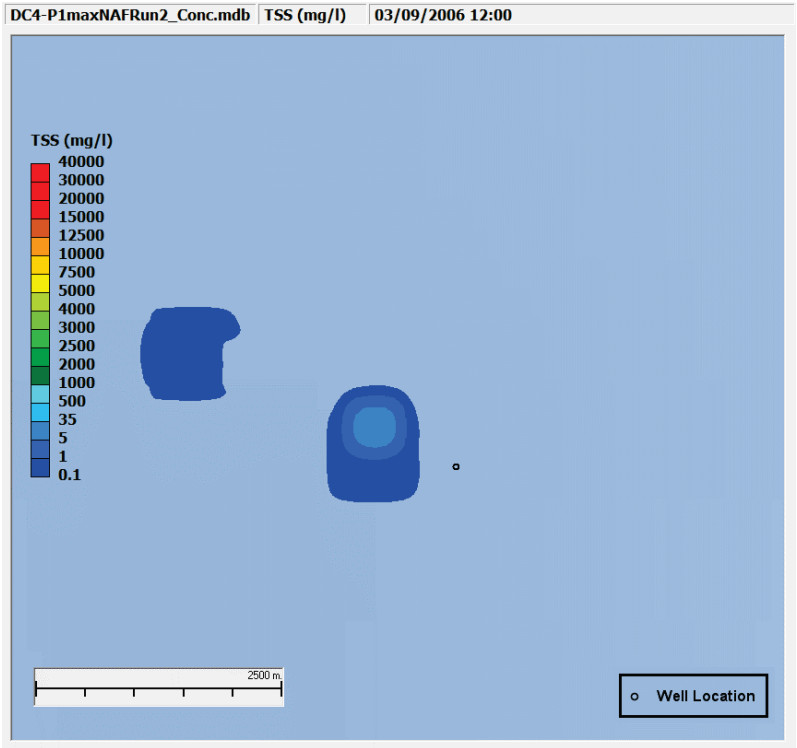
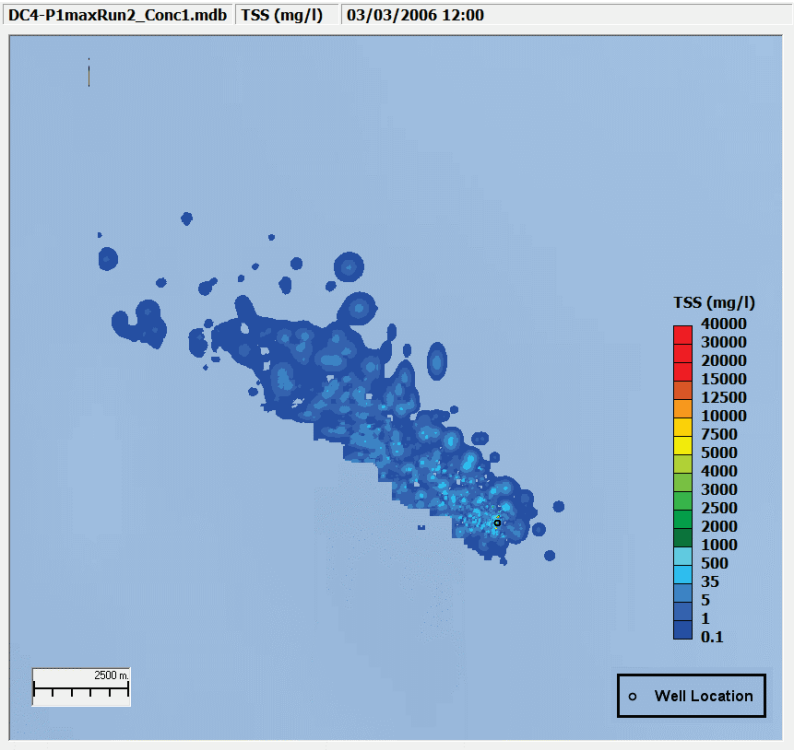


Figure 2-33 Maximum TSS Concentrations at the Bottom—Scenario 4b DC4-P1 Maximum Currents



2.4.3 Mass of Oil Deposited on the Seabed

Figures 2-34 through 2-41 present the predicted hydrocarbon deposition on the seabed based on the statistical summary identifying the maximum hydrocarbon deposition occurring on the ocean floor during the entire simulation period. At the end of the simulation period (23 days), non-aqueous base fluid adhered to the cuttings settled primarily within an approximately 3-kilometer radius region in all four scenarios. Within that region, the maximum and minimum values of the maximum hydrocarbon deposition predicted by the model were, respectively, 355.1 grams per square meter (g/m^2) in Scenario 1a (at Well DC4-I with minimum currents) and 246.5 g/m^2 in Scenario 4b (at Well DC4-P1 with maximum currents). In Scenario 1a at DC1-I, hydrocarbon deposition above 5 g/m^2 occupied an area of 10.2 km^2. In Scenario 4b at DC4-P1, hydrocarbon deposition above 5 g/m^2 occupied an area of 8.0 km^2. Table 2-11 summarizes the maximum hydrocarbon deposition modeled at any point for the scenario and the area with hydrocarbon deposition exceeding 5 g/m^2 under minimum and maximum current conditions at each drill center.

Table 2-11 Hydrocarbon Deposition Summary

Scenario	Maximum Hydrocarbon Deposition (g/m²)	Area (km²) with Hydrocarbons > 5 g/m²
1a DC3-I Min Currents	355.1	10.2
1b DC3-I Max Currents	280.7	10.1
2a DC3-P1 Min Currents	280.8	9.9
2b DC3-P1 Max Currents	272.7	9.8
3a DC4-I Min Currents	354.9	9.9
3b DC4-I Max Currents	322.2	8.6
4a DC4-P1 Min Currents	247.7	9.9
4b DC4-P1 Max Currents	246.5	8.0

Figure 2-34 Total Deposited Adhered Oil—Scenario 1a DC3-I Minimum Currents

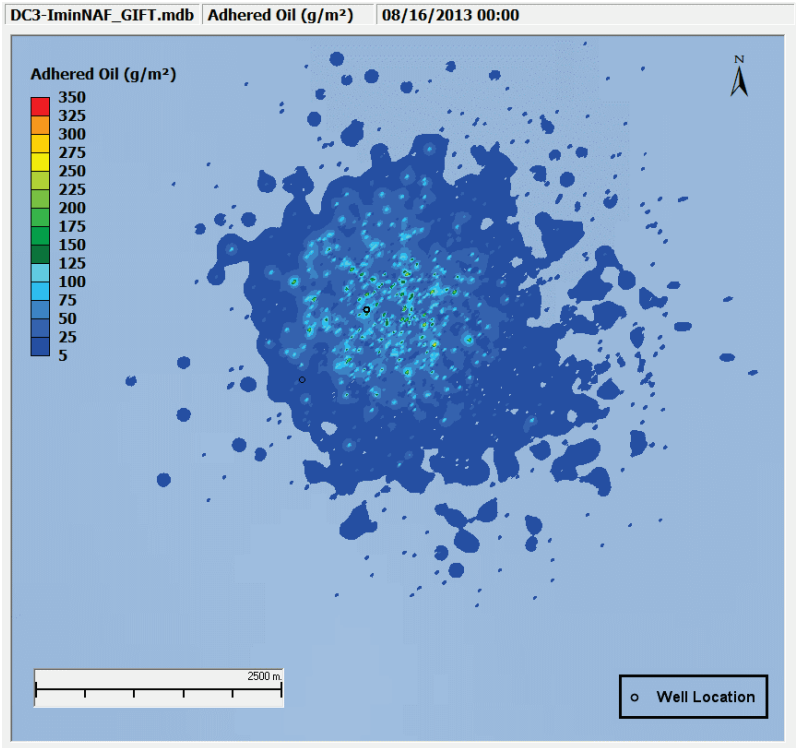


Figure 2-35 Total Deposited Adhered Oil—Scenario 1b DC3-I Maximum Currents

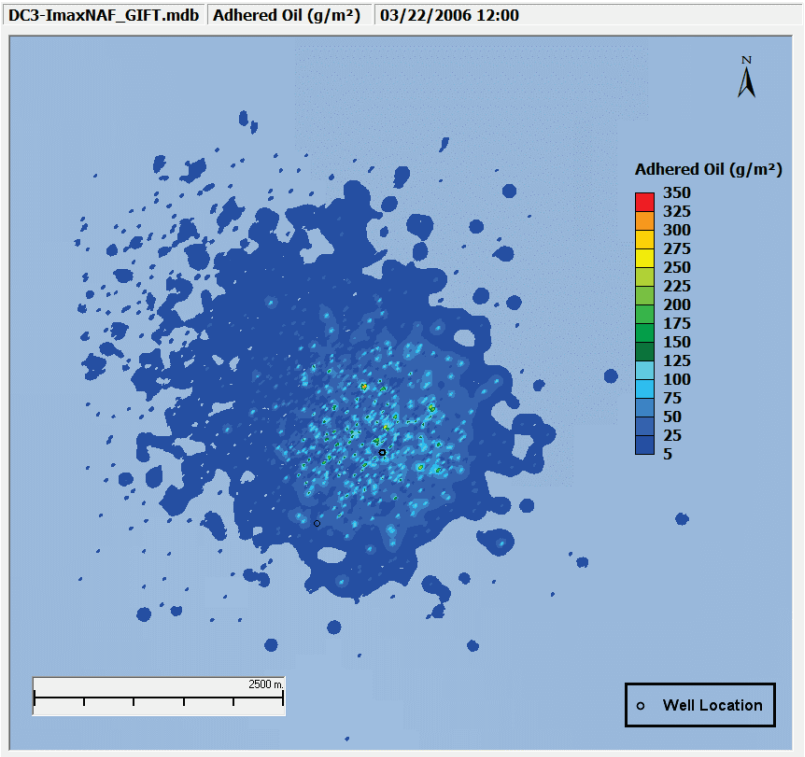


Figure 2-36 Total Deposited Adhered Oil—Scenario 2a DC3-P1 Minimum Currents

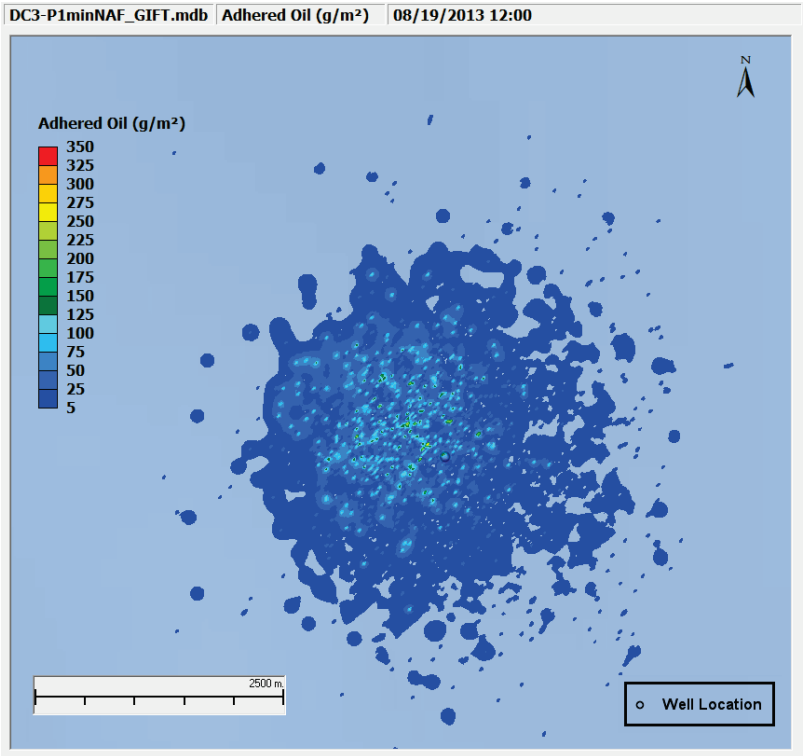


Figure 2-37 Total Deposited Adhered Oil—Scenario 2b DC3-P1 Maximum Currents

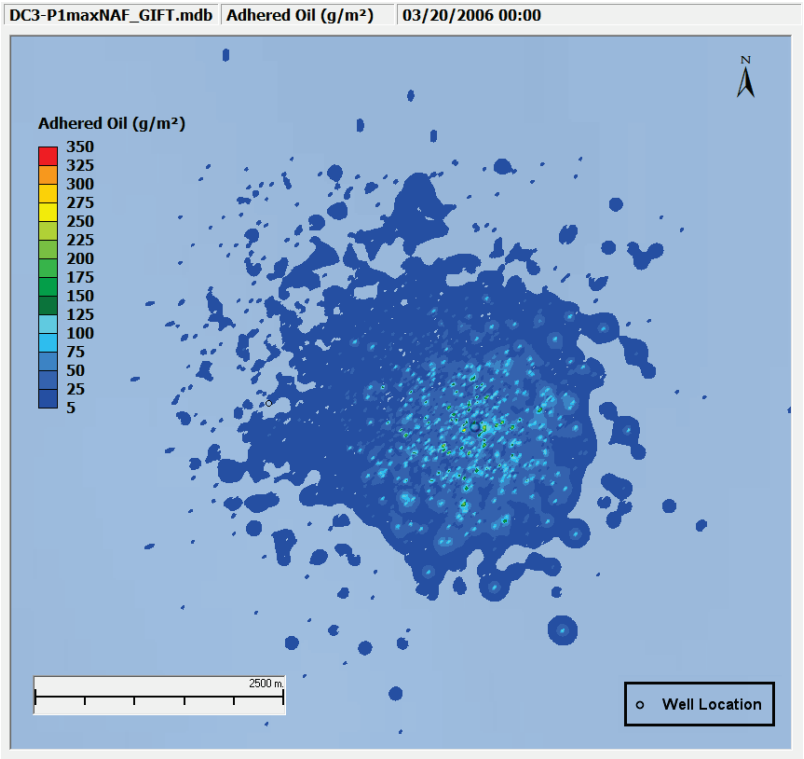


Figure 2-38 Total Deposited Adhered Oil—Scenario 1a DC4-I Minimum Currents

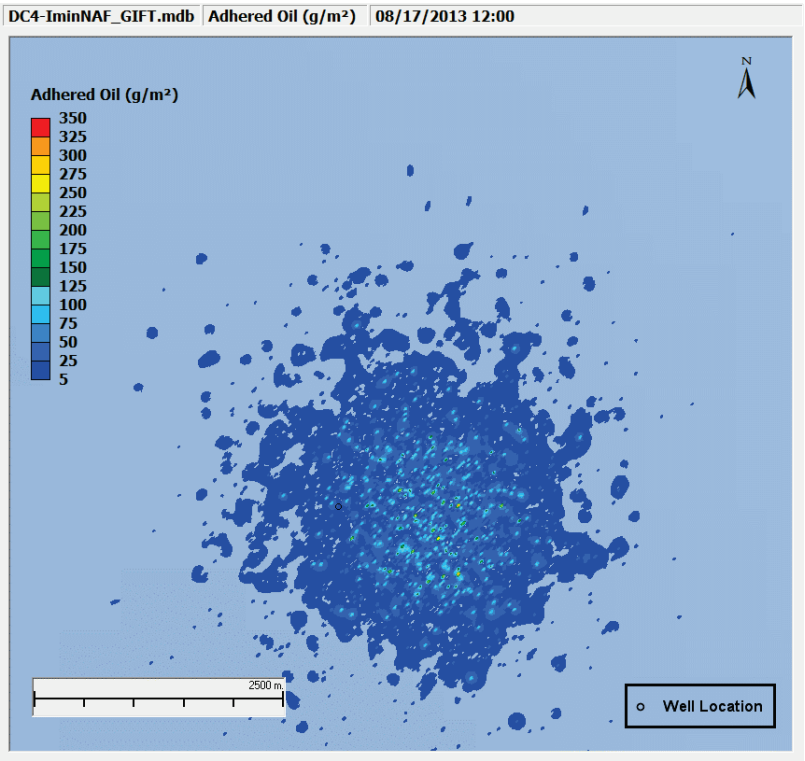


Figure 2-39 Total Deposited Adhered Oil—Scenario 1b DC4-I Maximum Currents

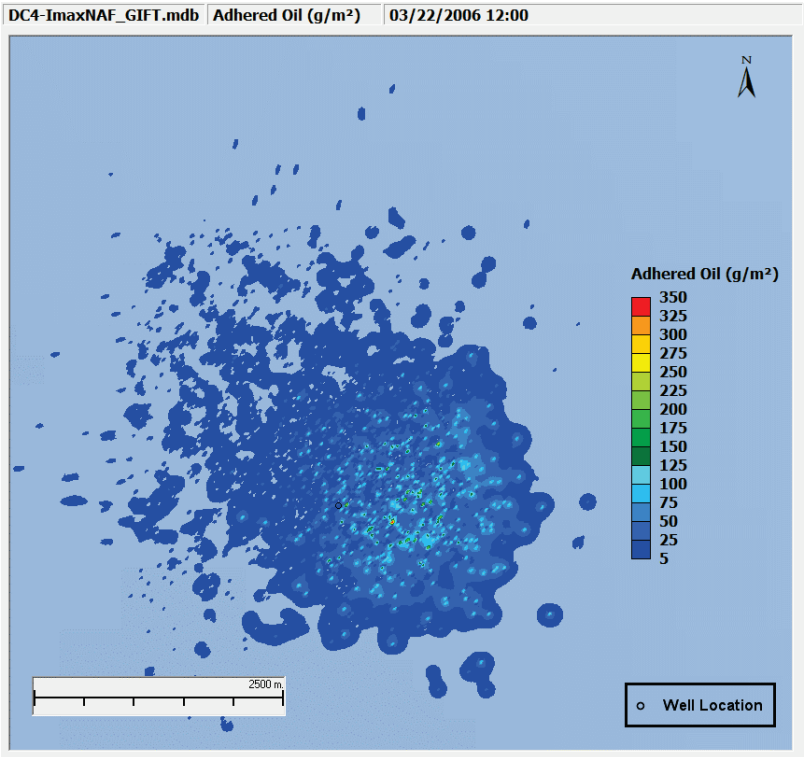


Figure 2-40 Total Deposited Adhered Oil—Scenario 2a DC4-P1 Minimum Currents

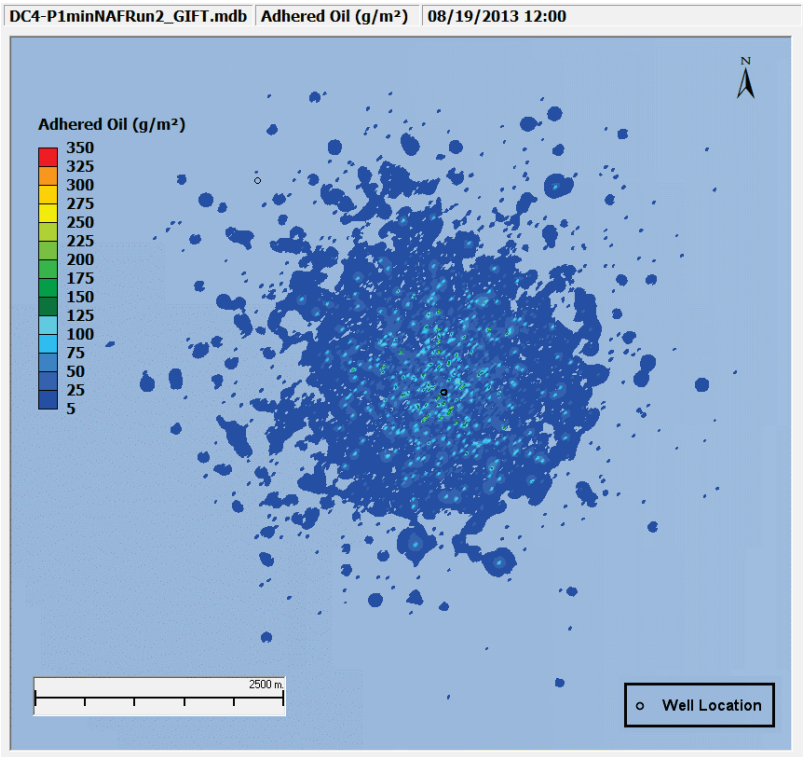
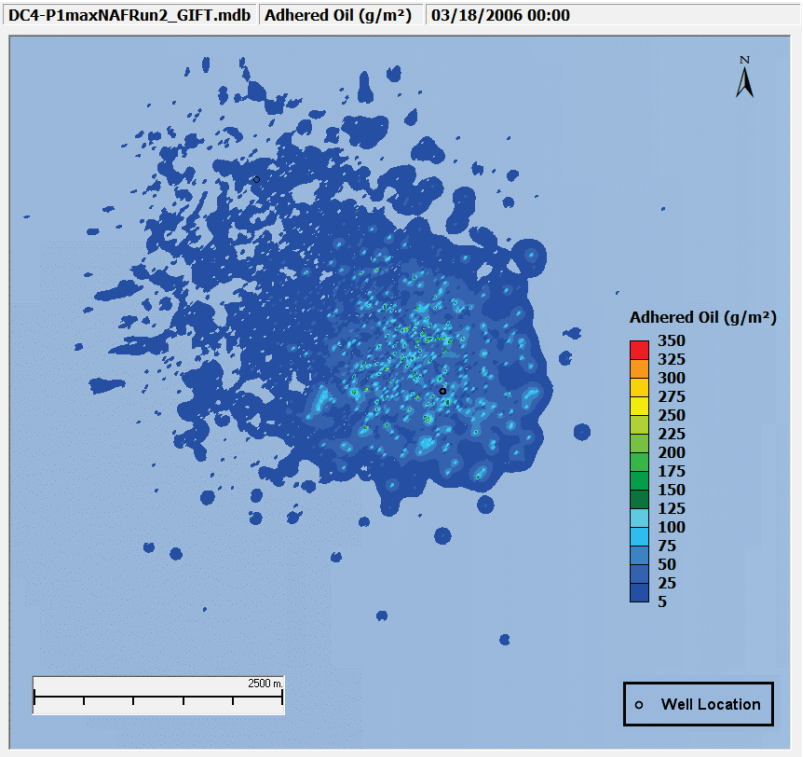


Figure 2-41 Total Deposited Adhered Oil—Scenario 2b DC4-P1 Maximum Currents



2.5 Conclusions

Drill cuttings deposition modeling was performed using GEMSS® and its drill cuttings and muds deposition module, GIFT. Eight simulations were modeled, representing at well at each of four different drill center locations (DC3-I, DC3-P1, DC4-I and DC4-P1), each under two ambient current conditions (minimum and maximum monthly-averaged, depth-averaged current speeds over a ten year period of record). At the beginning of the simulation, during a two-day period, cuttings and WBM were discharged directly at the seabed while jetting and drilling the first two well sections. After a one day break, drill cuttings and adhered NADF muds from the subsequent three sections were simulated to be released 11 meters below sea level over the following 13 days.

Output from the drill cutting modeling included estimations of the lateral distribution of deposited cuttings thickness on the sea floor, the maximum increase in TSS concentrations above ambient conditions, and the lateral distribution of mass of hydrocarbons adhered to cuttings deposited on the sea floor. The results of the modeling are shown below in Table 2-12.

Table 2-12 Model Results Summary

Scenario	Maximum Depositional Thickness (cm)	Area (m^2) with Thickness > 5 cm Threshold	Maximum TSS (mg/L) Surface/Bottom	Area (km^2) with TSS > 35 mg/L Threshold Surface/Bottom	Maximum Adhered Oil Deposition (g/m^2)	Area (km^2) with Adhered Oil Deposition > 5 g/m^2
1a DC3-I Min Currents	58.5	5,961	7.2/12,591	0/0.080	355.1	10.2
1b DC3-I Max Currents	20.5	3,210	14.1/9,801	0/0.282	280.7	10.1
2a DC3-P1 Min Currents	98.3	7,386	6.3/5,783	0/0.069	280.8	9.9
2b DC3-P1 Max Currents	25.2	6,347	6.9/7,269	0/0.208	272.7	9.8
3a DC4-I Min Currents	16.2	1,468	6.0/39,613	0/0.405	354.9	9.9
3b DC4-I Max Currents	17.3	1,759	3.1/19,857	0/0.521	322.2	8.6
4a DC4-P1 Min Currents	20.8	1,483	8.1/41,055	0/0.325	247.7	9.9
4b DC4-P1 Max Currents	19.1	1,773	10.4/15,690	0/0.475	246.5	8.0

According to the model results, the thickness of drill cuttings and adhered muds deposited on the seafloor may exceed the threshold value of 5 centimeters within as much as a 62-meter radius from the drill center. The bulk of the depositional mound results from the cuttings and muds discharged during the jetting and drilling of the top two sections. The maximum TSS concentration of ambient in the bottom of the water column are predicted to be as much as 41,000 mg/L at the point of release; however, these concentrations will occur at water depths below the photic zone, in areas where photosynthesis inhibition is not a concern. At the surface, where photosynthesis inhibition is more of a concern, TSS increases above ambient from discharges were predicted to be below the 35 mg/L threshold. The maximum TSS concentration increases above ambient in the shallow water column is 14.1 mg/L. Hydrocarbon deposition on the seafloor had a maximum predicted value of 355.1 g/m^2, with deposition over 5 g/m^2 within an area no more than 10.2 km^2.

Variations in the current speeds are the primary cause for the variations in the model results provided. In general, scenarios with minimum currents have higher maximum cuttings deposition thicknesses and higher bottom TSS concentrations compared to the scenarios with maximum currents. Slower currents allow for a more laterally-concentrated deposition and more concentrated TSS. Though Scenario 3a has lower monthly and depth-averaged currents compared to Scenario 3b, the bottom currents where most of the deposition occurs during drilling of the riserless sections were higher in Scenario 3a, allowing lower depositional thickness in Scenario 3a compared to Scenario 3b. In addition, Scenario 2a with minimum currents showed lower TSS concentrations compared to Scenario 2b with maximum currents, because currents near the bottom in Scenario 2a are significantly lower than those for Scenario 2b, causing faster deposition of cuttings without causing larger TSS concentrations. Higher bottom currents result in a larger depositional area during drilling of the first two sections, with near-seabed discharges causing cuttings to settle across a larger area, and reducing the maximum depositional thickness in Scenario 3a and Scenario 4a with minimum currents versus Scenario 3b and Scenario 4b with maximum currents.

Similar to the depositional thickness, scenarios with minimum currents have higher maximum hydrocarbon deposition compared to scenarios with maximum currents. Slower currents allow for a more laterally concentrated deposition of hydrocarbon-containing cuttings.

3.0 OFFSHORE DISCHARGES MODELING

3.1 Approach

The Project will have several planned discharges to water associated with Subsea Umbilicals, Risers, and Flowlines (SURF) and FPSO commissioning activities as well as FPSO production operations. These discharges, based on the preliminary design information, are listed in Table 3-1.

Table 3-1 Summary of Commissioning and Production-Related Discharges

Type of Discharge and Effluent Characteristics	Expected Discharge Volume/Rate
Ballast Water (FPSO initial deballasting)	≤ 550,000 bbl total
Hydrostatic Test Water • Biocide: ≤ 500 ppm • Oxygen scavenger ≤ 100 ppm • Corrosion inhibitor ≤ 100 ppm	65,000 bbl (total volume for all flowlines and risers, occurring throughout SURF commissioning phase)
Gas Injection Line Commissioning Fluids • Hydrate inhibitor (e.g., methanol or ethylene glycol)	1,400 bbl total
Produced Water • Oil and Grease • Temperature (40-50°C at point of discharge) • Residual production and water treatment chemicals	≤ 300,000 BPD
Cooling Water • Hypochlorite: ≤ 5 ppm	≤ 1,600,000 BPD
Sulfate Removal and Potable Water Processing Brines • Hypochlorite: ≤ 1 ppm • Electrolyte: ≤ 1 ppm • Biocide: ≤ 5 ppm • Oxygen Scavenger: ≤ 10 ppm • Scale Inhibitor: ≤ 5 ppm	≤ 265,000 BPD
Subsea Hydraulic Fluid Discharge • Water soluble, low-toxicity	≤ 5 BPD
FPSO Bilge Water	1,800 BPD
Inert Gas Generator Cooling Water	Negligible
FPSO Slop Tank Water	Negligible
Miscellaneous Discharges including Boiler Blowdown, Desalinization Blowdown, Lab Sink Drainage	<10 BPD
Tanker Ballast Water	Maximum 1,200,000 bbl total (at each tanker crude loading)
Blowout Preventer System Testing Water-Soluble Low-Toxicity Hydraulic Fluid	30 bbl every two weeks
Gray Water	250 BPD

Type of Discharge and Effluent Characteristics	Expected Discharge Volume/Rate
Black Water (sewage)	200 BPD
Food Preparation Wastes	<40 BPD

BPD = barrels per day; ppm = parts per million

Cooling water, produced water, and brines from the Sulfate Removal Unit (SRU) and freshwater reverse osmosis system (all associated with the production operations stage) are the main operational discharges that are significant enough to require an assessment of the extent of the discharge plume. Although the discharge of hydrotest water and commissioning fluids will occur over only a short time period during the SURF installation and commissioning stage, they were also included in the offshore discharge modeling as a conservative measure. Additionally, a scenario simulating a failure in the sewage treatment plant occurs requiring all black water to bypass the macerator (and assuming it also bypasses the holding tank) and be discharged directly overboard via an emergency outfall was considered.

The constituents considered from these discharges are listed in Table 3-2.

Table 3-2 Operational and Maintenance Offshore Discharges and their Constituents Modeled

Discharge	Modeled Constituents
Cooling Water	• Temperature • Residual Chlorine
Produced Water	• Temperature • Oil and grease • Residual production and water treatment chemicals (e.g., scale and corrosion inhibitors)
Sulfate Removal and Potable Water Processing Brines	• Hypochlorite • Electrolyte • Biocide • Oxygen Scavenger • Scale Inhibitor
Hydrotest Water	• Biocides • Oxygen Scavenger • Corrosion Inhibitor
Gas Injection Line Commissioning Fluid	• Hydrate inhibitor (e.g., methanol or ethylene glycol)
Black Water	• TSS • BOD_5 • Coliform bacteria

As the standards applicable to marine discharges are typically applied at the edge of the mixing zone, modeling of the near-field mixing zone is necessary. The model used for the mixing zone calculations is the U.S. Environmental Protection Agency's (USEPA) Cornell Mixing Zone Expert System (CORMIX) dilution model. CORMIX is a design tool routinely used by regulatory agencies to estimate the size and configuration of proposed and existing mixing zones resulting from wastewater discharges. CORMIX is

primarily a near-field model (i.e., it applies to the region adjacent to the discharge structure in which the wastewater plume is recognizable as separate from the ambient water and its trajectory is dominated by the discharge rate, effluent density, and geometry of the discharge structure).

The CORMIX calculation is based on defining the various hydraulic zones the effluent plume traverses in the receiving waterbody, then applying an analytical solution or empirical relationship to compute the plume trajectory and dilution rate in each zone. Each of these analytical solutions and empirical relationships has been validated by the developers and other researchers against laboratory and field studies. CORMIX has been applied to many cases (http://www.cormix.info) and is recognized by the USEPA and other national regulatory agencies as an appropriate model for computing trajectories, dilution rates and mixing zone dimensions.

To represent the short-term nature of the discharge for the untreated black water discharge scenario, the 3D hydrodynamic and water quality model GEMSS was used. Unlike CORMIX, the GEMSS model is capable of simulating temporally and spatially varying conditions.

3.2 Scenario Selection

Understanding the mixing characteristics of the various discharges and assessing compliance with applicable regulatory standards requires an understanding of the properties of the receiving (ambient) water. The properties of the ambient water, in combination with the discharge port configuration (pipe or diffuser), control the near-field mixing and dilution of the discharge. Properties of the ambient water relevant to the current analysis include current velocity, temperature and salinity. While the ambient current velocity (and its strength relative to the discharge/exit velocity) determines the level of initial mixing, temperature and salinity influence the behavior of the discharge plume and its relative configuration due to density differences (i.e., buoyancy effects). Significant density differences between the discharge and ambient water will impede mixing. Balancing that effect, significant differences between discharge velocity and ambient current increase entrainment of the ambient water into the discharge plume, resulting in rapid mixing.

3.2.1 Discharge Velocity

Discharge velocity is directly related to the pipe diameter used for the various effluent streams. Smaller pipe diameters result in higher exit velocities, facilitating increased mixing. However, engineering constraints may require a minimum pipe diameter. As is typically the case, details are not yet available for all aspects of the Phase 2 Project discharge design. However, detailed design information is available for the Phase 1 Project; accordingly, where appropriate design values from Phase 1 were used for the analysis for Phase 2. If smaller discharge pipe diameters are used for Phase 2, the discharge will result in increased mixing and smaller plumes. A larger pipe diameter was also evaluated for some scenarios to confirm the plume under a larger pipe will

continue to meet the targeted environmental guidelines. The pipe configurations considered for the discharge streams modeled are listed in Table 3-3.

Table 3-3 Pipe Diameters Considered for Offshore Discharges

Type of Discharge	Pipe Diameter (inches)	Vertical Location Relative to Sea Level
Produced Water	12.5	2 m above water surface
Cooling Water	22.6 and 45.2	2 m above water surface
Sulfate Removal and Potable Water Process Brines	12	2 m above water surface
Hydrostatic Test Water	2 and 6	Seafloor
Hydrate Control Fluid	2 and 6	Seafloor
Black Water	8	1 m below water surface

3.2.2 Discharge Properties

Discharge rates for the various operational discharges were based on the preliminary design (see Table 3-1). For modeling of hydrotesting discharges, SURF volumes were also based on preliminary design information. The discharge rates and SURF volumes reflect conservative (high) estimates. Anticipated constituent concentrations and temperatures in discharge streams were also based on preliminary design. The selected discharge rates and constituent concentrations are shown in Table 3-4.

Table 3-4 Modeled Discharge Properties

Type of Discharge	Modeled Discharge Rate	Modeled Parameter Values
Produced Water	300,000 BPD (conservative)	• Temperature: 131 °F (55°C) • Oil and Grease: 42 mg/l (daily maximum) • Residual production and water treatment chemicals (100 ppm scale inhibitor and 200 ppm corrosion inhibitor used as examples)
Cooling Water	1,600,000 BPD	• Temperature: 122 °F (50°C) • Hypochlorite: ≤ 5 ppm
Sulfate Removal and Potable Water Processing Brines	265,000 BPD	• Hypochlorite: ≤ 1 ppm • Electrolyte: ≤ 1 ppm • Biocide: ≤ 5 ppm • Oxygen Scavenger: ≤ 10 ppm • Scale Inhibitor: ≤ 5 ppm
Hydrostatic Test Water	65,000 bbl (total volume for all flowlines and risers, occurring across approximately one year)	• Biocide: 500 ppm • Oxygen Scavenger: 100 ppm • Corrosion Inhibitor: 100 ppm
Hydrate Control Fluid	2,500 bbl (may be as low as 1,400 bbl)	• Concentrated methanol or ethylene glycol

Type of Discharge	Modeled Discharge Rate	Modeled Parameter Values
Black Water	3,200 gallons/day[4]	• TSS: 650 mg/l • BOD_5: 350 mg/l • Coliform: 10,000,000 CFU/ 100 ml

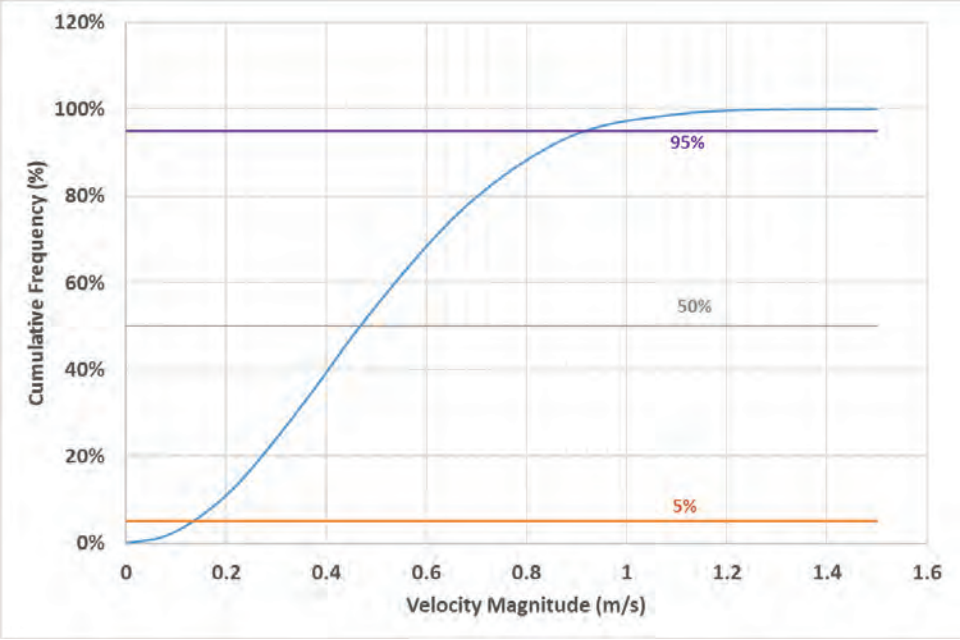
BPD = barrels per day; ppm = parts per million

3.2.3 Ambient Currents

Ambient current velocities for the region were available from ExxonMobil Upstream Research Company using the SAT-OCEAN model and analyzed in order to select appropriate values for the specific locations for the discharges at the FPSO location. Although the operational discharges will occur near the surface, the hydrotesting and hydrate control fluid releases will occur near the seabed. Therefore, the ambient current velocities were analyzed to select appropriate values depending on the discharge being modeled.

Ambient current velocities were analyzed for the period of 2005 to September 2014. A frequency distribution analysis was performed to evaluate the magnitude and exceedance percentages for current velocities. The ambient current velocities selected for modeling consisted of bounding cases (5 percent and 95 percent) and typical (50 percent). The frequency distributions for the two depths are shown in Figure 3-1 and Figure 3-2. The selected current velocities are shown in Table 3-5.

Figure 3-1 Cumulative Frequency Distribution for Current Velocities at FPSO Location (near surface)



[4] 10 gallons/day sewage per person; 160 PoB; 200% contingency factor applied

Figure 3-2 Cumulative Frequency Distribution for Current Velocities at FPSO Location (near seabed)

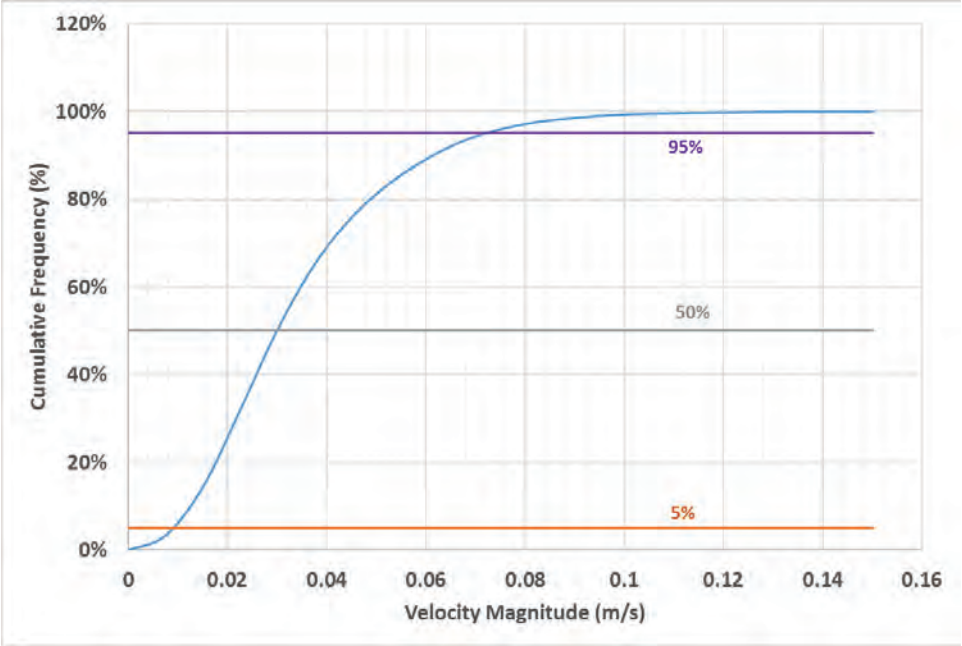


Table 3-5 Selected Ambient Current Velocities (meters/second)

Cumulative Frequency	Surface	Seabed
Low (5%)	0.13	0.009
Typical (50%)	0.47	0.03
High (95%)	0.92	0.072

3.2.4 Ambient Temperatures

An analysis of ambient temperatures for the FPSO location was conducted based on data available from ExxonMobil Upstream Research Company using the SAT-OCEAN model. Since the ambient temperatures do not vary significantly within the Stabroek Block, only the FPSO location was considered. The temperature data are available for the period of May 2008 to September 2016. A frequency distribution analysis was completed to evaluate the temperatures and exceedance percentages. Selected ambient temperatures consisted of two bounding cases (1 percent and 99 percent) and a typical case (50 percent). Only the cooling water discharge, whose plume is influenced by the ambient temperatures and releases a large amount of water, was considered for the bounding cases and all remaining discharges were run for the typical case. The frequency distribution is shown in Figure 3-3 and the selected temperatures are shown in Table 3-6. For discharges released near the seafloor (hydrostatic discharge), a single value of temperature at 4.5°C was used, as the temperature values near the seafloor do not vary considerably with time and space.

Figure 3-3 Cumulative Frequency Distribution for Temperatures at FPSO Location (near surface)

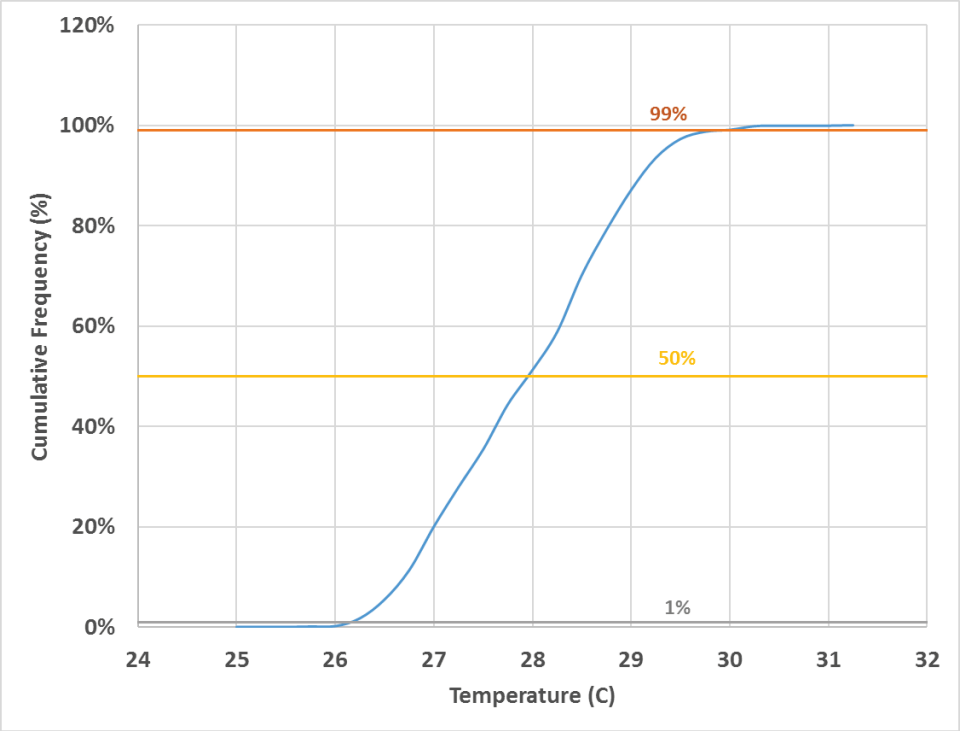


Table 3-6 Selected Ambient Near-Surface Temperatures (degrees Celsius)

Cumulative Frequency	FPSO
Low (1%)	26.25
Typical (50%)	28.00
High (99%)	30.00

3.2.5 Scenarios

A combination of the discharges, ambient properties (currents and temperatures) and discharge velocities (pipe diameter) were used to develop a comprehensive list of scenarios for simulation with CORMIX (Table 3-7). All potential pipe diameters listed in Table 3-3 were used to model these scenarios.

Table 3-7 List of Modeled Scenarios

No	Discharge	Scenario Name	Ambient Currents	Ambient Temperature	Location
1	Cooling Water - Thermal	T Sc. 01	Low (5%)	High (99%)	FPSO; 2 m above water surface
		T Sc. 02	Typical (50%)	High (99%)	FPSO; 2 m above water surface
		T Sc. 03	High (95%)	High (99%)	FPSO; 2 m above water surface
		T Sc. 04	Low (5%)	Low (1%)	FPSO; 2 m above water surface
		T Sc. 05	Typical (50%)	Low (1%)	FPSO; 2 m above water surface

No	Discharge	Scenario Name	Ambient Currents	Ambient Temperature	Location
		T Sc. 06	High (95%)	Low (1%)	FPSO; 2 m above water surface
2	Cooling Water - Hypochlorite	C Sc. 01	Low (5%)	High (99%)	FPSO; 2 m above water surface
		C Sc. 02	Typical (50%)	High (99%)	FPSO; 2 m above water surface
		C Sc. 03	High (95%)	High (99%)	FPSO; 2 m above water surface
		C Sc. 04	Low (5%)	Low (1%)	FPSO; 2 m above water surface
		C Sc. 05	Typical (50%)	Low (1%)	FPSO; 2 m above water surface
		C Sc. 06	High (95%)	Low (1%)	FPSO; 2 m above water surface
3	Sulfate Removal and Potable Water Processing Brines	W Sc. 01	Low (5%)	Typical (50%)	FPSO; 2 m above water surface
		W Sc. 02	Typical (50%)	Typical (50%)	FPSO; 2 m above water surface
		W Sc. 03	High (95%)	Typical (50%)	FPSO; 2 m above water surface
4	Produced Water	P Sc. 01	Low (5%)	Typical (50%)	FPSO; 2 m above water surface
		P Sc. 02	Typical (50%)	Typical (50%)	FPSO; 2 m above water surface
		P Sc. 03	High (95%)	Typical (50%)	FPSO; 2 m above water surface
5	Hydrostatic Test Water	H Sc. 01	Low (5%)	Typical (50%)	FPSO; seafloor
		H Sc. 02	Typical (50%)	Typical (50%)	FPSO; seafloor
		H Sc. 03	High (95%)	Typical (50%)	FPSO; seafloor
6	Hydrate Control Fluid - Methanol	Methanol Sc01 2in	Low (5%)	Typical (50%)	FPSO; seafloor
		Methanol Sc03 2in	High (95%)	Typical (50%)	FPSO; seafloor
		Methanol Sc01 6in	Low (5%)	Typical (50%)	FPSO; seafloor
		Methanol Sc03 6in	High (95%)	Typical (50%)	FPSO; seafloor
7	Hydrate Control Fluid – Ethylene glycol	MEG Sc01 2in	Low (5%)	Typical (50%)	FPSO; seafloor
		MEG Sc03 2in	High (95%)	Typical (50%)	FPSO; seafloor
		MEG Sc01 6in	Low (5%)	Typical (50%)	FPSO; seafloor
		MEG Sc03 6in	High (95%)	Typical (50%)	FPSO; seafloor

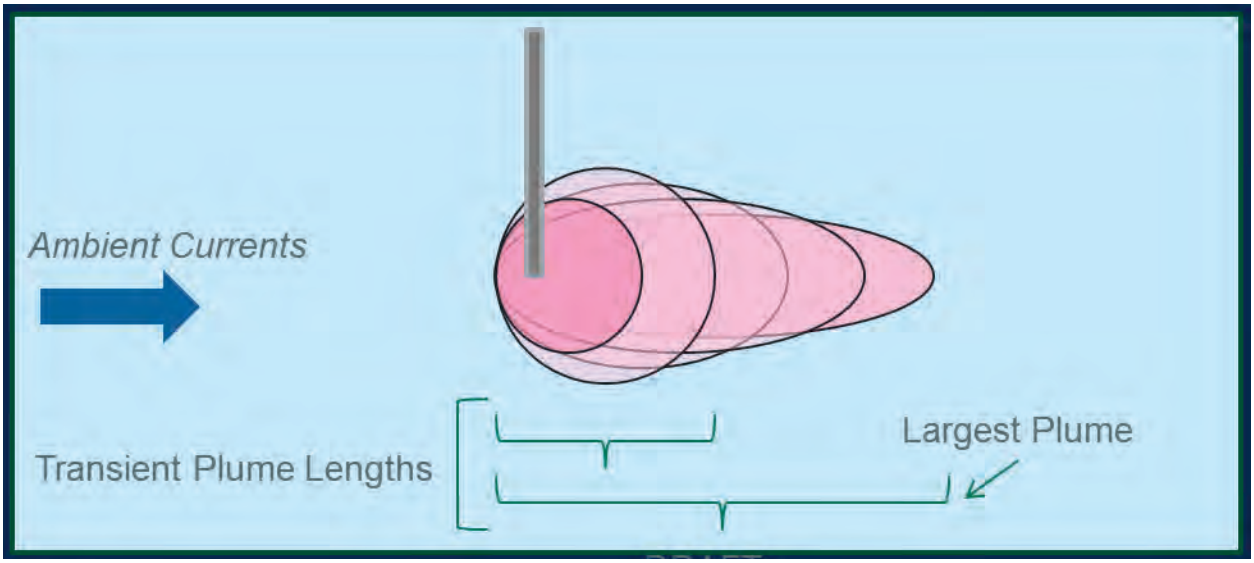
3.3 Standards and Thresholds

The cooling water discharges are typically regulated regionally with consideration of native aquatic species. These standards are more stringent in coastal and inland waters due to the presence of sensitive aquatic receptors and the limited area available for mixing. In offshore waters, such standards are usually absent. For this study, an internationally recognized thermal standard of 3°C maximum temperature change at 100 meters from the point of discharge was used. Hypochlorite, added to cooling water

to avoid biofouling, is either regulated as an end of pipe concentration or at the end of a mixing zone (100 meters in this case). However, the residual chlorine from the hypochlorite only poses risk to aquatic species if they are exposed to elevated concentrations for extended periods of time (72 to 96 hours). Although not technically applicable to a cooling water discharge, the IMO's 2012 Guidelines on Implementation of Effluent Standards and Performance Tests for Sewage Treatment Plants recommends that when chlorine is used as a disinfectant, the best technical practice is used to keep the disinfectant residual in the effluent below 0.5 mg/L.

The scenarios designed in this study are highly conservative (i.e., they assume extended periods of time during which ambient conditions - primarily currents, salinity and temperature) persist. This approach assumes a static plume which, in reality, will be transient in extent and configuration. For instance, the small ambient currents (5 percent bounding condition) will only exist for a short duration as these currents only exist for 5 percent of the total time. In actuality, the currents will increase and decrease, and the resulting plume will disperse more rapidly than the model predicts. Figure 3-4 shows a schematic of such a transient plume, where the extent and dilution continues to change as ambient currents decrease or increase. When modeling slower ambient current velocities (5 percent bounding condition), the analysis will predict a more concentrated plume. However, this plume will exist for only a short duration, as velocities will change (increase), increasing dilution. Furthermore, the directionality of these currents will change the orientation of this transient plume, resulting in regions around the discharge that are only exposed to increased concentrations (or temperatures) for short durations.

Figure 3-4 Transient Discharge Plume from Various Offshore Releases



Discharges such as produced water, hydrotest or sulfate removal and potable water processing brines are not subject to any regulatory standards for ambient water quality. The total concentration of oil and grease at the end of pipe is regulated by MARPOL

standards at a maximum monthly average of 29 milligrams per liter (mg/L) and a daily maximum of 42 mg/L. The USEPA compliance guidance document for the Gulf of Mexico (Final NPDES[5] General Permit for New and Existing Sources and New Discharges in the Offshore Subcategory of the Oil and Gas Extraction Category for the Western Portion of the Outer Continental Shelf of the Gulf of Mexico [GMG290000]) requires treatment chemicals such as biocides, corrosion inhibitors, or other chemicals used to prevent corrosion or fouling of piping or equipment to be limited by the following constraints:

- The maximum concentration and any other conditions specified in the USEPA product registration labelling, or
- The maximum manufacturer's recommended concentration, or
- 500 mg/L

At the time of the study, no manufacturer's recommended limits are available for constituents within the SRU processing brines, produced water or hydrotest water. It is noted that the maximum concentrations of any treatment chemicals in the discharge streams will be less than 500 mg/L.

With respect to the emergency black water discharge scenario, the IMO's 2012 Guidelines on Implementation of Effluent Standards and Performance Tests for Sewage Treatment Plants recommends the following standards for effluent discharge:

- TSS should not exceed 35 mg/L
- BOD_5 should not exceed 25 mg/L
- Thermotolerant coliforms should not exceed 100 CFU/100 ml

Since no ambient water quality standards exist or are applicable to the various offshore discharge streams except for the cooling water discharge, only percentage dilution values are reported at a reference distance of 100 meters.

3.4 Results

Each CORMIX simulation codes its results in a prediction (*.prd) file that consists of the plume centerline coordinates (0,0,0 at the discharge location), dilution (S) and concentrations. For thermal discharge (cooling water), concentration refers to the temperature rise above ambient and includes heat loss from the surface. For all other constituents, the dilution value does not include any decay and therefore represents a conservative (high) result. Inclusion of a decay term would result in a smaller plume. Since the concentrations are always the highest at the plume centerline, the results discussed here are shown as centerline concentrations at a particular distance directly down current from the discharge.

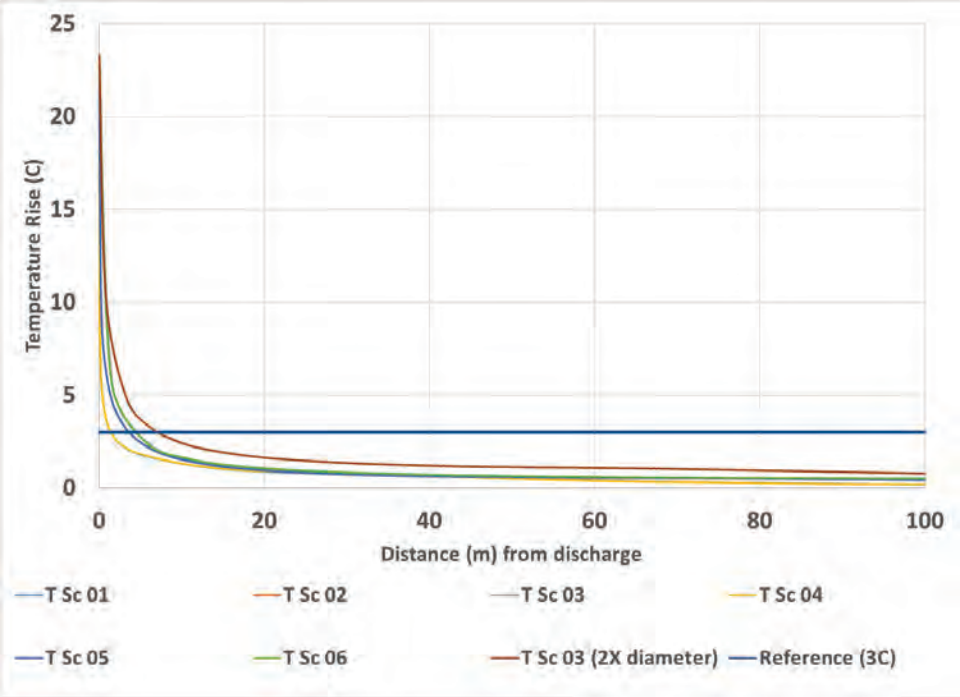
[5] National Pollutant Discharge Elimination System

3.4.1 Cooling Water

The design of the cooling water discharge structure, at this early stage of the Phase 2 Project, is not finalized. However, information from the Phase 1 Project is available that can be used as reference since both FPSOs will have similar overall design themes. The design will only consider pipe configurations that allow compliance with the thermal standard of temperature rise within 100 meters of the discharge to be less than 3°C. The Phase 1 design was based on this requirement and, as such, provides a good basis for use in Phase 2. Furthermore, the Phase 2 discharge rate is higher than that of Phase 1, so an additional configuration consisting of a larger pipe diameter was considered. Typically, larger pipes result in reduced exit velocity, resulting in reduced mixing; however, the release of the discharge above the water surface results in significant gravitational acceleration such that the loss in exit velocity from a larger pipe has a relatively small influence. Two ambient temperatures (1 percent and 99 percent) were selected for simulation because different ambient temperatures will influence the plume behavior and the effluent temperature rise.

Based on the initial assessments, Scenario 03 (summer – high ambient temperature and high ambient currents) was found to result in the longest thermal plume. This scenario was then re-run for a pipe diameter twice the size used for Phase 1. Even with the diameter doubled (4 times the area), the thermal plume complied with the reference standard of 3°C within 10 meters. Figure 3-5 shows the temperature rise diminishing with distance from the discharge, showing compliance with 3°C within 10 meters from the discharge for all scenarios.

Figure 3-5 Temperature Rise Above Ambient Versus Distance Downstream for All Scenarios



Compliance with the thermal discharge standard requires sufficient mixing within the immediate vicinity of the discharge. The pipe configurations designed to ensure compliance for thermal standards will therefore result in adequate mixing for the hypochlorite discharge as well. Since the thermal mixing at 100 meters results in the reduction of concentrations by a factor of at least 7.8 (=23.3 °C/3 °C), the residual chlorine concentrations resulting from hypochlorite addition will reduce by at least the same factor. For the scenarios considered here, the worst scenario (T Sc. 03 with 2X diameter) results in a dilution factor of 32.2 (=23.3 °C/0.72 °C). This means that for this same scenario, for a hypochlorite dosing of 5 parts per million (ppm), hypochlorite concentrations will be 0.16 ppm at 100 m. As noted earlier, these concentrations represent conservative estimates (i.e., peak values) and will be transient in nature.

3.4.2 Produced Water

Produced water is characterized by an elevated temperature, and concentrations of oil and grease and residual production and water treatment chemicals. Scale inhibitor and corrosion inhibitor were modeled at discharge concentrations of 100 ppm and 200 ppm, respectively, as examples of residual production chemicals that may exist as constituents in the produced water discharge. The pipe configuration (diameter and location) were assumed to be the same as used for Phase 1. Of the constituents of concern in produced water, only oil and grease end-of-pipe concentrations are regulated under MARPOL. The applicable standard is a maximum monthly average of 29 mg/L and a daily maximum of 42 mg/L, measured at the end of pipe. These

standards are applied prior to the release of produced water. The daily maximum value of 42 mg/L was used as the discharge concentration for this analysis. The thermal standard applied to cooling water (less than 3 °C temperature rise within 100 meters of the discharge) also applies to produced water. No ambient water quality standards exist for the other constituents.

Concentrations of oil and grease, scale inhibitor and corrosion inhibitor are shown for the three scenarios (see Table 3-7) in Figure 3-6, Figure 3-7 and Figure 3-8, respectively. Oil and grease concentration decreases to less 0.57 mg/L within 100 meters while scale inhibitor and corrosion inhibitor drop to less than 1.43 ppm and 2.9 ppm, respectively, within 100 meters. The same level of mixing is expected for temperature rise, as seen in Figure 3-9, where the temperature rise drops to less than 0.4°C within 100 meters.

Figure 3-6 Concentration of Oil and Grease (mg/L) with Distance (meters) from the Discharge for the Three Scenarios Modeled

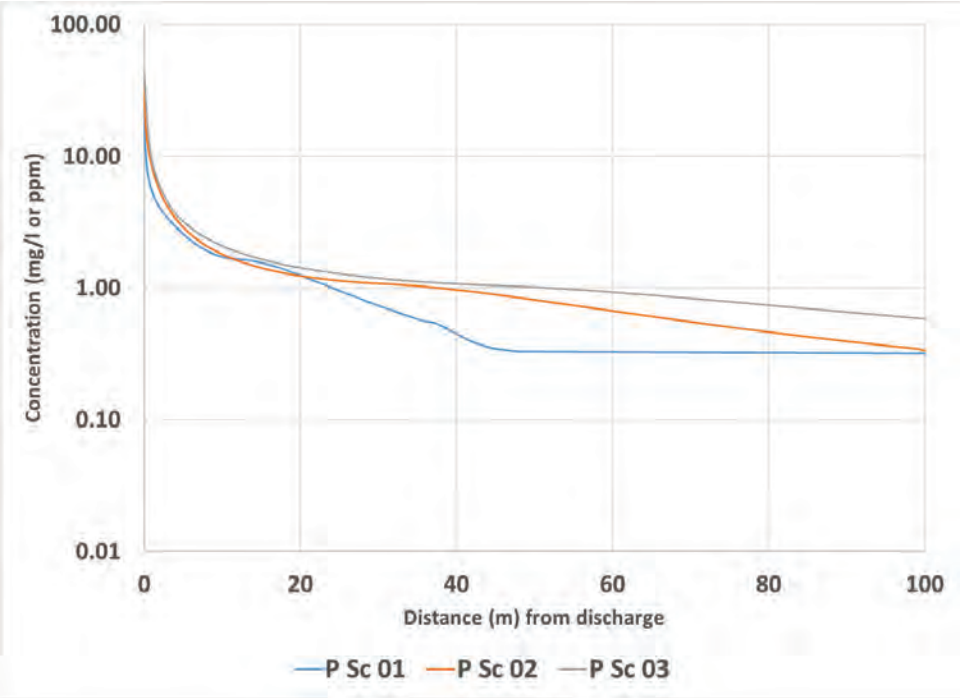


Figure 3-7 Concentration of Scale Inhibitor (ppm) with Distance (meters) from the Discharge for the Three Scenarios Modeled

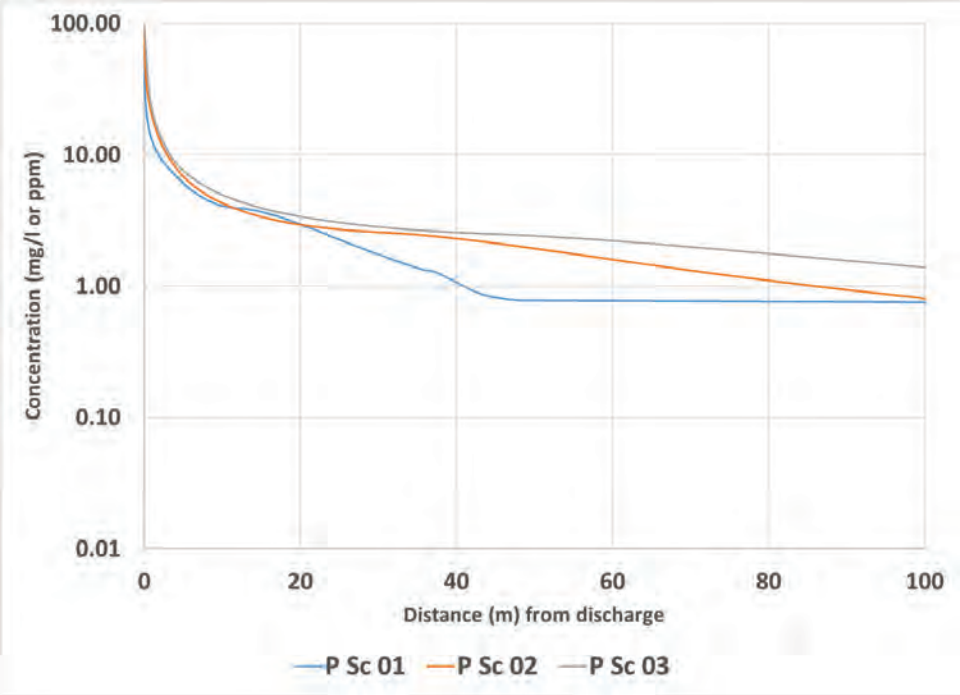


Figure 3-8 Concentration of Corrosion Inhibitor (ppm) with Distance (meters) from the Discharge for the Three Scenarios Modeled

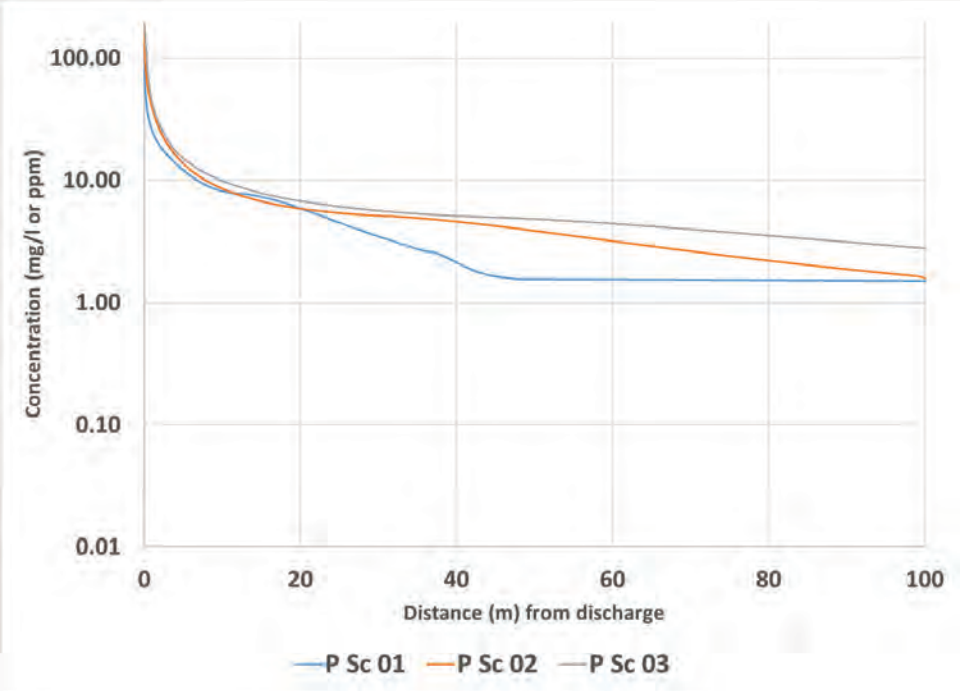
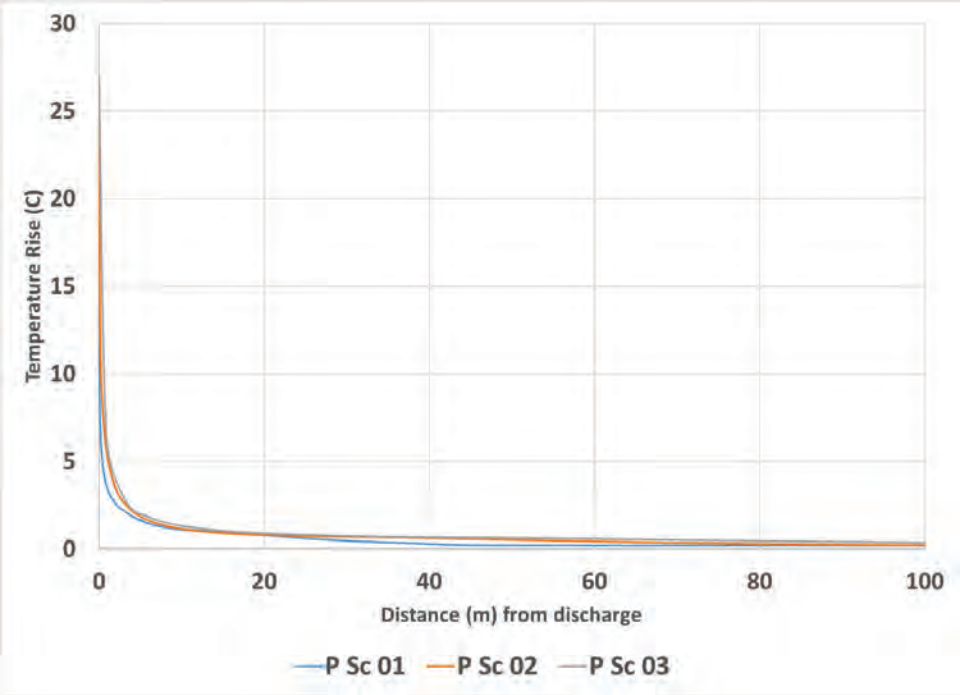


Figure 3-9 Temperature Rise with Distance (meters) from the Discharge for the Three Scenarios Modeled

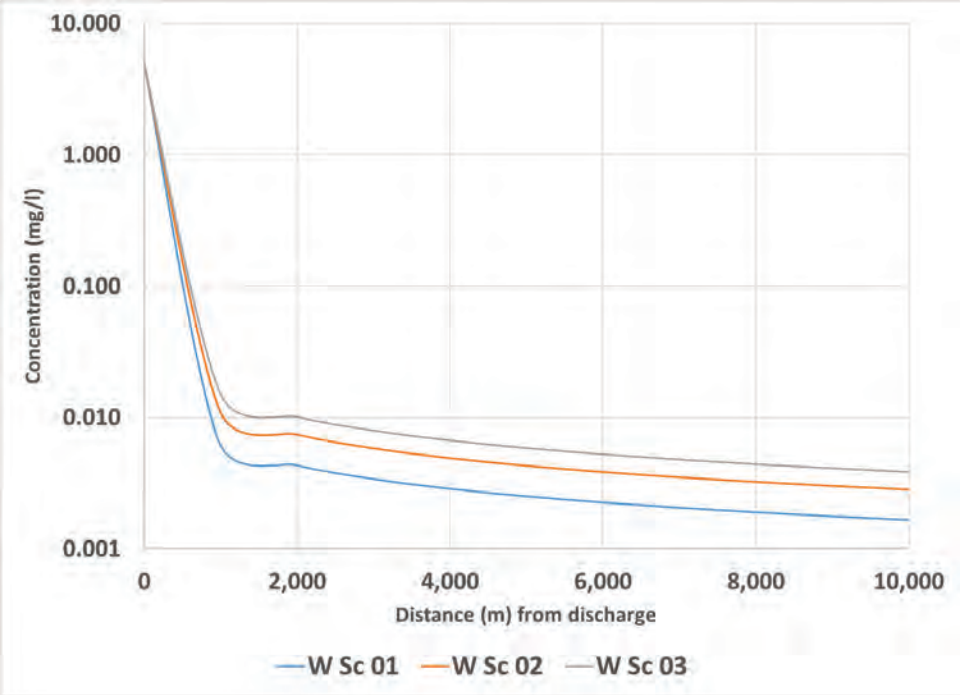


3.4.3 Sulfate Removal and Potable Water Processing Brines

This discharge stream consists of a combination of processing brines from the SRU and freshwater reverse osmosis. The main constituents are hypochlorite, electrolytes, biocides, oxygen scavenger and scale inhibitor. No ambient water quality standards exist for any of these constituents. It was assumed that the discharge pipe will not exceed a diameter of 12 inches, and that the stream will be released at least 2 meters above the water surface. Any pipe of smaller diameter will result in increased mixing and a smaller plume.

The predicted biocide concentrations for the three scenarios modeled (see Table 3-7) are shown in Figure 3-10. The biocide concentration decreases to 0.015 mg/L within 1,000 meters (99.7 percent reduction) for the worst case scenario (high ambient currents). All other constituents will follow the same mixing pattern and experience the same percent reduction.

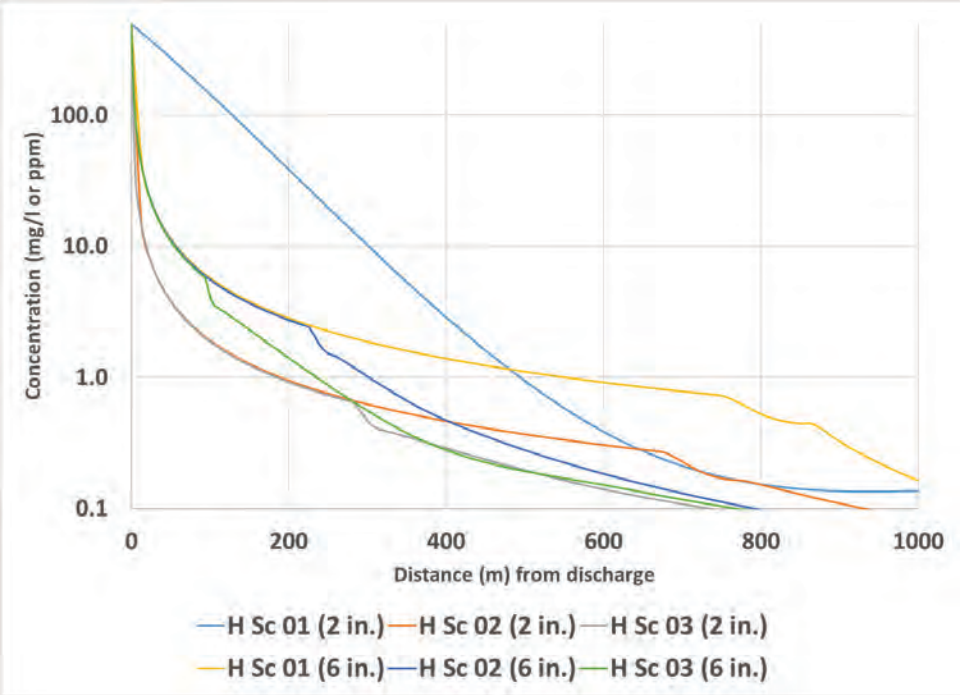
Figure 3-10 Concentration of Biocide (ppm) with Distance (meters) from the Discharge for the Three Scenarios Modeled



3.4.4 Hydrostatic Test Water

Hydrotesting will be conducted routinely for various pipeline and risers. All pipeline and riser volumes were considered for this analysis and the largest single release was selected for modeling. It was assumed that once testing is complete, the total volume will be released within 60 minutes. Since the pipelines and risers are of different diameters, all three scenarios were run for pipe diameters of 2 inches and 6 inches. Results for all three scenarios showing reduction in biocide concentration with the bounding pipe diameter cases are shown in Figure 3-11. For the worst case (H Sc. 01 with 6-inch pipe), biocide decreases to 5.5 ppm within 100 meters of the discharge. The H Sc. 01 scenario with a 2-inch pipe also will experience a similar mixing pattern, but CORMIX does not provide results at a higher resolution within the first 600 meters. The other constituents (oxygen scavenger and corrosion inhibitor) will follow the same mixing pattern and experience the same percent reduction.

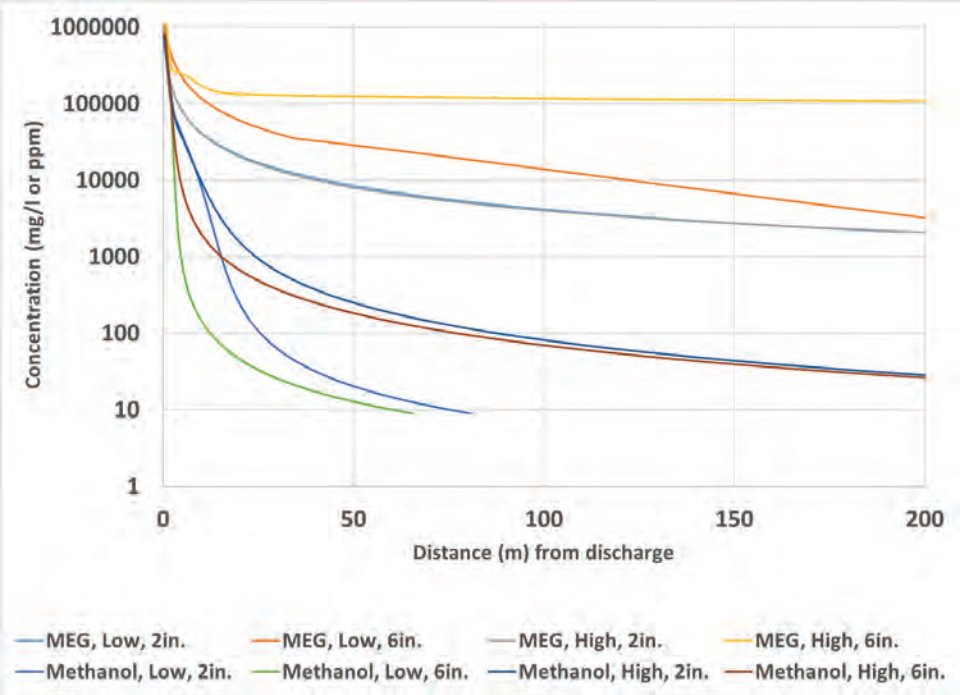
Figure 3-11 Concentration of Biocide (ppm) with Distance (meters) from the Discharge for the Three Scenarios and Two Pipe Diameters



3.4.5 Gas Injection Line Commissioning Fluids

As part of the gas injection line commissioning, a hydrate control fluid (concentrated methanol or ethylene glycol) will be discharged at the seafloor. The most probable volume for the hydrate control fluid will be 1,400 barrels (bbl), but a very conservative value of 2,500 bbl was assumed for the modeling analysis. Since the pipelines and risers are of different diameters, all three scenarios were run for pipe diameters of 2 inches and 6 inches. Figure 3-12 shows the results for both methanol and ethylene glycol under the low and high ambient currents and 2-inch and 6-inch pipe diameters.

Figure 3-12 Concentration of Methanol or MEG (ppm) with Distance (meters) from the Discharge for the Low and High Currents and 2-inch and 6-inch Pipe Diameters



3.4.6 Black Water

An emergency scenario where an upset occurs for the onboard black water treatment system was considered. Under this emergency scenario, it was assumed that untreated black water from accommodations and the clinic would bypass the macerator and the sewage holding tank and be discharged directly overboard through an emergency outfall. The FPSO is designed for a maximum of 160 persons on board (PoB); at an estimated 10 gallons/day/person, the sewage generation rate is 1,600 gallons/day. A contingency of 200% was applied to arrive at the modeled sewage generation and emergency discharge rate of 3,200 gallons/day.

Figure 3-13 shows the modeled maximum BOD_5 concentration across the model domain. As shown on the figure, there is no region in the modeling domain with a predicted BOD_5 concentration above 25 mg/L. Figure 3-14 shows the modeled maximum concentrations of TSS across the model domain. As shown on the figure, there is no region in the modeling domain with a predicted TSS concentration above 35 mg/L. Figure 3-15 shows the modeled maximum concentrations of coliform across the model domain. As shown on the figure, there is no region in the modeling domain with a predicted coliform concentration above 100 CFU/100 ml. Further analysis of modeling results indicates that by three hours after the cessation of the discharge, the coliform concentration drops to less than 1 CFU/100 ml.

Figure 3-13 Modeled Maximum Concentration of BOD_5 from an Untreated Black Water Discharge

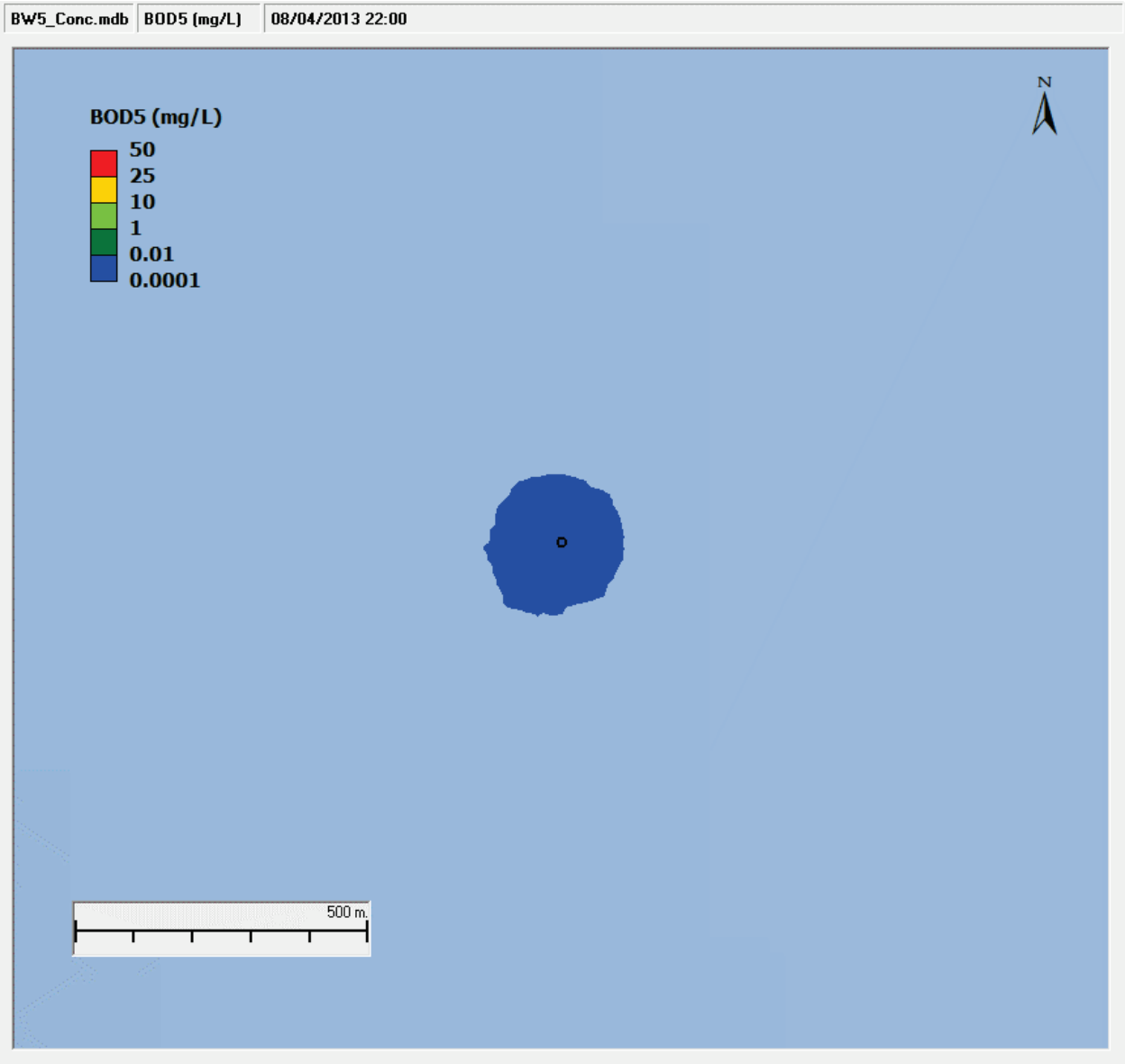


Figure 3-14 Modeled Maximum Concentration of TSS from an Untreated Black Water Discharge

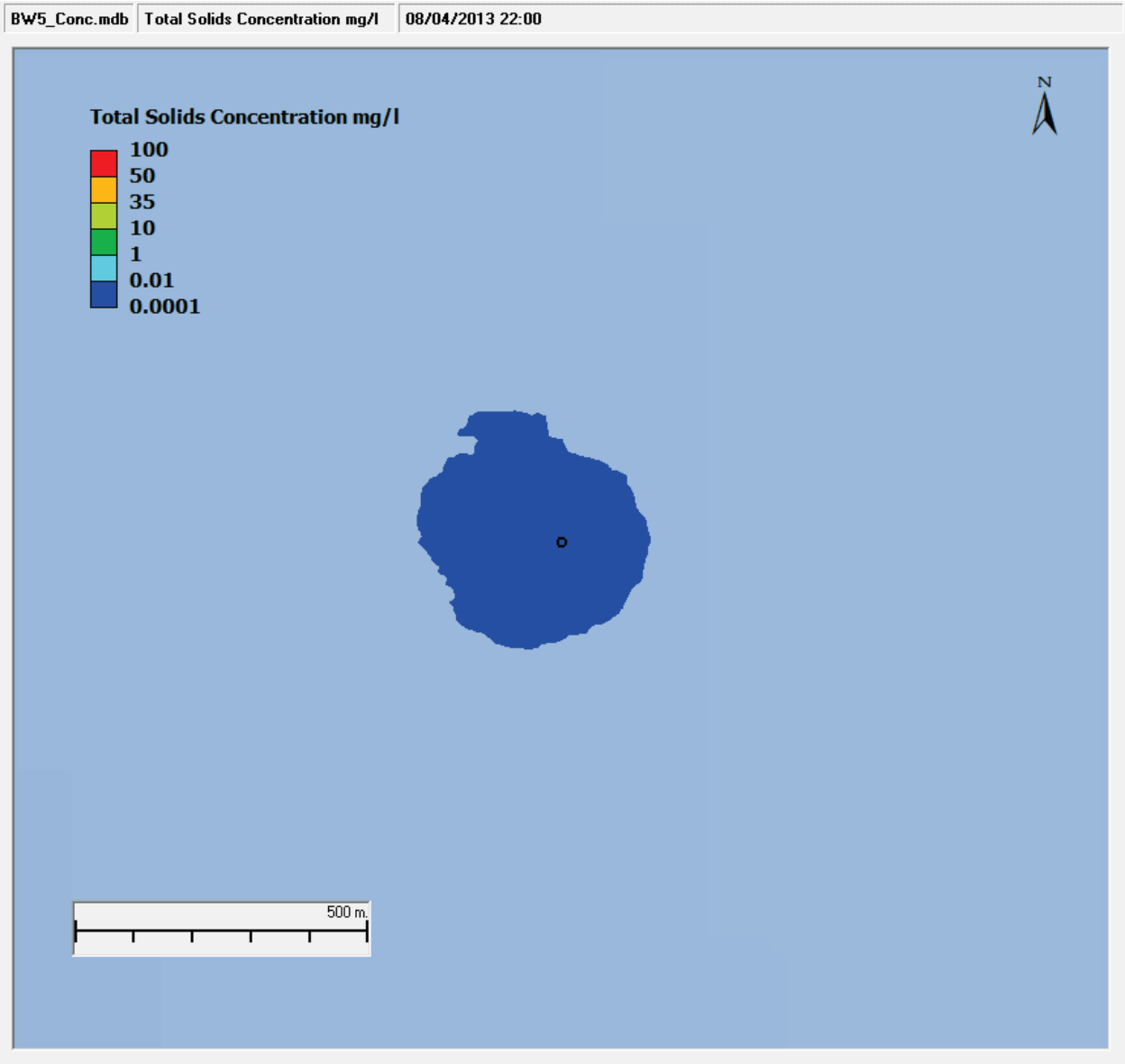
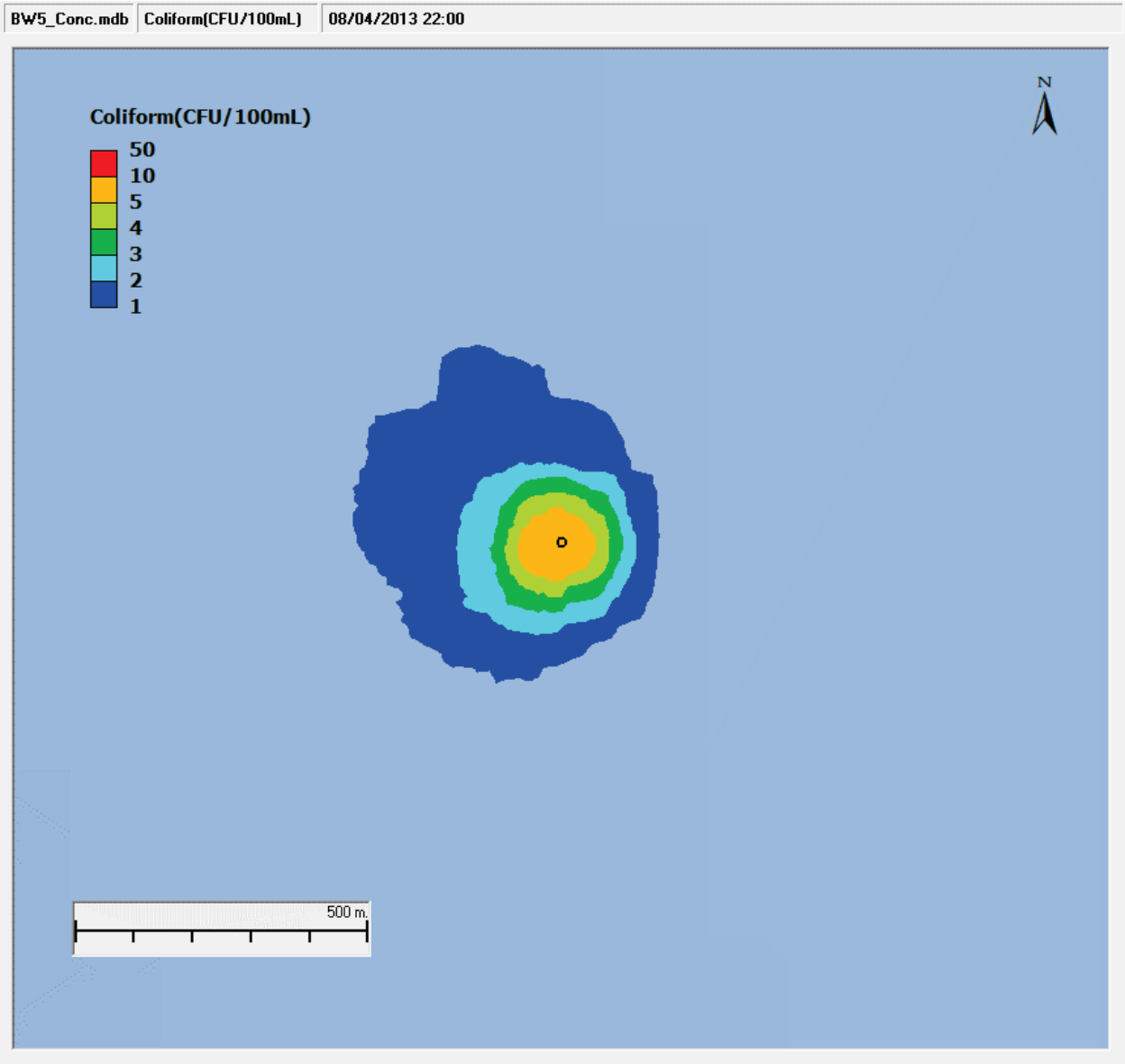


Figure 3-15 Modeled Maximum Concentration of Coliform Bacteria from an Untreated Black Water Discharge



3.5 Conclusions

The various operational and maintenance discharges and activities identified in the proposed project description were modeled to estimate the extent of the discharge plume. Extreme conditions and maximum expected discharge rates and concentrations were considered in this conservative analysis. The only relevant regulatory standard related to ambient water quality is for the thermal discharges: temperature rises within 100 meters of the discharge point are recommended to be less than 3°C. Since the Project is in a preliminary design phase, design specifications for the various discharge ports were not available. To address this lack of specific information, conservative estimates of the largest feasible pipe diameter were made, and modeling simulations

were used to confirm that these upper-bound diameters will allow the standard to be met.

CORMIX, a near-field mixing zone model approved by USEPA, was used to simulate the size and configuration of the mixing zones of the various discharges (aside from the untreated black water discharge). It was found that even under upper-bound conditions, discharge plumes were relatively small and subject to rapid mixing within the first 100 meters. Although only thermal discharges are subject to regulatory limits, the reference distance of 100 meters is used for reporting purposes for all the discharges to demonstrate the rapid mixing that the discharge plumes experience. Table 3-8 summarizes the results of the modeling study for the planned offshore discharges.

Additionally, based on modeling of an untreated black water discharge using the GEMSS model, maximum concentrations of BOD_5, TSS, and coliform remain below the thresholds of 25 mg/L, 35 mg/L, and 100 CFU/100 ml, respectively.

Table 3-8 Summary of Results of Modeling for Planned Offshore Discharges and Concentrations at 100-meter Reference Distance

No'	Discharge	Scenario Name	Discharge Concentration	Concentrations at 100 Meters[6]
1	**Cooling Water - Thermal**	**Worst Case**	Temperature: 50°C	Temperature Rise: <3°C
2	**Cooling Water - Hypochlorite**	**Worst Case**	Residual Chlorine: 5 ppm	Residual Chlorine: 0.16 ppm
3	**Sulfate Removal and Potable Water Processing Brines**[7]	**W Sc. 01**	Hypochlorite: 5 ppm Electrolyte: 1 ppm Biocide: 5 ppm Oxygen Scavenger: 10 ppm Scale Inhibitor: 5 ppm	Hypochlorite: 0.001 ppm Electrolyte: 0.001 ppm Biocide: 0.007 ppm Oxygen Scavenger: 0.013 ppm Scale Inhibitor: 0.007 ppm
		W Sc. 02	Hypochlorite: 5 ppm Electrolyte: 1 ppm Biocide: 5 ppm Oxygen Scavenger: 10 ppm Scale Inhibitor: 5 ppm	Hypochlorite: 0.002 ppm Electrolyte: 0.002 ppm Biocide: 0.011 ppm Oxygen Scavenger: 0.022 ppm Scale Inhibitor: 0.011 ppm
		W Sc. 03	Hypochlorite: 5 ppm Electrolyte: 1 ppm Biocide: 5 ppm Oxygen Scavenger: 10 ppm Scale Inhibitor: 5 ppm	Hypochlorite: 0.003 ppm Electrolyte: 0.003 ppm Biocide: 0.015 ppm Oxygen Scavenger: 0.030 ppm Scale Inhibitor: 0.015 ppm

[6] Note: Except for the thermal discharge (temperature rise), no standards exist for any discharge constituents. The distance of 100 meters is used as a widely accepted reference distance and should not be interpreted as a criterion for regulatory compliance.

[7] Values reported at 1,000 meters as detailed results within 1,000 meters are not available from CORMIX

No'	Discharge	Scenario Name	Discharge Concentration	Concentrations at 100 Meters[6]
4	**Produced Water**	**P Sc. 01**	Temperature: 55°C Oil and Grease: 42 mg/L Scale Inhibitor: 100 ppm Corrosion Inhibitor: 200 ppm	Temperature Rise: <3°C Oil and Grease: 0.314 mg/L Scale Inhibitor: 0.75 ppm Corrosion Inhibitor: 1.5 ppm
		P Sc. 02	Temperature: 55°C Oil and Grease: 42 mg/L Scale Inhibitor: 100 ppm Corrosion Inhibitor: 200 ppm	Temperature Rise: <3°C Oil and Grease: 0.34 mg/L Scale Inhibitor: 0.81 ppm Corrosion Inhibitor: 1.62 ppm
		P Sc. 03	Temperature: 55°C Oil and Grease: 42 mg/L Scale Inhibitor: 100 ppm Corrosion Inhibitor: 200 ppm	Temperature Rise: <3°C Oil and Grease: 0.59 mg/L Scale Inhibitor: 1.41 ppm Corrosion Inhibitor: 2.82 ppm
5	**Hydrotest**	**H Sc. 01**	Biocide (6-inch pipe): 500 ppm Biocide (2-inch pipe): 500 ppm	Biocide (6-inch pipe): 5.74 ppm Biocide (2-inch pipe): 1.87 ppm
		H Sc. 02	Biocide (6-inch pipe): 500 ppm Biocide (2-inch pipe): 500 ppm	Biocide (6-inch pipe): 5.58 ppm Biocide (2-inch pipe): 1.92 ppm
		H Sc. 03	Biocide (6-inch pipe): 500 ppm Biocide (2-inch pipe): 500 ppm	Biocide (6-inch pipe): 4.21 ppm Biocide (2-inch pipe): 1.88 ppm
6	**Hydrate Control Fluid**	**Methanol Sc01 2in**	Methanol (2-inch pipe): pure chemical at 800 kg/m^3	Methanol (2-inch pipe): 8.83 ppm
		Methanol Sc03 2in	Methanol (2-inch pipe): pure chemical at 800 kg/m^3	Methanol (2-inch pipe): 8.91 ppm
		Methanol Sc01 6in	Methanol (6-inch pipe): pure chemical at 800 kg/m^3	Methanol (6-inch pipe): 81.43 ppm
		Methanol Sc03 6in	Methanol (6-inch pipe): pure chemical at 800 kg/m^3	Methanol (6-inch pipe): 70.69 ppm

No'	Discharge	Scenario Name	Discharge Concentration	Concentrations at 100 Meters[6]
		MEG Sc01 2in	MEG (2-inch pipe): pure chemical at 1,115 kg/m^3	MEG (2-inch pipe): 4,190 ppm
		MEG Sc03 2in	MEG (2-inch pipe): pure chemical at 1,115 kg/m^3	MEG (2-inch pipe): 4,023 ppm
		MEG Sc01 6in	MEG (6-inch pipe): pure chemical at 1,115 kg/m^3	MEG (6-inch pipe): 1,049 ppm
		MEG Sc03 6in	MEG (6-inch pipe): pure chemical at 1,115 kg/m^3	MEG (6-inch pipe): 116,999 ppm

4.0 CUMULATIVE IMPACTS

The Phase 2 Project will initiate after the Phase 1 Project, and activities for these two Projects will overlap in time. Although the two FPSOs are approximately 8.5 kilometers apart, modeling was conducted to assess whether there is a potential for cumulative impacts on water quality due to offshore discharges from the respective developments. The CORMIX model considered to evaluate individual discharges is limited in its ability to appropriately include other local or regional discharges, and the resulting plume interactions. To address this limitation, and to appropriately quantify cumulative impacts from the two FPSOs, a separate 3D hydrodynamic and water quality model was applied. The GEMSS model is capable of simulating temporally and spatially varying conditions, and can incorporate any number of discharges into one single model simulation. This section describes the use, application and results of the GEMSS model for the cumulative impacts analysis.

4.1 GEMSS

GEMSS is an integrated system of three-dimensional hydrodynamic and transport modules embedded in a geographic information and environmental data system. GEMSS is in the public domain and has been used by the USBR, Washington State Department of Ecology, the Norwegian Institute of Water Research, the Royal Institute of Sweden, and other international organizations.

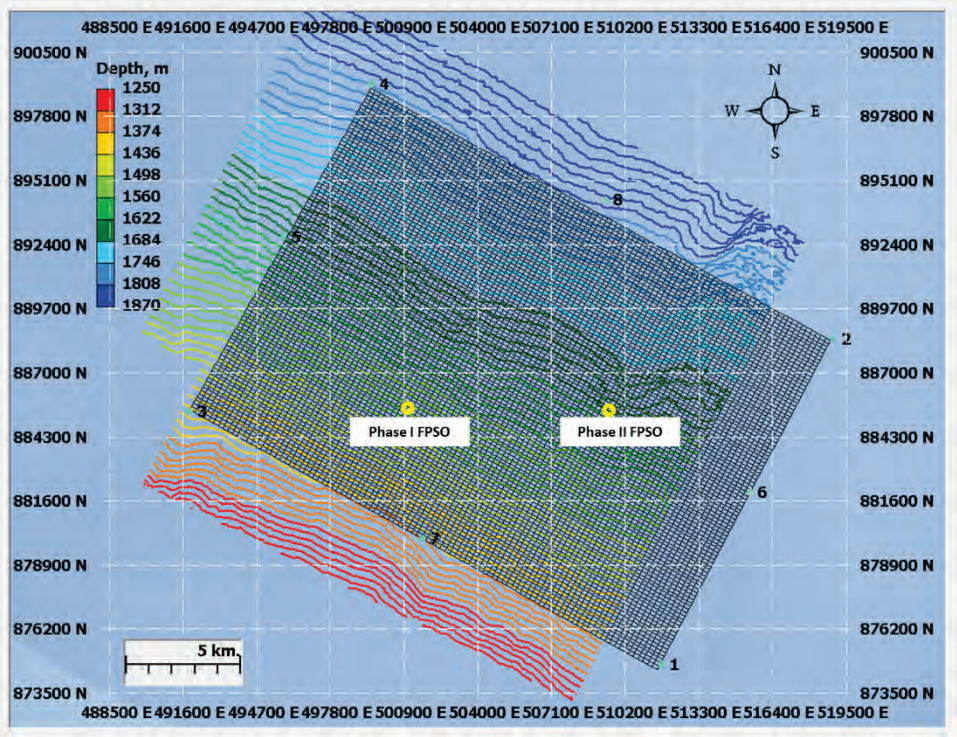
The theoretical basis of the hydrodynamic kernel of GEMSS is the three-dimensional Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport (GLLVHT) model which was first presented in Edinger and Buchak (1980) and subsequently in Edinger and Buchak (1985). The GLLVHT computation has been peer reviewed and published (Edinger and Buchak 1995; Edinger et al. 1994 and 1997; Edinger and Kolluru 1999). The kernel is an extension of the well-known longitudinal-vertical transport model written by Buchak and Edinger (1984) that forms the hydrodynamic and transport basis of the United States Army Corps of Engineers' water quality model CE-QUAL-W2 (U. S. Army Engineer Waterways Experiment Station 1986). Improvements to the transport model, construction of the constituent modules, incorporation of supporting software tools, GIS interoperability, visualization tools, graphical user interface, and post-processors have been developed by Kolluru et al. (1998; 1999; 2003a; 2003b).

GEMSS and its component modules have met agency approval among federal and state governments within the United States. GEMSS has also been approved by regulatory agencies in the Bahamas, Qatar, India, Australia, Canada, and other countries.

4.2 Model Domain

A three-dimensional model such as GEMSS requires specification of a model domain that defines the boundaries of the region of interest. Based on the CORMIX modeling assessment, the region of interest around each of the FPSO discharges is very small due to the small sizes of the plumes. However, for the cumulative impact assessment, it is important to have a model domain that covers the region including all operational discharges (i.e., both FPSOs). The model domain, therefore, was selected as a region that would cover the two FPSOs and have sufficient region beyond these FPSOs to allow discharge plume spreading. The model domain, including the model computational grid, location of the FPSOs and the regional bathymetry, is shown in Figure 4-1. The selected model domain is large enough to accommodate all operational discharges from the two FPSOs to assess cumulative impacts within a single model simulation.

Figure 4-1 Cumulative Impact Assessment Model Domain and Computational Grid



4.3 Model Setup

As discussed in Section 3, there are several discharges from each FPSO. All of these discharges were included within a single GEMSS model simulation. Inclusion of all of these discharges for both FPSOs affords the ability to perform a cumulative impact assessment by determining the extent of overall discharge plumes. The main constituent of concern was the temperature rise above ambient, as there is thermal load associated with cooling water streams and produced water discharge from both FPSOs. There is

potential for overlap of the thermal discharge plume near each FPSO, as the two plumes from cooling water and produced water may theoretically interact, and the combined plume from individual FPSOs may experience further overlap. Although the individual assessments of the discharges performed in Section 3 show relatively small extents for these plumes, the lower values (<3°C) may combine to reach levels above 3°C. Both cooling water and produced water discharges were included in the model. Furthermore, the sulfate removal and potable water process brines discharges release relatively large amounts of water, and thus were also included in the model.

The model was configured such that the boundaries of the model computation grid received available time-varying temperature and salinity data from the HYCOM model and available time-varying water surface elevations from the SAT-OCEAN model. These data provide the necessary input for the GEMSS model to perform hydrodynamic and transport computations within the model computational domain. Each of the discharges were specified to the details available as shown in Table 4-1.

Table 4-1 List of discharges and their characteristics included in the GEMSS model

Offshore Discharge	Phase 1 FPSO	Phase 2 FPSO
Cooling Water		
Flow (kBPD)	227	1,600
Temperature, °C	50	50
Produced Water		
Flow (kBPD)	114	300
Temperature, °C	55	55
Oil and Grease (mg/L)	42	42
Sulfate Removal and Potable Water Processing Brines		
Flow (kBPD)	100	265
Hypochlorite (ppm)	1	1

kBPD = thousand barrels per day

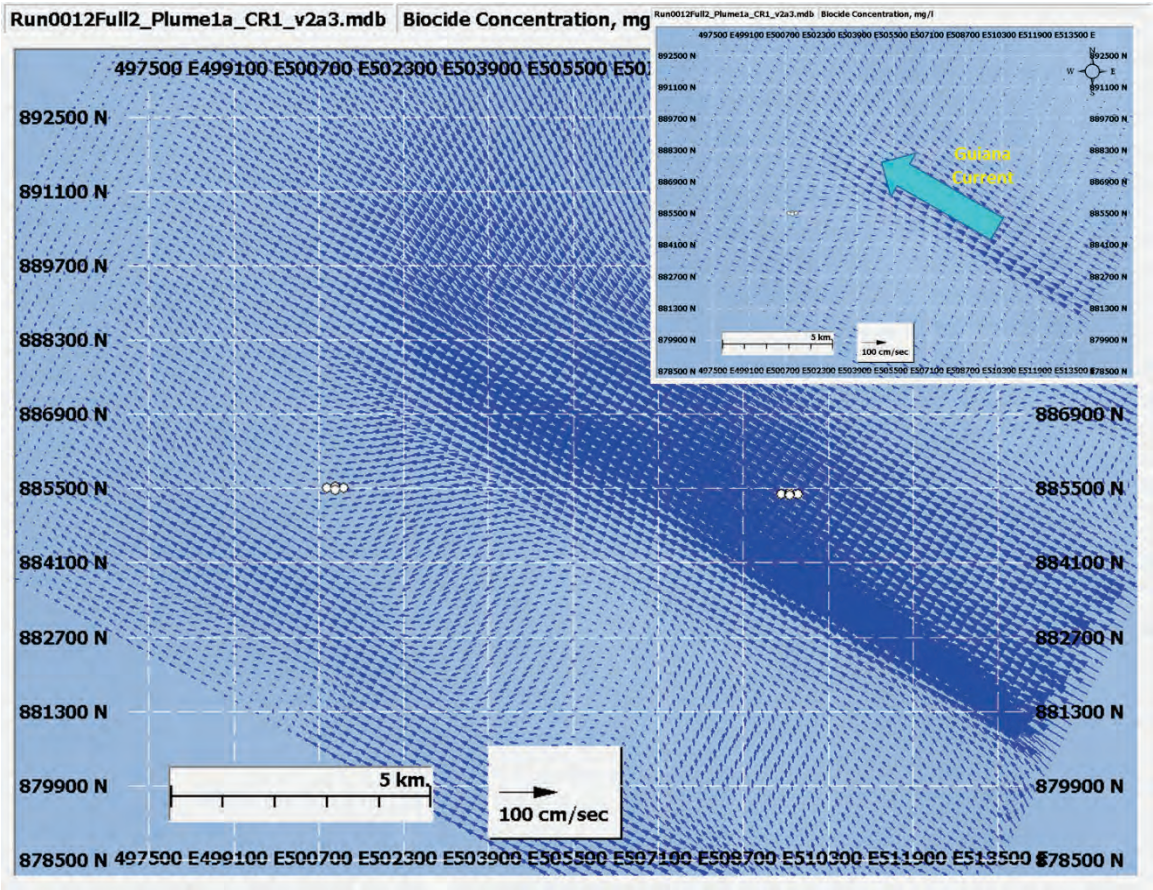
The model was run for a period of 28 days that included a period of 7 days for model "spin-up". Model spin-up is defined as a time during which the computational model ramps up from stagnant condition to realistic conditions as forced by the conditions specified at the boundaries. All model results were summarized statistically to obtain worst conditions (i.e., maximum concentrations during the entire model simulation period).

4.4 Model Results

The model, under conditions specified through the boundaries, provided results that consisted of currents, water surface elevations, temperature, salinity, temperature rise above ambient, oil and grease, hypochlorite, and a dye constituent. Dye constituent was included in the model simulation such that concentrations of additional constituents, if needed, could be estimate by scaling the dye concentrations to the discharge values. The

modeled currents were consistent with the known circulation pattern in the region (Section 6.4.2.1). The results show a strong Guiana Current toward the northwest.

Figure 4-2 Snapshot of Modeled Hydrodynamics within the GEMSS Model Domain



Note: The two groups of white dots denote the locations of the two FPSOs. Main image shows full resolution and inset shows lower resolution to demonstrate overall circulation patterns and strength.

4.4.1 Temperature Rise

As noted earlier, the key constituent of concern is the temperature rise above ambient. The reference standard of no more than 3°C above ambient beyond 100 meters was used to evaluate if any region within the entire computational domain (outside of the 100m distance from each FPSO discharge) was predicted to experience a temperature rise above 3°C. To evaluate if such a condition exists, the statistical maxima of the temperature rises above ambient were computed during the entre model simulation period. Note that the map showing the statistical maxima only shows the maximum values, but this does not mean these maximum values occurred at the same time. Different maximum values at different locations could have occurred at different times during the simulation period. However, they can still be evaluated within a single map to evaluate the potential of any region reaching the maximum temperature rise above ambient.

Figure 4-3 shows the maximum temperature rise above ambient across the model domain. The color scale uses a hybrid approach, where all temperature rise iso-lines below 3°C are unfilled, and all temperature rise iso-lines above 3°C are filled with a designated color. As shown on the map, there is no region in the modeling domain with a predicted temperature rise above 3°C. The blue iso-lines that extend between the two FPSOs denote a 0.05°C temperature rise. Individual snapshots (representing actual predicted conditions across the domain at a given time) show the plumes much smaller than what is shown below; Figure 4-4 shows four such snapshots. Based on these results, it is clear that no thermal plume overlapping occurs and that both FPSOs operating concurrently will result in conditions that adhere to the less than 3°C temperature rise beyond 100 meters reference standard.

Figure 4-3 Modeled Maximum Temperature Rise above Ambient when All Discharges (Both FPSOs with Cooling Water and Produced Water) are Operational

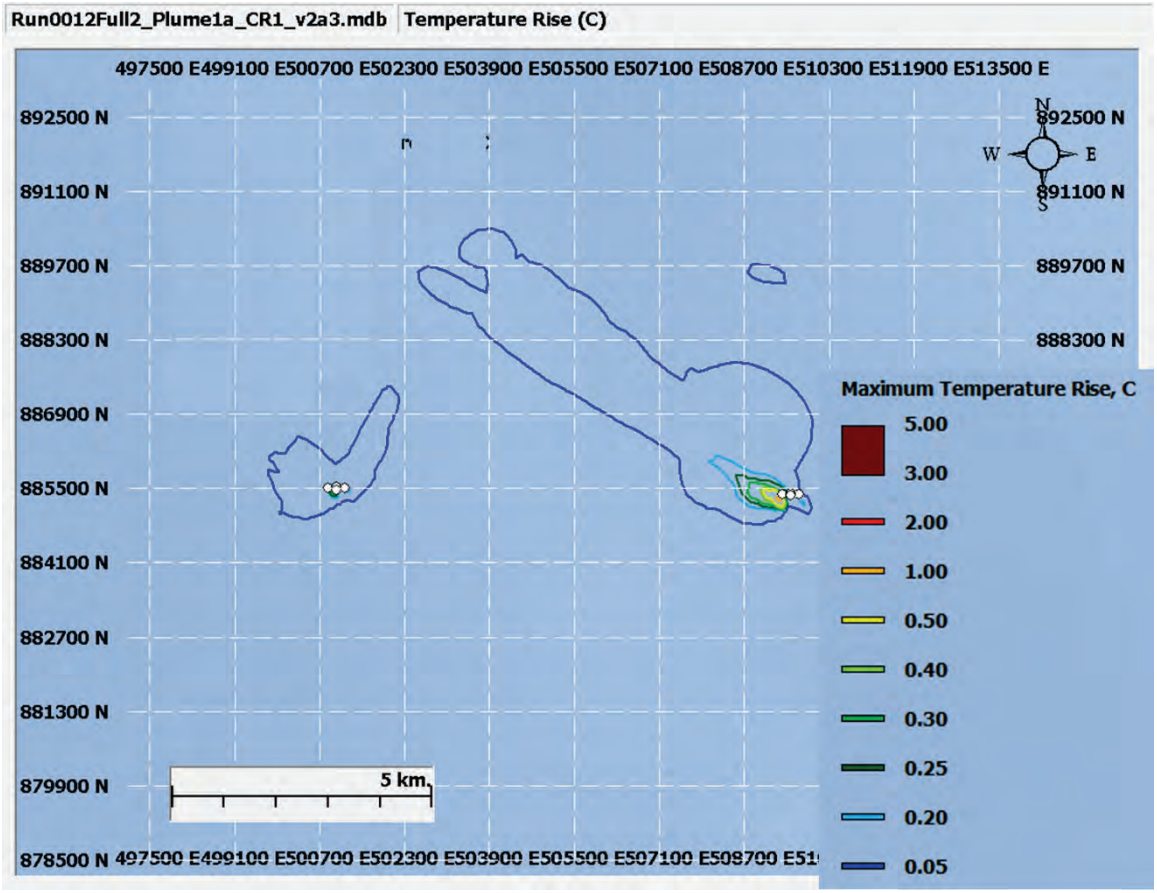
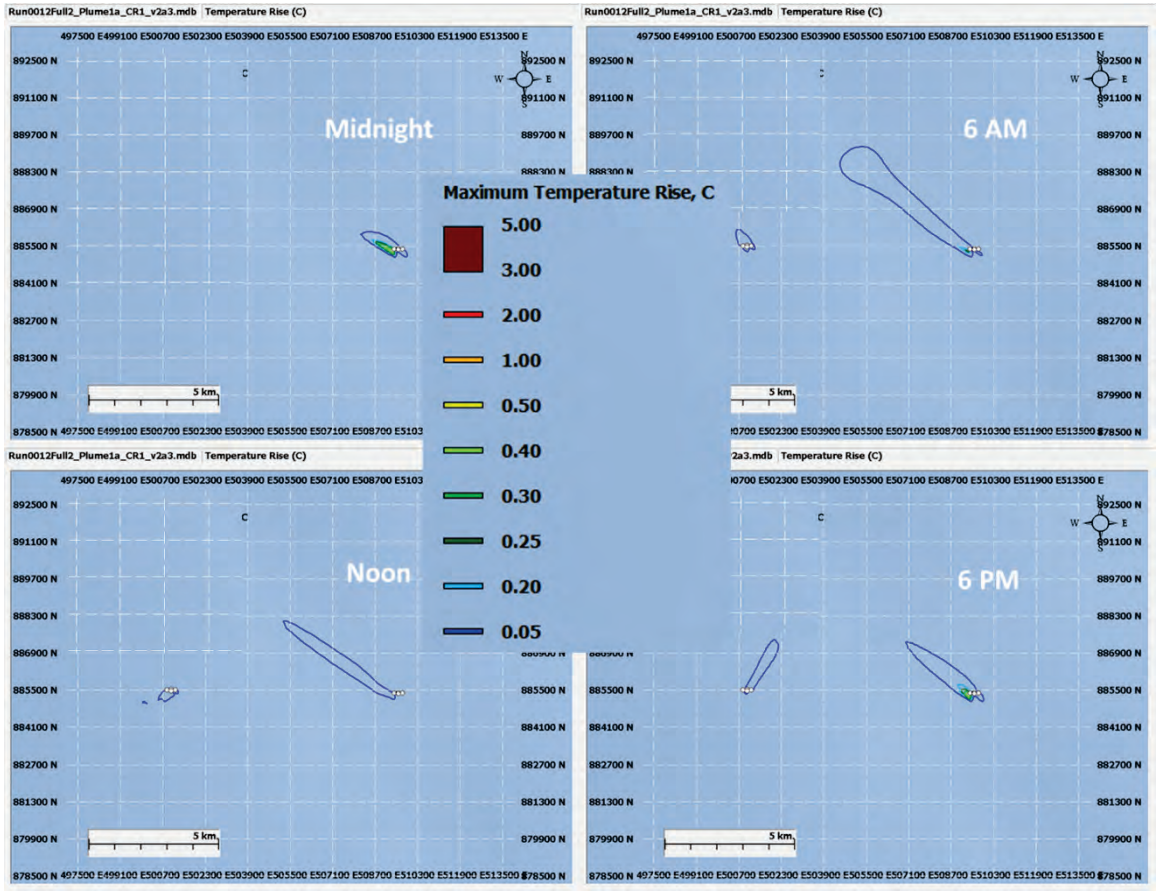


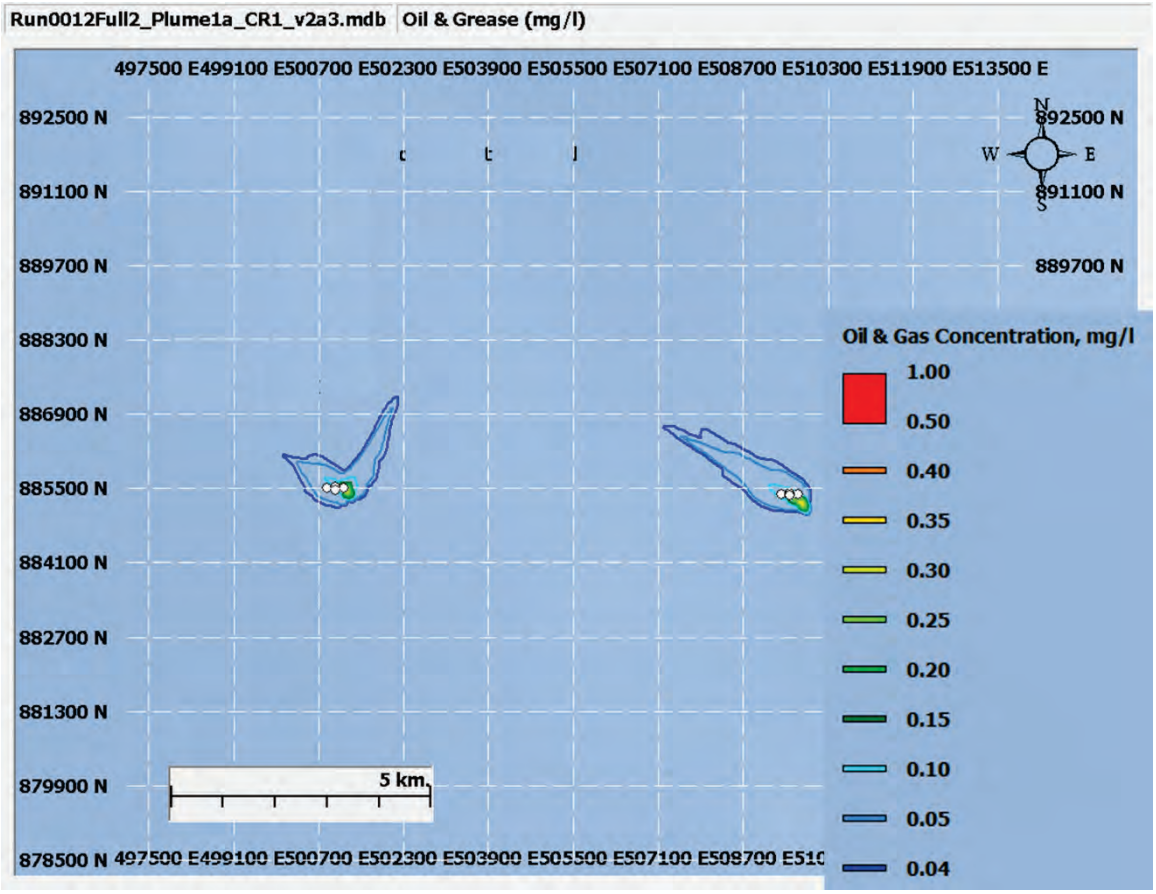
Figure 4-4 Modeled Time-Varying Temperature Rise above Ambient at Different Times (Every 6 Hours) during a Day



4.4.2 Oil and Grease

Oil and grease is a constituent within the produced water limited at a daily maximum value of 42 mg/L. Similar to the temperature rise above ambient, oil and grease experience rapid dilution and mixing, with no overlap between the discharges of the two FPSOs. Figure 4-5 shows the modeled maximum concentration of oil and grease in the model domain. The outermost iso-lines extending from each FPSO (0.04 mg/L) are more than 5 kilometers apart.

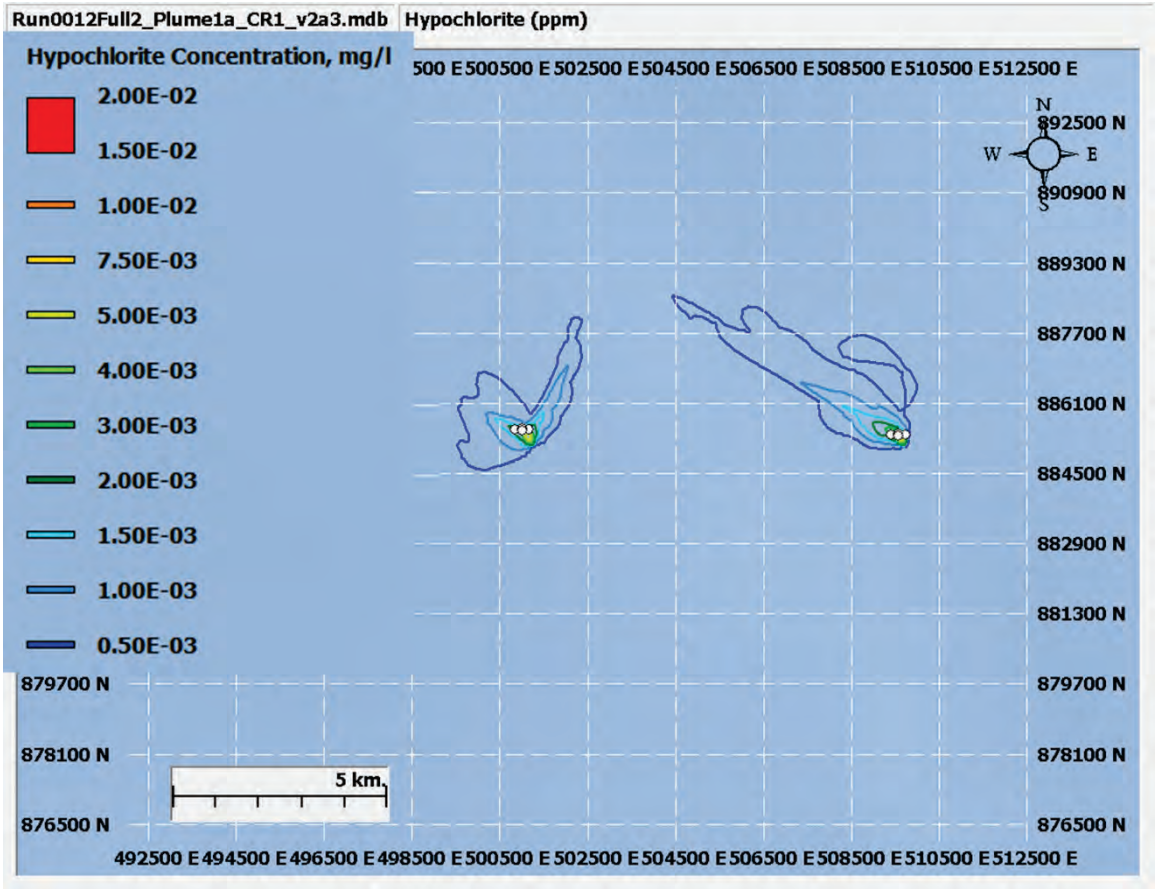
Figure 4-5 Modeled Maximum Oil and Grease Concentrations from Produced Water Streams of Both FPSOs



4.4.3 Hypochlorite

Hypochlorite is a constituent included in both cooling water and sulfate removal and potable water processing brines discharge. As noted earlier, there are no standards for hypochlorite in offshore waters. Similar to temperature rise and oil and grease, hypochlorite experiences rapid dilution and mixing once discharged. Figure 4-6 shows the maximum modeled concentrations of hypochlorite during operation of both FPSOs. The color scale is chosen to show the modeled plume and its potential to overlap. The color scale range is 0.0025 ppm to 0.1 ppm and even at these low values, there is no plume overlap.

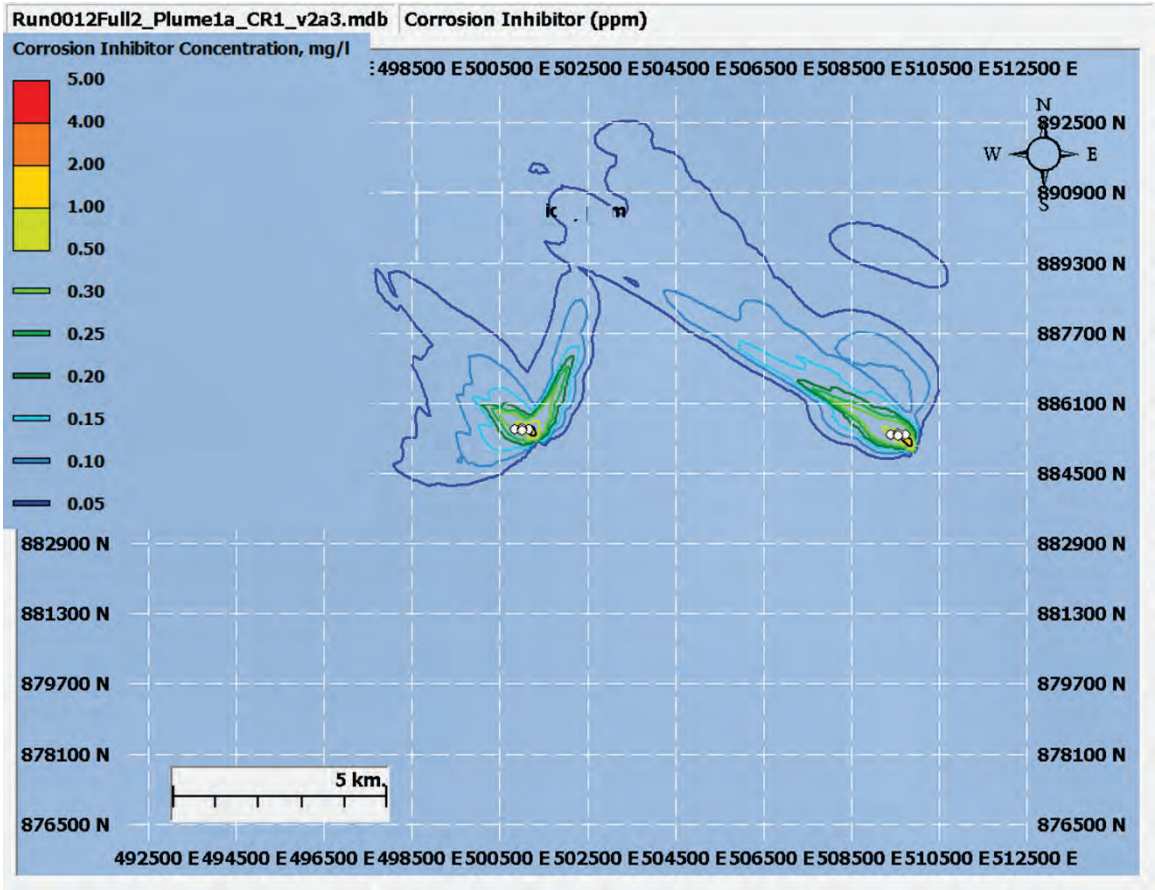
Figure 4-6 Modeled Maximum Concentrations of Hypochlorite during Operation of Both FPSOs



4.4.4 Other Chemicals

In addition to temperature rise, oil and grease and hypochlorite, the various discharge streams include other production chemicals such as corrosion inhibitor and scale inhibitor. None of these constituents have any regulatory standards and experience similar rapid mixing and dilution as the other constituents described above. The plumes rarely overlap, even at extremely low concentrations. An example of modeled maximum concentrations for corrosion inhibitor is shown in Figure 4-7, where only the lowest iso-lines in the color scale (0.05 ppm) show minimal overlap.

Figure 4-7 Modeled Maximum Concentrations of Corrosion Inhibitor



4.5 Conclusions

Spatially and time-varying modeling of cumulative impacts due to multiple discharges from each FPSO was performed using the GEMSS model. The modeling included the major operational discharges and assessed the potential for plumes from the two FPSOs to overlap and result in cumulative impacts. None of the plumes constituents that were included in the assessment (see Table 3-4) showed overlaps. The only constituent with a reference standard (<3°C above ambient beyond 100 meters) is temperature rise. With both FPSOs operating, and each FPSO discharging both produced water and cooling water (both of which add a thermal load), there was no overlap in plumes, even when the "plume" from each FPSO was defined as a temperature rise as low as 0.05 °C. Based on the results of the detailed modeling of all discharges, the significance of cumulative impacts on water quality from simultaneous operation of the Phase 1 and Phase 2 FPSOs is considered negligible.

5.0 REFERENCES

British Oceanographic Data Centre (BODC). 2014. The GEBCO_2014 Grid, version 20150318. Available at: www.gebco.net

Buchak, E. M. and J. E. Edinger. 1984. Generalized, Longitudinal-Vertical Hydrodynamics and Transport: Development, Programming and Applications. Prepared for U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss. Contract No. DACW39-84-M-1636. Prepared by J. E. Edinger Associates, Wayne, PA. Document No. 84-18-R. June.

Edinger, J. E. and E. M. Buchak. 1980. Numerical Hydrodynamics of Estuaries in Estuarine and Wetland Processes with Emphasis on Modeling, (P. Hamilton and K. B. Macdonald, eds.). Plenum Press, New York, New York, pp. 115 146.

_____. 1985. Numerical Waterbody Dynamics and Small Computers. Proceedings of ASCE 1985 Hydraulic Division Specialty Conference on Hydraulics and Hydrology in the Small Computer Age. American Society of Civil Engineers, Lake Buena Vista, FL. Aug. 13-16.

_____. 1995. Numerical Intermediate and Far Field Dilution Modelling. Journal Water, Air and Soil Pollution 83: 147-160, 1995. Kluwer Academic Publishers, The Netherlands.

Edinger, J. E., E. M. Buchak, and M. D. McGurk. 1994. Analyzing Larval Distributions Using Hydrodynamic and Transport Modelling. Estuarine and Coastal Modeling III. American Society of Civil Engineers, New York.

Edinger J.E., J. Wu and E.M. Buchak. 1997. Hydrodynamic and Hydrothermal Analyses of the Once-through Cooling Water System at Hudson Generating Station. Prepared for Public Service Electric and Gas (PSE&G). Prepared by J. E. Edinger Associates, Inc., June 1997.

Edinger, J. E., V. S. Kolluru, 1999. “Implementation of Vertical Acceleration and Dispersion Terms in an Otherwise Hydrostatically Approximated Three-Dimensional Model.” In Spaulding, M.L, H. L. Butler (eds.). Proceedings of the 6th International Conference on Estuarine and Coastal Modeling. pp. 1019 – 1034.

Ellis, D., C. Heim. 1985. Submersible surveys of benthos near a turbidity cloud. Marine Pollution Bulletin, 16(5), 197-203.

Fichera, M. J., and V. S. Kolluru. 2007. GEMSS-GIFT: A comprehensive sediment discharge and transport modelling system. SETAC North America 28th Annual Meeting, 11-15 November 2007

Fichera, M. J., V. S. Kolluru, C. Buahin, C. Reed, 2013. A Comprehensive Modelling Approach for EIA Studies in Oil and Gas Industry. Poster presentation at the 2013 International Association of Impact Assessment Conference on Impact Assessment: The Next Generation, 13-16 May 2013, Calgary, Alberta, Canada.

FUGRO EMU Limited. 2016. Environmental Baseline Survey Report. Liza Development, Offshore Guyana. Prepared for Esso Exploration and Production Guyana Ltd. March 2016.

International Maritime Organization (IMO). 2006. International Regulations (MARPOL 73/78). "Revised Guidelines on Implementation of Effluent Standards and Performance Tests for Sewage Treatment Plants." Annex 26. Resolution MEPC.159(55). Adopted on 13 October 2006. MEPC 55/23.

Kolluru, V. S., E. M. Buchak and J. E. Edinger. 1998. Integrated Model to Simulate the Transport and Fate of Mine Tailings in Deep Waters. In *Proceedings of the Tailings and Mine Waste 1998*. Balkema Press Rotterdam.

Kolluru, V. S., E. M. Buchak, J. Wu, 1999. "Use of Membrane Boundaries to Simulate Fixed and Floating Structures in GLLVHT." In Spaulding, M.L, H.L. Butler (eds.). Proceedings of the 6th International Conference on Estuarine and Coastal Modeling. pp. 485 – 500.

Kolluru, V. S., J. E. Edinger, E. M. Buchak and P. Brinkmann 2003a. "Hydrodynamic Modeling of Coastal LNG Cooling Water Discharge." Journal of Energy Engineering. Vol. 129, No. 1, April 1, 2003. pp 16 – 31.

Kolluru, V.S. and M.J. Fichera, 2003b. "Development and Application of Combined 1-D and 3-D Modeling System for TMDL Studies." Proceedings of the Eighth International Conference on Estuarine and Coastal Modeling. American Society of Civil Engineers. pp. 108-127, 2003.

Kolluru, V.S. and M.L. Spaulding, 1993. SEASHELL - Software for the Simulation of Fate and Transport of pollutants in Coastal Waters. In Proceedings of the 3rd International Conference of Estuarine and Coastal Modelling, Oakbrook, September 8-10, Illinois.

Marine Life Information Network (MarLIN). 2011. Benchmarks for the Assessment of Sensitivity and Recoverability. The Marine Biological Association of the UK, Citadel Hill, Plymouth, Devon, U.K. URL: http://www.marlin.ac.uk/sensitivitybenchmarks.php (Accessed April 2011).

Prakash, S. and. V. S. Kolluru, 2014. Implementation of Integrated Modelling Approach to Impact Assessment Applications for LNG Operations Using 3-D Comprehensive Modelling Framework. International Environmental Modelling and Software Society (iEMSs), 7th Intl. Congress on Env. Modelling and Software, San Diego, CA, USA, Daniel P. Ames, Nigel W.T. Quinn and Andrea E. Rizzoli (Eds.), URL: http://www.iemss.org/society/index.php/iemss-2014-proceedings

Smit, M.G.D., K.I.E., Holthaus, J.E. Tamis, R.G. Jak, C.C. Karman, G. Kjeilen-Eilertsen, H. Trannum, J. Neff. 2006. Threshold levels and risk functions for non-toxic sediment stressors: burial, grain size changes, and hypoxia. TNO-report. 2006-DH-0046/A.

U. S. Army Engineer Waterways Experiment Station, Environmental Laboratory, Hydraulics Laboratory. 1986. CE-QUAL-W2: A Numerical Two-Dimensional, Laterally Averaged Model of Hydrodynamics and Water Quality; User's Manual. Instruction Report E-86-5. Prepared for Department of the Army, U.S. Army Corps of Engineers, Washington, DC. Final Report. August.

APPENDIX K

Flora and Fauna of Shell Beach

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APPENDIX IV. BIODIVERSITY

List of Biodiversity found within the Shell Beach Area

Appendix IVa: Avifauna of Shell Beach

Source: *Mendonca, Sean; Michelle Kalamandeen and Robin S. McCall (2006). A Bird's Eye View: Coastal Birds of Shell Beach. Proceedings of International Conference on the Status of Biological Sciences in Caribbean and Latin American Societies.*

Common Name	Scientific Name
Amazilia Hummingbird	*Amazilia spp.*
Amazon Kingfisher	*Chloroceryle amazona*
American Flamingo	*Phoenicopterus ruber*
American Kestrel	*Falco sparverius*
American Pgymy Kingfisher	*Chloroceryle aenea*
Anhinga	*Anhinga anhinga*
Bananaquit	*Coereba flaveola*
Barn Swallow	*Hirundo rustica*
Barred Antshrike	*Thamnophilus doliatus*
Barred Forest-Falcon	*Micrastur ruficollis*
Bat Falcon	*Falco rufigularis*
Bicolored Conebill	*Conirostrum bicolor*
Black Caracara	*Daptrius ater*
Black Skimmer	*Rynchops niger*
Black Vulture	*Coragyps atratus*
Blackbellied Cuckoo	*Piaya melanogaster*
Blackbellied Whistling-duck	*Dendrocyna autumnalis*
Black-collared Hawk	*Busarellus nigricollis*
Black-crested Antshrike	*Sakesphorus canadensis*
Blackcrowned Night-heron	*Nycticorax nycticorax*
Blackface Ant-thrush	*Formicarius analis*
Blacknecked Aracari	*Pteroglossus aracari*
Blackthroated Antbird	*Myrmceciza atrothorax*
Blackthroated Antshrike	*Frederickena viridis*
Blue & Gold Macaw	*Ara ararauna*
Blue Ground-Dove	*Claravis prestiosa*
Blue-black Grassquit	*Volatinia jacarina*
Blue-chinned Sapphire	*Chlorestes notatus*
Blue-crowned Motmot	*Momotus momota*
Blue-gray Tanager	*Thraupis episcopus*
Blue-headed Parrot	*Pionus menstruus*
Boat-billed Flycatcher	*Megarynchus pitangua*

Common Name	Scientific Name
Boat-billed Heron	*Cochlearius cochlearius*
Bridled Tern	*Sterna anaethetus*
Bright-rumped Attila	*Attila spadiceus*
Brown Pelican	*Pelecanus occidentalis*
Buff throated Woodcreeper	*Xiphorhynchus guttatus*
Buff-breasted Wren	*Thryothorus leucotis*
Buff-throated Woodcreeper	*Xiphorhynchus guttatus*
Carib Grackle	*Quiscalus lugubris*
Cattle Egret	*Bubulcus ibis*
Cayanne Jay	*Cyanocorax cayanus*
Channel-billed Toucan	*Ramphastos vitellinus*
Chestnut-bellied Seedeater	*Oryzoborus angolensis*
Cocoi Heron	*Ardea cocoi*
Collared Plover	*Charadrius collaris*
Common Black Hawk	*Buteogallus anthracinus*
Common Paraque	*Nyctidromus albicollis*
Common Piping-guan	*Pipile pipile*
Common Tody-flycatcher	*Todirostrum cinereum*
Coraya Wren	*Thryothorus coraya*
Crane Hawk	*Geranospiza caerulescens*
Creamcolored Woodpecker	*Celeus flavus*
Crested Eagle	*Morphnus guianensis*
Crested Oropendula	*Psarocolius decumanus*
Crimson-hooded Manakin	*Pipra aureola*
Dark-billed Cuckoo	*Coccyzus melacoryphus*
Dull-colored Grassquit	*Tiaris obscura*
Dusky Antshrike	*Cercomacra tyrannina*
Fasciated Antshrike	*Cymbilaimus lineatus*
Forest Elaenia	*Myiopagis gaimardi*
Forktailed Flycatcher	*Tyrannus savana*
Forktailed Palm-Swift	*Tachornis squamata*
Giant Cowbird	*Scaphidura oryzivora*
Glittering-throat Emerald	*Amazilia fimbriata*
Gray fronted Dove	*Leptotila rufaxilla*
Gray Hawk	*Asturina nitida*
Gray Kingbird	*Tyrannus dominicensis*
Graybreasted Martin	*Progne chalybea*
Graybrested Sabrewing	*Campylopterus largipennis*
Grayish Saltator	*Saltator coerulescens*
Gray-necked Woodrail	*Aramides cajanea*
Great Egret	*Ardea alba*
Great Horned-owl	*Bubo virginianus*
Great Pootoo	*Nyctibius grandis*
Great Tinamou	*Tinamus major*
Greater Ani	*Crotophaga major*
Greater Kisskadee	*Pitangus sulphuratus*
Greater Yellowlegs	*Tringa melanoleuca*

Common Name	Scientific Name
Green & Rufous Kingfisher	*Chloroceryle inda*
Green Honeycreeper	*Chlorophanes spiza*
Green Ibis	*Mesembrinibis cayennensis*
Green Kingfisher	*Chloroceryle americana*
Green Oropendula	*Psarocolius viridis*
Grosbeak	*Pitylus spp*
Gull-billed Tern	*Sterna nilotica*
Harpy Eagle	*Harpia harpyja*
Helmeted pygmy Tyrant	*Lophotriccus galeatus*
King Vulture	*Sarcoramphus papa*
Large-billed Tern	*Phaetusa simplex*
Laughing Falcon	*Herpetotheres cachinnans*
Laughing Gull	*Larus atricilla*
Least Sandpiper	*Calidris minutilla*
Least Tern	*Sterna antillarum*
Lesser Kiskadee	*Philohydor lictor*
Lesser Yellowlegs	*Tringa flavipes*
Lineated Woodpecker	*Dryocopus lineatus*
Little Blue Heron	*Egretta caerulea*
Little Chacalaca	*Ortalis motmot*
Little Cuckoo	*Piaya minuta*
Longtailed Hermit	*Phaethornis superciliosus*
Longtailed Woodcreeper	*Dendrocyna longicauda*
Long-winged Harrier	*Circus buffoni*
Magnificent Frigatebird	*Fregata magnificens*
Magpie Tanager	*Cissopis leveriana*
Maguari Stork	*Ciconia maguari*
Marbled Woodquail	*Odontophorus gujanensis*
Moriche Oriole	*Icterus chrysocephalus*
Mouse-coloured Antshrike	*Thamnophilus murinus*
Muscovy Duck	*Cairina moshata*
Neotropical Cormorant	*Phalacrocorax brasilianus*
Northern Waterthrush	*Seiurus noveboracensis*
Nothern Scrub-Flycatcher	*Sublegatus arenarum*
Orange-winged Parrot	*Amazona amazonica*
Osprey	*Pandion haliaetus*
Pale breasted Thrush	*Turdus leucomelas*
Palm Tanager	*Thraupis palmarum*
Peregrine Falcon	*Falco peregrinus*
Piculet	*Picumus spp*
Pied Plover	*Hoploxypterus cayanus*
Pied Water-Tyrant	*Fluvicola pica*
Plumbeous Pigeon	*Columba plumbea*
Purplethroated Fruitcrow	*Querula purpurata*
Pygmy Antwren	*Myrmotherula brachyura*
Pygmy Kingfisher	*Chloroceryle aenea*
Red & Green Macaw	*Ara chloropterus*

Common Name	Scientific Name
Red-bellied Macaw	*Ara manilata*
Red-billed Toucan	*Ramphastos tucanus*
Redbreasted Blackbird	*Sturnella militaris*
Red-eyed Vireo	*Vireo olivaceus*
Red-rumped Cacique	*Cacicus haemorrhous*
Red-shouldered Macaw	*Ara nobilis*
Red-throated Caracara	*Ibycter americanus*
Ring kingfisher	*Ceryle torquata*
River Warbler	*Phaeothlypis flaveola*
Roadside Hawk	*Buteo magnirostris*
Royal Tern	*Sterna maxima*
Ruddy Ground-dove	*Columbina talpacoti*
Ruddy Pigeon	*Columba subvinacea*
Ruddy Turnstone	*Arenaria interpres*
Rufescent Tiger Heron	*Tigrisoma lineatum*
Rufous Crab-hawk	*Buteogallus aequinoctialis*
Rufous-breasted Hermit	*Glaucis hirsuta*
Rusty-margined Flycatcher	*Myiozetetes cayanensis*
Scarlet Ibis	*Eudocimus ruber*
Screaming Piha	*Lipaugus vociferans*
Semipalmated Sandpiper	*Calidris pusilla*
Short-crested Flycatcher	*Myiarchus ferox*
Silverbeak Tanager	*Ramphocelus carbo*
Slaty Antwren	*Cercomacra spp*
Smooth-billed Ani	*Crotophaga ani*
Snail Kite	*Rostrhamus sociabilis*
Snowy Egret	*Egretta thula*
Solitary Sandpiper	*Tringa solitaria*
Sora Crake	*Porzana carolina*
Southern beardless Tyrantlet	*Camptostoma obsoletum*
Southern Housewren	*Troglodytes aedon*
Southern Lapwing	*Vanellus chilensis*
Spectacled Owl	*Pulsatrix perspicillata*
Spix's Guan	*Penelope jacquacu*
Spotted Sandpiper	*Actitis macularia*
Spotted Tody-flycatcher	*Todirostrum maculatum*
Squirrel Cuckoo	*Piaya cayana*
Straight-billed Woodcreeper	
Streaked Flycatcher	*Myiodynastes maculatus*
Striated Heron	*Butorides striatus*
Striped Cuckoo	*Tapera naevia*
Sun Grebe	*Heliornis fulica*
Sunbittern	*Eurypga helias*
Swainson's Flycatcher	*Myiarchus swainsoni*
Swallow-tailed Kite	*Elanoides forficatus*
Swallow-wing Puffbird	*Chelidoptera tenebrosa*
Tricolored Heron	*Egretta tricolor*

Common Name	Scientific Name
Tropical Kingbird	*Tyrannus melancholicus*
Tropical Screech-Owl	*Otus choliba*
Turkey Vulture	*Cathartes aura*
Turquoise Tanager	*Tangara mexicana*
Violaceous Euphonia	*Euphonia violacea*
Wattled Jacana	*Jacana jacana*
Wedge billed wood creeper	*Glyphorynchus spirurus*
Whibrel	*Numenius phaeopus*
White bearded Manakin	*Manacus manacus*
White- headed Marsh Tyrant	*Arundinicola leucocephala*
White-Chested Emerald	*Amazilia chionopectus*
White-earred Conebill	*Conirostrum leucogenys*
White-lined tananger	*Tachyphonus rufus*
White-necked Heron	*Ardei cocoi*
White-tail Hawk	*Elanus leucurus*
Whitetailed Trogon	*Trogon viridis*
White-tipped Dove	*Leptotila verreauxi*
White-winged Swallow	*Tachycineta albiventer*
Wilson's Plover	*Charadrius wilsonia*
Wing-banded Antbird	*Myrmornis torquata*
Yellow bellied Elania	*Elaenia flavogaster*
Yellow billed Jacamar	*Galbula albirostris*
Yellow chinned Spinetail	*Certhiaxis cinnamomea*
Yellow Oriole	*Icterus nigrogularis*
Yellow Warbler	*Dendroica aestiva*
Yellow-billed Tern	*Sterna superciliaris*
Yellow-crowned Night-Heron	*Nyctanassa violacea*
Yellow-crowned Parrot	*Amazona ochrocephala*
Yellow-headed Caracara	*Milvago chimachima*
Yellow-headed Vulture	*Cathartes burrovianus*
Yellow-hooded Blackbird	*Agelaius icterocephalus*
Yellow-rump Cacique	*Cacicus cela*
Yellow-throated Spinetail	*Certhiaxis cinnamomea*
Yellow-tufted woodpecker	*Melanerpes cruentatus*

Appendix IVa (Supplement): Additional Avifauna Documented During April 3-13, 2018 Coastal Bird Survey of Region 1

The following species were observed during an April 2018 coastal bird survey conducted in Region 1. The April 2018 survey did not replicate the survey producing the observations in the table above (*Appendix IVa: Avifauna of Shell Beach*) in terms of survey area or level of effort; some of the observations reflected in the April 2018 survey were made farther inland. However, as all observations were collected within 20 kilometers from the coastline of Shell Beach, it is considered reasonably possible that these species could be present at times within the Shell Beach Protected Area.

Common Name	Scientific Name
American Woodstork	*Mycteria americana*
Lesser Yellow-headed Vulture	*Cathartes burrovianus*
Grey-lined Hawk	*Buteo nitidus*
Zone-tailed Hawk	*Rupornis magnirostris*
Plumbeous Kite	*Ictinia plumbea*
Gray-headed Kite	*Leptodon cayanensis*
Crested Caracara	*Caracara cheriway*
Rock Pigeon	*Columba livia domestica*
Pale-vented Pigeon	*Patagioenas cayennensis*
Common Ground-Dove	*Columbina passerina*
Northern Red-shouldered Macaw	*Diopsittaca nobilis*
Brown-throated Parakeet	*Eupsittula pertinax*
Neotropical Palm-Swift	*Tachornis squamata*
Gray-rumped Swift	*Chaetura cinereiventris*
Reddish Hermit	*Phaethornis ruber*
Fork-tailed Woodnymph	*Thalurania furcata*
Tufted Cocquette	*Lophornis ornatus*
Green-tailed Jacamar	*Glabula galbula*
White-throated Toucan	*Rhamphastus tucanus*
Chestnut Woodpecker	*Celeus elegans*
Pale-breasted Spinetail	*Synallaxis albescens*
White-browed Antbird	*Myrmoborus leucophrys*
Silvered Antbird	*Sclateria naevia*
Black-chinned Antbird	*Hypocnemoides melanopogon*
White-flanked Antwren	*Myrmotherula axillaris*
Piratic Flycatcher	*Legatus leucophaius*
Brown-crested Flycatcher	*Myiarchus tyrannulus*
Yellow-crowned Tyrannulet	*Tyrannulus elatus*
Mouse-colored Tyrannulet	*Phaeomyias murina*
Guianan Tyrannulet	*Zimmerius acer*
Pale-eyed Pygmy-Tyrant	*Atalotriccus pilaris*
Cinnamon Attila	*Attila cinnamomeus*

Common Name	Scientific Name
Grayish Mourner	*Rhytipterna simplex*
Tropical Mockingbird	*Mimus gilvus*
Black-tailed Tityra	*Tityra cayana*
Lemon-chested Greenlet	*Hylophilus thoracicus*
Ashy-headed Greenlet	*Hylophilus pectoralis*
White-shouldered Tanager	*Tachyphonus luctuosus*
Riverbank Warbler	*Myiothlypis rivularis*
Masked Yellowthroat	*Geothlypis aequinoctialis*
Ruddy-breasted Seedeater	*Sporophila minuta*
Lined Seedeater	*Sporophila lineola*
Pectoral Sparrow	*Arremon taciturnus*
Finsch's Euphonia	*Euphonia finschi*
Shiny Cowbird	*Molothrus bonariensis*

Appendix IVb: Herpetofauna of Shell Beach

Sources: *(1) Kalamandeen, Michelle and Phillip DaSilva (2005) A Preliminary Survey of the Herpetofauna of Shell Beach. Biodiversity and Conservation Studies in Guyana: Volume 2.*
(2) Prince, Waldyke et al. (2004) Report on the Rapid Biodiversity Assessment of the proposed Shell Beach Protected Area. GMTCS Publication.

Common Name	Scientific Name
Reptiles	
Ameiva lizard	*Ameiva ameiva*
Anaconda	*Eunectus marinus*
Anolis lizard	*Anolis spp*
Blind snake	*Leptotyphlops spp*
Boa constrictor	*Constrictor constrictor*
-	*Cnemidophorus gramivagus*
Cooks Tree-boa	*Corallus hortulanus*
Gecko	*Gonatodes humeralis*
Gecko	*Gonatodes spp*
Green turtle	*Chelonia mydas*
Hawksbill turtle	*Eretmochelys imbricata*
-	*Hydropis spp*
Green Iguana	*Iguana iguana*
-	*Kentropyx calcarata*
Labaria	*Bothrops atrox*
Labaria turtle	*Rhinoclemmys punctularia*
Leatherback turtle	*Dermochelys coriacea*
Mabuya	*Mabuya mabuya*
Mud turtle	Kinosternon scropiodes
Spectacle Caiman	*Caiman crocodilus*
Tegu	*Tupinambis negropunctatus*
Tiger snake	*Drymarchon corais*
Tree lizard	*Plica plica*
Turnip tail Gecko	*Thecadactylus rapicauda*
Water labaria	*Helicops angulatus*
Water snake	*Liophis cobella*
Whiptail lizard	*Cnemidorphous lemniscatus*
Yakman snake	*Chironius spp*
Amphibians	
	Hyla crepitans
	Hyla marmorata
	Hyla minuta
	Hyla spp1
	Hyla spp2
	Hyla spp3
	Hyla spp4
	Leptodactylus mystaceus
	Leptodactylus spp
Paradox frog	*Psuedes paradox*
	Scinax rubra
Surinamese Toad	*Pipa pipa*
Toad	*Rhaebo marinus*

Appendix IVc: Mammals of Shell Beach

Sources: *(1) Kalamandeen, Michelle and Phillip DaSilva (2005) A Preliminary Survey of the Herpetofauna of Shell Beach. Biodiversity and Conservation Studies in Guyana: Volume 2.*
(2) Prince, Waldyke et al (2004) Report on the Rapid Biodiversity Assessment of the proposed Shell Beach Protected Area. GMTCS Publication.

Common Name	Scientific Name
Wedge capped capuchin	*Cebus olivaceus*
Agouti	*Dasyprocta agouti*
-	*Artibeus obscurus*
-	*Artibeus spp*
-	*Artibeus spp 2*
Brown Capuchins	*Cebus apella*
Bulldog bat	*Noctilio leporinus*
Coati	*Nasua nasua*
Common long-tongue bat	*Glossophaga soricina*
Common Tent-making Bat	*Uroderma bilobatum*
Deer	*unidentified genera*
Giant River Otter	*Pteronura brasiliensis*
Jaguar	*Panthera onca*
Long nose bat	*unidentified genera*
Manatee	*Trichechus manatus*
Porpoises	*Inia geoffrensis*
Raccoon	*Procyon cancrivorus*
Rat	*unidentified genera*
Red Howler monkey	*Alouatta seniculus*
Southern River otter	*Lontra longicaudis*
Southern Tamandua	*Tamandua tetradactyla*
Spider Monkey	*Ateles paniscus*
Squirrel monkey	*Saimiri sciureus*
Tayra	*Eira barbara*
Three-toe sloth	*Bradypus tridactylus*
Two-lined riverside bat	*Saccopteryx bilineata*
White face Saki	*Pithecia pithecia*

Appendix IVd: Fishes of Shell Beach

Sources: *(1) Kalamandeen, Michelle and Phillip DaSilva (2005) A Preliminary Survey of the Herpetofauna of Shell Beach. Biodiversity and Conservation Studies in Guyana: Volume 2.*
(2) Prince, Waldyke et al (2004) Report on the Rapid Biodiversity Assessment of the proposed Shell Beach Protected Area. GMTCS Publication.

Common Name	Scientific Name
Anafouk	*unidentified genera*
Banga mary	*Macrodon ancylodon*
Basha	*Plagioscion sp*
Black pirai	*Pygocentrus niger*
Blinker	*unidentified genera*
Butterhead	*unidentified genera*
Cassi	*Pimelodus blochii*
Catfish	*Bagre marinus*
Catfish	*Cathorops spixii*
Cock-a-net	*unidentified genera*
Couvalli	*Caranx hippos*
Cow stingray	*Dasyatis sp*
Crocrer basha	*Plagioscion squamosissimus*
Cuffum	*Megaolops ottonticus*
Cuma Cuma/Black Cuirass	*unidentified genera*
Curimai	*Brycon falcatus*
Flounder	*Bothus ocellatus*
Foureye	*Anableps anableps*
Gillbacker	*Ariuz herzbergii*
Gillbacker	*Hexanematichthys parkeri*
Grey Anglefish	*Pomacanthus arcuatus*
Grey Snapper	*Cynoscion ocoupa*
Guppy	*Poecilia reticulata*
Guppy	*unidentified genera*
Hardhead Courass	*unidentified genera*
Hasser	*Hoplosternum sp.*
Highwater	*unidentified genera*
Houri	*Hoplias malabaricus*
Imeri	*Parauchenipterus galeatus*
Jewfish	*Epinephelus itajara*
Katabac	*Myleus rubripinnis*
Kavalli	*Caranx hippos*
Kokwari	*Hexanematichthys proops*
Lukanani	*Cichla ocellaris*
Mackerel	*Scomberomorus brasiliensis*
Manta Ray	*Manta birostris*
Mullet	*Mugil cephalus*
Pacu	*unidentified genera*
Pargee	*Lobotes surinamensis*
Patwa	*Cichlasoma sp*
Quamina	*unidentified genera*

Common Name	Scientific Name
Red Snapper	*Lutjanus campechanus*
Rock head	*unidentified genera*
Sabakoua stingray	*Dasyatis sp*
Sea patwa	*Diapterus rhombeus/Caitipa mojarra*
Seahassa	*unidentified genera*
Shark	*Heptranchias perlo*
Snapper	*Lutjanus griseus*
Snook	*Centropomus undecimalis*
Spadefish	*unidentified genera*
Spring Courass	*Cathorops spixii*
Sunfish	*Crenicichla sp.*
Swordfish	*Boulengerella cuvieri*
Tampocker	*unidentified genera*
Trout	*Cynoscion virescens*
Trout	*Oncorhynchus mykiss*
Wabaru	*unidentified genera*
Yadaro	*Pseudodoras (Oxydoras) niger*
Yarrow	*Hoplerythrinus unitaeniatus*

Appendix IVe: Plants of Shell Beach

Sources: *(1) Kalamandeen, Michelle and Phillip DaSilva (2005) A Preliminary Survey of the Herpetofauna of Shell Beach. Biodiversity and Conservation Studies in Guyana: Volume 2.*
(2) Prince, Waldyke et al (2004) Report on the Rapid Biodiversity Assessment of the proposed Shell Beach Protected Area. GMTCS Publication.

Common Name	Scientific Name
Almond trees	*Terminalia catappa*
Back Mangrove	*Avicennia germinans*
Bloodwood	*Vismia spp*
-	*Caesalpinia bonduc*
-	*Canvalia rosea*
-	*Carica papaya*
-	*Cecropia spp.*
-	*Ceiba pentandra*
-	*Cissus verticillatus*
Coconut trees	*Cocos nucifera*
Corkwood	*Pterocarpus spp*
Crab-wood	*Carapa guianensis*
-	*Cucurbita moschata*
-	*Cuscuta umbellata*
-	*Cyperus spp*
Dukalli	*Parahancornia spp*
-	*Hibiscus pernambucensis*
-	*Ipomea pes-caprae*
Ite Palms	*Mauritia flexuosa*
-	*Jatropha gossypiifolia*
Kabukalli	*Goupia glabra*
Kakaralli	*Eschiwella spp*
Kaunta	*Chrysobalanus spp*
Manicole	*Euterpe spp*
-	*Manihot esculenta*
Mora	*Mora excelsa*
Noni trees	*Morindra citrifolia*
Papaya trees	*Carica papaya*
Red Mangroves	*Rhizophora mangle*
-	*Sesuvium portulacastum*
Soft Wallaba	*Eperu falcata*
-	*Thespesia populnea*
White Mangrove	*Languncularia racemosa*

Appendix IVf: Marco-invertebrates of Shell Beach

Source: *Kalamandeen, Michelle and Phillip DaSilva (2005) A Preliminary Survey of the Herpetofauna of Shell Beach. Biodiversity and Conservation Studies in Guyana: Volume 2.*

Common Name	Scientific Name
Bee	*unidentified genera*
Blue Morpho	*Morpho menelaus*
Bug	*unidentified genera*
Bundari crab	*Cardisoma guanhumi*
Butterfly	*Euedes spp*
Butterfly	*Eurema spp*
Butterfly	*Parides spp*
Butterly	*Euptichia spp*
Centipede	*unidentified genera*
Coconut worm	*unidentified genera*
Dragonfly	*unidentified genera*
Fiddler crab	*Uca rapax*
Field cricket	*unidentified genera*
Flies	*unidentified genera*
Ghost crab	*Ocypode quadrata*
Grasshopper	*Thelpusa spp*
Lady bug	*unidentified genera*
Machusi Ant	*Atta spp*
Millipede	*unidentified genera*
Monarch	*Danaus plexipus*
Mosquito	*unidentified genera*
Roach	*unidentified genera*
Sand wasp	*unidentified genera*
Scorpion	*unidentified genera*
Spider	*unidentified genera*
Tarantula	*Avicularia spp*
Tree crab	*Aratus pisonii*

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APPENDIX L

IUCN-Listed Species in Guyana

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IUCN-LISTED SPECIES IN GUYANA

Table 1: IUCN-Listed Coastal and Marine Species Known From Guyana with Red List Status as NT or Higher

Scientific Name	Common Name	IUCN Status
Aetobatus narinari	Spotted Eagle Ray	NT
Agamia agami	Agami Heron	VU
Alopias vulpinus	Common Thresher Shark	VU
Balistes capriscus	Gray Tiggerfish	VU
Balistes vetula	Queen Triggerfish	NT
Calidris pusilla	Semipalmated Sandpiper	NT
Carcharhinus acronotus	Blacknose Shark	NT
Carcharhinus brevipinna	Spinner Shark	NT
Carcharhinus falciformis	Silky Shark	VU
Carcharhinus leucas	Bull Shark	NT
Carcharhinus limbatus	Blacktip Shark	NT
Carcharhinus longimanus	Oceanic Whitetip Shark	VU
Carcharhinus obscurus	Dusky Shark	VU
Carcharhinus perezi	Caribbean Reef Shark	NT
Carcharhinus signatus	Night Shark	VU
Chelonia mydas	Green Turtle	EN
Eretmochelys imbricata	Hawksbill Sea Turtle	CR
Dasyatis geijskesi	Sharpsnout Stingray	NT
Dermatolepis inermis	Sickelfish Grouper	NT
Dermochelys coriacea	Leatherback Sea Turtle	VU
Diplobatis pictus	Variegated Electric Ray	VU
Epinephelus itajara	Atlantic Goliath Grouper	CR
Epinephelus morio	Red Grouper	NT
Epinephelus striatus	Nassau Grouper	EN
Galeocerdo cuvier	Tiger Shark	NT
Geochelone denticulata	Yellow-foot tortoise	VU
Gymnura altavela	Spiny Butterfly Ray	VU
Hyporthodus flavolimbatus	Poey's Grouper	VU
Hyporthodus niveatus	Spotted Grouper	VU
Isogomphodon oxyrhynchus	Daggernose Shark	CR
Isurus oxyrinchus	Shortfin Mako	VU
Kajikia albida	White Marlin	VU
Lachnolaimus maximus	Hogfish	VU
Lepidochelys olivacea	Olive Ridley Sea Turtle	VU
Lontra longicaudis	Neotropical Otter	NT
Lopholatilus chamaeleonticeps	Golden Tilefish	EN
Lutjanus analis	Mutton snapper	NT

Scientific Name	Common Name	IUCN Status
Lutjanus cyanopterus	Cubera Snapper	VU
Manta birostris	Giant Manta Ray	VU
Megalops atlanticus	Tarpon	VU
Mola mola	Ocean Sunfish	VU
Mycteroperca bonaci	Black Grouper	NT
Mycteroperca venenosa	Yellowfin Grouper	NT
Narcine bancroftii	Caribbean Electric Ray	CR
Negaprion brevirostris	Lemon Shark	NT
Physeter macrocephalus	Sperm Whale	VU
Prionace glauca	Blue Shark	NT
Pristis pristis	Largetooth Sawfish	CR
Pterodroma hasitata	Black-capped Petrel	EN
Pteronura brasiliensis	Giant Otter	EN
Raja cervigoni	Venezuela Skate	NT
Rhincodon typus	Whale Shark	EN
Rhinobatos percellens	Southern Guitarfish	NT
Rhinoptera bonasus	Cownose Ray	NT
Sciades parkeri	Gillbacker Sea Catfish	VU
Sphyrna lewini	Scalloped Hammerhead	EN
Sphyrna mokarran	Squat-headed Hammerhead Shark	EN
Sphyrna tudes	Smalleye Hammerhead Shark	VU
Thunnus alalunga	Albacore Tuna	NT
Thunnus albacares	Yellowfin Tuna	NT
Thunnus obesus	Bigeye Tuna	VU
Thunnus thynnus	Atlantic Bluefin Tuna	EN
Trichechus manatus	West Indian Manatee	VU

Source: International Union for Conservation of Nature. 2018. 2017 Red List of Threatened Species Version 2017.3. Accessed: May 2018. Retrieved from: http://www.iucnredlist.org/

CR = Critically Endangered; EN = Endangered; NT = Near Threatened; VU = Vulnerable

Table 2: IUCN-Listed Coastal and Marine Species Known From Guyana with Red List Status Classified as Data Deficient

Scientific Name	Common Name	IUCN Status
Ginglymostoma cirratum	Nurse Shark	DD
Globicephala macrorhynchus	Short-finned Pilot Whale	DD
Gymnura micrura	Smooth Butterfly Ray	DD
Hexanchus nakamurai	Bigeyed Sixgill Shark	DD
Himantura schmardae	Chupare Stingray	DD
Holothuria arenicola	[no common name]	DD
Kogia breviceps	Pygmy Sperm Whale	DD
Kogia sima	Dwarf Sperm Whale	DD
Mesoplodon densirostris	Blainville's Beaked Whale	DD
Ancylopsetta kumperae	Foureyed Flounder	DD
Balaenoptera brydei	Bryde's Whale	DD
Myliobatis freminvillii	Bullnose Ray	DD
Myliobatis goodei	Southern Eagle Ray	DD
Tetrapturus georgii	Roundscale Spearfish	DD
Torpedo nobiliana	Great Torpedo Ray	DD
Sphyrna media	Scoophead Shark	DD
Scyllarides delfosi	Three-spot Slipper Lobster	DD
Sotalia guianensis	Guiana Dolphin	DD
Rhizoprionodon lalandii	Brazilian Sharpnose Shark	DD
Pseudorca crassidens	False Killer Whale	DD
Orcinus orca	Killer Whale	DD
Panulirus argus	Caribbean Spiny Lobster	DD
Panulirus laevicauda	Smoothtail Spiny Lobster	DD
Breviraja nigriventralis	Blackbelly Skate	DD
Fenestraja plutonia	Pluto Skate	DD
Feresa attenuata	Pygmy Killer Whale	DD
Elops smithi	Malacho	DD
Delphinus capensis	Long-beaked Common Dolphin	DD
Dactylobatus clarkii	Hookskate	DD
Dasyatis americana	Southern Stingray	DD
Carcharhinus porosus	Smalltail Shark	DD

Source: International Union for Conservation of Nature. 2018. 2017 Red List of Threatened Species Version 2017.3. Accessed: May 2018. Retrieved from: http://www.iucnredlist.org/

DD = Data Deficient

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APPENDIX M

Protected Species Observer Summary

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Protected Species Observer Summary

Prepared for: ExxonMobil

ExxonMobil

Guyana

2015-2018







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1 Executive Summary

This report summarizes the protected species observer data collected by ExxonMobil on various programs from 2015 through 2018 in Guyana, including visual observations performed on existing marine operations as required by the Environmental Permit 20160705-EEDPF Condition 1.5. Data from four survey types—3D/4D Surface Seismic, AUV, Vertical Seismic Profile (VSP), and Environmental Baseline—is summarized in this report. The following surveys are included:

3D/4D Surface Seismic
- Stabroek 3D: 12 July 2015 to 17 February 2016
- Canje 3D: 18 March 2016 to 20 August 2016
- Liza 3D/4D: 23 August 2017 to 19 November 2017

AUV
- Liza AUV: 17 December 2015 to 23 March 2016

Vertical Seismic Profile
- Liza-1 Stabroek Zero-Offset Vertical Seismic Profile: 09 May 2015 to 12 May 2015
- Liza-1 Stabroek Walk Away Vertical Seismic Profile: 06 June 2015 to 08 June 2015
- Liza-2 Stabroek Walk Above Vertical Seismic Profile: 28 March 2016 to 01 April 2016
- Payara-1 Stabroek Zero-Offset Vertical Seismic Profile: 04 December 2016 to 05 December 2016
- Stabroek Vertical Seismic Profile 1: 29 September 2017 to 02 October 2017
- Stabroek Vertical Seismic Profile 2: 15 December 2017 to 17 December 2017
- Stabroek Vertical Seismic Profile 3: 03 January 2018 to 08 January 2018

Environmental Baseline
- Liza Environmental Baseline 1: 27 September 2017 to 02 October 2017
- Liza Environmental Baseline 2: 18 October 2017 to 28 October 2017
- Liza Environmental Baseline 3: 28 October 2017 to 20 November 2017
- Liza Environmental Baseline 4: 19 March 2018 to 16 April 2018

During all surveys, two protected species observers (PSOs) provided by RPS were on board the vessels to undertake visual observations in accordance with Joint Nature Conservation Committee (JNCC) *guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys*. During the Stabroek 3D, Canje 3D, and Liza 3D/4D Surveys, there was also one passive acoustic monitoring (PAM) Operator provided by RPS on board each vessel to undertake acoustic observations in accordance with JNCC guidelines.

In addition to permit requirements, ExxonMobil voluntarily mandated that soft starts would be delayed for sea turtles in addition to marine mammals if detected within in the 500 meter exclusion zone during the search period prior to initiation of the source and if the source activity ceased or reduced power, a silent period of only five minutes would be permitted after which a soft-start was required to resume source operations. Note: this does not apply to the Environmental Baseline surveys as there was no acoustic source utilized on these surveys.

Throughout all surveys, PSOs conducted visual observations for a total of 10012 hours and 50 minutes. PAM Operators performed acoustic monitoring for a total of 5909 hours and 43 minutes.

During the seismic surveys and VSPs, the seismic source was active for a total of 9727 hours and 58 minutes. This included 8873 hours and 09 minutes while in production, 284 hours and 09 minutes while

at full volume or partial volume while not in production, 420 hours and 46 minutes of soft-start, and 149 hours and 54 minutes conducting source testing. There was no use of the mitigation source throughout any survey. During the AUV survey, there was a total of 786 hours of AUV Payload Ops, 201 hours and 30 minutes of MBES (EM302) activity, 104 hours and 03 minutes of SBP activity, and 469 hours and 51 minutes of Single Beam (EA600) activity.

There were 583 total protected species detections recorded during all surveys, including 219 visual detections, 359 acoustic detections and 05 correlated visual-acoustic detections. Visual detections consisted of 68 detections of whales, 142 detections of dolphins (five of which were correlated with acoustic detections), and 13 detections of turtles. Acoustic detections consisted of 22 sperm whale detections and 342 dolphin detections, five of which were correlated with visual detections.

There were a total of 13 mitigation actions conducted throughout these surveys due to marine mammals detected within the exclusion zone prior to source operations, with 2.39% of all detections during surveys with source activity resulting in mitigation actions. Nine mitigation actions occurred aboard the *CGG Alize* during the Stabroek survey and were delays to initiation of the source, including eight of which were undertaken for dolphin detections and one for a sperm whale detection. One mitigation action occurred during the Liza AUV survey and was a delay to the initiation of the source for a dolphin detection. Three mitigation actions occurred during the Liza 3D/4D survey and were delays to initiation of the source for dolphin detections.

2 Introduction

2.1 General Program Information

2.1.1 Stabroek 3D Survey

The Stabroek I 3D survey was conducted by CGG on behalf of ExxonMobil. The survey area was located off the coast of Guyana in the Stabroek block (Figure 1). The survey was conducted under regulatory permit number GUY 05 5099 0 00 B and consisted of 472 sail lines, shot in the Northeast to Southwest direction. The average length of each sail line was 72 kilometers. The survey was broken into three priority sections which were independently surveyed by the *CGG Alize* and the *CGG Geo Celtic* where the *CGG Alize* surveyed priority area three and the CGG *Geo Celtic* surveyed priority areas one and two.

2.1.2 Canje 3D Survey

The Canje survey was a 3D survey conducted by Polarcus on behalf of ExxonMobil. The survey area was approximately 7742 square kilometres off the coast of Guyana (Figure 1). The survey was conducted under a Letter of Authorization issued by the Environmental Protection Agency of Guyana. The Canje survey consisted of 201 sail lines, shot in the North to South direction. The average length of each sail line was 64 kilometers. The survey was broken into an eastern and western section with the eastern section given priority. The *Polarcus Adira* began the survey in the eastern priority area.

2.1.3 Liza 3D/4D Survey

The Liza 3D/4D survey was conducted by PGS on behalf of ExxonMobil. The survey area was 1,325 square kilometers located approximately 198 kilometers off the coast of Guyana in water depths of 900 to 2,600 meters (Figure 1). The survey was conducted under a Letter of Authorization (Regulatory Reference Number 20170403-EDSES) issued by the Environmental Protection Agency of Guyana. The Liza survey consisted of 103 sail lines, shot in a North to South direction and oblique lines shot in an East to West direction. The length of each North-South sail line was 51.15 kilometers.

2.1.4 Liza AUV Survey

The Liza Deep Water Field AUV survey was conducted off the coast of Guyana in the Stabroek Block. The survey was separated into two segments: geophysical and geotechnical. The geophysical survey took place in the approximate area of 8°14 to 7°09 North and 56°4 to 57°05 West, where water depths ranged from approximately 200 to 2200m covering an area approximately 350 square km, potentially increasing up to 1000 square km (Figure 1).

The geotechnical survey began on 26 February and concluded on 23 March 2016 and consisted of three coring phases. The first phase of this survey lasted for approximately 1 week where a piston core was used to collect 8 - 9 meter sediment samples. The second phase lasted for approximately 2 weeks and a

box core was used to collect environmental samples as well as CTD and water samples. The final phase continued for 2 days and also used the box core to collect samples.

2.1.5 Liza-1 Stabroek Zero-Offset Vertical Seismic Profile

The zero-offset vertical seismic profile (ZVSP) was performed on-board the drillship *Deepwater Champion* by the seismic contractor Schlumberger at the Stabroek Liza-1 well location. This well is approximately 190 kilometers offshore and to the northwest of Georgetown, Guyana. The water depth in this project area was 1,740 meters (m) measured at the site of the vessel (Figure 1).

2.1.6 Liza-1 Stabroek Walk Away Vertical Seismic Profile

The walk-away vertical seismic profile (WAVSP) was performed on-board the *Laird Tide* by the seismic contractor Schlumberger at the Stabroek Liza-1 well location. This well is approximately 190 kilometers offshore and to the northwest of Georgetown, Guyana. The water depth in this project area was between 1,200 and 1,740 meters (m) measured at the site of the vessel (Figure 1).

2.1.7 Liza-1 Stabroek Walk Above Vertical Seismic Profile

The walk-above vertical seismic profile (WAVSP) was performed on-board the *MV Dante* by the seismic contractor Schlumberger and the survey was conducted at the Stabroek Liza-2 well location. The drillship, *Stena Carron*, was located at the site of the well approximately 164 kilometers offshore and to the northwest of Georgetown, Guyana. The water depth in this project area was approximately 1630 meters at the site of the drillship (Figure 1).

2.1.8 Payara-1 Stabroek Zero-Offset Vertical Seismic Profile

The zero-offset vertical seismic profile (ZVSP) was performed on-board the drillship *Stena Carron* by the seismic contractor Schlumberger, which was performed at the Stabroek Payara-1 well location. This well is approximately 196 kilometers offshore and to the northwest of Georgetown, Guyana. The water depth in this project area is 2,356 meters (m) measured at the site of the vessel (Figure 1).

2.1.9 Stabroek Vertical Seismic Profile 1

The vertical seismic profile was completed on-board the *Stena Carron* drillship by the seismic contractor Schlumberger, on behalf of ExxonMobil, off the coast of Guyana at a depth of 802 meters (Figure 1).

2.1.10 Stabroek Vertical Seismic Profile 2

The vertical seismic profile was completed on-board the *Stena Carron* drillship by the seismic contractor Schlumberger, on behalf of ExxonMobil, off the coast of Guyana at a depth of 2738 meters (Figure 1).

2.1.11 Stabroek Vertical Seismic Profile 3

The vertical seismic profile was completed on-board the *Stena Carron* drillship by the seismic contractor Schlumberger, on behalf of ExxonMobil, off the coast of Guyana at a depth of 802 meters (Figure 1).

2.1.12 Liza Environmental Baseline 1

The environmental baseline survey Exxon Guyana Metocean project was conducted aboard the *M/V Sea Service*. The work was conducted in shallow coastal waters near Demerara and Berbice Rivers delta, from ten to eighty miles offshore Georgetown, Guyana. The transect lines begin approximately 7 nautical miles away from the coast of Guyana and ends approximately 75 nautical miles off the coast Guyana. The water depth of the survey area ranged from 5 to 2100 meters.

2.1.13 Liza Environmental Baseline 2

The environmental baseline survey Exxon Guyana Metocean project was conducted aboard the *M/V Sea Service* off the coast of Guyana in water depths that ranged from approximately 20 to 1400 meters. During the first part of the environmental survey, from 18 October through 28 October 2017, the vessel completed box cores at all environmental baseline stations and the majority of the ROV transects.

2.1.14 Liza Environmental Baseline 3

The environmental baseline survey Exxon Guyana Metocean project was conducted aboard the *M/V Sea Service* to obtain photos and videos of the seabed by a drop camera survey while in shallow waters and with a Remote Operated Vehicle (ROV) Camera survey while in deep waters.

The camera surveys were conducted along three transect lines using recordings as the primary method of study the seabed. The transect lines run in the southeast to northwest direction, spaced between three meters each in parallel transects. The drop cameras were towed within the transect lines which were 10 to 50 meters in length. They were also dropped in ten near-shore locations. The ROV was towed in three parallel transects which were 50 to 95/110 meters in length. The ROV was deployed primarily in deep waters and in three deep-water drill centre transects (East, West, North and South from 500 meters of each wellsite to 1500 meters outwards) named Liza 1, Liza 3 and Payara 1.

The transect lines begin approximately 7 nautical miles away from the coast of Guyana and ends approximately 75 nautical miles off the coast Guyana. The water depth of the survey area ranged from 5 to 2100 meters.

2.1.15 Liza Environmental Baseline 4

The environmental baseline survey Exxon Guyana Metocean project was conducted aboard the *M/V Sea Service* off the coast of Guyana. This survey was scheduled in two phases. The first phase was an

operation to monitor orientations of the pipeline TRBM and tripod mounts. Assessment of these mounts was carried out as well as retrievals during orientation surveys.

The second phase of this survey was to perform fish study operations, re-sampling sediment sites from a previous trip for hydrocarbon analysis, and collection of water samples at two sites for particle size analysis.

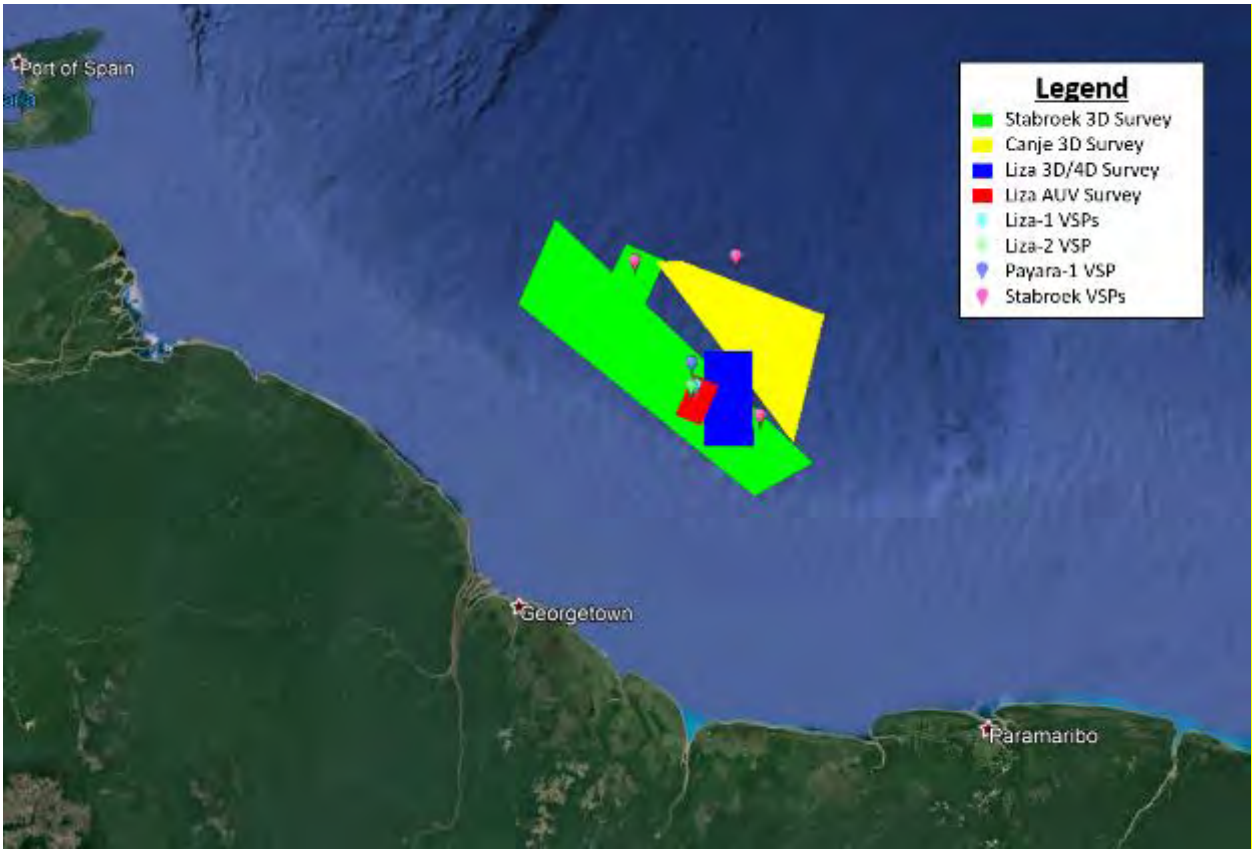


Figure 1: Map indicating the general location of the seismic, AUV, and VSP surveys.

2.2 Vessel and Seismic Equipment Specifications

2.2.1 Stabroek 3D Survey

The *CGG Alize* and *CGG Geo Celtic* were the two source vessels utilized to complete this survey, however the two vessels worked independently of one another in different sections of the prospect area. The chase/support vessels, which did not deploy seismic sound sources, utilized during this survey consisted of the *Thor Omega, The Fenny, the Bourbon Cormorant, the Linda C, the Bourbon Grebe, and the Bourbon Petrel.*

Each source vessel was towing ten streamers at the start of the survey, each 10 kilometers in length with a 100 meter separation and a tow depth of seven meters. The *CGG Alize* reduced to an eight-

streamer configuration for a period of 17 days in December 2015, then returned to the original ten-streamer configuration. The seismic source on each vessel consisted of six source strings, each made up of 12 elements. While in production, the source used a flip-flop firing pattern, where the starboard three source strings fire one shot, then the port side three source strings fire on the next shot and continue to flip-flop throughout the survey line. The source arrays were towed at a depth of six meters. The full volume of each source was 4070 cubic inches with a frequency response of 200-370 kHz and an intensity of 45-70 dB re 1 µPa (Table 1). Soft-starts were conducted by gradually increasing the numbers of active airguns over a period of 20 to 40 minutes.

2.2.2 Canje 3D Survey

The *Polarcus Adira* was the sole source vessel utilized to complete this survey. The chase vessels, which did not deploy seismic sound sources, utilized during this survey consisted of the *Vos Athos* and the *7 Oceans*.

The *Polarcus Adira* is a streamer vessel 92 meters in length and 21 meters in breadth. The seismic source consisted of six source strings each made up of 12 elements. While in production, the source used a flip-flop firing pattern where the starboard three source strings fire one shot, then the port side three source strings fire on the next shot and continue to flip-flop throughout the survey line. The individual source modules varied in volume from 45 to 380 cubic inches. The full volume of the source was 4240 cubic inches with a frequency response of 128 Hz and an intensity of 52.4 dB. During acquisition, the shot point interval was approximately 11.5 seconds, at a distance of 25 meters. The source arrays were towed 488 meters astern at a depth of six meters. The vessel towed 12 streamers, each 8.1 kilometers in length, with a 100-meter separation and a tow depth of 12 meters (Table 1). Soft-starts were conducted by gradually increasing the numbers of active airguns over a period of 20 to 40 minutes.

2.2.3 Liza 3D/4D Survey

The PGS *Ramform Hyperion* was the sole source and acquisition vessel utilized to complete this survey. Support vessels used during the survey were the *Thor Assister* and the *Thor Omega*. The PGS *Ramform Hyperion* is a streamer vessel 104.21 meters in length and 70 meters in breadth. The vessel towed 14 streamers, each 8.1 kilometers in length with a 50-meter separation and a tow depth of 20 meters.

The PGS *Ramform Hyperion* also towed six acoustic source strings, at a depth of five meters and a distance of 353.7 meters from stern to center of source (COS). Three of the strings were grouped to form a port array and three strings formed the starboard array. The two outer strings in each array consisted of 11 individual source elements while the middle string in each array contained only nine; individual elements varied in volume from 40 to 250 cubic inches. The full power discharge was the simultaneous activation of the 31 elements in an array, producing a total volume of 4,130 cubic inches, a frequency response of 10-70 Hz, and an intensity of 138 bar meters. While in production, the source was activated in a flip-flop pattern, alternating shots between the port and starboard arrays. The shot point interval for survey lines was approximately nine seconds, or 18.75 meters.

2.2.4 Liza AUV Survey

The *Fugro Americas* was utilized to complete this survey. The geophysical Deep Water Field Development survey employed an Autonomous Underwater Vehicle (AUV) equipped with standard equipment including a Multi-Beam Echo Sounder (MBES), Side Scan Sonar (SSS), and Sub-Bottom Profiler (SBP).

The AUV payload source consisted of three acquisition acoustic systems. These systems included a Multi-Beam Echo Sounder (MBES), Side Scan Sonar (SSS), and Sub-Bottom Profiler (SBP). The Multibeam system was a Kongsberg EM2040 with a frequency of 200 kHz and range of 250 meters. The Side Scan Sonar was an Edgetech 2200M, with a low frequency of 105 kHz and a high frequency of 410 KHz and a range of 200 meters. The Sub-Bottom Profiler was an Edgetech DW-106 with a pulse rate of 20m/sec, and record length of 200m/sec (Table 2).

In addition to the operations of the AUV, a Kongsberg EM302 multibeam echo sounder (MBES), a Kongsberg EA600 Single Beam Echo Sounder, and an Edgetech Sub-bottom profiler were operated from the *Americas* throughout the survey. These sound sources are operated from the *Americas* during transits into and out of port as well as throughout the Stabroek Block.

2.2.5 Vertical Seismic Profiles

The vertical seismic profiles were all conducted from with the acoustic source deployed at a depth of approximately five meters. The acoustic source consisted of six airgun elements, resulting in a total source volume of 1200 in^3 (Table 3).

Table 1. Seismic Acquisition Parameters Summary Table

General Specifications				
Client / Contractor:	CGG		Polarcus	PGS
Program/Project Name:	Stabroek 3D Guyana 2015 Survey		Stabroek II 3D Guyana 2016 Survey	Liza 3D/4D Guyana 2017 Survey
Program Period:	12 July 2015 to 17 February 2016		19 March 2016 to 20 August 2016	23 August 2017 to 19 November 2017
Type of Survey:	3D Seismic		3D Seismic	3D/4D Seismic
General Location:	Guyana		Guyana	Guyana
Prospect Size (km²):	8209		7742	1325
Vessel / Vessel Length (m):	*CGG Alize* / 101.4, *CGG Geo Celtic* / 108.3		*Polarcus Adira* / 92	*Ramform Hyperion* / 104.21
Support/Chase Vessels:	*Thor Omega, The Fenny, the Bourbon Cormorant, the Linda C, the Bourbon Grebe, and the Bourbon Petrel.*		*Vos Athos, 7 Oceans*	*Thor Assister / Thor Omega*
Vessel Configuration description:	Two streamer vessels working independently of one another in different areas		Single source and recording vessel	Single source and recording vessel
Energy Source (Airgun) Specifications				
	CGG Alize	***CGG Geo Celtic***	***Polarcus Adira***	***Ramform Hyperion***
Total source volume (in³)	4070	4070	4240	4130
Number of source arrays:	6	6	6	2, activated in “flip-flop” sequence
Total number of source elements per array / In full volume source	12 elements per array/ 72 elements total	12 elements per array/ 72 elements total	12 elements per array/ 72 elements total, 66 active with 6 spares	11 elements x 2 sub-arrays per array, 9 elements x 1 sub-array per array =31 total active elements
Source depth:	6 meters	6 meters	6 meters	5 meters
Source distance astern (meters):	200-341	369-424	488	353.7
Source frequency (Hz):	200	370	128	10-70
Source intensity (dB re 1µPa or bar meters)	45	69.8	52.4	138
Shot point interval (meters and seconds)	25 meters	25 meters	25 meters, 11.5 seconds	18.75 meters, 9 seconds
Recording System Specifications:				
Number of streamers or nodes/cables:	8-10	10	12	14
Streamer depth (meters):	7	7	12	20
Streamer length /separation (meters)	10000 / 100	10000 / 100	8100 / 100	8100 / 50
Streamer description:	Sentinel solid streamers	Sentinel solid streamers	Sentinel solid streamers	Geostreamer

Table 2. AUV Acquisition Parameters Summary Table

General Specifications			
Client / Contractor:	Fugro		
Program/Project Name:	Liza AUV Survey		
Program Period:	17 December 2015 to 23 March 2016		
General Location:	Stabroek Block of Guyana		
Prospect Size (km²):	350		
Vessel / Vessel Length (m):	Fugro Americas/58.8 meters		
Energy Source AUV Specifications			
Vehicle Altitude:	42 meters		
Ping rate:	2.8Hz (Payload – Multibeam, Sub-bottom Profiler, Sidescan Sonar)		
Sub-bottom Profiler (SBP):	Edgetech DW-106	Frequency: 1-6 kHz	Pulse rate of 20m/sec, Record length of 200m/sec
Side Scan Sonar (SSS):	Edgetech 2200M	Frequency: 105 kHz (Low), 410 kHz (High)	Range of 200m
Multibeam Echo Sounder (MBES)	Kongsberg EM2040	Frequency: 200 kHz	Range of 250m
Energy Source Hull mount Specifications			
Multibeam Echo Sounder (MBES)	Kongsberg EM302	Frequency: 30 kHz	
Sub-bottom Profiler (SBP):	Edgetech 7X	Frequency: 1-6 kHz	
Single Beam Echo Sounder	Kongsberg EA600	Frequency: 200kHz, 38kHz	

Table 3. VSP Surveys Acquisition Parameter Summary Table

General Specifications	
Client / Contractor:	Schlumberger
Type of Survey:	VSP
General Location:	Guyana
Energy Source (Airgun) Specifications	
Total source volume (in³)	1200
Number of source arrays:	1
Total number of source elements per array / In full volume source	6
Source depth:	5 meters

2.3 Passive Acoustic Monitoring (PAM) Parameters

A Passive Acoustic Monitoring (PAM) system, designed to detect most species of marine mammals found in the waters off Guyana, was installed on board each seismic source vessel during the 3D and 4D programs (Stabroek, Canje, and Liza). The system was provided by Seiche Measurements and consisted of a conventionally towed hydrophone array cable, deck cable, data processing unit, headphones for

aural monitoring, and a rack mounted computer with an acoustic analysis software package. In addition to the main array setup, a full spare system was available on each source vessel to serve as a back-up in case of equipment failure.

Each hydrophone array consisted of two broadband hydrophone elements (200Hz to 200kHz) and two standard hydrophone elements (2kHz to 200kHz) and a depth gauge (100m capacity) potted directly into the 14 millimeter cable.

At the data processing unit, a buffer box circuitry splits each hydrophone input into low frequency and high frequency band outputs. Four hydrophone channels are input to an *ASIO* sound card to be digitized at 48 kilohertz (two channels). This was the primary audio input for lower frequency detections in *Pamguard*. The *RME Fireface800* software allowed the PAM Operator to control which hydrophone signals were monitored over headphones. The headphone mix could consist of the raw hydrophone signals or the processed playback signal from the data processing unit. The high frequency output of the buffer box was digitized at the buffer box by the National Instruments data acquisition card at 333 kilohertz (two channels). The custom rack mount data processing unit contained Intel core i5 processors with clock speeds of 3.40 gigahertz and eight gigabytes of RAM. Two wide screen computer monitors were provided to divide the monitoring into low frequency and high frequency displays. Figure 2 outlines the system data flow for the PAM system. An entire second electronic processing system and rack mounted data processing unit were configured for use as spares.

Pamguard was the primary software utilized. *Pamguard* is an open-source software program that is widely considered the world standard for acoustic detection, localization, and classification for mitigation regarding marine mammals and for research into their abundance, distribution, and behaviour (www.*Pamguard*.org).

One monitor was configured for monitoring high frequency clicks, and the second monitor was configured for monitoring low frequency moans, creaks, whistles, clicks, and burst pulses. The high frequency monitor received the raw audio from the *National Instruments DAQ* sound card and contained *Pamguard* modules for monitoring and recording high frequency cetacean clicks, spectrogram, and a sound recorder. The low frequency monitor received raw audio from the *ASIO Fireface* sound card and contained a more elaborate configuration of *Pamguard* modules than the high frequency monitor. This included a click detector, whistle and moan detector, spectrogram, depth gauge display and tracker, map with a GPS feed from the vessel, and a sound recorder.

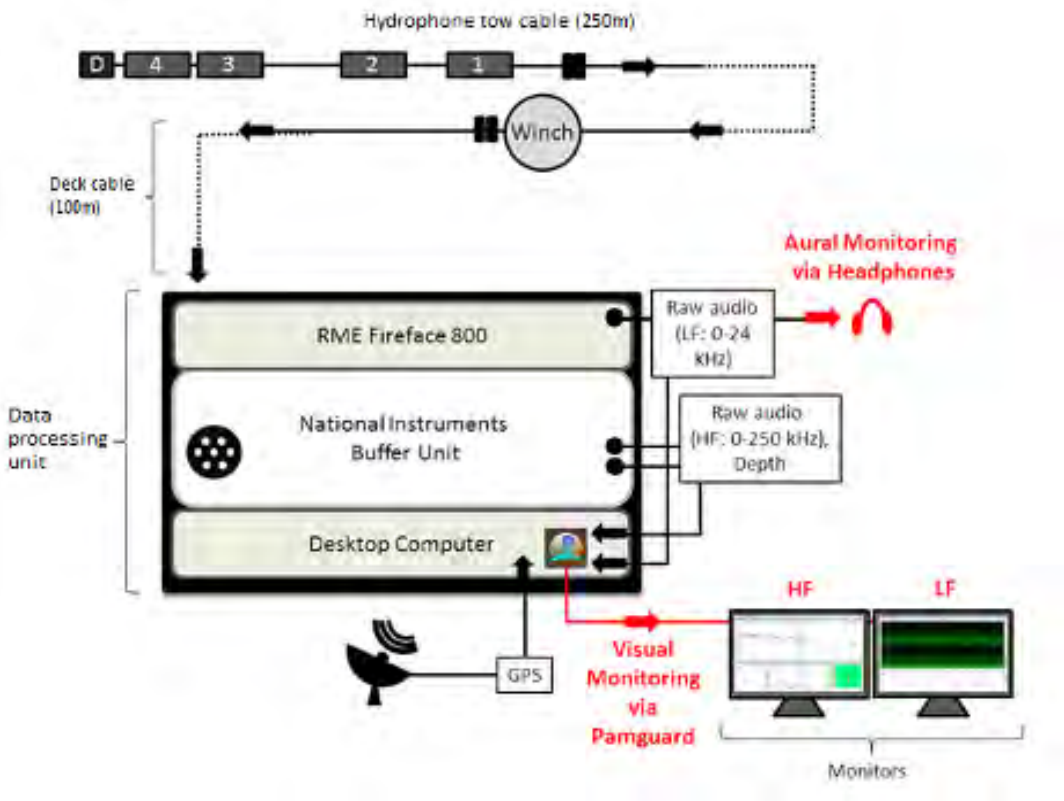


Figure 2. Data pathway through PAM system

3 Methodology

3.1 Visual Survey Methodology

Visual monitoring for protected species was conducted by two PSOs provided by RPS, each of whom have completed a PSO training program. One observer was on watch at a time and monitored the exclusion zone and surrounding areas during all daytime operations when the acoustic source was in the water, regardless of source activity.

Observers scanned the sea surface with the naked eye and the aid of various binoculars, and big-eyes per ExxonMobil's request during the Stabroek 3D Survey. Shifts lasted no more than four hours followed by a break of no less than two hours. Monitoring occurred daily beginning at dawn (defined as approximately 15 minutes before sunrise) and continued throughout the day until the exclusion zone could no longer be effectively observed due to darkness (approximately 15 minutes after sunset).

PSOs collected data at approximately 20-minute intervals while on watch and recorded in observation logs. Daily observation logs included information about environmental conditions, vessel and survey operations, marine debris observed, any vessel/gear and wildlife interactions, and any wildlife sightings.

Identification of marine mammals and sea turtles and wildlife was made or confirmed using identification guides:

- *Guide to Marine Mammals and Turtles of the U.S. Atlantic & Gulow frequency of Mexico* (Wynne, K. and Schwartz, M. 1999)
- *Guide to Marine Mammals of the World* (Reeves et al. 2002).
- *Sea Birds of the World (Harrison, Peter, Princeton University press, Princeton, New Jersey, 2003)*

Distances to protected species were determined visually by comparing an animal or an object's position relative to other vessels and/or installations at known distances, and/or by use of reticle binoculars. Prior to the initiation of the source for ramp-ups or tests during daylight hours, dedicated watches of no less than 30 minutes in waters less than 200 meters and 60 minutes in waters greater than 200 meters were conducted to monitor for protected species within the exclusion zone. Communication between visual observers, PAM Operators and seismic operators was carried out using handheld very high-frequency (VHF) radios.

3.2 Acoustic Monitoring Methodology

One PAM Operator was present on board each seismic source vessel to conduct acoustic monitoring prior to all ramp ups conducted during periods of reduced visibility and/or darkness. In addition, acoustic monitoring was conducted opportunistically during source operations as much as possible, allowing breaks for the PAM Operator to maintain concentration.

Acoustic monitoring was conducted nightly, beginning approximately 15 to 20 minutes prior to dusk, and continuing until daylight, so long as the PAM hydrophone cable was deployed. Acoustic monitoring overlapped visual monitoring efforts by 15 to 20 minutes at dawn and dusk.

During an acoustic monitoring period, the PAM Operator aurally monitored audio feed using Sennheiser headphones from up to all four hydrophone elements which was first mixed using a RME *Fireface800* unit. Visualizations of the audio feed were also monitored via the *Pamguard* software on two computer monitors: one configured to display low frequency modules and the other configured to display the high frequency modules.

Audible clicks, burst pulses, moans, and creaks at frequencies less than 24 kilohertz, including sperm whale clicks and delphinid whistles and clicks, can be detected on the low frequency spectrogram display, the low frequency click detector display, and the low frequency whistle/moan detector display within *Pamguard*.

Vocalizations at frequencies greater than 24 kilohertz including pulse emissions from beaked whales, Kogia whales, and various delphinid species are detected on high frequency click detector displays. The click detector is configured to sample audio at 333 kilohertz for vocalizations with frequency spectra up to approximately 166.5 kilohertz.

During an acoustic monitoring period, the Operators were specifically looking for a combination of factors that may indicate biological pulse emissions. The Operators monitored for click trains on the high frequency bearing/time display; specifically, click trains that showed a progressive change in bearing (Figure 3). When click trains were present, individual clicks were highlighted by the Operator, and the click spectrum module referenced to determine if the clicks had broadband frequencies and consistent peak intensities near a frequency of 30 kilohertz or higher. The click waveform display module provided additional indication of an acoustic detection; biological pulse emissions are generally associated with clean, extremely brief waveforms (Figure 4). Operators also referenced the high frequency amplitude/time display module during monitoring periods; the intensity of pulse emissions generally register at higher intensities than a majority of the ambient noise with click amplitudes for delphinid clicks registering between 155 and 190 decibels relative to 1 micro Pascal (Figure 5). Additionally, consistent click intervals are indicators of pulse emissions; intervals are designated by the unit clicks per second. High frequency dolphin click trains vary widely in click intervals with most click trains displaying an interval of 5 to 40 clicks per second. Click trains within this range are labelled as *echolocation* click trains. Additionally, pulse emissions with much higher click intervals of more than 200 clicks per second are labelled as *burst pulses*. Recorded sound files of vocalizing marine mammals were analysed using *Spectrogram 16*, visualization software that allows the operators to slow down and aurally/visually audit for ultrasonic pulse emissions recorded during a high frequency acoustic detection.

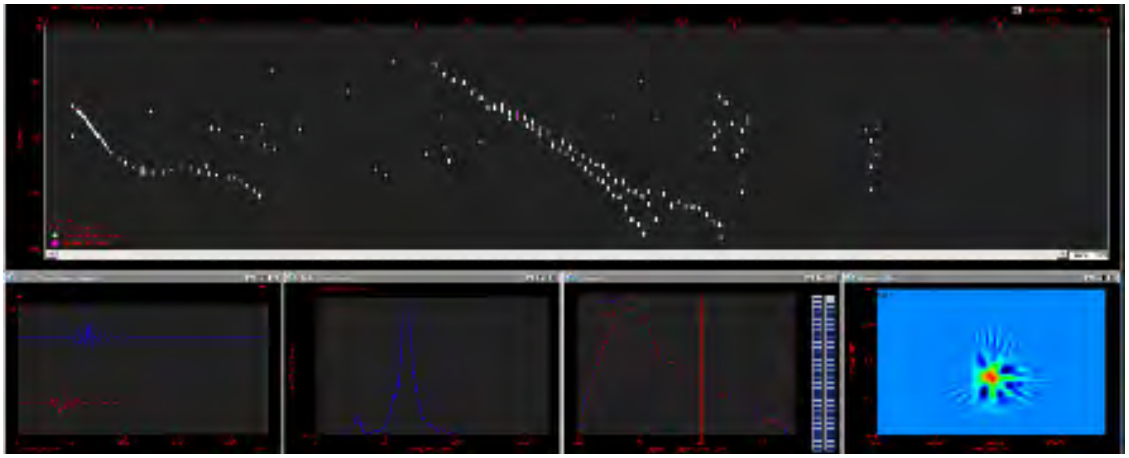


Figure 3: High frequency delphinid click trains on the bearing/time display

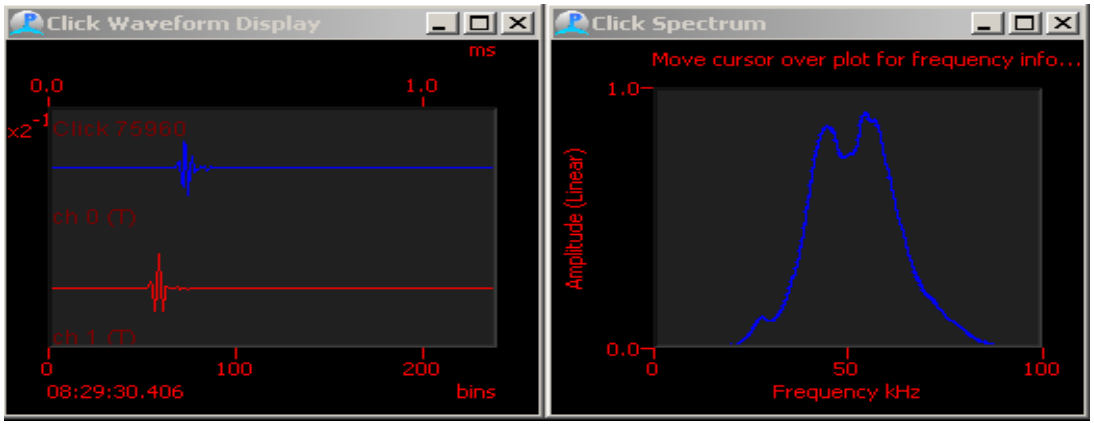


Figure 4: Clean click waveform display and click spectrum of delphinid pulse emissions

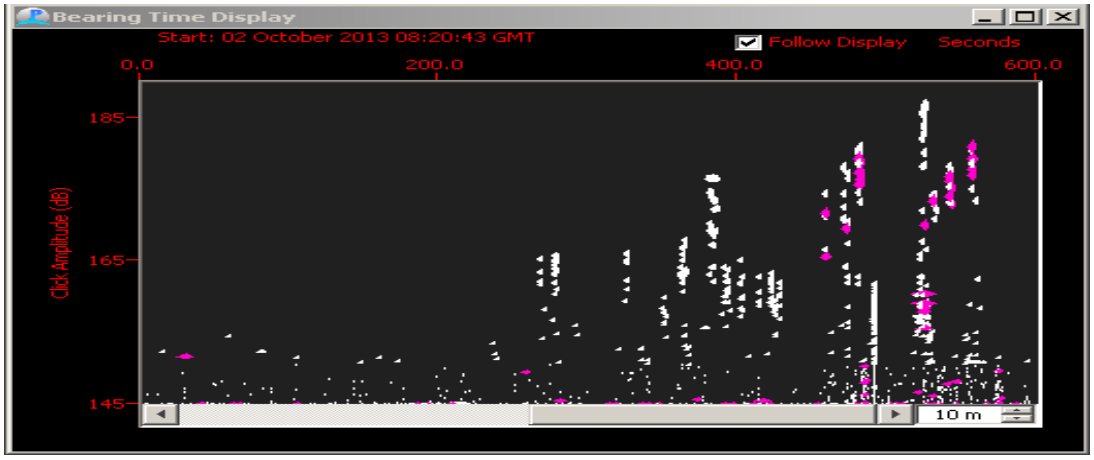


Figure 5: The amplitude/time module during a high frequency delphinid detection

Pamguard contains a function for calculating the range to vocalizing marine mammals based upon the least squares fit test. This method is most effective with animals that are relatively stationary in comparison to the moving vessel, such as sperm whales. The mathematical function estimates the range to vocalizing marine mammals by calculating the most likely crossing of a series of bearing lines generated from tracked clicks or whistles and plotted on a map display. Since the hydrophones are linear, and in close proximity to each other, there is a left-right ambiguity to these localizations, meaning that there is a 1:2 probability that recorded vocalizations are originating from the equal but opposite bearing to that indicated in *Pamguard's* bearing/time display. Thus, a bearing of zero degrees refers to a location directly ahead of the hydrophone array while a bearing of 180 degrees is directly astern of the hydrophone array. A 90 degree bearing could be located at either 90 or 270 degrees in relation to the array. All bearings for acoustic detections indicated in this report are relative to the hydrophone, and this left/right ambiguity should be understood.

Since ultrasonic sounds have a high attenuation rate in water, the distance of a mammal detected vocalizing at frequencies greater than 24 kilohertz is generally estimated to be well within the 500 meter exclusion zone. When the distance to a vocalizing animal could not be determined by *Pamguard*, the experienced PAM Operator made a distance estimation assisted by the noise or detection score system developed by Gannier et al. (2002). Gannier et al. monitored sperm whales in the Mediterranean both visually and acoustically. A scale was developed based upon the strength or intensity of the sperm whale

clicks at various distances that were then measured when the sperm whales surfaced and were visually observed. Although the scale is subjective and sounds produced in marine environments will vary according to local conditions, the scale provides a measure for approximating distances when using a single, linear hydrophone array.

Sound recordings were made using a recorder whenever potential marine mammal vocalizations were detected by the PAM Operator.

PAM Operators communicated with seismic personnel via handheld VHF radios or by word of mouth while in the instrument room.

3.3 Detections Data Analysis Methodology

Raw visual and acoustic detection data from the 3 seismic surveys (Staebroek 3D, Canje 3D, and Liza 3D/4D), the Liza AUV survey, and all 7 VSPs were compiled and analyzed for the following:

- Average closest approach by species and species group to active and silent source
- Median closest approach by species and species group to active and silent source
- Mitigation action summary by species and species group
- Percent of detections by species and species group resulting in a mitigation action
- Detection rate (detections per hour of effort) by monitoring method

Statistical analysis was not completed during the analysis due to the low sample size available. Source activity for all analysis was grouped as “source active” or “source silent”, where “source active” included full volume, soft start, and all other reduced volume including the mitigation source. This was done due to the small sample size of data, making further categorization impractical.

Closest approach by species and species group to active and silent source

All visual and acoustic detections during surveys which utilized an acoustic source—surface seismic, AUV, and VSPs—were compiled and grouped based on species and source activity. The number of detections that fell into each category were counted and the average and median closest approach to the source were calculated for each group using Excel. Detections were then combined into species groups (whales, dolphins, and turtles) and the same analysis was run for the groups.

Mitigation actions

All visual and acoustic detections were compiled and grouped based on species and mitigation actions implemented. The number of detections that fell into each category were compiled and percentages of detections for each species resulting in a mitigation action were calculated using Excel. Detections were then combined into species groups (whales, dolphins, and turtles) and the same analysis was run for the groups.

Detection rate

The total numbers of visual and acoustic detections were tallied, along with the total visual and acoustic monitoring effort for all surveys. Monitoring effort was converted into decimal numbers for analysis and the total number of detections were divided by the total monitoring effort to determine the detection rates for visual, acoustic, and total detections. VSP data was excluded from this analysis due to the static nature of the surveys in comparison to the seismic and AUV surveys, with only a small area covered in VSP surveys, leading to potential bias in detection rate.

Detection Seasonality

All visual and acoustic detections were compiled and grouped based on month of detection, and month/year of detection. The number of detections that fell into each category were compiled. Visual and acoustic effort was also parsed into month and month/year categories for normalization of detection totals. A detection rate per hour of observation effort was calculated for each month and month/year category to determine if seasonal trends were apparent in the data. Visual and acoustic effort was utilized to normalize dolphin and whale detections, while only visual effort was utilized to normalize turtle detections.

4 Survey Data

4.1 Source Operations Summary

Over the course of all of the survey programs, except the baseline surveys where there was no source, the seismic source was active for a total of 9727 hours and 58 minutes including: 420 hours and 46 minutes spent in ramp up, 149 hours and 54 minutes spent conducting source testing, 8873 hours and 09 minutes in production, and 284 hours and 09 minutes spent at full volume or partial volume not in production, including time prior to the start of lines and during line changes. During the AUV survey, there was a total of 786 hours of AUV Payload Operations, 201 hours and 30 minutes of MBES (EM302) activity, 104 hours and 03 minutes of SBP activity, and 469 hours and 51 minutes of Single Beam (EA600) activity (Figure 6, Figure 7, and Figure 8).

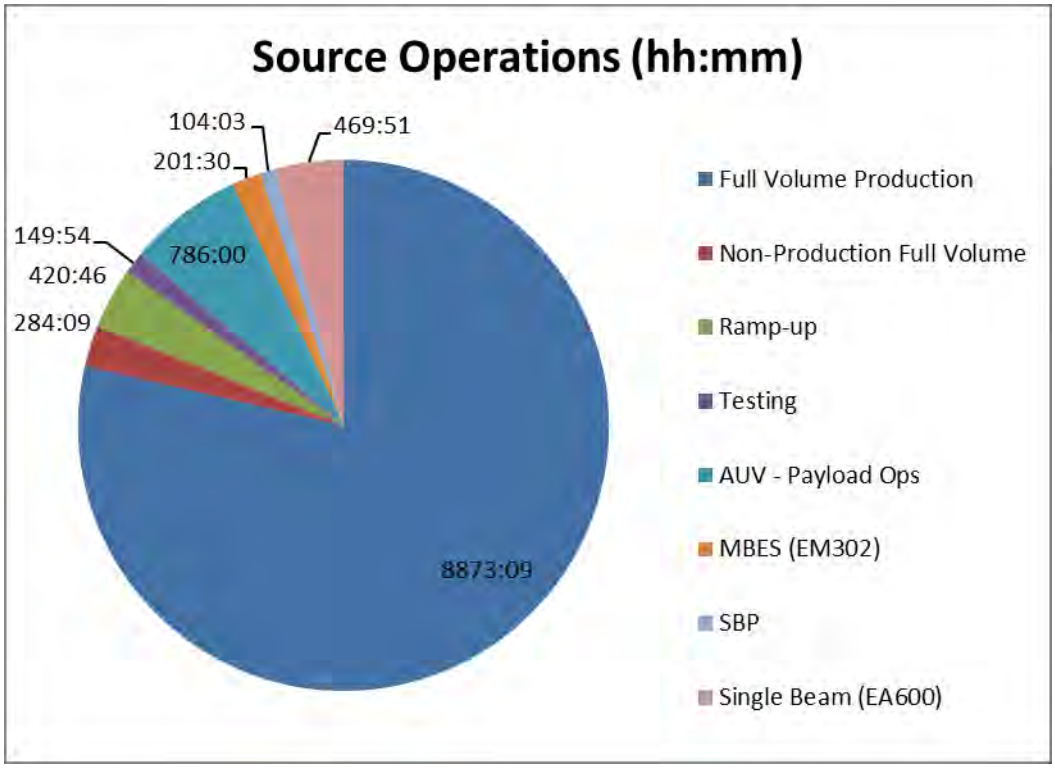


Figure 6: Breakdown of acoustic source operations

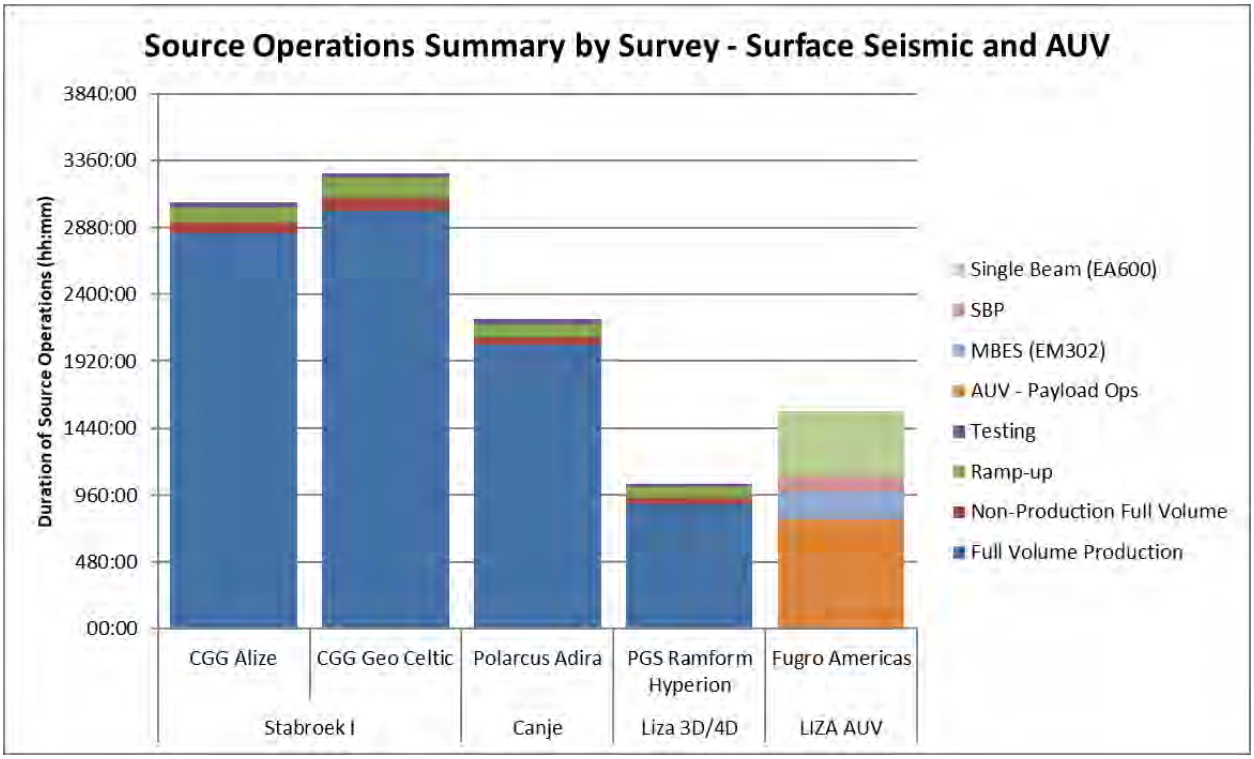


Figure 7: Breakdown of source operations by source activity and survey for surface seismic and AUV projects

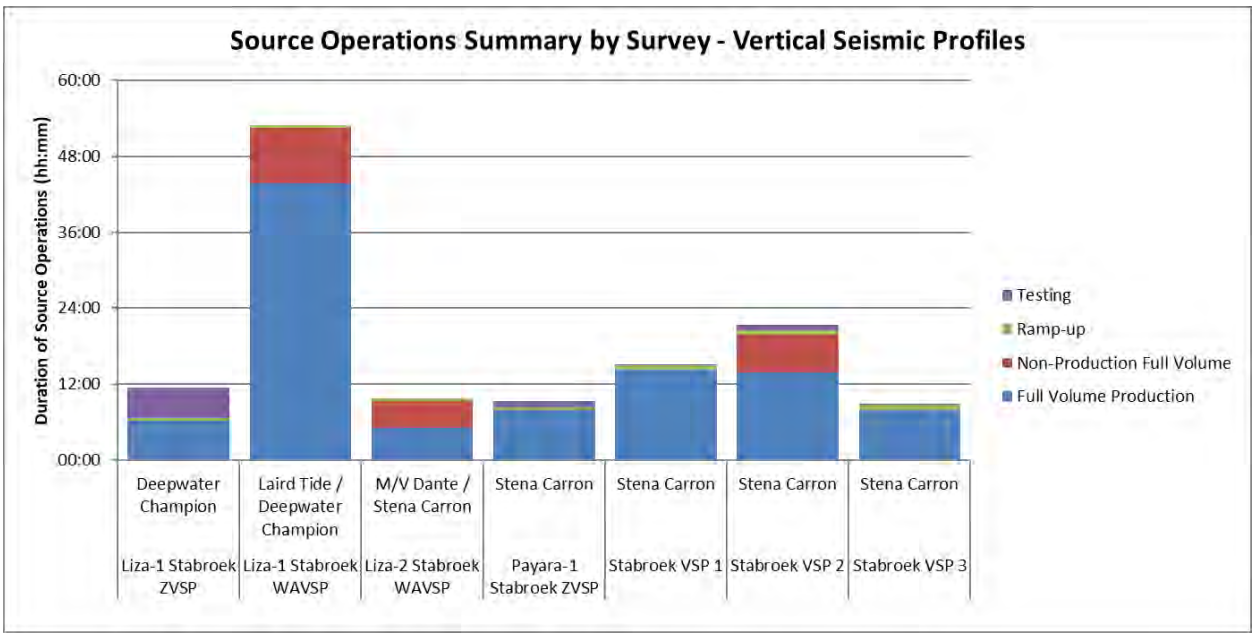


Figure 8. Breakdown of source operations by source activity and survey for vertical seismic profiles

4.2 Visual Monitoring Summary

PSOs conducted visual observations throughout these surveys for a total of 8187 hours and 37 minutes. Visual observations while the source was active accounted for 4504 hours and 24 minutes, observations during periods of source inactivity accounted for 2663 hours and 48 minutes, and observations during the AUV survey accounted for 1019 hours and 25 minutes (Figure 9).

Only visual monitoring was conducted during the VSP surveys and Environmental Baselines. The duration of monitoring during source silence and activity on VSP surveys is summarized in Figure 10. The duration of visual monitoring on each of the Environmental Baseline surveys is summarized in Figure 11.

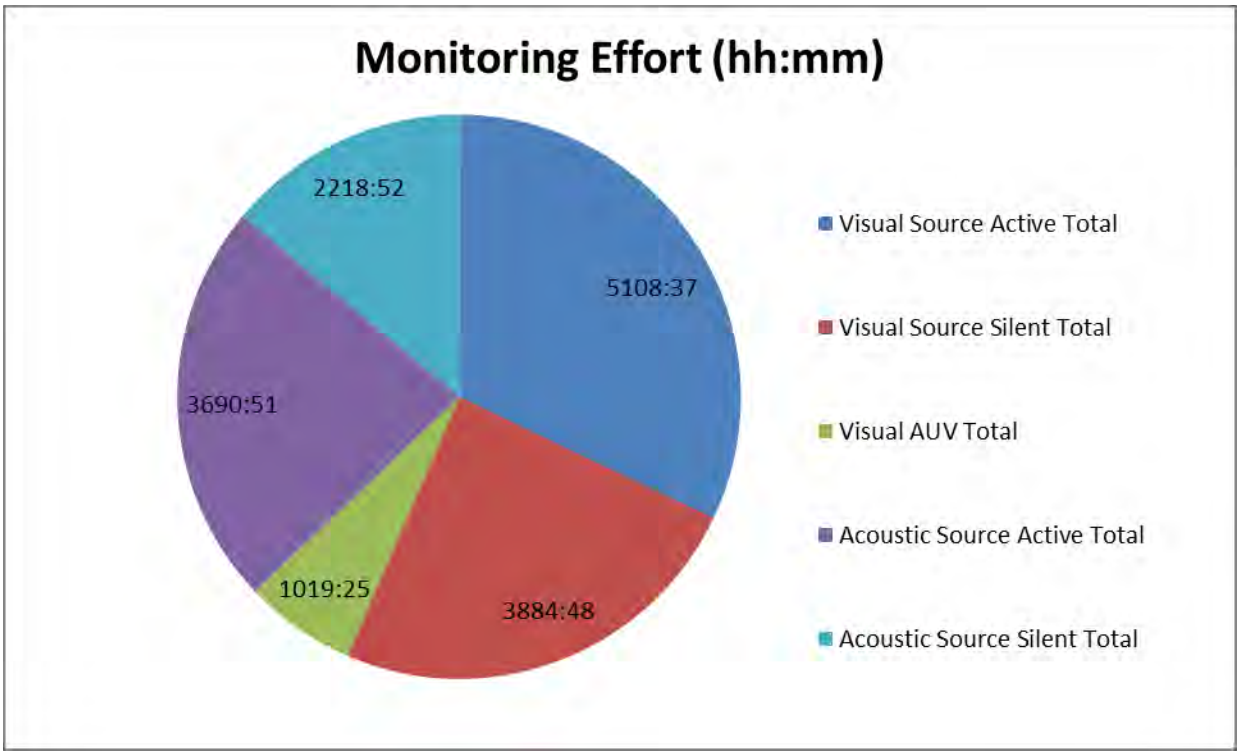


Figure 9. Monitoring effort summary for all projects

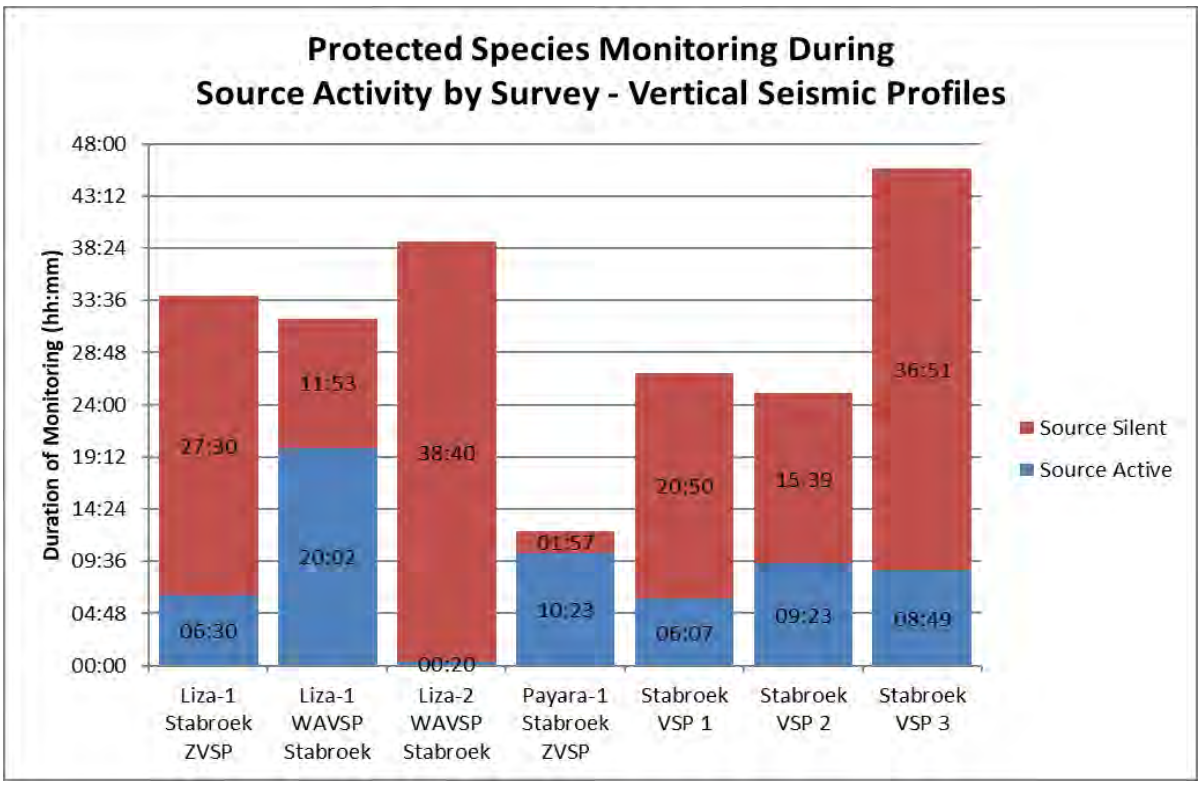


Figure 10. Breakdown of visual and acoustic monitoring while source active and silent by survey for vertical seismic profiles

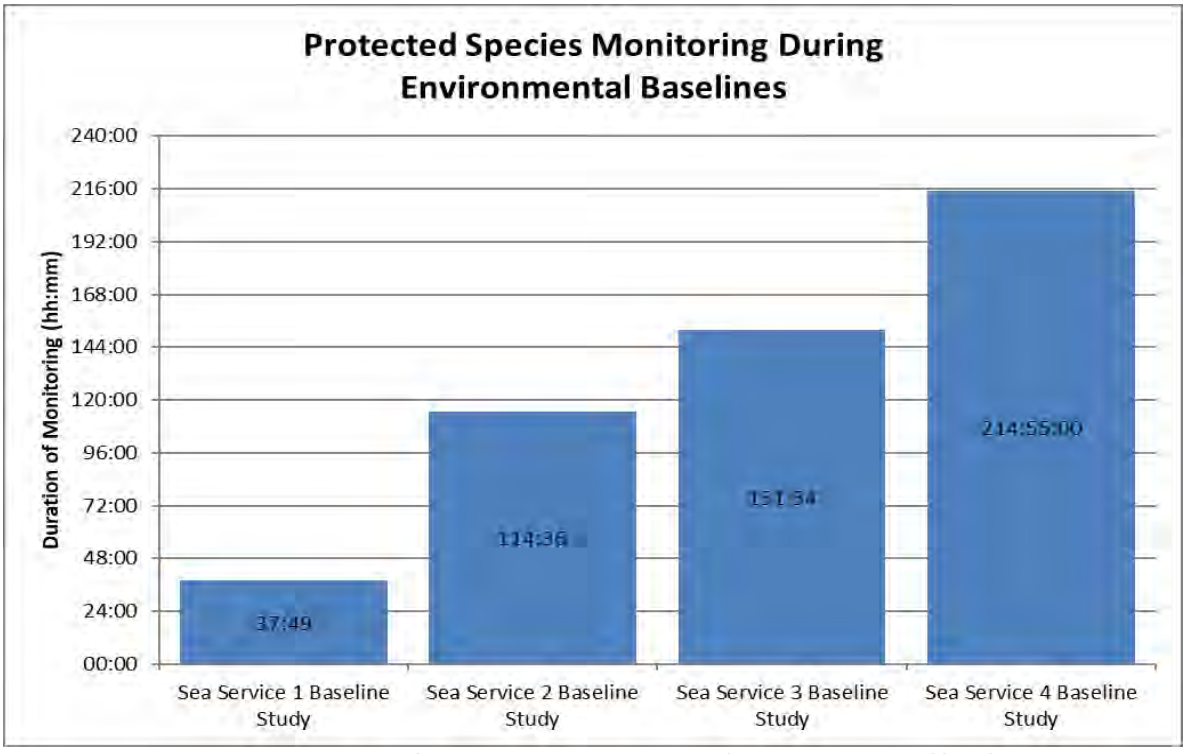


Figure 11. Protected species monitoring summary during environmental baselines

4.3 Acoustic Monitoring Summary

Passive acoustic monitoring (PAM) was conducted for a total of 5135 hours and 55 minutes throughout the Stabroek 3D, Canje 3D, and Liza 3D/4D Surveys, which included 3282 hours and 24 minutes of acoustic observations while the source was active and 1853 hours and 31 minutes while the source was inactive (Figure 12).

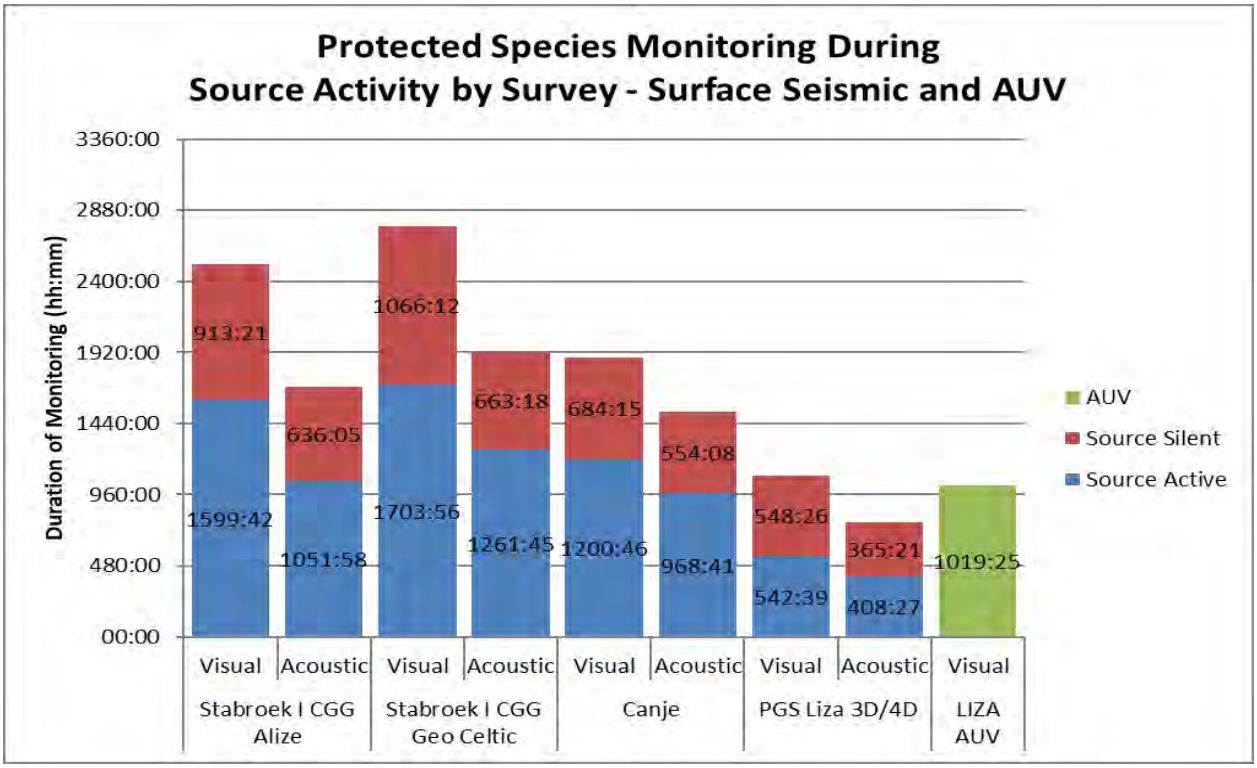


Figure 12: Breakdown of visual and acoustic monitoring while source active and silent by survey for surface seismic and AUV

4.4 Mitigation Actions

The *Joint Nature Conservation Committee (JNCC) guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys* were implemented during each of the survey programs summarized in this report. As such, delays to initiation of the sound source, airguns or otherwise, were implemented if marine mammals or sea turtles were detected inside the 500 meter exclusion zone around the center of the sound source in the search period conducted prior to initiating the source from silence.

There were a total of 13 mitigation actions conducted throughout these surveys due to marine mammals detected within the exclusion zone prior to source operations, with 2.39% of all detections during surveys with source activity resulting in mitigation actions. Nine mitigation actions occurred aboard the *CGG Alize* during the Stabroek survey and were delays to initiation of the source, including eight of which were undertaken for dolphin detections and one for a sperm whale detection. One mitigation action occurred during the Liza AUV survey and was a delay to the initiation of the source for

a dolphin detection. Three mitigation actions occurred during the Liza 3D/4D survey and were delays to initiation of the source for dolphin detections.

4.5 Wildlife Summary

4.5.1 Protected Species Detections Summary

There were 583 total protected species detections recorded during all surveys, including 219 visual detections, 359 acoustic detections and 05 correlated visual-acoustic detections (Table 4). The majority of detections were of dolphins (82.5% of all detections, 63.8% of visual detections and 94% of acoustic detections), with acoustic detections of unidentifiable dolphins accounting for the majority of all detections (58.2%).

Table 4. Summary of visual and acoustic detections

Species	Number of Visual Detections	Number of Acoustic Detections	Total Number of Detections
Bryde's Whale	17	0	17
Unidentified Baleen Whale	17	0	17
Unidentified Whale	13	0	13
Unidentified Beaked Whale	2	0	2
Sperm Whale	18	22	40
Unidentified Cetacean	1	0	1
All Whales	**68**	**22**	**90**
Atlantic Spotted Dolphin	7	0	7
Common Bottlenose Dolphins	19	1	20
Common Dolphin	3	0	3
Fraser's Dolphin	3	1	4
Melon-headed Whales	5	0	5
Pantropical Spotted Dolphins	34	1	35
Risso's Dolphin	2	0	2
Rough-toothed Dolphins	1	0	1
Short-finned Pilot Whales	4	0	4
Spinner Dolphin	19	0	19
Unidentifiable dolphin	46	339	385
All Dolphins	**143**	**342**	**485**
Green Sea Turtle	2	0	2
Hawksbill Sea Turtle	2	0	2
Loggerhead Sea Turtle	2	0	2
Olive Ridley Sea Turtle	2	0	2
Unidentified Shelled Sea Turtle	5	0	5
All Turtles	**13**	**-**	**13**
TOTAL	**224**	**364**	**583**

*This total includes 5 correlated visual and acoustic detections, which are included in both the visual and acoustic totals, but only counted once each in this total leading to the difference of 5 detections between the sum of visual and acoustic totals and the overall total.

The visual detections included whales, dolphins and sea turtles while acoustic detections consisted of whales and dolphins (Table 4, Figure 13, Figure 14).

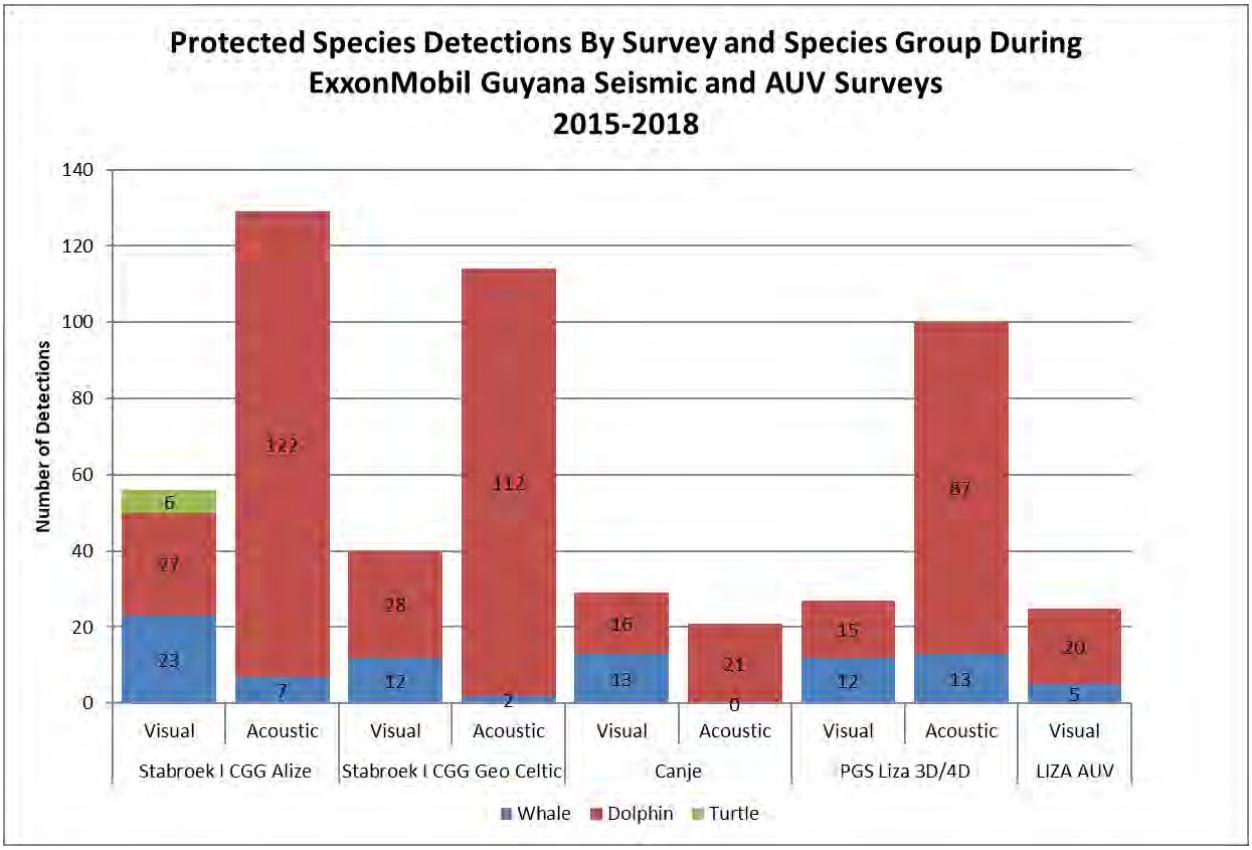


Figure 13. Protected species detections by species group on each of the ExxonMobil Guyana seismic and AUV surveys

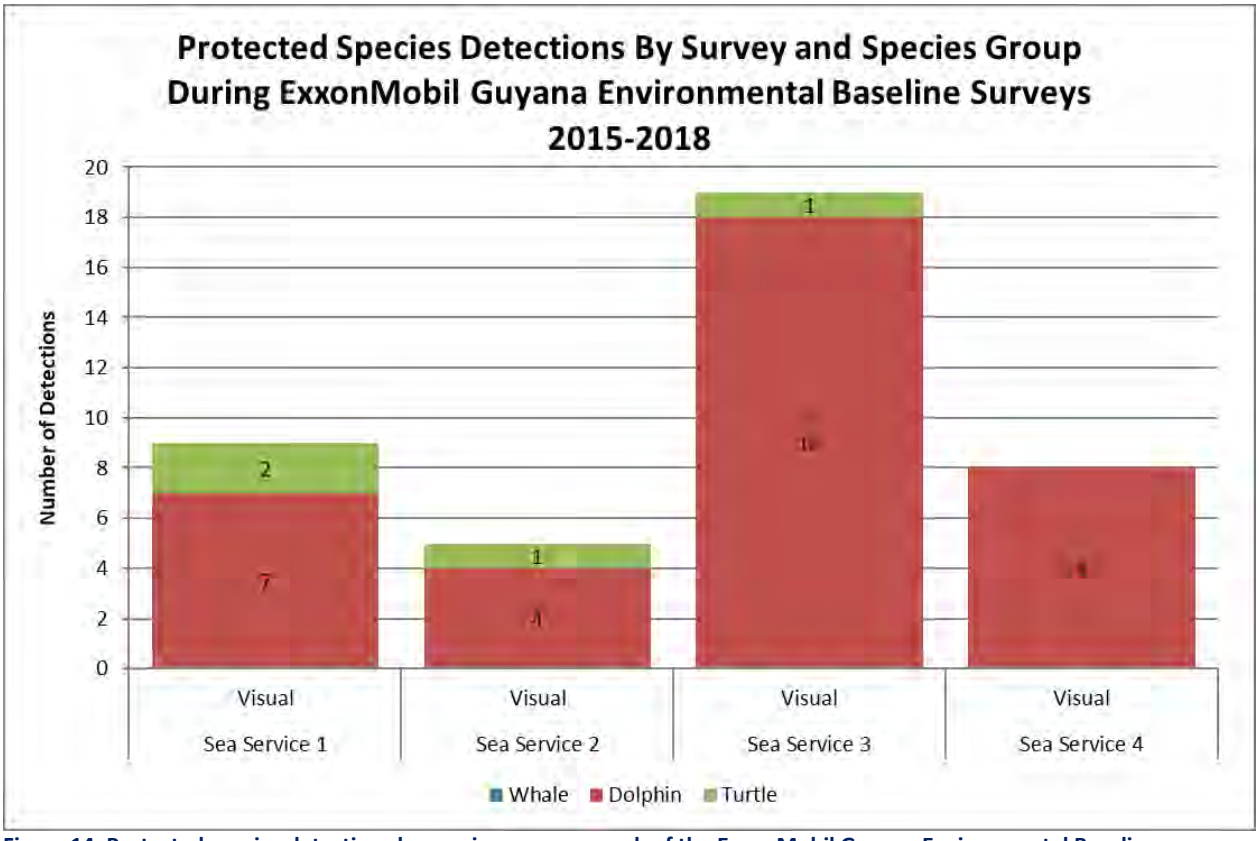


Figure 14. Protected species detections by species group on each of the ExxonMobil Guyana Environmental Baseline surveys

A total of 16 different identified species were observed over the course of all of the programs, two species of whales, 10 species of delphinid and four species of sea turtles (Figure 15).

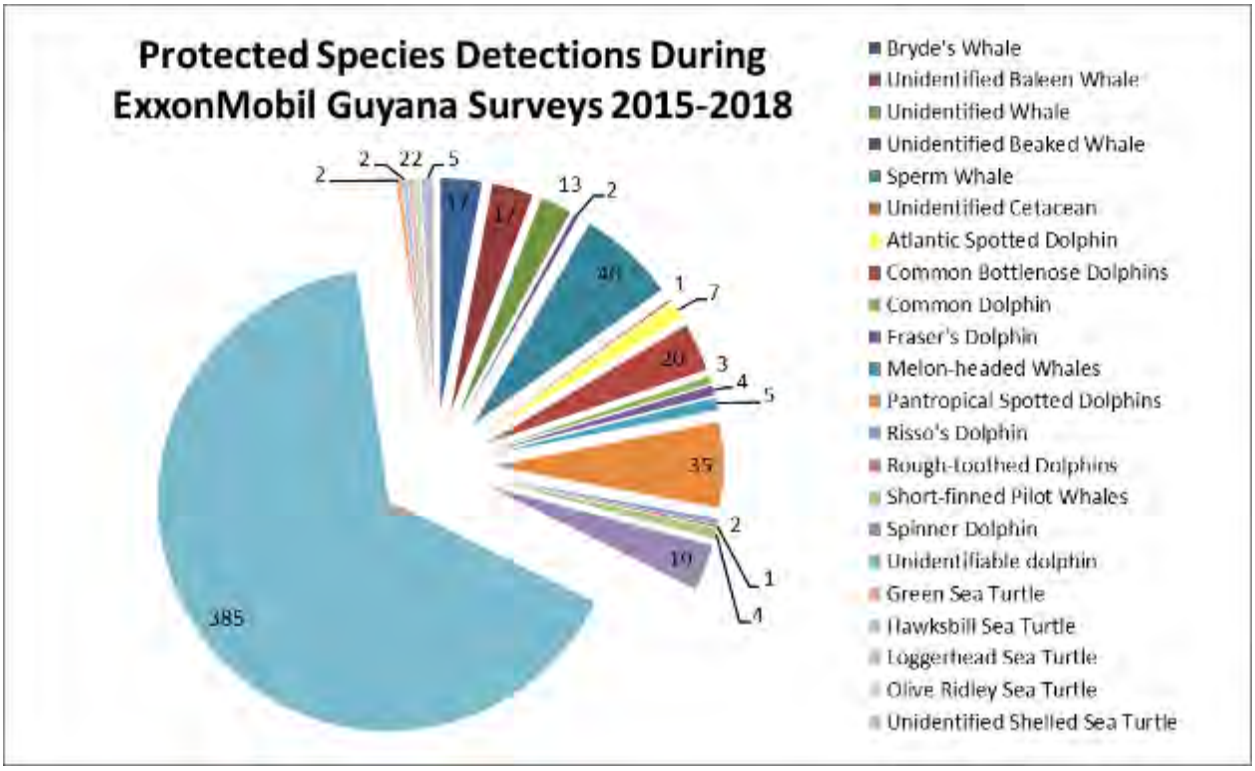


Figure 15: Protected species detections (visual and acoustic) shown as a breakdown by species over all ExxonMobil Guyana programs during 2015-2018

Of the 583 total protected species detections made during all programs, 307 occurred while the acoustic source was active. Of the detections during source activity, 13 occurred during soft starts, nine occurred during reduced power source testing, four occurred during full volume non-production firing and 281 occurred during full volume production. The remaining 276 protected species detections occurred while the acoustic source was silent—this total includes the Environmental Baseline surveys where no source activity occurred (Figure 16).

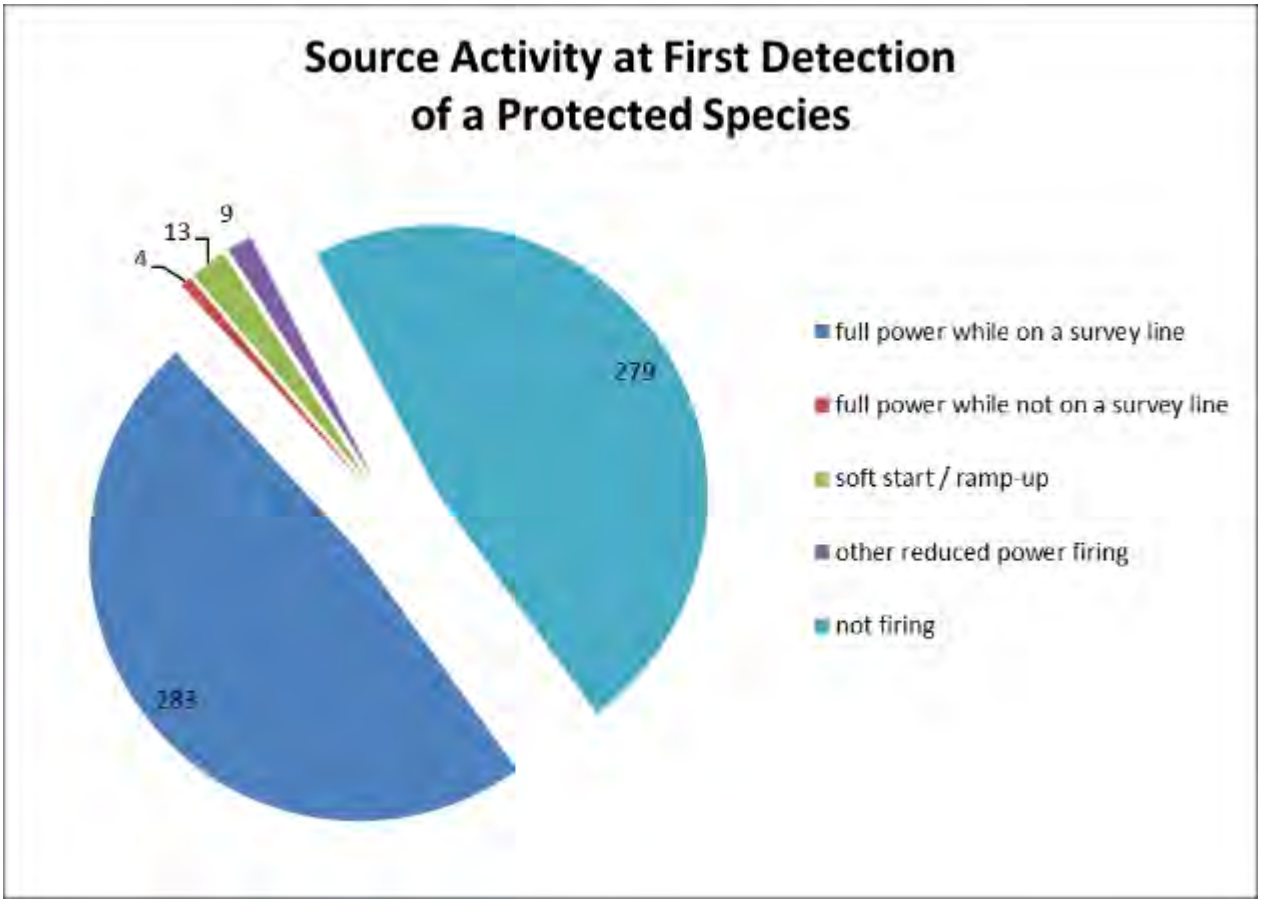


Figure 16: Seismic source activity at the initial detection of a marine mammal or sea turtle

4.5.2 Visual Detections

Protected species were visually detected on 224 occasions during the surveys included in this summary. Delphinids were detected more frequently than any other species group, with 10 species identified in 143 separate visual detection events. Two whale species were identified, Bryde's whales and sperm whales and additional sightings were made of unidentified beaked whales, unidentified baleen whales and unidentified whales. A total of 68 whale detections were made visually during all of the programs. Four sea turtle species were observed in additional to sightings of unidentified shelled turtles and a total of 13 sea turtles were detected (Figure 17, Table 4).

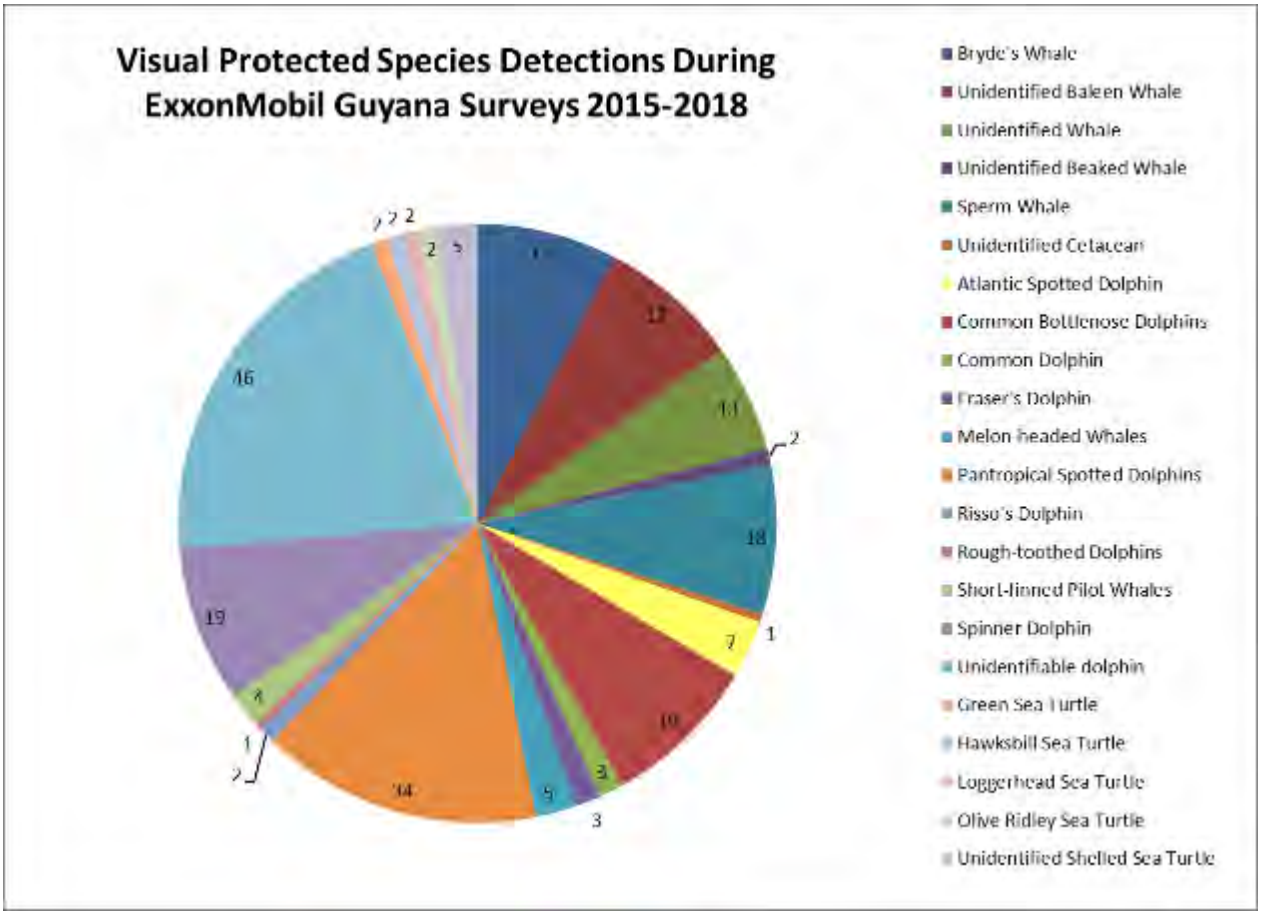


Figure 17: Visual protected species detections shown as a breakdown by species over all ExxonMobil Guyana programs during 2015-2018

4.5.3 Acoustic Detections

Marine mammals were acoustically detected on 264 occasions throughout this survey where unidentified delphinids were by far the most frequently detected species with 254 detections. Sperm whales were detected on nine occasions and Fraser's dolphins were detected as part of a correlated visual sighting of the pod (Figure 18, Table 4).

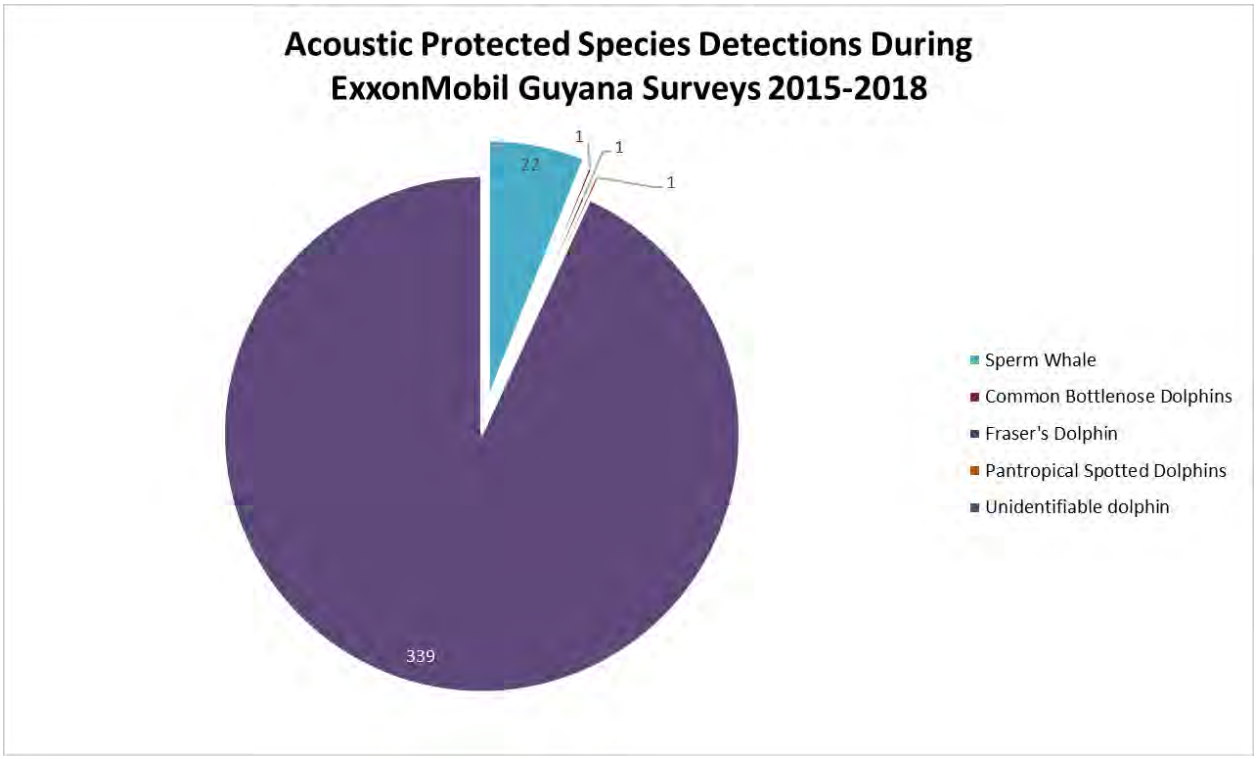


Figure 18: Acoustic protected species detections shown as a breakdown by species over all ExxonMobil Guyana programs during 2015 and 2016

A summary of detections across all surveys is provided in Table 5. Figure 19 shows the distribution of visual protected species detections, while Figure 20 depicts acoustic protected species detections—both maps include the five correlated visual and acoustic detections and have survey area polygons superimposed for reference. The distribution of dolphin and turtle detections was fairly consistent across the surveyed areas, however visual and acoustic whale detections only occurred beyond the 2000-meter isobath (Figure 19 and Figure 20).

Table 5: Protected species visual and acoustic detection summary during the 2015 – 2018 ExxonMobil Guyana survey programs

	Stabroek I *CGG Alize*		Stabroek I *CGG Geo Celtic*		Canje		PGS Liza 3D/4D		LIZA AUV	Liza-2 Stabroek WAVSP	Sea Service 1	Sea Service 2	Sea Service 3	Sea Service 4	Total Number of Detection Events
	Visual	Acoustic	Visual	Acoustic	Visual	Acoustic	Visual	Acoustic	Visual	Visual	Visual	Visual	Visual	Visual	
Bryde's Whale	3		5		3		1		2	3					17
Unidentified Baleen Whale	5		1		2		8		1						17
Unidentified Whale	11				2										13
Unidentified Beaked Whale					2										2
Sperm Whale	4	7	6	2	4		2	13	2						40
Unidentified Cetacean							1								1
Total number of whale detections	**23**	**7**	**12**	**2**	**13**	**0**	**12**	**13**	**5**	**3**	**0**	**0**	**0**		**90**
Atlantic Spotted Dolphin											2	1	4		7
Common Bottlenose Dolphins							2	1*	8		1	2	4	2	20
Common Dolphin													3		3
Fraser's Dolphin	1	1*			2										4
Melon-headed Whales			2		1		1		1						5
Pantropical Spotted Dolphins	6		6		5		6	1*	7					4	35
Risso's Dolphin			1										1		2
Rough-toothed Dolphin													1		1
Short-finned Pilot Whales	2								2						4
Spinner Dolphin	5		9		3		1					1			19
Unidentifiable dolphin	13	121**	10	112	5	21	5	85	2		4		5	2	385
Total number of dolphin detections	**27**	**122**	**28**	**112**	**16**	**21**	**15**	**87**	**20**	**0**	**7**	**4**	**18**	**8**	**485**
Total number of marine mammal detections	**50**	**129**	**40**	**114**	**29**	**21**	**27**	**100**	**25**						**575**
Green Sea Turtle	1								1						2
Hawksbill Sea Turtle									2						2
Loggerhead Sea Turtle	2														2
Olive Ridley Sea Turtle											2				2
Unidentified Shelled Sea Turtle	3											1	1		5
Total number of sea turtle detections	**6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**2**	**1**	**1**		**13**

Note: Only surveys with detections are included in this table
*Correlated with a visual detection
**Two detections correlated with visual detections

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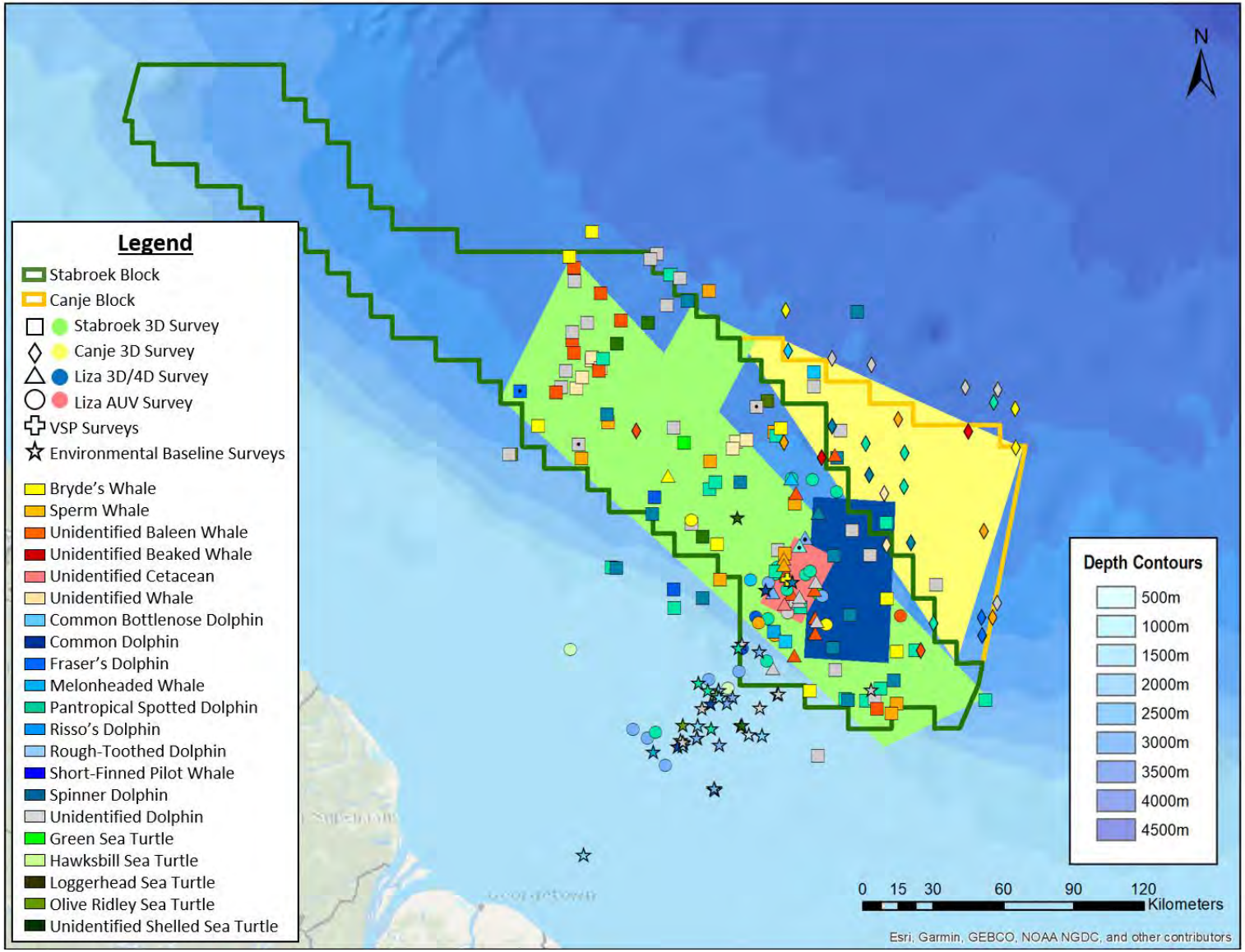


Figure 19: Distribution of visual protected species detections during ExxonMobil Guyana 2015 - 2018 programs. Bathymetry data from the GEBCO_2014 Grid, version 20150318, www.gebco.net

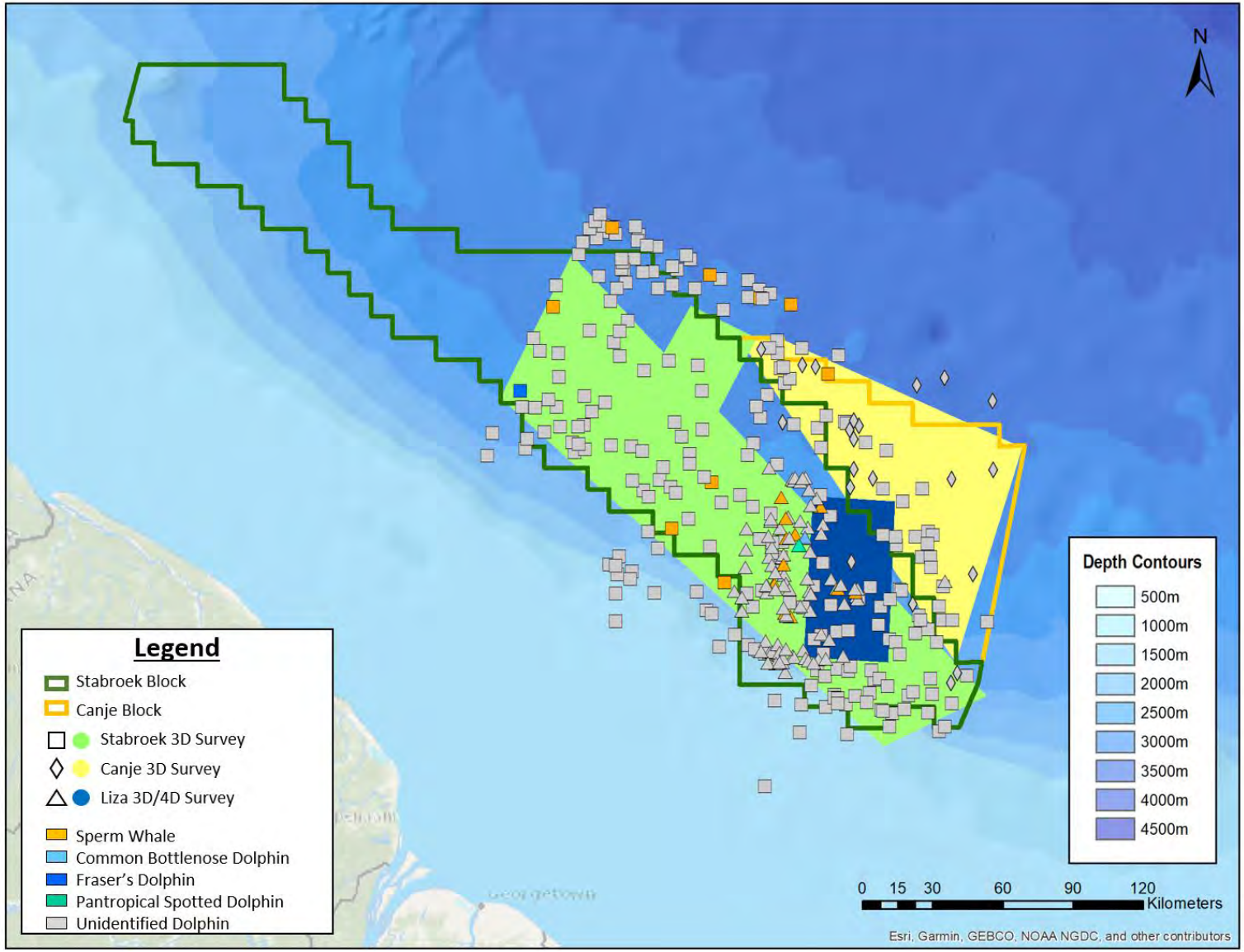


Figure 20: Distribution of acoustic protected species detections during ExxonMobil Guyana 2015 – 2018 programs. Bathymetry data from the GEBCO_2014 Grid, version 20150318, www.gebco.net

4.5.4 Other Wildlife Summary

In addition to data collected during marine mammal and sea turtle detections, PSOs also recorded observations for other wildlife observed during monitoring watches. Additional wildlife observed throughout this survey included 76 avian species (12 of which were not identifiable to species level) and 32 fish species (eight of which were not identifiable to species level).

The most frequently observed avian species in terms of number of individuals observed was the masked booby (*Sula dactylatra*, 32.1%) which had 1942 individuals recorded over a period of 498 days. Other frequently observed avian species, each with at least 100 individuals recorded throughout the surveys, included magnificent frigatebird (*Fregata magnificens*, 16.141%, 973 individuals over 147 days), unidentified birds (9.423%, 568 individuals over 93 days), barn swallow (*Hirundo rustica*, 4.048%, 244 individuals over 101 days), Cory's shearwater (*Calonectris diomedea*, 3.898%, 235 individuals over 47 days), scarlet ibis (*Eudocimus ruber*, 3.318%, 200 individuals over one day), brown booby (*Sula leucogaster*, 3.036%, 183 individuals over 116 days), unidentified jaeger (2.837%, 171 individuals over 23 days), unidentified sandpiper (2.372%, 143 individuals over 29 days), sooty tern (*Onychoprion fuscatus*, 2.339%, 141 individuals over 4 days), white-tailed tropic bird (*Phaethon lepturus*, 2.273%, 137 individuals over 58 days), greater shearwater (*Puffinus gravis*, 2.173%, 131 individuals over 32 days), unidentified shearwater (2.057%, 124 individuals over 25 days), laughing gull (*Larus atricilla*, 2.024%, 122 individuals over 38 days), and pomarine jaeger (*Stercorarius pomarinus*, 1.659%, 100 individuals over 36 days) (Figure 21, Table 6).

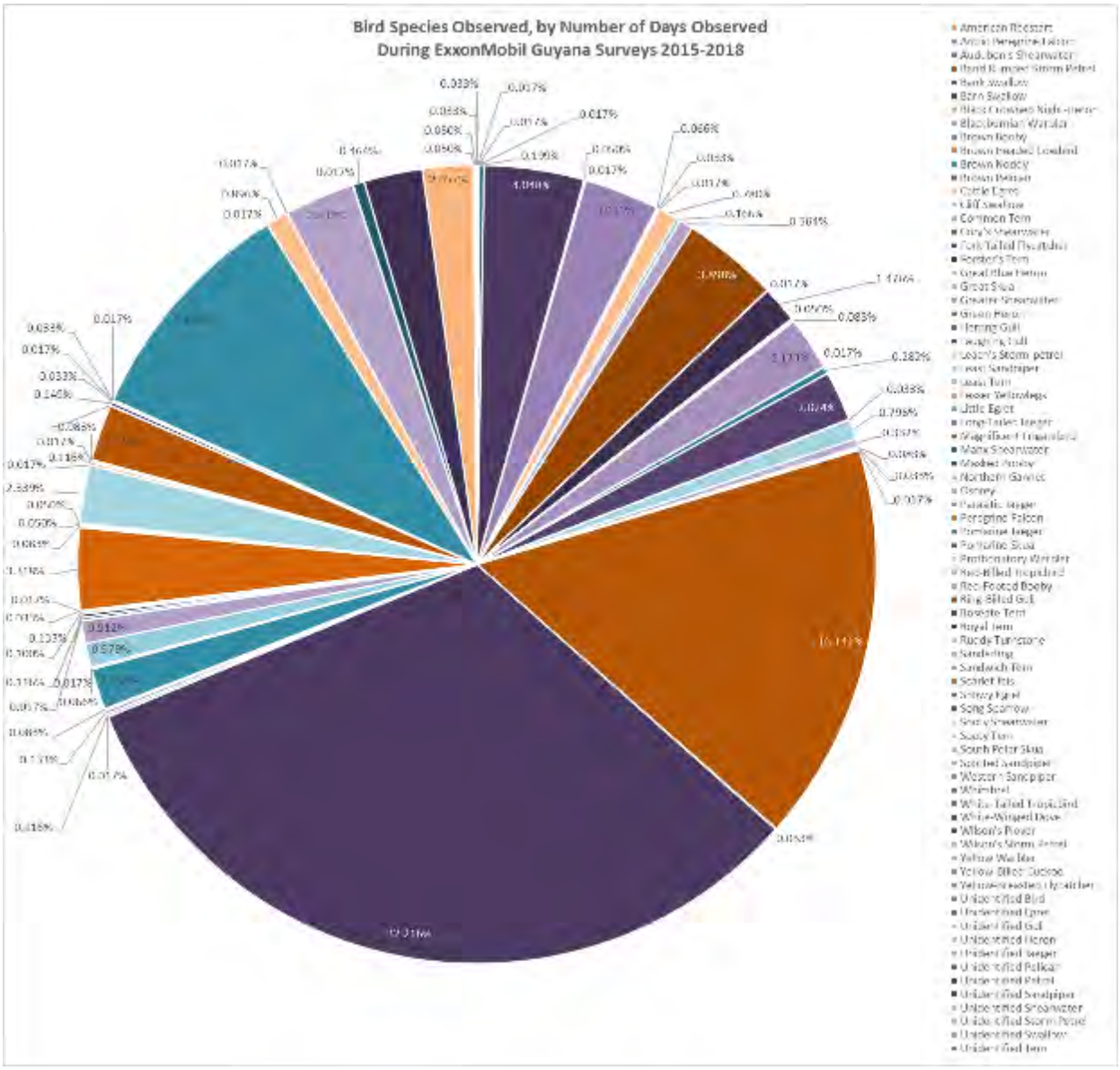


Figure 21: Bird species observed during the ExxonMobil Guyana 2015-2018 surveys

Table 6. Bird species identified throughout 2015-2018 surveys

Common name	*Species*	Number of Individuals	Number of Days Observed
American Redstart	*Steophaga ruticilla*	2	2
Arctic Peregrine Falcon	*Falco peregrinus tundrius*	1	1
Audubon's Shearwater	*Puffinus lherminieri*	1	1
Band Rumped Storm Petrel	*Oceanodroma castro*	1	1
Bank swallow	*Riparia riparia*	12	1
Barn Swallow	*Hirundo rustica*	244	101
Black Crowned Night-Heron	*Nycticorax nycticorax*	3	2
Blackburnian Warbler	*Setophaga fusca*	1	1
Brown Booby	*Sula leucogaster*	183	116
Brown Headed Cowbird	*Molothrus ater*	4	1
Brown Noddy	*Anous stolidus*	2	2
Brown Pelican	*Pelecanus occidentalis*	1	1
Cattle Egret	*Bubulcus ibis*	47	27
Cliff Swallow	*Petrochelidon pyrrhonota*	10	6
Common Tern	*Sterna hirundo*	34	9
Cory's Shearwater	*Calonectris diomedea*	235	47
Fork Tailed Flycatcher	*Tyrannus savana*	1	1
Forster's Tern	*Sterna forsteri*	89	3
Great Blue Heron	*Ardea herodias*	3	2
Great Skua	*Stercorarius skua*	5	3
Greater Shearwater	*Puffinus gravis*	131	32
Green Heron	*Butorides virescens*	1	1
Herring Gull	*Larus argentatus*	17	9
Laughing Gull	*Larus artricilla*	122	38
Leach's Storm-petrel	*Oceanodroma leucorhoa*	2	2
Least Sandpiper	*Calidris minutilla*	48	17
Least Tern	*Sternula antillarum*	20	4
Lesser Yellowlegs	*Tringa flavipes*	5	5
Little Egret	*Egretta garzetta*	2	2
Long-Tailed Jaeger	*Stercorarius longicaudus*	1	1
Magnificent Frigatebird	*Fregata magnificens*	973	147
Manx Shearwater	*Puffinus puffinus*	2	2
Masked Booby	*Sula dactylatra*	1942	498
Northern Gannet	*Morus bassanus*	1	1
Osprey	*Pandion haliaetus*	7	7
Parasitic Jaeger	*Stercorarius parasiticus*	8	2
Peregrine Falcon	*Falco peregrinus*	5	5
Pomarine Jaeger	*Stercorarius pomarinus*	100	36
Pomarine Skua	*Stercorarius pomarinus*	4	3
Prothonatory Warbler	*Protonotaria citrea*	1	1
Red-Billed Tropicbird	*Phaethon aethereus*	59	33
Red-Footed Booby	*Sula sula*	55	34
Ring-Billed Gull	*Larus delawarensis*	1	1
Roseate Tern	*Sterna dougalli*	7	6
Royal Tern	*Sterna maxima*	8	5
Ruddy Turnstone	*Arenaria interpres*	6	3
Sanderling	*Calidris alba*	1	1
Sandwich Tern	*Sterna sandvicenis*	2	2
Scarlet Ibis	*Eudocimus ruber*	200	1
Snowy Egret	*Egretta thula*	5	4
Song Sparrow	*Melospiza melodia*	3	2
Sooty Shearwater	*Puffinus griseus*	3	3
Sooty Tern	*Onychoprion fuscatus*	141	4
South Polar Skua	*Stercorarius maccormicki*	1	1
Spotted Sandpiper	*Actitis macularius*	7	7
Western Sandpiper	*Calidris mauri*	1	1
Whimbrel	*Numenius phaeopus*	5	3
White-Tailed Tropicbird	*Phaethon lepturus*	137	58
White-Winged Dove	*Zenaida asiatica*	1	1

Wilson's Plover	*Charadriaus wilsonia*	9	7
Wilson's Storm Petrel	*Oceanitus oceanicus*	2	2
Yellow Warbler	*Dendroica petechia*	1	1
Yellow-Billed Cuckoo	*Cuccyzus americanus*	2	2
Yellow-Breasted Flycatcher		1	1
Unidentified Bird		568	93
Unidentified Egret		1	1
Unidentified Gull		54	27
Unidentified Heron		1	1
Unidentified Jaeger		171	23
Unidentified Pelican		1	1
Unidentified Petrel		28	18
Unidentified Sandpiper		143	29
Unidentified Shearwater		124	25
Unidentified Storm Petrel		3	3
Unidentified Swallow		3	3
Unidentified Tern		2	2

The most commonly observed fish species in terms of number of individuals observed was the unidentified flying fish (Family Exocoetidae, 87.236%) which had 111285 individuals recorded over a period of 706 days throughout the surveys. Other notable fish species observed, each with more than 100 individuals recorded throughout the surveys, included yellow fin tuna (*Thunnus albacares*, 10.090%, 12871 individuals over 21 days), skipjack tuna (*Katsuwonus pelamis*, 0.734%, 936 individuals over 36 days), mahi mahi (*Coryphaena hipparus*, 0.401%, 512 individuals over 87 days), unidentified tuna (0.365%, 465 individuals over 31 days), unidentified fish (0.340%, 434 individuals over 57 days), Atlantic tripletail (*Lobotes surinamensis*, 0.172%, 220 individuals over 33 days), clearwing flying fish (*Cypselurus comatus*, 0.103%, 131 individuals over two days), Atlantic bonito tuna (*Sarda sarda*, 0.094%, 120 individuals over one day), and Atlantic flying fish (*Cheliopogon melanurus*, 0.091%, 116 individuals over one day) (Figure 22, Table 7).

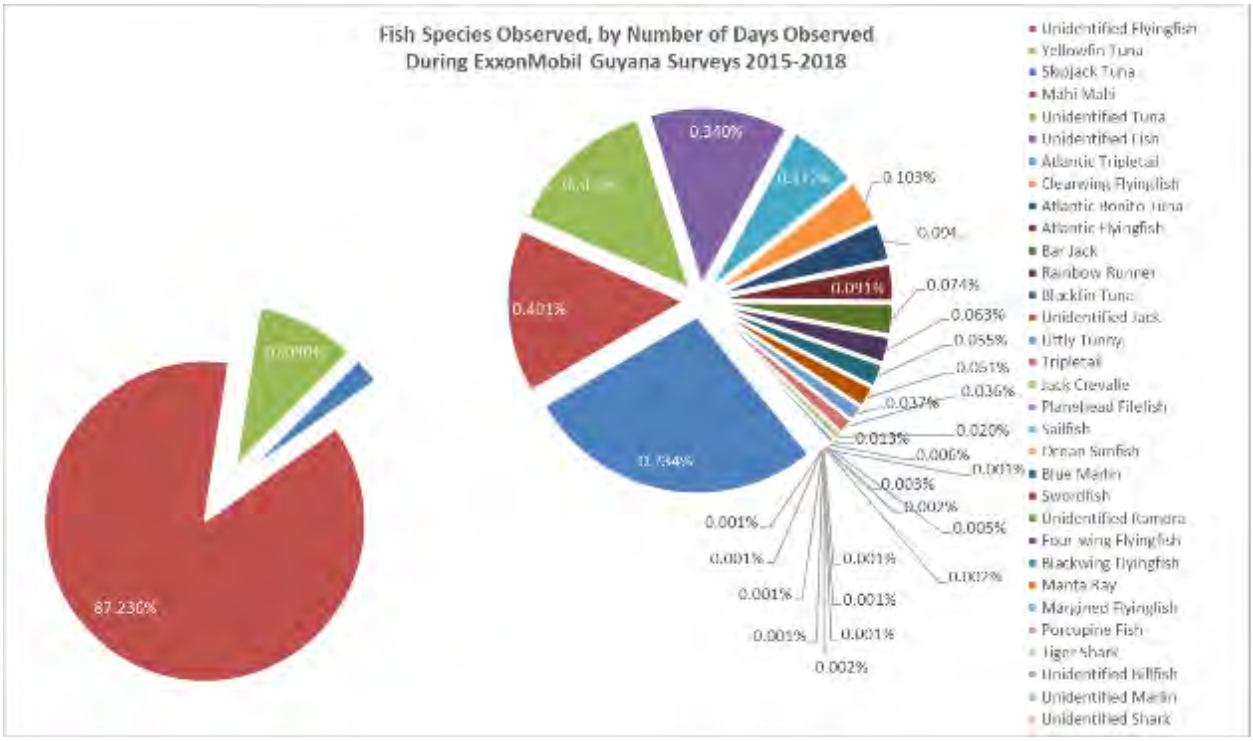


Figure 22: Fish species observed during the ExxonMobil Guyana 2015-2018 surveys

Table 7. Fish species observed

Common name	*Species*	Number of Individuals	Number of Days Observed
Atlantic Bonito Tuna	*Sarda sarda*	120	1
Atlantic Flyingfish	*Cheilopogon melanurus*	116	1
Atlantic Tripletail	*Lobotes surinamensis*	220	33
Bar Jack	*Caranx ruber*	95	4
Blackfin Tuna	*Thunnus atlanticus*	70	5
Blackwing Flyingfish	*Hirundichthys rondeletii*	1	1
Blue Marlin	*Makaira nigricans*	4	4
Clearwing Flyingfish	*Cypselurus comatus*	131	2
Four-wing Flyingfish	*Hirundichthys affinis*	2	1
Jack Crevalle	*Caranx hippos*	25	1
Little Tunny	*Euthynnus alletteratus*	47	2
Mahi Mahi	*Coryphaena hippurus*	512	87
Manta Ray	*Manta*	1	1
Margined Flyingfish	*Cheilopogon cyanopterus*	1	1
Ocean Sunfish	*Mola mola*	6	2
Planehead Filefish	*Stephanolepis hispidus*	17	5
Porcupine Fish		1	1
Rainbow Runner	*Elagatis bipinnulata*	81	4
Sailfish	*Istiophorus albicans*	8	7
Skipjack Tuna	*Katsuwonus pelamis*	936	36
Swordfish	*Xiphias gladius*	2	2
Tiger Shark	*Galeocerdo cuvier*	1	1
Tripletail	*Lobotes surinamensis*	46	17
Yellowfin Tuna	*Thunnus albacares*	12871	21
Unidentified Billfish		1	1
Unidentified Fish		434	57
Unidentified Flyingfish		111285	706
Unidentified Jack		65	4
Unidentified Marlin		1	1
Unidentified Ramora		2	2
Unidentified Shark		1	1
Unidentified Tuna		465	31

4.6 Closest Approach to the Source

All species groups (whales, dolphins, and turtles) observed during surveys with source activity—surface seismic, AUV, and VSPs—were recorded at greater average distances from the active source than from the silent source (Figure 23) and both whales and turtles were recorded at greater median distances from the active source than from the silent source, while the median distances to the active and silent source were the same for dolphins (Figure 24).

Statistical analysis was not completed during the analysis due to the low sample size available. Source activity for all analysis was grouped as “source active” or “source silent”, where “source active” included full volume, soft start, and all other reduced volume including the mitigation source. This was done due to the small sample size of data, making further categorization impractical.

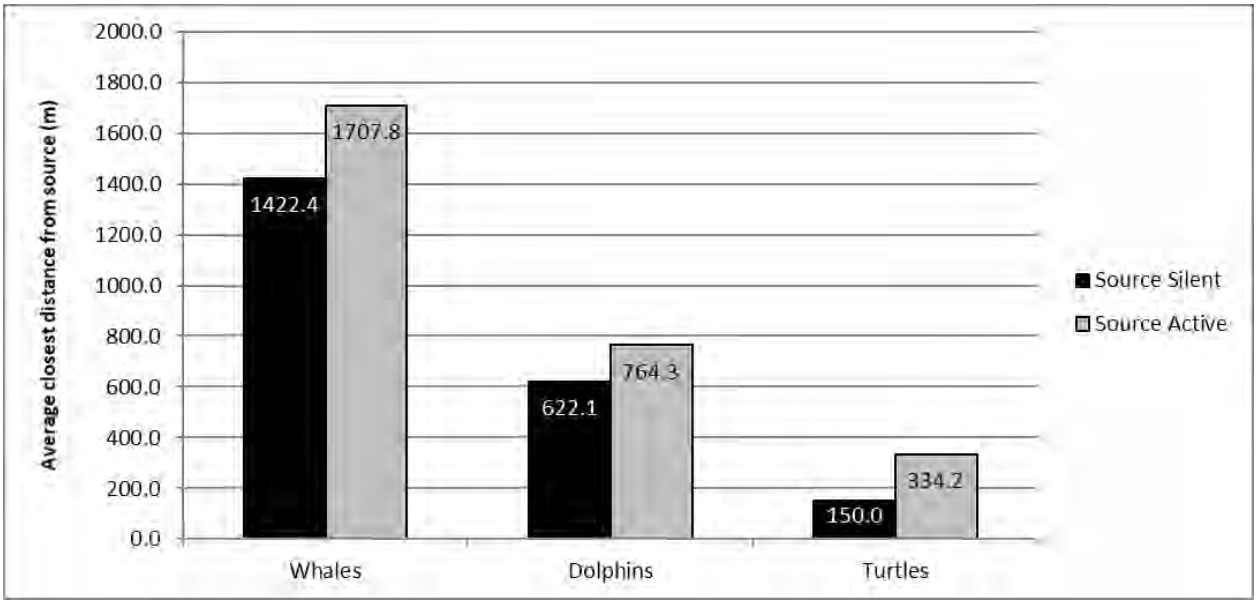


Figure 23. Average closest distance from source

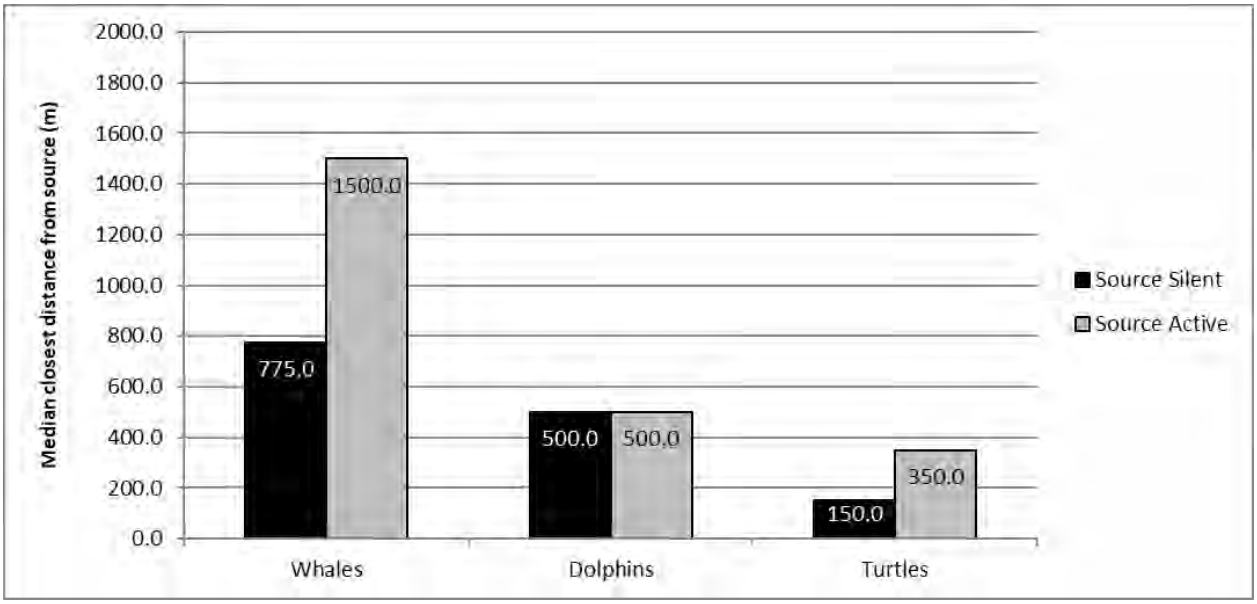


Figure 24. Median closest distance from source

Average distances from the active and silent source varied by species, with only four species (Bryde's whale, n=14; unidentifiable baleen whale, n=17; sperm whale, n=37; pantropical spotted dolphin, n=24) being observed at average closer distances during source activity than source silence (Figure 25). All species had median closest approach to the source that were higher during source activity than source silence, or equal (Figure 26). Beaked whales (n=2), unidentifiable cetaceans (n=1), Fraser's dolphins (n=3), Risso's dolphins (n=1), green sea turtles (n=1), and unidentifiable sea turtles (n=3) were only

observed during source activity, and no distances from the source were recorded for hawksbill sea turtles (Figure 25 and Figure 26).

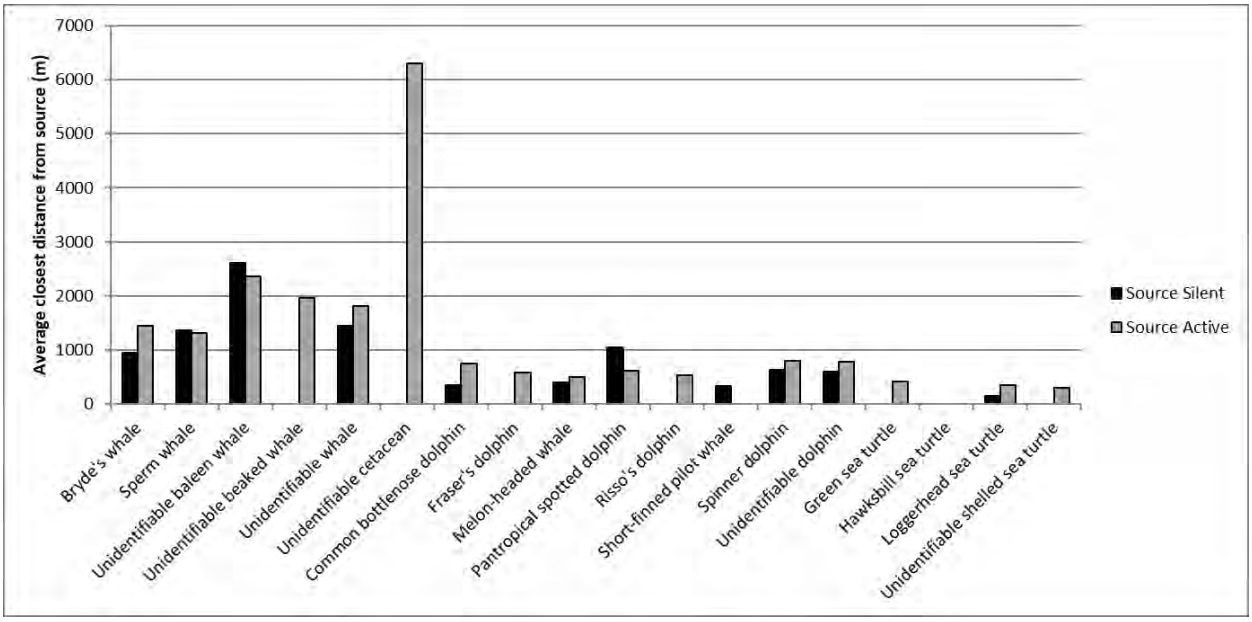


Figure 25. Average closest distance from the source by species

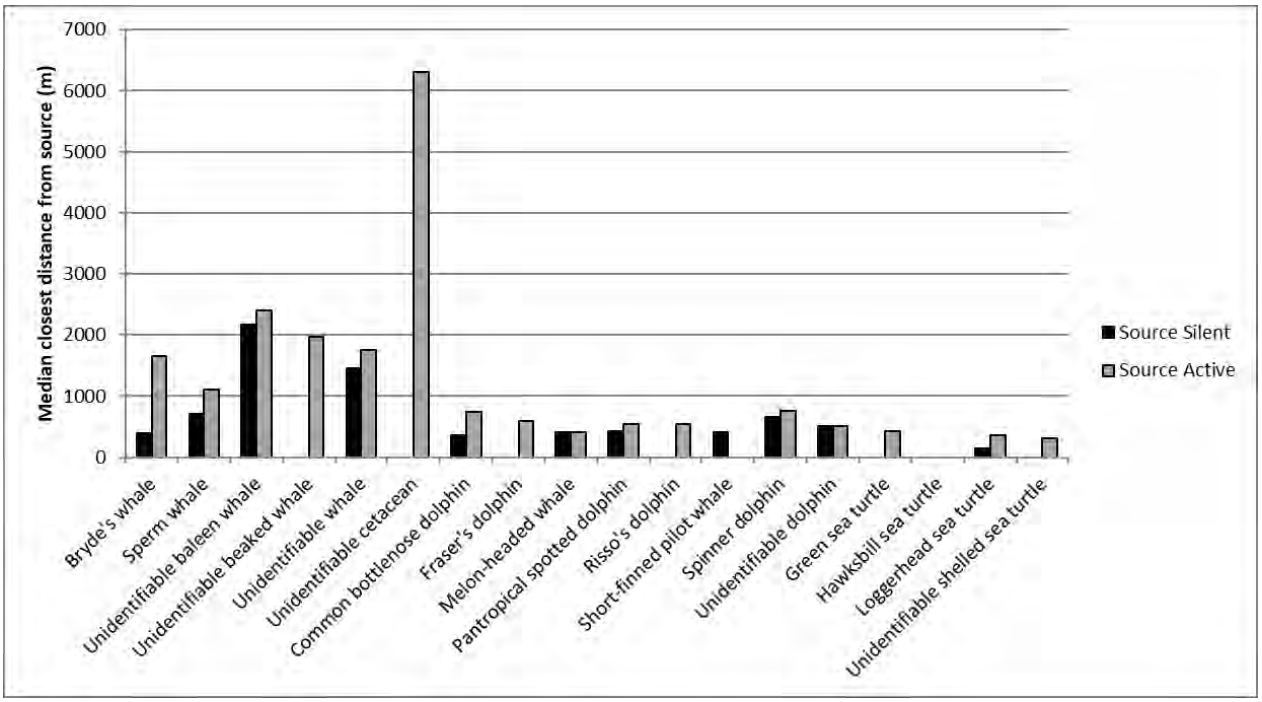


Figure 26. Median closest distance from the source by species

4.7 Detection Rate

There were a total of 221 visual detections and 364 acoustic detections throughout all surveys, excluding the VSPs, including 5 which were correlated visual and acoustic detections, for a total of 580 detections. There were 9786.02 hours of visual monitoring conducted, for a visual detection rate of 0.0226 detections per hour of effort. There were 5909.72 hours of acoustic monitoring conducted, for an acoustic detection rate of 0.0616 detections per hour of effort. The overall detection rate for the project was 0.0370 detections per hour of monitoring effort (Table 8).

Table 8. Detection rate summary

Number of Visual Detections	221
Visual Monitoring Effort (hours)	9786.02
Visual Detection Rate (Detections per hour)	0.0226
Number of Acoustic Detections	364
Acoustic Monitoring Effort (hours)	5909.72
Acoustic Detection Rate (Detections per hour)	0.0616
Total Number of Detections	580
Total Monitoring Effort (hours)	15695.73
Overall Detection Rate (Detections per hour)	0.0370

4.8 Detection Seasonality

Dolphins were observed more frequently in Fall and Winter months, with a marked drop in detections during the Spring and Summer months and some annual variations (Figure 27 and Figure 28). Whales showed the lowest level of seasonal variability, with a slight increase in early Spring followed by a drop in observations in late Spring and levelling off in the Summer and Fall (Figure 27 and Figure 28). Turtles were only observed in the Fall, Winter, and early Spring, with no detections recorded in late Spring or Summer (Figure 27 and Figure 28).

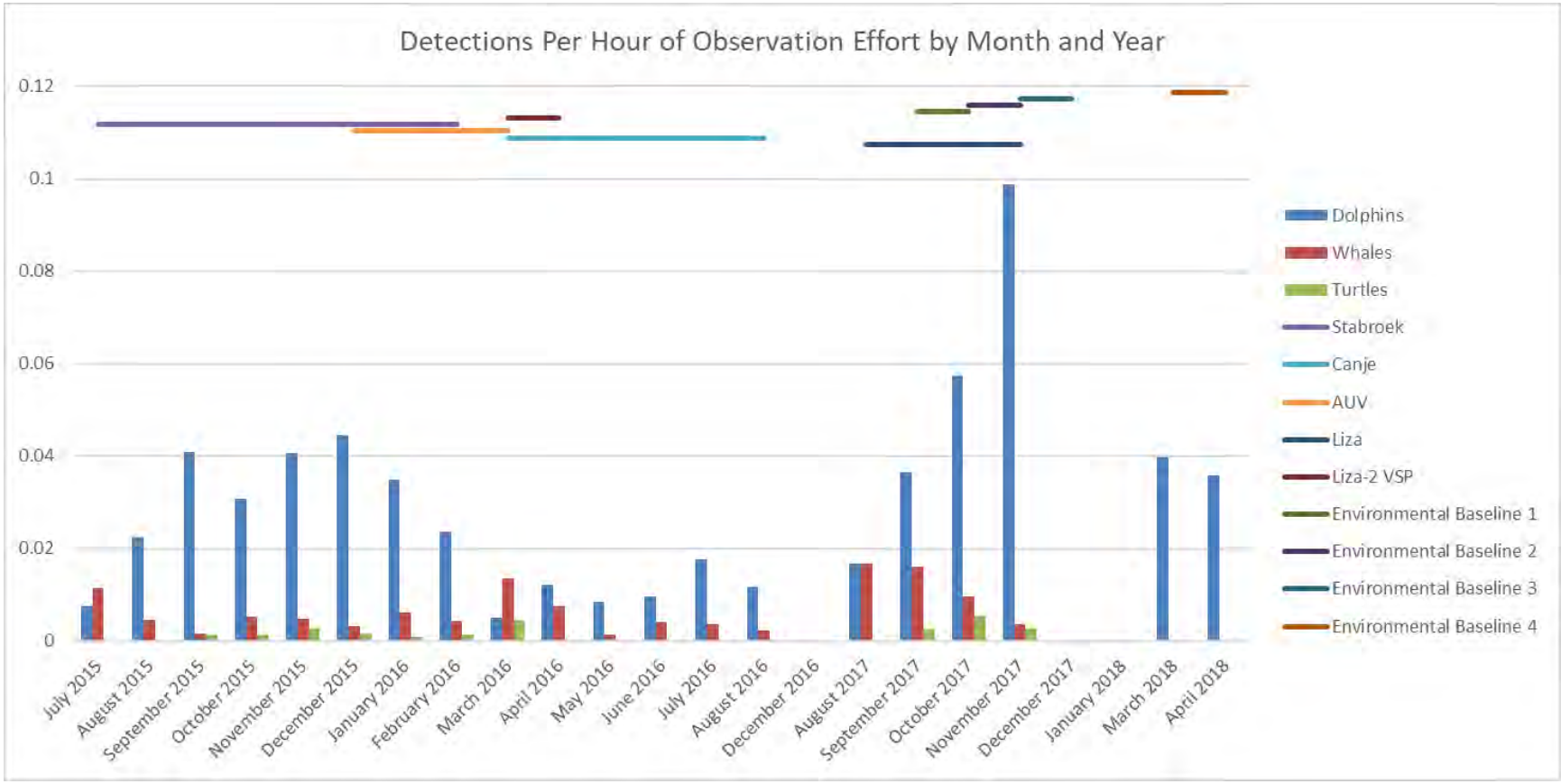


Figure 27. Detections per hour of effort by month and year during ExxonMobil Guyana Surveys 2015 - 2018

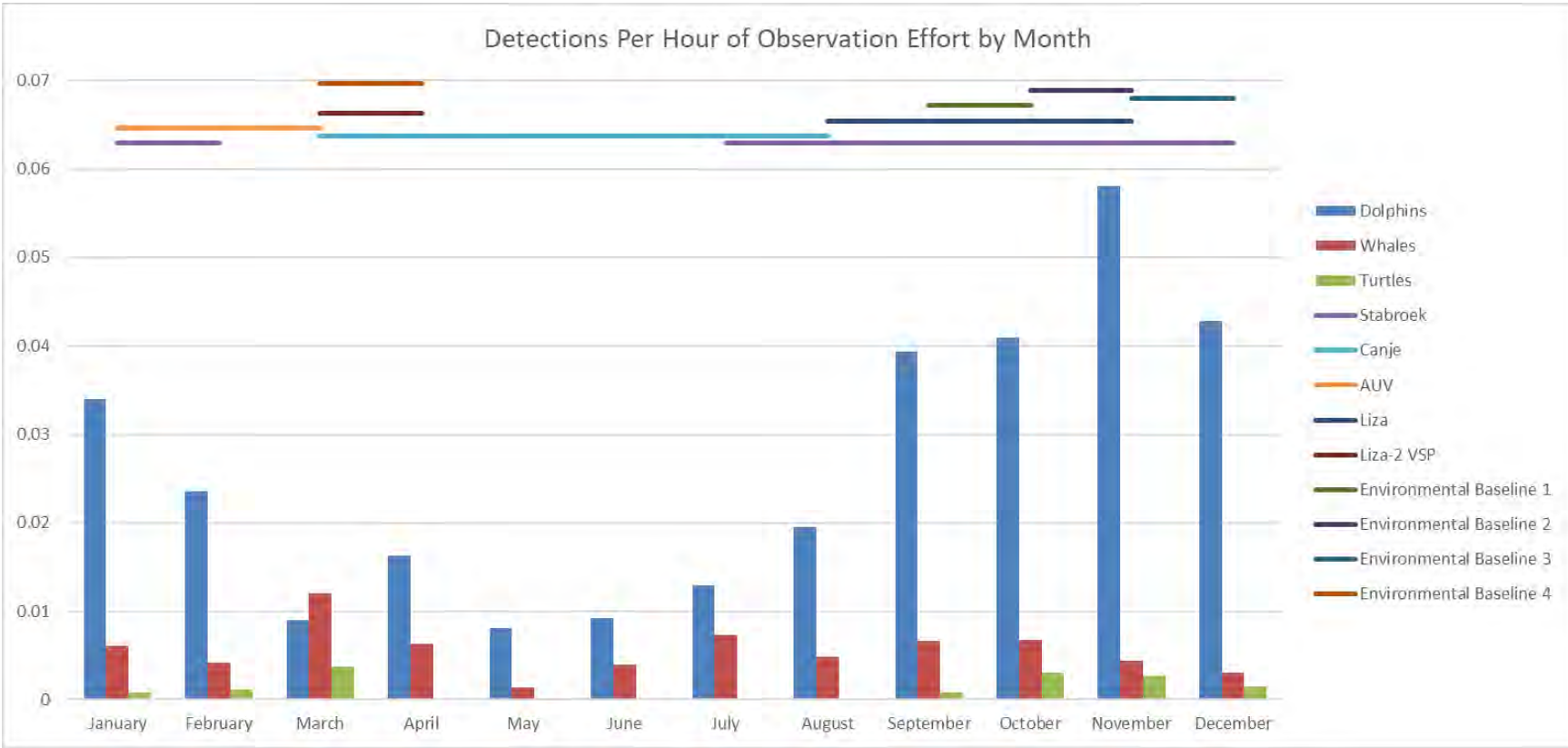


Figure 28. Detections per hour of effort by month during ExxonMobil Guyana Surveys 2015 - 2018

5 Discussion

Very broad comparisons to the Stone (2015) and Barkaszi et al (2012) papers were made, as the scale of this study is not comparable to those. Stone (2015) analyzed protected species observer data from 1,196 seismic surveys over a period of 16 years, comprising over 190,000 hours of monitoring effort—over 181,000 hours of visual monitoring and over 9,000 hours of acoustic monitoring—with a total of 9,073 detections of marine mammals. Barkaszi et al (2012) analyzed protected species observer data from seismic surveys over a period of six years, comprising 194,273 hours of visual monitoring effort with a total of 3,963 sightings of protected species. This analysis, in comparison, includes data from 15 surveys, including seven short VSP surveys, over the span of four years, comprising 15,696 hours of monitoring effort—9786 hours of visual monitoring effort and 5910 hours of acoustic monitoring effort—with a total of 580 detections of protected species. Despite the disparity in scales, comparisons of general trends across all three studies are possible.

In all studies, dolphins were the predominantly observed species group followed by whales. Turtles were the least commonly observed species for this study and Barkaszi et al (2012)—turtles were not included in Stone (2015). The species composition of recorded sightings varied from study to study, which is expected due to the difference in study area between the studies—Stone (2015) analyzed data offshore the United Kingdom, Barkaszi et al (2012) analyzed data from the U.S. Gulf of Mexico, and this study focuses on data offshore Guyana.

Across all studies, the spatial distribution of dolphin and turtle detections was fairly consistent across the surveyed areas, however visual and acoustic whale detections only occurred beyond the 2000-meter isobath. This is consistent with knowledge of habitat use by species groups, as whales are known to inhabit deeper waters, while dolphins and turtles have wider distribution across various depths.

Closest approach to the source for this study was calculated as both an average and a median by species and species group, while Stone (2015) and Barkaszi et al (2012) analyzed only the median closest approach to the source with Stone (2015) analyzing this by species and Barkaszi et al (2012) analyzing it by species group. Similar to the analysis conducted by Stone (2015), closest approach was analyzed based on source activity with only two categories—source active and source silent—where "source active" comprised full volume, soft start, and all other reduced volume activity including the mitigation source, due to the small sample size of this data. These comparisons were made based on the "large array" data in Stone (2015), as the parameters for a "large array" were sources with production output greater than 500 in^3 and the sources utilized in the ExxonMobil Guyana surveys were >4000 in^3 for seismic surveys, and 1200in^3 for VSPs. Barkaszi et al (2012) analyzed this separately by source volume, so comparisons with this study are made in reference to the full volume results from that study—as the majority of detections from this study were during full volume.

The average and median closest approach to the source by species group for whales and turtles were higher during source activity than source silence. The average closest approach to the source for dolphins was also higher during source activity than source silence, but the median closest approach was equal for dolphins. This was similar to the results from Barkaszi et al 2012, with the exception of the median closest approach of dolphins, which was significantly greater during source activity than source silence in their study while it was equal here. The average and median closest approach to the source by species generally agreed with the findings of Stone (2015), with most individual species exhibiting a larger closest approach to the source during source activity than during source silence. Only four species overlapped between the studies—baleen whales, sperm whales, Risso's dolphin, and bottlenose dolphin—however, there was only one recorded Risso's dolphin for this study and 3 recorded closest

approaches for bottlenose dolphins, so the direct comparison is limited to baleen whales and sperm whales. In both studies, Baleen whales were recorded at much greater distances at closest approach during source activity than source silence, while sperm whales were observed to have equal median closest approaches by Stone (2015) and were observed at greater median closest approaches during source silence than source activity in this study.

The implementation of mitigation actions for this study and Stone (2015) was limited to delays to the initiation of source activity as the surveys analyzed implemented JNCC guidelines. During the surveys analyzed by Barkaszi et al (2012), mitigation actions included delays to the initiation of source activity as well as shutdowns of the active source for certain species. For comparability to this study and Stone (2015), we will only include information on the delays to initiation of source activity. Across all three studies, mitigation actions were implemented for less than 3% of all protected species detections. Mitigation actions were minimal during the ExxonMobil Guyana surveys, with only 13 delays to the initiation of source activity, required for all 543 detections during projects with source activity, resulting in only 2.39% of detections requiring mitigation actions. Mitigation requirements based on JNCC guidelines were not implemented until the second year of the Stone (2015) study timeframe, with a total of 165 delays to the initiation of source activity, required for the 9,073 detections of marine mammals during the surveys, resulting in 1.82% of detections requiring mitigation actions. There were 32 delays to the initiation of source activity required for the 3,963 sightings of protected species during the surveys reviewed by Barkaszi et al (2010), resulting in 0.81% of all sightings requiring delays to the initiation of source activity.

Detection rate can vary based on seasonality, geographic area, and observer skill. Overall detection rates for all three studies were less than 0.05 detections per hour of monitoring effort. For this study, the detection rate was 0.0370 detections per hour, while the overall rates for Stone (2015) and Barkaszi et al (2012) were 0.0478 and 0.0204 detections per hour, respectively.

There was apparent seasonal variability in number of sightings per hour of effort for all species groups (dolphins, whales, and turtles) observed during the surveys summarized in this study. Dolphins showed the most marked variability, which is potentially explained by the greater sample size of dolphins compared with whales and turtles, with detection peaks in Fall and Winter and dips in Spring and Summer. This pattern was consistent across all years of the study, indicating that there may be seasonality of dolphin occurrence in the survey areas. Whales showed some temporal variability in detection rate, but it was not as seasonal as those of dolphins. Turtles were quite seasonal, with detections falling only within Fall, Winter, and early Spring. However, due to the sample size for whales and turtles, making strong conclusions regarding their seasonality in the survey areas is impossible.

While this study was limited by sample size, some correlations to similar studies with statistically significant sample size are useful and potentially insightful into the usefulness of protected species observations and the implementation of mitigation actions during seismic surveys, as well as potentially contributory toward future analysis of similar datasets.

6 References

Barkaszi, M.J., M. Butler, R. Compton, A. Unietis, and B. Bennet. 2012. Seismic survey mitigation measures and marine mammal observe reports. U.S. Dept. of Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2012-2015.

Stone, C.J. 2015. Marine mammal observations during seismic surveys from 1994-2010. JNCC report, No. 463a.

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Appendix A: Protected Species Summary Table

Date	Visual Det. #	Acoustic Det. #	Time at Initial Det.	Time at Last Det.	Common Name	Detection Method	Latitude	Longitude	Water Depth (m)	No. of Animals	Range when First Detected	Source Activity at First Det.	Source Activity at Last Det.	Closest distance to source (m)	Mitigation Actions	Total Duration Animals Observed inside EZ	Total Duration of Production Loss
Stabroek 3D CGG Alize																	
18-Jul-2015		1001	1:30	1:48	Unidentifiable dolphin	acoustically	07.90733	-057.64238	65	1	1000	not firing	not firing		none	0:00	0:00
18-Jul-2015		1002	3:05	5:30	Unidentifiable dolphin	acoustically	08.01395	-057.64163	93	1	700	not firing	not firing		none	0:00	
26-Jul-2015		1003	4:13	4:34	Unidentifiable dolphin	acoustically	09.22342	-057.23768	2974	5	1000	not firing	not firing	500	none	0:15	0:00
26-Jul-2015		1004	4:50	5:50	Sperm whale	acoustically	09.23773	-057.27802	2965	3	800	not firing	not firing	600	none	0:00	0:00
01-Aug-2015		1005	22:11	22:39	Unidentifiable dolphin	acoustically	09.10558	-057.22688	2931	3	1000	full power while on survey line	not firing	1000	none	0:00	
02-Aug-2015		1006	5:22	7:03	Unidentifiable dolphin	acoustically	08.90803	-057.43658	2593	3	1000	full power while on survey line	full power while on survey line	500	none	1:26	0:00
06-Aug-2015	1		10:42	10:43	Unidentifiable whale	visually	09.17818	-057.28305	2904	1	1000	not firing	not firing	1450	none	0:00	
06-Aug-2015	2		10:46	10:48	Sperm whale	visually	09.17818	-057.28305	2904	3	700	not firing	not firing	850	none	0:00	
07-Aug-2015		1007	23:17	0:17	Unidentifiable dolphin	acoustically	08.57878	-057.58092	2136	5	1000	full power while on survey line	not firing	500	none	0:47	0:00
09-Aug-2015		1008	8:52	9:20	Unidentifiable dolphin	acoustically	08.86990	-057.53170	2527	1	1000	full power while on survey line	full power while on survey line	1000	none	0:00	0:00
12-Aug-2015	3		13:33	13:48	Spinner dolphin	visually	09.14000	-057.36667	2869	17	150	full power while on survey line	full power while on survey line	460	none	0:13	0:00
13-Aug-2015		1009	6:04	6:08	Unidentifiable dolphin	acoustically	08.58455	-057.66033	2002	3	500	not firing	not firing	400	delayed start of firing	0:04	0:11
16-Aug-2015		1010	22:05	22:15	Unidentifiable dolphin	acoustically	09.18830	-057.33705	2992	3	500	not firing	not firing	500	none	0:10	0:00
19-Aug-2015		1011	9:30	9:33	Unidentifiable dolphin	acoustically	08.56165	-057.53953	2132	1	500	full power while on survey line	full power while on survey line	500	none	0:03	0:00
20-Aug-2015		1012	0:28	1:21	Unidentifiable dolphin	acoustically	09.29868	-057.35438	2753	4	500	not firing	not firing	500	none	0:21	0:00
21-Aug-2015		1013	1:17	1:50	Unidentifiable dolphin	acoustically	09.31478	-057.36933	2951	2	500	not firing	not firing	500	none	0:33	0:00
22-Aug-2015	4		14:51	15:05	Sperm whale	visually	08.53500	-057.77400	1858	4	700	not firing	not firing	700	none	0:00	0:00
23-Aug-2015		1014	0:26	0:28	Unidentifiable dolphin	acoustically	09.18782	-057.47913	2789	1	500	full power while on survey line	full power while on survey line	500	none	0:02	0:00
24-Aug-2015	5		12:23	12:25	Sperm whale	visually	08.67267	-057.67067	2195	4	30	full power while on survey line	full power while on survey line	120	none	0:02	0:00

Date	Visual Det. #	Acoustic Det. #	Time at Initial Det.	Time at Last Det.	Common Name	Detection Method	Latitude	Longitude	Water Depth (m)	No. of Animals	Range when First Detected	Source Activity at First Det.	Source Activity at Last Det.	Closest distance to source (m)	Mitigation Actions	Total Duration Animals Observed inside EZ	Total Duration of Production Loss
25-Aug-2015	6	1015	20:26	21:28	Unidentifiable dolphin	visually and acoustically	08.58800	-057.78500	1966	50	1000	not firing	not firing	500	delayed start of firing	0:31	0:09
28-Aug-2015		1016	2:11	2:12	Unidentifiable dolphin	acoustically	08.89212	-057.32488	2740	1	500	full power while on survey line	full power while on survey line	500	none	0:01	0:00
28-Aug-2015	7		19:44	19:56	Short-finned pilot whale	visually	08.38517	-057.49167	1750	10	300	not firing	not firing	600	none	0:00	
02-Sep-2015		1017	7:50	9:40	Unidentifiable dolphin	acoustically	08.45103	-057.47260	1931	4	500	not firing	not firing	500	None	1:50	0:00
05-Sep-2015		1018	6:00	6:39	Unidentifiable dolphin	acoustically	09.21905	-057.13223	2503	7	1342	not firing	not firing	500	None	0:13	0:00
05-Sep-2015	8		14:23	14:24	Unidentifiable dolphin	visually	08.65183	-057.41883	2441	3	300	full power while on survey line	full power while on survey line	700	None	0:00	
05-Sep-2015	9		20:09	20:56	Spinner dolphin	visually	08.32167	-057.50083	1552	10	400	not firing	not firing	800	None	0:00	
05-Sep-2015		1019	21:51	0:10	Unidentifiable dolphin	acoustically	08.41005	-057.53445	1751	10	1320	not firing	not firing	333	Delayed start of firing	2:19	6:18
06-Sep-2015		1020	3:57	4:01	Unidentifiable dolphin	acoustically	08.44833	-057.57648	1848	1	500	not firing	not firing	500	None	0:04	0:00
06-Sep-2015		1021	7:45	8:29	Unidentifiable dolphin	acoustically	08.67262	-057.41407	2420	3	500	not firing	not firing	500	None	0:44	0:00
06-Sep-2015		1022	23:18	23:31	Unidentifiable dolphin	acoustically	08.79262	-057.31035	2740	1	500	not firing	not firing	500	None	0:13	0:00
07-Sep-2015		1023	3:45	4:03	Unidentifiable dolphin	acoustically	08.49943	-057.45878	2221	1	500	full power while on a survey line	full power while on a survey line	500	None	0:18	0:00
07-Sep-2015		1024	5:34		Unidentifiable dolphin	acoustically	08.38515	-057.51537	2200	2	500	full power while on a survey line	full power while on a survey line	500	None	0:33	0:00
07-Sep-2015	10		20:28	20:33	Spinner dolphin	visually	08.44320	-057.16280	2642	15	600	full power while on a survey line	full power while on a survey line	600	None	0:00	0:00
08-Sep-2015		1025	3:31	3:36	Unidentifiable dolphin	acoustically	09.18232	-057.09012	2882	1	500	not firing	not firing	500	None	0:05	0:00
08-Sep-2015		1026	4:15	4:25	Unidentifiable dolphin	acoustically	09.15390	-057.13107	2880	1	146	not firing	not firing	331	None	0:10	0:00
09-Sep-2015		1027	0:28	1:45	Unidentifiable dolphin	acoustically	08.25095	-057.51753	922	10	500	full power while on a survey line	full power while on a survey line	500	None	1:47	0:00
09-Sep-2015		1028	3:09	6:15	Unidentifiable dolphin	acoustically	08.42433	-057.42923	1914	10	500	full power while on a survey line	full power while on a survey line	500	None	3:06	0:00
10-Sep-2015		1029	0:44	1:15	Unidentifiable dolphin	acoustically	08.61807	-057.38715	2730	5	500	full power while on a survey line	full power while on a survey line	500	None	0:26	0:00
10-Sep-2015		1030	8:47	9:10	Unidentifiable dolphin	acoustically	08.12568	-057.66637	850	8	407	not firing	not firing	407	None	0:23	0:00

Date	Visual Det. #	Acoustic Det. #	Time at Initial Det.	Time at Last Det.	Common Name	Detection Method	Latitude	Longitude	Water Depth (m)	No. of Animals	Range when First Detected	Source Activity at First Det.	Source Activity at Last Det.	Closest distance to source (m)	Mitigation Actions	Total Duration Animals Observed inside EZ	Total Duration of Production Loss
11-Sep-2015	11		21:02	21:14	Pantropical spotted dolphin	visually	08.11667	-057.65633	4316	10	400	not firing	not firing	400	None	6:00	0:00
11-Sep-2015		1031	22:42	22:45	Unidentifiable dolphin	acoustically	08.09720	-057.57962	438	10	338	not firing	not firing	337	none	0:03	0:00
12-Sep-2015		1032	5:12	6:15	Unidentifiable dolphin	acoustically	08.55130	-057.35698	920	5	500	full power while on a survey line	full power while on a survey line	500	None	1:03	0:00
14-Sep-2015		1033	8:10	8:20	Unidentifiable dolphin	acoustically	09.16730	-057.04782	3024	4	359	not firing	not firing	359	None	0:10	0:00
16-Sep-2015		1034	23:50	23:59	Unidentifiable dolphin	acoustically	08.64438	-057.30863	2526	1	500	not firing	not firing	500	Delayed start of firing	0:09	0:20
17-Sep-2015	12		18:05	18:07	Green sea turtle	visually	08.59483	-057.37996	2354	1	50	full power while on a survey line	full power while on a survey line	421	None	0:02	0:00
18-Sep-2015		1035	2:34	2:45	Unidentifiable dolphin	acoustically	08.15653	-057.62753	605	4	500	not firing	not firing	500	None	0:11	0:00
18-Sep-2015		1036	4:06	4:08	Unidentifiable dolphin	acoustically	08.08700	-057.63545	122	2	500	not firing	not firing	500	None	0:02	0:00
19-Sep-2015		1037	22:50	23:09	Unidentifiable dolphin	acoustically	08.40208	-057.41120	1943	5	1000	full power while on a survey line	full power while on a survey line	500	None	0:01	0:00
20-Sep-2015		1038	0:25	1:02	Unidentifiable dolphin	acoustically	08.51187	-057.35605	2231	5	500	full power while on a survey line	full power while on a survey line	500	None	0:07	0:00
21-Sep-2015		1039	3:58	4:28	Unidentifiable dolphin	acoustically	08.12010	-057.64147	225	3	500	not firing	not firing	500	None	0:14	0:00
21-Sep-2015		1040	5:23	6:16	Unidentifiable dolphin	acoustically	08.06973	-057.58560	127	5	500	not firing	not firing	500	None	0:20	0:00
22-Sep-2015	13		16:53	17:04	Spinner dolphin	visually	08.11443	-057.63953	132	10	500	not firing	not firing	500	None	0:08	0:00
24-Sep-2015		1041	23:22	23:33	Sperm Whale	acoustically	09.14933	-057.08477	3028	1	1000	not firing	not firing	350	None	0:03	0:00
29-Sep-2015		1042	8:35	9:25	Unidentifiable dolphin	acoustically	09.14770	-057.07647	3032	3	1000	not firing	not firing	500	None	0:10	0:00
03-Oct-2015		1043	3:21	3:33	Unidentifiable dolphin	acoustically	08.98752	-057.01937	3002	3	1000	soft-start / ramp-up	full power while not on a survey line	750	None	0:00	
05-Oct-2015		1044	0:39	1:32	Unidentifiable dolphin	acoustically	08.30182	-057.36012	1735	2	1000	full power while on a survey line	full power while on a survey line	750	None	0:00	
05-Oct-2015		1045	8:30	8:45	Unidentifiable dolphin	acoustically	08.18663	-057.47893	1056	10	500	full power while on a survey line	full power while on a survey line	500	None	0:15	0:00
08-Oct-2015		1046	4:03	5:21	Unidentifiable dolphin	acoustically	08.01672	-057.49263	123	5	500	not firing	not firing	500	None	1:15	0:00
09-Oct-2015	14		13:11	13:15	Unidentifiable dolphin	visually	08.28333	-057.35000	1738	20	2000	full power while on a survey line	full power while on a survey line	1400	None	0:00	

Date	Visual Det. #	Acoustic Det. #	Time at Initial Det.	Time at Last Det.	Common Name	Detection Method	Latitude	Longitude	Water Depth (m)	No. of Animals	Range when First Detected	Source Activity at First Det.	Source Activity at Last Det.	Closest distance to source (m)	Mitigation Actions	Total Duration Animals Observed inside EZ	Total Duration of Production Loss
09-Oct-2015		1047	21:56	22:20	Sperm whale	acoustically	08.26367	-057.42602	1476	1	1369	full power while on a survey line	full power while on a survey line	1105	None	0:00	
10-Oct-2015		1048	23:15	23:52	Sperm whale	acoustically	08.44087	-057.27262	2169	2	600	full power while on a survey line	full power while on a survey line	300	None	0:25	0:00
12-Oct-2015		1049	4:45	5:05	Unidentifiable dolphin	acoustically	08.93798	-057.01742	2976	10	1000	full power while on a survey line	full power while on a survey line	500	None	0:12	0:00
12-Oct-2015	15		13:42	14:14	Pantropical spotted dolphin	visually	08.41557	-057.28070	2136	20	60	full power while on a survey line	full power while on a survey line	442	None	0:31	0:00
13-Oct-2015	16	1050	21:26	21:41	Unidentifiable dolphin	visually and acoustically	08.73333	-057.10000	2792	5	200	full power while on a survey line	full power while on a survey line	430	None	0:15	0:00
14-Oct-2015	17		18:52	19:04	Sperm whale	visually	08.52390	-057.27819	2372	5	1500	full power while on a survey line	full power while on a survey line	500	None	0:07	0:00
15-Oct-2015		1051	4:27	4:52	Sperm whale	acoustically	09.12403	-056.96693	3110	3	600	not firing	not firing	374	None	0:02	0:00
15-Oct-2015	18		12:58	13:04	Unidentifiable whale	visually	08.59878	-057.17948	2581	3	1800	full power while on a survey line	full power while on a survey line	2240	None	0:00	0:00
15-Oct-2015	19		13:27	13:32	Unidentifiable whale	visually	08.57330	-057.19220	2531	4	2000	full power while on a survey line	full power while on a survey line	2440	None	0:00	0:00
15-Oct-2015	20		15:43	16:07	Pantropical spotted dolphin	visually	08.44278	-057.25804	2210	100	800	full power while on a survey line	full power while on a survey line	442	None	0:22	0:00
18-Oct-2015		1052	2:02	2:25	Unidentifiable dolphin	acoustically	08.95842	-057.04987	2972	3	750	not firing	not firing	750	None	0:00	
18-Oct-2015	21		21:05	21:16	Short-finned pilot whale	visually	08.03112	-057.41902	486	5	700	not firing	not firing	400	None	0:06	0:00
19-Oct-2015		1053	0:21	0:23	Unidentifiable dolphin	acoustically	08.15270	-057.00508	984	2	500	soft-start / ramp-up	soft-start / ramp-up	500	None	0:02	0:00
19-Oct-2015		1054	5:01	6:01	Unidentifiable dolphin	acoustically	08.46072	-057.29995	2225	10	500	full power while on a survey line	not firing	500	None	0:43	0:00
19-Oct-2015		1055	22:17	22:27	Unidentifiable dolphin	acoustically	08.59060	-057.11205	2619	4	750	full power while on a survey line	full power while on a survey line	750	None	0:00	
21-Oct-2015		1056	4:23	4:26	Unidentifiable dolphin	acoustically	08.82142	-056.99062	2926	3	750	full power while on a survey line	full power while on a survey line	750	None	0:00	
27-Oct-2015		1057	3:07	3:14	Unidentifiable dolphin	acoustically	08.84043	-056.97112	2932	2		full power while on a survey line	full power while on a survey line	500	None	0:07	0:00
28-Oct-2015		1058	6:53	9:15	Unidentifiable dolphin	acoustically	08.77717	-057.05850	2410	2		full power while not on a survey line	not firing	500	None	0:44	0:00
29-Oct-2015		1059	7:26	7:55	Unidentifiable dolphin	acoustically	08.88080	-057.00790		8		full power while on a survey line	full power while on a survey line	500	None	0:29	0:00

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29-Oct-2015	22		13:30	13:33	Unidentifiable whale	visually	08.60700	-057.13767	2631	1	850	full power while on a survey line	full power while on a survey line	1250	None	0:00	0:00
29-Oct-2015	23		15:48	15:49	Loggerhead sea turtle	visually	08.75417	-057.05917	2825.2	1	15	full power while on a survey line	full power while on a survey line	350	None	0:00	0:00
31-Oct-2015		1060	3:18	8:23	Unidentifiable dolphin	acoustically	08.88362	-056.99505	2854	1		full power while on a survey line	full power while on a survey line	500	None	0:05	0:00
02-Nov-2015		1061	5:06	5:34	Unidentifiable dolphin	acoustically	08.19388	-057.27792	1142	4	500	full power while on a survey line	full power while on a survey line	500	None	0:28	0:00
02-Nov-2015	24		13:45	13:46	Unidentifiable shelled sea turtle	visually	08.23450	-057.30733	2792	1	100	full power while on a survey line	full power while on a survey line	400	None	0:01	0:00
02-Nov-2015		1062	21:35	23:36	Unidentifiable dolphin	acoustically	08.69015	-057.08478	2763	4	453	full power while on a survey line	full power while on a survey line	453	None	2:01	0:00
03-Nov-2015		1063	4:27	4:43	Unidentifiable dolphin	acoustically	08.01915	-057.33055	1501	2	500	full power while on a survey line	full power while on a survey line	500	None	0:16	0:00
06-Nov-2015		1064	8:06	8:43	Unidentifiable dolphin	acoustically	08.39257	-057.16237	2200	2	500	full power while on a survey line	full power while on a survey line	500	None	0:36	0:00
06-Nov-2015		1065	22:29	23:04	Unidentifiable dolphin	acoustically	08.36418	-057.23382	2001	3	500	full power while on a survey line	full power while on a survey line	500	None	0:35	0:00
09-Nov-2015	25		9:51	9:57	Pantropical spotted dolphin	visually	07.95917	-057.41783	121	12	15	not firing	not firing	400	None	0:06	0:00
10-Nov-2015		1066	1:36	2:10	Unidentifiable dolphin	acoustically	08.95882	-056.92400	3036	10	383	not firing	not firing	383	None	0:34	0:00
10-Nov-2015		1067	8:19	9:23	Unidentifiable dolphin	acoustically	08.32000	-057.04570	2200	1	500	full power while on a survey line	full power while on a survey line	500	None	1:05	0:00
11-Nov-2015		1068	3:50	4:23	Unidentifiable dolphin	acoustically	08.54578	-057.13402	2531	10	500	full power while on a survey line	full power while on a survey line	500	None	0:33	0:00
12-Nov-2015		1069	22:12	22:33	Unidentifiable dolphin	acoustically	08.55805	-057.80012	1901	6	500	not firing	not firing	500	None	0:31	0:00
13-Nov-2015		1070	0:49	0:55	Unidentifiable dolphin	acoustically	08.71340	-057.73418	2079	2	500	soft-start / ramp-up	soft-start / ramp-up	500	None	0:06	0:00
13-Nov-2015		1071	4:17	4:50	Unidentifiable dolphin	acoustically	08.92755	-057.62565	2611	2	500	full power while on a survey line	full power while on a survey line	500	None	0:33	0:00
14-Nov-2015		1072	4:06	7:30	Unidentifiable dolphin	acoustically	08.66088	-057.76525	2127	10	500	not firing	not firing	500	Delayed start of firing	3:24	6:30
14-Nov-2015		1073	23:55	0:05	Unidentifiable dolphin	acoustically	09.20032	-057.42403	2920	1	500	other reduced power firing	other reduced power firing	500	None	0:10	0:00
17-Nov-2015		1074	6:46	8:25	Unidentifiable dolphin	acoustically	09.25777	-057.40563	2522	2	500	not firing	not firing	500	None	1:22	0:00
17-Nov-2015	26		15:39	15:47	Spinner dolphin	visually	08.70400	-057.67617	2241	30	1500	full power while on a survey line	full power while on a survey line	400	None	0:06	0:00

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18-Nov-2015		1075	21:34	23:05	Unidentifiable dolphin	acoustically	08.65553	-057.78728	2147	10	500	not firing	full power while on a survey line	355	Delayed start of firing	0:45	0:00
19-Nov-2015	27		14:12	14:14	Unidentifiable shelled sea turtle	visually	09.05638	-057.51774	2755	1	50	full power while on a survey line	full power while on a survey line	200	None	0:02	0:00
19-Nov-2015		1076	21:26	21:50	Unidentifiable dolphin	acoustically	08.56820	-057.76073	1979	3	750	not firing	not firing	750	None	0:00	
20-Nov-2015	28		11:09	11:27	Unidentifiable dolphin	visually	09.32019	-057.48297	3057	15	1500	not firing	not firing	1942	None	0:00	
21-Nov-2015	29		20:54	21:00	Pantropical spotted dolphin	visually	09.24086	-057.43351	2843	5	5	not firing	not firing	420	None	0:06	
22-Nov-2015		1077	5:38	5:44	Unidentifiable dolphin	acoustically	08.74820	-057.68258	2283	2	750	full power while on a survey line	full power while on a survey line	750	None	0:00	
23-Nov-2015		1078	0:27	1:08	Unidentifiable dolphin	acoustically	09.06267	-057.59407	2710	2	750	full power while on a survey line	full power while on a survey line	750	None	0:00	
23-Nov-2015		1079	3:41	4:02	Unidentifiable dolphin	acoustically	09.25142	-057.49875	2909	5	500	full power while on a survey line	not firing	500	None	0:12	0:00
23-Nov-2015		1080	7:44	8:09	Unidentifiable dolphin	acoustically	09.27097	-057.42252	2804	10	500	not firing	not firing	500	Delayed start of firing	0:11	0:50
24-Nov-2015	30		11:48	11:58	Unidentifiable dolphin	visually	09.22631	-057.39363	2938	8	800	not firing	not firing	1242	None	0:00	0:00
24-Nov-2015	31		13:59	14:00	Unidentifiable dolphin	visually	09.12170	-057.44577	2862	3	3000	full power while on a survey line	full power while on a survey line	3440	None	0:00	0:00
25-Nov-2015		1081	7:07	7:26	Unidentifiable dolphin	acoustically	08.97973	-057.64765	2693	4	750	full power while on a survey line	full power while on a survey line	750	None	0:00	
26-Nov-2015		1082	7:15	7:33	Unidentifiable dolphin	acoustically	08.65577	-057.85497	2100	4	750	not firing	not firing	750	None	0:00	
26-Nov-2015	32		11:07	11:15	Unidentifiable whale	visually	08.90997	-057.73462	2562	1	1000	full power while on a survey line	full power while on a survey line	1000	None	0:00	
27-Nov-2015		1083	6:50	6:58	Unidentifiable dolphin	acoustically	09.02320	-057.62645	2646	2	500	full power while on a survey line	full power while on a survey line	318	None	0:08	0:00
27-Nov-2015	33		18:38	18:40	Unidentifiable whale	visually	08.80333	-057.79269	2386	1	2000	full power while on a survey line	full power while on a survey line	2000	None	0:00	0:00
27-Nov-2015	34		19:15	19:34	Unidentifiable whale	visually	08.84745	-057.77071	2411	2	1500	full power while on a survey line	full power while on a survey line	1500	None	0:00	0:00
27-Nov-2015	35		20:35	20:35	Unidentifiable whale	visually	08.92152	-057.73368	2555	1	2000	full power while on a survey line	full power while on a survey line	2440	None	0:00	0:00
28-Nov-2015		1084	3:50	4:06	Unidentifiable dolphin	acoustically	09.39188	-057.55263	3030	2	750	not firing	not firing	750	None	0:00	
28-Nov-2015	36		15:45	15:45	Unidentifiable whale	visually	08.88180	-057.70027	2543	1	800	full power while on a survey line	full power while on a survey line	1240	None	0:00	0:00

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28-Nov-2015	37		15:59	16:09	Unidentifiable baleen whale	visually	08.87042	-057.70625	2525	1	200	full power while on a survey line	full power while on a survey line	490	None	0:00	0:00
30-Nov-2015		1085	3:22	5:25	Unidentifiable dolphin	acoustically	08.59388	-057.80985	2027	3	750	not firing	not firing	500	None	0:06	0:00
01-Dec-2015		1086	5:25	5:53	Unidentifiable dolphin	acoustically	08.77293	-057.76179	2294	2	500	full power while on a survey line	full power while on a survey line	500	None	0:28	0:00
01-Dec-2015		1087	22:18	23:02	Unidentifiable dolphin	acoustically	09.42600	-057.56707	3062	4	500	not firing	not firing	500	None	0:44	0:00
02-Dec-2015		1088	1:23	2:11	Unidentifiable dolphin	acoustically	09.34757	-057.48392	3090	5	200	other reduced power firing	not firing	200	None	0:31	0:00
02-Dec-2015	38		16:20	16:31	Pantropical spotted dolphin	visually	08.91807	-057.69172	1941	12	200	not firing	not firing	400	None	0:10	0:00
14-Dec-2015		1089	3:24	4:00	Unidentifiable dolphin	acoustically	09.21040	-057.60275	2969	10	750	full power while on a survey line	full power while on a survey line	500	None	0:07	0:00
14-Dec-2015	39		11:08	11:20	Unidentifiable baleen whale	visually	09.06485	-057.62260	2693	1	900	full power while on a survey line	full power while on a survey line	900	None	0:00	
16-Dec-2015		1090	7:32	7:58	Unidentifiable dolphin	acoustically	09.25063	-057.53803	2968	10	500	soft-start / ramp-up	full power while on a survey line	100	None	0:26	0:00
17-Dec-2015		1091	6:30	7:02	Unidentifiable dolphin	acoustically	09.36972	-057.55643	2935	3	500	not firing	not firing	500	None	0:32	0:00
18-Dec-2015		1092	7:53	8:07	Unidentifiable dolphin	acoustically	09.30182	-057.57132	2950	6	500	not firing	not firing	500	None	0:14	0:00
19-Dec-2015		1093	0:08	0:36	Unidentifiable dolphin	acoustically	08.63513	-057.91538	2453	1	500	not firing	not firing	500	None	0:15	0:00
25-Dec-2015		1094	5:36	5:42	Unidentifiable dolphin	acoustically	09.35305	-057.52217	3140	3	223	not firing	not firing	223	None	0:06	0:00
26-Dec-2015	40		16:42	16:42	Unidentifiable shelled sea turtle	visually	08.97607	-057.63832	2600	1	250	soft-start / ramp-up	soft-start / ramp-up	300	None	0:01	0:00
28-Dec-2015		1095	9:51	10:02	Unidentifiable dolphin	acoustically	08.73075	-057.86927	2120	1	500	full power while on a survey line	full power while on a survey line	500	None	0:11	0:00
02-Jan-2016		1096	5:47	6:00	Unidentifiable dolphin	acoustically	09.18667	-057.63637	2070	5	500	full power while on a survey line	full power while on a survey line	500	None	0:13	0:00
02-Jan-2016		1097	22:54	1:10	Unidentifiable dolphin	acoustically	08.57063	-057.99030	1916	2	500	not firing	not firing	500	None	1:19	0:00
03-Jan-2016		1098	8:12	8:56	Unidentifiable dolphin	acoustically	09.13872	-057.66220	2567	5	500	full power while on a survey line	full power while on a survey line	500	None		0:00
05-Jan-2016		1099	2:43	9:55	Unidentifiable dolphin	acoustically	08.73105	-058.00340	2147	5	233	full power while on a survey line	not firing	134	None	6:21	0:00
08-Jan-2016		1100	2:37	5:40	Unidentifiable dolphin	acoustically	09.25820	-057.61100	2932	5	500	full power while on a survey line	full power while on a survey line	134	None	2:57	0:00

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10-Jan-2016		1101	4:25	4:42	Unidentifiable dolphin	acoustically	09.02477	-057.74255	2198	1	500	full power while on a survey line	full power while on a survey line	500	None	0:18	0:00
10-Jan-2016		1102	8:33	9:39	Unidentifiable dolphin	acoustically	09.26178	-057.61925	2725	3	500	full power while on a survey line	full power while on a survey line	500	None		0:00
11-Jan-2016		1103	5:17	5:36	Unidentifiable dolphin	acoustically	08.54360	-058.13680	1725	3	500	not firing	not firing	500	None	0:19	0:00
11-Jan-2016	41		12:21	12:27	Unidentifiable dolphin	visually	08.80942	-057.85178	2389	15	3500	full power while on a survey line	full power while on a survey line	3940	None	0:00	0:00
11-Jan-2016		1104	21:50	22:09	Unidentifiable dolphin	acoustically	09.42273	-057.65097	2995	1	500	not firing	not firing	500	None	0:19	0:00
12-Jan-2016		1105	21:41	22:30	Unidentifiable dolphin	acoustically	09.28750	-057.61505	2936	5	500	full power while on a survey line	not firing	500	None	0:49	0:00
13-Jan-2016		1106	0:09	0:15	Unidentifiable dolphin	acoustically	09.41852	-057.66805	2850	2	500	not firing	not firing	500	None	0:06	0:00
13-Jan-2016	42		16:52	17:23	Unidentifiable baleen whale	visually	08.78913	-057.87182	2433	5	5000	full power while on a survey line	full power while on a survey line	5000	None	0:00	0:00
13-Jan-2016	43		18:12	18:23	Unidentifiable dolphin	visually	08.87162	-057.83352	2456	5	350	full power while on a survey line	full power while on a survey line	400	None	0:06	0:00
14-Jan-2016	44		17:44	17:52	Bryde's whale	visually	08.65883	-057.94017	3246	1	500	not firing	not firing	300	None	0:08	0:00
14-Jan-2016	45		21:59	22:10	Unidentifiable baleen whale	visually	08.93992	-057.80128	2602	2	4000	full power while on a survey line	full power while on a survey line	4300	None	0:00	0:00
15-Jan-2016		1107	3:15	3:40	Unidentifiable dolphin				2998		500	full power while on a survey line	full power while on a survey line	500	None	0:25	0:00
15-Jan-2016		1108	5:29	6:50	Unidentifiable dolphin				2810		500	not firing	not firing	500	None	0:50	0:00
15-Jan-2016		1109	21:52	3:15	Unidentifiable dolphin				2278		500	full power while on a survey line	full power while on a survey line	500	None	5:23	0:00
16-Jan-2016		1110	22:23	0:00	Unidentifiable dolphin				1997		500	not firing	not firing	500	Delayed start of firing	1:05	5:35
17-Jan-2016		1111	7:39	8:08	Unidentifiable dolphin				2227		500	full power while on a survey line	full power while on a survey line	500	None	0:29	0:00
17-Jan-2016	46		10:47	11:25	Unidentifiable dolphin				2706		4000	full power while on a survey line	full power while on a survey line	4000	None	0:00	0:00
19-Jan-2016		1112	4:02	5:08	Unidentifiable dolphin				2599		327	full power while on a survey line	full power while on a survey line	224	None	1:06	0:00
19-Jan-2016	47		18:41	18:51	Unidentifiable baleen whale				2698		2000	full power while on a survey line	full power while on a survey line	2400	None	0:00	0:00
19-Jan-2016		1113	23:01	0:03	Unidentifiable dolphin				2811		500	not firing	not firing	500	None	1:02	0:00

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22-Jan-2016	48	1114	21:41	22:09	Fraser's dolphin				2257		1500	full power while on a survey line	full power while on a survey line	600	None	0:00	
23-Jan-2016	49		21:31	21:36	Unidentifiable dolphin				2767		2000	full power while on a survey line	full power while on a survey line	2400	None	0:00	
26-Jan-2016		1115	0:47	0:51	Unidentifiable dolphin				2115		600	full power while on a survey line	full power while on a survey line	600	None	0:00	
27-Jan-2016		1116	5:23	5:55	Unidentifiable dolphin				2501		600	not firing	not firing	600	None	0:00	
29-Jan-2016		1117	8:17	8:35	Unidentifiable dolphin				2877		500	not firing	not firing	500	None	0:18	0:00
29-Jan-2016	50		19:22	20:57	Unidentifiable baleen whale	visually	08.98860	-057.80987	2469	1	4000	full power while on a survey line	full power while on a survey line	2400	None	0:00	
02-Feb-2016	51		21:38	21:44	Unidentifiable dolphin	visually	09.02032	-057.80798	2451	15	1500	full power while on a survey line	full power while on a survey line	1300	None	0:00	0:00
03-Feb-2016	52		17:59	17:59	Unidentifiable baleen whale	visually	09.26725	-057.80270	2800	1	2000	full power while on a survey line	full power while on a survey line	2400	None	0:00	0:00
03-Feb-2016		1118	22:00	22:33	Unidentifiable dolphin	acoustically	09.39725	-057.64078	2897	3	500	not firing	not firing	500	None	0:02	0:00
04-Feb-2016		1119	5:24	5:42	Unidentifiable dolphin	acoustically	08.93837	-057.86118	2466	2	600	full power while on a survey line	full power while on a survey line	600	None	0:00	0:00
04-Feb-2016	53		13:01	13:03	Loggerhead sea turtle	visually	08.54941	-058.04350	1784	1	20	not firing	not firing	150	None	0:03	0:00
05-Feb-2016		1120	0:51	2:45	Unidentifiable dolphin	acoustically	09.31858	-057.78522	2881	5	600	full power while on a survey line	not firing	600	None	0:00	
05-Feb-2016		1121	3:39	5:10	Sperm whale	acoustically	09.42168	-057.65608	2985	3	1000	not firing	not firing	500	None	1:11	0:16
05-Feb-2016	54		19:14	19:15	Unidentifiable dolphin	visually	08.55120	-058.05164	1781	6	350	not firing	not firing	370	None	0:01	0:00
06-Feb-2016		1122	4:41	4:57	Sperm whale	acoustically	09.11672	-057.88290	2706	1	1000	full power while on a survey line	full power while on a survey line	600	None	0:00	0:00
09-Feb-2016		1123	0:05	2:04	Unidentifiable dolphin	acoustically	09.41593	-057.74115	2909	10	300	not firing	not firing	100	None	0:24	0:00
10-Feb-2016		1124	7:16	7:35	Unidentifiable dolphin	acoustically	09.36637	-057.76788	2847	10	500	full power while on a survey line	not firing	100	None	0:19	0:00
10-Feb-2016		1125	8:54	9:33	Unidentifiable dolphin	acoustically	09.44592	-057.71917	2954	3	600	not firing	not firing	600	None	0:00	
11-Feb-2016		1126	22:53	23:29	Unidentifiable dolphin	acoustically	08.62942	-058.11560	1959	3	1000	not firing	not firing	1000	None	0:00	0:00
12-Feb-2016		1127	5:21	6:39	Unidentifiable dolphin	acoustically	08.99613	-057.95902	2592	10	600	full power while on a survey line	full power while on a survey line	100	None	0:47	0:00

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15-Feb-2016		1128	6:50	7:15	Unidentifiable dolphin	acoustically	09.47290	-057.70115	2923	5	1000	not firing	not firing	500	None	0:03	0:00
16-Feb-2016		1129	7:57	8:16	Unidentifiable dolphin	acoustically	09.19907	-057.87067	2751	5	500	full power while on a survey line	full power while on a survey line	500	None	0:19	0:00
16-Feb-2016	55		13:49	14:19	Bryde's whale	visually	09.40503	-057.73413	2891	1	500	not firing	not firing	375	None	0:22	0:00
17-Feb-2016	56		20:16	20:36	Bryde's whale	visually	09.30907	-057.81919	2829	5	3000	full power while on a survey line	not firing	350	None	0:11	0:00
Stabroek 3D *CGG Geo Celtic*																	
13-Jul-2015	1		12:36	12:41	Pantropical spotted dolphin	Visually	07.60667	-056.22050	1427	6	100	not firing	not firing		none	0:05	0:00
14-Jul-2015	2		22:11	22:11	Unidentified dolphin	Visually	09.30017	-057.50767	3030	1	50	not firing	not firing		none	0:01	0:00
20-Jul-2015	3		12:27	13:01	Bryde's whale	Visually	08.20433	-057.25233	1611	2	2500	full power while on survey line	full power while on survey line	2000	none	0:00	
21-Jul-2015		1	7:50	8:40	Sperm whale	Acoustically	08.85870	-056.82468	2924	3	1200	not firing	not firing	1200	none	0:00	
21-Jul-2015	4		15:58	16:04	Sperm whale	Visually	08.63817	-057.03200	2725	1	1000	full power while on survey line	full power while on survey line	1500	none	0:00	0:00
22-Jul-2015		2	8:23	8:51	Sperm whale	Acoustically	08.05523	-057.22383	1117	3	122	soft start / ramp-up	full power while on survey line	222	none	0:12	0:00
24-Jul-2015	5		15:18	15:21	Pantropical spotted dolphin	Visually	08.62217	-057.02433	2714	15	1000	full power while on survey line	full power while on survey line	700	none	0:00	
31-Jul-2015	6		15:31	15:39	Bryde's whale	Visually	08.64968	-057.00645	2746	1	1500	full power while on survey line	full power while on survey line	2000	none	0:00	
04-Aug-2015	7		21:17	21:53	Unidentified dolphin	Visually	08.81022	-056.87942	2084	9	1000	not firing	not firing	500	none	0:06	0:00
06-Aug-2015	8		17:31	17:36	Melon-headed whale	Visually	08.86733	-056.88033	2971	20	350	not firing	not firing	400	none	0:02	0:00
13-Aug-2015		3	4:12	4:22	Unidentified dolphin	Acoustically	08.22350	-057.08743	2799		500	full power while on survey line	full power while on survey line	500	none	0:10	0:00
15-Aug-2015		4	5:14	5:21	Unidentified dolphin	Acoustically	07.94860	-057.29223	401		500	not firing	not firing	500	none	0:07	
16-Aug-2015		5	0:54	1:04	Unidentified dolphin	Acoustically	08.66362	-056.95570	2759		500	full power while on survey line	full power while on survey line	500	none	0:10	
16-Aug-2015		6	5:45	5:51	Unidentified dolphin	Acoustically	08.34687	-057.11478	1935			full power while on survey line	full power while on survey line	500	none		
16-Aug-2015		7	23:46	23:52	Unidentified dolphin	Acoustically	08.64960	-056.86345	1938			full power while on survey line	full power while on survey line	500	none		

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18-Aug-2015		8	1:08	1:22	Unidentified dolphin	Acoustically	07.93547	-057.27138	1567			not firing	not firing	500	none	0:10	
20-Aug-2015		9	3:29	3:35	Unidentified dolphin	Acoustically	08.51128	-057.02087	2539			full power while on survey line	full power while on survey line	500	none	0:06	
23-Aug-2015		10	3:38	3:54	Unidentified dolphin	Acoustically	08.92945	-056.78423	1877			not firing	not firing	500	none	0:11	
23-Aug-2015	9		20:01	20:28	spinner dolphin	Visually	07.99855	-057.30675	676	6	70	not firing	not firing	350	none	0:25	
25-Aug-2015	10		20:48	20:51	Sperm Whale	Visually	08.06923	-057.24155	1132	2	700	full power while on survey line	full power while on survey line	1100	none	0:00	0:00
27-Aug-2015		11	2:16	2:21	Unidentified dolphin	acoustically	08.16987	-057.03950	1953			not firing	not firing		none		
28-Aug-2015	11		21:28	21:40	Sperm Whale	visually	08.35993	-056.95387	2336	2	1200	full power while on survey line	full power while on survey line	1600	none	0:00	
28-Aug-2015		12	23:35	23:39	Unidentified dolphin	acoustically	08.67388	-057.00000	1938			full power while on survey line	full power while on survey line		none		
29-Aug-2015		13	4:42	5:12	Unidentified dolphin	acoustically	07.85503	-057.18397	754		500	not firing	not firing	392	none	0:03	0:00
29-Aug-2015		14	21:40	21:41	Unidentified dolphin	acoustically	08.67388	-056.76073			500	Not firing	Not firing		none		0:00
01-Sep-2015	12		11:54	12:08	Unidentified dolphin	visually	08.18255	-057.01922	1887	30	2300	full power while on survey line	full power while on survey line	1900	none	0:00	0:00
04-Sep-2015	13		19:18	19:31	Spinner dolphin	visually	09.09712	-056.71303	3195	40	400	not firing	not firing		none	0:00	0:00
06-Sep-2015		15	4:58	5:09	Unidentified dolphin	acoustically	08.57487	-056.85153	2665			full power while on survey line	full power while on survey line		none		
06-Sep-2015		16	6:38	6:50	Unidentified dolphin	acoustically	08.69658	-056.83220	2455			not firing	not firing		none		
06-Sep-2015		17	8:05	8:08	Unidentified dolphin	acoustically	08.66855	-056.75297	2805			not firing	not firing		none		
07-Sep-2015		18	0:21	0:56	Unidentified dolphin	acoustically	08.01387	-057.13650				full power while not on survey line	full power while on survey line		none		
07-Sep-2015		19	3:16	4:14	Unidentified dolphin	acoustically	08.20857	-057.03802	1988			full power while on survey line	full power while on survey line		none		
08-Sep-2015		20	2:31	3:22	Unidentified dolphin	acoustically	07.80817	-057.24317	104			not firing	not firing		none		
08-Sep-2015		21	6:28	6:42	Unidentified dolphin	acoustically	08.02537	-057.07737	1768			full power while on survey line	full power while on survey line		none		
09-Sep-2015		22	4:00	4:31	Unidentified dolphin	acoustically	07.79208	-057.09225	1855			not firing	not firing		none		

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11-Sep-2015	14		16:43	17:00	Pantropical spotted dolphin	visually	08.09942	-057.02707	1700	25	1100	full power while on survey line	full power while on survey line	400	none	0:10	0:00
11-Sep-2015	15		17:44	17:48	Sperm whale	visually	08.17018	-056.99213	1917	1		full power while on survey line	full power while on survey line	630	none	0:00	
12-Sep-2015		23	6:11	6:20	Unidentified dolphin	acoustically	08.31147	-056.81557	1508			full power while on survey line	full power while on survey line		none		
13-Sep-2015	16		17:26	17:52	Risso's dolphin	visually	07.86913	-057.03428	919	4		full power while on survey line	full power while on survey line	540	none	0:08	0:00
14-Sep-2015		24	1:18	1:21	Unidentified dolphin	acoustically	08.10058	-057.01753	1899			full power while on survey line	full power while on survey line		none		
14-Sep-2015		25	23:42	0:21	Unidentified dolphin	acoustically	07.79044	-057.06839	2184			not firing	not firing		none		
15-Sep-2015	17		12:24	13:30	Spinner dolphin	visually	08.53735	-056.79117	2656	30		full power while on survey line	not firing	400	none	0:40	0:00
16-Sep-2015		26	0:57	1:12	Unidentified dolphin	acoustically	07.97797	-056.97057	1586			full power while on survey line	full power while on survey line		none		
16-Sep-2015		27	4:03	4:11	Unidentified dolphin	acoustically	07.78223	-057.06783	1233			not firing	not firing		none		
17-Sep-2015		28	8:16	8:17	Unidentified dolphin	acoustically	07.27117	-057.06772	155		1100	not firing	not firing	500	none		
18-Sep-2015		29	23:34	0:40	Unidentified dolphin	acoustically	08.39273	-056.85323	2464		550	full power while on survey line	full power while on survey line	166	none	0:04	0:00
21-Sep-2015		30	0:42	1:07	Unidentified dolphin	acoustically	07.81638	-057.13172	212			not firing	soft start / ramp-up		none		
30-Sep-2015	18		18:53	18:58	Pantropical spotted dolphin	visually	07.96317	-056.93150	1457	8	1700	full power while on survey line	full power while on survey line	600	none	0:00	
02-Oct-2015		31	4:51	4:56	Unidentified dolphin	acoustically	07.60242	-057.02920	439			not firing	not firing		none	0:00	0:00
02-Oct-2015		32	9:30	9:34	Unidentified dolphin	acoustically	07.79998	-057.10415	318			not firing	not firing	500	none	0:04	0:00
03-Oct-2015		33	3:00	3:02	Unidentified dolphin	acoustically	08.56353	-056.59932	2790		600	not firing	not firing	500	none	0:00	0:00
04-Oct-2015	19		18:46	19:16	Melon-headed whale	visually	07.83033	-056.98933	850	15		full power while on survey line	full power while on survey line	400	none	0:01	0:00
05-Oct-2015		34	1:40	2:03	Unidentified dolphin	acoustically	07.96310	-057.11443	1388			full power while on survey line	full power while on survey line	268	none	0:07	0:00
07-Oct-2015		35	0:33	1:23	Unidentified dolphin	acoustically	08.13062	-056.84512	1918	3		full power while on survey line	full power while on survey line	500	none	0:12	0:00
07-Oct-2015		36	2:00	2:58	Unidentified dolphin	acoustically	08.04267	-056.88077	1648	2		not firing	not firing		none	0:00	0:00

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07-Oct-2015		37	3:30	3:48	Unidentified dolphin	acoustically	07.95915	-056.91913	1473	2		not firing	soft start / ramp-up		none	0:00	0:00
07-Oct-2015		38	23:49	23:59	Unidentified dolphin	acoustically	08.59402	-056.67885	2767	4		not firing	not firing	500	none	0:10	0:00
11-Oct-2015	20		14:51	15:19	Spinner dolphin	visually	08.16017	-056.80217	2049	23	2000	full power while on survey line	full power while on survey line	1200	none	0:00	
12-Oct-2015		39	5:30	6:14	Unidentified dolphin	acoustically	07.85208	-056.85037	1155	1		full power while on survey line	full power while on survey line		none	0:00	0:00
15-Oct-2015	21		14:10	14:12	Unidentified dolphin	visually	08.25883	-056.73400	2283	4	2500	full power while on survey line	full power while on survey line	2800	none	0:00	
18-Oct-2015		40	4:35	5:23	Unidentified dolphin	acoustically	08.41775	-056.61290	2627	6		not firing	not firing	91	none	0:11	0:00
19-Oct-2015	22		13:05	13:26	Pantropical spotted dolphin	visually	08.28647	-056.60217	2412	8	2000	not firing	not firing	900	none	0:00	
19-Oct-2015	23		15:18	15:35	Unidentified dolphin	visually	08.16267	-056.66383	2207	4	1500	full power while on survey line	full power while on survey line	1200	none	0:00	
23-Oct-2015		41	23:59	0:25	Unidentified dolphin	acoustically	08.23862	-086.61222	2346			full power while on survey line	full power while on survey line		none		
24-Oct-2015		42	7:04	7:38	Unidentified dolphin	acoustically	07.78198	-056.84243	1889			full power while on survey line	full power while on survey line		none		
27-Oct-2015		43	3:25	3:26	Unidentified dolphin	acoustically	07.86668	-056.79000	1099			full power while on survey line	full power while on survey line		none		
27-Oct-2015		44	5:34	5:39	Unidentified dolphin	acoustically	07.71652	-056.86600	1201			full power while on survey line	full power while on survey line		none		
29-Oct-2015		45	4:45	4:45	Unidentified dolphin	acoustically	07.65978	-056.88998	1037			full power while on survey line	full power while on survey line		none		
29-Oct-2015		46	5:57	6:40	Unidentified dolphin	acoustically	07.58553	-056.92792	1233			full power while on survey line	full power while on survey line		none		
31-Oct-2015	24		11:20	11:32	Spinner dolphin	visually	07.93313	-056.74172	1727	30	700	full power while on survey line	full power while on survey line	800	none	0:00	
31-Oct-2015	25		13:13	13:27	Spinner dolphin	visually	07.80727	-056.80727	1274	20	1200	full power while on survey line	full power while on survey line	1500	none	0:00	
03-Nov-2015		47	22:25	22:28	Unidentified dolphin	acoustically	08.41632	-056.46133	2672			not firing	not firing		none		
05-Nov-2015		48	3:52	4:15	Unidentified dolphin	acoustically	08.36812	-056.53823	1899			not firing	not firing		none		
05-Nov-2015		49	6:26	6:34	Unidentified dolphin	acoustically	08.19742	-056.56077	1029			full power while on survey line	full power while on survey line		none		
09-Nov-2015		50	22:46	22:58	Unidentified dolphin	acoustically	08.23267	-056.56398	2400			soft-start / ramp-up	soft-start / ramp-up		none		

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10-Nov-2015		51	2:07	4:08	Unidentified dolphin	acoustically	08.03747	-056.66157	1890			full power while on a survey line	full power while on a survey line		none		
10-Nov-2015		52	4:58	6:14	Unidentified dolphin	acoustically	07.87063	-056.74725	1230			full power while on a survey line	full power while on a survey line		none		
10-Nov-2015		53	7:58	8:03	Unidentified dolphin	acoustically	07.69500	-056.83497	1098			not firing	not firing		none		
10-Nov-2015		54	8:43	8:58	Unidentified dolphin	acoustically	07.69500	-056.83497	933			not firing	not firing		none		
11-Nov-2015		55	2:02	2:16	Unidentified dolphin	acoustically	07.83748	-056.87770	1117			full power while on a survey line	full power while on a survey line		none		
11-Nov-2015		56	4:05	4:10	Unidentified dolphin	acoustically	07.96932	-056.81335	1988			full power while on a survey line	full power while on a survey line		none		
13-Nov-2015		57	20:45	20:48	Unidentified dolphin	acoustically	07.99315	-056.70533	1888			full power while on a survey line	full power while on a survey line		none		
16-Nov-2015		58	1:10	1:16	Unidentified dolphin	acoustically	07.89363	-056.63023	660			not firing	not firing		none		
18-Nov-2015		59	1:58	2:02	Unidentified dolphin	acoustically	07.47978	-056.93305	69			not firing	not firing		none		
20-Nov-2015		60	5:12	5:40	Unidentified dolphin	acoustically	08.02847	-056.54880	2082			full power while on a survey line	full power while on a survey line	60	none	0:05	0:00
20-nov-2015	26		12:49	12:53	Pantropical spotted dolphin	visually	07.60975	-056.76030	354	3	200	full power while on a survey line	full power while on a survey line	500	None	0:04	0:00
22-Nov-2015	27		16:00	16:03	Unidentified dolphin	visually	07.72223	-056.79850	1012	3	100	full power while on a survey line	full power while on a survey line	500	None	0:03	0:00
23-Nov-2015		61	6:42	6:50	Unidentified dolphin	acoustically	08.02463	-056.54223	2065			full power while on a survey line	full power while on a survey line	500	None	0:01	0:00
23-Nov-2015		62	22:00	22:08	Unidentified dolphin	acoustically	07.72385	-056.78882	1042			full power while on a survey line	full power while on a survey line	500	None	0:02	0:00
24-Nov-2015	28		18:53	19:00	Spinner dolphin	visually	07.60555	-056.74868	354	6	250	full power while on a survey line	full power while on a survey line	600	None	0:00	
26-Nov-2015		63	2:29	2:35	Unidentified dolphin	acoustically	07.58505	-056.75477	118			full power while on a survey line	full power while on a survey line	500	None	0:03	0:00
26-Nov-2015		64	23:25	23:39	Unidentified dolphin	acoustically	08.15307	-056.46447	2376			full power while on a survey line	full power while on a survey line	500	None	0:08	0:00
01-Dec-2015		65	5:33	5:48	Unidentified dolphin	acoustically	07.61903	-056.72003	568			full power while on a survey line	full power while on a survey line		None		
04-Dec-2015		66	2:08	2:37	Unidentified dolphin	acoustically	07.57792	-056.83318	105			not firing	not firing	500	None	0:18	0:00
05-Dec-2015	29		13:07	13:25	Unidentified dolphin	visually	08.04855	-056.41083	2353	30	1000	not firing	not firing	1400	None	0:00	

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06-Dec-2015		67	23:08	23:09	Unidentified dolphin	acoustically	08.25187	-056.43815	2357			other reduced power firing	other reduced power firing		None	0:00	
07-Dec-2015		68	6:18	6:35	Unidentified dolphin	acoustically	07.83805	-056.58882	1747			full power while on a survey line	full power while on a survey line		None		
08-Dec-2015		69	5:45	5:55	Unidentified dolphin	acoustically	08.23802	-056.42053	2554			not firing	not firing		None		
08-Dec-2015		70	7:07	7:17	Unidentified dolphin	acoustically	08.15310	-056.43042	2419			not firing	not firing		None		
09-Dec-2015		71	1:04	1:13	Unidentified dolphin	acoustically	07.62438	-056.79972	384			full power while on a survey line	full power while on a survey line	500	None	0:09	
10-Dec-2015	30		19:44	19:51	Bryde's whale	visually	07.64177	-056.89598	108	1	2500	not firing	not firing	2500	None	0:00	
11-Dec-2015		72	3:31	3:53	Unidentified dolphin	acoustically	07.61323	-056.80063	829			full power while on a survey line	full power while on a survey line		None		
12-Dec-2015		73	4:33	5:05	Unidentified dolphin	acoustically	08.23237	-056.48737	2500			not firing	not firing	500	None	0:07	0:00
12-Dec-2015	31		19:53	20:01	Unidentified dolphin	visually	07.39123	-056.86523	61	1	3500	not firing	not firing	3000	None	0:00	
13-Dec-2015		74	1:04	1:05	Unidentified dolphin	acoustically	07.71405	-056.74670	1136			full power while on a survey line	full power while on a survey line	500	None	0:01	0:00
13-Dec-2015		75	1:21	1:38	Unidentified dolphin	acoustically	07.73217	-056.73752	1240			full power while on a survey line	full power while on a survey line		None		
13-Dec-2015		76	4:50	5:08	Unidentified dolphin	acoustically	07.96230	-056.62072	1948			full power while on a survey line	full power while on a survey line		None		
14-Dec-2015	32		13:11	13:17	Bryde's Whale	Visually	07.99662	-056.59930	1998	1	1500	full power while on a survey line	full power while on a survey line	1300	None	0:00	0:00
15-Dec-2015		77	3:24	3:33	Unidentified dolphin	acoustically	07.68190	-056.64597	1196			full power while on a survey line	full power while on a survey line	500	None	0:01	0:00
15-Dec-2015		78	6:36	6:38	Unidentified dolphin	acoustically	07.47328	-056.75178	80			full power while on a survey line	full power while on a survey line		None		
16-Dec-2015		79	4:07	4:08	Unidentified dolphin	acoustically	08.11353	-056.42775	2398			not firing	not firing	98	None	0:05	
16-Dec-2015	33		12:16	12:19	Pantropical spotted dolphin	visually	07.60367	-056.68063	670			full power while on a survey line	full power while on a survey line	450	None	0:03	
18-Dec-2015		80	5:03	5:06	Unidentified dolphin	acoustically	07.61032	-056.78712	890			full power while on a survey line	full power while on a survey line		None	0:03	
19-Dec-2015		81	0:56	1:32	Unidentified dolphin	acoustically	07.82755	-056.56463	1302	3		full power while on a survey line	full power while on a survey line	500	None		
19-Dec-2015		82	4:12	5:23	Unidentified dolphin	acoustically	07.63088	-056.66412	889	1		full power while on a survey line	full power while on a survey line	500	None		

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19-Dec-2015		83	21:13	21:19	Unidentified dolphin	acoustically	07.71777	-056.65807	1309	5		not firing	not firing	1500	None		
20-Dec-2015		84	5:50	5:56	Unidentified dolphin	acoustically	07.59125	-056.78597	1099	1		soft-start / ramp-up	soft-start / ramp-up	1000	None		
22-Dec-2015		85	2:50	3:19	Unidentified dolphin	acoustically	07.91055	-056.38272	1088			not firing	not firing	500	None		
24-Dec-2015		86	6:25	6:51	Unidentified dolphin	acoustically	08.20438	-056.44178	1306			not firing	not firing	500	None		
24-Dec-2015		87	23:06	23:21	Unidentified dolphin	acoustically	07.99050	-056.58660	1899			full power while on a survey line	full power while on a survey line	500	None		
29-Dec-2015	34		16:45	16:46	Unidentified dolphin	visually	08.64070	-056.77875	2765	1	250	not firing	not firing		None	0:00	0:00
07-Jan-2016		88	23:00	23:04	Unidentified dolphin	acoustically	07.59452	-056.67487	2304	1		full power while on a survey line	full power while on a survey line	1500	None		
08-Jan-2016		89	0:23	0:25	Unidentified dolphin	acoustically	07.68625	-056.62702	2216	1		full power while on a survey line	full power while on a survey line	500	None		
09-Jan-2016	35		19:34	19:38	Pantropical spotted dolphin	visually	07.79715	-056.49132	1777	8	400	full power while on a survey line	full power while on a survey line	600	None	0:00	
11-Jan-2016	36		13:35	13:45	Bryde's whale	visually	07.79320	-056.56128	1649	1	150	full power while on a survey line	full power while on a survey line	380	None	0:07	
11-Jan-2016		90	23:28	23:33	Unidentified dolphin	acoustically	07.96468	-056.39753	252	1	500	full power while on a survey line	full power while on a survey line	500	None		
13-Jan-2016		91	2:10	2:50	Unidentified dolphin	acoustically	07.87522	-056.44013	446	5	500	full power while on a survey line	full power while on a survey line	500	None		
13-Jan-2016	37		15:25	15:30	Unidentified dolphin	visually	07.61243	-056.64640	882	5	5000	full power while on a survey line	full power while on a survey line	5500	None	0:00	0:00
14-Jan-2016	38		18:38	18:45	Pantropical spotted dolphin	visually	07.65023	-056.62297	1111	15	600	full power while on a survey line	full power while on a survey line	600	None	0:00	0:00
16-Jan-2016		92	3:09	3:30	Unidentified dolphin	acoustically	07.92925	-056.47488	367	1		full power while on a survey line	full power while on a survey line		None		
17-Jan-2016		93	3:50	4:20	Unidentified dolphin	acoustically	07.77890	-056.54897	664	1		full power while on a survey line	full power while on a survey line		None		
17-Jan-2016	39		20:38	21:14	Spinner dolphin	visually	07.59259	-056.56273	828	40	4000	full power while on a survey line	full power while on a survey line	1100	None	0:00	0:00
17-Jan-2016	40		20:38	20:43	Sperm whale	visually	07.59259	-056.56273	828	1	4000	full power while on a survey line	full power while on a survey line	4500	None	0:00	0:00
17-Jan-2016	41		21:17	21:18	Sperm whale	visually	07.55542	-056.58175	496	1	3000	full power while on a survey line	full power while on a survey line	3000	None	0:00	0:00

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18-Jan-2016		94	3:42	3:54	Unidentified dolphin	acoustically	07.55280	-056.57818		3	500	full power while on a survey line	full power while on a survey line	500	None		
20-Jan-2016	42		20:18	20:26	Unidentified baleen whale	visually	07.57283	-056.63638	537	1	1200	full power while on a survey line	full power while on a survey line	1500	None	0:00	0:00
20-Jan-2016		95	21:35	21:37	Unidentified dolphin	acoustically	07.65657	-056.59522	678	1	800	full power while on a survey line	full power while on a survey line	800	None		
21-Jan-2016		96	1:19	1:32	Unidentified dolphin	acoustically	07.91010	-056.46873	576	3	1000	full power while on a survey line	full power while on a survey line	1000	None		
22-Jan-2016		97	6:28	6:32	Unidentified dolphin	acoustically	07.86007	-056.48872	898	2	500	full power while on a survey line	full power while on a survey line	500	None		
23-Jan-2016		98	0:52	1:19	Unidentified dolphin	acoustically	07.50032	-056.58780	123	3	1000	full power while on a survey line	full power while on a survey line	1000	None		
23-Jan-2016	43		10:49	10:56	Spinner dolphin	visually	688.98333	-056.57243	450	15	500	full power while on a survey line	full power while on a survey line	450	None	3:00	0:00
26-Jan-2016		99	2:50	3:26	unidentified dolphin	acoustically	07.56685	-056.61857	489	3	1000	full power while on a survey line	full power while on a survey line	1000	None		
26-Jan-2016		100	22:50	0:30	unidentified dolphin	acoustically	07.62162	-056.51397	1049	5	1000	full power while on a survey line	full power while on a survey line	250	None		
30-Jan-2016		101	20:13	20:18	unidentified dolphin	acoustically	08.03940	-056.38148	2355	3	1000	not firing	not firing	800	None		
31-Jan-2016		102	3:25	3:34	unidentified dolphin	acoustically	07.56065	-056.61190	445	1	1000	full power while on a survey line	full power while on a survey line	500	None		
01-Feb-2016		103	0:10	0:19	Unidentified dolphin	acoustically	07.56907	-056.53042	686	1	1000	full power while on a survey line	full power while on a survey line	500	None		
01-Feb-2016		104	1:33	1:42	Unidentified dolphin	acoustically	07.63507	-056.49682	1049	1	500	full power while on a survey line	full power while on a survey line	500	None		
01-Feb-2016		105	5:00	5:10	Unidentified dolphin	acoustically	07.82620	-056.40653	2009	1	1000	full power while on a survey line	full power while on a survey line	500	None		
04-Feb-2016		106	23:14	0:08	Unidentified dolphin	acoustically	07.91117	-056.34532	980	3	1000	not firing	not firing	1000	None		
08-Feb-2016		107	23:54	23:58	Unidentified dolphin	acoustically	07.68675	-056.43133	899	3	1000	full power while on a survey line	full power while on a survey line	1000	None		
09-Feb-2016		108	3:20	3:33	Unidentified dolphin	acoustically	07.90452	-056.21250	1766	NA	NA	not firing	not firing	100	None		
14-Feb-2016		109	3:08	4:12	Unidentified dolphin	acoustically	07.59007	-056.34805	1033	5	1500	full power while on a survey line	full power while on a survey line	1000	None		
14-Feb-2016		110	22:56	23:03	Unidentified dolphin	acoustically	07.69835	-056.29043	1488		1000	full power while on a survey line	full power while on a survey line	1000	None		

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15-Feb-2016		111	3:02	4:08	Unidentified dolphin	acoustically	07.48422	-056.39773	502		2000	full power while on a survey line	full power while on a survey line	1000	None		
17-Feb-2016		112	5:41	5:50	Unidentified dolphin	acoustically	07.62690	-056.42300	1242	2	1500	full power while on a survey line	full power while on a survey line	1500	None		
17-Feb-2016		113	22:00	22:27	Unidentified dolphin	acoustically	07.50063	-056.37557	770	5	1000	full power while on a survey line	full power while on a survey line	300	None		
19-Feb-2016		114	3:22	3:26	Unidentified dolphin	acoustically	07.55490	-056.43820	102	2	500	full power while on a survey line	full power while on a survey line	500	None		
LIZA AUV Survey																	
21-Dec-2015	1		19:31	19:31	Short-finned pilot whale	visually	07.80372	-057.15685	400	1	20	not firing	not firing		none	00:00	
25-Dec-2015	2		10:16	10:26	Common bottlenose dolphin	visually	08.10027	-057.01693	1702	8	100	full power while on survey line	full power while on survey line		none	00:10	00:00
25-Dec-2015	3		13:44	14:23	Pantropical spotted dolphin	visually	08.10938	-057.02723	1718	10	20	full power while on survey line	full power while on survey line		none	00:39	00:00
29-Dec-2015	4		13:27	13:29	Common bottlenose dolphin	visually	07.49228	-057.57785	48	4	10	not firing	not firing		none	00:02	00:00
01-Jan-2016	5		20:47	20:48	Pantropical spotted dolphin	visually	08.08897	-057.02958	343	20	400	not firing	not firing		none	00:01	00:00
06-Jan-2016	6		18:19	18:26	Pantropical spotted dolphin	visually	08.11558	-057.02025	1752	50	100	full power while on survey line	full power while on survey line		none	00:05	00:00
07-Jan-2016	7		19:25	19:59	Short-finned pilot whale	visually	07.92542	-057.10417	1200	22	100	not firing	not firing		none	00:19	00:00
10-Jan-2016	8		13:43	13:49	Common bottlenose dolphin	visually	08.05623	-057.05670	1550	32	10	full power while on survey line	full power while on survey line		none	00:05	00:00
12-Jan-2016	9		14:00	14:10	Pantropical spotted dolphin	visually	08.08613	-056.91308	1811	10	20	not firing	not firing		none	00:07	00:00
14-Jan-2016	10		19:18	19:43	Pantropical spotted dolphin	visually	07.91857	-057.05837	1200	55	10	not firing	not firing		none	00:14	00:00
18-Jan-2016	11		17:04	17:05	Green Sea Turtle	visually	08.01568	-056.86687	1657	1	10	full power while on survey line	full power while not on survey line		none	00:01	00:00
27-Jan-2016	12		12:34	12:36	Common bottlenose dolphin	visually	08.00553	-056.84902	1554	10	2	not firing	not firing		none	00:02	00:00
28-Jan-2016	13		21:21	21:24	Common bottlenose dolphin	visually	07.35323	-057.45280	41	10	20	full power while not on survey line	full power while not on survey line		none	00:02	00:00
29-Jan-2016	14		10:05	10:05	Unidentifiable dolphin	visually	07.97517	-056.95390	1467	5	2	not firing	not firing		none	00:01	00:00
29-Jan-2016	15		16:40	16:51	Sperm whale	visually	07.85222	-057.03092	1209	4	800	full power while on survey line	full power while on survey line		none	00:00	

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29-Jan-2016	16		19:56	20:13	Unidentifiable dolphin	visually	07.94035	-056.98360	1313	10	1500	full power while on survey line	full power while on survey line		none	00:00	
05-Feb-2016	17		13:10	13:15	Pantropical spotted dolphin	visually	08.10133	-056.89590	1850	20	4	full power while on survey line	full power while on survey line		none	00:05	00:00
08-Feb-2016	18		10:03	10:10	Common bottlenose dolphin	visually	07.68338	-057.28462	75	10	2	not firing	not firing		none	00:07	00:00
08-Feb-2016	19		12:45	13:08	Common bottlenose dolphin	visually	07.45865	-057.52113	51	15	400	not firing	not firing		none	00:23	00:00
13-Feb-2016	20		19:30	19:36	Melon-headed whale	visually	08.06668	-057.12560	1093	50	200	not firing	not firing		delayed start of firing	00:06	00:00
03-Mar-2016	21		20:30	20:32	Hawksbill sea turtle	visually	07.80083	-057.81800	60	1	30	not firing	not firing		none	02:00	00:00
03-Mar-2016	22		21:05	21:08	Pantropical spotted dolphin	visually	07.48217	-057.49083	50	1	150	not firing	not firing		none	03:00	00:00
05-Mar-2016	23		15:04	15:05	Hawksbill sea turtle	visually	07.65150	-057.21100	71	1	30	other reduced power firing	other reduced power firing		none	01:00	00:00
06-Mar-2016	24		15:05	15:08	Sperm whale	visually	07.90298	-057.09298	1000	1	1000	other reduced power firing	other reduced power firing		none	00:00	00:00
11-Mar-2016	25		10:58	11:02	Unidentifiable baleen whale	visually	07.92797	-056.54735	1820	1	1500	other reduced power firing	other reduced power firing		none	00:00	00:00
11-Mar-2016	26		13:25	13:35	Bryde's whale	visually	07.89517	-056.83417	1500	1	200	other reduced power firing	other reduced power firing		none	10:00	00:00
17-Mar-2016	27		20:44	20:50	Bryde's whale	visually	08.29683	-057.35317	1896	1	600	other reduced power firing	other reduced power firing		none	00:00	00:00
21-Mar-2016	28		17:40	17:45	Common bottlenose dolphin	visually	07.71488	-057.16995	90	2	10	other reduced power firing	other reduced power firing		none	00:05	00:00
Canje 3D Survey																	
20-Mar-2016	1		13:05	13:07	Unidentifiable dolphin	visually	07.97825	-056.17697	2278	10	250	not firing	not firing	842	none		00:00
29-Mar-2016	2		21:11	21:13	Sperm whale	visually	07.92200	-056.19385	2160	1	3700	not firing	not firing	4000	none		00:00
02-Apr-2016	3		16:35	19:15	Fraser's dolphin	visually	07.92298	-056.23653	2218	1	50	full power while on survey line	full power while on survey line	590	none		00:00
03-Apr-2016	4		15:00	16:50	Fraser's dolphin	visually	07.85427	-056.23342	2018	1	150	full power while on survey line	full power while on survey line	560	none		00:00
04-Apr-2016	5		11:37	11:45	Unidentifiable baleen whale	visually	08.64020	-057.56457	3128	2	1500	full power while on survey line	full power while on survey line	1600	none		00:00
05-Apr-2016	6		15:57	15:58	Sperm whale	visually	08.25383	-056.22693	2756	1	800	full power while on survey line	full power while on survey line	1440	none		00:00
13-Apr-2016	7		9:48	9:49	Unidentifiable dolphin	visually	08.80603	-056.29915	3214	11	20	not firing	not firing	637	none		00:00

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16-Apr-2016	8		10:29	10:44	Bryde's whale	visually	08.72498	-056.10738	3149	1	1200	not firing	not firing	1337	none		00:00
17-Apr-2016	9		16:16	16:16	Unidentifiable dolphin	visually	08.79703	-056.17315	3172	1	200	not firing	not firing	620	none		00:00
19-Apr-2016	10		20:25	20:41	Bryde's whale	visually	08.57515	-056.10538	3012	1	2500	full power while on survey line	full power while on survey line	2700	none		00:00
24-Apr-2016	11		18:17	18:21	Pantropical spotted dolphin	visually	08.74803	-056.18900	3146	50	300	not firing	not firing	737	none		00:00
26-Apr-2016		1	19:50	19:54	Unidentifiable dolphin	acoustically	08.75265	-056.19203	3152	3	1500	not firing	not firing	1500	none		00:00
26-Apr-2016		2	23:20	23:51	Unidentifiable dolphin	acoustically	08.48763	-056.18960	2977	1	1500	full power while on survey line	full power while on survey line	1500	none		00:00
27-Apr-2016	12		10:07	10:22	Unidentifiable baleen whale	visually	07.79478	-056.47098	1816	1	1000	not firing	not firing	595	none		00:00
30-Apr-2016		3	22:30	22:40	Unidentifiable dolphin	acoustically	08.08677	-056.26832	2546	3	1000	full power while on survey line	full power while on survey line	1000	none		00:00
01-May-2016	13		13:50	13:56	Unidentifiable beaked whale	Visually	08.63773	-056.28852	3106	1	300	full power while on survey line	full power while on survey line	837	none		00:00
10-May-2016	14		11:45	12:11	Pantropical spotted dolphin	Visually	07.89978	-056.42068	2137	100	1400	full power while on survey line	full power while on survey line	1500	none		
12-May-2016		4	22:28	22:30	Unidentifiable dolphin	Acoustically	07.70700	-056.32828	1345	2	1500	full power while on survey line	full power while on survey line	1500	none		00:00
12-May-2016		5	23:03	23:08	Unidentifiable dolphin	Acoustically	07.66883	-056.35267	1466	2	1500	not firing	not firing	1500	none		00:00
19-May-2016		6	4:09	4:11	Unidentifiable dolphin	Acoustically	08.45215	-056.34965	2677	2	1800	full power while on survey line	full power while on survey line	1800	none		00:00
20-May-2016		7	7:10	7:37	Unidentifiable dolphin	acoustically	08.84265	-056.37600	2897	4	1000	not firing	not firing	1000	none		00:00
22-May-2016		8	22:24	23:23	Unidentifiable dolphin	acoustically	08.45418	-056.65300	2530	4	1000	not firing	not firing	1000	none		00:00
03-June-2016	15		12:29	12:30	Unidentifiable dolphin	visually	08.89283	-056.65928	3044	2	300	not firing	not firing	580	none	00:00	00:00
06-June-2016	16		14:56	14:58	Spinner dolphin	visually	08.46977	-056.66849	2793	80	600	full power while on survey line	full power while on survey line	600	none	00:00	00:00
10-Jun-2016		9	6:44	6:47	Unidentifiable dolphin	acoustically	08.81343	-056.48455	3045	2	1500	not firing	not firing	1500	none	00:00	00:00
12-Jun-2016	17		12:29	12:32	Pantropical spotted dolphin	visually	08.59130	-056.68162	2767	10	100	full power while on survey line	full power while on survey line	680	none	00:00	00:00
15-Jun-2016	18		22:15	22:17	Unidentifiable whale	visually	08.20167	-056.60167	2322	1	1000	full power while on survey line	full power while on survey line	1500	none	00:00	00:00

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18-Jun-2016		10	3:03	3:07	Unidentifiable dolphin	acoustically	07.97215	-056.50000	2127	1	1000	full power while on survey line	full power while on survey line	1000	none		00:00
18-Jun-2016	19		12:29	12:33	Unidentifiable whale	visually	08.39858	-056.60995	2599	1	2000	full power while on survey line	full power while on survey line	1000	none	00:00	00:00
27-Jun-2016	20		14:13	14:36	Pantropical spotted dolphin	visually	08.55483	-056.53190	2815	30	100	full power while on survey line	full power while on survey line	580	none	00:00	00:00
27-Jun-2016	21		15:43	16:32	Pantropical spotted dolphin	visually	08.42527	-056.53418	2666	30	350	full power while on survey line	full power while on survey line	485	none	00:00	00:00
29-Jun-2016	22		20:20	20:25	Sperm whale	visually	08.68422	-056.55772	2913	1	300	full power while on survey line	full power while on survey line	780	none	00:00	00:00
01-Jul-2016	23		15:24	15:25	Spinner dolphin	visually	08.20915	-056.50747	2430	15	650	full power while on survey line	full power while on survey line	860	none	00:00	00:00
11-Jul-2016		11	1:10	1:34	Unidentifiable dolphin	acoustically	08.65758	-056.70718	2899	4	1500	full power while on survey line	full power while on survey line	1500	none	00:00	00:00
15-Jul-2016		12	1:19	1:32	Unidentifiable dolphin	acoustically	08.67695	-056.72610	2821	3	1500	full power while on survey line	full power while on survey line	1500	none	00:00	00:00
15-Jul-2016		13	2:15	2:20	Unidentifiable dolphin	acoustically	08.60683	-056.72640	2467	3	1200	full power while on survey line	full power while on survey line	1200	none	00:00	00:00
15-Jul-2016		14	3:47	4:02	Unidentifiable dolphin	acoustically	08.48968	-056.72717	2636	4	1000	full power while on survey line	full power while on survey line	1000	none	00:00	00:00
18-Jul-2016		15	0:34	0:40	Unidentifiable dolphin	acoustically	08.64185	-056.74250	2788	2	1500	full power while on survey line	full power while on survey line	1500	none	00:00	00:00
18-Jul-2016		16	3:15	3:29	Unidentifiable dolphin	acoustically	08.42110	-056.74078	2433	4	1500	full power while on survey line	full power while on survey line	1500	none	00:00	00:00
18-Jul-2016	24		10:55	11:03	Unidentifiable beaked whale	visually	08.53655	-056.85025	2615	1	2500	full power while on survey line	full power while on survey line	3100	none		00:00
20-Jul-2016	25		11:07	11:39	Spinner dolphin	visually	08.65650	-056.81087	2762	100	2000	full power while on survey line	full power while on survey line	1070	none		00:00
20-Jul-2016	26		14:50	14:53	Unidentifiable dolphin	visually	08.91803	-056.81168	3027	4	2000	full power while on survey line	full power while on survey line	2300	none		00:00
21-Jul-2016		17	4:32	4:36	Unidentifiable dolphin	acoustically	08.13485	-056.73510	2675	3	1200	not firing	not firing	1200	none		00:00
22-Jul-2016	27		11:52	12:58	Bryde's whale	visually	09.10263	-056.98917	3087	2	1800	not firing	not firing	2200	none		00:00
02-Aug-2016	28		19:52	19:56	Sperm whale	visually	08.59483	-056.99615	2661	2	5000	not firing	not firing	5430	none		00:00
04-Aug-2016		18	1:50	2:09	Unidentifiable dolphin	acoustically	08.88523	-056.87285	2899	3	1500	full power while on a survey	full power while on a survey line	1500	none		00:00

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11-Aug-2016		19	1:11	1:29	Unidentifiable dolphin	acoustically	08.89125	-056.92425	2844	3	1500	full power while on a survey	full power while on a survey	1500	none		0:00
12-Aug-2016		20	2:21	2:47	Unidentifiable dolphin	acoustically	08.67013	-057.00000	2679	2	1200	not firing	not firing	1200	none		0:00
12-Aug-2016		21	5:50	6:11	Unidentifiable dolphin	acoustically	08.95213	-057.08207	2855	4	1000	full power while on a survey line	full power while on a survey line	1000	none		0:00
17-Aug-2016	29		18:14	18:33	Melon-headed whale	visually	08.94688	-056.97955	3033	15	700	full power while on a survey	full power while on a survey	700	none		0:00
Liza-2 Stabroek WAVSP Survey																	
31-Mar-2016	1		16:00	16:30	Bryde's whale	visually	08.06632	-056.98727	1630	2	400	not firing	not firing	400	none	0:10	0:00
31-Mar-2016	2		17:15	17:37	Bryde's whale	visually	08.06897	-056.98175	1630	3	100	not firing	not firing	100	none	0:02	0:00
31-Mar-2016	3		19:35	19:37	Bryde's whale	visually	08.06913	-056.98178	1630	1	300	not firing	not firing	300	none	0:02	0:00
Liza 3D/4D Survey																	
8/24/2017	1		12:48	13:19	Unidentifiable baleen whale	visually	8.54778	-56.80056	2285	3	5000	not firing	not firing		none	0:00	
8/28/2017	2		21:03	21:06	Pantropical spotted dolphin	visually	8.40611	-56.79306	2120	5	300	not firing	not firing		none	0:00	
8/29/2017	3		11:01	11:02	Bryde's whale	visually	8.46809	-57.4419	2026	1	300	not firing	not firing		none		0:00
8/30/2017	4	1	21:31	21:57	Common bottlenose dolphin	visually and acoustically	8.22958	-56.91444	2087	70	400	not firing	not firing	350	none	0:26	0:00
9/1/2017	5		21:22	21:32	Spinner dolphin	visually	8.32587	-56.86323	2303	30	700	full power while on survey line	full power while on survey line	754	none	0:00	0:00
9/2/2017		2	1:41	1:43	Unidentifiable dolphin	acoustically	8.30795	-56.97888	2084	2	500	full power while on survey line	full power while on survey line	500	none	0:03	0:00
9/6/2017		3	8:06	8:41	Unidentifiable dolphin	acoustically	8.45217	-56.96305	2480	3	500	not firing	not firing	500	none	0:35	0:00
9/7/2017		4	7:02	7:05	Unidentifiable dolphin	acoustically	8.44818	-56.95473	2475	2	500	not firing	not firing	500	none	0:03	0:00
9/8/2017		5	2:35	3:23	Sperm Whale	acoustically	8.3476	-56.85283	2380	2		full power while on survey line	not firing	170	none	0:24	0:00
9/10/2017	6		20:01	20:03	Unidentifiable baleen whale	visually	8.01257	-56.96767	1580	2	5000	not firing	not firing	5500	none	0:00	0:00
9/10/2017	7		20:04	20:09	Pantropical spotted dolphin	visually	8.02806	-56.98444	1284	7	500	not firing	not firing	5300	none	0:00	
9/10/2017		6	3:20	3:56	Unidentifiable dolphin	acoustically	7.77217	-56.76692	1262	10	500	not firing	not firing	100	none	1:36	0:00

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9/10/2017		7	5:12	6:10	Unidentifiable dolphin	acoustically	7.85678	-56.85028	1342	10	500	soft start / ramp-up	full power while on survey line	100	none	0:58	0:00
9/11/2017	8		21:45	21:46	Unidentifiable cetacean	visually	7.97583	-56.99417	1765	3	4000	soft start / ramp-up	soft start / ramp-up	6300	none	0:00	
9/11/2017		8	22:32	22:35	Sperm whale	acoustically	7.92543	-56.9683	1257	1	500	full power while on survey line	full power while on survey line	500	none	0:03	0:00
9/13/2017		9	4:17	6:03	Unidentifiable dolphin	acoustically	8.27893	-56.84552	2228	10	500	full power while on survey line	not firing	50	none	1:16	0:00
9/15/2017		10	0:02	1:04	Unidentifiable dolphin	acoustically	8.45873	-56.9105	2512	5	500	not firing	not firing	500	none	1:02	0:00
9/16/2017	9		15:18	15:28	Pantropical spotted dolphin	visually	8.45187	-56.88697	2506	40	1000	not firing	not firing	458	none	0:12	0:00
9/18/2017	10		13:00	13:01	Unidentifiable baleen whale	visually	8.09393	-56.98663	1735	1	1500	full power while on survey line	full power while on survey line	1550	none	0:00	0:00
9/18/2017		11	6:30	7:18	Unidentifiable dolphin	acoustically	8.37973	-56.86857	2400	5	500	full power while on survey line	not firing	100	none	0:48	0:00
9/20/2017	11		11:08	11:11	Unidentifiable baleen whale	visually	7.77822	-56.95691	737	2	2500	not firing	not firing	2000	none	0:00	0:00
9/20/2017	12		13:26	13:29	Unidentifiable baleen whale	visually	7.86132	-56.87525	1278	1	3200	soft start / ramp-up	soft start / ramp-up	3500	none	0:00	0:00
9/20/2017	13		14:09	14:16	Unidentifiable baleen whale	visually	7.92273	-56.87523	1452	2	2600	full power while on survey line	full power while on survey line	2700	none	0:00	0:00
9/20/2017		12	0:19	0:29	Unidentifiable dolphin	acoustically	8.4589	-56.95043	2496	2	500	not firing	not firing	500	none	0:10	0:00
9/20/2017		13	8:27	8:51	Sperm Whale	acoustically	7.93723	-56.99077	1189	2	2495	full power while on survey line	full power while on survey line	1170	none	0:00	0:00
9/21/2017	14		11:52	12:13	Unidentifiable baleen whale	visually	8.02998	-56.87685	1691	1	2600	full power while on survey line	full power while on survey line	2000	none	0:00	0:00
9/21/2017	15		12:14	12:19	Unidentifiable dolphin	visually	8.06102	-56.8743	1871	20	1700	full power while on survey line	full power while on survey line	700	none	0:00	0:00
9/21/2017	16		18:04	18:32	Melon-headed whale	visually	8.45622	-56.9665	2487	28	100	full power while on survey line	full power while on survey line	400	none	0:28	0:00
9/21/2017	16		18:04	18:32	Pantropical spotted dolphin	visually	8.45622	-56.9665	2487	7	100	full power while on survey line	full power while on survey line	400	none	0:28	0:00
9/21/2017		14	2:48	3:31	Unidentifiable dolphin	acoustically	8.08452	-56.99288	1703	20	500	full power while on survey line	full power while on survey line	50	none	0:43	0:00
9/21/2017		15	22:26	22:45	Unidentifiable dolphin	acoustically	8.162	-56.99533	1868	30	500	full power while on survey line	full power while on survey line	50	none	0:19	0:00
9/22/2017		16	4:15	4:29	Unidentifiable dolphin	acoustically	7.77253	-56.95983	690	3	500	not firing	not firing	500	none	0:14	0:00

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9/25/2017		17	8:24	8:27	Sperm whale	acoustically	8.3831	-57.00433	2328	1	1371	not firing	not firing	1371	none	0:00	0:00
9/27/2017		18	0:05	0:42	Unidentifiable dolphin	acoustically	8.266	-57.00818	1968	10	500	not firing	not firing	50	delayed start of firing	0:37	0:00
9/28/2017		19	8:12	8:16	Unidentifiable dolphin	acoustically	7.70983	-56.9894	118	1	500	not firing	not firing	500	none	0:04	0:00
9/28/2017		20	10:07	10:16	Unidentifiable dolphin	acoustically	7.83188	-57.06582	900	3	500	not firing	not firing	400	delayed start of firing	0:09	0:00
9/28/2017		21	23:07	23:36	Sperm whale	acoustically	8.24057	-56.951	2000	3	1831	full power while on survey line	full power while on survey line	1831	none	0:00	
10/1/2017	17		18:30	18:31	Unidentifiable baleen whale	visually	8.40093	-56.94915	2409	1	2000	not firing	not firing	2350	none	0:00	0:00
10/1/2017		22	9:34	9:57	Sperm whale	acoustically	8.04928	-57.0331	1586	3		full power while on survey line	full power while on survey line	1117	none	0:00	0:00
10/3/2017	18		14:15	14:19	Unidentifiable dolphin	visually	7.90833	-56.87		14	300	not firing	not firing		none	0:00	0:00
10/7/2017	19		9:40	9:44	Unidentifiable dolphin	visually	7.98789	-56.93693	1523	4	250	full power while on survey line	full power while on survey line	707	none	0:00	0:00
10/8/2017	20		19:41	19:55	Unidentifiable dolphin	visually	8.00257	-56.93516	1581	10	3704	full power while on survey line	full power while on survey line	3000	none	0:00	0:00
10/12/2017		23	3:04	3:26	Unidentifiable dolphin	acoustically	8.02967	-57.05088	1510	3	550	full power while on survey line	full power while on survey line	500	none	0:10	0:00
10/12/2017		24	4:31	4:35	Unidentifiable dolphin	acoustically	8.15417	-57.051	1797	2	600	full power while on survey line	full power while on survey line	600	none	0:00	0:00
10/12/2017		25	21:40	21:43	Unidentifiable dolphin	acoustically	7.74563	-57.0136	280	1	500	not firing	not firing	500	none	0:03	0:00
10/12/2017		26	22:19	22:22	Unidentifiable dolphin	acoustically	7.78722	-57.04832	1120	3	500	not firing	not firing	500	none	0:03	0:00
10/13/2017		27	7:35	8:03	Unidentifiable dolphin	acoustically	8.49767	-57.05133	2500	1	500	not firing	not firing	500	none	0:08	0:00
10/15/2017		28	5:10	5:10	Unidentifiable dolphin	acoustically	8.292	-57.04383	2111	1	500	not firing	not firing	500	none	0:01	0:00
10/15/2017		29	23:54	0:05	Unidentifiable dolphin	acoustically	8.30182	-57.0447	2019	1	500	full power while on survey line	full power while on survey line	500	none	0:10	0:00
10/16/2017		30	4:04	4:15	Unidentifiable dolphin	acoustically	8.443	-56.93133	2482	1	500	full power while on survey line	full power while on survey line	500	none	0:05	0:00
10/17/2017		31	4:54	5:01	Unidentifiable dolphin	acoustically	8.22443	-56.9131	1950	1	500	full power while on survey line	full power while on survey line	500	none	0:07	0:00
10/17/2017		32	23:14	23:47	Unidentifiable dolphin	acoustically	7.7887	-57.04002	481	3	700	not firing	soft start / ramp-up	500	none	0:01	0:00

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10/18/2017	21		21:15	21:27	Unidentifiable dolphin	visually	7.72833	-57.03833		12	80	not firing	soft start / ramp-up	4600	none	0:00	0:00
10/18/2017		33	3:34	3:56	Unidentifiable dolphin	acoustically	8.1229	-57.03967	1928	3	600	full power while on survey line	full power while on survey line	500	none	3:38	0:00
10/18/2017		34	4:26	5:41	Unidentifiable dolphin	acoustically	8.19197	-57.03962	1928	7	700	full power while on survey line	full power while on survey line	500	none	0:22	0:00
10/19/2017		35	23:18	23:30	Unidentifiable dolphin	acoustically	7.76023	-57.02383	425	2	600	not firing	not firing	500	none	0:02	0:00
10/20/2017		36	3:04	4:14	Sperm whale	acoustically	8.04842	-57.03055	1590	6		full power while on survey line	full power while on survey line	2085	none	0:00	0:00
10/23/2017		37	0:31	0:52	Unidentifiable dolphin	acoustically	8.26833	-56.90133	2171	2	43	full power while on survey line	full power while on survey line	500	none	0:07	0:00
10/23/2017		38	8:03	8:27	Unidentifiable dolphin	acoustically	7.74767	-57.00133	366	2	700	not firing	not firing	600	none	0:00	0:00
10/24/2017		39	2:29	2:39	Unidentifiable dolphin	acoustically	8.06845	-56.81348	1867	2	700	not firing	not firing	700	none	0:00	0:00
10/24/2017		40	4:57	6:04	Unidentifiable dolphin	acoustically	8.242	-56.85145	2110	3	700	not firing	not firing	500	none	0:09	0:00
10/24/2017		41	23:16	23:17	Unidentifiable dolphin	acoustically	8.412	-56.898	2433	1	500	not firing	not firing	500	none	0:01	0:00
10/26/2017		42	2:52	3:37	Unidentifiable dolphin	acoustically	8.023	-56.89517	1515	2	500	full power while on survey line	full power while on survey line	500	none	0:04	0:00
10/26/2017		43	8:22	8:26	Unidentifiable dolphin	acoustically	7.81772	-57.01763	725	1	600	not firing	not firing	600	none	0:00	0:00
10/26/2017		44	22:15	22:21	Unidentifiable dolphin	acoustically	8.17433	-56.8925	1999	1	700	full power while on survey line	full power while on survey line	700	none	0:00	0:00
10/27/2017		45	1:07	1:34	Unidentifiable dolphin	acoustically	7.94633	-56.89283	1467	2	600	full power while on survey line	full power while on survey line	500	none	0:05	0:00
10/27/2017		46	8:45	9:10	Unidentifiable dolphin	acoustically	7.96367	-56.93133	893	6	500	not firing	not firing	500	none	0:25	0:00
10/27/2017		47	22:51	23:53	Unidentifiable dolphin	acoustically	8.45695	-56.92297	2506	7	600	not firing	not firing	500	delayed start of firing	0:03	0:00
10/28/2017		48	0:25	0:43	Unidentifiable dolphin	acoustically	8.35117	-56.8905	2334	1	700	full power while on survey line	full power while on survey line	700	none	0:00	0:00
10/28/2017		49	4:36	7:10	Unidentifiable dolphin	acoustically	8.0115	-56.89067	1645	2		full power while on survey line	full power while on survey line	500	none	0:04	0:00
10/28/2017		50	9:12	9:25	Sperm whale	acoustically	7.77783	-57.01117	546	2		not firing	not firing	457	none	0:01	0:00
10/29/2017		51	4:12	5:05	Unidentifiable dolphin	acoustically	7.79633	-56.92083	921	2		not firing	not firing	500	none	0:04	0:00

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10/29/2017		52	5:50	5:56	Unidentifiable dolphin	acoustically	7.78583	-57.011	583	1	600	not firing	not firing	500	none	0:04	0:00
10/29/2017		53	22:16	22:19	Unidentifiable dolphin	acoustically	8.05217	-56.987	1647	4	500	not firing	not firing	500	none	0:03	0:00
10/29/2017		54	23:37	23:38	Unidentifiable dolphin	acoustically	7.92683	-56.98383	1252	2	500	soft start / ramp-up	soft start / ramp-up	500	none	0:01	0:00
10/30/2017	22	56	8:57	9:44	Pantropical spotted dolphin	visually and acoustically	8.19767	-56.93617	2010	6	600	not firing	not firing	390	none	0:13	0:00
10/30/2017	23		10:14	10:17	Sperm whale	visually	8.1494	-56.99562	1856	2	3000	not firing	not firing	2457	none	0:00	0:00
10/30/2017	24	57	10:33	11:18	Sperm whale	visually and acoustically	8.12433	-56.99517	1787	3		soft start / ramp-up	full power while on survey line	3457	none	0:00	0:00
10/30/2017		55	7:10	7:27	Unidentifiable dolphin	acoustically	8.061	-56.37367	1775	2	700	not firing	not firing	700	none	0:00	0:00
10/31/2017	25		12:22	12:27	Common bottlenose dolphin	visually	8.02108	-57.03805	1528	15	200	full power while on survey line	full power while on survey line	745	none	0:00	0:00
10/31/2017		58	0:12	0:43	Sperm whale	acoustically	8.30353	-56.98632	2150	4		not firing	soft start / ramp-up	551	none	0:00	0:00
10/31/2017		59	1:14	1:25	Sperm whale	acoustically	8.2245	-56.98567	2009	2	1277	full power while on survey line	full power while on survey line	939	none	0:00	0:00
10/31/2017		60	5:19	5:20	Unidentifiable dolphin	acoustically	7.9305	-56.98583	1266	1	1266	full power while on survey line	full power while on survey line	500	none	0:01	0:00
10/31/2017		61	7:41	8:00	Unidentifiable dolphin	acoustically	7.768	-56.95683	673	1		not firing	not firing	800	none	0:00	0:00
10/31/2017		62	8:37	8:43	Unidentifiable dolphin	acoustically	7.74383	-57.0255	208	2		not firing	not firing	500	none	0:08	0:00
10/31/2017		63	23:15	23:43	Unidentifiable dolphin	acoustically	8.23333	-57.05417	1976	8		not firing	other reduced power firing	500	none	0:04	0:00
11/1/2017		64	2:02	2:18	Unidentifiable dolphin	acoustically	8.29267	-56.932	2206	2	700	not firing	not firing	700	none	0:00	0:00
11/1/2017		65	23:55	0:21	Unidentifiable dolphin	acoustically	8.2281	-56.9726	2024	2	700	full power while on survey line	full power while on survey line	500	none	0:02	0:00
11/2/2017		66	6:43	7:00	Unidentifiable dolphin	acoustically	7.76003	-56.86128	1040	1	800	not firing	not firing	700	none	0:00	0:00
11/3/2017		67	5:50	6:25	Unidentifiable dolphin	acoustically	8.2635	-57.13817	1935	1	700	not firing	not firing	700	none	0:00	0:00
11/3/2017		68	6:50	6:54	Unidentifiable dolphin	acoustically	8.18317	-57.141	1935	1	800	not firing	not firing	800	none	0:00	0:00
11/3/2017		69	7:50	8:07	Unidentifiable dolphin	acoustically	8.11333	-57.1435	1522	1	800	not firing	not firing	800	none	0:00	0:00
11/3/2017		70	23:39	23:41	Unidentifiable dolphin	acoustically	8.0225	-57.18583	1178	1	800	not firing	not firing	800	none	0:00	0:00

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11/4/2017		71	22:11	22:31	Unidentifiable dolphin	acoustically	7.9735	-56.762	1802	2	700	not firing	not firing	700	none	0:00	0:00
11/5/2017		72	3:28	4:11	Unidentifiable dolphin	acoustically	7.94667	-57.15633	897	1	800	not firing	not firing	700	none	0:00	0:00
11/7/2017		73	6:22	6:35	Unidentifiable dolphin	acoustically	8.03172	-56.7118	1926	2	500	not firing	not firing	500	none	0:13	0:00
11/7/2017		74	6:49	6:56	Unidentifiable dolphin	acoustically	8.0032	-56.71457	1926	2	500	not firing	not firing	500	none	0:07	0:00
11/8/2017		75	5:44	5:47	Unidentifiable dolphin	acoustically	8.0171	-57.06062	1502	1	600	not firing	soft start / ramp-up	600	none	0:00	0:00
11/9/2017		76	2:30	3:05	Unidentifiable dolphin	acoustically	7.991	-56.7115	1880	1		not firing	not firing	700	none	0:00	0:00
11/9/2017		77	2:46	3:12	Sperm whale	acoustically	8.01867	-56.71867	1910	3		not firing	not firing	588	none	0:00	0:00
11/9/2017		78	3:36	4:03	Unidentifiable dolphin	acoustically	8.03067	-56.79383	1910	2	700	not firing	not firing	700	none	0:00	0:00
11/9/2017		79	3:49	3:52	Sperm whale	acoustically	8.03148	-56.7864	1910	1		not firing	not firing	1324	none	0:00	0:00
11/9/2017		80	6:08	6:35	Unidentifiable dolphin	acoustically	8.03017	-56.97417	1605	4	700	full power while on survey line	full power while on survey line	500	none	0:07	0:00
11/10/2017		81	23:02	23:47	Unidentifiable dolphin	acoustically	8.03033	-56.72217	1901	3	700	not firing	not firing	600	none	0:00	0:00
11/11/2017		82	20:32	20:40	Unidentifiable dolphin	acoustically	7.9975	-57.15717	1103	1	800	not firing	not firing	800	none	0:00	0:00
11/12/2017		83	4:57	5:00	Unidentifiable dolphin	acoustically	8.04767	-56.77482	1807	1	800	not firing	not firing	700	none	0:00	0:00
11/12/2017		84	8:24	9:02	Unidentifiable dolphin	acoustically	8.04217	-57.05917	1504	3	700	full power while on survey line	not firing	500	none	0:01	0:00
11/12/2017		85	22:43	23:01	Unidentifiable dolphin	acoustically	8.044	-56.9955	1564	3		full power while on survey line	full power while on survey line	500	none	0:11	0:00
11/12/2017		86	23:36	23:59	Unidentifiable dolphin	acoustically	8.04398	-57.06372	1564	1		full power while on survey line	not firing	800	none	0:00	0:00
11/13/2017		87	4:34	4:36	Unidentifiable dolphin	acoustically	8.02817	-57.0275	1515	1		full power while not on survey line	full power while on survey line	800	none	0:00	0:00
11/14/2017	26		11:59	12:15	Pantropical spotted dolphin	visually	7.755	-57.06333		11	350			9445	none	0:00	0:00
11/14/2017		88	3:01	3:21	Unidentifiable dolphin	acoustically	7.7455	-57.05517	199	3		not firing	not firing	500	none	0:18	0:00
11/14/2017		89	6:12	6:16	Unidentifiable dolphin	acoustically	7.9585	-56.99533	1335	3	500	full power while on survey line	full power while on survey line	500	none	0:04	0:00
11/14/2017		90	8:14	9:07	Unidentifiable dolphin	acoustically	8.09467	-57.028	1689	3	700	not firing	not firing	600	none	0:00	0:00

Date	Visual Det. #	Acoustic Det. #	Time at Initial Det.	Time at Last Det.	Common Name	Detection Method	Latitude	Longitude	Water Depth (m)	No. of Animals	Range when First Detected	Source Activity at First Det.	Source Activity at Last Det.	Closest distance to source (m)	Mitigation Actions	Total Duration Animals Observed inside EZ	Total Duration of Production Loss
11/14/2017		91	23:21	0:07	Unidentifiable dolphin	acoustically	7.7905	-57.082	265	7		not firing	not firing	500	none	0:25	0:00
11/15/2017		92	0:56	0:58	Unidentifiable dolphin	acoustically	7.76433	-56.99783	513	1		not firing	not firing	600	none	0:00	0:00
11/15/2017		93	21:48	21:54	Unidentifiable dolphin	acoustically	7.74783	-57.01167	317	1	800	not firing	not firing	700	none	0:00	0:00
11/15/2017		94	22:23	23:13	Unidentifiable dolphin	acoustically	7.79963	-56.98635	747	1	800	not firing	soft start / ramp-up	600	none	0:00	0:00
11/17/2017		95	6:12	6:15	Unidentifiable dolphin	acoustically	7.76308	-56.91077	873	1	500	not firing	not firing	500	none	0:03	0:00
11/18/2017		96	2:27	2:29	Unidentifiable dolphin	acoustically	7.76083	-56.83267	1067	2	500	not firing	not firing	500	none	0:01	0:00
11/18/2017		97	3:30	3:33	Unidentifiable dolphin	acoustically	7.75485	-56.89908	894	1	500	not firing	not firing	500	none	0:03	0:00
11/18/2017		98	23:29	0:10	Unidentifiable dolphin	acoustically	7.83517	-56.81917	1351	2	700	not firing	not firing	500	none	0:07	0:00
11/19/2017		99	1:36	2:25	Unidentifiable dolphin	acoustically	7.74633	-56.88083	841	1	700	not firing	not firing	600	none	0:00	0:00
11/19/2017		100	5:36	5:37	Unidentifiable dolphin	acoustically	8.07083	-56.9055	1860	1	500	not firing	not firing	500	none	0:01	0:00
Liza Environmental Baseline Survey 1																	
9/29/2017	1		12:45	12:47	Unidentifiable dolphin	visually	07.26283	-057.26028	46.6	1	2	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
9/29/2017	2		14:15	14:17	Atlantic spotted dolphin	visually	07.26136	-057.26296	45.2	4	4	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
9/29/2017	3		22:30	00:00	Atlantic spotted dolphin	visually	07.64345	-057.24711	67.2	2	0	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
9/30/2017	4		19:42	19:55	Unidentifiable dolphin	visually	07.81915	-057.15633	162	3	700	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
10/1/2017	5		16:36	16:49	Common bottlenose dolphin	visually	07.62450	-057.25498	65	5	0	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
10/1/2017	6		16:36	16:38	Olive Ridley sea turtle	visually	07.62450	-057.25498	65	1	100	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
10/1/2017	7		19:15	19:17	Olive Ridley sea turtle	visually	07.50777	-057.38413	52.4	1	1000	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
10/1/2017	8		20:30	20:33	Unidentifiable dolphin	visually	07.44005	-057.38138	48	3	20	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
10/1/2017	9		20:44	20:45	Unidentifiable dolphin	visually	07.45005	-057.39138	48	1	600	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Liza Environmental Baseline Survey 2																	
10/19/2017	1		17:28	17:28	Unidentifiable shelled sea turtle	visually	08.30600	-057.17487		1	30	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*

Date	Visual Det. #	Acoustic Det. #	Time at Initial Det.	Time at Last Det.	Common Name	Detection Method	Latitude	Longitude	Water Depth (m)	No. of Animals	Range when First Detected	Source Activity at First Det.	Source Activity at Last Det.	Closest distance to source (m)	Mitigation Actions	Total Duration Animals Observed inside EZ	Total Duration of Production Loss
10/25/2017	2		11:18	11:42	Spinner dolphin	visually	08.05863	-056.96165		28	1500	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
10/26/2017	3		14:05	14:17	Common bottlenose dolphin	visually	07.61417	-057.19278	60	2	100	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
10/26/2017	4		14:27	14:38	Common bottlenose dolphin	visually	07.59158	-057.21527	60	12	150	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
10/26/2017	5		16:14	16:27	Atlantic spotted dolphin	visually	07.50732	-057.32793	55	7	800	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Liza Environmental Baseline Survey 3																	
11/1/2017	1		12:10	12:12	Unidentifiable dolphin	visually	07.50599	-057.16044	61.3	2	1	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/1/2017	2		12:20	12:21	Unidentifiable shelled sea turtle	visually	07.50843	-057.15608	60.5	1	600	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/1/2017	3		18:05	18:10	Common bottlenose dolphin	visually	07.43211	-057.24410	51.6	7	50	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/1/2017	4		19:05	19:25	Common bottlenose dolphin	visually	07.45852	-057.32741	51.4	5	3	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/1/2017	5		19:55	19:56	Common bottlenose dolphin	visually	07.45933	-057.32983	49.5	1	1	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/1/2017	6		21:23	21:23	Unidentifiable dolphin	visually	07.44255	-057.38391	46.4	1	50	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/2/2017	7		15:33	15:35	Atlantic spotted dolphin	visually	07.43020	-057.38632	47.5	5	1	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/2/2017	8		16:30	16:38	Common dolphin	visually	07.42628	-057.40356	46.1	8	2	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/2/2017	9		18:34	18:37	Risso's dolphin	visually	07.40617	-057.49610	43	5	200	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/3/2017	10		15:07	15:17	Rough-toothed dolphin	visually	07.47187	-057.13001	60.7	20	1	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/3/2017	11		16:45	16:48	Common bottlenose dolphin	visually	07.47187	-057.12994	60.7	5	1	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/5/2017	12		11:46	11:49	Unidentifiable dolphin	visually	07.57563	-057.08816	71.8	2	30	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/5/2017	13		17:45	17:46	Unidentifiable dolphin	visually	07.62660	-057.01930	91.7	1	50	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/5/2017	14		18:00	18:01	Unidentifiable dolphin	visually	07.62906	-057.01673	90.3	1	1	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/6/2017	15		20:40	20:43	Common dolphin	visually	07.59018	-057.27709	64.3	2	10	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/8/2017	16		12:30	12:35	Atlantic spotted dolphin	visually	07.61616	-057.24462	65.8	4	50	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*

Date	Visual Det. #	Acoustic Det. #	Time at Initial Det.	Time at Last Det.	Common Name	Detection Method	Latitude	Longitude	Water Depth (m)	No. of Animals	Range when First Detected	Source Activity at First Det.	Source Activity at Last Det.	Closest distance to source (m)	Mitigation Actions	Total Duration Animals Observed inside EZ	Total Duration of Production Loss
11/8/2017	17		20:11	20:13	Atlantic spotted dolphin	visually	07.01225	-057.76667	21.7	10	3	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/17/2017	18		19:43	19:48	Atlantic spotted dolphin	visually	07.47035	-057.08017	121	4	1	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
11/18/2017	19		21:17	21:34	Common dolphin	visually	08.02760	-057.06590	750	10	3	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Liza Environmental Baseline Survey 4																	
3/27/2018	1		16:00	16:28	Common bottlenose dolphin	visually	07.79056	-057.09028		6	50	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
3/28/2018	2		10:05	10:22	Pantropical spotted dolphin	visually	07.64250	-057.28694	65	3	30	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
3/29/2018	3		10:28	10:43	Common bottlenose dolphin	visually	07.26472	-057.26242	56	5	5	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
4/4/2018	4		18:57	18:58	Unidentifiable dolphin	visually	07.57360	-057.31060	59	2	40	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
4/10/2018	5		16:50	16:51	Unidentifiable dolphin	visually	07.64466	-056.65962		1	50	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
4/12/2018	6		21:23	21:57	Pantropical spotted dolphin	visually	07.67139	-057.32306	66	10	50	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
4/14/2018	7		13:09	13:15	Pantropical spotted dolphin	visually	07.49426	-057.27362	57	2	2	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
4/15/2018	8		20:56	20:58	Pantropical spotted dolphin	visually	07.80417	-057.16944	125	3	30	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*

APPENDIX N

List of Marine Fishes in Guyana

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Scientific Name
Acanthurus hepatus
Alutera monoceros
Alutera schoepfi
Alutera ventralis
Amphiarius phrygiatus
Amphiarius rugispinis
Anchoa spinifer
Anchoviella lepidentostole
Anisotremus virginicus
Antennarius scaber
Antigonia capros
Aspistor quadriscutis
Bagre bagre
Balistes carolinensis
Balistes vetula
Bathystoma aurolineatum
Bathystoma rimator
Bathystoma striatum
Bellator militaris
Bodianus sp.
Bothus sp.
Brachyplatystoma vaillantii
Calamus proridens
Carcharhinus brevipinna
Caulolatilus guppyi
Chaetodon bimaculatus
Chaetodon sp.
Carcharhinus acronatus
Cathorops arenatus
Cathorops melanopus
Coloconger meadi
Cathorops aurenatus
Cathorops melanopus
Centropomus ensiferus
Centropomus pectinatus
Chloroscombrus chrysurus
Colomesus psitacus
Coryphaena hippurus
Cryptomus sp.
Cubiceps sp.
Cyclopsetta fimbriata
Cynoscion acoupa
Cynoscion nothus
Cynoscion steindachneri
Dactylopterus volitans
Decapterus punctatus
Decapturus macarellus
Diplectrum formosum
Diplectrum radiale
Diplectrum sp.
Elops saurus
Eqeus lanceolatus

Scientific Name
Eucinostomus gula
Fistularia petimba
Genyatremus luteus
Gobionellus sp
Gymnachirus sp.
Gymnothorax ocellatus
Haemulon melanurum
Haemulon sciurus
Haemulon steindachneri
Halichoeres sp.
Halieutichthys sp.
Hippocampus longirostris
Holocanthus tricolor
Holocentrus ascensionis
Holocentrus bullisi
Hoplias malabaricus
Hypopthalmus edentatus
Lactophrys tricornis
Larimus breviceps
Lobotes surinamensis
Lonchurus elegans
Lutjanus analis
Lutjanus aya
Lutjanus spp.
Lutjanus synagris
Macrodom anciclos
Macrodon ancylodon
Micropogonias furnieri
Monocanthus ciliatus
Monocanthus hispidus
Mugil incilis
Mullus sp.
Mustelus sp.
Myxine c.f. robinsorum
Nebris microps
Ocyurus p.
Odontognathus mucronatus
Ogocephalus vespertilio
Plagioscion squamosissimus
Plagioscion surinamensis
Polydactylus oligodon
Pomacanthus arcuatus
Pomacanthus paru
Priacanthus arenatus
Prionodes phoebe
Prionotus sp.
Psenes sp.
Pseudauchenipterus nodosus
Remora brachyptera
Rhinobatos percellens
Rhomboplites aurorubens
Rypticus sp.

Scientific Name
Saurida sp.
Schedophilus sp.
Sciades couma
Scoliodon sp.
Scoliodon terrae-novae
Scomberomorus cavalla
Scorpaena agassizii
Scorpaena brasiliensis
Scorpaena plumieri
Scorpaena sp.
Selar crumenophthalmus
Spariosoma aqualidum
Sphoeroides dorsalis
Sphoeroides marmoratus
Sphyraena guachancho
Stellifer microps
Stellifer rastrifer
Syacium papillosum
Symphurus tessellatus
Synodus foetens
Synodus intermedius
Synodus poeyi
Trachinocephalus myops
Trachurus lathami
Upeneus maculatus
Trichiurus lepturus
Trinectes paulistanus
Upeneus parvus

Sources:

Environmental Resources Management. 2018. Nearshore and Offshore Fisheries Study Summary Report. May 2018.

Lowe-McConnell, R.H. 1962. The fishes of the British Guiana continental shelf, Atlantic coast of South America, with notes on their natural history. J.Linn. Soc. Lond. (Zool.), 44: 669-700

APPENDIX O

Traffic Impact Assessment

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ESSO EXPLORATION AND PRODUCTION GUYANA, LIMITED (EEPGL)

Liza Phase 2 Development Project

TRAFFIC IMPACT ASSESSMENT



CARITRANS

APRIL, 2018

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Introduction

Caribbean Transportation Consultancy Services (CARITRANS) Company Limited was contracted by Environmental Resources Management (ERM) to undertake a Traffic Impact Assessment (TIA) along the East Bank Public Road, Guyana, around the vicinity of the shorebase facility planned for use in support of Esso Exploration and Production Guyana, Limited's (EEPGL's) proposed Liza Phase 2 Development Project ("Phase 2 Project"). There is expected on-shore trip generation associated with the Phase 2 Project's use of the shorebase facility (study area shown in Figure 1). The TIA is intended to support the required Environmental Impact Assessment (EIA) for the Phase 2 Project.

The TIA involves the analysis and assessment of the impact of the Phase 2 Project on the surrounding road network, under scenarios with the existing Demerara Harbour Bridge and the proposed Demerara Harbour Bridge.



Figure 1: Location Map

The study area runs along the East Bank Public Road bounded by Mandela Avenue to the north and the Providence Cricket Stadium to the South.

Background

On a typical weekday, the East Bank Public Road experiences heavy traffic in the northbound (towards Georgetown) and southbound (from Georgetown) directions, during the AM and PM peak hours, respectively. This traffic pattern is attributed to work and school trips from residential areas south and west of Georgetown.

In an attempt to reduce delays experienced by the dominant movements along the East Bank Public Road during the AM and PM peak hours, the following traffic management measures have been instituted:

1. Closing of the Demerara Harbour Bridge during a specific time during the morning peak hours to westbound traffic on weekdays to facilitate an additional lane along the bridge for the eastbound direction.
2. Closing of the Demerara Harbour Bridge during a specific time during the afternoon peak hours to eastbound traffic to facilitate an additional lane along the bridge for the westbound direction.
3. Managed lane scenarios for the morning and afternoon periods where an additional lane will be permitted in the peak direction, allowing for three lanes to accommodate the additional demand.
4. During the times indicated for measures one (1) and three (3) above, traffic warden assistance with the direction of traffic where the East Bank Public Road intersected with Mandela Road and the Demerara Harbour Bridge.

In addition to these measures taken (above), in March 2018 the Ministry of Public Infrastructure, Guyana released the feasibility study (“GGFD-R-014”), dated August 2017, for the new Demerara Harbour Bridge to be located at Houston-Versailles. The new bridge location was provided via diagram in the report as seen below.

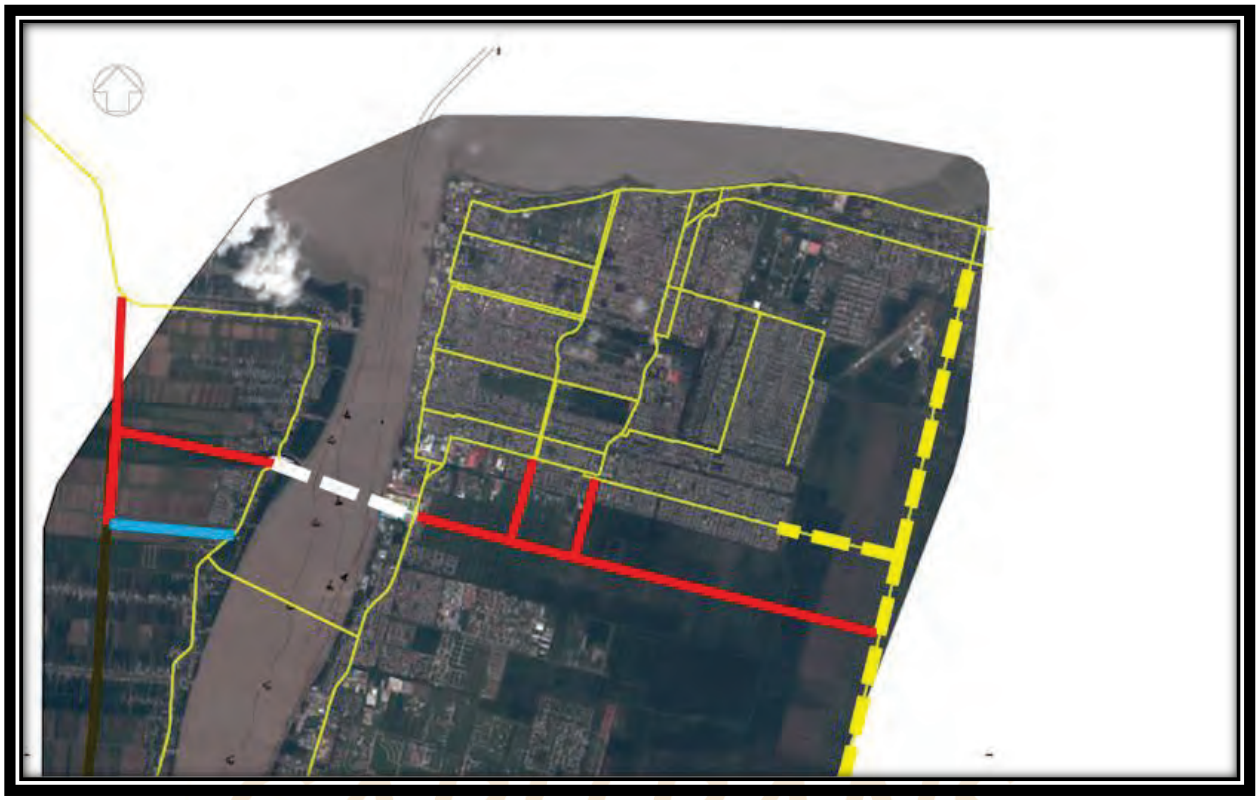


Figure 2: New Bridge Location (White dashed line)
(Image: Feasibility Study New Demerara Bridge GGFD-R-014)

The planned installation of a new Demerara Harbour Bridge is also accompanied by planned bypass routes that include a link from south of Great Diamond to East of the Ogle International Airport (Figure 3).



Figure 3: Bypass Route (Blue)

Methodology

The first step in assessing the Phase 2 Project's impact on the existing road network was to establish the base or current year operating conditions. This was done by undertaking five (5) Turning Movement Counts (TMCs) and two (2) Average Daily Traffic (ADT) Counts along the East Bank Public Road. The ADT counts were undertaken to establish control points for the surveys and to calibrate the TMCs if deemed necessary.

The TMCs were performed at the following intersections (Figure 4):

- East Bank Public Road at Houston Split
- East Bank Public Road at Eccles Intersection
- East Bank Public Road at the Demerara Harbour Bridge
- East Bank Public Road at Nandy Park Intersection
- East Bank Public Road at Massy Intersection

The ADT Counts were performed at the following locations (Figure 4):

- East Bank Public Road at Houston
- East Bank Public Road at Providence



Figure 4: Count Locations

Following the collection of the data, a model was developed using VISSIM microsimulation software to analyze typical scenarios such as the AM Peak, PM Peak and closed Demerara Harbour Bridge for the Existing and New Demerara Harbour Bridge scenarios. The traffic to be generated from the Phase 2 Project was considered via two (2) sources:

1. Expected traffic as reported by the client
2. Expected traffic as estimated via the ITE Trip Generation Rates Manual (TGM) 9th Edition

The combined traffic from the existing conditions and the Phase 2 Project traffic was then evaluated for a current year scenario and a future scenario (2023).

Existing Traffic Conditions

The Five (5) 16-hour TMCs were performed on Thursday 15th and Friday 16th March 2018 from 6:00am to 10:00pm.

The following tables (1-10) summarize the AM and PM Peak Hour volume data collected at the study locations.

Table 1: Intersection A.M. Peak Hour Count - East Bank Public Road at Houston Split (15/03/18)

Time Period	Northbound (Left)					Northbound (Through)					Southbound					Total
	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	
7:30 AM - 7:45 AM	22	0	0	542	0	28	0	457	0	1	17	0	199	0	0	1266
7:45 AM - 8:00 AM	2	0	0	474	0	5	0	466	0	0	14	0	178	0	0	1139
8:00 AM - 8:15 AM	21	0	0	479	0	13	0	542	0	1	52	0	206	0	0	1314
8:15AM - 8:30 AM	11	0	0	444	0	31	0	416	0	2	54	0	647	0	0	1605
TOTAL	56	0	0	1939	0	77	0	1881	0	4	137	0	1230	0	0	5324

Table 2: Intersection P.M. Peak Hour Count - East Bank Public Road at Houston Split (15/03/18)

Time Period	Northbound					Southbound					Eastbound					Total
	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	
4:30 PM - 4:45 PM	7	0	0	233	0	27	0	222	0	2	46	0	520	0	0	1057
4:45 PM - 5:00 PM	25	0	0	325	0	18	0	253	0	2	55	0	537	0	1	1216
5:00 PM - 5:15 PM	14	0	0	258	0	22	0	220	0	0	53	0	591	0	2	1160
5:15 PM - 5:30 PM	9	0	0	236	0	23	0	189	0	0	40	0	553	0	1	1051
TOTAL	55	0	0	1052	0	90	0	884	0	4	194	0	2201	0	4	4484

Table 3: Intersection A.M. Peak Hour Count - East Bank Public Road at Eccles Intersection (15/03/18)

Time Period	Northbound					Southbound					Westbound					Total
	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	
7:00 AM - 7:15 AM	12	6	605	0	0	12	0	196	21	0	0	90	0	6	0	948
7:15 AM - 7:30 AM	15	8	569	0	0	4	0	176	25	0	0	93	0	10	0	900
7:30 AM - 7:45 AM	19	5	588	0	0	9	0	201	23	0	0	86	0	2	0	933
7:45 AM - 8:00 AM	18	6	544	0	0	10	0	173	23	0	0	67	0	5	0	846
TOTAL	64	25	2306	0	0	35	0	746	92	0	0	336	0	23	0	3627

Table 4: Intersection P.M. Peak Hour Count- East Bank Public Road at Eccles Intersection (15/03/18)

Time Period	Northbound					Southbound					Westbound					Total
	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	
4:15 PM - 4:30 PM	11	6	280	0	0	21	0	443	26	0	0	47	0	17	0	851
4:30 PM - 4:45 PM	12	3	259	0	0	18	0	442	21	0	3	48	0	12	0	818
4:45 PM - 5:00 PM	8	6	246	0	0	9	0	453	20	0	0	43	0	19	0	804
5:00 PM - 5:15 PM	6	3	285	0	0	21	0	439	39	1	0	47	0	14	0	855
TOTAL	37	18	1070	0	0	69	0	1777	106	1	3	185	0	62	0	3328

Table 5: Intersection A.M. Peak Hour Count - East Bank Public Road at the Demerara Harbour Bridge (15/03/18)

Time Period	Northbound					Southbound					Eastbound					Total
	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	
6:30 AM - 6:45 AM	4	0	355	16	0	2	47	98	0	0	43	42	0	153	0	760
6:45AM - 7:00 AM	2	0	298	16	0	2	23	126	0	0	18	32	0	215	0	732
7:00 AM - 7:15 AM	2	0	167	11	0	1	5	137	0	0	22	20	0	233	0	598
7:15 AM - 7:30 AM	5	0	234	23	0	1	7	126	0	0	14	30	0	222	0	662
TOTAL	13	0	1054	66	0	6	82	487	0	0	97	124	0	823	0	2752

Table 6: Intersection P.M. Peak Hour Count - East Bank Public Road at the Demerara Harbour Bridge (15/03/18)

Time Period	Northbound					Southbound					Eastbound					Total
	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	
1:15 PM - 1:30 PM	4	0	211	23	0	4	80	214	0	0	7	31	0	87	0	661
1:30 PM - 1:45 PM	6	0	221	23	0	3	91	218	0	0	6	34	0	95	0	697
1:45 PM - 2:00 PM	3	0	225	24	0	2	97	218	0	0	9	34	0	91	0	703
2:00 PM - 2:15 PM	1	0	235	21	0	3	107	224	0	0	12	15	0	30	0	648
TOTAL	14	0	892	91	0	12	375	874	0	0	34	114	0	303	0	2709

Table 7: Intersection A.M. Peak Hour Count - East Bank Public Road at Nandy Park Intersection (16/03/18)

Time Period	Northbound					Southbound					Westbound					Total
	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	
7:00 AM - 7:15 AM	23	17	437	0	0	18	0	188	4	19	1	8	0	5	0	720
7:15 AM - 7:30 AM	28	24	336	0	0	23	0	193	3	18	0	4	0	2	0	631
7:30 AM - 7:45 AM	34	28	337	0	0	30	0	210	2	18	2	3	0	12	0	676
7:45 AM - 8:00 AM	29	32	332	0	0	28	0	196	4	20	0	2	0	8	0	651
TOTAL	114	101	1442	0	0	99	0	787	13	75	3	17	0	27	0	2678

Table 8: Intersection P.M. Peak Hour Count - East Bank Public Road at Nandy Park Intersection (16/03/18)

Time Period	Northbound					Southbound					Westbound					Total
	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	
1:45 PM - 2:00 PM	10	11	262	0	0	12	0	256	7	18	2	7	0	13	0	598
2:00 PM - 2:15 PM	10	10	246	0	0	8	0	270	6	22	0	4	0	10	0	586
2:15 PM - 2:30 PM	11	15	205	0	0	9	0	254	5	21	0	5	0	8	0	533
2:30 PM - 2:45 PM	12	14	248	0	0	14	0	258	6	20	1	7	0	12	0	592
TOTAL	43	50	961	0	0	43	0	1038	24	81	3	23	0	43	0	2309

Table 9: Intersection A.M. Peak Hour Count - East Bank Public Road at Massey Intersection (15/03/18)

Time Period	Northbound					Southbound					Westbound					Total
	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	
6:45AM - 7:00 AM	17	3	381	0	4	26	0	204	11	0	1	14	0	5	1	667
7:00 AM - 7:15 AM	18	4	509	0	4	18	0	183	15	0	3	14	0	7	2	777
7:15 AM - 7:30 AM	27	9	432	0	4	21	0	213	16	0	1	14	0	4	2	743
7:30 AM - 7:45 AM	32	22	325	0	2	33	0	187	31	0	2	16	0	12	1	663
TOTAL	94	38	1647	0	14	98	0	787	73	0	7	58	0	28	6	2850

Table 10: Intersection P.M. Peak Hour Count - East Bank Public Road at Massey Intersection (15/03/18)

Time Period	Northbound					Southbound					Westbound					Total
	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	Bikes	Right	Through	Left	U-Turn	
6:45 PM - 7:00 PM	7	24	224	0	3	2	0	297	39	0	1	13	0	18	1	628
7:00 PM - 7:15 PM	5	19	193	0	2	3	0	262	35	1	1	19	0	18	2	558
7:15 PM - 7:30 PM	7	17	170	0	5	8	0	284	38	0	2	15	0	12	0	558
7:30 PM - 7:45 PM	7	10	187	0	0	7	0	255	21	0	2	12	0	14	2	515
TOTAL	26	70	774	0	10	20	0	1098	133	1	6	59	0	62	5	2259

The following tables (11-12) summarize the Bi-directional 7-day ADT counts at the study locations:

Table 11: Bi-directional Average Daily Traffic Count Data – East Bank Public Road at Houston Village

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	19/03/2018	20/03/2018	21/03/2018	15/03/2018	16/03/2018	17/03/2018	18/03/2018
0 - 1	931	658	750	589	904	1281	823
1 - 2	651	476	581	636	694	980	722
2 - 3	543	413	360	441	503	745	662
3 - 4	469	363	438	372	431	685	711
4 - 5	568	549	542	441	655	759	745
5 - 6	840	958	897	823	619	910	679
6 - 7	1735	1953	1805	2061	2083	1592	1345
7 - 8	4000	3751	3200	3784	3791	2849	2306
8 - 9	3699	3606	2874	3574	3492	3153	2517
9 - 10	3252	3259	2740	3066	3116	3395	2590
10 - 11	2835	3077	2821	3021	3060	3280	2611
11 - 12	2993	3056	2660	2551	2968	3028	2554
12 - 13	3136	3077	2902	3007	3094	3024	2463
13 - 14	3066	3125	3030	3070	3081	3233	2716
14 - 15	3109	3045	3179	3108	3093	2995	2738
15 - 16	3084	3048	3109	2867	3009	3114	2542
16 - 17	3242	3048	3041	3055	2603	3109	2548
17 - 18	3135	3140	3062	2950	1866	3066	2724
18 - 19	3046	2832	2815	2906	2358	3030	2890
19 - 20	2829	2794	2625	2999	3107	3069	2925
20 - 21	2331	2576	2563	2562	2946	2953	2799
21 - 22	1827	2205	2100	2299	2614	2566	2408
22 - 23	1613	1499	1744	1737	2177	2275	1854
23 - 24	987	1081	1085	787	1805	1694	1425
Totals	53922	53589	50925	52707	54068	56783	48297

Table 12: Bi-directional Average Daily Traffic Count Data – East Bank Public Road at Providence Village

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	19/03/2018	20/03/2018	21/03/2018	15/03/2018	16/03/2018	17/03/2018	18/03/2018
0 - 1	512	403	467	491	529	692	780
1 - 2	308	265	290	338	394	438	564
2 - 3	212	194	208	218	272	344	390
3 - 4	260	247	226	204	277	340	376
4 - 5	276	278	299	244	336	344	364
5 - 6	372	478	456	359	362	442	354
6 - 7	767	799	791	836	786	726	559
7 - 8	2060	2189	1696	2042	2000	1434	1111
8 - 9	2243	2221	1903	2189	2197	1848	1375
9 - 10	2104	2129	1855	2166	2179	2158	1504
10 - 11	1900	1922	1616	1783	1942	2088	1616
11 - 12	1819	1765	1654	1816	1852	1963	1486
12 - 13	1919	1783	1670	1830	1849	1914	1463
13 - 14	1817	1891	1696	1800	1799	1890	1595
14 - 15	1878	1877	1774	1871	1954	1909	1642
15 - 16	1955	1932	1826	1895	2057	1931	1580
16 - 17	2029	1976	1892	1986	1880	1760	1554
17 - 18	2173	2237	2168	2148	1838	1786	1549
18 - 19	2207	2196	2090	2238	2165	1900	1668
19 - 20	1847	1774	1787	1884	1758	2006	1865
20 - 21	1675	1532	1495	1645	1949	1940	1693
21 - 22	1382	1274	1326	1295	1541	1590	1472
22 - 23	943	906	1008	1025	1217	1325	1084
23 - 24	676	574	653	629	1004	1040	856
Totals	33335	32844	30846	32932	34138	33809	28499

Phase 2 Project Build Conditions

Table 13 summarizes the traffic (2020 to 2023) expected to be generated by the Phase 2 Project and for the Phase 2 Project together with other planned EEPGL projects (indicated as "Cumulative" in the table).

Table 13: Expected Trip Generation for Phase 2 Project

Projected Years	2020				2021			
Development Trip Generation Totals	Light Vehicles		Heavy Vehicles		Light Vehicles		Heavy Vehicles	
	to/from North	to/from South	to/from North	to/from South	to/from North	to/from South	to/from North	to/from South
Phase 2	8	4	2	4	8	4	2	4
Cumulative	20	12	4	8	20	12	4	8
Projected Years	**2022**				**2023**			
Development Trip Generation Totals	Light Vehicles		Heavy Vehicles		Light Vehicles		Heavy Vehicles	
	to/from North	to/from South	to/from North	to/from South	to/from North	to/from South	to/from North	to/from South
Phase 2	8	4	2	4	8	4	2	4
Cumulative	20	12	4	8	20	12	4	8

Source: ERM 2018

Please note that these tables display the estimated total trip generation volumes for the development, sourced from projections provided by ERM.

Capacity and Level of Service analysis

Design Traffic flows

This section describes the results and conclusions of the VISSIM analysis performed, with particular reference to the Level of Service (LOS) for Peak AM and Peak PM periods.

CARITRANS applied the traffic analysis model VISSIM to estimate the LOS for each intersection in the study area. Analyses were done for several scenarios to represent development as expected based on data derived from TMCs and ADT counts performed. These included the estimated number of trips generated by the Phase 2 Project (see section "Phase 2 Project Build Conditions" above), the expected new Demerara Harbour Bridge (according to the "Feasibility Study New Demerara Bridge GGFD-R-014" release), and the projected (non-Project related) increase in traffic volumes over the next five (5) years.

The following scenarios were modelled using the VISSIM microsimulation software:

1. Existing Conditions – AM Peak (WB approach on the Demerara Harbour Bridge closed), PM Peak (EB approach on the Demerara Bridge closed), Demerara Bridge both approaches closed.
2. Existing Conditions with the inclusion of Phase 2 Project traffic – AM Peak (WB approach on the Demerara Harbour Bridge closed), PM Peak (EB approach on the Demerara Bridge closed), Demerara Bridge both approaches closed.

3. Proposed New Demerara Bridge and bypass lanes, which connect East of Georgetown to Great Diamond – AM Peak, PM Peak, Bridge closed.
4. Five-year projections at a traffic growth rate of 5% per annum[1].

[1] The Feasibility Study and Design for the New Demerara River Crossing, Final Report; Doc. No. GGFD-R-014 (Lievense CSO Engineering Contracting B.V., 2017 projects a 5% per annum growth rate based on historical growth over the past decade.

2018 Traffic Conditions

Table 14: Existing Network 2018 – AM Peak (1), Existing Network with Phase 2 Traffic 2018 – AM Peak (2), Existing Network with Cumulative Traffic 2018 – AM Peak (3)

Site	Direction	Movement	Q_{95} 1 (m)	Q_{95} 2 (m)	Q_{95} 3 (m)	Delay 1 (s/veh)	Delay 2 (s/veh)	Delay 3 (s/veh)	LOS 1	LOS 2	LOS 3
Massy	NB	Through	48	104	104	3	17	17	A	C	C
		Right	49	105	105	4	10	10	A	A	A
		U-Turn	49	105	105	7	19	19	A	C	C
	SB	Left	0	0	0	1	1	1	A	A	A
		Through	0	0	0	0	0	0	A	A	A
	WB	Right	9	13	13	10	38	38	A	E	E
		U-Turn	7	10	10	0	0	0	A	A	A
		Left	8	13	13	5	10	10	A	A	A
DHB	DHB (Exit)	Right	147	252	252	79	79	79	F	F	F
		Left	147	251	251	30	36	36	D	D	D
	NB	U-Turn	75	108	108	20	20	20	C	B	B
		Left	66	98	98	9	26	26	A	C	C
		Through	154	184	184	30	36	36	D	D	D
	SB	Through	315	258	258	46	48	48	E	D	D
		Right	317	260	260	68	70	70	E	E	E
		U-Turn	317	260	260	94	88	88	F	F	F
Houston	SB	Through	0	26	26	0	4	4	A	A	A
	NB	Right	462	467	467	42	43	43	E	E	E
		Left	462	466	466	80	80	80	F	F	F
Nandy Park	NB	Through	86	149	149	15	31	31	B	C	C
		Right	92	158	158	27	30	30	D	C	C
	SB	U-Turn	1	1	1	17	12	12	C	B	B
		Through	0	0	0	1	1	1	A	A	A
		Left	1	0	0	1	1	1	A	A	A
	WB	Right	4	5	5	63	43	43	F	E	E
		Left	4	4	4	9	4	4	A	A	A
Eccles	SB	Through	443	448	456	48	55	64	D	B	B
		Left	0	0	0	21	20	21	C	C	C
	NB	Right	125	357	340	144	65	62	F	E	E
		Through	281	7	10	127	21	32	D	D	D
	WB	Left	125	239	269	144	200	302	F	F	F
		Right	138	251	280	153	250	274	F	F	F
Mandela	NB	Through	501	490	493	232	243	247	F	F	F
		Right	501	490	493	233	230	220	F	F	F
		Left	501	490	493	250	264	248	F	F	F
	WB	Right	425	422	416	118	123	142	F	F	F
		Left	439	436	430	137	134	143	F	F	F
		Through	439	436	430	132	134	134	F	F	F
	SB	Through	17	16	16	56	55	55	D	D	D
		Left	22	22	22	53	50	50	D	D	D
	EB	Right	0	0	0	1	0	2	A	A	A
		Through	6	6	7	33	32	37	C	C	C
Base Access	SB	Through	-	97	154	-	17	21	-	C	C
		Right	-	99	155	-	70	41	-	F	F
	EB	Right	-	0	0	-	0	0	-	A	A
		Left	-	0	0	-	0	0	-	A	A
	NB	Left	-	492	487	-	48	29	-	E	E
		Through	-	492	487	-	58	58	-	F	F

*Q_{95} = Queue lengths

Table 15: Existing Network 2018 – PM Peak (1), Existing Network with Phase 2 Traffic 2018 – PM Peak (2), Existing Network with Cumulative Traffic 2018 – PM Peak (3)

Site	Direction	Movement	Q_{95} 1 (m)	Q_{95} 2 (m)	Q_{95} 3 (m)	Delay 1 (s/veh)	Delay 2 (s/veh)	Delay 3 (s/veh)	LOS 1	LOS 2	LOS 3
Massy	NB	Through	0	0	0	0	0	0	A	A	A
		Right	1	0	0	7	4	6	A	A	A
		U-Turn	0	0	0	7	4	7	A	A	A
	SB	Left	0	0	0	2	1	2	A	A	A
		Through	0	0	0	0	0	0	A	A	A
	WB	Right	1	1	1	7	8	10	A	A	A
		U-Turn	0	0	0	1	10	2	A	A	A
		Left	0	1	1	2	5	5	A	A	A
DHB	DHB	Right	148	431	411	24	25	25	C	C	C
		Left	278	426	408	1	1	1	A	A	A
	NB	U-Turn	0	0	0	0	0	0	A	A	A
		Left	6	12	12	21	23	22	C	C	C
		Through	6	12	12	7	11	11	A	B	B
	SB	Through	287	411	414	10	17	15	A	B	B
		Right	294	416	418	211	276	280	F	F	F
		U-Turn	0	0	0	2	0	0	A	A	A
Houston	SB	Through	6	49	52	0	9	9	A	A	A
	NB	Right	0	0	0	0	0	0	A	A	A
		Left	0	0	0	0	0	0	A	A	A
Nandy Park	NB	Through	0	0	0	0	0	0	A	A	A
		Right	1	0	0	14	6	10	B	A	A
	SB	U-Turn	0	0	0	2	2	2	A	A	A
		Through	0	0	0	1	1	1	A	A	A
		Left	0	0	0	1	1	1	A	A	A
	WB	Right	1	1	1	13	10	14	B	A	B
		Left	1	1	1	6	8	9	A	A	A
Eccles	NB	Through	175	289	287	16	90	88	B	F	F
		Right	0	0	0	47	27	29	D	C	C
	SB	Through	74	162	188	40	16	17	D	B	B
		Left	74	162	188	10	49	48	A	D	D
	WB	Left	26	27	21	74	77	64	E	E	E
		Right	26	27	21	47	48	42	D	D	D
Mandela	NB	Through	0	0	0	1	1	1	A	A	A
		Right	0	0	0	2	2	2	A	A	A
		Left	0	0	0	3	3	2	A	A	A
	WB	Right	0	0	0	1	1	1	A	A	A
		Left	0	0	0	4	4	5	A	A	A
		Through	0	0	0	1	1	1	A	A	A
	SB	Through	0	1	1	1	1	1	A	A	A
		Left	0	1	2	5	5	6	A	A	A
	EB	Right	0	0	0	1	1	1	A	A	A
		Through	0	0	0	1	1	1	A	A	A
Base Access	SB	Through	-	116	117	-	26	26	-	D	D
		Right	-	120	120	-	5	30	-	A	D
	EB	Right	-	0	0	-	0	0	-	A	A
		Left	-	0	0	-	0	0	-	A	A
	NB	Left	-	0	0	-	0	0	-	A	A
		Through	-	0	0	-	1	1	-	A	A

Table 16: Existing Network 2018 – Bridge Closed (1), Existing Network with Phase 2 Traffic 2018 – Bridge Closed (2), Existing Network with Cumulative Traffic 2018 – Bridge Closed (3)

Site	Direction	Movement	Q_{95} 1 (m)	Q_{95} 2 (m)	Q_{95} 3 (m)	Delay 1 (s/veh)	Delay 2 (s/veh)	Delay 3 (s/veh)	LOS 1	LOS 2	LOS 3
Massy	NB	Through	0	0	0	0	0	0	A	A	A
		Right	0	0	0	3	3	3	A	A	A
		U-Turn	0	0	0	3	3	3	A	A	A
	SB	Left	0	0	0	2	1	2	A	A	A
		Through	0	0	0	0	0	0	A	A	A
	WB	Right	0	0	0	4	5	4	A	A	A
		U-Turn	0	0	0	0	1	1	A	A	A
		Left	0	0	0	2	1	2	A	A	A
DHB	NB	U-Turn	0	0	0	1	0	4	A	A	A
		Left	0	0	0	1	2	1	A	A	A
		Through	0	0	0	0	0	0	A	A	A
	SB	Through	0	0	0	1	1	1	A	A	A
		Right	0	0	0	3	3	3	A	A	A
		U-Turn	0	0	0	3	4	4	A	A	A
Houston	SB	Through	0	0	0	0	0	0	A	A	A
	NB	Right	0	0	0	0	0	0	A	A	A
		Left	0	0	0	0	0	0	A	A	A
Nandy Park	NB	Through	0	0	0	0	0	0	A	A	A
		Right	0	0	0	4	3	2	A	A	A
	SB	U-Turn	0	0	0	2	3	3	A	A	A
		Through	0	0	0	1	2	1	A	A	A
		Left	0	0	0	2	2	2	A	A	A
	WB	Right	0	0	0	4	7	4	A	A	A
		Left	0	0	0	2	3	3	A	A	A
Eccles	WB	Right	11	11	11	33	33	31	C	C	C
		Left	11	11	11	31	34	34	C	C	C
	NB	Right	7	7	7	31	32	30	C	C	C
		Through	6	6	6	7	7	8	C	A	A
	SB	Through	8	9	9	20	20	20	B	B	B
		Left	0	0	0	1	1	1	A	A	A
Mandela	NB	Right	14	15	15	37	37	36	D	D	D
		Left	14	15	15	32	34	32	C	C	C
	WB	Right	6	6	6	16	16	16	B	B	B
		Left	16	16	16	48	48	48	D	D	D
		Through	16	16	16	53	53	53	D	D	D
	SB	Left	83	83	83	145	145	146	F	F	F
		Through	72	72	72	163	164	163	F	F	F
	EB	Left	6	4	6	21	8	30	C	A	C
		Through	5	4	5	34	31	36	C	C	D
		Right	0	0	0	2	1	2	A	A	A
Base Access	SB	Through	-	0	0	-	0	0	-	A	A
		Right	-	0	0	-	3	2	-	A	A
	EB	Right	-	0	0	-	0	0	-	A	A
		Left	-	0	0	-	0	0	-	A	A
	NB	Left	-	0	0	-	0	0	-	A	A
		Through	-	0	0	-	0	0	-	A	A

2023 Projected Traffic Conditions

Table 17: Existing Network 2023 – AM Peak (1), Existing Network with Phase 2 Traffic 2023 – AM Peak (2), Existing Network with Cumulative Traffic 2023 – AM Peak (3)

Site	Direction	Movement	Q_{95} 1 (m)	Q_{95} 2 (m)	Q_{95} 3 (m)	Delay 1 (s/veh)	Delay 2 (s/veh)	Delay 3 (s/veh)	LOS 1	LOS 2	LOS 3
Massy	NB	Through	336	320	338	48	43	53	E	E	D
		Right	337	321	339	51	44	50	F	E	D
		U-Turn	337	321	339	35	32	28	D	D	C
	SB	Left	0	0	0	2	1	1	A	A	A
		Through	0	0	0	0	0	0	A	A	A
	WB	Right	131	128	124	245	198	296	F	F	F
		U-Turn	124	121	117	0	0	0	A	A	A
		Left	130	127	124	235	98	398	F	F	F
DHB	DHB	Right	481	484	476	133	188	121	F	F	F
		Left	481	483	476	63	76	66	E	E	E
	NB	Through	160	171	179	66	34	33	E	C	C
		Left	161	156	165	68	61	71	E	E	E
	SB	Through	454	417	422	55	45	58	D	D	E
		Right	454	418	423	96	78	87	F	E	F
		U-Turn	454	418	423	137	110	136	F	F	F
Houston	SB	Through	465	463	423	58	49	48	F	E	D
	NB	Right	477	469	478	217	44	43	F	E	D
		Left	476	468	478	80	80	80	F	F	F
Nandy Park	NB	Through	324	313	326	65	58	71	F	F	F
		Right	340	329	342	62	58	61	F	F	F
	SB	U-Turn	2	2	1	25	24	22	C	D	C
		Through	1	1	0	2	1	1	A	A	A
		Left	2	1	1	2	1	1	A	A	A
	WB	Right	16	26	14	243	331	146	F	F	F
		Left	15	25	13	156	239	69	F	F	F
Eccles	NB	Through	14	13	8	19	16	15	B	B	B
		Right	14	13	8	42	38	25	D	D	C
	SB	Through	472	472	471	83	90	86	F	F	F
		Left	472	101	471	84	85	92	F	F	F
	WB	Left	464	441	0	76	414	26	E	C	C
		Right	0	445	427	29	580	540	C	F	F
Mandela	NB	Through	434	499	501	358	234	234	F	F	F
		Right	437	499	501	655	220	222	F	F	F
		Left	500	499	501	234	268	254	F	F	F
	WB	Right	500	443	445	221	181	151	F	F	F
		Left	500	457	458	296	209	223	F	F	F
		Through	445	457	458	194	186	188	F	F	F
	SB	Through	50	53	53	242	187	215	F	F	F
		Left	50	55	55	199	211	211	F	F	F
		Right	50	63	55	304	39	33	F	F	F
	EB	Right	8	2	1	70	39	33	E	D	C
		Through	24	14	12	62	48	47	E	D	D
Base Access	SB	Through	-	452	450	-	45	48	-	E	E
		Right	-	178	128	-	79	81	-	F	F
	EB	Right	-	0	0	-	0	0	-	A	A
		Left	-	0	0	-	0	0	-	A	A
	NB	Left	-	492	492	-	41	36	-	E	E
		Through	-	492	492	-	58	58	-	F	F

Table 18: Existing Network 2023 – PM Peak (1), Existing Network with Phase 2 Traffic 2023 – PM Peak (2), Existing Network with Cumulative Traffic 2023 – PM Peak (3)

Site	Direction	Movement	Q_{95} 1 (m)	Q_{95} 2 (m)	Q_{95} 3 (m)	Delay 1 (s/veh)	Delay 2 (s/veh)	Delay 3 (s/veh)	LOS 1	LOS 2	LOS 3
Massy	NB	Through	148	173	281	48	52	66	E	E	F
		Right	155	180	287	49	48	72	E	E	F
		U-Turn	155	181	287	70	100	89	F	F	F
	SB	Left	0	0	0	2	1	1	A	A	A
		Through	0	0	0	0	1	0	A	A	A
	WB	Right	115	125	151	265	250	382	F	F	F
		U-Turn	109	118	118	491	493	493	F	F	F
		Left	115	124	150	168	231	367	F	F	F
DHB	DHB	Right	140	392	396	177	186	156	F	F	F
		Left	124	388	318	20	21	21	B	C	C
	NB	Left	210	216	215	50	45	55	D	A	D
		Through	210	216	215	61	63	71	E	E	E
	SB	Through	493	495	496	20	19	18	B	B	B
		Right	494	496	496	321	308	291	F	F	F
Houston	SB	Through	270	259	251	55	46	45	F	E	E
	NB	Right	0	0	0	0	0	0	A	A	A
		Left	0	0	0	0	0	0	A	A	A
Nandy Park	NB	Through	358	366	377	108	110	118	F	F	F
		Right	377	385	396	118	122	129	F	F	F
	SB	U-Turn	19	14	20	77	49	81	F	E	F
		Through	14	10	15	9	10	12	A	A	B
		Left	18	13	20	3	4	7	A	A	A
	WB	Right	208	224	224	904	934	934	F	F	F
		Left	208	224	224	902	766	766	F	F	F
Eccles	NB	Through	361	363	438	18	18	18	B	B	B
		Right	361	363	363	49	48	45	D	D	D
	SB	Through	451	434	373	142	128	128	F	F	F
		Left	0	0	0	44	45	53	D	D	D
	WB	Left	67	57	57	178	131	131	F	F	F
		Right	67	57	57	107	87	87	F	F	E
Mandela	NB	Through	0	0	0	1	1	1	A	A	A
		Right	0	0	0	2	2	2	A	A	A
		Left	0	0	0	0	0	0	A	A	A
	WB	Right	176	183	183	19	27	27	B	C	C
		Left	176	183	183	55	54	51	D	D	D
		Through	176	183	183	25	54	54	C	E	E
	SB	Through	41	37	37	2	2	2	A	A	A
		Left	46	0	42	7	6	9	A	A	A
		Right	41	0	157	1	1	62	A	A	A
	EB	Left	159	156	157	43	42	41	D	D	D
		Right	159	156	156	64	61	67	E	E	E
Base Access	SB	Through	-	320	305	-	62	60	-	F	F
		Right	-	0	0	-	0	0	-	A	A
	EB	Right	-	0	0	-	0	0	-	A	A
		Left	-	0	0	-	0	0	-	A	A
	NB	Left	-	0	0	-	1	1	-	A	A
		Through	-	0	0	-	0	0	-	A	A

Table 19: Existing Network 2023 – Bridge Closed (1), Existing Network with Phase 2 Traffic 2023 – Bridge Closed (2), Existing Network with Cumulative Traffic 2023 – Bridge Closed (3)

Site	Direction	Movement	Q_{95} 1 (m)	Q_{95} 2 (m)	Q_{95} 3 (m)	Delay 1 (s/veh)	Delay 2 (s/veh)	Delay 3 (s/veh)	LOS 1	LOS 2	LOS 3
Massy	NB	Through	0	0	0	0	0	1	A	A	A
		Right	1	1	1	5	4	7	A	A	A
		U-Turn	1	1	1	4	5	5	A	A	A
	SB	Left	0	0	0	2	1	1	A	A	A
		Through	0	0	0	0	0	0	A	A	A
	WB	Right	1	1	1	6	5	5	A	A	A
		U-Turn	0	0	0	2	2	2	A	A	A
		Left	0	0	0	3	2	4	A	A	A
DHB	NB	U-Turn	0	0	0	2	1	3	A	A	A
		Left	0	0	0	2	2	1	A	A	A
		Through	0	0	0	0	0	0	A	A	A
	SB	Through	0	1	2	1	1	1	A	A	A
		Right	0	2	3	4	4	5	A	A	A
		U-Turn	0	2	3	4	5	4	A	A	A
Houston	SB	Through	0	0	0	0	0	0	A	A	A
	NB	Right	0	0	0	0	0	0	A	A	A
		Left	0	0	0	0	0	0	A	A	A
Nandy Park	NB	Through	0	0	0	0	0	0	A	A	A
		Right	0	0	0	4	4	3	A	A	A
	SB	U-Turn	1	1	1	3	3	3	A	A	A
		Through	0	0	0	2	2	2	A	A	A
		Left	1	1	0	1	1	2	A	A	A
	WB	Right	0	0	0	5	4	6	A	A	A
		Left	0	0	0	2	2	2	A	A	A
Eccles	NB	Through	16	16	15	36	36	34	D	D	C
		Right	16	16	15	32	33	32	C	C	C
	SB	Through	9	8	8	33	28	28	C	C	C
		Left	8	7	7	8	7	7	A	A	A
	WB	Left	10	10	10	19	19	18	B	B	B
		Right	0	0	0	1	1	2	A	A	A
Mandela	NB	Right	21	21	19	42	39	38	D	D	D
		Left	21	21	19	38	37	37	D	D	C
	WB	Right	9	9	9	24	24	23	C	C	B
		Left	20	20	20	48	48	48	D	D	D
		Through	20	20	20	44	44	46	D	D	D
	SB	Left	83	83	83	145	145	147	F	F	F
		Through	72	72	72	164	163	163	F	F	F
	EB	Left	7	9	8	9	18	19	A	C	C
		Right	6	8	7	31	35	34	C	D	D
		Through	1	1	1	3	4	4	A	A	A
Base Access	SB	Through	-	0	0	-	0	1	-	A	A
		Right	-	0	0	-	7	7	-	A	A
	EB	Right	-	0	0	-	0	0	-	A	A
		Left	-	0	0	-	0	0	-	A	A
	NB	Left	-	0	0	-	0	0	-	A	A
		Through	-	0	0	-	0	0	-	A	A

Table 20: New DHB Network 2023 – AM Peak (1), New DHB Network with Phase 2 Traffic 2023 – AM Peak (2), New DHB Network with Cumulative Traffic 2023 – AM Peak (3)

Site	Direction	Movement	Q_{95} 1 (m)	Q_{95} 2 (m)	Q_{95} 3 (m)	Delay 1 (s/veh)	Delay 2 (s/veh)	Delay 3 (s/veh)	LOS 1	LOS 2	LOS 3
Massy	NB	Through	27	31	43	8	8	9	A	A	A
		Right	31	35	48	10	6	9	A	A	A
		U-Turn	31	35	48	10	16	11	A	C	B
	WB	Right	8	11	12	7	9	16	A	A	C
		U-Turn	1	4	5	2	0	0	A	A	A
		Left	7	11	11	3	3	3	A	A	A
	SB	Left	0	0	0	3	2	2	A	A	A
		Through	0	0	0	1	1	1	A	A	A
Eccles	WB	Right	232	185	167	201	181	174	F	F	F
		Left	232	185	167	155	149	140	F	F	F
	NB	Right	350	348	354	109	114	99	F	F	F
		Through	350	348	354	75	75	75	E	E	E
	SB	Through	16	15	17	21	21	22	C	C	C
		Left	0	0	0	7	6	8	A	A	A
Houston	NB	Right	186	197	200	27	27	27	D	D	D
		Left	186	197	200	79	77	76	F	F	F
	SB	Through	0	0	0	0	0	0	A	A	A
Nandy Park	NB	Through	105	107	113	18	19	20	C	C	C
		Right	113	114	121	21	19	18	C	C	C
		U-Turn	113	114	121	22	21	23	C	C	C
	WB	Right	3	6	4	51	92	61	F	F	F
		Left	2	5	3	11	32	17	B	D	C
	SB	U-Turn	3	2	3	13	12	14	B	B	B
		Left	2	2	3	6	2	3	A	A	A
		Through	1	0	1	4	3	5	A	A	A
New Harbour Bridge	WB	Through	41	42	43	97	99	102	F	F	F
		Right	41	42	43	106	118	121	F	F	F
		Left	41	42	43	90	91	91	F	F	F
	EB	Through	369	381	397	120	135	128	F	F	F
		Left	369	381	397	201	190	192	F	F	F
		Right	369	381	397	110	135	129	F	F	F
	NB	Left	37	37	37	15	15	11	B	B	B
		Right	37	37	37	22	22	23	C	C	C
		Through	37	37	37	13	13	13	B	B	B
	SB	Right	49	68	81	51	81	85	D	F	F
		Left	49	68	81	5	11	10	A	B	A
		Through	49	68	81	61	81	94	E	F	F
Mandela	WB	Right	349	344	349	90	111	90	F	F	F
		Left	349	344	349	106	108	106	F	F	F
		Through	349	344	349	118	120	118	F	F	F
	NB	Through	339	298	271	148	146	145	F	F	F
		Left	349	307	281	132	135	119	F	F	F
		Right	339	298	271	140	142	139	F	F	F
	SB	Through	67	67	67	139	139	139	F	F	F
		Left	76	76	76	119	119	119	F	F	F
	EB	Right	21	21	21	37	35	37	D	C	D
		Through	21	21	21	38	43	37	D	D	D
ShoreBase	NB	Through	-	461	460	-	61	61	-	F	E
		Left	-	461	461	-	59	66	-	F	E
	SB	Through	-	0	0	-	0	0	-	A	A
		Right	-	0	0	-	1	33	-	A	D

Table 21: New DHB Network 2023 – PM Peak (1), New DHB Network with Phase 2 Traffic 2023 – PM Peak (2), New DHB Network with Cumulative Traffic 2023 – PM Peak (3)

Site	Direction	Movement	Q_{95} 1 (m)	Q_{95} 2 (m)	Q_{95} 3 (m)	Delay 1 (s/veh)	Delay 2 (s/veh)	Delay 3 (s/veh)	LOS 1	LOS 2	LOS 3
Massy	NB	Through	0	0	0	0	0	0	A	A	A
		Right	1	1	1	8	5	7	A	A	A
		U-Turn	0	0	0	5	11	9	A	B	A
	WB	Right	1	1	1	8	6	5	A	A	A
		U-Turn	0	0	0	0	0	0	A	A	A
		Left	1	0	1	5	4	4	A	A	A
	SB	Left	0	0	0	2	2	2	A	A	A
		Through	0	0	0	1	1	1	A	A	A
Eccles	WB	Right	20	20	20	40	39	41	D	D	D
		Left	20	20	20	40	40	43	D	D	D
	NB	Right	9	10	12	34	43	36	C	D	D
		Through	9	10	12	16	17	19	B	B	B
	SB	Through	23	21	22	22	23	23	C	C	C
		Left	0	0	0	9	6	5	A	A	A
Houston	NB	Right	0	0	0	0	0	0	A	A	A
		Left	0	0	0	0	0	0	A	A	A
	SB	Through	308	367	298	49	67	53	E	F	F
Nandy Park	NB	Through	0	0	0	0	0	0	A	A	A
		Right	0	0	0	8	0	0	A	A	A
	WB	Right	0	0	0	7	7	5	A	A	A
		Left	0	0	0	3	5	5	A	A	A
	SB	U-Turn	1	2	3	5	5	5	A	A	A
		Left	1	2	3	4	4	3	A	A	A
		Through	1	1	1	3	5	4	A	A	A
New Harbour Bridge	WB	Through	32	32	32	54	54	54	D	D	D
		Right	32	32	32	61	57	57	E	E	E
		Left	32	32	32	53	55	55	D	D	D
	EB	Through	21	21	21	39	39	39	D	D	D
		Left	21	21	21	43	43	44	D	D	D
		Right	21	21	21	53	53	53	D	D	D
	NB	Left	45	45	45	27	24	19	C	C	B
		Right	45	45	45	58	61	59	E	E	E
		Through	45	45	45	22	23	24	C	C	C
	SB	Right	403	459	437	102	113	100	F	F	F
		Left	403	459	437	12	19	17	B	B	B
		Through	403	459	437	89	94	90	F	F	F
Mandela	WB	Right	362	365	364	131	174	138	F	F	F
		Left	362	365	364	142	150	146	F	F	F
		Through	362	365	364	130	133	141	F	F	F
	NB	Through	39	36	36	58	53	54	E	D	D
		Left	45	42	42	15	25	22	B	C	C
		Right	39	36	36	52	47	48	D	D	D
	SB	Through	75	75	74	181	202	175	F	F	F
		Left	84	85	81	163	184	153	F	F	F
	EB	Right	176	256	195	81	94	84	F	F	F
		Through	176	256	195	78	88	84	E	F	F
ShoreBase	NB	Through	-	448	453	-	104	104	-	F	F
		Left	-	448	453	-	95	100	-	F	F
	SB	Through	-	0	0	-	0	0	-	A	A
		Right	-	0	0	-	1	0	-	A	A

Table 22: New DHB Network 2023 – Bridge Closed (1), New DHB Network with Phase 2 Traffic 2023 – Bridge Closed (2), New DHB Network with Cumulative Traffic 2023 – Bridge Closed (3)

Site	Direction	Movement	Q_{95} 1 (m)	Q_{95} 2 (m)	Q_{95} 3 (m)	Delay 1 (s/veh)	Delay 2 (s/veh)	Delay 3 (s/veh)	LOS 1	LOS 2	LOS 3
Massy	NB	Through	0	0	0	0	0	0	A	A	A
		Right	1	1	1	10	6	8	A	A	A
		U-Turn	1	1	1	6	7	7	A	A	A
	WB	Right	1	1	1	8	9	8	A	A	A
		U-Turn	0	0	0	0	0	0	A	A	A
		Left	0	0	0	3	3	3	A	A	A
	SB	Left	0	0	0	2	2	2	A	A	A
		Through	0	0	0	1	1	1	A	A	A
Eccles	WB	Right	9	9	9	29	27	29	C	C	C
		Left	9	9	9	33	33	35	C	C	C
	NB	Right	7	7	8	31	31	37	C	C	D
		Through	6	6	7	6	6	7	A	A	A
	SB	Through	33	32	30	26	26	25	C	C	C
		Left	0	0	0	10	9	7	A	A	A
Houston	NB	Right	0	0	0	0	0	0	A	A	A
		Left	0	0	0	0	0	0	A	A	A
	SB	Through	52	33	84	19	16	25	C	C	C
Nandy Park	NB	Through	0	0	0	0	0	0	A	A	A
		Right	0	0	0	9	8	5	A	A	A
	WB	Right	0	0	0	8	7	7	A	A	A
		Left	1	0	1	6	4	6	A	A	A
	SB	U-Turn	4	3	4	6	6	7	A	A	A
		Left	4	3	4	2	2	3	A	A	A
		Through	2	2	2	4	4	5	A	A	A
Harbour Bridge	WB	Through	44	44	44	67	67	67	E	E	E
		Right	44	44	44	57	57	57	E	E	E
		Left	44	44	44	82	82	82	F	F	F
	EB	Left	5	4	5	61	52	57	E	D	E
		Right	5	4	5	42	35	35	D	C	C
	NB	Left	45	45	44	39	40	36	D	D	D
		Right	45	45	44	56	59	57	E	E	E
		Through	45	45	44	22	23	23	C	C	C
	SB	Right	243	250	291	121	103	114	F	F	F
		Left	243	250	291	18	19	18	B	B	B
		Through	243	250	291	93	87	102	F	F	F
Mandela	WB	Right	58	58	58	87	87	87	F	F	F
		Left	58	58	58	75	75	75	E	E	E
		Through	58	58	58	80	80	80	E	E	E
	NB	Through	28	28	29	43	43	41	D	D	D
		Left	33	33	35	1	0	0	A	A	A
		Right	28	28	29	42	42	43	D	D	D
	SB	Through	73	73	73	151	151	151	F	F	F
		Right	73	73	73	146	146	146	F	F	F
		Left	80	80	80	133	133	133	F	F	F
	EB	Left	30	30	29	8	24	40	A	C	D
		Right	27	26	25	42	41	37	D	D	D
		Through	27	26	25	43	39	42	D	D	D
ShoreBase	NB	Through	-	361	349	-	97	94	-	F	F
		Left	-	361	349	-	94	74	-	F	E
	SB	Through	-	0	0	-	0	0	-	A	A
		Right	-	0	0	-	0	1	-	A	A

Observations

From the 15th-21st March 2018, on-site visits to the East Bank Public Road from Mandela Avenue to Providence were conducted. During these site visits, the following notable observations were made:

1. The ratio of the volume of vehicles exiting the Demerara Harbour Bridge to the volume of vehicles proceeding northbound along the East Bank Public Road during the AM Peak is almost equal (947:1,054 according to TMC data).
2. On average, the NB queue spillback along the East Bank Public Road during the AM peak hours extends from the Mandela and East Bank Public Road intersection to approximately 600m south of the Demerara Harbour Bridge.
3. On average, the SB queue spillback along the East Bank Public Road during the PM peak hours extends from the Demerara Harbour Bridge to the Eccles at East Bank Public Road Intersection.

Discussion

Observed Existing Traffic Conditions

All bridge closings ultimately resulted in obstructions to the flow of traffic along the northbound and southbound lanes of the East Bank Public Road. This occurred due to reduced capacity on the bridge at the time.

The relatively even volumes exiting the Demerara Harbour Bridge (Observation 1) and the conflicting traffic heading northbound along the East Bank Public Road during the AM peak created excessive delays for southbound commuters attempting to turn right onto the Harbour Bridge, resulting in unsatisfactory[2] LOS.

During the AM peak hours, on entering Georgetown via Saffron and Lombard street from the East Bank Public Road, there were several factors causing delays along the access roads including vehicular obstructions, sharp corners, parking maneuvers, pedestrian traffic which spilled over onto the roadway and reduced capacity with the two-lane exit from the East Bank Public Road quickly becoming a single lane to enter the city. This resulted in a bottleneck, with the formation of queues up to the Demerara Harbour Bridge (Observation 2). This was supported by the

[2] Levels of Service are referenced from the Institute of Transportation Engineers' Highway Capacity Manual (HCM) 2010; given the descriptions of the various LOS categories, it is an industry standard that LOS ratings of A-D are conditions that the general public will consider acceptable when utilizing the roadway, using any mode of transportation. Accordingly, satisfactory and unsatisfactory conditions are generally indicated by LOS ratings of (A-D) and (E-F), respectively.

unsatisfactory LOS observed for northbound movements from the Harbour Bridge proceeding northward.

During the PM peak hours, unsatisfactory LOS conditions were observed at the Demerara Harbour Bridge Intersection for commuters proceeding southbound turning right. This occurred as thirty percent (30%) of the southbound traffic at that intersection sought to make the right turn maneuver, which conflicted with the northbound through movement (33% of all traffic passing through intersection). At the Eccles Intersection, the westbound and southbound approaches also operate under unsatisfactory LOS conditions.

The Demerara Harbour Bridge is closed at off-peak hours and as such, satisfactory LOS conditions have been observed across the site locations. Due to the bridge closing at scheduled periods, commuters are aware of the restriction and there appears less traffic attempting to turn onto the bridge during this period.

The traffic signal at the East Bank Public Road and Mandela Avenue intersection was observed and incorporated into the VISSIM model. The existing configuration of the signal was found to cause significant delays throughout, suggesting improvements are warranted to existing timing and management plans. The evening peak, however, when modeled for free flow through the intersection, revealed significant delays and queues along the three southbound lanes of the East Bank Public Road from the Demerara Harbour Bridge. This was found to be as a result of a combination of delays caused by the right turn at the Harbour Bridge and the volume of southbound traffic.

One of the limitations of the developed model was the inability to replicate human-controlled intersections as observed. During the morning and afternoon peak periods when the East Bank Public Road was reconfigured to allow three lanes of traffic in one direction, teams of traffic control

officers assisted with traffic management at the Mandela and Demerara Harbour Bridge intersections along the East Bank Public Road. They directed traffic according to their discretion and no consistent patterns were observed to enable the reproduction of their direction. As such, these intersections were modeled as they operate when the officers are not present - traffic signals at Mandela and no traffic control devices at the Demerara Harbour Bridge. This configuration was able to generally match conditions noted via field observations at the Demerara Harbour Bridge intersection.

Modelled 2018 Existing Road Network with Proposed Phase 2 Project Traffic

The entrance of the shorebase was analyzed in the model for the proposed 'Phase 2' and 'Cumulative' expected traffic additions. The delays observed at the shorebase are reflective of the queue spillback from the northbound movement during the AM peak. Some delays were also observed for southbound movements during the PM peak as the right-turn maneuver to enter the shorebase conflicts with the northbound through movement. In spite of these delays, the intersection was found to operate with satisfactory LOS conditions.

The addition of the expected traffic for both the 'Phase 2' and 'Cumulative' conditions increased the total number of vehicles by less than one percent (<1%) and as such, the results of the model have not varied significantly.

Modelled 2018 Proposed Road Network with New Demerara Harbour Bridge

The Demerara Harbour Bridge facilitates significant movement of northbound traffic during the AM peak (44% of all northbound traffic). This was also evidenced by northbound queues which stretched from Mandela to the bridge during this period. The modeled relocation of the bridge to a northern position at Houston allowed for less congestion along the northbound lanes of the East

Bank Road which, in turn, created less delays for conflicting movements from the southbound commuters. As such, improved, satisfactory LOS conditions were observed for all sites south of the bridge. The conditions observed to the north of the bridge, however, remained consistent with that of the existing road network.

The LOS modeled at the shorebase under this scenario was also found to have improved conditions for the movements around the shorebase. The northbound approach, however, displayed unsatisfactory LOS conditions during the AM peak period. This could be attributed to the proximity of the access road to the intersection of the new Demerara Harbour Bridge and the East Bank Public Road, estimated to be within fifty meters (50m). Therefore, queues from the new intersection heavily influence the flow of traffic around the shorebase.

The model's configuration for this scenario was developed with information obtained via the feasibility study "GGFD-R-014". This study however, did not disclose the intended traffic signal timing and as such, the signal timings used in the model were estimated based on an optimized cycle and splits.

Modelled Projected Conditions for Year 2023

The traffic data recorded for the current year was modified at a growth rate of five percent (5%) per annum as used in the feasibility report "GGFD-R-014" to obtain projected traffic conditions for the year 2023.

At the year 2023, with the existing road network, all northbound movements experience failing LOS during the AM peak period, indicative of significant congestion as vehicles head toward Georgetown. Westbound exits located south of the Demerara Bridge also experience severe delays as northbound queues spill over into these intersections. Southbound movements south

of the Harbour Bridge, however, all operate at satisfactory LOS. All intersections from Demerara Harbour Bridge and northward experience severe deterioration in their LOS, with failing LOS conditions.

During the PM peak period at the year 2023, modeled LOS conditions have worsened for the southbound movement due to the increased number of vehicles on the road network. Northbound movements at the Demerara Harbour Bridge and southward experience failing LOS conditions due to the prevailing southbound right turn movement at the bridge. Traffic conditions observed during the hours of closing the bridge do not vary significantly from existing as the demand at critical intersections is low.

Similar to current-year analyses, the conditions modeled for 2023 do not differ measurably with the addition of the expected traffic due to the Phase 2 Project.

Modeling of the new Demerara Harbour Bridge in 2023 shows that even with increased traffic volumes the system exhibits generally satisfactory LOS south of the bridge. The northbound movement at Eccles, however, still exhibits failing LOS conditions due to queue spillbacks from the bridge intersection. All other intersections generally exhibit increased delays for all scenarios but maintained satisfactory LOS conditions. The most significant delays predicted were due to conflicting movements at major intersections, most notably the southbound right turn at the Demerara Harbour Bridge during the PM peak period.

In addition to the delays experienced by the dominant movements due to bottlenecks and insufficient capacity, conflicting movements such as exits from the bridge and southbound right-turn movements contributed significantly to congestion.

Generally, the models suggest that there will be no operational impact to the East Bank Public Road from the addition of assumed Phase 2 Project traffic.

Conclusion

Analysis of the existing road network shows that there are shortcomings with the existing system, with failing levels of service (LOS) observed during the AM and PM peak periods. The addition of traffic due to the Phase 2 Project, however, does not measurably exacerbate the existing situation. All scenarios remain unaffected by the added Phase 2 Project traffic for both AM and PM peak periods, with or without bridge closing, for the existing road network configuration or the road network configuration with the new Demerara Harbour Bridge. The analysis indicated that these conclusions will remain the case through at least 2023.

CARITRANS

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Telphone: (868) 225 6926
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APPENDIX P

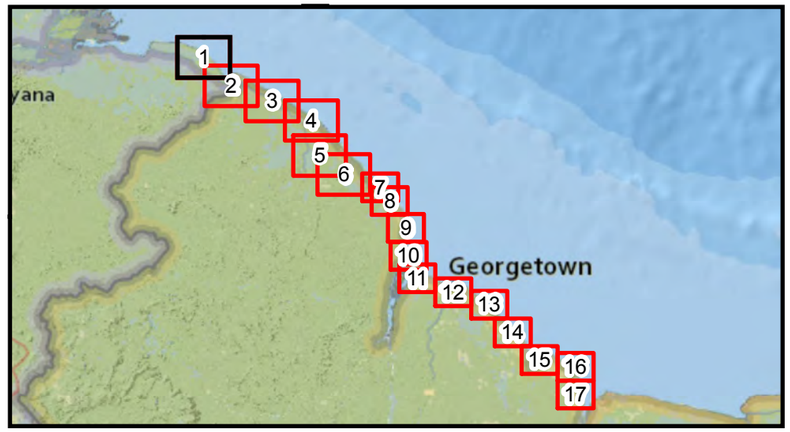
Coastal Sensitivity Maps

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Guyana

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Ecosystem Services Types

- Crabbing
- Agriculture
- Biodiversity
- Carbon Sequestration
- Ecotourism
- Fishing
- Mangroves
- Traditional Resources
- Ritual Religious
- Social Cultural
- Trapping/Hunting
- Other

ESS Priority

- Low
- Medium
- High
- Critical
- Important Fish Habitats
- Essequibo Islands Important Bird Habitat
- Important Bird Habitats

Environmental Sensitivity Index Shorelines

- 1B: Exposed, Solid Man-Made Structures
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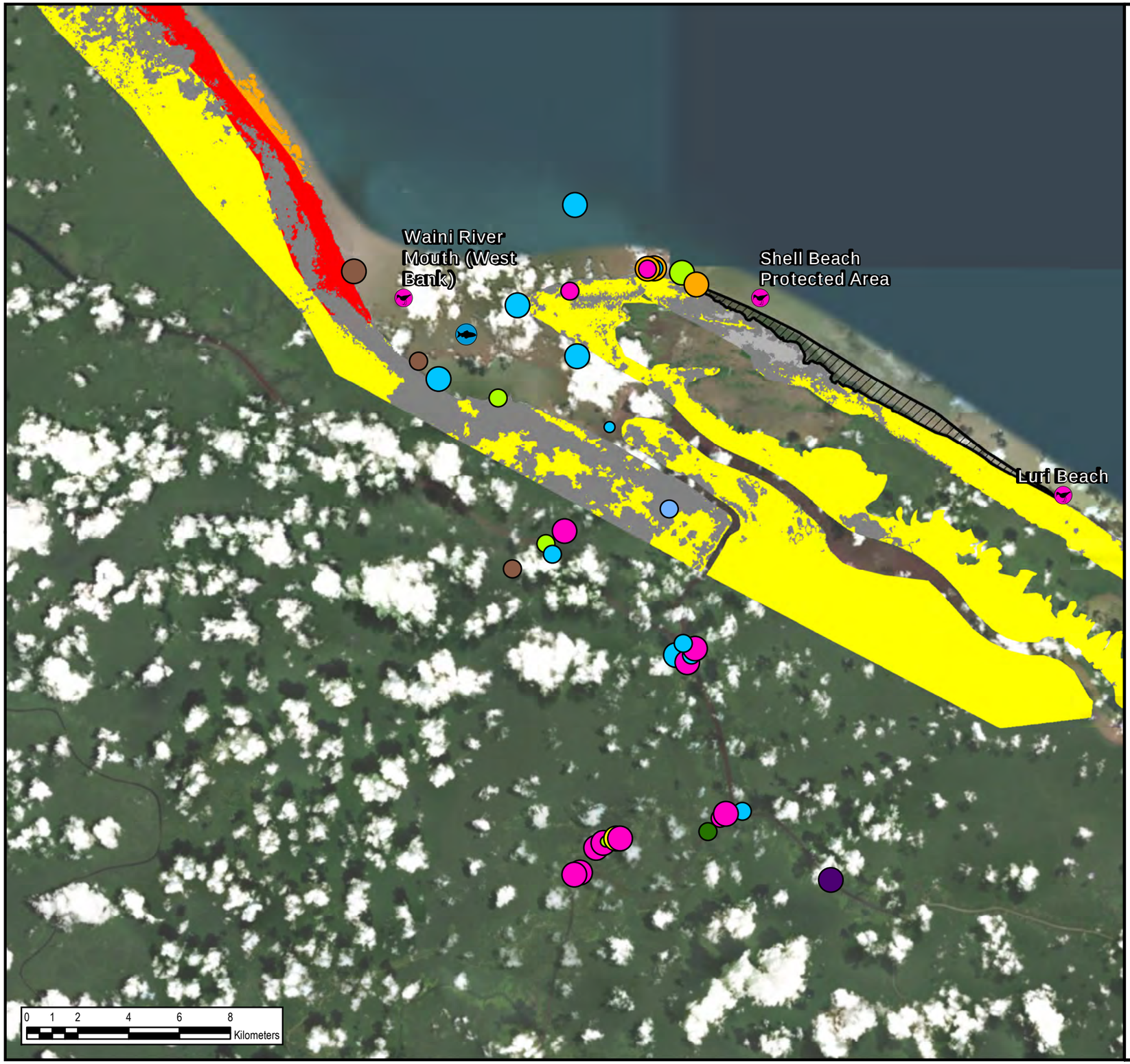
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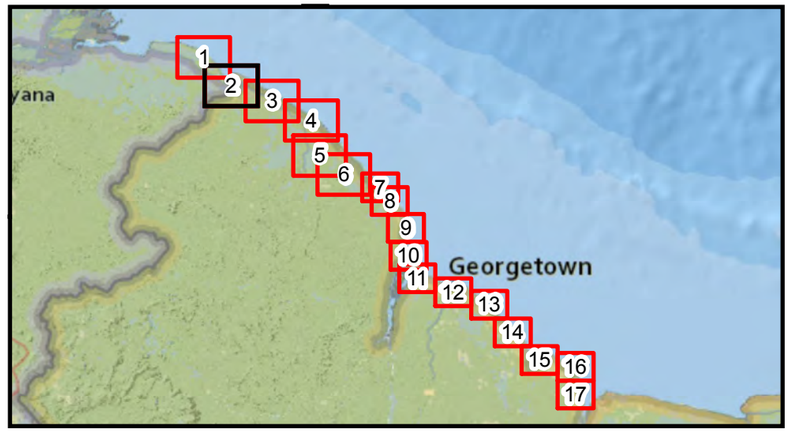
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Ecosystem Services

Types

- **Crabbing**
- **Agriculture**
- **Biodiversity**
- **Carbon Sequestration**
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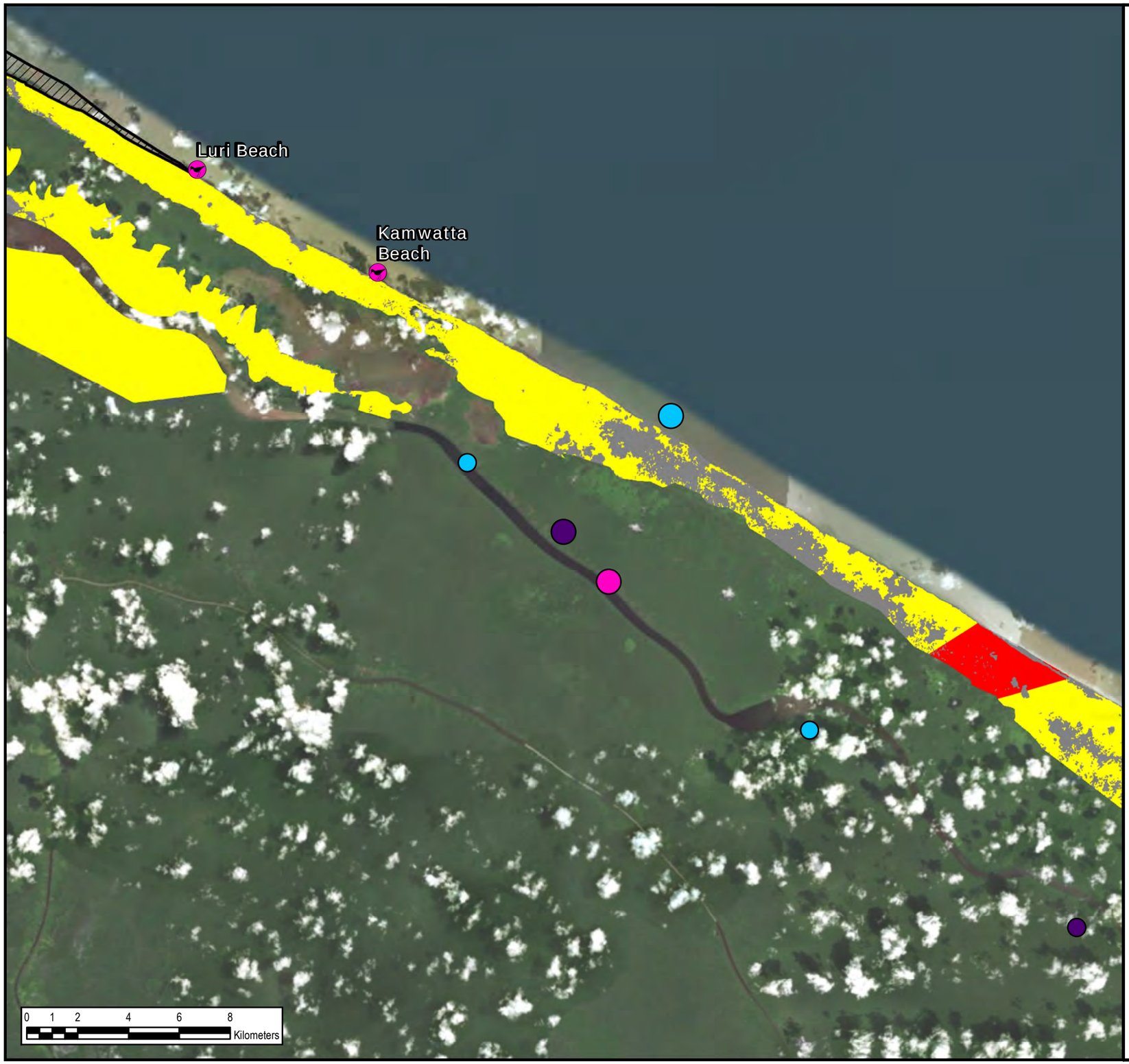
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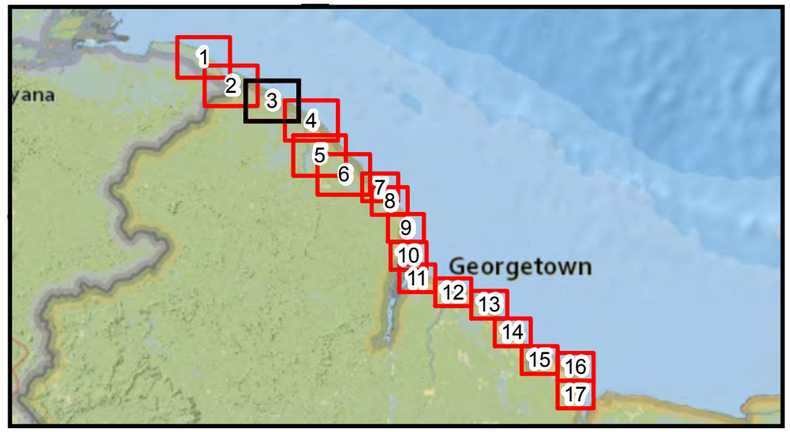
Social and Biodiversity Sensitivities

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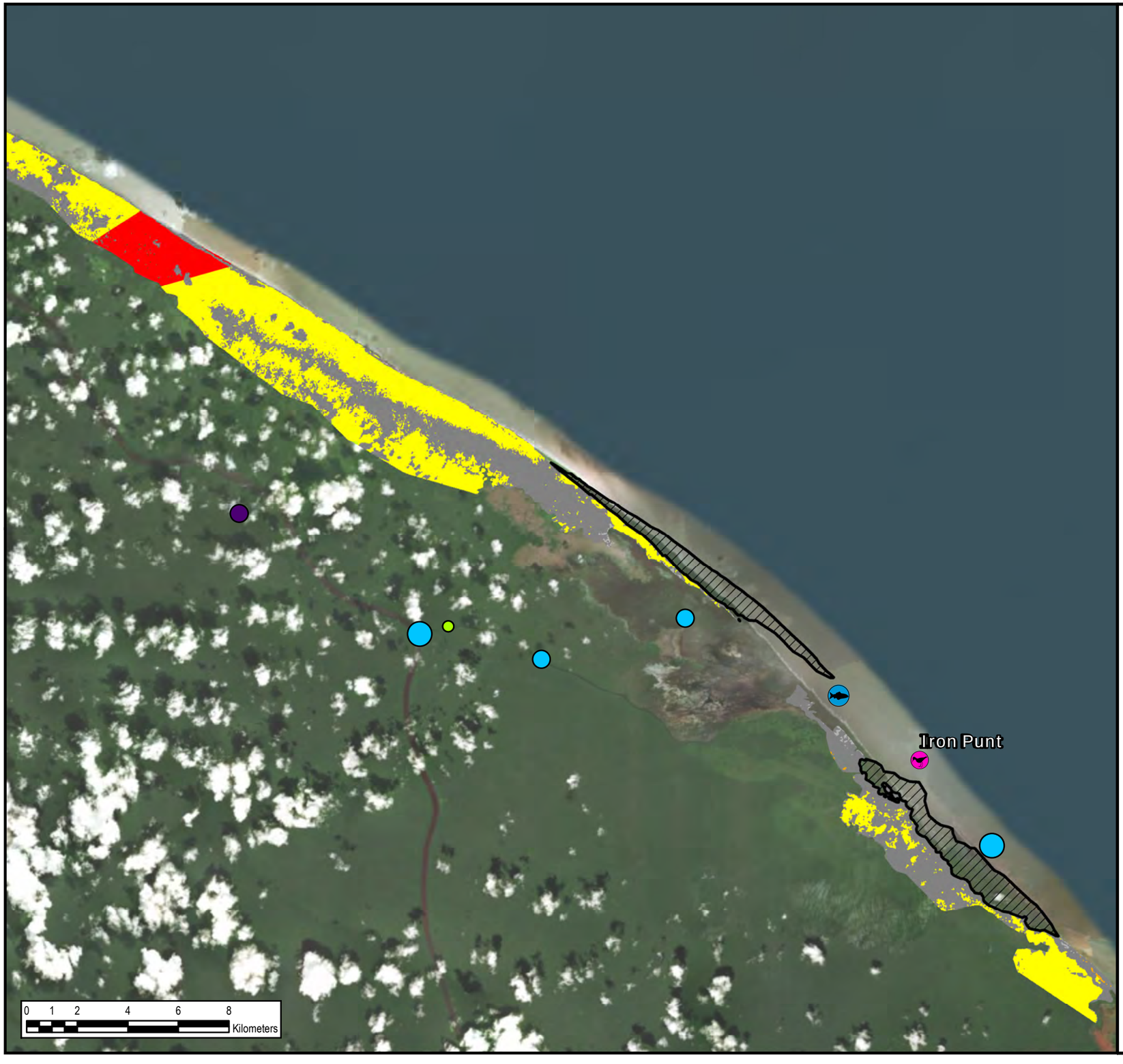
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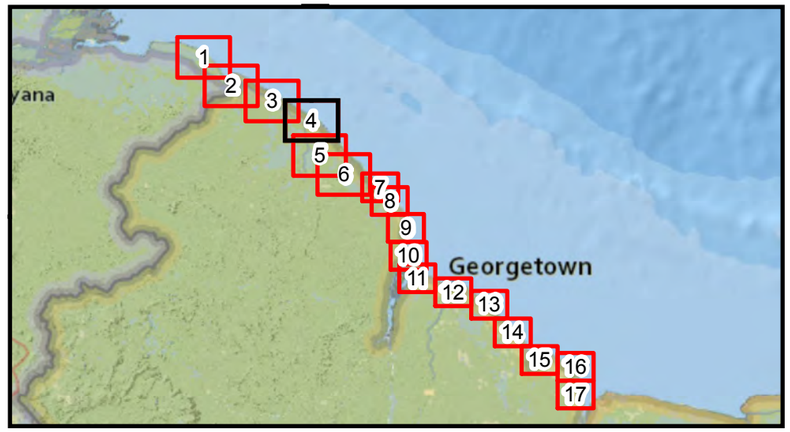
Social and Biodiversity Sensitivities

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Ecosystem Services

Types

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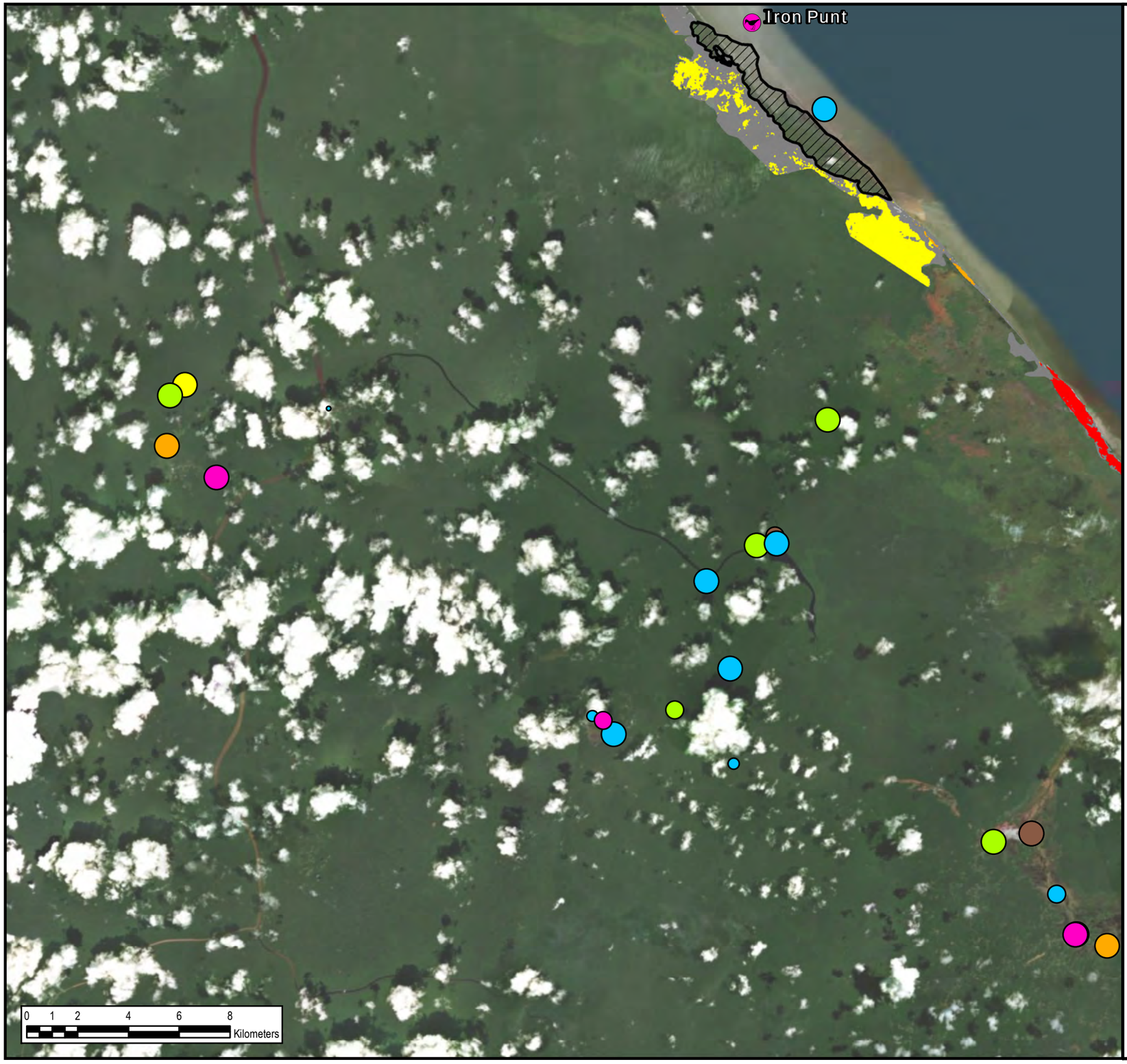
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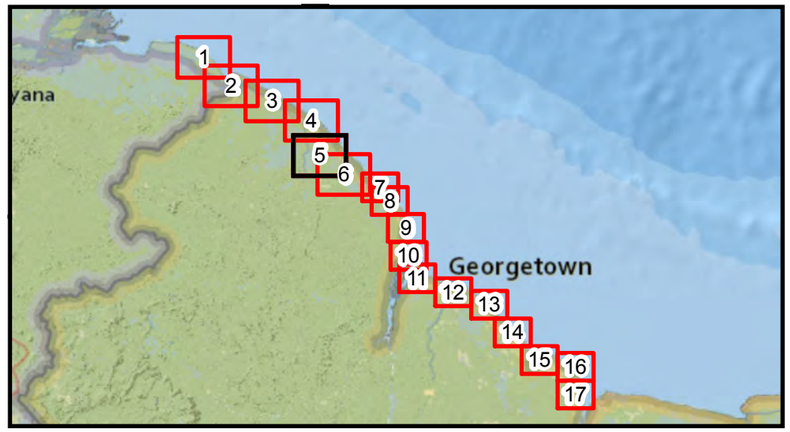
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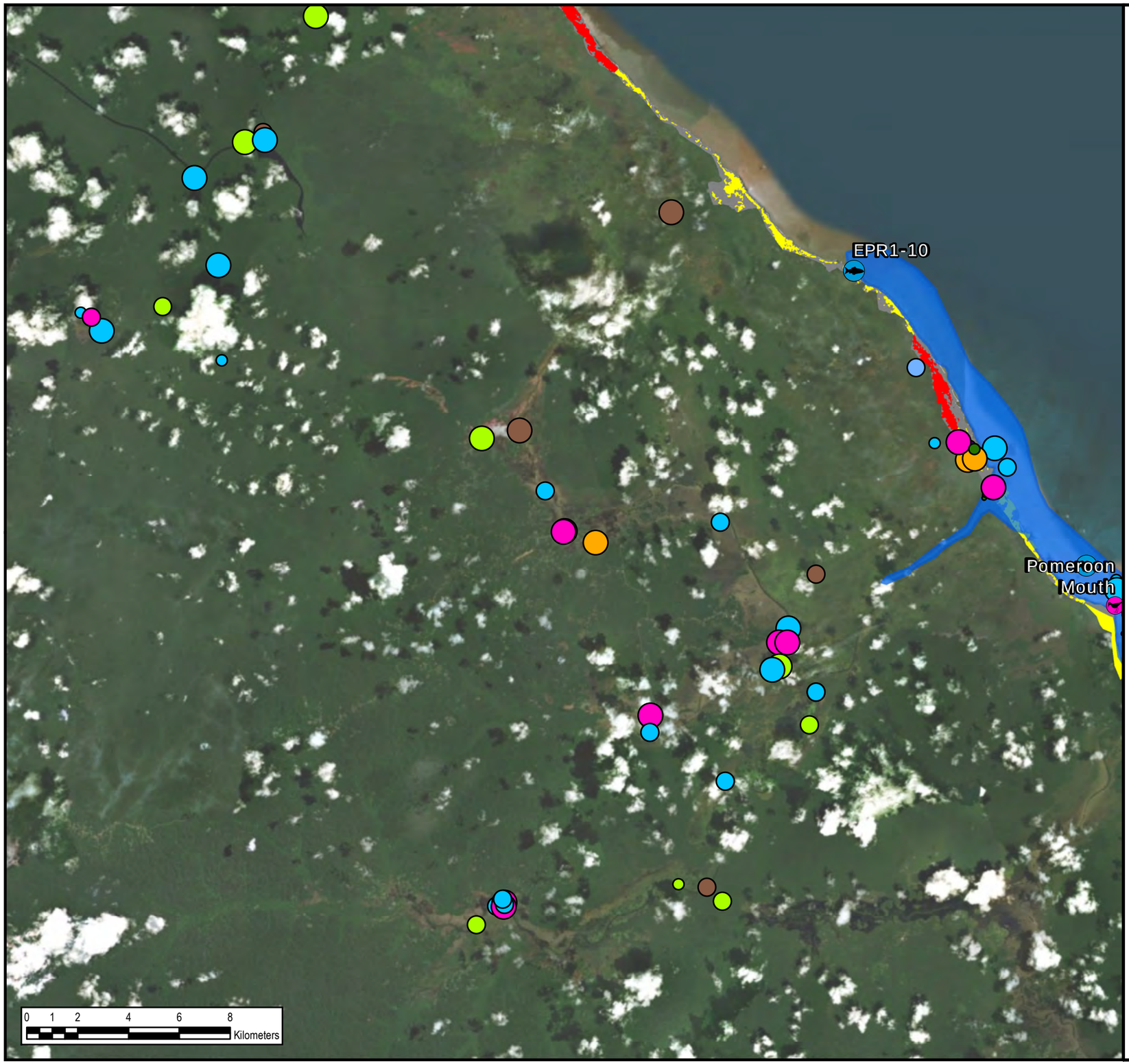
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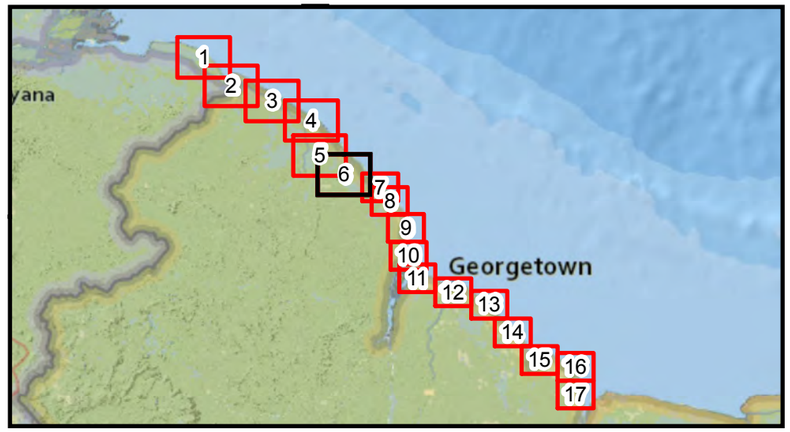
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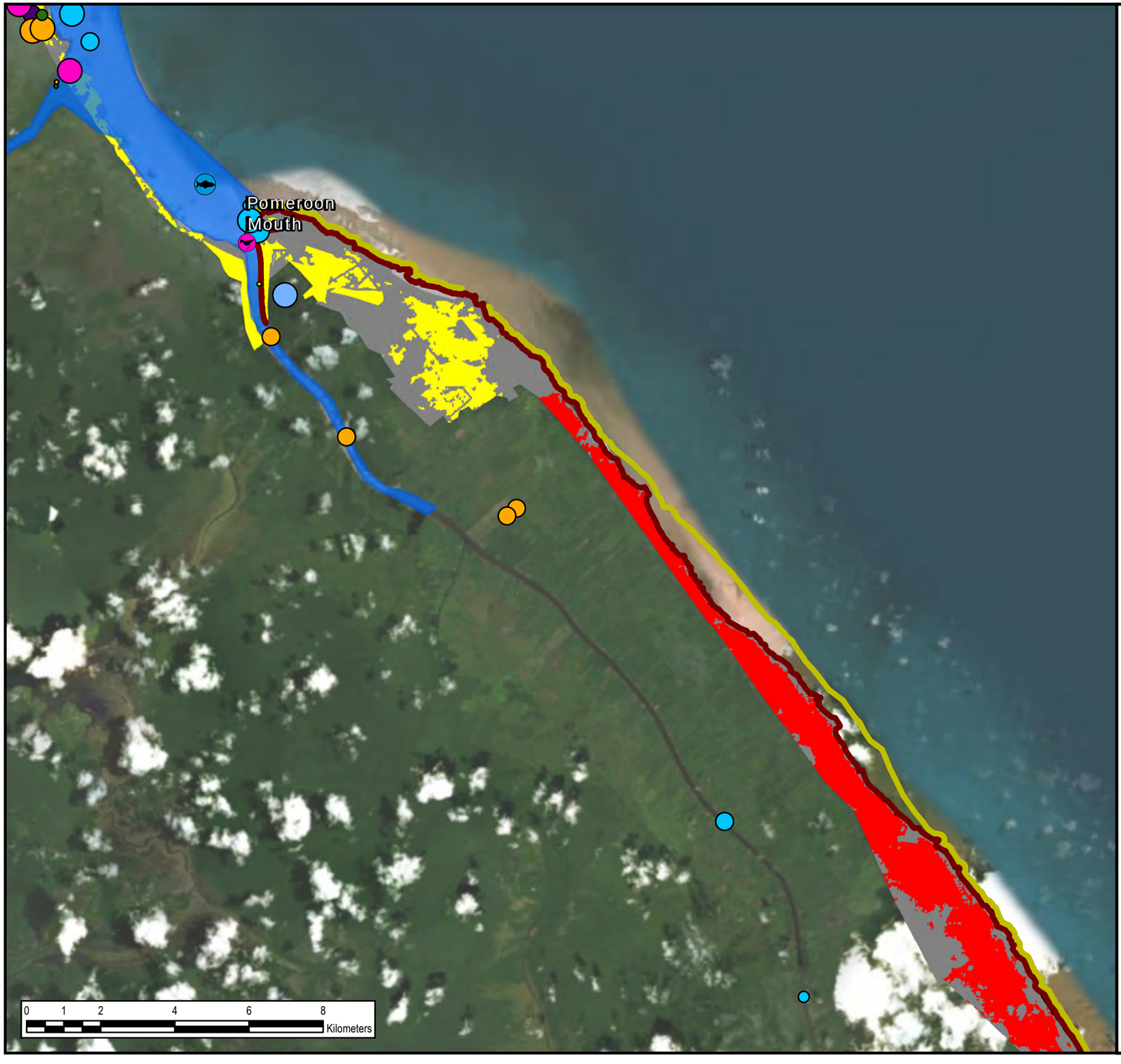
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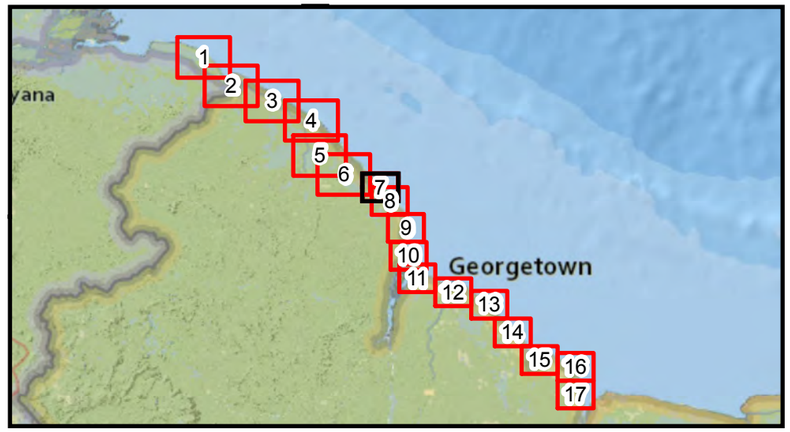
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Ecosystem Services

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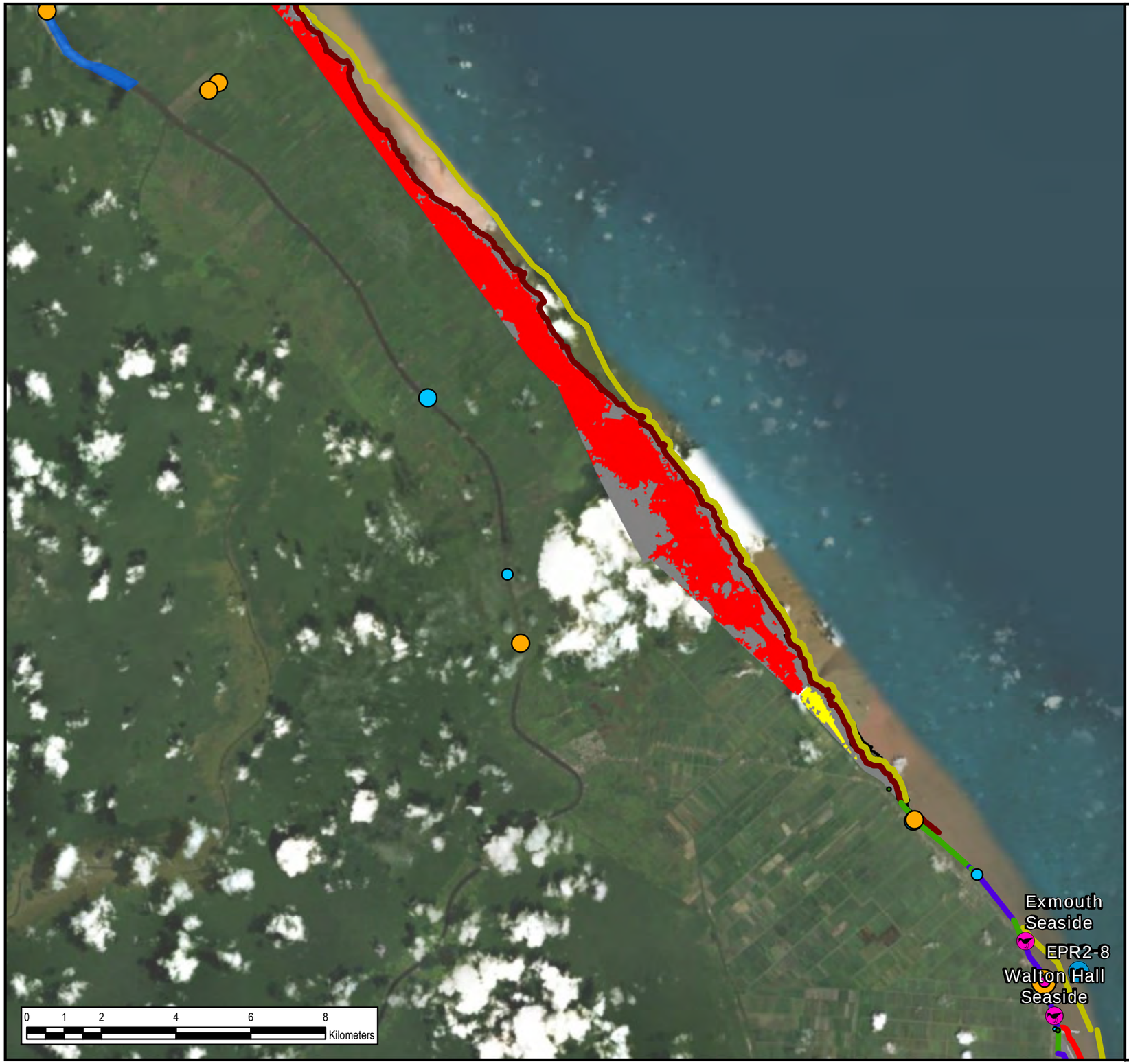
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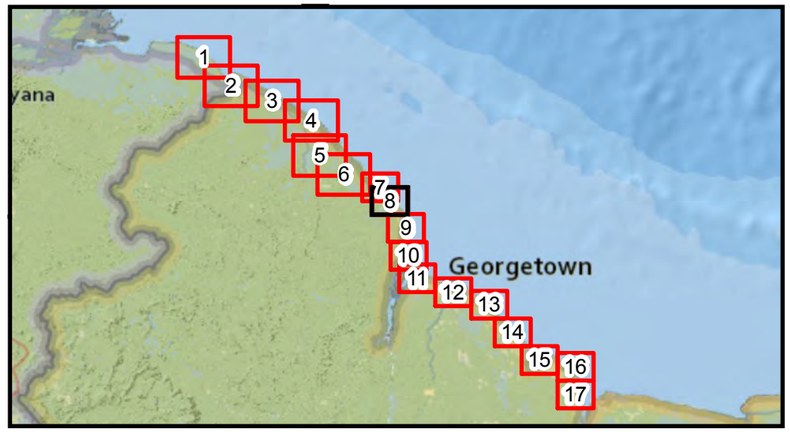
Social and Biodiversity Sensitivities

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Ecosystem Services

Types

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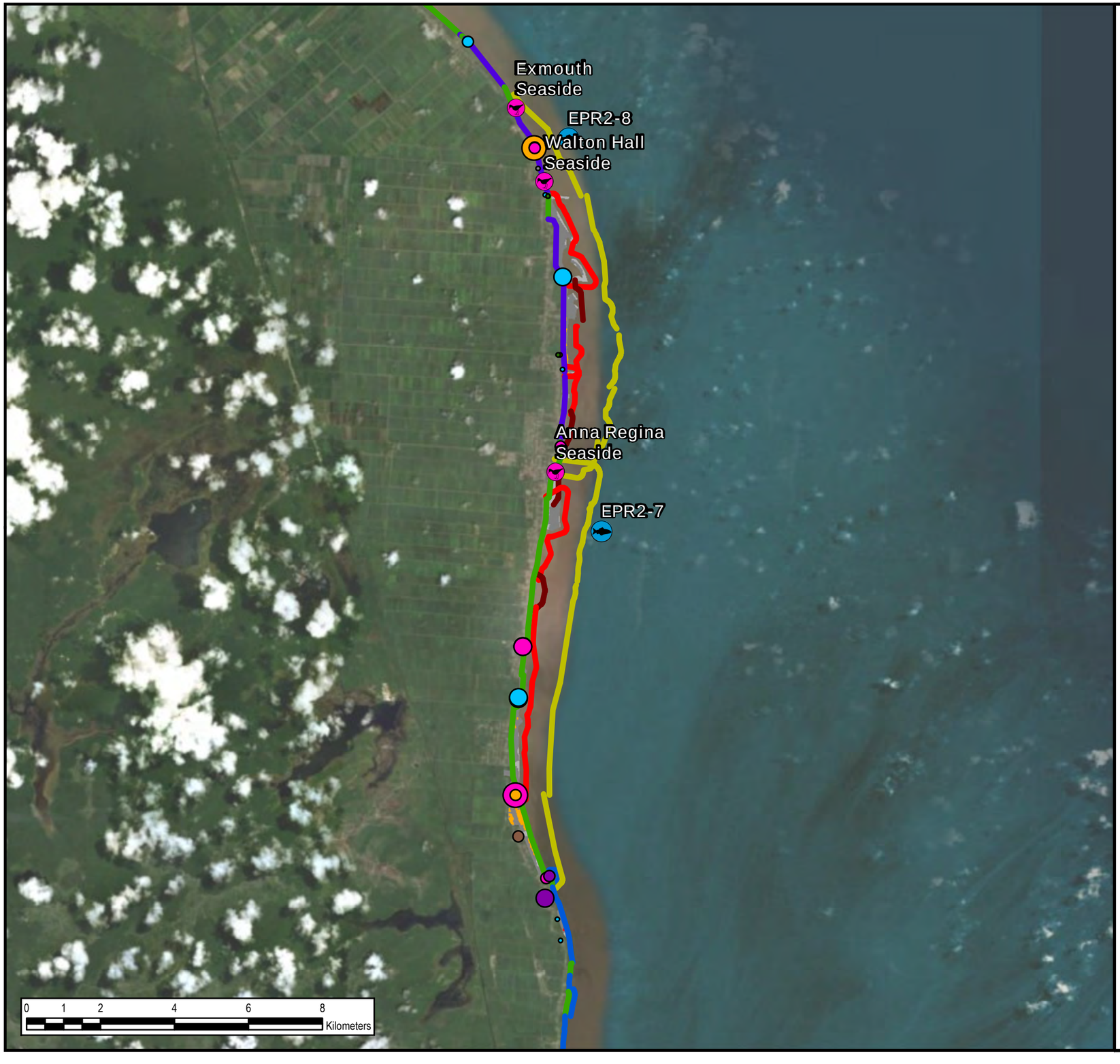
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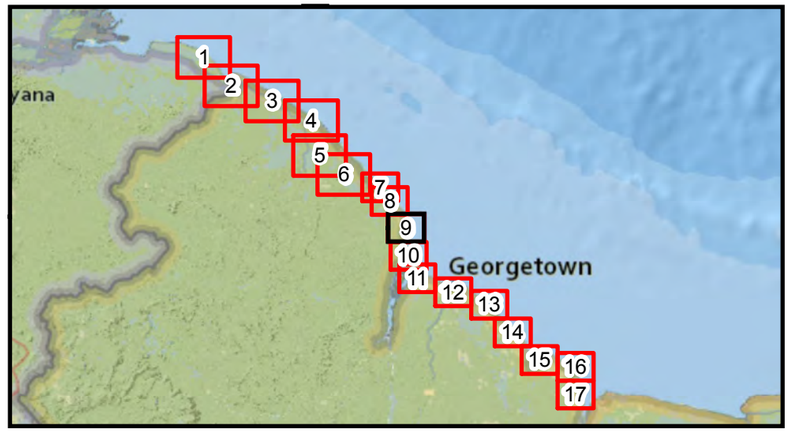
Social and Biodiversity Sensitivities

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Ecosystem Services

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- **Crabbing**
- **Agriculture**
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- **Carbon Sequestration**
- **Ecotourism**
- **Fishing**
- **Mangroves**
- **Traditional Resources**
- **Ritual Religious**
- **Social Cultural**
- **Trapping/Hunting**
- **Other**

ESS Priority

- Low
- Medium
- High
- Critical
- Important Fish Habitats
- Essequibo Islands Important Bird Habitat
- Important Bird Habitats

Environmental Sensitivity Index

Shorelines

- 1B: Exposed, Solid Man-Made Structures
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- 10A: Salt and Brackish Water Marshes
- 10D: Mangroves

Mangrove Sensitivity

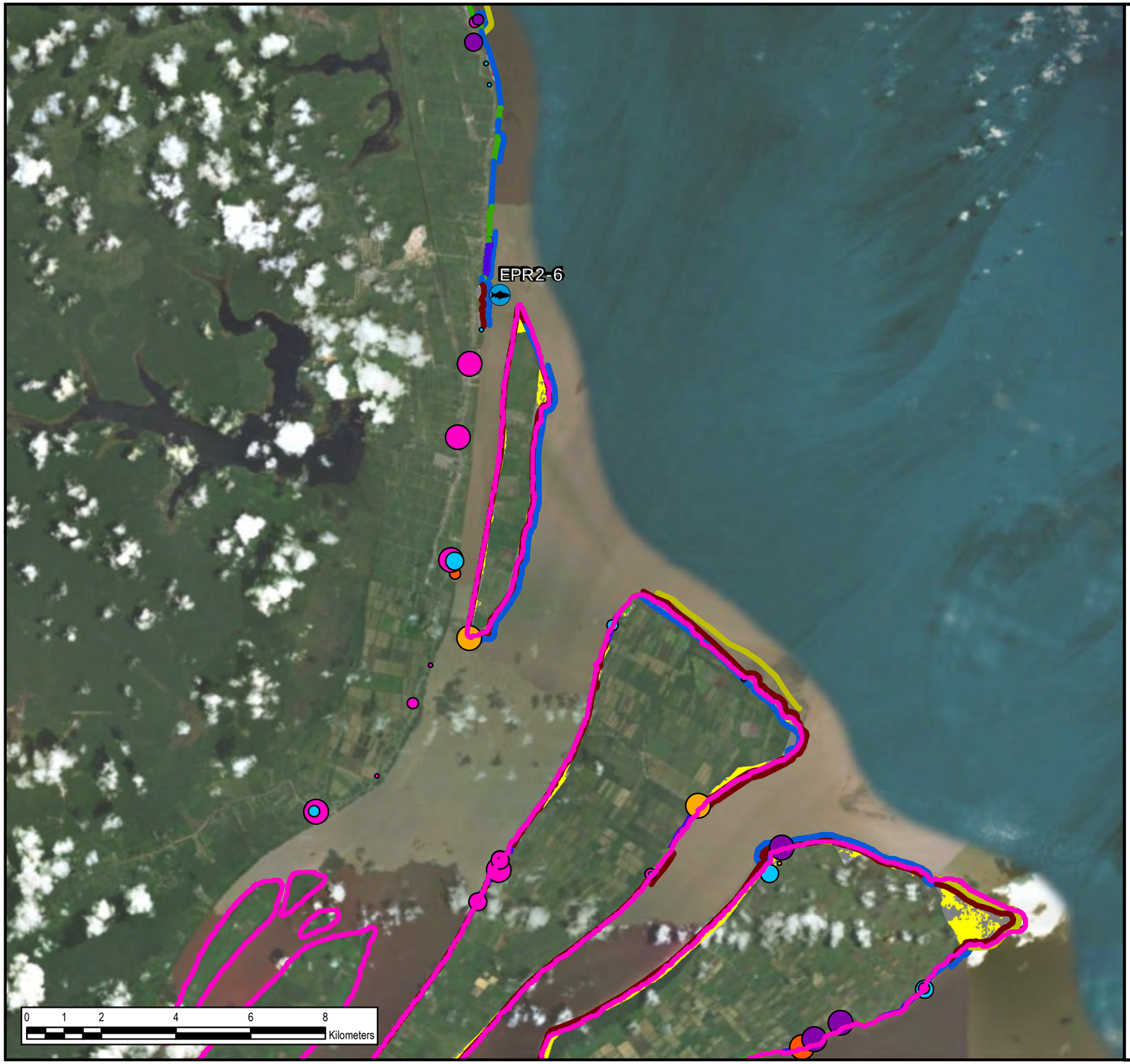
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- Very High Sensitivity (Young and Growing)
- High Sensitivity (Mature and Degrading)
- Medium Sensitivity
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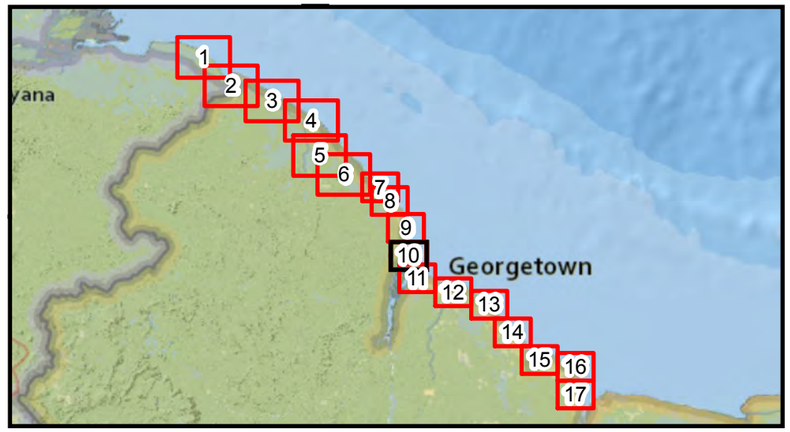
Social and Biodiversity Sensitivities

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Ecosystem Services

Types

- **Crabbing**
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- **Biodiversity**
- **Carbon Sequestration**
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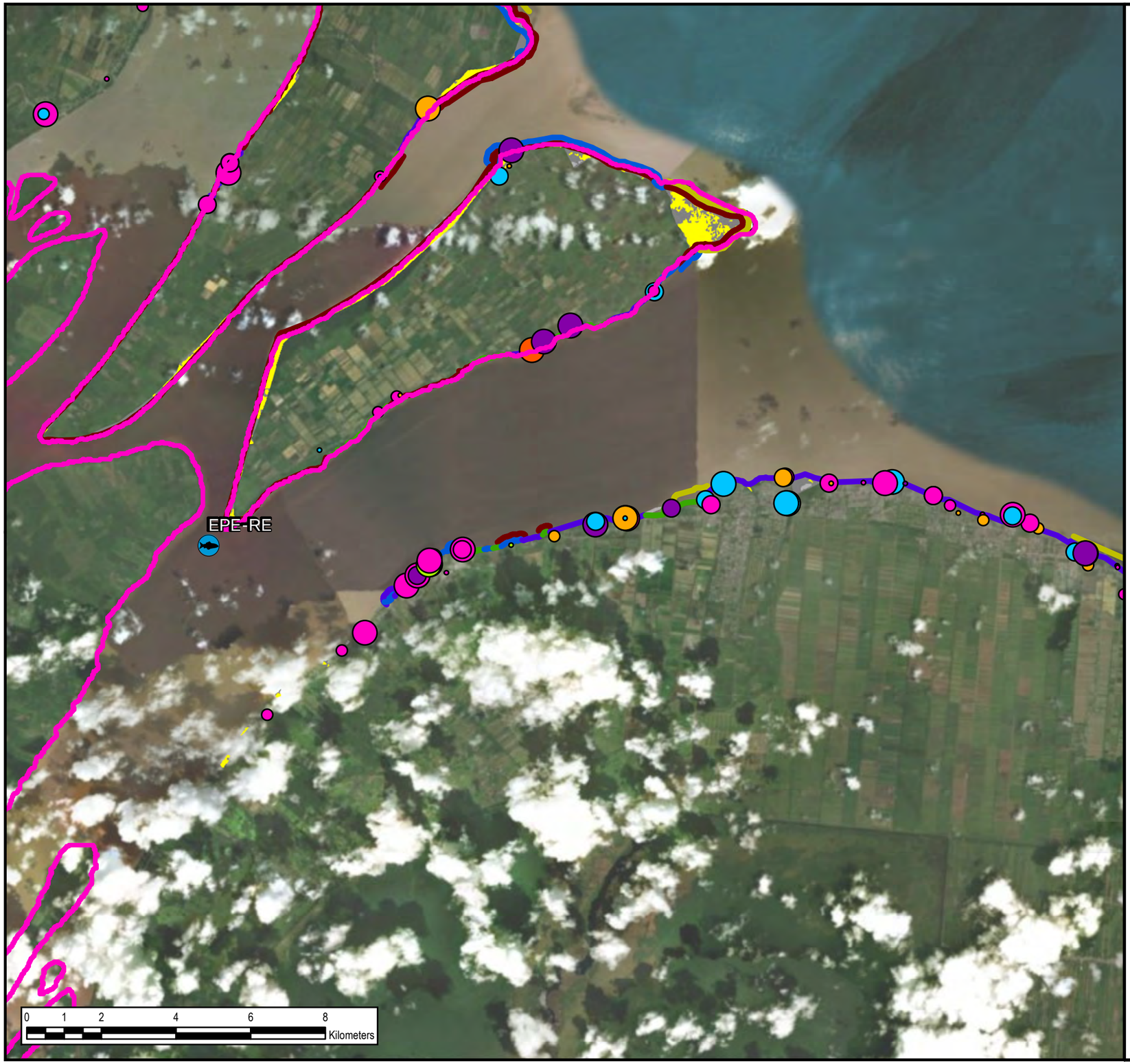
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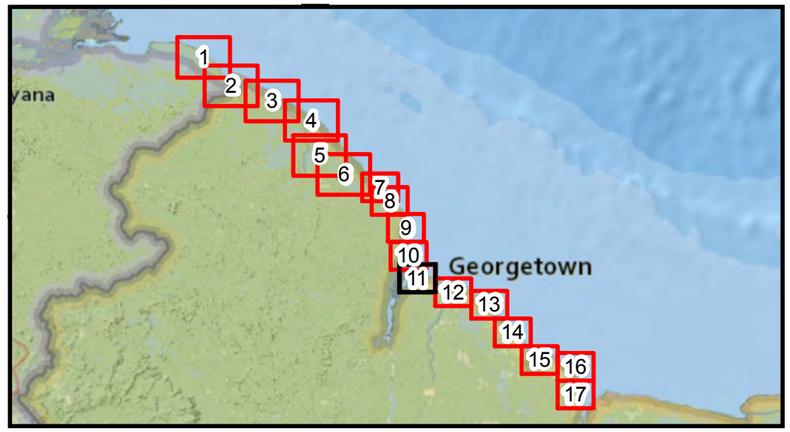
Social and Biodiversity Sensitivities

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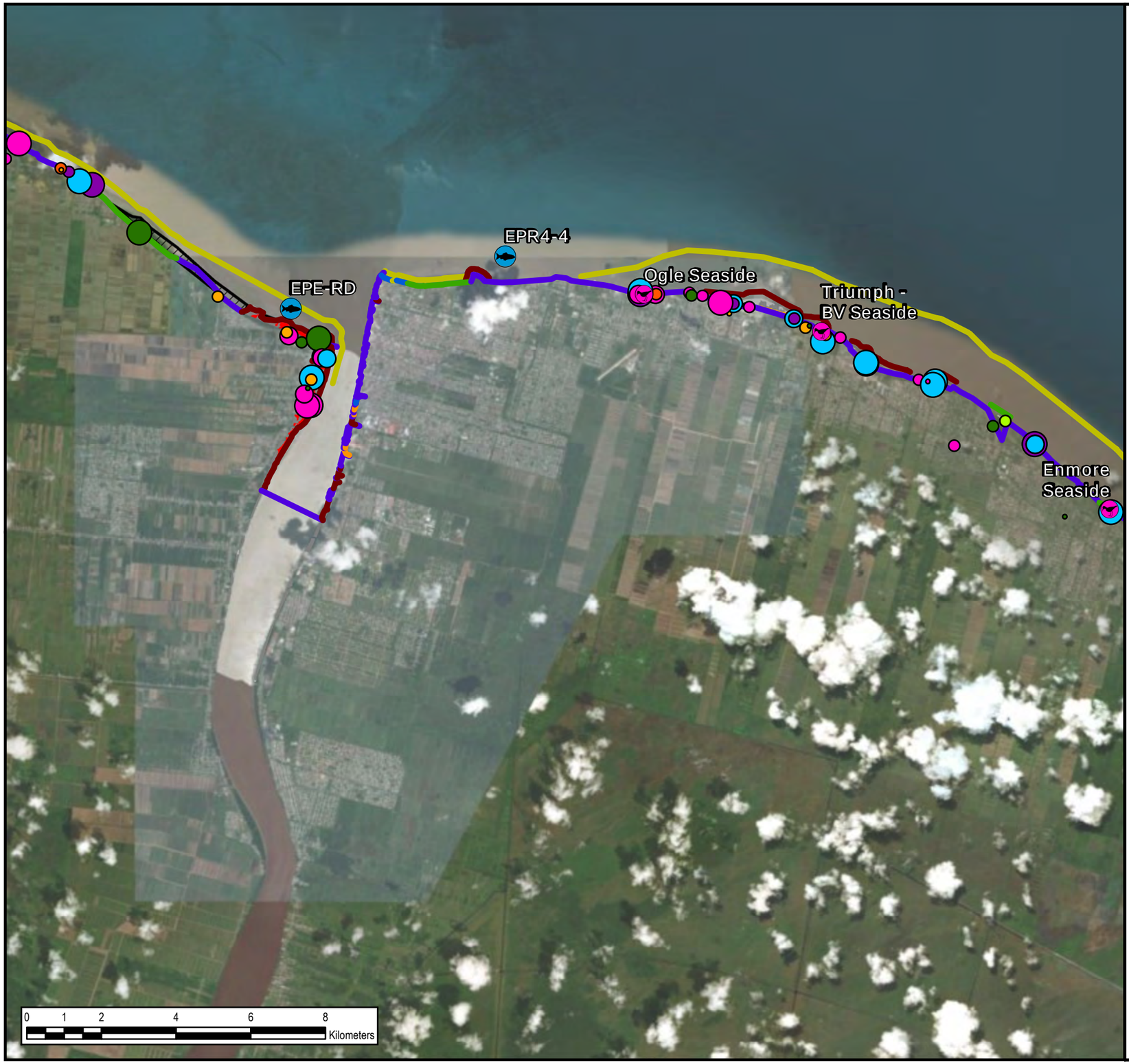
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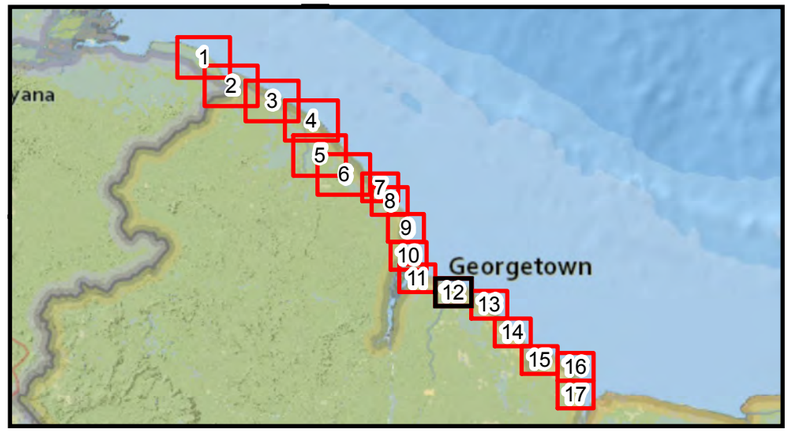
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Ecosystem Services

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Mangrove Sensitivity

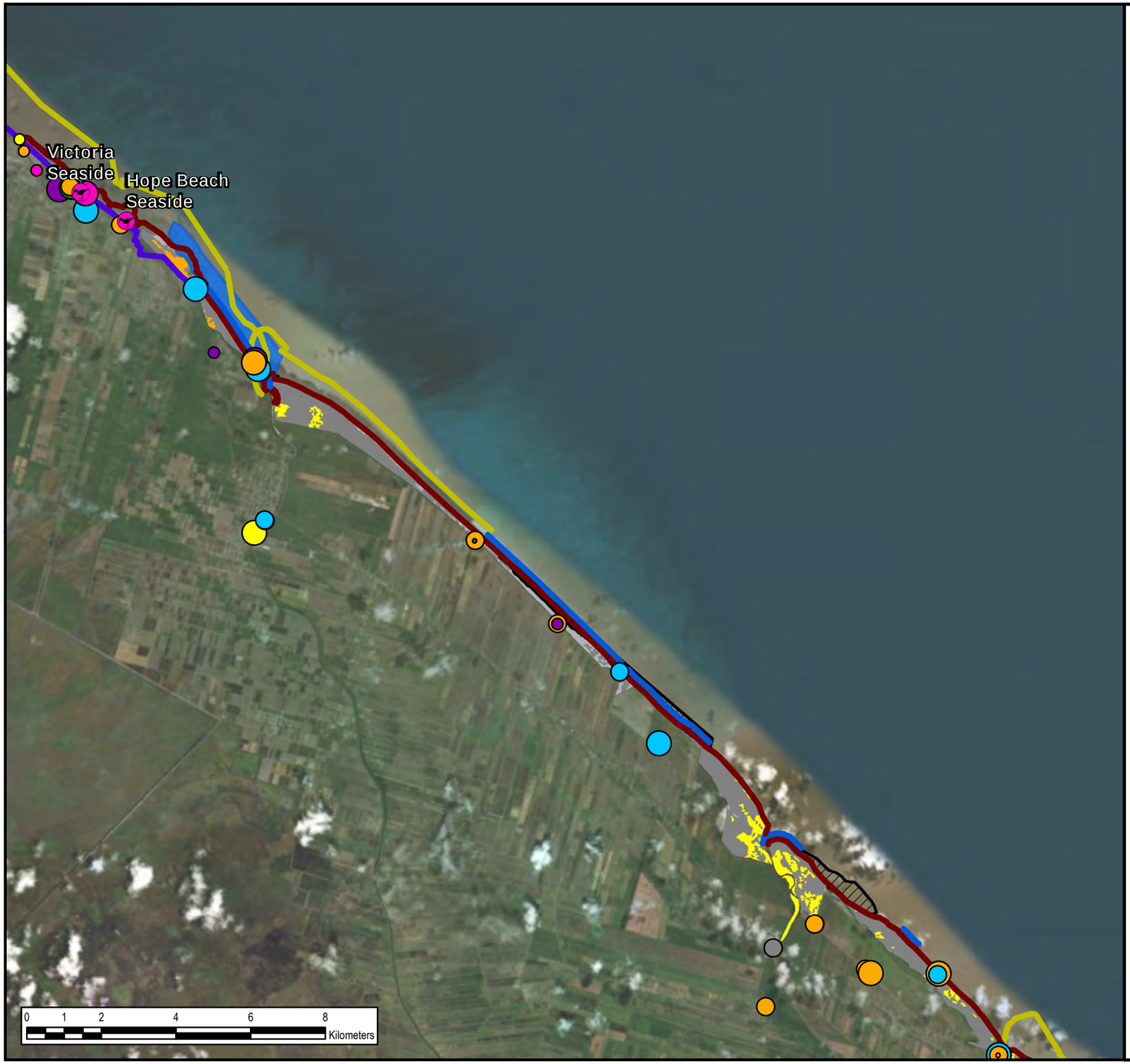
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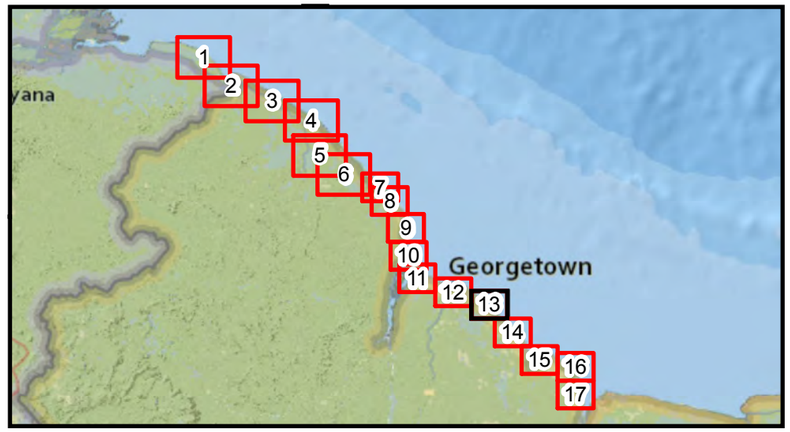
Social and Biodiversity Sensitivities

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Ecosystem Services

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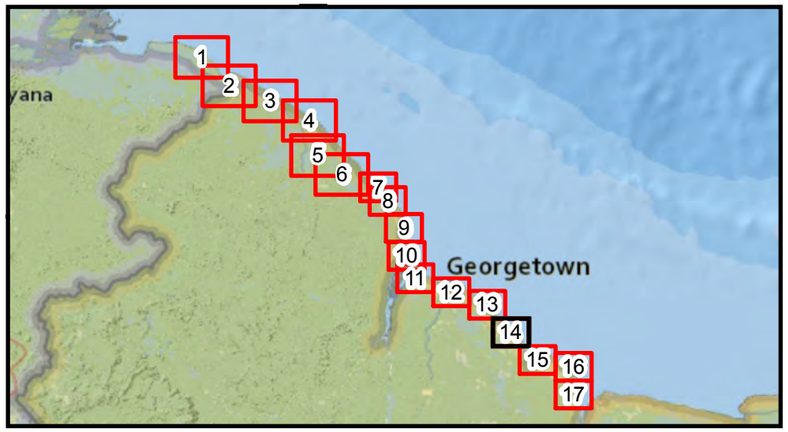
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Social and Biodiversity Sensitivities

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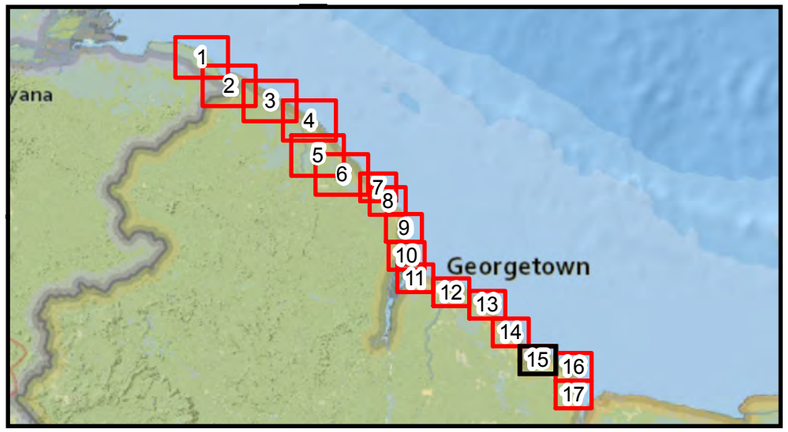
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Social and Biodiversity Sensitivities

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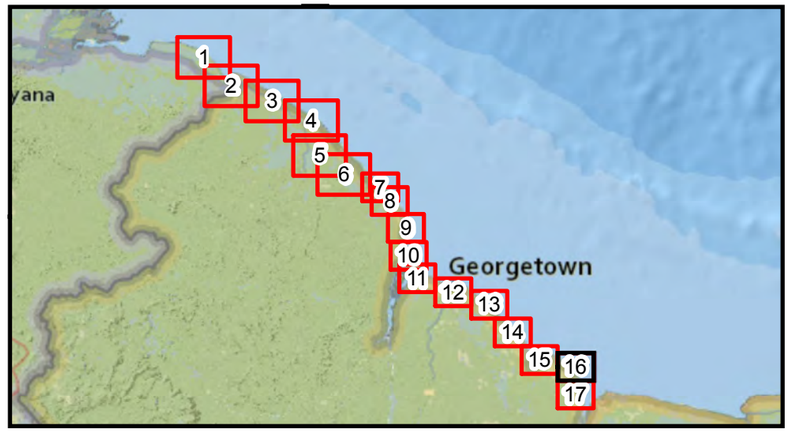
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Social and Biodiversity Sensitivities

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0 1 2 4 6 8 Kilometers

Social and Biodiversity Sensitivities

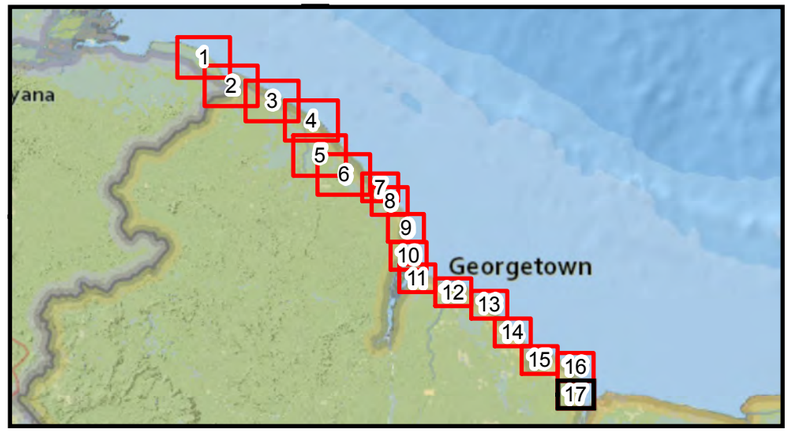
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Ecosystem Services

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Social and Biodiversity Sensitivities

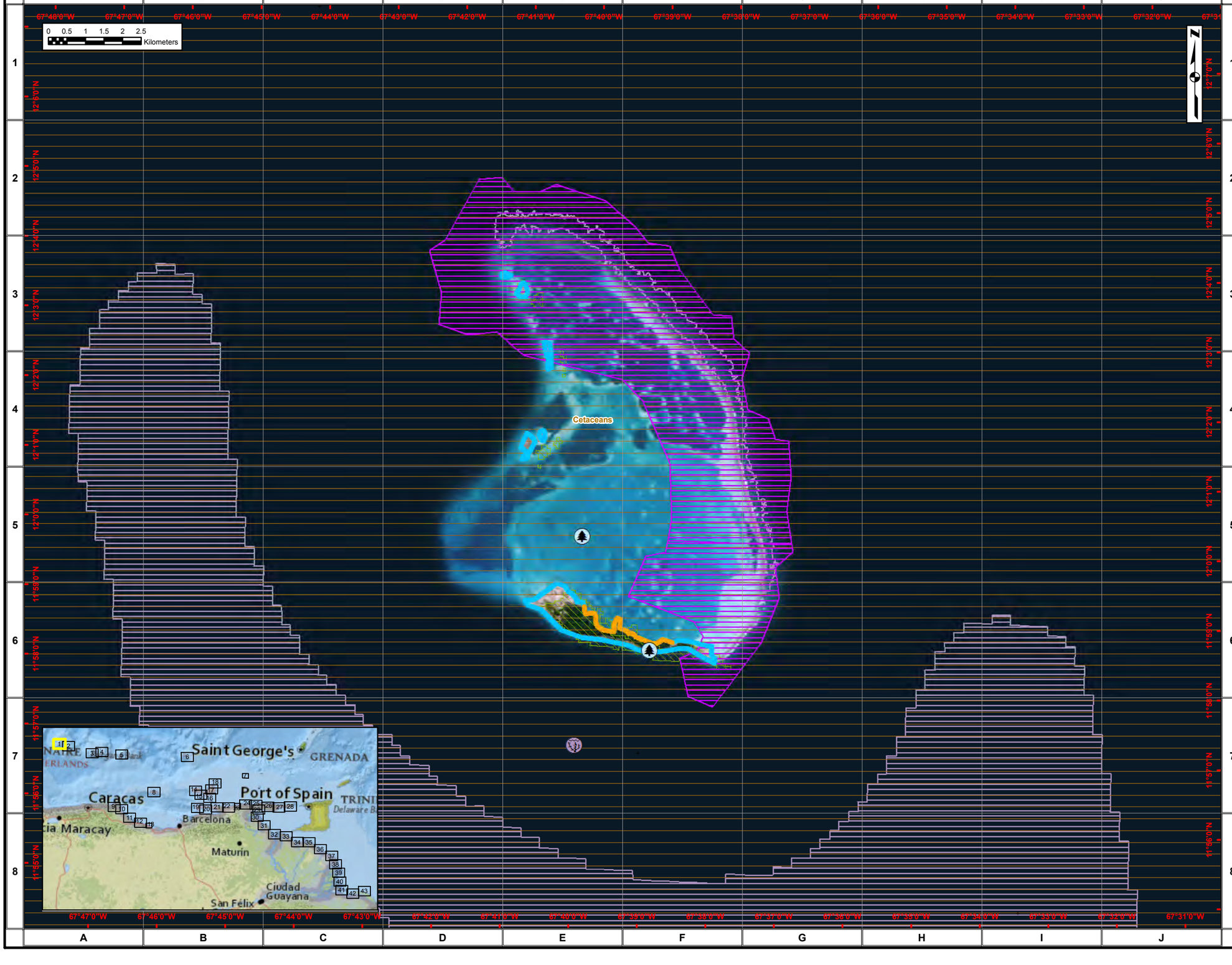
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Venezuela

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Legend

Shoreline Sensitivity (ESI)

- 3/4 - Sandy beaches or slopes
- 9B - Vegetated low banks
- Nesting Birds
- Marine Mammals
- Coral Reefs
- Coral Reef

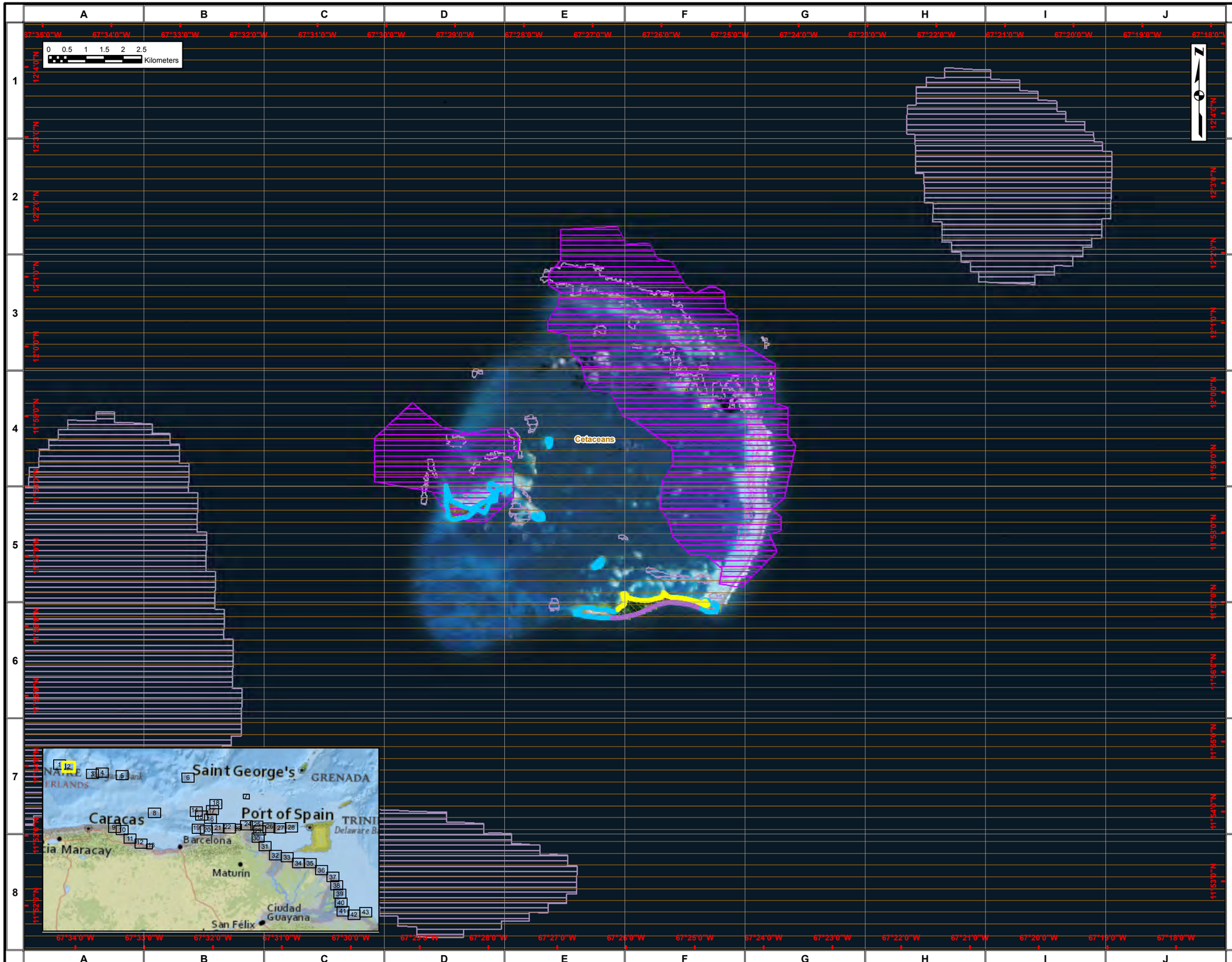
Marine National Protected Areas

- IUCN Category Not Reported
- Hazardous Reefs

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Isla de Aves (West)
Map 1 of 43
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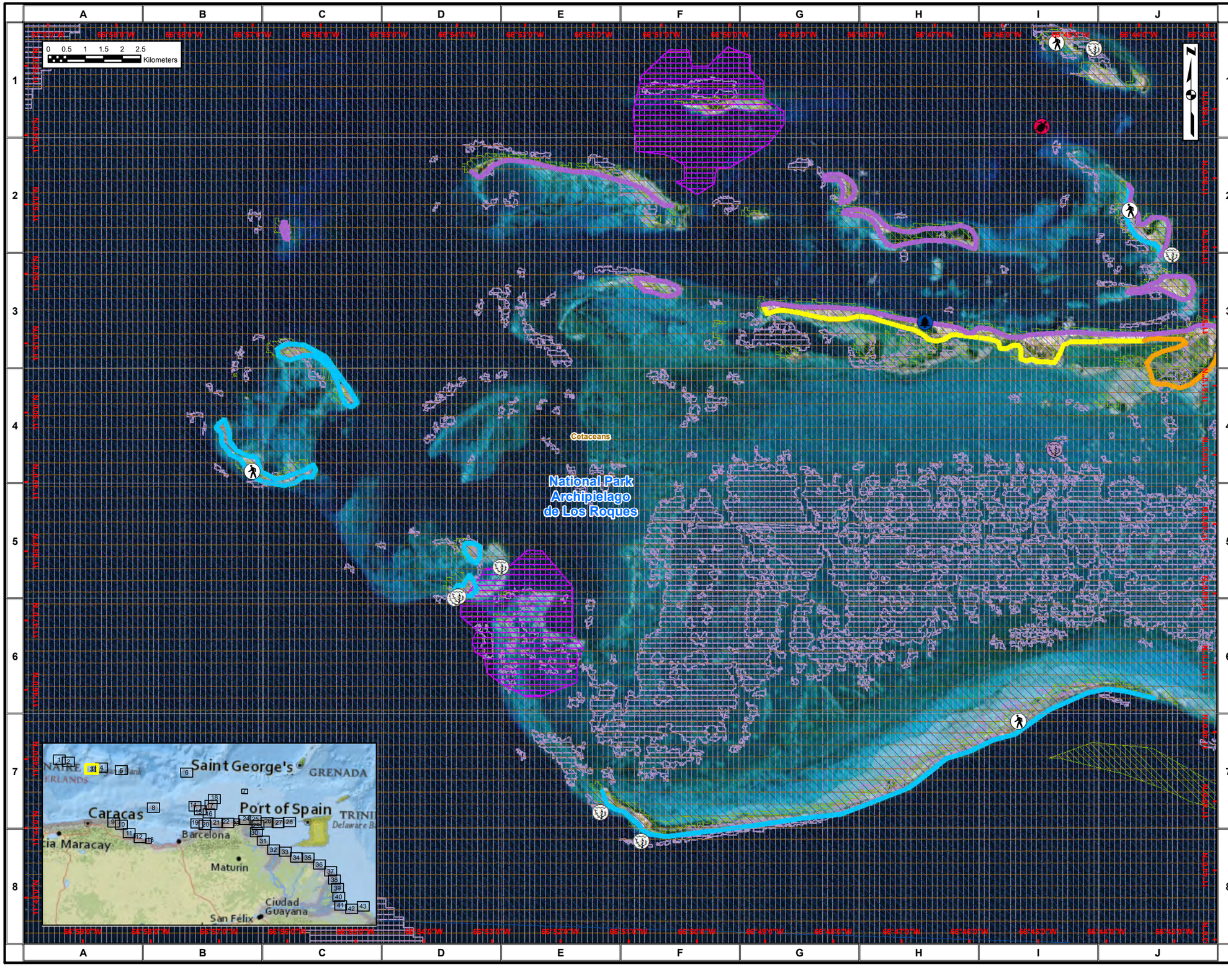
Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 3/4 - Sandy beaches or slopes
- 8 - Sheltered bedrock or man-made structures
- Nesting Birds
- Marine Mammals
- Coral Reefs
- Hazardous Reefs

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Isla de Aves (East)
Map 2 of 43
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Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 3/4 - Sandy beaches or slopes
- 8 - Sheltered bedrock or man-made structures
- 9B - Vegetated low banks
- Turtle Nesting
- Nesting Birds
- Marine Mammals
- Coral Reefs
- Coral Reef

REEF_SYSTEM

- Bleached Coral
- Seagrass

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category I, II

prj_ENV_ShorelineAccessPotential

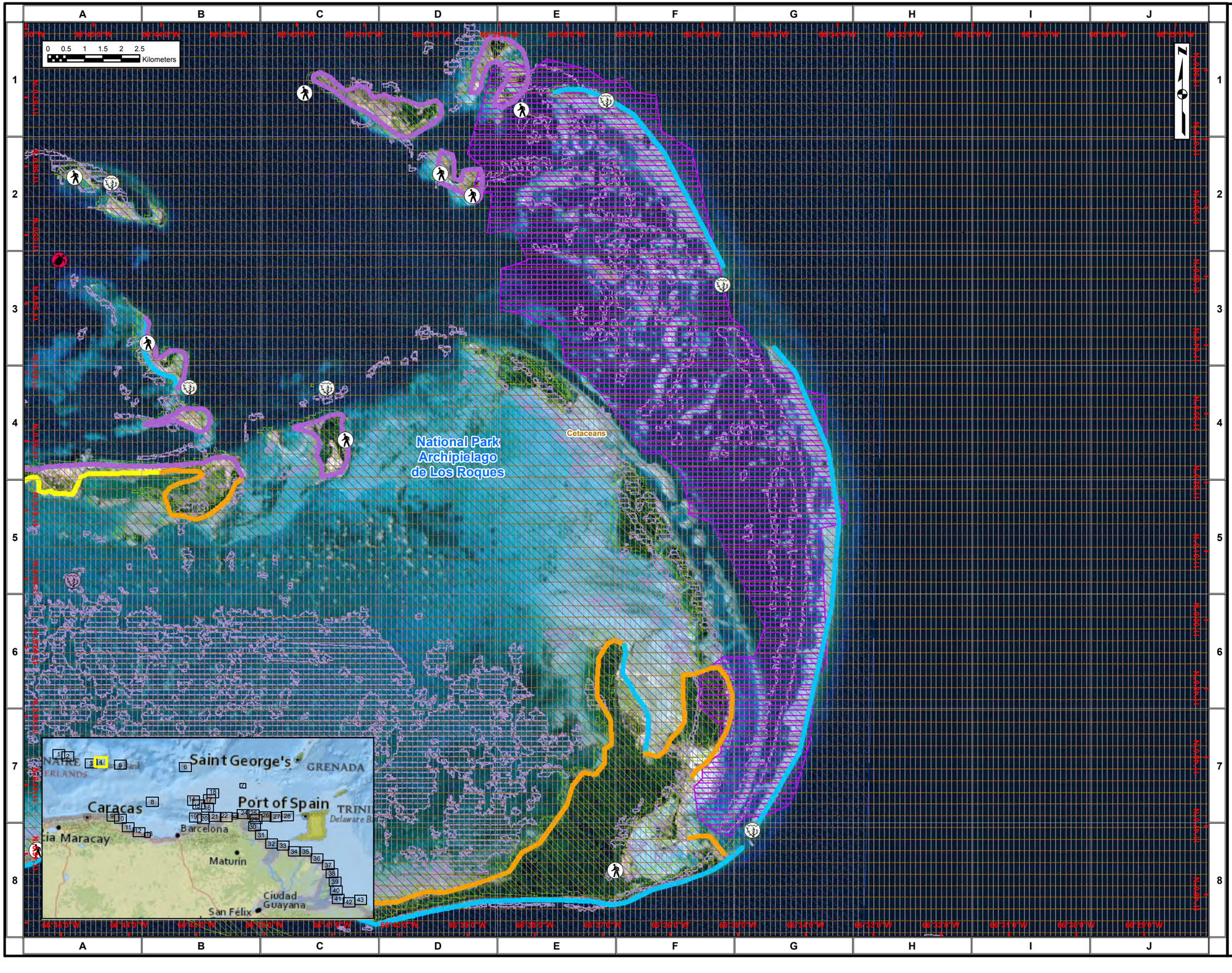
AccessType

- Access by Foot (Beach)
- Hazardous Reefs

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Isla los Roques (West)
Map 3 of 43
EEPGL
08 February 2017

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Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 3/4 - Sandy beaches or slopes
- 8 - Sheltered bedrock or man-made structures
- 9A - Sheltered tidal flats
- 9B - Vegetated low banks
- Turtle Nesting
- Nesting Birds
- Marine Mammals
- Coral Reefs
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REEF_SYSTEM

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- IUCN Category I, II

prj_ENV_ShorelineAccessPotential

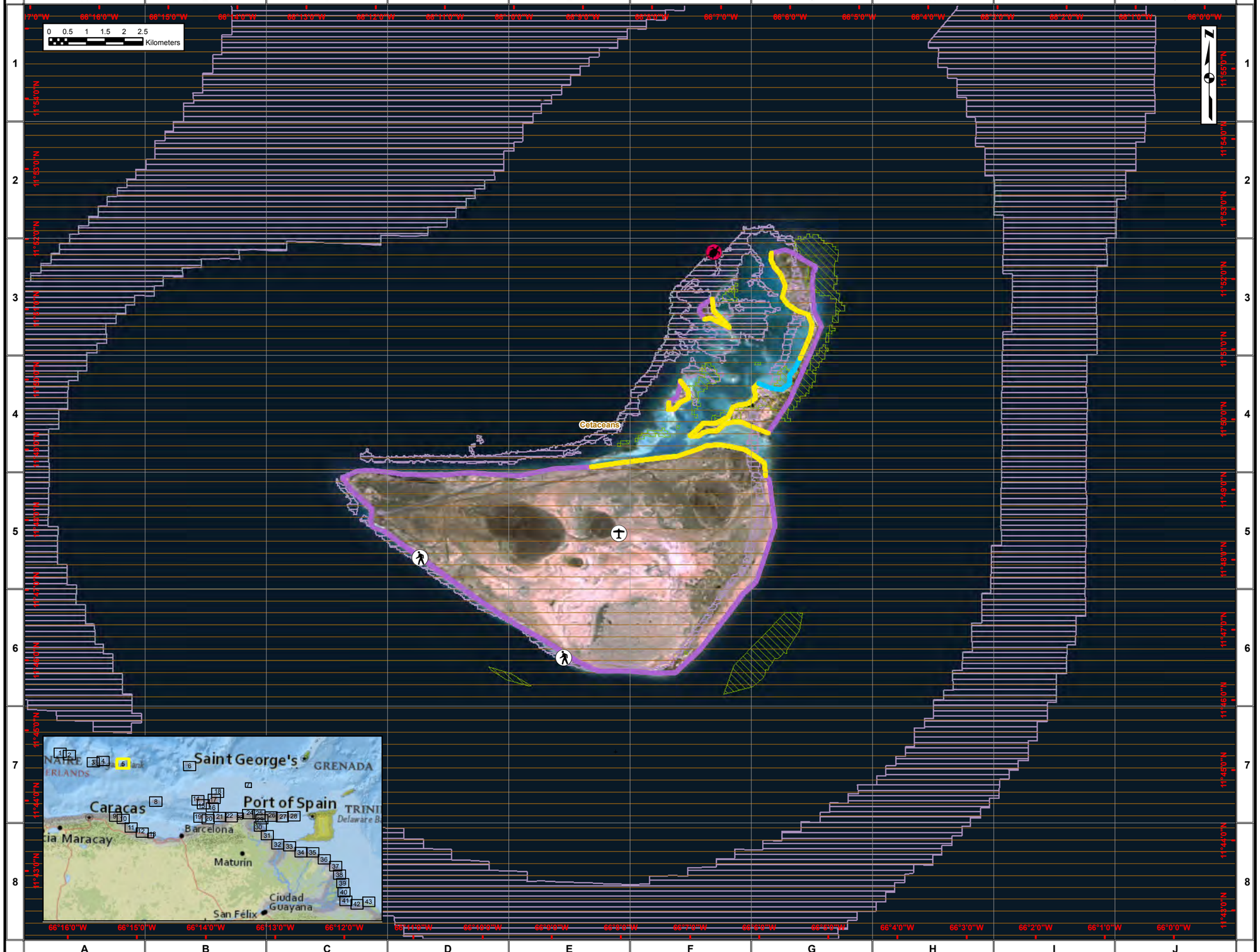
AccessType

- Access by Foot (Beach)
- Hazardous Reefs

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Isla los Roques (East)
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Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 3/4 - Sandy beaches or slopes
- 8A - Sheltered scarps in bedrock, mud or clay
- Turtle Nesting
- Nesting Birds
- Marine Mammals
- Coral Reefs

prj_ENV_ShorelineAccessPotential

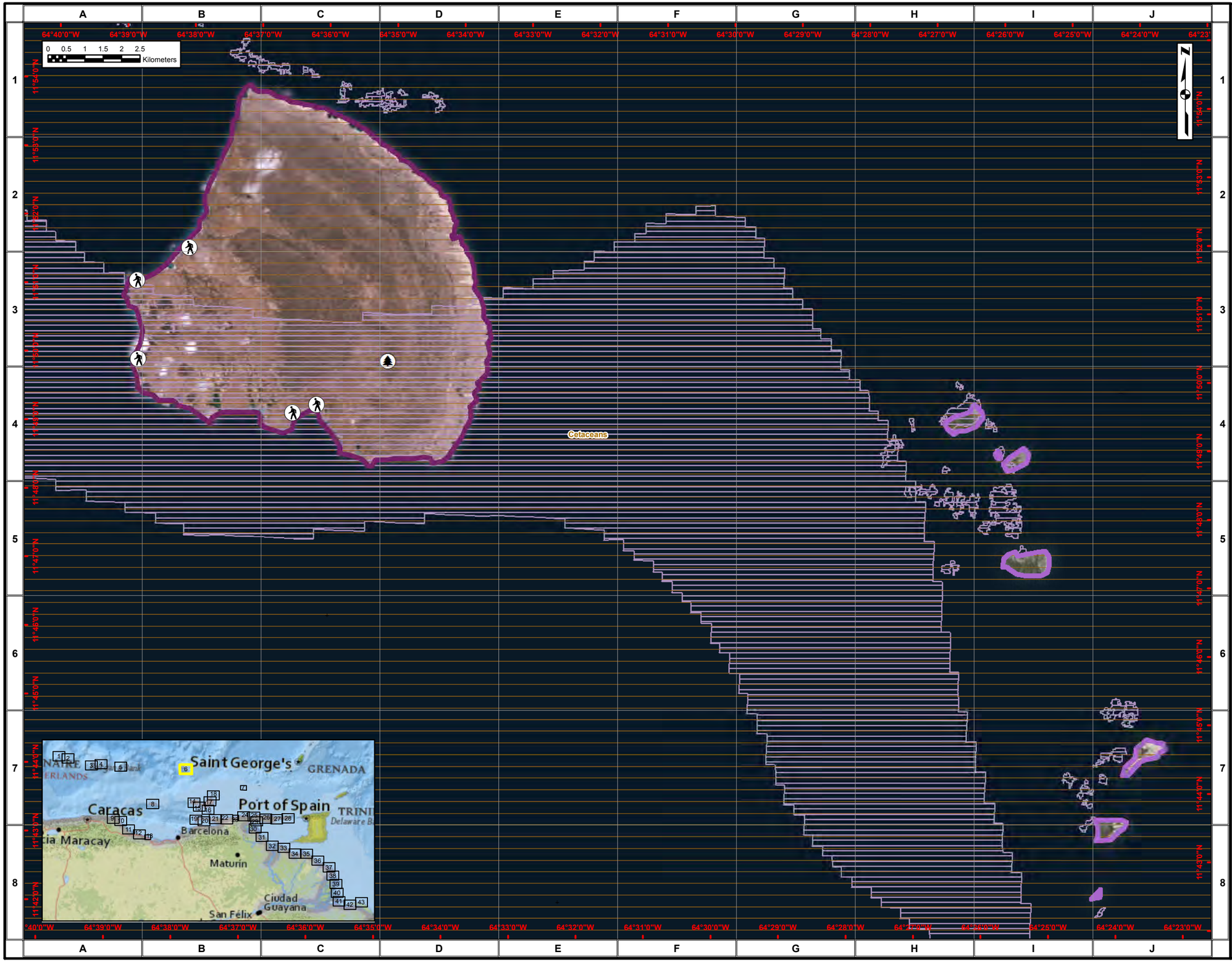
AccessType

- Access by Foot (Beach)

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Isla la Orchila
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1/2 - Exposed cliffs, scarp slopes or rock
- Marine Mammals
- Coral Reefs

Onshore National Protected Areas

- IUCN Category Not Reported

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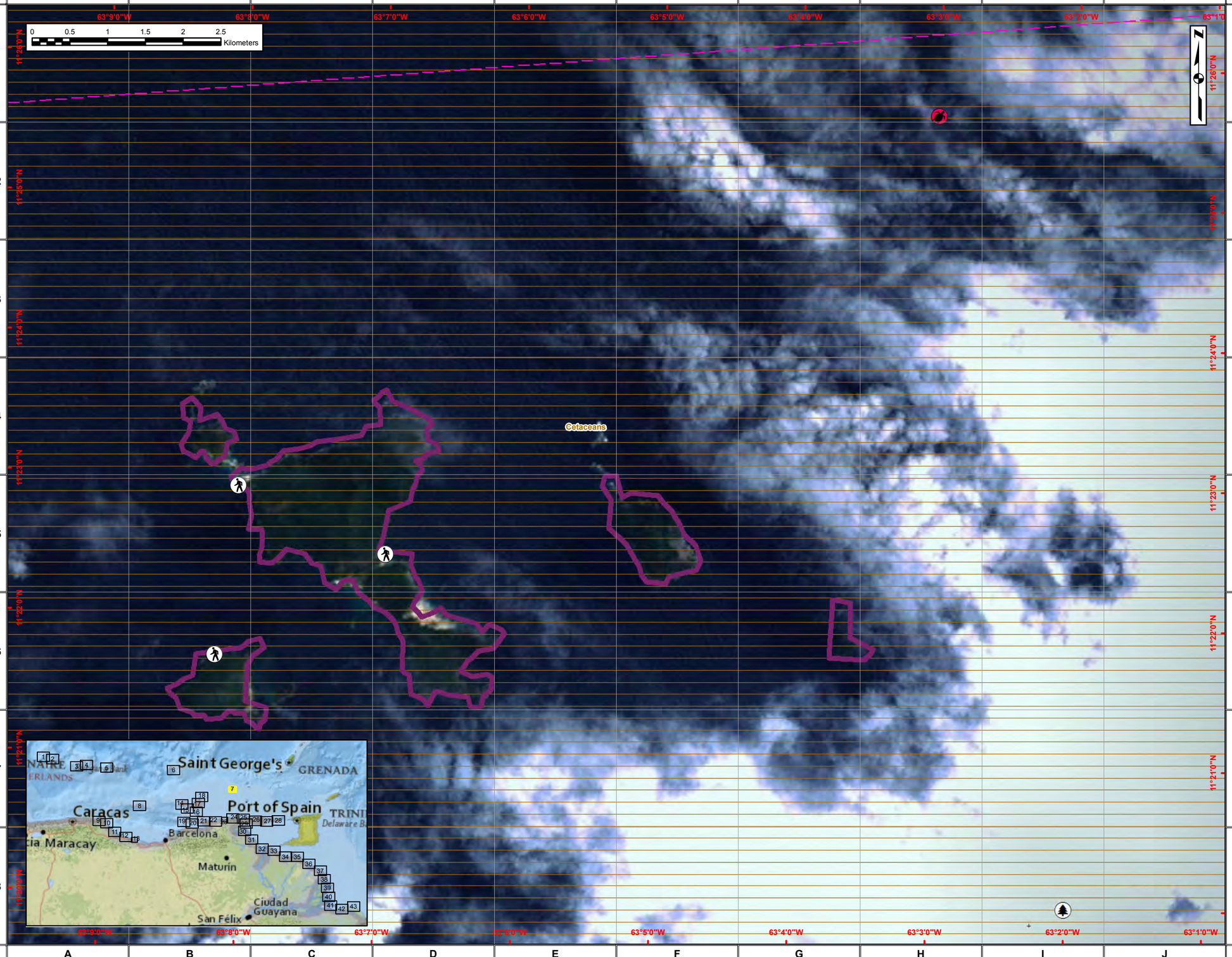
AccessType

- Access by Foot (Beach)

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Isla la Blanquilla
Map 6 of 43
EEPGL
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- Turtle Nesting
- Marine Mammals

Onshore National Protected Areas

- IUCN Category Not Reported

prj_ENV_ShorelineAccessPotential

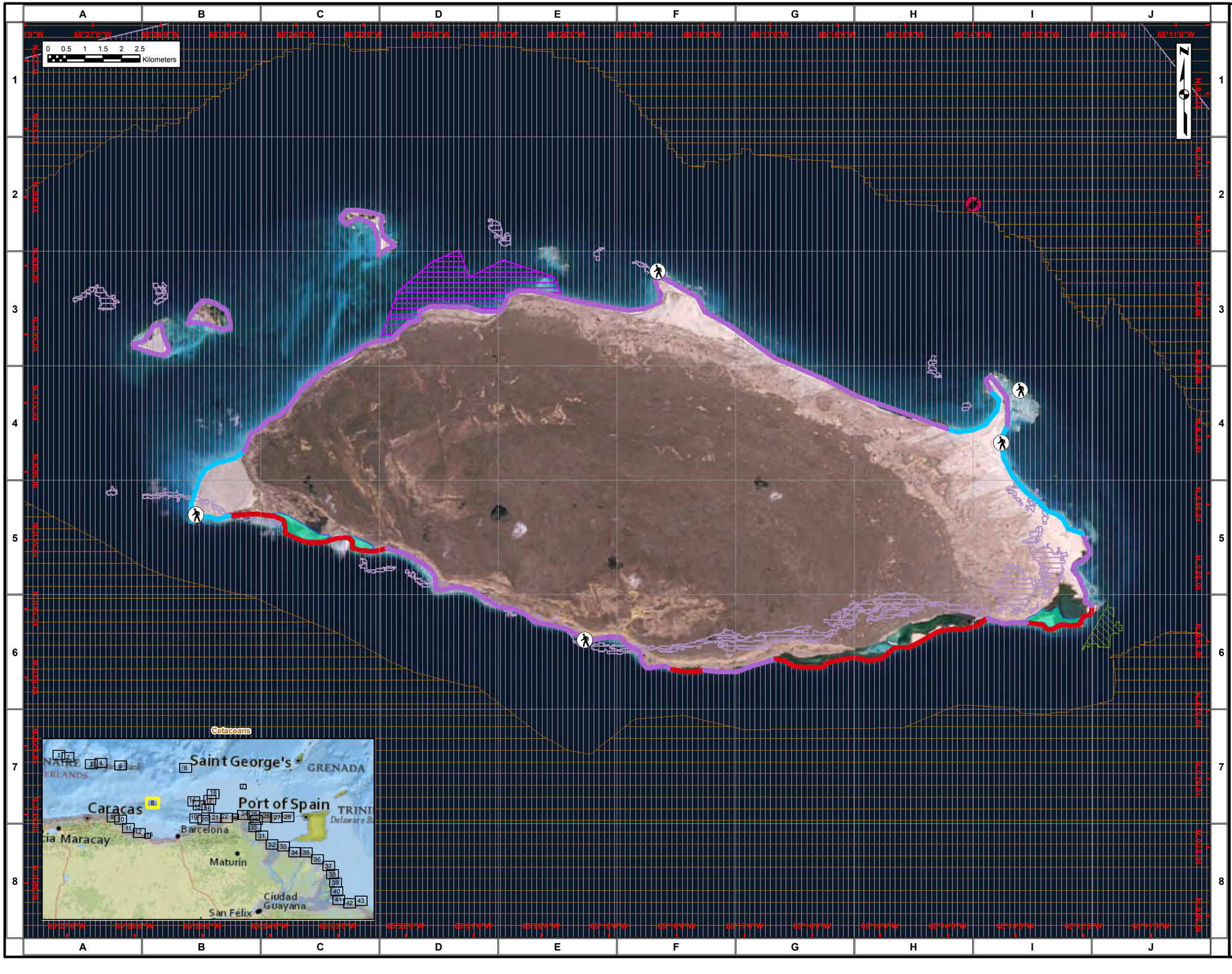
AccessType

- Access by Foot (Beach)
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Isla los Testigos
Map 7 of 43
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08 February 2017

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Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 3/4 - Sandy beaches or slopes
- 10A - Salt and brackish water marshes
- Turtle Nesting
- Nesting Birds
- Marine Mammals
- Coral Reefs
- Seagrass
- Lagoon

prj_ENV_ShorelineAccessPotential

AccessType

- Access by Foot (Beach)
- Hazardous Reefs

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Isla la Tortuga
Map 8 of 43
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08 February 2017

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Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 3A - Fine to medium-grained sand beaches
- 3/4 - Sandy beaches or slopes
- Turtle Nesting
- Seagrass

Onshore National Protected Areas

- IUCN Category III & IV
- IUCN Category V & VI

Onshore National Protected Areas

- IUCN Category I, II
- IUCN Category V, VI

prj_ENV_ShorelineAccessPotential

AccessType

- Access by Foot (Beach)
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Litoral Central
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Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 3/4 - Sandy beaches or slopes
- 8B - Sheltered, solid man-made structures
- 9B - Vegetated low banks
- 10C - Swamps
- Marine Mammals
- Seagrass

Onshore National Protected Areas

- IUCN Category V & VI

Onshore National Protected Areas

- IUCN Category V, VI

prj_ENV_ShorelineAccessPotential

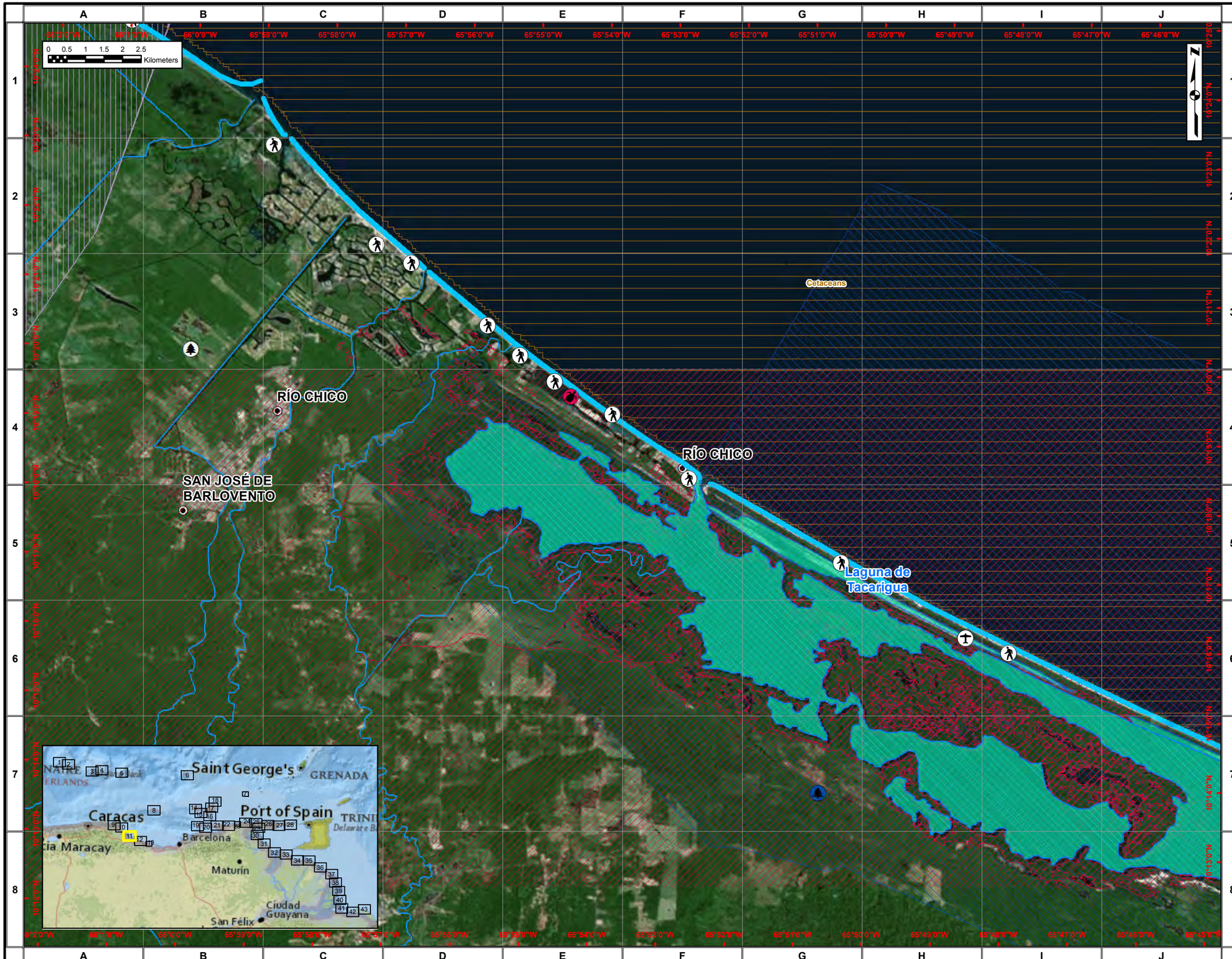
AccessType

- Access by Foot (Beach)
- Rivers
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Brion
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Legend

Shoreline Sensitivity (ESI)

- 3/4 - Sandy beaches or slopes
- Turtle Nesting
- Reptiles
- Marine Mammals
- Seagrass
- Lagoon

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category I, II

Onshore National Protected Areas

- IUCN Category Not Reported

prj_ENV_ShorelineAccessPotential

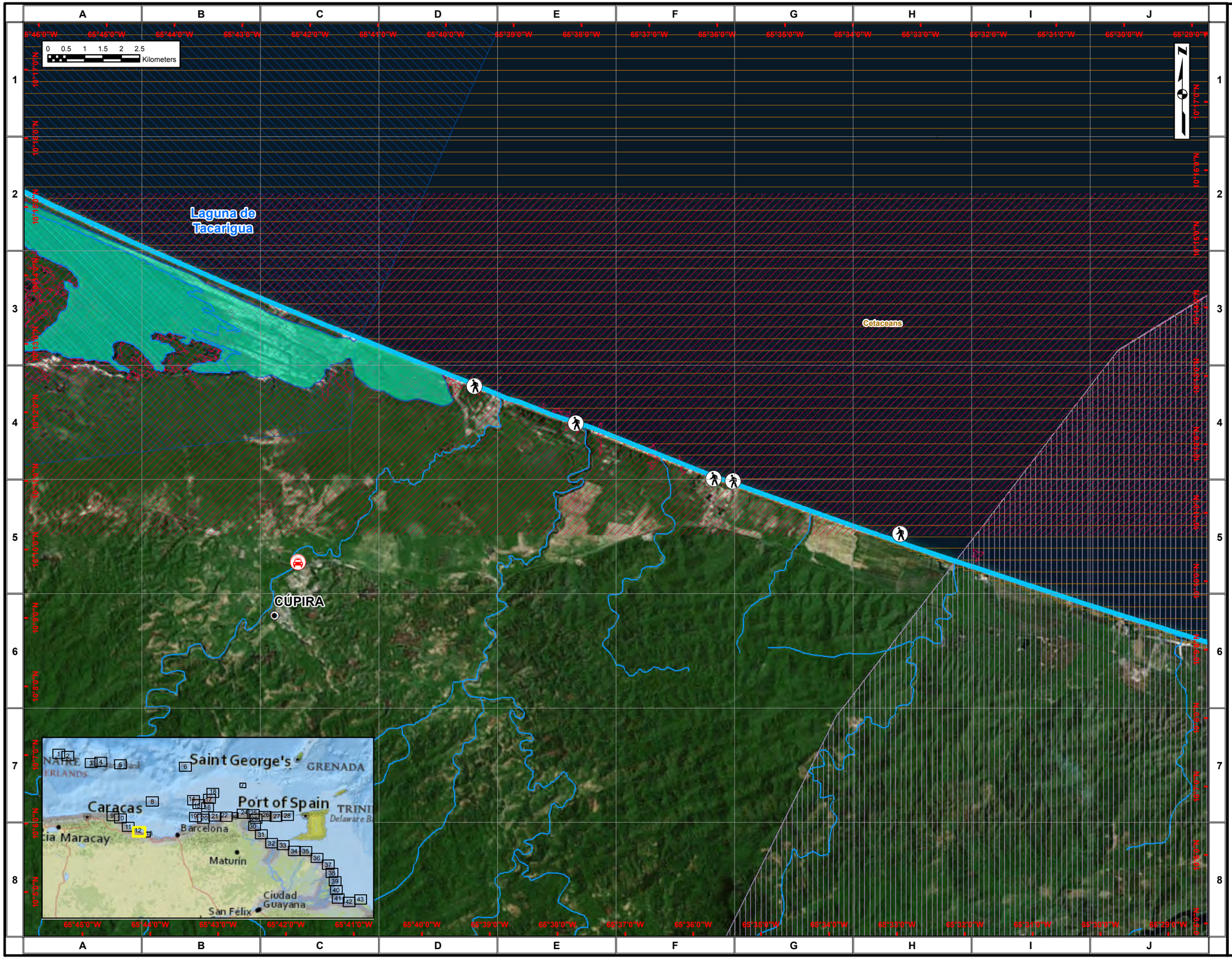
AccessType

- Access by Foot (Beach)
- Rivers
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Laguna de Tacarigua (West)
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Legend

Shoreline Sensitivity (ESI)

- 3/4 - Sandy beaches or slopes
- Reptiles
- Marine Mammals
- Seagrass
- Lagoon
- IUCN Category I, II
- Police Stations

prj_ENV_ShorelineAccessPotential

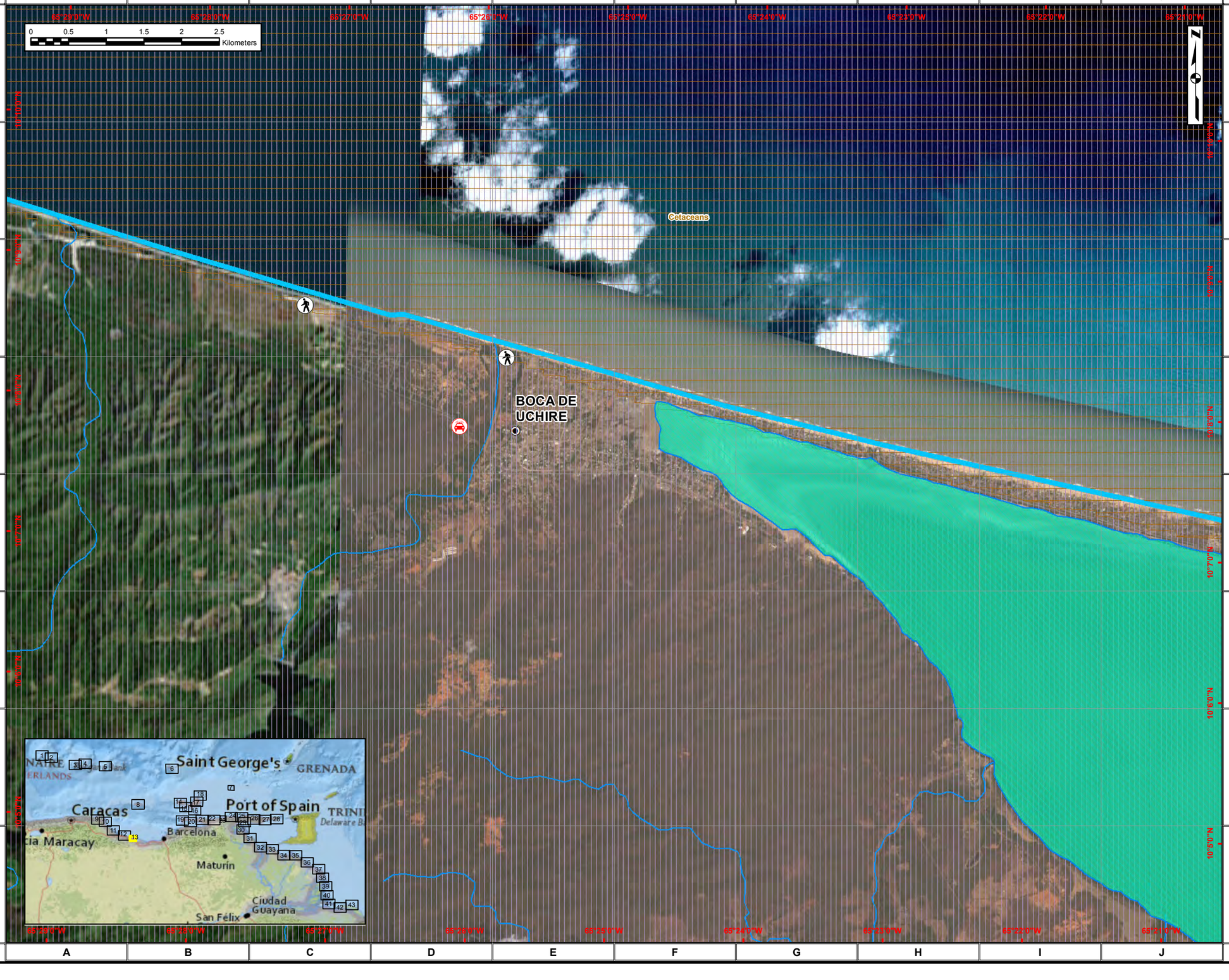
AccessType

- Access by Foot (Beach)
- Rivers
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Laguna de Tacarigua (West)
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Legend

Shoreline Sensitivity (ESI)

- 3/4 - Sandy beaches or slopes
- Marine Mammals
- Seagrass
- Lagoon
- Police Stations

prj_ENV_ShorelineAccessPotential

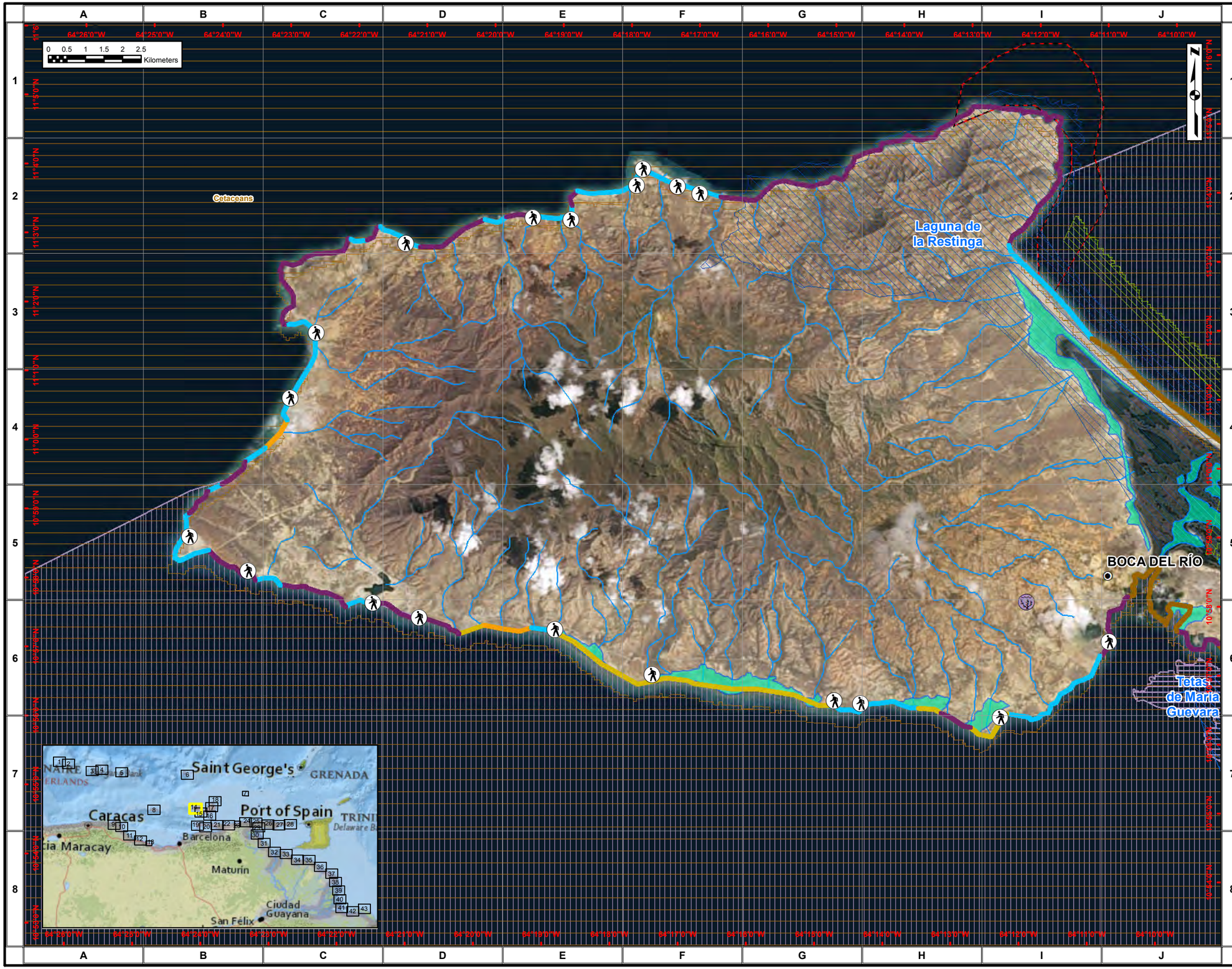
AccessType

- Access by Foot (Beach)
- Rivers
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - San Juan de Capistrano
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 7 - Exposed tidal flats
- 9A - Sheltered tidal flats
- 9B - Vegetated low banks
- 10D - Mangroves
- Nesting Birds
- Marine Mammals
- Coral Reefs
- Coral Reef
- Seagrass
- Lagoon
- IUCN Category I, II
- IUCN Category III, IV

prj_ENV_ShorelineAccessPotential

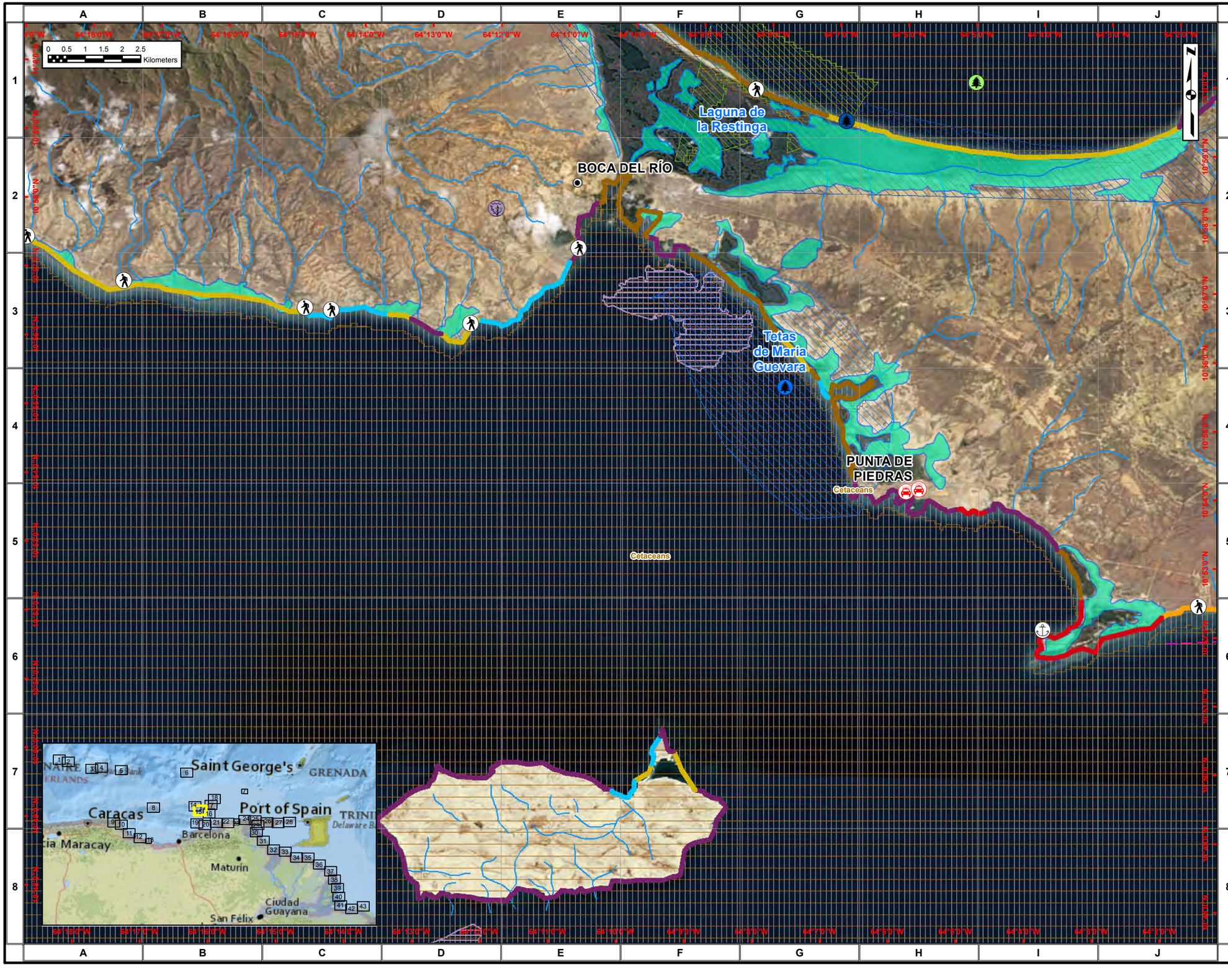
AccessType

- Access by Foot (Beach)
- Rivers
- Hazardous Areas
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Peninsula de Macano
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 7 - Exposed tidal flats
- 9B - Vegetated low banks
- 10A - Salt and brackish water marshes
- 10D - Mangroves
- Nesting Birds
- Marine Mammals
- Coral Reefs
- Coral Reef
- Seagrass
- Lagoon

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category III & IV
- IUCN Category I, II
- IUCN Category III, IV

Onshore National Protected Areas

- IUCN Category V & VI
- Police Stations
- Port or Marina

prj_ENV_ShorelineAccessPotential

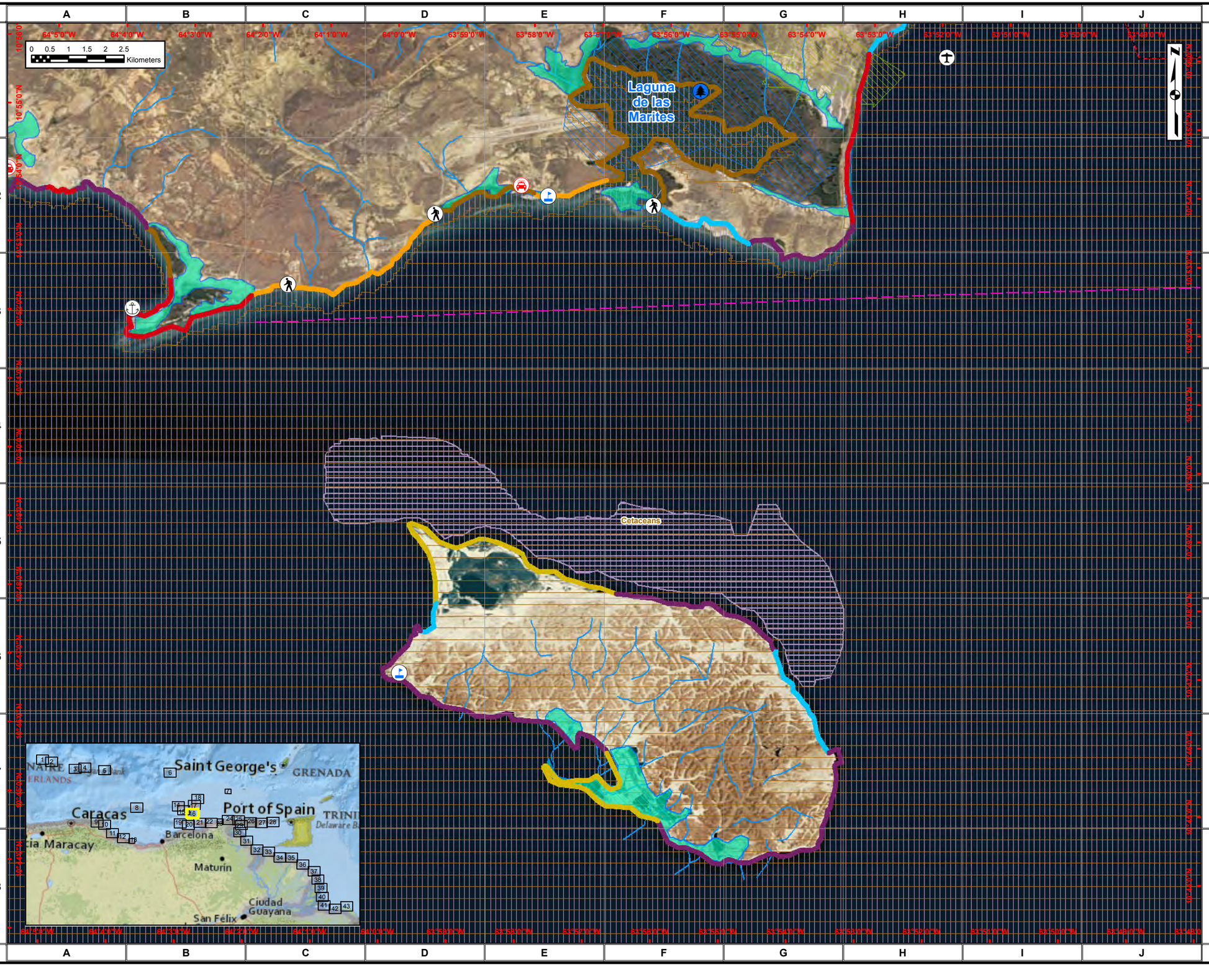
AccessType

- Access by Foot (Beach)
- Rivers
- Shipping Route
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Laguna de la Restinga
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 7 - Exposed tidal flats
- 9B - Vegetated low banks
- 10A - Salt and brackish water marshes
- 10D - Mangroves
- Nesting Birds
- Marine Mammals
- Coral Reefs
- Seagrass
- Lagoon

Marine National Protected Areas

- IUCN Category III & IV
- IUCN Category III, IV
- Police Stations
- School
- Port or Marina

prj_ENV_ShorelineAccessPotential

AccessType

- Access by Foot (Beach)
- Rivers
- Hazardous Areas
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Laguna de las Marites / Isla Coche
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0 0.5 1 1.5 2 2.5 Kilometers

N

Cetaceans

JUANGRIEGO

SANTA ANA

LA PLAZA DE PARAGUACHÍ

Cerros Matasiete y Guayamurí

LA ASUNCIÓN

SAN JUAN BAUTISTA

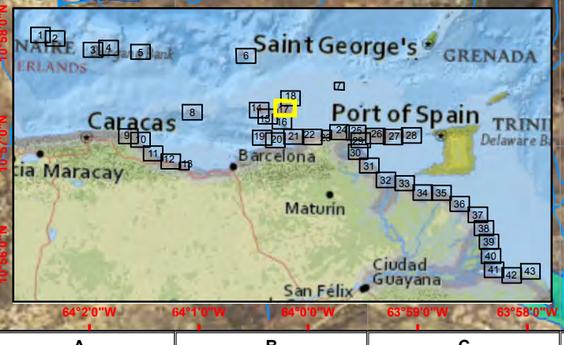
Cerro El Copey

EL VALLE DEL ESPÍRITU SANTO

PORLAMAR

Laguna de la Restinga

Laguna de las Marites



Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 7 - Exposed tidal flats
- 10A - Salt and brackish water marshes
- 10D - Mangroves
- Turtle Nesting
- Nesting Birds
- Marine Mammals
- Coral Reefs
- Seagrass
- Lagoon

Marine National Protected Areas

- IUCN Category III & IV
- IUCN Category I, II
- IUCN Category III, IV

Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category V & VI
- IUCN Category Not Reported

Onshore National Protected Areas

- IUCN Category I, II
- IUCN Category Not Reported
- School

prj_ENV_ShorelineAccessPotential

AccessType

- Access by Foot (Beach)
- Rivers
- Hazardous Areas
- State Capital
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Isla de Margarita
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0 0.5 1 1.5 2 2.5 Kilometers

N

Cotaceans

LA PLAZA DE PARAGUACHÍ

Saint George's
GRENADA
Caracas
Port of Spain
Barcelona
Maturin
Ciudad Guayana
San Félix

Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- Turtle Nesting
- Nesting Birds
- Marine Mammals
- Seagrass
- Lagoon

Onshore National Protected Areas

- IUCN Category Not Reported

prj_ENV_ShorelineAccessPotential

AccessType

- Access by Foot (Beach)
- Rivers
- Hazardous Areas
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Isla de Margarita (North)
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0 0.5 1 1.5 2 2.5 Kilometers

N

Cataceans

ARAYA

Saint George's
GRENADA
Caracas
Port of Spain
TRINI
Barcelona
Maturin
Ciudad Guayana
San Félix

Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 9C - Hypersaline tidal flats
- 10A - Salt and brackish water marshes
- Marine Mammals
- Seagrass
- Police Stations
- School
- College

prj_ENV_ShorelineAccessPotential

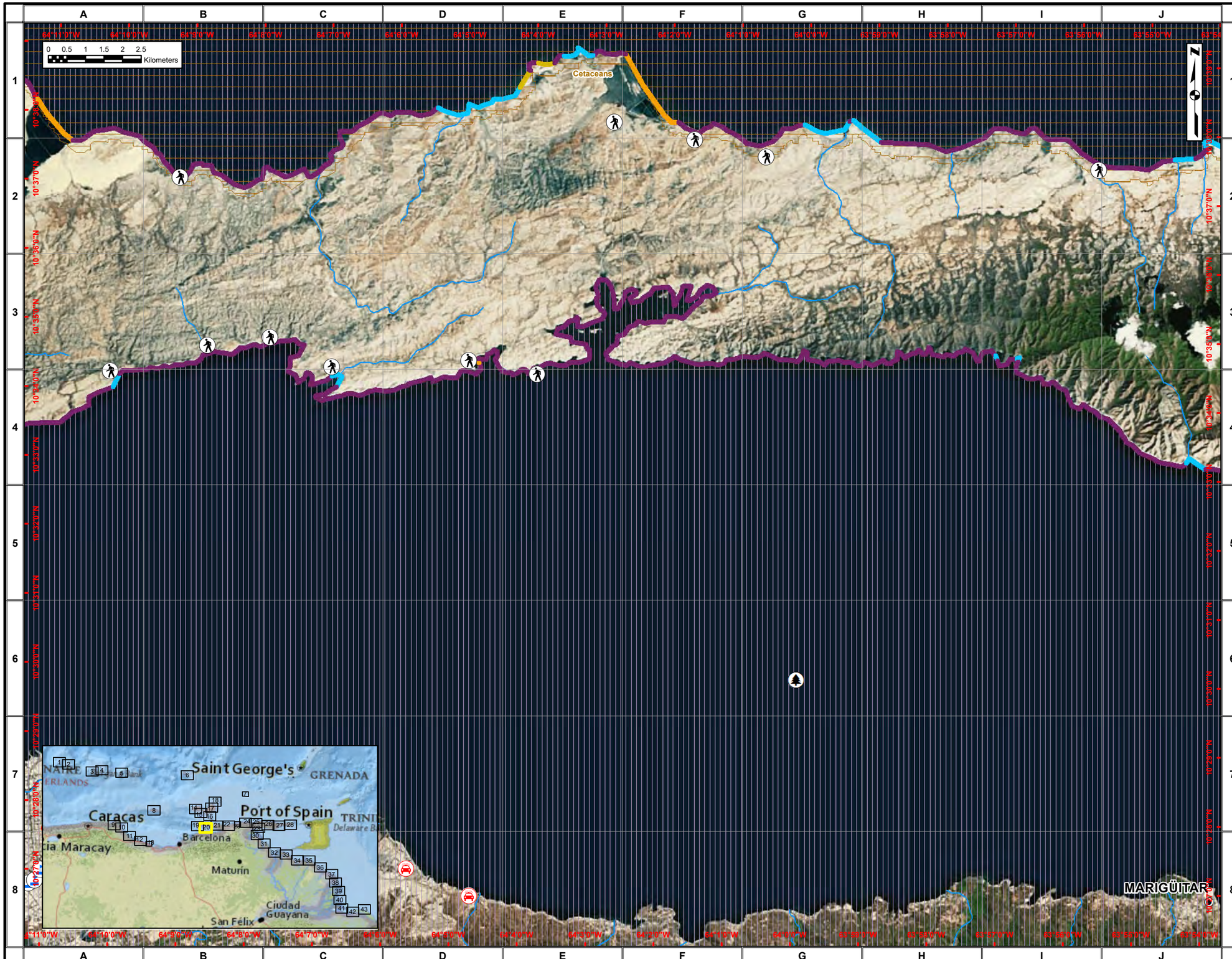
AccessType

- Access by Foot (Beach)
- Rivers
- Wreck
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Punta Arenas
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 7 - Exposed tidal flats
- 9A - Sheltered tidal flats
- 9C - Hypersaline tidal flats
- Marine Mammals
- Seagrass

Onshore National Protected Areas

- IUCN Category Not Reported
- Police Stations
- Kindergarten
- School
- College

prj_ENV_ShorelineAccessPotential

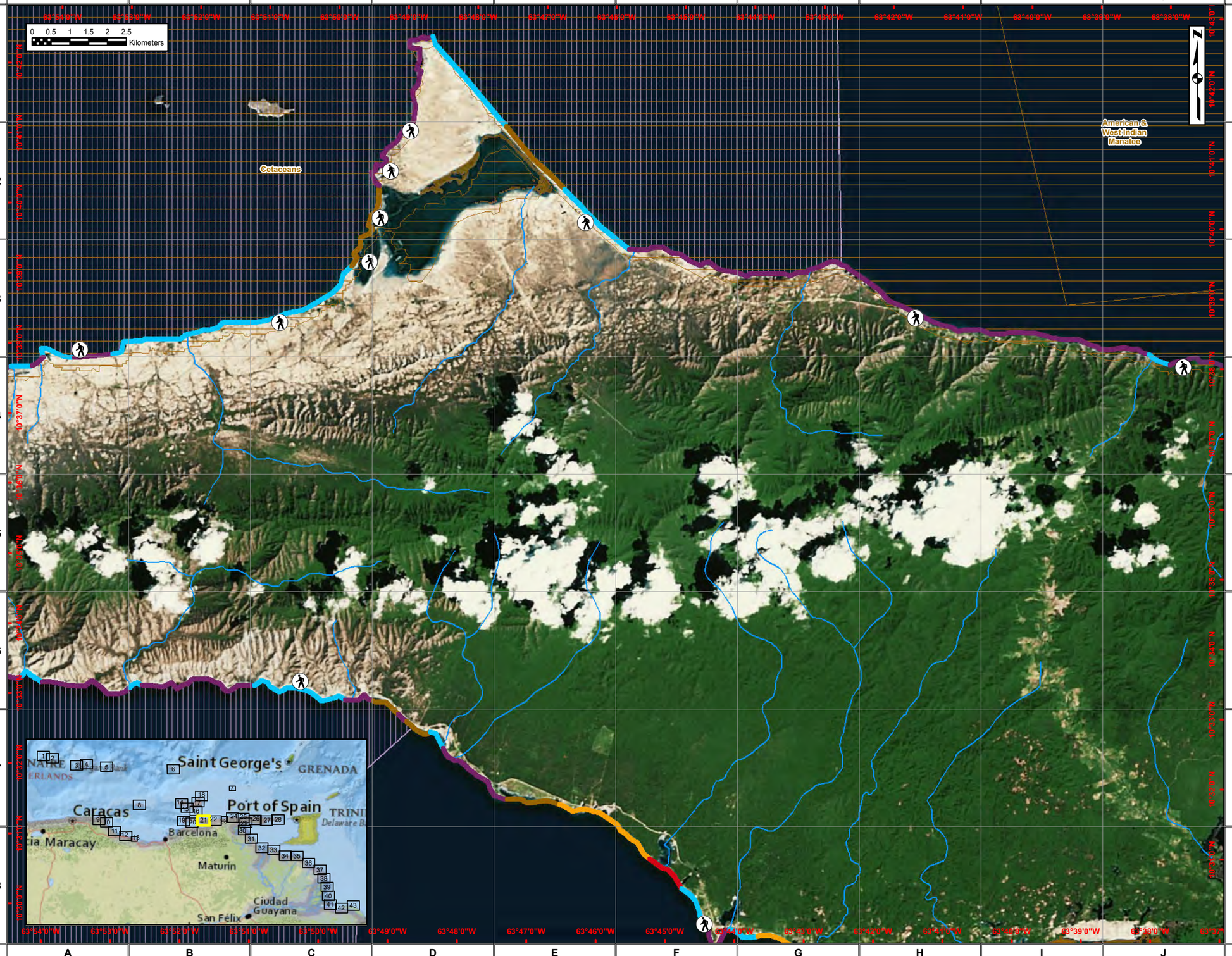
AccessType

- Access by Foot (Beach)
- Rivers
- State Capital
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Cumana
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 9B - Vegetated low banks
- 10A - Salt and brackish water marshes
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Marine Mammals
- Seagrass

prj_ENV_ShorelineAccessPotential

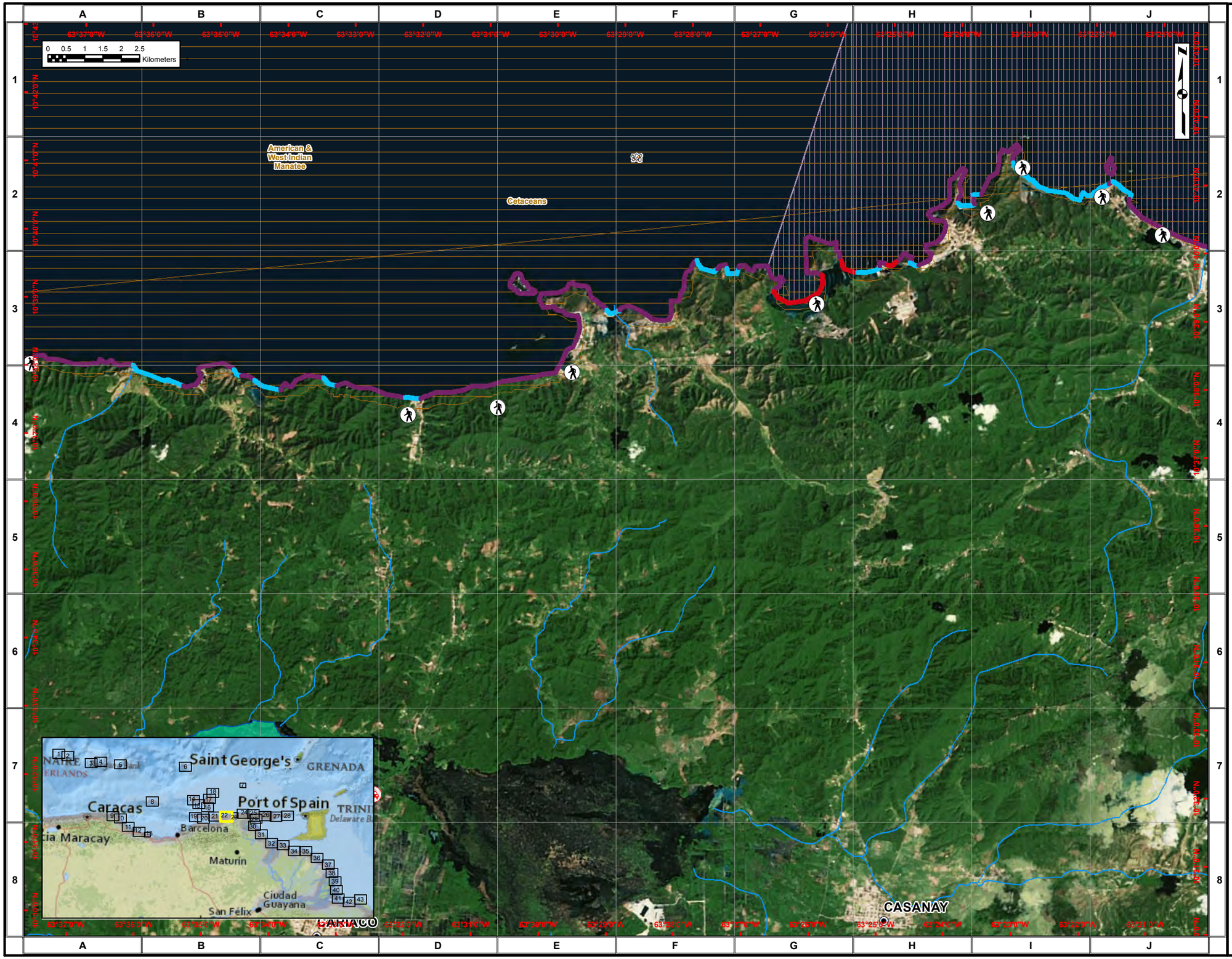
AccessType

- Access by Foot (Beach)
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Cruz Salmeron Acosta
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 10A - Salt and brackish water marshes
- Marine Mammals
- Seagrass
- Lagoon
- Police Stations

prj_ENV_ShorelineAccessPotential

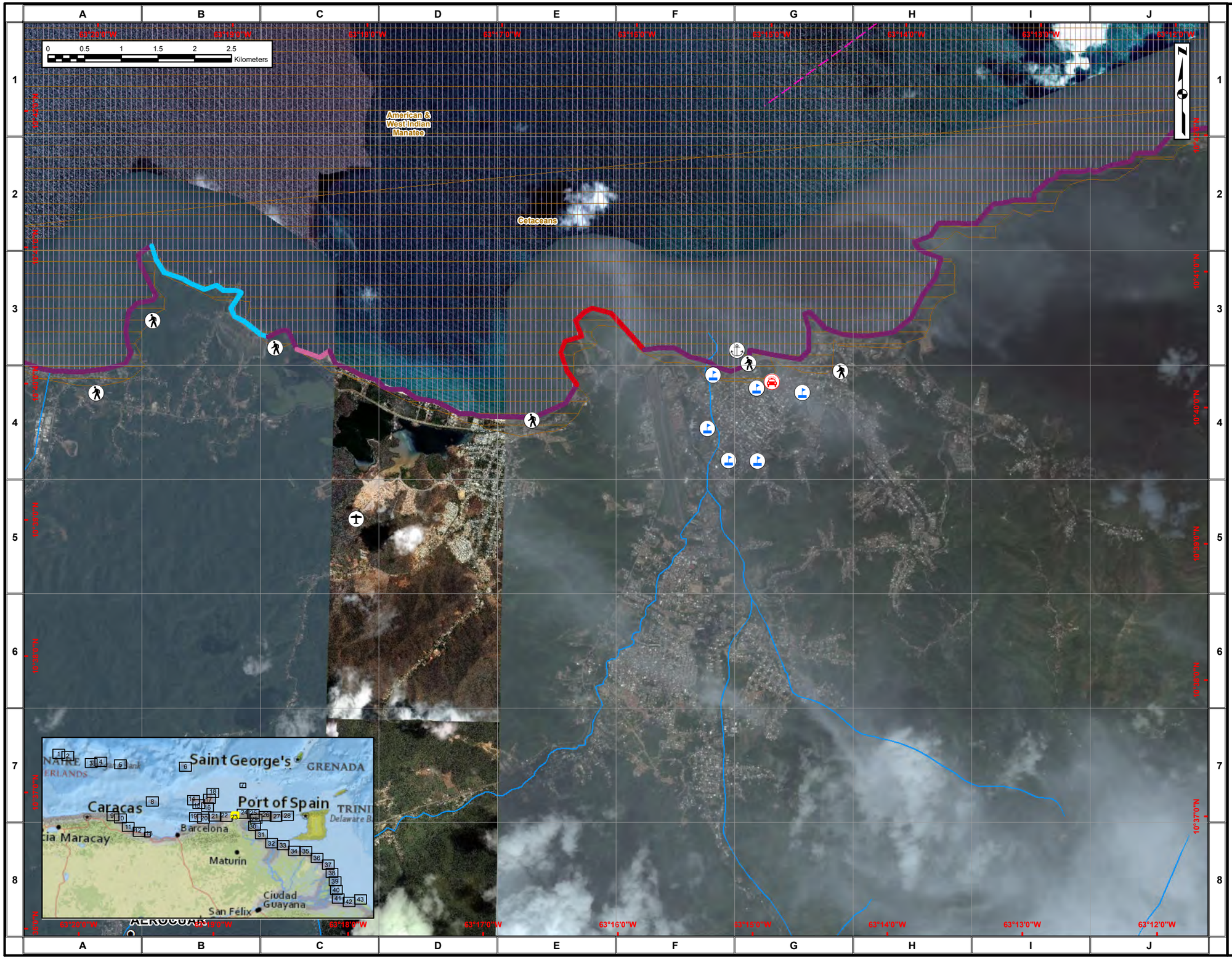
AccessType

- Access by Foot (Beach)
- Rivers
- Rock
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Saucedo to La Esmeralda
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 10A - Salt and brackish water marshes
- 10B - Freshwater marsh
- Marine Mammals
- Seagrass
- Police Stations
- School
- Port or Marina

prj_ENV_ShorelineAccessPotential

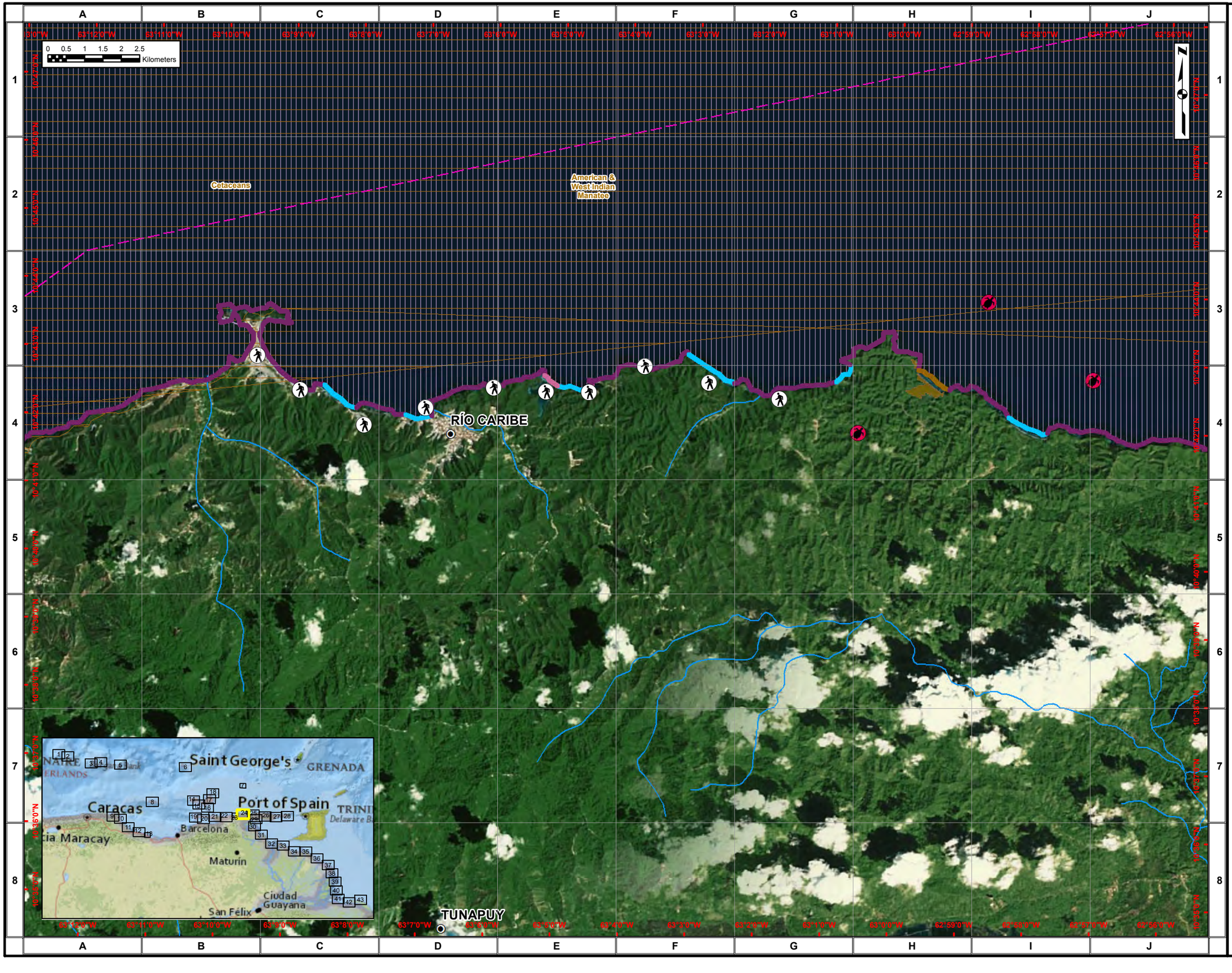
AccessType

- Access by Foot (Beach)
- Rivers
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Carupano
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 10B - Freshwater marsh
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- Marine Mammals
- Seagrass

prj_ENV_ShorelineAccessPotential

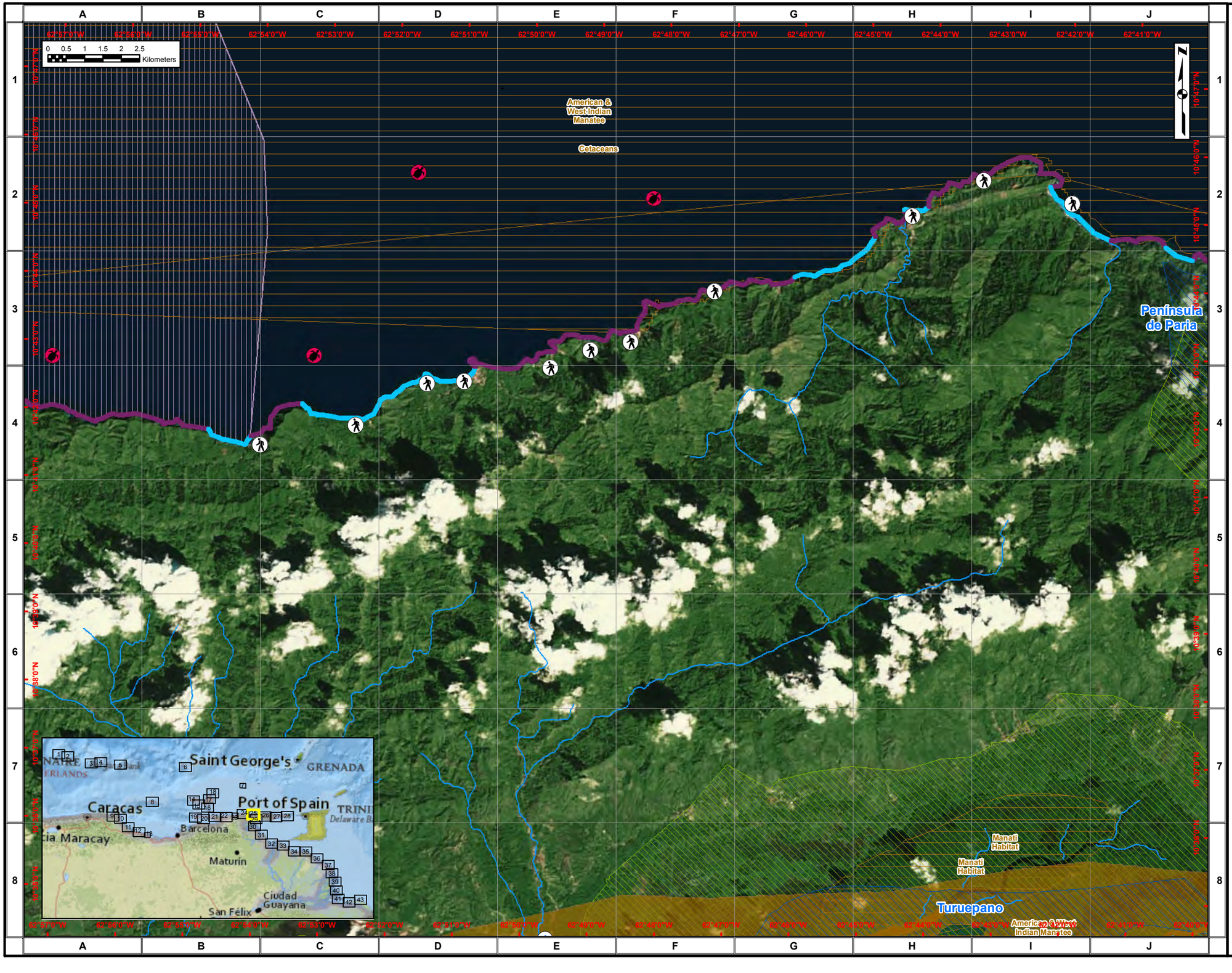
AccessType

- Access by Foot (Beach)
- Rivers
- Shipping Route
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - El Morro de Puerto Santo
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 3/4 - Sandy beaches or slopes
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- Nesting Birds
- Marine Mammals
- Seagrass
- IUCN Category I, II
- School

prj_ENV_ShorelineAccessPotential

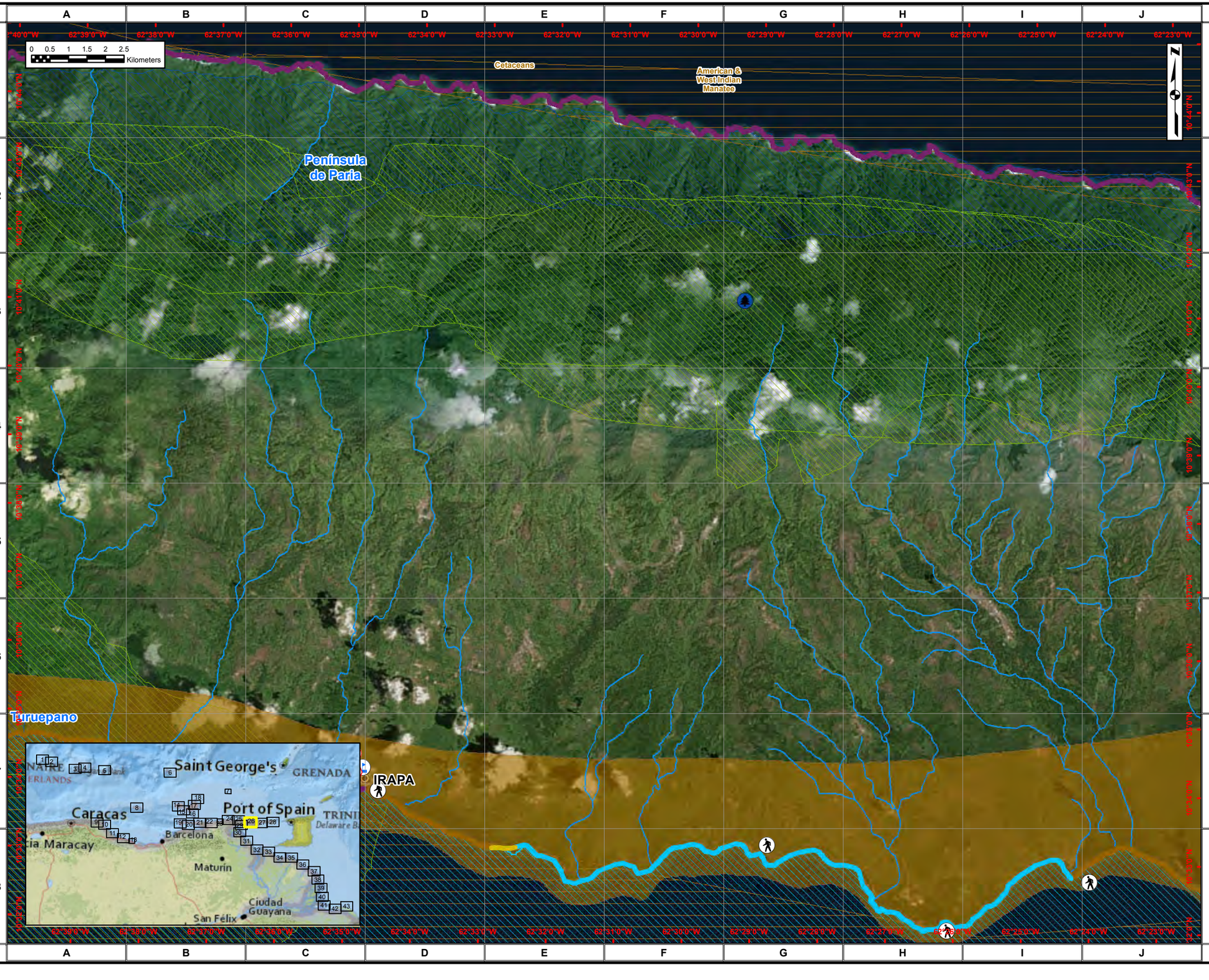
AccessType

- Access by Foot (Beach)
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Peninsula de Paria (West)
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 7 - Exposed tidal flats
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Nesting Birds
- Marine Mammals

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category I, II
- Hospitals
- Police Stations
- School

prj_ENV_ShorelineAccessPotential

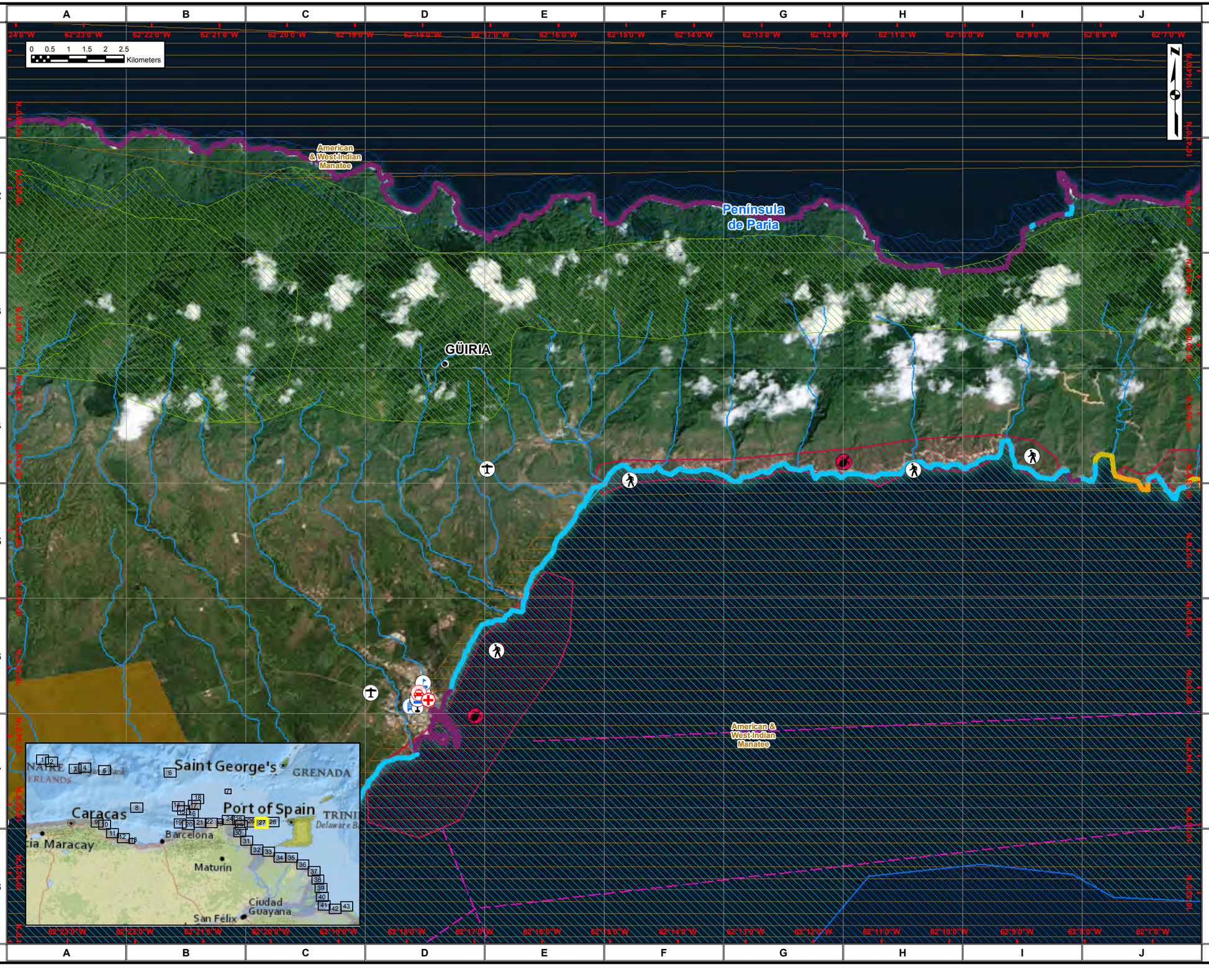
AccessType

- Access by Foot (Beach)
- Rivers
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Peninsula de Paria (West-Central)
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 7 - Exposed tidal flats
- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- Nesting Birds
- Turtle Nesting Areas
- Marine Mammals
- IUCN Category I, II
- Hospitals
- Police Stations
- School
- Port or Marina
- Places of Worship
- Government Facilities

prj_ENV_ShorelineAccessPotential

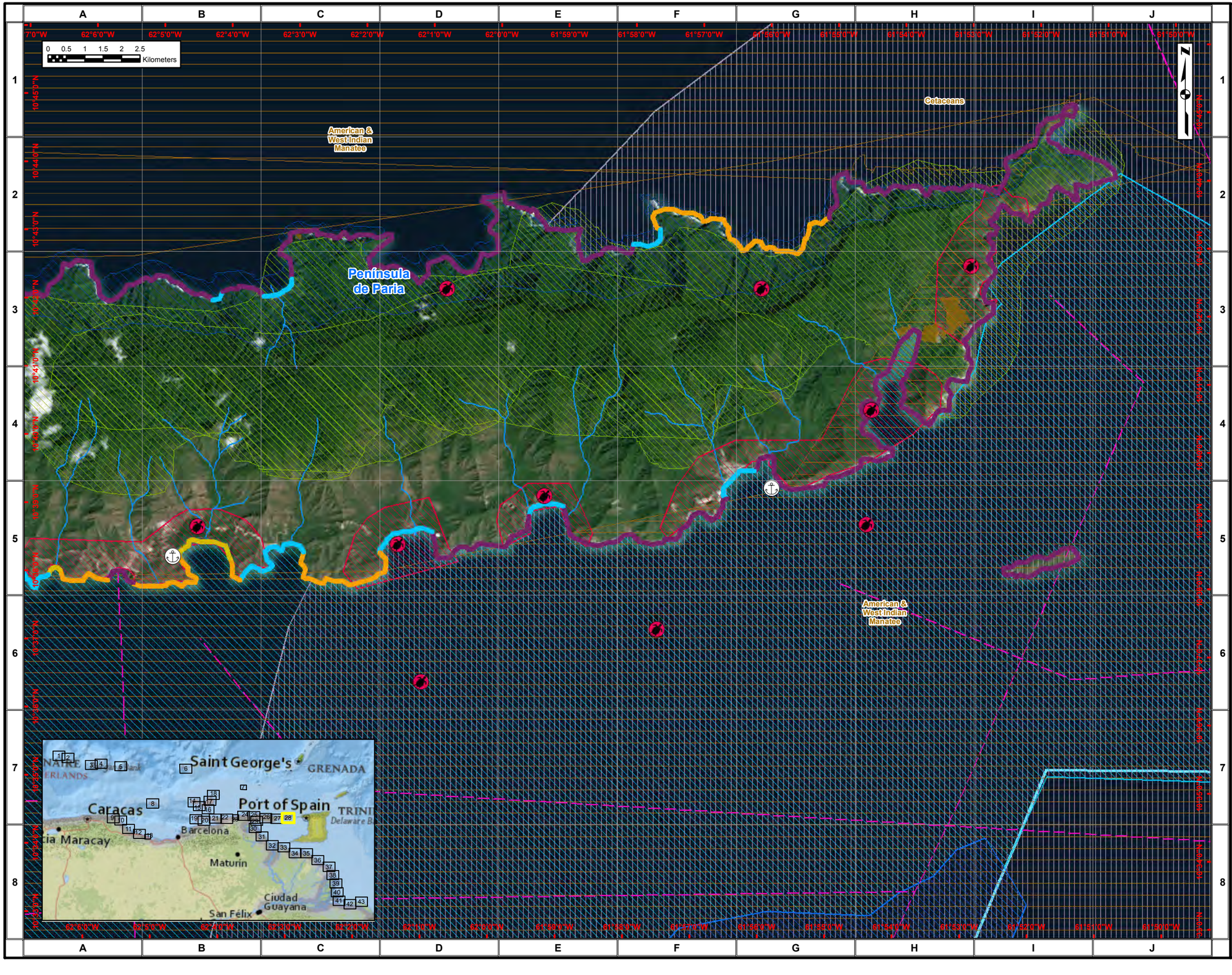
AccessType

- Access by Foot (Beach)
- Rivers
- Shipping Route
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Peninsula de Paria (East-Central)
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 3/4 - Sandy beaches or slopes
- 7 - Exposed tidal flats
- 9B - Vegetated low banks
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- Nesting Birds
- Turtle Nesting Areas
- Marine Mammals
- Seagrass
- IUCN Category I, II
- Port or Marina
- Rivers
- Shipping Route
- Territorial Waters Boundary

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Peninsula de Paria (East)
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Legend

Shoreline Sensitivity (ESI)

- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Nesting Birds
- Marine Mammals
- IUCN Category I, II

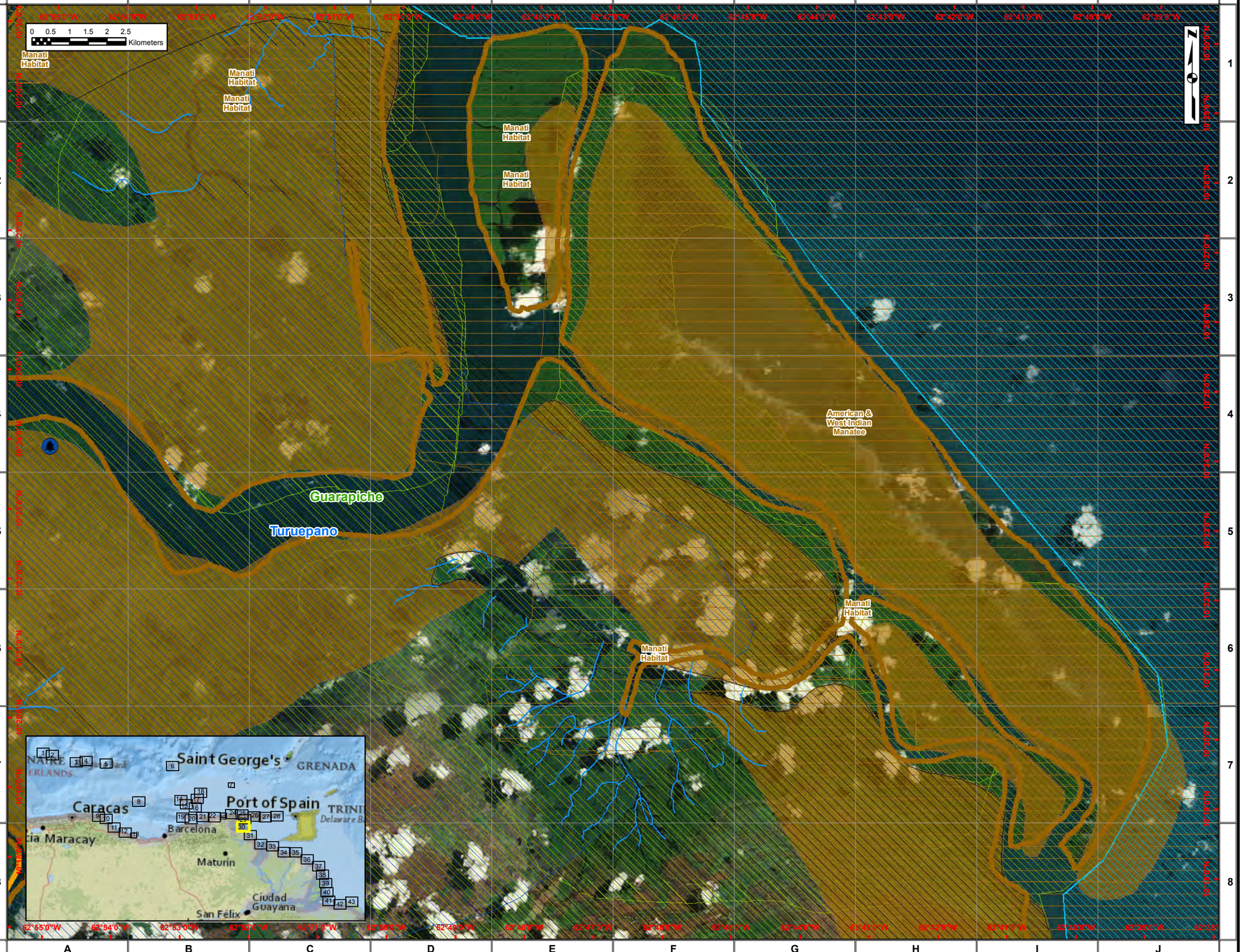
Onshore National Protected Areas

- IUCN Category Not Reported
- Hospitals
- Police Stations
- School
- Places of Worship
- Rivers
- Municipal Capital

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Turuepano (North)
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Legend

Shoreline Sensitivity (ESI)

- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Nesting Birds
- Marine Mammals

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category I, II

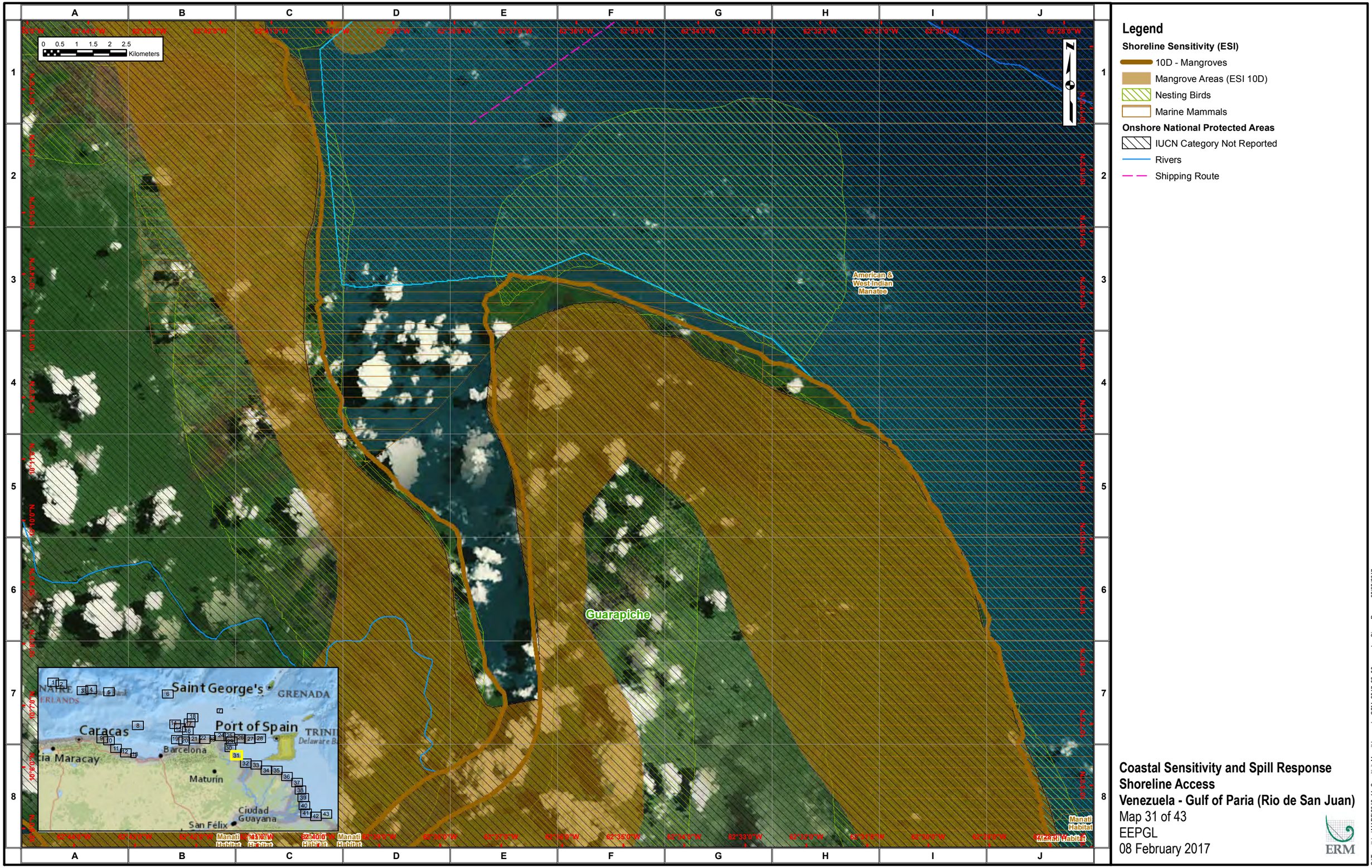
Onshore National Protected Areas

- IUCN Category Not Reported
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Turuepano (South)
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Legend

Shoreline Sensitivity (ESI)

- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Nesting Birds
- Marine Mammals

Onshore National Protected Areas

- IUCN Category Not Reported
- Rivers
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Gulf of Paria (Rio de San Juan)
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0 0.5 1 1.5 2 2.5 Kilometers

N

Manati Habitat

Manati Habitat

American & West Indian Manatee

Guarapiche

Manati Habitat

Manati Habitat



Legend

Shoreline Sensitivity (ESI)

- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Nesting Birds
- Marine Mammals

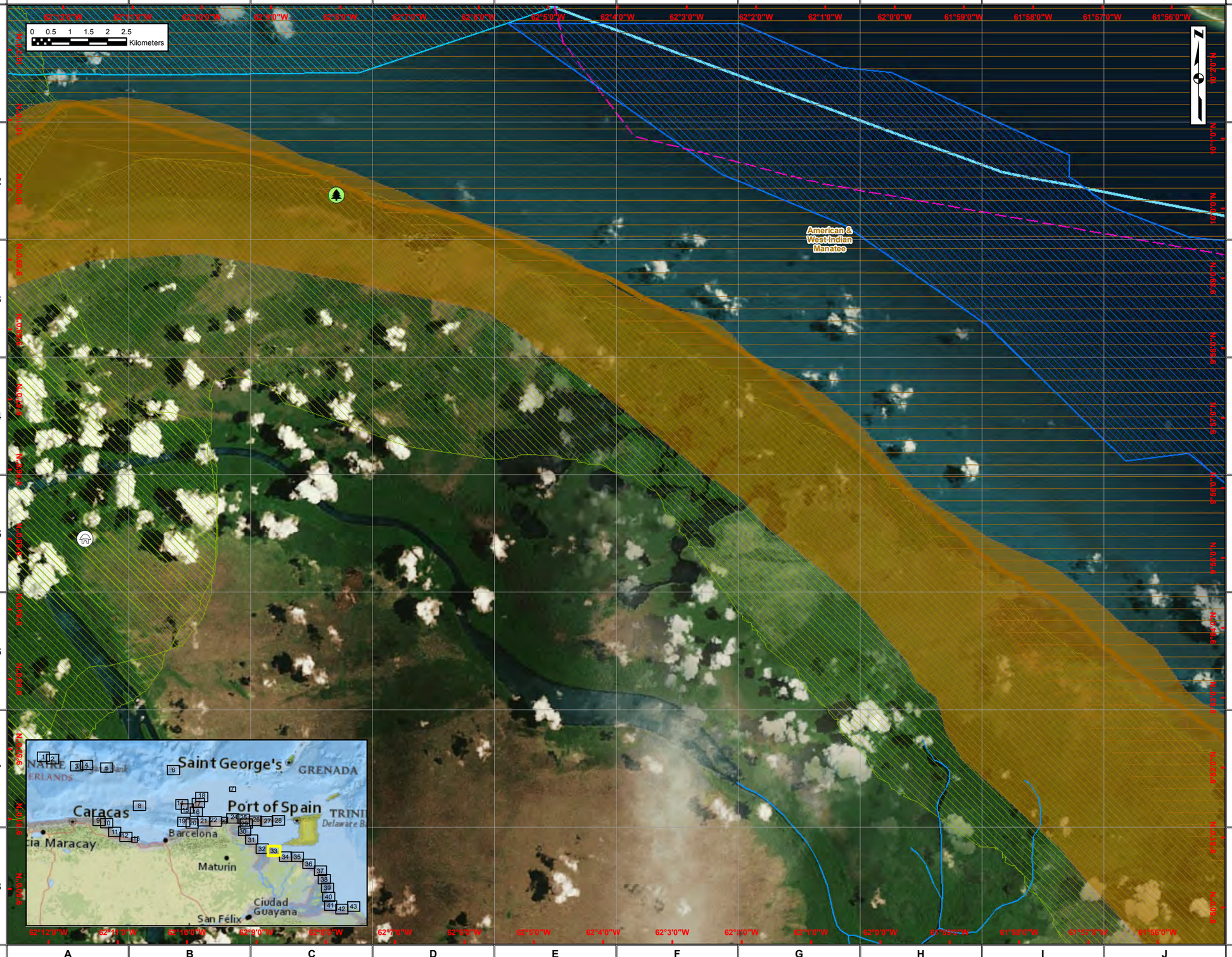
Onshore National Protected Areas

- IUCN Category Not Reported
- Hospitals
- School
- Amerindian Village

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Gulf of Paria (Isla Cotorra)
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Legend

Shoreline Sensitivity (ESI)

- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Nesting Birds
- Marine Mammals

Onshore National Protected Areas

- IUCN Category V & VI
- Amerindian Village
- Rivers
- Shipping Route
- Territorial Waters Boundary

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Gulf of Paria (Columbus Channel)
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0 0.5 1 1.5 2 2.5 Kilometers

American & West Indian Manatee

Manati Habitat

Manati Habitat

Manati Habitat

Manati Habitat

Manati Habitat

Manati Habitat

Saint George's
GRENADA
Caracas
Port of Spain
TRINI
Barcelona
Maturin
Ciudad Guayana
San Félix

Legend

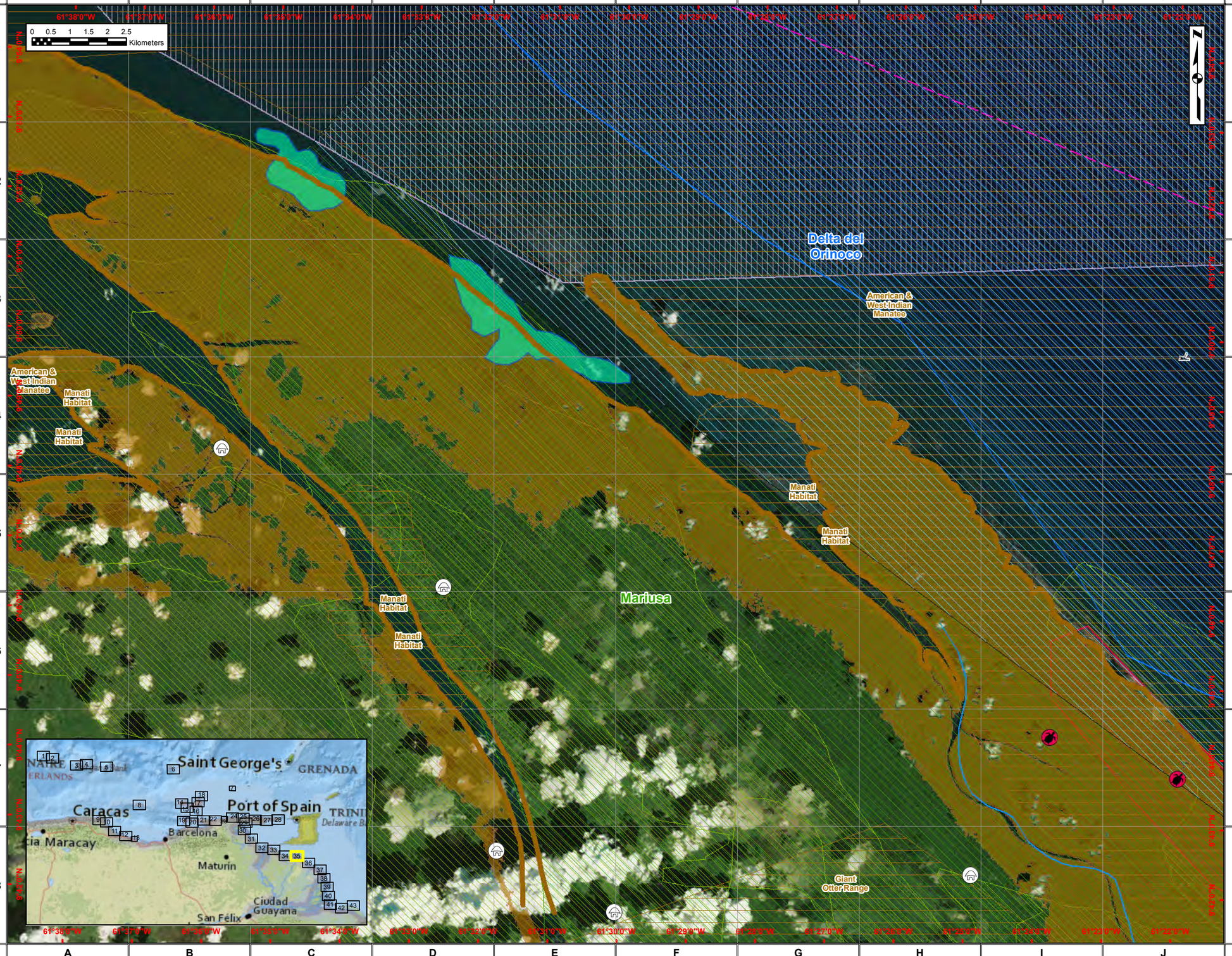
Shoreline Sensitivity (ESI)

- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Nesting Birds
- Marine Mammals
- Amerindian Village
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Tucupita (West)
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Legend

Shoreline Sensitivity (ESI)

- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- Nesting Birds
- Turtle Nesting Areas
- Marine Mammals
- Seagrass
- Lagoon
- IUCN Category Not Reported

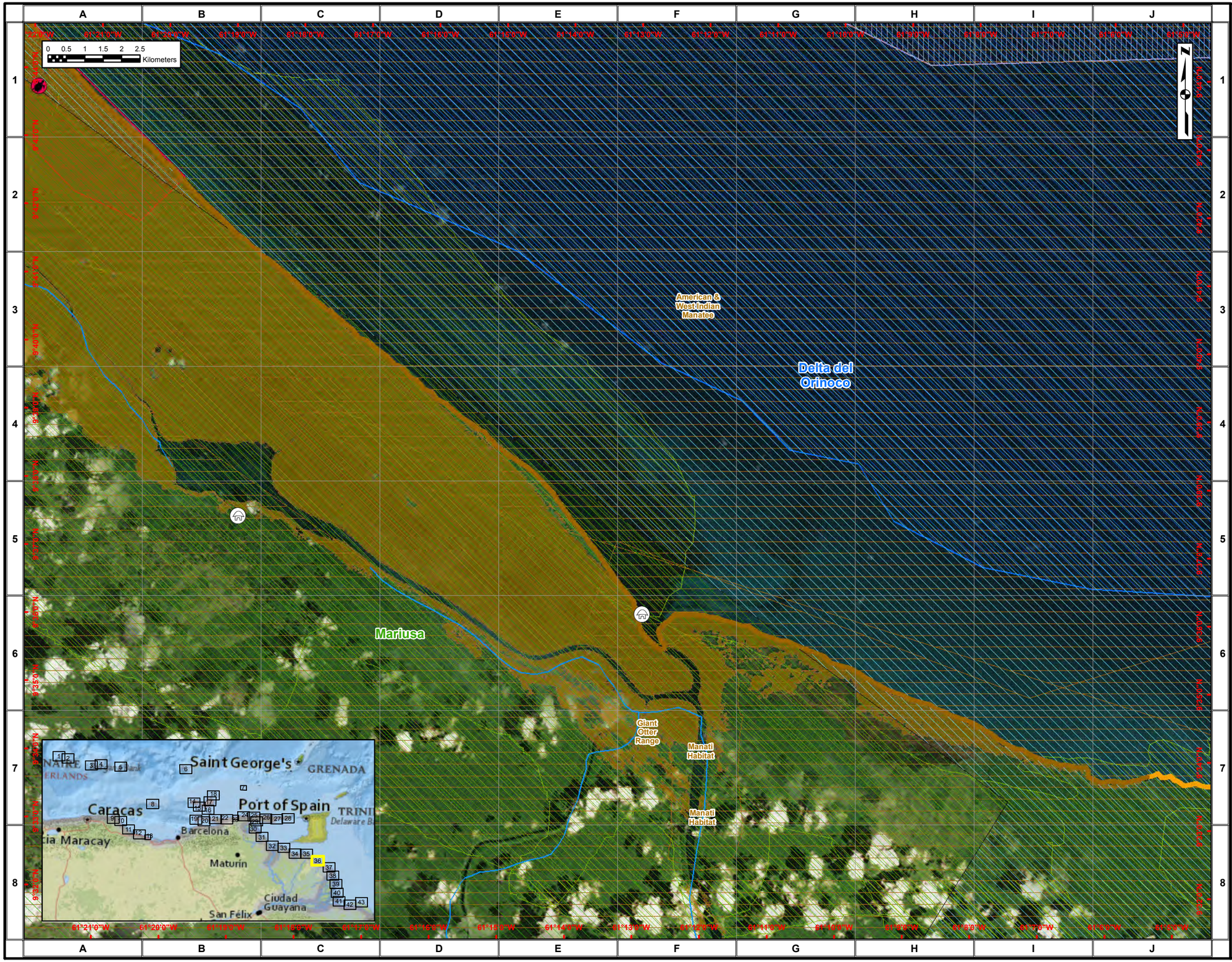
Onshore National Protected Areas

- IUCN Category I, II
- Amerindian Village
- Rivers
- Wreck
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Orinoco Delta 1
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Legend

Shoreline Sensitivity (ESI)

- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- Nesting Birds
- Turtle Nesting Areas
- Marine Mammals
- Seagrass
- IUCN Category Not Reported

Onshore National Protected Areas

- IUCN Category I, II
- Amerindian Village
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Orinoco Delta 2
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Legend

Shoreline Sensitivity (ESI)

- 3/4 - Sandy beaches or slopes
- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- Nesting Birds
- Turtle Nesting Areas
- Marine Mammals
- IUCN Category Not Reported
- Amerindian Village
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Orinoco Delta 3
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0 0.5 1 1.5 2 2.5 Kilometers

Giant Otter Range

Delta del Orinoco

American & West Indian Manatee



Legend

Shoreline Sensitivity (ESI)

- 3/4 - Sandy beaches or slopes
- 7 - Exposed tidal flats
- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- Nesting Birds
- Turtle Nesting Areas
- Marine Mammals
- IUCN Category Not Reported
- Amerindian Village
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Orinoco Delta 4
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Legend

Shoreline Sensitivity (ESI)

- 3/4 - Sandy beaches or slopes
- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Nesting Birds
- Marine Mammals
- IUCN Category Not Reported
- Amerindian Village
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Orinoco Delta 5
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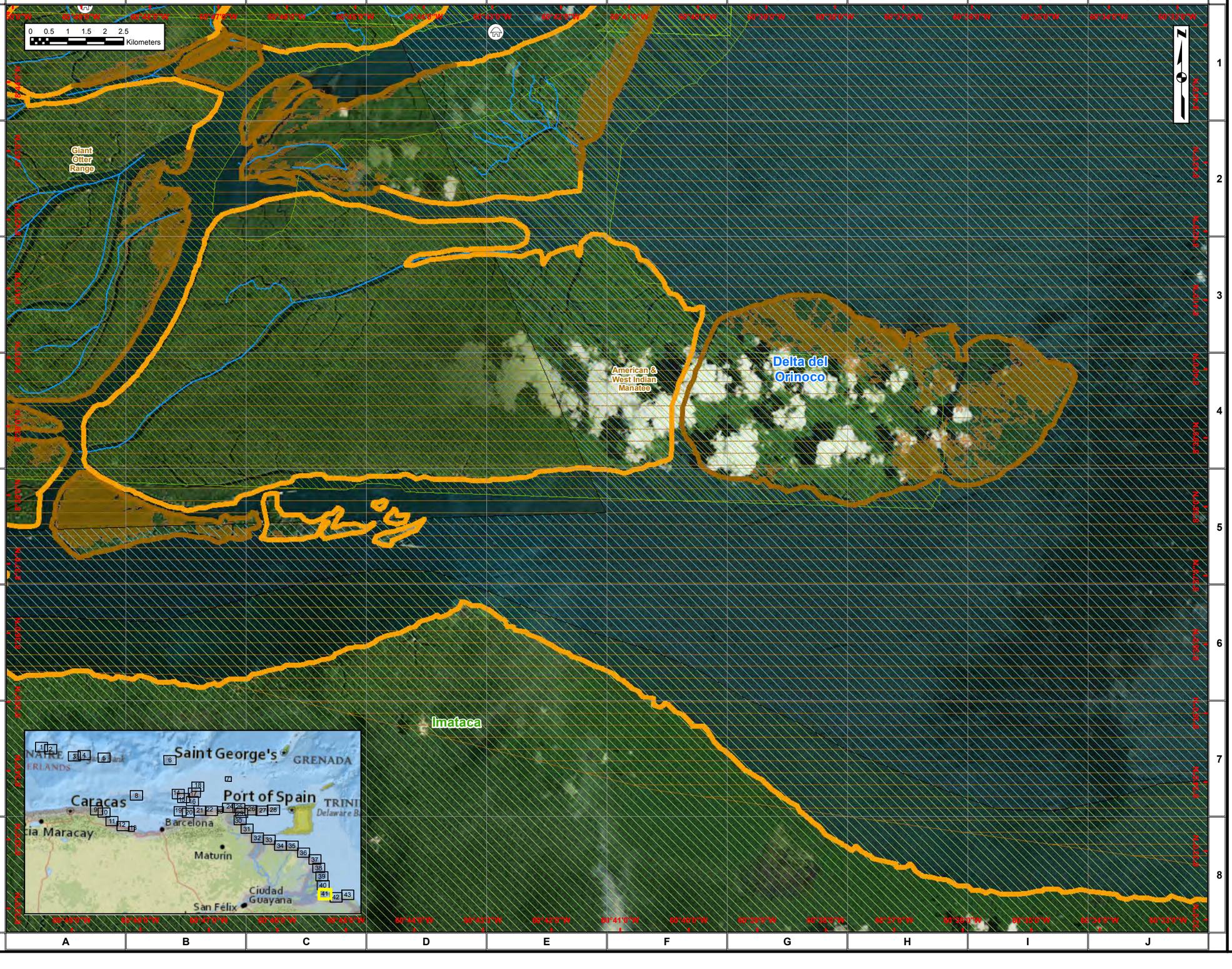
Shoreline Sensitivity (ESI)

- 7 - Exposed tidal flats
- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Nesting Birds
- Marine Mammals
- IUCN Category Not Reported
- Amerindian Village
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Orinoco Delta 6
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Legend

Shoreline Sensitivity (ESI)

- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Nesting Birds
- Marine Mammals
- IUCN Category Not Reported

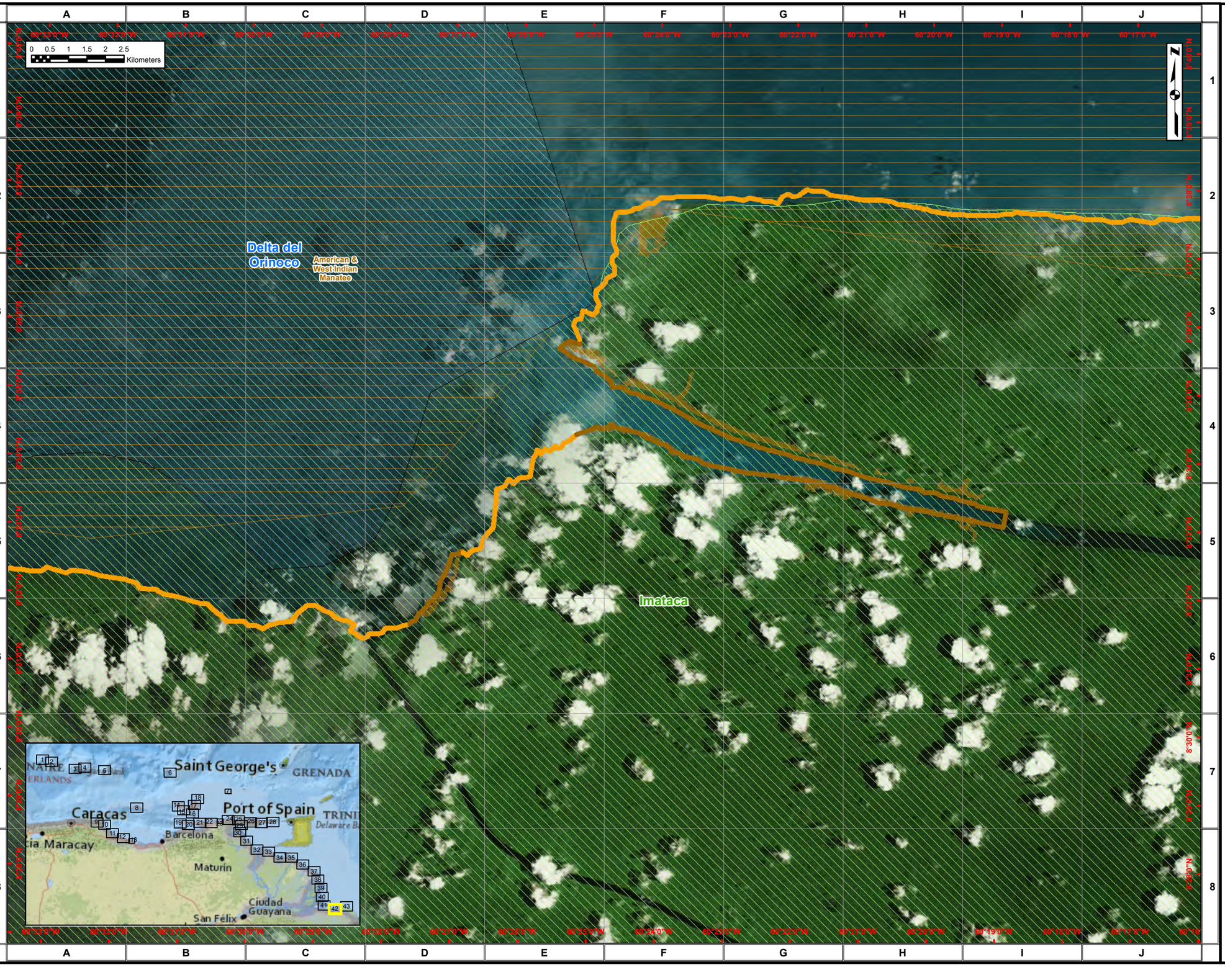
Onshore National Protected Areas

- IUCN Category V, VI
- Amerindian Village
- Rivers

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Orinoco Delta 7
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Legend

Shoreline Sensitivity (ESI)

- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Marine Mammals
- IUCN Category Not Reported

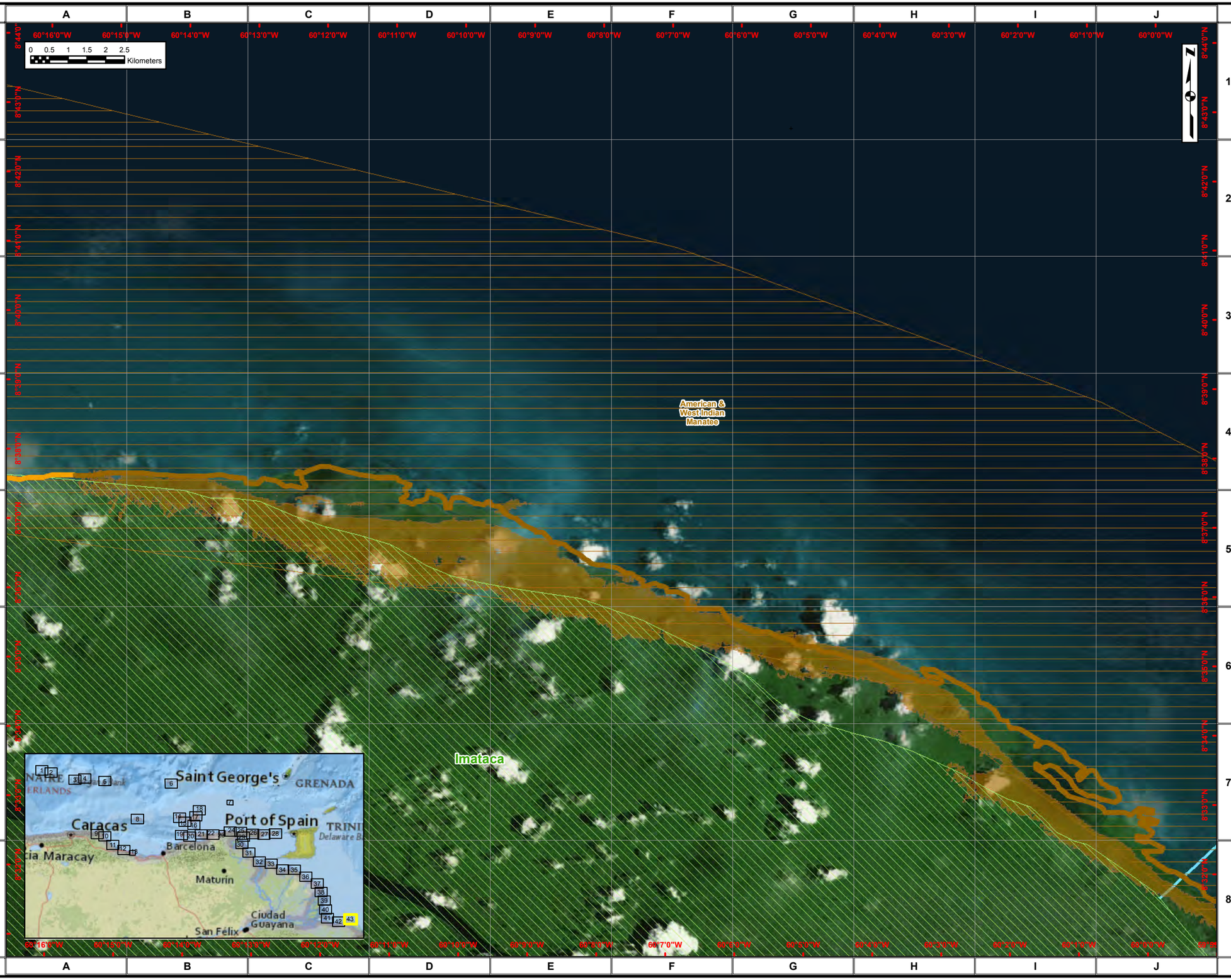
Onshore National Protected Areas

- IUCN Category V, VI

Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Orinoco Delta 8
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Legend

Shoreline Sensitivity (ESI)

- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Marine Mammals

Onshore National Protected Areas

- IUCN Category V, VI
- Territorial Waters Boundary

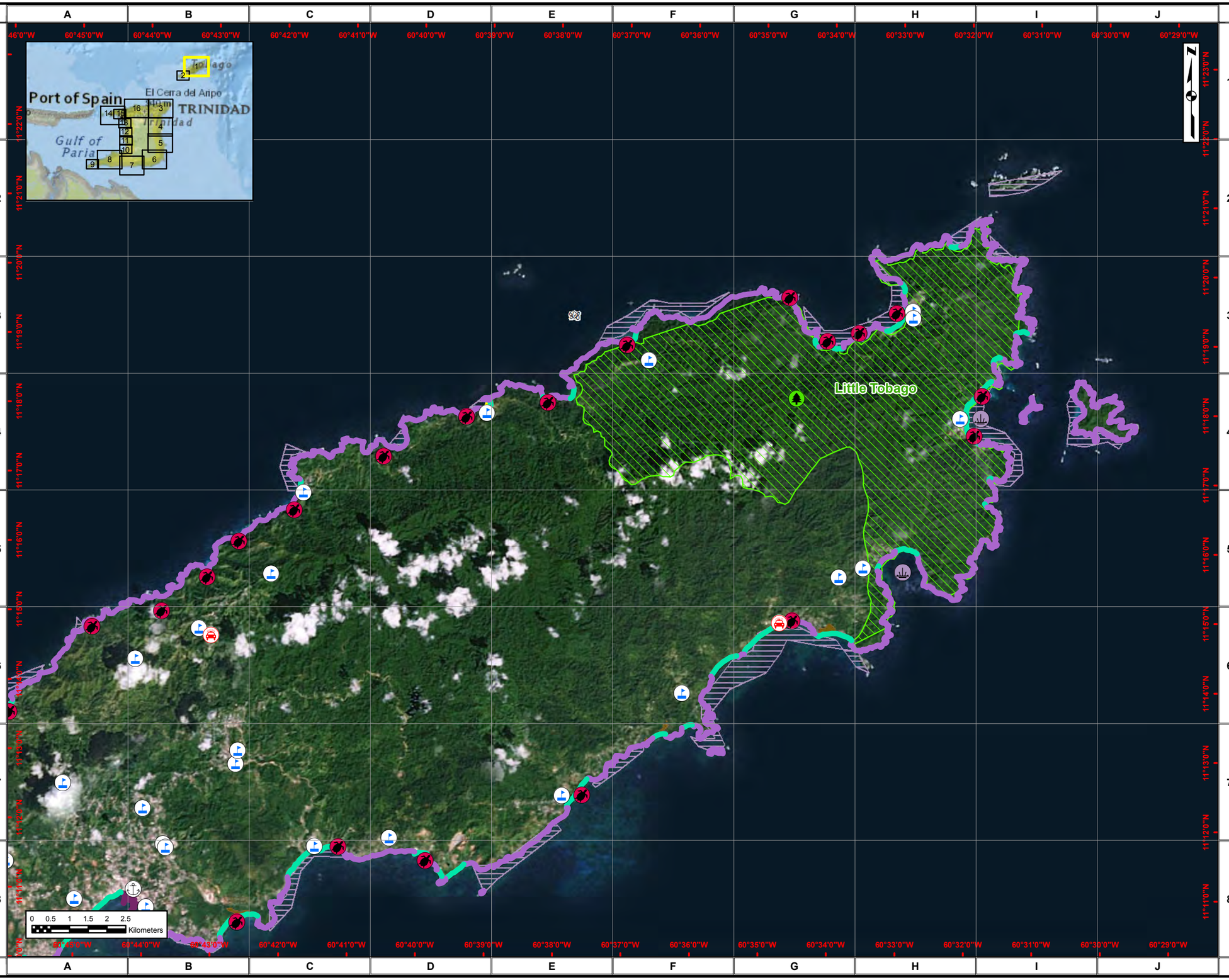
Coastal Sensitivity and Spill Response
Shoreline Access
Venezuela - Guyana Border
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Trinidad and Tobago

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Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- Mangrove Areas (ESI 10D)
- Coral Reefs
- Turtle Nesting
- Seagrass

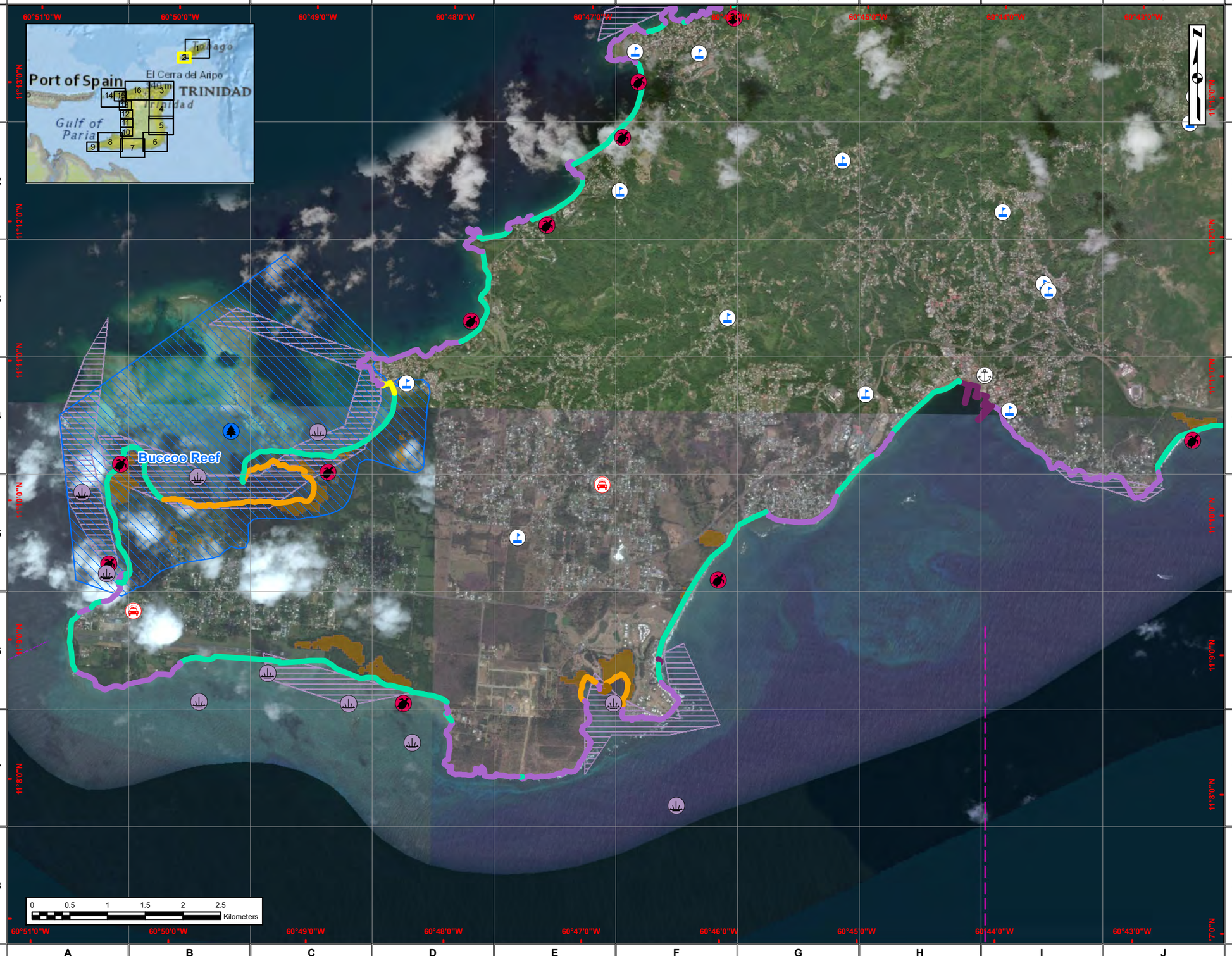
Onshore National Protected Areas

- IUCN Category III & IV
- IUCN Category III, IV
- Police Stations
- School
- Port or Marina
- Rock

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 9B - Vegetated low banks
- 10D - Mangroves
- Mangrove Areas (ESI 10D)
- Coral Reefs
- Turtle Nesting
- Seagrass

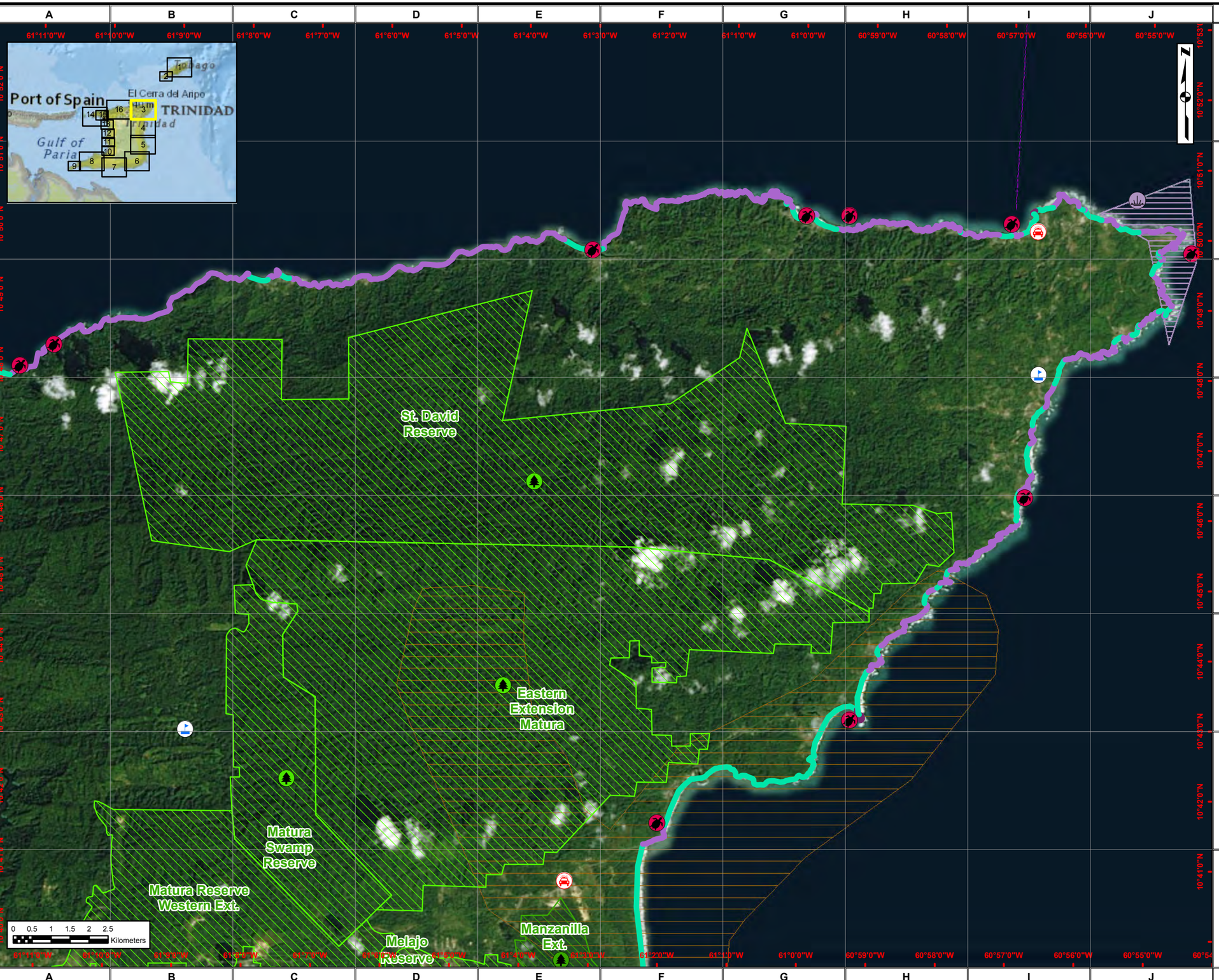
Marine National Protected Areas

- IUCN Category III & IV
- IUCN Category III, IV
- Police Stations
- School
- Port or Marina
- Shipping Route
- Seabed Cables

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- Manatees
- Coral Reefs
- Turtle Nesting
- Seagrass

Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category III & IV
- IUCN Category I, II
- IUCN Category III, IV
- Police Stations
- School
- Seabed Cables

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- Mangrove Areas (ESI 10D)
- Manatees
- Turtle Nesting

Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category III & IV
- IUCN Category I, II
- IUCN Category III, IV
- Kindergarten
- School
- Rock

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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Nariva Windbelt Reserve

Ecclesville Windbelt Reserve

Victoria Mayo Reserve

0 0.5 1 1.5 2 2.5 Kilometers

Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- Mangrove Areas (ESI 10D)
- Manatees

Onshore National Protected Areas

- IUCN Category III & IV
- IUCN Category III, IV
- Police Stations
- School
- Underwater Danger /Underwater Hazard

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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Victoria Mayo Reserve

0 0.5 1 1.5 2 2.5 Kilometers

Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 9B - Vegetated low banks
- Mangrove Areas (ESI 10D)
- Manatees
- Turtle Nesting
- Seagrass

Onshore National Protected Areas

- IUCN Category III & IV
- IUCN Category III, IV
- Port or Marina
- Rock
- Shipping Route
- Seabed Pipelines

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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Rochard Douglas Reserve

Victoria Mayo Reserve

Southern Watershed Reserve

Delta del Orinoco

0 0.5 1 1.5 2 2.5 Kilometers

Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- IUCN Category Not Reported

Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category III & IV
- IUCN Category I, II
- IUCN Category III, IV
- Police Stations
- School
- Territorial Waters Boundary

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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Godineau Swamp Reserve

Morne L'Enfer Reserve

Siparia Reserve

Cap de Ville Reserve

Erin Reserve

Cedros Reserve

Southern Watershed Reserve

0 0.5 1 1.5 2 2.5 Kilometers

Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 10C - Swamps
- Mangrove Areas (ESI 10D)

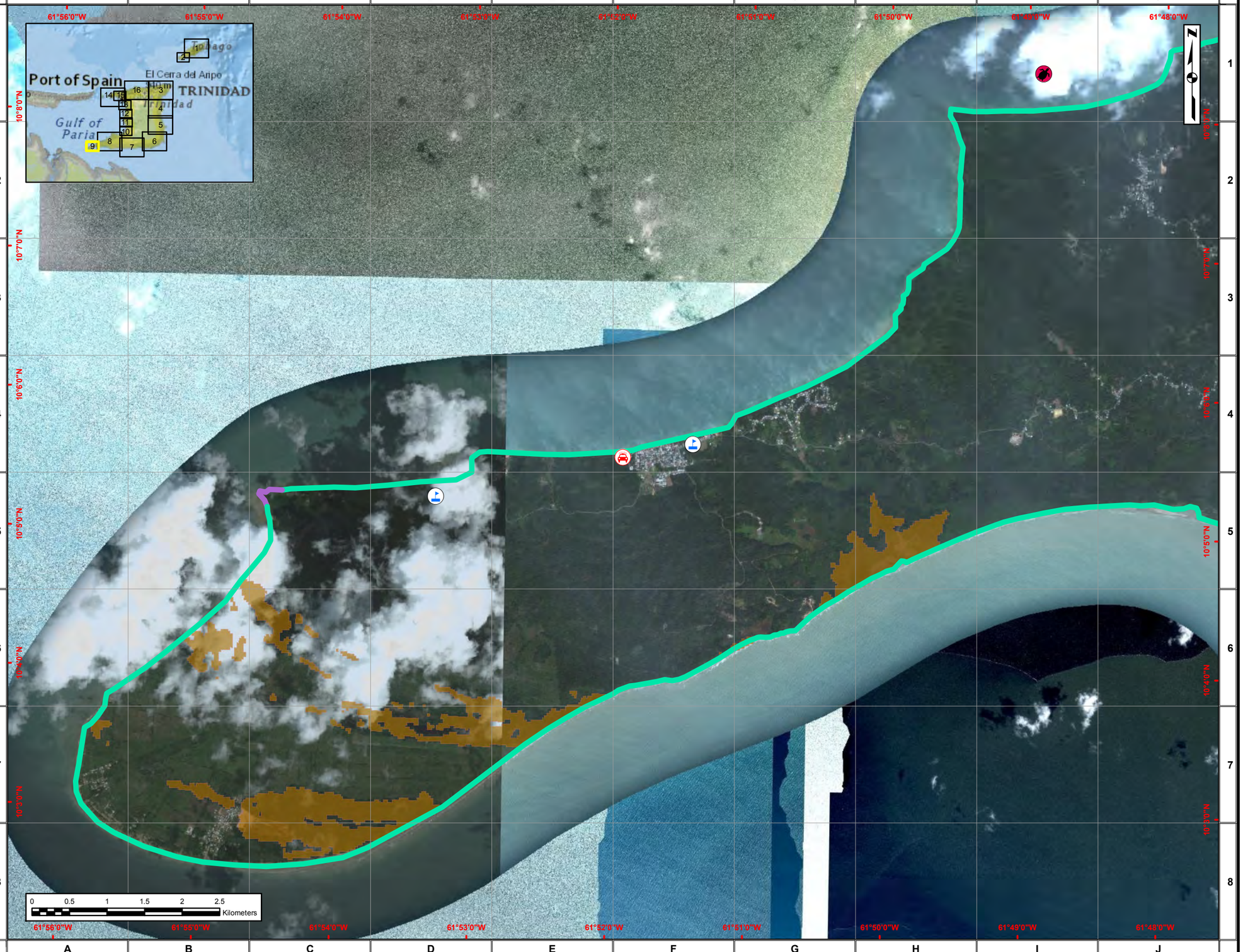
Onshore National Protected Areas

- IUCN Category III & IV
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category III, IV
- IUCN Category Not Reported
- Police Stations
- School
- Port or Marina
- Shipping Route
- Seabed Pipelines

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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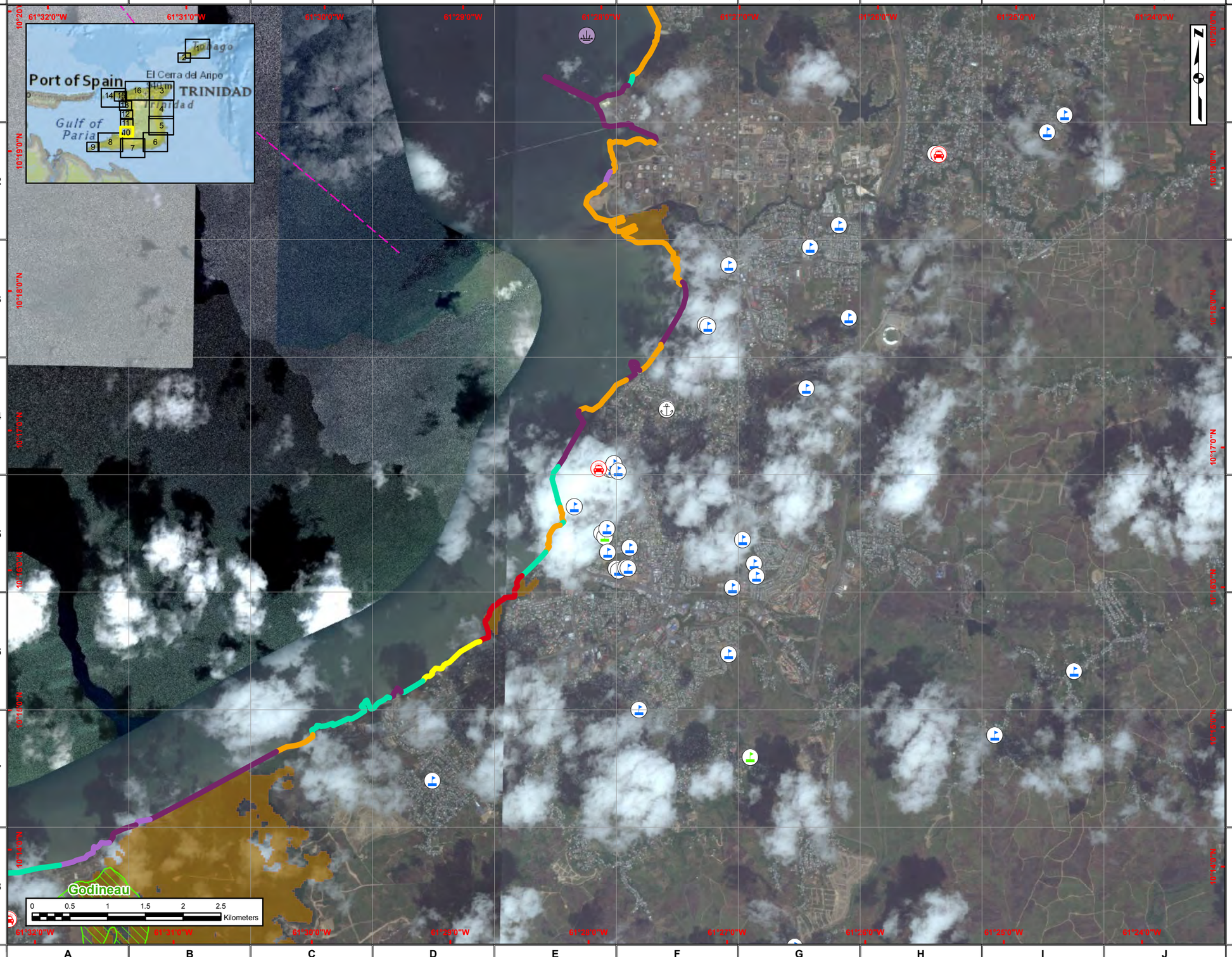
Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- IUCN Category III, IV
- Police Stations
- School

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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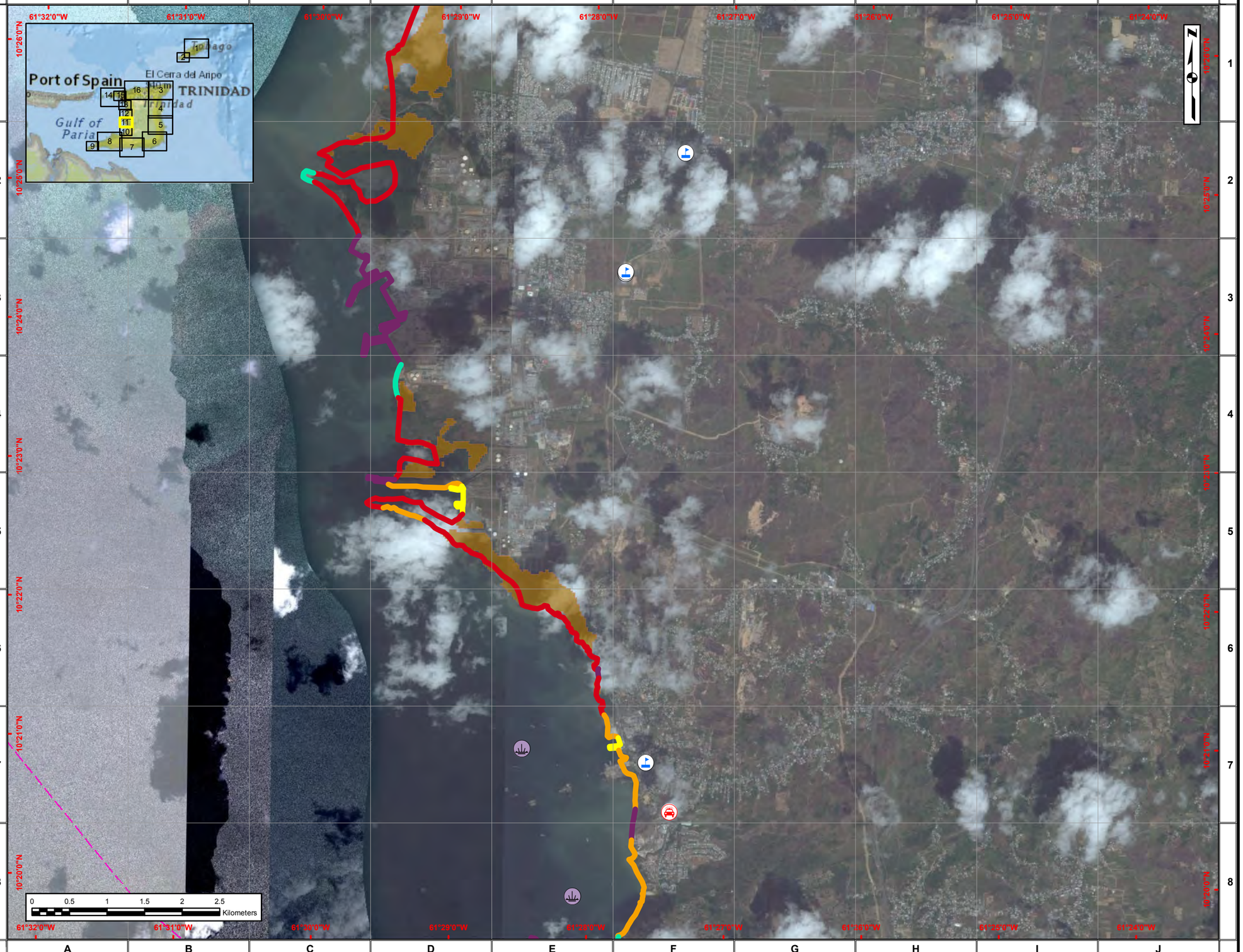
Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 9B - Vegetated low banks
- 10C - Swamps
- Mangrove Areas (ESI 10D)
- Seagrass
- IUCN Category III, IV
- Police Stations
- Kindergarten
- School
- Port or Marina
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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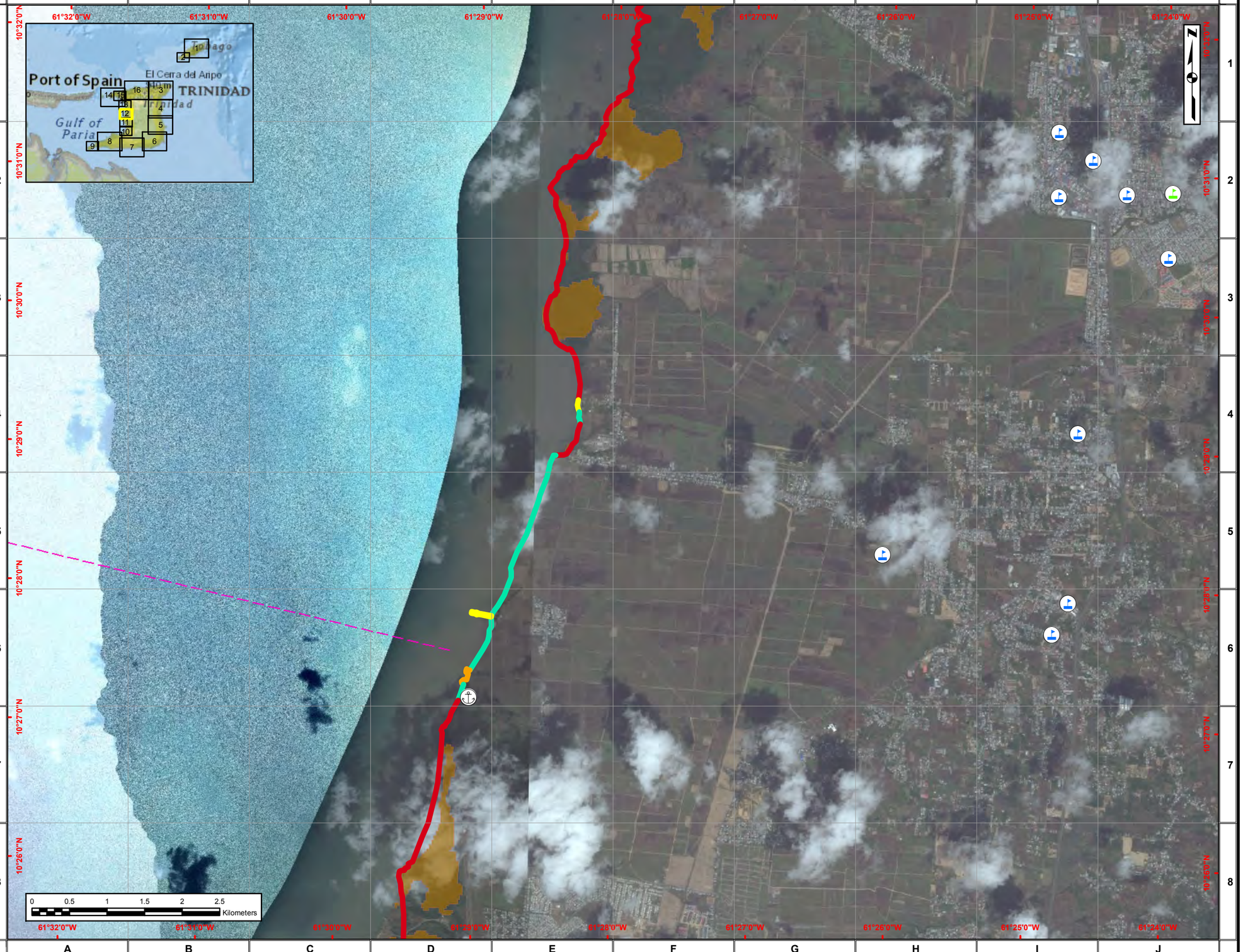
Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 9B - Vegetated low banks
- 10C - Swamps
- Mangrove Areas (ESI 10D)
- Seagrass
- Police Stations
- School
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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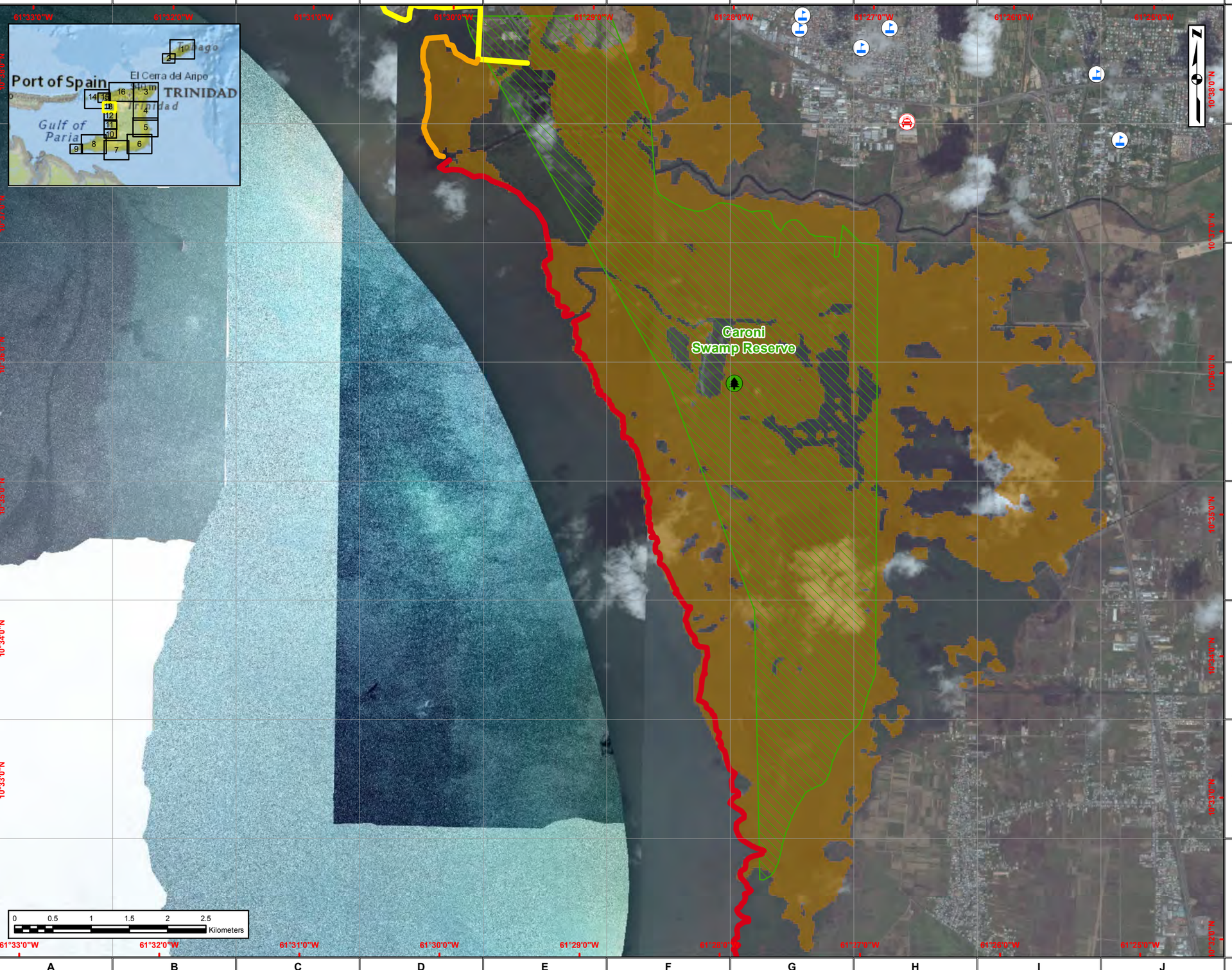
Shoreline Sensitivity (ESI)

- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 9B - Vegetated low banks
- 10C - Swamps
- Mangrove Areas (ESI 10D)
- Kindergarten
- School
- Port or Marina
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access
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Shoreline Sensitivity (ESI)

- 8 - Sheltered bedrock or man-made structures
- 9B - Vegetated low banks
- 10C - Swamps
- Mangrove Areas (ESI 10D)

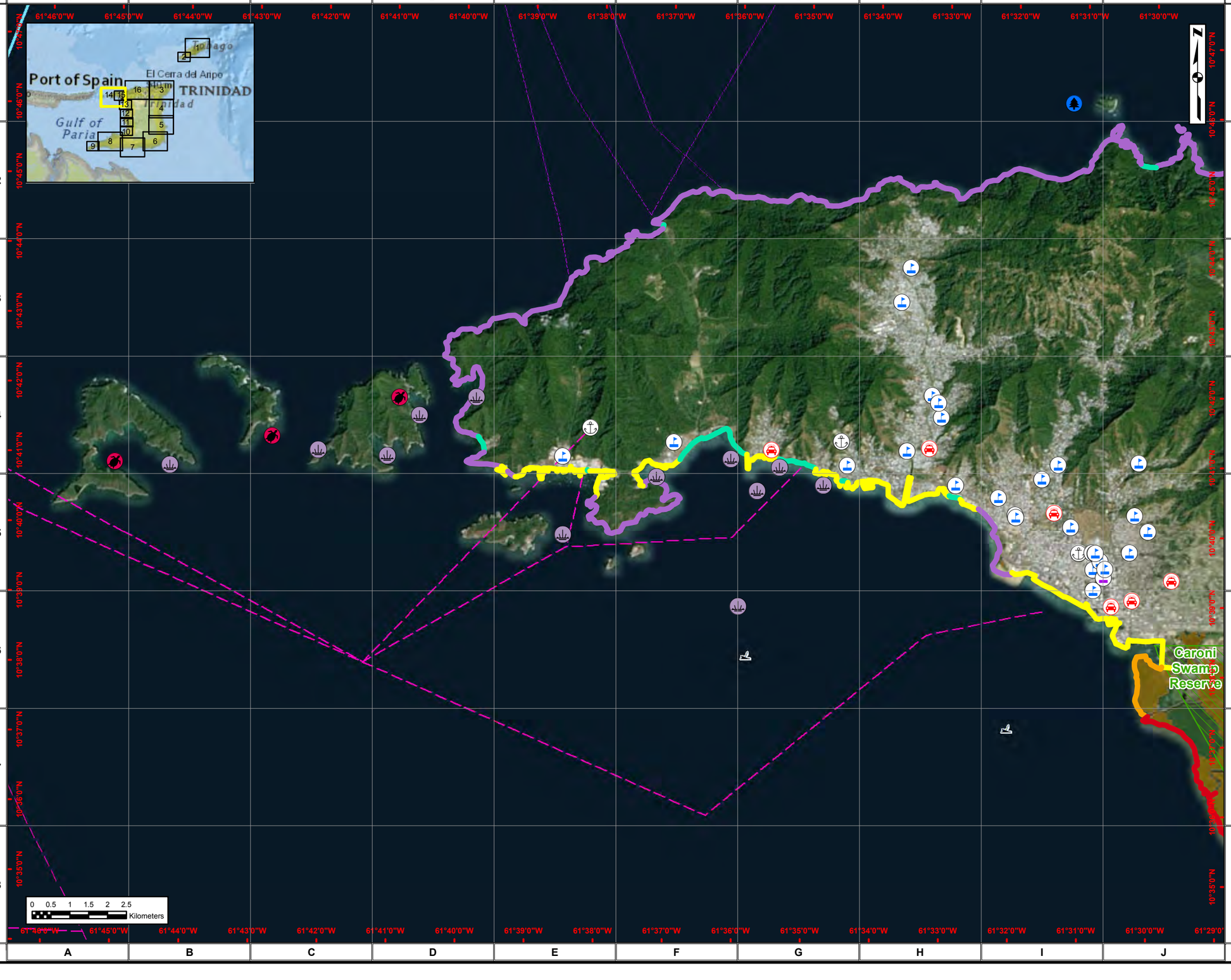
Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category I, II
- Police Stations
- School
- Wreck
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 9B - Vegetated low banks
- 10C - Swamps
- Mangrove Areas (ESI 10D)
- Turtle Nesting
- Seagrass

Marine National Protected Areas

- IUCN Category III & IV
- IUCN Category I, II
- Police Stations
- School
- College
- Port or Marina
- Wreck
- Shipping Route
- Seabed Cables
- Territorial Waters Boundary

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- Mangrove Areas (ESI 10D)
- Seagrass
- Police Stations
- School
- College
- Port or Marina
- Shipping Route
- Seabed Cables

Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
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Legend

Shoreline Sensitivity (ESI)

- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- Turtle Nesting

Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category III & IV
- IUCN Category I, II
- IUCN Category III, IV
- Police Stations
- School

Las Cuevas Reserve
Yarra Reserve
Blanchisseuse Reserve
Paria Reserve
Nrrb.
Nrrc
Nrra.
Tacarigua Reserve
Arima Reserve

0 0.5 1 1.5 2 2.5 Kilometers

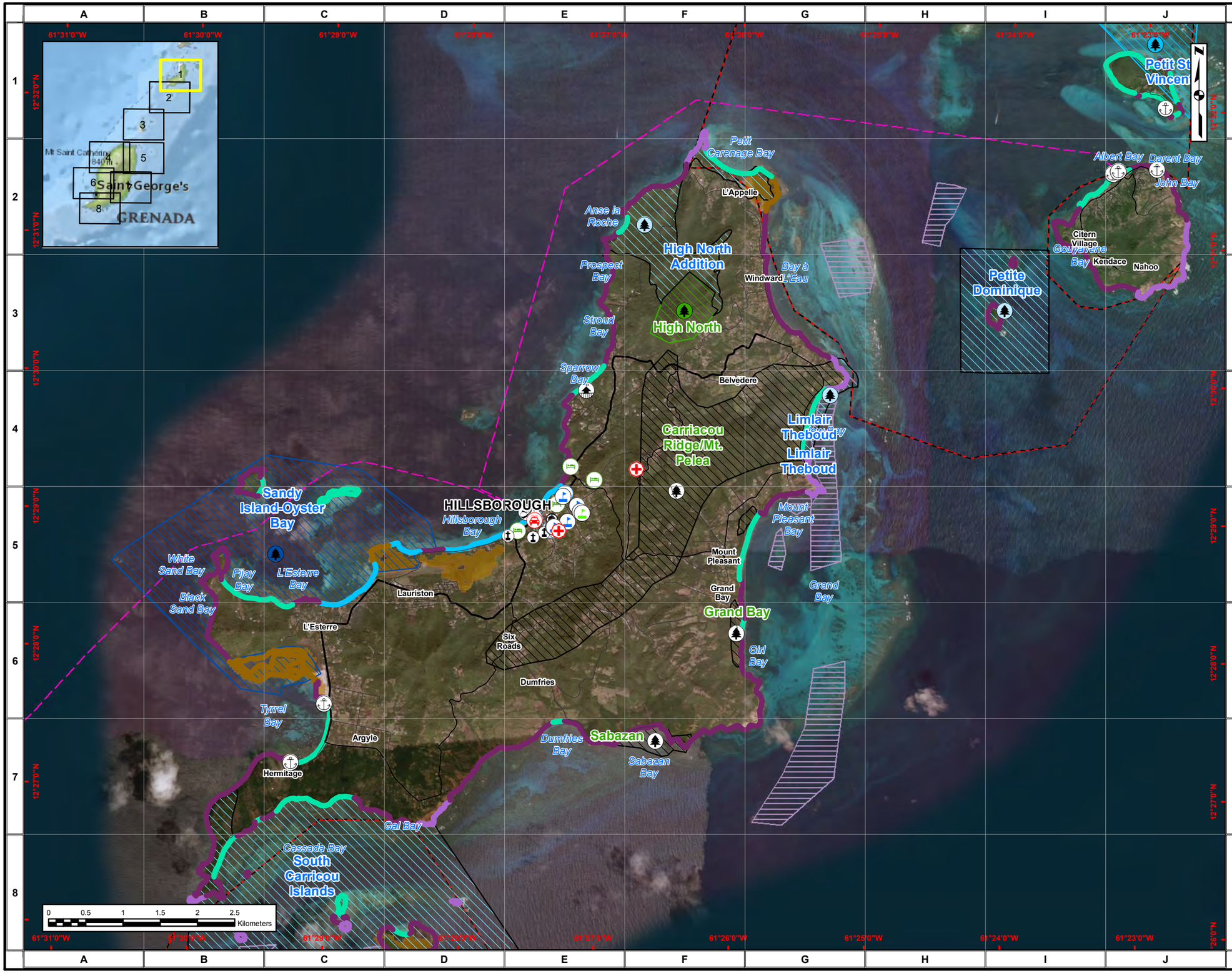
Coastal Sensitivity and Spill Response
Shoreline Access
Trinidad & Tobago
Map 16 of 16
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Grenada

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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 3/4 - Sandy beaches or slopes
- 4/5 - Sand or gravel beach
- 10D - Mangroves

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category V, VI
- IUCN Category Not Reported

Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category Not Reported
- Mangrove Areas (ESI 10D)
- Coral Reefs
- Hospitals
- Police Stations
- Kindergarten
- School
- Port or Marina
- Ferry Dock
- Historic Site
- Places of Worship
- Government Facilities
- Hotels
- Regional Capital
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Hazardous Areas
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access - Grenada
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach

Marine National Protected Areas

- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category Not Reported

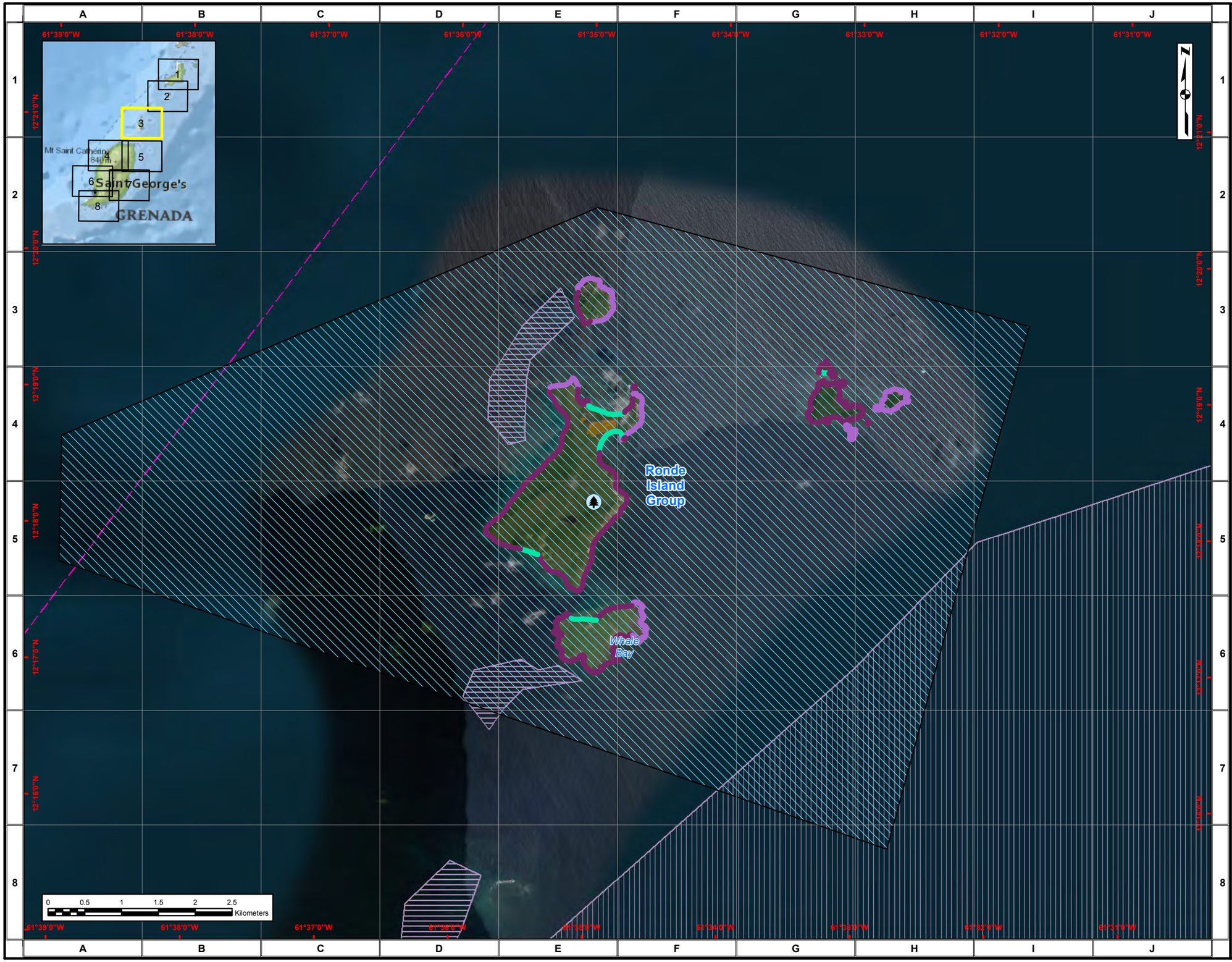
Onshore National Protected Areas

- IUCN Category Not Reported
- IUCN Category Not Reported
- Mangrove Areas (ESI 10D)
- Coral Reefs
- Port or Marina
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Hazardous Areas
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access - Grenada
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach

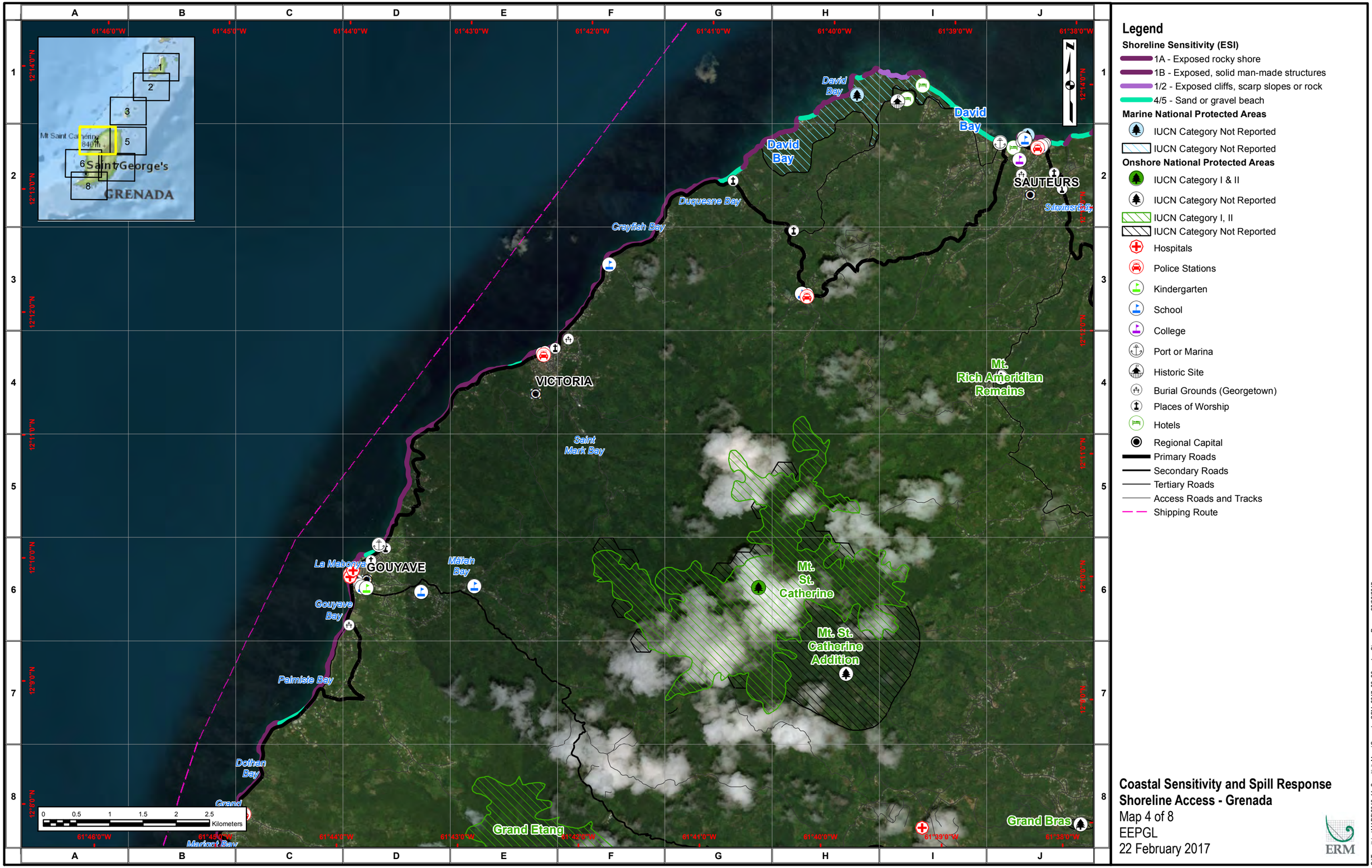
Marine National Protected Areas

- IUCN Category Not Reported
- IUCN Category Not Reported
- Mangrove Areas (ESI 10D)
- Coral Reefs
- Seagrass
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access - Grenada
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach

Marine National Protected Areas

- IUCN Category Not Reported
- IUCN Category Not Reported

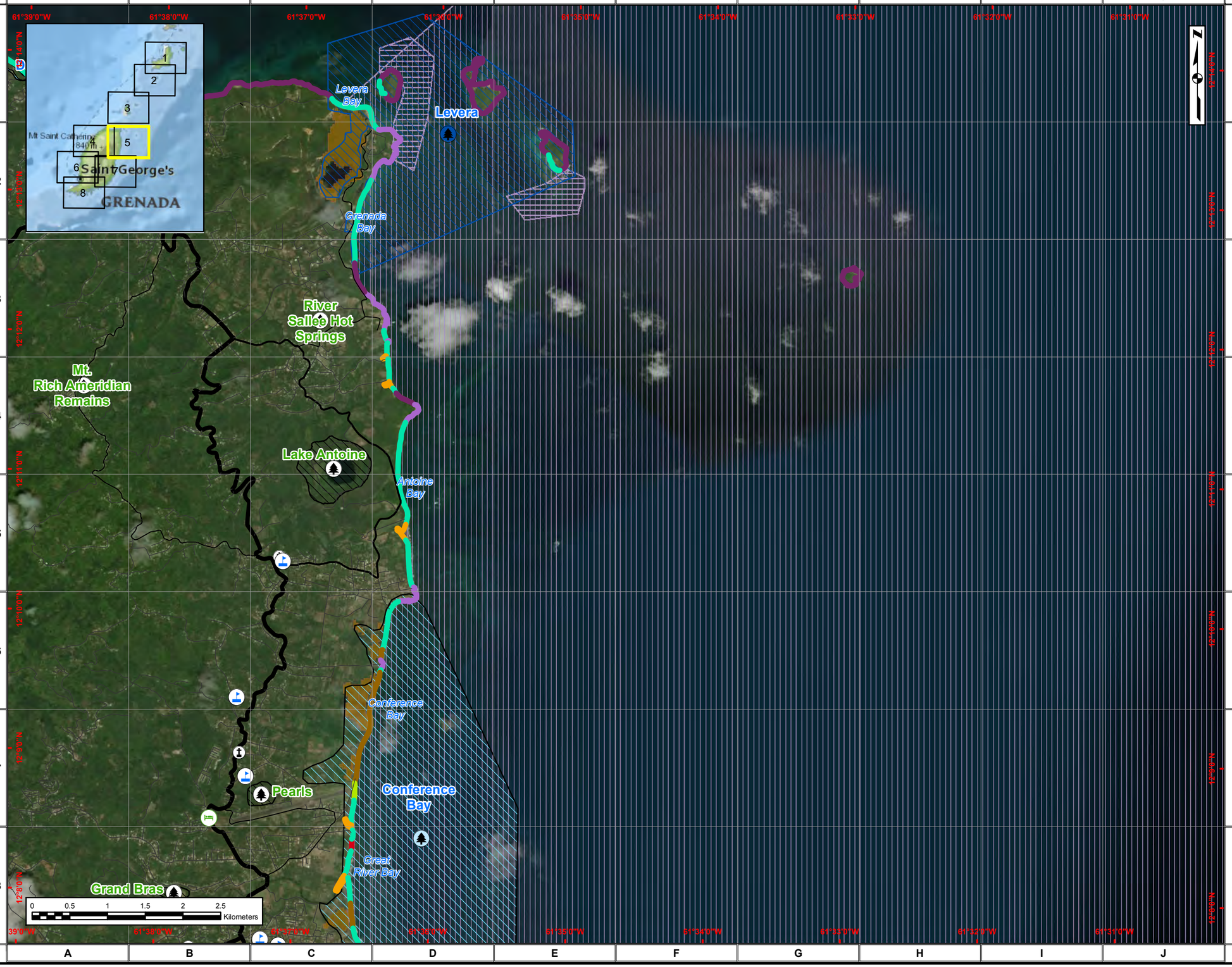
Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category Not Reported
- Hospitals
- Police Stations
- Kindergarten
- School
- College
- Port or Marina
- Historic Site
- Burial Grounds (Georgetown)
- Places of Worship
- Hotels
- Regional Capital
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access - Grenada
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1C - Exposed rocky cliffs with boulder talus base
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 6B - Riprap structures and gravel beaches (cobbles and boul
- 9B - Vegetated low banks
- 10A - Salt and brackish water marshes
- 10D - Mangroves

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category Not Reported

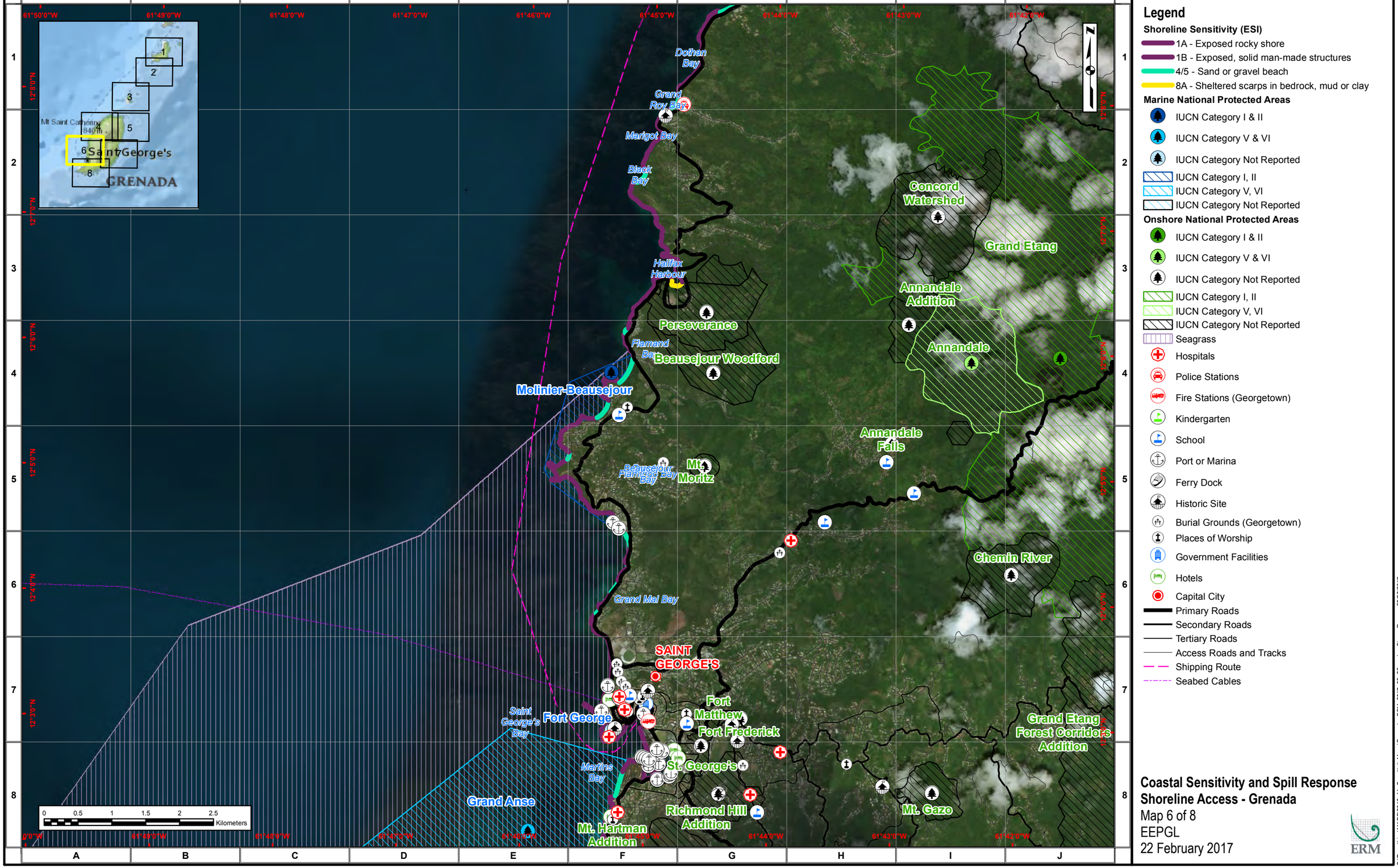
Onshore National Protected Areas

- IUCN Category Not Reported
- IUCN Category Not Reported
- Mangrove Areas (ESI 10D)
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- School
- College
- Port or Marina
- Burial Grounds (Georgetown)
- Places of Worship
- Hotels
- Regional Capital
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks

Coastal Sensitivity and Spill Response
Shoreline Access - Grenada
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 4/5 - Sand or gravel beach
- 8A - Sheltered scarps in bedrock, mud or clay

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category V, VI
- IUCN Category Not Reported

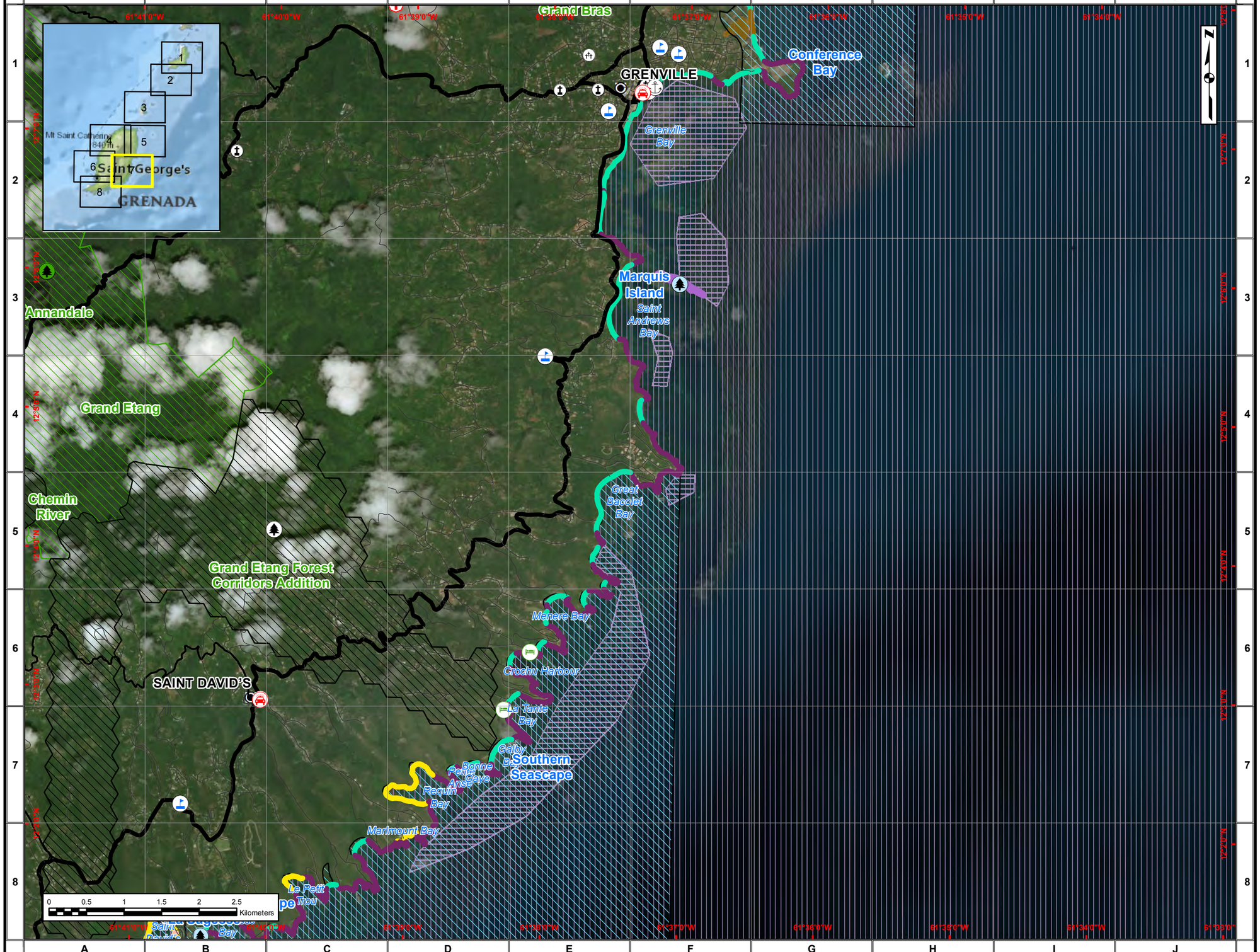
Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category V, VI
- IUCN Category Not Reported
- Seagrass
- Hospitals
- Police Stations
- Fire Stations (Georgetown)
- Kindergarten
- School
- Port or Marina
- Ferry Dock
- Historic Site
- Burial Grounds (Georgetown)
- Places of Worship
- Government Facilities
- Hotels
- Capital City
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Shipping Route
- Seabed Cables

Coastal Sensitivity and Spill Response
Shoreline Access - Grenada
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8A - Sheltered scarps in bedrock, mud or clay
- 8B - Sheltered, solid man-made structures
- 10D - Mangroves

Marine National Protected Areas

- IUCN Category Not Reported
- IUCN Category Not Reported

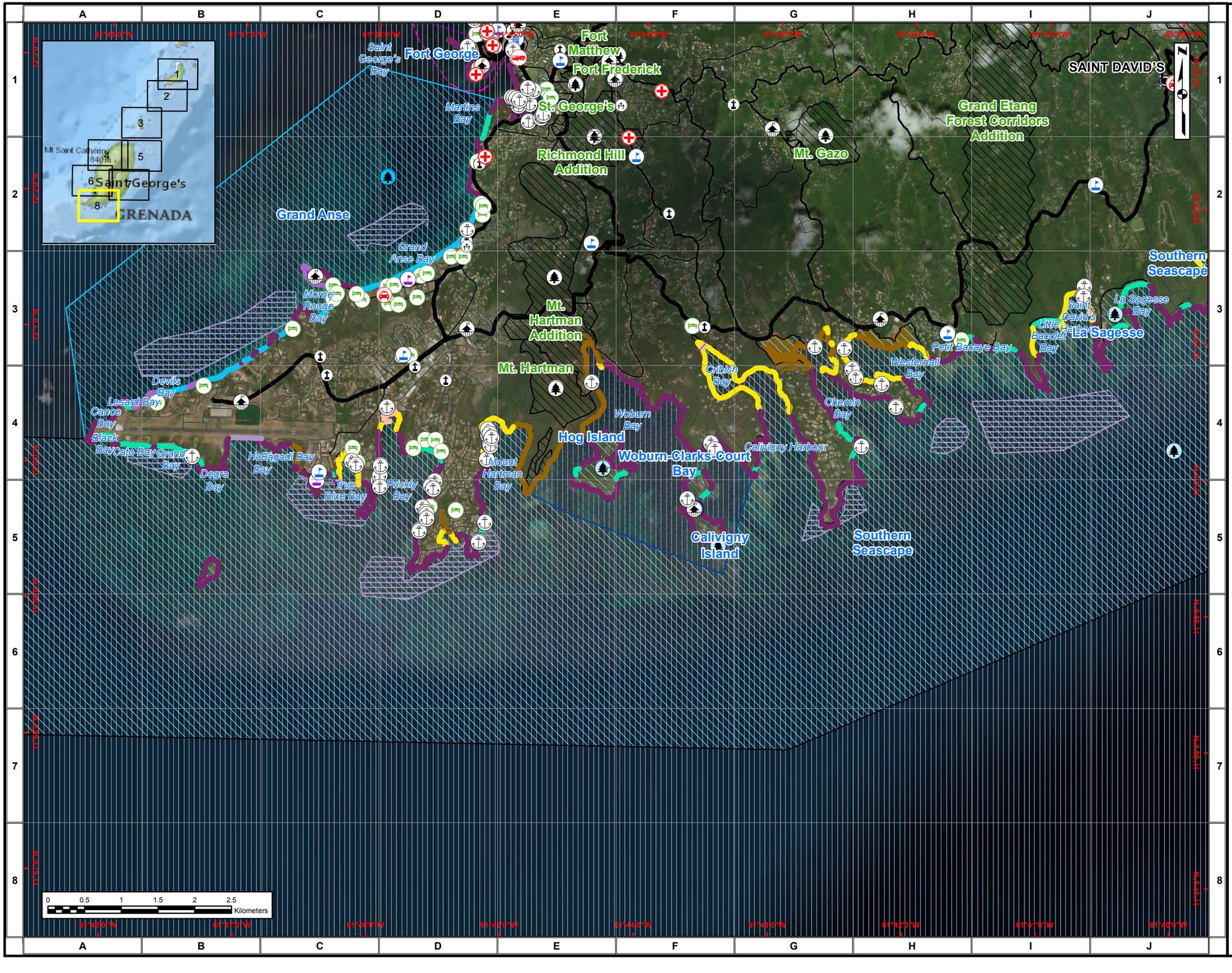
Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category V, VI
- IUCN Category Not Reported
- Mangrove Areas (ESI 10D)
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- School
- Port or Marina
- Ferry Dock
- Burial Grounds (Georgetown)
- Places of Worship
- Hotels
- Regional Capital
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks

Coastal Sensitivity and Spill Response
Shoreline Access - Grenada
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1C - Exposed rocky cliffs with boulder talus base
- 1/2 - Exposed cliffs, scarp slopes or rock
- 2B - Exposed scarps and steep slopes in clay
- 3/4 - Sandy beaches or slopes
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 8A - Sheltered scarps in bedrock, mud or clay
- 8B - Sheltered, solid man-made structures
- 10D - Mangroves

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category V, VI
- IUCN Category Not Reported

Onshore National Protected Areas

- IUCN Category Not Reported
- IUCN Category Not Reported
- Mangrove Areas (ESI 10D)
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- Fire Stations (Georgetown)
- Kindergarten
- School
- College
- Port or Marina
- Ferry Dock
- Historic Site
- Burial Grounds (Georgetown)
- Places of Worship
- Government Facilities
- Hotels
- Regional Capital
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Shipping Route
- Seabed Cables

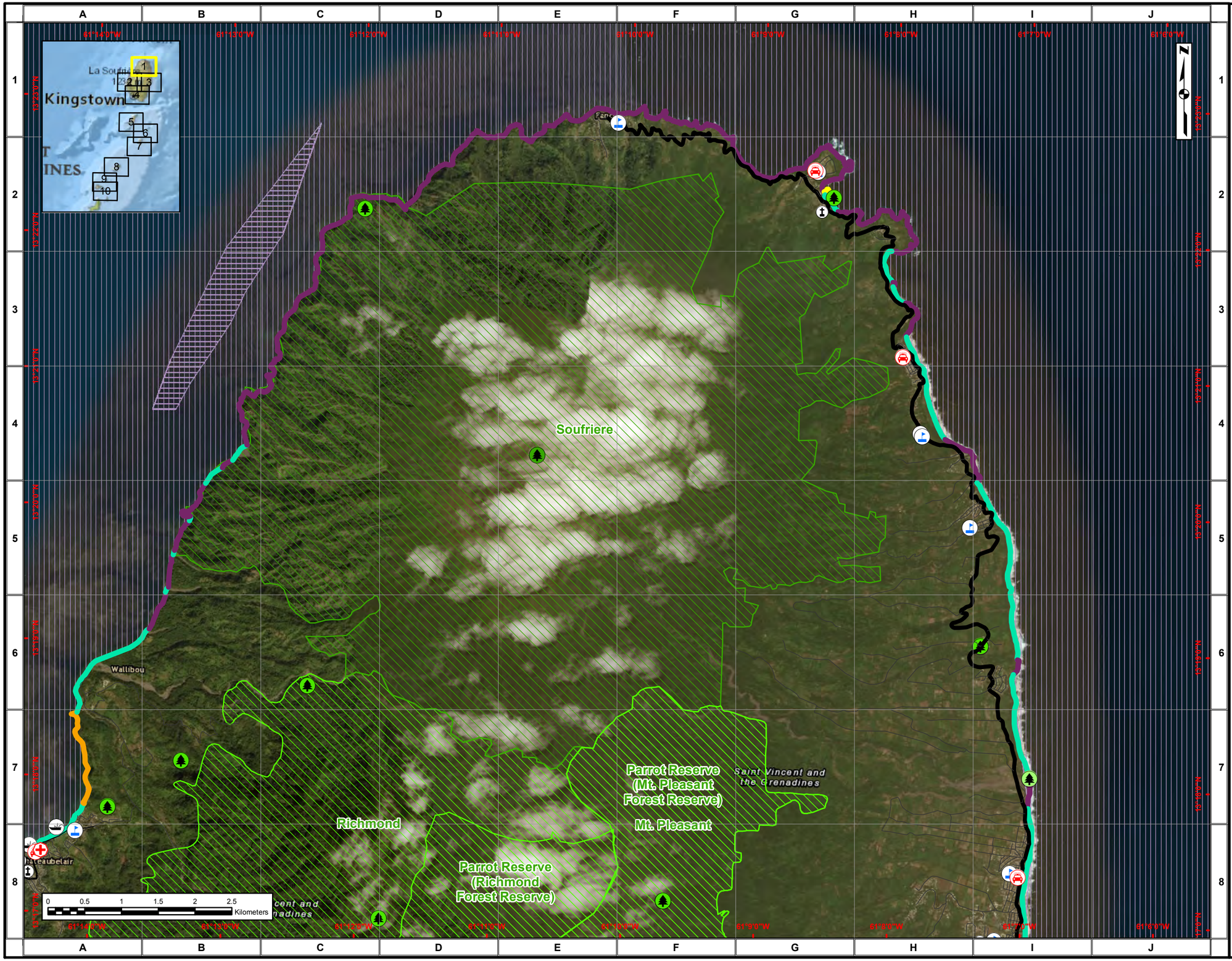
Coastal Sensitivity and Spill Response
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St. Vincent and the Grenadines

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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1C - Exposed rocky cliffs with boulder talus base
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 9B - Vegetated low banks

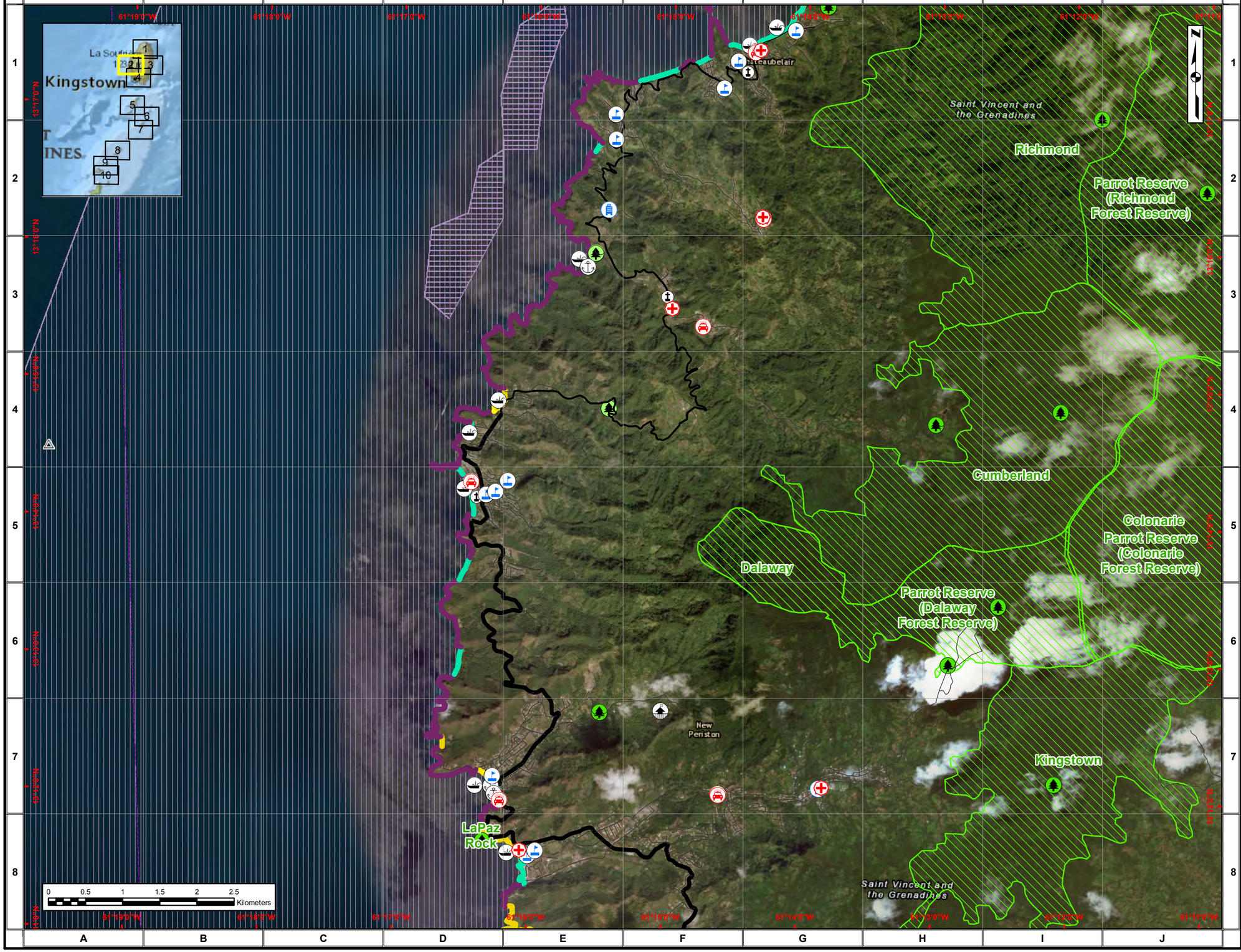
Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category III & IV
- IUCN Category V & VI
- IUCN Category I, II
- IUCN Category III, IV
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- School
- Fishing Dock or Landing
- Places of Worship
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks

Coastal Sensitivity and Spill Response
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1C - Exposed rocky cliffs with boulder talus base
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 8A - Sheltered scarps in bedrock, mud or clay
- 8D - Sheltered rocky rubble shores
- IUCN Category III, IV

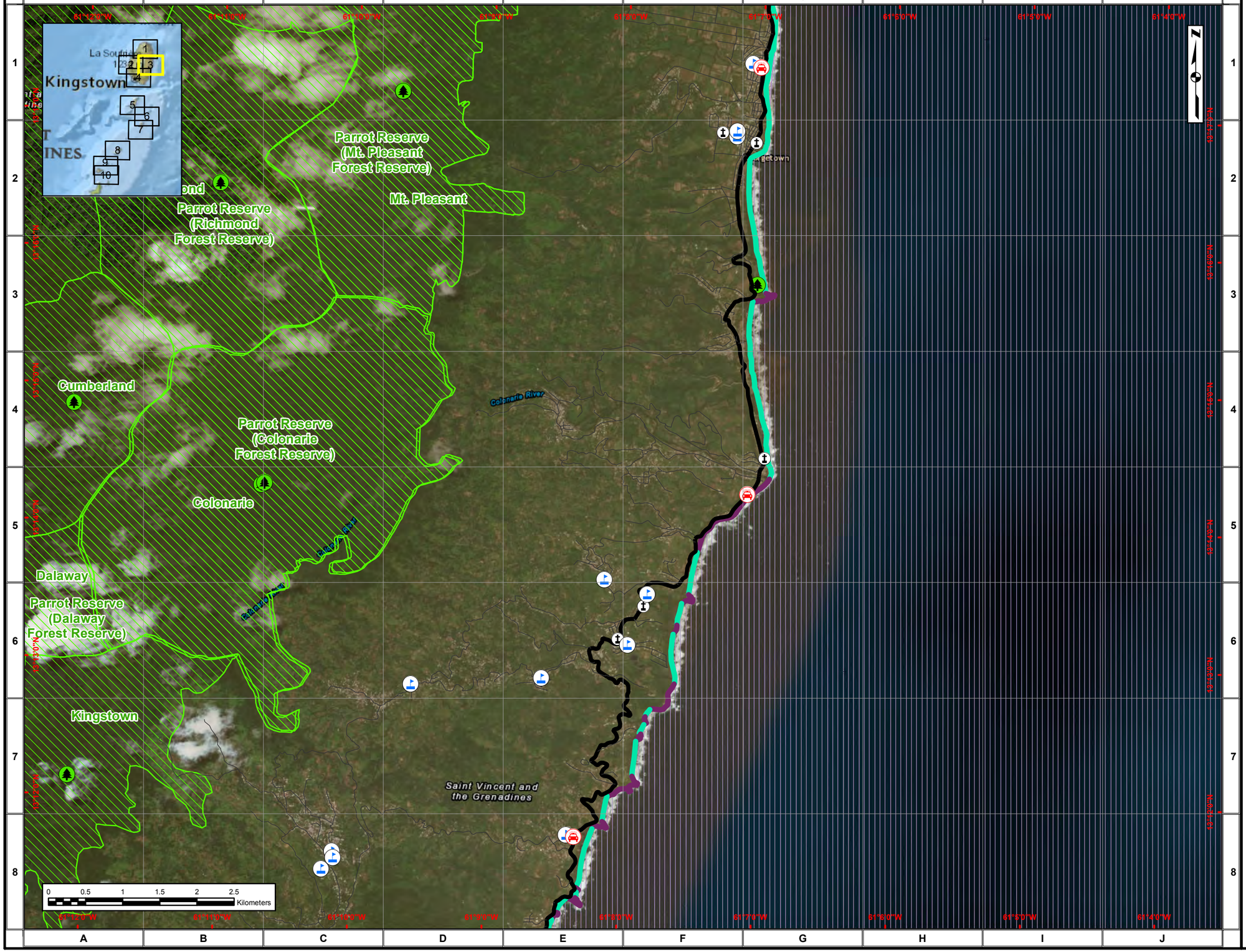
Onshore National Protected Areas

- IUCN Category III & IV
- IUCN Category V & VI
- IUCN Category III, IV
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- School
- Port or Marina
- Fishing Dock or Landing
- Historic Site
- Places of Worship
- Government Facilities
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Underwater Danger /Underwater Hazard
- Seabed Cables

Coastal Sensitivity and Spill Response
Shoreline Access
St Vincent and The Grenadines
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 4/5 - Sand or gravel beach

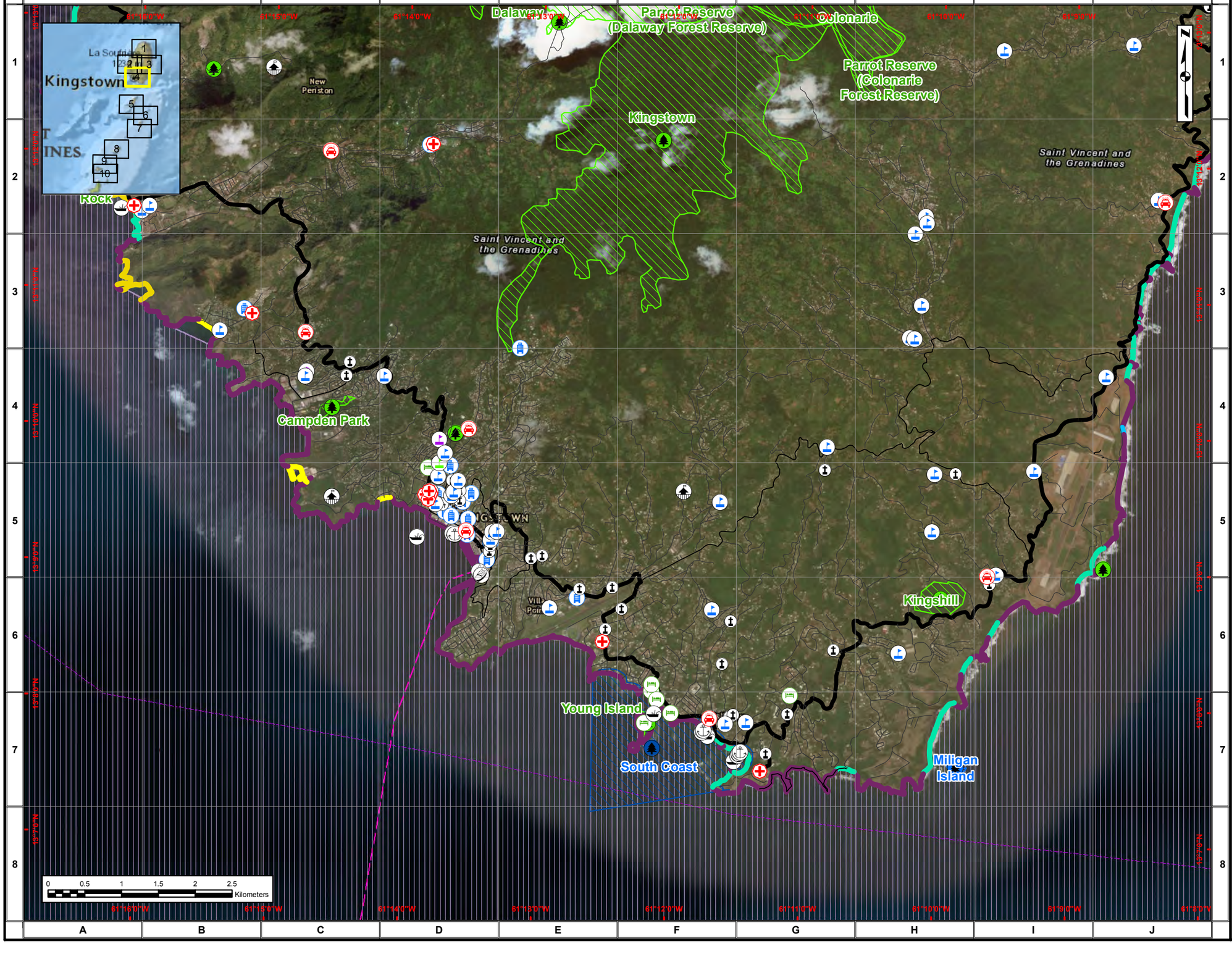
Onshore National Protected Areas

- IUCN Category III & IV
- IUCN Category III, IV
- Seagrass
- Police Stations
- School
- Places of Worship
- Primary Roads
- Access Roads and Tracks

Coastal Sensitivity and Spill Response
Shoreline Access
St Vincent and The Grenadines
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1C - Exposed rocky cliffs with boulder talus base
- 3/4 - Sandy beaches or slopes
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 8A - Sheltered scarps in bedrock, mud or clay
- 8D - Sheltered rocky rubble shores

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category III & IV
- IUCN Category I, II
- IUCN Category III, IV

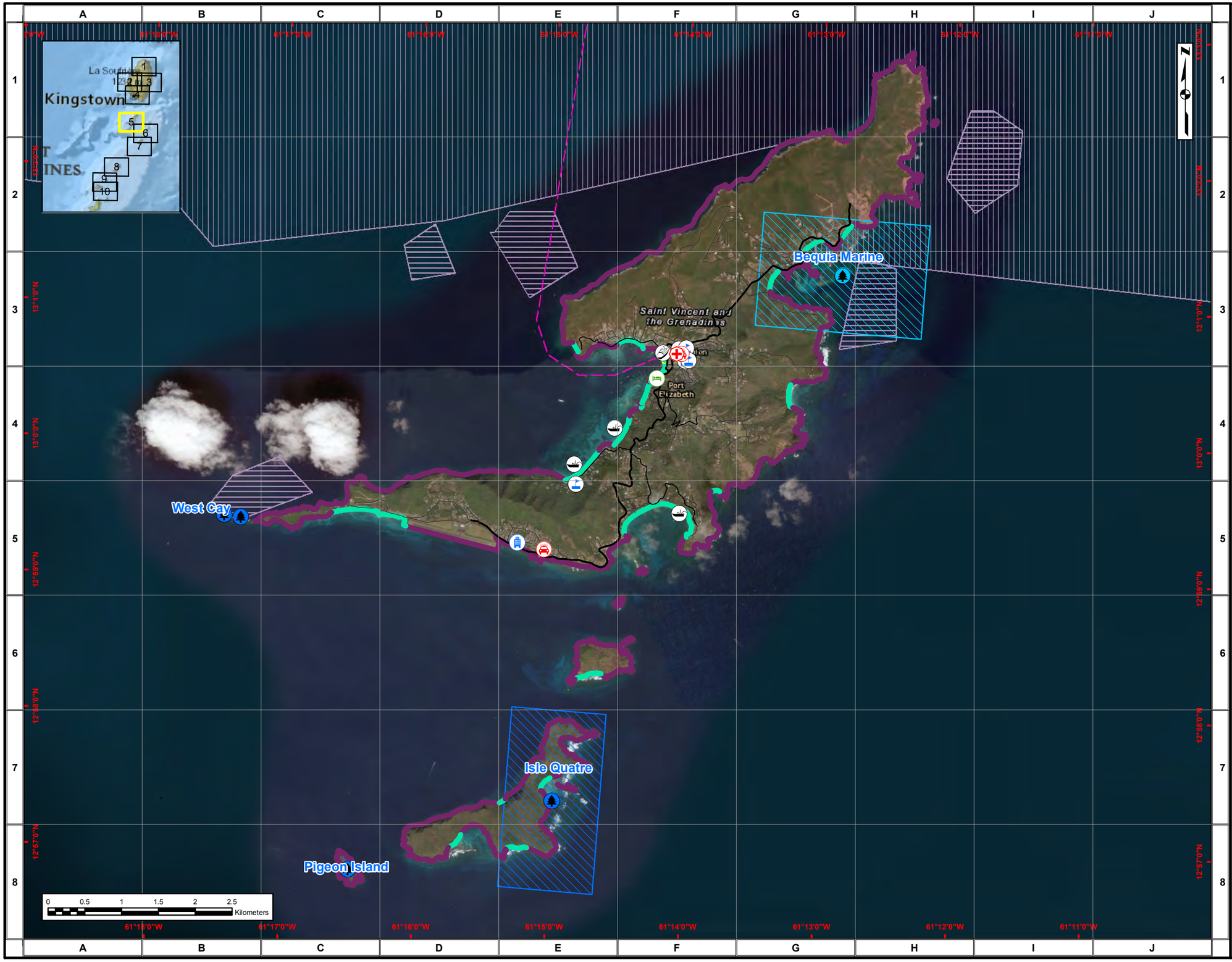
Onshore National Protected Areas

- IUCN Category III & IV
- IUCN Category III, IV
- Seagrass
- Hospitals
- Police Stations
- Kindergarten
- School
- College
- Port or Marina
- Fishing Dock or Landing
- Ferry Dock
- Historic Site
- Burial Grounds
- Places of Worship
- Government Facilities
- Hotels
- Primary Roads
- Tertiary Roads
- Access Roads and Tracks
- Shipping Route
- Seabed Cables

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Shoreline Access
St Vincent and The Grenadines
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1C - Exposed rocky cliffs with boulder talus base
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures

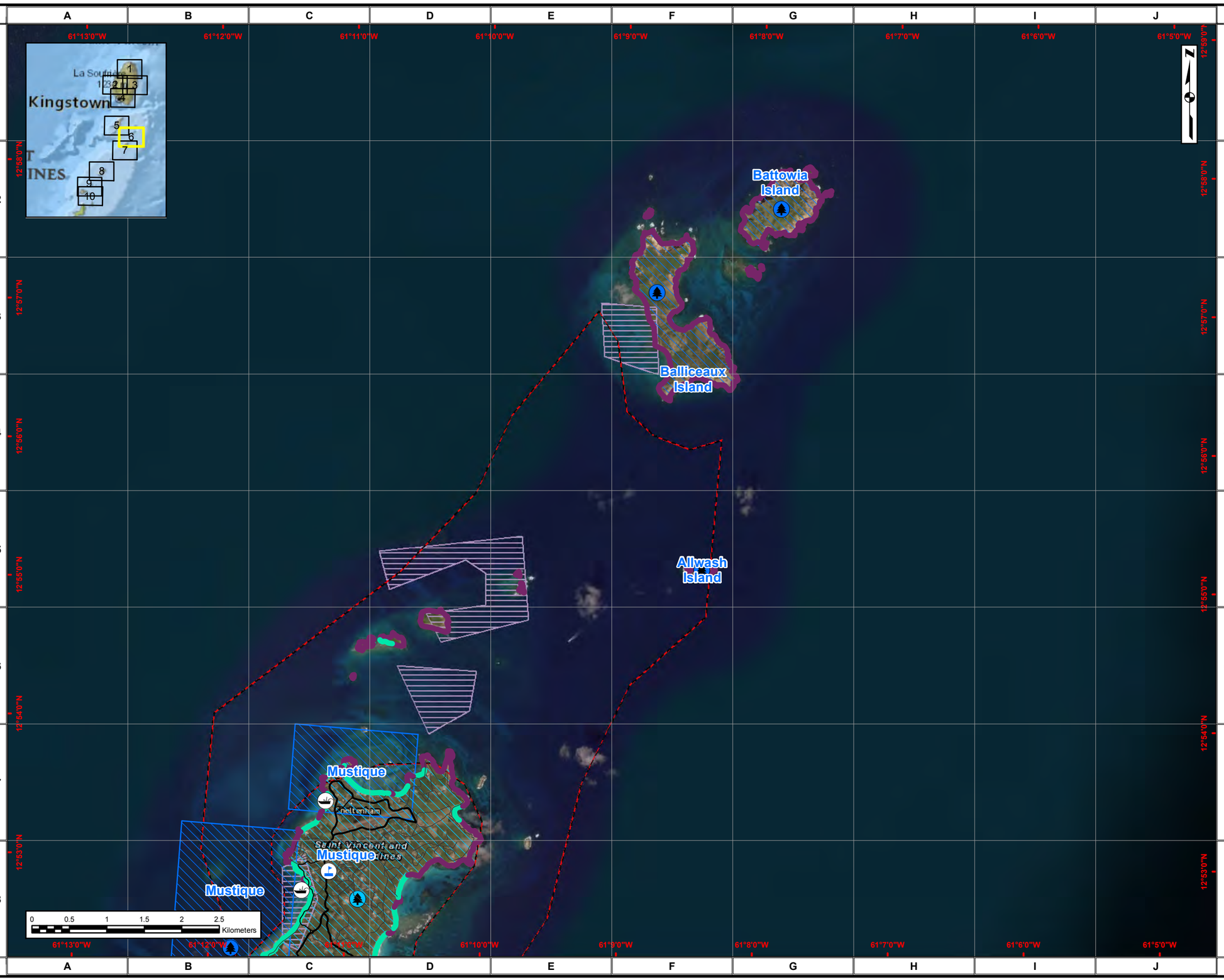
Marine National Protected Areas

- IUCN Category III & IV
- IUCN Category V & VI
- IUCN Category III, IV
- IUCN Category V, VI
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- School
- Fishing Dock or Landing
- Ferry Dock
- Government Facilities
- Hotels
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Shipping Route

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Shoreline Access
St Vincent and The Grenadines
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1C - Exposed rocky cliffs with boulder talus base
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures

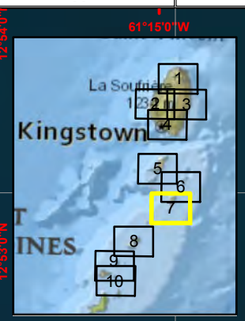
Marine National Protected Areas

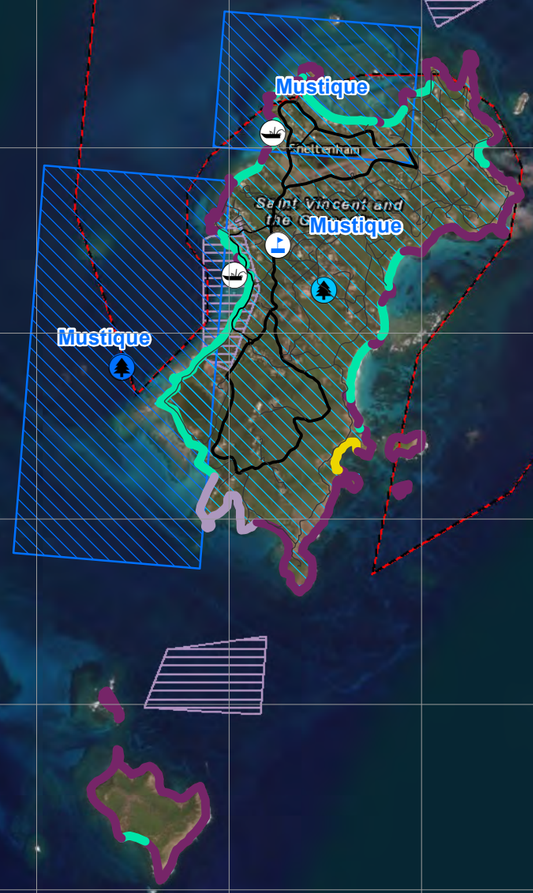
- IUCN Category III & IV
- IUCN Category V & VI
- IUCN Category III, IV
- IUCN Category V, VI
- Coral Reefs
- School
- Fishing Dock or Landing
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Hazardous Areas

Coastal Sensitivity and Spill Response
Shoreline Access
St Vincent and The Grenadines
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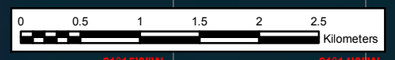
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1C - Exposed rocky cliffs with boulder talus base
- 2B - Exposed scarps and steep slopes in clay
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 8D - Sheltered rocky rubble shores

Marine National Protected Areas

- IUCN Category III & IV
- IUCN Category V & VI
- IUCN Category III, IV
- IUCN Category V, VI
- Coral Reefs
- School
- Fishing Dock or Landing
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Hazardous Areas

Coastal Sensitivity and Spill Response
Shoreline Access
St Vincent and The Grenadines
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1C - Exposed rocky cliffs with boulder talus base
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures

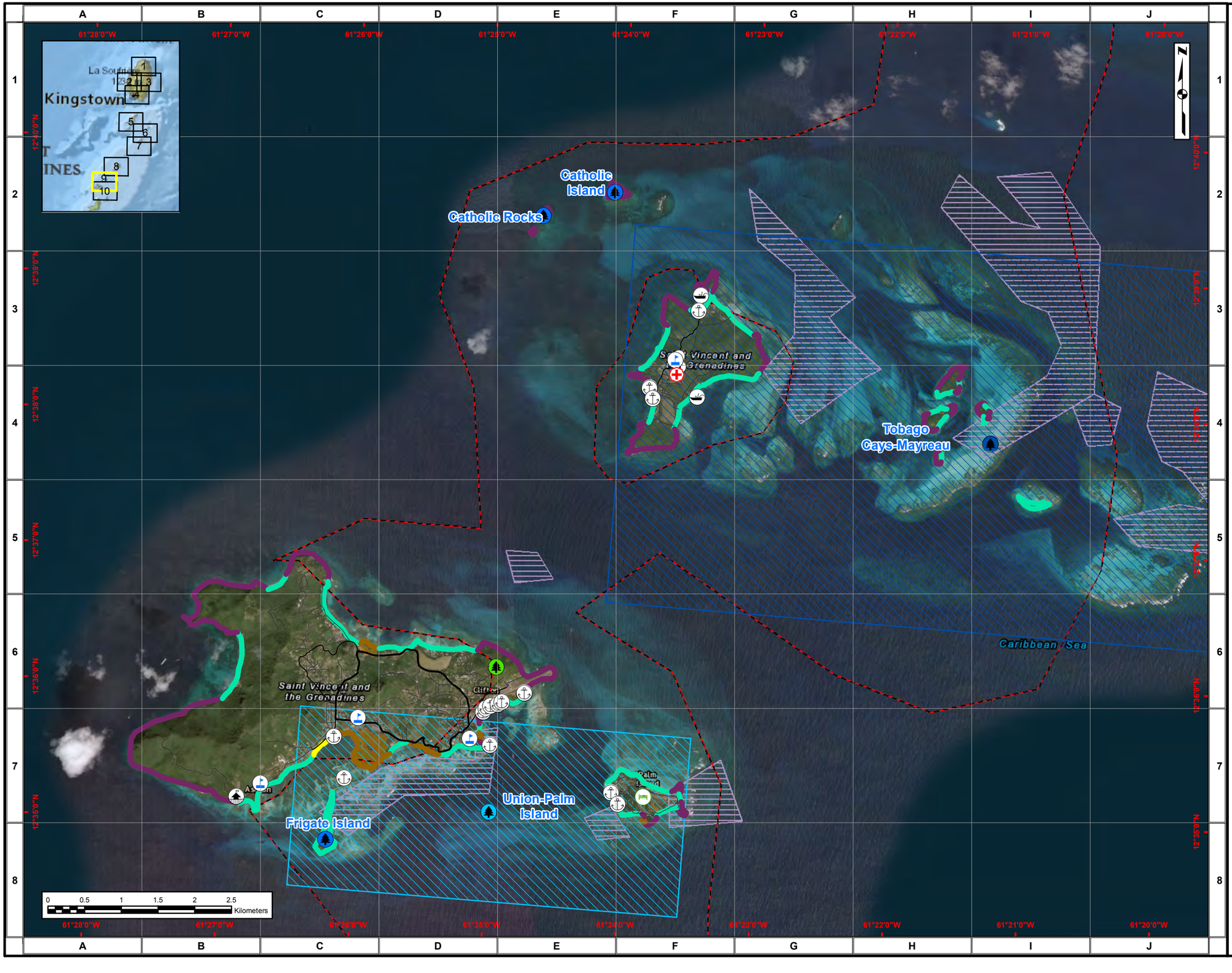
Marine National Protected Areas

- IUCN Category III & IV
- IUCN Category III, IV
- Coral Reefs
- School
- Port or Marina
- Fishing Dock or Landing
- Places of Worship
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Hazardous Areas

Coastal Sensitivity and Spill Response
Shoreline Access
St Vincent and The Grenadines
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1C - Exposed rocky cliffs with boulder talus base
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 10D - Mangroves

Marine National Protected Areas

- IUCN Category I & II
- IUCN Category III & IV
- IUCN Category V & VI
- IUCN Category I, II
- IUCN Category III, IV
- IUCN Category V, VI

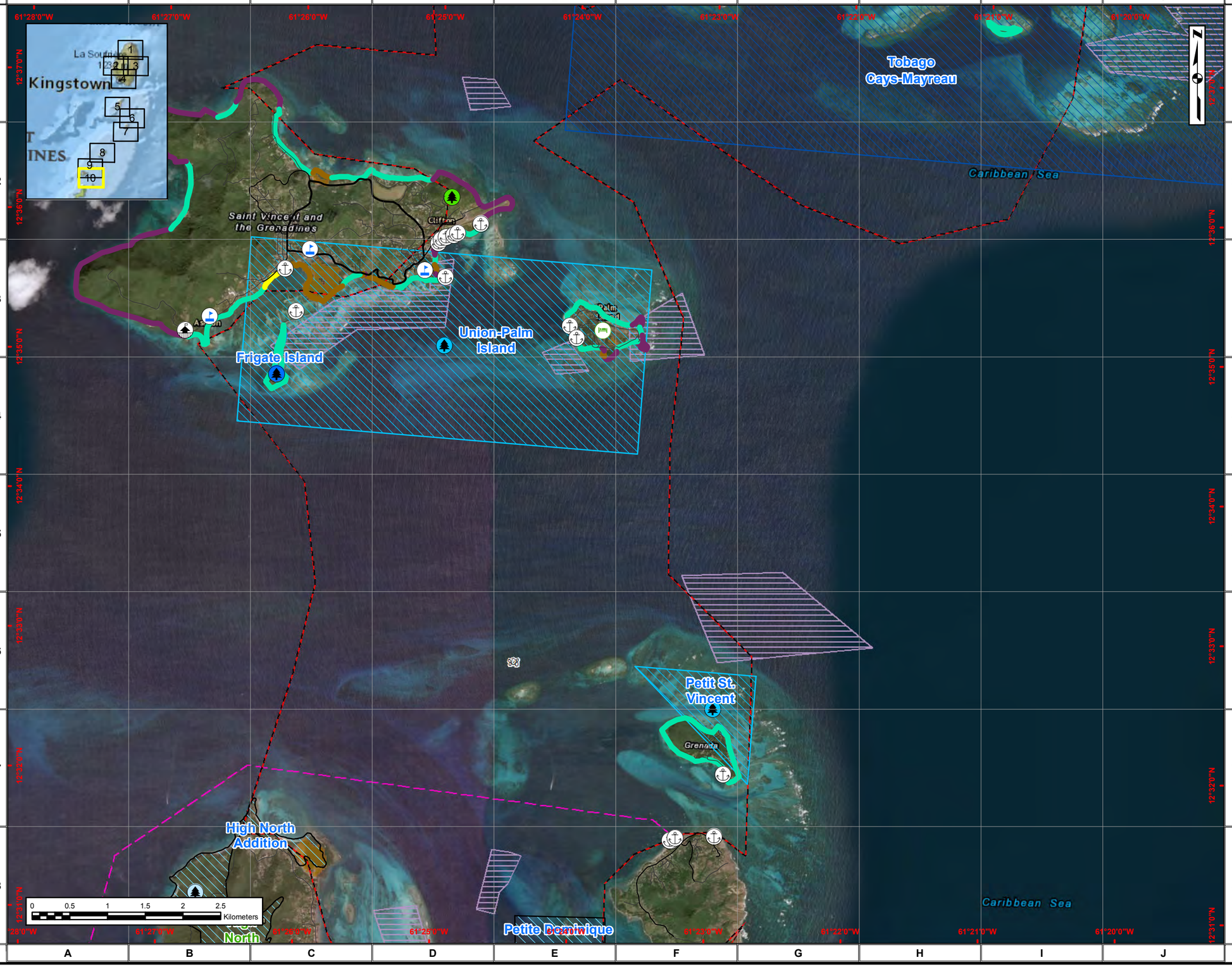
Onshore National Protected Areas

- IUCN Category III & IV
- Mangrove Areas (ESI 10D)
- Coral Reefs
- Hospitals
- School
- Port or Marina
- Fishing Dock or Landing
- Historic Site
- Burial Grounds
- Places of Worship
- Hotels
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Hazardous Areas

Coastal Sensitivity and Spill Response
Shoreline Access
St Vincent and The Grenadines
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Legend

Shoreline Sensitivity (ESI)

- 1A - Exposed rocky shore
- 1B - Exposed, solid man-made structures
- 1C - Exposed rocky cliffs with boulder talus base
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 10D - Mangroves

Marine National Protected Areas

- IUCN Category III & IV
- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category III, IV
- IUCN Category V, VI
- IUCN Category Not Reported

Onshore National Protected Areas

- IUCN Category III & IV
- IUCN Category I, II
- Mangrove Areas (ESI 10D)
- Coral Reefs
- School
- Port or Marina
- Historic Site
- Hotels
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Rock
- Hazardous Areas
- Shipping Route

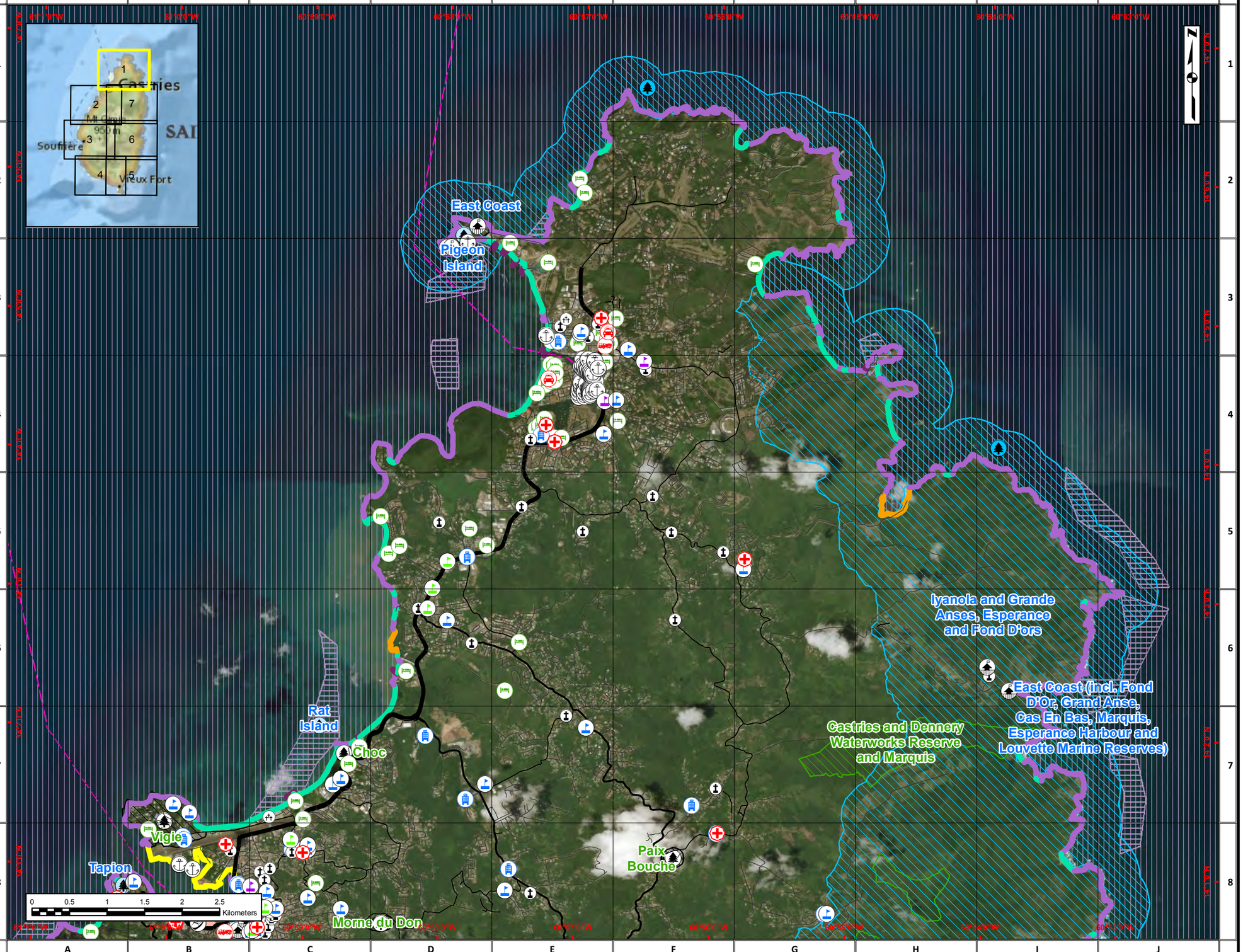
Coastal Sensitivity and Spill Response
Shoreline Access
St Vincent and The Grenadines
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St. Lucia

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Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 8B - Sheltered, solid man-made structures
- 9B - Vegetated low banks

Marine National Protected Areas

- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category V, VI
- IUCN Category Not Reported

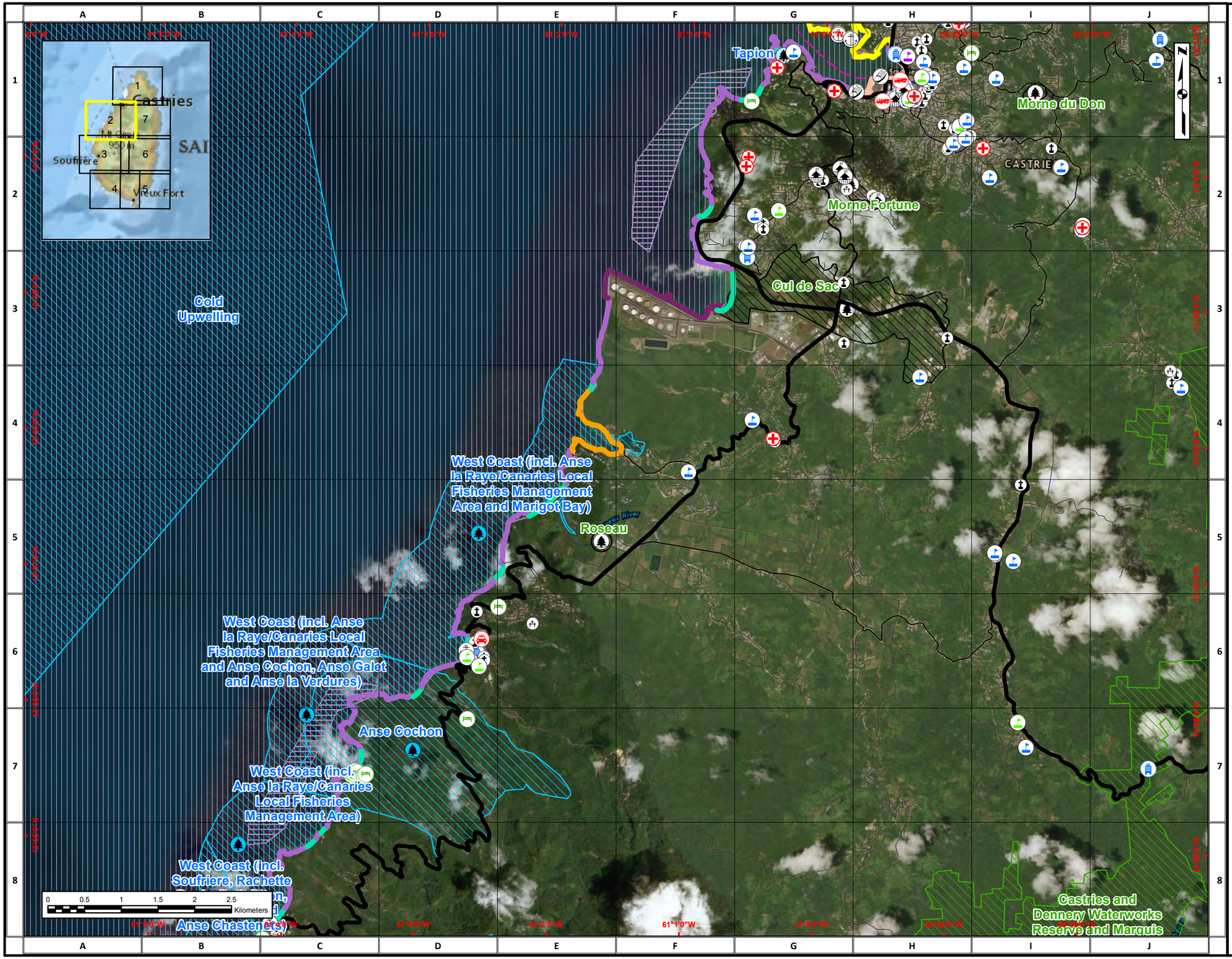
Onshore National Protected Areas

- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category Not Reported
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- Fire Stations (Georgetown)
- Kindergarten
- School
- College
- Port or Marina
- Ferry Dock
- Historic Site
- Burial Grounds
- Places of Worship
- Government Facilities
- Hotels
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Navigation Aids
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access - St Lucia
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Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 8B - Sheltered, solid man-made structures
- 9B - Vegetated low banks

Marine National Protected Areas

- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category V, VI
- IUCN Category Not Reported

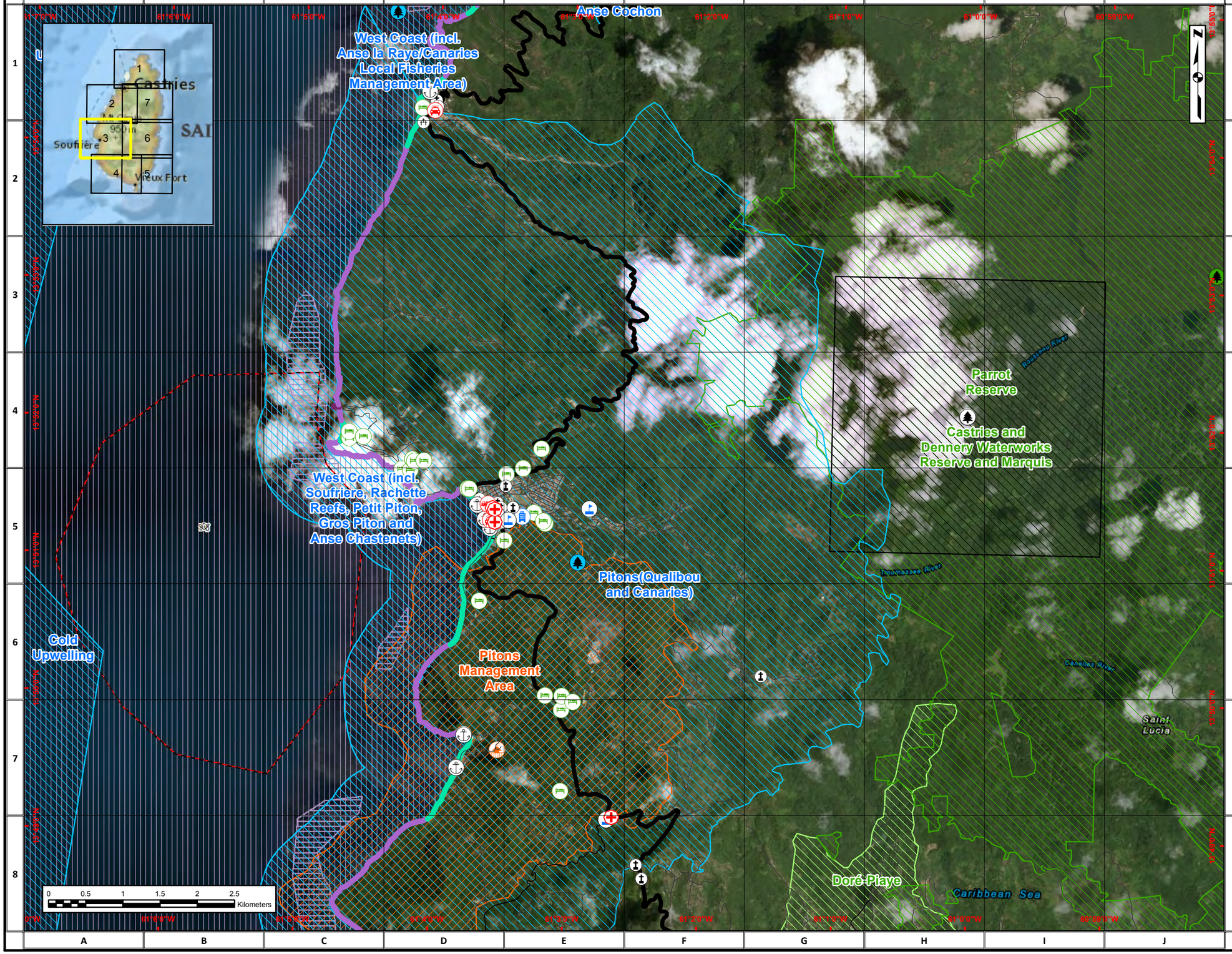
Onshore National Protected Areas

- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category Not Reported
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- Fire Stations (Georgetown)
- Kindergarten
- School
- College
- Port or Marina
- Ferry Dock
- Historic Site
- Burial Grounds
- Places of Worship
- Government Facilities
- Hotels
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access - St Lucia
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Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures

Marine National Protected Areas

- IUCN Category V & VI
- IUCN Category V, VI

Onshore International Protected Areas

- Onshore - World Heritage Site
- International Onshore Protected Area

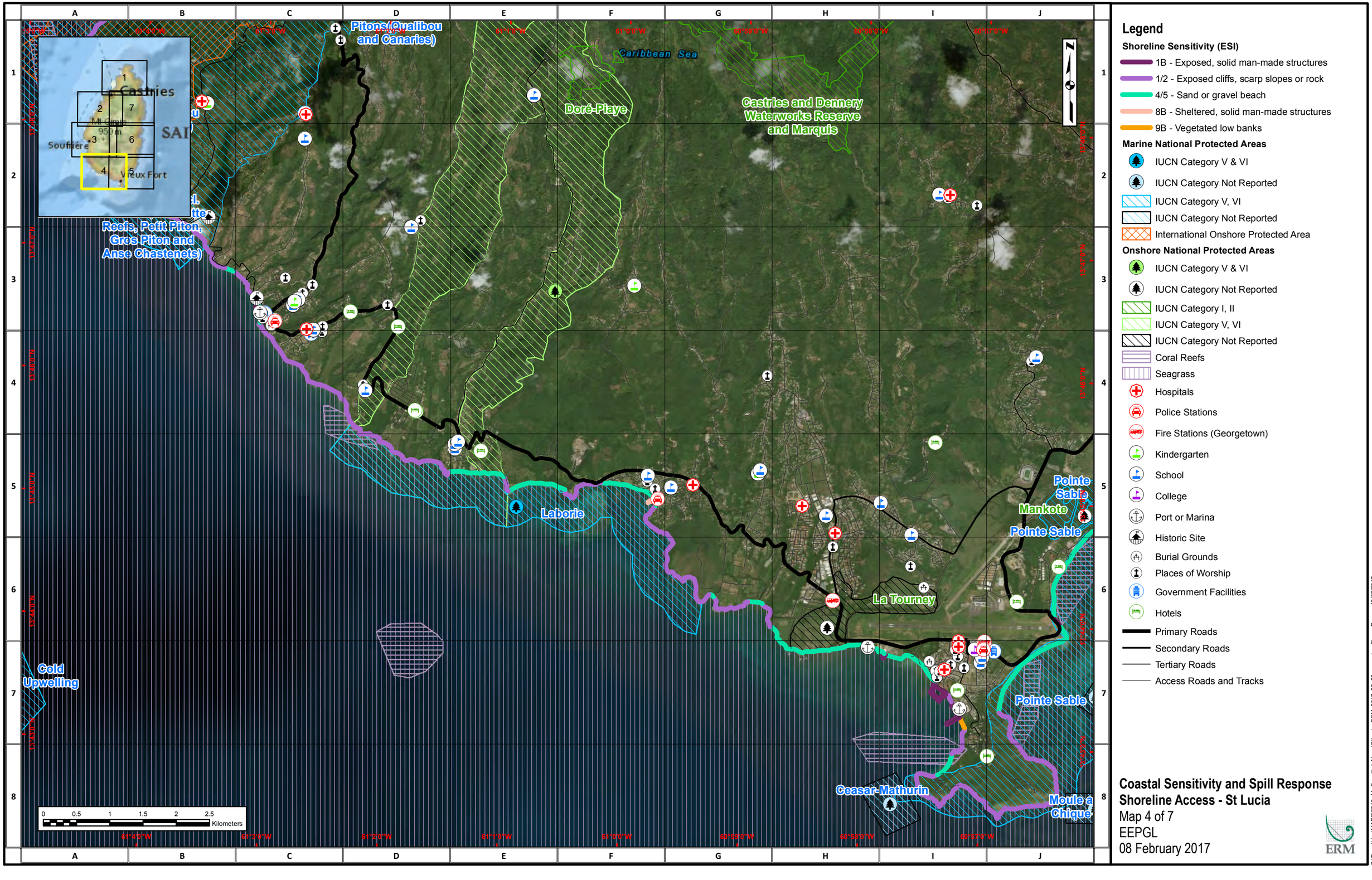
Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category V, VI
- IUCN Category Not Reported
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- Fire Stations (Georgetown)
- Kindergarten
- School
- Port or Marina
- Burial Grounds
- Places of Worship
- Government Facilities
- Hotels
- Primary Roads
- Tertiary Roads
- Access Roads and Tracks
- Rock
- Hazardous Areas

Coastal Sensitivity and Spill Response
Shoreline Access - St Lucia
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Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8B - Sheltered, solid man-made structures
- 9B - Vegetated low banks

Marine National Protected Areas

- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category V, VI
- IUCN Category Not Reported
- International Onshore Protected Area

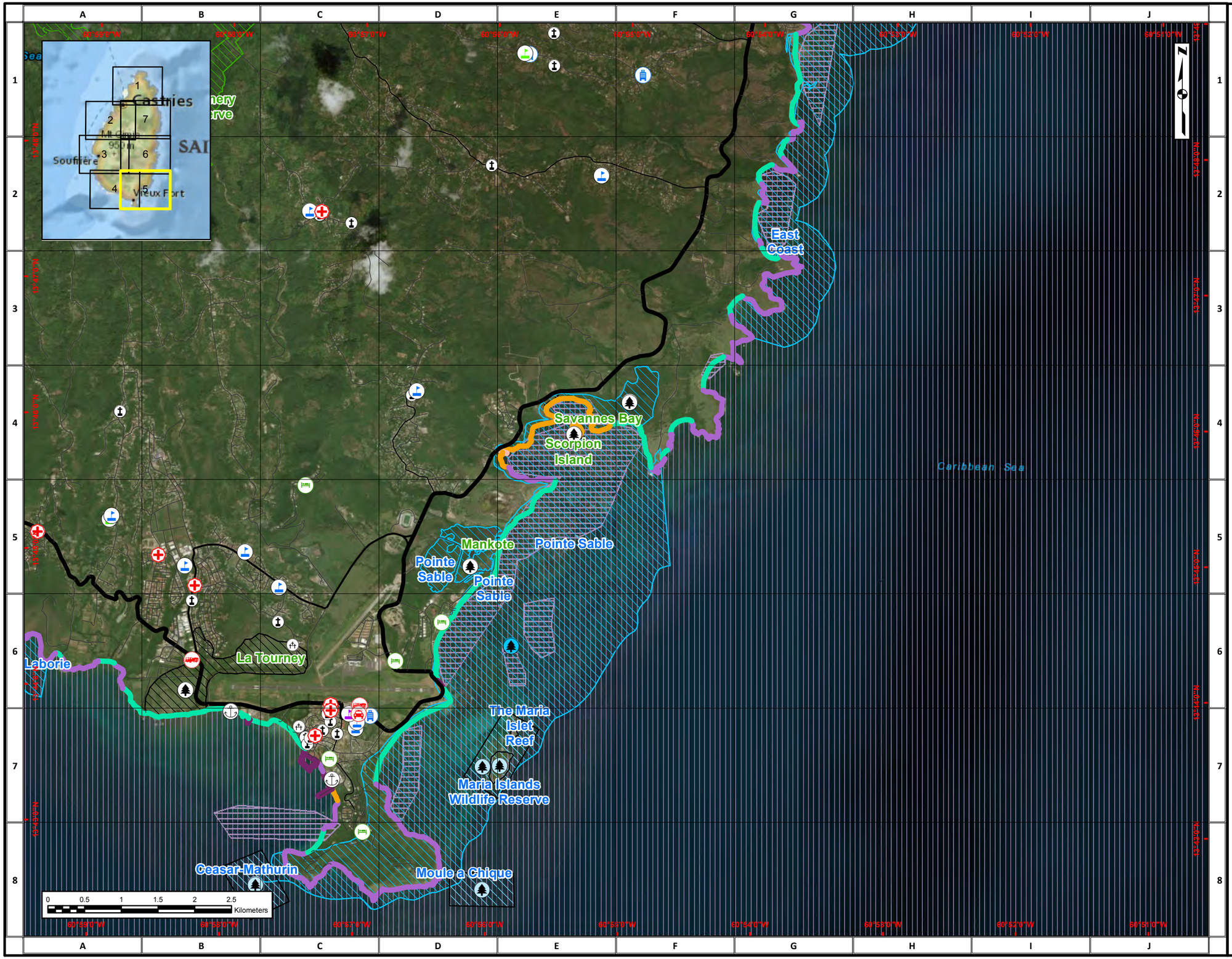
Onshore National Protected Areas

- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category V, VI
- IUCN Category Not Reported
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- Fire Stations (Georgetown)
- Kindergarten
- School
- College
- Port or Marina
- Historic Site
- Burial Grounds
- Places of Worship
- Government Facilities
- Hotels
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks

Coastal Sensitivity and Spill Response
Shoreline Access - St Lucia
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Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8B - Sheltered, solid man-made structures
- 9B - Vegetated low banks

Marine National Protected Areas

- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category V, VI
- IUCN Category Not Reported

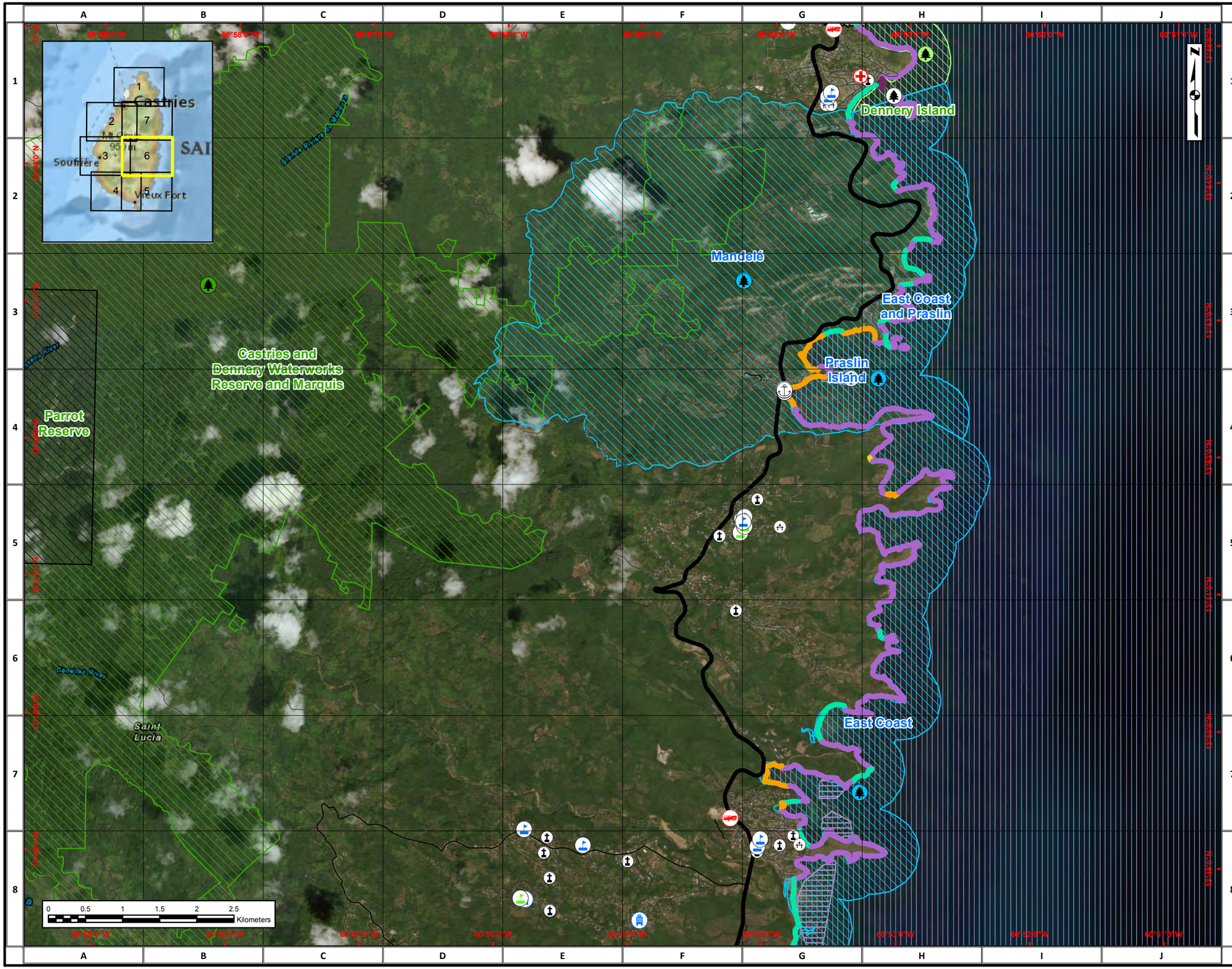
Onshore National Protected Areas

- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category Not Reported
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- Fire Stations (Georgetown)
- Kindergarten
- School
- College
- Port or Marina
- Burial Grounds
- Places of Worship
- Government Facilities
- Hotels
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks

Coastal Sensitivity and Spill Response
Shoreline Access - St Lucia
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Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8D - Sheltered rocky rubble shores
- 9B - Vegetated low banks

Marine National Protected Areas

- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category V, VI
- IUCN Category Not Reported

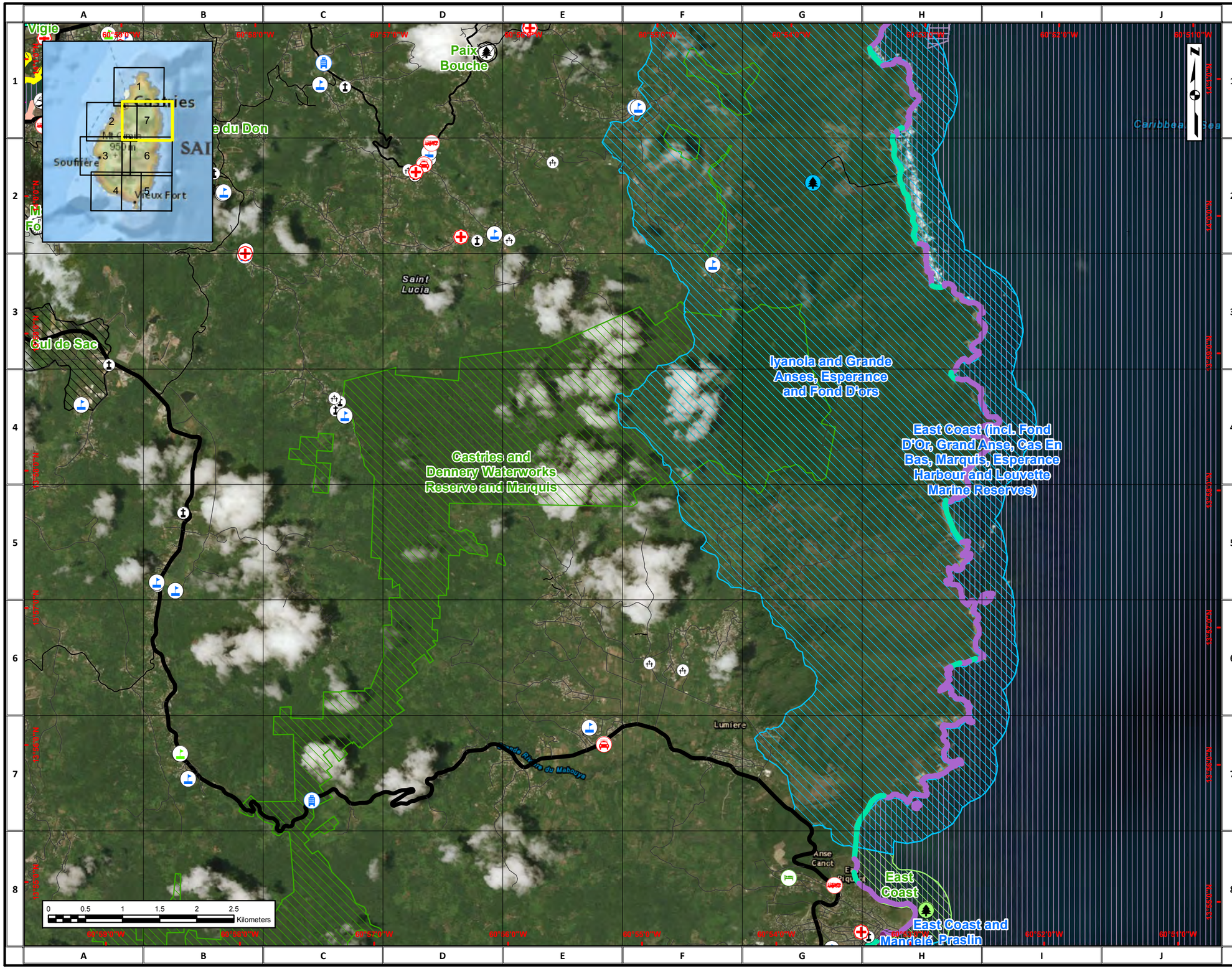
Onshore National Protected Areas

- IUCN Category I & II
- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category V, VI
- IUCN Category Not Reported
- Coral Reefs
- Seagrass
- Hospitals
- Fire Stations (Georgetown)
- Kindergarten
- School
- Port or Marina
- Burial Grounds
- Places of Worship
- Government Facilities
- Hotels
- Primary Roads
- Tertiary Roads
- Access Roads and Tracks

Coastal Sensitivity and Spill Response
Shoreline Access - St Lucia
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Legend

Shoreline Sensitivity (ESI)

- 1B - Exposed, solid man-made structures
- 1/2 - Exposed cliffs, scarp slopes or rock
- 4/5 - Sand or gravel beach
- 8 - Sheltered bedrock or man-made structures
- 8B - Sheltered, solid man-made structures

Marine National Protected Areas

- IUCN Category V & VI
- IUCN Category V, VI

Onshore National Protected Areas

- IUCN Category V & VI
- IUCN Category Not Reported
- IUCN Category I, II
- IUCN Category V, VI
- IUCN Category Not Reported
- Coral Reefs
- Seagrass
- Hospitals
- Police Stations
- Fire Stations (Georgetown)
- Kindergarten
- School
- College
- Ferry Dock
- Historic Site
- Burial Grounds
- Places of Worship
- Government Facilities
- Hotels
- Primary Roads
- Secondary Roads
- Tertiary Roads
- Access Roads and Tracks
- Shipping Route

Coastal Sensitivity and Spill Response
Shoreline Access - St Lucia
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