Environmental Impact Assessment

Technical Appendices

Liza Phase 1 Development Project

Esso Exploration and Production Guyana, Limited

February 2017

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David W. Blaha

ERM Partner

The business of sustainability

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APPENDICES

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APPENDIX A – List of Preparers Signatures

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LIST OF PREPARERS

David Blaha, Project Director
Chapters 1 and 11, Section 7.4, and EIS

Jason Willey, Project Manager
Chapter 10 and Sections 6.2.5-7 and 7.2.5-7 and Appendix G

Greg Lockard, EIA Coordinator
Chapters 4, 5, 8, and 12

Kamal Govender
Chapters 2 and 9

Melinda Todorov
Chapters 1, 3 and Sections 6.2.8 and 7.2.8

Adeyinka Afon
Sections 6.1.2 and 7.1.2

Jonathan Connelly
Sections 6.2.1-2 and 7.2.1-3 and Appendices D and E

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Sections 6.1.3 and 7.1.3

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Sections 6.1.4 and 7.1.4

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Sections 6.1.1 and 7.1.1

Dusty Insley
Sections 6.1.3 and 7.1.3

Peyun Kok
Sections 6.3.1-4 & 6-7 & 9 and 7.3.1-4 & 6-7 & 9 and Appendix C

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Sections 6.3.1-4 & 6-7 & 9 and 7.3.1-4 & 6-7 & 9 and Appendix C

Benjamin Siegel
Sections 6.3.8 and 7.3.8

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Sections 6.3.5 and 7.3.5

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Sections 6.2.3 and 7.2.4 and Appendix F

Noella Arispe
Coastal Sensitivity Mapping

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Coastal Sensitivity Mapping

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Coastal Sensitivity Mapping and
Stakeholder Engagement

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Senior Review

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APPENDIX B – CVs

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David W. Blaha, AICP

Technical Director

Mr. Blaha has 31 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.

Jason Willey

Project Manager

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.

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Greg Lockard, PhD

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

Tres Mesas Project / OPIC (5/16-present).
Project Manager. Conducting 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).

Lafito Industrial Free Zone and Power Plant Project / CIFI (4/16-present).
Project Manager. Conducting an ESDD for a port, industrial free zone, and power plant in Haiti. Sent a team to Haiti as part of the ESDD to visit the project site and interview project personnel and affected communities.

Fields Point Liquefaction Project / National Grid LNG, LLC (4/16-present).
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.

Driftwood LNG Project / Driftwood LNG, LLC (3/16-present).
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 1200-acre liquefied natural gas (LNG) liquefaction export facility in Calcasieu 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.

G2 Project / G2 LNG, LLC (2/16-present).
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.

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

Sucden Sugar and Bio-Energy Lending Program / Inter-American Development Bank (IDB) (7/15-present).
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.

Susquehanna West, Triad, and Orion Projects / Tennessee Gas Pipeline Company (7/15-present).
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-present).
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.

Red Vial 4 Highway Project, Environmental and Social Monitoring / Banco de Crédito del Perú, Corporación Andina de Fomento, and Crédit Agricole (5/15-present).
Cultural Heritage Lead. Monitoring review, including alignment with IFC performance standards, of the cultural heritage program for a 283 km highway project in northern Peru.

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.

Gasoducto Sur Peruano Project, Independent Environmental & Social Consultant / Citi and Sumitomo Mitsui Banking Corporation (1/15-12/15).
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 pre-closing monitoring to assess the project's progress towards addressing ESAP requirements.

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.

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.

Project Zilkha / EIG (8/15-10/15).
Project Manager. Environmental and Social Due Diligence (ESDD) for investment in a biomass energy project in the United States and the United Kingdom.

Farim Phosphate Project / GB Minerals (6/15-8/15).
Senior Reviewer. Reviewed the cultural heritage baseline and cultural heritage sections of an Environmental and Social Impact Assessment (ESIA) for a mining project in Guinea-Bissau.

Tyre Casino Project (6/15-7/15).
Consultant. Conducted a cultural resources desktop analysis, including historic map research, for a casino project in Seneca County, New York.

Project Zedd / Harbour Energy (6/15).
Consultant. Worked on a small team conducting a transactional Environmental and Social Due Diligence (ESDD) of an oil & gas company in Peru.

Circum Minerals Potash Mining Project / Circum Minerals (5/15).
Senior Reviewer. Reviewed the cultural heritage baseline and cultural heritage sections of an Environmental and Social Impact Assessment (ESIA) for a potash mining project in Ethiopia's Danakil Depression.

GAC Project / Guinea Aluminum Corporation (4/15).
Senior Reviewer. Reviewed the cultural heritage baseline and cultural heritage sections of an Environmental, Social, and Health Impact Assessment (ESIA) for an aluminum mining project in Guinea.

Franklin Project / Shell (11/14-5/15).
Technical Section Lead. Prepared the cultural resources sections for an Environmental, Social, and Health Impact Assessment (ESHIA) for a proposed petrochemical facility in western Pennsylvania.

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.

Project Pisco / Harbour Energy (4/15-5/15).
Consultant. Worked on a small team conducting a transactional Environmental and Social Due Diligence (ESDD) of an oil & gas company in Colombia.

AMBU Project / Chevron (11/14-4/15).
Technical Section Lead. Prepared the cultural resources sections for an Environmental, Social, and Health Impact Assessment (ESHIA) for potential gas development in 26 counties in western Pennsylvania, eastern Ohio, and northern West Virgina.

Appalachia Project / Shell (3/15-4/15).
Consultant. Prepared a Cultural Heritage Support document for potential oil & gas development in Potter and Tioga Counties, Pennsylvania.

Ras al-Khair Industrial City Project / Saudi Arabia Royal Commission (4/15).
Consultant. Prepared a Cultural Heritage Management Plan (CHMP) for an economic diversification and industrialization project for the development of hydrocarbon based and energy intensive industries in eastern Saudi Arabia.

Nicaragua Grand Canal Project / Hong Kong Nicaragua Development Company (12/14-2/15).
Cultural Heritage Specialist. Wrote the Cultural Heritage Management Plan (CHMP) and peer reviewed the cultural heritage sections of an Environmental and Social Impact Assessment (ESIA) for a major canal project in Nicaragua.

Project Base / The Carlyle Group (1/15).
Cultural Heritage Lead. Prepared the cultural resource sections of an Environmental Due Diligence report of a mining company in Wyoming.

PERU LNG Project / PERU LNG S.R.L. (4/08-9/10).
Archaeological Coordinator, Environmental Resource Management Perú, S.A. (4/08-4/09) and Compañía Operadora de LNG del Perú S.A.C (4/09-9/10). Lead archaeologist for a $3.8 billion natural gas pipeline and liquefaction plant project; Manager of a team of eight archaeologists; Coordinator with the national and local offices of Peru's Instituto Nacional de Cultura (INC) concerning archaeological work permits, document approvals, site supervisions, and construction permits; Developed, negotiated, and managed the project's archaeological services contracts, which have a combined value of over $10 million, with four separate companies; Supervised the Phase III rescue excavation of 130 archaeological sites by contractors; Supervised the investigation of 134 "chance finds," 90 of which were fully or partially excavated by contractors, as part of archaeological monitoring plans; Served as Director for one INC-approved project, Project Manager for three projects directed by COLP archaeologists, and Client-based Manager for 16 projects directed by contractors.

Non-ERM Experience

Master Environmental Consulting Services Contract / BP Exploration & Production, Inc. (8/12-11/14).
Contract Manager. Managed a contract to provide environmental services to an oil and gas client. The contract had three work releases totaling over $10M in value.

Cultural Resources-related Services at Various Locations within the NAVFAC, Southwest Area of Responsibility / NAVFAC Southwest (11/12-11/14).
Contract Manager. Managed an IDIQ contract to provide cultural resource services to the Navy. A total of 32 task orders were issued under the contract during this time period, totaling over $3.5M.

Cultural Resources Services Agreement / Delaware Department of Transportation (10/13-11/14).
Contract Manager. Managed a contract to provide cultural resource services to the Delaware DOT. Four task orders were issued under the contract during this time period, totaling over $250K.

MC 252 (Deepwater Horizon) Oil Spill Response Cultural Resources Program / BP Exploration and Production, Inc. (5/11-11/14).
Project Manager. Supervised a multi-disciplinary team providing cultural resources support for the Deepwater Horizon oil spill cleanup in coastal Louisiana, Mississippi, Alabama, and Florida. Responsible for managing subcontracts with six separate companies that supported the project. Supervised the archaeological

survey of over 6,000 km of shoreline, which recorded 115 new sites and revisited 447 previously recorded sites. Supervised an ethnographic survey of the Gulf Coast, which recorded 348 potential traditional cultural properties (TCPs) and 17 traditional cultural landscapes.

MC 252 Natural Resources Damage Assessment (NRDA) Section 106 Support Program / BP Exploration and Production, Inc. (10/11-11/14).
Project Manager. Supervised a team providing cultural resources support for the NRDA activities of the National Oceanic and Atmospheric Administration (NOAA) and the Department of Interior (DOI) related to the Deepwater Horizon oil spill cleanup.

Tactical Infrastructure Maintenance and Repair Project / U.S. Customs and Border Protection (10/10-11/14).
Technical Section Lead. Assisted in the preparation of a Programmatic Agreement (PA) and prepared the cultural resources sections for four Environmental Assessments that cover the international borders of California, Arizona, New Mexico, and Texas.

Spindrift Project / Private Client (11/12-11/14).
Contract Manager. Managed the contract for an Archaeological Data Recovery Plan (ADRP) and Cultural Materials Inventory Program (CMIP) in La Jolla, San Diego, California.

Biological and Cultural Surveys and Site Protection on the North Range Maneuver Areas of White Sands Missile Range, New Mexico / USACE Tulsa District (12/12-11/14).
Consultant. Provided project management guidance and client coordination support for the biological and archaeological survey of three tracts of land totaling 125,000 acres and subsequent testing of archaeological sites in east-central New Mexico.

Tappan Zee Hudson River Crossing / Tappan Zee Constructors / New York State Thruway Authority (2/13-11/14).
Consultant. Provided project management guidance and client coordination support for the implementation of the Section 106 Memorandum of Agreement (MOA) for the construction of the new Tappan Zee Bridge in New York. The project includes HAER documentation of the old bridge.

CSX North Branch Project / CSX Transportation (8/13-11/14).
Consultant. Oversaw a subcontractor in the execution of an MOA and provided Section 106 expertise for a project to replace a historic railroad bridge crossing the Potomac River between Maryland and West Virginia.

Champlain Hudson Power Express Project / U.S. Department of Energy (9/10-9/14).
Technical Section Lead. Prepared the cultural resources sections for an Environmental Impact Statement (EIS) for a 335-mile transmission line project in New York.

Phase I Archaeological Survey at Blossom Point Tracking Facility, Charles County, Maryland / NAVFAC Washington (8/13-6/14).
Supervised the Phase I archaeological survey of approximately 66 acres in Charles County, Maryland and peer reviewing the technical report and cultural resource sections to an Environmental Assessment.

Phase I Archaeological Survey of the DoD Owned Rail System RoW from Marine Corps Air Station Cherry Point and the Marine Corps Base Camp Lejeune, North Carolina / NAVFAC Atlantic Division (9/12-3/14).
Contract Manager. Supervised a subcontractor conducting a Phase I archaeological survey of five miles of a 6.2-mile corridor in Carteret County, North Carolina.

Phase I Archaeological Survey of Approximately 218 Acres at Marine Corps Air Station Cherry Point, North Carolina / NAVFAC Atlantic Division (9/12-3/14).
Contract Manager. Supervised a subcontractor conducting a Phase I archaeological survey of 11 areas totaling 218 acres in Craven County, North Carolina.

Section 110 Compliance Support Project / U.S. Customs and Border Protection (10/11-12/13).
Consultant. Provided client coordination support and peer review of deliverables for a multi-disciplinary and multi-faceted project to assist CBP in complying with Sections 106 and 110 of the National Historic Preservation Act for its 361 facilities nationwide. In the first phase of the project, HDR collected 361 cultural

resource reports for CBP facilities nationwide and created a database that is cross-referenced with CBP's real property inventory to store this cultural resources data. In the second phase, HDR developed a program plan that identifies facilities and locations needing cultural resources survey and NRHP eligibility evaluations and a process for systematically conducting cultural resource inventories at CBP facilities. For the third phase, HDR developed standard operating procedures for the curation of archaeological artifacts from CBP facilities nationwide. In the fourth phase, HDR surveyed 45 CBP facilities nationwide for archaeological and historic architectural resources, completed survey reports and SHPO forms, and made NRHP eligibility evaluation recommendations for surveyed resources.

Phase I Archaeological Survey of North Smithfield Air National Guard Station / Air National Guard (5/11-12/13).
Task Manager. Supervised the Phase I archaeological survey of a 34-acre ANG installation in Providence County, Rhode Island.

Archaeological Survey and Condition Assessment of Fort Livingston (16JE49), Jefferson Parish, Louisiana / BP Exploration and Production, Inc. (5/12-8/13).
Project Manager. Supervised the survey and assessment of Fort Livingston (16JE49) in Jefferson Parish, Louisiana. Fort Livingston is Civil War era fort that is listed on the National Register of Historic Places. The project includes a structural engineering assessment, LiDAR mapping, geophysical survey, historical research, archaeological shovel testing, and an architectural treatment analysis by conservation specialists.

Archaeological Survey of Cat Island, Harrison County, Mississippi / BP Exploration and Production, Inc. (1/12-6/13).
Project Manager. Supervised the Phase I archaeological survey of 37.7 km (23.4 miles) of shoreline on Cat Island in Harrison County, Mississippi.

Phase I Archaeological Investigations at Friendship Hill National Historic Site, Point Marion, Pennsylvania / National Park Service (9/12-10/12).
Project Manager. Supervised the Phase I archaeological survey of two small parcels at a historic NPS site in Fayette County, Pennsylvania.

Geoarchaeological Survey of the Proposed Car Barn Training Center for the H Street/Benning Road Streetcar Project / District Department of Transportation (DDOT) (6/12-9/12).
Task Manager. Supervised the geoarchaeological survey of a two-acre parcel in Washington, DC.

Phase I Archaeological Survey for the Homer City Upgrade Project, Wetland Replacement Areas, Black Lick and Center Townships, Indiana County, Pennsylvania / Edison Mission Energy (9/12).
Task Manager. Supervised the Phase I archaeological survey of two one-acre parcels in Indiana County, Pennsylvania.

Environmental Specialty Services Master Services Agreement / Atlantic Richfield Company (4/11-7/12).
Contract Manager. Managed a contract to provide environmental services to an oil and gas client. The contract had multiple work releases totaling over $13M in value.

Defense Supply Center Richmond / Defense Logistics Agency Enterprise Support (DES) Richmond (5/12-7/12).
Principal Investigator and Field Director. Directed the Phase II evaluations of two prehistoric artifact scatters (44CF616 and 44CF648) and a historic site (44CF650) in Chesterfield County, Virginia.

Archaeological Monitoring for Road Construction and Landscaping in the Glasshouse Area of Colonial Parkway Jamestown Unit, Colonial National Historical Park / National Park Service (10/11-7/12).
Project Manager. Supervised the archaeological monitoring of construction activities near the Glasshouse and New Towne areas of Jamestown at Colonial National Historical Park.

Phase I Archaeological Survey of Charlotte International Airport Air National Guard Base and Stanly County Airport Air National Guard Station / Air National Guard (3/12-5/12).
Principal Investigator and Field Director. Directed the Phase I archaeological survey of a 99-acre ANG installation in Mecklenberg County and a 111-acre ANG installation in Stanly County, North Carolina.

Phase I Archaeological Survey of Luis Muñoz Marín International Airport Air National Guard Base / Air National Guard (8/11-10/11).
Principal Investigator and Field Director. Directed the Phase I archaeological survey of a 95-acre Air National Guard Base in Municipality Carolina, Puerto Rico.

Defense Supply Center Richmond / Defense Logistics Agency Enterprise Support (DES) Richmond (11/10-8/11).
Principal Investigator and Field Director. Directed the Phase II evaluations of a prehistoric lithic scatter (44CF615) and two historic sites (44CF647 and 44CF649) in Chesterfield County, Virginia.

Phase IA Cultural Resources Survey of the NEON Site in Ponce, Puerto Rico / National Ecological Observatory Network (3/11-4/11).
Principal Investigator and Field Director. Directed the Phase IA cultural resources survey of a 50-acre property in Ponce, Puerto Rico.

Anacostia Streetcar Project / District Department of Transportation (DDOT) (1/11-4/11).
Archaeology Consultant. Environmental Assessment.

Cultural Resources Survey of Memphis Air National Guard Base / Air National Guard (4/11).
Archaeology Consultant. Cultural Resources Survey of a 200-acre ANG installation in Shelby County, Tennessee. No archaeological survey was required due to disturbance.

Environmental Assessment Addressing Infrastructure Upgrades for the Replacement of Nimitz-Class Carriers with Ford-Class Carriers / U.S. Naval Facilities Engineering Command (NAVFAC), Atlantic Division (10/10-3/11).
Technical Section Lead. Prepared the cultural resources sections for an Environmental Assessment (EA).

Phase I Cultural Resources Survey of the NEON Site at the Blandy Experimental Farm, Clarke County, Virginia / National Ecological Observatory Network (1/11-2/11).
Principal Investigator and Field Director. Directed the Phase I cultural resources survey of a small property in Clarke County, Virginia.

Phase IA Cultural Resources Overview of the I-64 Regional Pipeline, Shelby and Franklin Counties, Kentucky / Louisville District of the United States Army Corps of Engineers (USACE) (9/10-12/10).
Principal Investigator and Technical Section Lead. Conducted a Phase IA cultural resources overview (archival research) and prepared the cultural resources sections for an EID for a 31 mile water pipeline in Shelby and Franklin Counties, Kentucky.

Lake Royal / Fairfax County Park Authority (1/08-4/08).
Field Director. Directed the Phase III data recovery of a Late Archaic/Early Woodland campsite (44FX3175) in Fairfax County, Virginia.

Bayou Ysclosky / New Orleans, Louisiana TRO of FEMA (10/07-12/07).
Lab analyst. Assisted in the analysis of ceramic sherds, processed flotation samples, sorted faunal and botanical remains, and analyzed the malacological (i.e., shell) remains recovered during the Phase I archaeological survey of a 6.2 acre residential tract in St. Bernard Parish, Louisiana.

Surratt Property / Private Developer (7/07-9/07).
Principal Investigator and Field Director. Directed the Phase I archaeological survey of three tracts of land totaling 36 acres in Prince George's County, Maryland.

Charles Walker Community Center Relocation Project / Biloxi, Mississippi Transitional Recovery Office (TRO) of the Federal Emergency Management Agency (FEMA) (6/07-7/07).
Principal Investigator and Field Director. Directed the Phase I cultural resources survey of seven acres to be used for the relocation of a community center damaged beyond repair during Hurricane Katrina in Harrison County, Mississippi.

Charles Murphy Elementary School Relocation Project / Biloxi, Mississippi TRO of FEMA (6/07-7/07).
Principal Investigator and Field Director. Directed the Phase I cultural resources survey of 30 acres to be used for the relocation of an elementary school damaged beyond repair during Hurricane Katrina in Hancock County, Mississippi.

United States Coast Guard Waterways Project / New Orleans, Louisiana TRO of FEMA (3/07-6/07).
Archaeological Monitor. Monitored the removal of Hurricane-Katrina related debris from the Mississippi River and other waterways and assessed the impact of this work to cultural resources in the area during a three-month FEMA deployment in southern Louisiana.

Harper McCaughan Elementary School Relocation Project / FEMA's Biloxi, Mississippi TRO (2/07-3/07).
Field Director. Co-directed the Phase I cultural resources survey of 86 acres for the relocation of an elementary school damaged beyond repair during Hurricane Katrina in Harrison County, Mississippi.

Harbor Station Parkway / Private Developer (11/06-1/07).
Principal Investigator and Field Director. Directed the Phase II archaeological evaluations of an Archaic Period lithic reduction site (44PW40) and a mid 18th to early 19th century midden with a minor prehistoric component (44PW1714) in Prince William County, Virginia.

Sunrise Development / Private Developer (10/06-11/06).
Principal Investigator and Field Director. Directed the Phase I archaeological survey of two acres for a residential development in Prince George's County, Maryland.

Westphalia Property / Private Developer (10/06).
Crew Chief. Participated in the Phase I archaeological survey of 543 acres for a residential development in Prince George's County, Maryland.

Inter-County Connector (ICC) Project / Maryland State Highway Administration (9/06-10/06).
Crew Chief. Participated in the Phase II evaluation of a multi-component Archaic Period and historic site for a highway project in Montgomery County, Maryland.

Land Conveyance and Transfer (C&T) Project / U.S. Department of Energy (4/04-6/06).
Field Director, Los Alamos National Laboratory. Supervised the excavation and artifact analysis and prepared the final reports for 15 Ancestral Pueblo field houses and an early 20th century homestead consisting of a cabin, horno, shed, corral, and reservoir in Los Alamos, New Mexico.

Land Conveyance and Transfer (C&T) Project / U.S. Department of Energy (10/02-1/04).
Field Technician, Los Alamos National Laboratory. Took part in the excavation and artifact analysis of a multi-component site consisting of a Classic Period field house and a Coalition Period room block and grid garden, a Coalition Period room block with nine rooms and multiple features, a late 19th to early 20th century Jicarilla Apache tipi ring site, and an early 20th century homestead consisting of a cabin with a cistern and root cellar (not part of the C&T Project) in Los Alamos, New Mexico.

Galindo Archaeological Project / Academic project funded by the National Science Foundation and the University of New Mexico (2000-2002).
Project Director. Directed an archaeological research project at the site of Galindo, located in the Moche Valley on the North Coast of Peru. Responsibilities included obtaining funding, obtaining permission to excavate from the *Instituto Nacional de Cultura* (INC) of the Peruvian government, planning, recruiting project personnel, directing field operations and laboratory analyses, performing data analyses, and writing the final field reports to be submitted to the INC. The principal goal of the project was to study the political power of Galindo rulers through an examination of civic/ceremonial monuments and a comparison of the architectural and artifactual remains of elite vs. commoner residences. The occupational history of the site was a secondary research topic.

Proyecto Arqueológico San José de Moro / Academic project run by the Pontificia Universidad Católica del Perú (1999).
Crew Chief. Directed a crew of three Peruvian workers and an undergraduate student in the excavation of a 10 by 5 meter area at the site of San José de Moro in the Jequetepeque Valley, Peru. Responsibilities included the preliminary analysis of all recovered artifacts, filling out forms and paperwork, drawing profiles and plan view maps, and the writing of a final field report for the area.

Moche Origins Project / Academic project (1998).
Archaeologist. Responsibilities included excavation, screening, cleaning and cataloging of recovered artifacts, filling out forms and paperwork, and drawing profiles and plan view maps.

Upper Basin Archaeological Project / Archaeological field school run by the University of Cincinnati (1995).
Student Archaeologist. Responsibilities included survey, excavation, screening, cleaning and cataloging of recovered artifacts, filling out forms and paperwork, and drawing profiles and plan view maps.

Professional Publications

2013 Social Differentiation as Indicated by Archaeological Data from Late Moche Households at Galindo, Moche Valley, Peru. *Andean Past* 11:139-167.

2011 *Proyecto Arqueológico / Archaeological Project*. Bilingual book published by PERU LNG. Comunica2, Lima, Peru. Texts by Greg Lockard, editing and Design by David Vexler and Kick Off & Asociados.

2009 A Design Analysis of Moche Fineline Sherds from the Archaeological Site of Galindo, Moche Valley, Peru. *Andean Past* 9:195–228.

2009 The Occupational History of Galindo, Moche Valley, Peru. *Latin American Antiquity* 20(2):279–302.

2008 La ocupación Chimú en Galindo: Un asentamiento rural en el corazón del Reino Chimor. *Revista Arqueológica SIAN* 19:2-17.

2008 A New View of Galindo: Results of the Galindo Archaeological Project. In *Arqueología Mochica: Nuevos Enfoques*, edited by L.J. Castillo, H. Bernier, G. Lockard, and J. Rucabado, pp. 275–294. Actas del Primer Congreso Internacional de Jóvenes Investigadores de la Cultura Mochica, Lima, 4 y 5 de agosto de 2004. Instituto Francés de Estudios Andinos y Fondo editorial de la Pontificia Universidad Católica del Perú, Lima, Peru.

2008 *Arqueología Mochica: Nuevos Enfoques*. Actas del Primer Congreso Internacional de Jóvenes Investigadores de la Cultura Mochica, Lima, 4 y 5 de agosto de 2004. Instituto Francés de Estudios Andinos y Fondo editorial de la Pontificia Universidad Católica del Perú, Lima, Peru. Editor with Luis Jaime Castillo Butters, Hélène Bernier, and Julio Rucabado Yong.

2008 Intrasite Spatial Analysis. In The Land Conveyance and Transfer Data Recovery Project: 7000 Years of Land Use on the Pajarito Plateau, Volume 3: Artifact and Sample Analyses, edited by B. Vierra, K. Schmidt, and B. Harmon, pp. 839-858. Cultural Resources Report No. 273. LA-UR-07-6205, Los Alamos National Laboratory, New Mexico. With Brian Harmon and Bradley Vierra.

2005 *Political Power and Economy at the Archaeological Site of Galindo, Moche Valley, Peru*. Ph.D. dissertation, University of New Mexico. University Microfilms International, Ann Arbor.

Professional Presentations

2015 The PERU LNG Project's Contribution to World Heritage. Paper presented to the Pre-Columbian Society at the Penn Museum.

2014 The PERU LNG Project's Contribution to World Heritage. Paper presented to the Pre-Columbian Society of Washington, DC.

2013 Lithic Technology during the Transition to Agriculture at the Defense Supply Center Richmond, Chesterfield County, Virginia. Paper presented at the 78th Annual Meeting of the Society for American Archaeology, Honolulu. Second author, with Brandon Gabler.

2012 Galindo and the Last of the Southern Moche. Paper presented to the Pre-Columbian Society of Washington, DC.

2012 The PERU LNG Project's Contribution to World Heritage. Paper presented at the 32nd Annual Conference of the International Association for Impact Assessment, Porto, Portugal.

2012 Public Archaeology in Peru: Lessons Learned from the PERU LNG Archaeological Project. Paper presented at the 77th Annual Meeting of the Society for American Archaeology, Memphis.

2011 The Last of the Southern Moche: Establishing Galindo's Place in Moche History through Radiocarbon Dates and Ceramic Design Analysis. Paper presented at the roundtable Times of Change, Changes of Time: An Inquiry about Absolute and Relative Chronologies of the Moche from Northern Peru. Sponsored by Dumbarton Oaks, Washington, DC.

2011 The Last of the Moche in the Southern Moche Region, North Coast of Peru. Paper presented at the 76th Annual Meeting of the Society for American Archaeology, Sacramento.

2010 Diferenciación social en base a la evidencia doméstica durante la ocupación Moche Tardío en Galindo, valle de Moche, Perú. Paper presented at the conference Áreas Domésticas: Reflexiones, Avances y Perspectivas. Organized by the Grupo de Investigación de Arqueología Andina (GIAA), Lima, Peru.

2009 From the Highlands to the Coast: Preliminary Results of the PERU LNG Archaeological Project. Paper presented at the Society of Petroleum Engineers (SPE) International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production, Rio de Janeiro, Brazil. First author, with David Vexler. Won the Knowledge Sharing Award for the best Social Responsibility Program.

2009 From the Highlands to the Coast: Preliminary Results of the PERU LNG Archaeological Project. Paper presented at the 74th Annual Meeting of the Society for American Archaeology, Atlanta.

2008 La Ocupación Chimu en Galindo: Un asentamiento rural en el corazón del reino. Paper presented at the seminario Arqueología Peruana. Sponsored by the Universidad Nacional de San Cristobal de Huamanga. Ayacucho, Peru.

2008 La Ocupación Chimu en Galindo: Un asentamiento rural en el corazón del reino. Paper presented at the roundtable Reconsidering the Late Intermediate Period on the North Coast of Peru. Sponsored by Dumbarton Oaks and the Universidad Nacional de Trujillo. Trujillo, Peru.

2007 Classic Period Field Houses in Rendija Canyon, Pajarito Plateau, New Mexico. Paper presented at the 72nd Annual Meeting of the Society for American Archaeology, Austin.

2006 A Jungian Analysis of Moche Iconography. Paper presented at the 71st Annual Meeting of the Society for American Archaeology, San Juan, Puerto Rico.

2005 Classic Period Field Houses in Rendija Canyon, Pajarito Plateau. Paper presented at the 78th Pecos Conference, Los Alamos, New Mexico.

2005 The Chimu Occupation of Galindo, Moche Valley, Peru. Paper presented at the 70th Annual Meeting of the Society for American Archaeology, Salt Lake City.

2005 Grid Gardens and Field houses: Agricultural Intensification on the Pajarito Plateau, Northern New Mexico. Poster presented at the 78th Pecos Conference, Los Alamos, New Mexico. With J. Nisengard and K. Schmidt.

2005 Grid Gardens and Field houses: Agricultural Intensification on the Pajarito Plateau, Northern New Mexico. Poster presented at the 70th Annual Meeting of the Society for American Archaeology, Salt Lake City. With J. Nisengard and K. Schmidt.

2004 A New View of Galindo: Results of the Galindo Archaeological Project. Paper presented at the Primera Conferencia Internacional de Jóvenes Investigadores sobre la Cultura Mochica. Conference sponsored by Dumbarton Oaks, the Pontificia Universidad Católica del Perú and the Museo Arqueológico Rafael Larco Herrera.

2004 La Huaca de las Abejas, Galindo. Poster presented at the Primera Conferencia Internacional de Jóvenes Investigadores sobre la Cultura Mochica. Conference sponsored by Dumbarton Oaks, the Pontificia Universidad Católica del Perú and the Museo Arqueológico Rafael Larco Herrera.

2003 Late Moche Platform Mound Architecture at the Site of Galindo, North Coast, Peru. Paper presented at the 68th Annual Meeting of the Society for American Archaeology, Milwaukee.

2003 Ceramics and the Late Moche-Chimu Transition at the Site of Galindo, North Coast, Peru. Poster presented at the 68th Annual Meeting of the Society for American Archaeology, Milwaukee. With K. Schleher.

2002 Platform Mounds and the Occupational History of the Archaeological Site of Galindo, North Coast, Peru. Paper presented at the 6th Annual Anthropology Graduate Student Union Graduate Student Spring Symposium.

2002 A Design Analysis of Moche Fineline Ceramic Sherds from the Site of Galindo, Moche Valley, Peru. Poster presented at the 66th Annual Meeting of the Society for American Archaeology, New Orleans.

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Kamal Govender

Principal Consultant
Impact Assessment and Planning (IAP)

Kamal Govender is a Principal Consultant within ERM's Impact Assessment and Planning team based in ERM's Houston office.

Kamal has 13 years of experience in environmental management, specialising in Complex Project Management, Environmental, Social and Health Impact Assessments (ESHIAs), Environmental and Social Management Plans (ESMPs), Public Participation Processes and various other activities associated with Integrated Environmental Management. Over the last seven years, Kamal has worked primarily in Africa, but also in Europe and the USA. Kamal's international experience has allowed him to deliver projects that meet local expectations and international good practice.

Kamal's focus is Capital Project support in the oil and gas, mining and energy sectors. He has managed large multi-disciplinary teams and delivered ESHIAs and ESMPs to national and international standards. Kamal has worked on projects under the requirements if the IFC Performance Standards, Equator Principles and World Bank policies. Working on Capital Projects, Kamal is able to interface with the projects' technical team easily, and ensure optimum integration of environmental and social risks with safety, technical and financial parameters.

Kamal's strengths lie in understanding clients' needs, in understanding key process and non-technical risks, and in managing people in order to deliver large, complex projects that meet expectations. He employs his skill set at all stages of a projects lifecycle from pre-feasibility (input into design, site selection, environmental and social screening and sensitivity analysis) to feasibility (managing multi-disciplinary ESHIAs and regulatory compliance, public consultation, managing non-technical risks, input into design) and to construction and operation (ongoing studies, managing performance and assurance teams, assisting with handing over environmental and social management from the project's feasibility team to operations team). The following experience listing provides examples of key projects demonstrating the above competencies.

Fields of Competence

- Capital Project support
- Project management of ESHIAs for large, complex projects
- Environmental Management Plans (EMPs)
- Public Participation

Professional Affiliations & Registrations

- Member, South African affiliate of International Association for Impact Assessment (IAIAsa)

Education

- MSc (Environmental and Geographical Science), University of Cape Town, South Africa, 2004
- BSc (Hons) (Environmental and Geographical Science), University of Cape Town, South Africa, 1999
- BSc (Environmental and Geographical Science), University of Cape Town, South Africa, 1998

Languages

- English
- Afrikaans

Key Industry Sectors

- Oil and Gas
- Mining
- Energy

Key Projects

EIA for a 3D Seismic Survey in Gabon
October 2014 to date
Project Manager
Kamal is managing the EIA process to meet Gabon standards and align with international standards for Noble Energy's offshore 3D seismic survey. The Project is located in deep water but in a region where there is growing focus on marine ecology and the need for adequate protection of endangered marine wildlife.

Pre-FID Contractor Interface support to Anadarko LNG Project
July 2014 to date
Project Manager
Kamal is responsible for liaising with the FEED/ Pre-FID contractors with respect to the implementation of the environmental and social mitigation measures in the EIA. Kamal also reviewed the final bid for on the contractors from an environmental and social perspective.

IFC Performance Standard Gap Review for Anadarko LNG Project
July 2014 to date
Project Manager
Kamal is responsible for leading a team to analyse the LNG Project with a view to identify gaps against the IFC Performance Standards and to develop actions plans to close gaps.

EIA for Maersk Oil Angola, Chissonga Project
May 2014 to date
Project Manager
Kamal took over the management of the EIA and public consultation for the Project. This entailed, liaising with specialists and the in-country partner, reviewing and finalising deliverables and managing three secondees to Maersk. The project comprises offshore drilling, a Tension Leg Well Platform, an FPSO and a gas export pipeline.

Equator Principles/ IFC Performance Standard Gap Assessment for Cobalt
July 2014
Project Manager
Undertook an Equator Principles and IFC Performance Standards Gap Assessment for Cobalt's Cameia Project in Angola. The Gap Assessment was to prepare Cobalt for engagement with an Equator Principle Financial Institution.

IFC Performance Standard Gap Assessment of Gas to Liquids Project for G2X
July 2014 to October 2014
Project Manager
Undertook an Equator Principles Gap Assessment of the project in order to assist the client prepare for discussions with an Equator Principle Financial Institution.

Equator Principles/ IFC Performance Standard Training for Cobalt
July 2014
Project Manager
Developed and provided training to Cobalt personnel for their Cameia Project in Angola.

Secondment to Anadarko
2013 to 2014
Project Manager
Kamal was seconded to Anadarko during the final months of the ESHIA. Roles and responsibilities were broad ranging but focussed on delivery of the ESHIA report, interface with the project's technical team, input into non-technical risk assessment, managing post-ESHIA studies, and interfacing with the project's EHS team. The secondment was requested by the client to ensure that Kamal's history on the project and insight into key issues was not lost after the ESHIA.

ESHIA for the proposed Anadarko LNG Facility, Offshore wellfield and subsea pipeline, Mozambique, 2011 to 2013
Project Manager
The project comprises an offshore wellfield, subsea infrastructure, onshore LNG facility and all associated infrastructure (construction camp, housing, water treatment, sewage treatment, LNG jetties and a materials offloading facility). The ESHIA meets Mozambican standards and is aligned with the requirements of the IFC Performance Standards. The core project management team comprised five people. ERM managed a multi-disciplinary team of 17 specialist studies. The ESHIA was undertaken in parallel to the FEED process and resulted in several feedback loops to ensure adequate integration – the ESHIA needed to respond to changes in project design and to influence project design. Moreover, workshops with the technical team and EPC contractors were scheduled at key points in the schedule to allow for course correction and "sense-checking" of the ESHIA documentation. .

Site Selection and Sensitivity Analysis for the proposed Anadarko LNG Facility, Mozambique, 2011
Project Manager
ERM was appointed to undertake a site selection process to assist Anadarko with identifying the most appropriate site (from an integrated environmental, social and technical perspective) for the onshore facilities. The process entailed managing a team of key specialists to undertake a baseline sensitivity analysis and integrate findings with the project's technical and financial analyses. The environmental and social inputs were important determinants in the selection of the optimum site for the LNG Facility.

EPDA for Riversdale Zambeze Mine Project, Mozambique, 2011.
Project Manager
Appointed to undertake the EPDA (Scoping) Phase for the proposed coal coal mine and associated infrastructure in Tete Province, Mozambique. The EPDA Phase entailed initial scoping site visit, wet season specialist studies, the compilation of wet season baseline reports and the compilation of the EPDA Report is to meet the Mozambican regulatory requirements as well as best practice as defined by the IFC Performance Standards.

ESIA for Riversdale Coal Barging Project, Mozambique, 2010 to 2011.
Project Manager
Appointed to undertake an ESIA for the proposed coal barging project on the Zambezi River. The project comprised a load out point on the river near, Tete, dredging various sections of the Zambezi River, and transhipment of coal at the mouth of the Zambezi River. ERM managed a team which included nine specialist studies. Some of the key challenges for the ESIA were the size of the study area (approximately 540km of river), the remoteness of the study area and a comprehensive stakeholder engagement process which needed to manage the expectations of a range of stakeholders from local level to national level. The ESIA met the Mozambican regulatory requirements as well as best practice as defined by the IFC Performance Standards..

Riversdale Coal Barging Project, Phase 1, Mozambique, 2010
Project Manager
Appointed to undertake a baseline sensitivity analysis of the proposed Zambezi River coal barging project with a view to identifying baseline sensitivities and potential fatal flaws. This process allowed ERM and Riversdale to tailor an ESIA process to address the identified sensitivities and to identify key specialist studies.

Mphanda Nkuwa Hydropower Scheme, Mozambique, 2010 to 2011
Project Manager
Appointed to act as advisors to the EIA consultants undertaking the EIA for the proposed hydropower scheme on the Zambezi River. The role entails close interaction with the EIA consultants to ensure that the process followed and outcomes accord with the requirements of the IFC Performance Standards and the Mozambican regulatory EIA requirements.

ESIA for Riversdale Transhipment Project in Beira, Mozambique, 2010 to 2011.
Project Manager
Appointed to undertake an ESIA for the proposed transhipment project in Beira. The ESIA is to meet the Mozambican regulatory requirements as well as best practice as defined by the IFC Performance Standards. The comprehensive ESIA was downgraded to a simplified EIA process following engagement with the provincial environmental authority. The simplified EIA process entailed stakeholder engagement with local, provincial and national stakeholders as well as the development of an EIA Report and EMP.

Review of EIA Report for a Mine, South Africa 2010
Project Manager
Reviewed the EIA Report on behalf of the mine with a view to identifying gaps and amendments to ensure compliance with South African regulations.

Review of Kamoto Copper Mine, DRC 2010
Task Manager
Reviewed the Mine EIA and EMP to IFC Performance Standards on behalf of an International Finance Institution.

IFC Gap Analysis and Scoping Exercise, 2010
Project Manager
Appointed to undertake an audit of a resort in the Seychelles with a view to identifying gaps between the resort's operations and the requirements if the IFC Performance Standards and EHS Guidelines. Part of the scope of work was also to develop an Action Plan to address the identified gaps. An IFC representative attended the site visit and interviews and reviewed aspects of the report.

Sasol Mafutha Project, 2009 to 2010
Project Manager
The project entails the construction and operation of a coal to liquid plant, coal mine, town and associated infrastructure in Limpopo Province, South Africa. Appointed to undertake the EIA for the Services Corridor as part of Project Mafutha. The project was undertaken to the World Bank Equator Principles.

Bannerman Uranium Mine, 2009 to 2010
Task Manager
The project entails the construction and operation of a new uranium mine in Namibia. Appointed to review the Namibian EIA, to manage the radiation study and the occupational health and safety study and to compile an ESHIA to meet international good practice, particularly the requirements of the IFC Performance Standards.

Sasol Mafutha Environmental Baseline Study, 2008 to 2009
Project Manager
Project Mafutha comprises a coal-to-liquid plant, a coal mine a town, water supply infrastructure and associated activities. As part of the pre-feasibility studies for Project Mafutha, ERM was appointed to undertake the Environmental Baseline Assessment. The project required delicate managing, in light of stakeholder expectations, Sasol's on going property purchasing negotiations, Sasol's prospecting activities, and a related basic assessment for road construction and widening (also undertaken by ERM). Managing a multi-disciplinary team of specialists (15 specialist studies), managing a desktop and detailed assessment and managing the public participation aspect required integration of different expertise and project components. The timeframe was short (12 months) and required innovative solutions to run processes in parallel to deliver on time.

Review of EIA for Tobacco Factory in Nigeria, 2009
Project Manager
Appointed to undertake a review of the EIA process and report for the tobacco factory. The EIA process and report was audited against the Nigerian regulatory EIA requirements. Recommendations were made to address gaps.

Review of EIA for Cement Factory in Nigeria, 2009
Project Manager
Appointed to undertake a detailed review of the project to IFC Performance Standards for the extension to the Larfarge WAPCO cement factory in Nigeria.

IFC Performance Appraisal, 2008
Project Manager
Appointed undertake an appraisal of several retail sites to determine degree of compliance with IFC Auditable Criteria.

Proposed Railway Link and Services Corridor in Botswana, 2007 to 2008
Project Manager
The project entailed a railway line, railway turning triangle, service yard, new road, and water supply pipelines for the Mmamabula Energy Project. The project was complex, requiring flexibility and innovation in addressing project changes, and a vociferous, organized stakeholder group of objectors.

Mmamabula Energy Project: ESHIA for Proposed coal mine and power station in Botswana, 2006 to 2009
Project Manager
The Mmamabula Energy Project involved the development of a coal mine, power station and associated infrastructure (residential area, roads, railway lines, transmission lines, etc) in southern Botswana. ERM was appointed to undertake the Bankable Feasibility Study and the ESHIA for the project to meet the IFC Performance Standards and EHS Guidelines.

Proposed coal-fired power station near Witbank, Eskom, 2006
Assistant Project Manager
Appointed by Eskom to undertake a site screening process and EIA for a proposed coal-fired power station near Witbank in Mpumalanga. Responsibilities include project management, financial management, managing the team of specialists, report writing and managing the Public Participation Process. This complex project entailed liaising closely with Eskom's technical team, identifying and proposing solutions to potential risks, and integrating a range of specialist studies into a coherent whole. The project was delivered on time to Eskom's standards.

Mossel Bay OCGT EIA: Additional units, Eskom, 2006
Project Manager
Appointed by Eskom to undertake EIA process in terms of NEMA for three additional units at the Mossel Bay OCGT power plant. Responsibilities include project management, financial management, managing the team of specialists, report writing and managing the Public Participation Process.

PetroSA Emergency Generation, Eskom, 2006
Assistant Project Manager
Assisted with EIA process for an emergency electricity generation units within the PetroSA gas-to-liquid facility in Mossel Bay.

Mossel Bay OCGT EIA, Eskom, 2005
Assistant Project Manager
Appointed by Eskom to undertake an EIA for the Open Cycle Gas Turbine power station adjacent to the PetroSA facility in Mossel Bay. Responsibilities included project and financial management (including managing the sub-consultant responsible for the EIA process) and undertaking the Public Participation Process.

Other Relevant Experience (EIAs, Basic Assessments, EMPs, etc)

Proposed decommissioning of coke oven and blast furnace gas holders at ArcelorMittal, Vanderbijlpark Works, 2008
Project Manager
Appointed to undertake a Basic Assessment process for the decommissioning of a coke oven and old blast furnace gas holder.

EIA for underground storage tank at Mafube Colliery, 2008
Project Manager
Appointed to undertake a Scoping/ EIA process for a proposed underground storage tank at Mafube Colliery.

Proposed aboveground storage facility and baghouse at ArcelorMittal, Vanderbijlpark Works, 2008
Project Manager
Appointed to undertake a Basic Assessment process for an aboveground storage facility and baghouse emission abatement technology for ArcelorMittal's Sinter Plant.

Basic Assessment for Automotive Galvanising Line, Mittal Steel, 2007.
Project Manager
Undertook a Basic Assessment process for proposed Automotive Galvanising Line in the Mittal Steel complex, Vanderbijlpark.

Basic Assessment of aboveground storage tanks, Mafube Colliery, 2007.
Project Manager
Undertook a Basic Assessment process for Anglo Mafube Colliery for a proposed aboveground storage tank facility.

Third Party Audit, Kriel Colliery, 2007.
Project Manager
Undertook a third party audit of Kriel Colliery's Performance Assessment Report in terms of the Mineral and Petroleum Resources Development Act.

Metsi Chem iKapa Section 24G application, 2006.
Project Manager
Appointed by Metsi Chem iKapa to undertake the environmental process required by S24G of NEMA (Amendment Act) for a chemical storage facility. Solely responsible for liaison with the client, liaison with the authorities, the Public Participation and the reporting.

MR108 Upgrade, Gordons Bay, 2005
Task Manager
Appointed to compile an Opportunities and Constraints report for the widening of the MR108 from the N2 to Gordon's Bay.

Chapman's Peak Toll Plaza and Realignment, Entabeni, 2003
Project Consultant
Appointed by Entabeni to undertake the environmental process associated with the Toll plaza and realignment of a section of road on Chapman's Peak Drive. Assisting with the environmental requirements, including a public participation and environmental impact assessment process.

Pniel Wastewater Treatment Works Upgrade, Pniel, 2003
Project Consultant
Facilitated compliance by the Boland District Municipality with the environmental requirements for proposed extensions to the Pniel Wastewater Treatment Works in Pniel. Completed and submitted the application form and screening checklist to the Environmental Authority.

Athlone Wastewater Treatment Works Refurbishments, Cape Town, 2000
Project Consultant
Appointed by the City of Cape Towns Wastewater Department to facilitate compliance with the environmental requirements for refurbishment activities at the Athlone Wastewater Treatment Works, which included a public process and the completion and submission of project description forms in terms of the Bulk Wastewater EIA Compliance Procedure.

Upgrading of Trunk Road 19, Eastern Cape, 2001 – 2002
Project Consultant
Appointed by the Eastern Cape Department of Roads and Public Works, and later the South African National

Roads Agency, to provide various environmental services for the proposed upgrading of a 64 km stretch of trunk road 19 in the Eastern Cape. This entailed extensive liaison with the environmental authorities and undertaking a scoping process in terms of the Environment Conservation Act.

Velddrif Jetties, 2001
Project Consultant
Assisted with the compilation of a Motivation for Exemption, on behalf of the Bergriver Municipality, for the upgrade of a jetty in Velddrif.

Engelhard, 2000 – 2001
Project Consultant
Compiled a Motivation for Exemption Report, on behalf of Engelhard, for the relocation and expansion of a catalytic converter manufacturing plant in Port Elizabeth.

Blaauwberg City East Bulk Infrastructure, Table View, 2000
Project Consultant
Assisted with the compilation of a Scoping Report on behalf of Blaauwberg Municipality for proposed bulk water and wastewater infrastructure to service the Blaauwberg City East development north of Table View.

Charcoal Pilot Project, Villiersdorp, 2000
Project Consultant
Assisted with the compilation of a Scoping Report on behalf of the Working for Water Programme, for a proposed charcoal production project near Villiersdorp.

Milnerton Golf Course Treated Effluent Pipeline, Table View, 2000
Project Consultant
Assisted with the environmental requirements for the construction of a treated effluent pipeline across the Milnerton Lagoon, within the Rietvlei Protected Natural Environment, including the compilation of a Scoping Report in terms of the Environment Conservation Act.

Resealing of TR1/2, Uniondale, 2005
Project Consultant
Appointed to develop an EMP, develop and present an education course and monitor implementation of the EMP for the resealing of Trunk Road 1, Section 2, near Uniondale.

Mossel River Dam 2003
Project Consultant
Appointed by Overstrand Municipality to develop an EMP for the refurbishment of the outlet works of the dam as well as liaise with the Fernkloof Management Committee and Fernkloof Nature Reserve.

DEAT IEM Guidelines 2003
Project Consultant
Appointed by CSIR to develop an EMP Guideline Document as part of the DEAT IEM Information Series of guideline documents. Responsible for compiling the guideline

Carinus Scour Protection, Velddirf 2003
Project Consultant
Appointed by the Provincial Administration of the Western Cape to monitor the implementation of the Environmental Management Plan for the scour protection measures to the Carinus Bridge. The Environmental Management Plan included detailed revegetation measures.

Noordhoek Social Housing Development, Velddrif, 2003
Project Consultant
Appointed by the Berg River Municipality to compile an Environmental Management Plan for the construction of a social housing development in Velddrif. This appointment included assisting with monitoring the implementation of the Environmental Management Plan during construction.

Coega: Main Road 435, Port Elizabeth, 2003
Project Consultant
Compiled the EMP compliance checklist for the rehabilitation and upgrading of Main Road 435 in the Coega Development, Port Elizabeth

Karin K. Nunan

Ms. Karin Nunan is a Principal Consultant and senior social specialist within ERM based in Washington DC. She has over 23 years of experience in the fields of stakeholder engagement, human rights, social performance, and government affairs.

Over the past several decade, Karin has been working in the extractives sector providing project management and technical support on social performance, with a focus on social impact assessment and due diligence; stakeholder engagement planning and implementation; OHS and labor and working conditions; physical and economic resettlement; human rights; and local content. She is also focused on E&S lender compliance for international financing and has acted as both the lender or client representative for over 75 international projects. Her field work has ranged from running stakeholder engagement for a $4b oilfield operation on the ground in Iraq to developing stakeholder engagement plans for the South Stream Pipeline project in Russia, Turkey and Bulgaria.

Prior to consulting, Karin was in the oil and gas sector where she spent several years in the social performance departments within the HSEE/P&GA functions for Chevron and ExxonMobil. She worked on socioeconomic initiatives within development and production projects, primarily in the Middle East and Europe. During this time she developed and implemented stakeholder engagement plans; 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 resettlement, local content, community investment and human rights implementation and compliance.

Karin has also worked as a consultant providing geopolitical analysis, security and conflict assessments and social risk expertise to major corporations operating in hostile and challenging business environments – including developing corporate policies and engagement planning for the Voluntary Principles and compliance with the Global Compact.

A former US diplomat, Karin has worked in over 100 countries. She was the Human Rights officer in two of her overseas posts and contributed to the U.S. State Department Country Reports on Human Rights Practices. She has authored several technical papers on the positive social impacts of extractives companies in disadvantaged communities.

Fields of Competence

- Social Impact Assessment and Due Diligence
- Stakeholder Engagement
- Resettlement
- Human Rights
- Local Content and Supplier Development
- Community Health, Safety and Security
- Labor and Working Conditions
- Community Investment Planning

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

Key Recent Projects

Socioeconomics Corporate Policy, Plans and Procedures, O&G Major, 2014 – 2016
Development of corporate policies, plans and procedures, including tools and guidance notes, for various socioeconomic aspects, including local content development, indigenous people, stakeholder engagement, social investment, resettlement and human rights. Also working at project level to create fit-for-purpose asset plans including community feedback mechanisms.

Social Impact Assessment Due Diligence, Israel, O&G Mid-level, 2014 – 2016
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 labour management, stakeholder engagement, 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.

Capacity Building Workshop – Social Challenges in Infrastructure Projects, IFC, Pakistan, 2016
Designed, organized and facilitated a capacity building workshop in partnership with IFC for their Pakistan-based Infrastructure clients. The focus of the workshop was developing solutions to the challenges faced by companies when trying to implement IFC social standards in a difficult regulatory and operating environment – including developing and implementing sound stakeholder engagement plans.

Environmental and Social Due Diligence, Confidential Client, Mexico, 2016
Project manager for E&S Due Diligence on $2b transaction of oil related assets in Mexico; developed stakeholder engagement plans for end-client; completed social due diligence and assessment to IFC PS, World Bank EHS and Equator Principle standards. Developed ESAP and conducted end-client capacity building training in E&S international standards.

Worker Welfare Assessments, Kuwait, IFI, 2016
On behalf of an Equator Principle Bank, developed the scopes of work and audit protocol for a 60,000 worker O&G development project. Work included serving as liaison with national Labor Relations Board, unions and international developers. Site issues include infringement on local fishing populations, traffic and noise concerns with local residents, and socioeconomic impacts as a result of worker livelihoods.

OHS Due Diligence, Port and Industrial Zone, Haiti, CIFI, 2016
Conducted field assessment and due diligence for a port and industrial park in Haiti facing challenges with implementing OHS and community health, safeguards and security measures throughout their supply chain. Provided recommendations on how the developer and financing team could align to PS2 existing systems with a focus on direct workers, contracted workers, workers engaged by third parties, and supply chain workers.

Social Management System Development and ESDD, World Bank, West Africa, 2015
Conducted field assessments in Mali, Senegal, Cote d'Ivoire, and Benin to assist tourism company in completing social investment and stakeholder engagement mapping for existing and new hotel facilities. Worked with senior management to build social management system and ESAP components of the ESDD to be compliant with World Bank standards. Completed gap analysis to be used at the site level to build capacity and training.

Stakeholder Engagement, SIA, RAP, Nicaragua Canal, HKND, 2014
Senior reviewer 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 resettlement, labour, human rights, influx, conflict, health, natural resource, livelihoods and project security linked to development and operations. Developed management and monitoring plans pertaining to influx, local content, resettlement, stakeholder engagement, and indigenous people.

Masela Offshore LNG Facility, Indonesia, INPEX, 2013 - 2014
Provided social performance expertise to an ESHIA submission for an offshore LNG facility in Indonesia with onshore facilities being developed by an O&G major. Provided input into the stakeholder engagement plan, resettlement action plan, 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, as well as RAP best practice procedures.

South Stream Pipeline Project, Russia, Bulgaria, Turkey, SSTTBV, 2013 - 2014
Technical director for three lender ESHIAs and three national ESIAs for all three countries. Worked alongside the South Stream ESIA teams to lead the stakeholder engagement efforts (from identification to disclosure through to monitoring) for Bulgaria, Russia and Turkey. Educated the client's key departments, including HSE, Procurement, HR and Security, on the importance of adhering to international disclosure and grievance mechanism standards as outlined by WB, IFC and other IOs. Developed Project-wide standards and a stakeholder engagement tool kit which can be applied on a regular basis to ensure constant improvement and continuous adherence.

RAP framework for Palm Oil Plantation and Processing Project, Cameroon, 2013
Developed Resettlement Action Plan Framework and Influx Management Plan for Palm Oil Plantation and Processing Facility in Cameroon. Framework and plan included linkages to other ESMS components, as well as baseline data collection and impact assessment for social aspects pertaining to the facility and local communities.

Oil Export Social Feasibility Study, E. Africa, O&G Major, 2012
Provided the social 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, including the identification of stakeholders, IPs, resettlement alternatives along the coastlines and likely mitigation measures which contributed to the site selection, ESIA, and RAP.

Labor and Industrial Relations benchmarking study, PNG, 2012
Benchmarking of Labour, IR and Working Conditions against best practice and national regulations for an LNG Project. Included development of management plans related to labour conditions and local content. Assessed monitoring, reporting and evaluation of OHS-relation concerns to ensure continual compliance and assurance, as well as use of recommended systems across other global development projects.

Community and Labor Working Conditions Assessment, BP Angola, 2012
As part of the SIA for a Subsea Systems Plant for BP, undertook a community and labour and working conditions assessment for onshore and offshore components. The outcome of the assessment was to consolidate mitigation measures and recommendations into the ESAP in consensus with the company's management that highlights: responsibilities for implementation of capacity, a timeframe for implementation and the process for monitoring outcomes.

ESIA and RAP for power facility, Cameroon, 2013
Drafted SIA to IFC PS12 standards, included development of a stand-alone RAP to relocate families in rural communities along 200-mile long transmission line right of way. Developed mitigations and community investment programs focused on agribusiness, microfinance in the small scale service sector, and local content.

ESIA and RAP for Tasiast Gold Mine, Mauritania, 2013
Part of multidisciplinary team preparing ESIAs for a phased expansion of a gold mine. Led social team in preparing the community sensitization toolkit and supporting literature for use in early community consultation. Also developed key components of the RAP and led later phases of resettlement monitoring.

Oil Refinery Expansion, Venezuela, PDVSA, 2014
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 and supply chain audits.

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Peyun Kok

Associate Scientist, Impact Assessment and Planning

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.

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Kristina Mitchell

Ms. Kristina Mitchell is a Senior Project Manager with ERM based in Seattle, Washington. She is a member of ERM's Impact Assessment Performance and Planning Group, and has 15 years of experience in corporate social responsibility including stakeholder engagement, crisis response management, policy analysis, risk identification and management, and impact assessment. Within these areas, she is skilled in policy, strategy, guidance, toolkit design, and in-field implementation. Her field experience includes Arctic regions of Alaska, North and Latin Americas, the Balkans, and Papua New Guinea.

Working within the public, non-governmental, and private sectors, Ms. Mitchell is skilled in building partnerships and fostering the conditions required for collaborative action and shared value. She is trained in crisis response, negotiation and conflict resolution, and leadership and behaviour-based coaching.

Fields of Competence

- Crisis response
- Stakeholder engagement and planning
- Policy analysis and development
- Social impact assessment
- Corporate social responsibility strategy
- Community investment strategy/policy
- Reputation risk management
- Program and tool development
- Program and gap assessment
- Social license to operate
- Corporate communications strategy and planning
- Conflict management and negotiation
- Leadership development and ontological coaching

Education

- M.A. International Relations, Johns Hopkins School of Advanced International Studies, 2007
- B.A. International Relations and Anthropology, Boston University, 2000
- Certificate. Negotiation and Conflict Resolution, Institute for International Mediation and Conflict Resolution, South Africa, 2005
- Crisis Response Training, ExxonMobil, 2010
- Executive Leadership and Coaching Training, Accomplishment Coaching, 2015

Languages

- English (native)
- Spanish (advanced)
- French (intermediate/basic)

Key Industry Sectors

- Government
- Mining
- Oil and Gas
- Power (hydro)

Honors & Awards

- Pew Charitable Trust Fellow

Papers

- Early Stage Risk Management: Strategic Community Investment and Project Planning
  Co-authored: Kristina Mitchell and Kim Swanzey
- Effective Stakeholder Engagement to Support Critical Capital Projects
  Co-authored: Kristina Mitchell and Rob Gronewold

Key Projects

Stakeholder Engagement

Community Engagement Study, North Slope, AK, Confidential Client. Social Lead
Developed a methodology to engage community stakeholders about changes to traditional knowledge, subsistence resources and activities, other cultural practices, and community wellbeing. Conducted focus group and key informant interviews with community members, and synthesized interview information in a report on community resources, priorities, and changes to those resources.

Stakeholder Identification and Mapping, California, Confidential Client. Technical Lead
Developed a stakeholder registry and mapped groups based on influence, impact, and concern in response to an oil spill affecting onshore and offshore resources.

Stakeholder Engagement Process Development, Alaska, Confidential Client. Social Advisor
Advised client on multiple aspects of a world-class, highly complex resource development project including developing and implementing an IFC Performance Standard compliant stakeholder engagement process. The project was located in an area of extremely high biodiversity and cultural value, with significant populations of indigenous peoples.

Labor Relations and Communications Issue Resolution, China, Confidential Information Technology Client. Lead
Developed a strategy and action plan to address longstanding conflict between labor force and management in a number of facilities, related to health and safety concerns.

Community Relations and Stakeholder Engagement Plan Gap Assessment, Peru, Confidential Mining Client. Social Lead
Conducted gap assessment of EIA and current Community Relations Plan for major mining project against corporate, national, and international standards. Key issues included stakeholder engagement and consultation of indigenous peoples.

Stakeholder Engagement, Land Acquisition and Resettlement Workshops, Mexico, Confidential Hydropower Client. Senior Social Consultant
Prepared and delivered training workshops on the appropriate application of stakeholder engagement in scenarios of land acquisition for government and private sector clients in hydropower project development. Workshop content included best practices for risk management through the application of international standards on stakeholder engagement, economic resettlement, compensation and livelihood restoration, and good practices in negotiation.

Stakeholder Engagement Plan Development, USA, Confidential Mining Client. Social Lead
Prepared a stakeholder engagement plan, as part of a due diligence process, targeted toward immediate goals around permitting post acquisition and longer term acquisition of social license to operate.

Stakeholder Engagement Plan Development and In-Field Implementation, Nicaragua, HKDC. Senior Social Consultant
Prepared stakeholder engagement plan and for major infrastructure development crossing Nicaragua. Led in-country focus group consultations related to social, health, and economic aspects.

Social Impact Assessment

Environmental, Health, and Social Impact Assessment, Albania, Petromanas. Senior Consultant
Identified and assessed impacts to worker rights related to oil and gas exploration activities, and developed recommended mitigations.

Environmental Impact Statement, US Territories and Non-contiguous States, FirstNet. Senior Social Consultant
Identified and evaluated potential socioeconomic impacts and effects of a nationwide telecommunications infrastructure project.

Integrated Social and Health Impacts Review, Alaska, Confidential Client. Senior Social Consultant
Conducted a review and assessment of multiple formal impact assessment, scoping, and perception reports to identify follow-on data needs and key areas of impact and risk.

Social and Health Impact Assessment, Nicaragua, HKDC. Senior Social and Health Consultant
Assessed a suite of social and health impacts related to conflict, human rights, cultural heritage, and community safety and wellbeing.

Retrospective Social Impact Assessment, Peru, Confidential Client. Strategic Aspects Project Manager/Social Consultant
Provided project management support and assessed retrospective and future impacts related to human

rights, conflict, supply chain, labor, and institutional development for major mining project.

Social Impact Scoping Workshop, Arizona, Confidential Client. Consultant
Co-led scoping level impact assessment workshop for a client considering re-opening development of an asset. Workshop elements included identification of direct and indirect area of influence, key stakeholders and gaps in information for stakeholder mapping and planning, and scoping level impacts and Project risks.

Social Impact Assessment, Mexico, Confidential Client. Senior Technical Review
Provided technical quality assurance and control review for baseline, impact assessment and management measures for social impact assessment in a complex environment including multiple regulatory regimes.

Social Due Diligence and Risk Assessment

Global Management Principles Assessment - Labor Issues, Global, Confidential Manufacturing Client. Social Lead
Conducted an assessment of corporate labor, supply chain, and workforce safety principles for compliance with international standards on good social practice.

Social, Safety, and Community Health Due Diligence - Oyu Tolgoi Project, Mongolia. Manager
Advised a consortium of lenders (including Equator Principles banks) on environmental and social sustainability aspects, all required to be IFC Performance Standard compliant. This was a combined open-pit and underground block caving copper/gold mining operation location in the South Gobi region of Mongolia, requiring the world's largest debt financing package for a mining project. Key issues included labor management, immigration, resettlement, impacts to cultural heritage, and environmental impacts.

Material Risks Assessment, Canada, Confidential Mining Client. Social Lead
Identified and assessed key risks associated with industrial development located in a pristine area of Canada. Key risks assessed related to indigenous peoples' rights, cultural heritage, traditional land use, and community health.

Social Investment and Corporate Social Responsibility

Community Investment Strategy Design and In-Field Implementation, Papua New Guinea. Esso Highlands Limited. Corporate Citizenship and Investments Lead
Designed and implemented a multi-million dollar community investment strategy for the largest natural resource project in Papua New Guinea's history. Strategic investments portfolio included formation of stakeholder partnerships across private, public, and not for profit sectors focused on education (including teacher training and education policy); health (including improved access to services, research, and treatment of infectious disease and job creation within the health care sector); women's empowerment (including support for female entrepreneurs and community leaders and job creation); and public policy. Strategically aligned investments with PNG National Action Plans, global corporate community investment priorities and branding, United Nations Millennium Development Goals, and in country business needs. Developed tools to ensure due diligence and compliance with internal guidelines and external legal standards, and mentored local staff into department leadership roles.

Community Investment, Impact Management, and Other Community Spending Analysis, Papua New Guinea, Esso Highlands Limited. Corporate Citizenship and Community Investments Lead
Managed comprehensive look back analysis, evaluation, and mapping of multiple tens of millions of dollars in cross functional community programs against internal standards and policies, business risks, international lending guidelines, and long term corporate citizenship and objectives.

Global Environmental Community Investment Portfolio Analysis, USA, ExxonMobil. Major Program Officer
Led evaluation of $10M community investment strategy in close collaboration with Environmental, Health, and Safety group and non-profit partners. Significantly restructured portfolio, designing and implementing exit strategies and replacing dated investments with higher value projects and partnerships.

Corporate Social Responsibility Strategy Development, Mexico, Confidential Client. Senior Social Technical Review
Provided technical quality assurance and control of key processes and deliverables associated with CSR strategy development including stakeholder engagement activities and planning and land access negotiations.

Benjamin D. Siegel

Project Archaeologist & Cultural Heritage Consultant

Benjamin D. Siegel is an Archaeologist and Cultural Heritage Consultant based in the Washington, D.C. office. He joined ERM in July of 2013 as a member of the DC Cultural Heritage team in order to help the office address both domestic and international clients' cultural heritage needs.

Ben has over 9 years of cultural hertiage experience, and has directed archaeological and historical research projects both inside the United States and abroad. Trained and well practiced in archival research, terrestrial archaeology, and underwater archaeology, Ben's unique and interdisciplinary background make him particularly well suited to assist with a wide range of cultural heritage projects.

Prior to joining ERM, Ben spent 3 years employed as an Archaeologist by domestic cultural resource management firms, where he specialized in Section 106 compliance, state archaeoligcal compliance, and archaeological surveys, throughout the Mid-Atlantic and Southeastern United States.

Over the years Ben has also accrued extensive international experience and consistently works on projects taking place around the world. Within the past year Ben has contributed to client projects in Albania, Azerbaijan, Haiti, Italy, Nicaragua, and Venezuela. Furthermore, Ben has served as the archaeological and research director for extensive international field projects including efforts in Rivas, Nicaragua (2014), Bluefields Bay, Jamaica (2009), and London, England (2006).

Familiar with both domestic and international archaeological standards and practices, and accustomed to working in a wide variety of environments, Ben consistently makes valuable contributions to cultural heritage projects for ERM's clients around the globe.

Professional Affiliations & Registrations

- Registery of Professional Archaeologists (R.P.A.)
- Archaeological Society of Maryland (A.S.M.)
- Society for Historical Archaeology (S.H.A.)
- Phi Alpha Theta Historical Honors Society
- American Academy of Underwater Sciences (AAUS)
- Certified PADI Dive Master (PADI)

Fields of Competence

- Terrestrial Archaeological field Survey and Excavations
- Underwater Archaeological Survey and Excavations
- Historical and Archival Research
- Section 106 Compliance
- International Cultural Heritage Management
- Culture and History of the U.S. and the U.K.
- Culture and History of the Caribbean & Latin America

Education

- M.A. Historical & Maritime Archaeology
  East Carolina University, 2011
- M.A. American History
  Emory University, 2007
- B.A. History & Philosophy
  Emory University, 2007

Languages

- English, native speaker

Publications

- "The Impact of Empire: The Effects of British Imperial Policy on the Maritime Landscape of Bluefields Bay, Jamaica" in *East Carolina University Press*
- "Dealing with an Independent America; the Debate Amongst British Merchants and Politicians over Anglo-American Trade Policy 1782-1785", in *Emory University Press.*

__ERM Project Experience__

Project: Ascent
Client: Confidential, *November/December 2014*
Co-Directed a Phase II archaeological investigation and extensive Phase I Deep Testing of an area intended for use as boat ramp and dock for an Oil and Gas refining plant along the Ohio River. The survey was designed to further refine a preliminary understanding of several sites already identified in the area during the Phase I survey.

Project: AMBU Marcellus Shale Baseline Study
Client: Chevron, *October 2014*
Conducted research for and developed the historical context for the 26 counties spread across Pennsylvania, West Virgina, and Ohio that fall within the project area. Also co-authored the Cultural Heritage section of the Baseline study, which made use of the three states' SHPO master site files to make assessments about the types and conditions of resources located within the project area.

Project: Nicaragua Canal
Client: HKND, *June - September 2014*
Directed the Archaeological Investigation of the canal route and projected canal impact areas within the Rivas Isthmus of Nicaragua. Managed a team of sub-contractors for the 2 month field effort, and was soley responsible for the write up of the field results and historical context that would comprise a large portion of the Cultural Heritage Team's baseline report.

Project: Ascent
Client: Confidential, *March - April 2014*
Co-Directed a Phase I archaeological investigation of an area intended for use as an Oil and Gas refining plant along the Ohio River. The survey was designed to further refine a preliminary understanding of several sites already identified in the area during pedestrian survey. All sites were bounded, and all artifacts collected were transported to a lab for further analysis.

Project: Azerbaijan Development
Client: Confidential, *March 2014*
Co-produced a cultural heritage management plan presentation to be distributed to construction workers and project staff to educate and inform with regard to the types of resources at risk on the project site, and explain the protocols in place for the project's chance finds plan.

Project: International Archaeological Guidance Notes
Client: Confidential, *February 2014*
Co-authored and co-edited a set of Archaeological Guidance Notes for an investment group, which codified and outlined internationally recognized best practices for lender based archaeological surveys and preservation efforts associated with major development projects. The deliverable is currently being assessed by the client, and will eventually be published by the client for distribution among its investors, benefactors, and borrowers.

Project Gulf Coast GTL Plant
Client Royal Dutch Shell, *October 2013*
Phase II archaeological investigation of future MCP site in south-central Louisiana. Carried out archaeological survey, exploratory excavation, and historical research to identify cultural resources associated with a 19th century sugar plantation in the project area. The Phase II efforts consisted of pedestrian survey, and mechanized stripping followed by ground probing.

Project Marcus Hook
Client Confidential, *Ongoing*
Created a GIS-based "change over time" study of Marcus Hook, PA, to ensure that future development in the area would comply with federal and state archaeological preservation law. Successfully managed to overlay historical maps and Sanborne fire insurance maps ontop of modern satellite images of the region to assist with the client's needs.

Project TAP
Client Confidential, *Ongoing*
Created a series of quantifiable metrics by which remote sensing data collected along a proposed underwater pipeline route within the Adriatic sea could be assessed. Conducted data assessments on data already collected and contributed to ERM's recommendations for future remote sensing surveys within the project area.

Project Nicaragua Canal
Client HKND, *Fall 2013*
Part of the team that developed a GIS-based predictive model highlighting prehistoric and historic-era archaeological site sensitivity for a region in Central America. The model will be updated as new information is received and will be used to guide field teams during archaeological survey.

Relevant Professional Experience

Excavation, Section 106 Application, and Archaelogical Review of 19th Century Farmstead and Homestead, for construction a Solar Farm in Frenchtown, NJ.
Assisted in the creation of the research design for the site assessment and Section 106 application of a historic property in Frenchtown New Jersey. Also co-directed fieldwork for the project, including test unit excavation, and shovel tests. Also created the project's master artifact catalog, and created the site map.

State Highway Administration Archaeological Surveying and Report Writing, in Talbot County, and Cumberland City, MD.
Conducted archaeological compliance surveys within the footprint of state roads to be expanded in Talbot County and Cumberland City, Maryland. Assisted in construction of the research design, aided in shovel testing, and performed research for the final reports.

Cumberland Pipeline Project, Cumberland City, MD.
Conducted a Phase I archaeological survey along a proposed pipeline cooridor that would supply natural gas to Cumberland City. The proposed coordior spanned across much of the city, and transveresed both public and private lands. The project involved extensive shovel testing, though few artifacts were ultimately recovered and processed.

Archaeological Excavation and Analysis of Cattle Pass Site, Historical Homestead, Martinsburg, WV.
Part of a small team which excavated an 18th and 19th century Homestead at the behest of the West Vrigina State Highway Administration. Extracted and later examined the architecture and cultural remains of the site, including construction materials, coins, faunal remains, and ceramics. Also helped create the project's artifact catalog, and curated all artifacts found to the standards of the West Virgina State Historic Preservation Office.

Road Development Project, Tabler Station, Maritnsburg, WV.
Conducted Phase I and Phase II investigations of a proposed route for a new road near Tabler Station, which would transect farmlands, railroad tracks, populated houses, and existing roads. Artifacts found were concentrated in one central loci, and consisted of 19th and turn of the 20th century artifacts. All artifacts were collected, labled, and taken to a lab for further analaysis.

Archaeological Investigation of Ships' Graveyards, Eagles Island, NC, and Dismal Swamp Canal in Elizabeth City, NC.
Coastline and submerged examinations of abandoned intracoastal and oceanic vessles in various sites along the North Carolina Coast. Efforts included Total Station surveying, site drawing, and follow up archival research on located vessel remains. Final report was submitted to the North Carolina State Historic Preservation Office and included Rhino 3d imaging of wrecks found.

Underwater Survey and Excavation of the Cashine River Wreck, Cashie River NC.
Conducted Archaeological Scuba dives as well as river bank terrestrial surveys to examine the remains from the Cashie River Wreck, a 16th or 17th century Collier, built in England and used in trans-Atlantic seafaring. Survey also included a bathymetric survey of the river, and a theodilte based survey of the west river bank, upon which a 17th century wharf was located. Diving consisted of low visability dives in a cold water environment.

Archaeological Survey and Monitoring and Project, Gulf of Mexico, Pensacola, FL, and Mobile, AL.
Directed Archaeological surveys along the Florida and Alabama's gulf coasts in order to document, and make assemsents on archaeological sites and resources in danger of contamination during the BP Oil Spill of 2010. Surveys were conducted on behalf of the Federal Government. Project also consisted of monitoring oil excavation efforts throughout the two states.

Archaeological Tribal Burial Reinternment Project Florida Water Management District, Everglades, Clewiston, FL.
Assisted in the relocation of, excavation of, and reinternment of Seminole Tribal remains in the Everglades at the behest of the State Tribial Historic Preservation Office and the State Historic Preservation Office. Efforts included baseline reconissance, metal detecting, and excavation.

Bluefields Bay Expedition, Jamaica.
Designed, directed, and obtained funding for an investigation of the cultural resources extant in Bluefields Bay, Jamaica. Project crew consisted of terrestrial archaeologists, underwater archaeologists, archival researches, and local support staff. Through extensive archaeological Scuba diving, site mapping, and artifact documentation, the crew located and identified a number of cultural resources from the 18th century, including British Longshank anchors, cannons, lime kilns, fortifications, and a tavern. The final report was published and submitted to the Jamaican National Heritage Trust as an advisory document for the future creation of a Cultural Heritage Museum in Bluefields Bay.

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Mark E. Garrison

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.

Yinka Afon, P.E.

Senior Acoustics and Air Quality Consultant

Mr. Yinka Afon is a Senior Project Engineer within ERM based in Annapolis, MD. He has over 11 years of experience in the field of physical resources management, with specific expertise in noise, vibration, and noise impact assessment, ambient sound surveys, noise modeling, ground-borne vibration and airblast assessments, air emissions quantification, meteorology, environmental managemnet and regulatory compliance. Most of his noise, vibration, air and GHG work has supported environmental and social impact assessments (ESIA) and permitting projects for power (thermal, hydro, biomass, wind and nuclear), oil and gas, mining, manufacturing, and transportation sector clients. Mr Afon is familiar with the US National Environmental Policy Act standards and the IFC Environmental Health and Safety Guidelines and Performance Standards. Aside from the United States, Mr Afon has international ESIA experience in countries such as Nicaragua, Suriname, Dominican Republic, Guatemala, Argentina, Chile, Bahamas, Greenland, Canada, Guinea, and Nigeria.

Mr. Afon provided noise and air quality expertise for development of multiple natural gas storage and liquefaction facilities, gas compressor stations, crude oil pump stations, and associated pipelines across the US and Canada. He also served as the Noise, Vibration, Air Quality, and GHG Lead for the construction and operation of a 272 km long canal to connect the Pacific Ocean to the Caribbean Sea through Lake Nicaragua. Mr. Afon managed a group of six staff engineers and coordinated environmental monitoring at sensitive areas along the canal corridor.

Professional Affiliations & Registrations

- Registered Professional Engineer #33760, MD, 2009
- Member of Acoustical Society of America
- Member of American Institute of Chemical Engineers
- Member of Air & Waste Management Association

Fields of Competence

- Noise, vibration, air quality, and GHG impact assessment
- Regulatory compliance (NEPA, FERC, IFC)
- Emissions inventory (criteria pollutants, HAPs, GHGs)
- Noise modeling (Predeictor-Lima Software, Type 7810-G)
- Blasting assessments (airblast, groun-borne vibration)
- Environmental management and monitoring plans

Key Industry Sectors

- Power generation (thermal, hydro, biomass, wind, and nuclear)
- Oil & gas (onshore and offshore)
- Mining & ore/metals processing
- Linear infractructure (pipeline, canal and transmission lines)
- Manufacturing/ petrochemical
- Transportation

Education

- M.S.E., Environmental Process Engineering, Johns Hopkins University, Baltimore, 2004
- B.S., Chemical Engineering, Ladoke Akintola University of Technology, Nigeria, 2001

Languages

- English, native speaker
- Yoruba

Publications

- Afon Y and Ervin D. An Assessment of Air Emissions from Liquefied Natural Gas Ships Using Different Power Systems and Different Fuels . Journal of Air & Waste Management Association No.3, Vol 58, 404 – 411 (2008).

Key Projects

Nicaragua Canal Project, HKND, Nicaragua. 2014-2015. Noise, Vibration, Air Quality, and GHG Lead for preparation of an ESIA for construction and operation of a 272 km long canal to connect the Pacific Ocean to the Caribbean Sea through Lake Nicaragua. Construction activities include dredging, excavation of over 4.4 billion m^3 of material, and blasting. Operational activities include ship traffic, assist tugs, ferries, port and lock operations. Conducted noise surveys and performed noise modeling for large ships that would use the canal using Predictor V9.12 software. Evaluated noise impacts of in-water piling, dredging, and vessel use on marine mammals and fish during project construction. Quantified GHG emissions from land use change, fossil fuel combustion and indirect electricity use. Also quantified the net GHG emissions due to changes in shipping patterns with and without the canal project.

Dalton Expansion Project, Transcontinental Gas Pipe Line Company, LLC, GA. 2014-2015. Air Quality and Noise Lead for preparation of a Resource Report 9 as part of a FERC application for construction and operation of 109.3 miles of new natural gas pipelines, one new gas-fired turbine compressor station, and three meter stations in Carroll, Bartow and Murray counties, Georgia. Quantified emissions of criteria pollutants, HAPs, and GHGs. Reviewed sound survey reports and performed acoustical analysis for all aboveground facilities and nine horizontal directional drill crossings associated with the project.

Shell Franklin Petrochemical Project, Shell Chemical Appalachia, PA. 2014-2015. As Noise Lead, provided noise expertise and reporting for development of a petrochemical complex in Beaver County, PA. Performed noise modeling for the Early Works (including blasting), Main Construction, and peak hour construction traffic using Predictor V9.12 software. The software used ISO 9613-2 and FHWA TNM calculation methods.

NorthMet Mine & Ore Processing Project, PolyMet Mining Inc., MN. 2007-2015. Lead Acoustic Specialist for preparing noise and vibration sections of an EIS for the development of a 11.3 million tonne per annum open pit mine (precious metals) and ore processing facility in northeast Minnesota over a nine year period. Task included evaluation of baseline noise conditions, noise and vibration modeling, and report writing. Prepared the noise and vibration sections of the EIS in accordance with Minnesota Rules, part 7030.0040 and 6132.2900, respectively. Coordinated with cooperating agencies (USEPA, USFWS, Tribes) and addressed all their comments and concerns related to noise.

Atlantic Sunrise Project, Transcontinental Gas Pipe Line Company, LLC, PA, VA, MD, and NC. 2014-2015. Noise Lead for preparation of a noise and air quality report as part of a FERC application for construction and operation of 196.5 miles of greenfield gas pipelines and aboveground facilities in PA,VA, MD, and NC. Reviewed sound survey and acoustical analysis reports for all aboveground facilities (five compressor stations, two meter stations, three regulator stations) and three horizontal directional drill crossings associated with project.

Noise Impact Study for the River Reach Boulevard Project, Prein & Newhof, MI. 2015. Lead Acoustics Specialist for preparing a Noise Impact Study as part of an EA for the development of a new road alignment corridor (River Reach Boulevard) in the Village of Parchment, Michigan. Coordinated noise survey and performed traffic noise modeling using Bruel & Kjaer's Predictor Version 9.12 noise modeling software and FHWA's approved Traffic Noise Model (TNM) calculation method.

Keystone XL Pipeline Project, TransCanada Keystone Pipeline, LP, Canada, U.S. 2012-2014. As Senior Project Engineer and 3rd Party EIS contractor with USDOS, provided noise, air quality, and GHG expertise for preparation of a Supplemental EIS for construction and operation of approximately 875-mile heavy crude oil pipeline and associated facilities (pump stations) from Alberta (Canada) to Nebraska (US). In addition, evaluated effects of other transport alternatives by quantifying air and noise emissions from other pipeline routes, rail (diesel locomotives), and water (oil tanker) transportation. Addressed several noise, air quality, and GHG-related comments from the public, NGOs, and environmental agencies.

Dry Sorbent Injection and Subbituminous Coal Use Projects, H.A. Wagner LLC (Wagner), Baltimore, MD. 2014. Developed an air emissions inventory as part of Wagner's CPCN application to the Maryland PSC for the modification of two coal firing units to achieve compliance with federal MATS rule through use of dry sorbent injection (a proven add-on control technology for reducing HCl emissions) and/ or subbituminous coal (to replace existing bituminous coal). As part of the emissions inventory development for the Maryland Department of Natural Resources (DNR) Power Plant Research Program (PPRP), reviewed Applicant's emissions calculations, identified minor errors (which were corrected by the Applicant through responses to data requests), and summarized findings in an ERD.

Noise Survey and Impact Study, Westward Ho Pipeline Project, Shell Pipeline Company, LA and TX. 2013-2014. Senior Project Engineer and Acoustics Lead for preparing a Noise Survey and Impact Study as part of an ESHIA for the development of a 206-mile pipeline from St. James Parish, LA to Port Neches, TX. Managed a group of four staff engineers and coordinated noise survey at multiple horizontal directional drilling (HDD) locations along the pipeline route, performed noise modeling, and assessed noise impacts to nearby receptors. Also performed a detailed noise abatement analysis for areas where noise impacts exceeded applicable limits.

Merian Gold Mine and Power Plant Project, Surgold Inc. (Newmont), Suriname. 2010-2013. Environmental Lead for preparing multiple sections of an ESIA for the development of an open pit gold mine in northeastern Suriname with planned production of 5.5 million ounces of gold over 12-14 years and processing of 150 million tonnes of ore and 680 million tonnes of waste rock. The Project also includes the installation of an onsite 52.5 MWe HFO-fired power plant. Resources evaluated include noise, ground vibration, airblast overpressure, air quality, GHGs, and climate. The Project was approved by the Government of Suriname in May 2013.

Buckeye Wind Project, Buckeye Wind LLC, Champaign County, OH. 2009-2013. Author of the noise and air quality impact assessment for a 3rd Party EIS for a 250 MW windfarm in Ohio on behalf of the USFWS. Calculated criteria pollutant and GHG emissions avoided from the proposed wind power project when compared to a typical fossil-fuel type project with the same energy generation capacity. In April 2015, the US District Court in Washington D.C. granted summary judgement in favor of the project following a suit that challenged the issuance in 2013 of an Incidental Take Permit for impacts to the endangered Indiana bat.

Perryman 6 Power Plant Project, Constellation Power Source Generation, Inc. (CPSG), Baltimore, MD. 2012-2013. Developed an air emissions inventory as part of CPSG's CPCN application to the Maryland PSC for the construction and operation of two dual natural gas/ultra low sulfur diesel-fired, simple-cycle combustion turbines with a nominal capacity of 120 MW. As part of the emissions inventory development for the Maryland DNR PPRP, reviewed Applicant's emissions calculations, identified minor errors (which were corrected by the Applicant through responses to data requests), and summarized findings in an ERD.

Fab 8 Steel Manufacturing Facility, Global Foundries, Malta, NY. 2012-2013. Completed a detailed survey of existing noise levels generated by routine manufacturing onsite and offsite to address the source of community noise complaints, given current planning of new facilities. Sound measurements were recorded at 5 minute intervals at multiple locations onsite and offsite using a Type 1 Sound Level meter equipped with a 1/3 octave band filter. Coordinated modeling of significant plant noise onsite in order to understand their relative contribution to the overall noise 'budget' at the community. Future iterations of the model considered the additive effect of the facility expansion.

Wageningen Sugarcane-to-ethanol Project, Suriname. 2010-2013. Senior Project Engineer and Physical Resources Lead for the preparation of an ESIA for constructing and operating a 80-90 million liter per year Sugarcane-to-Ethanol factory (25 MW biomass plant) in Suriname. Evaluated air quality, climate, and noise impact of the biomass project. Calculated GHG emissions avoided from the proposed biomass project when compared to a typical fossil-fuel type project with the same energy generation capacity.

Reventazon Hydroelectric Project, Instituto Costarricense de Electricidad (ICE), Costa Rica. 2011-2012. Senior Project Engineer and GHG Lead for the construction and operation of a dam and hydropower plant and associated facilities, with a total cost of US$1.06 billion. As part of the EIA required for the project to secure financing with the Inter-American Development Bank (lender). Quantified net and gross GHG emissions associated with flooding the reservoir as well as emissions that would be avoided per annum from generation of renewable energy as opposed to the annual GHG emissions that would be emitted by the generation of an equivalent amount of power from the generation supplying the Costa Rica grid.

Boca Chica Thermal Electric Power Plant Project, IIC, Dominican Republic. 2012. Acoustic lead and author of the noise section of an ESIA for the construction and operation of an 82 MW combined-cycle natural gas-fired thermal electric power plant in Boca Chica, Dominican Republic. Predicted Project noise effects on nearest receptors using ISO 9613-2 sound propagation modeling algorithms. Prepared a noise modeling report for the Project in accordance with DR noise standards and IFC Performance Standards and EHS guidelines. Recommended appropriate noise control measures for impacted receptors.

Nassau Plateau Bauxite Mine and Transport Road Project, Suralco Inc. (Alcoa), Suriname. 2008-2012. Senior Project Engineer for preparing multiple sections of an ESIA for the development of a 4.2 million tonne per annum open pit bauxite mine on Nassau Plateau and a 104 km transport road for transporting mined ore via trucks to an alumina refinery in Paranam, Suriname. Resources evaluated during pre-production, production, and closure phases include noise, ground vibration, airblast overpressure, flyrock, climate and air quality, GHGs, and natural hazards.

Greenhouse Gas Emissions Inventory, City of Bowie, MD. 2010. Developed a GHG emissions inventory (as part of an Energy Efficiency Conservation Strategy (EECS)) for the City of Bowie government facilities and operations for base year 2007 and forecast year 2015. Data from buildings and facilities, streetlights and traffic signals, water delivery facilities, wastewater facilities, vehicle fleet, and mobile source refrigerants were entered into the Clean Air and Climate Protection (CACP) software to compute municipal government operations GHG emissions in terms of carbon dioxide equivalents (CO_2e). The city's GHG inventory indicated that majority of the emissions came from government buildings and facilities and vehicle fleets. Provided strategies and opportunities for reducing GHG emissions from buildings and vehicle fleet energy use.

Agbara Industrial Estate Manufacturing Project, Proctor & Gamble, Agbara Town, Ogun State, Nigeria. 2010. Reviewed the draft ESIA associated with P&G's proposed development of a new 40 ha facility for manufacture, storage and distribution of consumer goods within Agbara Town, Ogun State, Nigeria. Participated in a Public Disclosure Meeting at the king's palace in Agbara Town to discuss potential social and environmental issues. Some of the major issues addressed at the meeting include the project's effect on traffic, solid waste handling, jobs for the locals, odor, wastewater treatment and discharge sources, noise, and air pollution.

White Pines Wind Power Project, Huron-Manistee National Forests, (Mason County, MI) 2009. Environmental Specialist for an EIS evaluating GHG emissions avoided and public safety and security issues associated with the development of a proposed wind farm near Manistee, Michigan. The wind farm is expected to have 28 wind turbine generators, each rated at 2.5 MW.

Review of AMRs and ESAPs for Projects Seeking IFC Funding, IFC, Washington D.C. 2009. Worked with IFC staff in the IFC Office in Washinton D.C for about 2 months reviewing Annual Monitoring Reports (AMRs) and Environmental and Social Action Plans (ESAP) for numerous manufacturing and pharmaceutical projects in developing countries seeking funding from the IFC. Some of the key issues identified during the AMR reviews include insufficient data quantification for parameters such as air quality, GHGs, noise monitoring, worker safety incidents, and non-compliace with some of IFC's Performance Standards (PS). Calculated environmental and Social Risk Rating (ESRR) for some of IFC's portfolio projects. The rating allows for a coincise, up-to-date assessment of client environmental and social risk throughout the life of the project. Recommended supervision missions/visits for facilities not meeting IFC PS and/or host country's requirements

Floridian Natural Gas Storage Project, Floridian Natural Gas Storage Company, FL. 2007-2008. As Project Engineer and 3rd Party EIS contractor with FERC, provided resource expertise and management for development of a 100 MMscf per day natural gas storage and liquefaction facility and a 4-mile pipeline in Martin County, Florida. Wrote noise and air quality sections of the EIS and provided quick responses to public and agency comments. Final EIS was approved by FERC in 2008 with some licensing conditions.

Refinery Modification and DRDA Expansion Project, Suralco Inc. (Alcoa), Suriname. 2007–2008. Project Engineer for evaluating the noise and air quality impacts for an ESIA for modifying an alumina refinery plant and expanding its dry residual disposal areas (DRDA) in

Suriname. Conducted ambient noise measurements and performed sound propagation modeling (ISO-9613-2 model) for major noise sources at the refinery and port area. Wrote noise and air quality sections of the ESIA in accordance with IFC Performace Standards and EHS guidelines.

Jaguar Thermal Electric Power Plant Project, AEI Inc., Guatemala. 2008. Author of the air quality and noise section of an ESIA for the development of a 300 MW thermal electric power plant in Guatemala in accordance with IFC Performance Standards. Reviewed and provided comments on applicant's ambient noise monitoring methodology. Coordinated the modeling of noise generated from over 1,200 identified major stationary and mobile noise sources at the site.

Technical Support for Licensing Two New Nuclear Power Plants, Areva, U.S. East Coast. 2008. Provided technical and environmental support for the preparation of combined license (COL) applications for two new 1600 MW nuclear reactors in PA and NY. Coordinated with other sub-contractors to address client's comments and ensured the applications were submitted to Nuclear Regulatory Commission within the scheduled time. Both applications were prepared in accordance with NRC's NUREG 1555 and Regulatory Guide 4.2.

Maniitsoq Aluminum Smelter, Transmission Line, Port, and Hydropower Project, Alcoa, Greenland. 2007. Author of the noise, climate, and air quality baseline assessment for an integrated hydropower, transmission line, aluminum smelter, and port complex in southwest Greenland.

New South Ocean Development (NSOD) Resort Project for NSOD Company Ltd, Nassau, Bahamas. 2007. As Project engineer, provided resource expertise and reporting for an EIA evaluating noise quality effects of developing a US$1 billion ocean-front resort including two hotels, casino, golf course, marina, and residential complex in Nassau, Bahamas. Conducted ambient noise measurements and modeled noise impacts from major noise sources such as an amphitheather, idling marina boats, and increased traffic volumes in the area.

Crown Landing LNG Project, Crown Landing LLC (a BP Energy Company), NJ. 2004-2007. Project Engineer and air and noise lead for the preparation of a FERC application for the development of a 1.2 Bscf per day onshore LNG facility in Logan Township, NJ, and associated pipeline extending under the Delaware River into PA. Performed a terminal system alternatives analysis and evaluated project impacts on noise, air quality, and water resources. Developed air emissions inventory and prepared an air conformity analysis report in accordance with NJ, DE, and PA State Implementation Plans.

Northeast Gateway Deepwater Port LNG Terminal and Pipeline Project, Excelerate Energy, Massachusetts Bay. 2006. As Project Engineer and 3rd Party EIS contractor with U.S Coast Guard, provided air quality and acoustic resource expertise and reporting for development of a 400 MMscfd per day LNG deepwater port with specially-designed regasification vessels and associated pipelines in Massachusetts Bay. Developed air emissions inventory and prepared an air conformity analysis report in accordance with MA State Implementation Plans. Conducted in-air and underwater sound propagation modeling for the marine vessels and determined impacts to sensitive receptors including marine mammals. The Maritime Administration issued a Record of Decision for the project in 2006. The deepwater port is currently in operation.

City of Buffalo Main Street Multi-Modal Access Project, Niagara Frontier Transportation Authority, NY. 2006. Acoustic Specialist for evaluating noise and vibration effects of improving an urban multi-modal transit system at Main Street, Buffalo, NY in accordance with USDOT's Transit Noise and Vibration Impact Assessment manual dated May 2006 and FHWA Traffic Noise Model (TNM), Version 2.5. Calculated existing noise and vibration levels from light rail vehicles in the Project's vicinity, estimated projected traffic noise levels on new road alignment, and wrote the noise section of the EA.

Field Supervisor, Shell Petroleum Development Company (SPDC), Port Harcourt, Nigeria. 2001. Working as a chemical engineer intern for SPDC, supervised oil well clean-ups for an oil production facility in Port Harcourt, Nigeria. Entered data regarding oil spillage sites and specific clean-up dates for various localities into a tracking database.

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Michael J. Fichera

Senior Project Engineer

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.

Shwet Prakash

Senior Consultant, Water Resources and Modeling

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.

<u>Water Quality</u>

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.

Matthew W. Erbe, P.G.

Principal Consultant

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.

Dusty Aeiker

Project Manager, Hydrogeologist

Ms. Aeiker 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. Aeiker'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. Aeiker 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. Aeiker 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. Aeiker 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

Project Scientist/ESIA 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.

Melinda K. Todorov

Project Scientist

Ms. Melinda Todorov is a Project Scientist within ERM based in Annapolis, Maryland. She has over nine years of experience in impact assessment and an additional four years experience in the field of aquatic ecology, including studies of marine invasive species. Ms. Todorov has a National Environmental Policy Act (NEPA) certificate from the Duke Environmental Leadership Program. Her responsibilities have included assisting in the preparation of Environmental Impact Statements, Environmental Assessments, 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

Atlantic Coast Pipeline, US, Dominion, 2015-present.
Provided Project support for the proposed interstate natural gas pipeline that will serve multiple public utilities and their energy needs in Virginia and North Carolina. Assisted in research of revegetation mixes and provide ongoing support to the biology team, including assisting with the Biological Evaluation and field data QA/QC.

LNG Re-gasification Plant Expansion Environmental Assessment, Barbados, Inter-American Development Bank, 2016.
Prepared several environmental setting sections (including Climate and Air Quality, Hydrology, Noise, Flora and Fauna, and Socioeconmics) of the Environmental Assessment (EA) for the Phase I strategy, which includes the expansion/upgrade of the existing LNG facility in Woodbourne, Barbados and the upgrade of natural gas transmission and distribution infrastructure.

NorthMet Mine Environmental Impact Statement, Minnesota, US, Minnesota, Department of Natural Resources, US Army Corps of Engineers, and US Forest Service, 2008-2016.
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.

FirstNet Programmatic Environmental Impact Statement, AK, HI, and US Territories, 2015.
Assisted in the preparation of 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.

Keystone XL Pipeline Supplemental Environmental Impact Statement, US, 2012-2014.
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, 2013 – 2014.
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, 2012.
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.

Buckeye Wind Project Environmental Impact Statement, Ohio, US, Buckeye Wind L.L.C., 2011-2012.
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.

Weda Bay ESHIA, Indonesia, Mining and Metals Sector Client, 2011 – 2012.
Assisted in the preparation of an Environmental Social and Health Impact Assessment (ESHIA) for construction and operation of a nickel and cobalt mining operation 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.

Columbia Gas Pipeline, Line MB Extension Environmental Assessment, Maryland, US, 2012.
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, 2008 -2012.
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.

Suriname Bauxite Mine ESIAs, Suriname, Mining Sector Client, 2011 - 2012.
Assisted in the preparation of two ESIAs for bauxite mines in northeastern Suriname, one of which was approvedby the National Institute for Environment and Development in Suriname (NIMOS) in June 2012. Prepared legislative chapters and assisted in the development of biological resources and alternatives chapters.

Environmental Impact Statement, Massena, New York, US, Mining and Metals Sector Client, 2008, 2012.
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.

Integrated Natural Resources Plan, Minot Air Force Base (AFB), North Dakota, US, 2011
Assisted in updating the Integrated Natural Resources Plan (INRMP) for the Minot AFB in North Dakota. The INRMP is a tool to help integrate natural resources management into Mission activities.

Environmental Impact Assessment Survey, Government (non-US) Client, 2009 - 2011.
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.

Natural Gas Pipeline Repair Permit, New Jersey, US, Sunoco, 2009-2010.
Assisted in the preparation of USACE Nationwide permit and NJDEP General Permit applications for the repair of a 8″ natural gas pipeline. The pipeline is in an area that qualifies as wetlands and is below the natural water line of the tidal pond at all times.

Joint Land Use Study, Maryland, US, National Capital Park and Planning Commission, 2008 – 2009.
Assisted with the Joint Land Use Study between Andrews Air Force Base (AAFB) and Prince George's County, which seeks to ensure cooperative land use planning between AAFB and the surrounding communities so that future growth and development are compatible with the training and operational missions of the installation.

Crown Landing LNG Terminal, New Jersey, US, BP America, 2007 – 2008.
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.

Subregion 5 and 6 Master Plans, Maryland-National Capital Park and Planning Commission, 2008.
Assisted on environmental aspects of the 2008 environmental master plan updates for the Subregion 5 and 6 Master Plans in Prince George's County, Maryland. Researched water resources and land planning issues in the Subregion 5 portion of the Mattawoman Creek Watershed.

BP Alternative Energy, Mehoopany Wind Farm Northeast, Pennsylvania, US, 2008.
Assisted in wetlands surveys in support of state and federal wetlands and jurisdictional water body impacts associated with an approximately 90 MW proposed wind farm located across over 10,000 acres of mountainous forested terrain.

BP Alternative Energy, Cape Vincent Wind Farm Thousand Islands Region, New York, US, 2008.
Assisted in performing a wetland survey and habitat assessment of state and federal wetlandsto determine jurisdictional water body impacts associated with an approximately 90 MW proposed wind farm located across over 12,000 acres of rural farmland and forested terrain.

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Julia L. Tims

Technical Director Biodiversity and Ecosystem Services

Ms. Tims has twenty four years of experience in terrestrial ecology and natural resource management and environmental impact assessment. Ms. Tims specializes in terrestrial biodiversity and provides technical leadership for international Environmental and Social Impact Assessment (ESIA) projects around the world, primarily within the renewable energy, agricultural, mining, and transportation sectors. Ms. Tims has extensive experience in developing and leading biodiversity baseline and impact studies in accordance with best practice and international standards, including IFC Performance Standards, IDB Safeguard Policies, Equator Principals, and other lender standards. Ms. Tims specializes in application of the mitigation hierarchy and development of Biodiversity Action Plans, management and monitoring plans, restoration plans, and offset strategy development to address unavoidable residual impacts. Ms. Tims has been an active member of the Business and Biodiversity Offsets Program (BBOP) for over 5 years and is involved in numerous projects currently developing or considering the need for offsets.

Fields of Competence

- Environmental and Social Impact Assessment
- Biodiversity assessment, management, and monitoring
- International standards, including Equator Principles, IFC Performance Standards, and others
- Environmental and Social Due Diligence
- Application of mitigation hierarchy
- Biodiversity offsets
- Ecosystem services assessment
- Project permitting and documentation
- Endangered species conservation and management
- Terrestrial biodiversity baseline studies
- Stakeholder engagement related to biodiversity and biological/social interactions
- Interaction with environmental NGOs
- Habitat restoration and enhancement
- Conservation planning
- Alternatives analysis
- Cumulative impact assessment

Professional Affiliations

- American Ornithologist's Union
- The Wildlife Society
- Waterbird Society

Credentials

- M.Sc., Natural Resources Management/Ecology, Cornell University, 1999, With Distinction
- B.Sc., Entomology and Applied Ecology/Wildlife Conservation, University of Delaware, 1990
- Habitat Suitability Index Modeling, United States Fish and Wildlife Service
- Environmental Impact Assessment, Inter-American Development Bank
- Monitoring and Evaluation of Projects, Inter-American Development Bank
- OSHA 40-hr Hazardous Materials Handling and Safety Training

Key Industry Sectors

- Energy
- Mining
- Agriculture
- Transportation
- Infrastructure

Papers and Publications

- Tims, J.L., I.C.T Nisbet, J. Hatch, and C. Mostello. 2004. Characteristics and performance of Common Terns in Old and Newly-established colonies: implications for long term conservation. *Waterbirds*. 27(2):134-143.
- Tims, J.L. and K.M. Brown. 2001. Food Items Obtained by Gulls at and Around JFK International Airport: Relevance to Airport Management. *Waterbirds*. 24(1): 44-52.
- Tims. J.L. and K.M. Brown. 2001. Changes in the Nesting Populations of Colonial Waterbirds in Jamaica Bay Wildlife Refuge, New York, 1974-1998. *Northeastern Naturalist*. 45:17-28.

Julia L. Tims

Technical Director Biodiversity and Ecosystem Services

Representative Projects

Environmental and Social Impact Assessment, Nicaragua Canal Project, Nicaragua. Led the biodiversity component of the ESIA and preliminary offset strategy for the world's largest infrastructure project, the proposed Nicaragua Canal. The project consists of the canal and related infrastructure including two ports, a transmission line, roads, and reservoirs. 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. All work on the project was conducted in alignment with international standards, particularly the IFC Performance Standards. The project was successfully conducted under an expedited timeframe and was subject to intense national and international scrutiny due to the high profile nature of the project.

Environmental and Social Impact Assessment for the Weda Bay Nickel Project, Indonesia. Lead biodiversity specialist for biodiversity baseline preparation and impact assessment for a nickel and cobalt mine and hydrometallurgical processing plant in Central Halmahera and East Halmahera Regencies, North Maluku Province, Indonesia. The island contains numerous endemic and red list flora and fauna and lies within the Northern Maluku Endemic Bird Area, which has the highest levels of bird endemism for its size anywhere in the world. Because of this high level of bird endemism, Halmehara and its neighboring isands rank number ten out of a total of 218 designated biological diversity hotspots in the world. Extensive baseline biodiversity studies were conducted over a ten year period and results were collated into a biodiversity baseline report. Ms. Tims conducted an ecosystem services review, IFC PS6 critical habitat assessment, and impact assessment and developed a robust Biodiversity Action Plan (BAP) and Biodiversity Management Strategy that focused on minimizing unavoidable impacts to critical habitats, endemic birds and other rare species, and important ecosystem services. Evaluated the feasibility of biodiversity offset options in accordance with Buisiness and Biodiversity Offet Program (BBOP) Principals.

Environmental and Social Due Diligence, Santander Sugarcane Operation, Belize. Currently leading the biodiversity and water aspects of an Environmental and Social Due Diligence (ESDD) of a sugarcane cultivation and processing mill for CIFI. The project is located in Belmopan District, Belize where rapid agricultural expansion is occurring. The greenfield site contained primary and secondary forest prior to clearing for project development and lies adjacent to a national protected area that was designated for the protection of jaguar and several sensitive water and wetland resources. Key issues facing the project include habitat loss, impacts to rare species, water quality, impacts of water abstraction on salinity and downstream water availability, maintenance of ecosystem services, cultural resources, resettlement, occupational health and safety, and induced and cumulative impacts from other sugarcane growers in the region that are growing sugarcane to supply the mill.

Environmental Impact Statement for an HCP and ITP for the Buckeye Wind Power Project, OH. Project Manager and avian/threatened and endangered species lead on an EIS for the United States Fish and Wildlife Service (USFWS) to assess the potential effects of the proposed 250 MW Buckeye Wind Power Project in west-central Ohio. The Project required an Incidental Take Permit (ITP) pursuant to the Endangered Species Act (ESA) to authorize the incidental take of Indiana bats, listed as federally endangered under the ESA, that would likely occur as a result of the Project. The EIS assessed the effects of issuance of the ITP on Indiana bats and other resources as required by the National Environmental Policy Act (NEPA) including migratory birds and compliance with the Migratory Bird Treaty Act and other applicable federal regulations and Executive Orders. The EIS included a robust cumulative impact assessment of numerous wind projects proposed for the region and their cumulative impact on Indiana bats and migratory birds. This high-profile and precedent-setting project was the first ITP issued for Indiana bat related to a wind project in the US. ERM assisted the USFWS in preparing a robust EIS that withstood extensive public, NGO, and legal scrutiny on an expedited schedule. The final EIS was published in April 2013, and the USFWS approved the HCP in July 2013. The EIS was challenged in US Federal court and ultimately upheld, with the ITP issued in 2015.

Environmental and Social Impact Assessment, Bui Hydroelectric Project, Bui National Park, Ghana. Led the biodiversity and ecosystem services portions of the ESIA for the proposed Bui Hydroelectric Project, located within the Bui National Park in western Ghana. The project was highly controversial amongst Ghanaians and national and international NGOs for biodiversity and social reasons: the project area was located within a portion of Bui National Park, which has high biodiversity value. The area also contains roughly 2,000 villagers that would require resettlement if the project were to proceed. The ESIA was conducted in accordance with World Bank/IFC policies and guidelines. ERM conducted extensive stakeholder consultation throughout the ESIA process, a major focus of which was the effect of the project on the National Park and management options to balance project and park needs.

Environmental, Social, and Health Impact Assessment, Kabata Refinery, Guinea. Project manager and biodiversity and ecosystem services lead for the ESIA for Alcoa and RioTinto's proposed Kabata refinery and related port, railway, and related infrastructure located in Boka Prefecture Guinea. Collaborated with an expert local biodiversity field team to execute a rapid assessment, conducted in three seasonal survey missions, of terrestrial and aquatic biodiversity at the site and surrounding region. Two key species of concern identified were the IUCN-listed critically endangered marsh crab *Afrithelphusa monodosa* and the West African chimpanzee *Pan troglodytes verus*. The project would have unavoidable direct and indirect impacts on the habitats for these species as well as sensitive coastal mangroves, local fishing grounds, and nursery habitat for commercially valuable marine species. Led the project team in application of the mitigation hierarchy and assessment of design and layout alternatives to reduce impacts on biodiversity and ecosystem services. Coordinated with the government of Guinea and local and international NGOs and other stakeholders regarding potential biodiversity offsets focused on chimpanzees. Supported Alcoa and Rio Tinto in consultations with Wildlife Chimpanzee Foundation regarding offsetting options and feasibility of offset implementation.

Environmental and Social Impact Assessment, Bekoko Transmission Line, Cameroon. Provided technical oversight on the biodiversity and ecosystem services aspects of an ESIA for a proposed 116 km, 225kV transmission line between Bekoko and Nkongsamba in western Cameroon. The proposed transmission line follows an existing line for much of its route; however, part of the line required clearing of relatively undisturbed rainforest habitat that is adjacent to the Mouyouka – Kombé Kompina Forest Reserve. Ecological issues addressed included habitat loss and fragmentation, endemic plant and wildlife species, loss of biodiversity, anthropogenic effects on wildlife populations, and erosion and associated increases in sediment loads to rivers and streams. The project involved extensive stakeholder consultation, including assessment of natural resource livelihoods and the interactions of social and ecological issues regarding the project.

Environmental and Social Impact Assessment, Baynes Hydroelectric Project, Angola. Led the biodiversity and ecosystem services portions of an ESIA for the proposed Baynes Hydropower Project located on the lower stretches of Kunene River, at the Angola-Namibia border. The project is located in a desert and mountainous region with high biodiversity and high species endemism. Provided technical oversight of five specialist studies (vegetation, avifauna, mammals, insects, and herptiles) that were conducted by local and international experts. Incorporated specialist input into the ESIA for the project and developed management recommendations in partnership with the specialists and the project proponent in order to minimize adverse biodiversity impacts and to maximize potential benefits of the project (e.g., access to stable water source, etc.).

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.

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. A combined raw sugar/ethanol plant and power exportation plant is planned to allow for flexibility to vary ethanol versus sugar production depending on market demands and to export power to the national grid. ERM developed the ESIA to conform with Suriname National Institute for Environmental and Development Standards (NIMOS) 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. ERM developed a GHG emissions inventory and assessed GHG impacts based on minimum GHG savings in terms of the project's GHG intensity against a fossil fuel comparator using the methodology and rules defined in the European Union Renewable Energy Directive (EU RED). ERM was able to predict GHG savings of 60 to 85 percent depending on the amount of electricity sold to the national grid.

Environmental and Social Impact Assessment, Alcoa Greenland Aluminium Smelter and Hydroelectric Project, West Greenland. Project manager and biodiversity lead for the ESIA for Alcoa's Greenland Aluminium and Hydroelectric Project, which consisted of an aluminium smelter, marine port, two hydroelectric projects, and electric transmission lines. This project constituted the largest industrial development in Greenlandic history. Issues identified during ESIA scoping included smelter air and water emissions and waste management; effects of the hydroelectric development on caribou migration, birds and internationally recognized Important Bird Areas, Arctic char, and cultural resources; and social and health effects related to immigration of foreign workers, housing, infrastructure, and social and health services. Collaborated with local and international experts to conduct baseline environmental, human health, and social studies. The impact assessment is currently on hold pending government negotiations relative to project development.

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. A combined raw sugar/ethanol plant and power exportation plant is planned to allow for flexibility to vary ethanol versus sugar production depending on market demands and to export power to the national grid. 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. ERM developed a GHG emissions inventory and assessed GHG impacts based on minimum GHG savings in terms of the project's GHG intensity against a fossil fuel comparator using the methodology and rules defined in the European Union Renewable Energy Directive (EU RED). ERM was able to predict GHG savings of 60 to 85 percent depending on the amount of electricity sold to the national grid.

Julia L. Tims

Technical Director Biodiversity and Ecosystem Services

Biodiversity Baseline Studies and Impact Assessment, Pascua Lama Mine and Related Infrastructure, Argentina and Chile. Led the analysis and reporting for a Rapid Biodiversity Assessment and Ecosystem Services Review to fill baseline data gaps for Barrick Gold's Pascua-Lama gold mine and related infrastructure located on the border of Chile and Argentina. The project has been under construction for over a decade and is now operational. Used the Valued Environmental Components (VEC) approach to assess the project's historic construction-related impacts and predicted future operational impacts on biodiversity. VEC's included rare flora, several rare terrestrial fauna species, migratory ungulates, *vegas* (i.e., wetlands), aquatic and riparian habitats, species known to provide important ecosystem services to local communities, and a internationally recognized Biosphere Reserve that is located just outside the Project's area of influence. Ms. Tims used the information generated during the baseline and impact assessment to update the project's Biodiversity Management Plan to define measures that will minimize and manage ongoing impacts to VECs during project operation and closure. Also prepared a Critical Habitat Assessment relative to IFC Performance Standard 6 and advised client on PS6 conformance.

Cumulative Impact Assessment for the Camisea Gas Project, International Development Bank and Pluspetrol Peru Corporation, Peru. As part of the ESIA for the Camisea Gas Project in Peru, Ms. Tims conducted a comprehensive cumulative impacts assessment on biological resources that could result from the planned oil and gas developments and expansion of the Malvinas Gas Separation Plant, combined with other past and reasonably foreseeable future activities within the lower Urubamba watershed. The assessment identified the probability and magnitude of cumulative effects on biodiversity, habitat quality, rare species, ecosystem services, and indigenous communities that rely on biological resources for sustenance fishing and hunting.

Environmental Impact Statement for the Clackamas Hydroelectric Project Relicensing. Portland, OR. Project manager for the EIS and technical leader for terrestrial ecological issues for relicensing the Clackamas River hydroelectric project. Managed the NEPA process for the project, including preparation of the Draft and Final EIS as third-party contractor to the Federal Energy Regulatory Commission and facilitated interactions with PGE and the FERC regarding relicensing issues. Led the interaction among cooperating agencies in the NEPA process including US Forest Service and BLM. Provided technical expertise within working groups and facilitated coordination among natural resource trustees on ecological issues. Key issues included the effects of the project on wildlife and habitat, threatened and endangered plant and animal species, habitat loss, habitat connectivity/ fragmentation and wildlife movement, and establishment and spread of exotic species. Collaborated on preparation of a Vegetation Management Plan, Invasive and Exotic Species Management Plan, and Threatened and Endangered Species Management Plan.

Environmental Impact Statement for the New York Power Authority-FDR Power Project. Massena, NY. Technical leader for terrestrial vegetation and wildlife sections of the EIS related to the proposed relicensing of the FDR hydroelectric power project. The EIS was prepared to meet federal NEPA and New York SEQRA standards and requirements. During the five year relicensing process, Ms. Tims provided technical expertise within working groups and facilitated coordination among natural resource trustees on ecological issues. Key issues includes the effects of the project on wildlife and habitat, threatened and endangered plant and animal species, habitat loss, habitat connectivity/ fragmentation and wildlife movement, and establishment and spread of exotic species. Facilitated interactions with NYPA, NYSDEC, and USACE.

Business and Biodiversity Offsets Program (BBOP). Ms. Tims is currently providing biodiversity expertise in an advisory group that is developing a standardized approach for identifying, developing, and implementing biodiversity offsets for projects with unavoidable adverse impacts on biodiversity. Advisory group members include corporate representatives, academic scientists, representatives of environmental NGOs, US state and federal regulators, and international government representatives. The group is currently developing a protocol and a set of tools for determining when an offset is appropriate and defining the scope and nature of appropriate offsets. Efforts are also focused on implementation and long term management and protection strategies for biodiversity offsets and the possibility of aggregating offsets into national or global protected areas management system aimed at specific conservation priorities.

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Benjamin Sussman, AICP

Mr. Ben Sussman is a consultant with ERM based in Annapolis, Maryland, US. He has more than seventeen years' experience in impact assessment and transportation planning for local and state governments across the United States, as well as mines, pipelines, and other major infrastructure projects in Africa, Europe, and North and South America.

As a transportation planner, 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.

As an impact assessment specialist, Mr. Sussman also evaluates the transportation, socioeconomic, land use, recreation, and visual impacts of proposed energy, mining, and other industrial projects. His experience in the United States includes third-party analyses to meet NEPA, CEQA, and other state-equivalent requirments. Mr. Sussman also oversees large public comment management processes for these projects. His international experience focues on IFC-compliant Environmental and Social Impact Assessments in Africa and South America.

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.

Professional Affiliations & Registrations
- American Institute of Certified Planners (2003)
- American Planning Association

Fields of Competence
- Transportation planning
- NEPA, CEQA, and other state-equivalents
- IFC-compliant Environmental and Social Impact Assessments (ESIA, ESHIA, EIS)
- Socioeconomics
- 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

Languages
- English, native speaker
- French, proficient
- Spanish, basic

Key Industry Sectors
- Government
- Mining
- Oil and Gas
- Transportation
- Government

Key Projects

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.

Skagit County, Washington, Environmental Impact Statement for Tesoro Anacortes Clean Projects Upgrade Project, Anacortes, WA, Ongoing.
Marine Transportation subject matter expert for a State Environmental Policy Act-compliant EIS, evaluating the impacts of the proposed upgrades to Tesoro's existing refinery near Anacortes. The project would add new vessel traffic to the heavily-used Puget Sound region, and could also increase the risk of spills and other marine casualty events.

ESIA, St. Vincent Geothermal Project (Phase 1), St. Vincent and the Grenadines. IDB, 2016.
Prepared the transportation and visual impacts sections of an IFC-compliant ESIA, evaluating the exploratory drilling phase of proposed geothermal energy development on the slopes of St. Vincent Island's *La Soufrière* volcano. Evaluated baseline traffic/road and aesthetic conditions, as well as the likely impacts from drilling activity, including vessel-delivered materials and heavy truck activity on the island's Windward Highway.

ESMP Review, Lekki Port, Nigeria. 2016.
Reviewed the Traffic and Safety Management Plan—a component of the Master Environmental and Social Management Plan for the proposed Lekki container port in Nigeria. Ensured that the plan met lender standards and adhered to international best practice for traffic operations and transportation safety practices.

Transportation Study for Proposed Mine, Confidential 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 transportation facilities and activities. Developed traffic study procedures and supervised traffic data collection and analysis.

Transportation Study, Confidential Oil and Gas Client, Albania, 2015.
Responsible for development of a traffic study (to be incorporated into an IFC-compliant ESIA) documenting existing and likely future traffic and transport safety condtions associated with construction and development of a proposed petroleum field in the central portion of the country.

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 mitigation measures.

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.

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. Conducted an in-country evaluation of the haul route, and interviewed internal stakeholders.

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.

Noam Raffel

Noam recently joined ERM after completing his Master's degree in GIS at Clark University. 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

Relevant Experience:

In his short time at ERM Noam has helped in various projects whether it has been the creation of data intensive suitability and sensitivity models, on the fly maps, georeferencing maps, developing efficient methods for data collection, or working on greater projects listed below.

Nicaragua Canal Project (HKND) – Nicaragua October 2014-ongoing

ERM has been 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, Jan 2015 – Feb 2015

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, March 2015 -ongoing

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, March 2015- Ongoing

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 Nov 2014

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 Summer 2013

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 Summer 2013

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 .

Erin Rykken

Ms. Erin Rykken is a Senior Technical Editor with ERM based in Livingston, Montana. She has 12 years of technical editing and writing experience and has spent the last 6 years with ERM performing a wide array of document editing, formatting, and publishing duties.

Ms. Rykken's specialized training includes reference librarianship, with an emphasis on academic research and government information. This background affords her a strong understanding of research methodologies and the best practices for assuring relevant and comprehensive information retrieval from a variety of resources.

While a majority of Ms. Rykken's time is spent on large document production, such as the Keystone XL SEIS, she also supports numerous smaller projects by applying her skills to report documents, letters and memos, data QA/QC, proposals, and SOQs.

Professional Affiliations & Registrations
- American Library Association

Fields of Competence
- Technical writing and editing
- Research and reporting
- Document formatting and print production

Education
- Master of Library Science, Indiana University, 2009
- M.A. English Literature, Boise State University, 2004
- B.A. English, University of Wisconsin—Green Bay, 2000

Languages
- English, native speaker

Key Industry Sectors
- Government
- Mining
- Oil and Gas
- Power

Key Projects

Draft Programmatic Environmental Impact Statement, Confidential Client, 2015-2016.
The multi-volume EIS was developed for a nationwide wireless broadband network dedicated to public safety. In addition to document editing and production, developed reference tracking, verification, and coordination procedures for all authors across all resource areas and geographical locations.

Canal de Nicaragua Environmental and Social Impact Assessment, HKND Group, 2014-2015.
Developed extensive reference tracking, verification, and coordination procedures for a large team developing an ESIA for the construction and operation of the Nicaragua Canal in Central America.

NorthMet Mining Project and Land Exchange Environmental Impact Statement Public Comment Processing, Minnesota Department of Natural Resources, 2014-2015.
Assisted with the processing of lengthy, substantive comments. Tasks involved reading full submittals,—some as long as 80 pages--and retrieving the most substantive and representative comments, entering and coding comments within the master database, and providing QA/QC of the data entry to ensure consistency/accuracy.

NorthMet Mining Project and Land Exchange Environmental Impact Statement, Minnesota Department of Natural Resources, 2012-2016.
In addition to editing, formatting, and production support, managed all aspects of author-cited materials in support of a large team developing an EIS for the construction and operation of the mine. Worked with project management and the client to coordinate the delivery of the 1,500-page impact assessment.

Keystone Pipeline National Interest Determination - Comment Processing, U.S. Department of State, 2014.
Assisted with the processing of over 2 million comments. Tasks involved reading full submittals and retrieving substantive comments, entering and coding comments within the master database, and providing QA/QC of the data entry to ensure consistency/accuracy.

Keystone Supplemental Environmental Impact Statement Technical Editing and Production, U.S. Department of State, 2012-2013.
Provided document coordination services, including technical editing and formatting. Improved the SEIS document template to ensure consistency throughout the document writing process, which involved 40+ contributors writing from offices across the United States and culminating in a multi-volume final product. Ensured text was readable/appropriately written for the general public and that all data and general information was presented with appropriately cited sources of information.

Environmental and Social Impact Assessment (ESIA) - Stage 1 and 2, Confidential Mining Company, 2012-2013.
Provided document editing and formatting services for company involved in a high profile and highly controversial new mine site development. Conducted professional reference/citation verification, sentence-level edits for audience readability, and final document print layout/pdf production.

Sampling and Analysis Plan & Baseline Assessment and Monitoring Plan Development, Confidential Oil and Gas Client, Wyoming, 2010.
Provided document coordination and editorial review for two 500+ page documents. Coordinated the writing and research efforts of 10+ staff from five different office locations. Ensured readability and uniform presentation of the documents' numerous sections, figures, tables, and corresponding appendices.

EMS Training Manual Development Support, Confidential Mining Client, 2011-2013.
Responsible for editing and formatting two Environmental Management System training guides. Ensured consistency between User Guide and Administrator Guide for both language use and overall visual aesthetics. Ensured documents met client-specific training template guidelines and provided quality review for Spanish translations.

Operations, Safety, and Maintenance (OSM) Manual Updates, Confidential Mining Company, 2012-2016.
Developed a document template that adhered to the Mining Association of Canada's (MAC) OSM Manual Guidelines for use at all client facilities going forward. Tasks included updating, editing, and reformatting existing manuals, and writing/creating manuals for new facilities.

NPS CSM Work Plan, and Report Editing and Formatting, National Park Service, 2010-2013.
Collaborated with numerous staff to compile, edit, and format a variety of Contaminated Site Management (CSM) work plans and reports for the National Park Service (NPS) in Alaska.

Culvert Inspection and Fish Passage Assessment Training Manual, BPXA, 2011-2013.
Assisted in the development of "accessible" text for a culvert inspection and fish passage assessment training manual whose intended audience was not necessarily familiar with scientific terminology or methods. Provided formatting and editing services, in addition to overseeing and ensuring quality of final electronic and print production.

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<u>HANCE THOMPSON</u>

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.

CURRICULUM VITAE

Arq. NOELIA ARISPE ARISPE

Mayo 2016

INFORMACIÓN PERSONAL

Noelia C. Arispe Arispe
Cédula de Identidad Nº: V-3.885.344
Estado civil: Casada
Nacionalidad: Venezolana
Lugar de nacimiento: Barquisimeto – Estado Lara
Dirección: Calle Sta. Isabel, Qta. Curarí, Sta. Fe Norte. Caracas 1080.
Teléfonos 0212--979.53.25 / 0414--8132385
Correo electrónico: naa1011@yahoo.es / naa1011@gmail.com

FORMACIÓN PROFESIONAL

ESTUDIOS DE POST- GRADO

1978 – 80: Architectural Association School of Architecture, University of London - Londres – Inglaterra

Curso: Planificación del Desarrollo Nacional, Regional y Urbano

Título obtenido: Diploma Honnus y Master

ESTUDIOS DE PRE-GRADO

1969 – 1975: -Universidad Central de Venezuela – Facultad de Arquitectura y Urbanismo - Caracas – Venezuela

Título obtenido: Arquitecto

ALGUNOS CURSOS REALIZADOS

- Introductorio del Desarrollo Urbano y Regional / Centro de estudios del Desarrollo, CENDES-UCV / 1976.
- Idioma Inglés / Instituto Venezolano-Británico /1977-1978.
- Idioma Inglés / International House - Londres Inglaterra / 1978.
- Formación de Instructores / Instituto Nacional de la Vivienda INAVI / Caracas, 1981.
- Curso General de Planificación /CORDIPLAN, Programa RH-Sinaplan / 1982.
- Idioma Italiano / centro Cultural Venezolano-Italiano/ 1982.
- Idioma Italiano / Escuela de Idiomas de la F.F.A.A. / 1986 – 1987

- Vialidad y Terraceo en Desarrollos Habitacionales / Instituto Nacional de la Vivienda INAVI /Caracas, 1986.
- Revisión y Evaluación de Estudios de Impacto Ambiental /MARN-CIARA/ 1992.
- Organización, Planificación y Marketing de los Atractivos Turísticos Naturales / CORPOTURISMO – OEA /Caracas, 1993.
- Desarrollo Sustentable / MARN /Caracas, 1994.
- Informática a Nivel Gerencial /Instit. Hispano de Informática / Caracas, 1996.
- Auditorias Ambientales / MARN /Caracas, 2000.
- Sistemas de Gestión Ambiental Bajo Stand ISO 14.000 / MARN / 2000.

EXPERIENCIA PROFESIONAL

- **2014 - Gecoplan, S.A.**
  Consultoría Ambiental y Urbana
- **2013 FII-CPDI**
  Asesoría Ambiental
- **2009—2013 Proconsult C.A.**
  Consultoría Ambiental
- **2007-- 2010 Ecodipla Consultores, C.A.**
  Consultoría Ambiental y Urbana
- **2006-- 2007 Gecoplan, S.A.**
  Consultoría Ambiental y Urbana
- **2002-- 2007 Ecology and Environment, S.A.**
  Consultoría Ambiental
- **2000 ARMO Estudios y Proyectos, C. A.**
  Desarrollo Urbano y Regional, Planificación Ambiental y Planificación en general
- **1998 –2000 Ministerio del Ambiente y de los Recursos Naturales (MARN)**
  Dirección General de Planificación y Ordenación del Ambiente (DGPOA)

  Cargo desempeñado: Directora de la Oficina de Coordinación de Proyectos Especiales
- **1988 – 1998 MARN - Dirección General de Planificación y Ordenación del Ambiente (DGPOA)**

Dirección de Ordenación del Territorio

Cargo desempeñado: Planificador Jefe

- **1981 - 1988 Instituto Nacional de la Vivienda (INAVI)**
  Gerencia de Planificación y Presupuesto

  Cargo desempeñado: Arquitecto Jefe III

- **1977 – 1978 MINDUR - Dirección General de Planificación Urbanística**
  Dirección de Estudios Urbanos

  Cargo desempeñado: Arquitecto III

- **1975 – 1977 MOP - Dirección de Planeamiento Urbano**

  División Región Los Andes
  Cargo desempeñado: Arquitecto I

ACTIVIDADES MAS IMPORTANTES A NIVEL PROFESIONAL

- Coordinación del Estudio: **"Desarrollo Urbano Regional de la Región Sur-Oeste Andina"**, trabajo realizado en la Dirección de Planeamiento Urbano del Ministerio de Desarrollo Urbano (MINDUR) durante los años 1977–1978

- Participación en la elaboración de los **planes de Desarrollo Urbano**, para las ciudades de la Fría, San Antonio, Aguas Calientes y San Juan de Colón realizado en la Dirección de Planeamiento Urbano del Ministerio del Desarrollo Urbano (MINDUR), durante los años 1975 – 1978.

- Elaboración de los **Programas de áreas, para Viviendas de Interés Social**, localizadas en las ciudades de Guasdualito, Santa Rosalía, Barbacoas, Altagracia de Orituco, Cantaura, Cumaná, Ciudad Losada, San Cristóbal, Clarines, Trujillo, Barinas, entre otras. Trabajo realizado para la Gerencia de Planificación y Presupuesto del Instituto Nacional de la Vivienda (INAVI) - años1981 – 1988.

- Participación en la elaboración del Proyecto de **“Normas para las Variables Ambientales Urbanas”**, para la Dirección de Planificación y Ordenación del Ambiente - Ministerio del Ambiente y de los Recursos Naturales, años 1988 a 1989.

- Participación en la elaboración del Documento Base para **las “Normas Ambientales aplicables en el Medio Rural”**, para la Dirección de Planificación y Ordenación del Ambiente - Ministerio del Ambiente y de los Recursos Naturales, durante los años 1989 – 1990.

- Coordinación Técnica en la elaboración del “**Plan de Ordenación del Territorio del Área Anaco-Maturín-Caripito”** bajo el Convenio MARNR-LAGOVEN-CORPOVEN, durante los años 1990 – 1991.

- Participación en la elaboración e implementación de diversos **Planes estadales de Ordenación del Territorio y de Áreas Bajo Régimen de Administración especial (ABRAE)**, en la Dirección de Planificación y Ordenación del Ambiente - Ministerio del Ambiente y de los Recursos Naturales, durante los años 1988 – 1998.

- **Revisión de Estudios de Impacto Ambiental (EIA) y Evaluaciones Ambientales Específicas (EAE) de proyectos de importancia nacional y regional** a ser ejecutados por empresas tales como CADAFE, EDELCA, PDVSA, SINCOR, PETROZUATA, AMERIVEN, CERRO NEGRO, BP, CANTV, entre otros, quienes tramitan la Autorización para la Ocupación del Territorio (AOT) y/o la Autorización para la Afectación de Recursos Naturales (AARN) ante el Ministerio del Ambiente y de los Recursos Naturales. Actividades realizadas en ese ministerio. Durante los años 1987 – 2000.

- **Coordinación y control de tramitaciones administrativas requeridas para obtener las autorizaciones para la ocupación del Territorio (AOT) y de Afectación de los Recursos Naturales (AARN)**. Solicitudes presentadas ante el Ministerio del Ambiente y de los Recursos Naturales para desarrollar proyectos caracterizados como de importancia nacional y de importancia regional. Actividades realizadas en la Oficina de Proyectos Especiales adscrita a la Dirección General de Planificación y Ordenación del Ambiente (DGPOA) - Ministerio del Ambiente y de los Recursos Naturales (MARN). Durante los años 1998 – 2000.

- Realización de los **“Aspectos Ambientales correspondientes al Plan de Manejo del Parque Metropolitano Vicente Emilio Sójo en Caracas”,** para FUNDACOMUN. Mayo-Agosto 2001.

- Realización de los **“Aspectos de Dinámica Espacial, Sistema de ciudades y Jerarquización de Centros Poblados”**, como apoyo al Proyecto Planta de Generación Térmica para la Empresa Termoyaracuy C.A. en la Consultora Ingeniería Piasa - Mayo 2002.

- Participación en la elaboración del Estudio de Impacto Ambiental del Proyecto: **“Campo de Desarrollo Pedernales**”, en la Empresa Ecology and Environment, S.A., para la Empresa PERENCO PETROLEOS, Año 2002.

- Elaboración del **“Documento Síntesis Estudio de Impacto Ambiental del Proyecto Complejo Criogénico de Occidente, ULE”,** Estado Zulia, en la Empresa Ecology and Environment S.A., para PDVSA, Años 2002-2003.

- Participación en la elaboración del Estudio de Impacto Ambiental y Socio Cultural (EIASC) del **“Proyecto Plataforma Deltana, Bloque 4”,** en la Empresa Ecology and Environment, S.A. para la Empresa petrolera STATOIL Venezuela, Año 2003-2004.

- Participación en **el “Estudio de Prefactibilidad para la Localización de una Planta Turbogas”** en el Estado Anzoátegui con la Empresa INELMECA, C.A. para EDELCA, Año 2.004.

- Participación en la formulación del Proyecto **“Desarrollo Sustentable de la Actividad Pesquera en el Nororiente de Venezuela”,** elaborado en la Empresa Ecology and Environment, S.A. para la Empresa Petrolera STATOIL Venezuela, Años 2004-2005.

- Participación en la elaboración del Estudio de Impacto Ambiental y Socio Cultural (EIASC) del Proyecto **“Autopista de los Llanos Centrales”,** en la Empresa Ecology and Environment, S.A. para la Fundación Fondo de Transporte Urbano (FONTUR), adscrito al Ministerio de Infraestructura (MINFRA) Años 2005-2006.

- Elaboración del estudio **“Plan Específico de Permisos Ambientales” en el contexto del desarrollo del Proyecto Libertador a ubicarse en el Complejo Jose**, estado Anzoátegui, en la Empresa Ecology and Environment, S.A. para, para Pequiven, S.A. - Año 2006
- Participación en la elaboración de la **“Auditoria Ambiental Fase I de la parcela Fertilizantes II, Proyecto Libertador”,** en la Empresa Ecology and Environment, S.A. para , para Pequiven, S.A. - Año 2006.

- Participación en la elaboración del Estudio de Impacto Ambiental y Socio Cultural (EIASC) del Proyecto**: “Acondicionamiento de las parcelas Jose norte y Jose sur, Urbanismo industrial en el Complejo Petroquímico Anzoátegui”** en la Empresa Ecology and Environment, S.A., para Pequiven, S.A. - Año 2007.

- Coordinación de la elaboración de tres Estudios de Impacto Ambiental y Socio Cultural (EIASC) para los Proyectos: **“Perforación de Pozos estratigráficos en el Bloque 1”, “Perforación de Pozos estratigráficos en el Bloque 2” y “Perforación de Pozos estratigráficos en el Bloque 3”,** todos ubicados en el Área Junín de la Magna Reserva, elaborados en la Empresa Ecology and Environment, S.A. para PDVSA-CVP, bajo Convenio CPDI, Años 2006-2008.

- Participación en la elaboración del Estudio **“Identificación de la Estructura actual del Sistema de Centros Poblados, comandados por Ciudad Guayana, Estado Bolívar “**, en la Empresa GECOPLAN, & Asociados, C.A, para el MINFRA, año 2006.

- Participación en la elaboración de los **Estudios Preliminares correspondientes al Environmental, Social and Health Impacts Assessment (ESHIA) del “Proyecto Delta Caribe”,** en Ecology and Environment, S.A, para la empresa CHEVRON, Año 2007.
- Participación en la elaboración del Estudio **“Identificación de la Estructura Actual del Sistema de Centros Poblados, comandados por el eje urbano Barcelona-Puerto La Cruz, Estado Anzoátegui**“, en la Empresa GECOPLAN, & Asociados, C.A, para el MINFRA, año 2007.

- Participación en la elaboración del **Estudio "Visualización preliminar de la Planificación y Gestión del Territorio de la Faja Petrolífera del Orinoco"** en la empresa Ecodipla Consultores C.A. para PDVSA-CVP. Año 2008.

- Participación en la elaboración del Estudio **"Plan de Ordenamiento y Reglamento de Uso (PORU) de la Zona de Interés Turístico, Estado Vargas y Estado Miranda", en la empresa** Grupo CONAHOL, S.C. para el MINTUR. Años 2008-2009.

- Participación en la elaboración del Estudio de Impacto Ambiental y Socio Cultural (EIASC) del Proyecto: **"Sistema de Recolección de Aguas Residuales en el eje El Consejo-Sabaneta, estado Aragua",** en la Empresa Proconsult, C.A, para HIDROVEN - Año 2009-2010.

- Participación en la elaboración del Estudio de Impacto Ambiental y Socio Cultural (EIASC) del Proyecto**: "II Etapa para Educación Básica y Diversificado del Liceo Agroecologico, Escuela Canaima"**, en la Empresa Proconsult, C.A, para la Fundación CANAIMA - Año 2009-2010.

- Participación en la elaboración de la Evaluación Ambiental del Proyecto **"Ola Cruises",** específicamente en los Aspectos Socio-Económicos y Culturales, en la empresa Ecodipla Consultores C.A. para la empresa Servicios Acuáticos de Venezuela Saveca C.A. Año 2009.

- Participación en "**Estudio de Opciones de Localización y Evaluación Socio-Ambiental preliminar de los sitios preseleccionados para desarrollar una refinería en Haití"**, en la empresa PCI Ingenieros Consultores S.A, para PDV Caribe – Año 2009-2010.

- Participación en la elaboración del Estudio de Impacto Ambiental y Socio Cultural (EIASC) para el **Proyecto diseño y construcción de arquitectura preliminar y avanzada de un conjunto de unidades habitacionales y sus servicios complementarios, infraestructura, urbanismo y demás obras civiles**, ubicado en el sector Yucatán parroquia Tamaca, municipio Iribarren del estado Lara, en la Empresa Proconsult, C.A, para la empresa Kayson C.A, año 2012.

- Participación en la elaboración del Estudio de Impacto Ambiental y Socio Cultural (EIASC) para el **Proyecto diseño y construcción de arquitectura preliminar y avanzada de un conjunto de unidades habitacionales y sus servicios complementarios, infraestructura, urbanismo y demás obras civiles**, ubicado al sur de la ciudad de Valencia, en el municipio Valencia del estado Carabobo, en la Empresa Proconsult, C.A, para la empresa Kayson C.A, año 2012.

- Elaboración del Estudio de Impacto Ambiental y Sociocultural para el **Proyecto Construcción de Vivienda Unifamiliar Casa Velasco**, ubicado en la Urb. La Lagunita Country Club, municipio El Hatillo, Estado Miranda, para la empresa Desarrollos VINCIPEOPLE C.A, año 2012.

- Participación como asesora y control de calidad en la elaboración del Estudio de Impacto Ambiental y Socio Cultural (EIASC) del proyecto denominado **"Modificación del Segmento 2 del Sistema del Cable de Fibra Optica Atlántica I/ Globenet (Segmento 2.3)",** para la empresa Brasil Telecom de Venezuela, S.A.- Mayo 2013.

- Participación como asesora en el **Proyecto "Servicios Profesionales en la elaboración de estudios ambientales correspondientes a la fase de Producción Temprana en la Faja Petrolífera del Orinoco"**, en el Instituto de Ingeniería, Centro de Procesamiento de Imágenes Satelitales (FII-CPDI) – desde el Año 2011.

- Participación y asesoramiento en el Estudio de Impacto Ambiental y Sociocultural (EIASC) para el **Proyecto Sistema Metrocable Mariche Tramo Local, Línea LB2",** elaborado en la **Empresa Gecoplan C.A para C.A. Metro de Caracas / Constructora Odebrecht, S.A.** desde Abril 2014.

- Participación en la en la elaboración de la **Caracterización y Diagnóstico de la situación actual en las ubicaciones de ocho (8) almacenes de CORPOELEC**, localizados en diversos estados del país, en la **Empresa ADR3 C.A.-VITAAMBIENTE C.A. para la empresa Corpoelec,** desde Octubre 2014 a Mayo 2015.

- Elaboración de la **Actualización de los Costos de las Medidas Ambientales propuestas en el Estudio de Impacto Ambiental y Socio Cultural del año 2008,** correspondiente al Proyecto **"Mantenimiento Correctivo del Sistema de Cable Submarino Internacional de Fibra Optica "Atlántica I" en Aguas Territoriales**

Venezolanas”. Addendum preparado para la empresa **Globenet Cabos Submarinos Vzla, S.A,** Noviembre 2015.

- Participación en la elaboración del Estudio de Impacto Ambiental y Socio Cultural (EIASC) para el **Proyecto Perforación Direccional para Cable Submarino**, localizado en el estado Vargas, en la Empresa Proconsult, C.A, para la empresa **Globenet Cabos Submarinos Vzla, S.A,** años 2015-2016.

- Servicios Profesionales para desarrollar actividades inherentes al proceso de obtención **de Permisos y Autorizaciones No Ambientales para el Proyecto Perforación Direccional y Sustitución de Tramos en Segmentos 2 y 3 del Cable Submarino Atlantica-1 (Venezuela), con** la empresa **Globenet Cabos Submarinos Vzla, S.A,** desde Febrero 2016.

- **Elaboración, coordinación, evaluación y asesorías de Proyectos de planificación y desarrollo a escala urbana, regional y nacional, Planificación ambiental y evaluaciones ambientales.** Actividades permanentes de Consultoría y Asesoría Individual.

ALGUNOS TRABAJOS REALIZADOS EN EL ÁMBITO ACADÉMICO

“Diseño Urbano en el Sector de Sabana Grande – El Rosal”

UCV, años 1973 a 1974 Tesis para optar al Título de **Arquitecto** en la Universidad Central de Venezuela.

“Polos de Desarrollo en Venezuela”

Londres, Inglaterra, Architectural Association (A.A), años 1978 a 1979, para optar al **Diploma Honus.**

“Desequilibrios Regionales en Venezuela”

Londres, Architectural Association, (A.A) años 1971 a 1980, para optar al Título de **Maestría en Planificación Nacional, Regional y Urbana**

IDIOMAS

INGLÉS E ITALIANO

Respaldos a disposición

HEMA DAVID

Date of Birth: June 24, 1982

Nationality: Citizen of Trinidad and Tobago

Current Post: Environmental Scientist
Ecoengineering Consultants Limited

Ms. Hema David is an Environmental Scientist and holds a Master of Science Degree in Biodiversity Conservation and Sustainable Development in the Caribbean from the University of the West Indies. She has in preparing Certificate of Environmental Clearance (CEC) Applications for various projects, including industrial projects. She also has experience in monitoring the Health, Safety and Environmental (HSE) performance of contractors during the construction phase of a highway extension, road rehabilitation works and an industrial estates. She has conducted noise, air quality , water quality and soil contamination monitoring, as well as worked on several Environmental Impact Assessments (EIAs), Environmental Management Plans, Environmental Audits and other Environmental Studies. In addition to her work in Trinidad and Tobago, Hema has undertaken assignments in Grenada, St. Vincent, St. Lucia, St. Kitts and Nevis, Dominica, Guyana and Suriname.

EDUCATION

M.Sc. Biodiversity Conservation and Sustainable Development in the Caribbean, University of the West Indies, St. Augustine (2014)

B.Sc. Environmental and Natural Resource Management, University of West Indies, St. Augustine (2009)

Associate Degree Environmental Management, College of Science, Technology and Applied Arts of Trinidad and Tobago (2004),

COMPUTER LITERACY

Working knowledge of Microsoft Office, Word Perfect, and Adobe Acrobat

TRAINING

- Point Lisas Energy Association (PLEA) of Upstream Operators Safety Training (2015)
- Standard Workplace First-Aid / C.P.R / A.E.D. (16hr) (2015)
- Tropical Further Offshore Emergency Training (2014)
- Accident Investigation (2013)
- Defensive Driving (2010)
- Supervisory Management (2009)
- Open Water Diver (PADI) (2007)
- Occupational Health and Safety for General Industry (30 hr) (2005)

EMPLOYMENT RECORD

Jan 2009 - Present	Environmental Scientist, Ecoengineering Consultants Limited
June 2008 - Jan 2009	Environmental Scientist (Trainee), Ecoengineering Consultants Limited
June 2007 - August 2007	Health and Safety Technician, Ecoengineering Consultants Limited
June 2005 - August 2006	Health and Safety Technician, Ecoengineering Consultants Limited.

WORK EXPERIENCE

Certificates of Environmental Clearance

2016	Environmental Scientist, Establishment of a Housing Development in Maracas, St. Joseph
2014	Environmental Scientist, Expansion of a Golf Course in Chaguaramas
2013	Study Manager, The Establishment of a Methanol Tank in Point Lisas
2013	Environmental Scientist/Assistant Study Manager, Proposed Residential Development in Endeavour, Chaguanas
2012	Environmental Scientist, Development of an Ammonia/Urea Facility in Point Lisas
2012	Environmental Scientist, CEC Application for the Establishment of a Town Centre in Sangre Grande
2011	Environmental Scientist, CEC Application for Site Preparation Works for a 45 ha site in Point Lisas
2008	Environmental Scientist, CEC Application for Reconditioning of Berth 3 and Change in Pipeline Route for an Ethanol Dehydration Plant at Petrotrin, Pointe-a-Pierre
2008	Environmental Scientist, CEC Application for expansion of an Ethanol Dehydration Plant at Petrotrin
2005	Technician, CEC Application for Proposed Housing Development at Felicity, Chaguanas

Environmental Monitoring

2016	Environmental Scientist, Salinity Profiling (Water and Soil) as part of a Drainage Study in South Oropouche
2016	Environmental Scientist, River Water Quality Monitoring and Benthic Ecology as part of a Limestone Quarry in Maracas, St. Joseph
2016	Environmental Scientist, Vegetation Survey at a Quarry in Matura
2013-2016	Environmental Scientist, Compliance Water Quality Monitoring and Benthic Sampling (offshore) for a Desalination Plant, Point Fortin
2015	Environmental Scientist, Air Quality Monitoring and River Quality Monitoring for a Proposed Steel Plant in La Brea
2015	Environmental Scientist, Water Quality and Sediment Sampling as part of a Port Expansion project in La Brea
2015	Environmental Scientist, Air Quality, Noise and Water Quality Monitoring as part of a Feasibility Study for Road Improvement Works in Diego Martin
2013-2014	Environmental Scientist, Compliance Water Quality Monitoring and Benthic Sampling for a Desalination Plant, Point Fortin
2014	Environmental Scientist, Sediment Sampling as part of Maintenance Dredging of a harbor in Point Lisas
2013	Environmental Scientist, Baseline Noise Monitoring for a proposed Industrial and Commercial Park in Paranam, Suriname
2007 - 2013	Environmental Scientist, Flow Characteristics of a site stream in the Point Lisas Industrial Estate
2007 - 2013	Environmental Scientist, Assessments of a Mangrove Wetland System, south-west of an Ammonia Facility in the Point Lisas Industrial Estate
2013	Marine Water Quality Monitoring near the Cooling Water Discharge Outfall of an Ammonia Complex, Point Lisas
2011-2012	Environmental Scientist, Ecological Assessments (Wetland and Terrestrial) south-west Tobago.
2012	Environmental Scientist, Monitoring of Thermal Effluent from a Power Station into Invaders Bay, Port of Spain.

2011	Environmental Scientist, Floral and Faunal Studies in the Guayaguayare Block
2011	Environmental Scientist, Ecology Survey for Site Preparation Works at a 41.5 ha Site in Point Lisas
2010	Environmental Scientist, Marine Baseline Monitoring in the Guayaguayare Block (Water and Sediment Quality and Benthic Macrofauna)
2009-2010	Environmental Scientist, Air and Noise Monitoring for a Rail System
2008 - 2010	Environmental Scientist, Compliance Monitoring for a Technology Park, Wallerfield
2008 -2010	Environmental Scientist, Particulate Matter (PM10) Monitoring at an Ammonia Complex, Point Lisas
2008	Environmental Scientist, Noise Monitoring at a Heliport, Couva
2007	Technician, Environmental Investigation (sub surface contamination survey) at three Service Stations in Tobago
2006	Technician, Air and Noise Monitoring at a Proposed Mall Complex in Sangre Grande

<u>Health and Safety Inspections</u>

2015-2016	Environmental Scientist, Undertaking HSE Inspections as part of Slope Stabilization Works, South Oropouche.
2008 - 2010	Environmental Scientist / Health and Safety Technician, undertaking inspections at Tamana Intech Park, Wallerfield
2005 - 2009	Health and Safety Technician, undertaking inspections on National Highways Program - Year III Roads Rehabilitation Packages 1 & 2
2005 - 2006	Health and Safety Technician, undertaking inspections on the extension of the Diego Martin Highway

Environmental Management and Related Plans

Present	Environmental Scientist, Best Management Practices Plan as part of a Water Pollution Permit for an Ammonia Facility in Point Lisas
Present	Environmental Scientist, Rehabilitation Plan for a Quarry in Matura
2015	Environmental Scientist, Environmental Management Plan for Improvement Works to the Diego Martin Highway / Western Main Road Intersection and Related Improvements
2014	Environmental Scientist, Environmental Management Plan, Erosion & Sediment Management Plan and Stormwater Management Plan for the establishment of a Fruit and Vegetable Crop Farm and Energy Services Facility at the Picton IV Estate, Debe
2013	Environmental Scientist, Environmental and Social Management Plan for the establishment of an Industrial and Commercial Park, Paranam, Suriname
2013	Assistant Study Manager, Environmental Management Plan for the Establishment of a Dam/Reservoir in Cumuto, Trinidad
2013	Environmental Scientist, Environmental Management Plan for the Establishment of a Port in Montserrat
2013	Environmental Scientist, Conceptual Erosion and Sediment Management Plan for the Establishment of a Science City, Couva
2012	Environmental Scientist, Dredge Spoil Sampling Plan as part of maintenance dredging of a harbor in Point Lisas
2012	Environmental Scientist, Air Quality Monitoring Plan for an Ammonia/Urea Complex in Point Lisas
2012	Environmental Scientist, Mangrove Replanting Plan for the development of an Ammonia/Urea Complex in Point Lisas
2012	Environmental Scientist, Stormwater, Sediment and Erosion Management Plan for the development of a Town Centre in Sangre Grande
2012	Environmental Scientist, Conceptual Environmental Management Plan for a Hotel and Residential Development at Londonderry, Dominica
2012	Air and Noise Monitoring Plans for various segments of the Point Fortin Highway Extension

2011-2012 Environmental Scientist, Flood, Water Quality and Sediment Management Plans for various segments of the Point Fortin Highway Extension

2010 Environmental Scientist, Conceptual Acquisition Plan for the Upgrade and Development of the Southern Main Road, from Paria Suites to St. Mary's Junction

2009 Environmental Scientist, Emergency Response Plan for the Community Roads Improvement Project for Regions 3, 4, 5 and 6, Guyana

Environmental Audits

2012 Environmental Scientist / Health and Safety Technician, Environmental Health and Safety Compliance Audit for Air Quality Monitoring at an Ammonia Facility in Point Lisas

2010 Environmental Scientist, Environmental, Health and Safety Compliance Audit at Lowman's Bay Power Station, St. Vincent and the Grenadines

Environmental Impact Assessments

Present Environmental Scientist, EIA for a proposed Limestone Quarry at Cuarita Estate, Maracas, St. Joseph

2015 Environmental Scientist, Draft EIA for Proposed Slope Stabilization Works at Belle Isle and Coull's Hill, St. Vincent.

2014-2015 Environmental Scientist, Draft EIA for Proposed Slope Stabilization works at Nine Sites in St. Vincent.

2014 Assistant Study Manager, EIA for the Establishment of a Fruit and Vegetable Crop Farm and Energy Service Facility in Debe.

2013 Assistant Study Manager, EIA for the Establishment of an Ammonia/Urea/Melamine Complex in Point Lisas

2012 Environmental Scientist, EIA for the drilling of Exploratory Wells in the Mayaro/Guayaguayare Block (Onshore)

2012 Environmental Scientist, EIA for the Mining of 209 acres of Sand and Gravel at Pine Road, Matura

2012	Environmental Scientist, EIA for the Drilling of Seven (7) Exploratory Wells (Onshore and Offshore) in the Guayaguayare Block
2010	Environmental Scientist, EIA for Exploratory Drilling of Three (3) Wells in Block 2(ab) Offshore the East Coast of Trinidad
2010	Environmental Scientist, EIA for Upgrade and Development of the Southern Main Road from Paria Suites to St. Mary's Junction
2010	Environmental Scientist, EIA for a Wind Turbine at Rosalie Bay Nature Resort, Dominica
2008	Environmental Scientist, EIA for a Road Tank Wagon Loading Facility at Pointe-a-Pierre
2008	Environmental Scientist, EIA for the Clearing and Grading of 7.5 ha of Land at Acono Road in Maracas Valley, St. Joseph
2007	Technician, EIA for 8" Natural Gas Pipeline to Diamond Vale Industrial Estate
2007	Technician, EIA for Establishment of a 152 mm Diameter Gas Pipeline to the Tamana In-Tech Park, Cumuto Along With Upgrade of a 50mm Diameter Gas Pipeline to the Unicell Plant, O'Meara Industrial Estate, Arima.
2007	Technician, EIA for the Extraction and Processing of Sand from Quarry Operations at Toco Main Road, Matura
2007	Technician, EIA for a Sulphuric Acid Regeneration Unit, Road Tank Wagon Loading Faciltiy, Off site Feed and Production Systems, Propylene / Butylene Alkalation Unit and Continuous Catalyst Regeneration Platforming Unit
2006	Technician, EIA for Science and Technology Park at Wallerfield
2006	Technician, EIA for Gas to Liquids Plant at Point-a-Pierre
2006	Technician, EIA for Princes Town to Mayaro Highway
2006	Technician, EIA for various segments of the Point Fortin Highway - Golconda to Debe, Debe to Mon Desir Segment and St. Mary's to Point Fortin Segments
2005 - 2006	Technician, EIA for HFO Power Plant in Suriname

Other Environmental Studies

Present	Environmental Scientist, Detailed Assessment of Impacts to the Natural Environment as part of a Flood Mitigation and Integrated Watershed Management Project in the South Oropouche River Basin
2016	Environmental Scientist, Coastal Mapping of the Southern, Eastern and Northeastern Coastline of Trinidad and Southern and Northeastern Coastline of Tobago
2016	Environmental Scientist, Desktop Survey and Reconnaissance of Baseline Vegetation Types and Associated Fauna within the South Oropouche Drainage Basin
2015	Environmental Scientist, Environmental Evaluation Report for Improvement Works to the Diego Martin Highway / Western Main Road Intersection and Related Improvements
2014	Environmental Scientist, Environmental Advisory Services for the Expansion of a Golf Course in Tucker Valley
2013	Study Manager, Environmental Scoping Report for the Establishment of a Methanol Tank at Point Lisas
2012	Peer Reviewer, Preliminary EIA for the Caroni River Basin Study
2012	Environmental Scientist, Environmental Scoping Report for the Rehabilitation of several Bridges in Trinidad.
2012	Environmental Scientist. Preliminary EIA for a Hotel and Residential Development at Londonderry, Dominica
2011	Environmental Scientist, Environmental Scoping Report, for Site Preparation Works at a 41.5 ha Parcel of Land in Point Lisas
2011	Environmental Scientist, Initial Environmental Impact Assessment for the Halls of Justice Project in OECS Member Countries (Grenada, St. Vincent and the Grenadines, St. Lucia, Dominica, Antigua, Anguilla, St. Kitts, Nevis and British Virgin Islands)
2010	Environmental Scientist, Noise Abatement Study for the Yara Trinidad Ammonia Plant, Point Lisas
2010	Environmental Scientist, Social Baseline Study for the Drilling of an Offshore Exploratory Well, Suriname

2010	Environmental Scientist, Preliminary Environmental Impact Assessment for the North Oropouche Drainage Improvement Works
2009 / 2010	Environmental Scientist, Preliminary Environmental Impact Assessment for Coastal Protection Works at Four Zones along the North Coast of Trinidad
2009	Environmental Scientist, Environmental Context Report for Consultancy Services to Assist the Siparia Regional Corporation in Preparing its Spatial Development Plan
2009	Environmental Scientist, Environmental Management Plan for the Guyana Community Roads Improvement Project, Regions 3, 4, 5 & 6
2009	Environmental Scientist, Environmental Scoping Report for a Proposed Port at LABIDCO Estate, La Brea
2009	Environmental Scientist, Protected Areas System Plan for St. Kitts and Nevis
2009	Environmental Scientist, Initial Environmental Evaluation for Telesur Submarine Fibre Optic Cable, Suriname
2008	Environmental Scientist, Environmental Scoping Report for Tamana Park North Area
2008	Environmental Scientist, Soil Contamination Study at the Lube Oil Tank Farm, Petrotrin Refinery, Pointe-a-Pierre
2008	Environmental Scientist, Environmental Scoping Report for Augmentation of WA - 1 Water Supply System, Dominica
2007	Technician, Baseline Environmental and Regulatory Framework Assessment for Barbados Offshore and Coastal Areas
2007	Technician, Environmental Scoping Report - Community Development Works at Felicity, Preysal and Spring Village.
2006	Technician, Development and Regulation of Hazardous Material Road Transport System
2006	Technician, Master Plan for Southwest Peninsula
2006	Technician, Environmental Scoping Report for Aluminum Smelter at Cap-de-Ville
2005	Technician, Modelling of Hydrotest Water Discharge From Dolphin A Platform

APPENDIX C – EIA Review Checklist

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Environmental Protection Act Checklist

Environmental Protection Act Citation	Text from Environmental Protection Act	Corresponding EIA Reference
Schedule IV, Section 11, Paragraph 1	*(1) A developer of any project listed in the Fourth Schedule, or any other project which may significantly affect the environment shall apply to the Agency for an environmental permit and shall submit with such application the fee prescribed and a summary of the project including information on:-* *(i) the site, design and size of the project;* *(ii) possible effects on the environment* *(iii) the duration of the project; and* *(iv) a non-technical explanation of the project.*	• All information required in 1. (i-iv) is contained in permit application and attachment to application July 5 2016, as well as in summary posted by the EPA on January 14 2017.
Schedule IV, Section 11, Paragraph 2	*(2) Where it is not clear whether a project will significantly affect the environment, the developer shall submit to the Agency a summary of the project which shall contain the information as required by subsection (1) and the Agency shall within a reasonable period publish in at least one daily newspaper a decision with reasons as to whether the project:* *(a) will not significantly affect the environment, and thereof exempt from the requirement for an environmental impact assessment; or* *(b) may significantly affect the environment and will require and environmental impact assessment.*	• Project summary posted by the EPA on January 14 2017, and EPA issued several notices of requirement to conduct EIA and public scoping meetings in fourth quarter 2016.
Schedule IV, Section 11, Paragraph 4	*(4) Every environmental impact assessment shall be carried out by an independent and suitably qualified person approved by the Agency and shall:* *(a) identify, describe and evaluate the direct and indirect effects of the proposed project on the environmental including:* *(i) human beings;* *(ii) flora and fauna and species habitats;* *(iii) water;* *(iv) soil;* *(v) air and climatic factors;* *(vi) material assets, the cultural heritage and the landscape;* *(vii) natural resources, including how much of a particular resource is degraded or eliminated, and how quickly the natural system may deteriorate;* *(viii) the ecological balance and ecosystems;* *(ix) the interaction between the factors listed above;* *(x) any other environmental factor which needs to be taken into account or which the Agency may reasonably require to be included; and* *(b) assess every project with a view to the need to protect and improve human health and living conditions and the need to preserve the stability of ecosystems as well as the diversity of species.*	• Impacts on human beings required under 4(a)(i) of the EP Act contained in multiple subsections of Section 7.3 of EIA. • Impacts on flora/fauna, water, air and climate, cultural heritage, and ecological balance/ecosystems required under 4(a)(ii, iii, and v) of the EP Act included as subsections of Chapter 7 of EIA. • Impacts on soil and landscape required under 4(a)(iv) of the EP Act mentioned but scoped out of detailed analysis in Table 5.2 of EIA • "Material assets" addressed as required under 4(a)(vi) of the EP Act under "Economic Conditions" in Section 7.3 of EIA. • Temporal aspect of impacts impacts addressed by categorizing impacts as short term/long term and temporary/permanent as required under 4(a)(vii)of the EP Act. • Impacts on "Natural Resources" required under 4(a)(vii) of the Act assessed throughout Sections 7.1 and 7.2 of EIA • Impacts on ecological stability addressed in Section 7.2.9 as required under 4(a)(viii) of the Act. • Interaction between factors required under 4(a)(ix) of the Act assessed as indirect impacts throughout Section 7 of EIA • "Other environmental factors" not specifically required to be assessed under 4(a) of the EP Act but assessed in the EIA include oceanographic conditions, sound, and protected areas (in accordance with 4(x) of the EP Act)aspect. • Impacts on "human health" and aspects of "living conditions" required under 4(b) of the Act assessed throughout Section 7.3 of EIA • Impacts on biodiversity required under 4(b) of the Act assessed by major taxonomic group in Section 7.2 of EIA

Environmental Protection Act Citation	Text from Environmental Protection Act	Corresponding EIA Reference
Schedule IV, Section 11, Paragraph 5	*(5) Every environmental impact assessment shall contain the following information:-* *(a) a description of the project, including in particular:-* *(i) the geographical area involved, the physical characteristics of the whole project and the land-use requirements during the construction and operational phases, including plans, drawings, and models;* *(ii) the main characteristics of the production process, including the nature and quantity of the materials used, plans, drawings and models;* *(iii) and estimate, by type and quantity, of expected contaminants, residues and emissions (water, air and soil pollution, noise, vibration, light, heat, radiation) resulting from the operation of the proposed project;* *(iv) the length of time of the project.* *(b) an outline of the main alternatives studied by the developer and an indication of the main reasons for his choice, taking into account the environmental factors;* *(c) a description of the likely significant effects of the proposed project on the environment resulting from:-* *(i) the existence of the project;* *(ii) the use of natural resources;* *(iii) the emission of contaminants, the creation of nuisances and the elimination of waste, and a description by the developer of the forecasting methods used to assess the effects on the environment.* *(d) an indication of any difficulties (technical deficiencies or lack of knowledge or expertise) encountered by the developer in compiling the required information;* *(e) a description of the best available technology;* *(f) a description of any hazards or dangers which may arise from the project and an assessment of the risk to the environment;* *(g) a description of the measures which the proposed developer intends to use to mitigate any adverse effects and a statement of reasonable alternatives (if any) and reasons for their rejection;* *(h) a statement of the degree of irreversible damage, and an explanation of how it is assessed;* *(i) an emergency response plan for containing and cleaning up any pollution or spill of any contaminant;* *(j) the developer's programme for rehabilitation and restoration of the environment;* *(k) a non-technical summary of the information provided under the preceding paragraphs.*	• Discussion of AOIs in Section 5.1 of EIA describe the geographical area involved as required in 5(a)(i) of the EP Act. • Project Description in Section 2 describes physical characteristics of the Project and production processes as required in 5(a)(ii), and Project schedule as required in 5(a)(iv) of the EP Act. • Section 2.10.3 of EIA discusses wastes, contamination, etc. as required in 5(a)(iii) of the EP Act; potential impacts from radiation scoped out in Table 5.2 of the EIA. • Section 2.15 of EIA discusses alternatives as required in 5(b) of the EP Act. • Section 7 of EIA discusses significant impacts from all aspects of the Project as required in 5(c) of the EP Act. • Data gaps and studies designed to address "technical deficiencies" and "lack of knowledge" are discussed in the TOR as required in 5(d) of the EP Act, and the information provided by these studies (including the Environmental Baseline Studies, Air Quality monitoring study, and Metocean Study) is included in the appropriate subsection of Chapter 6 of the EIA. • Technology to be used on the Project is discussed broadly in terms of having been proven effective in the industry as required in 5(e) of the EP Act. • Natural hazards discussed briefly in Section 5.3 of EIA as required in 5(f) of the EP Act but scoped out of further analysis. • ESMP framework (Section 9 of EIA) and actual ESMP document discuss measures required in 5(g) of the EP Act. • Irreversibility addressed for every impact as required in 5(h) of Act as part of the impact rating process described in Section 4 of the EP EIA. • Emergency response procedures are contained within the ESMP as required in 5(i) of the EP Act. • EIA concludes that disturbed habitats (primarily seafloor habitats) will recover naturally over time as required in 5(j) of the EP Act. ESMP addresses monitoring / mitigations for ensuring residual impacts of significance that could not be mitigated are remedied, where feasible. • EIS is provided as preface to EIA provides non-technical summary as required in 5(k) of the EP Act.
Schedule IV, Section 11, Paragraph 6	*(6) Before any environmental impact assessment is begun the Agency shall at the developer's cost publish in at least one daily newspaper a notice of the project and make available to members of the public the project summary referred to in subsection (1).*	• Summary posted by the EPA on January 14 2017, and EPA issued several notices of requirement to conduct EIA and public scoping meetings in fourth quarter 2016.
Schedule IV, Section 11, Paragraph 7	*(7) Members of the public shall have twenty-eight days from the date of publication referred to in subsection (6) to make written submission to the Agency setting out those questions and matters which they require to be answered or considered in the environmental impact assessment.*	• 28 day review period for the project summary currently being administered, expires on February 10 2017.
Schedule IV, Section 11, Paragraph 8	*(8) The Agency shall after consultation with the person chosen to carry out the environmental impact assessment, set the terms and scope of the environmental impact assessment taking into account any submissions made under subsection (7)*	• EPA accepted the final TOR for the EIA on February 17, 2017 as required in paragraph 8 of the EP Act.

Environmental Protection Act Citation	Text from Environmental Protection Act	Corresponding EIA Reference
Schedule IV, Section 11, Paragraph 9	*(9) During the course of the environmental impact assessment the developer and the person carrying out the environmental impact assessment shall:* *(a) consult members of the public, interested bodies and organizations;* *(b) provide to members of the public on request, and at no more than the reasonable cost of photocopying, copies of information obtained for the purpose of the environmental impact assessment.*	• ERM conducted regional and agency sector scoping meetings during preparation of the TOR and will ensure stakeholders are appropriately engaged / consulted during the EIA process as required in paragraph 9 of the EP Act.
Schedule IV, Section 11, Paragraph 10	*(10) The developer and the person carrying out the environmental impact assessment shall submit the environmental impact assessment together with an environmental impact statement to the Agency for evaluation and recommendations and publish a notice in at least one daily newspaper confirming that the environmental impact assessment and environmental impact statement have been submitted to the agency and members of the public shall have sixty days from the date of publication of such notice to make such submissions to the Agency as they consider appropriate.*	• Notice of availability to be completed and public review period to be administered once the EIA is submitted.
Schedule IV, Section 11, Paragraph 11	*(11) The environmental impact assessment and the environmental impact statement shall be public documents and the developer and the Agency shall have such documents available for the duration of the project and five years thereafter for inspection, subject to the deletion therefrom of such information as may disclose intellectual property rights, during normal working hours at their respective offices and shall supply on request and on payment of cost of photocopying copies of such documents.*	• To be completed once the EIA is submitted.
Schedule IV, Section 11, Paragraph 12	*(12) All expenses of the environmental impact assessment process (including the preparation of the preliminary and full environmental impact assessments, the environmental impact statements, and the conduct of public hearings) shall be borne by the developer.*	• EEPGL paying required costs for EIA process.
Schedule IV, Section 11, Paragraph 13	*(13) The Agency shall submit the environmental impact assessment together with the environmental impact statement to the Environmental Assessment Board for its consideration and recommendation as to whether the environmental impact assessment and the environmental impact statement are acceptable.*	• EPA to complete once the EIA is submitted.
Schedule IV, Section 12, Paragraph 1	*(1) The Agency shall approve or reject the project after taking into account:-* *(a) the submissions made under section 11 (10) and the recommendations of the Environmental Assessment Board made under section 18 (2); and* *(b) the views expressed during the consultations under section 11 (9); and (c) the environmental impact assessment and environmental impact statement.*	• EPA to complete once the EIA is submitted.
Schedule IV, Section 12, Paragraph 2	*(2) The Agency shall publish its decision and the grounds on which it is made.*	• EPA to complete once the EIA is submitted.
Schedule IV, Section 13, Paragraph 1	*(1) A decision by the Agency to issue an environmental permit for a project shall be subject to conditions which are reasonably necessary to protect human health and the environment and each environmental permit shall contain the following implied conditions:* *(a) the Agency shall have the right to cancel or suspend the environmental permit if any of the terms or conditions of the environmental permit are breached;* *(b) the developer shall have an obligation to use the most appropriate technology;* *(c) the developer shall have an obligation to comply with any directions by the Agency where compliance with such directions are necessary for the implementation of any obligations of Guyana under any treaty or international law relating to environmental protection; and* *(d) the developer shall have an obligation to restore and rehabilitate the environment.*	• Technological alternatives are discussed in Section 2.15 and technology to be used on the Project is discussed broadly in terms of having been proven effective in the industry.
Schedule IV, Section 13, Paragraph 2	*(2) The Agency shall not issue an environmental permit unless the Agency is satisfied that:-* *(a) the developer can comply with the terms and conditions of the environmental permit; and* *(b) the developer can pay compensation for any loss or damage which may arise from the project or breach of any term or condition of the environmental permit.*	• Environmental permit, determination of compliance with terms of the permit, and determination of the ability of developer to pay compensation for loss or damage arising from the project or breach of the permit to be completed following submission of the EIA (subject to EPA's review and acceptance of the EIA).

Environmental Protection Act Citation	Text from Environmental Protection Act	Corresponding EIA Reference
Schedule IV, Section 17 Paragraph 1	*(1) Where any activity by itself does not have a significant effect on the environment but the same activity or similar activities are carried out by any person in any place and cumulatively may significantly affect the environment, the Agency shall require to be carried out an environmental impact assessment of the cumulative effects of such activities by such persons.*	• Section 8 of the EIA addresses cumulative impacts
Schedule IV, Section 17 Paragraph 2	*(3) Where an environmental impact assessment is required under this section, the procedure set out in this Part shall be followed in so far as such procedure is applicable.*	• Section 8 of the EIA addresses cumulative impacts

APPENDIX D – Air Quality Monitoring Report

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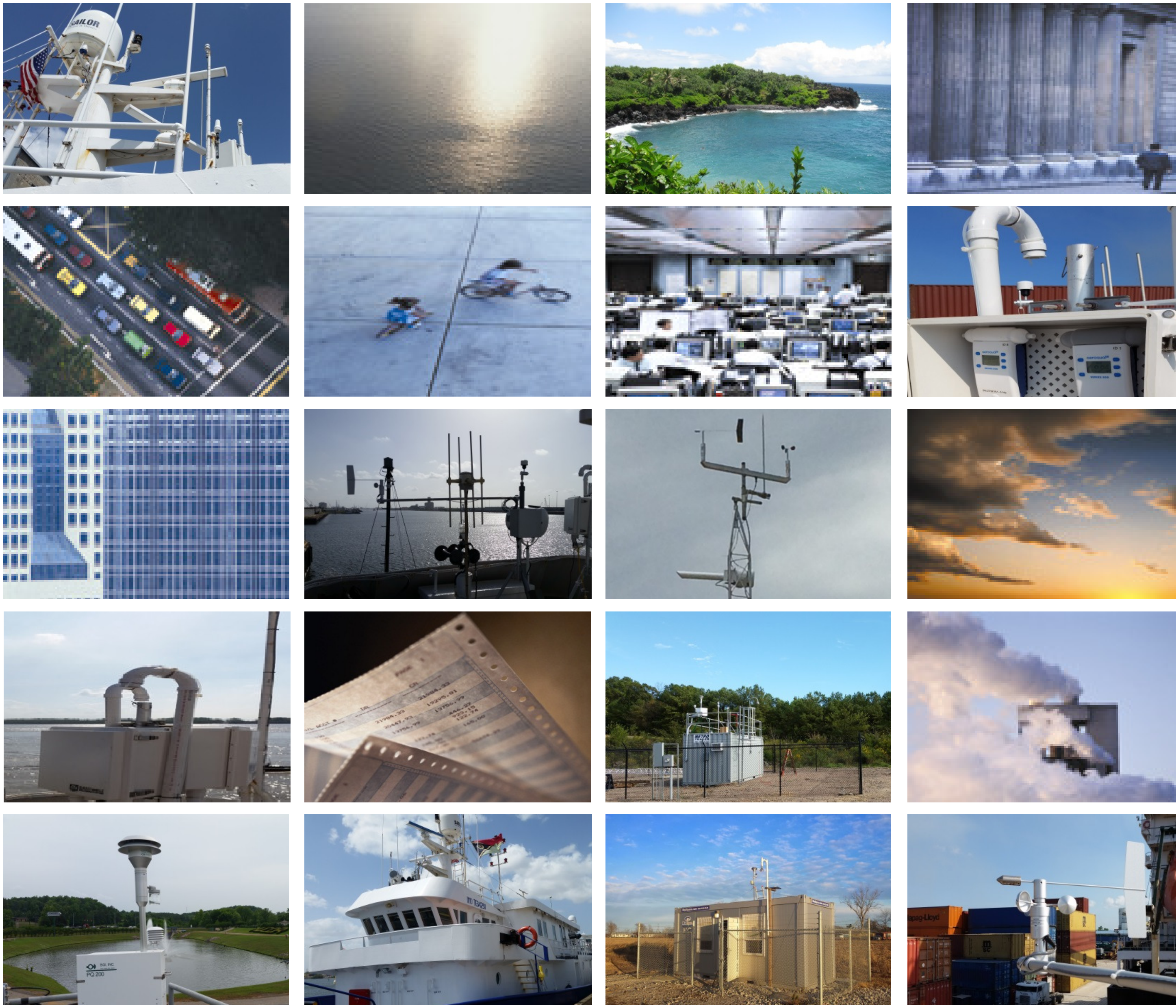


Exxon Mobil: Guyana Liza Phase 1

Air Quality Assessment Report

TDI Brooks RV Proteus On-Board Ambient Air Monitoring

December 3, 2016

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

I. EXECUTIVE SUMMARY

ERM performed ambient air quality monitoring of the Liza Phase 1 area, by instrumenting the research vessel Proteus to measure inhalable particulate matter (PM_{10}), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), nitrogen dioxide (NO_2), carbon monoxide (CO), and volatile organic compounds (VOC). To mitigate the 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 October 1, 2016 Air Quality Assessment Protocol prepared for ExxonMobil, by Environmental Resources Management, Inc. (ERM).

During the 20 day survey period, 50 discrete, integrated samples were collected, in addition to continuous PM_{10}, SO_2, H_2S, NO_2, CO, and VOC sensor measurements. Geographic position, relative wind direction, wind speed, ambient temperature, and relative humidity were also measured on a continuous basis.

In general, these measurements documented that ambient concentrations of the monitored air pollutants in the Liza Phase 1 area are very low, usually below the quantification level of the measurement systems.

Inhalable particulate matter was the only air pollutant consistently above the minimum reporting levels. The maximum 24 hour average PM_{10} concentration measured was 32 microgram per cubic meter—approximately sixty percent of the World Health Organization's Guideline concentration. Supplemental chemical analyses demonstrated that the primary constituent of sampled particulate matter was sea salt.

The continuous air quality sensors were a valuable supplement to the time-integrated samples that required post-survey laboratory analysis. However, it was essential that these units' measurements be compared to more established methods. The Liza Phase 1 results demonstrated that the sensor responses varied from the collocated reference method by as much as a factor of 16.

II. *ACRONYMS AND ABBREVIATIONS*

CO	Carbon Monoxide
H_2S	Hydrogen Sulfide
NO_2	Nitrogen Dioxide
PM_{10}	Inhalable Particulate Matter with an aerodynamic diameter of < 10 micrometer
ppb(v)	Parts Per Billion by Volume
ppm(v)	Parts Per Million by Volume
QA	Quality Assurance
QC	Quality Control
SO_2	Sulfur Dioxide
SOP	Standard Operating Procedure
VOC	Volatile Organic Compounds

III. MONITORING APPROACH

In order to confirm the validity of the background pollutant concentration assumptions upon which the air quality modeling was based, ERM assessed the ambient air quality in the Liza Phase 1 area, offshore Guyana. This was a verification exercise and was not intended as the basis for an ongoing monitoring program.

Monitoring and sampling equipment was mounted on the TDI Brooks research vessel Proteus and air was sampled during its 20-day deployment, from October 3 through 23, 2016. During the course of the air monitoring program, the TDI Brooks helmsman endeavored to maintain the bow of the Proteus in the upwind direction to the extent possible, in order to minimize the potential bias of the air samples by on-board emission sources.

This report presents the results of the monitoring effort. Six air pollutants (or class of pollutants) were selected for monitoring:

- Sulfur Dioxide (SO_2) ,
- Hydrogen Sulfide (H_2S);
- Nitrogen Dioxide (NO_2),
- Volatile Organic Compounds (VOC)
- Carbon Monoxide (CO), and
- Inhalable Particulate Matter, less than 10 micrometer in aerodynamic diameter (PM_{10}).

These are air contaminants that may be associated with oil and gas exploration and/or production. This assessment was performed to document baseline offshore air quality conditions.

Primary reliance was on a set of real-time sensors whose calibration was correlated to laboratory analysis results of collocated passive samplers and collected samples. 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 GPS logger.

A few periods of potential continuous sensor bias from on-board emission sources have been designated as “suspect” or “invalid”, based on concurrent measurement of wind direction, relative to the air sampling package and records of ship-board emission source operations. While all data have been retained in the raw data record, only validated data are reported herein.

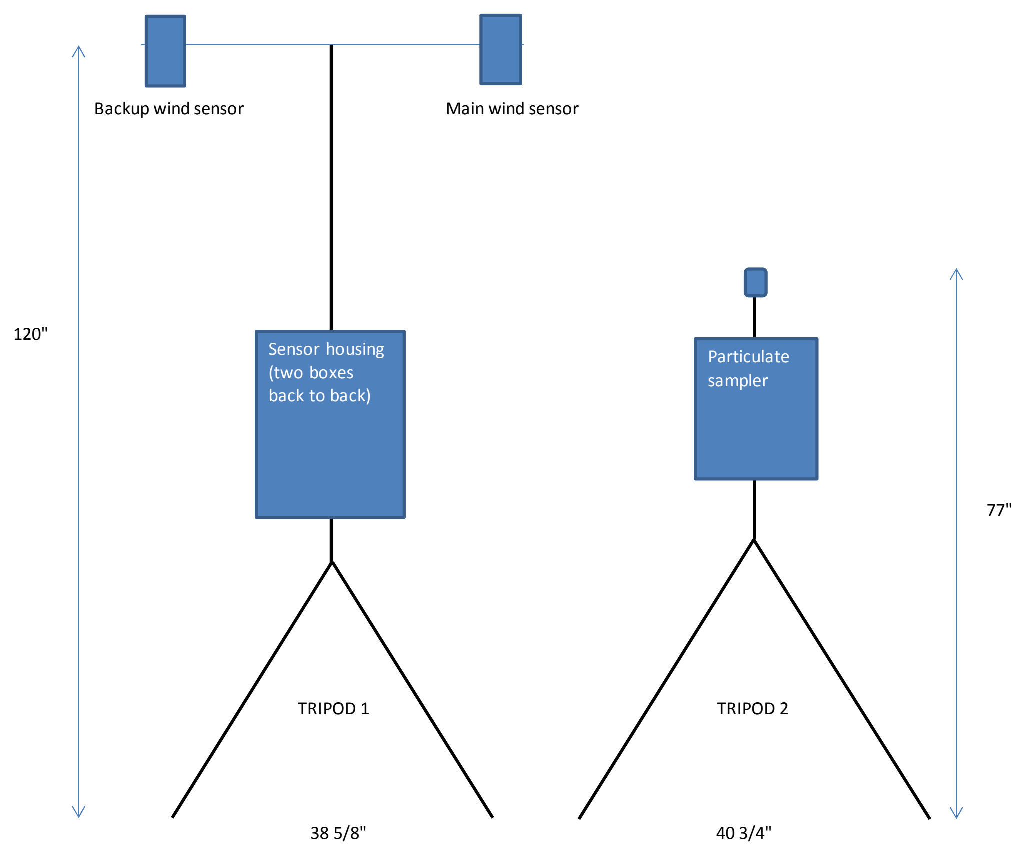
Upon the survey’s conclusion, air samples were retrieved and shipped for laboratory analysis. The real-time air quality, meteorological, and GPS data were downloaded from the instruments either at the dock site or, subsequently, in ERM’s Rolling Meadows, Illinois air quality laboratory.

Data processing consisted of using the laboratory data to validate and adjust the raw air quality sensor data. This report uses the validated laboratory results and the adjusted sensor data to characterize the baseline ambient air quality in the Liza Phase 1 area.

IV. INSTRUMENTATION

Air quality, meteorological, and miscellaneous instrumentation used for the Liza Phase 1 background ambient air quality assessment are described below. Figure IV-1 illustrates the physical configuration of the instruments.

Figure IV-1. Instrumentation Configuration



1. Air Quality Parameters

The program measured ambient concentrations of SO_2, H_2S, NO_2, CO, VOC, and PM_{10}. Each air contaminant was measured with a passive sampler or collected air sample that required laboratory analysis, as well as a continuously monitoring sensor. The laboratory results are considered more reliable, so they were used to validate and adjust the sensor data, as appropriate.

a. **SO_2 –** SKC passive sampling badges (SKC UMEx 200), as well as an Aeroqual Model 500 monitor equipped with a 0 to

10 ppm SO_2 sensor, were used to measure ambient concentrations during the study.

The Aeroqual monitor collected and recorded data throughout the duration of the field survey.

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 survey 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.

b. **H_2S –** 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.

   The Aeroqual monitor collected and recorded data throughout the duration of the field survey.

   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 survey period, with each tube exposed, sequentially. Duplicate samples were collected for the first few sampling periods in order to provide an estimate of measurement precision.

c. **NO_2 – T**he same SKC passive sampling badge was employed to measure SO_2 concentrations during the study. The badge was analyzed so that both SO_2 and NO_2 exposure was measured. Thus, 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 survey period, with each badge exposed, sequentially. Duplicate badges were employed for the first few sample periods to provide insight into the method's precision.

   In addition, an Aeroqual Model 500 monitor equipped with a 0 to 1 ppm NO_2 sensor provided a continuous reading of ambient concentrations throughout the duration of the field survey.

d. **VOC –** 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 study.

   Two-day integrated ambient air samples were collected using pairs of flow controlled evacuated passivated stainless steel ("Summa") canisters. One Summa was configured to draw its sample from within the enclosure housing an Aeroqual Model 500 VOC monitor. The other Summa drew a direct ambient air sample. This permitted assessment of whether the enclosure biased the VOC measurement, and facilitated interpretation of the continuous Aeroqual results. At the conclusion of each two-day sampling period, the canisters were capped and stored for subsequent laboratory analysis, a fresh pair of canisters installed, and another sample collection initiated.

   At the laboratory, each canister was analyzed for total and speciated VOC by GC/MS, in accordance with US EPA Method TO-15.

   The Aeroqual monitor continuously collected and recorded data throughout the duration of the field survey.

e. **CO –** The same pairs of 48-hour integrated Summa canister samples were analyzed in the laboratory for CO concentration.

   The Aeroqual monitor collected and recorded data throughout the duration of the field survey.

f. PM_{10} – A Met One Instruments E-Sampler measured PM_{10} using two methods. First, multi-day integrated ambient concentrations were determined by laboratory gravimetric analysis of pre-weighed Teflon filters. The filter samples were also analyzed using U.S. EPA Metho IO 3.3 (X-ray fluorescence) to assess their composition.

   Second, the E-Sampler also contains 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 had to be adjusted for the nature of the specific particulate matter being measured.

ERM used the laboratory gravimetric results to perform this adjustment.

2. Meteorological Parameters

Wind speed and wind direction (relative to the ship's axis) were continuously monitored by cup and vane sensors and the resultant data logged by the E-Sampler's internal data logger.

Sample relative humidity and temperature were measured by a sensor attached to one of the Model 500 monitors and recorded by its internal data logger. These data were used to identify any periods during which the air quality sensors operated outside their control limits. Data were invalidated as necessary.

3. Miscellaneous Parameters

A Garmin GPS logger was used to identify the location of the instrument package at each point in time, throughout the survey.

V. QUALTIY CONTROL/QUALITY ASSURANCE

Air monitoring on board a working research vessel introduces numerous challenges to obtaining reliable ambient air quality monitoring 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;
- Potential measurement bias due to impacts from on-board emission sources; and
- Reliability of electrical power with which to operate the monitoring instruments.

The Liza Phase 1 ambient air quality monitoring program's equipment proved to be relatively resilient to the challenges encountered at sea. The only significant aberrations were the failure of the CO sensor, 12 days into the survey and the NO_2 sensor malfunctioning, starting at 0300 on October 12, 2016. Summa canisters continued to provide 48 hour integrated CO samples for the duration of the survey but the loss of the CO sensor resulted in reduction of temporal resolution for this parameter. Similarly, the NO_2 passive samplers continued to provide 24 hour integrated values.

The E-Sampler's continuous data could not be downloaded dockside. These data were subsequently successfully retrieved in ERM's air quality laboratory and found to be valid.

The project's 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 is less certain. As noted above, TDI Brooks' helmsman endeavored to maintain the bow of the Proteus in the upwind direction to the extent possible, in order to minimize the potential bias of the air samples by on-board emission sources.

The program also relied on traditional quality control/quality assurance (QA/QC) measures such as the use of field and laboratory blanks, chain of custody documentation, and periodic calibrations against certified standards. Staff training and reliance on Standard Operating Procedures (SOPs) round out the overall QA/QC program. Appendix A contains the training class roster.

VI. RESULTS

In general, concentrations of the monitored air contaminants in the vicinity of the Liza Phase 1 area were found to be very low when compared with levels typically found in terrestrial environments, and with national and international ambient air quality standards.

The monitored values are summarized below. The entire valid data record is contained in Appendix B.

A. SULFUR DIOXIDE

The passive samplers yielded 24-hour (nominal) integrated sample values that were all below the 31 part per billion by volume [ppb(v)] Minimum Reporting Limit. Since the passive sampler results were all below the reporting limit, it was not possible to adjust the sensor data to align with the reference method. The maximum continuous SO_2 sensor recorded raw one hour concentrations of approximately 70 ppb(v). Daily average values were all less than 20 ppb(v), qualitatively consistent with the passive samplers (i.e., below their level of quantification). For comparative purposes, the World Health Organization (WHO) 10 minute average Guideline Concentration is 191 ppb(v) and the 24 hour Guideline is 7.6 ppb(v). Since the passive sampler results were all below the reporting limit, it is not possible to determine how accurate the sensor data are.

B. HYDROGEN SULFIDE

The passive samplers yielded 24-hour integrated sample values that were all below the Minimum Reporting Limit, which ranged from 5.9 to 7.1 ppb(v). The continuous H_2S sensor recorded a maximum one hour average concentration of approximately 50 ppb(v). Daily average values were all less than 10 ppb(v), qualitatively consistent with the passive samplers. For comparison purposes, the WHO 30 minute Guideline Concentration is equal to 14 ppb(v). Since the passive sampler results were all below the reporting limit, it is not possible to determine how accurate the sensor data are.

C. NITROGEN DIOXIDE

The passive samplers yielded 24-hour integrated sample values that were all below the 53 ppb(v) Minimum Reporting Limit. The continuous NO_2 sensor recorded raw maximum one hour average concentrations of approximately 70 ppb(v). Daily average values were all 53 ppb(v) or less, qualitatively consistent with the passive samplers.

For comparison, the WHO Guideline Concentrations are 106 ppb(v) for one hour and 21 for annual averages. Since the passive sampler results were all below the reporting limit, it is not possible to determine how accurate the sensor data are.

D. CARBON MONOXIDE

The Summa canisters were analyzed for CO using US EPA Method 25C (modified). Of the 18 valid (nominally) 48-hour composite samples, only one, a 7.1 ppm(v) measured value, was above its Minimum Reporting Limit (6.4 ppm(v), for this sample). It is notable that the duplicate value for this sample period was below its Minimum Reporting Limit. The Minimum Reporting Limits ranged from 4.6 to 13 ppm(v), depending on the specific sample.

The continuous CO sensor recorded a maximum one hour average concentration of 1.5 ppm(v). Daily average values were all less than 0.4 ppm(v), qualitatively consistent with the passive samplers. Given the single sample above the reporting limit, it was not possible to determine how accurate the sensor data are.

For comparison purposes, the WHO Guideline concentrations are 26.2 and 8.7 ppm(v) for one and eight hour averages, respectively.

E. VOLATILE ORGANIC COMPOUNDS

The Summa canisters were analyzed for volatile organic compounds and total volatile organic compounds calculated as toluene in accordance with United States EPA Method TO-15. The analytical system was comprised of a gas chromatography/mass spectrometer interfaced to a whole-air pre-concentrator. Over 70 discrete VOC species, and total VOCs, were quantified for each sample.

Total non-methane VOC concentrations ranged from 30 to 290 ppb(v) for these 48-hour (nominal) integrated samples. In most samples, most of the individual VOC species were below the Minimum Reporting Limits. The only individual compounds measured above 25 ppb(v) were ethyl acetate, ethanol, propene, acetone, and toluene. Ethanol was the most commonly found constituent at concentrations exceeding 25 ppb(v).

While all but three of the duplicate sample pairs agreed within 25%, there was little correlation between individual species identified in the sample pairs. This is probably due to the relatively low concentrations of the individual species, and the long hold times necessitated by the survey's duration—allowing transformation of some sampled species into secondary compounds.

The average of the raw one hour concentrations recorded by the continuous VOC sensor was 1,400 ppb(v). The concurrent Summa canister results suggested a sensor correction factor of 0.096. This value was used to adjust the hourly sensor results, yielding corrected values that agree with the Summa results.

WHO has not promulgated a Guideline Concentration for VOC.

F. INHALABLE PARTICULATE MATTER

Two integrated filter PM_{10} samples were collected—both yielding calculated concentrations of 11 μg/m^3. The continuous nephelometer-based measurement were corrected based on these filter gravimetric results. The resultant "k factor" (ratio of nephelometer value to filter value) was 1.8.

The maximum and average corrected nephelometer 24 hour average PM_{10} concentration measurement were 33 and 12 μg/m^3, respectively. For comparison purposes, the WHO Guideline Concentrations are 50 and 20 μg/m^3 for 24 hour and annual averages.

Based upon elemental analysis, sea salt (sodium chloride) constituted the largest component (approximately 30%) of the measured PM_{10}.

G. METEOROLOGICAL PARAMETERS

Data recovery of wind speed and relative wind direction was 100% over the duration of the survey. The relative wind direction results document that the helmsman was generally successful in orienting the vessel so as to minimize potential measurement interference from onboard emission sources. The relative wind direction was only from astern during 28 of the 480 hours the vessel was at sea.

The temperature and humidity measurements documented that these parameters were within the air quality sensors' acceptable use range throughout the survey period.

APPENDIX A: TRAINING CLASS ROSTER

ExxonMobil

Liza Phase I Ambient Air Quality Monitoring Program

Proteus Staff Training Record

October 3, 2016

Instructor: Richard H. Osa, QEP (ERM)

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APPENDIX E – 2014 EBS

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ENVIRONMENTAL BASELINE STUDY

GUYANA STABROEK BLOCK

Prepared for

Esso Exploration and Production Guyana Ltd.

Prepared by

Maxon Consulting, Inc.
San Diego, CA 92122

With

TDI Brooks International, Inc.
College Station, TX 77845

July 2014
Report

ENVIRONMENTAL BASELINE STUDY

GUYANA – STABROEK BLOCK

Report

Prepared For:

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July 2014

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 μg 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 -1.g g 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.

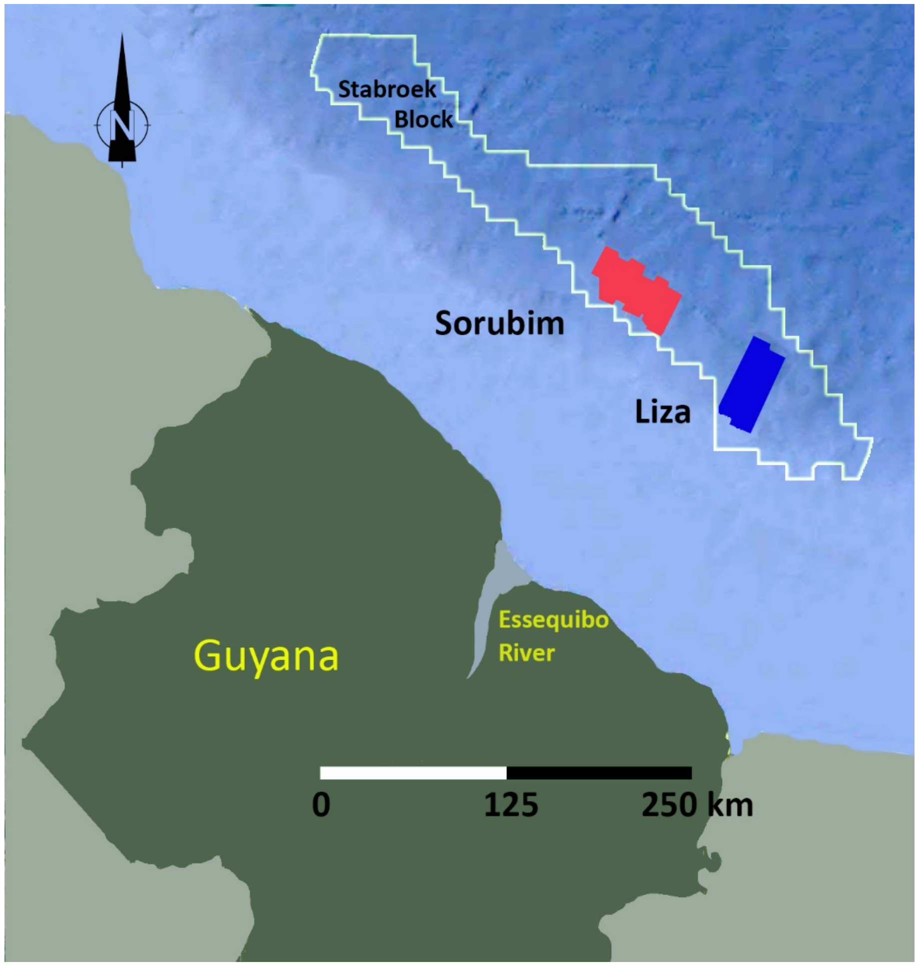

Figure 1-1. Stabroek Block with locations of Liza and Sorubim EBS project areas.

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.

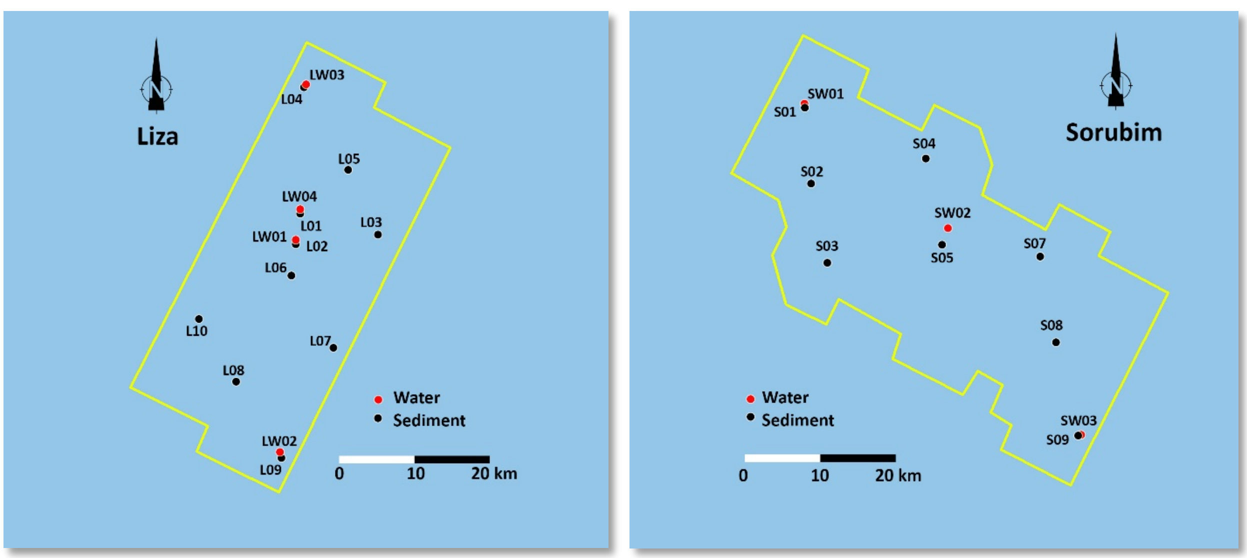

Figure 1-2. Locations of water and sediment sampling stations at Liza and Sorubim.

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
GC-FID = gas chromatography with flame ionization detector
ICP-MS= ICP with mass detector
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^{o} 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^{o} C, weighed. The resulting moisture-free sample was combusted at 1350^{o} 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^{o} 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^{o} 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^{o} 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^{o} 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^{o} 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^{o} 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^{o} 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^{o} 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^o C at the surface to 3^o 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^o to 28.5^o 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^o 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.

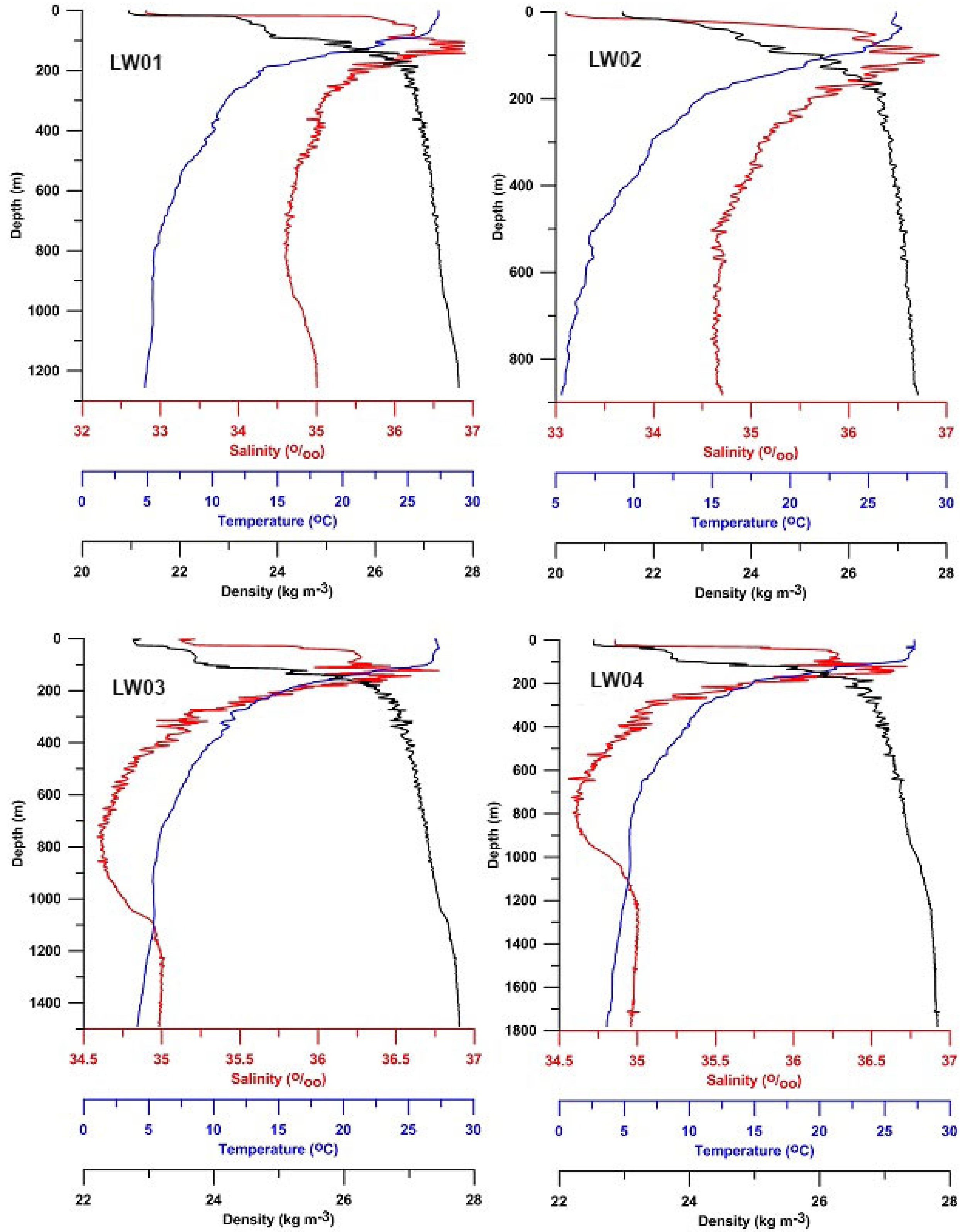

Figure 3-1. Profiles of salinity, temperature, and water density at each of four stations at Liza.

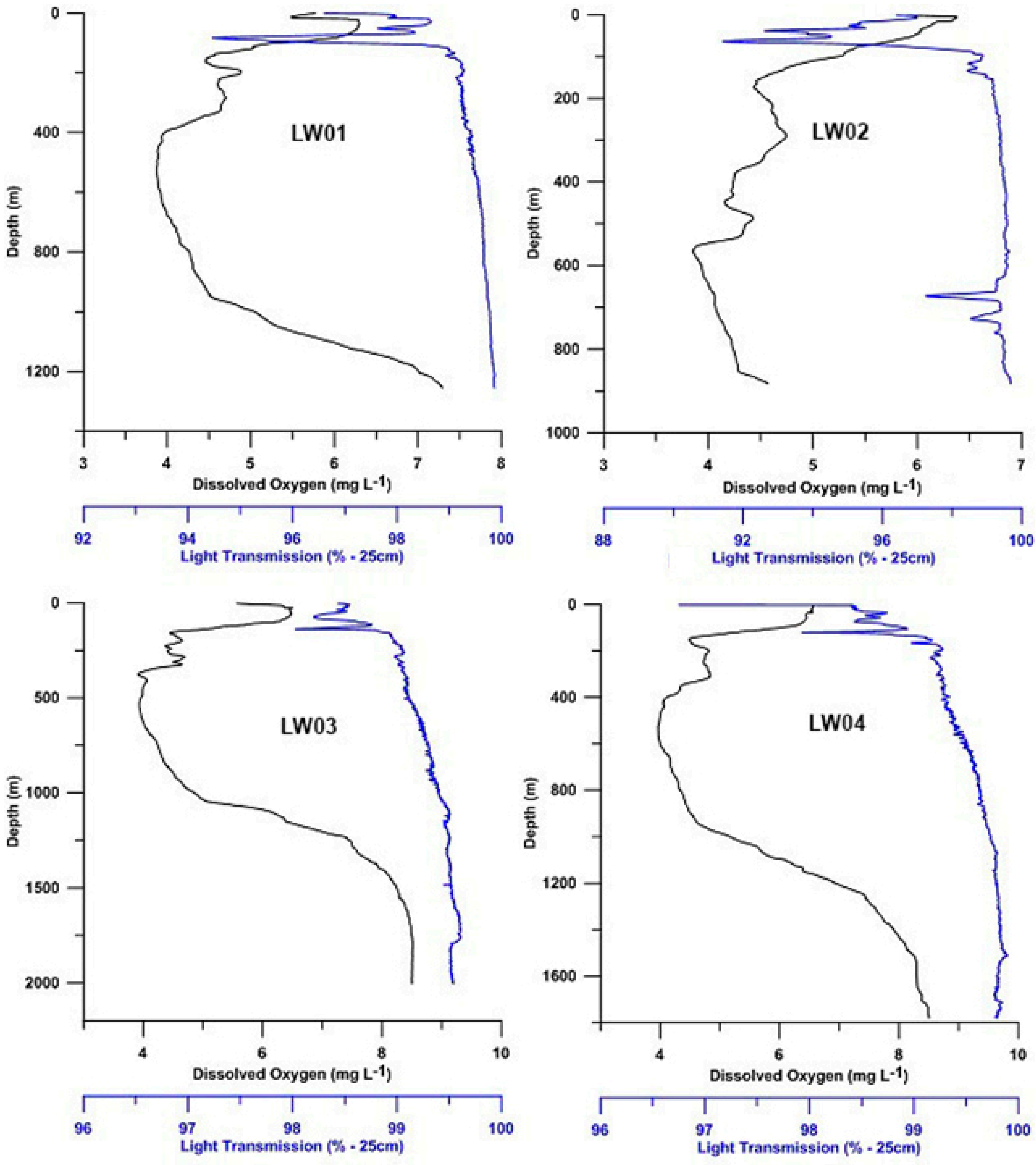

Figure 3-2. Profiles of dissolved oxygen and percent light transmission at each of four stations at Liza.

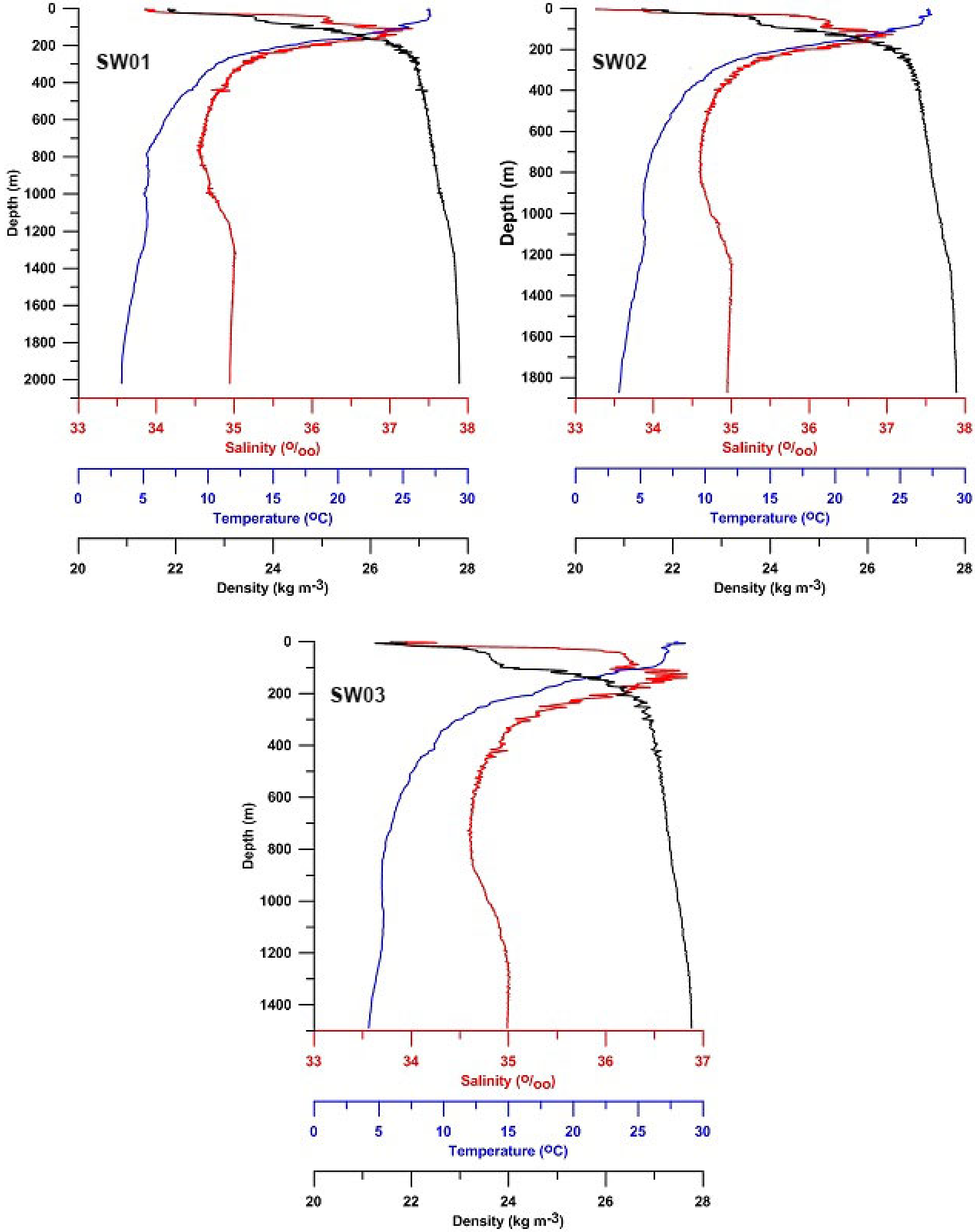

Figure 3-3. Profiles of salinity, temperature, and water density at each of three stations at Sorubim.

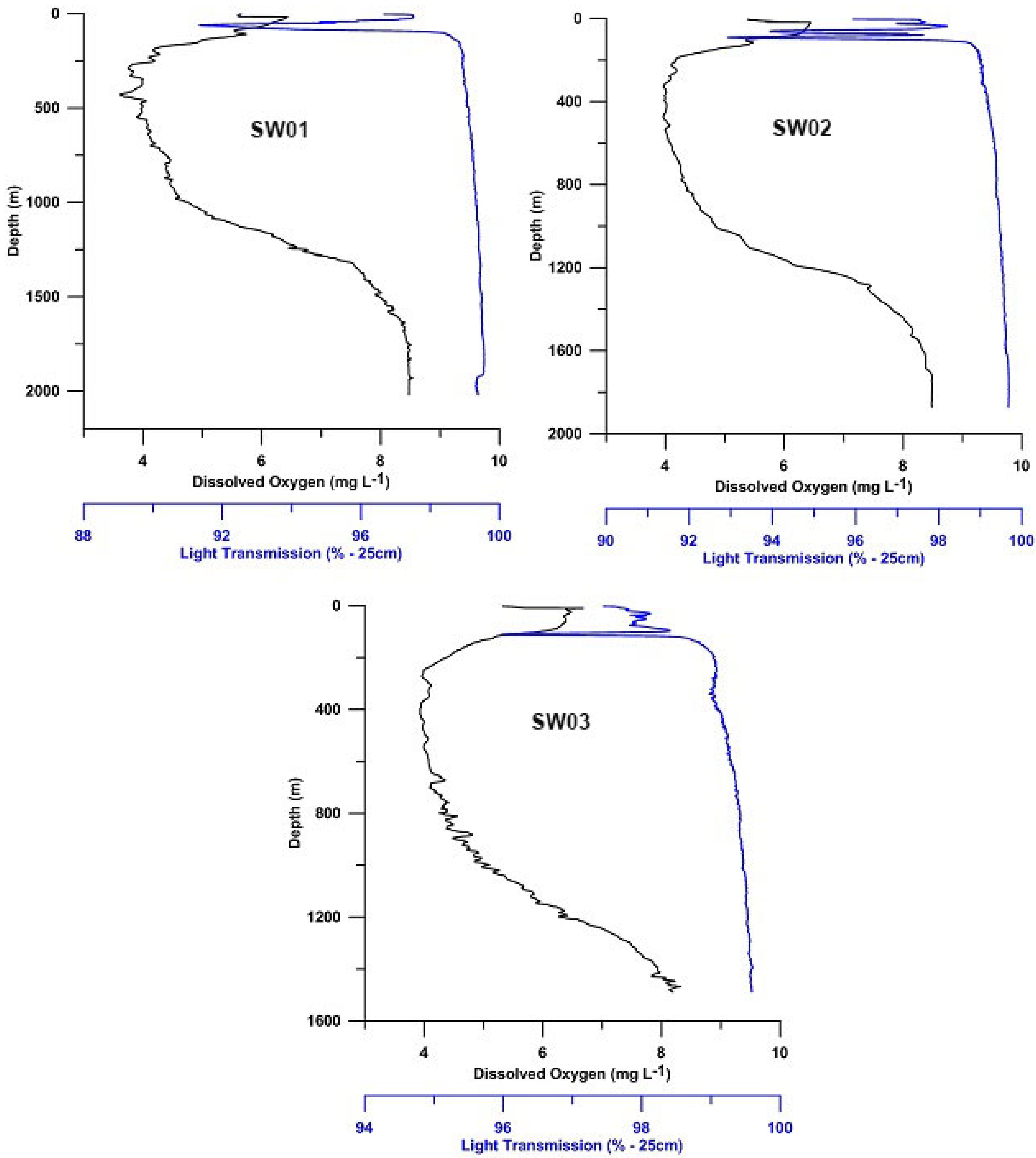

Figure 3-4. Profiles of dissolved oxygen and percent light transmission at each of three stations at Sorubim.

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

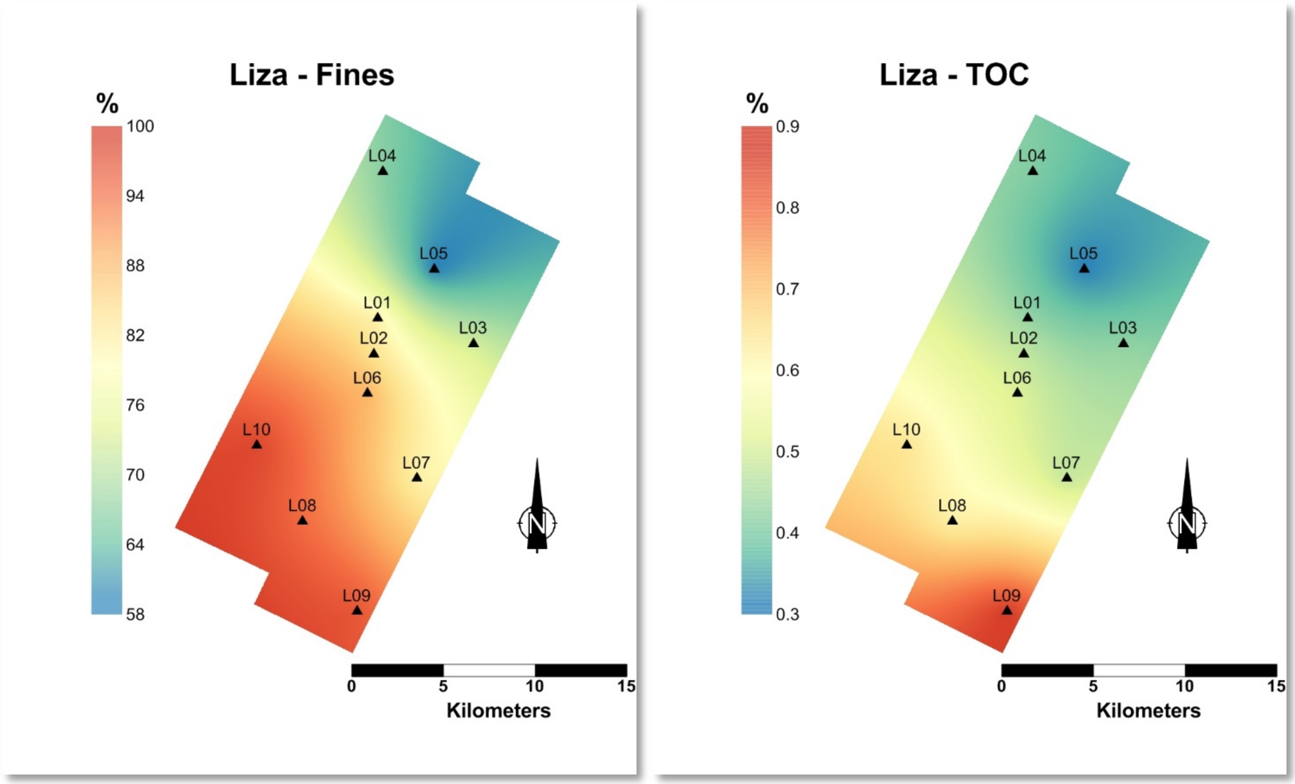

Figure 4-2. Spatial distribution of percent fines (silt + clay) and total organic carbon (TOC) at Liza.

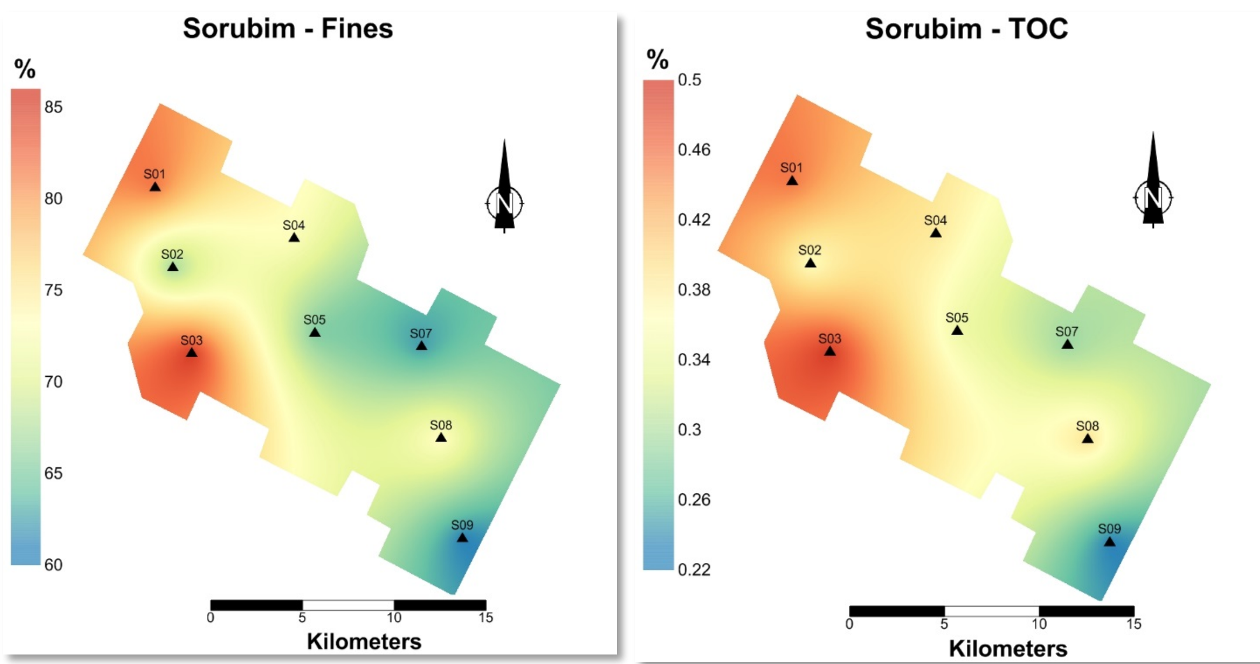

Figure 4-2. Spatial distribution of percent fines (silt + clay) and total organic carbon (TOC) at Sorubim.

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 $\mu g\ g^{-1}$ 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**

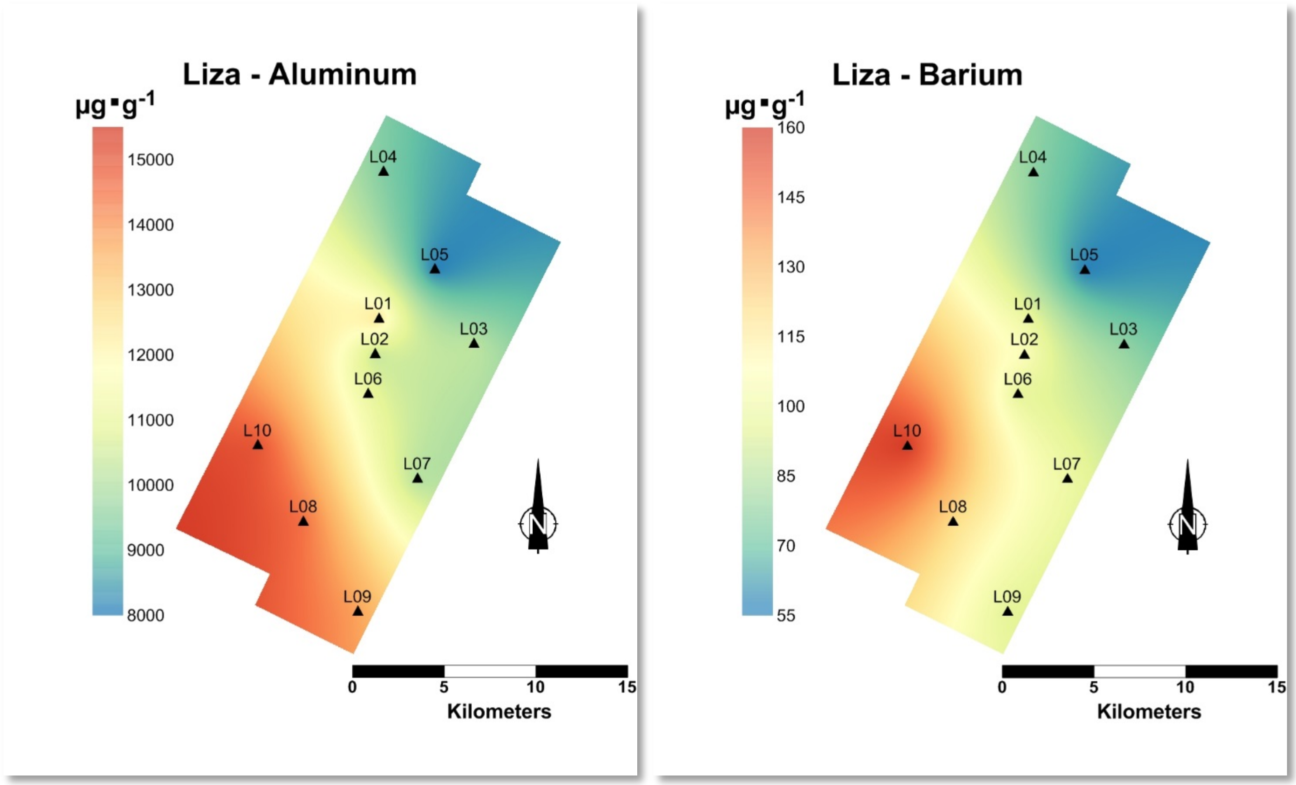

Figure 4-3. Spatial distribution of aluminum and barium in surface sediment at Liza.

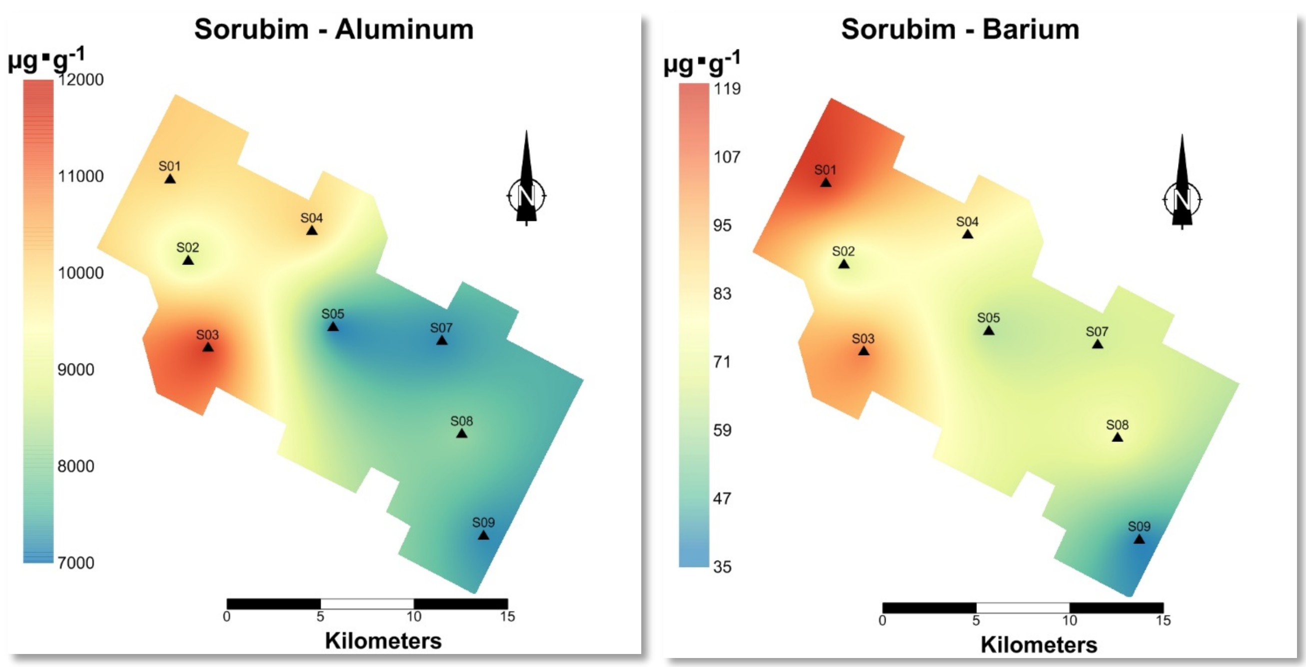

Figure 4-4. Spatial distribution of aluminum and barium in surface sediment at Sorubim.

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

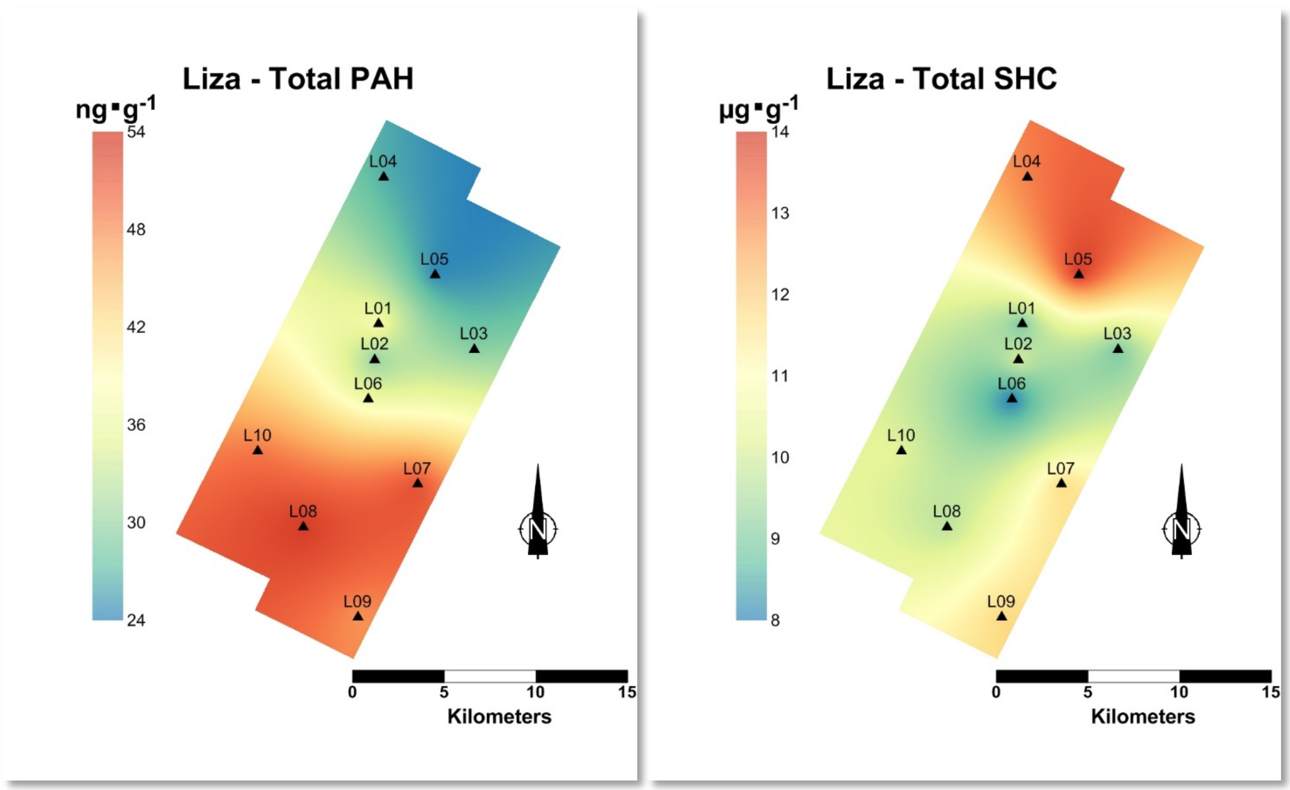

Figure 4-5. Spatial distribution of total PAH and total SHC in surface sediment at Liza.

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.

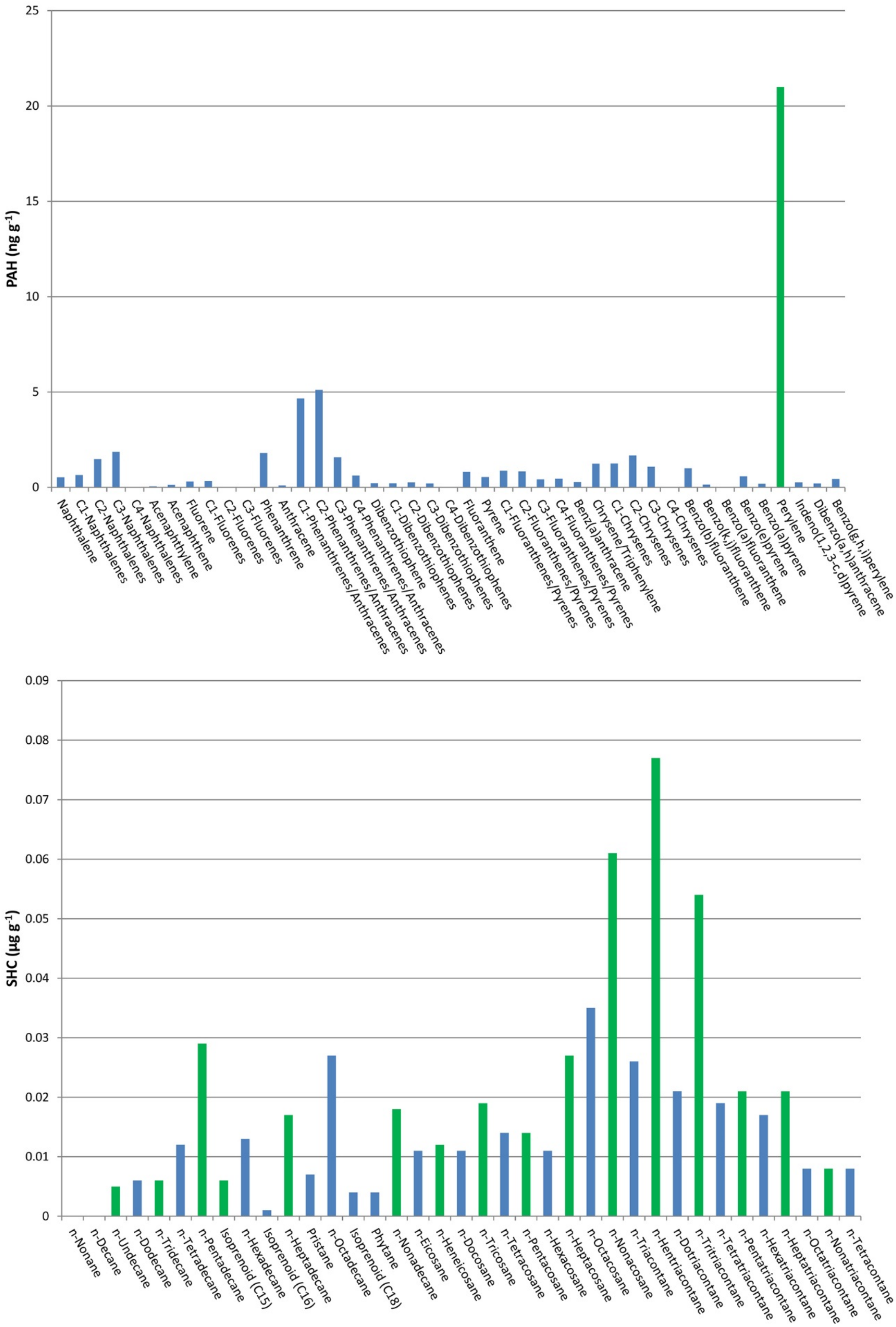

Figure 4-6. Distributions of individual PAH (top) and SHC (bottom) analytes in a representative sediment sample (station L08).

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.

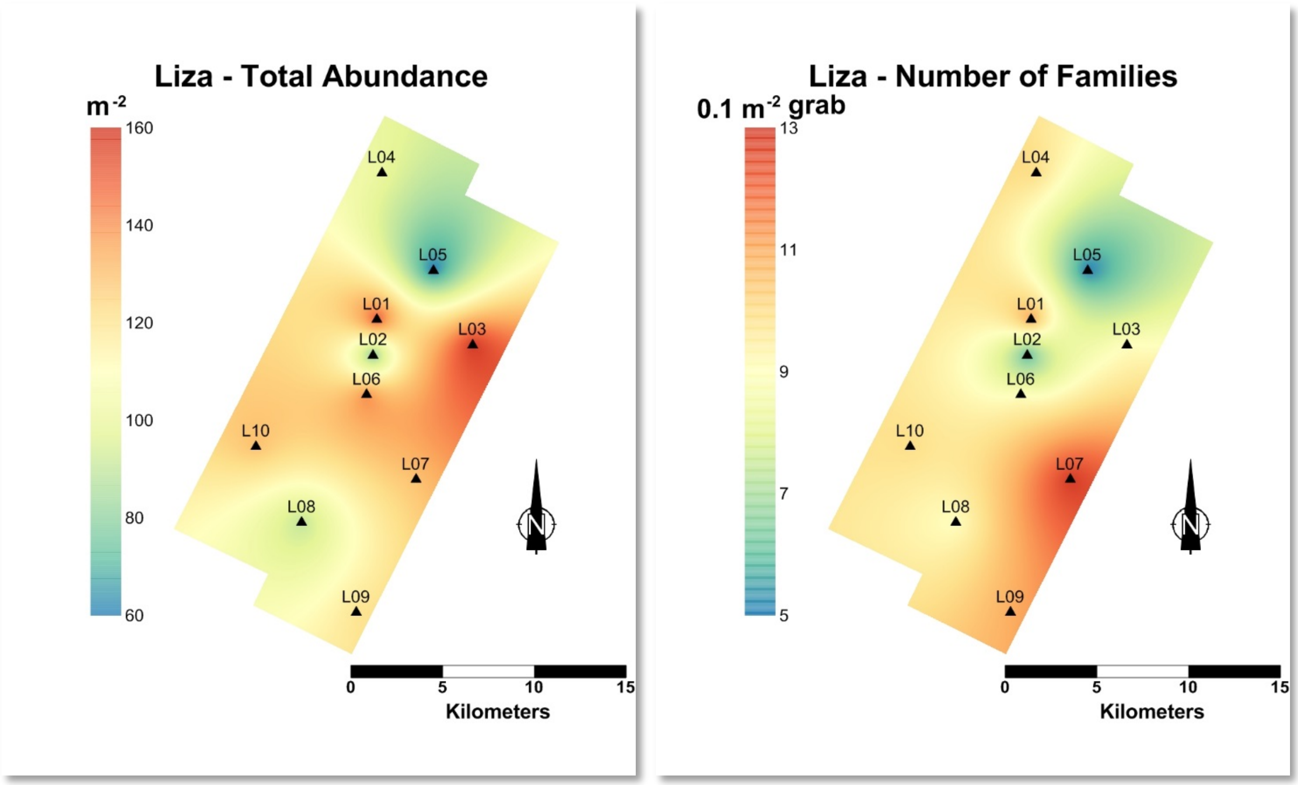

Figure 5-1. Spatial distribution of macrofauna total abundance and family diversity at Liza.

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.

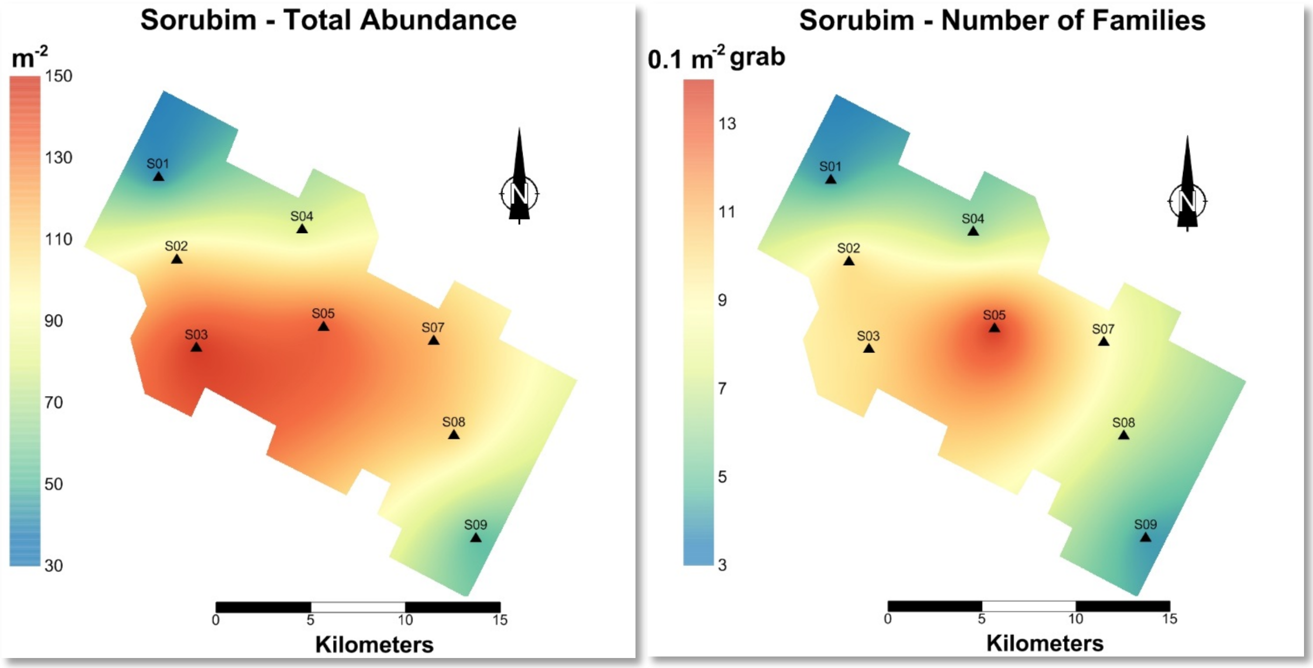

Figure 5-2. Spatial distribution of macrofauna total abundance and family diversity at Sorubim.

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.

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APPENDIX F – 2016 EBS

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FUGRO EMU LIMITED

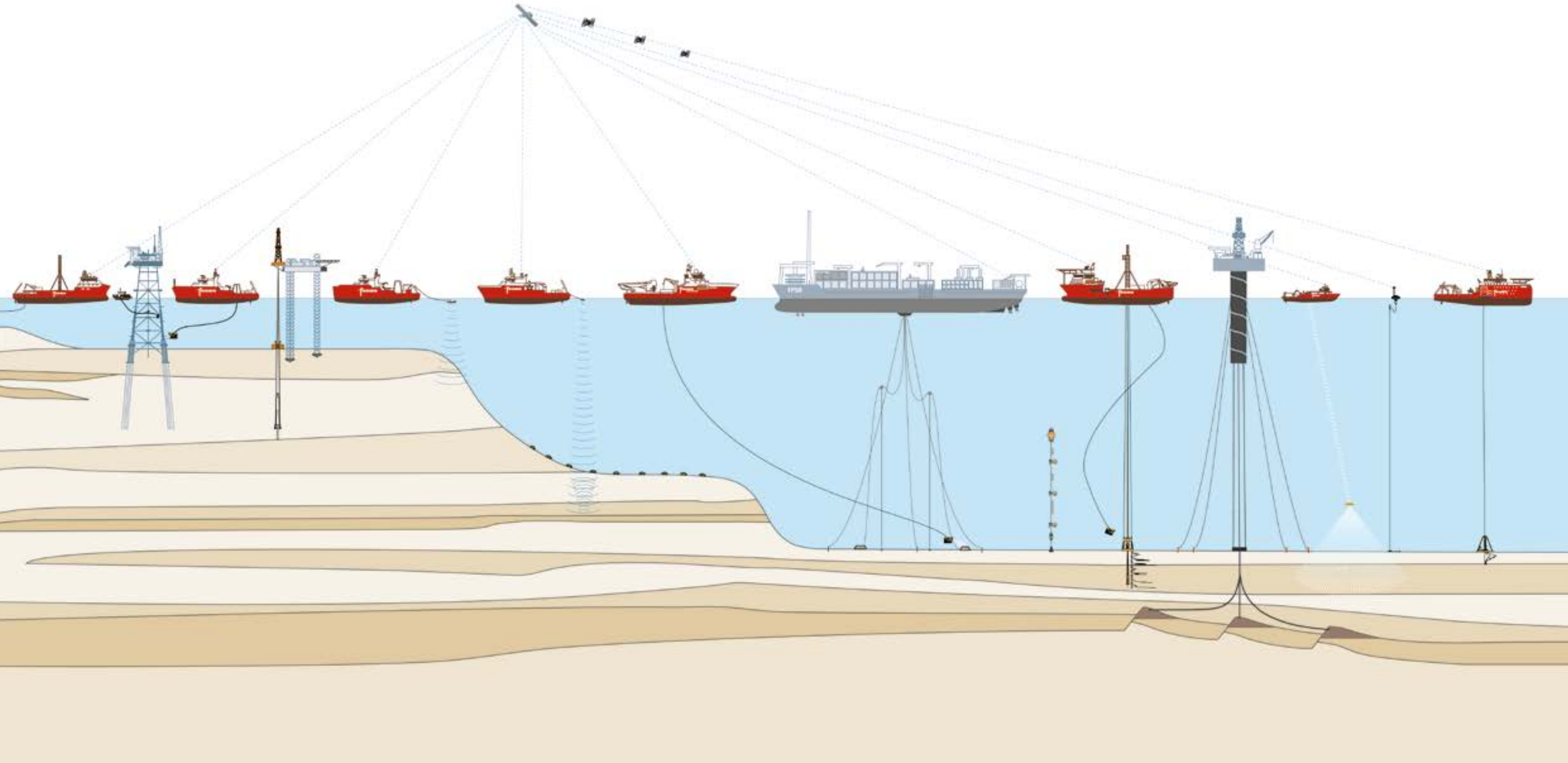
Environmental Baseline Survey Report
Liza Development, Offshore Guyana
4 March to 19 March 2016

Environmental Baseline Survey Report

Fugro Job No. 2415-3066-EBS
Esso Exploration and Production Guyana Limited

EEPGL

Final



FUGRO EMU LIMITED

Environmental Baseline Survey Report
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EEPGL

Final

1	Final	C. Barrett	S. Degregorio	S. Whyte	22/09/2016
0	Draft	C. Barrett	S. Whyte	S. Whyte	12/08/2016
Rev.	**Description**	**Prepared**	**Checked**	**Approved**	**Date**

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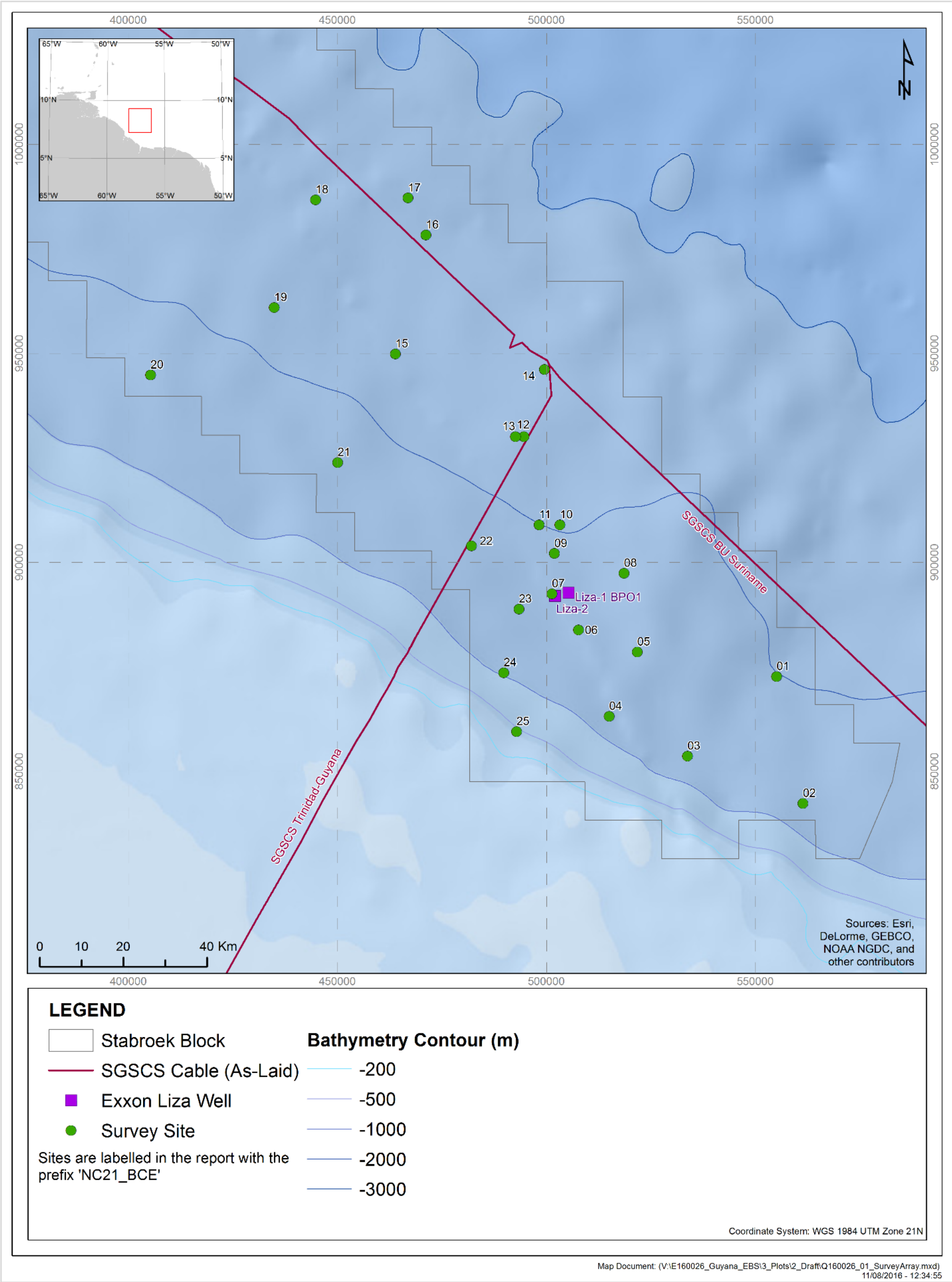

EXECUTIVE SUMMARY

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	08º 04′ 09.54″ N	056º 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.

AUTHORISATION PAGE

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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

CONTENTS

APPENDICES

TABLES IN THE MAIN TEXT

FIGURES IN THE MAIN TEXT

PLATES IN MAIN TEXT

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 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.

2.1 Environmental Survey Strategy

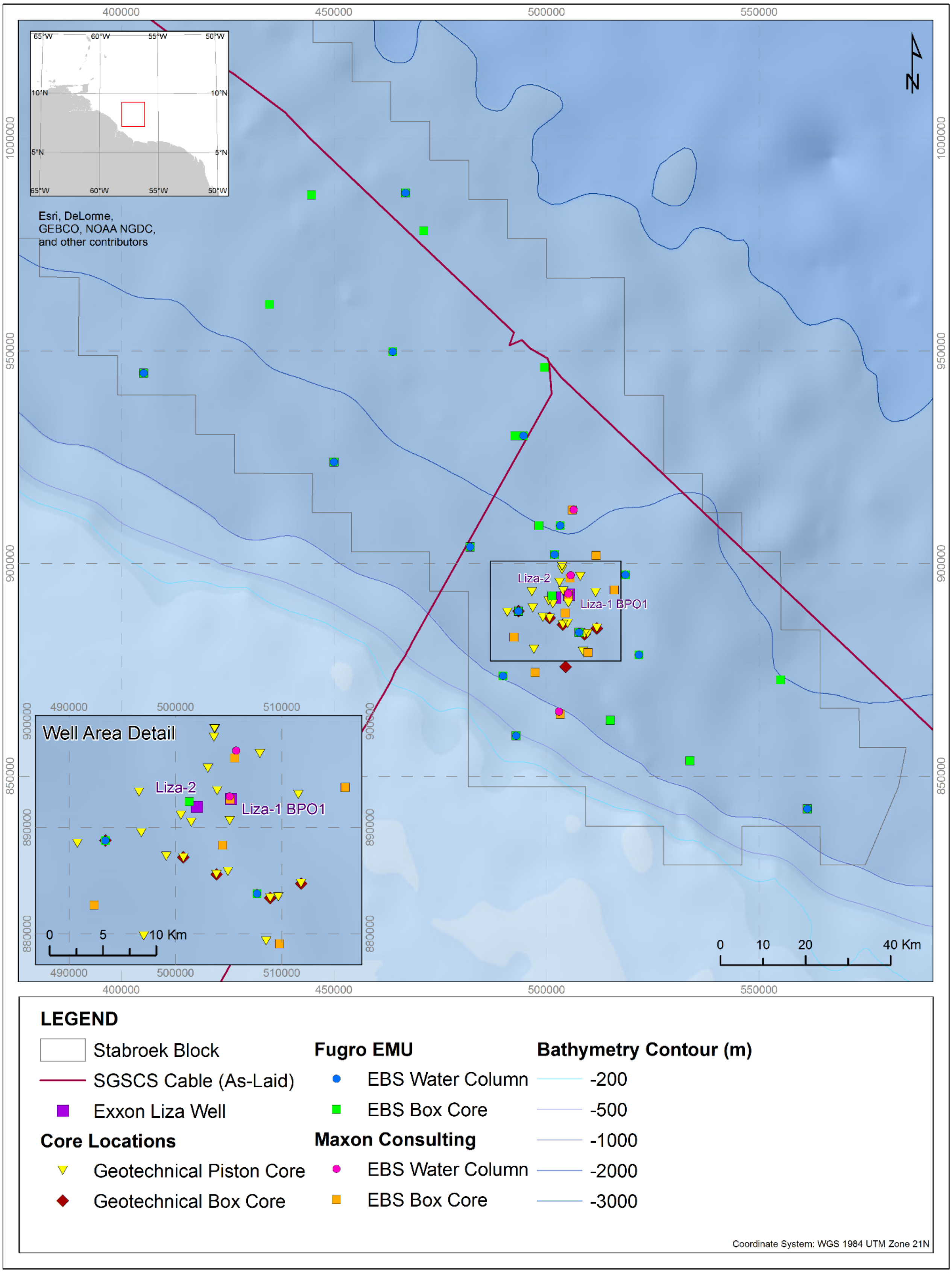
Box coring and sediment profile imaging (SPI) were proposed at 25 stations, of which 15 were selected for conductivity temperature and depth (CTD) data and water samples. Collection of water samples was proposed at the surface, below the thermocline and at the bottom of the water column, close to the 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 given the currents and counter currents that can be experienced in the Stabroek Block, Offshore Guyana. 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.

Table 2.1: Proposed Environmental Survey Stations

Stations	Easting [m]	Northing [m]	Sample Acquisition
NC21_16BCE001	555 087.5	872 666.7	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE002	561 362.9	842 298.1	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE003	533 722.2	853 586.9	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE004	515 005.1	863 106.6	
NC21_16BCE005	521 741.0	878 532.9	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE006	507 683.0	883 790.0	
NC21_16BCE007	501 316.1	892 438.6	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE008	518 555.0	897 354.7	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE009	501 900.3	902 086.7	
NC21_16BCE010	503 234.0	908 943.0	
NC21_16BCE011	498 234.0	908 950.9	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE012	494 587.2	930 071.3	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE013	492 587.2	930 071.3	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE014	499 542.0	946 110.0	
NC21_16BCE015	463 847.9	949 827.0	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE016	471 156.5	978 303.6	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE017	466 847.0	987 164.0	PC, FA, FB, DNA, plan and profile view photographs, CTD, water column samples
NC21_16BCE018	444 776.4	986 730.1	PC, FA, FB, DNA, plan and profile view photographs
NC21_16BCE019	434 883.5	960 957.7	
NC21_16BCE020	405 291.3	944 807.2	PC, FA, FB, DNA, plan and profile view photographs, CTD, water

Stations	Easting [m]	Northing [m]	Sample Acquisition
NC21_16BCE021	450 032.4	923 884.0	column samples
NC21_16BCE022	482 055.8	903 906.1	
NC21_16BCE023	493 428.0	888 781.0	
NC21_16BCE024	489 763.6	873 528.2	
NC21_16BCE025	492 834.0	859 481.8	

Notes:
PC = Physico-chemical sample
FA = Fauna sample A
FB = Fauna sample B
DNA = Deoxyribonucleic acid sample



Map Document: (V:\E160026_Guyana_EBS\3_Plots\2_Draft\Q160026_CoreLocations.mxd) 16/09/2016 - 11:55:03

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;
- Additional 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 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;
- 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. 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.

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 4th 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).

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).

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.

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.

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		
NC21_16BCE004D	514 969.8	863 122.2	1210		
NC21_16BCE003	533 689.7	853 622.4	1280		
NC21_16BCE002	561 350.3	842 307.2	1250		
NC21_16BCE001	555 100.2	872 654.1	1980		
NC21_16BCE005A	521 742.9	878 560.6	1550		
NC21_16BCE006	507 679.2	883 785.8	1570		
Phases II and III NC21_16BCE023	493 418.5	888 796.6	1510		
NC21_16BCE007	501 296.7	892 444.8	1700		
NC21_16BCE008A	518 560.9	897 371.5	1800		
NC21_16BCE009	501 901.8	902 067.1	1900		
NC21_16BCE010	503 236.3	908 940.4	2040		
NC21_16BCE011	498 238.0	908 974.6	2010		
NC21_16BCE012	494 550.4	930 119.5	2210		
NC21_16BCE013	492 558.1	930 097.7	2200		
NC21_16BCE014B	499 626.4	946 103.9	2550		
NC21_16BCE015	463 898.0	949 829.2	2400		
NC21_16BCE016	471 163.5	978 365.0	2760		
NC21_16BCE017	466 834.0	987 157.9	2760		
NC21_16BCE017D	466 846.3	987 168.7	2760		
NC21_16BCE018B	444 740.8	986 775.1	2680		

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	**Easting**	**Northing**	**Depth**	**Type**	**Samples**
NC21_16BCE019A	434 891.5	960 929.8	2240		
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		
NC21_16BCE022	482 091.3	903 844.9	1640		
NC21_16WC025_M2	492 841.3	859 484.2	100	Niskin	Water Sample
NC21_16WC025_T1	492 840.5	859 484.9	1		
NC21_16WC024_B2	489 870.6	873 478.0	922		
NC21_16WC024_M2	489 799.1	873 513.9	320		
NC21_16WC024_T1	489 762.4	873 532.2	1		
NC21_16WC002_B2	561 426.9	842 302.5	1171		
NC21_16WC002_M2	561 426.9	842 302.5	371		
NC21_16WC002_T1	561 294.3	842 336.4	1		
NC21_16WC005_B1	521 886.3	878 433.8	1681		
NC21_16WC005_M1	521 700.8	878 577.8	400		
NC21_16WC005_T1	521 655.6	878 595.6	1		
NC21_16WC005_CTD	521 855.4	878 458.6	1681		
NC21_16WC006_B1	507 771.2	883 708.2	1550		
NC21_16WC006_M1	507 771.2	883 708.2	400		
NC21_16WC006_T1	507 572.4	883 856.5	1		
NC21_16WC023_B1	493 466.7	888 755.4	1494		
NC21_16WC023_M1	493 466.7	888 755.4	400		
NC21_16WC023_M2	493 321.4	888 847.1	100		
NC21_16WC023_M3	493 319.9	888 849.1	40		
NC21_16WC023_T1	493 319.6	888 846.5	1		
NC21_16WC008_B1	518 607.9	897 311.7	1925		
NC21_16WC008_M1	518 471.1	897 428.0	500		
NC21_16WC008_T1	518 444.0	897 442.6	1		
NC21_16WC009_B1	501 947.2	902 090.7	1882		
NC21_16WC009_M1	501 812.6	902 154.1	350		
NC21_16WC009_B2	501 949.8	902 103.1	1880		
NC21_16WC009_B3	501 939.6	902 086.9	1880		
NC21_16WC009_T1	501 794.6	902 170.5	1		
NC21_16WC010_B1	503 288.6	908 925.4	2020		
NC21_16WC010_M1	503 155.2	909 004.0	500		
NC21_16WC010_T1	503 137.8	909 021.1	1		
NC21_16WC010_CTD1	503 289.6	908 950.0	2020		
NC21_16WC010_CTD2	503 351.8	908 856.3	2023		
NC21_16WC012_B1	494 651.6	930 043.8	2350		
NC21_16WC012_M1	494 503.0	930 153.8	600		
NC21_16WC012_T1	494 497.4	930 156.5	1		

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	**Easting**	**Northing**	**Depth**	**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		
NC21_16WC015_T1	463 802.9	949 881.0	1		
NC21_16WC017_B1	466 817.9	987 201.0	2747		
NC21_16WC017_M1	466 773.3	987 214.3	350		
NC21_16WC017_T1	466 798.2	987 203.5	1		
NC21_16WC017_B3	466 792.0	987 207.6	2743		
NC21_16WC018_B1	444 929.2	986 709.8	2637		
NC21_16WC018_T1	444 729.0	986 761.8	1		
NC21_16WC018_M1	444 722.5	986 765.9	350		
NC21_16WC020_B1	405 447.5	944 832.4	1845		
NC21_16WC020_T1	405 164.1	944 825.4	1		
NC21_16WC020_M1	405 212.3	944 808.9	400		
NC21_16WC021_B1	450 071.3	923 925.7	1740		
NC21_16WC021_T1	449 902.2	924 019.0	1		
NC21_16WC021_M1	449 910.3	924 005.3	265		
NC21_16WC022_B1	482 122.8	903 886.9	1690		
NC21_16WC022_T1	481 918.7	903 996.1	1		
NC21_16WC022_M1	481 934.0	903 973.6	300		
NC21_16WC025_M2	492 841.3	859 484.2	100		
NC21_16WC025_T1	492 840.5	859 484.9	1		
NC21_16WC024_B2	489 870.6	873 478.0	922		
NC21_16WC024_M2	489 799.1	873 513.9	320		
NC21_16WC024_T1	489 762.4	873 532.2	1		
NC21_16WC002_B2	561 426.9	842 302.5	1171		
NC21_16WC002_M2	561 426.9	842 302.5	371		
NC21_16WC002_T1	561 294.3	842 336.4	1		
NC21_16WC005_B1	521 886.3	878 433.8	1681		
NC21_16WC005_M1	521 700.8	878 577.8	400		
NC21_16WC006_B1	507 771.2	883 708.2	1550		
NC21_16WC006_M1	507 771.2	883 708.2	400		
NC21_16WC006_T1	507 572.4	883 856.5	1		
NC21_16WC023_B1	493 466.7	888 755.4	1494		
NC21_16WC023_M1	493 466.7	888 755.4	400		
NC21_16WC023_M2	493 321.4	888 847.1	100		
NC21_16WC023_M3	493 319.9	888 849.1	40		
NC21_16WC023_T1	493 319.6	888 846.5	1		
NC21_16WC008_B1	518 607.9	897 311.7	1925		
NC21_16WC008_M1	518 471.1	897 428.0	500		
NC21_16WC008_T1	518 444.0	897 442.6	1	Niskin	Water Sample

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	Easting	Northing	Depth	Type	Samples
NC21_16WC009_B1	501 947.2	902 090.7	1882		
NC21_16WC009_M1	501 812.6	902 154.1	350		
NC21_16WC009_B2	501 949.8	902 103.1	1880		
NC21_16WC009_B3	501 939.6	902 086.9	1880		
NC21_16WC009_T1	501 794.6	902 170.5	1		
NC21_16WC010_B1	503 288.6	908 925.4	2020		
NC21_16WC010_M1	503 155.2	909 004.0	500		
NC21_16WC010_T1	503 137.8	909 021.1	1		
NC21_16WC010_CTD1	503 289.6	908 950.0	2020		
NC21_16WC010_CTD2	503 351.8	908 856.3	2023		
NC21_16WC012_B1	494 651.6	930 043.8	2350		
NC21_16WC012_M1	494 503.0	930 153.8	600		
NC21_16WC012_T1	494 497.4	930 156.5	1		
NC21_16WC015_B1	463 946.6	949 801.0	2390		
NC21_16WC015_M1	463 800.4	949 883.7	600		
NC21_16WC015_T1	463 802.9	949 881.0	1		
NC21_16WC017_B1	466 817.9	987 201.0	2747		
NC21_16WC017_M1	466 773.3	987 214.3	350		
NC21_16WC017_T1	466 798.2	987 203.5	1		
NC21_16WC017_B3	466 792.0	987 207.6	2743		
NC21_16WC018_B1	444 929.2	986 709.8	2637		
NC21_16WC018_T1	444 729.0	986 761.8	1		
NC21_16WC018_M1	444 722.5	986 765.9	350		
NC21_16WC020_B1	405 447.5	944 832.4	1845		
NC21_16WC020_T1	405 164.1	944 825.4	1		
NC21_16WC020_M1	405 212.3	944 808.9	400		
NC21_16WC021_B1	450 071.3	923 925.7	1740		
NC21_16WC021_T1	449 902.2	924 019.0	1		
NC21_16WC021_M1	449 910.3	924 005.3	265		
NC21_16WC022_B1	482 122.8	903 886.9	1690		
NC21_16WC022_T1	481 918.7	903 996.1	1		
NC21_16SP025	492 839.9	859 483.1	264	SPI	Still
rep2	492 847.7	859 482.8	264		
rep3	492 844.5	859 480.9	264		
rep4	492 843.1	859 483.4	264		
rep5	492 841.3	859 484.3	264		
NC21_16SP024	489 773.5	873 511.5	938		
rep2	489 770.3	873 513.9	938		
rep3	489 776.8	873 516.3	938	SPI	Still
rep4	489 768.8	873 515.6	938		

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	**Easting**	**Northing**	**Depth**	**Type**	**Samples**
rep5	489 770.4	873 518.9	938		
NC21_16SP004D	515 043.4	863 083.3	1132		
rep2	515 043.6	863 086.5	1132		
rep3	515 047.0	863 086.5	1132		
rep4	515 044.0	863 087.4	1132		
rep5	515 045.1	863 089.5	1132		
NC21_16SP002	561 371.8	842 290.4	1188		
rep2	561 374.2	842 288.1	1188		
rep3	561 374.2	842 290.8	1188		
rep4	561 376.0	842 291.3	1188		
rep5	561 375.8	842 290.2	1188		
NC21_16SP001	555 085.7	872 693.4	1994		
rep2	555 095.1	872 692.7	1994		
rep3	555 100.5	872 692.0	1994		
rep4	555 105.8	872 692.6	1994		
rep5	555 109.3	872 693.0	1994		
NC21_16SP005B	521 746.8	878 545.7	1693		
rep2	521 751.9	878 545.6	1693		
rep3	521 757.7	878 544.3	1693		
rep4	521 759.1	878 549.4	1693		
rep5	521 764.5	878 547.1	1693		
NC21_16SP006	507 699.6	883 767.9	1568		
rep2	507 712.2	883 760.9	1568		
rep3	507 717.0	883 756.8	1568		
rep4	507 723.5	883 751.4	1568		
rep5	507 727.2	883 750.9	1568		
NC21_16SP023	493 425.7	888 741.4	1509		
rep2	493 432.6	888 735.5	1509		
rep3	493 437.1	888 731.5	1509		
rep4	493 440.0	888 726.9	1509		
rep5	493 445.4	888 721.7	1509		
NC21_16SP007	501 306.8	892 424.0	1695		
rep2	501 317.8	892 419.4	1695		
rep3	501 323.4	892 416.0	1695		
rep4	501 328.4	892 413.3	1695		
rep5	501 333.6	892 411.6	1695		
NC21_16SP008	518 582.2	897 363.6	1942		
rep2	518 592.6	897 358.6	1942		
rep3	518 597.5	897 356.9	1942	SPI	Still
rep4	518 608.0	897 351.6	1942		

Geodetic Datum: WGS84, UTM Zone 21N, CM 57°W					
Station	Easting	Northing	Depth	Type	Samples
rep5	518 616.4	897 345.9	1942		
NC21_16SP009	501 873.2	902 086.7	1887		
rep2	501 890.4	902 084.0	1887		
rep3	501 905.9	902 081.4	1887		
rep4	501 919.9	902 077.9	1887		
rep5	501 927.8	902 076.0	1887		

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.

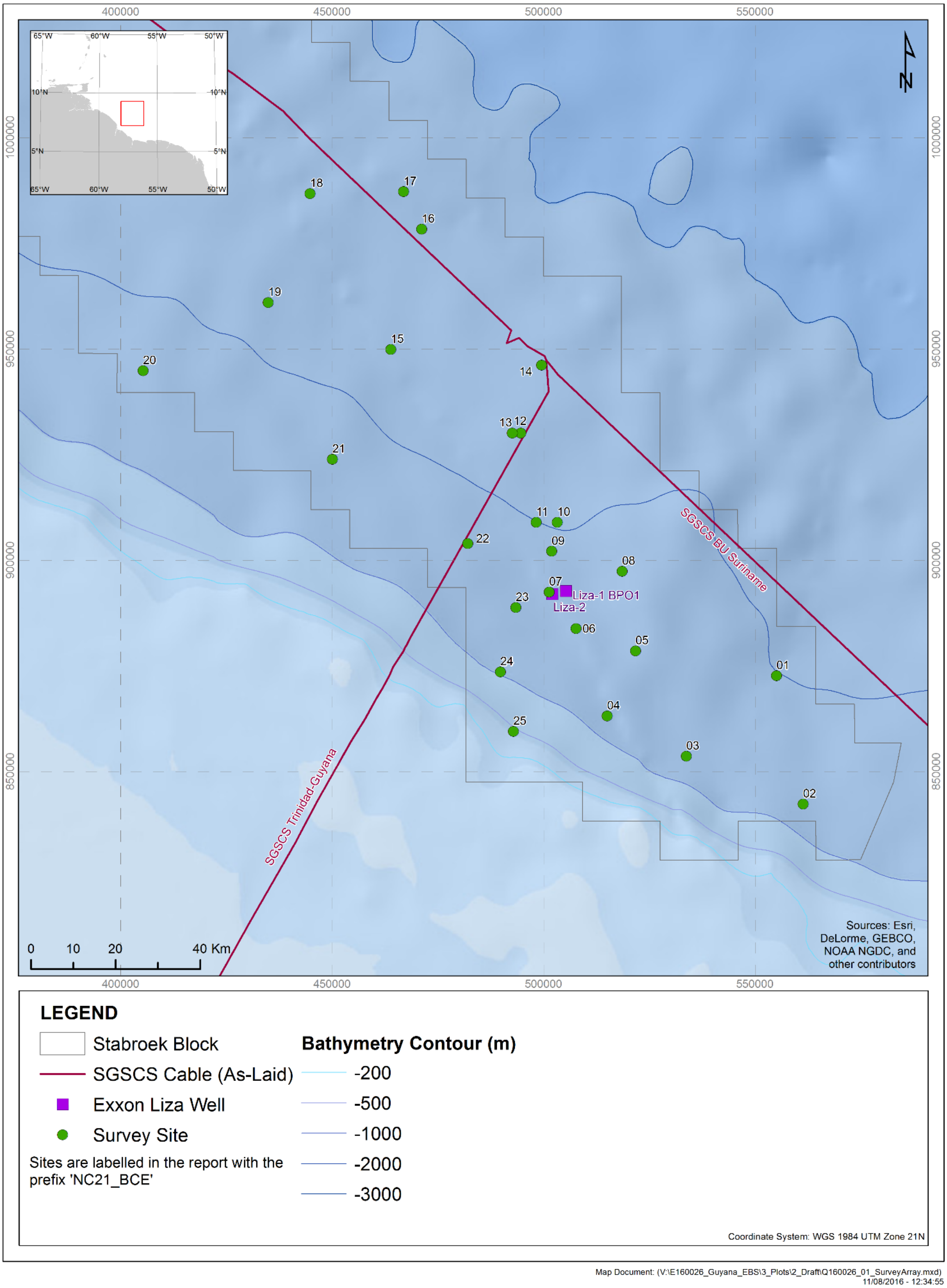


Figure 3.1: Survey area bathymetry and environmental survey stations

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.

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%).

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	TOC
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

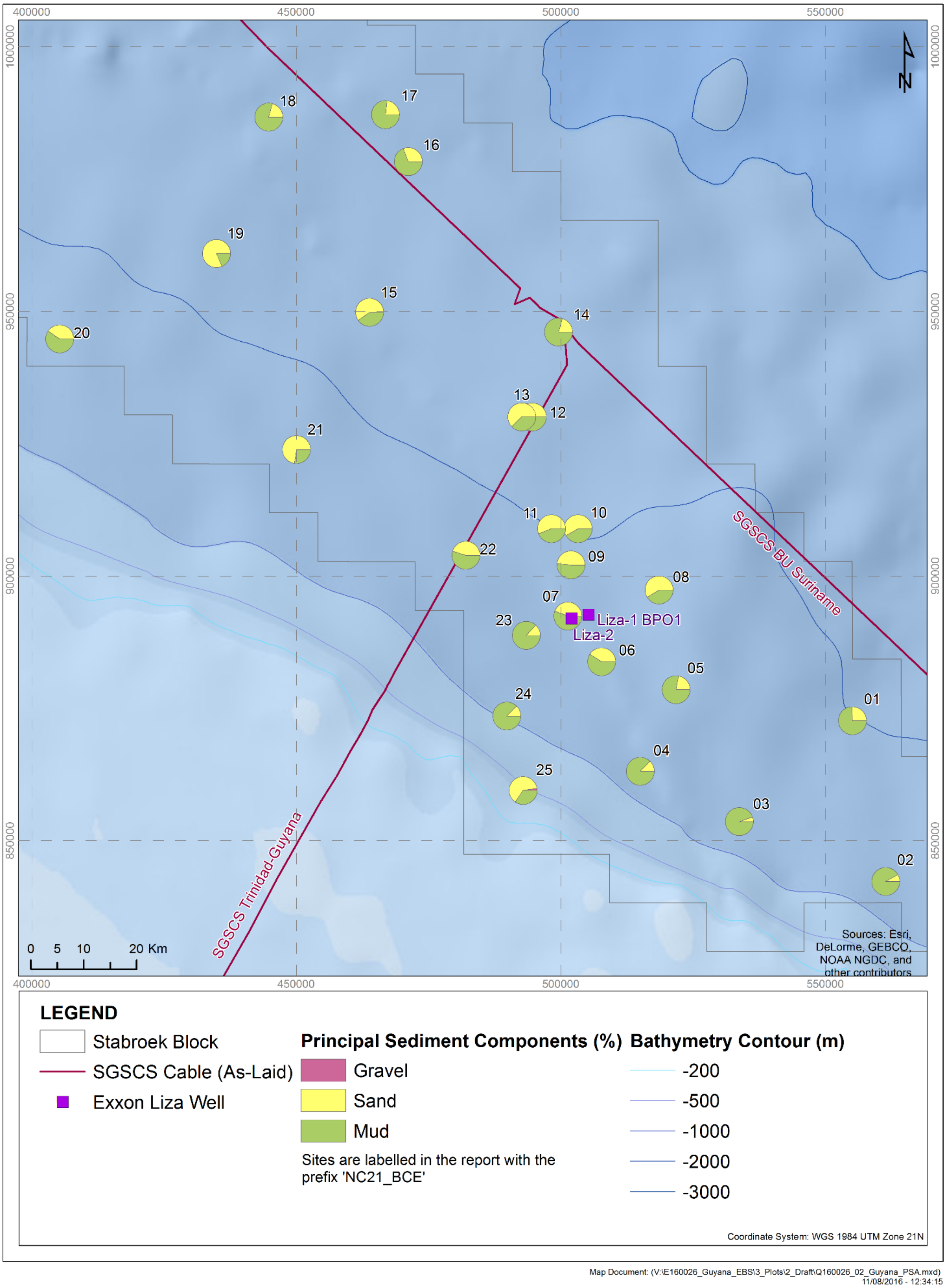


Figure 3.2: Spatial distribution of sediment characteristics

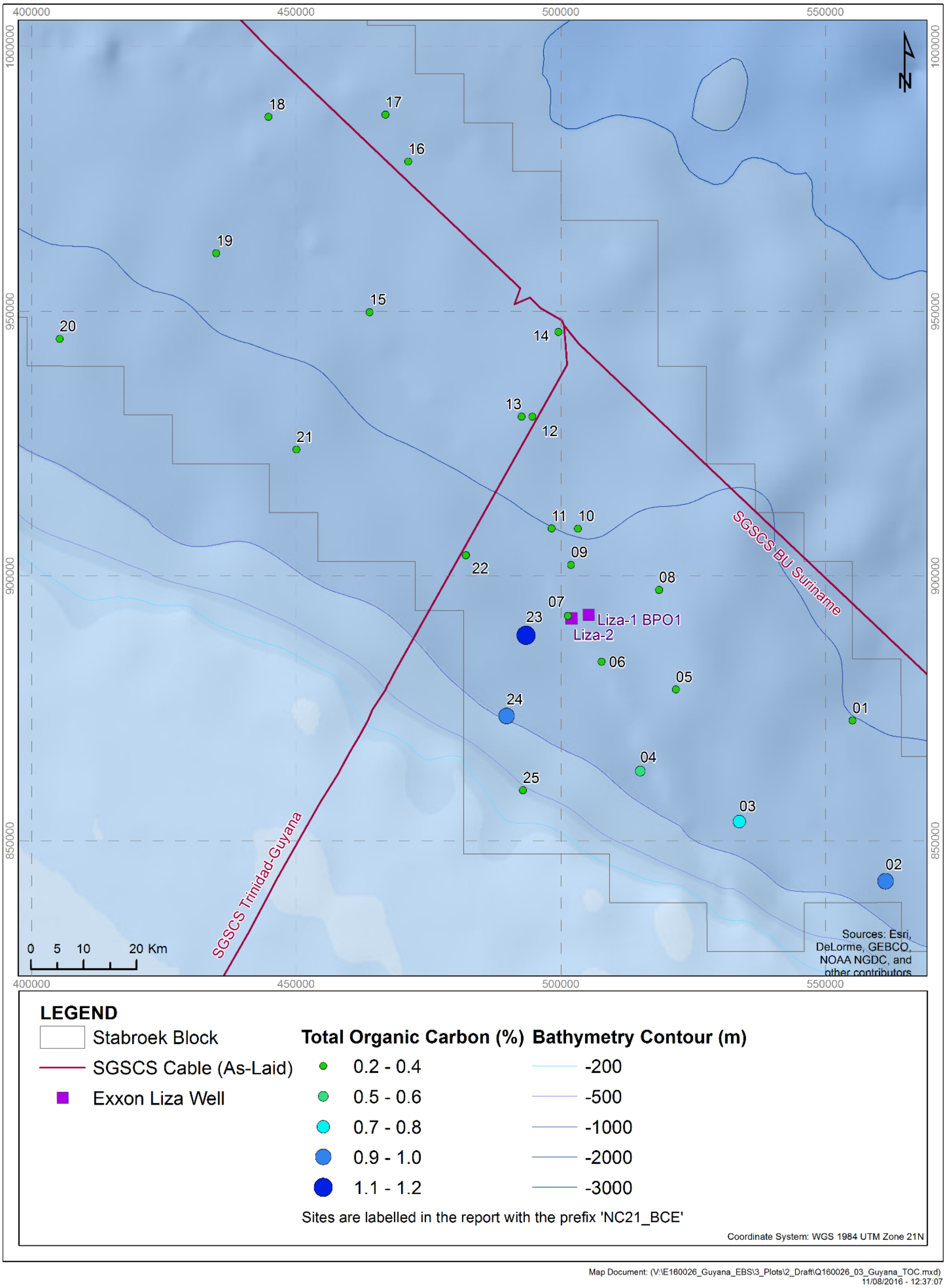


Figure 3.3: Spatial distribution of total organic carbon

3.4 SPI Results

The following results have been extracted from the SPI survey report (Aquafact, 2016). 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. 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 3.3: 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
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).

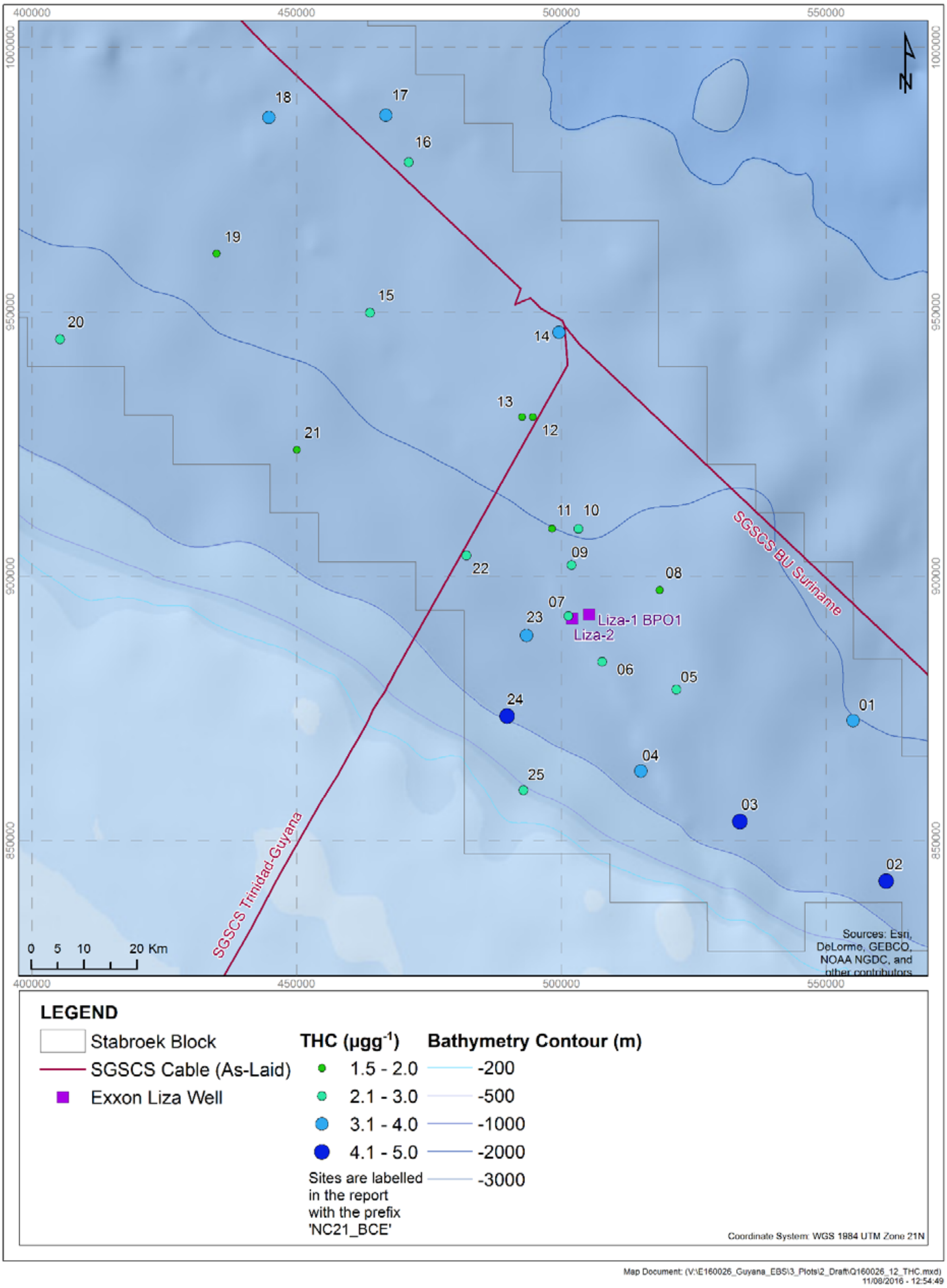


Figure 3.4: Spatial distribution of total hydrocarbon (THC) concentrations [ugg^{-1}]

Table 3.4: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**

3.5.1.1 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.

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 3.5: 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**

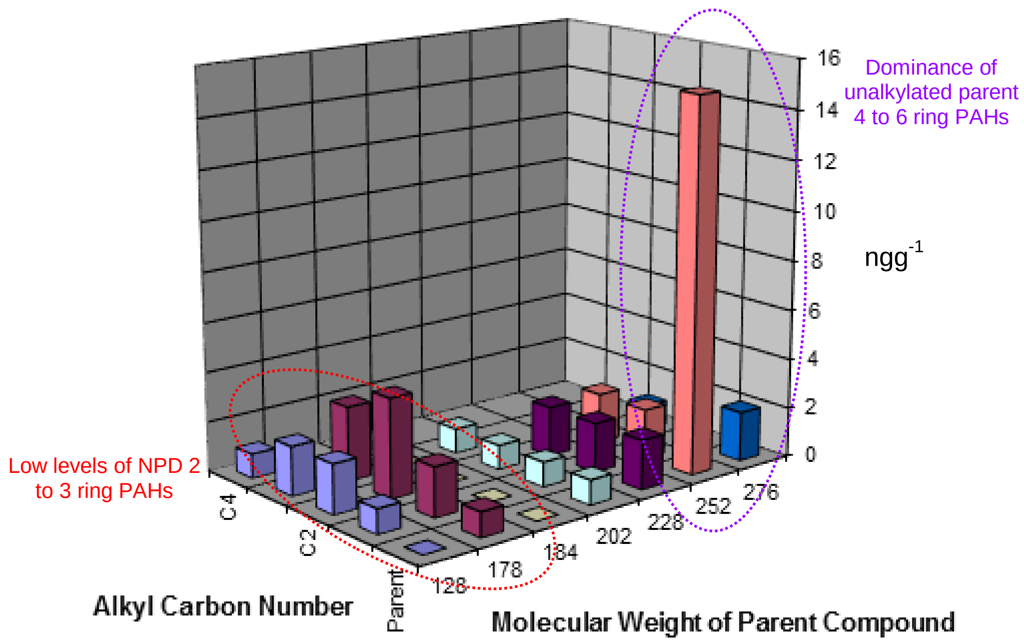
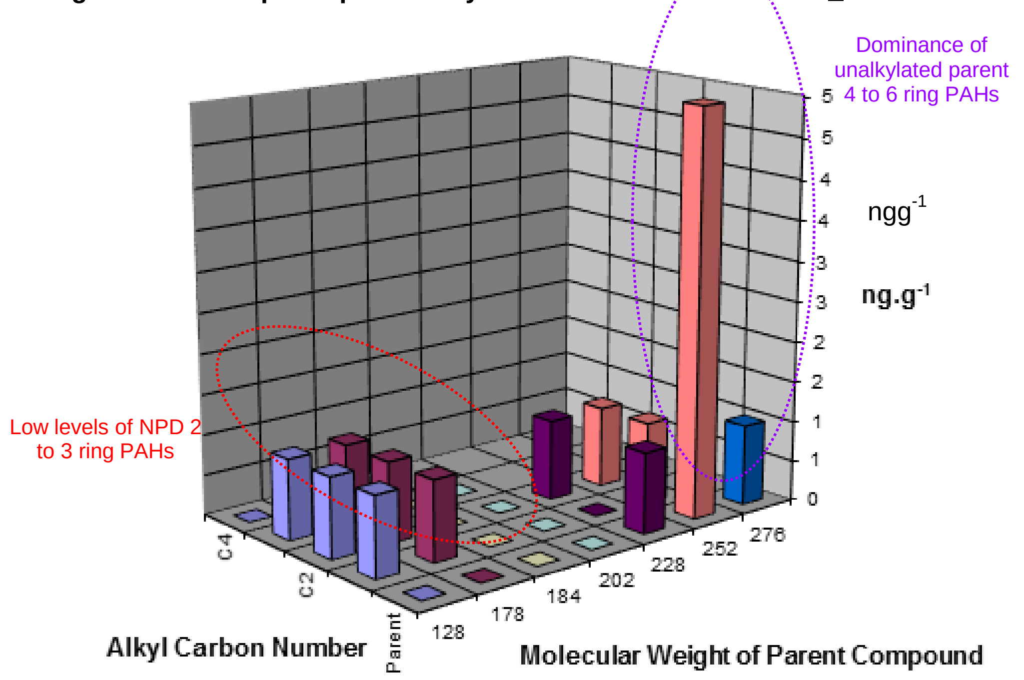


Figure 3.5: Example of parent/alkyl distribution - station NC21_BCE001

Figure 3.6: Example of parent/alkyl distribution - station NC21_BCE019



3.5.1.2 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 3.6: 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 μgg^{-1} at station NC21_BCE019 to 0.255 μgg^{-1} at station NC21_BCE002 (mean 0.120 μgg^{-1}). Nickel (Ni) levels for the sample stations ranged from 10.8 μgg^{-1} at station NC21_BCE019 to 51.5 μgg^{-1} at station NC21_BCE003 (mean 27.0 μgg^{-1}). Mercury (Hg) levels ranged from 0.0161 μgg^{-1} at station NC21_BCE025 to 0.0420 μgg^{-1} at station NC21_BCE003 (mean 0.0285 μgg^{-1}).

Chromium (Cr) concentrations in the sediments ranged from 14.5 μgg^{-1} at station NC21_BCE019 to 53.4 μgg^{-1} at station NC21_BCE025 (mean 36.1 μgg^{-1}). Copper (Cu) levels ranged from 6.88 μgg^{-1} at station NC21_BCE025 to 30.5 μgg^{-1} at station NC21_BCE017 (mean 20.2 μgg^{-1}). Lead (Pb) levels ranged from 9.85 μgg^{-1} at station NC21_BCE019 to 27.5 μgg^{-1} at station NC21_BCE025 (mean 15.5 μgg^{-1}). Finally, zinc levels ranged from 32.5 μgg^{-1} at station NC21_BCE019 to 101 μgg^{-1} at station NC21_BCE024 (mean 69.7 μgg^{-1}).

Barium (Ba) levels ranged from 43.7μgg^{-1} (station NC21_BCE019) to 272 μgg^{-1} (station NC21_BCE003), mean 175 μgg^{-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 μgg^{-1} at station NC21_BCE012 to 97.10 μgg^{-1} at station NC21_BCE025, the mean concentration was 11.59 μgg^{-1}.

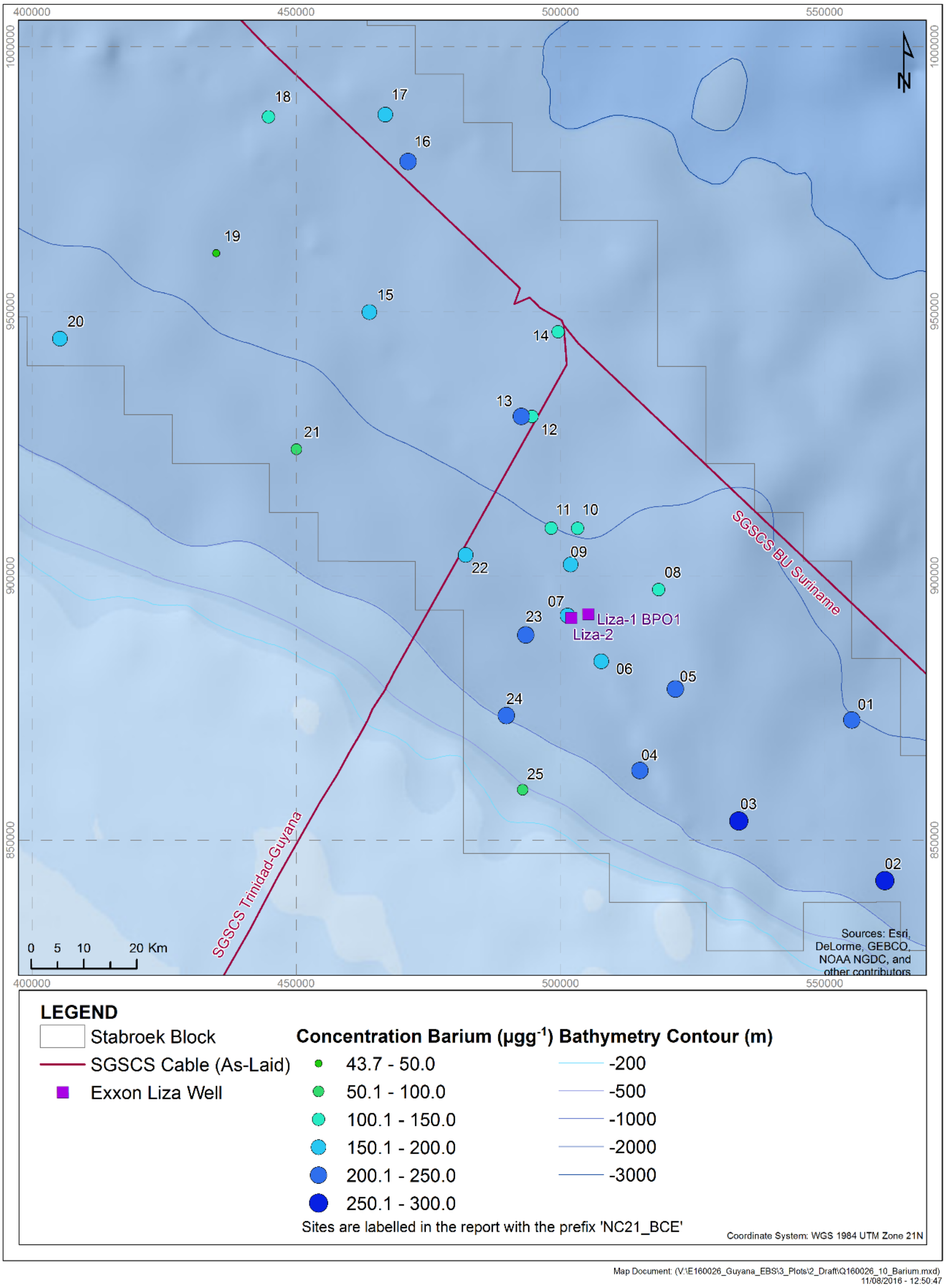


Figure 3.7: Spatial distribution of barium concentrations [ugg^{-1}]

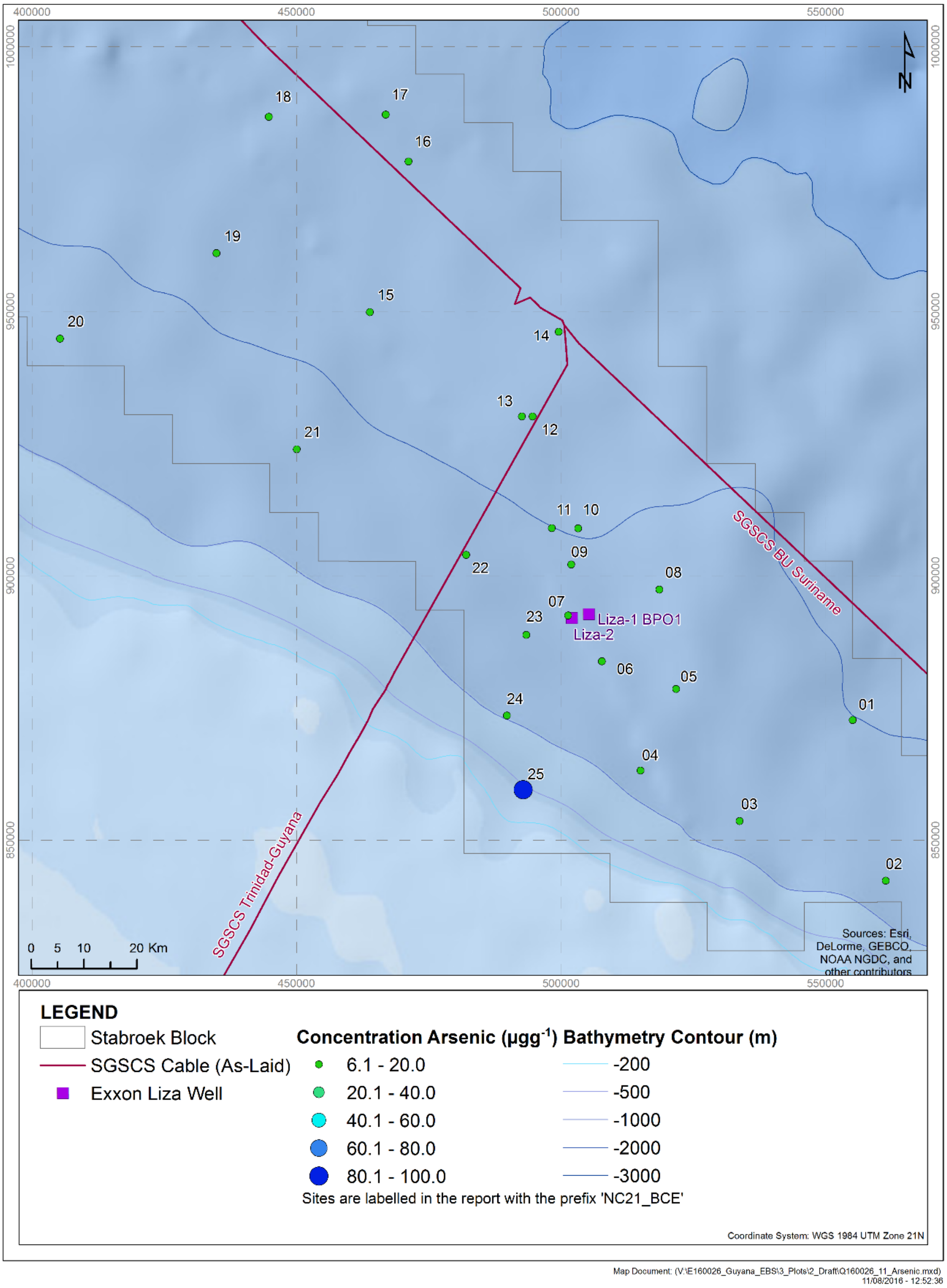


Figure 3.8: Spatial distribution of arsenic concentrations [ugg^{-1}]

Table 3.7: 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 3.8: 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).

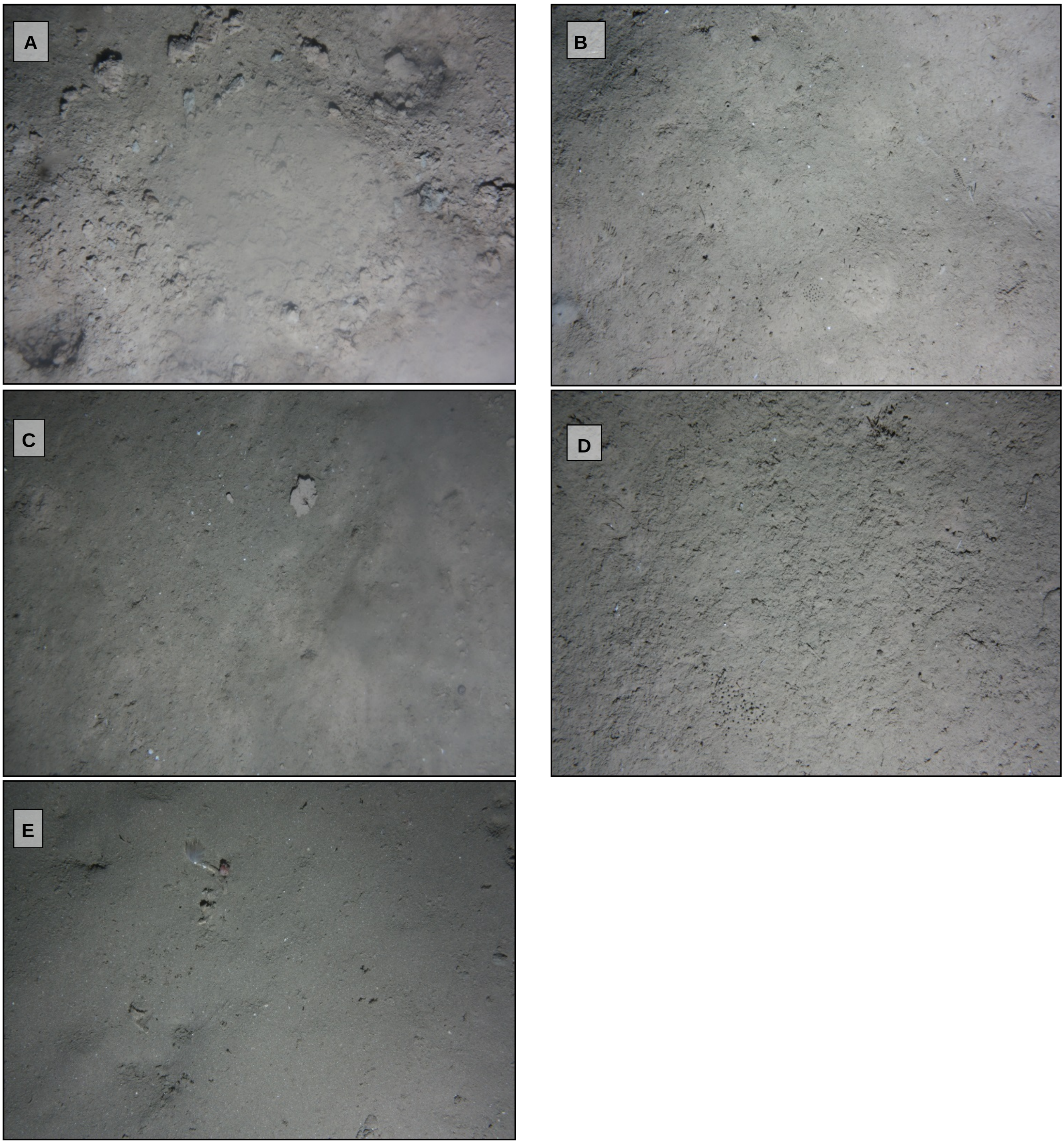


Photo A:	Station NC21_BCE002; *Mud*, *tube building polychaetes and amphipods, mud shrimp burrows, Scaphopoda (tusk shells), gastropods, foraminiferans*
Photo B:	Station NC21_BCE004; *Sandy Mud*, *tube building polychaetes and amphipods, mud shrimp burrows, foraminiferans. Unidentified hydroid*
Photo 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.

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 3.9: 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**

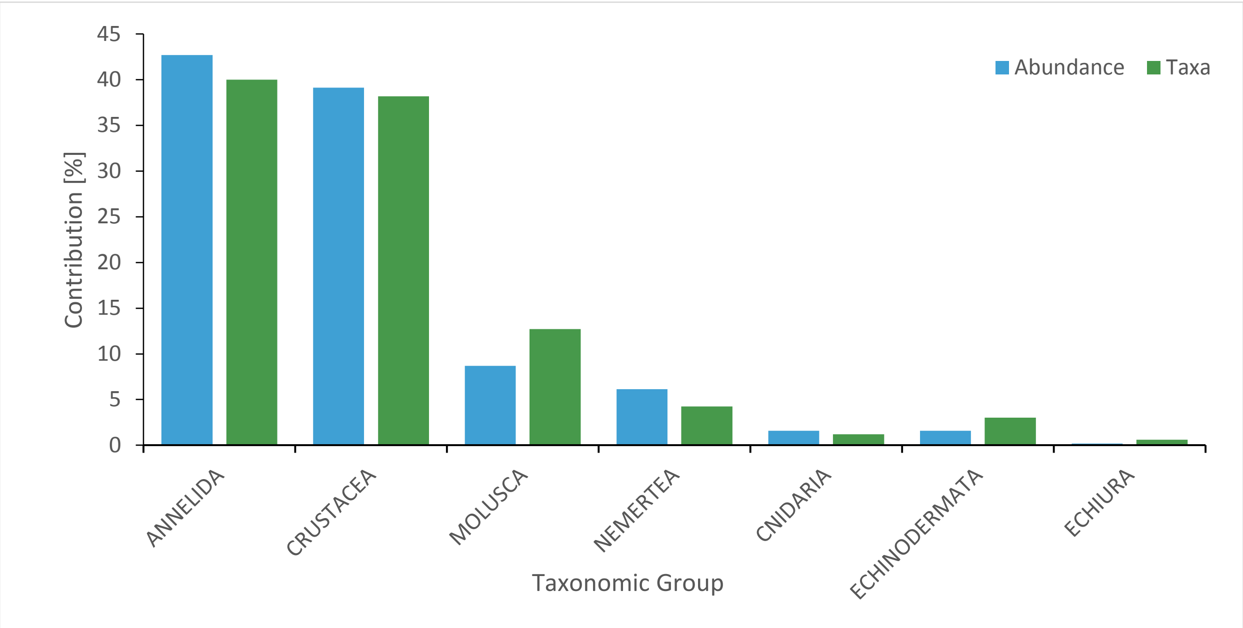


Figure 3.9: Abundance of major taxonomic groups

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 3.10: 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.

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. 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.

3.8.4.1 <u>Relationships between Physical and Biological Variables</u>

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%).

Table 3.11: Primary Variables and Diversity Indices by Sample [0.1 m²]

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).

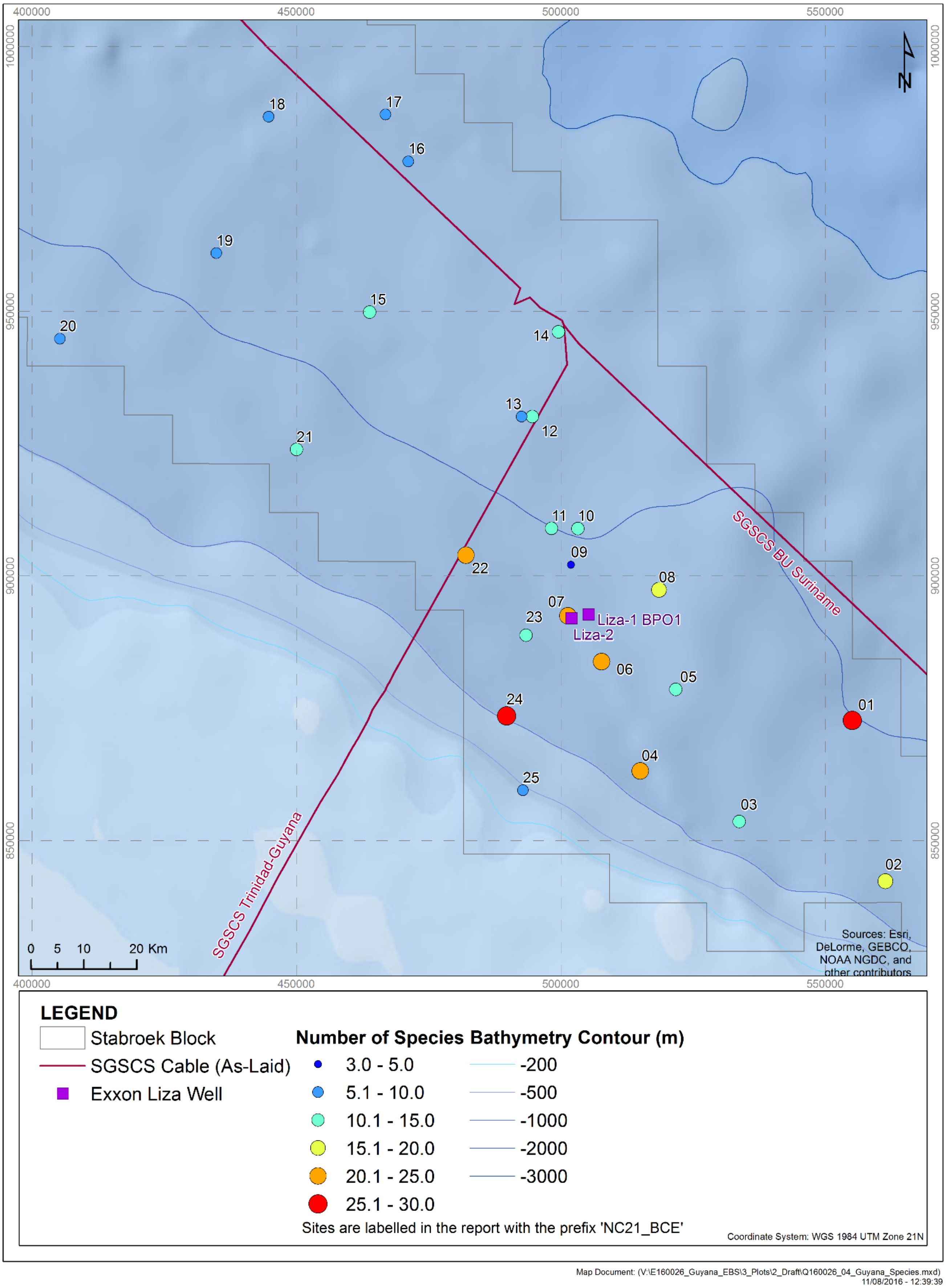


Figure 3.10: Spatial distribution of number of taxa (S) [0.1 m^2]

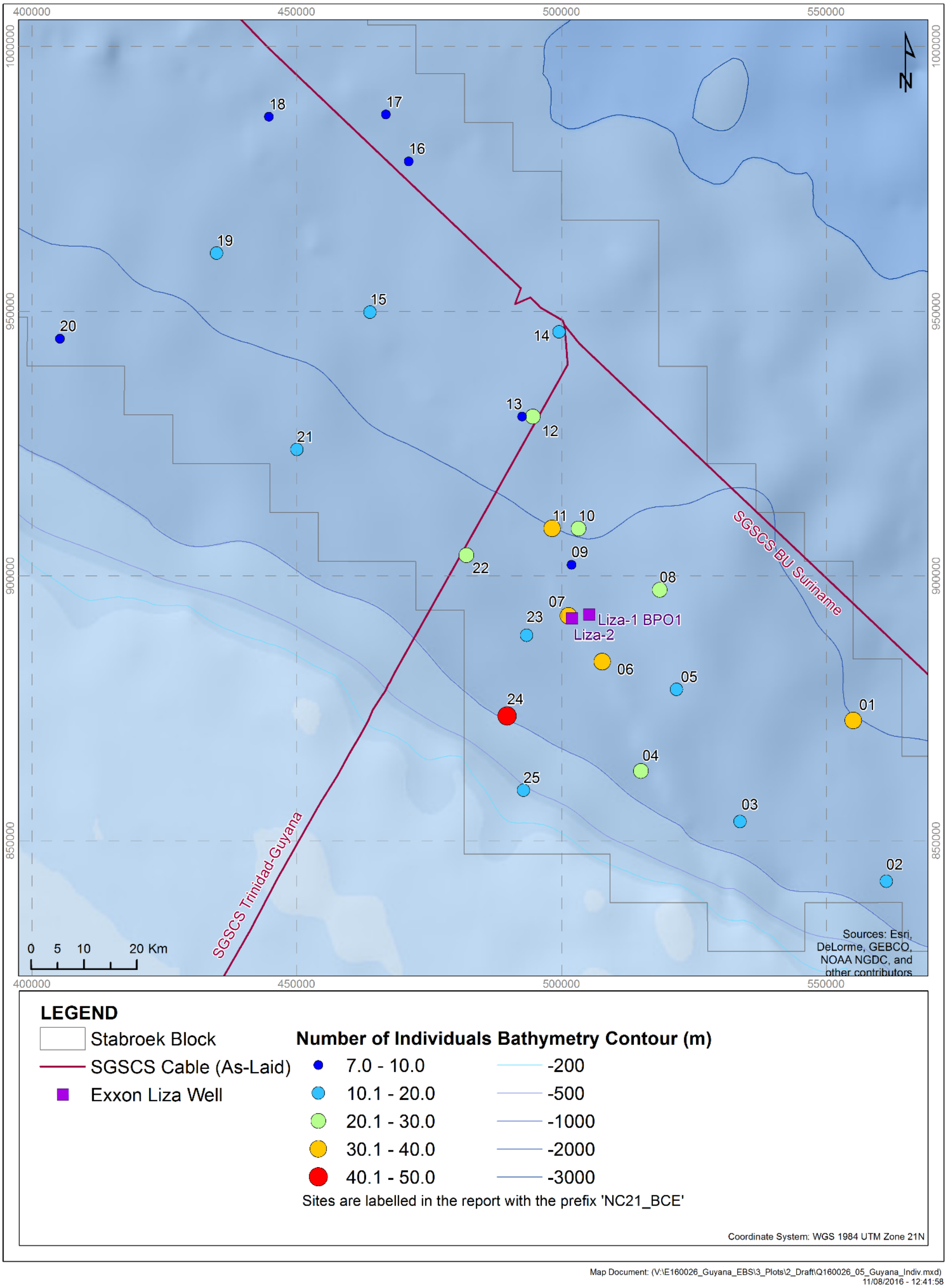


Figure 3.11: Spatial distribution of number of individuals (N) [0.1 m^2]

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.

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.

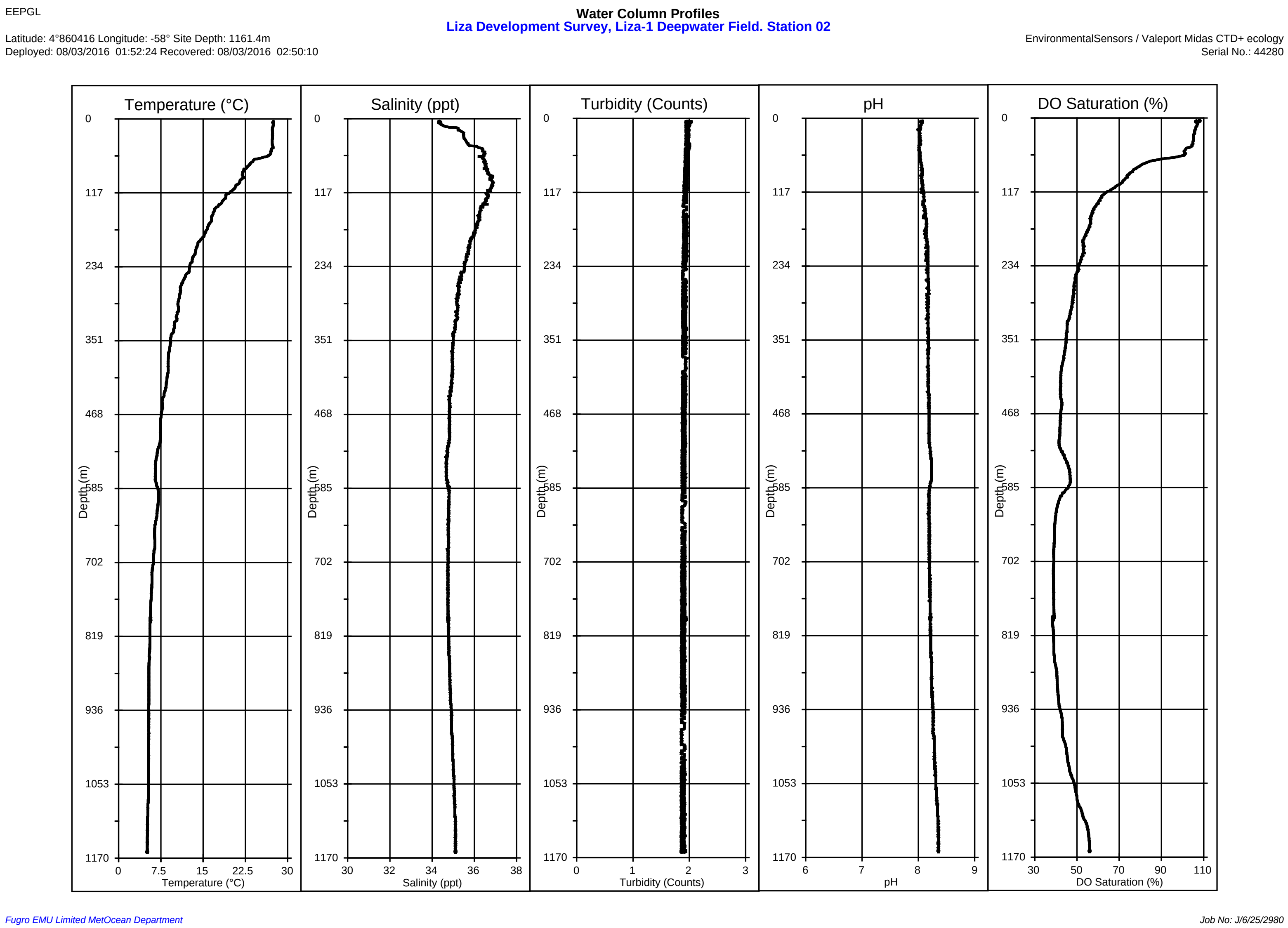


Figure 3.12: Water column profile at sampling station NC21_16WC002

Table 3.12: 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 3.13: 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 3.14: 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 3.15. 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 3.16: 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
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 3.17: 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 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.

Table 3.18: 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 3.19: 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 3.20: Summary of Water Sample Heavy Metal Analysis

Concentrations Expressed as $\mu g l^{-1}$										
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
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

Concentrations Expressed as µgl⁻¹										
Station	**Depth**	**Cadmium**	**Copper**	**Lead**	**Zinc**	**Barium**	**Iron**	**Mercury**	**Chromium**	**Arsenic**
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.

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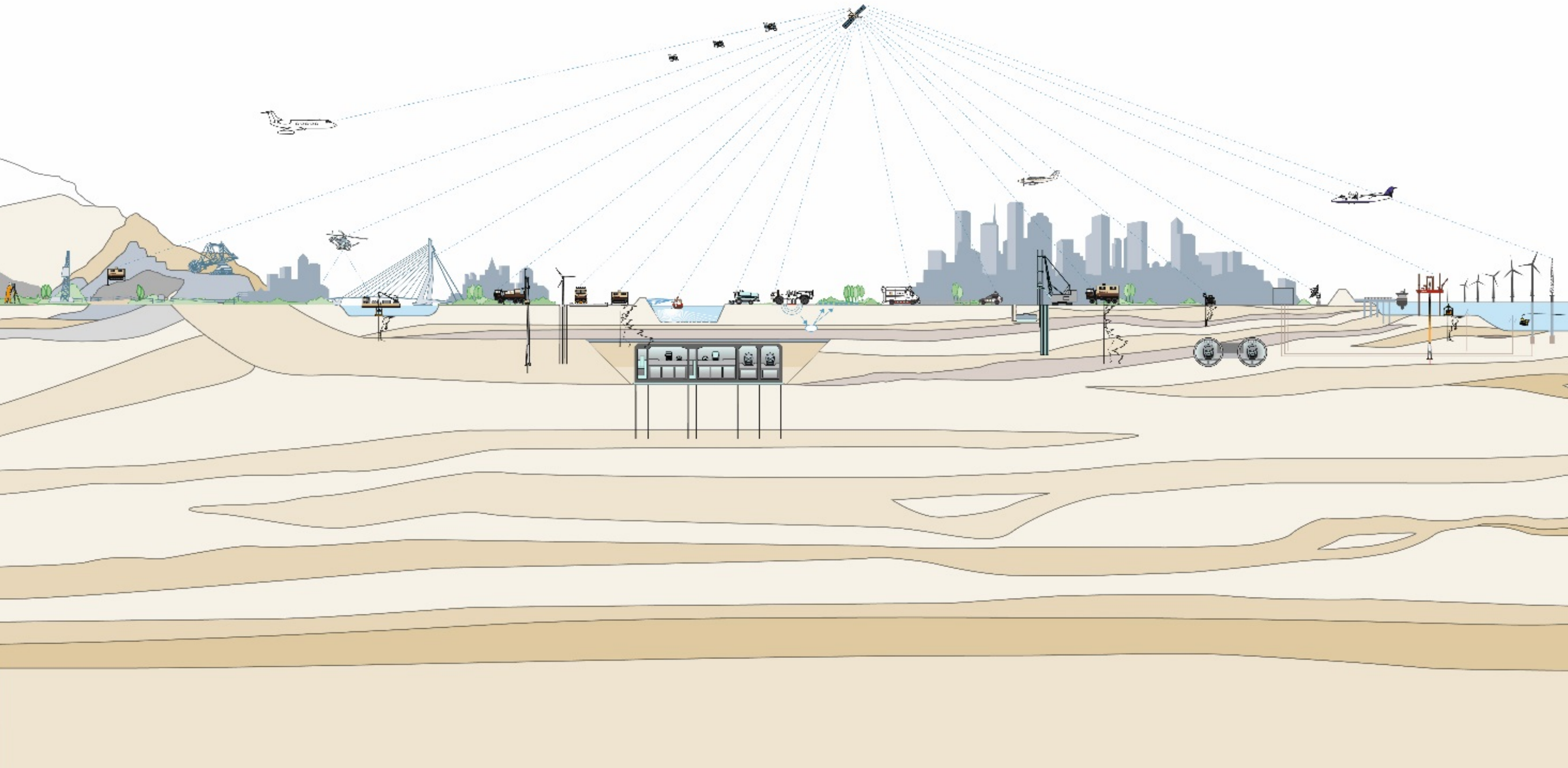

APPENDIX G – Flora and Fauna of Shell Beach

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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*

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*
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*
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*
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 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*
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 H – IUCN Listed Species

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Common Name	Scientific Name	Species Status
Spotted Eagle Ray	*Aetobatus narinari*	NT
Agami heron	*Agamia agami*	VU
Common Thresher Shark	*Alopias vulpinus*	VU
Foureyed Flounder	*Ancylopsetta kumperae*	DD
Bryde's Whale	*Balaenoptera edeni*	DD
Gray Tiggerfish	*Balistes capriscus*	VU
Blackbelly Skate	*Breviraja nigriventralis*	DD
Semipalmated Sandpiper	*Calidris pusilla*	NT
Blacknose Shark	*Carcharhinus acronotus*	NT
Spinner Shark	*Carcharhinus brevipinna*	NT
Silky Shark	*Carcharhinus falciformis*	NT
Bull Shark	*Carcharhinus leucas*	NT
Blacktip Shark	*Carcharhinus limbatus*	NT
Oceanic Whitetip Shark	*Carcharhinus longimanus*	VU
Dusky Shark	*Carcharhinus obscurus*	VU
Caribbean Reef Shark	*Carcharhinus perezi*	NT
Smalltail Shark	*Carcharhinus porosus*	DD
Night Shark	*Carcharhinus signatus*	VU
Green Turtle	*Chelonia mydas*	EN
Frilled Shark	*Chlamydoselachus anguineus*	NT
Hollowsnout Grenadier	*Coelorinchus caelorhincus*	DD
Hookskate	*Dactylobatus clarkii*	DD
Southern Stingray	*Dasyatis americana*	DD
Sharpsnout Stingray	*Dasyatis geijskesi*	NT
Red hogfish	*Decodon puellaris*	DD
Long-beaked Common Dolphin	*Delphinus capensis*	DD
Sickelfish Grouper	*Dermatolepis inermis*	NT
Leatherback	*Dermochelys coriacea*	VU
Variegated Electric Ray	*Diplobatis pictus*	VU
Malacho	*Elops smithi*	DD
Atlantic Goliath Grouper	*Epinephelus itajara*	CE
Red Grouper	*Epinephelus morio*	NT
Nassau Grouper	*Epinephelus striatus*	EN
Pluto Skate	*Fenestraja plutonia*	DD
Pygmy Killer Whale	*Feresa attenuata*	DD
Tiger Shark	*Galeocerdo cuvier*	NT
Nurse Shark	*Ginglymostoma cirratum*	DD
Short-finned Pilot Whale	*Globicephala macrorhynchus*	DD
Spiny Butterfly Ray	*Gymnura altavela*	VU

Common Name	Scientific Name	Species Status
Smooth Butterfly Ray	*Gymnura micrura*	DD
Striped Grunt	*Haemulon striatum*	DD
Bigeyed Sixgill Shark	*Hexanchus nakamurai*	DD
Chupare Stingray	*Himantura schmardae*	DD
	Holothuria arenicola	DD
Poey's Grouper	*Hyporthodus flavolimbatus*	VU
Spotted Grouper	*Hyporthodus niveatus*	VU
Daggernose Shark	*Isogomphodon oxyrhynchus*	CE
Shortfin Mako	*Isurus oxyrinchus*	VU
White Marlin	*Kajikia albida*	VU
Pygmy Sperm Whale	*Kogia breviceps*	DD
Dwarf Sperm Whale	*Kogia sima*	DD
Hogfish	*Lachnolaimus maximus*	VU
Olive Ridley	*Lepidochelys olivacea*	VU
Neotropical Otter	*Lontra longicaudis*	DD
Golden Tilefish	*Lopholatilus chamaeleonticeps*	EN
Mutton snapper	*Lutjanus analis*	VU
Cubera Snapper	*Lutjanus cyanopterus*	VU
Giant Manta Ray	*Manta birostris*	VU
Tarpon	*Megalops atlanticus*	VU
Blainville's Beaked Whale	*Mesoplodon densirostris*	DD
Ocean Sunfish	*Mola mola*	VU
Yellowfin Grouper	*Mycteroperca venenosa*	NT
Bullnose Ray	*Myliobatis freminvillii*	DD
Southern Eagle Ray	*Myliobatis goodei*	DD
Caribbean Electric Ray	*Narcine bancroftii*	CE
Lemon Shark	*Negaprion brevirostris*	NT
Killer Whale	*Orcinus orca*	DD
Caribbean Spiny Lobster)	*Panulirus argus*	DD
Smoothtail Spiny Lobster	*Panulirus laevicauda*	DD
Sperm Whale	*Physeter macrocephalus*	VU
Blue Shark	*Prionace glauca*	NT
Largetooth Sawfish	*Pristis pristis*	CE
False Killer Whale	*Pseudorca crassidens*	DD
Giant Otter	*Pteronura brasiliensis*	EN
Venezuela Skate	*Raja cervigoni*	NT
Whale Shark	*Rhincodon typus*	VU
Southern Guitarfish	*Rhinobatos percellens*	NT
Cownose Ray	*Rhinoptera bonasus*	NT
Brazilian Sharpnose Shark	*Rhizoprionodon lalandii*	DD

Common Name	Scientific Name	Species Status
Gillbacker Sea Catfish	*Sciades parkeri*	NT
Three-spot Slipper Lobster	*Scyllarides delfosi*	DD
Guiana Dolphin	*Sotalia guianensis*	DD
Scalloped Hammerhead	*Sphyrna lewini*	EN
Scoophead Shark	*Sphyrna media*	DD
Squat-headed Hammerhead Shark	*Sphyrna mokarran*	EN
Smalleye Hammerhead Shark	*Sphyrna tudes*	VU
Roundscale Spearfish	*Tetrapturus georgii*	DD
Albacore Tuna	*Thunnus alalunga*	NT
Yellowfin Tuna	*Thunnus albacares*	NT
Bigeye Tuna	*Thunnus obesus*	VU
Atlantic Bluefin Tuna	*Thunnus thynnus*	EN
Great Torpedo Ray	*Torpedo nobiliana*	DD
West Indian Manatee	*Trichechus manatus*	VU

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APPENDIX I – Birds of Guyana

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A Field Checklist of the Birds of Guyana

2nd Edition

Michael J. Braun
Davis W. Finch
Mark B. Robbins
and
Brian K. Schmidt

Smithsonian Institution

USAID
FROM THE AMERICAN PEOPLE

A Field Checklist of the Birds of Guyana

2nd Edition

by

Michael J. Braun,
Davis W. Finch,
Mark B. Robbins,
and
Brian K. Schmidt

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Cover Illustration:

Guyana's national bird, the Hoatzin or Canje Pheasant, O*pisthocomus hoazin,* by Dan Lane.

INTRODUCTION

This publication presents a comprehensive list of the birds of Guyana with summary information on their habitats, biogeographical affinities, migratory behavior and abundance, in a format suitable for use in the field. It should facilitate field identification, especially when used in conjunction with an illustrated work such as *Birds of Venezuela* (Hilty 2003). It is part of a series of comprehensive lists of the flora and fauna of Guyana being developed by the Smithsonian Institution's Biological Diversity of the Guiana Shield Program and the Centre for the Study of Biological Diversity, University of Guyana (Boggan *et al.* 1997, Hollowell & Reynolds 2005, www.nmnh.si.edu/biodiversity/bdg.htm).

The first edition of this list (Braun *et al*. 2000) included 786 species. The list presently stands at 814 species that have been documented as occurring in Guyana. It builds upon the long out-of-print work of Snyder (1966), who listed 720 species. Her list is largely treated as authoritative, but 10 species are removed for lack of concrete documentation. These are *Tinamus tao, Butorides virescens, Patagioenas fasciata, Crotophaga sulcirostris, Pharomachrus fulgidus, Iodopleura pipra, Tangara peruviana, Loxigilla noctis, Sporophila hypochroma* and *Gymnomystax mexicanus*. Species included are those whose occurrence in the country is supported by physical evidence (specimen, photograph, sound recording, or band recovery) or written documentation of a sight record by a reliable, experienced observer (see below). The nomenclature follows *A Classification of the Bird Species of South America* (Remsen *et al*. 2007).

DEFINITIONS

Abbreviations and symbols are used for various categories of habitat, endemism, migration and abundance. The endemism and habitat codes follow Stotz *et al*. (1996); some habitat codes are modified to reflect the authors' experience in Guyana. Figure 1 (inside back cover) shows the distribution of principal habitats in Guyana.

HABITAT CODES

LF	Lowland forest, including both *terra firme* and seasonally flooded forest.
MF	Montane forest.
RI	Riverine habitats, including the river and their islands, banks, waterfalls, and riparian forests.
MA	Marine or salt water habitats, including coastal and pelagic waters.
MU	Mudflats and coastal beaches.

FW Fresh water habitats, including lakes, impoundments, ponds, oxbows, marshes, and canals.
MN Mangrove forest.
HU Habitats altered by humans, such as gardens, towns, roadsides, agricultural lands, disturbed forests and forest edge.
SV Savanna grasslands.
SC Scrub or brush habitats, including white sand scrub, bush islands, and dense, low second growth.
PA Palm trees and forests.

Endemism and Migration Codes (EN/MI)

GUI Restricted to the Guianas and adjacent Venezuela and Brazil.
TEP Restricted to the tepui highlands of Venezuela, Brazil and Guyana. In Guyana, these include the Pacaraima and Merume Mountains.
AMN Restricted to Amazonian (and Guianan) lowlands north of the Amazon.
NEA Nearctic migrant; except for shorebirds, these occur September-May and are absent in the northern summer months of June-August.
AUS Austral migrant; typically present May- September.

Abundance Codes (ABU)

C Common; more than 20 individuals encountered daily in prime habitat and season.
F Fairly common; 5-20 individuals encountered daily in prime habitat and season.
U Uncommon; present in small numbers (fewer than 5 individuals per day); not encountered daily even in prime habitat and season.
S Scarce; only occasionally encountered in small numbers even in prime habitat and season.
? Occurs in Guyana but status unclear due to scarcity of data.
E Extirpated; no longer occurs, probably as a result of hunting (Horned Screamer).
† Extinct (Eskimo Curlew).
L Local; used with other abundance codes to indicate that a species' distribution in the country is patchy and that it is absent from large areas of apparently suitable habitat.
[ ] Sight records only (24 species).
* Reported for Guyana, but needs verification (14 species).

DOCUMENTING NEW RECORDS

While this list contains new information, much remains to be learned. Every effort should be made to document species not on this list, as well as those marked by brackets or asterisks, or with an abundance code of "?". Copies of photographs, tape recordings and/or written details of sight records may be sent to the first author. These should include date, time, specific locality, observers' names and addresses, description of size, shape and color pattern with specific field marks used to eliminate similar species, habitat, behavior, light conditions, optical equipment and previous experience of the observers with the species in question and its relatives.

Documenting new or unusual distributional records of birds is only the beginning. Little is known of the habitat, behavior, migration, breeding and ecology of many Neotropical birds. New and significant discoveries await any keen observer with a pair of binoculars and a field guide! We hope this publication will generate new information on the status and distribution of Guyana's birdlife and result in an increased commitment to its preservation.

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	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU
	Tinamous **Tinamidae**			
	1 **Great Tinamou** *Tinamus major*	LF		F
	2 **Cinereous Tinamou** *Crypturellus cinereus*	LF, SC		F
	3 **Little Tinamou** *Crypturellus soui*	SC, LF		F
	4 **Undulated Tinamou** *Crypturellus undulatus*	LF		F
	5 **Red-legged Tinamou** *Crypturellus erythropus*	LF, SC		U
	6 **Variegated Tinamou** *Crypturellus variegatus*	LF		F
	7 **Rusty Tinamou** *Crypturellus brevirostris*	LF, MF		S
	Screamers **Anhimidae**			
	8 **Horned Screamer** *Anhima cornuta*	FW		E
	Ducks, Geese **Anatidae**			
	9 **Fulvous Whistling-Duck** *Dendrocygna bicolor*	FW		S
	10 **White-faced Whistling-Duck** *Dendrocygna viduata*	FW		C
	11 **Black-bellied Whistling-Duck** *Dendrocygna autumnalis*	FW		C
	12 **Orinoco Goose** *Neochen jubata*	RI, FW		S
	13 **Muscovy Duck** *Cairina moschata*	FW, RI		C
	14 **Comb Duck** *Sarkidiornis melanotos*	FW		S
	15 **Brazilian Teal** *Amazonetta brasiliensis*	FW		C
	16 **Northern Pintail** *Anas acuta*	FW	NEA	S
	17 **White-cheeked Pintail** *Anas bahamensis*	FW, MN		S
	18 **Blue-winged Teal** *Anas discors*	FW	NEA	S
	19 **Masked Duck** *Nomonyx dominicus*	FW		U
	Curassows, Guans **Cracidae**			
	20 **Variable Chachalaca** *Ortalis motmot*	LF, SC		C
	21 **Marail Guan** *Penelope marail*	LF	GUI	U
	22 **Spix's Guan** *Penelope jacquacu*	LF		F
	23 **Blue-throated Piping-Guan** *Pipile cumanensis*	LF, MF		FL
	24 **Crestless Curassow** *Mitu tomentosum*	RI, LF	AMN	UL
	25 **Black Curassow** *Crax alector*	LF, MF	AMN	F
	Quails **Odontophoridae**			
	26 **Crested Bobwhite** *Colinus cristatus*	SV, SC, HU		F
	27 **Marbled Wood-Quail** *Odontophorus gujanensis*	LF		F
	Grebes **Podicipedidae**			
	28 **Least Grebe** *Tachybaptus dominicus*	FW		F
	29 **Pied-billed Grebe** *Podilymbus podiceps*	FW		S
	Shearwaters **Procellariidae**			
	30 **Cory's Shearwater** *Calonectris diomedea*	MA		?
	31 **Greater Shearwater** *Puffinus gravis* *	MA		?
	32 **Audubon's Shearwater** *Puffinus lherminieri*	MA		?
	Storm-Petrels **Hydrobatidae**			
	33 **Wilson's Storm-Petrel** *Oceanites oceanicus*	MA		?
	34 **Leach's Storm-Petrel** *Oceanodroma leucorhoa*	MA		?
	Pelicans **Pelecanidae**			
	35 **Brown Pelican** *Pelecanus occidentalis*	MA		F
	Boobies **Sulidae**			
	36 **Brown Booby** *Sula leucogaster*	MA		?

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	Cormorants **Phalacrocoracidae**			
	37 **Neotropic Cormorant** *Phalacrocorax brasilianus*	FW, RI		C
	Anhingas **Anhingidae**			
	38 **Anhinga** *Anhinga anhinga*	FW, RI		C
	Frigatebirds **Fregatidae**			
	39 **Magnificent Frigatebird** *Fregata magnificens*	MA, MN		C
	Herons **Ardeidae**			
	40 **Rufescent Tiger-Heron** *Tigrisoma lineatum*	FW		F
	41 **Fasciated Tiger-Heron** *Tigrisoma fasciatum*	RI		S
	42 **Agami Heron** *Agamia agami*	LF, RI		U
	43 **Boat-billed Heron** *Cochlearius cochlearius*	FW, MN		F
	44 **Zigzag Heron** *Zebrilus undulatus*	LF, RI		S
	45 **Pinnated Bittern** *Botaurus pinnatus*	FW		F
	46 **Least Bittern** *Ixobrychus exilis*	FW		F
	47 **Stripe-backed Bittern** *Ixobrychus involucris*	FW		?
	48 **Black-crowned Night-Heron** *Nycticorax nycticorax*	FW, MU		C
	49 **Yellow-crowned Night-Heron** *Nyctanassa violacea*	MN, FW, MU		U
	50 **Striated Heron** *Butorides striata*	FW, MN, RI		C
	51 **Cattle Egret** *Bubulcus ibis*	HU		C
	52 **Cocoi Heron** *Ardea cocoi*	FW, RI		C
	53 **Great Egret** *Ardea alba*	MU, FW		C
	54 **Capped Heron** *Pilherodius pileatus*	FW, RI		F
	55 **Tricolored Heron** *Egretta tricolor*	MN, MU		C
	56 **Snowy Egret** *Egretta thula*	MU, MN, FW		C
	57 **Little Blue Heron** *Egretta caerulea*	MN, MU, FW		C
	Ibises **Threskiornithidae**			
	58 **Scarlet Ibis** *Eudocimus ruber*	FW, MN, HU		C
	59 [**Glossy Ibis** *Plegadis falcinellus*] *	FW		?
	60 **Sharp-tailed Ibis** *Cercibis oxycerca*	FW, SV		F
	61 **Green Ibis** *Mesembrinibis cayennensis*	LF, RI		C
	62 **Bare-faced Ibis** *Phimosus infuscatus* *	FW		?
	63 **Buff-necked Ibis** *Theristicus caudatus*	FW, HU, SV		F
	64 **Roseate Spoonbill** *Platalea ajaja*	MU, FW		F
	Storks **Ciconiidae**			
	65 **Maguari Stork** *Ciconia maguari*	SV, HU, FW		F
	66 **Jabiru** *Jabiru mycteria*	FW, SV		F
	67 **Wood Stork** *Mycteria americana*	FW		C
	Vultures **Cathartidae**			
	68 **Turkey Vulture** *Cathartes aura*	HU, SC, SV		C
	69 **Lesser Yellow-headed Vulture** *Cathartes burrovianus*	SV,SC, FW		C

	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU
	70 **Greater Yellow-headed Vulture** *Cathartes melambrotus*	LF		C
	71 **Black Vulture** *Coragyps atratus*	SC, HU		C
	72 **King Vulture** *Sarcoramphus papa*	LF, SV		F

Flamingos **Phoenicopteridae**

	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU
	73 **Greater Flamingo** *Phoenicopterus ruber*	MU, MA		?

Osprey **Pandionidae**

	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU
	74 **Osprey** *Pandion haliaetus*	MA, FW, RI	NEA	F

Hawks, Eagles **Accipitridae**

	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU
	75 **Gray-headed Kite** *Leptodon cayanensis*	LF		U
	76 **Hook-billed Kite** *Chondrohierax uncinatus*	LF, RI, MF		U
	77 **Swallow-tailed Kite** *Elanoides forficatus*	LF, MF		F
	78 **Pearl Kite** *Gampsonyx swainsonii*	SV, SC, HU		U
	79 **White-tailed Kite** *Elanus leucurus*	HU, SV, SC		F
	80 **Snail Kite** *Rostrhamus sociabilis*	FW, HU		C
	81 **Slender-billed Kite** *Helicolestes hamatus*	RI, FW		S
	82 **Double-toothed Kite** *Harpagus bidentatus*	LF, MF		U
	83 **Rufous-thighed Kite** *Harpagus diodon*	LF, MF	AUS?	S
	84 **Plumbeous Kite** *Ictinia plumbea*	LF		F
	85 **Long-winged Harrier** *Circus buffoni*	SV, SC, FW		U
	86 **Gray-bellied Hawk** *Accipiter poliogaster*	LF	AUS?	S
	87 **Tiny Hawk** *Accipiter superciliosus*	LF, MF		S
	88 **Sharp-shinned Hawk** *Accipiter striatus*	LF, MF		S
	89 **Bicolored Hawk** *Accipiter bicolor*	LF, SC, SV		U
	90 **Crane Hawk** *Geranospiza caerulescens*	LF		F
	91 **Black-faced Hawk** *Leucopternis melanops*	LF		U
	92 **White Hawk** *Leucopternis albicollis*	LF, MF		F
	93 **Common Black-Hawk** *Buteogallus anthracinus*	MN, PA		UL
	94 **Rufous Crab-Hawk** *Buteogallus aequinoctialis*	MN, HU		F
	95 **Great Black-Hawk** *Buteogallus urubitinga*	LF, RI		F
	96 **Savanna Hawk** *Buteogallus meridionalis*	SV, SC		C
	97 [**Solitary Eagle** *Harpyhaliaetus solitarius*] *	?		?
	98 **Black-collared Hawk** *Busarellus nigricollis*	FW, RI		F
	99 **Roadside Hawk** *Buteo magnirostris*	HU, SC		F
	100 [**Broad-winged Hawk** *Buteo platypterus*]	LF, MF		S
	101 **Gray Hawk** *Buteo nitidus*	SC, HU		F
	102 **Short-tailed Hawk** *Buteo brachyurus*	LF		U
	103 **White-tailed Hawk** *Buteo albicaudatus*	SV, SC		F
	104 **Zone-tailed Hawk** *Buteo albonotatus*	LF, SC		U
	105 **Crested Eagle** *Morphnus guianensis*	LF		S
	106 **Harpy Eagle** *Harpia harpyja*	LF		S
	107 **Black-and-white Hawk-Eagle** *Spizaetus melanoleucus*	LF, MF		U
	108 **Black Hawk-Eagle** *Spizaetus tyrannus*	LF, MF, PA		U
	109 **Ornate Hawk-Eagle** *Spizaetus ornatus*	LF, MF		U

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Falcons, Caracaras **Falconidae**

	110 **Black Caracara** *Daptrius ater*	RI, LF, SC		F
	111 **Red-throated Caracara** *Ibycter americanus*	LF		F
	112 **Southern Caracara** *Caracara plancus*	SV, HU, SC		C
	113 **Yellow-headed Caracara** *Milvago chimachima*	SV, SC, HU		F
	114 **Laughing Falcon** *Herpetotheres cachinnans*	LF, SC		U
	115 **Barred Forest-Falcon** *Micrastur ruficollis*	LF		U
	116 **Lined Forest-Falcon** *Micrastur gilvicollis*	LF		U
	117 **Slaty-backed Forest-Falcon** *Micrastur mirandollei*	LF		S
	118 **Collared Forest-Falcon** *Micrastur semitorquatus*	LF, SC		U
	119 **American Kestrel** *Falco sparverius*	SV, SC, HU		F
	120 [**Merlin** *Falco columbarius*]	HU, MU, SV	NEA	S
	121 **Bat Falcon** *Falco rufigularis*	LF, SC, RI		F
	122 **Orange-breasted Falcon** *Falco deiroleucus*	LF, MF		S
	123 **Aplomado Falcon** *Falco femoralis*	SV, SC		U
	124 **Peregrine Falcon** *Falco peregrinus*	MU, SC, HU	NEA	U

Limpkin **Aramidae**

	125 **Limpkin** *Aramus guarauna*	FW		F

Trumpeters **Psophiidae**

	126 **Gray-winged Trumpeter** *Psophia crepitans*	LF		F

Rails **Rallidae**

	127 **Speckled Crake** *Coturnicops notatus*	SV		S
	128 **Ocellated Crake** *Micropygia schomburgkii*	SV		U
	129 **Clapper Rail** *Rallus longirostris*	MN		F
	130 **Gray-necked Wood-Rail** *Aramides cajanea*	FW, MN, LF		F
	131 **Rufous-necked Wood-Rail** *Aramides axillaris*	MN, LF		U
	132 **Uniform Crake** *Amaurolimnas concolor*	LF		S
	133 **Russet-crowned Crake** *Anurolimnas viridis*	SV, SC		U
	134 **Rufous-sided Crake** *Laterallus melanophaius*	FW		F
	135 **Gray-breasted Crake** *Laterallus exilis*	FW, SV		S
	136 **Yellow-breasted Crake** *Porzana flaviventer*	FW		U
	137 **Ash-throated Crake** *Porzana albicollis*	FW		F
	138 **Sora** *Porzana carolina*	FW	NEA	S
	139 **Paint-billed Crake** *Neocrex erythrops*	HU, FW		U
	140 **Common Moorhen** *Gallinula chloropus*	FW		S
	141 **Purple Gallinule** *Porphyrio martinica*	FW		F
	142 **Azure Gallinule** *Porphyrio flavirostris*	FW		F

Finfoots **Heliornithidae**

	143 **Sungrebe** *Heliornis fulica*	FW, RI		F

Sunbittern **Eurypygidae**

	144 **Sunbittern** *Eurypyga helias*	RI, LF		F

	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU
	Plovers — **Charadriidae**			
	145 **Pied Lapwing** *Vanellus cayanus*	RI		F
	146 **Southern Lapwing** *Vanellus chilensis*	FW, HU, SV		C
	147 **American Golden-Plover** *Pluvialis dominica*	SV, HU	NEA	F
	148 **Black-bellied Plover** *Pluvialis squatarola*	MU	NEA	C
	149 **Semipalmated Plover** *Charadrius semipalmatus*	MU	NEA	C
	150 **Wilson's Plover** *Charadrius wilsonia*	MU		U
	151 **Collared Plover** *Charadrius collaris*	MU, RI		F
	Stilts — **Recurvirostridae**			
	152 **Black-necked Stilt** *Himantopus mexicanus*	FW	NEA?	S
	Thick-knees — **Burhinidae**			
	153 **Double-striped Thick-knee** *Burhinus bistriatus*	SV, HU		F
	Sandpipers — **Scolopacidae**			
	154 **Wilson's Snipe** *Gallinago delicata*	FW, SV	NEA	?
	155 **South American Snipe** *Gallinago paraguaiae*	FW, SV		F
	156 **Giant Snipe** *Gallinago undulata*	SV, FW		S
	157 **Short-billed Dowitcher** *Limnodromus griseus*	MU	NEA	C
	158 [**Hudsonian Godwit** *Limosa haemastica*]	MU, FW	NEA	S
	159 **Eskimo Curlew** *Numenius borealis* †	SV	NEA	†
	160 **Whimbrel** *Numenius phaeopus*	MU, MN, HU	NEA	F
	161 **Upland Sandpiper** *Bartramia longicauda*	SV, HU	NEA	S
	162 **Willet** *Tringa semipalmata*	MU, MN	NEA	F
	163 **Greater Yellowlegs** *Tringa melanoleuca*	FW, MU, HU	NEA	C
	164 **Lesser Yellowlegs** *Tringa flavipes*	FW, MU, HU	NEA	C
	165 **Solitary Sandpiper** *Tringa solitaria*	FW, RI	NEA	F
	166 **Spotted Sandpiper** *Actitis macularius*	RI, MN, FW	NEA	C
	167 **Ruddy Turnstone** *Arenaria interpres*	MU	NEA	C
	168 **Red Knot** *Calidris canutus*	MU	NEA	C
	169 **Sanderling** *Calidris alba*	MU	NEA	C
	170 **Semipalmated Sandpiper** *Calidris pusilla*	MU	NEA	C
	171 **Western Sandpiper** *Calidris mauri*	MU	NEA	C
	172 **Least Sandpiper** *Calidris minutilla*	MU, FW	NEA	F
	173 **White-rumped Sandpiper** *Calidris fuscicollis*	MU, FW	NEA	C
	174 **Pectoral Sandpiper** *Calidris melanotos*	MU, FW, HU	NEA	F
	175 [**Stilt Sandpiper** *Calidris himantopus*]	MU, FW	NEA	U
	176 [**Buff-breasted Sandpiper** *Tryngites subruficollis*]	SV, HU	NEA	S
	Jacanas — **Jacanidae**			
	177 **Wattled Jacana** *Jacana jacana*	FW		C
	Skuas — **Stercorariidae**			
	178 **Great Skua** *Stercorarius skua*	MA	NEA	?
	179 **Pomarine Jaeger** *Stercorarius pomarinus*	MA	NEA	S
	180 [**Parasitic Jaeger** *Stercorarius parasiticus*]	MA	NEA	?
	Gulls, Terns — **Laridae**			
	181 [**Lesser Black-backed Gull** *Larus fuscus*]	MA, MU	NEA	U

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	182 **Laughing Gull** *Larus atricilla*	MA, MU		C
	183 **Brown Noddy** *Anous stolidus*	MA		S
	184 **Sooty Tern** *Onychoprion fuscatus*	MA		S
	185 [**Bridled Tern** *Onychoprion anaethetus*]	MA		?
	186 **Least Tern** *Sternula antillarum*	MA, MU	NEA	F
	187 **Yellow-billed Tern** *Sternula superciliaris*	RI, FW		C
	188 **Large-billed Tern** *Phaetusa simplex*	RI, FW		F
	189 **Gull-billed Tern** *Gelochelidon nilotica*	MA, MU, FW		U
	190 [**Black Tern** *Chlidonias niger*]	MA	NEA	F
	191 **Common Tern** *Sterna hirundo*	MA, MU	NEA	C
	192 **Roseate Tern** *Sterna dougallii*	MA, MU	NEA	C
	193 [**Arctic Tern** *Sterna paradisaea*]	MA	NEA	?
	194 **Sandwich Tern** *Thalasseus sandvicensis*	MA, MU		C
	195 [**Royal Tern** *Thalasseus maximus*]	MA, MU		C

Skimmers **Rynchopidae**

	196 **Black Skimmer** *Rynchops niger*	MA, MU, RI		C

Pigeons, Doves **Columbidae**

	197 **Common Ground-Dove** *Columbina passerina*	SC, HU, SV		C
	198 **Plain-breasted Ground-Dove** *Columbina minuta*	SV, SC		U
	199 **Ruddy Ground-Dove** *Columbina talpacoti*	SC, HU		C
	200 **Blue Ground-Dove** *Claravis pretiosa*	LF, SC		F
	201 **Rock Pigeon** *Columba livia*	HU		CL
	202 **Scaled Pigeon** *Patagioenas speciosa*	LF, SC, SV		F
	203 **Pale-vented Pigeon** *Patagioenas cayennensis*	SC, SV, RI		C
	204 **Plumbeous Pigeon** *Patagioenas plumbea*	LF, MF		F
	205 **Ruddy Pigeon** *Patagioenas subvinacea*	LF, MF		F
	206 **Eared Dove** *Zenaida auriculata*	SC, HU, SV		C
	207 **White-tipped Dove** *Leptotila verreauxi*	SC		C
	208 **Gray-fronted Dove** *Leptotila rufaxilla*	LF		F
	209 **Violaceous Quail-Dove** *Geotrygon violacea*	LF		?
	210 **Ruddy Quail-Dove** *Geotrygon montana*	LF		U

Parrots **Psittacidae**

	211 **Blue-and-yellow Macaw** *Ara ararauna*	PA, LF, RI		F
	212 **Scarlet Macaw** *Ara macao*	LF		F
	213 **Red-and-green Macaw** *Ara chloropterus*	LF		F
	214 **Chestnut-fronted Macaw** *Ara severus*	LF, SC		SL
	215 **Red-bellied Macaw** *Orthopsittaca manilata*	PA, SV		C
	216 **Red-shouldered Macaw** *Diopsittaca nobilis*	PA, SV, SC		C
	217 **White-eyed Parakeet** *Aratinga leucophthalma*	LF		C
	218 **Sun Parakeet** *Aratinga solstitialis*	SV, SC	AMN	SL
	219 **Brown-throated Parakeet** *Aratinga pertinax*	SV, SC		C
	220 **Painted Parakeet** *Pyrrhura picta*	LF, MF		C
	221 **Fiery-shouldered Parakeet** *Pyrrhura egregia*	MF	TEP	F
	222 **Green-rumped Parrotlet** *Forpus passerinus*	LF, HU		C
	223 **Dusky-billed Parrotlet** *Forpus sclateri*	LF		U

	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU
	224 **Golden-winged Parakeet** *Brotogeris chrysoptera*	LF		C
	225 **Tepui Parrotlet** *Nannopsittaca panychlora*	MF, LF	TEP	C
	226 **Lilac-tailed Parrotlet** *Touit batavicus*	LF		C
	227 **Scarlet-shouldered Parrotlet** *Touit huetii*	LF		U
	228 **Sapphire-rumped Parrotlet** *Touit purpuratus*	LF, MF		U
	229 **Black-headed Parrot** *Pionites melanocephalus*	LF	AMN	F
	230 **Caica Parrot** *Gypopsitta caica*	LF	GUI	F
	231 **Blue-headed Parrot** *Pionus menstruus*	LF		C
	232 **Dusky Parrot** *Pionus fuscus*	LF		C
	233 **Blue-cheeked Parrot** *Amazona dufresniana*	LF, RI		U
	234 **Festive Parrot** *Amazona festiva*	LF		?
	235 **Yellow-crowned Parrot** *Amazona ochrocephala*	SV, SC		C
	236 **Orange-winged Parrot** *Amazona amazonica*	LF, SC		C
	237 **Mealy Parrot** *Amazona farinosa*	LF		C
	238 **Red-fan Parrot** *Deroptyus accipitrinus*	LF		C

Hoatzin **Opisthocomidae**

	239 **Hoatzin** *Opisthocomus hoazin*	RI, FW		CL

Cuckoos **Cuculidae**

	240 **Yellow-billed Cuckoo** *Coccyzus americanus*	LF	NEA	U
	241 **Pearly-breasted Cuckoo** *Coccyzus euleri*	LF	AUS?	S
	242 **Mangrove Cuckoo** *Coccyzus minor*	MN		U
	243 **Dark-billed Cuckoo** *Coccyzus melacoryphus*	LF	AUS?	U
	244 **Squirrel Cuckoo** *Piaya cayana*	LF		F
	245 **Black-bellied Cuckoo** *Piaya melanogaster*	LF		U
	246 **Little Cuckoo** *Piaya minuta*	SC, FW		F
	247 **Greater Ani** *Crotophaga major*	RI, MN, FW		C
	248 **Smooth-billed Ani** *Crotophaga ani*	SC, HU		C
	249 **Striped Cuckoo** *Tapera naevia*	SC, SV, HU		F
	250 **Pavonine Cuckoo** *Dromococcyx pavoninus*	LF, MF		U
	251 **Rufous-winged Ground-Cuckoo** *Neomorphus rufipennis*	LF	GUI	U

Barn Owls **Tytonidae**

	252 **Barn Owl** *Tyto alba*	SC, HU		U

Typical Owls **Strigidae**

	253 **Tropical Screech-Owl** *Megascops choliba*	SC, LF		F
	254 **Tawny-bellied Screech-Owl** *Megascops watsonii*	LF		U
	255 **Vermiculated Screech-Owl** *Megascops guatemalae*	MF		U
	256 **Crested Owl** *Lophostrix cristata*	LF, MF		U
	257 **Spectacled Owl** *Pulsatrix perspicillata*	LF		U
	258 **Great Horned Owl** *Bubo virginianus*	SC, SV		U
	259 **Mottled Owl** *Ciccaba virgata*	LF, MF		?
	260 **Black-banded Owl** *Ciccaba huhula*	LF, MF		?
	261 **Amazonian Pygmy-Owl** *Glaucidium hardyi*	LF, MF		U
	262 **Ferruginous Pygmy-Owl** *Glaucidium brasilianum*	SC, LF		F
	263 **Burrowing Owl** *Athene cunicularia*	SV, SC		F
	264 **Striped Owl** *Pseudoscops clamator*	SV, SC		S
	265 **Stygian Owl** *Asio stygius*	SC, LF		S
	266 **Short-eared Owl** *Asio flammeus*	SV, HU		S

	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU

Oilbird **Steatornithidae**

	267 **Oilbird** *Steatornis caripensis*	LF, MF		CL

Potoos **Nyctibiidae**

	268 **Great Potoo** *Nyctibius grandis*	LF		U
	269 **Long-tailed Potoo** *Nyctibius aethereus*	LF		S
	270 **Common Potoo** *Nyctibius griseus*	LF, SC, MN		F
	271 **White-winged Potoo** *Nyctibius leucopterus*	LF		U
	272 **Rufous Potoo** *Nyctibius bracteatus*	LF		S

Nighthawks, Nightjars **Caprimulgidae**

	273 **Short-tailed Nighthawk** *Lurocalis semitorquatus*	LF, RI		F
	274 **Least Nighthawk** *Chordeiles pusillus*	SV		C
	275 **Lesser Nighthawk** *Chordeiles acutipennis*	SC, SV		C
	276 **Band-tailed Nighthawk** *Nyctiprogne leucopyga*	RI		C
	277 **Nacunda Nighthawk** *Podager nacunda*	SV, SC		C
	278 **Common Pauraque** *Nyctidromus albicollis*	SC, HU		C
	279 **Rufous Nightjar** *Caprimulgus rufus*	SC, LF		F
	280 **Band-winged Nightjar** *Caprimulgus longirostris*	SC, SV		?
	281 **White-tailed Nightjar** *Caprimulgus cayennensis*	SV, SC		F
	282 **Spot-tailed Nightjar** *Caprimulgus maculicaudus*	SV, FW		F
	283 **Blackish Nightjar** *Caprimulgus nigrescens*	LF, SC, RI		F
	284 **Roraiman Nightjar** *Caprimulgus whitelyi*	SC, SV	TEP	UL
	285 **Ladder-tailed Nightjar** *Hydropsalis climacocerca*	RI		F

Swifts **Apodidae**

	286 **White-chinned Swift** *Cypseloides cryptus*	MF, RI		CL
	287 **Black Swift** *Cypseloides niger*	?	NEA?	?
	288 **Tepui Swift** *Streptoprocne phelpsi*	MF, RI	TEP	CL
	289 **White-collared Swift** *Streptoprocne zonaris*	MF, LF, SC		C
	290 **Band-rumped Swift** *Chaetura spinicaudus*	LF, RI		C
	291 **Gray-rumped Swift** *Chaetura cinereiventris*	LF, MF, RI		C
	292 **Chapman's Swift** *Chaetura chapmani*	LF, SC, RI		U
	293 **Short-tailed Swift** *Chaetura brachyura*	LF, SC, HU		C
	294 **[White-tipped Swift** *Aeronautes montivagus*]	MF		FL
	295 **Fork-tailed Palm-Swift** *Tachornis squamata*	PA, SV, SC		C
	296 **Lesser Swallow-tailed Swift** *Panyptila cayennensis*	LF		U

Hummingbirds **Trochilidae**

	297 **Rufous-breasted Hermit** *Glaucis hirsutus*	LF		U
	298 **Pale-tailed Barbthroat** *Threnetes leucurus*	LF, RI		U
	299 **Streak-throated Hermit** *Phaethornis rupurumii*	LF, RI		U
	300 **Little Hermit** *Phaethornis longuemareus*	LF		U
	301 **Reddish Hermit** *Phaethornis ruber*	LF		F
	302 **Sooty-capped Hermit** *Phaethornis augusti*	SC, LF, MF		U

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	303 **Straight-billed Hermit** *Phaethornis bourcieri*	LF, MF		F
	304 **Long-tailed Hermit** *Phaethornis superciliosus*	LF, MF		F
	305 **Blue-fronted Lancebill** *Doryfera johannae*	MF		U
	306 **Gray-breasted Sabrewing** *Campylopterus largipennis*	LF		F
	307 **Rufous-breasted Sabrewing** *Campylopterus hyperythrus*	MF	TEP	C
	308 **White-necked Jacobin** *Florisuga mellivora*	LF, RI		F
	309 **Brown Violetear** *Colibri delphinae*	MF		U
	310 [**Sparkling Violetear** *Colibri coruscans*]	MF, SC		FL
	311 **Green-throated Mango** *Anthracothorax viridigula*	MN, SC		U
	312 **Black-throated Mango** *Anthracothorax nigricollis*	SC, LF, RI		F
	313 **Fiery-tailed Awlbill** *Avocettula recurvirostris*	LF		S
	314 **Crimson Topaz** *Topaza pella*	RI, LF		U
	315 **Ruby-topaz Hummingbird** *Chrysolampis mosquitus*	SC, SV		F
	316 **Tufted Coquette** *Lophornis ornatus*	LF		U
	317 **Peacock Coquette** *Lophornis pavoninus*	MF	TEP	U
	318 **Racket-tailed Coquette** *Discosura longicaudus*	LF		U
	319 **Blue-chinned Sapphire** *Chlorestes notata*	LF, SC		F
	320 **Blue-tailed Emerald** *Chlorostilbon mellisugus*	SC, SV, LF		F
	321 **Fork-tailed Woodnymph** *Thalurania furcata*	LF, MF		F
	322 **Rufous-throated Sapphire** *Hylocharis sapphirina*	LF, SC		U
	323 **White-chinned Sapphire** *Hylocharis cyanus*	LF		F
	324 **White-tailed Goldenthroat** *Polytmus guainumbi*	SV		F
	325 [**Tepui Goldenthroat** *Polytmus milleri*] *	?	TEP	?
	326 **Green-tailed Goldenthroat** *Polytmus theresiae*	FW, SV		F
	327 **Plain-bellied Emerald** *Amazilia leucogaster*	LF, MN, HU		F
	328 **Versicolored Emerald** *Amazilia versicolor*	LF, SC		UL
	329 **White-chested Emerald** *Amazilia brevirostris*	LF, SC		F
	330 **Glittering-throated Emerald** *Amazilia fimbriata*	SV, SC, LF		C
	331 **Green-bellied Hummingbird** *Amazilia viridigaster*	MF, SC, RI		U
	332 **Velvet-browed Brilliant** *Heliodoxa xanthogonys*	MF, SC	TEP	C
	333 **Black-eared Fairy** *Heliothryx auritus*	LF		U
	334 **Long-billed Starthroat** *Heliomaster longirostris*	LF, RI		F
	335 **Amethyst Woodstar** *Calliphlox amethystina*	SC, LF		U

Trogons **Trogonidae**

	336 **White-tailed Trogon** *Trogon viridis*	LF		F
	337 **Violaceous Trogon** *Trogon violaceus*	LF		F
	338 **Collared Trogon** *Trogon collaris*	MF		F
	339 **Masked Trogon** *Trogon personatus*	MF		U
	340 **Black-throated Trogon** *Trogon rufus*	LF		F
	341 **Black-tailed Trogon** *Trogon melanurus*	LF		F

Kingfishers **Alcedinidae**

	342 **Ringed Kingfisher** *Megaceryle torquata*	RI, FW, MN		F
	343 [**Belted Kingfisher** *Megaceryle alcyon*]	FW	NEA	S

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	344 **Amazon Kingfisher** *Chloroceryle amazona*	RI, FW, MN		F
	345 **Green Kingfisher** *Chloroceryle americana*	RI, FW, MN		F
	346 **Green-and-rufous Kingfisher** *Chloroceryle inda*	RI, FW, LF		U
	347 **American Pygmy Kingfisher** *Chloroceryle aenea*	RI, LF, FW		U

Motmots **Momotidae**

	348 **Blue-crowned Motmot** *Momotus momota*	LF		F

Jacamars **Galbulidae**

	349 **Brown Jacamar** *Brachygalba lugubris*	RI, SC		CL
	350 **Yellow-billed Jacamar** *Galbula albirostris*	LF	AMN	F
	351 **Rufous-tailed Jacamar** *Galbula ruficauda*	LF, SC		UL
	352 **Green-tailed Jacamar** *Galbula galbula*	LF, SC		F
	353 **Bronzy Jacamar** *Galbula leucogastra*	SC, LF		F
	354 **Paradise Jacamar** *Galbula dea*	LF, RI		F
	355 **Great Jacamar** *Jacamerops aureus*	LF		U

Puffbirds **Bucconidae**

	356 **Guianan Puffbird** *Notharchus macrorhynchos*	LF	GUI	U
	357 **Pied Puffbird** *Notharchus tectus*	LF		U
	358 **Spotted Puffbird** *Bucco tamatia*	SC, LF		F
	359 **Collared Puffbird** *Bucco capensis*	LF		F
	360 **White-chested Puffbird** *Malacoptila fusca*	LF		U
	361 **Rusty-breasted Nunlet** *Nonnula rubecula*	LF		U
	362 **Black Nunbird** *Monasa atra*	LF	AMN	C
	363 **Swallow-winged Puffbird** *Chelidoptera tenebrosa*	RI, SC, LF		C

New World Barbets **Capitonidae**

	364 **Black-spotted Barbet** *Capito niger*	LF, MF		U

Toucans **Ramphastidae**

	365 **Toco Toucan** *Ramphastos toco*	SV, RI		UL
	366 **White-throated Toucan** *Ramphastos tucanus*	LF		C
	367 **Channel-billed Toucan** *Ramphastos vitellinus*	LF		C
	368 **Chestnut-tipped Toucanet** *Aulacorhynchus derbianus*	MF		U
	369 **Guianan Toucanet** *Selenidera culik*	LF	GUI	F
	370 **Tawny-tufted Toucanet** *Selenidera nattereri* *	LF		S
	371 **Green Aracari** *Pteroglossus viridis*	LF	GUI	F
	372 **Black-necked Aracari** *Pteroglossus aracari*	LF		F

Woodpeckers **Picidae**

	373 **Golden-spangled Piculet** *Picumnus exilis*	LF		F
	374 **White-bellied Piculet** *Picumnus spilogaster*	MN, RI, HU		F
	375 **White-barred Piculet** *Picumnus cirratus*	SC		F
	376 [**White Woodpecker** *Melanerpes candidus*]	HU		S
	377 **Yellow-tufted Woodpecker** *Melanerpes cruentatus*	LF, HU		F
	378 **Red-crowned Woodpecker** *Melanerpes rubricapillus*	LF, MN		?

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	379 **Little Woodpecker** *Veniliornis passerinus*	RI, SC		F
	380 **Blood-colored Woodpecker** *Veniliornis sanguineus*	LF, MN, HU	GUI	F
	381 **Red-rumped Woodpecker** *Veniliornis kirkii*	MF		U
	382 **Golden-collared Woodpecker** *Veniliornis cassini*	LF	GUI	F
	383 **Yellow-throated Woodpecker** *Piculus flavigula*	LF		F
	384 **Golden-green Woodpecker** *Piculus chrysochloros*	LF		U
	385 **Golden-olive Woodpecker** *Piculus rubiginosus*	MF, LF		F
	386 **Spot-breasted Woodpecker** *Colaptes punctigula*	RI, MN, SC		F
	387 **Waved Woodpecker** *Celeus undatus*	LF		F
	388 **Chestnut Woodpecker** *Celeus elegans*	LF		F
	389 **Cream-colored Woodpecker** *Celeus flavus*	LF		F
	390 **Ringed Woodpecker** *Celeus torquatus*	LF		U
	391 **Lineated Woodpecker** *Dryocopus lineatus*	LF, SC, HU		F
	392 **Red-necked Woodpecker** *Campephilus rubricollis*	LF, MF		F
	393 **Crimson-crested Woodpecker** *Campephilus melanoleucos*	LF, HU		F

Ovenbirds **Furnariidae**

	394 **Pale-legged Hornero** *Furnarius leucopus*	RI, SC		F
	395 **Pale-breasted Spinetail** *Synallaxis albescens*	SV, HU, SC		F
	396 **Ruddy Spinetail** *Synallaxis rutilans*	LF		U
	397 **McConnell's Spinetail** *Synallaxis macconnelli*	LF, MF	GUI	SL
	398 **Plain-crowned Spinetail** *Synallaxis gujanensis*	SC, HU		F
	399 **Hoary-throated Spinetail** *Synallaxis kollari*	RI, SC	GUI	FL
	400 **Rusty-backed Spinetail** *Cranioleuca vulpina* *	RI, SC		?
	401 **Tepui Spinetail** *Cranioleuca demissa*	MF	TEP	F
	402 **Yellow-chinned Spinetail** *Certhiaxis cinnamomeus*	FW, SC		C
	403 **Roraiman Barbtail** *Roraimia adusta*	MF	TEP	F
	404 **Point-tailed Palmcreeper** *Berlepschia rikeri*	PA		F
	405 **Rufous-tailed Foliage-gleaner** *Philydor ruficaudatum*	LF, MF		U
	406 **Rufous-rumped Foliage-gleaner** *Philydor erythrocercum*	LF, MF		F
	407 **Cinnamon-rumped Foliage-gleaner** *Philydor pyrrhodes*	LF		U
	408 **Buff-throated Foliage-gleaner** *Automolus ochrolaemus*	LF		F
	409 **Olive-backed Foliage-gleaner** *Automolus infuscatus*	LF		F
	410 **White-throated Foliage-gleaner** *Automolus roraimae*	MF	TEP	U
	411 **Ruddy Foliage-gleaner** *Automolus rubiginosus*	MF, LF		U
	412 **Chestnut-crowned Foliage-gleaner** *Automolus rufipileatus*	RI, LF		F
	413 **Tawny-throated Leaftosser** *Sclerurus mexicanus*	LF, MF		U
	414 **Short-billed Leaftosser** *Sclerurus rufigularis*	LF		U
	415 **Black-tailed Leaftosser** *Sclerurus caudacutus*	LF, MF		U
	416 **Sharp-tailed Streamcreeper** *Lochmias nematura*	MF, RI		UL
	417 **Rufous-tailed Xenops** *Xenops milleri*	LF		S

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	418 **Slender-billed Xenops** *Xenops tenuirostris*	LF		S
	419 **Plain Xenops** *Xenops minutus*	LF		F
	420 **Plain-brown Woodcreeper** *Dendrocincla fuliginosa*	LF		F
	421 **White-chinned Woodcreeper** *Dendrocincla merula*	LF		U
	422 **Long-tailed Woodcreeper** *Deconychura longicauda*	LF		U
	423 **Spot-throated Woodcreeper** *Deconychura stictolaema*	LF		U
	424 **Olivaceous Woodcreeper** *Sittasomus griseicapillus*	LF, SC		UL
	425 **Wedge-billed Woodcreeper** *Glyphorynchus spirurus*	LF, MF		F
	426 **Cinnamon-throated Woodcreeper** *Dendrexetastes rufigula*	RI, LF		UL
	427 **Red-billed Woodcreeper** *Hylexetastes perrotii*	LF		U
	428 **Strong-billed Woodcreeper** *Xiphocolaptes promeropirhynchus*	LF, MF		U
	429 **Amazonian Barred-Woodcreeper** *Dendrocolaptes certhia*	LF		F
	430 **Black-banded Woodcreeper** *Dendrocolaptes picumnus*	LF, MF		U
	431 **Straight-billed Woodcreeper** *Xiphorhynchus picus*	MN, RI, SC		F
	432 **Striped Woodcreeper** *Xiphorhynchus obsoletus*	LF, RI		F
	433 **Chestnut-rumped Woodcreeper** *Xiphorhynchus pardalotus*	LF, MF		F
	434 **Buff-throated Woodcreeper** *Xiphorhynchus guttatus*	LF		F
	435 **Streak-headed Woodcreeper** *Lepidocolaptes souleyetii*	RI, SC		UL
	436 **Lineated Woodcreeper** *Lepidocolaptes albolineatus*	LF		F
	437 **Curve-billed Scythebill** *Campylorhamphus procurvoides*	LF		U

Typical Antbirds **Thamnophilidae**

	438 **Fasciated Antshrike** *Cymbilaimus lineatus*	LF		F
	439 **Black-throated Antshrike** *Frederickena viridis*	LF	GUI	U
	440 **Great Antshrike** *Taraba major*	HU, SC		F
	441 **Black-crested Antshrike** *Sakesphorus canadensis*	SC, MN		F
	442 **Band-tailed Antshrike** *Sakesphorus melanothorax*	LF, RI	GUI	SL
	443 **Barred Antshrike** *Thamnophilus doliatus*	HU, SC		F
	444 **Mouse-colored Antshrike** *Thamnophilus murinus*	LF		F
	445 **Northern Slaty-Antshrike** *Thamnophilus punctatus*	LF, SC		F
	446 **Amazonian Antshrike** *Thamnophilus amazonicus*	LF, RI		F
	447 **Streaked-backed Antshrike** *Thamnophilus insignis*	MF, SC	TEP	U
	448 **Plain Antvireo** *Dysithamnus mentalis*	MF		U
	449 **Dusky-throated Antshrike** *Thamnomanes ardesiacus*	LF		F
	450 **Cinereous Antshrike** *Thamnomanes caesius*	LF		F
	451 **Spot-winged Antshrike** *Pygiptila stellaris*	LF		U
	452 **Brown-bellied Antwren** *Myrmotherula gutturalis*	LF	GUI	F
	453 **Pygmy Antwren** *Myrmotherula brachyura*	LF, RI		F
	454 **Guianan Streaked-Antwren** *Myrmotherula surinamensis*	RI, LF		F
	455 **Rufous-bellied Antwren** *Myrmotherula guttata*	LF	GUI	F
	456 **White-flanked Antwren** *Myrmotherula axillaris*	LF, SC		F
	457 **Long-winged Antwren** *Myrmotherula longipennis*	LF		F

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	458 **Plain-winged Antwren** *Myrmotherula behni*	MF		F
	459 **Gray Antwren** *Myrmotherula menetriesii*	LF		F
	460 **Spot-tailed Antwren** *Herpsilochmus sticturus*	LF	AMN	F
	461 **Todd's Antwren** *Herpsilochmus stictocephalus*	LF	GUI	F
	462 **Roraiman Antwren** *Herpsilochmus roraimae*	MF	TEP	F
	463 **Rufous-winged Antwren** *Herpsilochmus rufimarginatus*	LF, MF		FL
	464 **Dot-winged Antwren** *Microrhopias quixensis*	LF		U
	465 **White-fringed Antwren** *Formicivora grisea*	SC, RI		F
	466 **Rufous-rumped Antwren** *Terenura callinota*	MF		SL
	467 **Ash-winged Antwren** *Terenura spodioptila*	LF		F
	468 **Gray Antbird** *Cercomacra cinerascens*	LF		F
	469 **Dusky Antbird** *Cercomacra tyrannina*	LF, SC, HU		F
	470 **Willis's Antbird** *Cercomacra laeta*	SC		FL
	471 **Blackish Antbird** *Cercomacra nigrescens*	RI, LF		UL
	472 **Rio Branco Antbird** *Cercomacra carbonaria*	RI	GUI	UL
	473 **White-browed Antbird** *Myrmoborus leucophrys*	LF, RI, HU		F
	474 **Warbling Antbird** *Hypocnemis cantator*	LF		F
	475 **Black-chinned Antbird** *Hypocnemoides melanopogon*	LF, RI		F
	476 **Silvered Antbird** *Sclateria naevia*	RI, FW, LF		F
	477 **Black-headed Antbird** *Percnostola rufifrons*	LF	AMN	F
	478 **Spot-winged Antbird** *Schistocichla leucostigma*	LF, MF		F
	479 **Roraiman Antbird** *Schistocichla saturata*	MF, RI	TEP	F
	480 **White-bellied Antbird** *Myrmeciza longipes*	LF, SC		F
	481 **Ferruginous-backed Antbird** *Myrmeciza ferruginea*	LF		F
	482 **Black-throated Antbird** *Myrmeciza atrothorax*	LF, SC, HU		F
	483 **Wing-banded Antbird** *Myrmornis torquata*	LF		U
	484 **White-plumed Antbird** *Pithys albifrons*	LF		F
	485 **Rufous-throated Antbird** *Gymnopithys rufigula*	LF	GUI	F
	486 **Spot-backed Antbird** *Hylophylax naevius*	LF		F
	487 **Scale-backed Antbird** *Hylophylax poecilinotus*	LF		F

Ground Antbirds **Formicariidae**

	488 **Rufous-capped Antthrush** *Formicarius colma*	LF		F
	489 **Black-faced Antthrush** *Formicarius analis*	LF		F
	490 **Short-tailed Antthrush** *Chamaeza campanisona*	MF		S
	491 **Variegated Antpitta** *Grallaria varia*	LF, MF		U
	492 **Scaled Antpitta** *Grallaria guatimalensis*	MF		F
	493 **Spotted Antpitta** *Hylopezus macularius*	LF		U
	494 **Thrush-like Antpitta** *Myrmothera campanisona*	LF		F
	495 **Tepui Antpitta** *Myrmothera simplex*	MF	TEP	F
	496 **Slate-crowned Antpitta** *Grallaricula nana*	MF		U

Gnateaters **Conopophagidae**

	497 **Chestnut-belted Gnateater** *Conopophaga aurita*	LF		S

Tyrant Flycatchers **Tyrannidae**

	498 **Sooty-headed Tyrannulet** *Phyllomyias griseiceps*	LF		UL
	499 **Yellow-crowned Tyrannulet** *Tyrannulus elatus*	LF, SC		F
	500 **Forest Elaenia** *Myiopagis gaimardii*	LF		F
	501 **Gray Elaenia** *Myiopagis caniceps*	LF		SL

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	502 **Yellow-crowned Elaenia** *Myiopagis flavivertex*	RI, LF		F
	503 **Greenish Elaenia** *Myiopagis viridicata*	SC		F
	504 **Yellow-bellied Elaenia** *Elaenia flavogaster*	SC, HU		C
	505 **Small-billed Elaenia** *Elaenia parvirostris*	SC, LF	AUS	U
	506 **Plain-crested Elaenia** *Elaenia cristata*	SV, SC		F
	507 **Lesser Elaenia** *Elaenia chiriquensis*	SV, SC		F
	508 **Rufous-crowned Elaenia** *Elaenia ruficeps*	SC		U
	509 **Sierran Elaenia** *Elaenia pallatangae*	MF		F
	510 **White-lored Tyrannulet** *Ornithion inerme*	LF, RI, SC		F
	511 **Southern Beardless-Tyrannulet** *Camptostoma obsoletum*	SC, LF		F
	512 **Mouse-colored Tyrannulet** *Phaeomyias murina*	SC		F
	513 **Yellow Tyrannulet** *Capsiempis flaveola*	LF, SC		SL
	514 **Bearded Tachuri** *Polystictus pectoralis*	SV		U
	515 **Crested Doradito** *Pseudocolopteryx sclateri*	FW	AUS?	?
	516 **Ringed Antpipit** *Corythopis torquatus*	LF		U
	517 **Slender-footed Tyrannulet** *Zimmerius gracilipes*	LF		F
	518 **Chapman's Bristle-Tyrant** *Phylloscartes chapmani*	MF	TEP	F
	519 **Olive-green Tyrannulet** *Phylloscartes virescens*	LF	GUI	S
	520 **Black-fronted Tyrannulet** *Phylloscartes nigrifrons*	MF	TEP	U
	521 **Ochre-bellied Flycatcher** *Mionectes oleagineus*	LF		F
	522 **McConnell's Flycatcher** *Mionectes macconnelli*	LF, MF		F
	523 **Sepia-capped Flycatcher** *Leptopogon amaurocephalus*	LF, MF		U
	524 **Northern Scrub-Flycatcher** *Sublegatus arenarum*	MN, SC		F
	525 **Amazonian Scrub-Flycatcher** *Sublegatus obscurior*	LF, SC		U
	526 **Southern Scrub-Flycatcher** *Sublegatus modestus*	SV		F
	527 **Pale-tipped Tyrannulet** *Inezia caudata*	SC, MN, RI		F
	528 **Short-tailed Pygmy-Tyrant** *Myiornis ecaudatus*	LF		F
	529 **Double-banded Pygmy-Tyrant** *Lophotriccus vitiosus*	LF		F
	530 **Helmeted Pygmy-Tyrant** *Lophotriccus galeatus*	LF, MF		F
	531 **Pale-eyed Pygmy-Tyrant** *Atalotriccus pilaris*	SC		F
	532 **Boat-billed Tody-Tyrant** *Hemitriccus josephinae*	LF	GUI	SL
	533 **White-eyed Tody-Tyrant** *Hemitriccus zosterops*	LF		F
	534 **Pearly-vented Tody-Tyrant** *Hemitriccus margaritaceiventer*	SC		F
	535 **Ruddy Tody-Flycatcher** *Poecilotriccus russatus*	MF, SC	TEP	U
	536 **Slate-headed Tody-Flycatcher** *Poecilotriccus sylvia*	SC		F
	537 **Spotted Tody-Flycatcher** *Todirostrum maculatum*	MN, SC, RI		C
	538 **Common Tody-Flycatcher** *Todirostrum cinereum*	SC, HU		F
	539 **Painted Tody-Flycatcher** *Todirostrum pictum*	LF	GUI	F
	540 **Olivaceous Flatbill** *Rhynchocyclus olivaceus*	LF		U
	541 **Yellow-olive Flycatcher** *Tolmomyias sulphurescens*	LF		F
	542 **Yellow-margined Flycatcher** *Tolmomyias assimilis*	LF		F
	543 **Gray-crowned Flycatcher** *Tolmomyias poliocephalus*	LF		F
	544 **Yellow-breasted Flycatcher** *Tolmomyias flaviventris*	SC, MN		F
	545 **Cinnamon-crested Spadebill** *Platyrinchus saturatus*	LF		U

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	546 **White-throated Spadebill** *Platyrinchus mystaceus*	MF		U
	547 **Golden-crowned Spadebill** *Platyrinchus coronatus*	LF		U
	548 **White-crested Spadebill** *Platyrinchus platyrhynchos*	LF		U
	549 **Royal Flycatcher** *Onychorhynchus coronatus*	LF		U
	550 **Roraiman Flycatcher** *Myiophobus roraimae*	MF, SC		F
	551 **Bran-colored Flycatcher** *Myiophobus fasciatus*	SC		S
	552 **Sulphur-rumped Flycatcher** *Myiobius barbatus*	LF		F
	553 **Ruddy-tailed Flycatcher** *Terenotriccus erythrurus*	LF		F
	554 **Cinnamon Manakin-Tyrant** *Neopipo cinnamomea*	LF		U
	555 **Cliff Flycatcher** *Hirundinea ferruginea*	MF		UL
	556 **Euler's Flycatcher** *Lathrotriccus euleri*	LF		UL
	557 **Fuscous Flycatcher** *Cnemotriccus fuscatus*	LF, SC		U
	558 **Olive-sided Flycatcher** *Contopus cooperi*	MF, LF	NEA	S
	559 **Smoke-colored Pewee** *Contopus fumigatus*	MF		U
	560 **Tropical Pewee** *Contopus cinereus*	LF		S
	561 **Blackish Pewee** *Contopus nigrescens*	MF		FL
	562 **Vermilion Flycatcher** *Pyrocephalus rubinus*	SV, SC	AUS?	F
	563 **Amazonian Black-Tyrant** *Knipolegus poecilocercus*	RI		UL
	564 **Rufous-tailed Tyrant** *Knipolegus poecilurus*	MF, SC		UL
	565 **Drab Water-Tyrant** *Ochthornis littoralis*	RI		CL
	566 **Pied Water-Tyrant** *Fluvicola pica*	FW		F
	567 **White-headed Marsh-Tyrant** *Arundinicola leucocephala*	FW		F
	568 **Long-tailed Tyrant** *Colonia colonus*	LF, MF		F
	569 **Piratic Flycatcher** *Legatus leucophaius*	LF, HU	AUS	F
	570 **Rusty-margined Flycatcher** *Myiozetetes cayanensis*	HU, SC, RI		C
	571 **Dusky-chested Flycatcher** *Myiozetetes luteiventris*	LF, RI		S
	572 **Great Kiskadee** *Pitangus sulphuratus*	HU, SC, MN		C
	573 **Lesser Kiskadee** *Philohydor lictor*	FW, RI		F
	574 **Yellow-throated Flycatcher** *Conopias parvus*	LF	AMN	F
	575 **Streaked Flycatcher** *Myiodynastes maculatus*	LF	AUS	U
	576 **Boat-billed Flycatcher** *Megarynchus pitangua*	LF, RI		F
	577 **Sulphury Flycatcher** *Tyrannopsis sulphurea*	PA		F
	578 **Variegated Flycatcher** *Empidonomus varius*	LF, SC	AUS	F
	579 **Crowned Slaty Flycatcher** *Empidonomus aurantioatrocristatus*	SC, SV	AUS	S
	580 **White-throated Kingbird** *Tyrannus albogularis*	SV, RI	AUS?	U
	581 **Tropical Kingbird** *Tyrannus melancholicus*	SC, HU, SV	AUS	C
	582 **Fork-tailed Flycatcher** *Tyrannus savana*	SV, HU, SC	AUS	C
	583 **Eastern Kingbird** *Tyrannus tyrannus*	SC, HU, LF	NEA	S
	584 **Gray Kingbird** *Tyrannus dominicensis*	HU, SC, MN	NEA	F
	585 **Grayish Mourner** *Rhytipterna simplex*	LF		F
	586 **Pale-bellied Mourner** *Rhytipterna immunda*	SC		SL
	587 **Sirystes** *Sirystes sibilator*	LF		S
	588 **Dusky-capped Flycatcher** *Myiarchus tuberculifer*	MF, LF		U
	589 **Swainson's Flycatcher** *Myiarchus swainsoni*	LF, RI	AUS	U
	590 **Short-crested Flycatcher** *Myiarchus ferox*	LF, SC		F

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	591 **Brown-crested Flycatcher** *Myiarchus tyrannulus*	SC, RI, MN		F
	592 **Large-headed Flatbill** *Ramphotrigon megacephalum*	LF		S
	593 **Rufous-tailed Flatbill** *Ramphotrigon ruficauda*	LF		U
	594 **Cinnamon Attila** *Attila cinnamomeus*	LF, SC, RI		F
	595 **Bright-rumped Attila** *Attila spadiceus*	LF, MF		U

Sharpbill **Oxyruncidae**

	596 **Sharpbill** *Oxyruncus cristatus*	MF		U

Cotingas **Cotingidae**

	597 **Red-banded Fruiteater** *Pipreola whitelyi*	MF	TEP	C
	598 **Guianan Cock-of-the-Rock** *Rupicola rupicola*	MF, LF	AMN	F
	599 **Guianan Red-Cotinga** *Phoenicircus carnifex*	LF		F
	600 **Purple-breasted Cotinga** *Cotinga cotinga*	LF		U
	601 **Spangled Cotinga** *Cotinga cayana*	LF		U
	602 **White Bellbird** *Procnias albus*	MF, LF		U
	603 **Bearded Bellbird** *Procnias averano*	MF		FL
	604 **Screaming Piha** *Lipaugus vociferans*	LF		C
	605 **Rose-collared Piha** *Lipaugus streptophorus*	MF	TEP	S
	606 **Pompadour Cotinga** *Xipholena punicea*	LF		U
	607 **Bare-necked Fruitcrow** *Gymnoderus foetidus*	RI, LF		U
	608 **Purple-throated Fruitcrow** *Querula purpurata*	LF		F
	609 **Crimson Fruitcrow** *Haematoderus militaris*	LF		S
	610 **Red-ruffed Fruitcrow** *Pyroderus scutatus*	?		?
	611 **Capuchinbird** *Perissocephalus tricolor*	LF	AMN	F
	612 **Amazonian Umbrellabird** *Cephalopterus ornatus*	LF		S

Manakins **Pipridae**

	613 **Pale-bellied Tyrant-Manakin** *Neopelma pallescens*	SC		U
	614 **Saffron-crested Tyrant-Manakin** *Neopelma chrysocephalum*	SC, LF	AMN	F
	615 **Tiny Tyrant-Manakin** *Tyranneutes virescens*	LF	GUI	F
	616 **White-throated Manakin** *Corapipo gutturalis*	MF, LF	GUI	F
	617 **Striped Manakin** *Machaeropterus regulus*	LF, MF		?
	618 **White-fronted Manakin** *Lepidothrix serena*	LF, MF	GUI	F
	619 **Orange-bellied Manakin** *Lepidothrix suavissima*	LF, MF	TEP	F
	620 **White-bearded Manakin** *Manacus manacus*	RI, LF, SC		F
	621 **Blue-backed Manakin** *Chiroxiphia pareola*	SC, LF		C
	622 **Olive Manakin** *Xenopipo uniformis*	MF	TEP	S
	623 **Black Manakin** *Xenopipo atronitens*	SC		F
	624 **White-crowned Manakin** *Pipra pipra*	LF, MF		F
	625 **Crimson-hooded Manakin** *Pipra aureola*	LF		U
	626 **Scarlet-horned Manakin** *Pipra cornuta*	MF	TEP	F
	627 **Golden-headed Manakin** *Pipra erythrocephala*	LF		F

INCERTAE SEDIS

	628 **Black-crowned Tityra** *Tityra inquisitor*	LF		UL
	629 **Black-tailed Tityra** *Tityra cayana*	LF		U
	630 **Thrush-like Schiffornis** *Schiffornis turdina*	LF, MF		F
	631 **Cinereous Mourner** *Laniocera hypopyrra*	LF		U
	632 **Dusky Purpletuft** *Iodopleura fusca*	LF	GUI	U

	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU
	633 **White-naped Xenopsaris** *Xenopsaris albinucha*	SV, SC		S
	634 **Green-backed Becard** *Pachyramphus viridis* *	MF		?
	635 **Cinereous Becard** *Pachyramphus rufus*	SC, LF		F
	636 **White-winged Becard** *Pachyramphus polychopterus*	LF, SC		F
	637 **Black-capped Becard** *Pachyramphus marginatus*	LF		F
	638 **Glossy-backed Becard** *Pachyramphus surinamus*	LF		SL
	639 **Pink-throated Becard** *Pachyramphus minor*	LF		F
	640 **Wing-barred Piprites** *Piprites chloris*	LF		F

Vireos **Vireonidae**

	641 **Rufous-browed Peppershrike** *Cyclarhis gujanensis*	SC, RI, MF		F
	642 **Slaty-capped Shrike-Vireo** *Vireolanius leucotis*	LF, MF		F
	643 **Red-eyed Vireo** *Vireo olivaceus*	LF	NEA	F
	644 **Black-whiskered Vireo** *Vireo altiloquus*	LF, MN	NEA	U
	645 **Lemon-chested Greenlet** *Hylophilus thoracicus*	LF		F
	646 **Ashy-headed Greenlet** *Hylophilus pectoralis*	SC, MN		C
	647 **Tepui Greenlet** *Hylophilus sclateri*	MF	TEP	F
	648 **Buff-cheeked Greenlet** *Hylophilus muscicapinus*	LF, MF		F
	649 **Tawny-crowned Greenlet** *Hylophilus ochraceiceps*	LF		F

Jays **Corvidae**

	650 **Violaceous Jay** *Cyanocorax violaceus* *	LF		?L
	651 **Cayenne Jay** *Cyanocorax cayanus*	LF	GUI	F

Swallows **Hirundinidae**

	652 **Tree Swallow** *Tachycineta bicolor* *	FW	NEA	?
	653 **White-winged Swallow** *Tachycineta albiventer*	RI, FW		C
	654 **Brown-chested Martin** *Progne tapera*	SV, SC, RI	AUS	F
	655 **Purple Martin** *Progne subis*	SC, HU, RI	NEA	S
	656 [**Caribbean Martin** *Progne dominicensis*] *	SC, HU	NEA	?
	657 **Gray-breasted Martin** *Progne chalybea*	HU, SC		C
	658 **Blue-and-white Swallow** *Pygochelidon cyanoleuca*	SC, HU	AUS	U
	659 **White-banded Swallow** *Atticora fasciata*	RI		C
	660 **Black-collared Swallow** *Atticora melanoleuca*	RI		FL
	661 **White-thighed Swallow** *Neochelidon tibialis*	MF, LF		UL
	662 **Tawny-headed Swallow** *Alopochelidon fucata*	SV		F
	663 **Southern Rough-winged Swallow** *Stelgidopteryx ruficollis*	FW, RI, SC		C
	664 **Bank Swallow** *Riparia riparia*	SV, HU, FW	NEA	F
	665 **Barn Swallow** *Hirundo rustica*	SV, HU, SC	NEA	C
	666 [**Cliff Swallow** *Petrochelidon pyrrhonota*]	HU, FW	NEA	?

Wrens **Troglodytidae**

	667 **Flutist Wren** *Microcerculus ustulatus*	MF	TEP	F
	668 **Wing-banded Wren** *Microcerculus bambla*	LF		U
	669 **House Wren** *Troglodytes aedon*	SC, HU		C
	670 **Tepui Wren** *Troglodytes rufulus*	MF	TEP	U
	671 **Sedge Wren** *Cistothorus platensis*	SV		S
	672 **Bicolored Wren** *Campylorhynchus griseus*	SC, PA		F

	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU
	673 **Coraya Wren** *Thryothorus coraya*	LF		F
	674 **Buff-breasted Wren** *Thryothorus leucotis*	LF, RI, SC		F
	675 **White-breasted Wood-Wren** *Henicorhina leucosticta*	LF, MF		F
	676 **Musician Wren** *Cyphorhinus arada*	LF		F

Gnatwrens, Gnatcatchers **Polioptilidae**

	677 **Collared Gnatwren** *Microbates collaris*	LF, MF	AMN	U
	678 **Long-billed Gnatwren** *Ramphocaenus melanurus*	LF		F
	679 **Tropical Gnatcatcher** *Polioptila plumbea*	SC, LF		F
	680 **Guianan Gnatcatcher** *Polioptila guianensis*	LF		U

INCERTAE SEDIS

	681 **Black-capped Donacobius** *Donacobius atricapillus*	FW		F

Thrushes **Turdidae**

	682 **Veery** *Catharus fuscescens*	LF	NEA	S
	683 **Gray-cheeked Thrush** *Catharus minimus*	LF	NEA	S
	684 **Rufous-brown Solitaire** *Cichlopsis leucogenys*	MF		U
	685 **Yellow-legged Thrush** *Turdus flavipes*	MF		S
	686 **Pale-eyed Thrush** *Turdus leucops*	MF		?
	687 **Black-hooded Thrush** *Turdus olivater*	MF		F
	688 **Pale-breasted Thrush** *Turdus leucomelas*	HU, SC		C
	689 **Black-billed Thrush** *Turdus ignobilis*	LF, MF, SC		CL
	690 **Cocoa Thrush** *Turdus fumigatus*	LF		F
	691 **Bare-eyed Robin** *Turdus nudigenis*	SC, HU		F
	692 **White-necked Robin** *Turdus albicollis*	LF, MF		F

Mockingbirds **Mimidae**

	693 **Tropical Mockingbird** *Mimus gilvus*	SC, HU		C

Pipits **Motacillidae**

	694 **Yellowish Pipit** *Anthus lutescens*	SV, HU		F

Tanagers **Thraupidae**

	695 **Black-faced Tanager** *Schistochlamys melanopis*	SV, SC, FW		U
	696 **Magpie Tanager** *Cissopis leveriana*	LF, HU		UL
	697 **Red-billed Pied Tanager** *Lamprospiza melanoleuca*	LF		U
	698 **Hooded Tanager** *Nemosia pileata*	SC		F
	699 **Gray-headed Tanager** *Eucometis penicillata*	LF		S
	700 **Flame-crested Tanager** *Tachyphonus cristatus*	LF		F
	701 **Fulvous-crested Tanager** *Tachyphonus surinamus*	LF		F
	702 **White-shouldered Tanager** *Tachyphonus luctuosus*	LF		U
	703 **White-lined Tanager** *Tachyphonus rufus*	SC, HU		F
	704 **Red-shouldered Tanager** *Tachyphonus phoenicius*	SC, SV		F
	705 **Fulvous Shrike-Tanager** *Lanio fulvus*	LF	AMN	U
	706 **Silver-beaked Tanager** *Ramphocelus carbo*	SC, HU		C
	707 **Blue-gray Tanager** *Thraupis episcopus*	SC, HU		C
	708 **Palm Tanager** *Thraupis palmarum*	SC, HU, PA		C

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	709 **Blue-backed Tanager** *Cyanicterus cyanicterus*	LF	GUI	U
	710 **Turquoise Tanager** *Tangara mexicana*	LF, HU		F
	711 **Paradise Tanager** *Tangara chilensis*	LF, MF		F
	712 **Yellow-bellied Tanager** *Tangara xanthogastra*	MF		F
	713 **Spotted Tanager** *Tangara punctata*	LF, MF		F
	714 **Speckled Tanager** *Tangara guttata*	MF		UL
	715 **Dotted Tanager** *Tangara varia*	MF		S
	716 **Bay-headed Tanager** *Tangara gyrola*	MF, LF		F
	717 **Burnished-buff Tanager** *Tangara cayana*	SC, SV, HU		C
	718 **Masked Tanager** *Tangara nigrocincta* *	LF		?
	719 **Black-headed Tanager** *Tangara cyanoptera*	MF, SC		F
	720 **Opal-rumped Tanager** *Tangara velia*	LF		F
	721 **Swallow-Tanager** *Tersina viridis*	LF, RI		F
	722 **Black-faced Dacnis** *Dacnis lineata*	LF, MF		U
	723 **Blue Dacnis** *Dacnis cayana*	LF, SC		C
	724 **Short-billed Honeycreeper** *Cyanerpes nitidus*	LF		S
	725 **Purple Honeycreeper** *Cyanerpes caeruleus*	LF, MF		F
	726 **Red-legged Honeycreeper** *Cyanerpes cyaneus*	LF		F
	727 **Green Honeycreeper** *Chlorophanes spiza*	LF		C
	728 **Guira Tanager** *Hemithraupis guira*	LF		F
	729 **Yellow-backed Tanager** *Hemithraupis flavicollis*	LF		F
	730 **Chestnut-vented Conebill** *Conirostrum speciosum*	SC, LF		F
	731 **Bicolored Conebill** *Conirostrum bicolor*	MN		F
	732 **Greater Flowerpiercer** *Diglossa major*	MF	TEP	F

INCERTAE SEDIS

	733 **Hepatic Tanager** *Piranga flava*	SV, SC, MF		U
	734 **Summer Tanager** *Piranga rubra*	LF, MF	NEA	S
	735 [**Scarlet Tanager** *Piranga olivacea*] *	LF	NEA	S
	736 **White-winged Tanager** *Piranga leucoptera*	MF, SC		S
	737 **Olive-backed Tanager** *Mitrospingus oleagineus*	MF	TEP	F
	738 **Bananaquit** *Coereba flaveola*	LF, SC, HU		C
	739 **Sooty Grassquit** *Tiaris fuliginosus*	MF, SC		?

Emberizine Finches Emberizidae

	740 **Rufous-collared Sparrow** *Zonotrichia capensis*	SC, HU		FL
	741 **Grassland Sparrow** *Ammodramus humeralis*	SV, HU		C
	742 **Stripe-tailed Yellow-Finch** *Sicalis citrina*	SV, HU		UL
	743 **Saffron Finch** *Sicalis flaveola*	SC, HU		?
	744 **Grassland Yellow-Finch** *Sicalis luteola*	SV, HU		F
	745 **Wedge-tailed Grass-Finch** *Emberizoides herbicola*	SV, SC, FW		F
	746 **Blue-black Grassquit** *Volatinia jacarina*	HU, FW, SC		C
	747 **Slate-colored Seedeater** *Sporophila schistacea*	LF, RI		CL
	748 **Gray Seedeater** *Sporophila intermedia*	SV, SC		F
	749 **Plumbeous Seedeater** *Sporophila plumbea*	SV		F
	750 **Wing-barred Seedeater** *Sporophila americana*	SC, HU		F
	751 **Lesson's Seedeater** *Sporophila bouvronides*	SC		U
	752 **Lined Seedeater** *Sporophila lineola*	SC	AUS	U
	753 **Yellow-bellied Seedeater** *Sporophila nigricollis*	SC, HU		CL
	754 **Ruddy-breasted Seedeater** *Sporophila minuta*	SC, FW, HU		C

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	755 **Chestnut-bellied Seedeater** *Sporophila castaneiventris*	SC, HU		F
	756 **Chestnut-bellied Seed-Finch** *Oryzoborus angolensis*	SC, HU, LF		F
	757 **Large-billed Seed-Finch** *Oryzoborus crassirostris*	FW, SC		U
	758 **Great-billed Seed-Finch** *Oryzoborus maximiliani*	FW, SC		?
	759 **White-naped Seedeater** *Dolospingus fringilloides*	SC, SV	AMN	FL
	760 [**Paramo Seedeater** *Catamenia homochroa*]	SV, SC		CL
	761 **Pectoral Sparrow** *Arremon taciturnus*	LF		F
	762 **Tepui Brush-Finch** *Atlapetes personatus*	MF, SC	TEP	U
	763 **Red-crested Finch** *Coryphospingus cucullatus* *	SC		?
	764 **Red-capped Cardinal** *Paroaria gularis*	RI, SC		C

Grosbeaks, Saltators **Cardinalidae**

	765 **Yellow-green Grosbeak** *Caryothraustes canadensis*	LF		F
	766 **Red-and-black Grosbeak** *Periporphyrus erythromelas*	LF		U
	767 **Slate-colored Grosbeak** *Saltator grossus*	LF		F
	768 **Buff-throated Saltator** *Saltator maximus*	SC, LF		F
	769 **Grayish Saltator** *Saltator coerulescens*	SC, HU		F
	770 **Blue-black Grosbeak** *Cyanocompsa cyanoides*	LF		F
	771 **Dickcissel** *Spiza americana*	HU, SV	NEA	?

Wood Warblers **Parulidae**

	772 **Tropical Parula** *Parula pitiayumi*	MF, LF		U
	773 **Yellow Warbler** *Dendroica petechia*	MN, SC, HU	NEA	F
	774 **Blackpoll Warbler** *Dendroica striata*	LF	NEA	U
	775 [**Bay-breasted Warbler** *Dendroica castanea*]	LF	NEA	S
	776 [**Blackburnian Warbler** *Dendroica fusca*]	MF	NEA	S
	777 **American Redstart** *Setophaga ruticilla*	LF, MF, MN	NEA	U
	778 **Prothonotary Warbler** *Protonotaria citrea*	MN	NEA	S
	779 **Northern Waterthrush** *Seiurus noveboracensis*	MN	NEA	C
	780 **Masked Yellowthroat** *Geothlypis aequinoctialis*	FW, SC		F
	781 **Slate-throated Redstart** *Myioborus miniatus*	MF		F
	782 **Tepui Redstart** *Myioborus castaneocapillus*	MF, SC	TEP	F
	783 **Two-banded Warbler** *Basileuterus bivittatus*	MF, SC		F
	784 **Golden-crowned Warbler** *Basileuterus culicivorus*	MF, LF		UL
	785 **Flavescent Warbler** *Basileuterus flaveolus*	SC		FL
	786 **Riverbank Warbler** *Phaeothlypis rivularis*	LF, RI		F

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	787 **Rose-breasted Chat** *Granatellus pelzelni*	LF		U

New World Blackbirds **Icteridae**

	788 **Green Oropendola** *Psarocolius viridis*	LF, MF		C
	789 **Crested Oropendola** *Psarocolius decumanus*	LF		C
	790 **Yellow-rumped Cacique** *Cacicus cela*	RI, LF, HU		C
	791 **Red-rumped Cacique** *Cacicus haemorrhous*	LF		C
	792 **Troupial** *Icterus icterus*	SC, SV		F
	793 **Epaulet Oriole** *Icterus cayanensis*	SC, PA, HU		F
	794 **Yellow Oriole** *Icterus nigrogularis*	SC, HU, MN		F

	ENGLISH NAME - SCIENTIFIC NAME	HABITAT	EN/MI	ABU
	795 **Golden-tufted Grackle** *Macroagelaius imthurni*	MF	TEP	F
	796 **Velvet-fronted Grackle** *Lampropsar tanagrinus*	LF, MN		U
	797 **Yellow-hooded Blackbird** *Chrysomus icterocephalus*	FW		C
	798 **Giant Cowbird** *Molothrus oryzivorus*	LF, SC, HU		C
	799 **Shiny Cowbird** *Molothrus bonariensis*	SC, HU		C
	800 **Carib Grackle** *Quiscalus lugubris*	SC, HU, MN		C
	801 **Red-breasted Blackbird** *Sturnella militaris*	HU, FW, SV		C
	802 **Eastern Meadowlark** *Sturnella magna*	SV, HU		C
	803 **Bobolink** *Dolichonyx oryzivorus*	HU, FW, SV	NEA	S

Cardueline Finches **Fringillidae**

	804 **Red Siskin** *Carduelis cucullata*	SC, SV		CL
	805 **Hooded Siskin** *Carduelis magellanica*	SC, SV	GUI	SL
	806 **Plumbeous Euphonia** *Euphonia plumbea*	LF, SC, MF		U
	807 **Purple-throated Euphonia** *Euphonia chlorotica*	LF, MF		U
	808 **Finsch's Euphonia** *Euphonia finschi*	LF, SC	GUI	F
	809 **Violaceous Euphonia** *Euphonia violacea*	LF, HU		F
	810 **Golden-bellied Euphonia** *Euphonia chrysopasta*	LF, RI		F
	811 **White-vented Euphonia** *Euphonia minuta*	LF		F
	812 **Orange-bellied Euphonia** *Euphonia xanthogaster*	MF, LF		F
	813 **Golden-sided Euphonia** *Euphonia cayennensis*	LF		F
	814 **Blue-naped Chlorophonia** *Chlorophonia cyanea*	MF		U

NOTES

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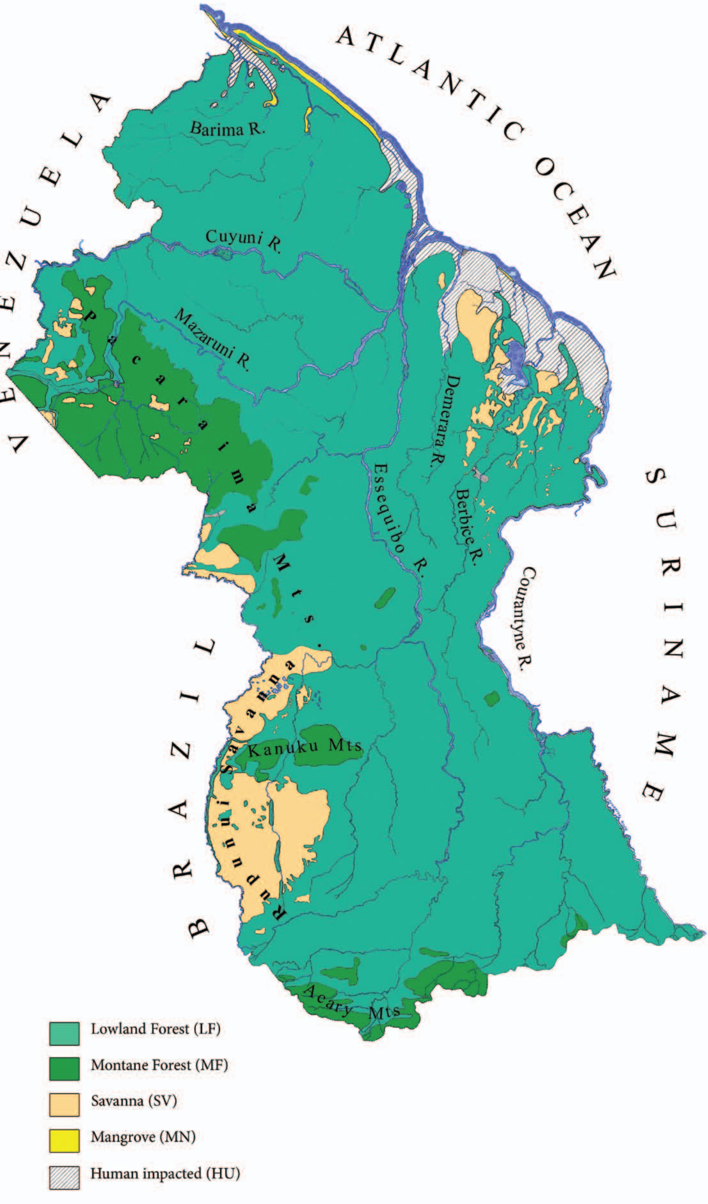
ATLANTIC OCEAN
VENEZUELA
SURINAME
BRAZIL
Barima R.
Cuyuni R.
Mazaruni R.
Pacaraima Mts.
Demerara R.
Essequibo R.
Berbice R.
Courantyne R.
Rupununi Savanna
Kanuku Mts
Acary Mts
Lowland Forest (LF)
Montane Forest (MF)
Savanna (SV)
Mangrove (MN)
Human impacted (HU)

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APPENDIX J – Protected Species Observer Summary

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Protected Species Observer Summary

Prepared for: ExxonMobil

ExxonMobil

Guyana

2015-2016

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Table of Contents

List of Figures

List of Tables

1 Executive Summary

This report summarizes the protected species observer data collected by ExxonMobil on various programs from 2014 through 2016 in Guyana. Data from the Stabroek 3D, LIZA AUV, and Canje 3D surveys conducted over the periods of 12 July 2015 to 17 February 2016, 17 December 2015 to 23 March 2016, and 18 March 2016 to 20 August 2016 respectively are included in this report.

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 and Canje 3D 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.

Throughout all surveys, PSOs conducted visual observations for a total of 8187 hours and 37 minutes. PAM Operators performed acoustic monitoring for a total of 5135 hours and 55 minutes.

During the seismic surveys, the seismic source was active for a total of 8558 hours and 30 minutes. This included 7879 hours and 28 minute while in production, 218 hours and 40 minutes while at full volume or partial volume while not in production, 344 hours and 23 minutes of soft-start, and 115 hours and 59 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 417 total protected species detections recorded during all surveys, including 153 visual detections, 264 acoustic detections and three correlated visual-acoustic detections. Visual detections consisted of 53 detections of whales, 91 detections of dolphins, and 09 detections of turtles. Acoustic detections consisted of 09 sperm whale detections and 255 dolphin detections, three of which were correlated with visual detections.

There were a total of nine mitigation actions conducted throughout these surveys due to marine mammals detected within the exclusion zone prior to source operations. All 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.

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 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.

2.1.3 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.

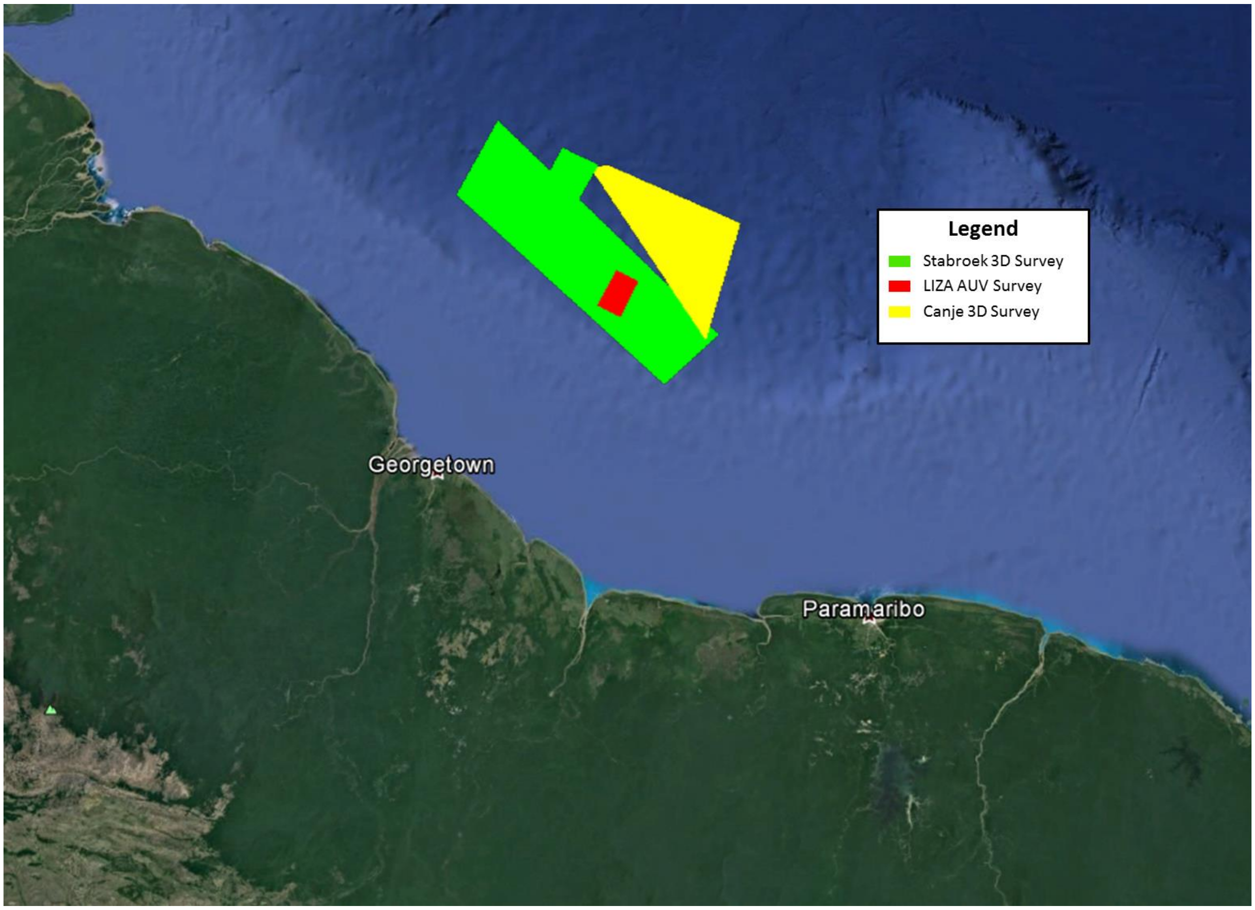

Figure 1: Map indicating the general location of the surveys.

2.2 Vessel and Seismic Equipment Specifications

2.2.1 Stabroek 3D Survey

The *CGG Alize* and *CGG Geo Celtic* were the two vessels utilized to complete this survey, however the two vessels worked independently of one another in different sections of the prospect area. The chase vessels 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 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 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.

2.2.3 Canje 3D Survey

The *Polarcus Adira* was the sole vessel utilized to complete this survey. The chase vessels 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.

Table 1. Seismic Acquisition Parameters Summary Table

General Specifications			
Client / Contractor:	CGG		Polarcus
Program/Project Name:	Stabroek 3D Guyana 2015 Survey		Stabroek II 3D Guyana 2016 Survey
Program Period:	12 July 2015 to 17 February 2016		19 March 2016 to 20 August 2016
Type of Survey:	3D Seismic		3D Seismic
General Location:	Guyana		Guyana
Prospect Size (km²):	8209		7742
Vessel / Vessel Length (m):	*CGG Alize* / 101.4 *CGG Geo Celtic* / 108.3		*Polarcus Adira* / 92
Support/Chase Vessels:	*Thor Omega, The Fenny, the Bourbon Cormorant, the Linda C, the Bourbon Grebe, and the Bourbon Petrel.*		*Vos Athos, 7 Oceans*
Vessel Configuration description:	Two streamer vessels working independently of one another on different areas of the prospect area.		Single source and recording vessel
Energy Source (Airgun) Specifications			
	CGG Alize	***CGG Geo Celtic***	
Total source volume (in^3)	4070	4070	4240
Number of source arrays:	6	6	6
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
Source depth:	6 meters	6 meters	6 meters
Source distance astern (meters):	200-341	369-424	488
Source frequency (Hz):	200	370	128
Source intensity (dB re 1μPa or bar meters)	45	69.8	52.4
Shot point interval (meters and seconds)	25 meters	25 meters	25 meters, 11.5 seconds
Recording System Specifications:			
Number of streamers or nodes/cables:	8-10	10	12
Streamer depth (meters):	7	7	12
Streamer length /separation (meters)	10000 / 100	10000 / 100	8100 / 100
Streamer description:	Sentinel solid streamers	Sentinel solid streamers	Sentinel solid streamers

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 – Mulitbeam, 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
Mulitbeam Echo Sounder (MBES)	Kongsberg EM2040	Frequency: 200 kHz	Range of 250m
Energy Source Hull mount Specifications			
Mulitbeam 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	

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 of Guyana, was installed on board each seismic source vessel. 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.

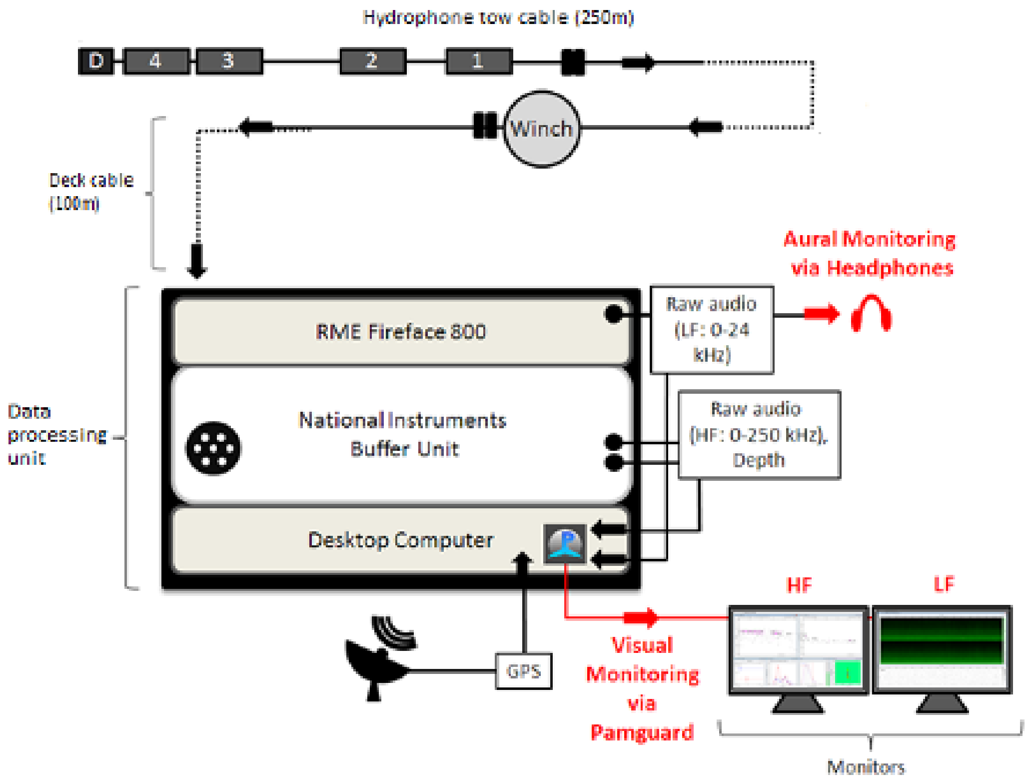

Figure 2. Data pathway through PAM system

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.

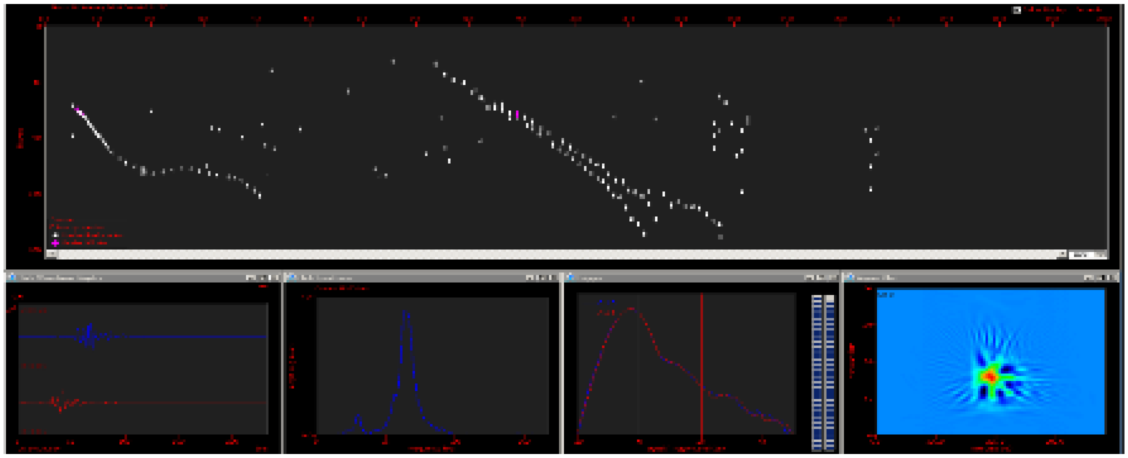

Figure 3: High frequency delphinid click trains on the bearing/time display

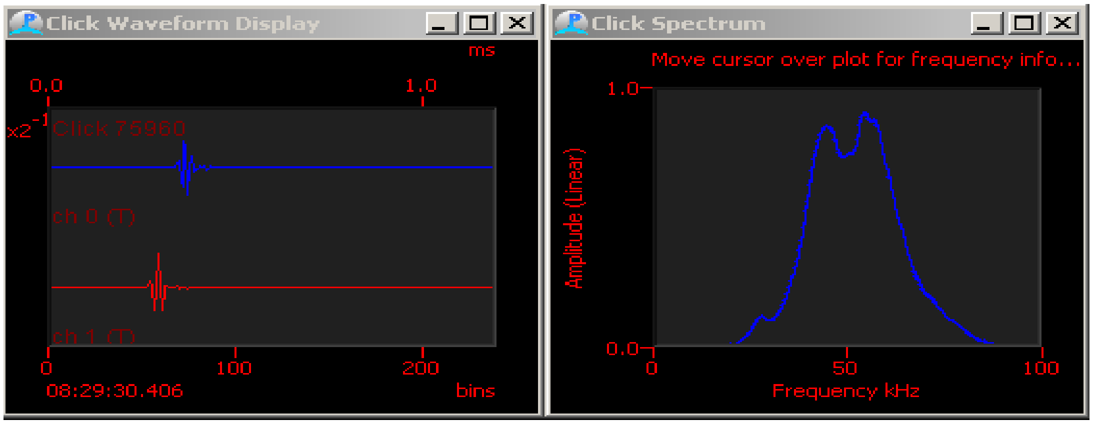

Figure 4: Clean click waveform display and click spectrum of delphinid pulse emissions

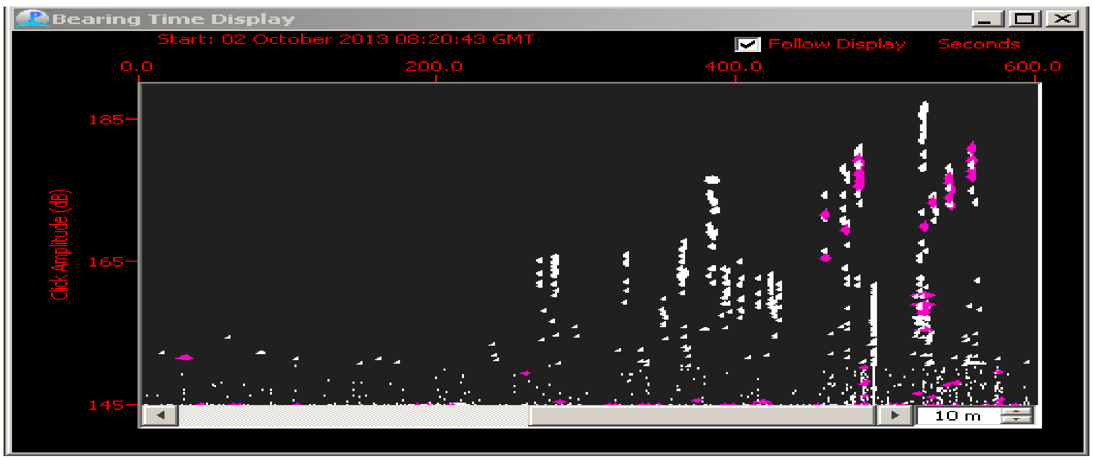

Figure 5: The amplitude/time module during a high frequency delphinid detection

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.

4 Survey Data

4.1 Source Operations Summary

Over the course of all of the survey programs, the seismic source was active for a total of 8558 hours and 30 minutes including: 344 hours and 23 minutes spent in ramp up, 115 hours and 59 minutes spent conducting source testing, 7879 hours and 28 minutes in production and 218 hours and 40 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 (Figures 6 and 7).

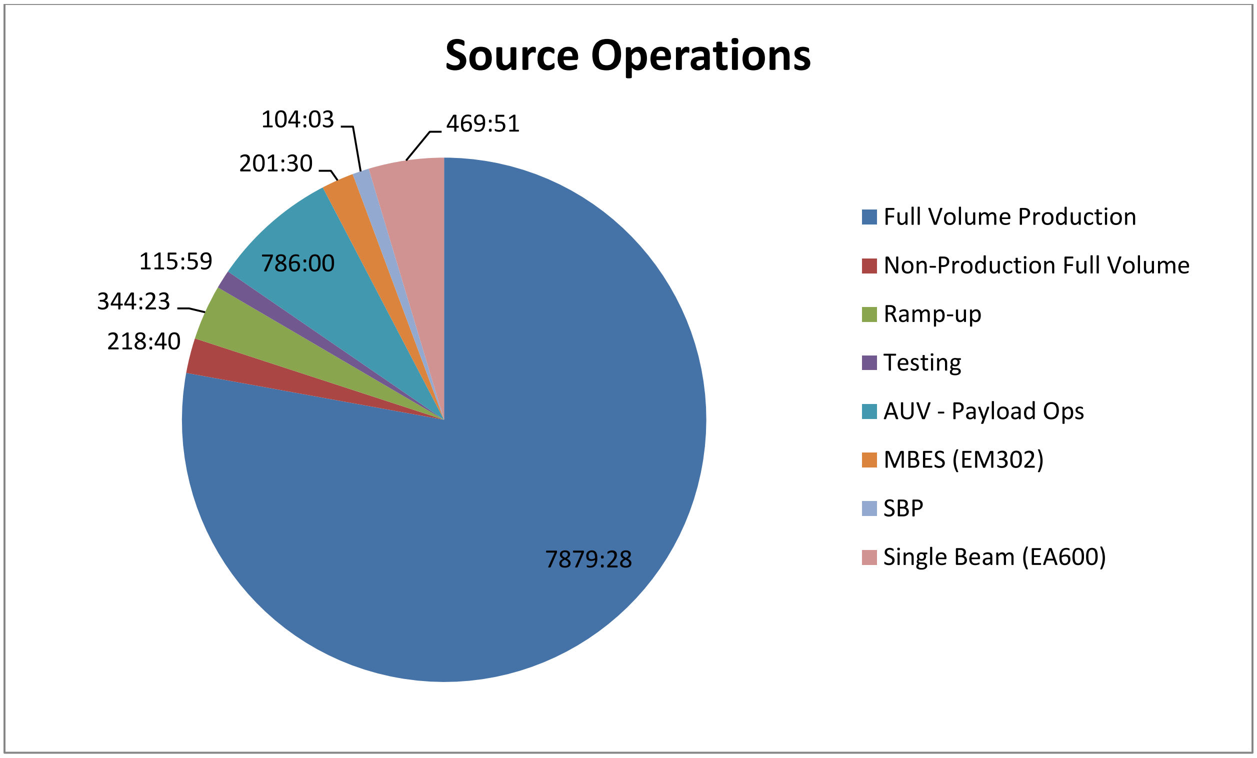

Figure 6: Breakdown of acoustic source operations

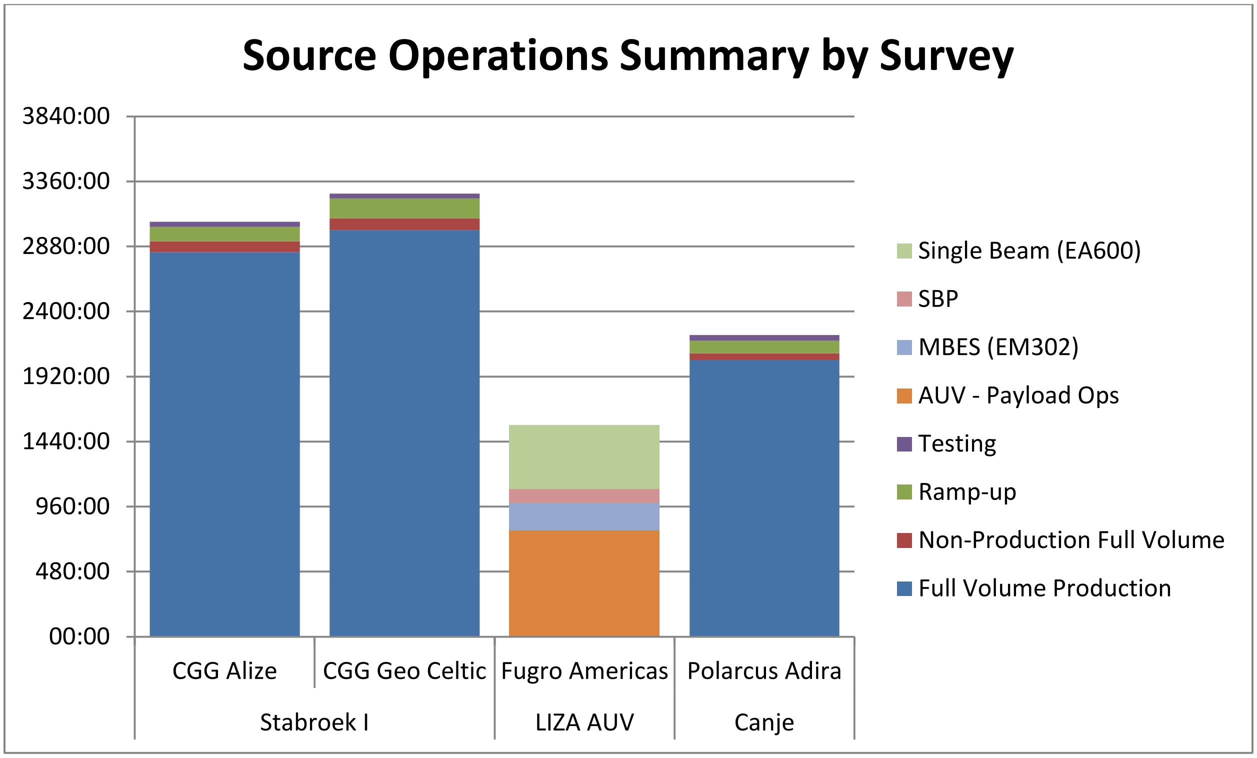

Figure 7: Breakdown of source operations by source activity and survey

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 8).

4.3 Acoustic Monitoring Summary

Passive acoustic monitoring (PAM) was conducted for a total of 5135 hours and 55 minutes throughout the Stabroek 3D and Canje 3D 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 8).

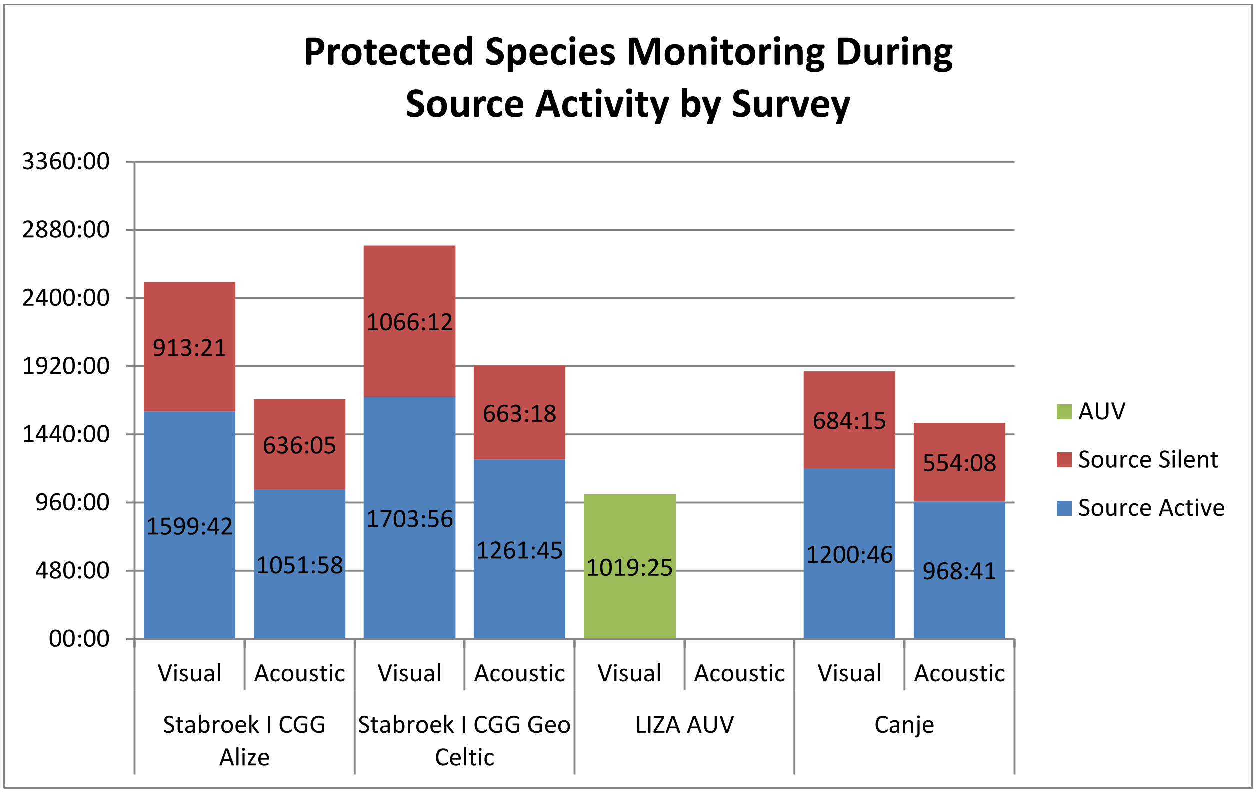

Figure 8: Breakdown of visual and acoustic monitoring while source active and silent by survey

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 nine mitigation actions implemented throughout this survey due to marine mammals detected within the exclusion zone prior to source operations, all occurred aboard the *CGG Alize* during the Stabroek 3D Survey and were delays to soft-start implemented for protected species detected inside the mitigation zone prior to commencement of soft-start. Eight of the nine delays were implemented for delphinids and one delay was implemented for sperm whales (Table 3). All mitigation actions were implemented as a result of acoustic detections where one acoustic detection was also accompanied by a visual sighting of the animals.

Table 3: Summary of mitigation actions by visual and acoustic observers.

	Total Number	Duration
Total number of delays to ramp-up for acoustic detections of dolphins	08*	19:54
Total number of delays to ramp-up for acoustic detections of whales	01	00:16
Total delays to ramp-up for acoustic detections	09	20:10
Total number of delays to ramp-up for visual detections of dolphins	01	
Total number of delays to ramp-up for visual detections of whales	00	00:00
Total delays to ramp-up for visual detections	**01***	**00:09***
Total delays to ramp-up for dolphins	**08**	**19:54**
Total delays to ramp-up for whales	**01**	**00:16**
Total delays to ramp-up up	**09**	**20:10**

*One delay was implemented as a result of a correlated visual and acoustic detection

4.5 Wildlife Summary

4.5.1 Overview

There were a total of 417 protected species detections made both visually and acoustically throughout all of the survey programs: 153 visual detections, 264 acoustic detections, and three detections that were made both visually and acoustically. The visual detections included whales, dolphins and sea turtles while acoustic detections consisted of whales and dolphins (Table 4, Figure 9).

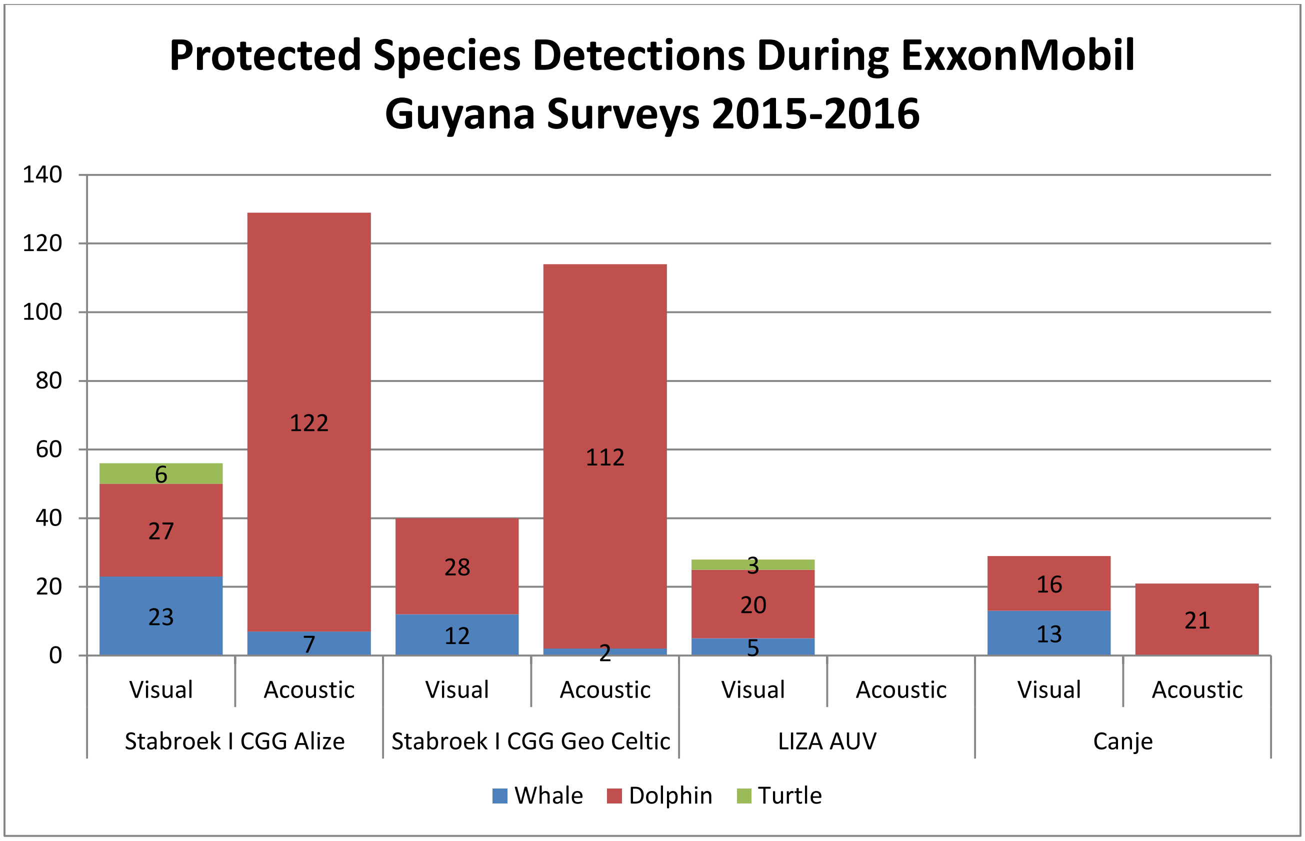

Figure 9: Protected species detections by species group on each of the ExxonMobil Guyana survey programs

A total of 12 different identified species were observed over the course of all of the programs, two species of whales, seven species of delphinid and three species of sea turtles (Figure 10).

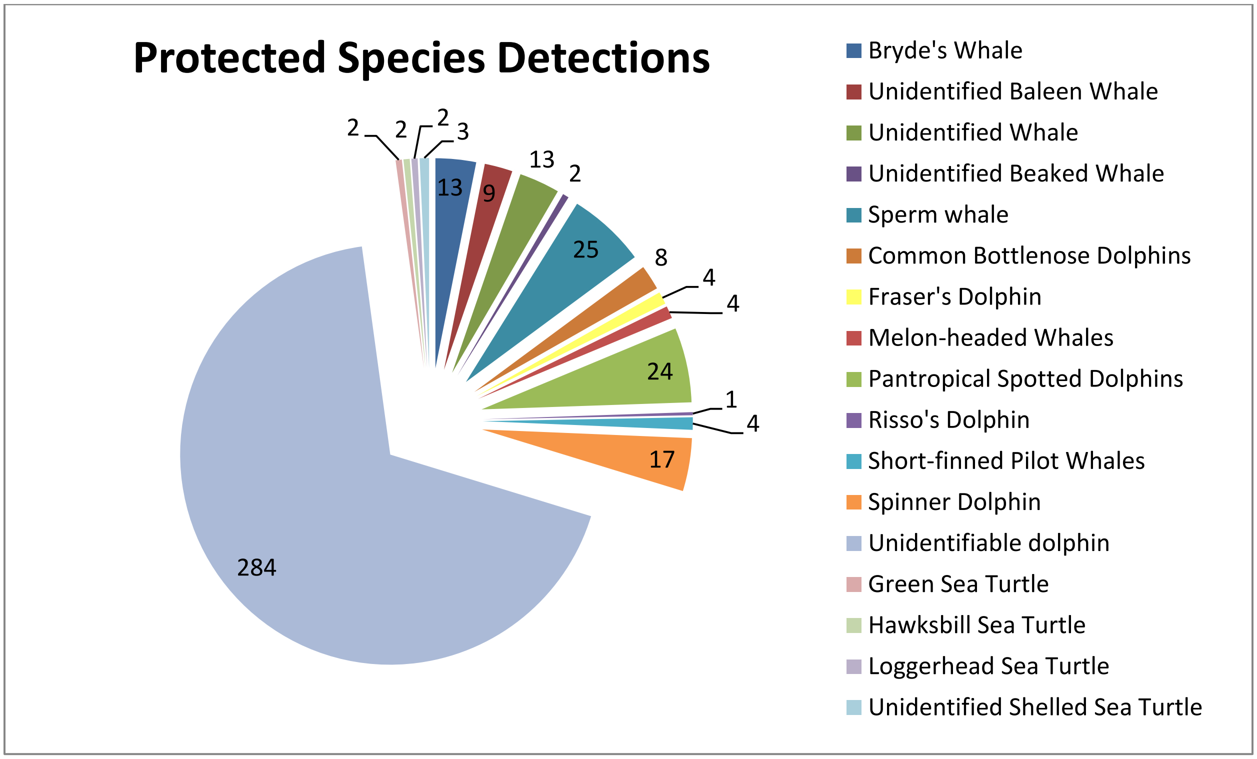

Figure 10: Protected species detections (visual and acoustic) shown as a breakdown by species over all ExxonMobil Guyana programs during 2015 and 2016

Of the 417 total protected species detections made during all programs, 260 occurred while the acoustic source was active. Of the 260 detections during source activity, eight occurred during soft starts, nine occurred during reduced power source testing, three occurred during full volume non-production firing and 240 occurred during full volume production. The remaining 157 protected species detections occurred while the acoustic source was silent (Figure 11).

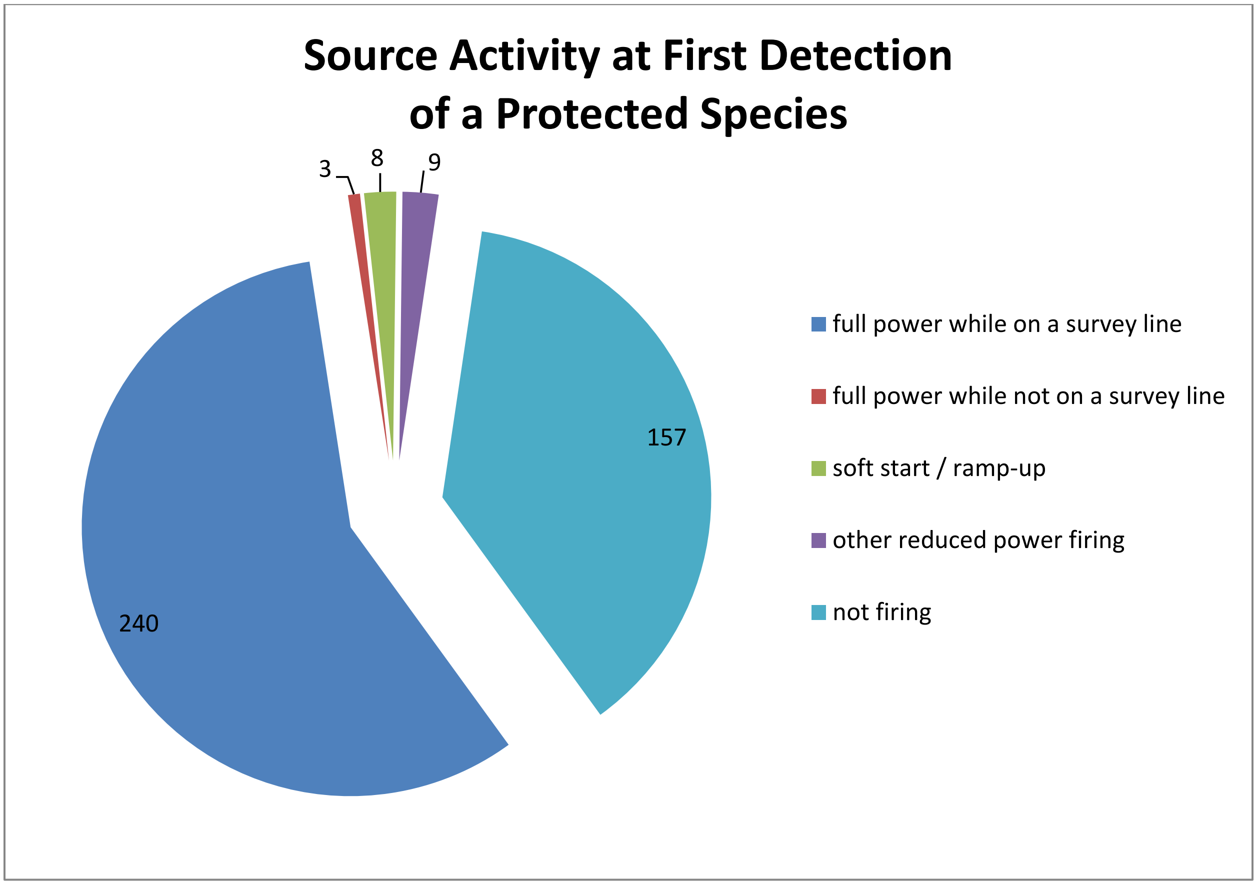

Figure 11: Seismic source activity at the initial detection of a marine mammal or sea turtle

4.5.2 Visual Detections

Protected species were visually detected on 153 occasions during the surveys included in this summary. Delphinids were detected more frequently than any other species group, with seven species identified in 346 separate 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 53 whale detections were made during all of the programs. Three sea turtle species were observed in additional to sightings of unidentified shelled turtles and a total of nine sea turtles were detected (Figure 12, Table 4).

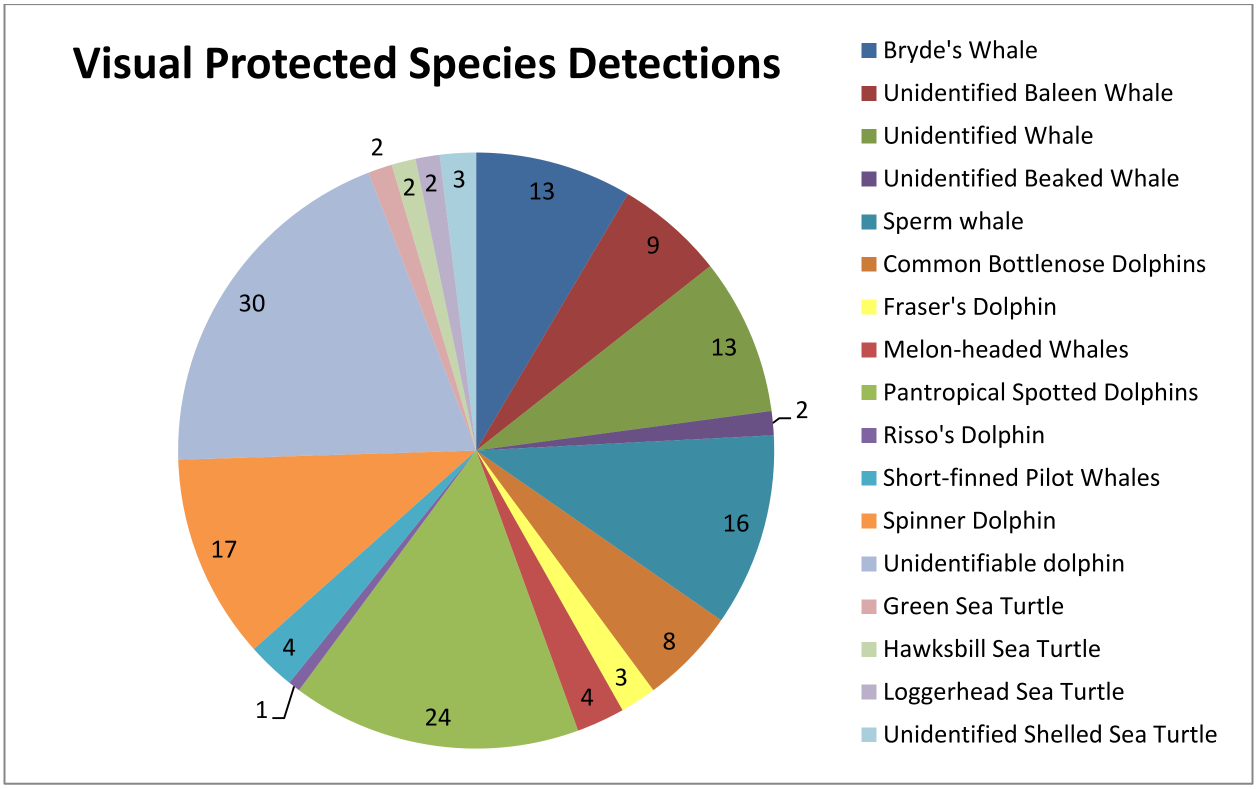

Figure 12: Visual protected species detections shown as a breakdown by species over all ExxonMobil Guyana programs during 2015 and 2016

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 13, Table 4).

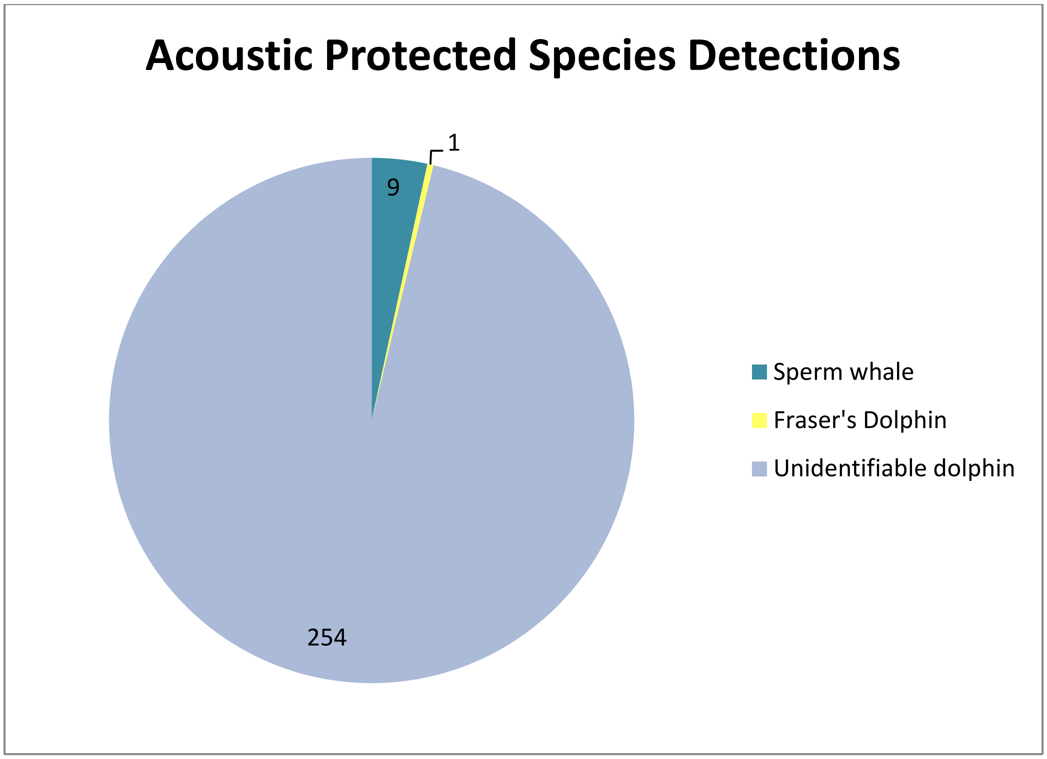

Figure 13: Acoustic protected species detections shown as a breakdown by species over all ExxonMobil Guyana programs during 2015 and 2016

Figure 14 shows the distribution of visual protected species detections, while Figure 15 depicts acoustic protected species detections—both maps include the three correlated visual and acoustic detections.

Table 4: Protected species visual and acoustic detection summary during the Stabroek survey program

	Stabroek I *CGG Alize*		Stabroek I *CGG Geo Celtic*		LIZA AUV		Canje		Total Number of Detection Events
	Visual	Acoustic	Visual	Acoustic	Visual	Acoustic	Visual	Acoustic	
Bryde's Whale	3		5		2		3		13
Unidentified Baleen Whale	5		1		1		2		9
Unidentified Whale	11						2		13
Unidentified Beaked Whale							2		2
Sperm whale	4	7	6	2	2		4		25
Total number of whale detections	**23**	**7**	**12**	**2**	**5**	**0**	**13**	**0**	**62**
Common Bottlenose Dolphins					8				8
Fraser's Dolphin	1*	1*					2		4
Melon-headed Whales			2		1		1		4
Pantropical Spotted Dolphins	6		6		7		5		24
Risso's Dolphin			1						1
Short-finned Pilot Whales	2				2				4
Spinner Dolphin	5		9				3		17
Unidentifiable dolphin	13	121**	10	112	2		5	21	284
Total number of dolphin detections	**27**	**122**	**28**	**112**	**20**	**0**	**16**	**21**	**346**
Total number of marine mammal detections	**50**	**129**	**40**	**114**	**25**	**0**	**29**	**21**	**408**
Green Sea Turtle	1				1				2
Hawksbill Sea Turtle					2				2
Loggerhead Sea Turtle	2								2
Unidentified Shelled Sea Turtle	3								3
Total number of sea turtle detections	**6**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**9**

*Correlated with a visual detection
**Two detections correlated with visual detections

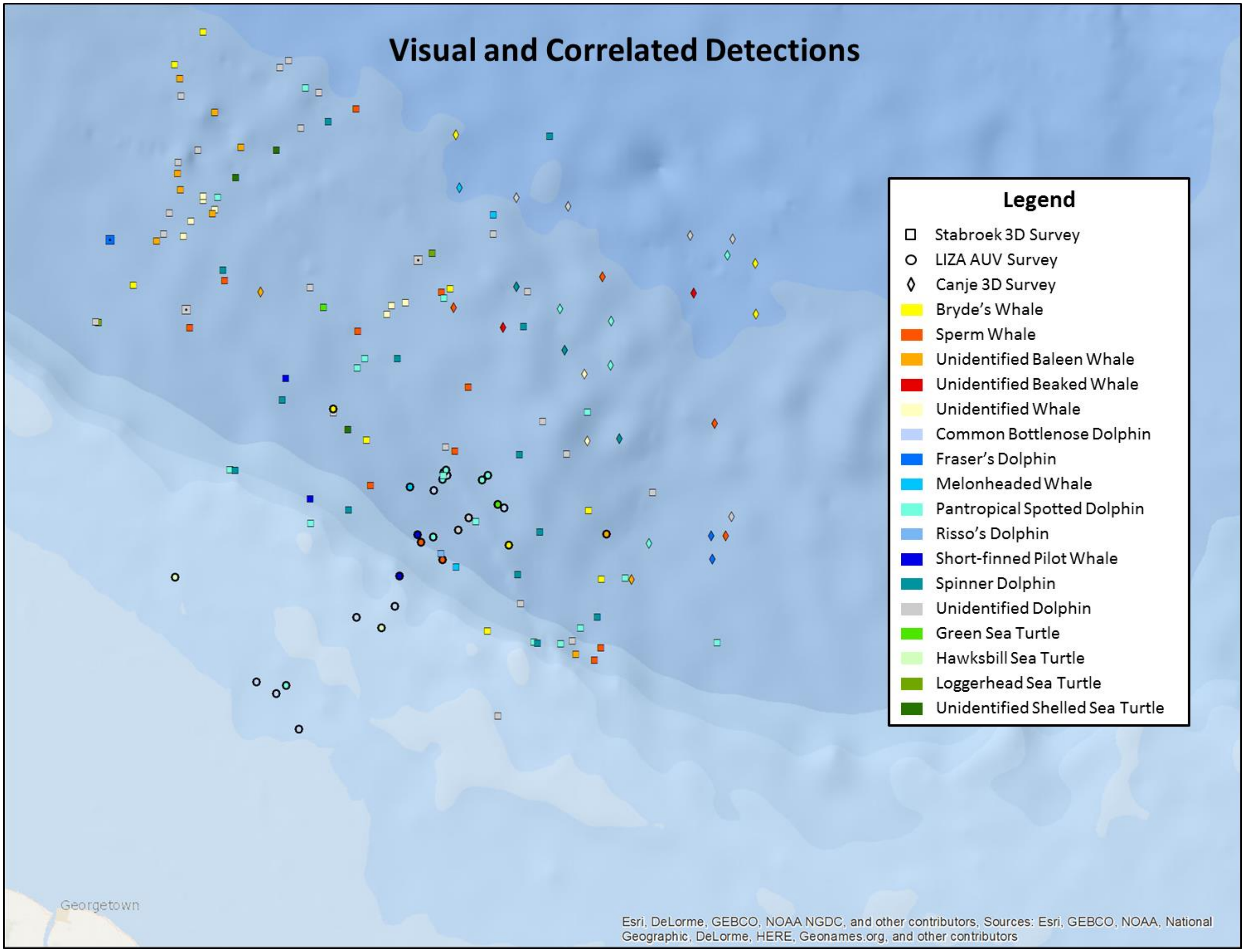

Figure 14: Distribution of visual protected species detections during ExxonMobil Guyana Stabroek 3D, LIZA AUV, and Canje 3D programs

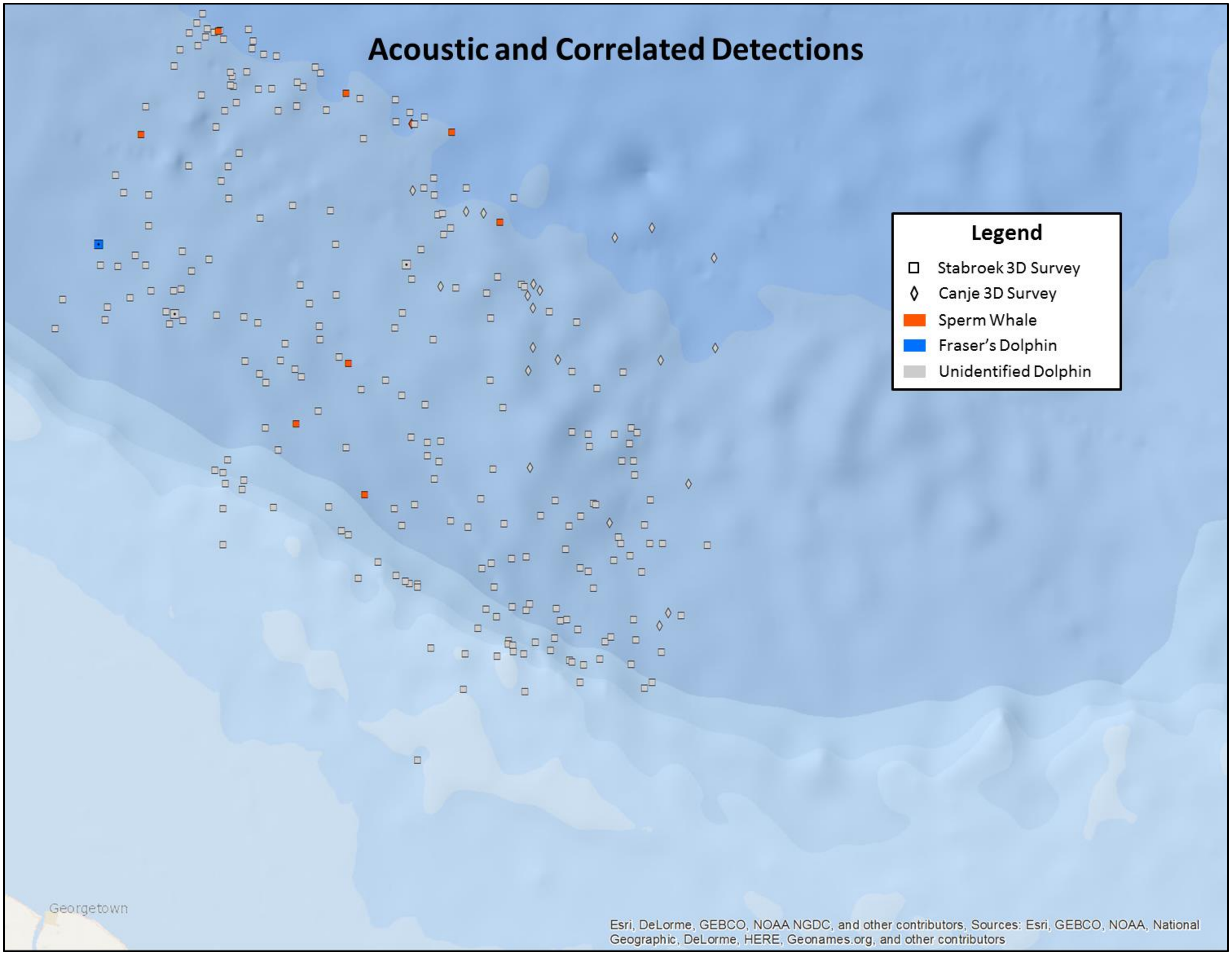

Figure 15: Distribution of acoustic protected species detections during ExxonMobil Guyana Stabroek 3D and Canje 3D programs

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 59 avian species, 10 of which were unidentifiable, 31 fish species, seven of which were unidentifiable, three marine invertebrate species, and five other wildlife species.

The most frequently observed avian species was the masked booby (*Sula dactylatra*, 36.6%) which had 1016 individuals recorded over a period of 385 days. Other frequently observed avian species, each with at least 100 individuals recorded throughout the surveys, included unidentified birds (18.6%), Cory's shearwater (*Calonectris diomedea*, 8%), magnificent frigatebird (*Fregata magnificens*, 4.9%), white-tailed tropic bird (*Phaethon lepturus*, 4.9%), great shearwater (*Puffinus gravis*, 4.6%), bank swallow (*Riparia riparia*, 4.6%), and brown booby (*Sula leucogaster*, 4.3%) (Figure 16, Table 5).

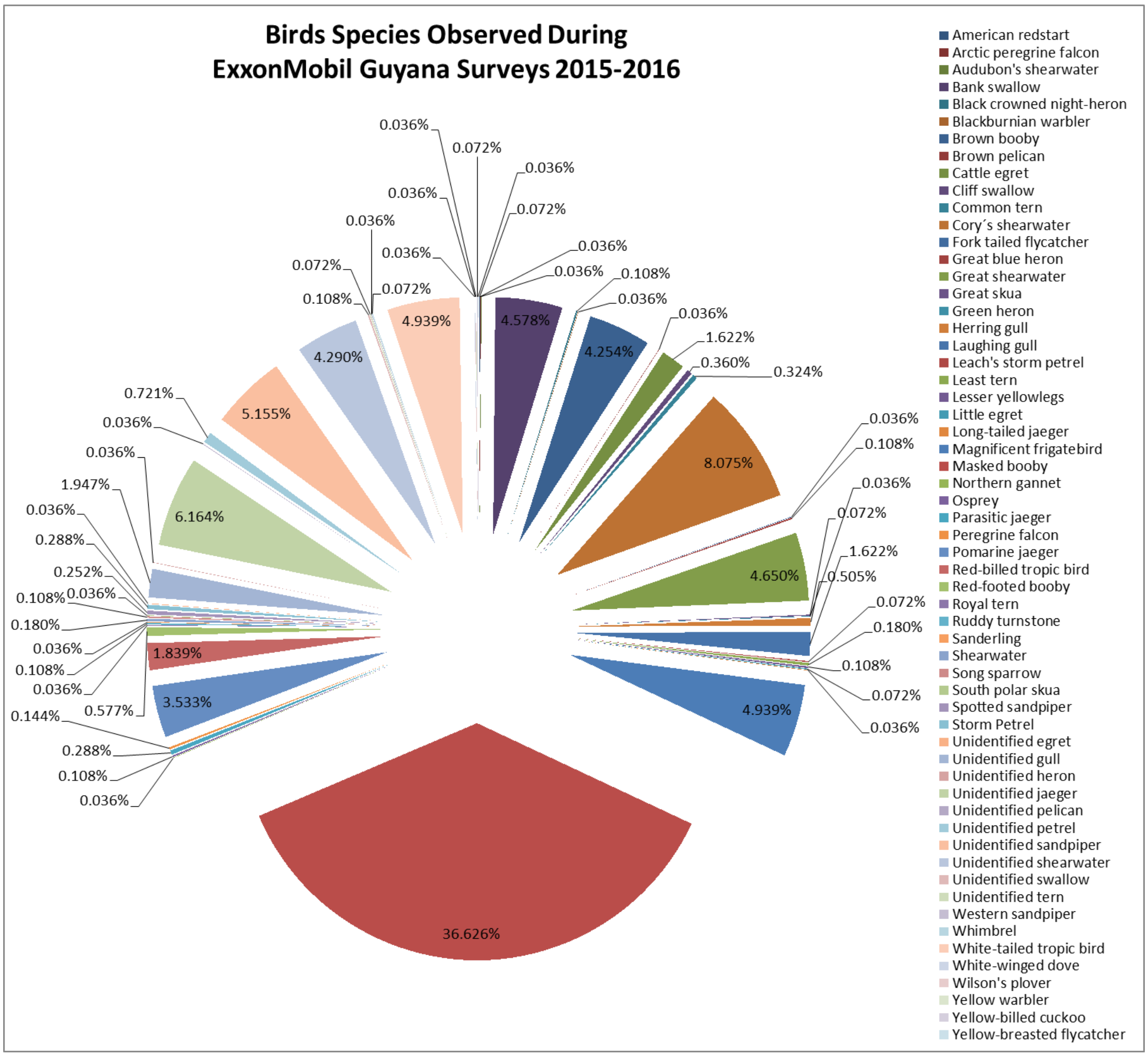

Figure 16: Bird species observed during Stabroek 3D Survey, LIZA AUV Survey, and Canje 3D Survey

The most commonly observed fish species was the unidentified flying fish (Family Exocoetidae, 97%) which had 88281 individuals recorded over a period of 589 days throughout the surveys. Other notable fish species observed, each with more than 100 individuals recorded throughout the surveys, included unidentified fish (1.02%), including a large number of unidentified tuna species (0.47%), skip jack tuna (*Katsuwonus pelamis*, 0.78%), Atlantic tripletail (*Lobotes surinamensis*, 0.26%), mahi mahi (*Coryphaena hipparus*, 0.26%), clearwing flying fish (*Cypselurus comatus*, 0.14%), Atlantic bonito tuna (*Sarda sarda*, 0.13%), yellow fin tuna (*Thunnus albacares*, 0.13%), and Atlantic flying fish (*Cheliopogon melanurus*, 0.13%) (Figure 17, Table 6).

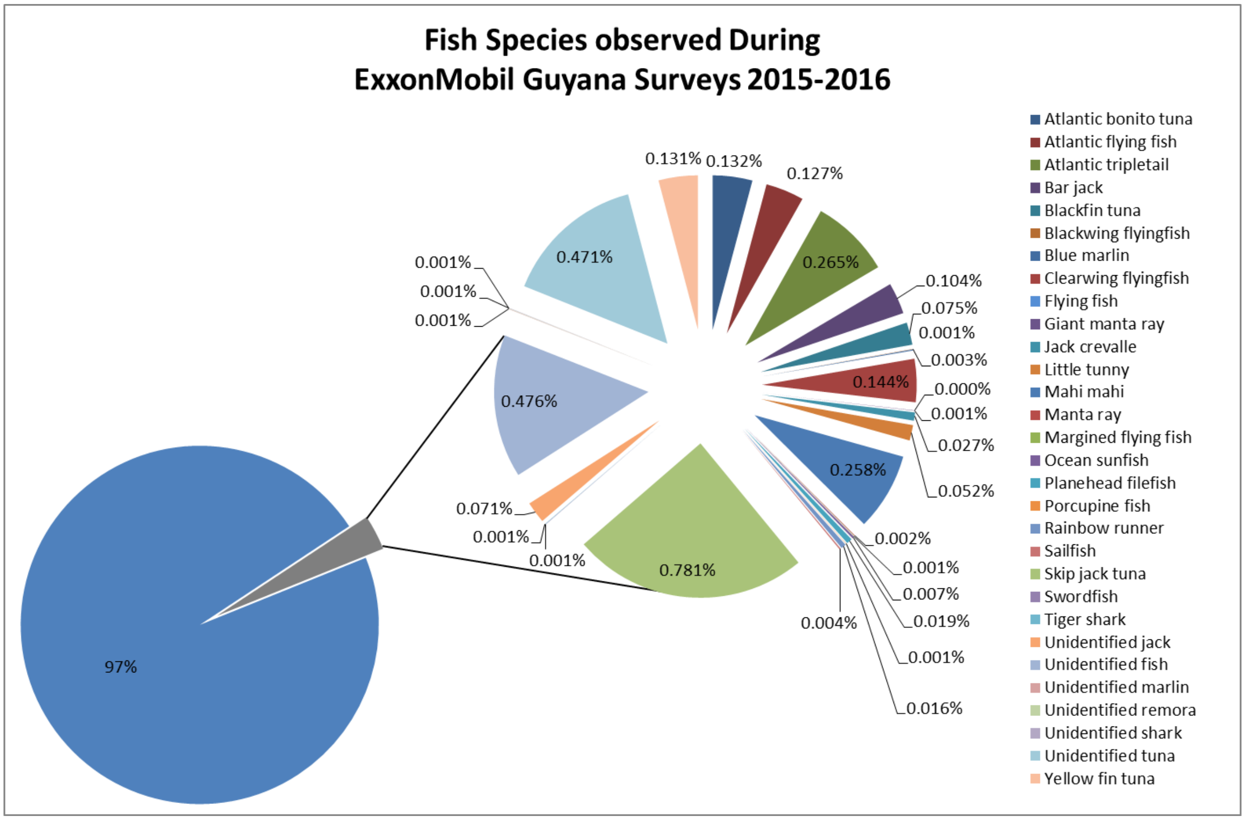

Figure 17: Fish species observed during Stabroek 3D Survey, LIZA AUV Survey, and Canje 3D Survey

Marine invertebrate species observed throughout the surveys, in order of frequency of observation, were the Portuguese man o' war (*Physalia physalis*), unidentified salps (Family Salpidae), and an unidentified jellyfish (Table 7).

Other wildlife species observed throughout the surveys included, in order of observation frequency, houseflies (*Musca domestica*), dragon flies (Order Odonata), butterflies (Order Lepidoptera), green-banded Urania (*Urania leilus*), and moths (Order Lepidoptera) (Table 8).

4.5.4 Wildlife Summary Tables

Table 5: Birds observed during visual monitoring

Common Name	Class	Order	Family	Genus	Species	Number of Individuals Observed	Number of Days Observed
American redstart	Aves	Passeriformes	Parulidae	*Steophaga*	*ruticilla*	2	2
Arctic peregrine falcon	Aves	Falconiformes	Falconidae	*Falco*	*peregrinus tundrius*	1	1
Audubon's shearwater	Aves	Procellariformes	Procellariidae	*Puffinus*	*lherminieri*	1	1
Bank swallow	Aves	Passeriformes	Hirundinidae	*Riparia*	*riparia*	127	59
Black crowned night-heron	Aves	Ciconiiformes	Ardeidae	*Nycticorax*	*nycticorax*	3	2
Blackburnian warbler	Aves	Passeriformes	Parulidae	*Setophaga*	*fusca*	1	1
Brown booby	Aves	Pelecaniformes	Sulidae	*Sula*	*leucogaster*	118	92
Brown pelican	Aves	Pelecaniformes	Pelecanidae	*Pelecanus*	*occidentalis*	1	1
Cattle egret	Aves	Ciconiiformes	Ardeidae	*Bubulcus*	*ibis*	45	25
Cliff swallow	Aves	Passeriformes	Hirundinidae	*Petrochelidon*	*pyrrhonota*	10	6
Common tern	Aves	Charadriformes	Sternidae	*Sterna*	*hirundo*	9	8
Cory´s shearwater	Aves	Procellariiformes	Procellariidae	*Calonectris*	*diomedea*	224	45
Fork tailed flycatcher	Aves	Passeriformes	Tyrannidae	*Tyrannus*	*savana*	1	1
Great blue heron	Aves	Ciconiiformes	Ardeidae	*Ardea*	*herodias*	3	2
Great shearwater	Aves	Procellariiformes	Procellariidae	*Puffinus*	*gravis*	129	30
Great skua	Aves	Charadriiformes	Stercorariidae	*Stercorarius*	*skua*	2	2
Green heron	Aves	Ciconiiformes	Rallidae	*Butorides*	*virescens*	1	1
Herring gull	Aves	Charadriiformes	Laridae	*Larus*	*argentatus*	14	6
Laughing gull	Aves	Charadriiformes	Laridae	*Larus*	*atricilla*	45	18
Leach's storm petrel	Aves	Procellariiformes	Hydrobatidae	*Oceanodroma*	*leucorhoa*	2	2
Least tern	Aves	Charadriiformes	Sternidae	*Sternula*	*antillarum*	5	3
Lesser yellowlegs	Aves	Charadriiformes	Scolopacidae	*Tringa*	*flavipes*	3	3
Little egret	Aves	Ciconiiformes	Ardeidae	*Egretta*	*garzetta*	2	2
Long-tailed jaeger	Aves	Charadriiformes	Stercorariidae	*Stercoarius*	*longicaudus*	1	1
Magnificent frigatebird	Aves	Suliformes	Fregatidae	*Fregata*	*magnificens*	137	69
Masked booby	Aves	Suliformes	Sulidae	*Sula*	*dactylatra*	1016	385
Northern gannet	Aves	Pelecaniformes	Sulidae	*Morus*	*bassanus*	1	1
Osprey	Aves	Falconiformes	Pandionidae	*Pandion*	*haliaetus*	3	3
Parasitic jaeger	Aves	Charadriiformes	Stercorariidae	*Stercorarius*	*parasiticus*	8	2
Peregrine falcon	Aves	Falconiformes	Falconidae	*Falco*	*peregrinus*	4	4
Pomarine jaeger	Aves	Charadriiformes	Stercorariidae	*Stercorarius*	*pomarinus*	98	34
Red-billed tropic bird	Aves	Pelecaniformes	Phaethontidae	*Phaethon*	*aethereus*	51	26
Red-footed booby	Aves	Suliformes	Sulidae	*Sula*	*sula*	16	12

Common Name	Class	Order	Family	Genus	Species	Number of Individuals Observed	Number of Days Observed
Royal tern	Aves	Charadriiformes	Laridae	*Sterna*	*maxima*	1	1
Ruddy turnstone	Aves	Charadriiformes	Scolopacidae	*Arenaria*	*interpres*	3	2
Sanderling	Aves	Charadriiformes	Scolopacidae	*Calidris*	*alba*	1	1
Shearwater	Aves	Procellariiformes	Procellariidae	*NA*	*NA*	5	4
Song sparrow	Aves	Passeriformes	Emberizidea	*Melospiza*	*melodia*	3	2
South polar skua	Aves	Charadriiformes	Stercorariidae	*Stercorarius*	*maccormicki*	1	1
Spotted sandpiper	Aves	Charadriiformes	Scolopacidae	*Actitis*	*macularius*	7	7
Storm Petrel	Aves	Procellariiformes	Hydrobatidae	*NA*	*NA*	8	7
Unidentified egret	Aves	Ciconiiformes	Ardeidae	*n/a*	*n/a*	1	1
Unidentified gull	Aves	Charadriformes	Laridae	*n/a*	*n/a*	54	27
Unidentified heron	Aves	Ciconiiformes	Ardeidae	*n/a*	*n/a*	1	1
Unidentified jaeger	Aves	Charadriformes	Stercorariidae	*n/a*	*n/a*	171	23
Unidentified pelican	Aves	Pelecaniformes	Pelecanidae	*n/a*	*n/a*	1	1
Unidentified petrel	Aves	Procellariformes	n/a	*n/a*	*n/a*	20	11
Unidentified sandpiper	Aves	Charadriformes	Scolopacidae	*n/a*	*n/a*	143	29
Unidentified shearwater	Aves	Procellariformes	Procellariidae	*n/a*	*n/a*	119	21
Unidentified swallow	Aves	Passeriformes	Hirundinidae	*n/a*	*n/a*	3	3
Unidentified tern	Aves	Charadriformes	Sternidae	*n/a*	*n/a*	2	2
Western sandpiper	Aves	Charadriiformes	Scolopacidae	*Calidris*	*mauri*	1	1
Whimbrel	Aves	Charadriiformes	Scolopacidae	*Numenius*	*phaeopus*	2	1
White-tailed tropic bird	Aves	Phaethontiformes	Phaethontidae	*Phaethon*	*lepturus*	137	58
White-winged dove	Aves	Columbiformes	Columbidae	*Zenaida*	*asiatica*	1	1
Wilson's plover	Aves	Charadriiformes	Charadriidae	*Charadriaus*	*wilsonia*	1	1
Yellow warbler	Aves	Passeriformes	Parulidae	*Dendroica*	*petechia*	1	1
Yellow-billed cuckoo	Aves	Cuculiformes	Cuculidae	*Cuccyzus*	*americanus*	2	2
Yellow-breasted flycatcher	Aves	Passeriformes	Tyrannidae	*Tolmomyias*	*flaviventris*	1	1

Table 6: Fish species observed during visual monitoring

Common Name	Class	Order	Family	Genus	Species	Number of Individuals Observed	Number of Days Observed
Atlantic bonito tuna	Actinopterygii	Perciformes	Scrombidae	*Sarda*	*sarda*	120	1
Atlantic flying fish	Actinopterygii	Beloniformes	Exocoetidae	*Cheilopogon*	*melanurus*	116	1
Atlantic tripletail	Actinopterygii	Perciformes	Lobotidae	*Lobotes*	*surinamensis*	242	46
Bar jack	Actinopterygii	Perciformes	Carangidae	*Caranx*	*ruber*	95	4
Blackfin tuna	Actinopterygii	Perciformes	Scombridae	*Thunnus*	*atlanticus*	68	3
Blackwing flyingfish	Actinopterygii	Beloniformes	Exocoetidae	*Hirundichthys*	*rondeletii*	1	1
Blue marlin	Actinopterygii	Perciformes	Istiophoridae	*Makaira*	*nigricans*	3	3
Clearwing flyingfish	Actinopterygii	Beloniformes	Exocoetidae	*Cypselurus*	*comatus*	131	2
Flying fish	Actinopterygii	Beloniformes	Exocoetidae	*n/a*	*n/a*	88281	589
Giant manta ray	Chondrichthyes	Myliobatiformes	Myliobatidae	*Manta*	*birostris*	1	1
Jack crevalle	Actinopterygii	Perciformes	Carangidae	*Caranx*	*hippos*	25	1
Little tunny	Actinopterygii	Perciformes	Scombridae	*Euthynnus*	*alleteratus*	47	2
Mahi mahi	Actinopterygii	Perciformes	Coryphaenidae	*Coryphaena*	*hippurus*	235	52
Manta ray	Chondrichthyes	Myliobatiformes	Myliobatidae	*Manta*	*n/a*	2	2
Margined flying fish	Actinopterygii	Beloniformes	Exocoetidae	*Cheilopogon*	*cyanopterus*	1	1
Ocean sunfish	Actinopterygii	Tetraodontiformes	Molidae	*Mola*	*mola*	6	2
Planehead filefish	Actinopterygii	Tetraodontiformes	Monacanthidae	*Stephanolepis*	*hispidus*	17	5
Porcupine fish	Actinopterygii	Tetraodontiformes	Diodontidae	*Diodon*	*hystrix*	1	1
Rainbow runner	Actinopterygii	Perciformes	Carangidae	*Elagatis*	*bipinnulata*	15	1
Sailfish	Actinopterygii	Perciformes	Istiophoridae	*Istiophorus*	*platypterus*	4	3
Skip jack tuna	Actinopterygii	Perciformes	Scombridae	*Katsuwonus*	*pelamis*	712	33
Swordfish	Actinopterygii	Perciformes	Xiphiidae	*Xiphias*	*gladius*	1	1
Tiger shark	Chondrichthyes	Carcharhiniformes	Carcharhinidae	*Galeocerdo*	*cuvier*	1	1
Unidentified jack	Actinopterygii	Perciformes	Carangidae	*NA*	*NA*	65	4
Unidentified fish	Actinopterygii	n/a	n/a	*n/a*	*n/a*	434	57
Unidentified marlin	Actinopterygii	Perciformes	Istiophoridae	*n/a*	*n/a*	1	1
Unidentified remora	Actinopterygii	Actinopterygii	Perciformes	*n/a*	*n/a*	1	1
Unidentified shark	Chondrichthyes	n/a	n/a	*n/a*	*n/a*	1	1
Unidentified tuna	Actinopterygii	Perciformes	Scombridae	*n/a*	*n/a*	429	23
Yellow fin tuna	Actinopterygii	Perciformes	Scombridae	*Thunnus*	*albacares*	119	8

Table 7: Marine invertebrates observed during visual monitoring

Common Name	Class	Order	Family	Genus	Species	Number of Individuals Observed	Number of Days Observed
Portuguese Man O'War	Hydrozoa	Siphonophora	Physaliidae	*Physalia*	*physalis*	53	30
Salp	Thaliacea	Salpida	Salpidae	*n/a*	*n/a*	2	2
Unidentified jellyfish	n/a	n/a	n/a	*n/a*	*n/a*	1	1

Table 8: Other wildlife observed during visual monitoring

Common Name	Class	Order	Family	Genus	Species	Number of Individuals Observed	Number of Days Observed
Butterly	Insecta	Lepidoptera	n/a	*n/a*	*n/a*	3	2
Dragon fly	Insecta	Odonata	NA	*NA*	*NA*	30	9
Green-banded Urania	Insecta	Lepidoptera	Uraniidae	*Urania*	*leilus*	1	1
Housefly	Insecta	Diptera	Muscidae	*Musca*	*domestica*	35	1
Moth	Insecta	Lepidoptera	n/a	*n/a*	*n/a*	1	1

5 Protected Species Summary Table

Table 9: Protected species detected visually and acoustically during the Stabroek 3D Survey, LIZA AUV Survey, and Canje 3D Survey

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

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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
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

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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
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

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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	
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

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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
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

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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
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	

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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
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

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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
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

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19-Jan-2016		1113	23:01	0:03	Unidentifiable dolphin				2811		500	not firing	not firing	500	None	1:02	0:00
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

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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
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		

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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		
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		

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09-Sep-2015		22	4:00	4:31	Unidentified dolphin	acoustically	07.79208	-057.09225	1855			not firing	not firing		none		
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

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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
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		

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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		
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

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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	
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		

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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		
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

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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
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		

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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		
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

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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	
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

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
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
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

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
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
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

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
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
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

APPENDIX K – Marine Fish of Guyana

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Appendix K. Finfish species from Zone (McConnell, 1962)

Scientific Name
Abudefduf sp.
Acanthurus hepatus
Alutera monoceros
Alutera schoepfi
Alutera ventralis
Anisotremus virginicus
Antennarius scaber
Antigonia capros
Balistes carolinensis
Balistes vetula
Bathystoma aurolineatum
Bathystoma rimator
Bathystoma striatum
Bellator militaris
Bodianus sp.
Bothus sp.
Calamus proridens
Caulolatilus guppyi
Chaetodon bimaculatus
Chaetodon sp.
Carcharhinus acronatus
Coryphaena hippurus
Cryptomus sp.
Cubiceps sp.
Cyclopsetta fimbriata
Dactylopterus volitans
Decapterus punctatus
Decapturus macarellus
Diplectrum formosum
Diplectrum radiale
Diplectrum sp.
Eqeus lanceolatus
Eucinostomus gula
Fistularia petimba
Gymnachirus sp.
Gymnothorax ocellatus
Haemulon melanurum
Haemulon sciurus
Haemulon steindachneri
Halichoeres sp.
Halieutichthys sp.
Hippocampus longirostris
Holocanthus tricolor

Holocentrus ascensionis
Holocentrus bullisi
Lactophrys tricornis
Lutjanus analis
Lutjanus aya
Lutjanus spp.
Lutjanus synagris
Monocanthus ciliatus
Monocanthus hispidus
Mullus sp.
Mustelus sp.
Ocyurus p.
Ogocephalus vespertilio
Pomacanthus arcuatus
Pomacanthus paru
Priacanthus arenatus
Prionodes phoebe
Prionotus sp.
Psenes sp.
Rhinobatos percellens
Rhomboplites aurorubens
Rypticus sp.
Saurida sp.
Scoliodon sp.
Scoliodon terrae-novae
Scorpaena agassizii
Scorpaena brasiliensis
Scorpaena plumieri
Scorpaena sp.
Selar crumenophthalmus
Spariosoma aqualidum
Sphoeroides dorsalis
Sphoeroides marmoratus
Syacium papillosum
Synodus foetens
Synodus intermedius
Synodus poeyi
Trachinocephalus myops
Trachurus lathami
Upeneus maculatus
Upeneus parvus

APPENDIX L – Air Quality Modeling Report

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Appendix L-Air Quality Modeling Report

The business of sustainability

ERM

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AM3	Actual cubic meters
AOI	Area of Influence
Cal/sec	Calories/second
CALPUFF	CALifornia PUFF model
CO	Carbon Monoxide
DC	Drill Centre
EEPGL	Esso Exploration and Production Guyana Limited
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
ERM	Environmental Resources Management
FPSO	Floating Production Storage and Offloading (Vessel)
H_2S	Hydrogen Sulfide
HHV	Higher Heating Value
K	Degrees Kelvin
kbd	Thousand barrels per day
m	Meters
m^3	Cubic Meters
MMBtu	Million British Thermal Units
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
PDA	Project Development Area

PM10	Particulate Matter (less than 10 microns)
PM25	Particulate Matter (less than 2.5 microns)
ppb	Parts Per Billion
ppg	Pounds Per Gallon
ppm	Parts Per Million
SO_2	Sulfur Dioxide
TOR	Terms Of Reference
VOC	Volatile Organic Compounds
$\mu g/m^3$	Micrograms per cubic meter
UTM	Universal Transverse Mercator (East or North)
WHO	World Health Organization
WRF	Weather Research and Forecasting (meteorological model)

1.0 INTRODUCTION

1.1 Purpose

For the production of an Environmental Impact Assessment (EIA) of the Liza Phase 1 Development Project (the Project), Esso Exploration and Production Guyana Limited (EEPGL) commissioned ERM to perform modeling of air emissions from the Project, to estimate concentrations at locations onshore where exposure to these concentrations may occur. This Appendix provides a description of modeling methodology including source characteristics and emissions, receptor locations, model selection, 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 FPSO and Drill Centers DC1 and DC2), and of the area sources (including support vessels, construction vessels, and other sources without a fixed location), as configured for the modeling. Terrain elevations used in the modelling 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: a) 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, vents and onboard incineration of wastes; and b) general area sources such as support vessels, construction vessels, tug boats, and helicopters. Such emissions contribute to increases in the ambient air concentrations of certain pollutants at onshore receptors.

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 of the parameters that were used in this analysis, along with the stack locations in UTM coordinates. Table 2-1 also displays area source characteristics. These values are based on current knowledge of the Project design. If the parameters change as a result of final design considerations, the modeling will be reviewed to determine if additional analysis is necessary. It should be noted that due to the distance from Project sources to onshore receptors, modeled concentrations are not very sensitive to changes in physical parameters.

Table 2-1 Source Parameters for Model Input

Name	UTME	UTMN	Base Elevation	Height	Exhaust Flow	Exhaust Temp	Diameter	Exhaust Velocity
	m	m	m	m	Am3/hour	K	m	m/s
FPSO Sources								
Combustion Turbines	501000	885512	30	28.00	638,716	803.15	3.100	23.507
Flare - HP Normal Flaring (Note 1)	501000	885512	30	136.29	n/a	1273.00	0.243	20.000
Flare - LP Normal Flaring (Note 1)	501000	885512	30	135.72	n/a	1273.00	0.133	20.000
Flare - HP Full Flaring (Note 1)	501000	885512	30	194.51	n/a	1273.00	13.378	20.000
Flare - LP Full Flaring (Note 1)	501000	885512	30	162.48	n/a	1273.00	5.962	20.000
Auxiliary Boiler (Heaters)	501000	885512	30	24.40	98,457	681.15	1.150	26.330
Essential Services Gens	501000	885512	30	15.50	14,791	578.15	0.305	56.234

Emergency Generators	501000	885512	30	3.20	15,229	719.15	0.300	59.845
Incinerator	501000	885512	30	10.00	5,000	600.00	0.500	7.074
Deck Cranes	501000	885512	30	28.90	7,360	795.55	0.522	9.539
Export Tanker	501000	885512	30	24.40	98,457	681.15	1.150	26.330
Drill Center Sources								
Drill Center1	502901	891211	0	22.00	73,470	682.60	0.800	40.601
Drill Center2	505105	898442	0	22.00	73,470	682.60	0.800	40.601
Area Sources								
Support Vessels Project Area	Note 2		0	10.00	n/a	n/a	n/a	n/a
Support Vessels FPSO shore to Project Area								
Helicopters	Note 2		0	300.00	n/a	n/a	n/a	n/a
General Project Area (Construction)	Note 3		0	10.00	n/a	n/a	n/a	n/a

Notes
1. Effective height/diameter calculated based on heat release to maintain buoyancy flux
2. Area sources to distribute emissions between shore and Project area
3. General area Source in Project area

Flares associated with the Project are modeled as stack 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[1]	Physical Stack Height	Effective Release Height[1]
	MMscf/hr	Btu/scf	MMBtu/hr	cal/sec	cal/sec	m		m
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	4.53	1284.6	5,820.7	4.07E+08	1.83E+08	13.378	135	194.51
LP	0.68	1707.4	1,156.1	8.09E+07	3.64E+07	5.962	135	162.48

NOTES
1 - Effective diameter and effective stack height calculated based on U.S. EPA guidance, using 20 m/s exit velocity and 1273 K exhaust temp

Emissions to air from the Project have been estimated based on a number of factors including activity levels, fuel type, equipment capacities, and standard emission factors that are published by the USEPA in the publication *AP-42: Compilation of Air Pollutant Emission* Factors (AP-42). 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 NO_x emitted per cubic meter of natural gas combusted). The use of these factors allows estimation of emissions from various sources of air pollution. 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 Project activities for three time periods: 2018-2019 (Drilling, SURF Installation, and operation of related support and installation vessels); 2020-2021 (Drilling, operation of related support vessels, FPSO startup and associated temporary non-routine flaring, tanker loading); and 2022-2040 (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 summarized in Table 2-3 represent the overall maximum anticipated for any one year during that time period for the source category indicated. 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. Detailed listings of emissions by year are displayed in Table 2-4 (found at the end of this report).

Table 2-3 Annual Air Emissions Summary

Pollutant	Source Category	Annual Emissions (tonnes)		
		2018-2019	2020-2021	2022-2040
Nitrogen Oxides (NOx)	FPSO	0.0	1,637.2	1,542.9
	FPSO Flaring (temporary, non-routine)	0.0	372.8	171.9
	Tanker Loading	0.0	131.1	136.5
	Area Sources	2,382.9	1,122.5	1,122.5
	Drill ship	1,253.0	1,670.1	0.0
	Total	3,635.9	4,933.6	2,973.9
Sulfur Oxides (SO_2)	FPSO	0.0	45.0	47.1
	FPSO Flaring (temporary, non-routine)	0.0	0.0	3.8
	Tanker Loading	0.0	109.9	114.5
	Area Sources	81.4	38.7	38.7

Pollutant	Source Category	Annual Emissions (tonnes)		
		2018-2019	2020-2021	2022-2040
	Drill ship	42.3	56.0	0.0
	Total	123.7	249.6	204.0
Particulate Matter (PM)	FPSO	0.0	40.2	33.6
	FPSO Flaring (temporary, non-routine)	0.0	10.7	4.9
	Tanker Loading	0.0	9.2	9.6
	Area Sources	167.5	78.9	78.9
	Drill ship	88.1	117.4	0.0
	Total	255.6	256.4	127.0
Carbon Monoxide (CO)	FPSO	0.0	422.4	402.8
	FPSO Flaring (temporary, non-routine)	0.0	2,028.3	935.6
	Tanker Loading	0.0	27.3	28.4
	Area Sources	496.4	233.9	233.9
	Drill ship	261.0	347.9	0.0
	Total	757.5	3,059.8	1,600.6
Hydrogen Sulfide (H_2S)	FPSO Flaring (temporary, non-routine)	n/a	0.0	0.1
Volatile Organic Compounds (VOCs)	All Sources	92.6	10,248.6	10,717.5
Greenhouse Gasses (GHGs [kilotonnes CO_2-equivalents])	All Sources	190.2	1,508.5	976.7

Notes:
1. The years indicated for the various Project stages reflect the current project execution plan, 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 ambient air quality criteria have been established for these substances.
3. PM emissions represent total PM; for the purpose of the impact assessment, the total PM values were used for modeling of both PM_{10} and $PM_{2.5}$ emissions (producing conservatively high modelling results).
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 AOI. The intent of this grid was to identify maximum predicted pollutant concentrations generated by the Project across the onshore portion of the AOI. The methodology utilized was to predict maximum concentrations at all of the onshore grid points using the dispersion model, and then to compare these maximum values to concentrations that may potentially result in significant impacts; if the maximum predicted concentrations are determined to be not significant, it follows that air quality impacts on any specific receptors 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 locations of the receptor points modeled. For each receptor, terrain elevations were specified and are used by CALPUFF to model plume interaction with onshore terrain.

Figure 2-1 Air Quality Modeling Receptor Locations

2.3 Model Selection

The CALPUFF model (a non-steady-state model used in the U.S. and around the globe for long-range transport and complex wind modeling) was selected for use in the assessment. CALPUFF is a Lagrangian "puff" model that treats a plume as a series of puffs that it tracks as the wind carries the plume towards potential receptor locations. The selection of CALPUFF was based on the long distance between the principal Project-related sources and the receptors. As shown in Figure 2-1, the distance from the PDA to the closest shoreline is greater than 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/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 the emission sources as plumes interact with the onshore receptors; CALPUFF, combined with gridded meteorological data, is capable of accounting for the LSBC phenomenon. The modeling was conducted with CALPUFF (Version 7.2.1, level 150618). 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 one year – calendar year 2014. 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 km, so that a two-dimensional profile of hourly winds and temperature was developed every 12 km 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 WRF accounts for the effects on meteorological variables of 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 km grid points (WRF created 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 level 10 meters above the surface; the wind roses shown in Figure 2-3 were created from the profile level 240 meters above the surface (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 is considerably less pronounced than the effects at 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

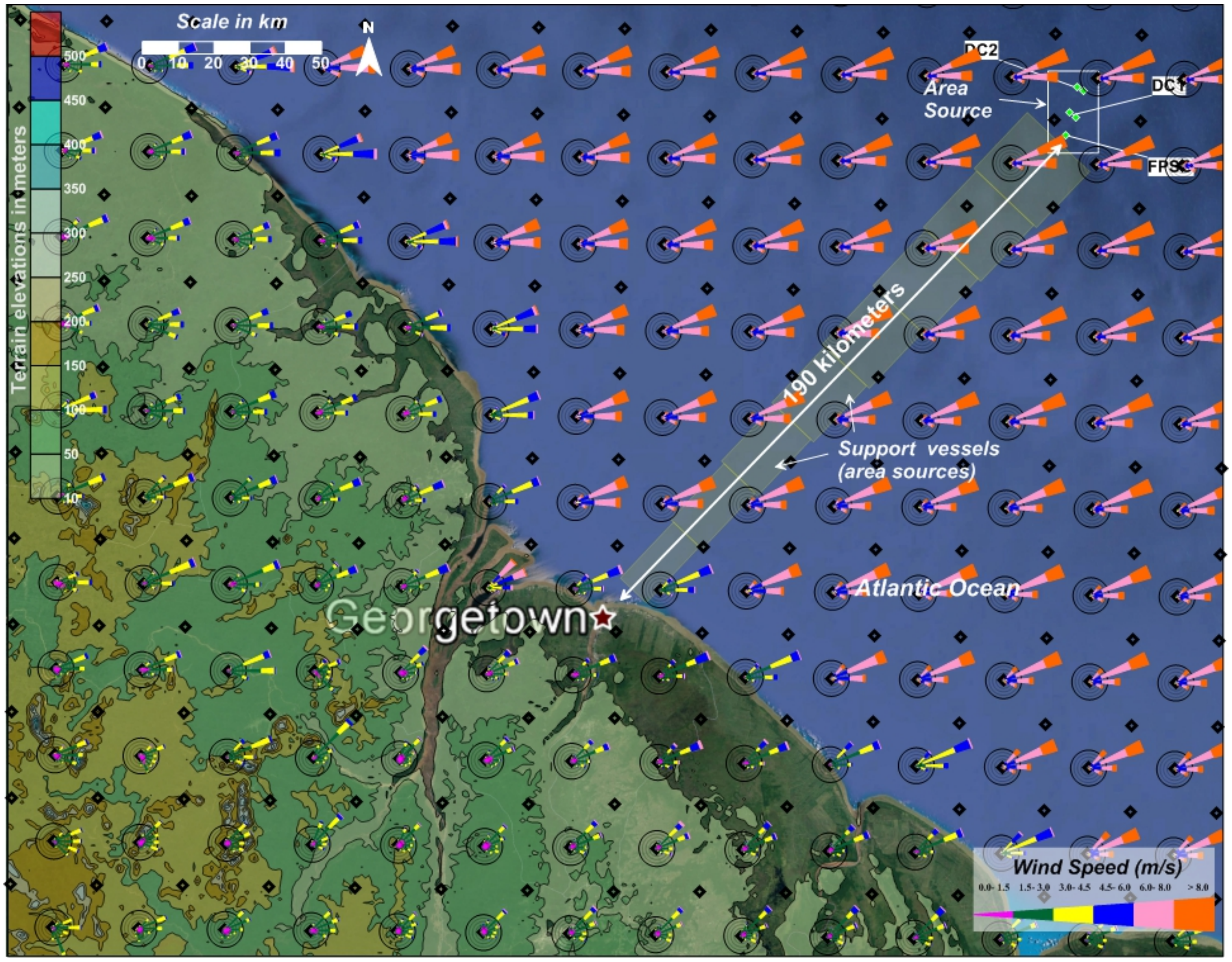
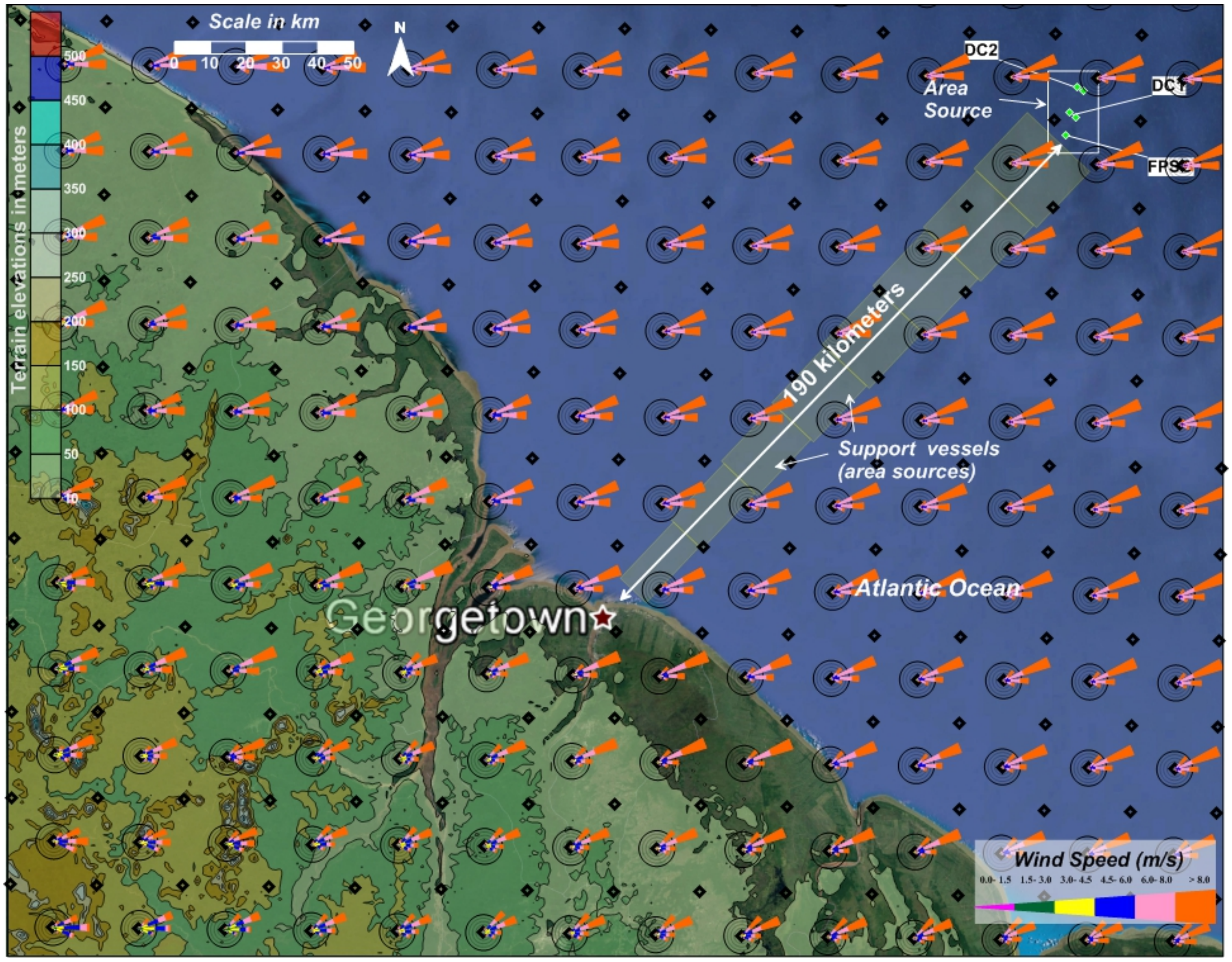


Figure 2-3 Wind Roses: 240 meter Level



3.0 MODEL RESULTS

3.1 Ambient Air Quality Guidelines and Concentrations

Ambient air quality guidelines are concentration levels in air that are established by governing authorities 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 CO and H_2S, which were published in WHO *A*ir *Q*uality Guidelines *for Europe, 2nd edition, 2000* (WHO, 2000).

Table 3-1 WHO Ambient Air Quality Guidelines

Pollutant	Averaging Period	Guideline Concentration ($\mu g/m^3$)
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

3.2 Model Results

Using the methodology described above, modeling was conducted with CALPUFF to estimate maximum ambient concentrations of Project-generated constituents of interest at potential onshore receptor locations. Model results were developed for each modeled constituent, for each averaging period with an associated WHO guideline concentration (Table 3-1). Results are summarized in Table 3-2.

Table 3-2 Modeling Results Summary at Potential Onshore Receptor Locations

Pollutant	Averaging Period	Guideline Concentration (µg/m³)	Maximum Predicted Concentration (µg/m³)			Percent of WHO Guideline		
			2018-2019	2020-2021	2022-2040	2018-2019	2020-2021	2022-2040
NO_2	1-hour	200	1.3	2.1	1.5	0.6%	1.0%	0.7%
	Annual	40	0.1	0.2	0.1	0.3%	0.4%	0.2%
SO_2	10-minute	500	0.1	0.7	0.6	0.0%	0.1%	0.1%
	24-hour	20	0.0	0.2	0.2	0.1%	0.9%	0.9%
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%	0.1%	0.0%
$PM_{2.5}$	24-hour	25	0.0	0.1	0.0	0.2%	0.2%	0.1%
	Annual	10	0.0	0.0	0.0	0.1%	0.1%	0.0%
CO	1-hour	30,000	0.3	2.6	2.6	0.0%	0.0%	0.0%
	8-hour	10,000	0.3	1.5	1.4	0.0%	0.0%	0.0%
H_2S	30-minute	7	n/a	n/a	0.00002	n/a	n/a	0.0002%

As shown in this table, maximum modeled concentrations at any onshore receptor are less than or equal to 1% of the applicable guideline for all pollutants and averaging periods. This result is consistent with the expectation that air quality impacts would be minimal, based on the distance of Project emissions sources from the nearest receptor on-shore.

Table 2-4a NOx Emissions By Year

Source Sector	Emissions (tonnes) Modeled for Each Time Period			Emissions (tonnes) Per Year							
	const.	oper/drill	operations	2018	2019	2020	2021	2022	2023	2024	2025
Combustion Turbines	0.00	1509.21	1509.21	0.00E+00	0.00E+00	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03
Flare - HP Normal Flaring (Note 1)	0.00	0.12	0.06	0.00E+00	0.00E+00	1.23E-01	5.11E-02	5.35E-02	5.55E-02	5.69E-02	5.69E-02
Flare - LP Normal Flaring (Note 1)	0.00	0.18	0.09	0.00E+00	0.00E+00	1.84E-01	7.64E-02	8.00E-02	8.29E-02	8.51E-02	8.51E-02
Flare - HP Full Flaring (Note 1)	0.00	324.00	149.45	0.00E+00	0.00E+00	3.24E+02	1.34E+02	1.40E+02	1.46E+02	1.49E+02	1.49E+02
Flare - LP Full Flaring (Note 1)	0.00	48.46	22.35	0.00E+00	0.00E+00	4.85E+01	2.01E+01	2.10E+01	2.18E+01	2.24E+01	2.24E+01
Auxiliary Boiler (Heaters)	0.00	14.26	14.26	0.00E+00	0.00E+00	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01
Essential Services Gens	0.00	101.68	7.84	0.00E+00	0.00E+00	1.02E+02	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00
Emergency Generators	0.00	0.20	0.20	0.00E+00	0.00E+00	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01
Incinerator	0.00	1.87	1.44	0.00E+00	4.32E-01	1.87E+00	1.87E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00
Deck Cranes	0.00	9.94	9.94	0.00E+00	0.00E+00	4.97E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00
Export Tanker	0.00	131.06	136.54	0.00E+00	0.00E+00	5.89E+01	1.31E+02	1.36E+02	1.36E+02	1.37E+02	1.24E+02
Drill Center1	626.49	835.04	0.00	2.78E+02	6.26E+02	8.35E+02	1.04E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	626.49	835.04	0.00	2.78E+02	6.26E+02	8.35E+02	1.04E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	579.41	740.36	740.36	1.93E+02	5.79E+02	7.40E+02	7.40E+02	7.40E+02	4.75E+02	4.75E+02	4.75E+02
Support Vessels FPSO shore to Project Area	289.71	370.18	370.18	9.66E+01	2.90E+02	3.70E+02	3.70E+02	3.70E+02	2.37E+02	2.37E+02	2.37E+02
Helicopters	17.43	11.98	11.98	5.81E+00	1.74E+01	1.20E+01	1.20E+01	1.20E+01	2.18E+00	2.18E+00	2.18E+00
General Project Area (Construction)	1496.33	0.00	0.00	0.00E+00	1.50E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	3635.86	4933.59	2973.89	852	3636	4856.4	3160.1	2962.7	2561.1	2565.7	2552.8

Source Sector	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Combustion Turbines	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03
Flare - HP Normal Flaring (Note 1)	5.69E-02	5.69E-02	5.69E-02	5.69E-02	5.69E-02	5.69E-02	5.69E-02	5.69E-02	5.69E-02	5.69E-02	5.69E-02	5.69E-02	5.69E-02	5.64E-02	5.69E-02
Flare - LP Normal Flaring (Note 1)	8.51E-02	8.51E-02	8.51E-02	8.51E-02	8.51E-02	8.51E-02	8.51E-02	8.51E-02	8.51E-02	8.51E-02	8.51E-02	8.51E-02	8.51E-02	8.43E-02	8.51E-02
Flare - HP Full Flaring (Note 1)	1.49E+02	1.49E+02	1.49E+02	1.49E+02	1.49E+02	1.49E+02	1.49E+02	1.49E+02	1.49E+02	1.49E+02	1.49E+02	1.49E+02	1.49E+02	1.48E+02	1.49E+02
Flare - LP Full Flaring (Note 1)	2.24E+01	2.24E+01	2.24E+01	2.24E+01	2.24E+01	2.24E+01	2.24E+01	2.24E+01	2.24E+01	2.24E+01	2.24E+01	2.24E+01	2.24E+01	2.21E+01	2.24E+01
Auxiliary Boiler (Heaters)	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01	1.43E+01
Essential Services Gens	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00	7.84E+00
Emergency Generators	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01	1.96E-01
Incinerator	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00
Deck Cranes	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00	9.94E+00
Export Tanker	1.18E+02	9.95E+01	8.54E+01	6.93E+01	5.70E+01	4.86E+01	4.26E+01	3.78E+01	3.50E+01	3.26E+01	2.74E+01	2.21E+01	1.88E+01	1.66E+01	1.51E+01
Drill Center1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02	4.75E+02
Support Vessels FPSO shore to Project Area	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02	2.37E+02
Helicopters	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00	2.18E+00
General Project Area (Construction)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	2547.3	2528.7	2514.6	2498.5	2486.2	2477.8	2471.8	2467.0	2464.2	2461.8	2456.6	2451.3	2448.0	2444.2	2444.3

Table 2-4b SO_2 Emissions By Year

Source Sector	Maximum emissions by source sector			Emissions (tonnes) Per Year							
	const.	oper/drill	operations	2018	2019	2020	2021	2022	2023	2024	2025
Combustion Turbines	0.0	39.9	45.3	0.00E+00	0.00E+00	3.99E+01	3.99E+01	3.99E+01	3.99E+01	4.00E+01	4.08E+01
Flare - HP Normal Flaring (Note 1)	0.0	0.0	0.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.87E-05	2.12E-04
Flare - LP Normal Flaring (Note 1)	0.0	0.0	0.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.79E-05	3.17E-04
Flare - HP Full Flaring (Note 1)	0.0	0.0	3.3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-02	5.57E-01
Flare - LP Full Flaring (Note 1)	0.0	0.0	0.5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.33E-03	8.33E-02
Auxiliary Boiler (Heaters)	0.0	0.0	0.1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.54E-03	1.75E-02
Essential Services Gens	0.0	3.4	0.3	0.00E+00	0.00E+00	3.41E+00	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01
Emergency Generators	0.0	0.0	0.0	0.00E+00	0.00E+00	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03
Incinerator	0.0	1.3	1.0	0.00E+00	3.11E-01	1.35E+00	1.35E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00
Deck Cranes	0.0	0.3	0.3	0.00E+00	0.00E+00	1.67E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01
Export Tanker	0.0	109.9	114.5	0.00E+00	0.00E+00	4.93E+01	1.10E+02	1.14E+02	1.14E+02	1.14E+02	1.04E+02
Drill Center1	21.2	28.0	0.0	9.33E+00	2.10E+01	2.80E+01	3.50E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	21.2	28.0	0.0	9.33E+00	2.10E+01	2.80E+01	3.50E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	19.4	24.8	24.8	6.48E+00	1.94E+01	2.48E+01	2.48E+01	2.48E+01	1.59E+01	1.59E+01	1.59E+01
Support Vessels FPSO shore to Project Area	9.7	12.4	12.4	3.24E+00	9.71E+00	1.24E+01	1.24E+01	1.24E+01	7.96E+00	7.96E+00	7.96E+00
Helicopters	2.1	1.5	1.5	7.08E-01	2.12E+00	1.46E+00	1.46E+00	1.46E+00	2.66E-01	2.66E-01	2.66E-01
General Project Area (Construction)	50.2	0.0	0.0	0.00E+00	5.02E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	123.7	249.6	204.0	29	124	188.9	197.4	194.0	180.0	180.3	170.9

Source Sector	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Combustion Turbines	4.15E+01	4.24E+01	4.36E+01	4.48E+01	4.34E+01	4.38E+01	4.43E+01	4.43E+01	4.43E+01	4.43E+01	4.48E+01	4.45E+01	4.46E+01	4.53E+01	4.52E+01
Flare - HP Normal Flaring (Note 1)	3.68E-04	5.72E-04	8.52E-04	1.13E-03	8.03E-04	9.19E-04	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.15E-03	1.06E-03	1.09E-03	1.25E-03	1.23E-03
Flare - LP Normal Flaring (Note 1)	5.50E-04	8.55E-04	1.27E-03	1.69E-03	1.20E-03	1.37E-03	1.55E-03	1.54E-03	1.54E-03	1.54E-03	1.72E-03	1.59E-03	1.62E-03	1.87E-03	1.84E-03
Flare - HP Full Flaring (Note 1)	9.66E-01	1.50E+00	2.24E+00	2.98E+00	2.11E+00	2.41E+00	2.71E+00	2.71E+00	2.70E+00	2.71E+00	3.01E+00	2.79E+00	2.85E+00	3.29E+00	3.22E+00
Flare - LP Full Flaring (Note 1)	1.44E-01	2.25E-01	3.34E-01	4.45E-01	3.15E-01	3.61E-01	4.06E-01	4.06E-01	4.04E-01	4.05E-01	4.51E-01	4.17E-01	4.27E-01	4.92E-01	4.82E-01
Auxiliary Boiler (Heaters)	3.03E-02	4.71E-02	7.02E-02	9.34E-02	6.62E-02	7.57E-02	8.52E-02	8.51E-02	8.49E-02	8.49E-02	9.46E-02	8.76E-02	8.96E-02	1.04E-01	1.01E-01
Essential Services Gens	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01	2.63E-01
Emergency Generators	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03	4.59E-03
Incinerator	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00
Deck Cranes	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01
Export Tanker	9.90E+01	8.34E+01	7.16E+01	5.81E+01	4.78E+01	4.08E+01	3.57E+01	3.16E+01	2.93E+01	2.73E+01	2.30E+01	1.85E+01	1.58E+01	1.39E+01	1.26E+01
Drill Center1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01	1.59E+01
Support Vessels FPSO shore to Project Area	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00	7.96E+00
Helicopters	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01	2.66E-01
General Project Area (Construction)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	167.5	153.3	143.6	132.1	119.4	113.3	109.1	105.0	102.6	100.6	97.2	92.1	89.5	88.9	87.4

Table 2-4c H_2S Emissions By Year

Source Sector	Maximum emissions by source sector			Emissions (tonnes) Per Year																						
	const.	oper/drill	operations	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Combustion Turbines	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Flare - HP Normal Flaring (Note 1)	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.74E-07	3.11E-06	5.40E-06	8.39E-06	1.25E-05	1.66E-05	1.18E-05	1.35E-05	1.52E-05	1.52E-05	1.51E-05	1.51E-05	1.68E-05	1.56E-05	1.59E-05	1.84E-05
Flare - LP Normal Flaring (Note 1)	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.09E-07	4.65E-06	8.06E-06	1.25E-05	1.87E-05	2.49E-05	1.76E-05	2.01E-05	2.27E-05	2.26E-05	2.26E-05	2.26E-05	2.52E-05	2.33E-05	2.38E-05	2.75E-05
Flare - HP Full Flaring (Note 1)	0.00	0.00	0.05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.19E-04	8.17E-03	1.42E-02	2.20E-02	3.28E-02	4.37E-02	3.09E-02	3.54E-02	3.98E-02	3.98E-02	3.97E-02	3.97E-02	4.42E-02	4.09E-02	4.19E-02	4.82E-02
Flare - LP Full Flaring (Note 1)	0.00	0.00	0.01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-04	1.22E-03	2.12E-03	3.29E-03	4.91E-03	6.53E-03	4.62E-03	5.29E-03	5.96E-03	5.95E-03	5.93E-03	5.94E-03	6.61E-03	6.12E-03	6.26E-03	7.22E-03
Auxiliary Boiler (Heaters)	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Essential Services Gens	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Emergency Generators	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Incinerator	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Deck Cranes	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Export Tanker	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center1	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels FPSO shore to Project Area	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Helicopters	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
General Project Area (Construction)	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	0.0	0.0	0.1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008	0.0094	0.0163	0.0253	0.0377	0.0502	0.0356	0.0407	0.0458	0.0458	0.0456	0.0457	0.0509	0.0471	0.0482	0.0555

Table 2-4d PM Emissions By Year

Source Sector	Maximum emissions by source sector			Emissions (tonnes) Per Year																						
	const.	oper/drill	operations	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Combustion Turbines	0.0	31.1	31.1	0.00E+00	0.00E+00	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01	3.11E+01
Flare - HP Normal Flaring (Note 1)	0.0	0.0	0.0	0.00E+00	0.00E+00	3.53E-03	1.46E-03	1.53E-03	1.59E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.63E-03	1.61E-03	1.63E-03
Flare - LP Normal Flaring (Note 1)	0.0	0.0	0.0	0.00E+00	0.00E+00	5.27E-03	2.18E-03	2.29E-03	2.37E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.43E-03	2.41E-03	2.43E-03
Flare - HP Full Flaring (Note 1)	0.0	9.3	4.3	0.00E+00	0.00E+00	9.26E+00	3.84E+00	4.02E+00	4.16E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.27E+00	4.23E+00	4.27E+00
Flare - LP Full Flaring (Note 1)	0.0	1.4	0.6	0.00E+00	0.00E+00	1.39E+00	5.74E-01	6.01E-01	6.23E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.39E-01	6.33E-01	6.39E-01
Auxiliary Boiler (Heaters)	0.0	1.1	1.1	0.00E+00	0.00E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00
Essential Services Gens	0.0	7.1	0.6	0.00E+00	0.00E+00	7.15E+00	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01	5.51E-01
Emergency Generators	0.0	0.0	0.0	0.00E+00	0.00E+00	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02	1.38E-02
Incinerator	0.0	0.1	0.1	0.00E+00	3.04E-02	1.32E-01	1.32E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01
Deck Cranes	0.0	0.7	0.7	0.00E+00	0.00E+00	3.49E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01	6.99E-01
Export Tanker	0.0	9.2	9.6	0.00E+00	0.00E+00	4.14E+00	9.21E+00	9.54E+00	9.58E+00	9.60E+00	8.69E+00	8.30E+00	6.99E+00	6.01E+00	4.87E+00	4.01E+00	3.42E+00	3.00E+00	2.65E+00	2.46E+00	2.29E+00	1.93E+00	1.55E+00	1.32E+00	1.17E+00	1.06E+00
Drill Center1	44.0	58.7	0.0	1.96E+01	4.40E+01	5.87E+01	7.34E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	44.0	58.7	0.0	1.96E+01	4.40E+01	5.87E+01	7.34E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	40.7	52.0	52.0	1.36E+01	4.07E+01	5.20E+01	5.20E+01	5.20E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01	3.34E+01
Support Vessels FPSO shore to Project Area	20.4	26.0	26.0	6.79E+00	2.04E+01	2.60E+01	2.60E+01	2.60E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01
Helicopters	1.2	0.8	0.8	4.08E-01	1.23E+00	8.42E-01	8.42E-01	8.42E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01	1.53E-01
General Project Area (Construction)	105.2	0.0	0.0	0.00E+00	1.05E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	255.6	256.4	127.0	59.9	255.6	251.0	140.8	126.6	98.2	98.3	97.4	97.0	95.7	94.7	93.6	92.7	92.1	91.7	91.4	91.2	91.0	90.6	90.3	90.0	89.8	89.8

Table 2-4e CO Emissions By Year

Source Sector	Maximum emissions by source sector			Emissions (tonnes) Per Year							
	const.	oper/drill	operations	2018	2019	2020	2021	2022	2023	2024	2025
Combustion Turbines	0.0	386.7	386.7	0.00E+00	0.00E+00	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02
Flare - HP Normal Flaring (Note 1)	0.0	0.7	0.3	0.00E+00	0.00E+00	6.71E-01	2.78E-01	2.91E-01	3.02E-01	3.10E-01	3.10E-01
Flare - LP Normal Flaring (Note 1)	0.0	1.0	0.5	0.00E+00	0.00E+00	1.00E+00	4.16E-01	4.35E-01	4.51E-01	4.63E-01	4.63E-01
Flare - HP Full Flaring (Note 1)	0.0	1763.0	813.2	0.00E+00	0.00E+00	1.76E+03	7.30E+02	7.64E+02	7.92E+02	8.13E+02	8.13E+02
Flare - LP Full Flaring (Note 1)	0.0	263.7	121.6	0.00E+00	0.00E+00	2.64E+02	1.09E+02	1.14E+02	1.19E+02	1.22E+02	1.22E+02
Auxiliary Boiler (Heaters)	0.0	12.0	12.0	0.00E+00	0.00E+00	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01
Essential Services Gens	0.0	21.2	1.6	0.00E+00	0.00E+00	2.12E+01	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00
Emergency Generators	0.0	0.0	0.0	0.00E+00	0.00E+00	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02
Incinerator	0.0	0.4	0.3	0.00E+00	9.00E-02	3.90E-01	3.90E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01
Deck Cranes	0.0	2.1	2.1	0.00E+00	0.00E+00	1.04E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00
Export Tanker	0.0	27.3	28.4	0.00E+00	0.00E+00	1.23E+01	2.73E+01	2.83E+01	2.84E+01	2.84E+01	2.58E+01
Drill Center1	130.5	174.0	0.0	5.80E+01	1.30E+02	1.74E+02	2.17E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	130.5	174.0	0.0	5.80E+01	1.30E+02	1.74E+02	2.17E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	120.7	154.2	154.2	4.02E+01	1.21E+02	1.54E+02	1.54E+02	1.54E+02	9.89E+01	9.89E+01	9.89E+01
Support Vessels FPSO shore to Project Area	60.4	77.1	77.1	2.01E+01	6.04E+01	7.71E+01	7.71E+01	7.71E+01	4.95E+01	4.95E+01	4.95E+01
Helicopters	3.6	2.5	2.5	1.21E+00	3.63E+00	2.50E+00	2.50E+00	2.50E+00	4.54E-01	4.54E-01	4.54E-01
General Project Area (Construction)	311.7	0.0	0.0	0.00E+00	3.12E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	757.5	3059.8	1600.6	177.5	757.5	3043.7	1547.9	1544.4	1491.7	1515.6	1512.9

Source Sector	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Combustion Turbines	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02	3.87E+02
Flare - HP Normal Flaring (Note 1)	3.10E-01	3.10E-01	3.10E-01	3.10E-01	3.10E-01	3.10E-01	3.10E-01	3.10E-01	3.10E-01	3.10E-01	3.10E-01	3.10E-01	3.10E-01	3.07E-01	3.10E-01
Flare - LP Normal Flaring (Note 1)	4.63E-01	4.63E-01	4.63E-01	4.63E-01	4.63E-01	4.63E-01	4.63E-01	4.63E-01	4.63E-01	4.63E-01	4.63E-01	4.63E-01	4.63E-01	4.59E-01	4.63E-01
Flare - HP Full Flaring (Note 1)	8.13E+02	8.13E+02	8.13E+02	8.13E+02	8.13E+02	8.13E+02	8.13E+02	8.13E+02	8.13E+02	8.13E+02	8.13E+02	8.13E+02	8.13E+02	8.06E+02	8.13E+02
Flare - LP Full Flaring (Note 1)	1.22E+02	1.22E+02	1.22E+02	1.22E+02	1.22E+02	1.22E+02	1.22E+02	1.22E+02	1.22E+02	1.22E+02	1.22E+02	1.22E+02	1.22E+02	1.20E+02	1.22E+02
Auxiliary Boiler (Heaters)	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01
Essential Services Gens	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00	1.63E+00
Emergency Generators	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02	4.08E-02
Incinerator	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01
Deck Cranes	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00	2.07E+00
Export Tanker	2.46E+01	2.07E+01	1.78E+01	1.44E+01	1.19E+01	1.01E+01	8.88E+00	7.87E+00	7.28E+00	6.78E+00	5.71E+00	4.61E+00	3.92E+00	3.47E+00	3.14E+00
Drill Center1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01	9.89E+01
Support Vessels FPSO shore to Project Area	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01	4.95E+01
Helicopters	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01	4.54E-01
General Project Area (Construction)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	1511.8	1507.9	1505.0	1501.6	1499.0	1497.3	1496.0	1495.0	1494.4	1493.9	1492.9	1491.8	1491.1	1481.8	1490.3

Table 2-4f VOC Emissions By Year

Source Sector	Emissions (tonnes) Modeled for Each Time Period			Emissions (tonnes) Per Year							
	const.	oper/drill	operations	2018	2019	2020	2021	2022	2023	2024	2025
Combustion Turbines	0.00	7.91	7.91	0.00E+00	0.00E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00
Flare - HP Normal Flaring (Note 1)	0.00	0.27	0.30	0.00E+00	0.00E+00	6.49E-01	2.69E-01	2.81E-01	2.92E-01	2.99E-01	2.99E-01
Flare - LP Normal Flaring (Note 1)	0.00	0.40	0.45	0.00E+00	0.00E+00	9.69E-01	4.02E-01	4.20E-01	4.36E-01	4.47E-01	4.47E-01
Flare - HP Full Flaring (Note 1)	0.00	706.32	786.29	0.00E+00	0.00E+00	1.70E+03	7.06E+02	7.39E+02	7.66E+02	7.86E+02	7.86E+02
Flare - LP Full Flaring (Note 1)	0.00	105.54	117.49	0.00E+00	0.00E+00	2.55E+02	1.06E+02	1.10E+02	1.14E+02	1.17E+02	1.17E+02
Auxiliary Boiler (Heaters)	0.00	0.41	0.41	0.00E+00	0.00E+00	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01
Essential Services Gens	0.00	0.20	0.20	0.00E+00	0.00E+00	2.60E+00	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01
Emergency Generators	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Incinerator	0.00	0.00	0.00	0.00E+00	1.09E-03	4.72E-03	4.72E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03
Deck Cranes	0.00	0.25	0.25	0.00E+00	0.00E+00	1.27E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01
Export Tanker	0.00	3.35	3.49	0.00E+00	0.00E+00	1.51E+00	3.35E+00	3.47E+00	3.49E+00	3.49E+00	3.16E+00
Drill Center1	16.03	2.67	0.00	7.12E+00	1.60E+01	2.14E+01	2.67E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	16.03	2.67	0.00	7.12E+00	1.60E+01	2.14E+01	2.67E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	14.83	18.95	12.15	4.94E+00	1.48E+01	1.89E+01	1.89E+01	1.89E+01	1.22E+01	1.22E+01	1.22E+01
Support Vessels FPSO shore to Project Area	7.41	9.47	6.08	2.47E+00	7.41E+00	9.47E+00	9.47E+00	9.47E+00	6.08E+00	6.08E+00	6.08E+00
Helicopters	0.01	0.01	0.00	2.70E-03	8.11E-03	5.57E-03	5.57E-03	5.57E-03	1.01E-03	1.01E-03	1.01E-03
General Project Area (Construction)	38.30	0.00	0.00	0.00E+00	3.83E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	92.61	10249.27	10718.21	22	93	6261.5	10249.3	10611.5	10679.3	10718.2	9792.3

Source Sector	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Combustion Turbines	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00	7.91E+00
Flare - HP Normal Flaring (Note 1)	2.99E-01	2.99E-01	2.99E-01	2.99E-01	2.99E-01	2.99E-01	2.99E-01	2.99E-01	2.99E-01	2.99E-01	2.99E-01	2.99E-01	2.99E-01	2.96E-01	2.99E-01
Flare - LP Normal Flaring (Note 1)	4.47E-01	4.47E-01	4.47E-01	4.47E-01	4.47E-01	4.47E-01	4.47E-01	4.47E-01	4.47E-01	4.47E-01	4.47E-01	4.47E-01	4.47E-01	4.43E-01	4.47E-01
Flare - HP Full Flaring (Note 1)	7.86E+02	7.86E+02	7.86E+02	7.86E+02	7.86E+02	7.86E+02	7.86E+02	7.86E+02	7.86E+02	7.86E+02	7.86E+02	7.86E+02	7.86E+02	7.79E+02	7.86E+02
Flare - LP Full Flaring (Note 1)	1.17E+02	1.17E+02	1.17E+02	1.17E+02	1.17E+02	1.17E+02	1.17E+02	1.17E+02	1.17E+02	1.17E+02	1.17E+02	1.17E+02	1.17E+02	1.16E+02	1.17E+02
Auxiliary Boiler (Heaters)	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01	4.13E-01
Essential Services Gens	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01	2.01E-01
Emergency Generators	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Incinerator	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03	3.63E-03
Deck Cranes	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01	2.54E-01
Export Tanker	3.02E+00	2.55E+00	2.19E+00	1.77E+00	1.46E+00	1.24E+00	1.09E+00	9.66E-01	8.95E-01	8.33E-01	7.02E-01	5.66E-01	4.82E-01	4.26E-01	3.86E-01
Drill Center1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01
Support Vessels FPSO shore to Project Area	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00	6.08E+00
Helicopters	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.01E-03
General Project Area (Construction)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	9399.0	8063.5	7055.3	5898.5	5018.7	4417.9	3988.3	3637.7	3436.9	3265.1	2897.7	2516.7	2281.8	2115.7	2011.9

Table 2-4g GHG (kilotonnes CO_2-equivalents) Emissions By Year

Source Sector	Emissions (Tonnes) for Each Time Period			Emissions (tonnes) Per Year										
	const.	oper/drill	operations	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Combustion Turbines	0.00	513.98	513.98	0.00E+00	0.00E+00	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02
Flare - HP Normal Flaring (Note 1)	0.00	0.27	0.12	0.00E+00	0.00E+00	2.70E-01	1.12E-01	1.17E-01	1.21E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01
Flare - LP Normal Flaring (Note 1)	0.00	0.40	0.19	0.00E+00	0.00E+00	4.04E-01	1.67E-01	1.75E-01	1.82E-01	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.86E-01
Flare - HP Full Flaring (Note 1)	0.00	709.63	327.32	0.00E+00	0.00E+00	7.10E+02	2.94E+02	3.08E+02	3.19E+02	3.27E+02	3.27E+02	3.27E+02	3.27E+02	3.27E+02
Flare - LP Full Flaring (Note 1)	0.00	106.14	48.96	0.00E+00	0.00E+00	1.06E+02	4.40E+01	4.60E+01	4.77E+01	4.90E+01	4.90E+01	4.90E+01	4.90E+01	4.90E+01
Auxiliary Boiler (Heaters)	0.00	9.47	9.47	0.00E+00	0.00E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00
Essential Services Gens	0.00	5.25	0.40	0.00E+00	0.00E+00	5.25E+00	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01
Emergency Generators	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Incinerator	0.28	1.22	0.94	0.00E+00	2.82E-01	1.22E+00	1.22E+00	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01
Deck Cranes	0.00	0.26	0.51	0.00E+00	0.00E+00	2.57E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01
Export Tanker	0.00	3.04	7.05	0.00E+00	0.00E+00	3.04E+00	6.77E+00	7.00E+00	7.04E+00	7.05E+00	6.38E+00	6.10E+00	5.14E+00	4.41E+00
Drill Center1	32.33	43.11	0.00	1.44E+01	3.23E+01	4.31E+01	5.39E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	32.33	43.11	0.00	1.44E+01	3.23E+01	4.31E+01	5.39E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	29.91	38.22	24.51	9.97E+00	2.99E+01	3.82E+01	3.82E+01	3.82E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01
Support Vessels FPSO shore to Project Area	14.96	19.11	12.26	4.99E+00	1.50E+01	1.91E+01	1.91E+01	1.91E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01
Helicopters	3.11	2.14	0.39	1.04E+00	3.11E+00	2.14E+00	2.14E+00	2.14E+00	3.89E-01	3.89E-01	3.89E-01	3.89E-01	3.89E-01	3.89E-01
General Project Area (Construction)	77.25	0.00	0.00	0.00E+00	7.72E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	190.17	1508.54	976.68	45	190	1508.5	970.2	976.2	967.0	976.7	973.1	971.6	966.5	962.6

Source Sector	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Combustion Turbines	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02	5.14E+02
Flare - HP Normal Flaring (Note 1)	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.23E-01	1.25E-01
Flare - LP Normal Flaring (Note 1)	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.85E-01	1.86E-01
Flare - HP Full Flaring (Note 1)	3.27E+02	3.27E+02	3.27E+02	3.27E+02	3.27E+02	3.27E+02	3.27E+02	3.27E+02	3.27E+02	3.27E+02	3.24E+02	3.27E+02
Flare - LP Full Flaring (Note 1)	4.90E+01	4.90E+01	4.90E+01	4.90E+01	4.90E+01	4.90E+01	4.90E+01	4.90E+01	4.90E+01	4.90E+01	4.85E+01	4.90E+01
Auxiliary Boiler (Heaters)	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00	9.47E+00
Essential Services Gens	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01	4.05E-01
Emergency Generators	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Incinerator	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01	9.41E-01
Deck Cranes	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01	5.13E-01
Export Tanker	3.58E+00	2.94E+00	2.51E+00	2.20E+00	1.95E+00	1.80E+00	1.68E+00	1.42E+00	1.14E+00	9.73E-01	8.59E-01	7.78E-01
Drill Center1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Drill Center2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Support Vessels Project Area	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01
Support Vessels FPSO shore to Project Area	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01
Helicopters	3.89E-01	3.89E-01	3.89E-01	3.89E-01	3.89E-01	3.89E-01	3.89E-01	3.89E-01	3.89E-01	3.89E-01	3.89E-01	3.89E-01
General Project Area (Construction)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	958.2	954.8	952.5	950.8	949.5	948.7	948.0	946.6	945.2	944.2	940.1	943.2

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APPENDIX M – Water Quality Modeling Report

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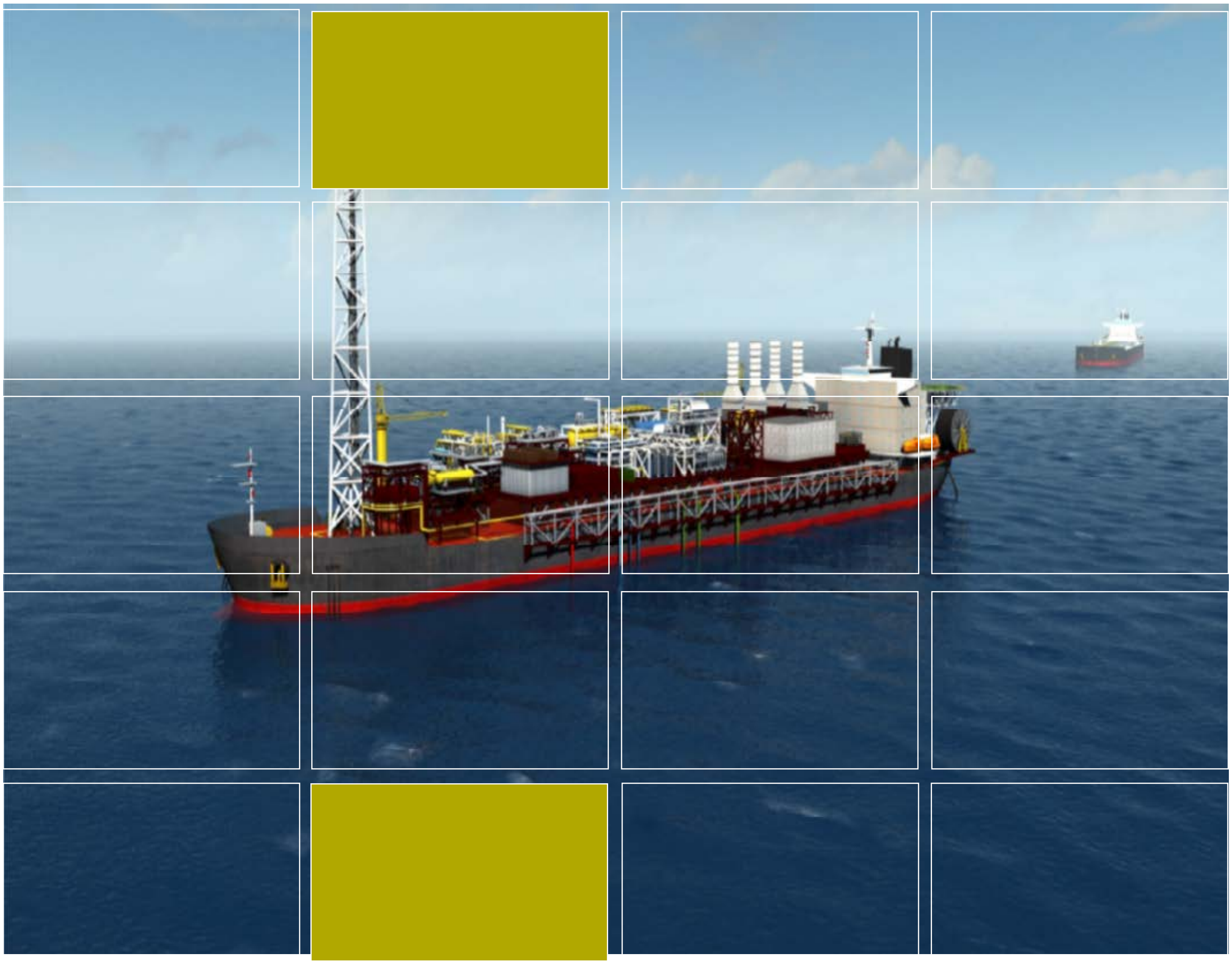


Technical Report: Water Modelling; Liza Well Development

The business of sustainability

ERM

TABLE OF CONTENTS

List of Figures

List of Tables

LIST OF ACRONYMS

AOP	Asphaltene Onset Pressure
AMS	Alarm Management System
AUV	Autonomous Underwater Vehicle
BFROC	Base fluid retention on cuttings
BOD	Biological Oxygen Demand
BOP	Blowout Preventer
BOPD	Barrels of Oil Per Day
CARICOM	Caribbean Community
CCR	Central Control Room
CH4	Methane
CO	Carbon Monoxide
CO2	Carbon Dioxide
COD	Chemical Oxygen Demand
CPACC	Caribbean Planning for Adaptation to Climate Change
DC	Drill Centre
EEPGL	Esso Exploration and Production Guyana Limited
EIA	Environmental Impact Assessment
EITI	Extractive Industries Transparency Initiative
EPA	Environmental Protection Agency
ERM	Environmental Resources Management
ESMP	Environmental and Social Management Plan

F&G	Fire and Gas
FA	Flow Assurance
FLET	Flowline End Termination
FPSO	Floating Production, Storage, and Offloading
GA	General Alarm
GGMC	Guyana Geology and Mines Commission
GI	Gas Injection
GIFT	Generalized Integrated Fate and Transport
GRA	Guyana Revenue Authority
H2S	Hydrogen Sulfide
HP	High Pressure
HVAC	Heating, Ventilating, and Air Conditioning
ICSS	Integral Control and Safety System
ICZM	Integrated Coastal Zone Management
ILO	International Labour Organization
IFC	International Finance Corporation
IMF	International Monetary Fund
IP	Intermediate Pressure
kbd	Thousand barrels per day
LMRP	Lower Marine Riser Package
LP	Low Pressure
m	Meters

m3	Cubic Meters
MARAD	Maritime Administration
MDBML	Mean Depth Below Mud Line
MeOH (or CH3OH)	Methanol
mi	Miles
MoNRE	Ministry of Natural Resources and Environment
MPV	Multi-Purpose Vessel
MSCFD (or mscfd)	Million Standard Cubic Feet per Day
MSWT	Mean Sea Water Temperature
NABF	Non-Aqueous Base Fluid
NADF	Non-Aqueous Drilling Fluid
nm	nautical miles
NMVOC	Non-Methane Volatile Organic Compounds
NOx	Nitrogen Oxide
OBR	Onboard Representative
OIMS	Operations Integrity Management System
OSRP	Oil Spill Response Plan
P&A	Plugging and Abandonment
PA	Public Address
PCS	Process Control System
PE	Parabolic Equation
PLET	Production Line End Termination

PM (2.5 or 10)	Particulate Matter
POB	Persons On Board
ppb	Parts per Billion
ppg	Pounds per Gallon
ppm	Parts per Million
psi (or psia)	Pounds per Square Inch (Atmospheric)
PSV	Platform Supply Vessel
ROC	Residual On Cuttings
ROV	Remotely Operated Underwater Vehicle
SCM	Subsea Control Module
SCSSV	Surface-Controlled Subsurface Safety Valve
SDU	Subsea Distribution Unit
SIMOPS	Simultaneous Operations
SIS	Safety Instrumented System
SITP	Shut In Tubing Pressure
SO2	Sulfur Dioxide
SOT	Safe Operating Temperature
SSHE	Safety, Security, Health, and Environment
SRU	Sulfate Removal Unit
SURF	Subsea Umbilicals Risers and Flowlines
TD	Total Depth
TEG	Tri-ethylene Glycol

TOR	Terms Of Reference
TSS	Total Suspended Solids
TV	Tug Vessel
UTA	Umbilical Termination Assembly
UPS	Uninterruptible Power Supply
TVD	True Vertical Depth
VLCC	Very Large Crude Carrier
VOC	Volatile Organic Compounds
VSP	Vertical Seismic Profile
WAT	Wax Appearance Temperature
WBDF	Water Based Drilling Fluid
WI	Water Injection

1.0 INTRODUCTION

1.1 Purpose

For the production of an Environmental Impact Assessment (EIA) of the Liza Phase 1 Development Project, Esso Exploration and Production Guyana Limited (EEPGL) commissioned 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 (Figure 1-1). These models included simulations of drill cuttings and fluid deposition, and discharges of cooling water, sulfate removal and potable water process brines, produced water, and hydrotest fluid.

For the purposes of this report, the Stabroek Petroleum Prospect License Area will be referred to as the "Stabroek Block."

Figure 1-1 Stabroek Petroleum Prospecting License Area (ERM, 2016)

1.2 Scope of work

This technical report describes the modeling study performed to understand the potential impacts from offshore releases in two sections. Section 2.0 describes the discharges related to drilling operations and Section 3.0 describes the operational and maintenance discharges. A separate report describing accidental discharges related to oil spills is provided in Volume 4. The selection of these discharges for the modeling were done based on the review of the project description, proposed project related activities and an understanding of accidental releases that could occur from proposed project activities. Computational models were used to estimate the potential extent of the discharge plumes based on estimated discharges and facility plans.

2.0 DRILL CUTTINGS AND FLUID DEPOSITION MODELLING

2.1 Approach

In this study, the discharge of drill cuttings is evaluated. It is assumed that there will be a direct discharge of cuttings during drilling of the riserless open hole section followed by discharge near the 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.

For the impact assessment, the modelling was performed to determine three key endpoints:

- the amount of suspended sediment concentrations added to water column background concentrations;
- the seabed accumulation (thickness) of the adhered fluids and drill cuttings over an area of seafloor (the footprint) for assessment of impacts to benthic organisms; and
- the amount of hydrocarbons settled upon the seafloor.

2.1.1 Simulation Design

Released material will pass vertically through the water column because cuttings and fluids 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 fluids dispersion therefore is fundamentally a three-dimensional phenomenon requiring three-dimensional hydrodynamic fate and transport modelling.

There are four well centre locations. Two of these centres were modelled representing the shallowest and the deepest wells. These are DC1-I at a depth of 1688 m and DC2-I at a depth of 1853 meters.

At each of these wells, the top hole (Section 1) and conductor (Section 2) will be jetted and drilled with water-based drilling fluids (WBDF) to a depth of 956 m below the mud line (BML). The subsequent three sections (with hole diameters sizes 17.5"and 12.25"followed by a hole 8.5" by 9.875") will be drilled with non-aqueous drilling fluid (NADF) until a total depth (TD) is reached at approximately 6,628 m BML. The discharge pipe from the drill platform will release treated cuttings 11 m below mean sea level (MSL).

Table 2-1 Well Profile

Section	Diameter (inches)	Well Interval (m)
Section 1 – Structural (Top Hole, Jet)	36″	82
Section 2 – Conductor	26″	1,065
Section 3 – Surface	17 ½″	1,530
Section 4 – Production	12 ¼″	3,150
Section 5 - Open	8 ½″ x 9 7/8″	1,000

To develop the three required endpoints, three model grids were used: a particle grid, a depositional grid, and a concentration grid. The movement of the discharged cuttings and fluids using Lagrangian particles was computed within the particle grid (Figure 2-1).

This particle grid is square approximately 55 km on each side, with each cell approximately 50 m by 50 m in length and width. Each grid cell contains an interpolated depth value derived from the bathymetry data described in Section 3.1.3.1. Particles are free to move horizontally and vertically within this grid's domain, independently of the grid except for movement past the grid boundaries on the seafloor (as defined by the bathymetry) and shorelines.

For computation of the mass deposition on the seafloor, the model used a smaller and finer square, two-dimensional (2-D) depositional grid, with each grid centered on a well. The depositional grid is a 20 km square grid with 520 cells on each side, each cell approximately 38 m in length and width (Figure 2-2).

The concentration grid, used for computations of total suspended solids (TSS), is three-dimensional with the same horizontal dimensions as the depositional grid. Vertically, the cells are 10 m 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. See Table 2-2 for a summary of these three grids' dimensions.

Table 2-2 Grid Dimensions

Grid	Horizontal Dimensions	Vertical Dimensions
Particle grid	50 m x 50 m	N/A
Depositional grid	38 m x 38 m	N/A
Concentration grid	Variable – smallest 25 m x 25 m at center	Variable – smallest 10 m at top and bottom

Figure 2-1 Particle Grid

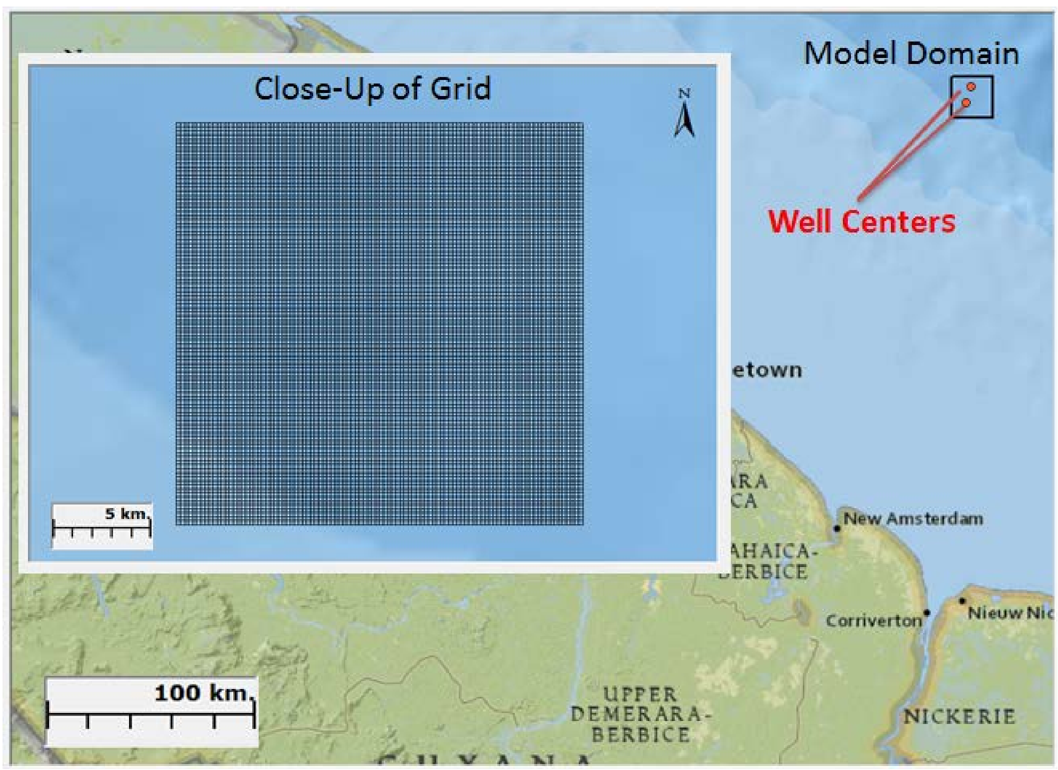
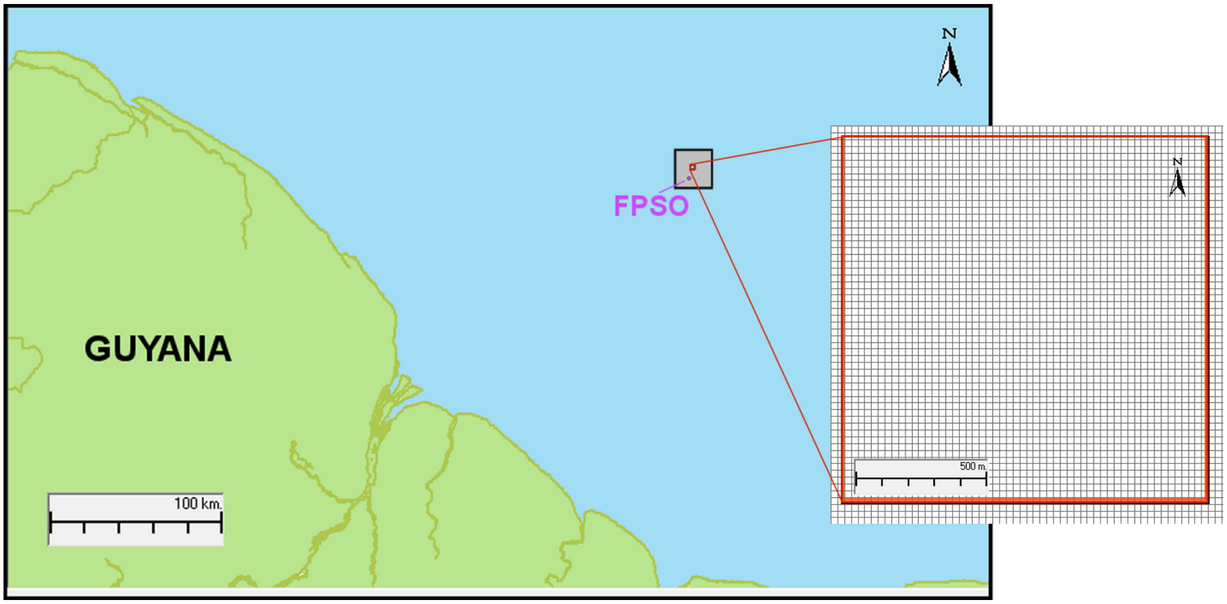


Figure 2-2 Depositional and Concentration Grid



2.1.2 Drill Cuttings and Fluid Deposition Software

The modelling was performed using GEMSS® (Generalized Environmental Modelling System for Surfacewaters) and its drill cuttings and fluids 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 simulates the fate of dissolved and particulate material discharged during dredging operations, disposal of mine tailings, well drill cuttings and fluids, and release of 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 fluids were modelled 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, resulted in the net accumulation of drill cuttings on the seabed.

Modelling data requirements included:

- drill section sizes and schedule;
- drilling fluid types;
- cuttings and fluid grain size distribution;
- fluid and cuttings densities; and
- fluid and cuttings release rates, durations, and discharge depths.

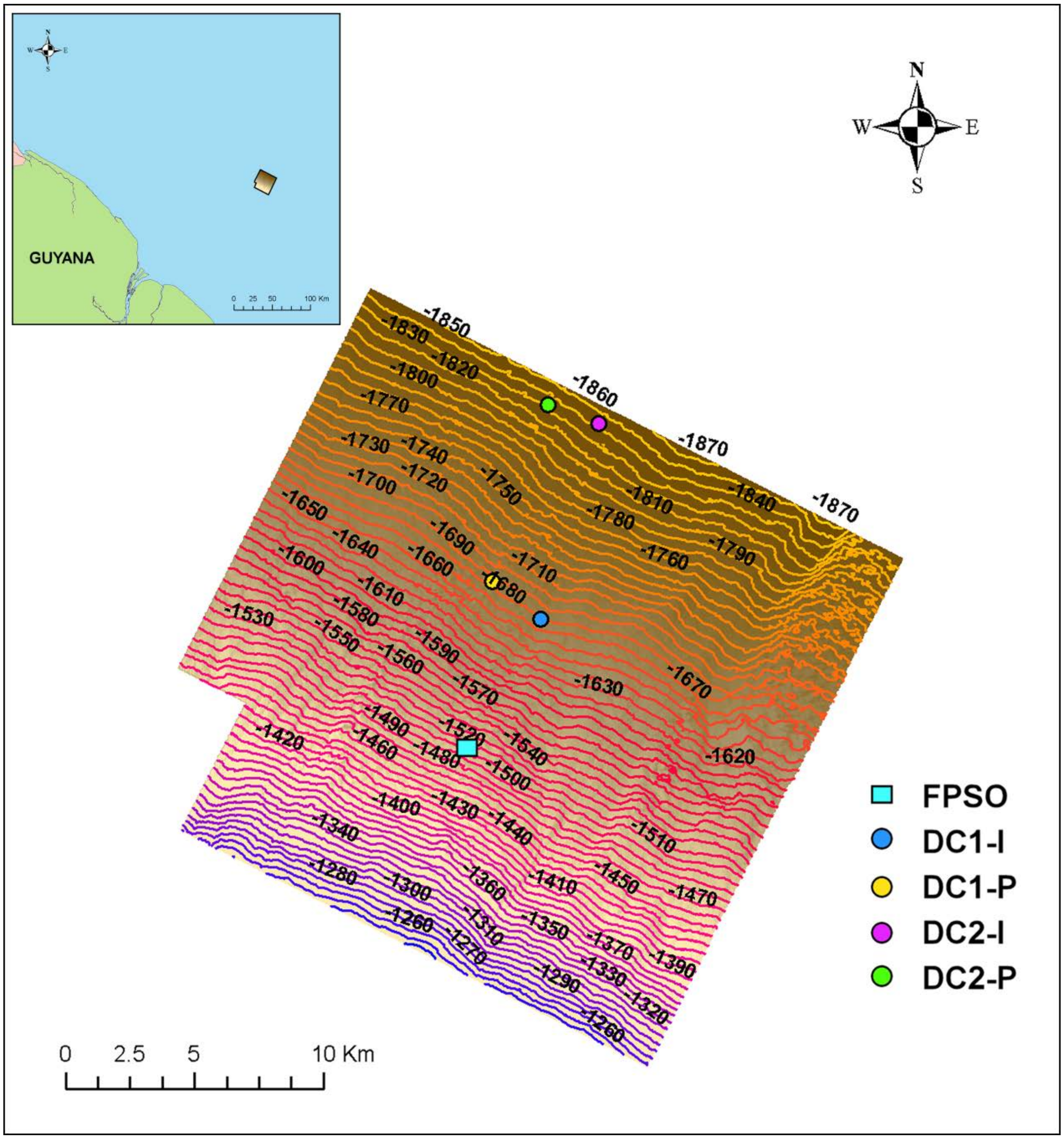
2.1.3 Environmental Data

Model inputs were assembled and formatted for use with GIFT. The environmental data used by the model include bathymetric data, ocean current, water temperature and salinity data. Spatially and temporally varying oceanic data were collected to characterize this area and determine appropriate simulation periods.

2.1.3.1 Bathymetry

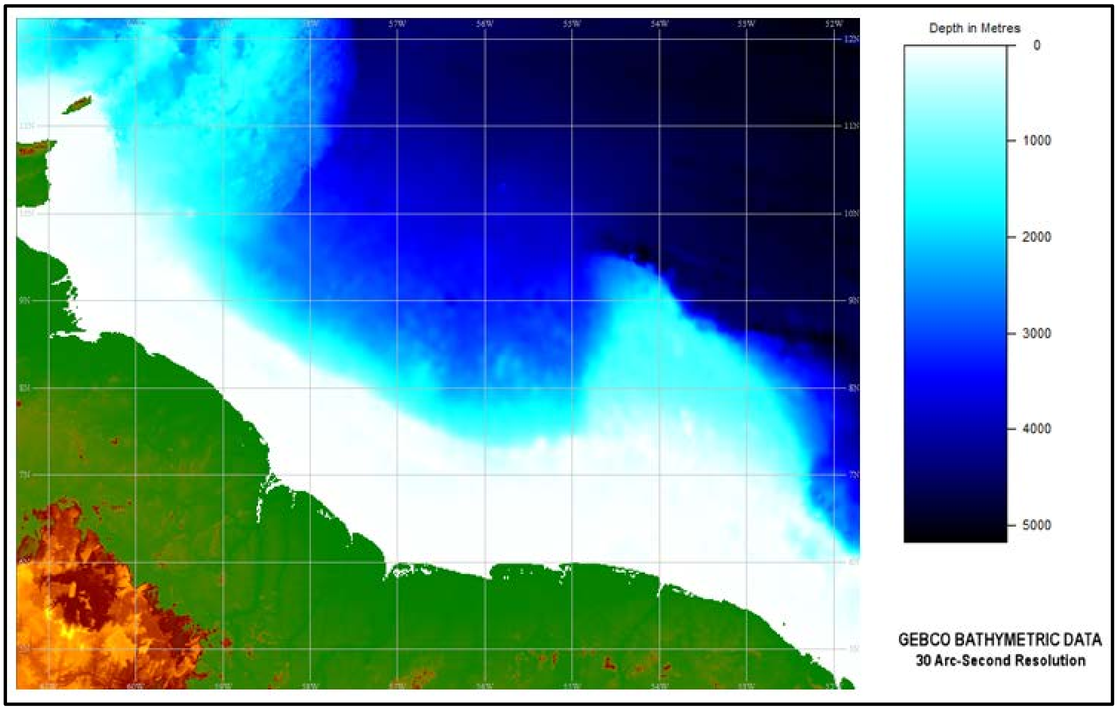
The primary spatial dataset is the bathymetric data, used to describe the depth and shape of the seafloor. Bathymetric data are used to develop the shape and depth of the lower boundary of the modelling grids. Two datasets were used. The primary source of bathymetry was the 2016 bathymetric survey performed by Fugro (Fugro, 2016). This dataset was provided as a set of depth contour lines covering a region approximately 23 km by 22 km within the block (Figure 2-3).

Figure 2-3 Bathymetric Data (Fugro, 2016)



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 bathymetric values beyond the Fugro database towards 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 2-4.

Figure 2-4 GEBCO Data Region



A polyline shapefile of the Guyanese coastline acts as boundary in the model domain between land and water. The coastlines were obtained from Esri's World Boundaries and Places Alternate product.

2.1.3.2 Time Varying Data: Ocean Current, Temperature and Salinity Data

The time-varying data for the drill cuttings deposition modelling include 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 HYCOM (HYbrid Coordinate Ocean Model) 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 m 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 full range of depositional patterns from a larger and thinner footprint when the current speeds are highest to a thicker, smaller footprint when the speeds are smallest.

Example current vector plots for March 2006 and August 2013 are shown below in Figure 2-5 and Figure 2-7 at the surface (0 m) and in Figure 2-6 and Figure 2-8 in deeper water (1000 m).

Figure 2-5 Example Current Vector Diagram, March 1, 2006 (surface)

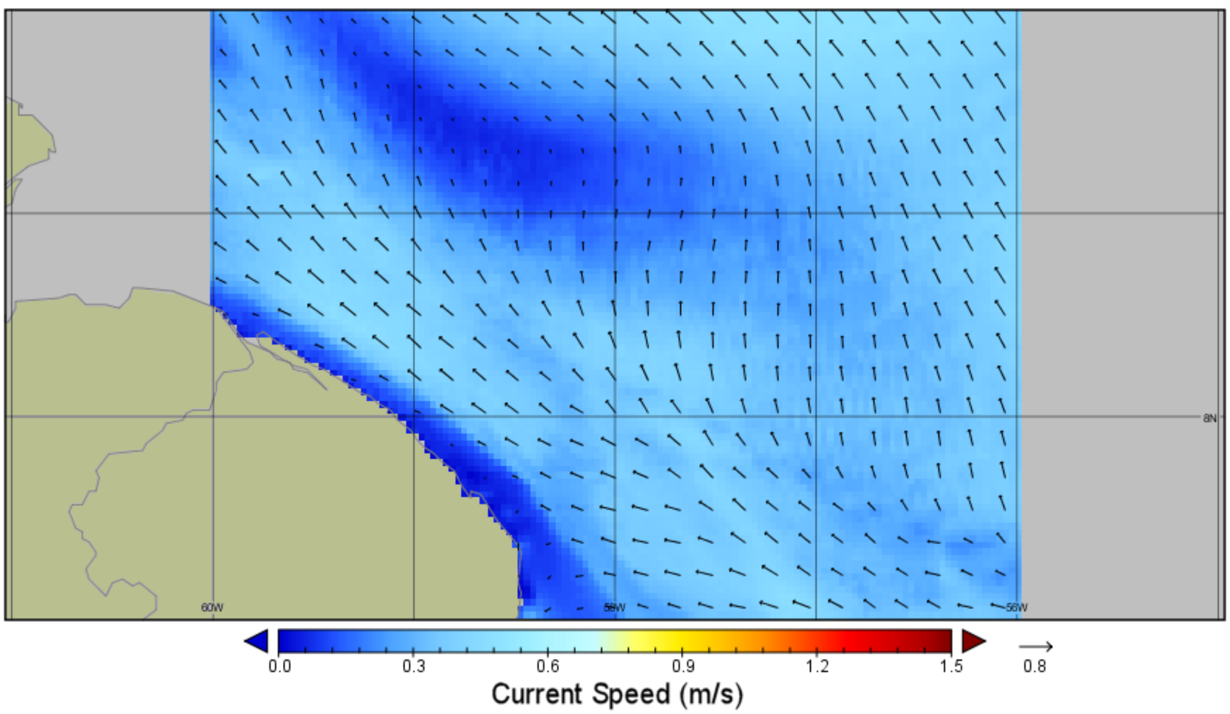


Figure 2-6 Example Current Vector Diagram, March 1, 2006 (1,000 m depth)

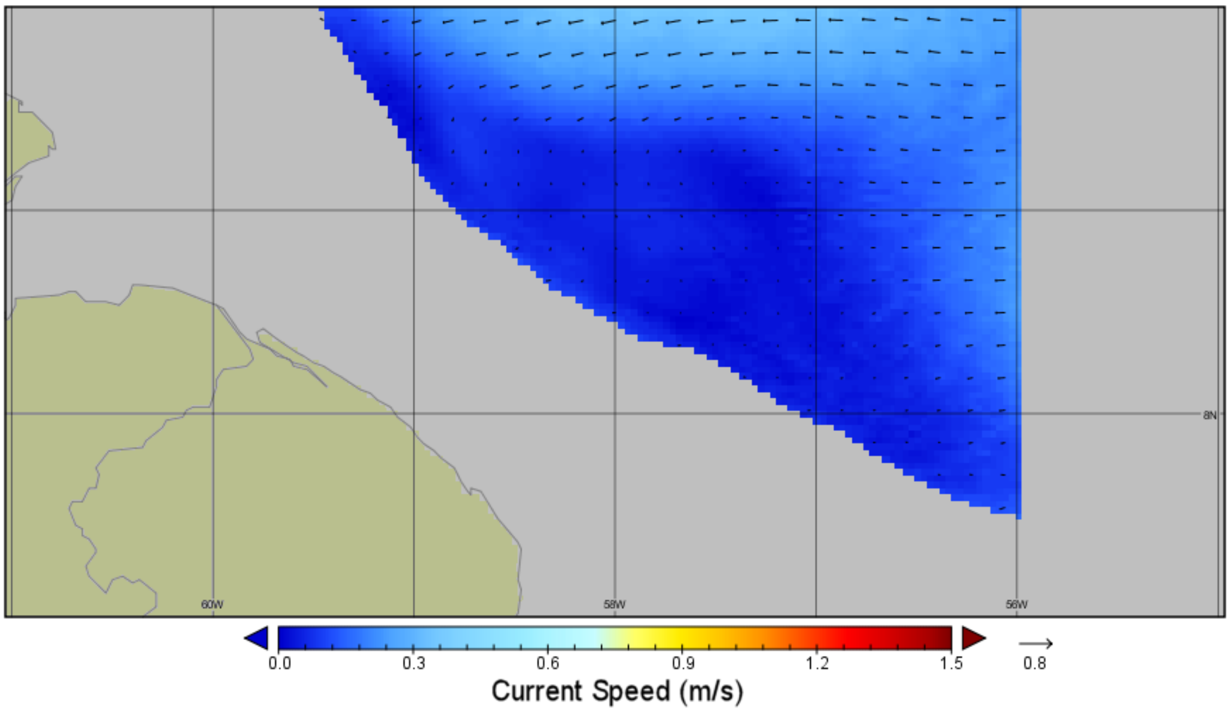


Figure 2-7 Example Current Vector Diagram, August 1, 2013 (surface)

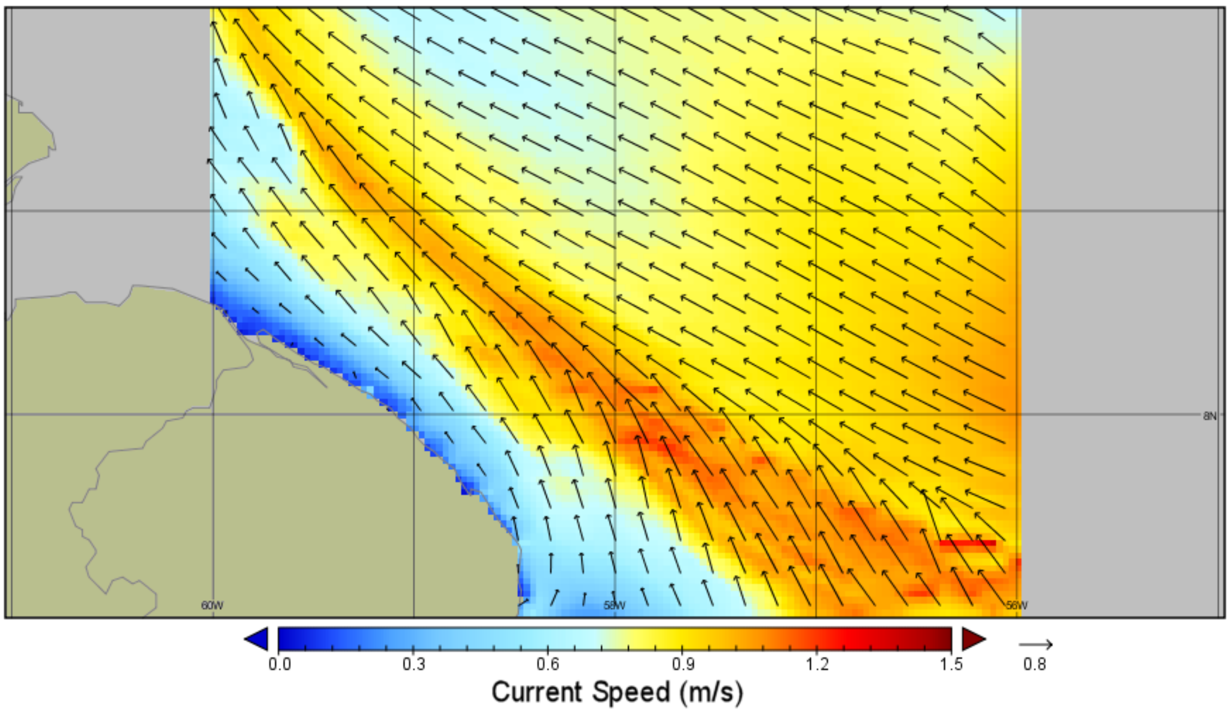
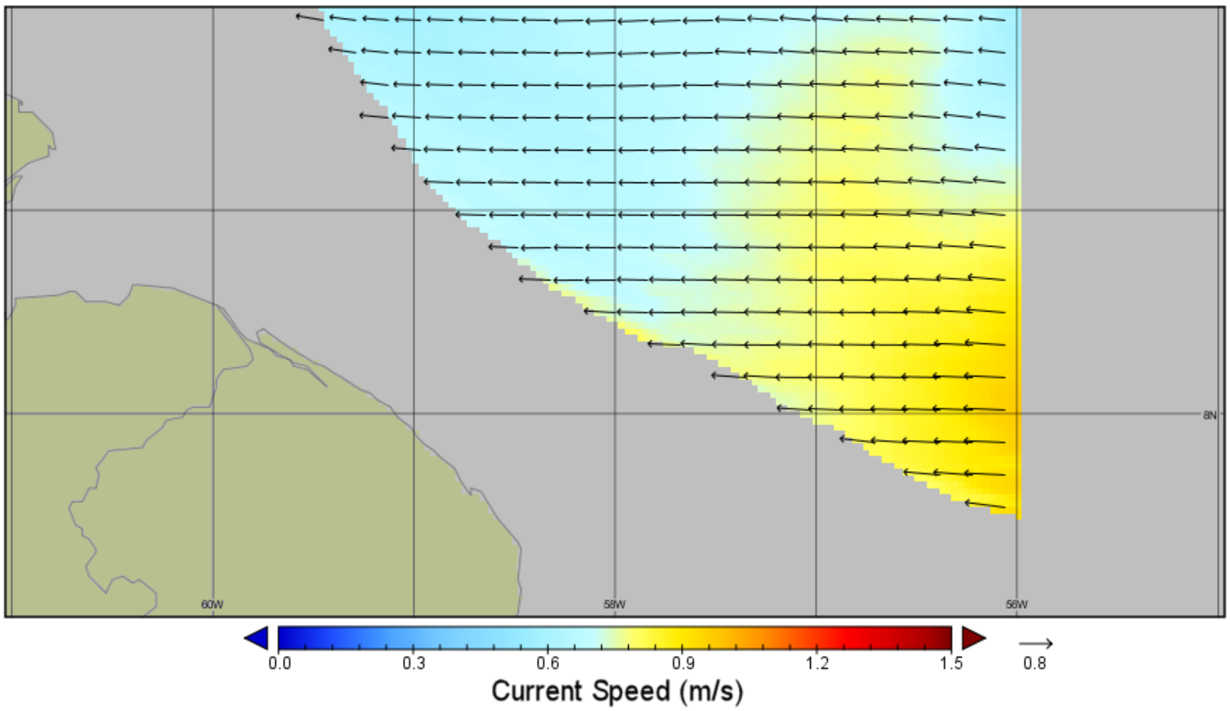


Figure 2-8 Example Current Vector Diagram, August 1, 2013 (1,000 m depth)



2.1.3.3 Drill cuttings and fluid volumes and properties

Estimated quantities of anticipated drill cuttings and fluids to be discharged during drilling are provided in Table 2-3. The estimated times to drill each section were provided by EEPGL. For the top hole sections, only WBDF are expected to be used. The volume of WBDF 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 fluids will be disposed at 11 m below sea level. No non-aqueous drilling fluids are to be directly discharged. Adhered fluids will not exceed 6.9% of the cuttings mass on average.

Table 2-3 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″	339	1,694	WBDF	0.5
26″	2,295	18,356	WBDF	1.5
17 ½″	1,493	248	NADF	3
12 ¼″	1,507	251	NADF	6
8 ½″ x 9 7/8″	303	56	NADF	4
TOTAL	**5,936**	**28.5**	**-**	**15**

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 15 days of drilling with a nominal one-day pause of discharges between well sections for a conservative estimate of TSS, and model performance efficiency.

2.1.3.4 *Cuttings and Fluid Volumes and Properties*

The grain size properties of the drill cuttings and fluids were provided by EEPGL. The distribution of particle sizes and associated fall velocities used in this study are listed in Table 2-4 for cuttings in Section 1 and 2, Table 2-5 for WBDF and Table 2-6 for treated cuttings released from Section 3 through 5 with adhered non-aqueous drilling fluid (NADF). Cuttings density was assumed to be 2.6 g/mL. The WBDF density was assumed to be 11 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 2-4 Cuttings When Water Based Fluid is Used

Mass Fraction (Wt %)	Fall Velocity (cm/s)	Estimated Diameter (cm)
2	0.00003	0.00005
3	0.0001	0.0001
5	0.0003	0.0002
10	0.0046	0.0006
10	0.0695	0.0007
20	0.4460	0.0059
20	1.8300	0.0363
10	6.9300	0.1350
10	14.3000	0.3730
5	19.8000	0.6680
3	23.4000	0.9510
2	26.1000	1.2200

Table 2-5 WBDF Grain Size Distribution

Mass Fraction (Wt %)	Fall Velocity (cm/s)	Estimated Diameter (cm)
7	0.0027	0.0005
8	0.0061	0.0007
5	0.0148	0.0011
10	0.0300	0.0015
13.3	0.0434	0.0018
13.3	0.0511	0.0020
19.2	0.0640	0.0007
19.2	0.0823	0.0008
4	0.4270	0.0058
1	1.1200	0.0250

Table 2-6 Treated Cuttings with Adhered NADF Grain Size Distribution

Mass Fraction (Wt %)	Fall Velocity (cm/s)	Estimated Diameter (cm)
43	0.02	0.00
1.01	0.20	0.01
4.99	2.00	0.04
5.55	8.00	0.16
7.99	14.00	0.36
10.99	19.00	0.62
13.01	21.99	0.83
6.81	23.99	1.00
3.69	26.99	1.32
2.47	30.97	1.89
0.49	124.97	*

* Fall velocity outside the range of available correlations; computed by GIFT model

2.2 Scenarios

Modelling was performed for four scenarios representing the shallowest and deepest wells (DC1-I and DC2-I, respectively) and for the minimum and maximum of the monthly-averaged, depth-averaged current speeds (Table 2-7). The water depth at the two well varied between 1,688 m at DC1-I and 1,853 m at DC2-I.The same drilling and fluid discharge schedule described in Table 2-3 was assumed at both wells.

Table 2-7 Drill Cuttings and Fluid Deposition Scenarios

Well Centre	Scenario Name	Ambient Currents	Water Depth (m)
DC1-I	1a	Minimum Monthly Avg	1,688
	1b	Maximum Monthly Avg	1,688
DC2-I	2a	Minimum Monthly Avg	1,853
	2b	Maximum Monthly Avg	1,853

These scenarios provide output that is presented in terms of depositional thickness, TSS concentrations, and deposition of adhered oil.

2.2.1 Depositional Thickness

Drill cuttings and adhered fluid discharges will create a footprint on the seabed. The deposition of cuttings and adhered fluids may result in physical damage and habitat loss or disruption over a defined area of the seabed. The discharge of fluids and cuttings may affect seabed habitats through physical smothering.

Burial by drilling fluids and cuttings may cause physical impacts upon benthic communities. The specific thickness of burial which may cause an impact can vary depending on the benthic species and the amount of oxygen depletion which may occur, causing anoxic conditions beneath the depositional layer.

The 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 thickness value of 5 cm above a substratum for a month deposition impacting benthic communities is recommended based on publications by Ellis and Heim (1985) and MarLIN (2011). Smaller threshold values as low as 1 mm have been reported (e.g., Smit et al., 2006), however they are associated with instantaneous burials on benthic species, not gradual smothering effects.

2.2.2 Total Suspended Solids

Increases in concentration of TSS will occur due to discharges of drill cuttings and fluid. The highest concentration increases will exist at the point of discharge from the drillship or at the seafloor during upper well section drilling, and decrease over time and distance as the suspended solids plume dissipates and settles. Larger particles will settle out more quickly than fine particles, such that the TSS plume of tiny particles may linger and travel further than plumes of larger grain-sizes. As such, elevated TSS may form in regions where tiny suspended particles linger in a cloud and mix with subsequent discharges. Impacts related to elevated TSS may occur if light penetration 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 of 35 mg/L was used as a threshold (IMO, 2006).

2.3 Adhered Oil

Discharges of cuttings after use of NADF must be treated through the on-board systems (shakers and dryers). The non-aqueous base fluid (NABF) portion of the NADF that remains will be reduced to approximately 6.9% base fluid retention on cuttings (BFROC) 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, taken at or above the well. The results are presented for the following parameters:

bottom thickness at the end of the simulation;

maximum TSS at any time in the simulation at the surface and bottom; and

mass of hydrocarbons per unit area deposited on the seafloor.

Based on the above parameters, the following set of threshold criteria has been applied in this analysis:

- Criterion 1 - The maximum allowable increase in total suspended solids should be no greater than 35 mg/L above ambient;
- Criterion 2 – The maximum allowable thickness deposited should not exceed 5 cm for the duration of one month; and

There are no available criteria applicable for the mass of hydrocarbons deposited on the seafloor.

2.4.1 Depositional thickness

When the first two sections are jetted and drilled before the riser is installed, cuttings and water based fluids are discharged directly to the seabed resulting in 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, which can be described as a footprint of cuttings with the majority of the material above 1 mm thick concentrated in a 1.5 km radius from the well. In three of the four scenarios, a small region close to the well exceeded the depositional thickness threshold value of 50 mm (5 cm) during the month. This exceedance ranged from roughly a 21 m to 43 m radius around the well. The maximum thickness reached was 753 mm (Scenario 2b: DC2-I, maximum currents), but slope failure (i.e. sudden collapse of the depositional mound) and resuspension of the particles are likely to reduce the height of the deposited materials over time.

Figure 2-9 through Figure 2-12 show the expected thicknesses of the cuttings and adhered fluid layer on the seabed as a result of the drilling activities at the end of the model simulation (when all deposition had occurred) from both surface and bottom releases. Figure 2-9 and Figure 2-10 show the results of Scenario 1a and 1b. Figure 2-11 and Figure 2-12 show the results of Scenario 2a and 2b

In Scenario 1, at Well DC1-I, the maximum thickness predicted by the model was 660 mm, located in the vicinity surrounding the well. Jetting and top hole drilling deposited the majority of the deposited mound’s peak (658.3 mm of the final 660 mm). The majority of the depositions (98.6% to 99.6%) were 1 cm thick or less.

In Scenario 2, at Well DC2-I, the maximum thickness predicted by the model was 753 mm, located in the vicinity surrounding the well. Jetting and top hole drilling deposited the majority of the deposited mound's peak (701.2 mm of the final 703 mm). The majority of the depositions (98.2% to 99.8%) were 1 cm thick or less.

Table 2-8 Depositional Thickness Summary

Scenario	Maximum Depositional Thickness (mm)	Area (m^2) with Thickness > 50 mm threshold
1a DC1-I Min Currents	660	4,575
1b DC1-I Max Currents	186	5,815
2a DC2-I Min Currents	703	1,442
2b DC2-I Max Currents	753	1,590

Figure 2-9 Maximum Depositional Thickness – Scenario 1a DC1-I Minimum Currents

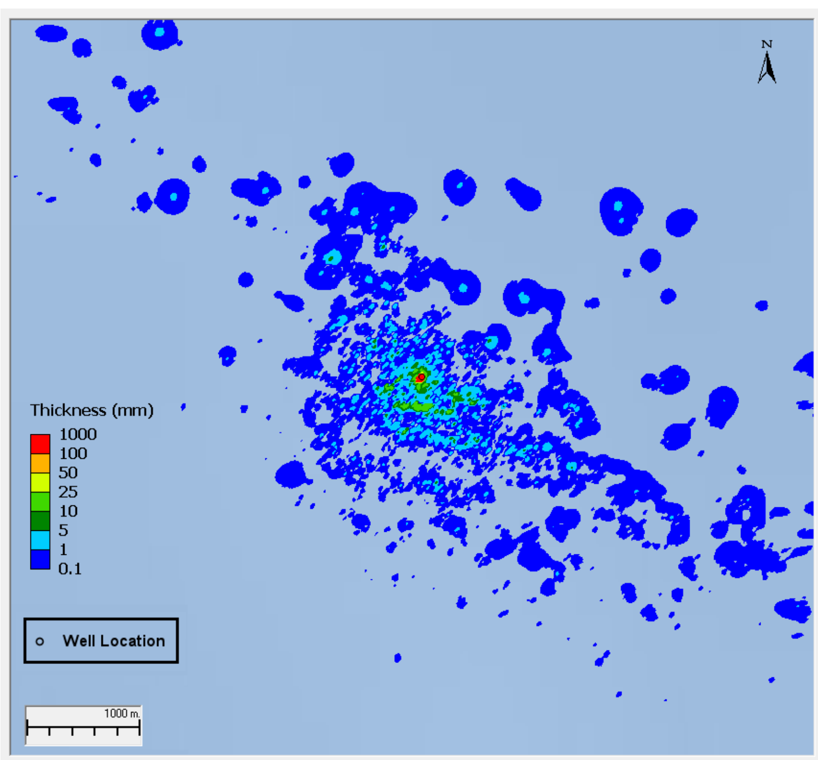


Figure 2-10 Maximum Depositional Thickness – Scenario 1b DC1-I Maximum Currents

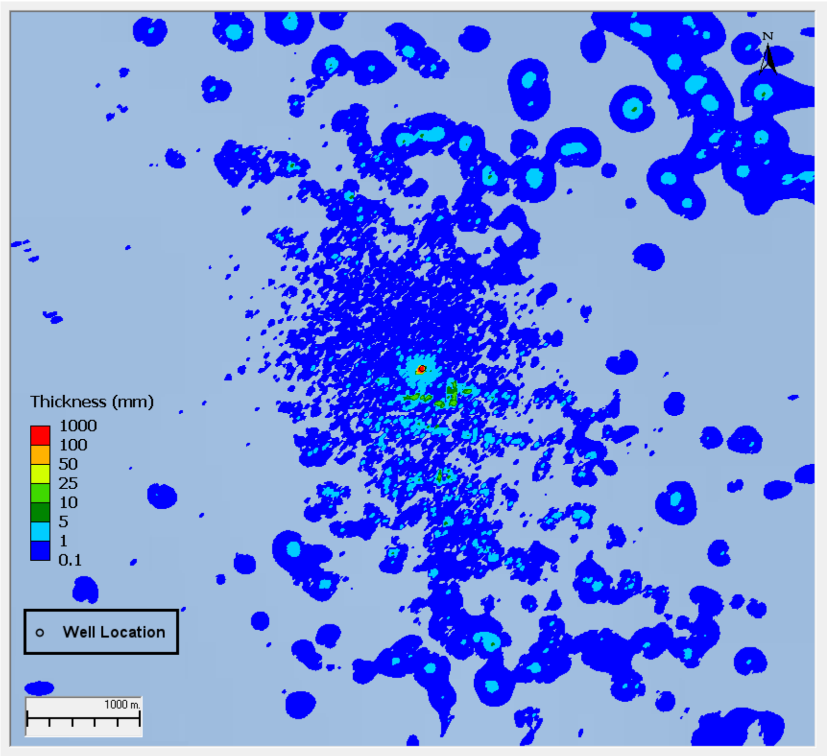


Figure 2-11 Maximum Depositional Thickness – Scenario 2a DC2-I Minimum Currents

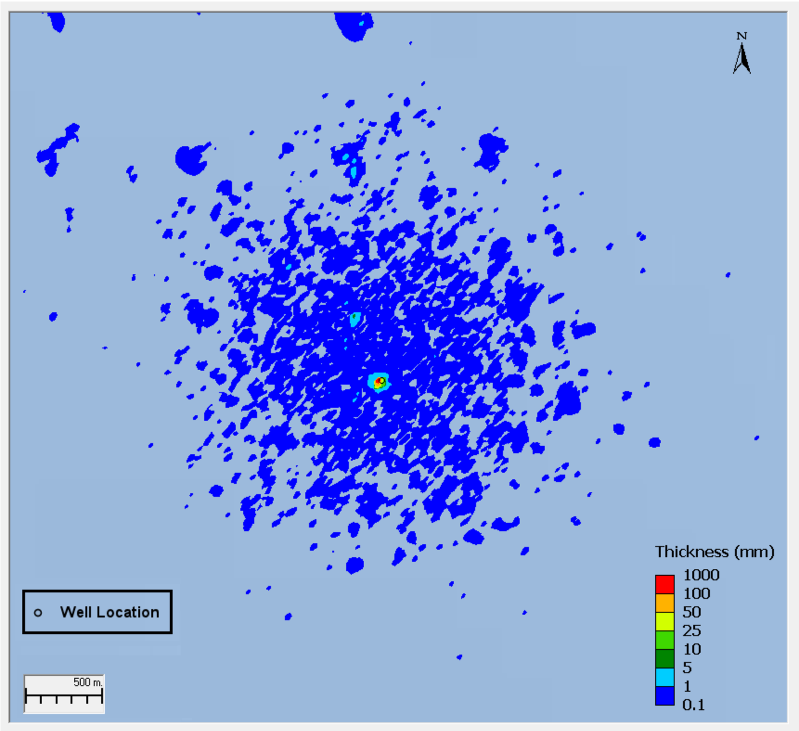
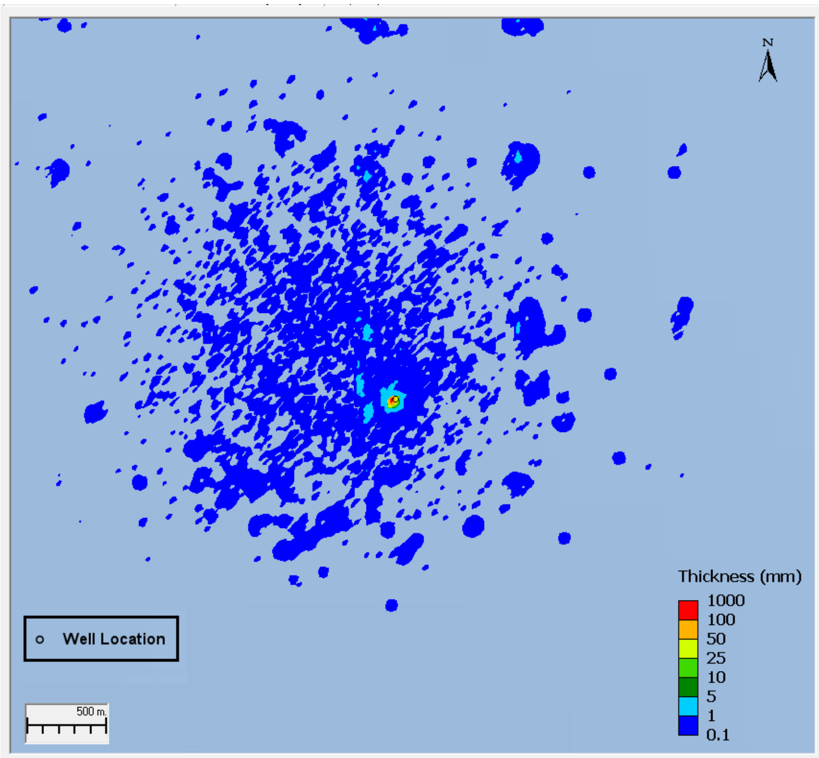


Figure 2-12 Maximum Depositional Thickness – Scenario 2b DC2-I Maximum Currents



2.4.2 Total Suspended Solids

The maximum TSS concentration added above ambient as a result of jetting and top hole drilling near the seafloor was 9,737 mg/L in Scenario 2b. The maximum TSS concentration added above ambient as a result of surface discharges was 5.3 mg/L in Scenario 2b. The 35 mg/L threshold is not predicted to be exceeded at the surface, where inhibition of photosynthesis would be a concern. At the sea floor, a maximum of approximately 0.168 km^2 of water is predicted to show concentrations that exceed the 35 mg/L threshold during drilling of the first two well sections. These maxima occur at the sea floor and are below the photic zone (the zone where high TSS could impact some organisms). Therefore the inhibition of light is not a concern at these depths.

In Scenario 1 at DC1-I, the maximum TSS ranged between 222 mg/L and 4,323 mg/L at the sea floor. In Scenario 2 at DC2-I, the maximum TSS ranged between 233 mg/L and 5,260 mg/L at the sea floor.

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 2-9 summarizes the maximum TSS modelled and area exceeding the 35 mg/L threshold under minimum and maximum current conditions at each drill center.

Table 2-9 Total Suspended Solids Summary

Scenario	Maximum TSS (mg/L)		Area (km²) with TSS > 35 mg/L threshold	
	Surface	Bottom	Surface	Bottom
1a DC1-I Min Currents	2.1	4,323	0	0.094
1b DC1-I Max Currents	2.9	5,517	0	0.168
2a DC2-I Min Currents	1.6	5,260	0	0.091
2b DC2-I Max Currents	5.3	9,737	0	0.088

Figure 2-13 Maximum TSS at Surface – Scenario 1a DC1-I Minimum Currents

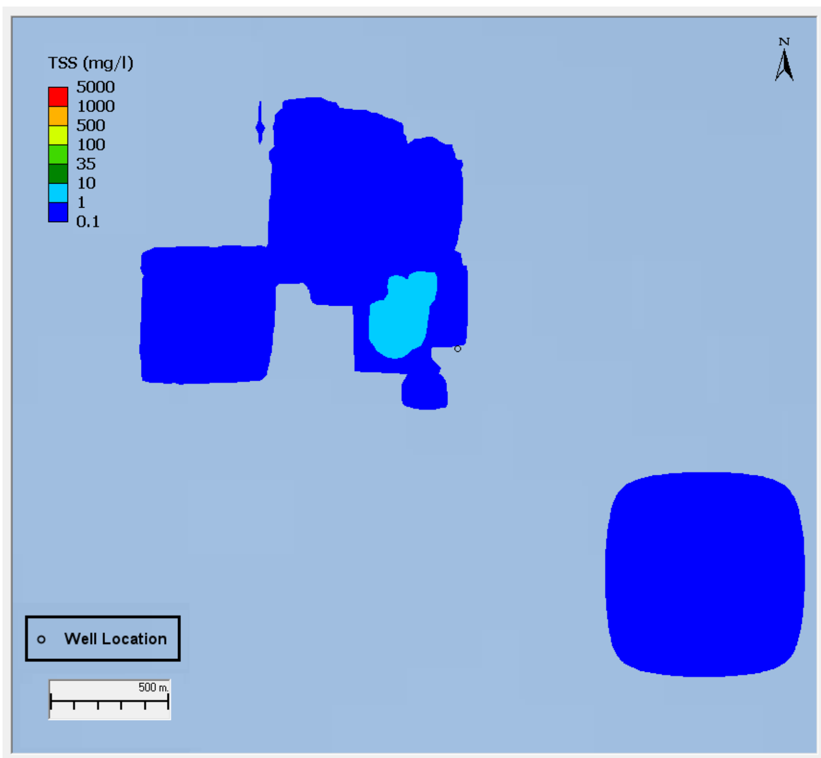


Figure 2-14 Maximum TSS at Bottom – Scenario 1a DC1-I Minimum Currents

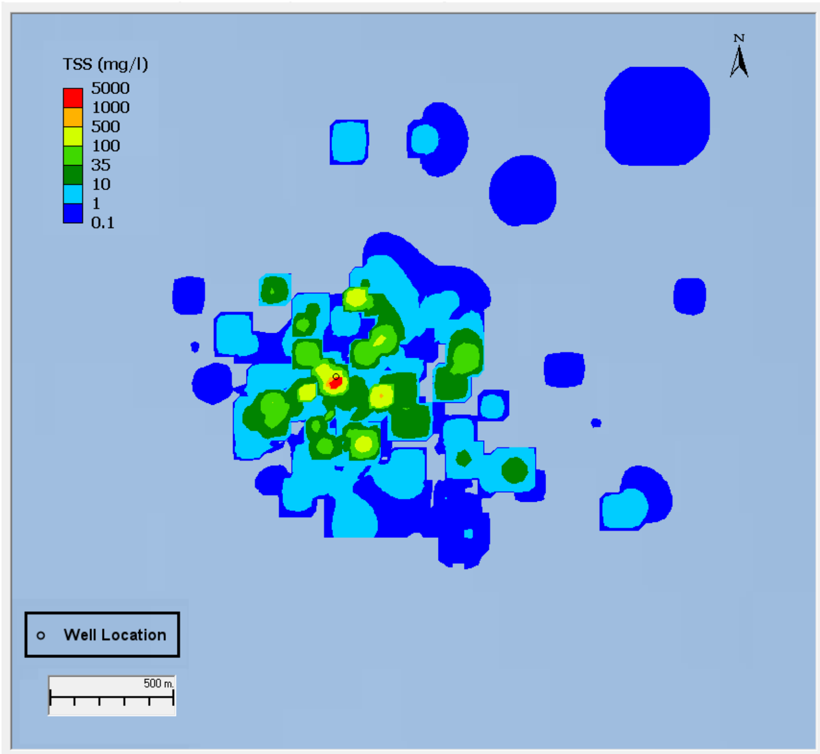


Figure 2-15 Maximum TSS at Surface – Scenario 1b DC1-I Maximum Currents

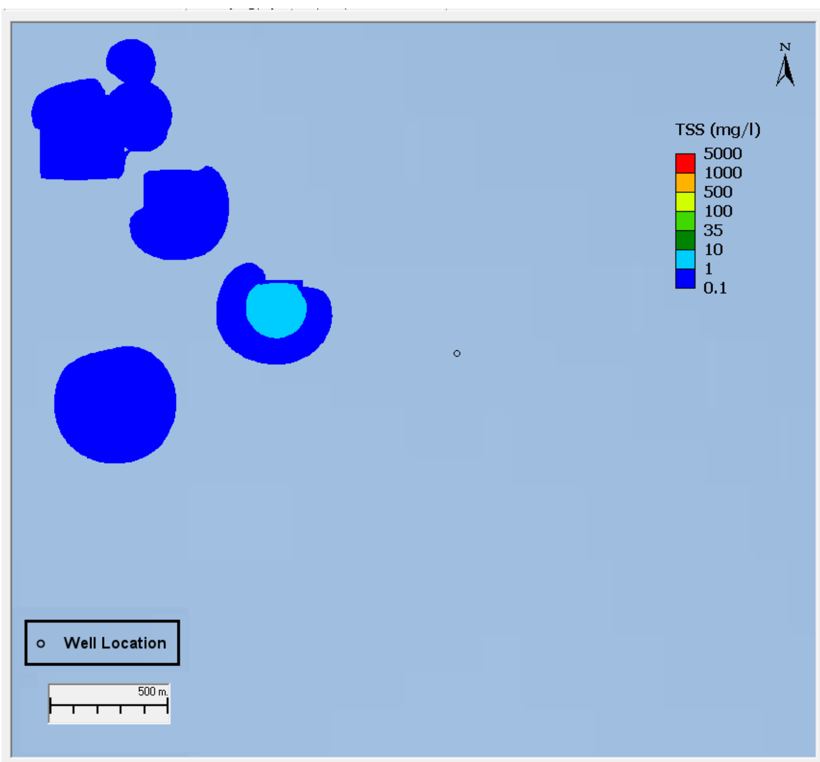


Figure 2-16 Maximum TSS at the Bottom – Scenario 1b DC1-I Maximum Currents

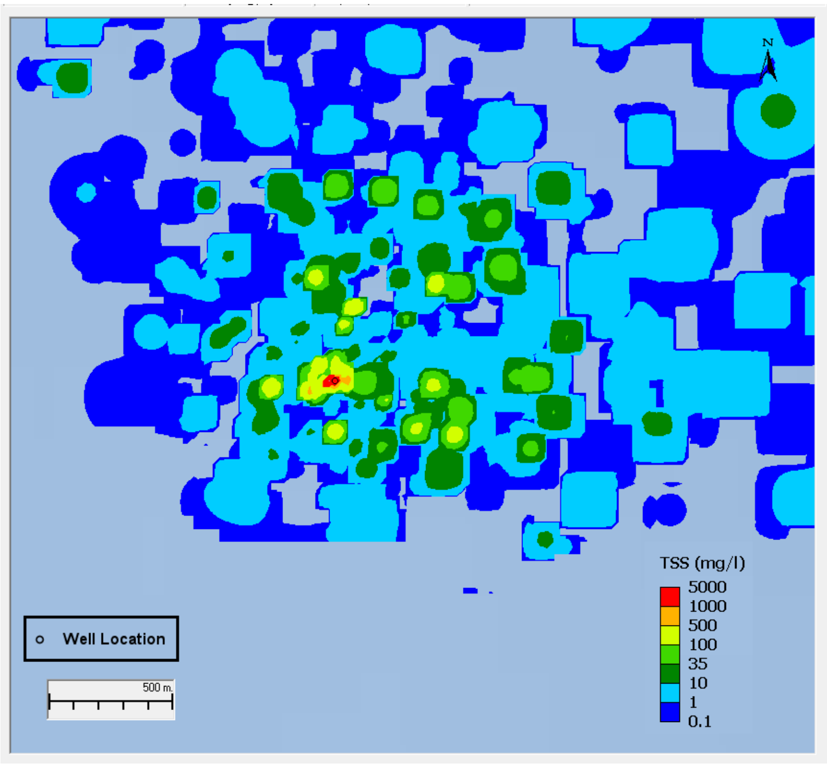


Figure 2-17 Maximum TSS at Surface – Scenario 2a DC2-I Minimum Currents

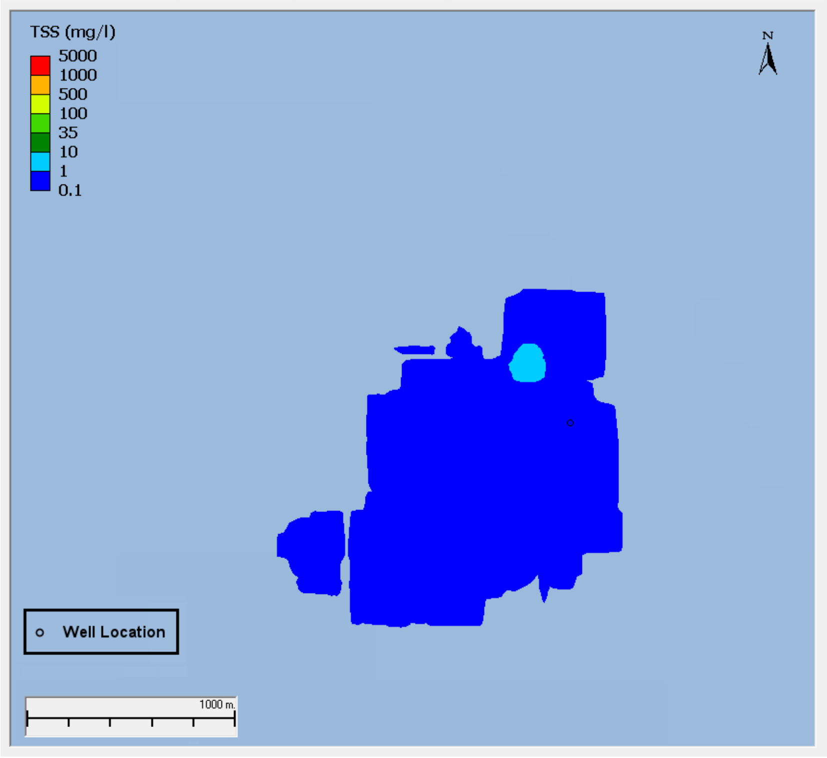


Figure 2-18 Maximum TSS at the Bottom– Scenario 2a DC2-I Minimum Currents

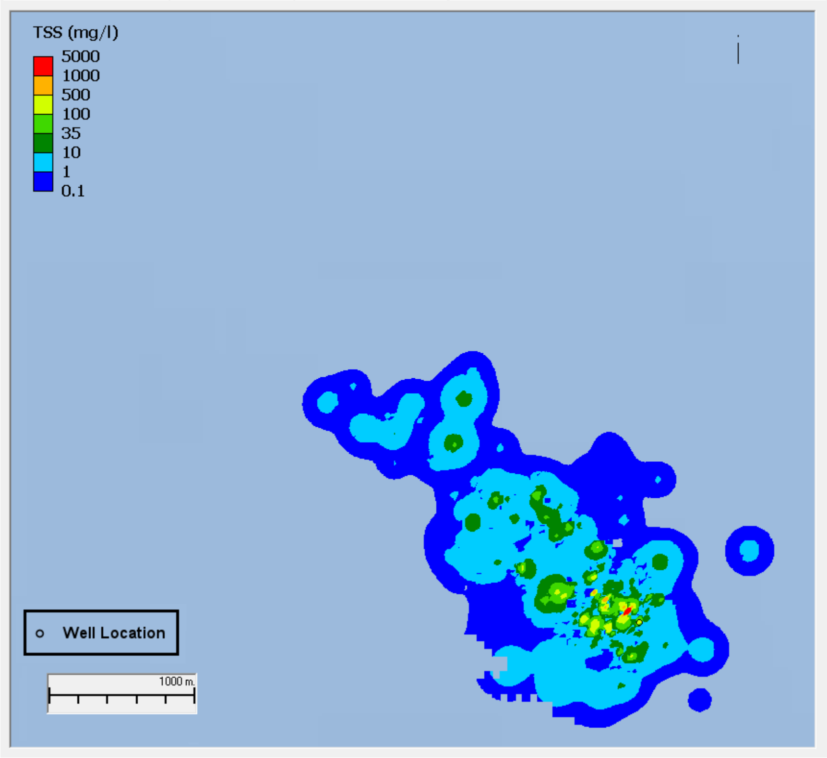


Figure 2-19 Maximum TSS at Surface – Scenario 2b DC2-I Maximum Currents

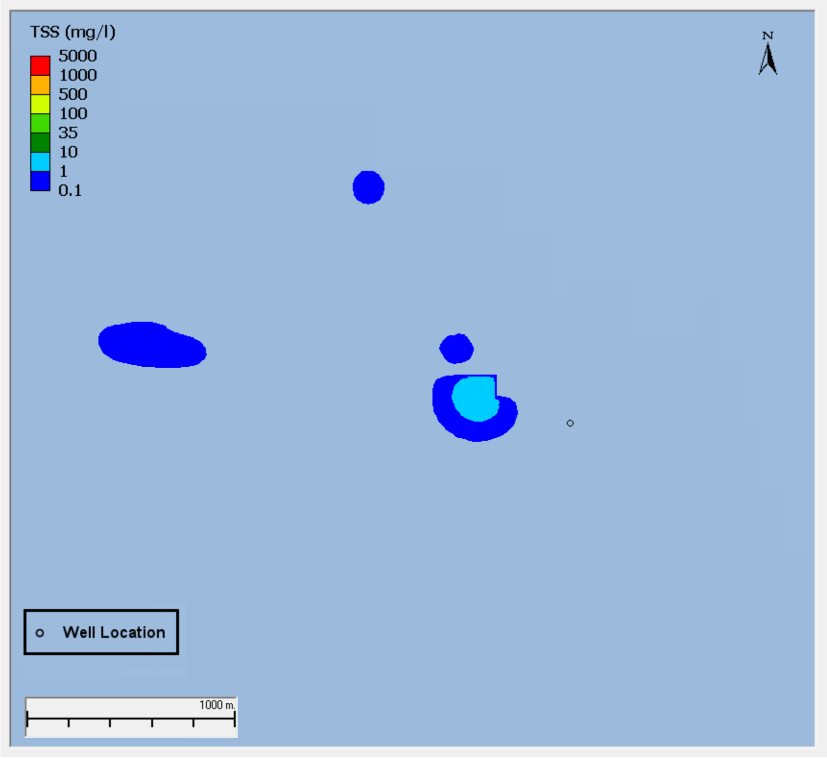
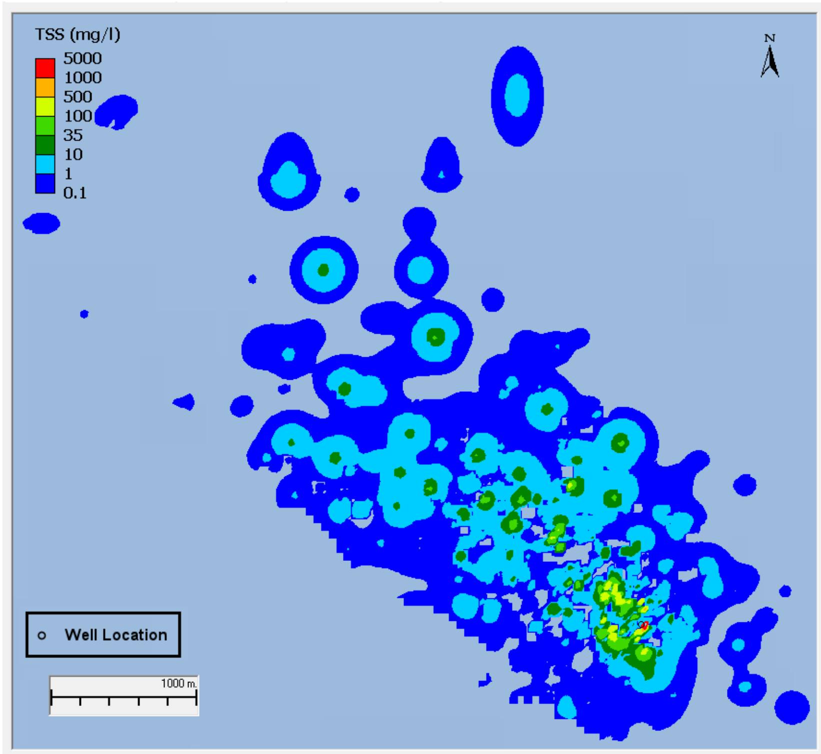


Figure 2-20 Maximum TSS at the Bottom – Scenario 2b DC2-I Maximum Currents



2.4.3 Oil Deposits on the Sediment

At the end of the simulation, NABF adhered to the cuttings settled primarily within approximately a 2 km radius region in all four scenarios. Within that region, the total hydrocarbon concentration reached a maximum of 334.7 g/m² in Scenario 1b.

In Scenario 1 at DC1-I, concentrations above 5 g/m² occupied an area between 10.4 km² and 10.6 km². In Scenario 2 at DC2-I, concentrations above 5 g/m² occupied an area between 8.0 km² and 10.1 km². Table 2-10 summarizes the maximum residual hydrocarbons modelled and area exceeding the 5 g/m² threshold under minimum and maximum current conditions at each drill center.

Table 2-10 Hydrocarbon Deposition Summary

Scenario	Maximum Hydrocarbon Deposition (g/m²)	Area (km²) with Hydrocarbons > 5 g/m²
1a DC1-I Min Currents	278.5	10.4
1b DC1-I Max Currents	334.7	10.6
2a DC2-I Min Currents	307.9	8.0
2b DC2-I	234.4	10.1

Scenario	Maximum Hydrocarbon Deposition (g/m²)	Area (km²) with Hydrocarbons > 5 g/m²
Max Currents		

Figure 2-21 Total Deposited Adhered Oil – Scenario 1a DC1-I Minimum Currents

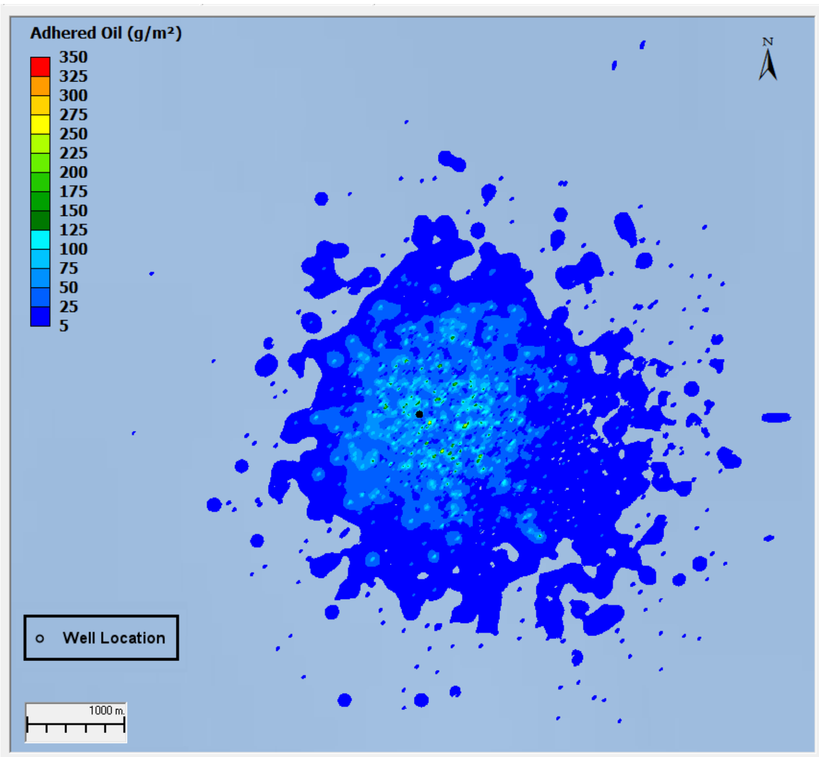


Figure 2-22 Total Deposited Adhered Oil – Scenario 1b DC1-I Maximum Currents

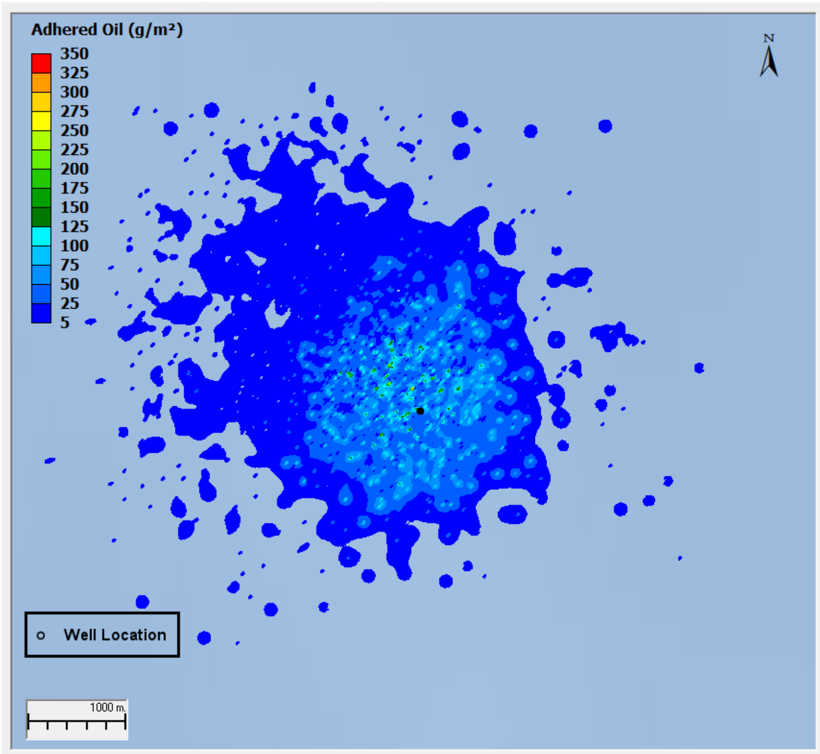


Figure 2-23 Total Deposited Adhered Oil – Scenario 2a DC2-I Minimum Currents

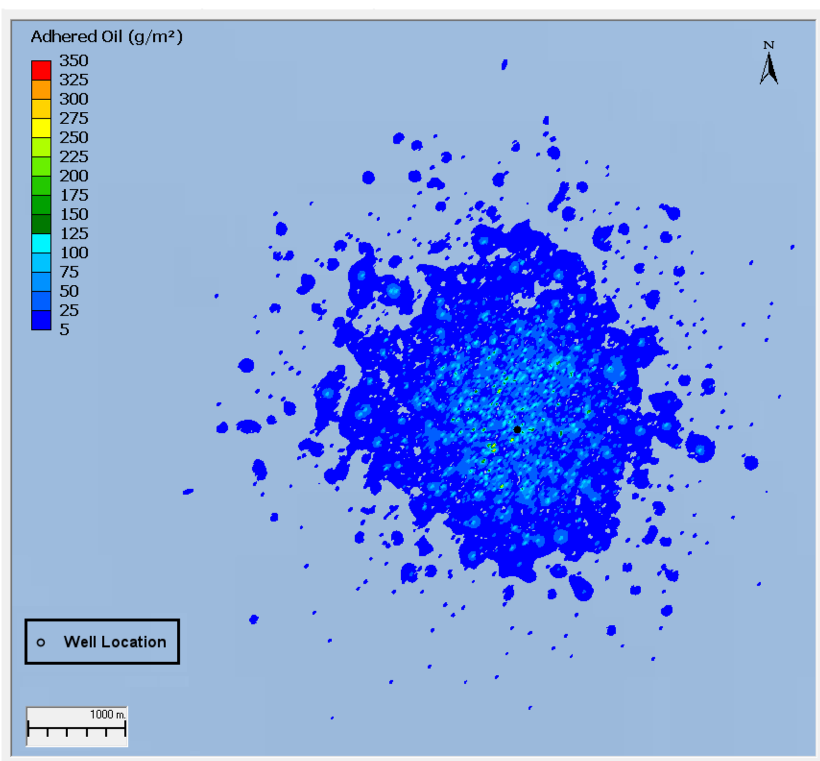
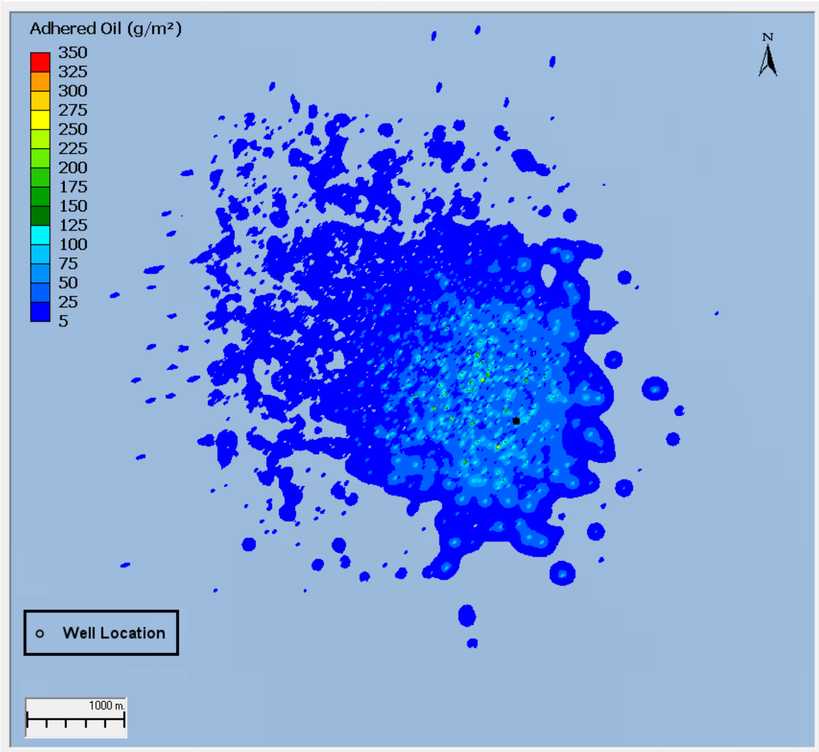


Figure 2-24 Total Deposited Adhered Oil – Scenario 2b DC2-I Maximum Currents



2.5 Conclusions

Modelling was performed using GEMSS® and its drill cuttings and fluids deposition module, GIFT. Four simulations were made representing the shallowest and deepest well locations (DC1-I and DC2-I, respectively) and 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 WBDF were discharged directly at the seabed while jetting and drilling the first two well sections. Drill cuttings and adhered NADF from the subsequent three sections were simulated to be release 11 m below sea level over 13 days.

Output from the drill cutting modelling included estimations of the total thickness of materials deposited on the sea floor, and maximum increased total suspended solids concentrations above ambient conditions. The concentration of hydrocarbons adhered to the cuttings that deposited on the sea floor was estimated in terms of mass per unit area. The results of the modelling are shown below in Table 2-11.

Table 2-11 Model Results Summary

Scenario	Maximum Depositional Thickness (mm)	Area (m²) with Thickness > 50 mm threshold	Maximum TSS (mg/L) Surface/Bottom	Area (km²) with TSS > 35 mg/L threshold Surface/Bottom	Maximum Adhered Oil Deposition (g/m²)	Area (km²) with Adhered Oil > 5 g/m²
1a DC1-I Min Currents	660	4,575	2.1 / 4,323	0 / 0.094	278.5	10.4
1b DC1-I Max Currents	186	5,815	2.9 / 5,517	0 / 0.168	334.7	10.6
2a DC2-I Min Currents	703	1,442	1.6 / 5,260	0 / 0.091	307.9	8.0
2b DC2-I Max Currents	753	1,590	5.3 / 9,737	0 / 0.088	234.4	10.1

According to the model results, the thickness of drill cuttings and adhered fluids deposited on the seafloor may exceed the threshold value of 50 mm within a 43 m radius from the well. This depositional mound is primarily due to the cuttings and fluids discharged during the jetting and drilling of the top two sections. The maximum TSS concentration in the water column directly above the well during the bottom releases may be initially high (over 9,700 mg/L) at the point of release, although in water depths below the photic zone in areas where light inhibition is not a concern and the population of biota is relatively low. At the surface where photosynthesis inhibition is more of a concern, TSS increases from discharges were below the 35 mg/L threshold. The maximum TSS concentration in the water column from the surface release is 5.3 mg/L. Hydrocarbons deposited on the seafloor had a maximum concentration of 334.7 g/m² with deposits generally settled in an area 10.4 km² at concentrations over 5 g/m².

Note that the variations in the current speeds are the primary cause for the variations in the model results provided. Scenario 2 has a higher maximum thickness and higher bottom TSS concentrations compared to the pair of simulations in Scenario 1. At the bottom depth of DC2-I, the currents are slower than at DC1-I allowing for a higher peak deposition, more compact deposition area, and more concentrated TSS. Though

Scenario 2b had higher average currents compared to Scenario 2a, the bottom currents where most of the deposition occurs during drilling of the riserless sections were slower in Scenario 2b. Higher in the water column the current speeds in Scenario 2b were higher than in Scenario 2a. The areas of deposits with adhered oil show the opposite effect as the near surface currents in Scenario 1 were higher than in Scenario 2, causing a larger scatter of particles and resulting footprint area of the oily SOBM particles once they reached the seafloor.

3.0 OFFSHORE DISCHARGES MODELLING

3.1 Approach

The Project will have several planned discharges to water associated with SURF & FPSO installation and commissioning activities as well as production operations. These discharges, based on the preliminary design information, are listed in Table 3-1.

Table 3-1 List of Operational and Maintenance Discharges from the Liza FPSO

Type of Discharge and Effluent Characteristics	Expected Discharge Volume/Rate
Ballast Water (FPSO initial deballasting)	≤ 500,000 bbl total
Hydrostatic Test Water • Biocide: ≤ 500 ppm • Oxygen scavenger ≤ 100 ppm • Corrosion inhibitor ≤ 100 ppm	25,000 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)	400 bbl total
Produced Water • Oil & Grease • Temperature (40-50 °C at point of discharge) • Residual production and water treatment chemicals	≤ 105,000 bpd
Cooling Water • Hypochlorite: ≤ 5 ppm	≤ 700,000 bpd
Sulfate Removal & Potable Water Processing Brines • Hypochlorite: ≤ 1 ppm • Electrolyte: ≤ 1 ppm • Biocide: ≤ 5 ppm • Oxygen Scavenger: ≤ 10 ppm • Scale Inhibitor: ≤ 5 ppm	≤ 100,000 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	<10 bpd

Type of Discharge and Effluent Characteristics	Expected Discharge Volume/Rate
Sink Drainage	
Tanker Ballast Water	1,100,000 bbl total (at each tanker crude loading)
BOP System Testing Water-Soluble Low-Toxicity Hydraulic Fluid	30 bbl every two weeks
Rain Water/Deck Drainage/Wash Down Water	Rainfall dependent
Gray Water	5,000 bpd
Black Water (sewage)	4,000 bpd
Food Preparation Wastes	<30 bpd

Cooling water, produced water, and brines from the Sulfate Removal Unit (SRU) and freshwater Reverse Osmosis (RO) 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. Additionally, although the discharge of hydrotest water and commissioning fluids will occur over only a short time period during the installation and SURF commissioning stage, they were also included in the offshore discharge modelling as a conservative measure.

The constituents considered from these discharges are listed in Table 3-2.

Table 3-2 Operational and Maintenance Offshore Discharges and their Constituents Modelled

Discharge	Modeled Constituents
Cooling Water	• Temperature • Residual Chlorine
Produced Water	• Temperature • Oil & Grease (O&G) • 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

Discharge	Modeled Constituents
	• Oxygen Scavenger • Corrosion Inhibitor
Gas Injection Line Commissioning Fluid	• Hydrate inhibitor (e.g., methanol or ethylene glycol)

As the standards applicable to marine discharges are typically at the end of the mixing zone, modelling of the near-field mixing zone is necessary. The model used for the mixing zone calculations is USEPA's 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.

3.2 Scenario Selection

Understanding the mixing characteristics of the various discharges and assessing compliance with applicable regulatory standards requires an understanding 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 are velocities, temperature and salinity. While the ambient velocity (and its strength relative to the discharge/exit velocity) determines the level of initial mixing, temperature and salinity influence the behaviour 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 increases 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. Since the front end engineering and design (FEED) for the project has not been completed, the maximum pipe diameter for each discharge that assured compliance with applicable regulatory standards was chosen by testing a number of diameters using CORMIX. Pipe diameters that are smaller than the ones shown here will result in increased mixing and smaller plumes. In addition, a variety of vertical discharge locations was considered to further ensure compliance with applicable regulatory standards. The range of pipe configurations considered for the four discharge streams considered are listed in Table 3-3.

Table 3-3 Pipe Diameters Considered for the Four Offshore Discharges

Type of Discharge	Pipe Diameter	Vertical Location Relative to Sea Level
Produced Water	18″	1m to 10m
Cooling Water	24″ to 40″	1m to 10m
Sulfate Removal and Potable Water Process Brines	12″	1m
Hydrostatic Test Water	2″, 6″	Seafloor
Hydrate Control Fluid	2″, 6″	Seafloor

3.2.2 Discharge Properties

Ranges of anticipated discharge rates for the various operational discharges were available from the preliminary design (see Table 3-11). Furthermore, the pipeline volumes for the various pipelines were available. The most conservative (highest) rates were used for the modelling. Expected concentrations of the constituents were also available. The selected discharge rates and constituent concentrations are shown in Table 3-4.

Table 3-4 Modelled Discharges and Selected Discharge Rates

Type of Discharge	Discharge Rate	Constituent Concentrations
Produced Water	105,000 bpd (conservative)	• Temperature: 125 °F (52°C) • Oil & 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	See Table 3-6	• Temperature: 125 °F • Hypochlorite: ≤ 5 ppm
Sulfate Removal & Potable Water Processing Brines	100,000 bpd	• Hypochlorite: ≤ 1 ppm • Electrolyte: ≤ 1 ppm • Biocide: ≤ 5 ppm • Oxygen Scavenger: ≤ 10 ppm • Scale Inhibitor: ≤ 5 ppm
Hydrostatic Test Water	25,000 barrels (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 400 bbl)	• Concentrated methanol or ethylene glycol

The cooling water discharge was evaluated in more detail due to anticipated changes in operational discharge rates. The cooling water discharge consists of two individual streams: cooling exchangers and produced water cooling. It is possible that both of these streams may be released through two separate pipes or through a combined pipe. A range of discharge rates based on the various phases of the project were available. Statistical summaries of these rates were used to bound the discharge plume using minimum and maximum rates as shown in Table 3-5.

Table 3-5 Statistical Summary of Cooling Water Discharge Rates (kbpd: thousand barrels per day)

Source	Minimum (kbpd)	Maximum (kbpd)

Combined Pipe		
Cooling Med Exchangers & Produced Water Cooler	269.6	739.2
Separate Pipes		
Cooling Med Exchangers	133.6	566.4
Produced Water Cooler	66.4	288

3.2.3 Ambient Currents

Ambient currents for the region were available from ExxonMobil Upstream Research Company using the SAT-OCEAN (2.1.3.2) and analysed in order to select appropriate values for the specific locations for the operational discharges at the FPSO and for the hydrotest discharge (largest single discharge) at the DC2-I location. Although the operational discharges occur near the surface, the hydrotest release occurs near the seabed. Therefore, the ambient currents were analysed to select appropriate values at the FPSO near the surface and at DC2-I near the seabed.

The ambient currents were analysed for the period of May 2008 to September 2016. A frequency distribution analysis was performed to evaluate the magnitude and exceedance percentages of the currents. The ambient currents selected for modelling consisted of bounding cases (5% and 95%) and typical (50%). The frequency distributions for the two locations are shown in Figure 3-1 and Figure 3-2. The selected current magnitudes are shown in Table 3-6.

Figure 3-1 Cumulative Frequency Distribution at FPSO (near surface)

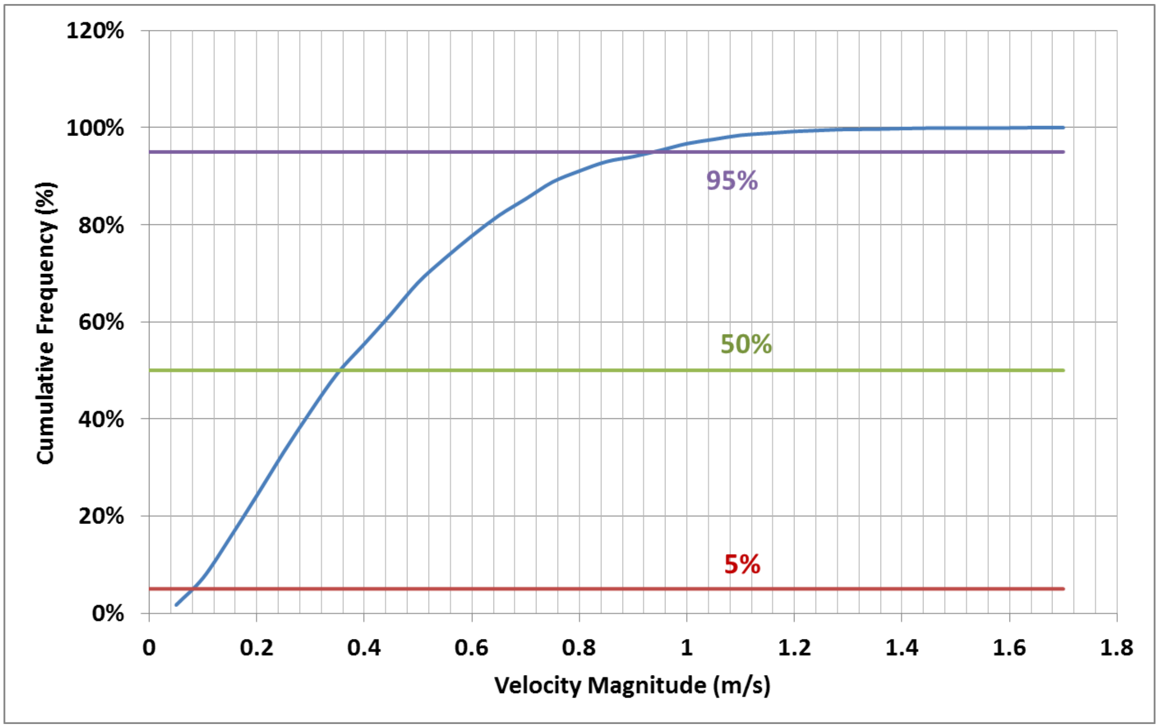


Figure 3-2 Cumulative Frequency Distribution at DC2-I (near seabed)

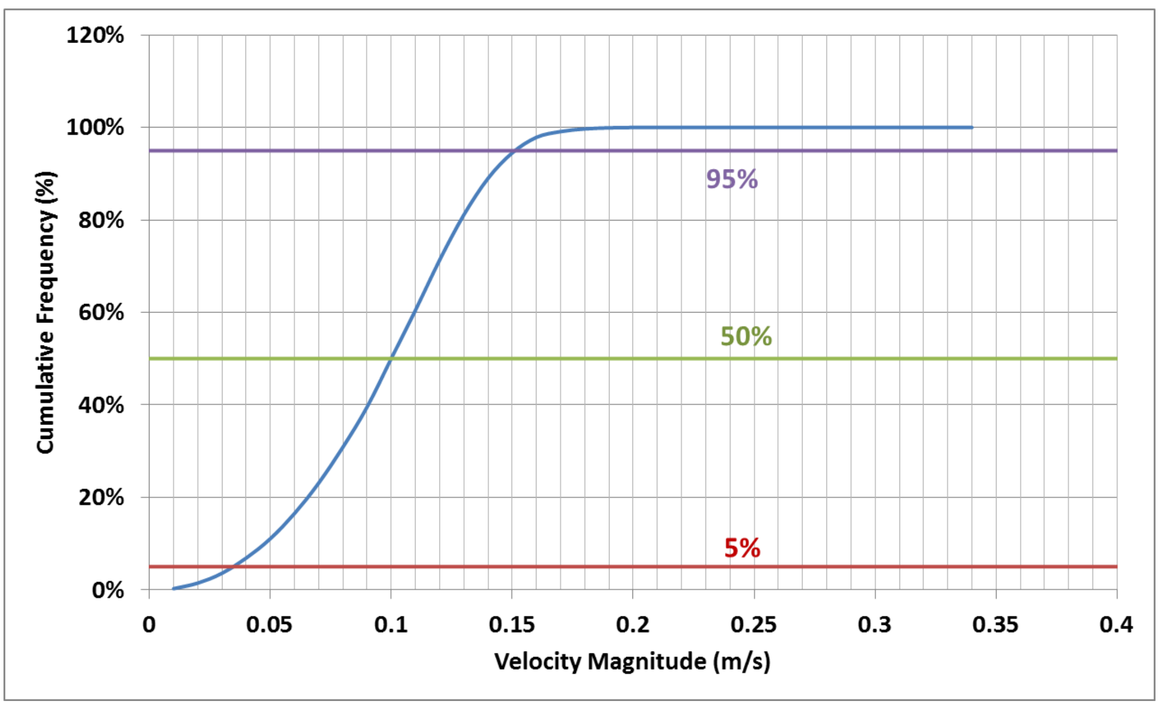


Table 3-6 Selected Ambient Current Magnitudes (m/s)

Cumulative Frequency	FPSO	DC2-I
Low (5%)	0.08	0.035
Typical (50%)	0.36	0.10
High (95%)	0.94	0.15

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 (2.1.3.2). Since the ambient temperatures do not vary significantly within the Stabroek Licensing Area, only the FPSO location, not the DC2-I location, was considered. As with the velocity data, the temperature data are available for a period of May 2008 to September 2016. A frequency distribution analysis was done to evaluate the temperatures and exceedance percentages. Selected ambient temperatures consisted of two bounding cases (1% and 99%) and a typical case (50%). Only the cooling water discharge whose plume is influenced by the ambient temperatures 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 3-7.

Figure 3-3 Cumulative Frequency Distribution at FPSO (near surface)

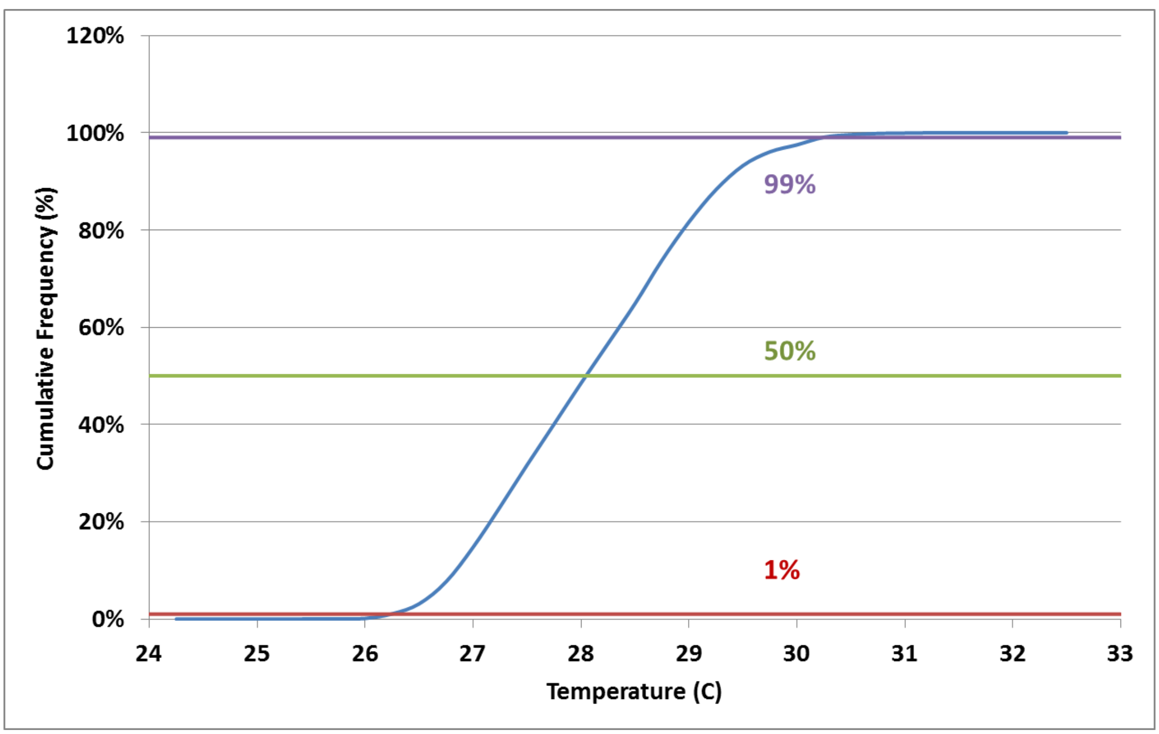


Table 3-7 Selected Ambient Current Temperatures (degrees Celsius)

Cumulative Frequency	FPSO
Low (1%)	25.25
High (99%)	30.25

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 3-8). Pipe diameters selected for these scenarios were the largest diameters shown in Table 3-3. Demonstration runs were done by selecting the worst scenario (largest plume) to show that the selection of smaller diameter will result in smaller plume.

Table 3-8 List of Modelled Scenarios

No	Discharge	Scenario Name	Ambient Currents	Ambient Temperature	Location
1	Cooling Water - Thermal	T Sc 01	Low (5%)	High (99%)	FPSO
		T Sc 02	Typical (50%)	High (99%)	FPSO
		T Sc 03	High (95%)	High (99%)	FPSO
		T Sc 04	Low (5%)	Low (1%)	FPSO
		T Sc 05	Typical (50%)	Low (1%)	FPSO
		T Sc 06	High (95%)	Low (1%)	FPSO
2	Cooling Water - Hypochlorite	C Sc 01	Low (5%)	High (99%)	FPSO
		C Sc 02	Typical (50%)	High (99%)	FPSO
		C Sc 03	High (95%)	High (99%)	FPSO
		C Sc 04	Low (5%)	Low (1%)	FPSO
		C Sc 05	Typical (50%)	Low (1%)	FPSO

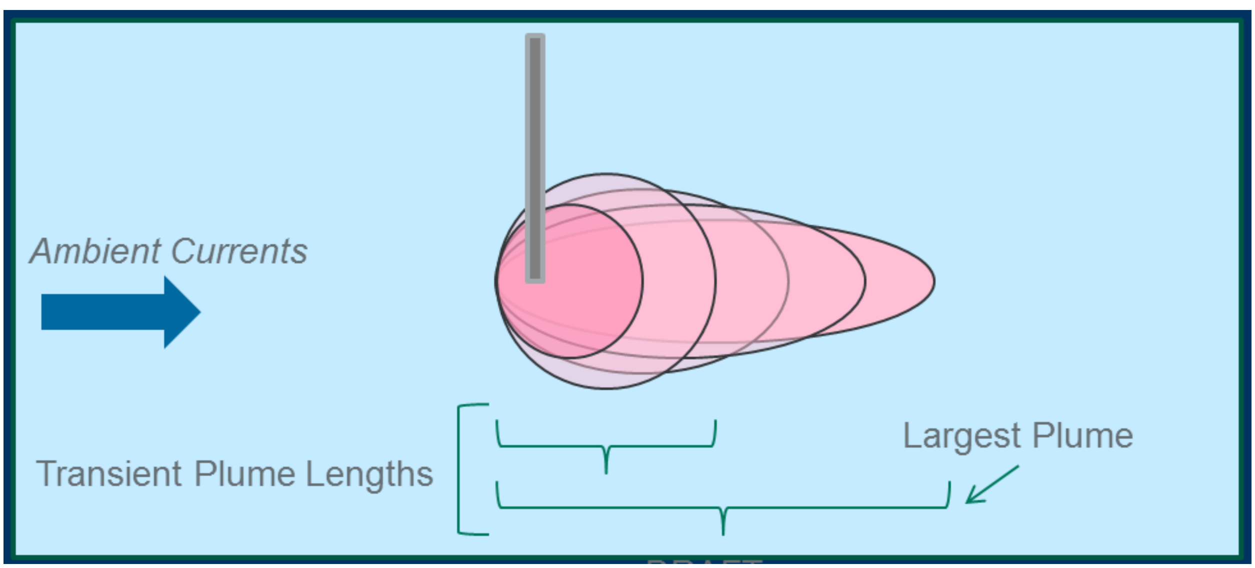
No	Discharge	Scenario Name	Ambient Currents	Ambient Temperature	Location
		C Sc 06	High (95%)	Low (1%)	FPSO
3	Sulfate Removal & Potable Water Processing Brines	W Sc 01	Low (5%)	Typical (50%)	FPSO; 1m above Surface
		W Sc 02	Typical (50%)	Typical (50%)	FPSO; 1m above Surface
		W Sc 03	High (95%)	Typical (50%)	FPSO; 1m above Surface
4	Produced Water	P Sc 01	Low (5%)	Typical (50%)	FPSO; 1m below Surface
		P Sc 02	Typical (50%)	Typical (50%)	FPSO; 1m below Surface
		P Sc 03	High (95%)	Typical (50%)	FPSO; 1m below Surface
5	Hydrostatic Test Water	H Sc 01	Low (5%)	Typical (50%)	DC2-I; Seabed
		H Sc 02	Typical (50%)	Typical (50%)	DC2-I; Seabed
		H Sc 03	High (95%)	Typical (50%)	DC2-I; Seabed
6	Hydrate Control Fluid - Methanol	Methanol Sc01 2in	Low (5%)	Typical (50%)	DC2-I; Seabed
		Methanol Sc03 2in	High (95%)	Typical (50%)	DC2-I; Seabed
		Methanol Sc01 6in	Low (5%)	Typical (50%)	DC2-I; Seabed
		Methanol Sc03 6in	High (95%)	Typical (50%)	DC2-I; Seabed
7	Hydrate Control Fluid – ethylene glycol	MEG Sc01 2in	Low (5%)	Typical (50%)	DC2-I; Seabed
		MEG Sc03 2in	High (95%)	Typical (50%)	DC2-I; Seabed
		MEG Sc01 6in	Low (5%)	Typical (50%)	DC2-I; Seabed
		MEG Sc03 6in	High (95%)	Typical (50%)	DC2-I; Seabed

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 avoid biofouling, is either regulated as an end of pipe concentration or at the end of a mixing zone (100 m 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 (72-96 hours).

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%) will only exist for a short duration suggesting that the resulting plumes will continue to evolve and devolve as currents change direction and magnitude. Figure 3-4shows a schematic of such transient plume suggesting that the existence of maximum concentrations calculated through this conservative approach will exist only for a short duration and result in considerably reduced exposure times.

Figure 3-4 Transient Discharge Plume from Various Offshore Releases



Discharges such as produced water, hydrotest or sulfate removal & potable water processing brines are not subject to any regulatory standards for ambient water quality. The total concentration of oil & grease at the end of pipe is regulated by MARPOL standards at maximum monthly average of 29 mg/l and a daily maximum of 42 mg/l. Furthermore, the USEPA compliance guidance document for the Gulf of Mexico (Final NPDES 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 EPA 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 will be less than 500 mg/l.

Since no ambient water quality standards exist or are applicable to the various offshore discharge streams except for the cooling water discharge, only dilution values are reported at a reference distance of 100 m.

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 without any decay is used to obtain a conservative result. Note that 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 with distance from the discharge.

3.4.1 Cooling Water

The cooling water discharge consists of two separate streams: cooling exchangers and produced water cooler. At this early stage of the project, it is undecided if these two streams will be combined and released through a single pipe or released separately. The project design will only consider pipe configurations that allow compliance with the thermal standard of temperature rise within 100 m of the discharge to be less than 3°C. To obtain this level of performance, several limiting pipe configurations were evaluated and design options developed such that compliance is achieved. Pipe diameters ranging from 24” to 40” were considered. Since larger pipes result in reduced exit velocity resulting in reduced mixing, deeper releases were considered to compensate for this reduction in mixing. Two ambient temperatures (1% and 99%) were selected for simulation because different in ambient temperatures will influence the plume behaviour and the effluent temperature rise.

Based on the initial assessments, Scenario 06 (winter – low ambient temperature and low ambient currents) was found to be limiting. Using this scenario, the minimum depth necessary for the combined release to achieve compliance was determined as shown in Table 3-9. Each of these pipe configurations (combination of pipe diameter and release depth) will ensure compliance with applicable thermal standards under both minimum and maximum flow rates (Table 3-6). Similarly, Table 3-10 shows the pipe configuration for the separate discharges that will ensure compliance. Figure 3-5 shows the temperature rise diminishing with distance from the discharge showing compliance with 3°C within 15 m from the discharge.

Table 3-9 Release Depth Needed to Ensure Compliance with the ≤3 deg. C Temperature Difference at 100 m Standard for Various Pipe Diameters (combined discharge)

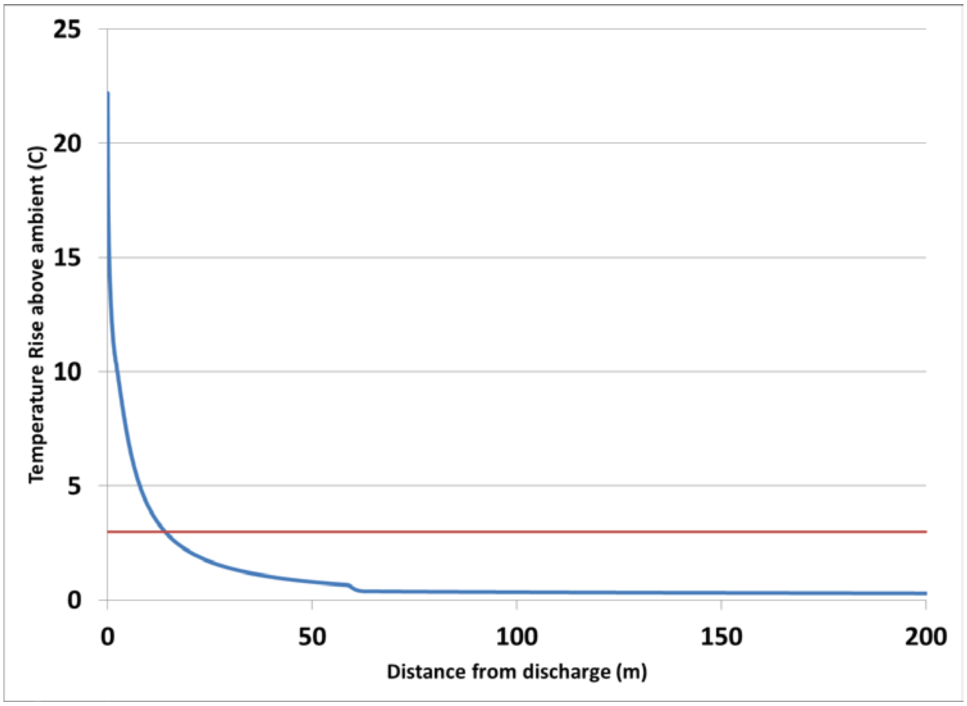
Pipe Diameter	Discharge Depth (m)
40 inch	7
38 inch	6
36 inch	6
34 inch	5
32 inch	4
30 inch	3
28 inch	2
24 inch	1

Table 3-10 Release Depth Needed to Ensure Compliance with the ≤3 deg. C Temperature Difference at 100 m Standard for Various Pipe Diameters (separate discharges)

Pipe Diameter	Discharge Depth (m)
40 inch	
Cooling Med Exchangers	6
Produced Water Cooler	7
38 inch	
Cooling Med Exchangers	6
Produced Water Cooler	6
36 inch	
Cooling Med Exchangers	6
Produced Water Cooler	6

Pipe Diameter	Discharge Depth (m)
34 inch	
Cooling Med Exchangers	6
Produced Water Cooler	5
32 inch	
Cooling Med Exchangers	5
Produced Water Cooler	5
30 inch	
Cooling Med Exchangers	5
Produced Water Cooler	5
28 inch	
Cooling Med Exchangers	4
Produced Water Cooler	4
24 inch	
Cooling Med Exchangers	3
Produced Water Cooler	4

Figure 3-5 Temperature Rise Above Ambient Versus Distance Downstream for Winter, Low Ambient Current Scenario; 40 inch Diameter Pipe and Combined Cooling Water Release



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 m results in the reduction of concentrations by a factor 8.8 (=26.4 C/3C), the residual chlorine resulting concentrations from hypochlorite addition will reduce by the same factor. For hypochlorite dosing resulting of 5 ppm, the highest dosing expected, residual chorine concentrations at 100 m will be 0.57 ppm. As noted earlier, these concentrations are the most conservative estimates (i.e., peak values) and will be transient in nature. In contrast, any risk to aquatic species from residual chlorine requires sustained exposure for 72 to 96 hours.

3.4.2 Produced Water

Produced water consists of higher temperatures, oil & grease and residual production and water treatment chemicals. Scale inhibitor and corrosion inhibitor were modelled 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. It was assumed that the pipe diameter will be 18”. Selection of pipe diameters less than 18” during the FEED will result in increased mixing and a smaller plume. Of the constituents of concern in produced water, only oil & 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 released 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 for this analysis. The thermal standard applied to cooling water (less than 3°C temperature rise within 100 m of the discharge) also applies to produced water. No ambient water quality standards exist for any other constituents.

Concentrations of oil & grease, scale inhibitor and corrosion inhibitor are shown for the three scenarios in Figure 3-6, Figure 3-7and Figure 3-8, respectively. Oil & grease concentration decreases to less 3.2 mg/l within 100 m while scale inhibitor and corrosion inhibitor drop to less than 7.6 ppm and 15.3 ppm, respectively, within 100 m. Releasing the same discharge approximately 10m below the water surface will result in further mixing and a smaller plume. While a near surface release is currently planned, the FEED study may recommend release of produced water 10 m below sea surface. A demonstration run for the worst case scenario (low ambient currents) was performed for this configuration. The plumes will shrink under this condition. Each constituent (oil & grease, scale inhibitor and corrosion inhibitor) shows lower concentrations at 100 m. For instance, corrosion inhibitor concentration at 100 m was 7.6 ppm when released at the surface, whereas it decreases to 2.4 ppm when released 10 m below surface. The same level of mixing is expected for the temperature rise as seen in Figure 3-9 where the temperature rise drops to less than 2°C within 100 m.

Figure 3-6 Concentration of Oil and Grease (mg/l) with Distance (m) from the Discharge for the Three Scenarios Modelled

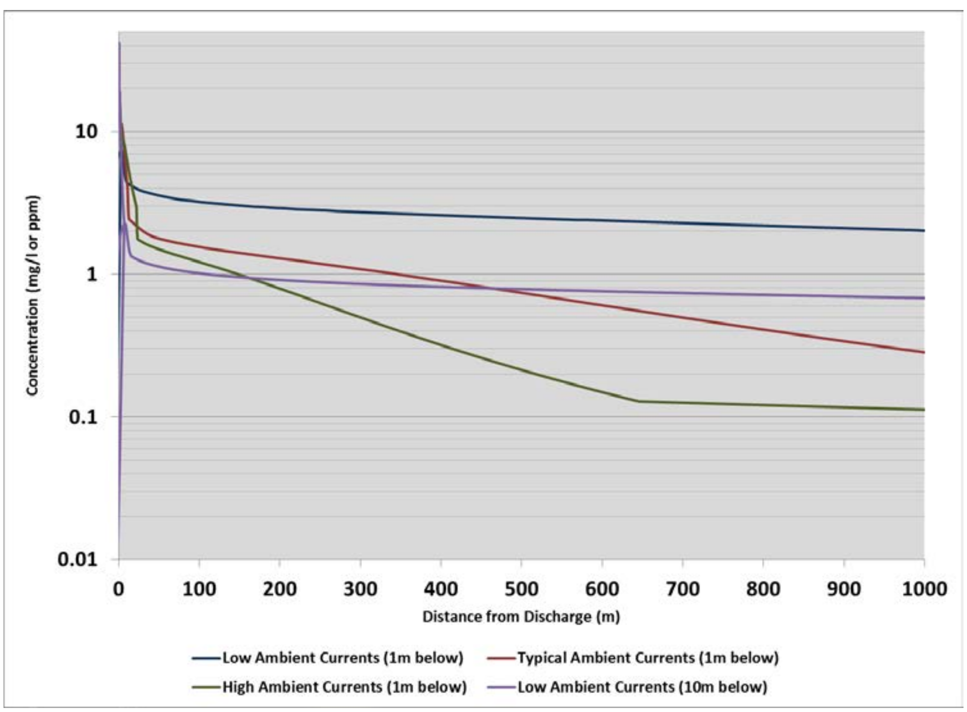


Figure 3-7 Concentration of Scale Inhibitor (ppm) with Distance (m) from the Discharge for the Three Scenarios Modelled

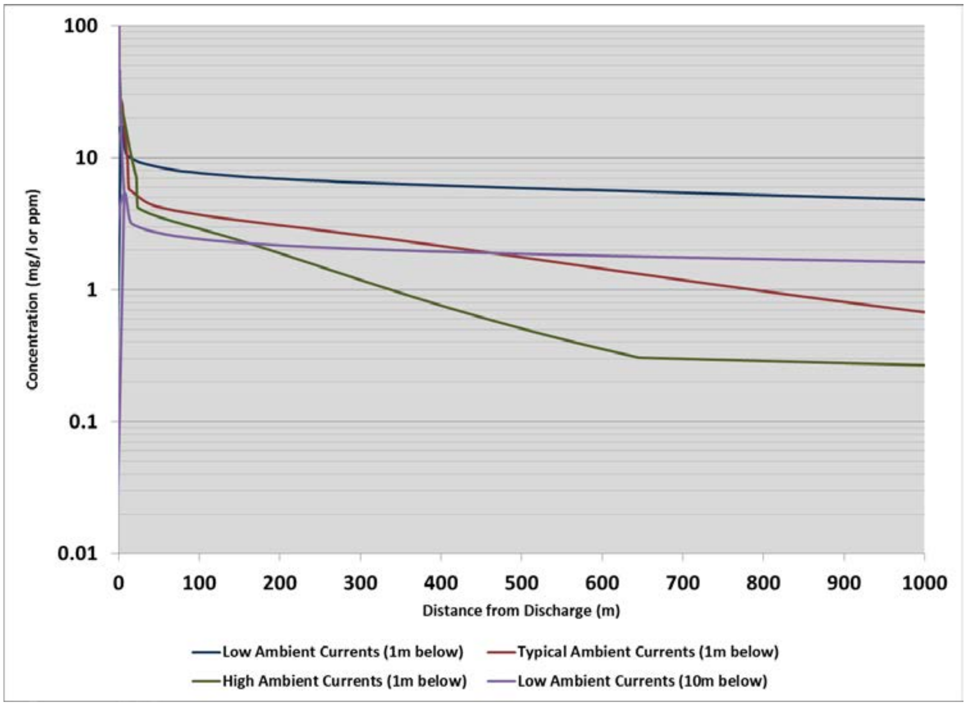


Figure 3-8 Concentration of Corrosion Inhibitor (ppm) with Distance (m) from the Discharge for the Three Scenarios Modelled

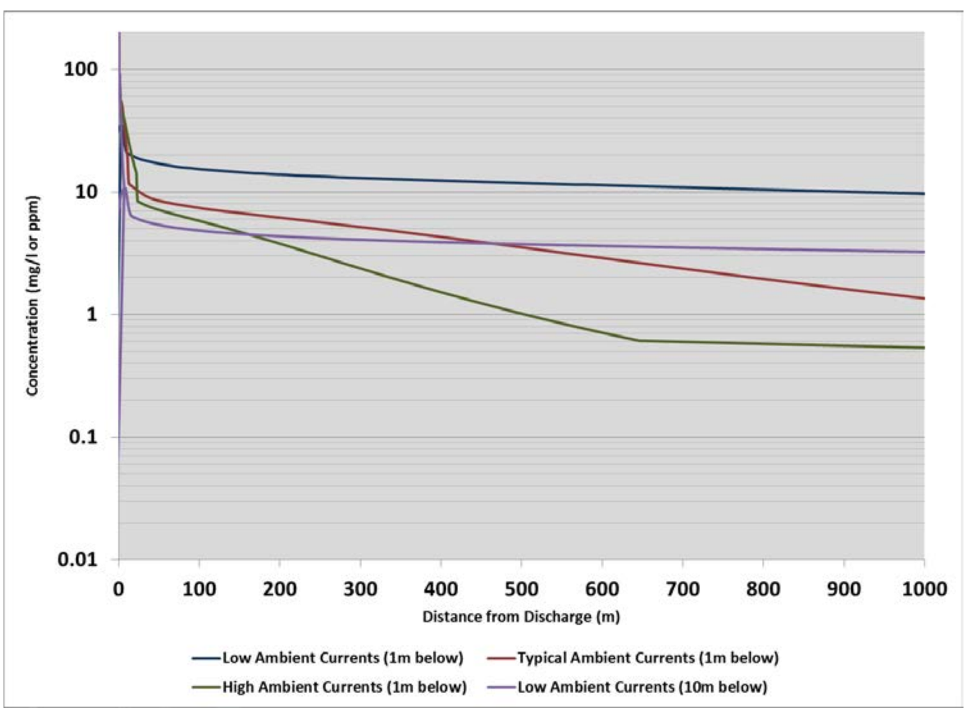
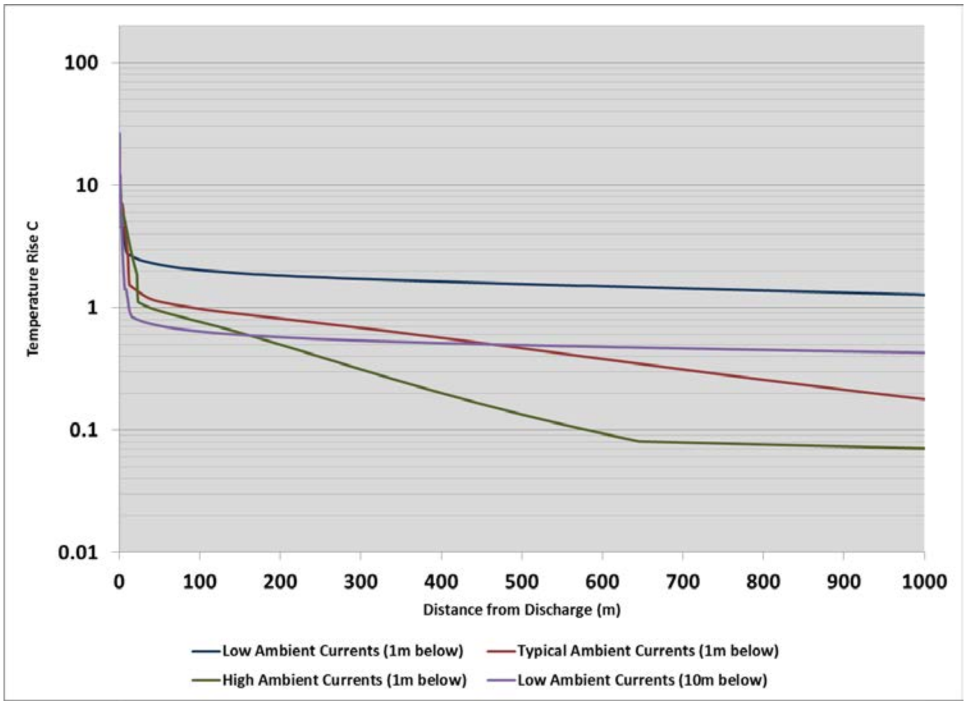


Figure 3-9 Temperature Rise with Distance (m) from the Discharge for the Three Scenarios Modelled

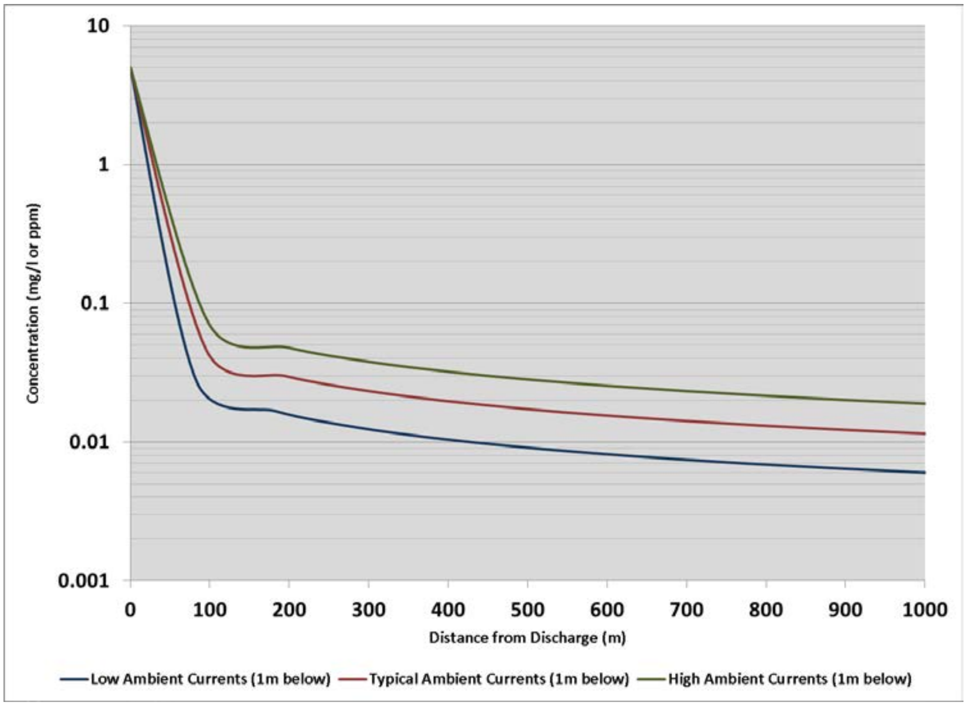


3.4.3 Sulfate Removal & Potable Water Processing Brines

Effluent waste stream consists of the combination of processing brines from the SRU and freshwater RO. The main constituent are hypochlorite, electrolytes, biocides, oxygen scavenger and scale inhibitor. No ambient water quality standards exist of any of these constituents. It was also assumed that the discharge pipe will not exceed a diameter of 12 inches. Any pipe of smaller diameter will result in increased mixing and smaller plume.

The results for biocides concentrations for the three scenarios are shown in Figure 3-10. The biocide concentration decreases to 0.07 mg/l within 100 m (98.6% reduction) even for the worst case scenario (high ambient currents). All other constituents will follow the same mixing pattern and experience the same percent reduction as summarized in Table 3-11.

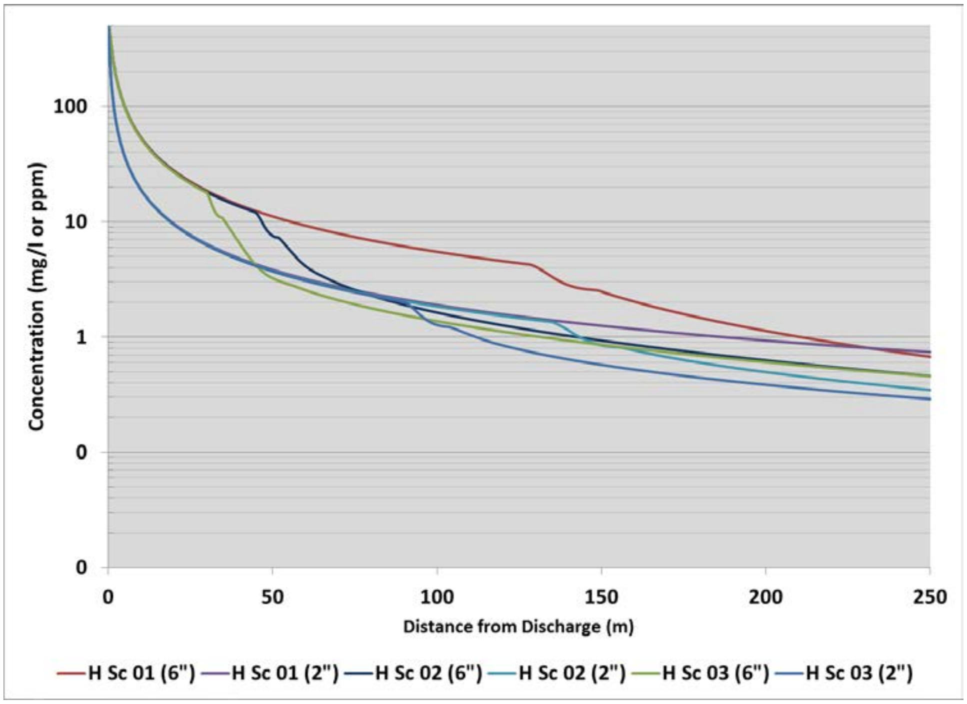
Figure 3-10 Concentration of Biocide (ppm) with Distance (m) from the Discharge for the Three Scenarios Modelled



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. 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 diameter of 2″ and 6″. 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″ pipe), biocide decreases to 5.5 ppm within 100 m of the discharge. The other constituents (oxygen scavenger and corrosion inhibitor) will follow the same mixing pattern and experience the same percent reduction.

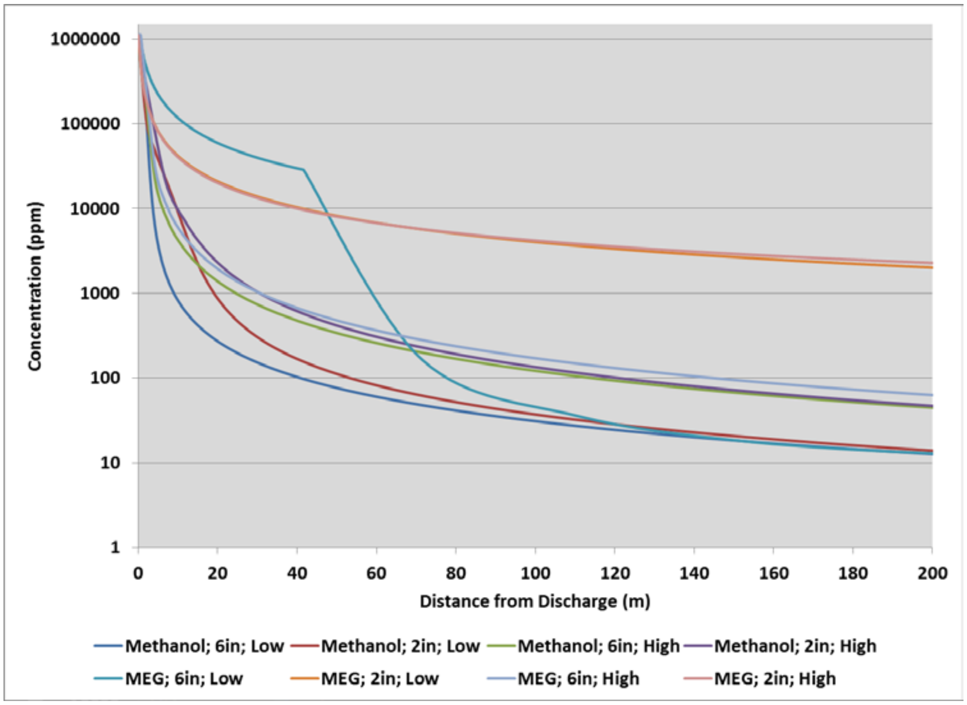
Figure 3-11 Concentration of Biocide (ppm) with Distance (m) from the Discharge for the Three Scenarios and Two Pipe Diameters



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 400 bbl, but a very conservative value of 2,500 bbl was assumed for the modelling analysis. Since the pipelines and risers are of different diameters, all three scenarios were run for pipe diameter of 2″ and 6″. Figure 3-12 shows the results for both methanol and ethylene glycol under the low and high ambient currents and 2″ and 6″ pipe diameters.

Figure 3-12 Concentration of Methanol or MEG (ppm) with Distance (m) from the Discharge for the Low and High Currents and 2" and 6" Pipe Diameters



3.5 Conclusions

The various operational and maintenance discharges and activities identified in the proposed project description were modelled 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 m of the discharge point are required to be less than 3°C. Since the project is in the pre-FEED phase, design specifications for the various discharge ports were not available. To address this lack of specific information, conservative estimates of the largest pipe diameter were made that allow the standard to be met. The final FEED will ensure that the designed discharge pipes will not exceed these conservative pipe diameters by using these, or smaller, pipe diameters.

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. It was found that even under the extreme conditions, discharge plumes were small and subject to rapid mixing within the first 100 m. Although only thermal discharges are subject to regulatory limits, the reference distance of 100 m is used for reporting purposes for all the discharges to demonstrate the rapid mixing that the discharge plumes experience.

Table 3-11 summarizes the results of the modelling study for offshore discharges.

Table 3-11 Results Summary of Offshore Discharges and Concentrations at 100 m Reference Distance

No'	Discharge	Scenario Name	Concentrations at 100 m[1]
1	**Thermal**	**Worst Case**	Temperature Rise: <3°C
2	**Hypochlorite**	**Worst Case**	Residual Chlorine: 0.57 ppm
3	**Sulfate Removal & Potable Water Processing Brines**	**W Sc 01**	Hypochlorite: 0.005 ppm Electrolyte: 0.005 ppm Biocide: 0.027 ppm Oxygen Scavenger: 0.055 ppm Scale Inhibitor: 0.027 ppm
		W Sc 02	Hypochlorite: 0.009 ppm Electrolyte: 0.009 ppm Biocide: 0.045 ppm Oxygen Scavenger: 0.09 ppm Scale Inhibitor: 0.045 ppm
		W Sc 03	Hypochlorite: 0.014 ppm Electrolyte: 0.014 ppm Biocide: 0.07 ppm Oxygen Scavenger: 0.14 ppm Scale Inhibitor: 0.07 ppm
4	**Produced Water**	**P Sc 01**	Temperature Rise: <3°C Oil & Grease: 3.2 mg/l Scale Inhibitor: 7.64 ppm Corrosion Inhibitor: 15.27 ppm

[1] Note: Except for the thermal discharge (temperature rise), no standards exist for any discharge constituents. The distance of 100 m is used as a widely accepted reference distance and should not be interpreted as a criterion for regulatory compliance.

No'	Discharge	Scenario Name	Concentrations at 100 m[1]
		P Sc 02	Temperature Rise: <3°C Oil & Grease: 1.52 mg/l Scale Inhibitor: 3.64 ppm Corrosion Inhibitor: 7.27 ppm
		P Sc 03	Temperature Rise: <3°C Oil & Grease: 1.21 mg/l Scale Inhibitor: 2.89 ppm Corrosion Inhibitor: 5.78 ppm
5	**Hydrotest**	**H Sc 01**	Biocide (6″ pipe): 5.50 ppm Biocide (2″ pipe): 1.89 ppm
		H Sc 02	Biocide (6″ pipe): 1.70 ppm Biocide (2″ pipe): 1.84 ppm
		H Sc 03	Biocide (6″ pipe): 1.51 ppm Biocide (2″ pipe): 1.28 ppm
6	**Hydrate Control Fluid**	**Methanol Sc01 2in**	Methanol (2″ pipe): 37.5 ppm
		Methanol Sc03 2in	Methanol (2″ pipe): 136.3 ppm
		Methanol Sc01 6in	Methanol (6″ pipe): 31.1 ppm
		Methanol Sc03 6in	Methanol (6″ pipe): 121.8 ppm
		MEG Sc01 2in	MEG (2″ pipe): 4,031.1 ppm
		MEG Sc03 2in	MEG (2″ pipe): 4,190.2 ppm
		MEG Sc01 6in	MEG (6″ pipe): 70.3 ppm
		MEG Sc03 6in	MEG (6″ pipe): 171.5 ppm

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APPENDIX N – Underwater Noise Modeling Report (JASCO)

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Underwater Sound Associated with Liza Phase 1 Project Activities

Offshore Guyana Stabroek Block

Submitted to:

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ExxonMobil Exploration Co.
Houston, TX
Contract: MSA A2346975, WA 1296

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1.0	2016 Oct 07	S. Carr	Released to client for review.
2.0	2016 Oct 28	S. Carr	Applied review comments. Delivered to client.
3.0	2016 Dec 02	S. Carr	Added results for underwater impact pile driving scenarios.
4.0	2016 Dec 14	S. Carr	Addressed client's comments. Delivered to client.

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Contents

Figures

Tables

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.

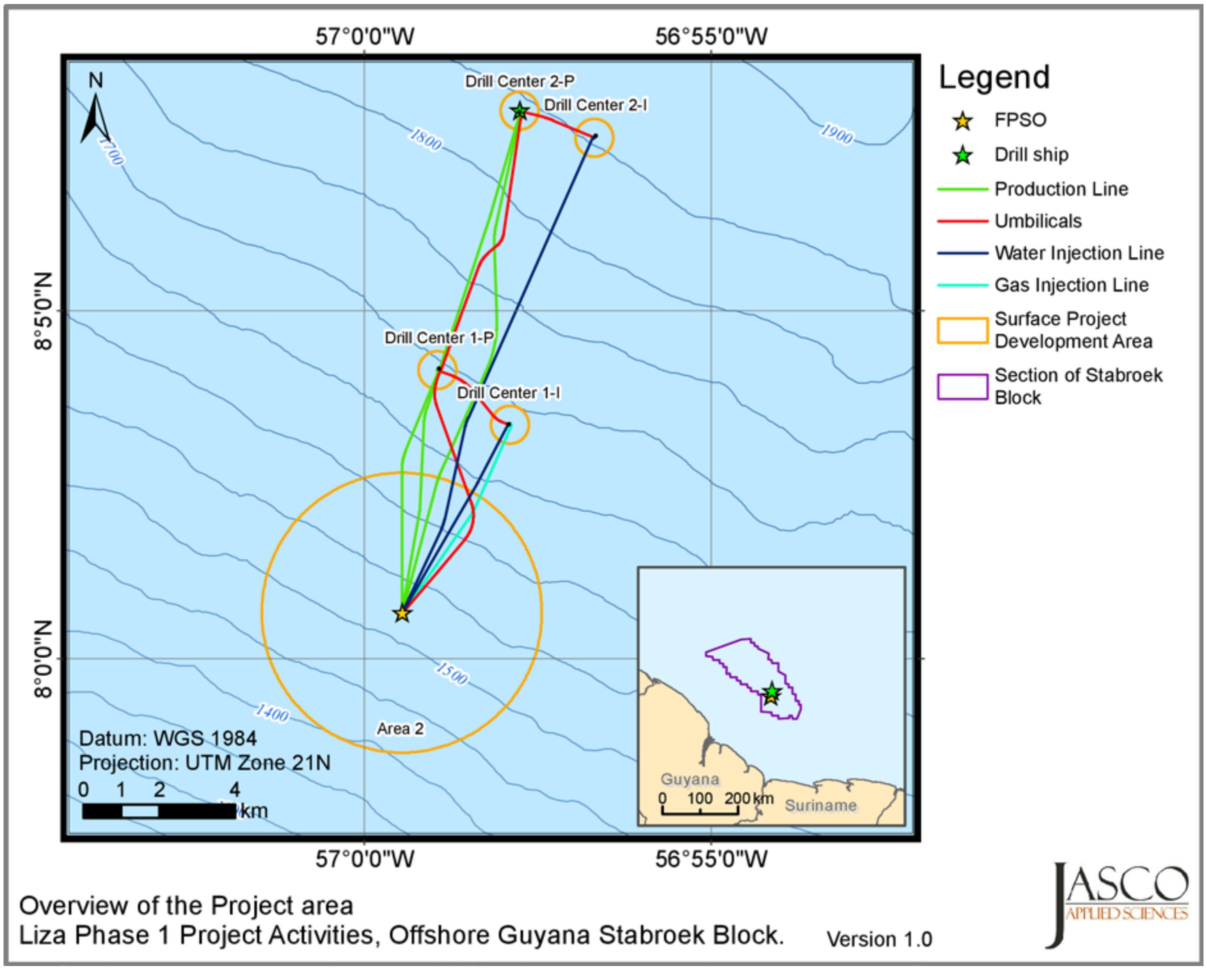

Figure 1. Overview of the Guyana Stabroek project area.

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

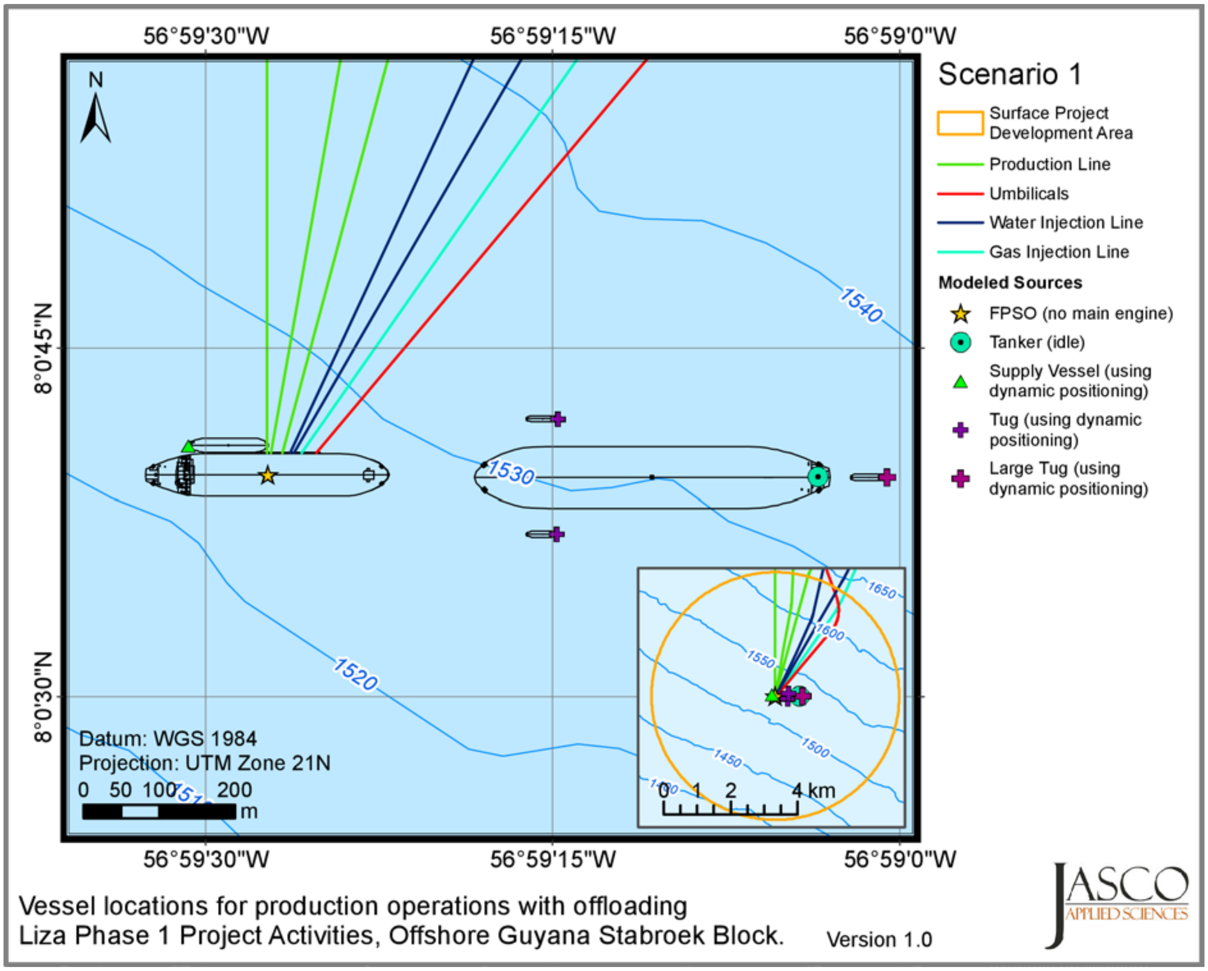

Figure 2. Scenario 1: Location of modeled vessels.

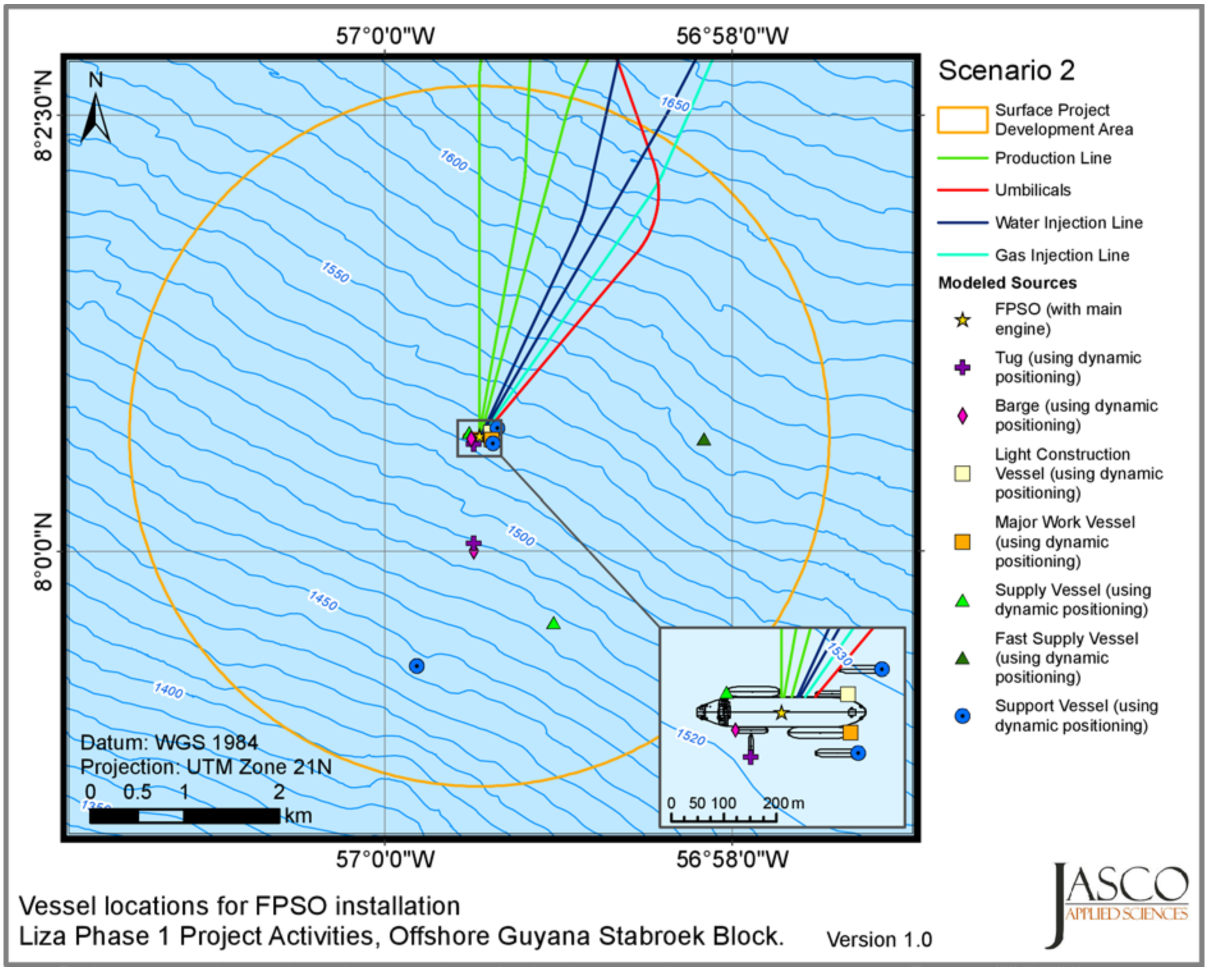

Figure 3. Scenario 2: Location of modeled vessels.

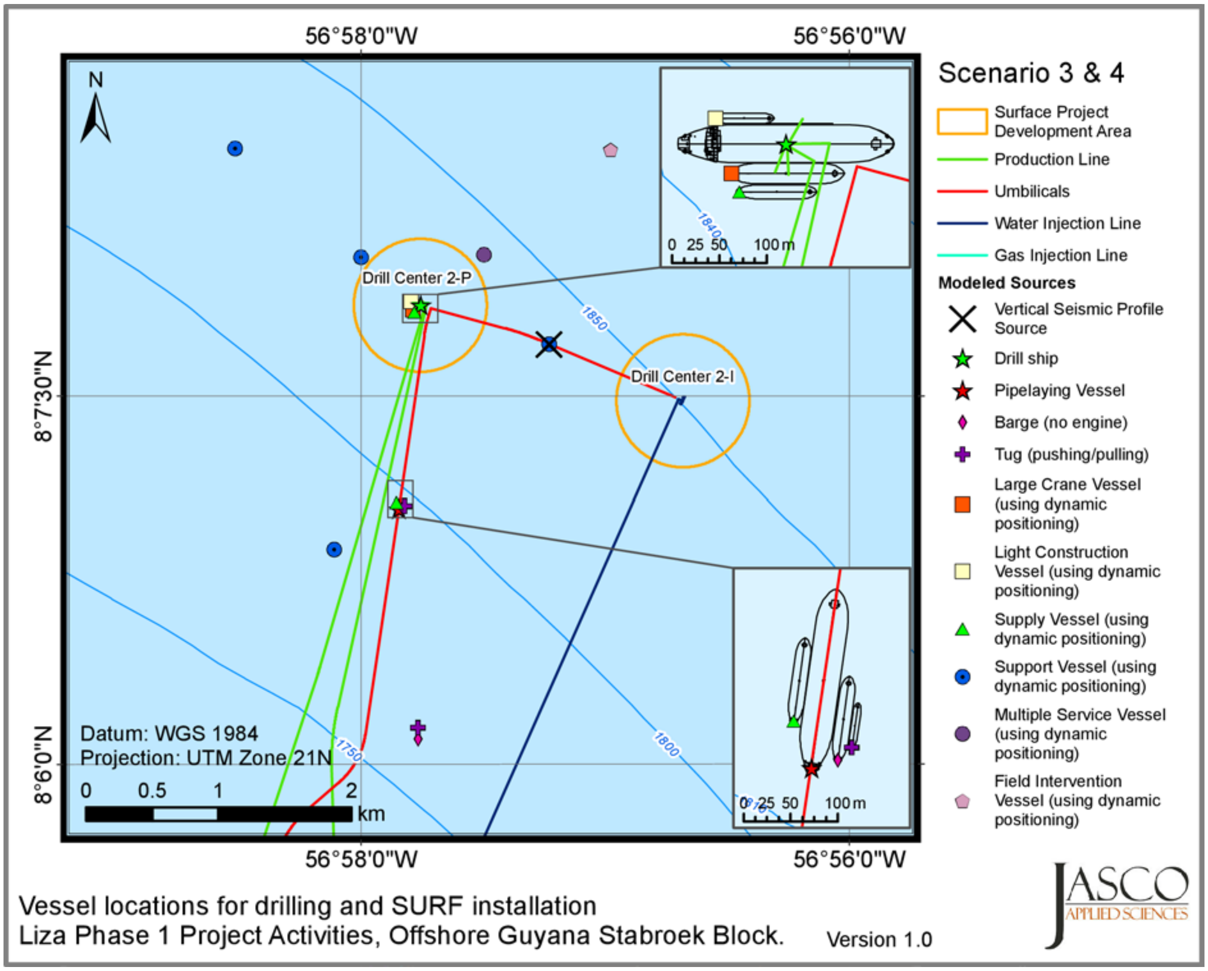

Figure 4. Scenarios 3 and 4: Location of modeled vessels and the VSP source at Drill Center 2.

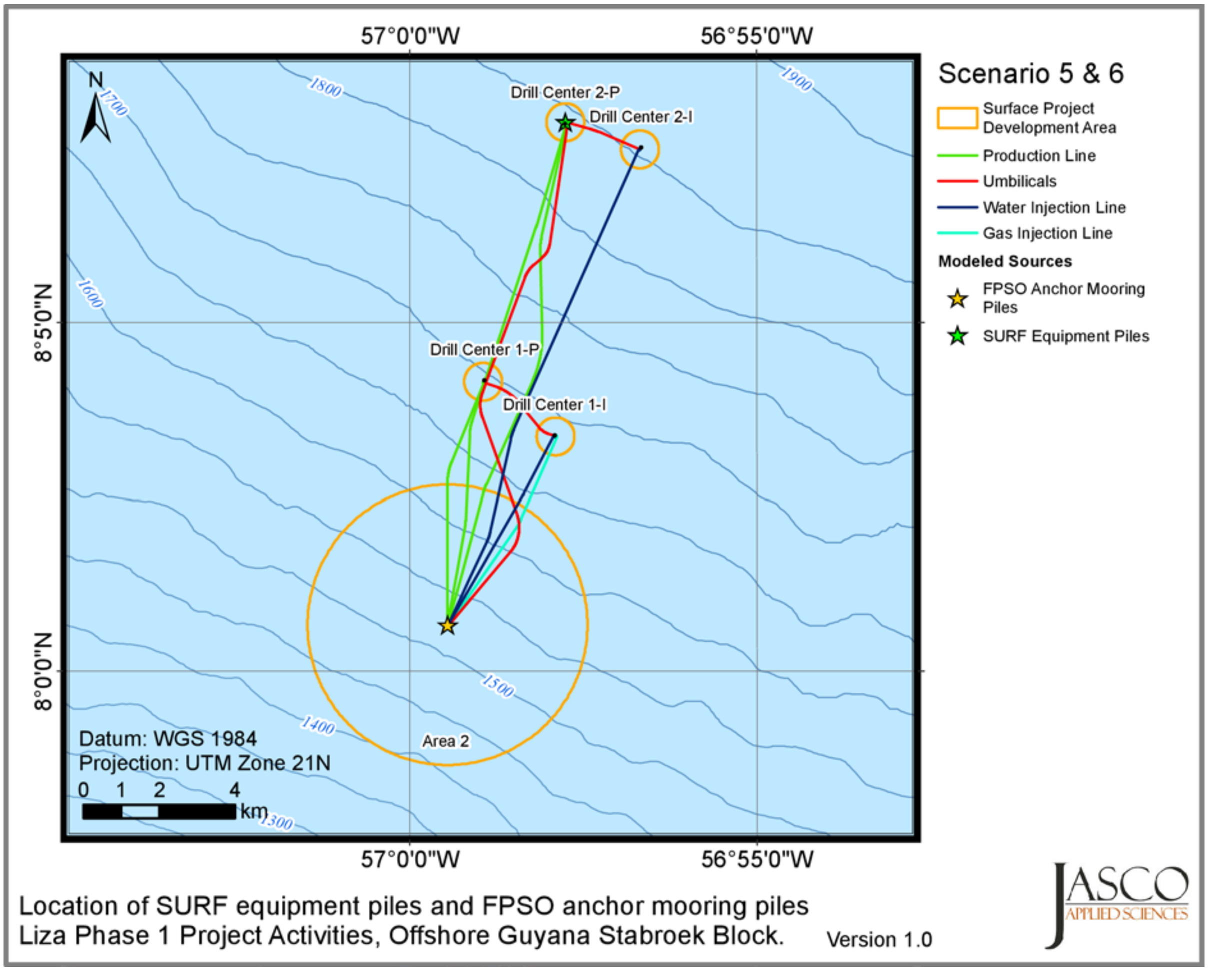

Figure 5. Scenarios 5 and 6: Location of modeled underwater impact pile driving operations at Drill Center 2-P and the FPSO (Area 2).

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:

$$R_{\mathrm{nf}} < \frac{l^2}{4\lambda} \qquad (1)$$

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.

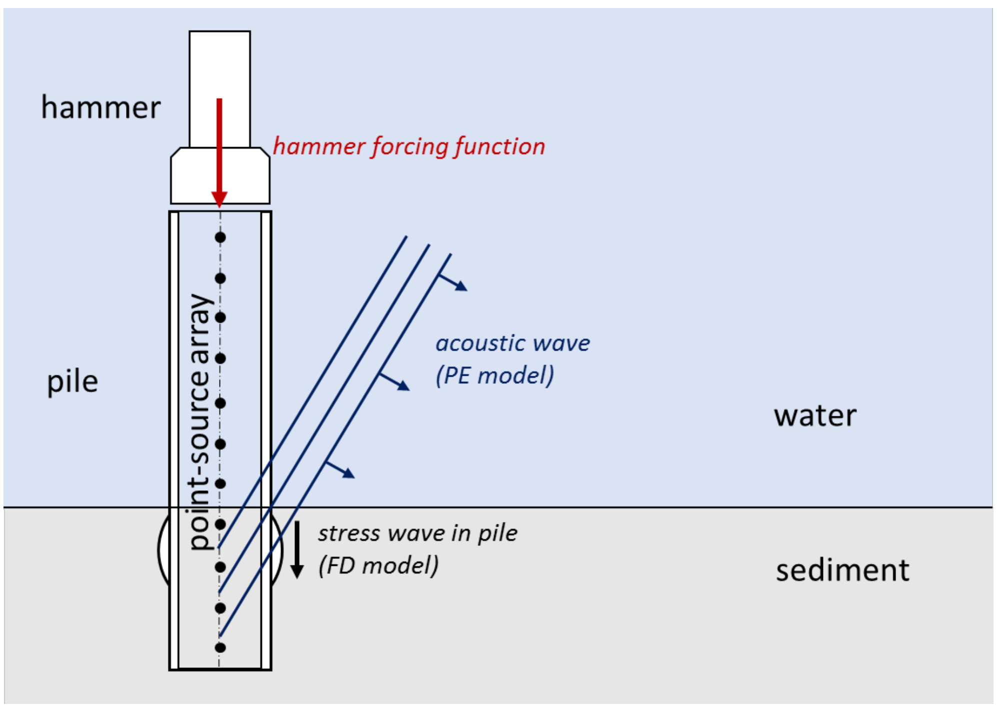

Figure 6. Physical model geometry for impact driving of a cylindrical pile (vertical cross-section). The hammer forcing function is used with the finite difference (FD) model to compute the stress wave vibration in the pile. A vertical array of point sources is used with the parabolic equation (PE) model 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:

$$\mathrm{SEL}_{24h} = \mathrm{SEL} + 10\log_{10}\left(N\right) . \tag{2}$$

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.

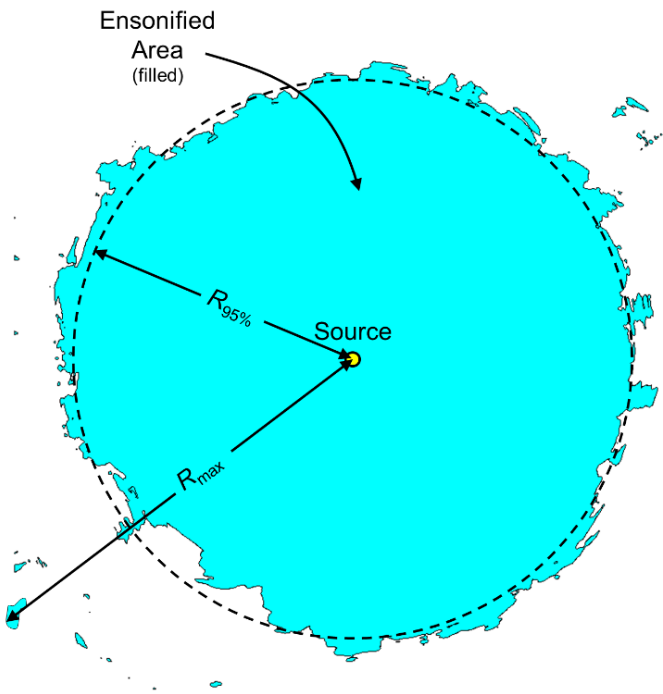

Figure 7. Example of an area ensonified to an arbitrary sound level showing R_{max} and $R_{95\%}$ radii.

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:

$$Z_s = D - 0.85 \times \phi_{prop} \quad (3)$$

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 $\varnothing_{prop}$ 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 Supply vessel Support vessel	*Hannah Chouest*	85	18	6	7200	n/a	Unknown	Unknown, assumed 3.2								
Light construction vessel Field intervention vessel	MEO *Ranger*	64	16	5.4	5000	n/a	2 x tunnel thrusters, 2 x Z-drive propeller	2.7								
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.

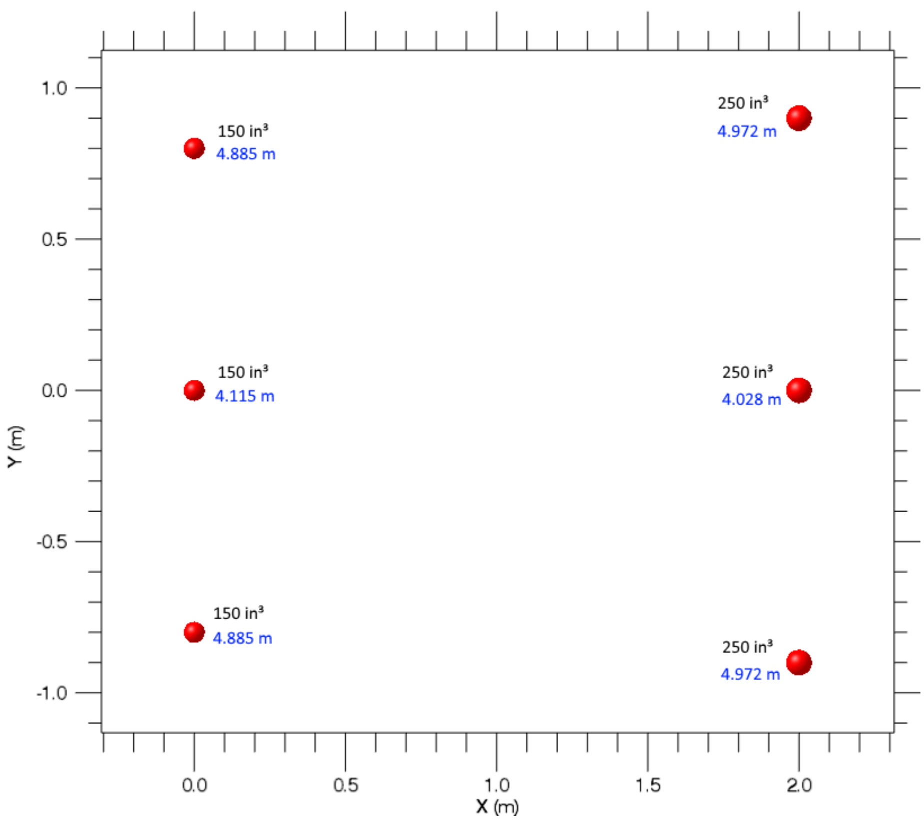

Figure 8. Layout of the High-performance Magnum six-gun array (1200 in^3 total volume, 4.5 m depth), composed of 6 elements. Black labels indicate element volume in cubic inches; blue labels indicate the depth of the element relative to the sea surface.

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):

$$\begin{aligned} c(z,T,S,\phi) &= 1449.05 + 45.7t - 5.21t^2 - 0.23t^3 \\ &\quad + \left(1.333 - 0.126t + 0.009t^2\right)\left(S - 35\right) + \Delta \\ \Delta &= 16.3Z + 0.18Z^2\,, \quad Z = \frac{z}{1000}\left[1 - 0.0026\cos\left(2\phi\right)\right], \quad t = \frac{T}{10} \end{aligned} \tag{4}$$

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.

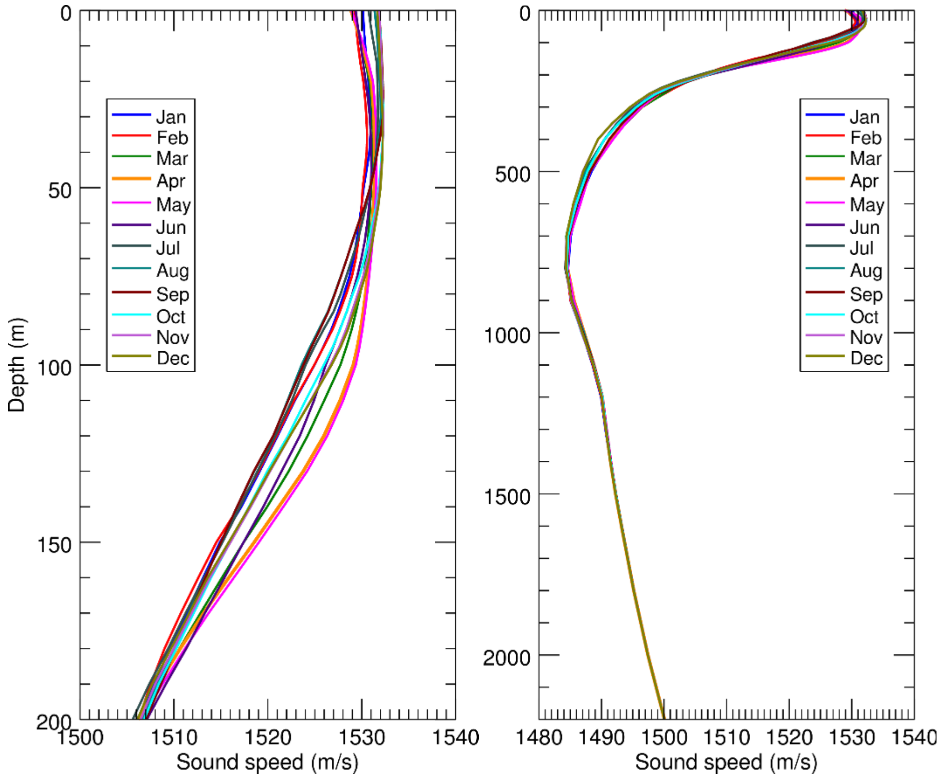

Figure 9. Mean monthly sound speed profiles (left: top 200 m; right: entire water column) at the FPSO location (08° 00' 39.53" N, 056° 59' 27.31" W) derived from data obtained from *GDEM V 3.0* (Teague et al. 1990, Carnes 2009).

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.

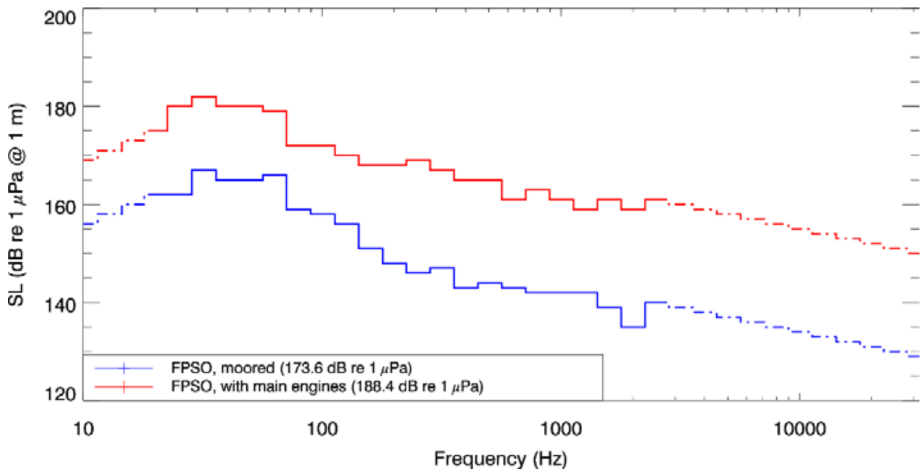

Figure 10. Estimated source level spectra for the FPSO. Dashed lines represent extrapolated levels based on Ross' spectrum (Ross 1976).

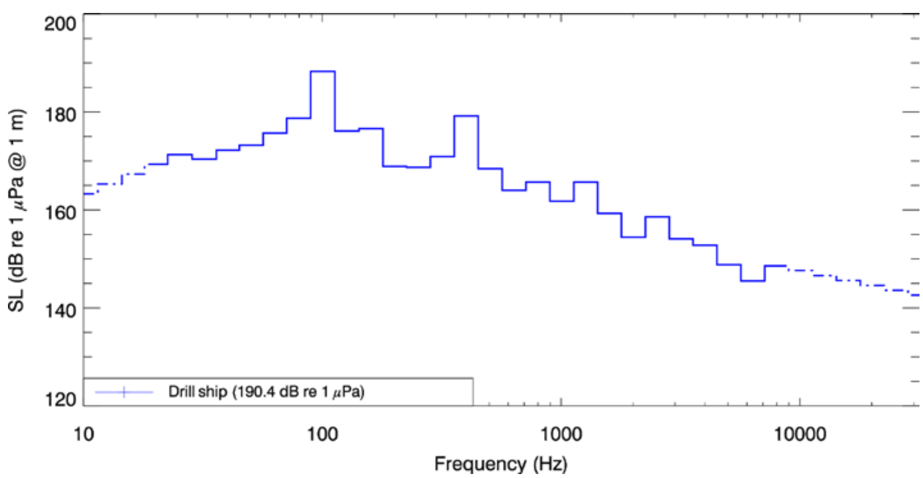

Figure 11. Estimated source level spectrum for the drill ship. Dashed lines represent extrapolated levels based on Ross' spectrum (Ross 1976).

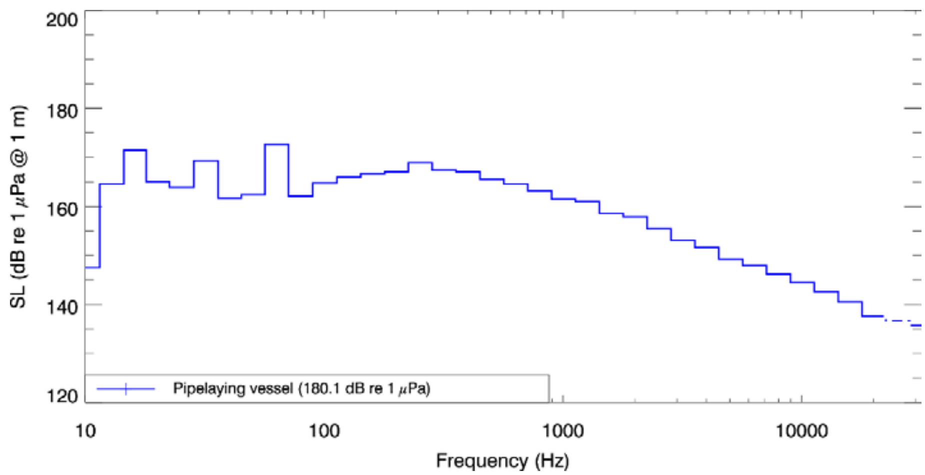

Figure 12. Estimated source level spectrum for the pipelaying vessel. Dashed lines represent extrapolated levels based on Ross' spectrum (Ross 1976).

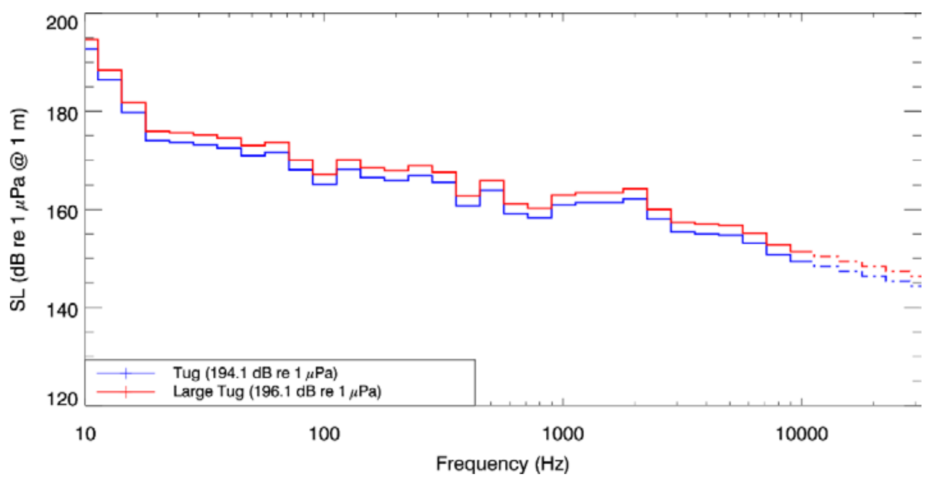

Figure 13. Estimated source level spectra for the tugs. Dashed lines represent extrapolated levels based on Ross' spectrum (Ross 1976).

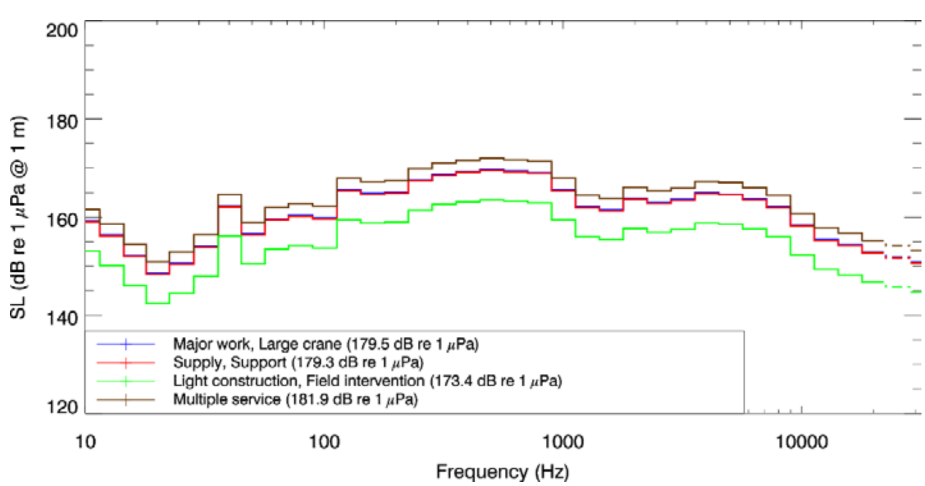

Figure 14. Estimated source level spectra for the various support vessels. Dashed lines represent extrapolated levels based on Ross' spectrum (Ross 1976).

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.

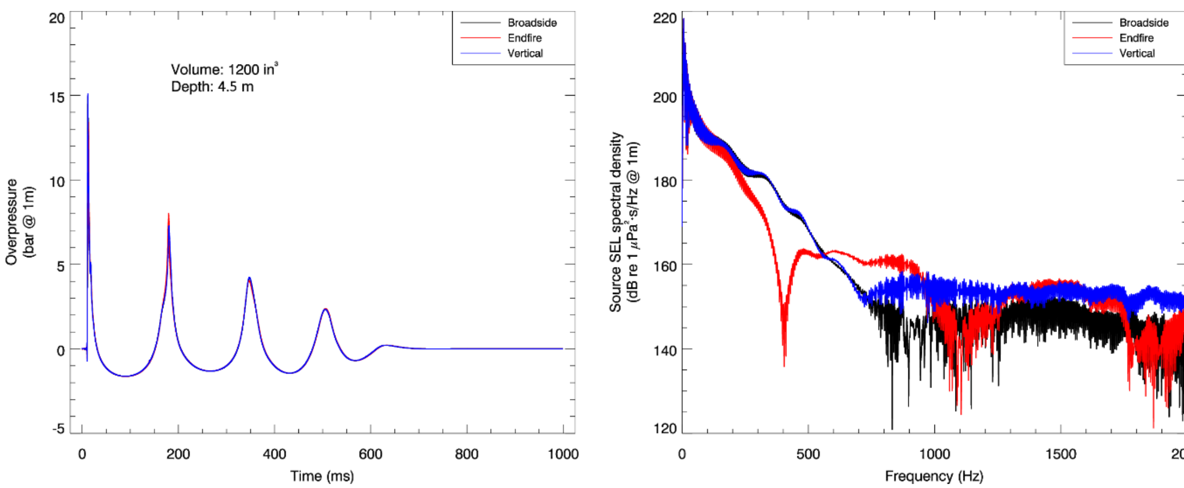

Figure 15. Predicted source level details for the 1200 in^3 array. (a) The overpressure signature and (b) the power spectrum in the broadside (perpendicular to tow direction), endfire (directly aft of the array), and downward (vertical) directions.

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 µPa^2·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

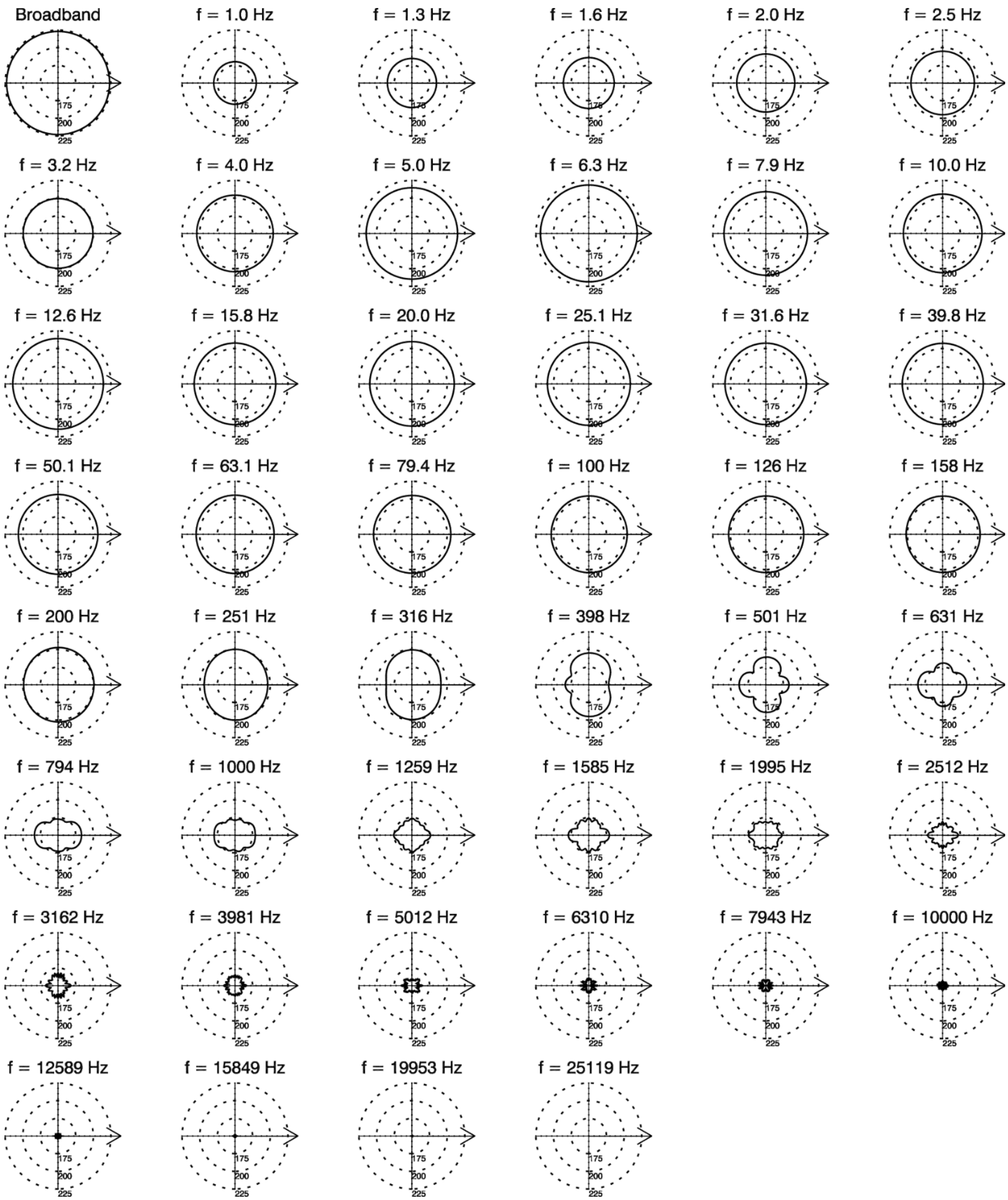

Figure 16. Directionality of the predicted horizontal source levels for the 1200 in^3 array, 10–25,000 Hz.Source levels (in dB re 1 µPa^2·s) are shown as a function of azimuth for the center frequencies of the 1/3-octave-bands modeled; frequencies are shown above the plots. Tow direction is to the right 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.

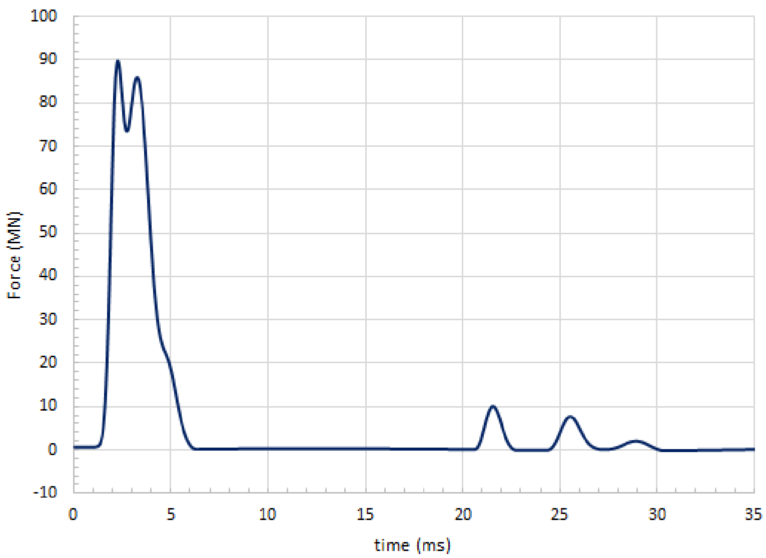

Figure 17. Force at the top of a pile during impact driving of a 25-m long, 5-m wide cylindrical steel pile with the MENCK 500T (underwater) hammer.

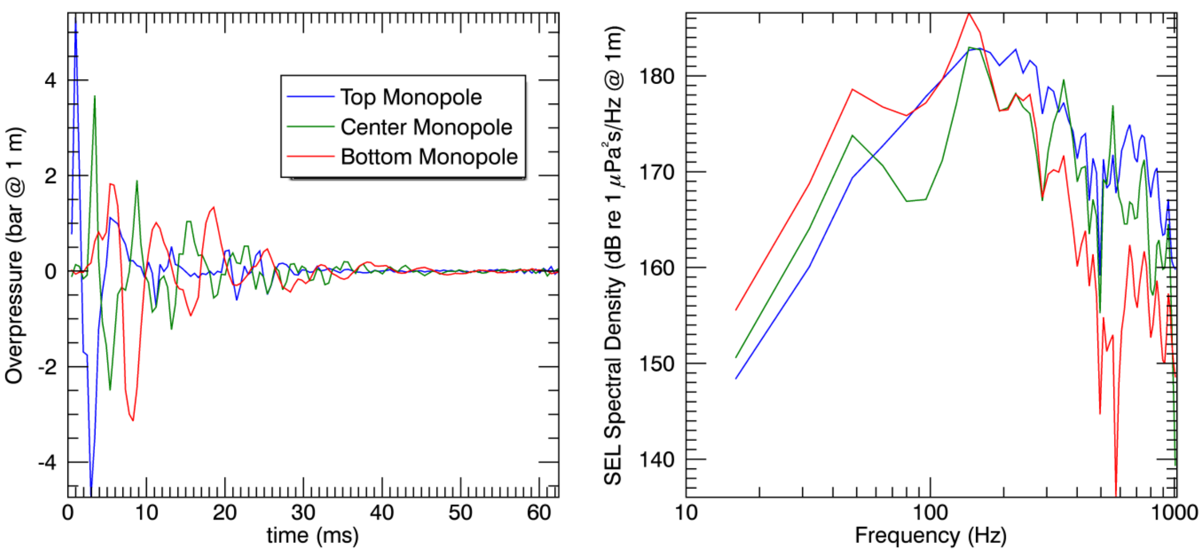

Figure 18. Predicted overpressure signature of three monopoles along the modeled pile: top (in water), center (in water), and bottom (in substrate).

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	-	-

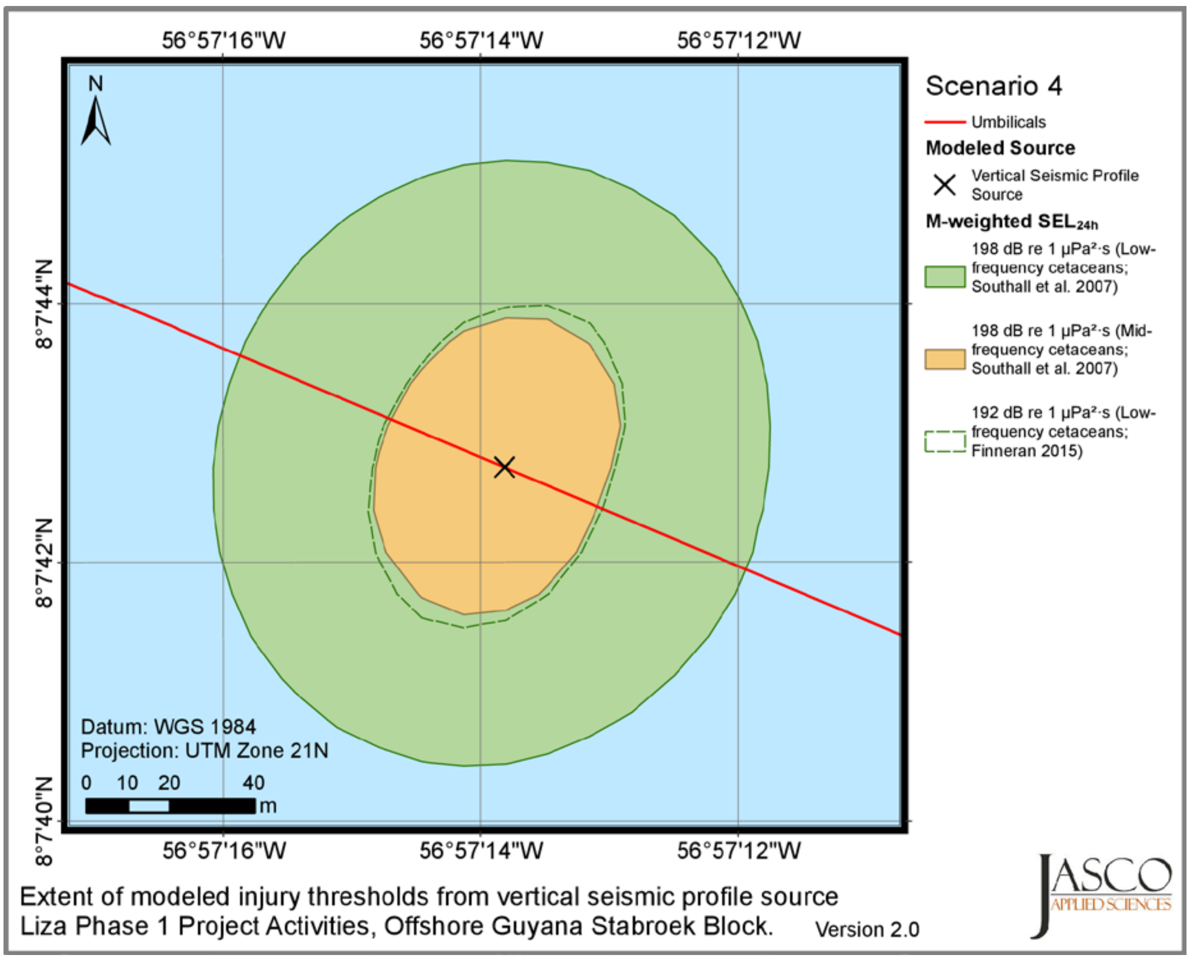

Figure 19. Scenario 4: Sound level contour map showing the extend of the maximum-over-depth M-weighted SEL_{24h} from the VSP source for marine mammal injury thresholds based on Southall et al. (2007) and Finneran (2015).

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

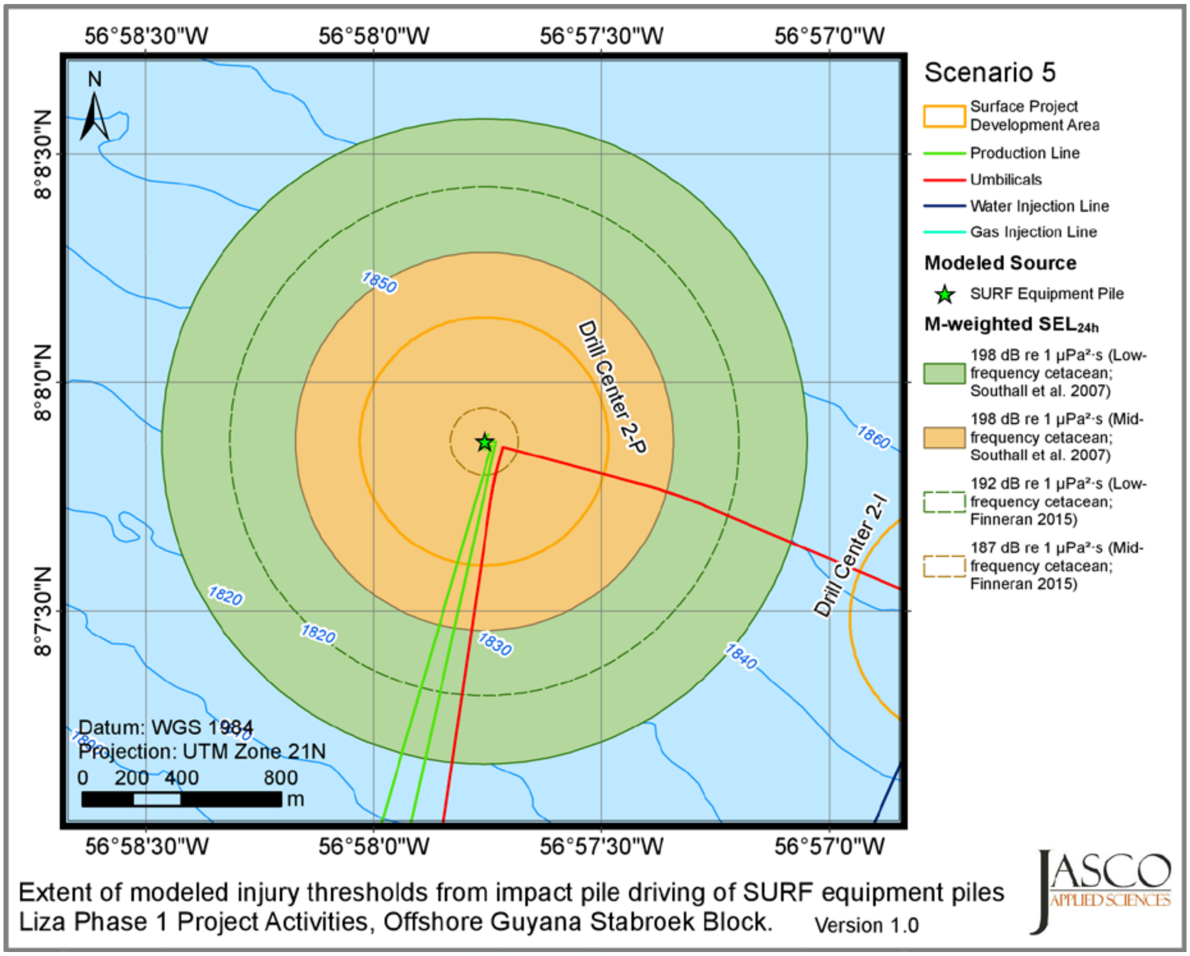

Figure 20. Scenario 5: Sound level contour map showing the extend of the maximum-over-depth M-weighted SEL_{24h} from impact pile driving for marine mammal injury thresholds based on Southall et al. (2007) and Finneran (2015).

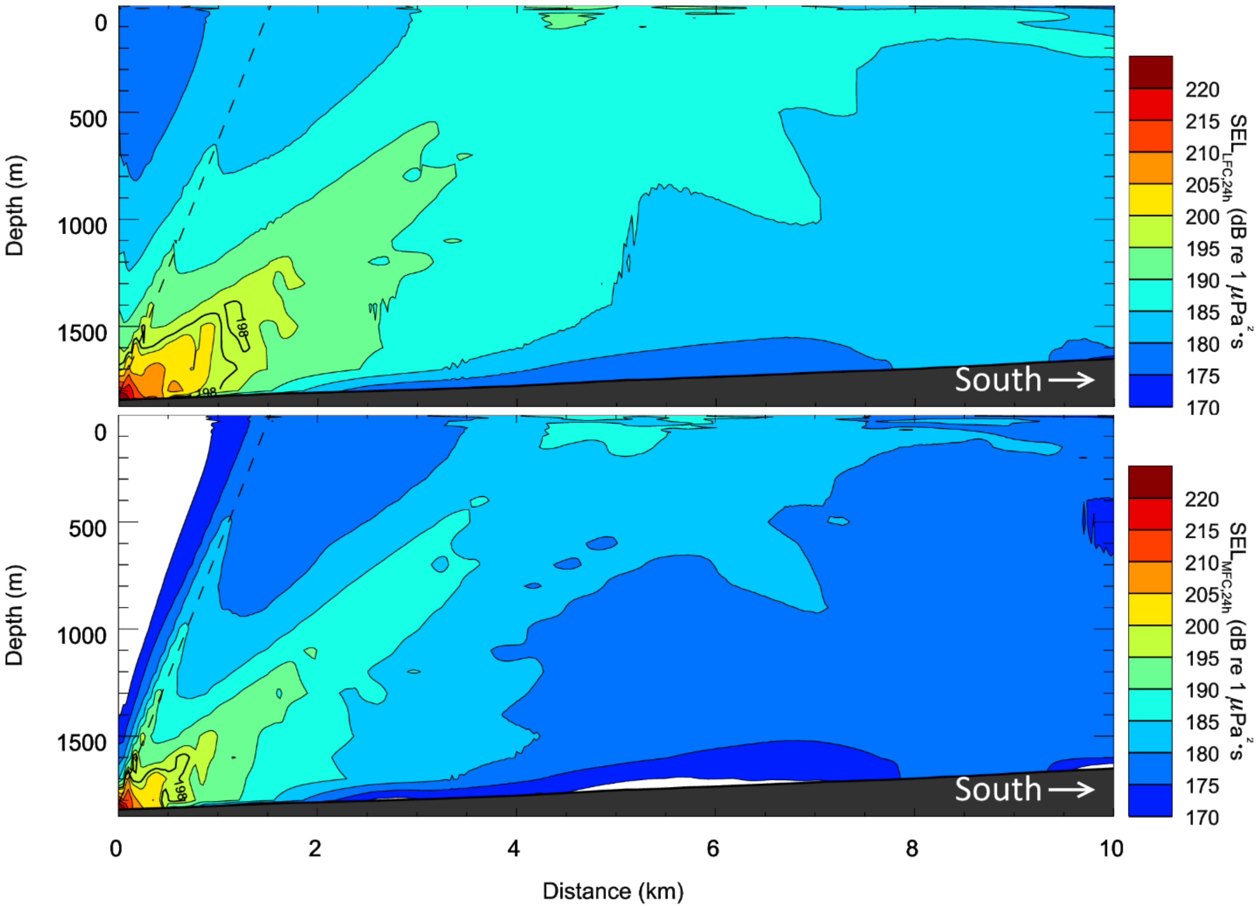

Figure 21. Scenario 5: Estimated M-weighted SEL_{24h} based on Southall et al. (2007), propagating south of the pile at Drill Center 2-P. The thicker black lines indicate sound level isopleths corresponding to the injury thresholds for (top) low- and (bottom) mid-frequency cetaceans. The dash line indicates 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.

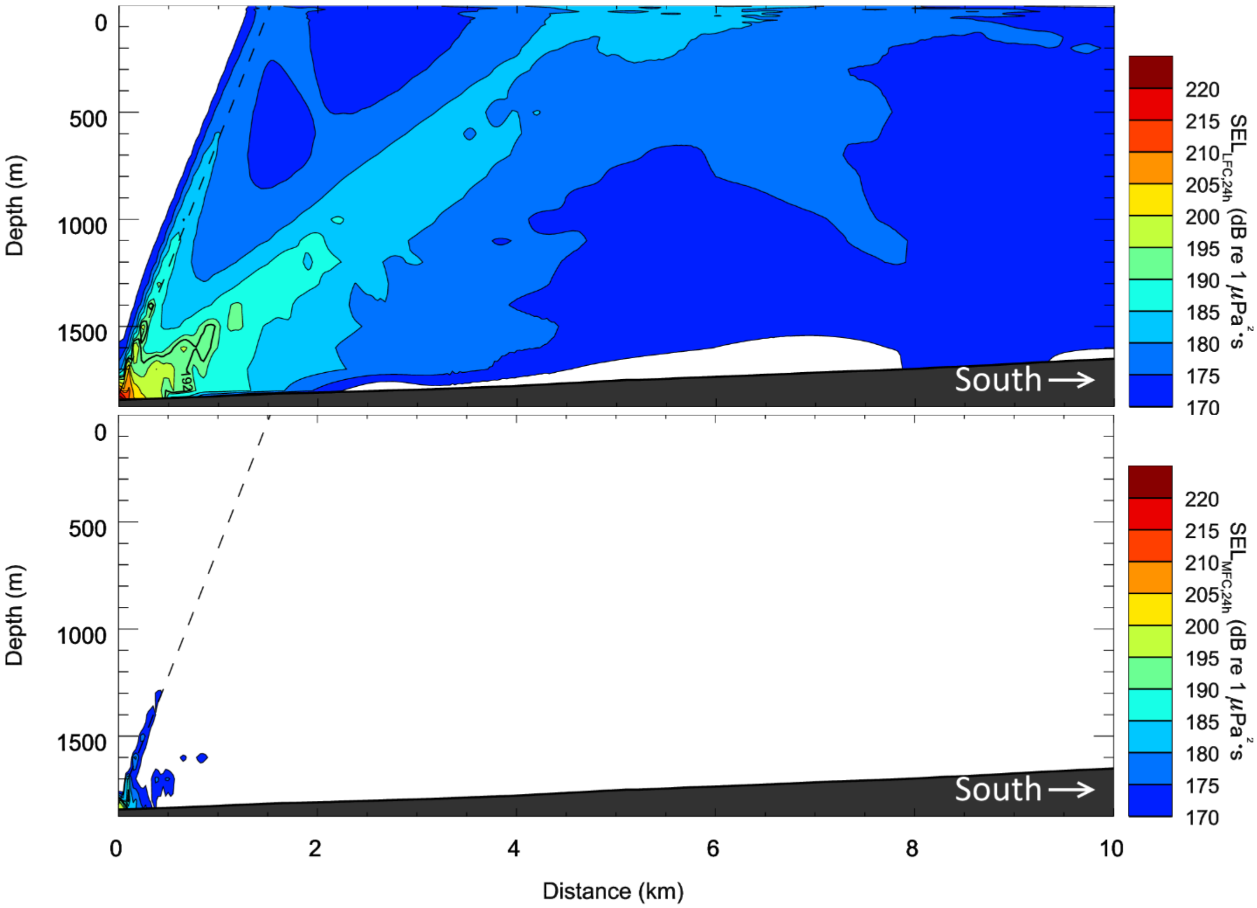

Figure 22. Scenario 5: Estimated M-weighted SEL_{24h} based on Finneran (2015), propagating south of the pile at Drill Center 2-P. The thicker black lines indicate sound level isopleths corresponding to the injury thresholds for (top) low- and (bottom) mid-frequency cetaceans. The dash line indicates 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

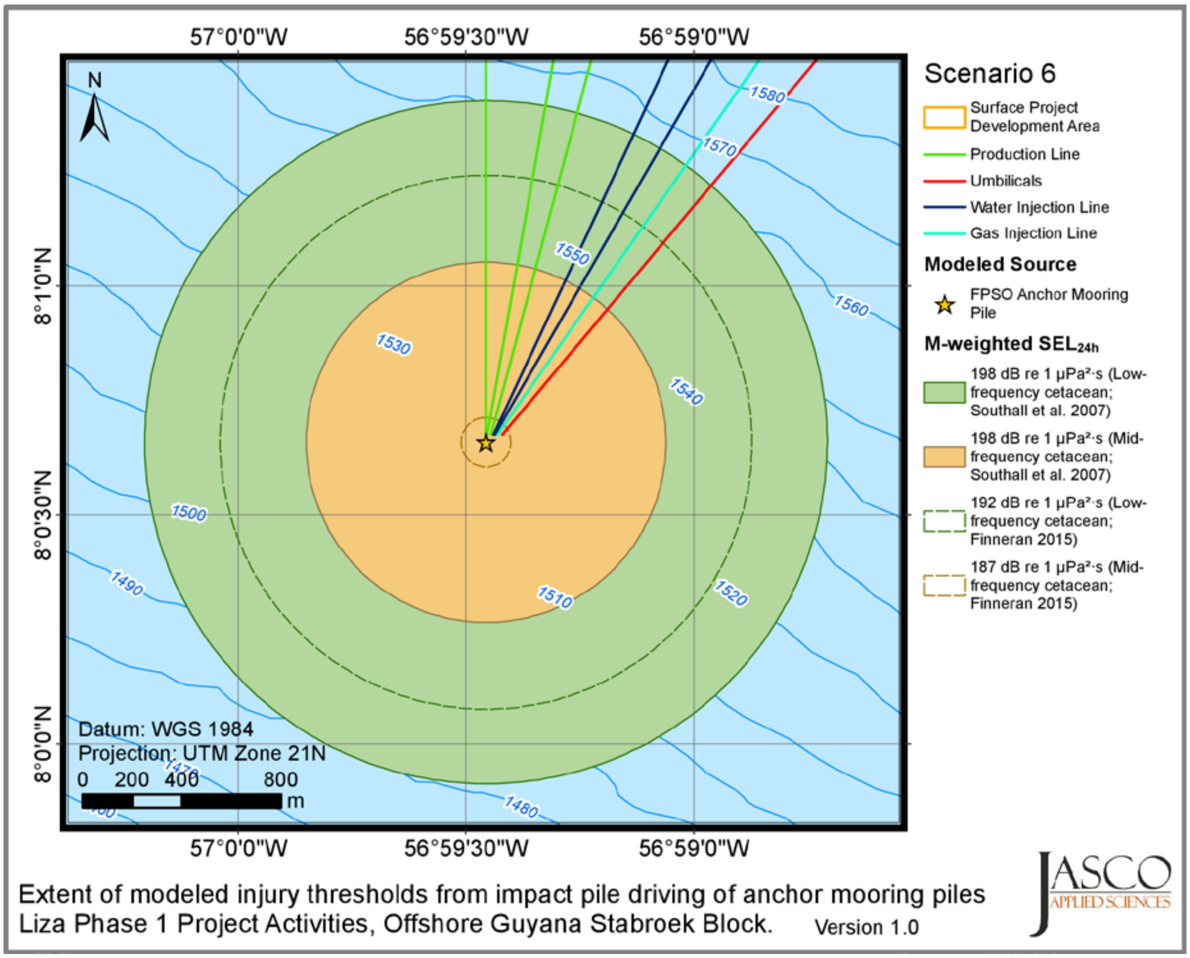

Figure 23. Scenario 6: Sound level contour map showing the extend of the maximum-over-depth M-weighted SEL_{24h} from impact pile driving for marine mammal injury thresholds based on Southall et al. (2007) and Finneran (2015).

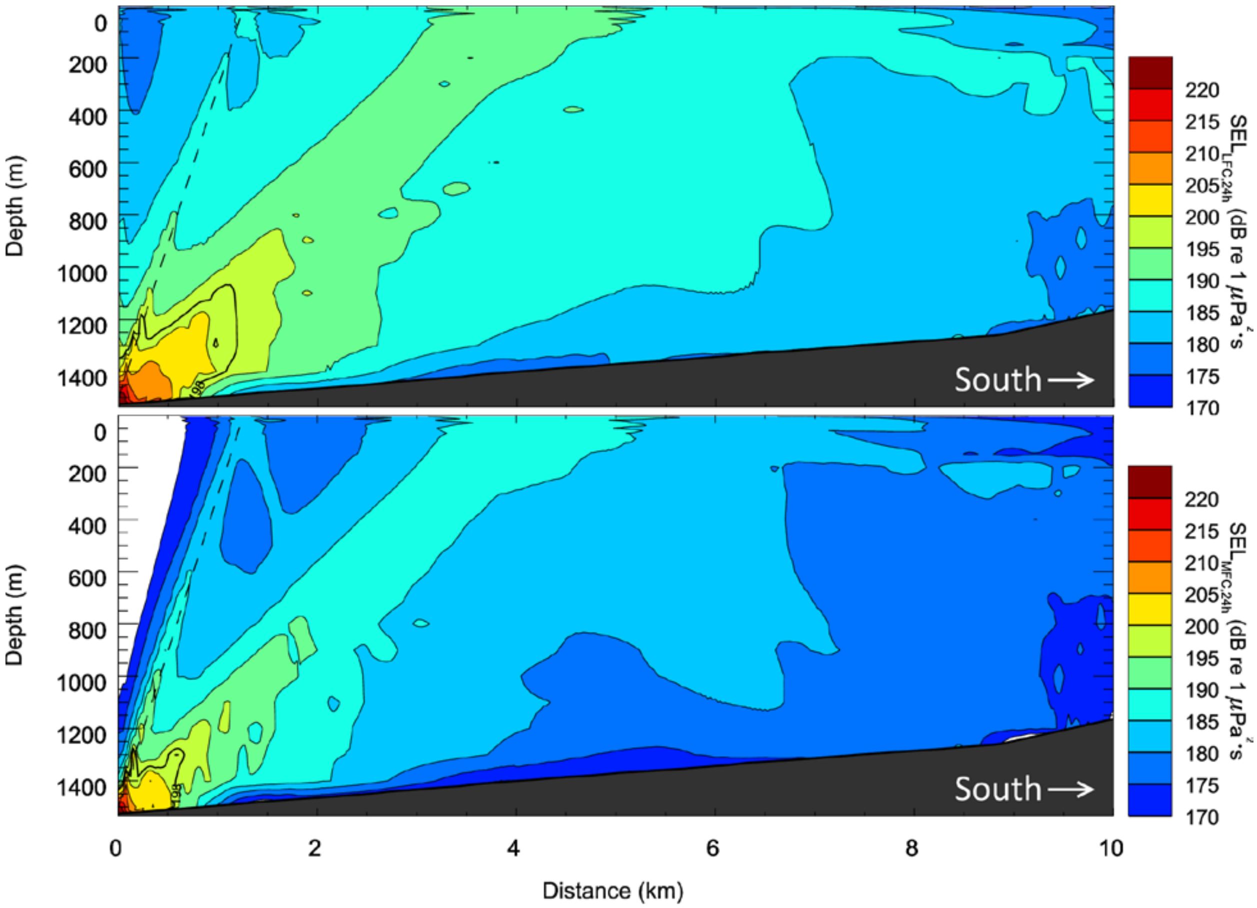

Figure 24. Scenario 6: Estimated M-weighted SEL_{24h} based on Southall et al. (2007), propagating south of the FPSO anchor mooring piles. The thicker black lines indicate sound level isopleths corresponding to the injury thresholds for (top) low- and (bottom) mid-frequency cetaceans. The dash line indicates 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.

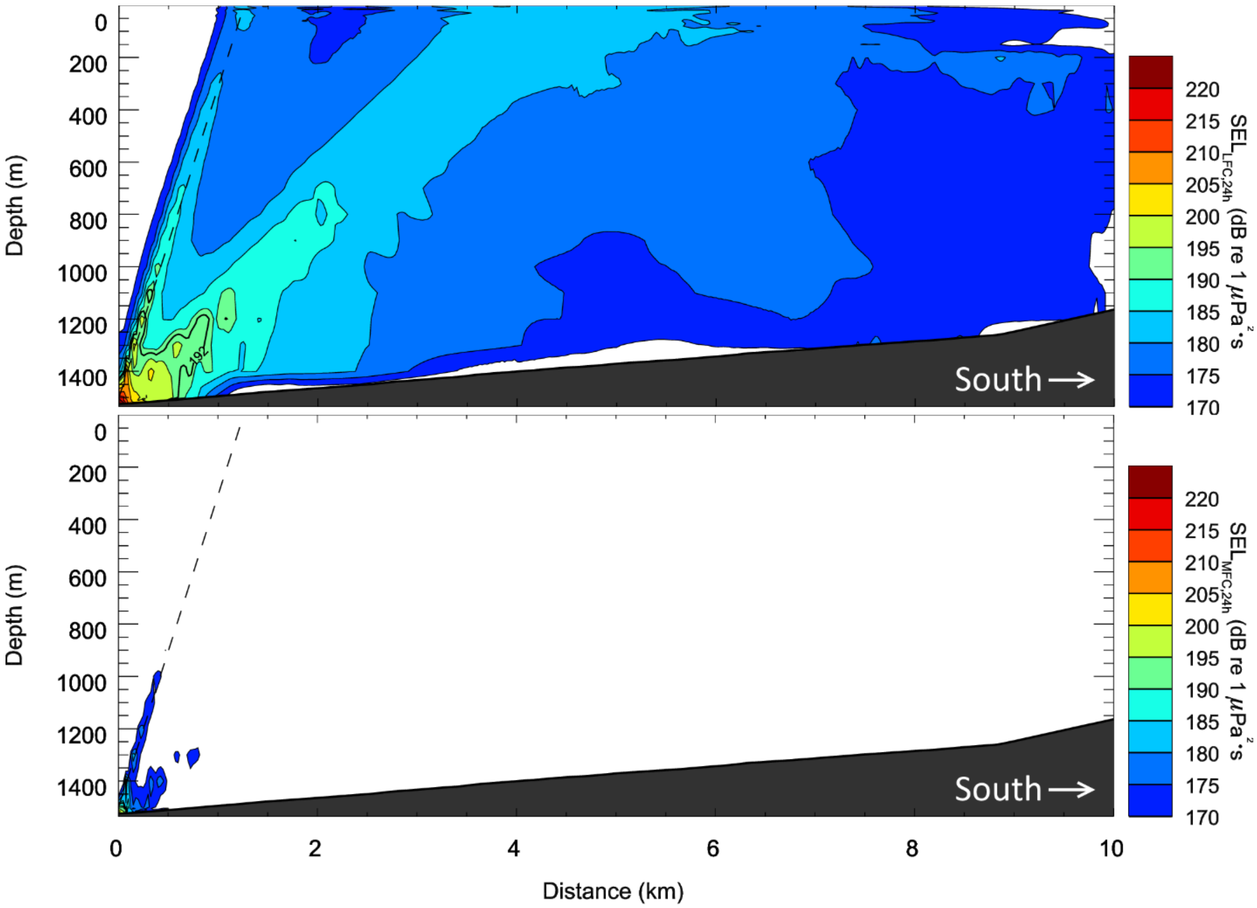

Figure 25. Scenario 6: Estimated M-weighted SEL_{24h} based on Finneran (2015), propagating south of the FPSO anchor mooring piles. The thicker black lines indicate sound level isopleths corresponding to the injury thresholds for (top) low- and (bottom) mid-frequency cetaceans. The dash line indicates 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 $\mu Pa^2 \cdot s$ @ 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 µPa^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·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 µPa^2·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.

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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:

$$f_c(i) = 10^{i/10} , \quad \text{(A-5)}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith 1/3-octave-band are defined as:

$$f_{lo} = 10^{-1/20} f_c(i) \text{ and } f_{hi} = 10^{1/20} f_c(i) . \quad \text{(A-6)}$$

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).

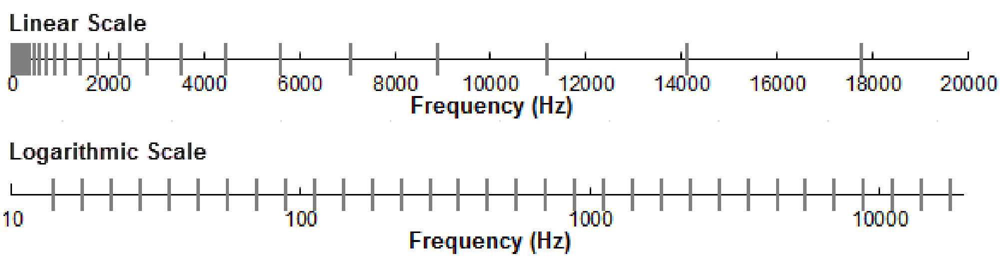

Figure A-1. One-third-octave-bands shown on a linear frequency scale and on a logarithmic scale.

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}:

$$L_b^{(i)} = 10\log_{10}\left(\int_{f_{lo}}^{f_{hi}} S(f)df\right) . \quad \text{(A-7)}$$

Summing the sound pressure level of all the 1/3-octave-bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10\log_{10}\sum_i 10^{L_b^{(i)}/10} . \quad \text{(A-8)}$$

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.

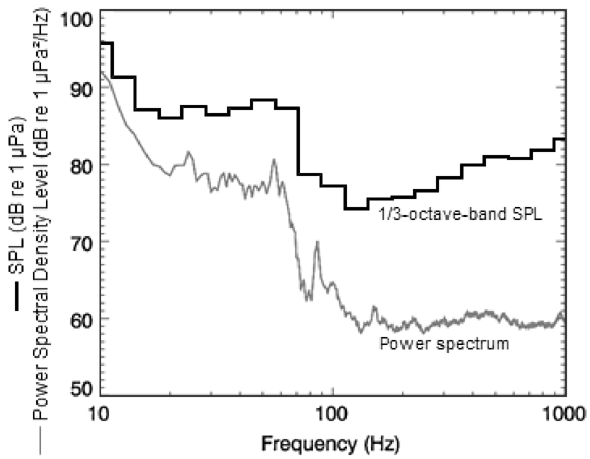

Figure A-2. A power spectrum and the corresponding 1/3-octave-band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

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:

$$G(f) = -20\log_{10}\left[\left(1+\frac{a^2}{f^2}\right)\left(1+\frac{f^2}{b^2}\right)\right] \tag{A-9}$$

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

[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.

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.

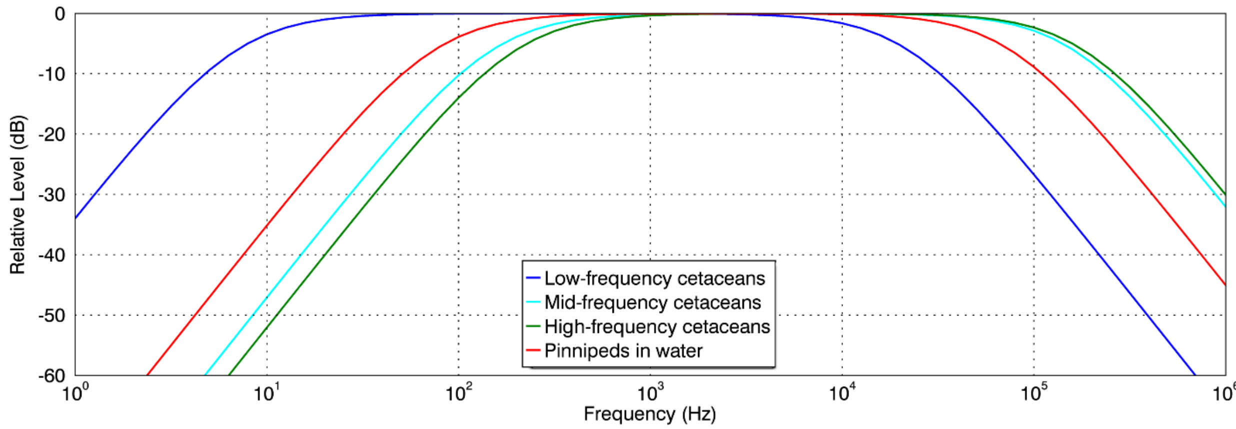

Figure A-3. Auditory weighting functions for functional marine mammal hearing groups as recommended by Southall et al. (2007).

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

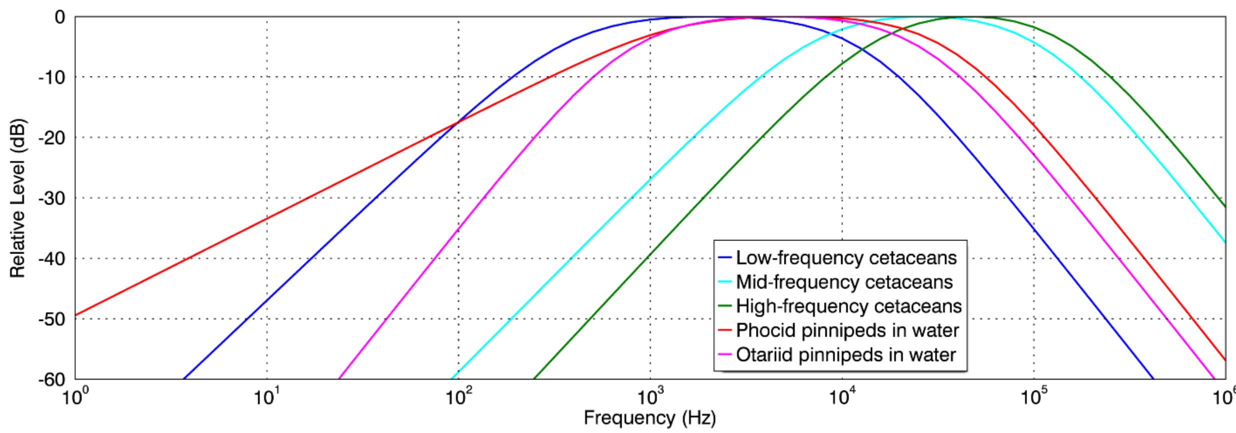

Figure A-4. Auditory weighting functions for functional marine mammal hearing groups as recommended by Finneran (2015).

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).

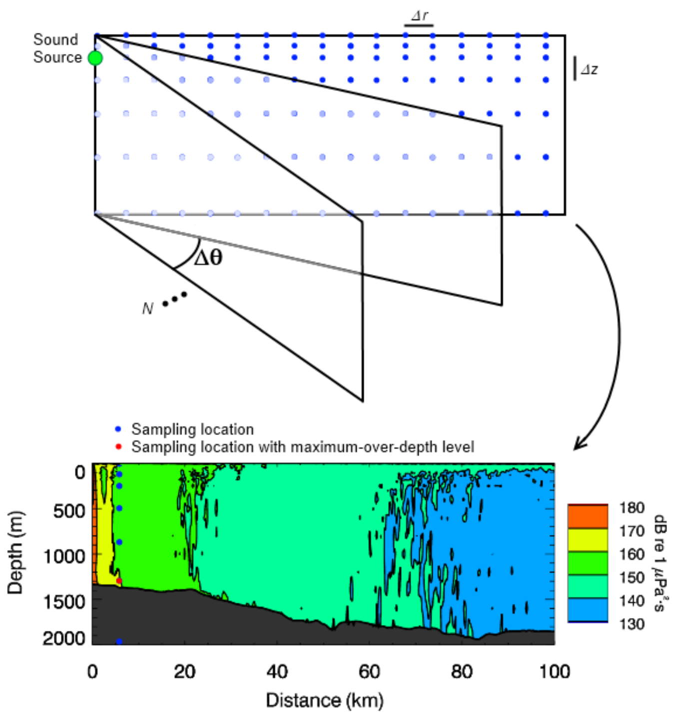

Figure A-5. The N×2-D and maximum-over-depth modeling approach used by MONM.

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).

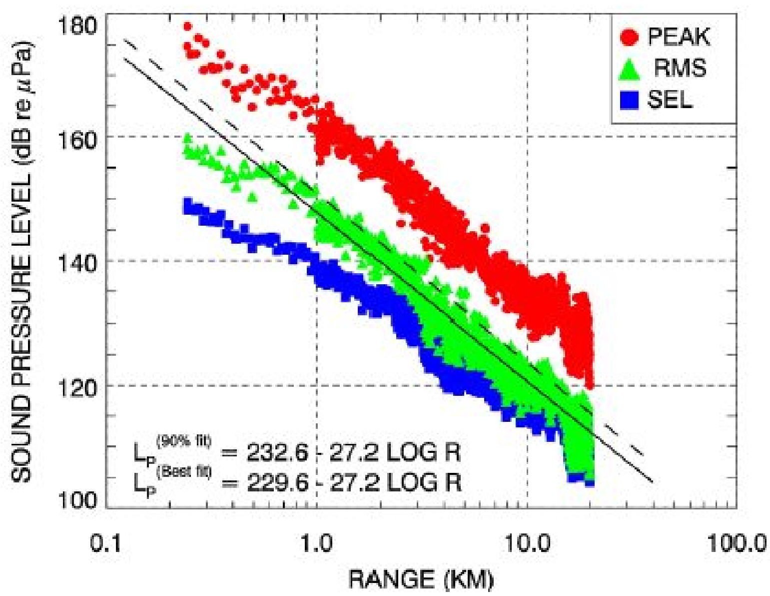

Figure A-6. Peak and SPL and per-pulse SEL versus range from a 20 in^3 air gun array. Solid line is the least squares best fit to SPL. Dashed line is the best fit line increased by 3.0 dB to exceed 90% of all SPL values (90th percentile fit) (Ireland et al. 2009, Figure 10).

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.