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APPENDIX A

EIS Guidelines

Canadian Environmental Assessment Agency
Agence canadienne d'évaluation environnementale

GUIDELINES FOR THE PREPARATION OF AN ENVIRONMENTAL IMPACT STATEMENT

pursuant to the

Canadian Environmental Assessment Act, 2012

For the

BHP Canada Exploration Drilling Project

BHP Petroleum (New Ventures) Corporation

June 28, 2019

Canada

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DISCLAIMER

This document is not a legal authority, nor does it provide legal advice or direction; it provides information only, and must not be used as a substitute for the *Canadian Environmental Assessment Act, 2012* (CEAA 2012) or its regulations. In the event of a discrepancy, CEAA 2012 and its regulations prevail. Portions of CEAA 2012 have been paraphrased in this document, but will not be relied upon for legal purposes.

Abbreviations and Short Forms

CEAA 2012	*Canadian Environmental Assessment Act*, *2012*
Agency	Canadian Environmental Assessment Agency
EA	environmental assessment
EIS	environmental impact statement
VC	valued component

Part 1 - Key Considerations

1. INTRODUCTION

The purpose of this document is to identify for the proponent the minimum information requirements for the preparation of an Environmental Impact Statement (EIS) for a designated project[1] to be assessed pursuant to the *Canadian Environmental Assessment Act, 2012* (CEAA 2012). This document specifies the nature, scope and extent of the information required. Part 1 of this document defines the scope of the environmental assessment (EA) and provides guidance and general instruction that must be taken into account in preparing the EIS. Part 2 outlines the information that must be included in the EIS.

Section 5 of CEAA 2012 describes the environmental effects that must be considered in an EA, including changes to the environment and effects of changes to the environment. The factors that are to be considered in an EA are described under section 19 of CEAA 2012. The Canadian Environmental Assessment Agency (the Agency) will use the proponent's EIS and other information received during the EA process to prepare a report that will inform the issuance of a decision statement by the Minister of Environment and Climate Change. Therefore the EIS must include a full description of the changes the project will cause to the environment that may result in adverse effects on areas of federal jurisdiction (i.e. section 5 of CEAA 2012) including changes that are directly linked or necessarily incidental to any federal decisions that would permit the project to be carried out. The EIS must also include a list of the mitigation measures that the proponent proposes to undertake in order to avoid or minimize any adverse environmental effects of the project. It is the responsibility of the proponent to provide sufficient data and analysis on potential changes to the environment to ensure a thorough evaluation of the environmental effects of the project by the Agency.

2. GUIDING PRINCIPLES

2.1. Environmental assessment as a planning and decision making tool

EA is a process to predict environmental effects of proposed projects before they are carried out. An EA:

- identifies potential adverse environmental effects;
- proposes measures to mitigate adverse environmental effects;
- predicts whether there will be significant adverse environmental effects, after mitigation measures are implemented; and
- includes a follow-up program to verify the accuracy of the EA and the effectiveness of the mitigation measures.

2.2. Public participation

One of the purposes identified in CEAA 2012 is to ensure that opportunities are provided for meaningful public participation during an EA. CEAA 2012 requires that the Agency provide the public

1 In this document, "project" has the same meaning as "designated project" as defined in CEAA 2012.

with an opportunity to participate in the EA. For EAs led by the Agency the public has an opportunity to comment on the draft EA report. Additional opportunities for participation may also be provided.

Meaningful public participation is best achieved when all parties have a clear understanding of the proposed project as early as possible in the review process. The proponent is required to provide current information about the project to the public and especially to the communities likely to be most affected by the project.

2.3. Engagement with Indigenous groups

The proponent is expected to engage with potentially affected Indigenous groups starting as early as possible in the project planning process in order to:

- Fulfil the statutory obligations of CEAA, 2012 to assess environmental effects of the proposed Project on Aboriginal peoples; and
- Assist the Agency fulfilling the Crown's constitutional obligations to consult with potentially impacted Indigenous groups on potential impacts to potential or established Aboriginal or Treaty rights.

The proponent is expected to work with potentially affected Indigenous groups to establish an engagement approach. The proponent will make reasonable efforts to integrate Indigenous knowledge into the assessment of environmental effects. For more information on requirements for the effects assessment, see Part 2, Section 7.1.8 and Section 7.3.7 of these guidelines. For more information on incorporating Indigenous knowledge, refer to Part 1, Section 4.2.2 of these guidelines.

2.4. Application of the precautionary approach

In documenting the analyses included in the EIS, the proponent will demonstrate that all aspects of the project have been examined and planned in a careful and precautionary manner in order to avoid significant adverse environmental effects.

3. SCOPE OF THE ENVIRONMENTAL ASSESSMENT

3.1. Designated project

On May 9, 2019, BHP Petroleum (New Ventures) Corporation, the proponent of the BHP Canada Exploration Drilling Project provided a project description to the Agency. Based on this project description, the Agency has determined that an EA is required under CEAA 2012 and will include the following project components and activities:

- the mobilization, operation and demobilization of Mobile Offshore Drilling Unit(s) designed for year-round operations for the drilling, testing and abandonment of up to 20 wells in Exploration Licences 1157 and 1158 operated by BHP Petroleum (New Ventures) Corporation, including consideration of any proposed safety exclusion zones. Drilling may occur in various water depths under consideration, using Mobile Offshore Drilling Unit(s), and with multiple drilling units operating simultaneously, if applicable;
- vertical seismic profiling or any other in-water works (e.g. wellsite surveys) to support the specific exploration wells under consideration, but excluding surveys potentially required to

support the conduct of the EA (e.g. environmental baseline surveys) and surveys related to the broader delineation of resources;

- well evaluation and testing; and
- the loading, refuelling and operation of marine support vessels (i.e. for re-supply and transfer of materials, fuel, and equipment; on-site safety during drilling operations; and transport between the supply base and the drilling unit(s) and helicopter support (i.e. for crew transport and delivery of light supplies and equipment) including transportation to the drilling unit(s).

Note: If the proponent acquires and becomes the operator of new or additional exploration licences issued by the Canada-Newfoundland and Labrador Offshore Petroleum Board and submits corresponding information to the Agency prior to the submission of the EIS, the Agency will consider whether activities on these additional licences may be incorporated into the scope of this EA.

3.2. Factors to be considered

Scoping establishes the parameters of the EA and focuses the assessment on relevant issues and concerns. Part 2 of this document specifies the factors to be considered in the EA, including the factors listed in subsection 19(1) of CEAA 2012:

- environmental effects of the project, including the environmental effects of malfunctions or accidents that may occur in connection with the project and any cumulative environmental effects that are likely to result from the project in combination with other physical activities that have been or will be carried out;
- the significance of the effects referred to above;
- comments from the public;
- mitigation measures that are technically and economically feasible and that would mitigate any significant adverse environmental effects of the project;
- the requirements of the follow-up program in respect of the project;
- the purpose of the project;
- alternative means of carrying out the project that are technically and economically feasible and the environmental effects of any such alternative means;
- any change to the project that may be caused by the environment; and
- the results of any relevant regional study pursuant to CEAA 2012.

3.2.1. Changes to the environment

Environmental effects occur as interactions between actions (the carrying out of the project or decisions made by the federal government in relation to the project) and receptors in the environment, and subsequently between components of the environment (e.g. change in water quality that may affect fish).

Under CEAA 2012, an examination of environmental effects that result from changes to the environment as a result of the project being carried out or as a result of the federal government exercising any power duty or function that would allow the project to be carried out must be considered in the EIS.

In scoping the potential changes to the environment that may occur, the proponent should consider any potential changes in the physical environment such as changes to air quality, water quality and quantity, and physical disturbance of land that could reasonably be expected to occur.

3.2.2. Valued components to be examined

Valued components (VCs) refer to environmental biophysical or human features that may be impacted by a project. The value of a component not only relates to its role in the ecosystem, but also to the value people place on it. For example, it may have been identified as having scientific, social, cultural, economic, historical, archaeological or aesthetic importance.

The proponent must conduct and focus its analysis on VCs as they relate to **section 5 of CEAA 2012,** including the ones identified in Section 7.3 (Part 2) of these guidelines that may be affected by changes in the environment, as well as species at risk and their critical habitat as per the requirement outlined in section 79 of the *Species at Risk Act*. Section 5 of CEAA 2012 defines environmental effects as:

- a change that may be caused to fish and fish habitat, marine plants and migratory birds;
- a change that may be caused to the environment on federal lands, in another province or outside Canada;
- with respect to aboriginal peoples, an effect of any change that may be caused to the environment on:
  - ✓ health and socio-economic conditions;
  - ✓ physical and cultural heritage;
  - ✓ the current use of lands and resources for traditional purposes; or
  - ✓ any structure, site or thing that is of historical, archaeological, paleontological or architectural significance.
- for projects requiring a federal authority to exercise a power or perform a duty or function under another Act of Parliament:
  - ✓ a change, other than the ones mentioned above, that may be caused to the environment and that is directly linked or necessarily incidental to the exercise of the federal power or the performance of a duty or function; and
  - ✓ the effect of that change, other than the effects mentioned above, on:
    - o health and socio-economic conditions,
    - o physical and cultural heritage, or
    - o any structure, site or thing that is of historical, archaeological, paleontological or architectural significance.

The list of VCs presented in the EIS will be completed according to the evolution and design of the project and reflect the knowledge acquired through public consultation and engagement with Indigenous groups. The EIS will describe what methods were used to predict and assess the adverse environmental effects of the project on these VCs.

The VCs will be described in sufficient detail to allow the reviewer to understand their importance and to assess the potential for environmental effects arising from the project activities. The EIS will provide a rationale for selecting specific VCs and for excluding any VCs or information specified in these guidelines. Challenges may arise regarding particular exclusions, so it is important to document the

information and the criteria used to justify the exclusion of a particular VC or piece of information. Justification may be based on, for example, primary data collection, computer modelling, literature references, public participation or engagement with Indigenous groups, or expert input or professional judgement. The EIS will identify those VCs, processes, and interactions that either were identified to be of concern during any workshops or meetings held by the proponent or that the proponent considers likely to be affected by the project. In doing so, the EIS will indicate to whom these concerns are important (i.e. the public or Indigenous groups) and the reasons why, including environmental, cultural, historical, social, economic, recreational, and aesthetic considerations, and traditional knowledge. If comments are received on a component that has not been included as a VC, these comments will be summarized and the rationale for excluding the component will address the comments.

3.2.3. Spatial and temporal boundaries

The spatial and temporal boundaries used in the EA may vary depending on the VC and will be considered separately for each VC, including for VCs related to the current use of lands and resources for traditional purposes by Aboriginal peoples, or other environmental effects referred to under paragraph 5(1)(*c*) of CEAA 2012. The proponent is encouraged to consult with the Agency, federal and provincial government departments and agencies, local government and Indigenous groups, and take into account public comments when defining the spatial and temporal boundaries used in the EIS.

The EIS will describe the spatial boundaries, including local and regional study areas, of each VC to be used in assessing the potential adverse environmental effects of the project and provide a rationale for each boundary. Spatial boundaries will be defined taking into account the appropriate scale and spatial extent of potential environmental effects, community knowledge and Aboriginal traditional knowledge, current or traditional land and resource use by Indigenous groups, ecological, technical, social and cultural considerations.

The temporal boundaries of the EA will span all phases of the project determined to be within the scope of this EA as specified under section 3.1 above. If effects are predicted after project decommissioning, this should be taken into consideration in defining boundaries. Community knowledge and Aboriginal traditional knowledge should factor into decisions around defining temporal boundaries.

If the temporal boundaries do not span all phases of the project, the EIS will identify the boundaries used and provide a rationale.

4. PREPARATION AND PRESENTATION OF THE ENVIRONMENTAL IMPACT STATEMENT

4.1. Guidance

The proponent should consult the Agency policy and guidance on topics to be addressed in the EIS, which is available on the Agency's website, and liaise with the Agency during the planning and development of the EIS. The proponent should also consult relevant guidance from other federal departments and ensure that the most up to date version is being used.

The proponent is encouraged to engage with Indigenous groups on the planning and development of relevant sections of the EIS, including effects from changes to the environment and impacts to

potential or established Aboriginal or Treaty rights as well as assessment of environmental effects as outlined in paragraph 5(1)(c) of CEAA 2012.

Submission of regulatory and technical information necessary for federal authorities to make their regulatory decisions during the conduct of the EA is at the discretion of the proponent. Although that information is not necessary for the EA decision, the proponent is encouraged to submit it concurrent with the EIS. While the EIS must outline applicable federal authorizations required for the project to proceed, the proponent must provide information relevant to the regulatory role of the federal government. It should be noted that the issuance of these other applicable federal legislative, regulatory and constitutional requirements are within the purview of the relevant federal authorities, and are subject to separate processes post EA decision.

4.2. Use of information

4.2.1. Government expert advice

Section 20 of CEAA 2012 requires that every federal authority with specialist or expert information or knowledge with respect to a project subject to an EA must make that information or knowledge available to the Agency. The Agency will advise the proponent of the availability of pertinent information or knowledge or expert and specialist knowledge received from other federal authorities or other levels of government so that it can be incorporated into the EIS.

4.2.2. Community knowledge and Aboriginal traditional knowledge

Sub-section 19(3) of CEAA 2012 states that “the environmental assessment of a designated project may take into account community knowledge and Aboriginal traditional knowledge”. For the purposes of these guidelines, community knowledge and Aboriginal traditional knowledge refers to knowledge acquired and accumulated by a local community or an Indigenous group.

The proponent will incorporate into the EIS the community knowledge and Aboriginal traditional knowledge to which it has access or that is acquired through public participation and engagement with Indigenous groups, in keeping with appropriate ethical standards and obligations of confidentiality. The proponent will engage in a respectful dialogue with Indigenous groups about the collection and use of Indigenous knowledge and enter into agreements where necessary regarding the use of information during and after the EA. The proponent should collaborate with Indigenous groups to ensure, where possible, that the Indigenous knowledge is incorporated into the EIS in a way that appropriate for the Indigenous group. The proponent will integrate Aboriginal traditional knowledge into all aspects of its assessment including both methodology (e.g. establishing spatial and temporal boundaries, defining significance criteria) and analysis (e.g. baseline characterization, effects prediction, development of mitigation measures). Agreement should be obtained from Indigenous groups regarding the use, management and protection of their existing traditional knowledge information during and after the EA. For more information on how Aboriginal traditional knowledge can be obtained and incorporated in the preparation of the EIS, please refer to the Agency’s reference guide on the topic. Should there be a lack of Indigenous knowledge, the proponent is still expected to seek information from other sources to complete the assessment of effects of changes to the environment on Aboriginal peoples or the assessment of impacts to rights. For more information on requirements for the effects assessment, see Part 2, Section 7.1.8 and 7.3.7 of these guidelines.

4.2.3. Existing information

In preparing the EIS, the proponent is encouraged to make use of existing information relevant to the project. When relying on existing information to meet requirements of the EIS Guidelines, the proponent will either include the information directly in the EIS or clearly direct the reader to where it may obtain the information (i.e. through cross-referencing). When relying on existing information, the proponent will also comment on how the data were applied to the project, separate factual lines of evidence from inference, and state any limitations on the inferences or conclusions that can be drawn from the existing information.

4.2.4. Confidential information

In implementing CEAA 2012, the Agency is committed to promoting public participation in the EA of projects and providing access to the information on which EAs are based. All documents prepared or submitted by the proponent or any other stakeholder in relation to the EA are included in the Canadian Environmental Assessment Registry and made available to the public on request. For this reason, the EIS will not contain information that:

- is sensitive or confidential (i.e. financial, commercial, scientific, technical, personal, cultural or other nature), that is treated consistently as confidential, and the person affected has not consented to the disclosure; or
- may cause substantial harm to a person or specific harm to the environment through its disclosure.

The proponent will consult with the Agency regarding whether specific information requested by these guidelines should be treated as confidential.

4.3. Study strategy and methodology

The proponent is expected to respect the intent of these guidelines and to consider the environmental effects that are likely to arise from the project (including situations not explicitly identified in these guidelines), the technically and economically feasible mitigation measures that will be applied, and the significance of any residual effects. Except where specified by the Agency, the proponent has the discretion to select the most appropriate methods to compile and present data, information and analysis in the EIS as long as they are justifiable and replicable.

It is possible these guidelines may include matters which, in the judgement of the proponent, are not relevant or significant to the project. If such matters are omitted from the EIS, the proponent will clearly indicate it, and provide a justification so the Agency, federal authorities, Indigenous groups, the public and any other interested party have an opportunity to comment on this decision. Where the Agency disagrees with the proponent's decision, it will require the proponent to provide the specified information.

The assessment will include the following general steps:

- ✓ identifying the activities and components of the project;
- ✓ predicting potential changes to the environment;
- ✓ predicting and evaluating the likely effects on identified VCs;
- ✓ identifying technically and economically feasible mitigation measures for any significant adverse environmental effects;

- ✓ determining any residual environmental effects;
- ✓ considering cumulative effects of the project in combination with other physical activities that have been or will be carried out; and
- ✓ determining the potential significance of any residual environmental effect following the implementation of mitigation measures.

For each VC, the EIS will describe the methodology used to assess project-related effects. The EIS could include an analysis of the pathway of the effects of environmental changes on each VC. The EIS will document where and how scientific, engineering, community knowledge and Aboriginal traditional knowledge were used to reach conclusions. Assumptions will be clearly identified and justified. All data, models and studies will be documented such that the analyses are transparent and reproducible. All data collection methods will be specified. The uncertainty, reliability, sensitivity and conservativeness of models used to reach conclusions must be indicated.

The EIS will identify all significant gaps in knowledge and understanding related to key conclusions, and the steps to be taken by the proponent to address these gaps. Where the conclusions drawn from scientific, engineering and technical knowledge are inconsistent with the conclusions drawn from Aboriginal traditional knowledge, the EIS will present each perspective on the issue and a statement of the proponent's conclusions.

The EIS will include a description of the environment (both biophysical and human), including the components of the existing environment and environmental processes, their interrelations as well as the variability in these components, processes and interactions over time scales appropriate to the likely effects of the project. The description will be sufficiently detailed to characterize the environment before any disturbance to the environment due to the project and to identify, assess and determine the significance of the potential adverse environmental effects of the project. These data should include results from studies done prior to any physical disruption of the environment due to initial project related activities. The information describing the existing environment may be provided in a stand-alone chapter of the EIS or may be integrated into clearly defined sections within the effects assessment of each VC. This analysis will include environmental conditions resulting from historical and present activities in the local and regional study areas.

If the baseline data have been extrapolated or otherwise manipulated to depict environmental conditions in the study areas, modelling methods and equations will be described and will include calculations of margins of error and other relevant statistical information, such as confidence intervals and possible sources of error. The proponent will provide the references used in creating their approach to baseline data gathering, including identifying where appropriate, the relevant federal or provincial standards. The proponent is encouraged to discuss the timeframe and considerations for its proposed baseline data with the Agency prior to submitting its EIS.

In describing and assessing effects to the physical and biological environment, the proponent will take an ecosystem approach that considers both scientific and community knowledge and Indigenous knowledge and perspectives regarding ecosystem health and integrity. The proponent will consider the resilience of relevant species populations, communities and their habitats. The assessment of environmental effects on Aboriginal peoples, pursuant to paragraph 5(1)(*c*) of CEAA 2012, will undergo the same rigour and type of assessment as any other VC (including setting of spatial and temporal boundaries, identification and analysis of effects, identification of mitigation measures, determination of residual effects, identification and a clear explanation of the methodology used for assessing the significance of residual effects and assessment of cumulative effects).

The proponent will consider the use of both primary and secondary sources of information regarding baseline information, changes to the environment and the corresponding effect on health, socio-economics, physical and cultural heritage and the current use of lands and resources for traditional purposes. Primary sources of information include traditional land use studies, socio-economic studies, heritage surveys or other relevant studies conducted specifically for the project and its EIS. Often these studies and other types of relevant information are obtained directly from Indigenous groups. Secondary sources of information include previously documented information on the area, not collected specifically for the purposes of the project, or desk-top or literature-based information. The proponent will provide Indigenous groups the opportunity to review and provide comments on the information used for describing and assessing effects on Aboriginal peoples (further information on engaging with Indigenous groups is provided in Part 2, Section 5 of this document). The proponent will respond to the comments of Indigenous groups prior to submitting the EIS to ensure that the comments are adequately addressed. Where there are discrepancies in the views of the proponent and Indigenous groups on the information to be used in the EIS, the EIS will document these discrepancies and the rationale for the proponent's selection of information.

The assessment of the effects of each of the project components and physical activities, in all phases, will be based on a comparison of the biophysical and human environments between the predicted future conditions with the project and the predicted future conditions without the project. In undertaking the environmental effects assessment, the proponent will use best available information and methods. All conclusions will be substantiated. Predictions will be based on clearly stated assumptions. The proponent will describe how each assumption has been tested. With respect to quantitative models and predictions, the EIS will document the assumptions that underlie the model, the quality of the data and the degree of certainty of the predictions obtained. Where there are discrepancies in the views of the proponent and Indigenous groups with respect to the outcomes of assessment(s), the EIS will document and provide a rationale for these discrepancies.

4.4. Presentation and organization of the environmental impact statement

To facilitate the identification of the documents submitted and their placement in the Canadian Environmental Assessment Registry, the title page of the EIS and its related documents will contain the following information:

- project name and location;
- title of the document, including the term "environmental impact statement";
- subtitle of the document;
- name of the proponent; and
- date of submission of the EIS.

The EIS will be written in clear, precise language. A glossary defining technical words, acronyms and abbreviations will be included. The EIS will include charts, diagrams, tables, maps and photographs, where appropriate, to clarify the text. Perspective drawings that clearly convey the various components of the project will also be provided. Wherever possible, maps will be presented in common scales and datum to allow for comparison and overlay of mapped features.

For purposes of brevity and to avoid repetition, cross-referencing is preferred. The EIS may make reference to the information that has already been presented in other sections of the document, rather

than repeating it. Detailed studies (including all relevant and supporting data and methodologies) will be provided in separate appendices and will be referenced by appendix, section and page in the text of the main document. The EIS will explain how information is organized in the document. This will include a table of content with a list of all tables, figures, and photographs referenced in the text. A complete list of supporting literature and references will also be provided. A table of concordance, which cross references the information presented in the EIS with the information requirements identified in the EIS Guidelines, will be provided. The proponent will provide copies of the EIS and its summary for distribution, including paper and electronic version in an unlocked, searchable PDF format, as directed by the Agency.

4.5. Summary of the environmental impact statement

The proponent will prepare a summary of the EIS in both of Canada's official languages (French and English) to be provided to the Agency at the same time as the EIS that will include the followings:

- a concise description of all key components of the project and related activities;
- a summary of the engagement with Indigenous groups, and the participation of the public and government agencies, including a summary of the issues raised and the proponent's responses;
- an overview of expected changes to the environment;
- an overview of the key environmental effects of the project, as described under section 5 of CEAA 2012, and proposed technically and economically feasible mitigation measures;
- an overview of how factors under paragraph 19(1) of CEAA 2012 were considered;
- the proponent's conclusions on the residual environmental effects of the project, and the significance of those effects, after taking into account the mitigation measures.

The summary is to be provided as a separate document and should be structured as follows:

1. Introduction and EA context
2. Project overview
3. Alternative means of carrying out the project
4. Public participation
5. Engagement with Indigenous Groups
6. Summary of environmental effects assessment for each VC, including:
    a. description of the baseline
    b. anticipated changes to the environment
    c. anticipated effects
    d. mitigation measures
    e. significance of residual effects
7. Follow-up and monitoring programs proposed

The summary will have sufficient details for the reader to understand the project, any potential environmental effects, proposed mitigation measures, and the significance of the residual effects. The summary will include key maps illustrating the project location and key project components.

Part 2 – Content of the Environmental Impact Statement

1. INTRODUCTION AND OVERVIEW

1.1. The proponent

In the EIS, the proponent will:

- provide contact information (e.g. name, address, phone, fax, email);
- identify itself and the name of the legal entity(ies) that would develop, manage and operate the project;
- describe corporate and management structures;
- specify the mechanism used to ensure that corporate policies will be implemented and respected for the project; and
- identify key personnel, contractors, and/or sub-contractors responsible for preparing the EIS.

1.2. Project overview

The EIS will describe the project, key project components and associated activities, scheduling details, the timing of each phase of the project and other key features. If the project is part of a larger sequence of projects, the EIS will outline the larger context.

The overview is to identify the key components of the project, rather than providing a detailed description, which will follow in Section 3 below.

1.3. Project location

The EIS will contain a description of the geographical setting in which the project will take place. This description will focus on those aspects of the project and its settings that are important in order to understand the potential environmental effects of the project. The following information will be included:

- the Universal Transverse Mercator (UTM) projection coordinates of the main project site;
- current land use in the area;
- distance of the project facilities and components to any federal lands;
- the environmental significance and value of the geographical setting in which the project will take place and the surrounding area;
- environmentally sensitive areas, such as national, provincial and regional parks, ecological reserves, ecologically and biologically sensitive areas, fishery closure areas, vulnerable marine ecosystems, marine refuge areas, and habitats of federally or provincially listed species at risk and other sensitive areas;
- description of local communities and Indigenous communities; and
- traditional territories and/or consultation areas, treaty lands, Indian Reserve lands.

1.4. Regulatory framework and the role of government

The EIS will identify:

- any federal power, duty or function that may be exercised that would permit the carrying out (in whole or in part) of the project or associated activities;
- legislation and other regulatory approvals that are applicable to the project at the federal, provincial, regional and municipal levels;
- government policies, resource management plans, planning or study initiatives pertinent to the project and/or EA and their implications;
- any treaty, self-government or other agreements between federal or provincial governments and Indigenous groups that are pertinent to the project and/or EA;
- any relevant land use plans, land zoning, or community plans; and
- regional, provincial and/or national objectives, standards or guidelines that have been used by the proponent to assist in the evaluation of any predicted environmental effects.

2. PROJECT JUSTIFICATION AND ALTERNATIVES CONSIDERED

2.1. Purpose of the project

The EIS will describe the purpose of the project by providing the rationale for the project, explaining the background, the problems or opportunities that the project is intended to satisfy and the stated objectives from the perspective of the proponent. If the objectives of the project are related to broader private or public sector policies, plans or programs, this information will also be included.

The EIS will also describe the predicted environmental, economic and social benefits of the project. This information will be considered in assessing the justifiability[2] of any significant adverse residual environmental effects as defined in section 5 of CEAA 2012, if such effects are identified.

2.2. Alternative means of carrying out the project

The EIS will identify and consider the environmental effects of alternative means of carrying out the project that are technically and economically feasible. The proponent will complete the assessment of alternative means in accordance with the Agency's Operational Policy Statement on this topic.

In its alternative means analysis, the proponent will address, at a minimum, the following project components:

- choice of drilling fluid (i.e. water-based drilling mud or synthetic-based drilling mud);
- choice of drilling unit (i.e. drillship or semi-submersible);
- management of drilling wastes (i.e. disposal on seabed or into water column, recover and ship to shore, re-inject);
- water management and location of the final effluent discharge points;

[2] See subsection 52(2) of CEAA 2012.

- alternative ways to light the platform at night (or flare at night when testing the well), to reduce attraction and associated mortality of birds, such as installing flare shields.

The *Offshore Waste Treatment Guidelines*[3] include minimum performance targets for concentrations and volumes of waste material in discharges resulting from offshore exploration and development. Offshore operators are expected to take all reasonable measures to minimize the volumes of waste materials generated by their operations, and to minimize the quantity of substances of potential environmental concern contained within these waste materials. The EIS should include a discussion on how wastes and potential associated toxic substances would be minimized. The proponent should also discuss any alternatives that would enable it to achieve these objectives and adopt best practices in waste management and treatment.

The *Offshore Chemical Selection Guidelines for Drilling & Production Activities on Frontier Lands*[4] provide a framework for the selection of chemicals in support of offshore operations. The guidelines outline minimum expectations on the selection of lower toxicity chemicals; recognizing that variations to the selection process described in the guidelines may be required in areas where increased risk to the environment has been identified. With the objective of minimizing potential environmental impacts of discharges to the marine environment, the proponent should identify the quantity and type of chemicals (or constituents) that may be used in support of the proposed project that are:

- included on the Canadian Environmental Protection Act's List of Toxic Substances;
- not included on the OSPAR[1] Pose Little or No Risk to the Environment (PLONOR) list of chemicals and have a PARCOM[2] Offshore Chemical Notification Scheme Hazard Rating of A, B or purple, orange, blue, or white; or
- not included on the PLONOR list of chemicals and have not been assigned a PARCOM Offshore Chemical Notification Scheme Hazard Rating.

Alternatives to the use of the above-listed chemicals (e.g. through alternative means of operating or use of less-toxic alternatives) should be discussed in the EIS.

For further information regarding the "purpose of" and "alternative means", please consult the Agency's Operational Policy Statement entitled "*Addressing "Purpose of" and "Alternative Means" under the Canadian Environmental Assessment Act, 2012".*

The Agency recognizes that projects may be in the early planning stages when the EIS is being prepared. Where the proponent has not made final decisions concerning the placement of project infrastructure, the technologies to be used, or that several options may exist for various project components, the proponent shall conduct an environmental effects analysis at the same level of detail for each of the various options available (alternative means) within the EIS.

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[3] National Energy Board, Canada-Nova Scotia Offshore Petroleum Board and Canada-Newfoundland and Labrador Offshore Petroleum Board. *Offshore Waste Treatment Guidelines*. December 2010. Available from: www.cnlopb.ca

[4] National Energy Board, Canada-Nova Scotia Offshore Petroleum Board and Canada-Newfoundland Offshore Petroleum Board. *Offshore Chemical Selection Guidelines for Drilling & Production Activities on Frontier Lands*. April 2009. Available from: www.cnlopb.ca

[1] Oslo and Paris Commissions

[2] Paris Commission

3. PROJECT DESCRIPTION

3.1. Project components

The EIS will describe the project, by presenting the project components, associated and ancillary works, and other characteristics that will assist in understanding the environmental effects. This will include:

- maps, at an appropriate scale, of the project location;
- project components;
- boundaries of exploration licences 1157 and 1158 with UTM coordinates;
- the major existing infrastructure;
- adjacent land and resource uses; and
- any important environmental features.

If the project is part of a larger sequence of projects, the proponent will outline the larger context and present the relevant references, if available.

In its EIS, the proponent will describe:

- the Mobile Offshore Drilling Unit(s) and their operations (drilling, testing, suspension or abandonment) in locations and water depths under consideration;
- navigation activities (number and frequency of trips), size and types of vessels, anticipated vessel routes and anchorages, predicted percentage of increase in vessel traffic of similar size vessels resulting from the project, icebreaking activities (time of year, frequency, duration, expected start and end dates), and ballast water management
- helicopters, including routes, number and frequency of trips;
- vertical seismic profiling or any other in-water works (e.g. wellsite surveys) to support the specific exploration wells under consideration, but excluding surveys potentially required to support the conduct of the EA (e.g. environmental baseline surveys) and surveys related to the broader delineation of resources;
- well evaluation and testing;
- reagent requirements and uses (e.g. volumes, storage, types);
- petroleum products (e.g. source, volume, storage, types);
- the nature, composition and fate (e.g. areal extent) of drilling wastes (e.g. muds, cuttings) at various water depths and at various stages of drilling, including during riserless drilling and drilling with the marine riser in place, using dispersion modelling;
- the management or disposal of wastes (e.g. type and constituents of waste, quantity, treatment and method of disposal) including:
  - ✓ drilling muds, drill solids;
  - ✓ deck drainage;
  - ✓ cooling water;
  - ✓ bilge and ballast water;
  - ✓ fire control system test water;

- ✓ operational discharges from subsea systems and the installation of subsea systems;
- ✓ sewage and food wastes;
- ✓ well treatment or testing fluids; and
- ✓ other operational discharges.

- contributions to atmospheric emissions, including emissions profile (i.e. type, rate and source) for activities including routine or upset flaring (including the contribution from any produced fluids that may be added to any flares), routine drilling, testing, shipping etc.;
- sources and extent of light, heat and noise;
- transfers of bulk materials (e.g. mud) and fuel;
- number of employees and transportation of employees;
- drinking and industrial water requirements (source, quantity required, need for water treatment);
- energy supply (source, quantity); and
- waste disposal (types of waste, methods of disposal, quantity).

3.2. Project activities

The EIS will include descriptions of the drilling, testing and decommissioning, suspension or abandonment of wells associated with the proposed project.

This will include descriptions of the activities to be carried out during each phase, the location of each activity, expected outputs and an indication of the activity's magnitude and scale. Water depths for potential drill sites will be specified.

Although a complete list of project activities should be provided, the emphasis will be on activities with the greatest potential to have environmental effects. Sufficient information will be included to predict environmental effects and address concerns identified by the public and Indigenous groups. Highlight activities that involve periods of increased environmental disturbance or the release of materials into the environment.

The EIS will include a summary of the changes that have been made to the project since originally proposed, including the benefits of these changes to the environment, Indigenous groups, and the public.

The EIS will include a schedule including time of year, frequency, and duration for all project activities.

The information will include a description of:

3.2.1. Drilling and testing activities

- operation of the Mobile Offshore Drilling Unit(s), including:
  - ✓ drilling at various water depths and in locations under consideration
  - ✓ well flow testing
  - ✓ waste management
  - ✓ water management
- vertical seismic profile surveys;

- flaring, including:
  - ✓ specifics on flare tip used, including type, manufacturer and/or model;
  - ✓ all flaring activities and estimation of flared volumes;
  - ✓ estimation of total greenhouse gas and criteria air contaminants emissions;
  - ✓ an estimate of the contribution of the flaring emissions at the local, provincial and federal scale;
  - ✓ justification for all estimated emissions and emission factors used; and
  - ✓ the estimation or derivation method, and a description of all assumptions and emission factors used;
- well evaluation and testing;
- equipment requirements (type, quantity); and
- storage and management of hazardous materials, fuels and residues.

3.2.2. Supply and servicing

- vessel support, including loading, refuelling and operation of marine support vessels (i.e. for transfer, re-supply and on-site safety during drilling activities); and
- helicopter support (i.e. crew transport and delivery of supplies and equipment).

3.2.3. Decommissioning, suspension or abandonment of wells

- the preliminary outline of a well decommissioning, suspension and abandonment plan for wells at varying water depths.

4. PUBLIC PARTICIPATION AND CONCERNS

The EIS will describe the ongoing and proposed public participation activities that the proponent will undertake or that it has already conducted on the project. It will provide a description of efforts made to distribute project information and provide a description of information and materials that were distributed during the consultation process. The EIS will indicate the methods used, where the consultation was held, the persons and organizations consulted, the concerns voiced and the extent to which this information was incorporated in the design of the project as well as in the EIS. The EIS will provide a summary of key issues raised related to the project and its potential effects to the environment as well as describe any outstanding issues and ways to address them.

5. ENGAGEMENT WITH INDIGENOUS GROUPS AND CONCERNS RAISED

As noted in Part 1, Section 2.3 of these guidelines, the proponent is expected to engage with potentially affected Indigenous groups. For the purposes of developing the EIS, the proponent will engage with Indigenous groups that may be affected by the project, to obtain their views on:

- the project;
- effects of changes to the environment on Aboriginal peoples (health and socio-economic conditions; physical and cultural heritage, including any structure, site or thing that is of historical, archaeological, paleontological or architectural significance; and current use of lands and resources for traditional purposes) pursuant to paragraph 5(1)(c) of CEAA 2012, and

- potential adverse impacts of the project on potential or established Aboriginal or Treaty rights, in respect of the Crown's duty to consult, and where appropriate, accommodate Aboriginal peoples.

Aboriginal rights are defined as: practices, traditions and customs integral to the distinctive culture of the Aboriginal group claiming the right that existed prior to contact with the Europeans. In the context of Métis groups, Aboriginal rights means practices, traditions, and customs integral to the distinctive culture of the Métis group that existed prior to effective European control, that is, prior to the time when Europeans effectively established political and legal control in the claimed area. Generally, these rights are fact and site specific. Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) Canada also define Aboriginal title as an Aboriginal right.

In order to allow the Indigenous groups to engage and provide views on the above, the proponent will provide the Indigenous groups with the following timely and relevant:

- opportunities to learn about the project including providing information about the proposed project (including but not limited to project design, location, potential effects, mitigation measures and follow-up and monitoring programs); and
- opportunities to provide input on the overall project; effects of changes to the environment on Aboriginal peoples pursuant to paragraph 5 (1)(c) of CEAA, 2012 and potential adverse impacts of the project on potential or established Aboriginal or Treaty rights.

The proponent will structure its engagement activities to provide adequate time for groups to review and comment on the relevant information. Engagement activities are to be appropriate to the groups' needs, arranged through discussions with the groups and in keeping with established consultation protocols, where available. The EIS will describe all efforts, successful or not, taken to solicit the information required from groups to support the preparation of the EIS. With respect to engagement activities, the EIS will document:

- the engagement activities undertaken with each group prior to the submission of the EIS, including the date and means of engagement (e.g. meeting, mail, telephone);
- document the main issues and comments raised during the engagement activities by each group and the proponent's responses (effort should be made to collating like issues together along VCs identified in the EIS);
- any future planned engagement activities;
- where and how Indigenous groups' perspectives were integrated into and/or contributed to decisions regarding the project, design, operation, decommissioning, suspension abandonment, follow-up and monitoring and associated potential effects (paragraph 5(1)(c)) and the associated mitigation utilized to manage those effects. The effects and mitigation measures should be clearly linked to VCs in the EIS as well as to specific project components or activities; and
- how engagement activities by the proponent allowed groups to understand the project and evaluate its impacts on their communities, activities, potential or established Aboriginal or Treaty rights,. Where impacts are identified, provide a discussion of how those would be managed or mitigated (and provide this information for each Indigenous group separately).

To assist with the provision of records as requested above, the Agency recommends the proponent create a tracking table of key issues raised by each Indigenous group and responses provided by the

Proponent. Information provided related to potential adverse impacts on potential or established Aboriginal or Treaty rights rights will be considered by the Crown in meeting its common law duty to consult obligations.

For the groups listed below, the proponent will ensure they are notified about key steps in the EIS development process and of opportunities to provide comments on key EA documents and/or information to be provided regarding their community. The proponent will ensure these groups are reflected in the baseline information and assessment of potential environmental effects as described under paragraph 5(1)(c) of CEAA 2012 and/or impacts to potential or established section 35 rights, including title and related interest in the EIS. These groups include:

Newfoundland and Labrador

- the Labrador Inuit (Nunatsiavut Government)
- the Labrador Innu (Innu Nation)
- the NunatuKavut Community Council

Nova Scotia

- 11 Mi'kmaq First Nation groups represented by Kwilmu'kw Maw-klusuaqn Negotiation Office (KMKNO):
  - ✓ Acadia First Nation
  - ✓ Annapolis Valley First Nation
  - ✓ Bear River First Nation
  - ✓ Eskasoni First Nation
  - ✓ Glooscap First Nation
  - ✓ Membertou First Nation
  - ✓ Paqtnkek Mi'kmaw Nation
  - ✓ Pictou Landing First Nation
  - ✓ Potlotek First Nation
  - ✓ Wagmatcook First Nation
  - ✓ Waycobah First Nation
- Millbrook First Nation
- Sipekne'katik First Nation

New Brunswick

- eight Mi'gmaq First Nations groups represented by Mi'gmawe'l Tplu'taqnn Inc. (MTI)
  - ✓ Fort Folly First Nation
  - ✓ Eel Ground First Nation
  - ✓ Pabineau First Nation
  - ✓ Esgenoôpetitj First Nation
  - ✓ Buctouche First Nation
  - ✓ Indian Island First Nation
  - ✓ Eel River Bar First Nation
  - ✓ Metepnagiag Mi'kmaq First Nation
- Elsipogtog First Nation

- five Maliseet First Nation groups represented by Wolastoqey Nation in New Brunswick (WNNB)
  - ✓ Kingsclear First Nation
  - ✓ Madawaska Maliseet First Nation
  - ✓ Oromocto First Nation
  - ✓ Saint Mary's First Nation
  - ✓ Tobique First Nation
- Woodstock First Nation
- Peskotomuhkati Nation at Skutik (Passamaquoddy)

Prince Edward Island

- Abegweit First Nation
- Lennox Island First Nation

Quebec

- three Mi'gmaq First Nation groups represented by Mi'gmawei Mawiomi Secretariat (MMS)
  - ✓ Micmas of Gesgapegiag
  - ✓ La Nation Micmac de Gespeg
  - ✓ Listuguj Mi'gmaq Government
- Les Innus de Ekuanitshit
- Innu First Nation of Nutashkuan

The groups referenced above may change as more is understood about the environmental effects of the project and/or if the project or its components change during the EA. The Agency reserves the right to alter the list of groups that the proponent will engage as additional information is gathered during the EA.

In addition, for the purposes of good governance, the proponent should also provide information to and discuss potential environmental effects from the Project, as described under section 5(1)(c) of CEAA 2012, with the Qalipu Mi'kmaq First Nation Band and the Miawpukek First Nation.

Upon receipt of knowledge or information of potential effects or adverse impacts to any Indigenous group, even those not listed above, the proponent shall provide that information to the Agency at the earliest opportunity.

With respect to the effects of changes to the environment on Aboriginal peoples, the assessment requirements are outlined in Part 2, Sections 7.1.8 and Part 2, 7.3.7 of these guidelines. With respect to the assessment requirements are outlined in Part 2, Section 6 of these guidelines.

6. IMPACTS TO POTENTIAL OR ESTABLISHED ABORIGINAL OR TREATY RIGHTS

With respect to potential adverse impacts of the project on potential or established Aboriginal or Treaty rights, the EIS will document for each group identified in Part 2, Section 5 of these guidelines (or in subsequent correspondence from the Agency):

- potential or established Aboriginal or Treaty rights[5], when this information is directly provided by a group to the proponent, the Agency or is available through public records, including but not limited to:
  - ✓ location of the right being practiced or exercised
  - ✓ context in which the right is practiced or exercised (including information about which groups of an Indigenous group practice the right (women, elders, youth), how the right was practiced historically),
  - ✓ how the Indigenous group's cultural traditions, laws and governance systems inform the manner in which they exercise their rights (the who, what, when, how, where and why)
  - ✓ the Indigenous group's perspectives on the importance of the land on which the Project is located and how it intersects with any land management uses and/or plans they may have,
  - ✓ how often the right is practiced or exercised and timing or seasonality of the practice or exercise of the right; and,
  - ✓ maps and data sets (e.g., fish catch numbers);
- potential adverse impacts of each of the project components and physical activities, in all phases, on potential or established Aboriginal or Treaty rights, including those raised by Indigenous groups.
- measures identified to accommodate potential adverse impacts of the project on the potential or established Aboriginal or Treaty rights. These measures will clearly describe how the proponent intends to implement them, and may go beyond mitigation measures that are developed to address potential adverse environmental effects. Include perspectives and specific suggestions raised of potentially impacted Indigenous groups; as well as any views of Indigenous groups on the effectiveness of mitigation measures.
- potential adverse impacts on potential or established Aboriginal or Treaty rights that have not been fully mitigated or accommodated as part of the EA and associated engagement with Indigenous groups. Include perspective of potentially impacted Indigenous groups; and
- potential adverse impacts that may result from the residual and cumulative environmental effects. Include the perspectives of potentially impacted Indigenous groups.

This information and assessment will be informed from engagement with Indigenous groups described in Part 2, Section 5 of these guidelines. The information sources, methodology and findings of the assessment of paragraph 5(1)(c) effects under CEAA 2012 may be used to inform the assessment of potential adverse impacts of the project on potential or established Aboriginal or Treaty rights. However, there may be distinctions between the adverse impacts on potential or established Aboriginal or Treaty rights and paragraph 5(1)(c) effects under CEAA 2012. The proponent will carefully consider the potential distinction between these two aspects and, where there are differences; will include the relevant information in its assessment.

[5] Refer to Crown-Indigenous Relations and Northern Affairs Canada or Indigenous Services Canada for more information.

7. EFFECTS ASSESSMENT

7.1. Project setting and baseline conditions

Based on the scope of the project described in Section 3 (Part 1), the EIS will present baseline information in sufficient detail to enable the identification of how the project could affect the VCs and an analysis of those effects. Should other VCs be identified during the conduct of the EA, the baseline condition for these components will also be described in the EIS. To determine the appropriate spatial boundaries to describe the baseline information, refer to Section 3.2.3 (Part 1) of these guidelines. As a minimum, the EIS will include a description of the following environmental components.

7.1.1. Atmospheric environment

The EIS will describe the atmospheric environment and climate at the project site and within areas that could be affected by routine project operations or accidents and malfunctions, such as:

- ambient air quality in the project area and in the airshed likely to be affected by the project, including consideration of the following contaminants: total suspended particulates (TSP), fine particulates smaller than 2.5 microns ($PM_{2.5}$), respirable particulates of less than 10 microns (PM_{10}), carbon monoxide (CO), sulphur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOCs), hydrogen sulfide (H2S) and any other potentially toxic air pollutants;
- identify and quantify existing greenhouse gas emissions[6] by individual pollutant measured as kilotonnes of CO_2 equivalent per year in the project study areas;
- direct (e.g. emissions related to vessel traffic) and indirect sources of air emissions;
- current provincial/territorial/federal limits for greenhouse gas emission targets;
- current ambient noise levels in the project area. Information on typical sound sources, geographic extent and temporal variations will be included;
- existing ambient night-time light levels in the project area and at any other areas where project activities could have an effect on light levels. The EIS will describe night-time illumination levels during different weather conditions and seasons; and
- historical records of relevant meteorological information (e.g. total precipitation (rain and snow); mean, maximum and minimum temperatures; and typical wind speed and direction (freezing spray; lighting; and visibility).

Particular attention should also be given to the analysis of extreme meteorological events that have the potential to result in adverse effects on the project (e.g. high wind events).

Relevant marine climate data sources should be consulted, including but not limited to data from Environment and Climate Change Canada moored weather buoys and any offshore platforms operating in the Eastern Newfoundland Strategic Environmental Assessment (SEA) area. Data from the International Comprehensive Atmosphere Ocean Dataset (ICOADS), the United States of America National Oceanographic and Atmospheric Administration (NOAA) database of tropical

[6] Greenhouse gas emissions include: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

cyclone activity in the North Atlantic, NOAA's Climate Forecast System Reanalysis (CFSR), and the Canadian Lightning Detection Network.

7.1.2. Marine environment

- marine water quality (e.g. water temperature, turbidity, salinity and pH);
- marine geology and geomorphology (i.e. bottom sediments, including quality, thickness, grain size, and mobility);
- physical oceanography including surface and subsurface current patterns, current velocities, waves, storm surges, long shore drift processes, tidal patterns, and tide gauges levels for the site, in proximity to the site, and along the marine transportation routes with consideration of predicted climate change effects;
- available bathymetric information (e.g. maximum and mean water depths) for the site and along marine transportation routes if applicable;
- ice climate in the regional study area, including ice formation and thickness, ridging, breakup and movement;
- ice conditions along the marine transportation routes with consideration of predicted climate change and its possible effect on the timing of ice formation in the future;
- fast-ice characteristics, including its surface area and seasonal stability and along the marine transportation routes;
- marine plants, including all benthic and detached algae, marine flowering plants, brown algae, red algae, green algae and phytoplankton;
- acoustic environment (ambient noise levels from natural sources, shipping, seismic surveys, and other sources), including information on geographic extent and temporal variations and how the acoustic environment may be affected by the project.

When describing the baseline marine environment, relevant data sources such as DFO Research Vessel Surveys/Science Reports and other primary and secondary scientific literature should be consulted. In addition to data sources discussed under Atmospheric Environment and Climate (some of which contain marine data), the proponent should consult MSC50 Wind and Wave Hindcast Data, and long term gridded hourly wind and wave measurements for the North Atlantic.

7.1.3. Fish and fish habitat

The EIS will describe fish and fish habitat within areas that could be affected by routine project operations or by accidents and malfunctions, including:

- a characterization of fish populations on the basis of species and life stage, including information on the surveys carried out (e.g. location of sampling stations, catch methods, date of catches, species, catch per-unit effort) and the source of data available (e.g. government and historical databases, commercial fishing data);
- a description of primary and secondary productivity in affected water bodies with a characterization of season variability; and

- benthic flora and fauna and their associated habitat, including sensitive features such as corals and sponges (Note: a benthic habitat survey (ROV / camera), including transects of seafloor in the area of the well locations, may be required).

Emphasis will be placed on the waters and benthic environments likely to be affected by the project. Hence, for all areas in which effects are anticipated, the EIS will describe the biophysical water and sediment characteristics, including:

- a description of the physical and biological characteristics of the fish and fish habitat likely to be directly or indirectly affected by the project;
- maps, at a suitable scale, indicating the surface area of potential or confirmed fish habitats and a description of these habitats as determined by water depths, type of substrate (sediments), aquatic vegetation, and potential use (i.e. spawning, rearing, nursery, feeding, overwintering, migration routes, etc.). Where appropriate, this information should be linked to water depths (bathymetry) to identify the extent of a water body's littoral / photic zone;
- quality, thickness, grain size and mobility of bottom sediments; and
- a discussion of sea bottom stability at the project site.

Any sampling survey methods used by the proponent will be described in order to allow experts to ensure the quality of the information provided. If previous studies on the habitat in the study area were conducted, they are to be submitted with the EIS.

7.1.4. Migratory birds and their habitat[7]

The EIS will describe migratory and non-migratory birds and their habitat at the project site and within areas that could be affected by routine project operations or accidents and malfunctions.

Migratory birds are protected under the *Migratory Bird Protection Act* (MBCA) and associated regulations. Preliminary data from existing sources will be gathered, including information such as:

- birds and their habitats that are found or are likely to be found in the study area. This description may be based on existing sources, but supporting evidence is required to demonstrate that the data used are representative of the avifauna and habitats found in the study area. The existing data must be supplemented by surveys, if required.
- abundance, distribution, and life stages of migratory and non-migratory birds likely to be affected in the project area based on existing information, or surveys, as appropriate, to provide current field data;
- year-round migratory bird use of the area (e.g. winter, spring migration, breeding season, fall migration), based on preliminary data from existing sources and surveys to provide current field data if appropriate; and
- areas of concentration of migratory birds, such as for breeding, feeding or resting.

[7] Surveys should be designed in light of the available references and recommendations in Environment and Climate Change Canada's document entitled "*Guidance for the Preparation of an Environmental Impact Statement and Useful References*" (2016) (available from the Department of Environment and Climate Change Canada), and in the Canadian Wildlife Service's Technical Report No. 508, *A Framework for the Scientific Assessment of Potential Project Impacts on Birds* (Hanson et al. 2009). Appendix 3 of the Framework provides examples of project types and recommended techniques for assessing impacts on migratory birds.

Other relevant datasets should be consulted, such as those available from the Canadian Wildlife Service (e.g. Eastern Canadian Seabirds at Sea (ECSAS), Programme intégré de recherches sur les oiseaux pélagiques (PIROP)), the Atlantic Canada Conservation Data Centre (ACCDC), recovery strategies, management plans, Newfoundland and Labrador Department of Fisheries and Land Resources Wildlife Division, previous petroleum operations in the area and university or other research programs, if available.

7.1.5. Species at Risk

The EIS will describe federal species at risk and their habitat, including critical habitat, at the project site and within areas that could be affected by routine project operations or accidents and malfunctions, such as:

- a list of all potential or known federally listed species at risk that may be affected by the project, using existing data and literature as well as surveys to provide current field data;
- a list of all federal species designated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) for listing on Schedule 1 of the Species at Risk Act. This will include those species in the risk categories of extirpated, endangered, threatened and of special concern[8];
- any published studies that describe the regional importance, abundance and distribution of species at risk including recovery management plans, recovery strategies and action plans. The existing data must be supplemented by surveys, if required;
- residences, seasonal movements, movement corridors, habitat requirements, key habitat areas, identified critical habitat and/or recovery habitat (where applicable) and general life history of species at risk that may occur in the project area, or be affected by the project; and
- identification of any potentially affected critical habitat as defined in the Species at Risk Act.

The following information sources on species at risk and species of conservation concern should be among those consulted:

- Species at Risk Act Registry (www.sararegistry.gc.ca);
- COSEWIC;
- Relevant government agencies;
- Local naturalist and interest groups; and
- Indigenous groups and First Nations.

7.1.6. Marine mammals

- *marine mammal species that may be present, the times of year they are present, the ranges of the species and their migration patterns; and*

[8] Proponents are encouraged to consult COSEWIC's latest annual report for a listing of the designated wildlife species posted on their website

- *important areas in the vicinity of the drilling sites or supply routes (e.g. for mating, breeding, feeding and nursing of young) or that could be impacted by the project (e.g. acoustics, spills, etc.)*

Relevant datasets should be consulted, such as DFO marine mammal sightings database, DFO Research Vessel Surveys, Scientific Reports, and other primary and secondary scientific literature.

7.1.7. Marine turtles

- *marine turtle species that may be present, the times of year they are present, the ranges of the species and their migration patterns; and*
- *important areas in the vicinity of the drilling sites or supply routes (e.g. for mating, breeding, and feeding) or that could be impacted by the project (e.g. routine discharges, spills, etc.)*

7.1.8. Indigenous peoples

The proponent shall gather and document baseline information in the EIS for each Indigenous group identified in Part 2, Section 5 of these guidelines (and any groups identified after these guidelines are finalized). The baseline information will:

- Describe and characterize the elements in paragraph 5(1)(c) of CEAA 2012 based on the spatial and temporal scope selected for the EA according to the factors outlined in Part 1, Section 3.2.3 of this document.
- Characterize the regional context of each of the elements of paragraph 5(1)(c) of CEAA 2012 to support the assessment of project related effects, including consideration of the differences of experiences by sub-populations within an Indigenous group, as appropriate (for example, women, youth, elders, families) and cumulative effects.
- Be sufficient to provide a comprehensive understanding of the current state of each VC related to effects of changes to the environment on Aboriginal peoples. Each of the VCs for effects of changes to the environment on Aboriginal peoples is interrelated and therefore baseline information will often overlap.

The proponent should engage with Indigenous groups to understand where baseline information and the respective assessment fit appropriately. Note: VCs identified for biophysical assessment (such as fish and fish habitat) may contribute to assessment and conclusion of VCs related to effects of changes to the environment on Aboriginal peoples.

Health and Socio-Economic Conditions

Baseline information is required for health[9] and socio-economic conditions. For health this includes the state of physical, mental and social well-being. For socio-economic conditions, as well as the economic and social activities of an individual Indigenous group, the baseline will include contextual information regarding their practices. Specific aspects that will be considered include:

- general information about Indigenous populations and sub-populations;

[9] The proponent should refer to Health Canada's guidance documents in order to include the appropriate baseline information relevant to human health.

- consumption of country foods (also known as traditional foods) including food that is trapped, fished, or hunted for subsistence or medicinal purposes, outside of the commercial food chain;
- which country foods are consumed by which groups, how frequently, and where these country foods are harvested;
- commercial activities (e.g. fishing, trapping, hunting, outfitting);
- any project components and a description of any activities (e.g. exclusion zones) that may affect commercial fisheries or other uses;
- human health, primarily with respect to potential contamination of food sources; and
- recreational uses.

Physical and Cultural Heritage

Baseline information for physical and cultural heritage (including any site, structure or thing of archaeological, paleontological, historical or architectural significance) will consider all elements of cultural and historical importance to Indigenous groups in the area and is not restricted to artifacts considered under provincial heritage legislative requirements.

Current Use of Lands and Resources for Traditional Purposes[10]

Baseline information for current use of lands and resources for traditional purposes will focus on the traditional activity (e.g. hunting, fishing) and include a characterization of all attributes of the activity that can be affected by environmental change. This includes understanding of the baseline conditions of the quality and quantity of resources (e.g. preferred species and perception of quality, cultural connections to species), access to resources (e.g. physical access, timing, seasonality, distance from community) and overall quality of the experience of the practice (e.g. noise, air quality, visual landscape and presence of others). Specific aspects that will be considered include, but are not limited to:

- location of traditional territory (including maps where available);
- location of reserves and communities;
- commercial and traditional fishing activity within the project's potential zone of influence, including licences and maps;
- fish, wildlife, birds, plants or other natural resources and their habitats of importance for traditional use;
- places where fish, wildlife, birds, plants or other natural resources are harvested, including places that are preferred;
- access and travel routes for conducting traditional practices;
- frequency, duration or timing of traditional practices;
- cultural values associated with the area affected by the project and the traditional uses identified;

[10] The proponent should refer to CEAA's guidance documents related to current use of lands and resources for traditional purposes in order to include the appropriate baseline information relevant to current use.

- other current uses identified by Indigenous groups.

Any other baseline information that supports the analysis of predicted effects on Indigenous peoples will be included as necessary.

The EIS will also indicate how input, including Indigenous knowledge, from groups was used in establishing the baseline conditions related to health and socio-economics, physical and cultural heritage and current use of lands and resources for traditional purposes. Information collected as part of Section 6 Aboriginal and Treaty rights can be used to inform the baseline information for the elements of 5(1)(c) listed above.

Should there be a lack of Indigenous knowledge; the proponent is still expected to seek information from other sources sufficient enough to allow for a complete the assessment of effects to be presented in the EIS. For more information on requirements for the effects assessment, see Part 2, Section 7.3.7 of these guidelines.

7.1.9. Other changes to the environment arising as a result of a federal decision or due to changes on federal lands, in another province or outside Canada

Should there be the potential for a change to the environment arising as a result of a federal decision(s), or on federal lands, lands in another province or lands outside Canada, the EIS will include baseline information on the environmental component likely to be affected (if this information is not already covered in other subsections of these guidelines).

7.1.9.1. Special areas

The EIS will describe special areas (e.g. marine refuges, species at risk critical habitat that has been designated and that has been proposed or that may be under consideration, Important Bird Areas, Migratory Bird Sanctuaries, ecological reserves, etc.) at the project site and within areas that could be affected by routine project operations or accidents and malfunctions, such as:

- Marine Protected Areas
- Ecologically and Biologically Significant Areas
- Fishery Closure Areas
- Vulnerable Marine Ecosystem
- Preliminary Representative Marine Areas

The EIS will describe the distances between the edge of the project area (i.e. drill sites and marine transportation routes) and special areas. It shall state the rationale for designating specific areas as “special” (i.e. the environmental features that define the special area).

7.1.9.2. Human environment

With respect to potential effects on the human environment, non-Indigenous people and the related VC baseline information will describe and characterize the following that could be affected by routine project operations or accidents and malfunctions. At a minimum, this should include:

- any federal lands, lands located outside the province or Canada that may be affected by the project operations or by accidents and malfunctions;

- the current and historical use of waters that may be affected by routine project operations or by accidents and malfunctions, including:
    - current commercial and recreational fishing activity, including licence holders and species fished;
    - other ocean uses (e.g. shipping, research, oil and gas, military, ocean infrastructure [e.g. subsea cable]);
- the location of and proximity of any permanent, seasonal or temporary residences or camps that could be affected by routine project operations or accidents and malfunctions;
- health[11] and socio-economic conditions that could be affected by routine project operations or accidents and malfunctions, including the functioning and health of the socio-economic environment, encompassing a broad range of matters that affect communities in the study area in a way that recognizes interrelationships, system functions and vulnerabilities;
- physical and cultural heritage, including structures, sites or things of historical, archaeological, paleontological or architectural significance that could be affected by routine project operations or accidents and malfunctions;
- the rural and urban settings that could be affected by routine project activities or accidents and malfunctions; and
- any project components and activities (e.g. exclusion zones) that may affect commercial or recreational fisheries or other uses.

The EIS should also discuss the potential to encounter unexploded ordnance (UXOs), based on consultation with the Department of National Defence.

7.2. Predicted changes to the physical environment

The EA will include a consideration of the predicted changes to the environment as a result of the project being carried out or as a result of any powers, duties or functions that are to be exercised by the federal government in relation to the project. These predicted changes to the environment are to be considered in relation to each phase of the project (e.g. drilling, testing, decommissioning, suspension, abandonment) and are to be described in terms of the magnitude, geographic extent, duration and frequency, and whether the environmental changes are reversible or irreversible. As changes to various parts of the physical environment may be inter-related as part of an ecosystem, the EIS will explain and describe the connections between the changes described.

7.3. Predicted effects on valued components

Based on the predicted changes to the environment identified in Section 6.2, the proponent is to assess the environmental effects of the project on the following VCs. All interconnections between VCs and between changes to multiple VCs will be described:

[11] The proponent should refer to Health Canada's guidance documents in order to include the appropriate baseline information relevant to human health

7.3.1. Fish and fish habitat

- the identification of any potential adverse effects to fish and fish habitat as defined in subsection 2(1) of the *Fisheries Act*, including the calculations of any potential habitat loss (temporary or permanent) in terms of surface areas (e.g. spawning grounds, fry-rearing areas, feeding). The assessment will include a consideration of:
  - ✓ effects on water quality including changes to chemical composition, temperature, oceanographic conditions, etc.;
  - ✓ the geomorphological changes and their effects on hydrodynamic conditions and fish habitats (e.g. modification of benthic habitat including corals and sensitive habitat, area affected by drilling waste, disturbance to water column);
  - ✓ the modifications of hydrological and hydrometric conditions on fish habitat and on the fish species' life cycle activities (e.g. reproduction, juvenile, rearing, and feeding, movements);
  - ✓ any potential imbalances in the food web in relation to baseline conditions;
  - ✓ underwater noise and vibration emissions from project activities (i.e. drilling, vertical seismic profiling, offshore supply vessel operation, well abandonment) and how it may affect fish health and behaviour; and
  - ✓ effects on the primary and secondary productivity of water bodies and how project-related effects may affect fish food sources.
- the effects of changes to the aquatic environment on fish and their habitat, including:
  - ✓ the anticipated changes in the composition and characteristics of the populations of various fish species, including shellfish and forage fish including mortality of fish, eggs and larvae;
  - ✓ any modifications in migration or local movements during and after project activities (e.g. vertical seismic profiling, drilling); and
  - ✓ any modifications and use of habitats by federally or provincially listed fish species at risk.
- a discussion of the effects of drilling waste disposal on fish health, marine benthos (fish habitat) and other components of the aquatic environment, recognizing that the disposal of these wastes is expected to be a primary cause of effect on benthos;
- a discussion of the length of time it would take for the benthic environment to return to baseline conditions in water depths within which the Project would occur;
- a discussion of how project timing correlates to key fisheries windows and any potential effects resulting from overlapping periods; and
- a discussion of how data examining the deposition of drilling-related wastes (e.g. fluid, mud residues, cuttings) and acoustic monitoring data could be collected during and after drilling operations and how this would be used to verify effects predictions.

7.3.2. Marine plants

- effects on marine plants, including all benthic and detached algae, marine flowering plants, brown algae, red algae, green algae and phytoplankton.

7.3.3. Marine mammals

- *effects on marine mammals, including but not limited to*:

- ✓ mortality and other effects from vessel collisions or disturbance;
- ✓ direct and indirect effects caused by increased disturbance (e.g. noise, light, vibrations) including mortality, physical injury and behavioural changes (e.g. habitat avoidance, disruption to feeding behaviour, deviation in migration routes, communication masking, and behavioural disturbance);
- ✓ exposure to spilled contaminants (e.g. fuel, oils) and operational discharges (e.g. deck drainage, gray water, black water); and
- ✓ change in marine habitat quality from drill muds and cuttings and sedimentation.

7.3.4. Marine turtles

- *effects on marine turtles, including but not limited to*:
  - ✓ mortality and other effects from vessel collisions or disturbance;
  - ✓ direct and indirect effects caused by increased disturbance (e.g. noise, light, vibrations) including mortality, physical injury and behavioural changes (e.g. habitat avoidance, disruption to feeding behaviour, deviation in migration routes, communication masking, and behavioural disturbance);
  - ✓ exposure to spilled contaminants (e.g. fuel, oils) and operational discharges (e.g. deck drainage, grey water, black water); and
  - ✓ change in marine habitat quality from drill muds and cuttings and sedimentation.

7.3.5. Migratory birds

- direct and indirect adverse effects on migratory birds, including population level effects that could be caused by project activities, including, but not limited to:
  - ✓ noise disturbance from seismic equipment including both direct effects (physiological), or indirect effects (foraging behaviour of prey species);
  - ✓ physical displacement as a result of vessel presence (e.g. disruption of foraging activities);
  - ✓ night-time illumination levels from lights and flares during different weather conditions and seasons and during different project activities (e.g. drilling, well testing) and associated nocturnal disturbance (e.g. increased opportunities for predators, attraction to the drilling unit and vessels and subsequent collision or exposure to vessel-based activities, incineration in flares, disruption of normal activities);
  - ✓ exposure to spilled contaminants (e.g. fuel, oils) and operational discharges (e.g. deck drainage, grey water, black water);
  - ✓ attraction of, and increase in, predator species as a result of waste disposal practices (i.e. sanitary and food waste) and the presence of incapacitated/dead prey near the Mobile Offshore Drilling Unit(s) or support vessels;
  - ✓ physical harm or mortality from flaring on the drilling unit or other vessel-based activities;
  - ✓ collision risk with the drilling unit and other project infrastructure;
  - ✓ the effects of oil spills in the nearshore or that reach land, on landbird species;
  - ✓ change in marine habitat quality from drill muds and cuttings and sedimentation; and
  - ✓ indirect effects caused by increased disturbance (e.g. noise, light, presence of workers), relative abundance movements and changes in migratory bird habitat.

7.3.6. Species at risk

- the potential adverse effects of the project on federally-listed species at risk and those species listed by the Committee on the Status of Endangered Wildlife in Canada classified as extirpated, endangered, threatened or of special concern (flora and fauna) and their critical habitat, including:
  - ✓ alteration of habitat (including critical habitat) features;
  - ✓ direct and indirect effects from noise, vibrations and increased exposure to contaminants of concern;
  - ✓ a discussion of migration patterns of federal species at risk and related effects (e.g. displacement, increased risk of collision); and
  - ✓ direct and indirect effects on the survival or recovery of federally listed species (list species).

7.3.7. Indigenous peoples

With respect to Indigenous peoples, a description and analysis, for each Indigenous group, of how changes to the environment caused by the project will affect the health and socio-economic conditions, physical and cultural heritage including any structure, site or thing of historical, archaeological or paleontological importance, and current use of lands and resources for traditional purposes.

Health and Socio-Economic Conditions

Baseline information gathered as part of the assessment of effects described in 5(1)(c) of CEAA 2012, as well as general information about Indigenous populations and sub-populations could inform the assessment of human health.

- The assessment of impacts to human health will be based on effects of changes to the environment on Aboriginal peoples' human health, focusing on effects on health outcomes or risks in consideration of, but not limited to, potential changes in noise exposure, current and future availability of country foods (e.g. marine species), and water quality (recreational and cultural uses).
- When risks to human health due to changes in one or more of these components are predicted, the proponent is expected to complete a Human Health Risk Assessment (HHRA) examining all exposure pathways for pollutants of concern to adequately characterize potential risks to human health.
- The proponent must provide a justification if it determines that an assessment of the potential for contamination of country foods is not required or if some contaminants are excluded from the assessment.
- Consider effects to mental and social well-being of Indigenous peoples. Where adverse health effects are predicted, any incidental effects such as effects on current use of lands and resources for traditional purposes should also be assessed.
- Consider and document how effects of changes to the environment could be different for particular sub-populations within an Indigenous group (for example, women, youth, elders, specific families);

- This assessment of impacts to human health will assess effects of changes to the environment on Indigenous peoples' socio-economic conditions, including, but not limited to:
  - ✓ the use of navigable waters (including any water used for Indigenous transport)
  - ✓ commercial fishing, hunting, and trapping activities
  - ✓ commercial outfitters
  - ✓ recreational use
  - ✓ food security[12]
  - ✓ income inequity
  - ✓ changes at the community level that affect socio-economic conditions for Indigenous peoples as result of increased population, economic activity, cost of living, among other factors
  - ✓ non-commercial / trade economy

Physical and Cultural Heritage

- This assessment will assess effects of changes to the environment on Aboriginal peoples' physical and cultural heritage, and structures, sites or things of historical, archaeological, paleontological or architectural significance to groups, including, but not limited to:
  - ✓ the loss or destruction of physical and cultural heritage
  - ✓ changes to access to physical and cultural heritage
  - ✓ changes to the cultural value or importance associated with physical and cultural heritage
  - ✓ changes to sacred, ceremonial or culturally important places, objects, or things

Current Use of Lands and Resources for Traditional Purposes

- This assessment will characterize the effects (including cumulative effects) on the use or activity (e.g. hunting, fishing, trapping, and cultural practices) as a result of the underlying changes to the environment (i.e. how will the activity change if the project proceeds), using the approach described in the Agency's guide entitled Technical Guidance for Assessing the Current Use of Lands and Resources for Traditional Purposes under CEAA 2012. This assessment should consider changes caused by the Project through changes to the environment, can cause effects to the practice of a current use or activity through the following interactions with:
  - ✓ Resources used, such as changes to the quantity, quality, and availability of resources and habitat, as well as to the sufficiency of resources required to conduct an activity or practice, including perception of effects, avoidance, and consideration of the seasonal round;
  - ✓ any changes or alterations to access into the areas used for traditional purposes and commercial fishing, including implementation of exclusion zones;
  - ✓ effects on food, social, ceremonial, and commercial fishing;
  - ✓ a discussion of how drilling activities correlates to key fisheries windows, and any potential impacts resulting from overlapping periods; and

[12] According to Health Canada and the Food and Agricultural Organisation "food security" is "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life".

- ✓ Experience by Indigenous peoples, including changes that affect the spiritual and cultural experiences of the activity or practice, as well as sense of place and wellbeing, and the applicability and transmission of Indigenous knowledge, laws, customs and traditions.

- Using the interactions listed in the above bullet, the proponent should also consider the following in their assessments:
  - ✓ the cultural value or importance associated with traditional uses or areas affected by the project (e.g. values or attributes of the area that make it important as a place for inter-generational teaching of language or traditional practices, communal gatherings, integrity of preferred traditional practice areas);
  - ✓ how timing of project activities (e.g. drilling, flaring) have the potential to interact with the timing of traditional practices, and any potential effects resulting from overlapping periods;
  - ✓ any changes to environmental quality (e.g. air, water), the sensory environment (e.g. noise, light, visual landscape), or perceived disturbance of the environment (e.g. fear of contamination of water or country foods) that could detract from use of the area or lead to avoidance of the area; and
  - ✓ an assessment of the potential to return affected areas to pre-project conditions to support traditional practices.

- Other effects of changes to the environment on groups should be reflected as necessary.

The proponent is expected to provide mitigation measures for effects of changes to the environment on Aboriginal peoples pursuant to section 5 (1)(c) of CEAA, 2012 (see Part 2, Section 7.4. of these guidelines).

7.3.8. Other valued components that may be affected as a result of a federal decision or due to effects on federal lands, another province or outside Canada

If there is the potential for a change to the environment arising as a result of a federal decision(s), for example an authorization under section 138(1) of the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Act* or section 35 of the *Fisheries Act*, the EIS should include a description of the specific project components for which a federal authorization/decision is required, and an assessment of any other VCs (not already covered in other subsections of these guidelines) that may be affected by the changes to the environment caused by these specific project components. If there is the potential for the project to result in environmental changes on federal lands (or waters), another province, or another country, then VCs of importance not already identified should be included. For example, if the project will result in the generation of greenhouse gas emissions, the EIS should include a description of the project's greenhouse gas emissions in a regional, provincial, national or international context if applicable. Suggested VCs are noted below for this project.

7.3.8.1. Air quality and greenhouse gas emissions

- comparison of anticipated air quality concentration against the Canadian Ambient Air Quality Standards (CAAQS) for fine particulate matter or other relevant federal and/or provincial criteria for other contaminants of potential concern;
- description of all methods and practices (e.g. control equipment) that will be implemented to minimize and control atmospheric emissions throughout the project life cycle. If the best

available technologies are not included in the project design, the proponent will need to provide a rationale for the technologies selected;

- an estimate of the direct greenhouse gas emissions associated with all phases of the project (i.e. including drilling, well testing and vessel and helicopter transportation) as well as any mitigation measures proposed to minimize greenhouse gas emissions. This information is to be presented by individual pollutant and should also be summarized in CO_2 equivalent per year. The proponent is responsible for the following:
  - ✓ provide an estimate of the contribution of the project emissions at the local, provincial and federal scale, and indicate the category into which the project falls in terms of the relative magnitude of its contribution to greenhouse gas emissions (project with low, medium or high emission rates);
  - ✓ provide the estimation or derivation method, and disclose, describe, and justify assumptions and emission intensity factors used;
  - ✓ compare and assess the level of estimated emissions to the regional, provincial and federal emission targets; and
  - ✓ provide information related to the project's electrical demand and sources of electrical power for equipment, i.e. the project's main source and any other additional sources (generators, etc.), as appropriate.
- changes in ambient noise levels; and
- changes in night-time light levels.

7.3.8.2. Commercial Fisheries

- effects of changes to the environment on commercial fishing activities (e.g. effects on fished species affecting fisheries success, displacement from fishing areas (e.g. exclusion zones), gear loss or damage);
- a discussion of how drilling activities correlates to key commercial fisheries windows, and any potential impacts resulting from overlapping periods;
- effects from subsea infrastructure that could be left in place (e.g. wellheads) following abandonment; and
- changes to habitat of commercial fish species (e.g. noise, water and sediment quality).

7.3.8.3. Special areas

- effects on special areas, including, but not limited to:
  - ✓ use of dispersants;
  - ✓ change to habitat quality (e.g. noise, light, water, sediment quality); and
  - ✓ change to the environmental features that define the special area (e.g. physical features, species assemblages, species abundance).

7.3.8.4. Human environment

- effects of changes to the environment on health and socio-economic conditions, physical and cultural heritage and any structure, site or thing that is of historical, archaeological, paleontological, or architectural value, including, but not limited to the following, as applicable:

- ✓ recreational activities;
- ✓ other ocean uses;
- ✓ socio-economic conditions;
- ✓ human health;
- ✓ physical and cultural heritage (e.g. shipwrecks); and
- ✓ rural and urban settings that could be affected by routine activities and/or accidents and malfunctions.

7.4. Mitigation measures

Every EA conducted under CEAA 2012 will consider measures that are technically and economically feasible and that would mitigate any significant adverse environmental effects of the project. Under CEAA 2012, mitigation measures includes measures to eliminate, reduce or control the adverse environmental effects of a designated project, as well as restitution for damage to the environment through replacement, restoration, compensation or other means. Measures will be specific, achievable, measurable and verifiable, and described in a manner that avoids ambiguity in intent, interpretation and implementation. Mitigation measures may be considered for inclusion as conditions in the EA decision statement and/or in other compliance and enforcement mechanisms provided by other authorities' permitting or licensing processes.

As a first step, the proponent is encouraged to use an approach based on the avoidance and reduction of the effects at the source. Such an approach may include the modification of the design of the project or relocation of project components.

The EIS will describe the standard mitigation practices, policies and commitments that constitute technically and economically feasible mitigation measures and that will be applied as part of standard practice regardless of location. The EIS will then describe the project's environmental protection plan and its environmental management system, through which the proponent will deliver this plan. The plan will provide an overall perspective on how potentially adverse effects would be minimized and managed over time. The EIS will further discuss the mechanisms the proponent would use to require its contractors and sub-contractors to comply with these commitments and policies and with auditing and enforcement programs.

The EIS will then describe mitigation measures that are specific to each environmental effect identified. Mitigation measures will be written as specific commitments that clearly describe how the proponent intends to implement them and the environmental outcome the mitigation measure is designed to address. The EIS will identify and describe mitigation measures to avoid, or lessen potential adverse effects on species and/or critical habitat listed under the *Species at Risk Act*. These measures will be consistent with any applicable recovery strategy and action plans. The EIS will also identify and describe mitigation measures to avoid or lessen adverse effects on listed COSEWIC species.

The EIS will specify the actions, works, minimal disturbance footprint techniques, best available technology, corrective measures or additions planned during the project's various phases to eliminate or reduce the significance of adverse effects. The EIS will also present an assessment of the effectiveness of the proposed technically and economically feasible mitigation measures. The reasons for determining if the mitigation measure reduces the significance of an adverse effect will be made explicit. The proponent is also encouraged to identify mitigation measures for effects that are adverse although not significant.

The EIS will indicate what other technically and economically feasible mitigation measures were considered, and explain why they were rejected. Trade-offs between cost savings and effectiveness of the various forms of mitigation measures will be justified. The EIS will identify who is responsible for the implementation of these measures and the system of accountability.

Where mitigation measures are proposed to be implemented for which there is little experience or for which there is some question as to their effectiveness, the potential risks and effects to the environment should those measures not be effective will be clearly and concisely described. In addition, the EIS will identify the extent to which technological innovations will help mitigate environmental effects. Where possible, it will provide detailed information on the nature of these measures, their implementation, management and the requirements of the follow-up program.

The EIS will document specific suggestions raise by each Indigenous group for mitigating the effects of changes to the environment on Aboriginal peoples (section 5(1)(c) of CEAA 2012*).* For those mitigation measures intended to address effects of changes to the environment on Aboriginal peoples, the proponent must discuss the residual effects with the Indigenous groups identified in Part 2, Section 5 of these guidelines prior to submitting the EIS.

Adaptive management is not considered as a mitigation measure, but if the follow-up program (refer to Section 8 below) indicates that corrective action is required, the proposed approach for managing the action should be identified.

7.5. Significance of residual effects

After having established the technically and economically feasible mitigation measures, the EIS will present any residual environmental effects of the project on the VCs identified in Section 7.3 above. For those VCs related to effects of changes to the environment on Aboriginal peoples, the proponent must discuss the residual effects with the Indigenous groups identified in Part 2, Section 7 of these guidelines prior to submitting the EIS. The residual effects, even if very small or deemed insignificant, will be described.

The EIS will then provide a detailed analysis of the significance of the residual environmental effects that are considered adverse following the implementation of mitigation measures, using the Agency's guidance on determining whether a project is likely to cause significant adverse environmental effects.

The EIS will identify the criteria used to assign significance ratings to any predicted adverse effects. It will contain clear and sufficient information to enable the Agency, technical and regulatory agencies, Indigenous groups, and the public to review the proponent's analysis of the significance of effects. For those predicted adverse effects that relate to effects of the changes to the environment on Aboriginal peoples, the proponent will consider the views of the Indigenous groups in the determination of the definitions of the significance criteria. The EIS will document the terms used to describe the level of significance.

The following criteria should be used in determining the significance of residual effects:

- magnitude
- geographic extent
- timing
- duration

- frequency
- reversibility
- ecological and social context[13]
- existence of environmental standards, guidelines or objectives for assessing the effect

In assessing significance against these criteria the proponent will, where possible, use relevant existing regulatory documents, environmental standards, guidelines, or objectives such as prescribed maximum levels of emissions or discharges of specific hazardous agents into the environment. The EIS will contain a section which explains the assumptions, definitions and limits to the criteria mentioned above in order to maintain consistency between the effects on each VC.

Where significant adverse effects are identified, the EIS will set out the probability (likelihood) that they will occur, and describe the degree of scientific uncertainty related to the data and methods used within the framework of this environmental analysis.

7.6. Other effects to consider

7.6.1. Effects of potential accidents or malfunctions

The failure of certain works caused by equipment malfunctions, human error or exceptional natural events (e.g. earthquake, hurricane, submarine landslide) could cause adverse environmental effects. The proponent will therefore conduct an analysis of the risks of accidents and malfunctions, determine their effects, and present preliminary emergency response measures.

Taking into account the lifespan of different project components, the proponent will identify the probability of potential accidents and malfunctions related to the project, including an explanation of how those events were identified, potential consequences (including the environmental effects as defined in section 5 of CEAA 2012), the plausible worst case scenarios and the effects of these scenarios.

This assessment will include an identification of the magnitude of an accident and/or malfunction, including the quantity, mechanism, rate, form and characteristics of the contaminants and other materials likely to be released into the environment during the accident and malfunction events and would potentially result in an adverse environmental effect as defined in section 5 of CEAA 2012.

The EIS will describe the safeguards that have been established to protect against such occurrences and the contingency and emergency response procedures that would be put in place if such events do occur.

Of particular concern with exploration drilling in the marine environment is the potential for accidental spills. This includes both low-probability, large-scale events (e.g. blowouts, either surface, sub-sea or underground) and relatively smaller-volume spills that may occur more frequently. These incidents may affect, among other things, the health and survival of plankton, fish eggs and larvae, juvenile and adult fish, marine mammals, marine birds, marine turtles, and marine invertebrates in the affected

[13] The ecological and social context within which potential environmental effects may occur should be taken into account when considering the key criteria above in relation to a particular VC, as the context may help better characterize whether adverse effects are significant.

area, which may include special areas and areas of high ecological significance. Fishing activity, including fishing by Indigenous peoples, and the commercial marketability of seafood products harvested in the Newfoundland and Labrador offshore may also be adversely affected by a spill or blowout. The effects of accidental spills and blowouts will therefore require assessment in the EIS, including fate and behaviour modelling, and hydrologic trajectory modelling for worst-case large-scale spill scenarios that may occur, including any assumptions, limitations, and formulated hypotheses, accompanied by supporting documentation of methodologies and the cumulative results of the modelling. Results should be reported in a manner that illustrates the effects of varying weather and oceanographic conditions that may occur throughout the year, and should include a projection for spills originating at the site and followed until the slick volume is reduced to a negligible amount or until a shoreline is reached. Spill scenarios should also consider potential worst–cases, including when species at risk and high concentrations of marine birds or fish are present or for areas important for reproduction. A discussion on water depth and its effect on blow-out rate and spill trajectory modelling assumptions must be provided. Where well locations have not yet been identified, points of origin selected for spill trajectory models should be conservative (e.g. selecting a potential location within the proposed drilling area that is closest to a sensitive feature or that could result in greatest effects).

Based on the results of the spill modelling and analysis in the EIS, an emergency response plan (e.g. oil spill contingency plan) for spills (small and large) and blowouts will be required. At a minimum, an outline of the emergency response plan along with key commitments is required in the EIS. Depending on the outcomes of the effects analysis, specific detail on key components of the plan will be required in the EIS. The proponent should commit to finalizing the plan in consultation with regulators prior to the application of permits. The EIS shall include a discussion on the use, availability (including nearest location), timing (testing and mobilizing) and feasibility of a capping stack to stop a blowout and resultant spills. If dispersants are to be used, the proponent shall consider associated environmental effects in the EIS (e.g. effects on marine life) and provide a plan for their use. The environmental effects of other measures outlined in the emergency response plan should also be considered (e.g. effects from in-situ burning). The EIS shall include the means by which design and/or operational procedures, including follow-up measures, will be implemented to mitigate significant adverse effects from malfunctions and/or accidental events.

The potential to encounter shallow gas pockets, and associated implications, should also be discussed.

The EIS should also consider effects of accidents in the near-shore environment (e.g. spills and ship groundings, as applicable) and of spills reaching shore; including effects on species at risk and their critical habitat, colonial nesters and concentrations of birds, and their habitat. The proponent will also demonstrate what long-term actions it would be prepared to undertake to remediate spill-affected lands and waters.

The EIS should include a summarization of the nature, extent and magnitude of spills, and accidental releases related to existing production installations and past exploration drilling programs in Atlantic Canada.

Comparisons with similar settings would also be meaningful for deep water drilling where there is very low probability but very high consequences associated with landslides.

7.6.2. Effects of the environment on the project

The EIS will take into account how local conditions and natural hazards, such as severe and/or extreme weather conditions and external events (e.g. icebergs, seismic events and submarine landslide potential), could adversely affect the project and how this in turn could result in effects to the environment (e.g. extreme environmental conditions result in malfunctions and accidental events). These events will be considered in different probability patterns (e.g. 5-year flood vs. 100-year flood).

The EIS will provide details of planning, design and construction strategies intended to minimize the potential environmental effects of the environment on the project.

7.6.3. Cumulative effects assessment

The proponent will identify and assess the project's cumulative effects using the approach described in the Agency's guidance documents related to cumulative environmental effects.

Cumulative effects are defined as changes to the environment due to the project combined with the existence of other past, present and reasonably foreseeable physical activities. Cumulative effects may result if:

- the implementation of the project may cause direct residual adverse effects on the VC, taking into account the application of technically and economically feasible mitigation measures; and,
- the same VC may be affected by other past, present and future physical activities[14].

VCs that would not be affected by the project or would be affected positively by the project can, therefore, be omitted from the cumulative effects assessment. A cumulative effect on an environmental component may, however, be important even if the assessment of the project's effects on this component reveals that the effects of the project are minor.

In its EIS, the proponent will:

- identify and provide a rationale for the VCs that will constitute the focus of the cumulative effects assessment, focussing the cumulative effects assessment on the VCs most likely to be affected by the project and other project and activities. To this end, the proponent must consider, without limiting itself thereto, the following components likely to be affected by the project:
  - ✓ fish and fish habitat,
  - ✓ migratory birds,
  - ✓ marine mammals and marine turtles,
  - ✓ species at risk,
  - ✓ marine plants,
  - ✓ special areas,
  - ✓ commercial fisheries,

[14] Definitions of these terms can be found in the Agency's technical guidance on cumulative environmental effects.

- ✓ Indigenous peoples,
- ✓ air quality and greenhouse gases, and
- ✓ human environment

- identify and justify the spatial and temporal boundaries for the cumulative effects assessment for each VC selected. The boundaries for the cumulative effects assessments will generally be different for each VC considered. These cumulative effects boundaries will also generally be larger than the boundaries for the corresponding project effects;
- identify the sources of potential cumulative effects. Specify other projects or activities that have been or that are likely to be carried out that could cause effects on each selected VC within the boundaries defined, and whose effects would act in combination with the residual effects of the project. This assessment may consider the results of any relevant study conducted by a committee established under section 73 or 74 of CEAA 2012.
- assess the cumulative effects on each VC selected by comparing the future scenario with the project and without the project. Effects of past activities (activities that have been carried out) will be used to contextualize the current state of the VC. In assessing the cumulative effects on current use of lands and resources for traditional purposes, the assessment will focus on the cumulative effects on the relevant activity (e.g. hunting, fishing, trapping).
- describe the mitigation measures that are technically and economically feasible. The proponent shall assess the effectiveness of the measures applied to mitigate the cumulative effects. In cases where measures exist that are beyond the scope of the proponent's responsibility that could be effectively applied to mitigate these effects, the proponent will identify these effects and the parties that have the authority to act. In such cases, the EIS will summarize the discussions that took place with the other parties in order to implement the necessary measures over the long term.
- determine the significance of the cumulative effects; and
- develop a follow-up program to verify the accuracy of the assessment or to dispel the uncertainty concerning the effectiveness of mitigation measures for certain cumulative effects.

The proponent is encouraged to consult with key stakeholders and Indigenous groups prior to finalizing the choice of VCs and the appropriate boundaries to assess cumulative effects.

8. SUMMARY OF ENVIRONMENTAL EFFECTS ASSESSMENT

The EIS will contain a table summarizing the following key information:

- potential environmental effects on VCs;
- proposed mitigation measures to address the effects identified above; and
- potential residual effects and the significance of the residual environmental effects.

The summary table will be used in the EA Report prepared by the Agency. An example of a format for the key summary table is provided in Appendix 1 of this document.

In a second table, the EIS will summarize all key mitigation measures and commitments made by the proponent which will more specifically mitigate any significant adverse effects of the project on VCs

(i.e. those measures that are essential to ensure that the project will not result in significant adverse environmental effects).

9. FOLLOW-UP AND MONITORING PROGRAMS

A follow-up program is designed to verify the accuracy of the effects assessment and to determine the effectiveness of the measures implemented to mitigate the adverse effects of the project. Considerations for developing a follow-up program include:

- whether the project will impact environmentally sensitive areas/VCs or protected areas or areas under consideration for protection;
- the nature of Indigenous and public concerns raised about the project;
- suggestions from Indigenous groups regarding the design of and involvement in follow-up and monitoring programs;
- incorporation of Indigenous knowledge, where available;
- the accuracy of predictions;
- whether there is a question about the effectiveness of mitigation measures or the proponent proposes to use new or unproven techniques and technology;
- the nature of cumulative environmental effects;
- the nature, scale and complexity of the program; and
- whether there was limited scientific knowledge about the effects in the EA.

The goal of a monitoring program is to ensure that proper measures and controls are in place in order to decrease the potential for environmental degradation during all phases of project development, and to provide clearly defined action plans and emergency response procedures to account for human and environmental health and safety.

9.1. Follow-up program

The duration of the follow-up program shall be as long as required to evaluate the effectiveness of the mitigation measures.

The EIS shall present a preliminary follow-up program and shall include:

- objectives of the follow-up program and the VCs targeted by the program;
- list of elements requiring follow-up;
- number of follow-up studies planned as well as their main characteristics (list of parameters to be measured, planned implementation timetable, etc.);
- intervention mechanism used in the event that an unexpected deterioration of the environment is observed;
- mechanism to disseminate follow-up results among the concerned populations;
- accessibility and sharing of data for the general population;
- opportunity for the proponent to include the participation of Indigenous groups and stakeholders on the affected territory, during the development and implementation of the program; and

- involvement of local and regional organizations in the design, implementation and evaluation of the follow-up results as well as any updates, including a communication mechanism between these organizations and the proponent.

The discussion / description of follow-up and monitoring programs relative to the currently proposed drilling program should include a short summary of the design and results/outcomes of monitoring programs that have been undertaken for previously assessed and/or completed offshore drilling programs in similar environments and how these will be factored into the verification of impact predictions and design of the follow-up and monitoring for the current exploration drilling program.

9.2. Monitoring

The proponent will prepare an environmental monitoring program for all phases of the project.

Specifically, the environmental impact statement shall present an outline of the preliminary environmental monitoring program, including the:

- identification of the interventions that pose risks to one or more of the environmental and/or VCs and the measures and means planned to protect the environment;
- identification of regulatory instruments that include a monitoring program requirement for the VCs;
- description of the characteristics of the monitoring program where foreseeable (e.g. location of interventions, planned protocols, list of measured parameters, analytical methods employed, schedule, human and financial resources required);
- description of the proponent's intervention mechanisms in the event of the observation of non-compliance with the legal and environmental requirements or with the obligations imposed on contractors by the environmental provisions of their contracts;
- guidelines for preparing monitoring reports (number, content, frequency, format) that will be sent to the authorities concerned; and
- plans to engage Indigenous groups in monitoring, where appropriate.

Appendix 1 Example - Summary Table of Environmental Assessment

						Key Criteria for Determining Significance[15]							
Valued Component affected	Area of federal jurisdiction[16] (√)	Project Activity	Potential effects	Proposed mitigation	Residual effect	*Magnitude*	*Geographical Extent*	*Timing*	*Duration*	*Frequency*	*Reversibility*	Significance of residual adverse effect	Likelihood of significance of residual adverse effect
Fish and fish habitat													
Migratory birds													
Species at risk													
Current use of land and resource for traditional purpose	√ 5(1)(c)(iii)												
Any other VCs identified													

[15] Other key criteria can be used to determine significance, as appropriate. The ecological and social context within which potential environmental effects may occur should be taken into account when considering the key criteria in relation to a particular VC, as the context may help better characterize whether adverse effects are significant.

[16] Indicate by a check mark which valued components can be considered "environmental effects" as defined in section 5 of CEAA 2012, and specify which subsection of section 5 is relevant. For example, for the VC "current use of lands and resources for traditional purposes", the appropriate cell would indicate, section 5(1)(c)(iii) of CEAA 2012.

APPENDIX B

Concordance Table

Table B.1 Concordance with Guidelines for the Preparation of an Environmental Impact Statement pursuant to the *Canadian Environmental Assessment Act, 2012* for the BHP Canada Exploration Drilling Project, BHP Petroleum (New Ventures) Corporation

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
1. INTRODUCTION	
The EIS must include a full description of the changes the project will cause to the environment that may result in adverse effects on areas of federal jurisdiction (i.e., section 5 of CEAA 2012) including changes that are directly linked or necessarily incidental to any federal decisions that would permit the project to be carried out.	Section 17.4.1 Chapters 8-16
The EIS must also include a list of the mitigation measures that the proponent proposes to undertake in order to avoid or minimize any adverse environmental effects of the project. It is the responsibility of the proponent to provide sufficient data and analysis on potential changes to the environment to ensure a thorough evaluation of the environmental effects of the project by the Agency.	Section 2.9.4 Section 17.2.1 Chapters 8-13
2. GUIDING PRINCIPLES	
2.1. Environmental assessment as a planning and decision-making tool	
EA is a process to predict environmental effects of proposed projects before they are carried out. An EA: • identifies potential adverse environmental effects; • proposes measures to mitigate adverse environmental effects; • predicts whether there will be significant adverse environmental effects, after mitigation measures are implemented; and • includes a follow-up program to verify the accuracy of the EA and the effectiveness of the mitigation measures.	Throughout the EIS Document
2.2. Public participation	
The proponent is required to provide current information about the project to the public and especially to the communities likely to be most affected by the project.	Chapter 3 Section 4.1.3
2.3. Engagement with Indigenous groups	
The proponent is expected to engage with potentially affected Indigenous groups starting as early as possible in the project planning process in order to: • Fulfil the statutory obligations of CEAA, 2012 to assess environmental effects of the proposed Project on Aboriginal peoples; and • Assist the Agency fulfilling the Crown's constitutional obligations to consult with potentially impacted Indigenous groups on potential impacts to potential or established Aboriginal or Treaty rights.	Section 3.2 Section 4.1.3
The proponent is expected to work with potentially affected Indigenous groups to establish an engagement approach.	Section 3.2
The proponent will make reasonable efforts to integrate Indigenous knowledge into the assessment of environmental effects.	Section 3.2 Section 4.1.3 Section 17.4.2 Chapters 8-16

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
2.4. Application of the precautionary approach	
The proponent will demonstrate that all aspects of the project have been examined and planned in a careful and precautionary manner in order to avoid significant adverse environmental effects	Section 4.2
3. SCOPE OF THE ENVIRONMENTAL ASSESSMENT	
3.1. Designated project	
On May 9, 2019, BHP Petroleum (New Ventures) Corporation, the proponent of the BHP Canada Exploration Drilling Project provided a project description to the Agency. Based on this project description, the Agency has determined that an EA is required under CEAA 2012 and will include the following project components and activities:	
• the mobilization, operation and demobilization of Mobile Offshore Drilling Unit(s) designed for year-round operations for the drilling, testing and abandonment of up to twenty wells in Exploration Licences 1157 and 1158 operated by BHP Petroleum (New Ventures) Corporation, including consideration of any proposed safety exclusion zones. Drilling may occur in various water depths under consideration, using Mobile Offshore Drilling Unit(s), and with multiple drilling units operating simultaneously, if applicable;	Section 2.3.1 Section 2.4.1
• vertical seismic profiling or any other in-water works (e.g. wellsite surveys) to support the specific exploration wells under consideration, but excluding surveys potentially required to support the conduct of the EA (e.g. environmental baseline surveys) and surveys related to the broader delineation of resources;	Section 2.4.2
• well evaluation and testing; and	Section 2.3.2 Section 2.4.3
• the loading, refuelling and operation of marine support vessels (i.e. for re-supply and transfer of materials, fuel, and equipment; on-site safety during drilling operations; and transport between the supply base and the drilling unit(s) and helicopter support (i.e. for crew transport and delivery of light supplies and equipment) including transportation to the drilling unit(s).	Section 2.3.3 Section 2.4.5
Note: If the proponent acquires and becomes the operator of new or additional exploration licences issued by the Canada-Newfoundland and Labrador Offshore Petroleum Board and submits corresponding information to the Agency prior to the submission of the EIS, the Agency will consider whether activities on these additional licences may be incorporated into the scope of this EA.	Noted.
3.2. Factors to be considered	
• environmental effects of the project, including the environmental effects of malfunctions or accidents that may occur in connection with the project and any cumulative environmental effects that are likely to result from the project in combination with other physical activities that have been or will be carried out;	Section 4.1.2 Chapters 8-16
• the significance of the effects referred to above;	Section 4.2.3 Section 8.4 Section 9.4 Section 10.4 Section 11.4 Section 12.4 Section13.4

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
• comments from the public;	Section 4.1 Chapter 3
• mitigation measures that are technically and economically feasible and that would mitigate any significant adverse environmental effects of the project;	Section 2.9.4 Section 8.3 Section 9.3 Section 10.3 Section 11.3 Section 12.3 Section 13.3 Section 17.2.1
• the requirements of the follow-up program in respect of the project;	Section 8.6 Section 9.6 Section 10.6 Section 11.6 Section 12.6 Section 13.6 Section 17.2.2
• the purpose of the project;	Section 2.1
• alternative means of carrying out the project that are technically and economically feasible and the environmental effects of any such alternative means;	Section 2.8
• any change to the project that may be caused by the environment; and	Section 4.6 Chapter 16
• the results of any relevant regional study pursuant to CEAA 2012.	Section 2.2
3.2.1. Changes to the environment	
Under CEAA 2012, an examination of environmental effects that result from changes to the environment as a result of the project being carried out or as a result of the federal government exercising any power duty or function that would allow the project to be carried out must be considered in the EIS.	Section 17.4 Chapters 8-13
In scoping the potential changes to the environment that may occur, the proponent should consider any potential changes in the physical environment such as changes to air quality, water quality and quantity, and physical disturbance of land that could reasonably be expected to occur.	Section 2.7.1 Section 4.1.3 Section 17.4.3

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BHP Canada Exploration Drilling Project Guidelines	EIS Reference
3.2.2. Valued components to be examined	
The proponent must conduct and focus its analysis on VCs as they relate to section 5 of CEAA 2012, including the ones identified in Section 7.3 (Part 2) of these guidelines that may be affected by changes in the environment, as well as species at risk and their critical habitat as per the requirement outlined in section 79 of the Species at Risk Act.	Section 4.1.3 Chapter 8-16
The list of VCs presented in the EIS will be completed according to the evolution and design of the project and reflect the knowledge acquired through public consultation and engagement with Indigenous groups.	Section 4.1.3 Chapter 3
The EIS will describe what methods were used to predict and assess the adverse environmental effects of the project on these VCs.	Section 4.2
The VCs will be described in sufficient detail to allow the reviewer to understand their importance and to assess the potential for environmental effects arising from the project activities.	Chapters 8-13
The EIS will provide a rationale for selecting specific VCs and for excluding any VCs or information specified in these guidelines. Challenges may arise regarding particular exclusions, so it is important to document the information and the criteria used to justify the exclusion of a particular VC or piece of information. Justification may be based on, for example, primary data collection, computer modelling, literature references, public participation or engagement with Indigenous groups, or expert input or professional judgement.	Section 4.1.3
The EIS will identify those VCs, processes, and interactions that either were identified to be of concern during any workshops or meetings held by the proponent or that the proponent considers likely to be affected by the project. In doing so, the EIS will indicate to whom these concerns are important (i.e. the public or Indigenous groups) and the reasons why, including environmental, cultural, historical, social, economic, recreational, and aesthetic considerations, and traditional knowledge. If comments are received on a component that has not been included as a VC, these comments will be summarized and the rationale for excluding the component will address the comments.	Section 4.1.3 Chapter 3
3.2.3. Spatial and temporal boundaries	
The spatial and temporal boundaries used in the EA may vary depending on the VC and will be considered separately for each VC, including for VCs related to the current use of lands and resources for traditional purposes by Aboriginal peoples, or other environmental effects referred to under paragraph 5(1)(c) of CEAA 2012. The proponent is encouraged to consult with the Agency, federal and provincial government departments and agencies, local government, and Indigenous groups, and take into account public comments when defining the spatial and temporal boundaries used in the EIS.	Section 4.1.4 Section 8.1.4 Section 9.1.4 Section 10.1.4 Section 11.1.4 Section 12.1.4 Section 13.1.4
The EIS will describe the spatial boundaries, including local and regional study areas, of each VC to be used in assessing the potential adverse environmental effects of the project and provide a rationale for each boundary. Spatial boundaries will be defined taking into account the appropriate scale and spatial extent of potential environmental effects, community knowledge and Aboriginal traditional knowledge, current or traditional land and resource use by Indigenous groups, ecological, technical, social, and cultural considerations.	Section 4.1.4 Section 8.1.4 Section 9.1.4 Section 10.1.4 Section 11.1.4 Section 12.1.4 Section 13.1.4

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
The temporal boundaries of the EA will span all phases of the project determined to be within the scope of this EA as specified under section 3.1 above. If effects are predicted after project decommissioning, this should be taken into consideration in defining boundaries. Community knowledge and Aboriginal traditional knowledge should factor into decisions around defining temporal boundaries.	Section 4.1.4 Section 8.1.4 Section 9.1.4 Section 10.1.4 Section 11.1.4 Section 12.1.4 Section 13.1.4
If the temporal boundaries do not span all phases of the project, the EIS will identify the boundaries used and provide a rationale.	Noted
4. PREPARATION AND PRESENTATION OF THE ENVIRONMENTAL IMPACT STATEMENT	
4.1. Guidance	
The proponent should consult the Agency policy and guidance on topics to be addressed in the EIS, which is available on the Agency's website, and liaise with the Agency during the planning and development of the EIS. The proponent should also consult relevant guidance from other federal departments and ensure the most up to date version is being used.	Section 1.5 Section 1.6 Section 3.1
The proponent is encouraged to engage with Indigenous groups on the planning and development of relevant sections of the EIS, including effects from changes to the environment and impacts to potential or established Aboriginal or Treaty rights as well as assessment of the environmental effects as outlined in paragraph 5(1)(c) of CEAA 2012.	Section 3.2
Submission of regulatory and technical information necessary for federal authorities to make their regulatory decisions during the conduct of the EA is at the discretion of the proponent. Although that information is not necessary for the EA decision, the proponent is encouraged to submit it concurrent with the EIS. While the EIS must outline applicable federal authorizations required for the project to proceed, the proponent must provide information relevant to the regulatory role of the federal government. It should be noted that the issuance of these other applicable federal legislative, regulatory, and constitutional requirements are within the purview of the relevant federal authorities and are subject to separate processes post EA decision.	Section 1.5 Section 1.6
4.2. Use of information	
4.2.1. Government expert advice	
The Agency will advise the proponent of the availability of pertinent information or knowledge or expert and specialist knowledge received from other federal authorities or other levels of government so that it can be incorporated into the EIS.	Noted
4.2.2. Community knowledge and Aboriginal traditional knowledge	
The proponent will incorporate into the EIS the community knowledge and Aboriginal traditional knowledge to which it has access or that is acquired through public participation and engagement with Indigenous groups, in keeping with appropriate ethical standards and obligations of confidentiality.	Section 1.6.2 Section 3.2 Section 7.4
The proponent will engage in a respectful dialogue with Indigenous groups about the collection and use of Indigenous knowledge and enter into agreements, where necessary, regarding the use of information during and after the EA. Agreement should be obtained from Indigenous groups regarding the use, management, and protection of their existing traditional knowledge information during and after	Section 3.2 Section 7.4

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
the EA. The proponent should collaborate with Indigenous groups to ensure, where possible, that the Indigenous knowledge is incorporated into the EIS in a way that is appropriate for the Indigenous group.	
The proponent will integrate Aboriginal traditional knowledge into all aspects of its assessment including both methodology (e.g. establishing spatial and temporal boundaries, defining significance criteria) and analysis (e.g. baseline characterization, effects prediction, development of mitigation measures).	Section 3.2 Section 4.1.3 Chapter 8-13
Should there be a lack of Indigenous knowledge, the proponent is still expected to seek information from other sources to complete the assessment of effects of changes to the environment on Aboriginal peoples or the assessment of impacts to rights.	Noted
4.2.3. Existing information	
In preparing the EIS, the proponent is encouraged to make use of existing information relevant to the project, if applicable. When relying on existing information to meet requirements of the EIS Guidelines, the proponent will either include the information directly in the EIS or clearly direct the reader to where it may obtain the information (i.e. through cross-referencing).	Section 4.2.4 Chapters 5-7
When relying on existing information, the proponent will also comment on how the data were applied to the project, separate factual lines of evidence from inference, and state any limitations on the inferences or conclusions that can be drawn from the existing information.	Chapters 5-7
4.2.4. Confidential information	
In implementing CEAA 2012, the Agency is committed to promoting public participation in the EA of projects and providing access to the information on which EAs are based. All documents prepared or submitted by the proponent or any other stakeholder in relation to the EA are included in the Canadian Environmental Assessment Registry and made available to the public on request. For this reason, the EIS will not contain information that: • is sensitive or confidential (i.e. financial, commercial, scientific, technical, personal, cultural or other nature), that is treated consistently as confidential, and the person affected has not consented to the disclosure; or • may cause substantial harm to a person or specific harm to the environment through its disclosure.	Confidential information is not included in the EIS
4.3. Study strategy and methodology	
Except where specified by the Agency, the proponent has the discretion to select the most appropriate methods to compile and present data, information and analysis in the EIS as long as they are justifiable and replicable.	Chapter 4
It is possible these guidelines may include matters which, in the judgement of the proponent, are not relevant or significant to the project. If such matters are omitted from the EIS, the proponent will clearly indicate it in the EIS, and provide a justification so the Agency, federal authorities, Indigenous groups, the public and any other interested party have an opportunity to comment on this decision. Where the Agency disagrees with the proponent's decision, it will require the proponent to provide the specified information.	Section 4.1
The assessment will include the following general steps:	
✓ identifying the activities and components of the project;	Section 2.3 Section 2.4
✓ predicting potential changes to the environment;	Chapters 8-16
✓ predicting and evaluating the likely effects on identified VCs;	Chapters 8-16
✓ identifying technically and economically feasible mitigation measures for any significant adverse environmental effects;	Section 2.9.4

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
	Section 8.3 Section 9.3 Section 10.3 Section 11.3 Section 12.3 Section 13.3 Section 17.2.1
✓ determining any residual environmental effects;	Section 8.3 Section 9.3 Section 10.3 Section 11.3 Section 12.3 Section 13.3 Section 17.3
✓ considering cumulative effects of the project in combination with other physical activities that have been or will be carried out; and	Section 4.4 Chapter 14
✓ determining the potential significance of any residual environmental effect following the implementation of mitigation measures.	Section 4.2.3 Section 8.4 Section 9.4 Section 10.4 Section 11.4 Section 12.4 Section 13.4 Section 17.5
For each VC, the EIS will describe the methodology used to assess project-related effects.	Section 4.2 Section 8.1 Section 9.1 Section 10.1 Section 11.1 Section 12.1 Section 13.1
The EIS could include an analysis of the pathway of the effects of environmental changes on each VC.	Section 8.3 Section 9.3 Section 10.3

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
	Section 11.3 Section 12.3 Section 13.3
The EIS will document where and how scientific, engineering, community knowledge and Aboriginal traditional knowledge were used to reach conclusions.	Chapters 8-13
Assumptions will be clearly identified and justified.	Chapters 8-13
All data, models and studies will be documented such that the analyses are transparent and reproducible.	Section 4.3 Chapters 8-15 Appendix D-F
All data collection methods will be specified. The uncertainty, reliability, sensitivity, and conservativeness of models used to reach conclusions must be indicated.	Section 4.3 Chapters 8-15 Appendix D-F
The EIS will identify all significant gaps in knowledge and understanding related to key conclusions, and the steps to be taken by the proponent to address these gaps. Where the conclusions drawn from scientific, engineering and technical knowledge are inconsistent with the conclusions drawn from Aboriginal traditional knowledge, the EIS will present each perspective on the issue and a statement of the proponent's conclusions.	Chapters 8-13
The EIS will include a description of the environment (both biophysical and human), including the components of the existing environment and environmental processes, their interrelations as well as the variability in these components, processes, and interactions over time scales appropriate to the likely effects of the project. The description will be sufficiently detailed to characterize the environment before any disturbance to the environment due to the project and to identify, assess and determine the significance of the potential adverse environmental effects of the project. These data should include results from studies done prior to any physical disruption of the environment due to project related activities. The information describing the existing environment may be provided in a stand-alone chapter of the EIS or may be integrated into clearly defined sections within the effects assessment of each VC. This analysis will include environmental conditions resulting from historical and present activities in the local and regional study areas.	Chapters 5-7
If the baseline data have been extrapolated or otherwise manipulated to depict environmental conditions in the study areas, modelling methods and equations will be described and will include calculations of margins of error and other relevant statistical information, such as confidence intervals and possible sources of error. The proponent will provide the references used in creating their approach to baseline data gathering, including identifying where appropriate, the relevant federal or provincial standards. The proponent is encouraged to discuss the timeframe and considerations for its proposed baseline data with the Agency prior to submitting its EIS.	Chapters 5-7
In describing and assessing effects to the physical and biological environment, the proponent will take an ecosystem approach that considers both scientific and community knowledge and Indigenous knowledge and perspectives regarding ecosystem health and integrity. The proponent will consider the resilience of relevant species populations, communities, and their habitats. The assessment of environmental effects on Aboriginal peoples, pursuant to paragraph 5(1)(c) of CEAA 2012, will undergo the same rigour and type of assessment as any other VC (including setting of spatial and temporal boundaries, identification and analysis of effects, identification of mitigation measures, determination of residual effects, identification and a clear explanation of the methodology used for assessing the significance of residual effects and assessment of cumulative effects).	Chapters 5-7

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
The proponent will consider the use of both primary and secondary sources of information regarding baseline information, changes to the environment and the corresponding effect on health, socio- economics, physical and cultural heritage and the current use of lands and resources for traditional purposes.	Chapters 5-7
The proponent will provide Indigenous groups the opportunity to review and provide comments on the information used for describing and assessing effects on Aboriginal peoples (further information on engaging with Indigenous groups is provided in Part 2, Section 5 of this document). The proponent will respond to the comments of Indigenous groups prior to submitting the EIS to ensure that the comments are adequately addressed. Where there are discrepancies in the views of the proponent and Indigenous groups on the information to be used in the EIS, the EIS will document these discrepancies and the rationale for the proponent's selection of information.	Section 3.2 Section 7.4
The assessment of the effects of each of the project components and physical activities, in all phases, will be based on a comparison of the biophysical and human environments between the predicted future conditions with the project and the predicted future conditions without the project. In undertaking the environmental effects assessment, the proponent will use best available information and methods. All conclusions will be substantiated. Predictions will be based on clearly stated assumptions. The proponent will describe how each assumption has been tested. With respect to quantitative models and predictions, the EIS will document the assumptions that underlie the model, the quality of the data and the degree of certainty of the predictions obtained. Where there are discrepancies in the views of the proponent and Indigenous groups, with respect to the outcomes of assessment(s), the EIS will document and provide a rationale for these discrepancies.	Section 17.4 Chapters 8-14
4.4. Presentation and organization of the environmental impact statement	
To facilitate the identification of the documents submitted and their placement in the Canadian Environmental Assessment Registry, the title page of the EIS and its related documents will contain the following information: • project name and location; • title of the document, including the term "environmental impact statement"; • subtitle of the document; • name of the proponent; and • date of submission of the EIS.	Title page
The EIS will be written in clear, precise language. A glossary defining technical words, acronyms and abbreviations will be included. The EIS will include charts, diagrams, tables, maps, and photographs, where appropriate, to clarify the text. Perspective drawings that clearly convey the various components of the project will also be provided. Wherever possible, maps will be presented in common scales and datum to allow for comparison and overlay of mapped features.	Entire EIS
Detailed studies (including all relevant and supporting data and methodologies) will be provided in separate appendices and will be referenced by appendix, section, and page in the text of the main document.	Throughout EIS and Appendices
The EIS will explain how information is organized in the document. This will include a table of contents with a list of all tables, figures, and photographs referenced in the text.	Table of Contents
A complete list of supporting literature and references will also be provided.	Throughout EIS and Appendices
A table of concordance, which cross references the information presented in the EIS with the information requirements identified in the EIS Guidelines, will be provided.	Appendix B
4.5. Summary of the environmental impact statement	

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
The proponent will prepare a summary of the EIS in both of Canada's official languages (French and English) to be provided to the Agency at the same time as the EIS that will include the following: • a concise description of all key components of the project and related activities; • a summary of the engagement with Indigenous groups, and the participation of the public and government agencies, including a summary of the issues raised and the proponent's responses; • an overview of expected changes to the environment; • an overview of the key environmental effects of the project, as described under section 5 of CEAA 2012, and proposed technically and economically feasible mitigation measures; an overview of how factors under paragraph 19(1) of CEAA 2012 were considered; • the proponent's conclusions on the residual environmental effects of the project, and the significance of those effects, after taking into account the mitigation measures.	EIS Summary
The summary is to be provided as a separate document and should be structured as follows:	EIS Summary
1. Introduction and EA context	
2. Project overview	
3. Alternative means of carrying out the project	
4. Public participation	
5. Engagement with Indigenous Groups	
6. Summary of environmental effects assessment for each VC, including: a. description of the baseline; b. anticipated changes to the environment; c. anticipated effects; d. mitigation measures; e. significance of residual effects.	
7. Follow-up and monitoring programs proposed	
The summary will have sufficient details for the reader to understand the project, any potential environmental effects, proposed mitigation measures, and the significance of the residual effects. The summary will include key maps illustrating the project location and key project components.	
Part 2 – Content of the Environmental Impact Statement	
1. INTRODUCTION AND OVERVIEW	
1.1. The proponent	
In the EIS, the proponent will: • provide contact information (e.g. name, address, phone, fax, email); • identify itself and the name of the legal entity(ies) that would develop, manage, and operate the project; • describe corporate and management structures; • specify the mechanism used to ensure that corporate policies will be implemented and respected for the project; and	Section 1.3

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
• identify key personnel, contractors, and/or sub-contractors responsible for preparing the EIS.	
1.2 Project Overview	
The EIS will describe the project, key project components and associated activities, scheduling details, the timing of each phase of the project and other key features. If the project is part of a larger sequence of projects, the EIS will outline the larger context.	Section 1.1
1.3. Project location	
The EIS will contain a description of the geographical setting in which the project will take place. This description will focus on those aspects of the project and its settings that are important in order to understand the potential environmental effects of the project. The following information will be included:	
• the Universal Transverse Mercator (UTM) projection coordinates of the main project site;	Section 2.2
• current land and resource use in the area;	Section 7.1
• distance of the project facilities and components to any federal lands;	Section 1.5.3
• the environmental significance and value of the geographical setting in which the project will take place and the surrounding area;	Chapters 5-7
• environmentally sensitive areas, such as national, provincial, and regional parks, ecological reserves, ecologically and biologically significant areas, fishery closure areas, vulnerable marine ecosystems, and habitats of federally or provincially listed species at risk and other sensitive areas;	Section 6.4
• description of local communities and Indigenous communities; and	Section 7.1 Section 7.4
• traditional territories and/or consultation areas, treaty lands, and Indian Reserve lands.	Section 3.2 Section 7.4
1.4. Regulatory framework and the role of government	
The EIS will identify:	
any federal power, duty or function that may be exercised that would permit the carrying out (in whole or in part) of the project or associated activities;	Section 1.5
legislation and other regulatory approvals that are applicable to the project at the federal, provincial, regional, and municipal levels;	Section 1.5.3
government policies, resource management plans, planning or study initiatives pertinent to the project and/or EA and their implications;	Section 1.6
any treaty, self-government, or other agreements between federal or provincial governments and Indigenous groups that are pertinent to the project and/or EA;	Section 1.6.2 Section 3.2
any relevant land use plans, land zoning, or community plans; and	Section 7.1
regional, provincial, and/or national objectives, standards or guidelines that have been used by the proponent to assist in the evaluation of any predicted environmental effects.	Section 6.4

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
2. PROJECT JUSTIFICATION AND ALTERNATIVES CONSIDERED	
2.1. Purpose of the project	
The EIS will describe the purpose of the project by providing the rationale for the project, explaining the background, the problems, or opportunities that the project is intended to satisfy and the stated objectives from the perspective of the proponent. If the objectives of the project are related to broader private or public sector policies, plans or programs, this information will also be included.	Section 2.1
The EIS will also describe the predicted environmental, economic, and social benefits of the project. This information will be considered in assessing the justifiability of any significant adverse residual environmental effects as defined in section 5 of CEAA 2012, if such effects are identified.	Section 1.4
2.2. Alternative means of carrying out the project	
The EIS will identify and consider the environmental effects of alternative means of carrying out the project that are technically and economically feasible.	Section 2.8
The proponent will complete the assessment of alternative means in accordance with the Agency's Operational Policy Statement on this topic.	Section 2.8
In its alternative means analysis, the proponent will address, at a minimum, the following project components:	
• choice of drilling fluid (i.e. water-based drilling mud or synthetic-based drilling mud); • choice of drilling unit (i.e. drillship or semi-submersible); • management of drilling wastes (i.e. disposal on seabed or into water column, recover and ship to shore, re-inject); • water management and location of the final effluent discharge points; and • alternative ways to light the platform at night (or flare at night when testing the well), to reduce attraction and associated mortality of birds, such as by installing flare shields.	Section 2.8
The EIS should include a discussion on how wastes and potential associated toxic substances would be minimized. The proponent should also discuss any alternatives that would enable it to achieve these objectives and adopt best practices in waste management and treatment.	Section 2.7 Section 2.8
With the objective of minimizing potential environmental impacts of discharges to the marine environment, the proponent should identify the quantity and type of chemicals (or constituents) that may be used in support of the proposed project that are: • included on the Canadian Environmental Protection Act's List of Toxic Substances; • not included on the OSPAR[1] Pose Little or No Risk to the Environment (PLONOR) list of chemicals and have a PARCOM[2] Offshore Chemical Notification Scheme Hazard Rating of A, B or purple, orange, blue, or white; or • not included on the PLONOR list of chemicals and have not been assigned a PARCOM Offshore Chemical Notification Scheme Hazard Rating.	Section 2.8.4
Alternatives to the use of the above-listed chemicals (e.g. through alternative means of operating or use of less-toxic alternatives) should be discussed in the EIS.	Section 2.7 Section 2.8.4

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
The Agency recognizes that projects may be in the early planning stages when the EIS is being prepared. Where the proponent has not made final decisions concerning the placement of project infrastructure, the technologies to be used, or that several options may exist for various project components, the proponent shall conduct an environmental effects analysis at the same level of detail for each of the various options available (alternative means) within the EIS.	Noted
3. PROJECT DESCRIPTION	
3.1. Project components	
The EIS will describe the project, by presenting the project components, associated and ancillary works, and other characteristics that will assist in understanding the environmental effects. This will include:	
• maps, at an appropriate scale, of the project location; • project components; • boundaries of exploration licences 1157 and 1158 with UTM coordinates; • the major existing infrastructure; • adjacent land and resource uses; and • any important environmental features.	Section 2.2 Section 2.3 Section 2.4 Section 6.4 Section 7.1 Section 7.3
If the project is part of a larger sequence of projects, the proponent will outline the larger context and present the relevant references, if available.	Noted
in its EIS, the proponent will describe:	
• the Mobile Offshore Drilling Unit(s) and their operations (drilling, testing, suspension or abandonment) in locations and water depths under consideration;	Section 2.3.1 Section 2.4.1
• navigation activities (number and frequency of trips), size and types of vessels, anticipated vessel routes and anchorages, predicted percentage of increase in vessel traffic of similar size vessels resulting from the project, icebreaking activities (time of year, frequency, duration, expected start and end dates), and ballast water management.	Section 2.3.3 Section 2.4.5
• helicopters, including routes, number, and frequency of trips;	Section 2.3.3 Section 2.4.5
• vertical seismic profiling or any other in-water works (e.g. wellsite surveys) to support the specific exploration wells under consideration, but excluding surveys potentially required to support the conduct of the EA (e.g. environmental baseline surveys) and surveys related to the broader delineation of resources;	Section 2.4.2
• well evaluation and testing;	Section 2.4.3
• reagent requirements and uses (e.g. volumes, storage, types);	Section 2.7.3 Note: drilling development has not progressed to the point where specific drilling materials have been

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
	identified to the level of source, volume, and types.
• petroleum products (e.g. source, volume, storage, types);	Section 2.7.3 Note: drilling development has not progressed to the point where specific drilling materials have been identified to the level of source, volume, and types.
• the nature, composition, and fate (e.g. areal extent) of drilling wastes (e.g. muds, cuttings) at various water depths and at various stages of drilling, including during riserless drilling and drilling with the marine riser in place, using dispersion modelling;	Section 2.7.2
• the management or disposal of wastes (e.g. type and constituents of waste, quantity, treatment, and method of disposal) including: ✓ drilling muds, drill solids; ✓ deck drainage; ✓ cooling water; ✓ bilge and ballast water; ✓ fire control system test water; ✓ operational discharges from subsea systems and the installation of subsea systems; ✓ sewage and food wastes; ✓ well treatment or testing fluids; and ✓ other operational discharges.	Section 2.7
• contributions to atmospheric emissions, including emissions profile (i.e. type, rate and source) for activities including routine or upset flaring (including the contribution from any produced fluids that may be added to any flares), routine drilling, testing, shipping etc.;	Section 2.7.1
• sources and extent of light, heat, and noise;	Section 2.7.5 Section 2.7.6
• transfers of bulk materials (e.g. mud) and fuel;	Section 2.4.5
• number of employees and transportation of employees;	Section 2.5
• drinking and industrial water requirements (source, quantity required, need for water treatment);	Section 2.7.3 Note: drilling development has not progressed to the point where specific drilling materials have been

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
	identified to the level of source, volume, and types.
• energy supply (source, quantity); and	Section 2.7.1 Note: drilling development has not progressed to the point where specific drilling materials have been identified to the level of source, volume, and types.
• waste disposal (types of waste, methods of disposal, quantity)	Section 2.7
3.2 . Project activities	
The EIS will include descriptions of the drilling, testing and decommissioning, suspension or abandonment of exploration wells associated with the proposed project.	Section 2.4
This will include descriptions of the activities to be carried out during each phase, the location of each activity, expected outputs and an indication of the activity's magnitude and scale. Water depths for potential drill sites will be specified.	Section 2.4
Although a complete list of project activities should be provided, the emphasis will be on activities with the greatest potential to have environmental effects. Sufficient information will be included to predict environmental effects and address concerns identified by the public and Indigenous groups. Highlight activities that involve periods of increased environmental disturbance or the release of materials into the environment.	Section 2.4
The EIS will include a summary of the changes that have been made to the project since originally proposed, including the benefits of these changes to the environment, Indigenous groups, and the public.	Section 1.1
The EIS will include a schedule including time of year, frequency, and duration for all project activities. The information will include a description of:	Section 2.6
3.2.1. Drilling and testing activities	
• operation of the Mobile Offshore Drilling Unit(s), including: ✓ drilling at various water depths and in locations under consideration ✓ well flow testing ✓ waste management ✓ water management	Section 2.3.1 Section 2.3.2 Section 2.4.1 Section 2.4.3 Section 2.7
• vertical seismic profile surveys;	Section 2.4.2
• flaring, including: ✓ specifics on flare tip used, including type, manufacturer and/or model;	Section 2.4.3 Section 2.7.1

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✓ all flaring activities and estimation of flared volumes; ✓ estimation of total greenhouse gas and criteria air contaminants emissions; ✓ an estimate of the contribution of the flaring emissions at the local, provincial and federal scale; ✓ justification for all estimated emissions and emission factors used; ✓ the estimation of derivation method, and a description of all assumptions and emission factors used	
• well evaluation and testing;	Section 2.4.3
• equipment requirements (type, quantity); and	Section 2.3
• storage and management of hazardous materials, fuels, and residues.	Section 2.7.4
3.2.2 Supply and servicing	
• vessel support, including loading, refuelling and operation of marine support vessels (i.e. for transfer, re-supply, and on-site safety during drilling activities); and	Section 2.3.3 Section 2.4.5
• helicopter support (i.e. crew transport and delivery of supplies and equipment).	Section 2.3.3 Section 2.4.5
3.2.3. Decommissioning, suspension, or abandonment of wells	
• the preliminary outline of a well decommissioning, suspension and abandonment plan for wells at varying water depths	Section 2.4.4
4. PUBLIC PARTICIPATION AND CONCERNS	
The EIS will describe the ongoing and proposed public participation activities that the proponent will undertake or that it has already conducted on the project. It will provide a description of efforts made to distribute project information and provide a description of information and materials that were distributed during the consultation process.	Chapter 3
The EIS will indicate the methods used, where the consultation was held, the persons and organizations consulted, the concerns voiced and the extent to which this information was incorporated in the design of the project as well as in the EIS.	Chapter 3
The EIS will provide a summary of key issues raised related to the project and its potential effects to the environment as well as describe any outstanding issues and ways to address them.	Chapter 3
5. ENGAGEMENT WITH INDIGENOUS GROUPS AND CONCERNS RAISED	
For the purposes of developing the EIS, the proponent will engage with Indigenous groups that may be affected by the project, to obtain their views on:	
• the project;	Section 3.2
• effects of changes to the environment on Aboriginal peoples (health and socio-economic conditions; physical and cultural heritage, including any structure, site or thing that is of historical, archaeological, paleontological, or architectural significance; and current use of lands and resources for traditional purposes) pursuant to paragraph 5(1)(c) of CEAA 2012; and	Section 17.4.3 Chapter 13
• potential adverse impacts of the project on potential or established Aboriginal or Treaty rights, in respect of the Crown's duty to consult, and where appropriate, accommodate Aboriginal peoples.	Section 3.2 Chapter 13

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In order to allow the Indigenous groups to engage and provide views on the above, the proponent will provide the Indigenous groups with the following timely and relevant opportunities to:	Section 3.2
• learn about the project including providing information about the proposed project (including but not limited to project design, location, potential effects, mitigation measures and follow-up and monitoring programs); and	Section 3.2 Section 7.4 Chapter 13
• provide input on the overall project; effects of changes to the environment on Aboriginal peoples pursuant to paragraph 5 (1)(c) of CEAA, 2012 and potential adverse impacts of the project on potential or established Aboriginal or Treaty rights.	Section 17.4
The proponent will structure its engagement activities to provide adequate time for groups to review and comment on the relevant information. Engagement activities are to be appropriate to the groups' needs, arranged through discussions with the groups and in keeping with established consultation protocols, where available. The EIS will describe all efforts, successful or not, taken to solicit the information required from groups to support the preparation of the EIS.	Section 3.2
With respect to engagement activities, the EIS will document:	Chapter 3 Section 3.2
• the engagement activities undertaken with each group prior to the submission of the EIS, including the date and means of engagement (e.g. meeting, mail, telephone);	
• the main issues and comments raised during the engagement activities by each group and the proponent's responses (effort should be made to collating like issues together along VCs identified in the EIS);	
• any future planned engagement activities;	
• where and how Indigenous groups' perspectives were integrated into and/or contributed to decisions regarding the project, design, operation, decommissioning, suspension abandonment, follow-up and monitoring and associated potential effects (paragraph 5(1)(c)) and the associated mitigation utilized to manage those effects. The effects and mitigation measures should be clearly linked to VCs in the EIS as well as to specific project components or activities; and	
• how engagement activities by the proponent allowed groups to understand the project and evaluate its impacts on their communities, activities, potential or established Aboriginal or Treaty rights. Where impacts are identified, provide a discussion of how those would be managed or mitigated (and provide this information for each Indigenous group separately).	
To assist with the provision of records as requested above, the Agency recommends the proponent create a tracking table of key issues raised by each Indigenous group and responses provided by the Proponent. Information provided related to potential adverse impacts on potential or established Aboriginal or Treaty rights will be considered by the Crown in meeting its common law duty to consult obligations.	
For the groups listed below, the proponent will ensure they are notified about key steps in the EIS development process and of opportunities to provide comments on key EA documents and/or information to be provided regarding their community. The proponent will ensure these groups are reflected in the baseline information and assessment of potential environmental effects as described under paragraph 5(1)(c) of CEAA 2012 and/or impacts to potential or established section 35 rights, including title and related interest in the EIS. These groups include: *Newfoundland and Labrador* • the Labrador Inuit (Nunatsiavut Government) • the Labrador Innu (Innu Nation)	Section 3.2 Section 7.4

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• the NunatuKavut Community Council *Nova Scotia* • 11 Mi'kmaq First Nation groups represented by Kwilmu'kw Maw-klusuaqn Negotiation Office (KMKNO): ✓ Acadia First Nation ✓ Annapolis Valley First Nation ✓ Bear River First Nation ✓ Eskasoni First Nation ✓ Glooscap First Nation ✓ Membertou First Nation ✓ Paqtnkek Mi'kmaw Nation ✓ Pictou Landing First Nation ✓ Potlotek First Nation ✓ Wagmatcook First Nation ✓ Waycobah First Nation • Millbrook First Nation • Sipekne'katik First Nation *New Brunswick* • eight Mi'gmaq First Nations groups represented by Mi'gmawe'l Tplu'taqnn Inc. (MTI) ✓ Fort Folly First Nation ✓ Eel Ground First Nation ✓ Pabineau First Nation ✓ Esgenoôpetitj First Nation ✓ Buctouche First Nation ✓ Indian Island First Nation ✓ Eel River Bar First Nation ✓ Metepnagiag Mi'kmaq First Nation • Elsipogtog First Nation • five Maliseet First Nation groups represented by Wolastoqey Nation in New Brunswick (WNNB) ✓ Kingsclear First Nation ✓ Madawaska Maliseet First Nation ✓ Oromocto First Nation ✓ Saint Mary's First Nation ✓ Tobique First Nation • Woodstock First Nation • Peskotomuhkati Nation at Skutik (Passamaquoddy) *Prince Edward Island* • Abegweit First Nation • Lennox Island First Nation	

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Quebec • three Mi'gmaq First Nation groups represented by Mi'gmawei Mawiomi Secretariat (MMS) ✓ Micmas of Gesgapegiag ✓ La Nation Micmac de Gespeg ✓ Listuguj Mi'gmaq Government • Les Innus de Ekuanitshit • Innu First Nation of Nutashkuan	
The groups referenced above may change as more is understood about the environmental effects of the project and/or if the project or its components change during the EA. The Agency reserves the right to alter the list of groups that the proponent will engage as additional information is gathered during the EA. In addition, for the purposes of good governance, the proponent should also provide information to and discuss potential environmental effects from the Project, as described under section 5(1)(c) of CEAA 2012, with the Qalipu Mi'kmaq First Nation Band and the Miawpukek First Nation.	Noted
6. IMPACTS TO POTENTIAL OR ESTABLISHED ABORIGINAL OR TREATY RIGHTS	
With respect to potential adverse impacts of the project on potential or established Aboriginal or Treaty rights, for each group identified in Part 2, Section 5 of these guidelines (or in subsequent correspondence from the Agency), the EIS will document:	
• potential or established Aboriginal or Treaty rights, when this information is directly provided by a group to the proponent, the Agency or is available through public records, including but not limited to: ✓ location of the right being practiced or exercised ✓ context in which the right is practiced or exercised (including information about which groups of an Indigenous group practice the right (women, elders, youth), how the right was practiced historically), ✓ how the Indigenous group's cultural traditions, laws and governance systems inform the manner in which they exercise their rights (the who, what, when, how, where and why) ✓ the Indigenous group's perspectives on the importance of the land on which the Project is located and how it intersects with any land management uses and/or plans they may have, ✓ how often the right is practiced or exercised and timing or seasonality of the practice or exercise of the right; and, ✓ maps and data sets (e.g., fish catch numbers);	Section 7.4
• potential adverse impacts of each of the project components and physical activities, in all phases, on potential or established Aboriginal or Treaty rights, including those raised by Indigenous groups.	Chapter 13
• measures identified to accommodate potential adverse impacts of the project on the potential or established Aboriginal or Treaty rights. These measures will clearly describe how the proponent intends to implement them and may go beyond mitigation measures that are developed to address potential adverse environmental effects. Include perspectives and specific suggestions raised of potentially impacted Indigenous groups; as well as any views of Indigenous groups on the effectiveness of mitigation measures.	Section 13.3

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• potential adverse impacts on potential or established Aboriginal or Treaty rights that have not been fully mitigated or accommodated as part of the EA and associated engagement with Indigenous groups. Include perspective of potentially impacted Indigenous groups; and	Section 13.3
• potential adverse impacts that may result from the residual and cumulative environmental effects. Include the perspectives of potentially impacted Indigenous groups.	Section 14.7
This information and assessment will be informed from engagement with Indigenous groups described in Part 2, Section 5 of these guidelines. The information sources, methodology and findings of the assessment of paragraph 5(1)(c) effects under CEAA 2012 may be used to inform the assessment of potential adverse impacts of the project on potential or established Aboriginal or Treaty rights. However, there may be distinctions between the adverse impacts on potential or established Aboriginal or Treaty rights and paragraph 5(1)(c) effects under CEAA 2012. The proponent will carefully consider the potential distinction between these two aspects and, where there are differences; will include the relevant information in its assessment.	Noted
7. EFFECTS ASSESSMENT	
7.1. Project setting and baseline conditions	
Based on the scope of the project described in Section 3 (Part 1), the EIS will present baseline information in sufficient detail to enable the identification of how the project could affect the VCs and an analysis of those effects. Should other VCs be identified during the conduct of the EA, the baseline condition for these components will also be described in the EIS. As a minimum, the EIS will include a description of the following environmental components.	Chapters 5-7
7.1.1. Atmospheric environment	
The EIS will describe the atmospheric environment and climate at the project site and within areas that could be affected by routine project operations or accidents and malfunctions, such as:	
• ambient air quality in the project area and in the airshed likely to be affected by the project, including consideration of the following contaminants: total suspended particulates (TSP), fine particulates smaller than 2.5 microns (PM2.5), respirable particulates of less than 10 microns (PM10), carbon monoxide (CO), sulphur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOCs), hydrogen sulfide (H2S) and any other potentially toxic air pollutants;	Section 5.4
• identify and quantify existing greenhouse gas emissions by individual pollutant measured as kilotonnes of CO_2 equivalent per year in the project study areas;	Section 5.4
• direct (e.g. emissions related to vessel traffic) and indirect sources of air emissions;	Section 5.4
• current provincial/territorial/federal limits for greenhouse gas emission targets;	Section 2.7.1
• current ambient noise levels in the project area. Information on typical sound sources, geographic extent and temporal variations will be included;	Section 2.7.5 Section 5.6
• existing ambient night-time light levels in the project area and at any other areas where project activities could have an effect on light levels. The EIS will describe night-time illumination levels during different weather conditions and seasons; and	Section 2.7.6
• historical records of relevant meteorological information (e.g. total precipitation (rain and snow); mean, maximum and minimum temperatures; and typical wind speed and direction (freezing spray; lighting; and visibility).	Section 5.3

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Particular attention should also be given to the analysis of extreme meteorological events that have the potential to result in adverse effects on the project (e.g. high wind events).	Section 5.5
Relevant marine climate data sources should be consulted, including but not limited to data from Environment and Climate Change Canada moored weather buoys and any offshore platforms operating in the Eastern Newfoundland Strategic Environmental Assessment (SEA) area. Data from the International Comprehensive Atmosphere Ocean Dataset (ICOADS), the United States of America National Oceanographic and Atmospheric Administration (NOAA) database of tropical cyclone activity in the North Atlantic, NOAA's Climate Forecast System Reanalysis (CFSR), and the Canadian Lightning Detection Network.	Section 5.3 Section 5.4 Section 5.5
7.1.2. Marine environment	
The EIS will describe the marine environment within areas that could be affected by routine project operations or by accidents and malfunctions, including:	
• marine water quality (e.g. water temperature, turbidity, salinity, and pH);	Section 5.5.4
• marine geology and geomorphology (i.e. bottom sediments, including quality, thickness, grain size, and mobility);	Section 5.1
• physical oceanography including surface and subsurface current patterns, current velocities, waves, storm surges, long shore drift processes, tidal patterns, and tide gauges levels for the site, in proximity to the site, and along the marine transportation routes with consideration of predicted climate change effects	Section 5.5
• available bathymetric information (e.g. maximum and mean water depths) for the site and along marine transportation routes if applicable	Section 5.2
• ice climate in the regional study area, including ice formation and thickness, breakup, and movement;	Section 5.7
• ice conditions along the marine transportation routes with consideration of predicted climate change and its possible effect on the timing of ice formation in the future;	Section 5.7
• fast-ice characteristics, including its surface area and seasonal stability along the marine transportation routes;	Section 5.7.1
• marine plants, including all benthic and detached algae, marine flowering plants, brown algae, red algae, green algae, and phytoplankton;	Section 6.1.4
• acoustic environment (ambient noise levels from natural sources, shipping, seismic surveys, and other sources), including information on geographic extent and temporal variations and how the acoustic environment may be affected by the project.	Section 5.6
When describing the baseline marine environment, relevant data sources such as DFO Research Vessel Surveys/Science Reports and other primary and secondary scientific literature should be consulted. In addition to data sources discussed under Atmospheric Environment and Climate (some of which contain marine data), the proponent should consult MSC50 Wind and Wave Hindcast Data, and long term gridded hourly wind and wave measurements for the North Atlantic.	Noted
7.1.3. Fish and fish habitat	
• The EIS will describe fish and fish habitat within areas that could be affected by routine project operations or by accidents and malfunctions, including:	

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• a characterization of fish populations on the basis of species and life stage, including information on the surveys carried out (e.g. location of sampling stations, catch methods, date of catches, species, catch per-unit effort) and the source of data available (e.g. government and historical databases, commercial fishing data);	Section 6.1
• a description of primary and secondary productivity in affected water bodies with a characterization of seasonal variability; and	Section 6.1.2 Section 6.1.3 Section 6.1.4
• benthic flora and fauna and their associated habitat, including sensitive features such as corals and sponges (Note: a benthic habitat survey (ROV / camera), including transects of seafloor in the area of the well locations, may be required).	Section 6.1.6
Emphasis will be placed on the waters and benthic environments likely to be affected by the project. Hence, for all areas in which effects are anticipated, the EIS will describe the biophysical water and sediment characteristics, including: • a description of the physical and biological characteristics of the fish and fish habitat likely to be directly or indirectly affected by the project; • maps, at a suitable scale, indicating the surface area of potential or confirmed fish habitats and a description of these habitats as determined by water depths, type of substrate (sediments), aquatic vegetation, and potential use (i.e. spawning, rearing, nursery, feeding, overwintering, migration routes, etc.). Where appropriate, this information should be linked to water depths (bathymetry) to identify the extent of a water body's littoral / photic zone;	Section 6.1.6 Section 6.1.10
• quality, thickness, grain size and mobility of bottom sediments; and	Section 6.1.6
• a discussion of sea bottom stability at the project site.	Section 6.1.6
Any sampling survey methods used by the proponent will be described in order to allow experts to ensure the quality of the information provided. If previous studies on the habitat in the study area were conducted, they are to be submitted with the EIS.	Noted
7.1.4. Migratory birds and their habitat	
The EIS will describe migratory and non-migratory marine birds and their habitat at the project site and within areas that could be affected by routine project operations or accidents and malfunctions.	Section 6.2
Migratory birds are protected under the Migratory Birds Convention Act (MBCA) and associated regulations. Preliminary data from existing sources will be gathered, including information such as:	Section 6.2.4
• birds and their habitats that are found or are likely to be found in the study area. This description may be based on existing sources, but supporting evidence is required to demonstrate that the data used are representative of the avifauna and habitats found in the study area. The existing data must be supplemented by surveys, if required.	Section 6.2
• abundance, distribution, and life stages of migratory and non-migratory birds likely to be affected in the project area based on existing information, or surveys, as appropriate, to provide current field data;	Section 6.2
• year-round migratory bird use of the area (e.g. winter, spring migration, breeding season, fall migration), based on preliminary data from existing sources and surveys to provide current field data if appropriate; and	Section 6.2 Section 6.2.5
• areas of concentration of migratory birds, such as for breeding, feeding or resting.	Section 6.2

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Other relevant datasets should be consulted, such as those available from the Canadian Wildlife Service (e.g. Eastern CanadianSeabirds at Sea (ECSAS), Programme intégré de recherches sur les oiseaux pélagiques (PIROP)), the Atlantic Canada ConservationData Centre (ACCDC), recovery strategies, management plans, Newfoundland and Labrador Department of Environment and ClimateChange Wildlife Division, previous petroleum operations in the area and university or other research programs, if available.	Noted
7.1.5. Species at Risk	
The EIS will describe federal species at risk and their habitat, including critical habitat, at the project site and within areas that could be affected by routine project operations or accidents and malfunctions, such as:	
• a list of all potential or known federally listed species at risk that may be affected by the project, using existing data and literature as well as surveys to provide current field data;	Section 6.1.9 Section 6.2.4 Section 6.3.7
• a list of all federal species designated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) for listing on Schedule 1 of the Species at Risk Act. This will include those species in the risk categories of extirpated, endangered, threatened and of special concern;	Section 6.1.9 Section 6.2.4, Section 6.3.7
• any published studies that describe the regional importance, abundance, and distribution of species at risk including management plans, recovery strategies and/or action plans. The existing data must be supplemented by surveys, if required;	Section 6.1.9 Section 6.2.4 Section 6.3.7
• residences, seasonal movements, movement corridors, habitat requirements, key habitat areas, identified and proposed critical habitat and/or recovery habitat (where applicable) and general life history of species at risk that may occur in the project area, or be affected by the project; and	Section 6.1.9 Section 6.2.4 Section 6.3.7
• identification of any potentially affected critical habitat as defined in the Species at Risk Act.	Section 6.1.9 Section 6.2.4 Section 6.3.7 Section 6.4.1.10
The following information sources on species at risk and species of conservation concern should be among those consulted: ✓ Species at Risk Act Registry (www.sararegistry.gc.ca); ✓ COSEWIC; ✓ Relevant government agencies; ✓ Local naturalist and interest groups; and ✓ Indigenous groups and First Nations.	Section 6.1.1 Section 6.2.1 Section 6.3.1 Section 6.4.1
7.1.6. Marine mammals	
The EIS will describe marine mammals and their habitat at the project site and within areas that could be affected by routine project operations or accidents and malfunctions, such as:	
• marine mammal species that may be present, the times of year they are present, the ranges of the species and their migration patterns; and	Section 6.3

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• important areas in the vicinity of the drilling sites or supply routes (e.g. for mating, breeding, feeding and nursing of young) or that could be impacted by the project (e.g. acoustics, spills, etc.).	Section 6.3.8
Relevant datasets should be consulted, such as DFO marine mammal sightings database, DFO Research Vessel Surveys, Scientific Reports, and other primary and secondary scientific literature.	Noted
7.1.7. Marine turtles	
The EIS will describe marine turtles and their habitat at the project site and within areas that could be affected by routine project operations or accidents and malfunctions, such as:	
• marine turtle species that may be present, the times of year they are present, the ranges of the species and their migration patterns; and	Section 6.3.6
• important areas in the vicinity of the drilling sites or supply routes (e.g. for mating, breeding, and feeding) or that could be impacted by the project (e.g. routine discharges, spills, etc.).	Section 6.3.8
7.1.8. Indigenous peoples	
The proponent shall gather and document baseline information in the EIS for each Indigenous group identified in Part 2, Section 5 of these guidelines (and any groups identified after these guidelines are finalized). The baseline information will:	
• Describe and characterize the elements in paragraph 5(1)(c) of CEAA 2012 based on the spatial and temporal scope selected for the EA according to the factors outlined in Part 1, Section 3.2.3 of this document.	Section 3.2 Section 7.4
• Characterize the regional context of each of the elements of paragraph 5(1)(c) of CEAA 2012 to support the assessment of project related effects, including consideration of the differences of experiences by sub-populations within an Indigenous group, as appropriate (for example, women, youth, elders, families) and cumulative effects.	Section 3.2 Section 7.4 Section 17.4.3
• Be sufficient to provide a comprehensive understanding of the current state of each VC related to effects of changes to the environment on Aboriginal peoples. Each of the VCs for effects of changes to the environment on Aboriginal peoples is interrelated and therefore baseline information will often overlap.	Chapters 5-7
The proponent should engage with Indigenous groups to understand where baseline information and the respective assessment fit appropriately. Note: VCs identified for biophysical assessment (such as fish and fish habitat) may contribute to assessment and conclusion of VCs related to effects of changes to the environment on Aboriginal peoples.	Section 3.2
Health and Socio-Economic Conditions	
Baseline information is required for health and socio-economic conditions. For health this includes the state of physical, mental and social well-being. For socio-economic conditions, as well as the economic and social activities of an individual Indigenous group, the baseline will include contextual information regarding their practices. Specific aspects that will be considered include:	
• general information about Indigenous populations and sub-populations;	Section 7.4
• consumption of country foods (also known as traditional foods) including food that is trapped, fished, or hunted for subsistence or medicinal purposes, outside of the commercial food chain;	Section 7.4
• which country foods are consumed by which groups, how frequently, and where these country foods are harvested;	Section 7.4

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• commercial activities (e.g. fishing, trapping, hunting, outfitting);	Section 7.4
• any project components and a description of any activities (e.g. exclusion zones) that may affect commercial fisheries or other uses;	Section 13.3
• human health, primarily with respect to potential contamination of food sources; and	Section 13.3
• recreational uses.	Section 7.4
Physical and Cultural Heritage	
Baseline information for physical and cultural heritage (including any site, structure or thing of archaeological, paleontological, historical or architectural significance) will consider all elements of cultural and historical importance to Indigenous groups in the area and is not restricted to artifacts considered under provincial heritage legislative requirements.	Section 7.4 Chapter 13
Current Use of Lands and Resources for Traditional Purposes	
Baseline information for current use of lands and resources for traditional purposes will focus on the traditional activity (e.g. hunting, fishing) and include a characterization of all attributes of the activity that can be affected by environmental change. This includes an understanding of the baseline conditions of the quality and quantity of resources (e.g. preferred species and perception of quality, cultural connections to species), access to resources (e.g. physical access, timing, seasonality, distance from community), and overall quality of the experience of the practice (e.g. noise, air quality, visual landscape, and presence of others). Specific aspects that will be considered include, but are not limited to:	
• location of traditional territory (including maps where available);	Section 3.2 Section 7.4
• location of reserves and communities;	Section 3.2 Section 7.4
• commercial and traditional fishing activity within the project's potential zone of influence, including licences and maps;	Section 7.2 Section 7.4
• fish, wildlife, birds, plants, or other natural resources and their habitats of importance for traditional use;	Section 7.4 Chapters 5-7
• places where fish, wildlife, birds, plants or other natural resources are harvested, including places that are preferred;	Section 7.4 Chapters 5-7
• access and travel routes for conducting traditional practices;	Section 7.4
• cultural values associated with the area affected by the project and the traditional uses identified;	Section 7.4
• other current uses identified by Indigenous groups.	Section 7.4
Any other baseline information that supports the analysis of predicted effects on Indigenous peoples will be included as necessary. The EIS will also indicate how input, including Indigenous knowledge, from groups was used in establishing the baseline conditions related to health and socio- economics, physical and cultural heritage and current use of lands and resources for traditional purposes.	Section 3.2 Section 7.4 Chapter 13

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Should there be a lack of Indigenous knowledge; the proponent is still expected to seek information from other sources sufficient enough to allow for a complete the assessment of effects to be presented in the EIS.	Noted
7.1.9. Other changes to the environment arising as a result of a federal decision or due to changes on federal lands, in another province or outside Canada	
Should there be the potential for a change to the environment arising as a result of a federal decision(s), or on federal lands, lands in another province or lands outside Canada, the EIS will include baseline information on the environmental component likely to be affected (if this information is not already covered in other subsections of these guidelines).	Section 17.4.2
7.1.9.1. Special areas	
The EIS will describe special areas (e.g. species at risk critical habitat that has been designated and that has been proposed or that may be under consideration, Important Bird Areas, Migratory Bird Sanctuaries, ecological reserves, etc.) at the project site and within areas that could be affected by routine project operations or accidents and malfunctions, such as:	
• Marine Protected Areas	Section 6.4.1.2
• Ecologically and Biologically Significant Areas	Section 6.4.1.7
• Fishery Closure Areas	Section 6.4.1.8
• Vulnerable Marine Ecosystems	Section 6.4.3.1
• Preliminary Representative Marine Areas	Section 6.4.1.3
The EIS will describe the distances between the edge of the project area (i.e. drill sites and marine transportation routes) and special areas. It shall state the rationale for designating specific areas as “special” (i.e. the defining environmental features of the special area).	Section 6.4
7.1.9.2. Human environment	
With respect to potential effects on the human environment, non-Indigenous people and the related VC baseline information will describe and characterize the following that could be affected by routine project operations or accidents and malfunctions. At a minimum, this should include:	
• any federal lands, lands located outside the province or Canada that may be affected by the project operations or by accidents and malfunctions;	Section 7.1
• the current and historical use of waters that may be affected by routine project operations or by accidents and malfunctions, including:	Section 7.1 Section 7.2 Section 7.3 Section 7.4
✓ current commercial and recreational fishing activity, including licence holders and species fished;	Section 7.2
✓ other ocean uses (e.g. shipping, research, oil, and gas, military, ocean infrastructure [e.g. subsea cable]);	Section 7.3
• the location of and proximity of any permanent, seasonal, or temporary residences or camps that could be affected by routine project operations or accidents and malfunctions;	Section 7.1

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• health and socio-economic conditions that could be affected by routine project operations or accidents and malfunctions, including the functioning and health of the socio-economic environment, encompassing a broad range of matters that affect communities in the study area in a way that recognizes interrelationships, system functions and vulnerabilities;	Section 7.4
• physical and cultural heritage, including structures, sites, or things of historical, archaeological, paleontological, or architectural significance that could be affected by routine project operations or accidents and malfunctions;	Section 7.4
• the rural and urban settings that could be affected by routine project activities or accidents and malfunctions; and	Section 7.1
• any project components and activities (e.g. exclusion zones) that may affect commercial or recreational fisheries or other uses.	Section 7.3
The EIS should also discuss the potential to encounter unexploded ordnance (UXOs), based on consultation with the Department of National Defence.	Section 7.2
7.2. Predicted changes to the physical environment	
The EA will include a consideration of the predicted changes to the environment as a result of the project being carried out or as a result of any powers, duties or functions that are to be exercised by the federal government in relation to the project. These predicted changes to the environment are to be considered in relation to each phase of the project (e.g. drilling, testing, decommissioning, suspension, abandonment) and are to be described in terms of the magnitude, geographic extent, duration, and frequency, and whether the environmental changes are reversible or irreversible. As changes to various parts of the physical environment may be inter-related as part of an ecosystem, the EIS will explain and describe the connections between the changes described.	Chapters 8-13
7.3. Predicted effects on valued components	
Based on the predicted changes to the environment identified in Section 6.2 above, the proponent is to assess the environmental effects of the project on the following VCs. All interconnections between VCs and between changes to multiple VCs will be described:	Chapter 8-13
7.3.1. Fish and fish habitat	
• the identification of any potential adverse effects to fish and fish habitat as defined in subsection 2(1) of the Fisheries Act, including the calculations of any potential habitat loss (temporary or permanent) in terms of surface areas (e.g. spawning grounds, fry-rearing areas, feeding). The assessment will include a consideration of:	
✓ effects on water quality including changes to chemical composition, temperature, oceanographic conditions, etc.;	Section 8.1.3
✓ the geomorphological changes and their effects on hydrodynamic conditions and fish habitats (e.g. modification of benthic habitat including corals and sensitive habitat, area affected by drilling waste, disturbance to water column);	Section 8.1.3
✓ the modifications of hydrological and hydrometric conditions on fish habitat and on the fish species' life cycle activities (e.g. reproduction, juvenile, rearing, and feeding, movements);	Section 8.1.3
✓ any potential imbalances in the food web in relation to baseline conditions;	Section 8.1.3
✓ underwater noise and vibration emissions from project activities (i.e. drilling, vertical seismic profiling, offshore supply vessel operation, well abandonment) and how it may affect fish health and behaviour;	Section 8.1.3
✓ effects on the primary and secondary productivity of water bodies and how project-related effects may affect fish food sources.	Section 8.1.3

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• the effects of changes to the aquatic environment on fish and their habitat, including:	
✓ the anticipated changes in the composition and characteristics of the populations of various fish species, including shellfish and forage fish including mortality of fish, eggs, and larvae;	Section 8.1.3
✓ any modifications in migration or local movements during and after project activities (e.g. vertical seismic profiling, drilling);	Section 8.1.3
✓ any modifications and use of habitats by federally or provincially listed fish species;	Section 8.1.3
• a discussion of the effects of drilling waste disposal on marine benthos and other components of the aquatic environment, recognizing that the disposal of these wastes is expected to be a primary cause of effect on benthos;	Section 8.3.1
• a discussion of the length of time it would take for the benthic environment to return to baseline conditions in water depths within which the Project would occur;	Section 8.3
• a discussion of how project timing correlates to key fisheries windows and any potential effects resulting from overlapping periods; and	Section 12.1.3
• a discussion of how data examining the deposition of drilling-related wastes (e.g. fluid, mud residues, cuttings) and acoustic monitoring data could be collected during and after drilling operations and how this would be used to verify effects predictions.	Section 8.6
7.3.2. Marine plants	
• effects on marine plants, including all benthic and detached algae, marine flowering plants, brown algae, red algae, green algae, and phytoplankton.	Section 8.1.3
7.3.3. Marine mammals	
• effects on marine mammals, including but not limited to:	
✓ mortality and other effects from vessel collisions or disturbance;	Section 10.1.3 Section 10.3.1 Section 10.3.2
✓ direct and indirect effects caused by increased disturbance (e.g. noise, light, vibrations) including mortality, physical injury and behavioural changes (e.g. habitat avoidance, disruption to feeding behaviour, deviation in migration routes, communication masking, and behavioural disturbance);	Section 10.1.3 Section 10.3.1 Section 10.3.2
✓ exposure to spilled contaminants (e.g. fuel, oils) and operational discharges (e.g. deck drainage, gray water, black water); and	Section 10.1.3
✓ change in marine habitat quality from drill muds and cuttings and sedimentation.	Section 10.1.3
7.3.4. Marine turtles	
• effects on marine turtles, including but not limited to:	

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✓ mortality and other effects from vessel collisions or disturbance;	Section 10.1.3 Section 10.3.1 Section 10.3.2
✓ direct and indirect effects caused by increased disturbance (e.g. noise, light, vibrations) including mortality, physical injury and behavioural changes (e.g. habitat avoidance, disruption to feeding behaviour, deviation in migration routes, communication masking, and behavioural disturbance).	Section 10.1.3 Section 10.3.1 Section 10.3.2
✓ exposure to spilled contaminants (e.g. fuel, oils) and operational discharges (e.g. deck drainage, gray water, black water); and	Section 10.1.3
✓ change in marine habitat quality from drill muds and cuttings and sedimentation.	Section 10.1.3
7.3.5. Migratory birds	
• direct and indirect adverse effects on migratory birds, including population level effects that could be caused by all project activities, including but not limited to:	
✓ noise disturbance from seismic equipment including both direct effects (physiological), or indirect effects (foraging behaviour of prey species);	Section 9.1.3
✓ physical displacement as a result of vessel presence (e.g. disruption of foraging activities);	Section 9.1.3
✓ night-time illumination levels from lights and flares during different weather conditions and seasons and during different project activities (e.g. drilling, well testing) and associated nocturnal disturbance (e.g. increased opportunities for predators, attraction to the drilling unit and vessels and subsequent collision or exposure to vessel-based activities, incineration in flares, disruption of normal activities);	Section 9.1.3
✓ exposure to spilled contaminants (e.g. fuel, oils) and operational discharges (e.g. deck drainage, grey water, black water);	Section 9.1.3
✓ attraction of, and increase in, predator species as a result of waste disposal practices (i.e. sanitary and food waste) and the presence of incapacitated/dead prey near the Mobile Offshore Drilling Unit(s) or support vessels;	Section 9.1.3
✓ physical harm or mortality from flaring on the drilling unit or other vessel-based activities;	Section 9.1.3
✓ collision risk with the drilling unit and other project infrastructure;	Section 9.1.3
✓ the effects of oil spills in the nearshore or that reach land on land bird species;	Section 9.3.2 Section 15.6.2
✓ change in marine habitat quality from drill muds and cuttings and sedimentation; and	Section 9.3.1 Section 9.3.2
✓ indirect effects caused by increased disturbance (e.g. noise, light, presence of workers), relative abundance movements and changes in migratory bird habitat.	Section 9.3.1 Section 9.3.2

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7.3.6. Species at risk	
• the potential effects of the project on federally listed species at risk and those species listed by the Committee on the Status of Endangered Wildlife in Canada classified as extirpated, endangered, threatened or of special concern (flora and fauna) and their critical habitat, including:	
✓ alteration of habitat (including critical habitat) features;	Section 8.3.3 Section 9.3.3 Section 10.3.3 Section 11.3
✓ direct and indirect effects from noise, vibrations, and increased exposure to contaminants of concern;	Section 8.3.3 Section 9.3.3 Section 10.3.3 Section 11.3
✓ a discussion of migration patterns of federal species at risk and related effects (e.g. displacement, increased risk of collision); and	Section 8.3.3 Section 9.3.3 Section 10.3.3 Section 11.3
✓ direct and indirect effects on the survival or recovery of federally listed species (list species).	Section 8.3.3 Section 9.3.3 Section 10.3.3 Section 11.3
7.3.7. Indigenous peoples	
With respect to Indigenous peoples, a description and analysis, for each Indigenous group, of how changes to the environment caused by the project will affect health and socio-economic conditions, physical and cultural heritage including any structure, site or thing of historical, archaeological or paleontological importance, and current use of lands and resources for traditional purposes.	Section 13.1.3 Section 13.3 Section 17.4.3
Health and Socio-Economic Conditions	
Baseline information gathered as part of the assessment of effects described in 5(1)(c) of CEAA 2012, as well as general information about Indigenous populations and sub-populations could inform the assessment of human health.	Noted
• The assessment of impacts to human health will be based on effects of changes to the environment on Aboriginal peoples' human health, focusing on effects on health outcomes or risks in consideration of, but not limited to, potential changes in noise exposure, current and future availability of country foods (e.g. marine species), and water quality (recreational and cultural uses).	Section 13.1.3 Section 13.3

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• When risks to human health due to changes in one or more of these components are predicted, the proponent is expected to complete a Human Health Risk Assessment (HHRA) examining all exposure pathways for pollutants of concern to adequately characterize potential risks to human health.	Section 13.1.3 Section 13.3
• The proponent must provide a justification if it determines that an assessment of the potential for contamination of country foods is not required or if some contaminants are excluded from the assessment.	Section 13.1.3 Section 13.3
• Consider effects to mental and social well-being of Indigenous peoples. Where adverse health effects are predicted, any incidental effects such as effects on current use of lands and resources for traditional purposes should also be assessed.	Section 13.1.3 Section 13.3
• Consider and document how effects of changes to the environment could be different for particular sub-populations within an Indigenous group (for example, women, youth, elders, specific families).	Section 13.1.3 Section 13.3
• The assessment of impacts to human health will assess effects of changes to the environment on Indigenous peoples' socio-economic conditions, including, but not limited to: ✓ the use of navigable waters (including any water used for Indigenous transport) ✓ commercial fishing, hunting, and trapping activities ✓ commercial outfitters ✓ recreational use ✓ food security ✓ income inequity ✓ changes at the community level that affect socio-economic conditions for Indigenous peoples as result of increased population, economic activity, cost of living, among other factors ✓ non-commercial / trade economy	Section 13.1.3 Section 13.3
Physical and Cultural Heritage	
This assessment will assess effects of changes to the environment on Aboriginal peoples' physical and cultural heritage, and structures, sites, or things of historical, archaeological, paleontological, or architectural significance to groups, including, but not limited to:	
• the loss or destruction of physical and cultural heritage	Section 13.1.3 Section 13.3
• changes to access to physical and cultural heritage	Section 13.1.3 Section 13.3
• changes to the cultural value or importance associated with physical and cultural heritage	Section 13.1.3 Section 13.3
• changes to sacred, ceremonial or culturally important places, objects, or things.	Section 13.1.3 Section 13.3
Current Use of Lands and Resources for Traditional Purposes	
• This assessment will characterize the effects (including cumulative effects) on the use or activity (e.g. hunting, fishing, trapping, and cultural practices) as a result of the underlying changes to the environment (i.e. how will the activity change if the project proceeds), using the approach described in the Agency's guide entitled *Technical Guidance for Assessing the Current Use of*	

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Lands and Resources for Traditional Purposes under CEAA 2012. This assessment should consider the following interactions with:	
✓ Resources used, such as changes to the quantity, quality, and availability of resources and habitat, as well as to the sufficiency of resources required to conduct an activity or practice, including perception of effects, avoidance, and consideration of the seasonal round;	Section 13.1.3 Section 13.3
✓ any changes or alterations to access into the areas used for traditional purposes and commercial fishing, including implementation of exclusion zones;	Section 13.1.3 Section 13.3
✓ effects on food, social, ceremonial, and commercial fishing;	Section 13.1.3 Section 13.3
✓ a discussion of how drilling activities correlates to key fisheries windows, and any potential impacts resulting from overlapping periods; and	Section 13.1.3 Section 13.3
✓ Experience by Indigenous peoples, including changes that affect the spiritual and cultural experiences of the activity or practice, as well as sense of place and wellbeing, and the applicability and transmission of Indigenous knowledge, laws, customs and traditions.	Section 13.1.3 Section 13.3
• Using the interactions listed in the above bullet, the proponent should also consider the following in their assessments:	
✓ the cultural value or importance associated with traditional uses or areas affected by the project (e.g. values or attributes of the area that make it important as a place for inter- generational teaching of language or traditional practices, communal gatherings, integrity of preferred traditional practice areas);	Section 13.1.3 Section 13.3
✓ how timing of project activities (e.g. drilling, flaring) have the potential to interact with the timing of traditional practices, and any potential effects resulting from overlapping periods;	Section 13.1.3 Section 13.3
✓ any changes to environmental quality (e.g. air, water), the sensory environment (e.g. noise, light, visual landscape), or perceived disturbance of the environment (e.g. fear of contamination of water or country foods) that could detract from use of the area or lead to avoidance of the area; and	Section 13.1.3 Section 13.3
✓ an assessment of the potential to return affected areas to pre-project conditions to support traditional practices	Section 13.1.3 Section 13.3
• Other effects of changes to the environment on groups should be reflected as necessary.	Section 13.1.3 Section 13.3
The proponent is expected to provide mitigation measures for effects of changes to the environment on Aboriginal peoples pursuant to section 5 (1)(c) of CEAA, 2012 (see Part 2, Section 7.4. of these guidelines).	Section 13.3
7.3.8. Other valued components that may be affected as a result of a federal decision or due to effects on federal lands, another province or outside Canada	
If there is the potential for a change to the environment arising as a result of a federal decision(s), for example an authorization under section 138(1) of the Canada-Newfoundland and Labrador Atlantic Accord Implementation Act or section 35 of the Fisheries Act, the EIS should include a description of the specific project components for which a federal authorization/decision is required, and an assessment of any other VCs (not already covered in other subsections of these guidelines) that may be affected by the changes to the environment caused by these specific project components. If there is the potential for the project to result in environmental changes on federal lands (or waters), another province, or another country, then VCs of importance not already identified should be included. For	Section 17.4

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example, if the project will result in the generation of greenhouse gas emissions, the EIS should include a description of the project's greenhouse gas emissions in a regional, provincial, national, or international context if applicable. Suggested VCs are noted below for this project.	
7.3.8.1. Air quality and greenhouse gas emissions	
• comparison of anticipated air quality concentration against the Canadian Ambient Air Quality Standards (CAAQS) for fine particulate matter or other relevant federal and/or provincial criteria for other contaminants of potential concern;	Section 2.7.1
• description of all methods and practices (e.g. control equipment) that will be implemented to minimize and control atmospheric emissions throughout the project life cycle. If the best available technologies are not included in the project design, the proponent will need to provide a rationale for the technologies selected;	Section 2.7.1
• an estimate of the direct greenhouse gas emissions associated with all phases of the project (i.e. including drilling, well testing and vessel and helicopter transportation) as well as any mitigation measures proposed to minimize greenhouse gas emissions. This information is to be presented by individual pollutant and should also be summarized in CO2 equivalent per year. The proponent is responsible for the following:	
✓ provide an estimate of the contribution of the project emissions at the local, provincial, and federal scale, and indicate the category into which the project falls in terms of the relative magnitude of its contribution to greenhouse gas emissions (project with low, medium, or high emission rates);	Section 2.7.1
✓ provide the estimation or derivation method, and disclose, describe, and justify all assumptions and emission intensity factors used;	Section 2.7.1
✓ compare and assess the level of estimated emissions to the regional, provincial, and federal emission targets; and	Section 2.7.1
✓ provide information related to the project's electrical demand and sources of electrical power for equipment, i.e. the project's main source and any other additional sources (generators, etc.), as appropriate.	Section 2.7.1
• changes in ambient noise levels; and	Section 2.7.5
• changes in night-time light levels.	Section 2.7.5
7.3.8.2. Commercial fisheries	
• effects of changes to the environment on commercial fishing activities (e.g. effects on fished species affecting fisheries success, displacement from fishing areas (e.g. exclusion zones), gear loss or damage);	Section 12.1.3 Section 12.3
• a discussion of how drilling activities correlates to key commercial fisheries windows, and any potential impacts resulting from overlapping periods;	Section 12.3
• effects from subsea infrastructure that could be left in place (e.g. wellheads) following abandonment; and	Section 12.3
• changes to habitat of commercial fish species (e.g. noise, water, and sediment quality).	Section 8.3 Section 12.3
7.3.8.3. Special areas	
• effects on special areas, including, but not limited to:	

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✓ use of dispersants,	Section 15.6.4
✓ change to habitat quality (e.g. noise, light, water, sediment quality); and	Section 11.3
✓ change to the environmental features that define the special area (e.g. physical features, species assemblages, species abundance).	Section 11.3
7.3.8.4. Human environment	
• effects of changes to the environment on health and socio-economic conditions, physical and cultural heritage and any structure, site or thing that is of historical, archaeological, paleontological, or architectural value, including, but not limited to the following, as applicable:	
✓ recreational activities	Section 12.3.1 Section 13.3.2
✓ other ocean uses;	Section 12.3.1
✓ socio-economic conditions;	Section 12.3.1 Section 13.3.2
✓ human health;	Section 13.3.2
✓ physical and cultural heritage (e.g. shipwrecks); and	Section 12.3.1 Section 13.3.2
✓ rural and urban settings that could be affected by routine activities and/or accidents and malfunctions.	Section 15.6.5 Section 15.6.6
7.4. Mitigation measures	
Every EA conducted under CEAA 2012 will consider measures that are technically and economically feasible and that would mitigate any significant adverse environmental effects of the project. Under CEAA 2012, mitigation measures include measures to eliminate, reduce or control the adverse environmental effects of a designated project, as well as restitution for damage to the environment through replacement, restoration, compensation, or other means. Measures will be specific, achievable, measurable, and verifiable, and described in a manner that avoids ambiguity in intent, interpretation, and implementation. Mitigation measures may be considered for inclusion as conditions in the EA decision statement and/or in other compliance and enforcement mechanisms provided by other authorities' permitting or licensing processes.	Section 2.9.4 Section 8.3 Section 9.3 Section 10.4 Section 11.4 Section 12.4 Section 13.4 Section 17.2.1
As a first step, the proponent is encouraged to use an approach based on the avoidance and reduction of the effects at the source.Such an approach may include the modification of the design of the project or relocation of project components.	Noted
The EIS will describe the standard mitigation practices, policies and commitments that constitute technically and economically feasible mitigation measures and that will be applied as part of standard practice regardless of location. The EIS will then describe the project's environmental protection plan and its environmental management system, through which the proponent will deliver this plan. The plan will provide an overall perspective on how potentially adverse effects would be minimized and managed over time. The EIS will further	Section 2.9.4 Section 8.3 Section 9.3

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discuss the mechanisms the proponent would use to require its contractors and sub-contractors to comply with these commitments and policies and with auditing and enforcement programs.	Section 10.4 Section 11.4 Section 12.4 Section 13.4 Section 17.2.1
The EIS will then describe mitigation measures that are specific to each environmental effect identified. Mitigation measures will be written as specific commitments that clearly describe how the proponent intends to implement them and the environmental outcome the mitigation measure is designed to address. The EIS will identify and describe mitigation measures to avoid, or lessen potential adverse effects on species and/or critical habitat listed under the Species at Risk Act. These measures will be consistent with any applicable recovery strategy and action plans. The EIS will also identify and describe mitigation measures to avoid or lessen adverse effects on listed COSEWIC species.	Section 2.9.4 Section 8.3 Section 9.3 Section 10.4 Section 11.4 Section 12.4 Section 13.4 Section 17.2.1
The EIS will specify the actions, works, minimal disturbance footprint techniques, best available technology, corrective measures, or additions planned during the project's various phases to eliminate or reduce the significance of adverse effects. The EIS will also present an assessment of the effectiveness of the proposed technically and economically feasible mitigation measures. The reasons for determining if the mitigation measure reduces the significance of an adverse effect will be made explicit. The proponent is also encouraged to identify mitigation measures for effects that are adverse although not significant.	Section 2.9.4 Section 8.3 Section 9.3 Section 10.4 Section 11.4 Section 12.4 Section 13.4 Section 17.2.1
The EIS will indicate what other technically and economically feasible mitigation measures were considered, and explain why they were rejected. Trade-offs between cost savings and effectiveness of the various forms of mitigation measures will be justified. The EIS will identify who is responsible for the implementation of these measures and the system of accountability.	Section 2.9.4 Section 8.3 Section 9.3 Section 10.4 Section 11.4 Section 12.4 Section 13.4 Section 17.2.1
Where mitigation measures are proposed to be implemented for which there is little experience or for which there is some question as to their effectiveness, the potential risks and effects to the environment should those measures not be effective will be clearly and concisely described. In addition, the EIS will identify the extent to which technological innovations will help mitigate environmental effects. Where possible, it will provide detailed information on the nature of these measures, their implementation, management, and the requirements of the follow-up program.	Section 2.9.4 Section 8.3 Section 9.3 Section 10.4

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	Section 11.4 Section 12.4 Section 13.4 Section 17.2.1
The EIS will document specific suggestions raise by each Indigenous group for mitigating the effects of changes to the environment on Aboriginal peoples (section 5(1)(c) of CEAA 2012). For those mitigation measures intended to address effects of changes to the environment on Aboriginal peoples, the proponent must discuss the residual effects with the Indigenous groups identified in Part 2, Section 5 of these guidelines prior to submitting the EIS.	Section 2.9.4 Section 8.3 Section 9.3 Section 10.4 Section 11.4 Section 12.4 Section 13.4 Section 17.2.1
Adaptive management is not considered as a mitigation measure, but if the follow-up program (refer to Section 8 below) indicates that corrective action is required, the proposed approach for managing the action should be identified.	Noted Section 17.2.2
7.5. Significance of residual effects	
After having established the technically and economically feasible mitigation measures, the EIS will present any residual environmental effects of the project on the VCs identified in Section 7.3 above. For those VCs related to effects of changes to the environment on Aboriginal peoples, the proponent must discuss the residual effects with the Indigenous groups identified in Part 2, Section 7 of these guidelines prior to submitting the EIS. The residual effects, even if very small or deemed insignificant, will be described.	Section 8.4 Section 9.4 Section 10.4 Section 11.4 Section 12.4 Section 13.4
The EIS will then provide a detailed analysis of the significance of the residual environmental effects that are considered adverse following the implementation of mitigation measures, using the Agency's guidance on determining whether a project is likely to cause significant adverse environmental effects.	Section 8.4 Section 9.4 Section 10.4 Section 11.4 Section 12.4 Section 13.4
The EIS will identify the criteria used to assign significance ratings to any predicted adverse effects. It will contain clear and sufficient information to enable the Agency, technical and regulatory agencies, Indigenous groups, and the public to review the proponent's analysis of the significance of effects. For those predicted adverse effects that relate to effects of the changes to the environment on Aboriginal	Section 8.4 Section 9.4 Section 10.4

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
peoples, the proponent will consider the views of the Indigenous groups in the determination of the definitions of the significance criteria. The EIS will document the terms used to describe the level of significance.	Section 11.4 Section 12.4 Section 13.4
The following criteria should be used in determining the significance of residual effects: • magnitude • geographic extent • timing • duration • frequency • reversibility • ecological and social context • existence of environmental standards, guidelines, or objectives for assessing the effect	Section 4.2.2 Section 8.3.4 Section 9.3.4 Section 10.3.4 Section 11.3.2 Section 12.3.2 Section 13.3.4
In assessing significance against these criteria, the proponent will, where possible, use relevant existing regulatory documents, environmental standards, guidelines, or objectives such as prescribed maximum levels of emissions or discharges of specific hazardous agents into the environment. The EIS will contain a section which explains the assumptions, definitions and limits to the criteria mentioned above in order to maintain consistency between the effects on each VC.	Section 8.1.6 Section 9.1.6 Section 10.1.6 Section 11.1.6 Section 12.1.6 Section 13.1.6
Where significant adverse effects are identified, the EIS will set out the probability (likelihood) that they will occur, and describe the degree of scientific uncertainty related to the data and methods used within the framework of this environmental analysis.	Section 8.4 Section 9.4 Section 10.4 Section 11.4 Section 12.4 Section 13.4
7.6. Other effects to consider	
7.6.1. Effects of potential accidents or malfunctions	
The failure of certain works caused by equipment malfunctions, human error, or exceptional natural events (e.g. earthquake, hurricane, submarine landslide) could cause major environmental effects. The proponent will therefore conduct an analysis of the risks of accidents and malfunctions, determine their effects, and present preliminary emergency response measures.	Chapter 15
Taking into account the lifespan of different project components, the proponent will identify the probability of potential accidents and malfunctions related to the project, including an explanation of how those events were identified, potential consequences (including the environmental effects as defined in section 5 of CEAA 2012), the plausible worst-case scenarios and the effects of these scenarios.	Chapter 15
This assessment will include an identification of the magnitude of an accident and/or malfunction, including the quantity, mechanism, rate, form and characteristics of the contaminants and other materials likely to be released into the environment during the accident and malfunction events and would potentially result in an adverse environmental effect as defined in section 5 of CEAA 2012.	Chapter 15

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
The EIS will describe the safeguards that have been established to protect against such occurrences and the contingency and emergency response procedures that would be put in place if such events do occur.	Section 2.3.4 Chapter 15
Of particular concern with exploration drilling in the marine environment is the potential for accidental spills. This includes both low-probability, large-scale events (e.g. blowouts, either surface, sub-sea or underground) and relatively smaller-volume spills that may occur more frequently. These incidents may affect, among other things, the health and survival of plankton, fish eggs and larvae, juvenile and adult fish, marine mammals, marine birds, marine turtles, and marine invertebrates in the affected area, which may include special areas and areas of high ecological significance. Fishing activity, including fishing by Indigenous peoples, and the commercial marketability of seafood products harvested in the Newfoundland and Labrador offshore may also be adversely affected by a spill or blowout.	Chapter 15
The effects of accidental spills and blowouts will therefore require assessment in the EIS, including fate and behaviour modelling, and hydrologic trajectory modelling for worst-case large-scale spill scenarios that may occur, including any assumptions, limitations, and formulated hypotheses, accompanied by supporting documentation of methodologies and the cumulative results of the modelling. Results should be reported in a manner that illustrates the effects of varying weather and oceanographic conditions that may occur throughout the year and should include a projection for spills originating at the site and followed until the slick volume is reduced to a negligible amount or until a shoreline is reached. Spill scenarios should also consider potential worst–cases, including when species at risk and high concentrations of marine birds or fish are present or for areas important for reproduction. A discussion on water depth and its effect on blow-out rate and spill trajectory modelling assumptions must be provided. Where well locations have not yet been identified, points of origin selected for spill trajectory models should be conservative (e.g. selecting a potential location within the proposed drilling area that is closest to a sensitive feature or that could result in greatest effects).	Chapter 15
Based on the results of the spill modelling and analysis in the EIS, an emergency response plan (e.g. oil spill contingency plan) for spills (small and large) and blowouts will be required. At a minimum, an outline of the emergency response plan along with key commitments is required in the EIS. Depending on the outcomes of the effects analysis, specific detail on key components of the plan will be required in the EIS. The proponent should commit to finalizing the plan in consultation with regulators prior to the application of permits. The EIS shall include a discussion on the use, availability (including nearest location), timing (testing and mobilizing) and feasibility of a capping stack to stop a blowout and resultant spills. If dispersants are to be used, the proponent shall consider associated environmental effects in the EIS (e.g. effects on marine life) and provide a plan for their use. The environmental effects of other measures outlined in the emergency response plan should also be considered (e.g. effects from in situ burning). The EIS shall include the means by which design and/or operational procedures, including follow-up measures, will be implemented to mitigate significant adverse effects from malfunctions and/or accidental events.	Section 15.5
The potential to encounter shallow gas pockets, and associated implications, should also be discussed.	Section 5.1.3.3 Section 16.1.1
The EIS should also consider effects of accidents in the near-shore environment (e.g. spills and ship groundings, as applicable) and of spills reaching shore; including effects on species at risk and their critical habitat, colonial nesters and concentrations of birds, and their habitat. The proponent will also demonstrate what long-term actions it would be prepared to undertake to remediate spill-affected lands and waters.	Chapter 15
The EIS should include a summarization of the nature, extent and magnitude of spills, and accidental releases related to existing production installations and past exploration drilling programs in Atlantic Canada. Comparisons with similar settings would also be meaningful for deep water drilling where there is very low probability but very high consequences associated with landslides.	Chapter 15.3

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
7.6.2. Effects of the environment on the project	
The EIS will take into account how local conditions and natural hazards, such as severe and/or extreme weather conditions and external events (e.g. icebergs, seismic events, and submarine landslide potential), could adversely affect the project and how this in turn could result in effects to the environment (e.g. extreme environmental conditions result in malfunctions and accidental events). These events will be considered in different probability patterns (e.g. 5- year flood vs. 100-year flood).	Chapter 16
The EIS will provide details of planning, design and construction strategies intended to minimize the potential environmental effects of the environment on the project.	Section 16.2
7.6.3. Cumulative effects assessment	
The proponent will identify and assess the project's cumulative effects using the approach described in the Agency's guidance documents related to cumulative environmental effects.	Chapter 14
Cumulative effects are defined as changes to the environment due to the project combined with the existence of other past, present and reasonably foreseeable physical activities. Cumulative effects may result if: • the implementation of the project may cause direct residual adverse effects on the VC, taking into account the application of technically and economically feasible mitigation measures; and, • the same VC may be affected by other past, present and future physical activities VCs that would not be affected by the project or would be affected positively by the project can, therefore, be omitted from the cumulative effects assessment. A cumulative effect on an environmental component may, however, be important even if the assessment of the project's effects on this component reveals that the effects of the project are minor.	Section 14.1
In its EIS, the proponent will:	
• Identify and provide a rationale for the VCs that will constitute the focus of the cumulative effects assessment, focusing the cumulative effects assessment on the VCs most likely to be affected by the project and other project and activities. To this end, the proponent must consider, without limiting itself thereto, the following components likely to be affected by the project: ✓ fish and fish habitat, ✓ migratory birds, ✓ marine mammals and marine turtles, ✓ species at risk, ✓ marine plants, ✓ special areas, ✓ commercial fisheries, ✓ Indigenous peoples, ✓ air quality and greenhouse gases, and ✓ human environment.	Section 14.1.1
• Identify and justify the spatial and temporal boundaries for the cumulative effects assessment for each VC selected. The boundaries for the cumulative effects assessments will generally be different for each VC considered. These cumulative effects boundaries will also generally be larger than the boundaries for the corresponding project effects;	Section 14.1.2
• Identify the sources of potential cumulative effects. Specify other projects or activities that have been or that are likely to be carried out that could cause effects on each selected VC within the boundaries defined, and whose effects would act in combination with	Section 14.1.3

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
the residual effects of the project. This assessment may consider the results of any relevant study conducted by a committee established under section 73 or 74 of CEAA 2012;	
• Assess the cumulative effects on each VC selected by comparing the future scenario with the project and without the project. Effects of past activities (activities that have been carried out) will be used to contextualize the current state of the VC. In assessing the cumulative effects on current use of lands and resources for traditional purposes, the assessment will focus on the cumulative effects on the relevant activity (e.g. hunting, fishing, trapping);	Section 14.2 Section 14.3 Section 14.4 Section 14.5 Section 14.6 Section 14.7
• Describe the mitigation measures that are technically and economically feasible. The proponent shall assess the effectiveness of the measures applied to mitigate the cumulative effects. In cases where measures exist that are beyond the scope of the proponent's responsibility that could be effectively applied to mitigate these effects, the proponent will identify these effects and the parties that have the authority to act. In such cases, the EIS will summarize the discussions that took place with the other parties in order to implement the necessary measures over the long term;	Section 14.8
• Determine the significance of the cumulative effects; and	Section 14.2 Section 14.3 Section 14.4 Section 14.5 Section 14.6 Section 14.7
• Develop a follow-up program to verify the accuracy of the assessment or to dispel any uncertainty concerning the effectiveness of mitigation measures for certain cumulative effects.	Section 14.8
The proponent is encouraged to consult with key stakeholders and Indigenous groups prior to finalizing the choice of VCs and the appropriate boundaries to assess cumulative effects.	Noted
8. SUMMARY OF ENVIRONMENTAL EFFECTS ASSESSMENT	
The EIS will contain a table summarizing the following key information:	
• potential environmental effects on VCs;	Section 17.1
• proposed mitigation measures to address the effects identified above; and	Section 17.2
• potential residual effects and the significance of the residual environmental effects.	Section 17.3
The summary table will be used in the EA Report prepared by the Agency. An example of a format for the key summary table is provided in Appendix 1 of this [EIS Guidelines] document.	Table 17.3
In a second table, the EIS will summarize all key mitigation measures and commitments made by the proponent which will more specifically mitigate any significant adverse effects of the project on VCs (i.e. those measures that are essential to ensure that the project will not result in significant adverse environmental effects).	Table 17.2

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
9. FOLLOW-UP AND MONITORING PROGRAMS	
A follow-up program is designed to verify the accuracy of the effects assessment and to determine the effectiveness of the measures implemented to mitigate the adverse effects of the project. Considerations for developing a follow-up program include: • whether the project will impact environmentally sensitive areas/VCs or protected areas or areas under consideration for protection; • the nature of Indigenous and public concerns raised about the project; • suggestions from Indigenous groups regarding the design of and involvement in follow-up and monitoring programs; • incorporation of Indigenous knowledge, where available; • the accuracy of predictions; • whether there is a question about the effectiveness of mitigation measures or the proponent proposes to use new or unproven techniques and technology; • the nature of cumulative environmental effects; • the nature, scale, and complexity of the program; and • whether there was limited scientific knowledge about the effects in the EA.	Section 17.2.2
9.1. Follow-up program	
The EIS shall present a preliminary follow-up program and shall include: • objectives of the follow-up program and the VCs targeted by the program; • list of elements requiring follow-up; • number of follow-up studies planned as well as their main characteristics (list of parameters to be measured, planned implementation timetable, etc.); • intervention mechanism used in the event that an unexpected deterioration of the environment is observed; • mechanism to disseminate follow-up results among the concerned populations; • accessibility and sharing of data for the general population; • opportunity for the proponent to include the participation of Indigenous groups and stakeholders on the affected territory, during the development and implementation of the program; and • involvement of local and regional organizations in the design, implementation and evaluation of the follow-up results as well as any updates, including a communication mechanism between these organizations and the proponent.	Section 17.2.2
The discussion / description of follow-up and monitoring programs relative to the currently proposed drilling program should include a short summary of the design and results/outcomes of monitoring programs that have been undertaken for previously assessed and/or completed offshore drilling programs in similar environments and how these will be factored into the verification of impact predictions and design of the follow up and monitoring for the current exploration drilling program.	Section 17.2.2 Details will be provided in the Environmental Protection Plan (EPP)
9.2. Monitoring	
The proponent will prepare an environmental monitoring program for all phases of the project.	Section 17.2.2 Details will be provided in the Environmental Protection Plan (EPP)

BHP Canada Exploration Drilling Project Guidelines	EIS Reference
Specifically, the environmental impact statement shall present an outline of the preliminary environmental monitoring program, including the: • identification of the interventions that pose risks to one or more of the environmental and/or VCs and the measures and means planned to protect the environment; • identification of regulatory instruments that include a monitoring program requirement for the VCs; • description of the characteristics of the monitoring program where foreseeable (e.g. location of interventions, planned protocols, list of measured parameters, analytical methods employed, schedule, human and financial resources required); • description of the proponent's intervention mechanisms in the event of the observation of non-compliance with the legal and environmental requirements or with the obligations imposed on contractors by the environmental provisions of their contracts; • guidelines for preparing monitoring reports (number, content, frequency, format) that will be sent to the authorities concerned; and • plans to engage Indigenous groups in monitoring, where appropriate.	Section 17.2.2 Details will be provided in the Environmental Protection Plan (EPP)

APPENDIX C

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APPENDIX D

Drill Cutting Dispersion Modelling Report

BHP CANADA ORPHAN BASIN REGION EXPLORATION DRILLING PROJECT 2019-2028
19-P-204068

Drill Release Risk Assessment

Drill Release Risk Assessment
BHP Orphan Basin Region
Exploration Drilling Project
2019-2028
EL 1156 & 1157
19-P-204068
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December 4, 2019

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EXECUTIVE SUMMARY

The operational release of drill cuttings and fluids were modelled to support an Environmental Impact Statement (EIS) for BHP Canada, associated with the Orphan Basin Region Exploration Drilling Project 2019-2028 The Project Area is located approximately 350 km northeast of St. John's, Newfoundland and northwest of the Flemish Pass. Water depths at the two proposed drilling sites selected for modelling are 2,338 m for site EL 1157 and 2,047 m for site EL 1158. Operational discharges from planned drilling sections were modelled as seafloor or sea surface releases, with release rate and location of the discharges in the water column depending on each drilling stage. Each of these simulations were performed for two different seasons (Fall and Summer) to evaluate how ocean current variability in the region may affect the patterns of cuttings and mud dispersion.

Discharge simulations were completed using the RPS MUDMAP modelling system. The MUDMAP model is used to predict the transport of drilling solids released in the marine environment and the resulting seabed deposition. The model inputs include information regarding the discharge characteristics (release location, rate of discharge, etc.), the properties of the sediment (particle sizes, density), as well as environmental characteristics (bathymetry and ocean currents), to predict the dispersion and transport of solids through the water column. The model output consists of the predicted three-dimensional movement and shape of the discharge plume, the concentrations of insoluble discharge components in the water column, and the accumulation of discharged solids on the seabed. The model predicts the transport of solid particles from the time of discharge or release to initial settling on the seabed. MUDMAP does not account for resuspension and transport of previously discharged solids; therefore, it provides a conservative estimate of the potential seafloor depositions.

Bathymetry was characterized using databases provided by NOAA National Geophysical Data Center and GEBCO. Currents for the North Atlantic region were acquired from the three-dimensional HYCOM (HYbrid Coordinate Ocean Model) circulation model. For this study, daily current data were obtained, and trends were analyzed for the period of January 2006 through December 2012 for the North Atlantic region. As with any hydrodynamic model, there is the potential that local currents may deviate from predictions based upon grid resolution and small-scale variability in ocean circulation dynamics. However, the data used is sufficient for this type of modelling.

In each modelled case, the deposition of muds and cuttings from operational discharges onto the seabed was controlled by the settling velocity of particles, the currents within the water column, and the depth of the water column. Modelled operational discharges from site EL 1157 (2,338 m) and site EL 1158 (2,047 m) were predicted to produce a spatially confined depositional area of up 5.45 mm thick. The difference in depth between both sites did not substantially influence the seabed deposition patterns, because only the first two sections (released at seabed) contributed to measurable thicknesses on the seafloor. Slow settling velocities associated with the fine silts/clays, which make up the largest fraction of the cuttings drilled with SBM, allowed for greater dispersion before settling out.

Summer simulations (scheduled drilling) for both sites were predicted to have weaker subsurface current regimes with greater directional variability, when compared to the fall simulations. This resulted in slightly more radial footprints for summer simulations, when compared to the more elongated results in the fall simulations. However, each predicted depositional footprint was similar in shape, size, and depositional thickness. Depositional thicknesses at or above 0.1 mm was predicted to extend up to 1.83 km to the southwest at EL 1157 and 1.86 km to the southeast at EL 1158. In total, the area exceeding a depositional thickness of 0.1 mm was predicted to be less than 0.94 km^2 for EL 1157 and 0.85 km^2 for EL 1158.The larger areal extent at EL 1157 was due to the variability of current direction during the summer season. During the first two sections of drilling, which was predicted to discharge approximately 60% of the total mass and of larger size fractions, there was a temporary shift in the currents from southeasterly to southwesterly. During all remaining drilling sections, where the remaining 40% of mass in the smaller size fractions was discharged, the currents returned to their predominant southeasterly direction. This resulted in a broader footprint that extended to the southwest. Depositional thicknesses at or above

1.5 mm were predicted to extend to the southwest up to approximately 0.36 km covering 0.11 km^2 at EL 1157 and to the southeast 0.47 km covering 0.12 km^2 at EL 1158. Maximum depositional thicknesses of 3.37 and 4.75 mm were predicted at EL 1157 and EL 1158, respectively. Again, the reduced distance, areal extent, and thickness predicted at EL 1157 is the result of the currents shifting direction over the course of drilling. Depositional thicknesses at or above 6.5 mm did not occur at either site or for either seasonal scenario.

Fall simulations (alternate drilling) for both sites were characterized by stronger subsurface current regimes, which led to slightly more elongated depositional footprints, when compared to summer scenarios. Depositional thicknesses at or above 0.1 mm were predicted to extend to the southeast for both locations up to approximately 2.08 km at EL 1157 and 2.28 km at EL 1158. In total, the area exceeding a depositional thickness of 0.1 mm was predicted to be less than 0.86 km^2 at EL 1157 and 0.90 km^2 at EL 1158. Depositional thicknesses at or above 1.5 mm were predicted to extend southeast up to approximately 0.45 km covering 0.12 km^2 at EL 1157 and 0.58 km covering 0.12 km^2 at EL 1158. Maximum depositional thicknesses of 5.45 and 4.18 mm were predicted at EL 1157 and EL 1158, respectively. Depositional thicknesses at or above 6.5 mm did not occur at either site or for either seasonal scenario.

The variations within predicted results between simulations were due to three main factors including: 1) settling velocity associated with different release substances, 2) current patterns (i.e. velocity) and 3) release height relative to the seabed. The discharges modelled in this study may be considered representative of other potential discharges in the Project Area, as the depth of the sites (~2,000 m) are similar in depth to other potential sites within the Project Area. While this dispersion modelling targeted the most likely drilling window for the Project (July-August), it also focused on an alternate season (October-November) as well. These two targeted seasons may be used to bound the variability in depositional footprints and predicted results may be applicable outside of this temporal window.

Document Summary

This report includes an introduction describing the region, a description of the modelling approach, and the results of the study. The model results are summarized in figures and tables in the main body of this document, describing the potential for WBM and SBM contamination within the water column and on the seabed. This document is broken down into several sections. Section 1 includes an introduction to the modelling study and a description of project area. Section 2 includes the modelling approach using the MUDMAP model, scenarios, and a description of the model input data. Section 3 summarizes the seabed deposition and water column concentration model results. Section 4 provides conclusions and discussion points. Section 5 contains the references cited. Additional information may be found in supporting Appendix A, which provides a detailed description of the MUDMAP model, fates processes, and algorithms used.

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LIST OF ACRONYMS AND ABBREVIATIONS

Term	Definition
3D	Three-dimensional referring to x, y, and z directions (i.e. latitude, longitude, and depth)
EIS	Environmental Impact Statement
GEBCO	The General Bathymetric Chart of the Oceans operated by the International Hydrographic Organization (IHO) and Intergovernmental Oceanographic Commission (IOC) of UNESCO.
HYCOM	The U.S. Navy HYbrid Coordinate Ocean Model used for currents
MICOM	Miami Isopycnic-Coordinate Ocean Model
MODU	Mobile Offshore Drilling Unit
NCODA	U.S. Navy Coupled Ocean Data Assimilation
NOAA	National Oceanic and Atmospheric Administration
NRC	U.S. National Research Council
NRDA	The U.S. Natural Resource Damage Assessment
PSD	Particle Size Distribution
SBM	Synthetic based mud

1 INTRODUCTION

RPS conducted drilling discharge modelling of operational releases of drill cuttings, water based mud (WBM), and synthetic based mud (SBM) in support of an Environmental Impact Statement (EIS) for the BHP Canada Orphan Basin Region Exploration Drilling Project 2019-2028. The Project Area is located approximately 350 km northeast of St. John's, Newfoundland including portions of the northern Flemish Pass. Water depth at the proposed drilling sites selected for modelling span 2,000-2,400 m. Major currents, including the Labrador Current and its inner and outer branch, influence the circulation and biological productivity in this region.

Simulations of operational releases of WBM and drill cuttings were completed using the RPS MUDMAP modelling system (Spaulding et al., 1994). MUDMAP predicts the transport of drilling solids released in the marine environment and the resulting seabed deposition. The model requires inputs describing: (i) the physical characteristics of the discharged effluent, (ii) the discharge timing and release location, and (iii) information describing the receiving waters (bathymetry, density structure, ocean currents). Model output includes estimates of environmental loadings to the seabed (deposition) from discharges associated with offshore drilling. A technical description of the MUDMAP model is included in Appendix A.

1.1 Project Area

Newfoundland is comprised of a series of islands off the east coast of Canada, and along with Labrador forms the easternmost Canadian province. The relatively shallow waters of the continental shelf extend eastward into the Northwest Atlantic Ocean, up to 500 km off the Newfoundland coast. The hypothetical modelled release location is within the Orphan Basin Exploration Drilling Project Area, located approximately 350 km northeast of St. John's, Newfoundland (Table 1-1 and Figure 1-1). Water depth at the proposed drilling sites selected for modelling are 2,338 m for EL 1157 and 2,047 m for EL 1158. This biologically productive region sits atop substantial petroleum resources, with the Hibernia and White Rose fields approximately 250 km to the south. Bathymetry within the area ranges between approximately 2,000-2,400 m deep. However, regions within the broader model domain do exceed 4,500 m deep, in regions such as the Laurentian Basin, Bonnition Basin, and the abyssal plain east of the Flemish Cap. The model domain extends from 42°N to 57°N and 40°W to 52°W, encompassing Canadian and international waters.

Table 1-1. Hypothetical release location within the Orphan Basin Exploration Drilling Project Area.

Site Name	Latitude	Longitude	Water Depth (m)
EL 1157	48°49'33.2" N	47°51'4.4" W	2,338
EL 1158	48°29'30.4" N	48°03'58.2" W	2,047

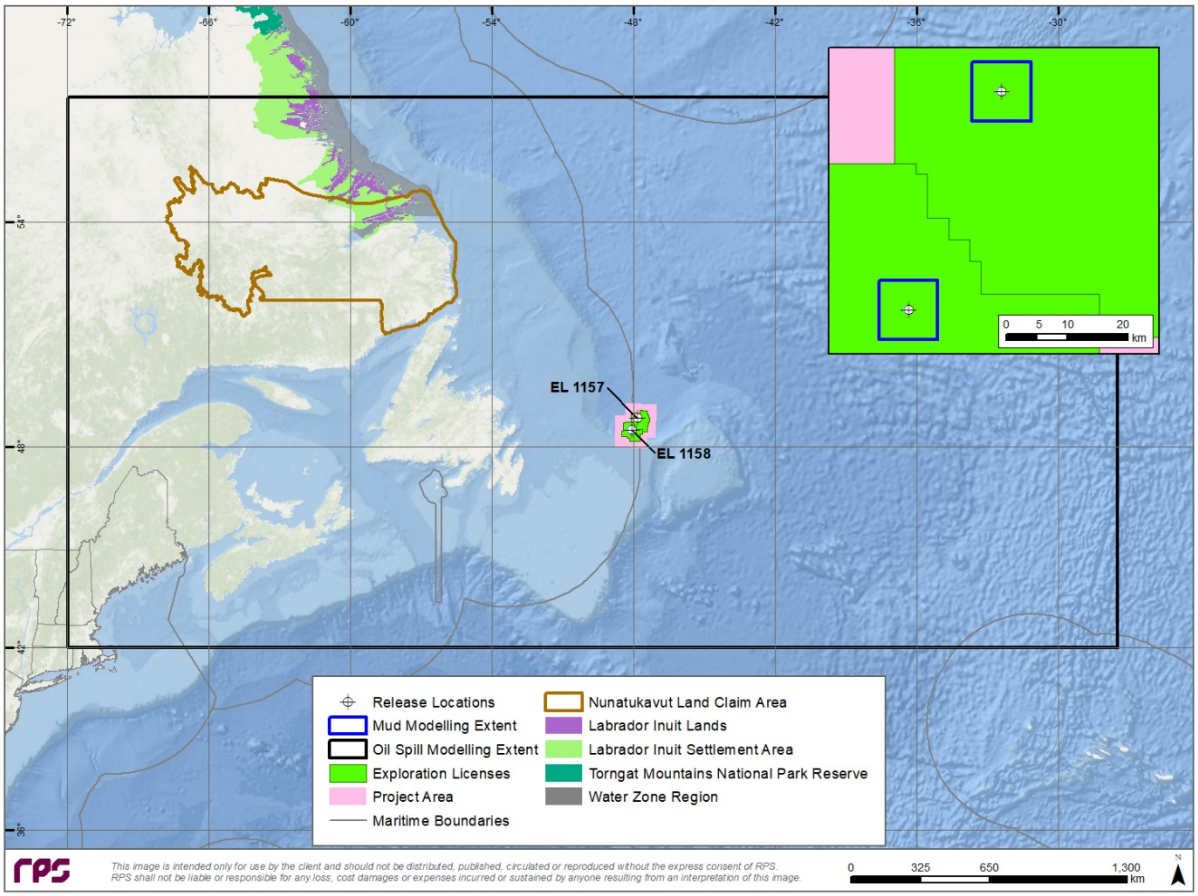

Figure 1-1. Site overview, including the two hypothetical release locations for EL 1157 and EL 1158. The smaller pink box represents the Project Area.

1.2 Circulation and Currents

The Labrador Current dominates the large-scale ocean circulation in the Newfoundland region, originating in the Arctic Ocean and flowing south along the coasts of Labrador and then Newfoundland (Figure 1-2). This southerly current intensifies as waters funnel through the offshore branch, which follows the Flemish Pass between the Grand Banks and Flemish Cap. To a lesser extent, a portion of the Labrador Current flows through an inshore branch, which follows the Avalon Channel between Newfoundland and the Grand Banks. Over parts of the Grand Banks, currents can be generally weak and flow southward (Fuller and Myers, 2014). Maximum current speeds in the upper 200 m of the water column range from 0.3 – 2.0 m/s (C-NLOPB, 2014). The strong southerly current dominates the yearly average flow and winds may only account for approximately 10% of current variability in this region (Petrie and Isenor, 1985). South of the Flemish Pass, the Labrador Current mixes with the North Atlantic current. The boundary where these two currents converge produces extremely energetic and variable frontal systems and eddies on smaller scales, on the order of kilometers (Volkov, 2005). Due to these eddies, local transport may advect parcels of water in nearly any direction. Satellite and drifter studies of current dynamics demonstrate this complexity; however, drifting parcels generally move to the south and east (Han and Tang, 1999; Petrie and Anderson, 1983; Richardson, 1983) where they intersect with the North Atlantic current.

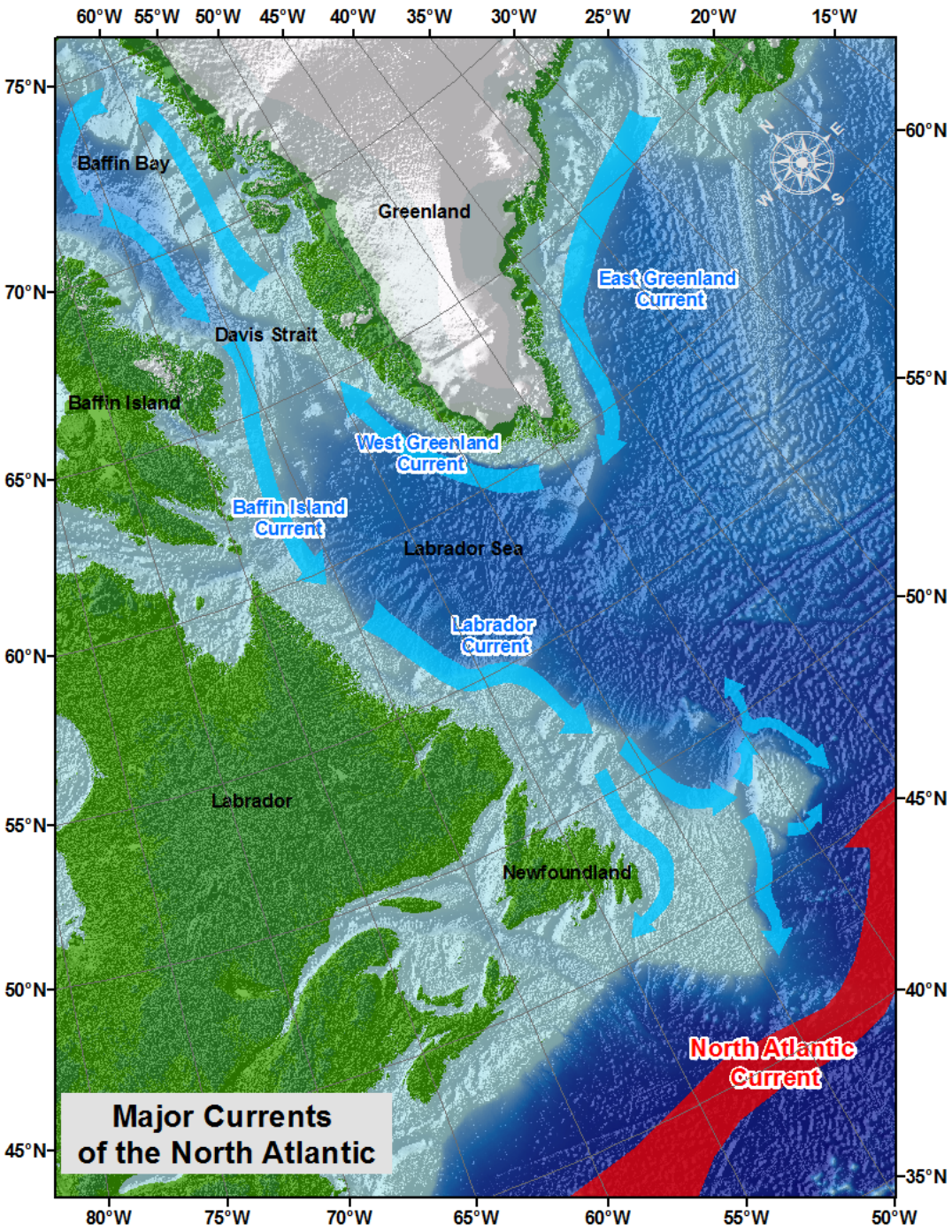

Figure 1-2. Large scale ocean currents in the Newfoundland region (USCG, 2009).

Currents for the North Atlantic region were acquired from the HYCOM (HYbrid Coordinate Ocean Model) circulation model. HYCOM is a primitive-equation ocean general circulation model that evolved from the Miami Isopycnic-Coordinate Ocean Model (MICOM) (Halliwell, 2002; Halliwell et al., 1998, 2000; Bleck, 2002). The HYCOM global ocean system is a 3D dynamic model and uses Mercator projections between 78° S and 47° N, and a bipolar patch for regions north of 47° N, to avoid computational problems associated with the convergence

of the meridians at the pole. The 1/12° equatorial resolution provides gridded ocean data with an average spacing of ~7-8 km between each point. Data is assimilated through the Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings, 2005). The NCODA system employs a Multi-Variate Optimal Interpolation scheme, which uses model forecasts as a first guess and then refines estimates from available satellite and in-situ temperature and salinity data that are applied through the water column using a downward projection of surface information (Cooper and Haines, 1996; Fox et al., 2002). The HYCOM model is updated regularly, which may result in differences in predicted currents based upon the HYCOM model calculations themselves, as opposed to environmental variability. A seven-year timespan was run using the latest HYCOM model in a process known as a re-analysis. Data for the period from 2006-2012 were acquired and is the most recent set of HYCOM re-analysis that uses a single HYCOM model. Bathymetry is derived the General Bathymetric Chart of the Oceans (GEBCO; Supporting Volume to the GEBCO Digital Atlas, 1994). Forcing for the model comes from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR, Saha et al., 2010).

The HYCOM surface current pattern for the area of interest for the period of 2006-2012 illustrates that the sites are very close to the location where Labrador Current divides into two branches near Flemish Cap (Figure 1-3). The monthly current roses of HYCOM at EL 1157 illustrate that predominant current direction is to the southeast during much of the year, and especially from January through March. However, current direction can be variable, especially during late summer and fall periods (Figure 1-4). The current direction at EL 1158 is more stable than that of EL 1157 and remains to the east-southeast for most of the year (Figure 1-5). Monthly surface current speeds (cm/s) derived from the HYCOM model at both sites are moderate, with monthly average current speeds between 20 and 40 cm/s and 95th percentile current speeds between 40 and 100 cm/s (Figure 1-6). Vertical current profiles and current roses for EL 1157 and EL 1158 are presented in Figure 1-7 and Figure 1-8, respectively. The figures compare the distribution of flow at various depths interpolated from the HYCOM nodes that contain the drilling sites. In addition, timeseries of horizontal current vectors (in cm/s) at five different depths for each location are used to portray variability in current speed and direction at different water levels (Figure 1-9 and Figure 1-10). Both the vertical profiles and the current vectors illustrate that the current speed decreases as the depth increases. Subsurface currents are predominantly to the southeast for both EL 1157 and EL 1158 and there is little variation in direction throughout the water column.

All figures display current data in the oceanographic convention, indicating the direction in which currents are flowing towards.

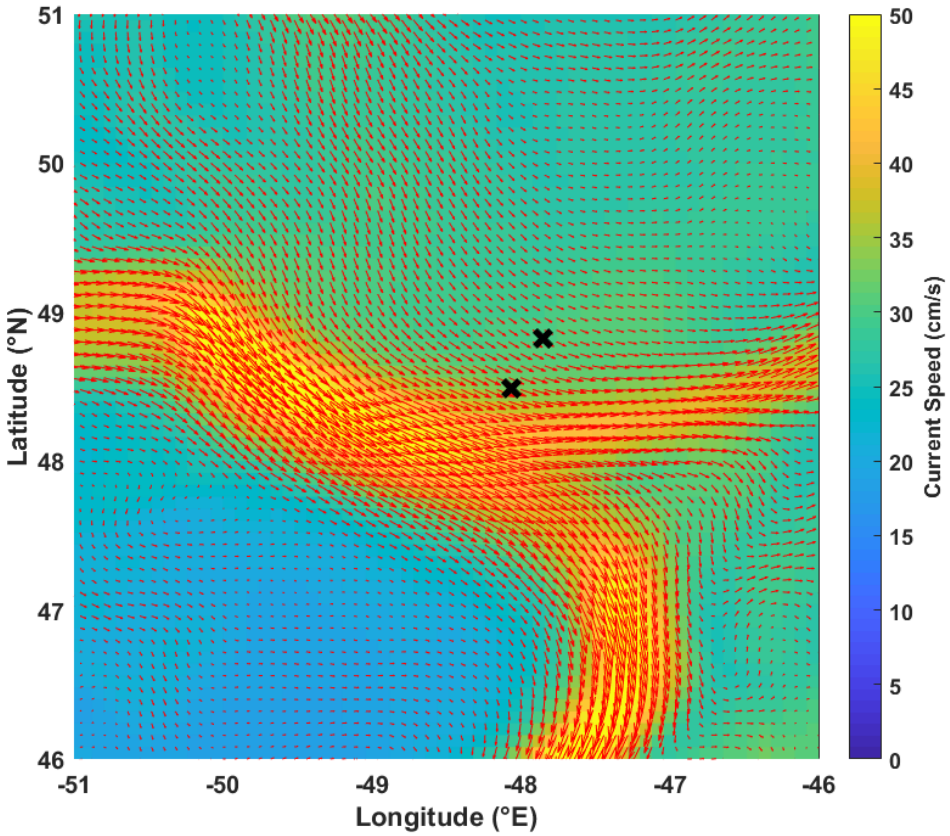

Figure 1-3. Average surface current speed (cm/s) in color, and speed and direction presented by red vectors offshore Newfoundland from HYCOM (2006 – 2012). Black X's depict the location of the representative drilling sites within EL 1157 (upper X) and EL 1158 (lower X).

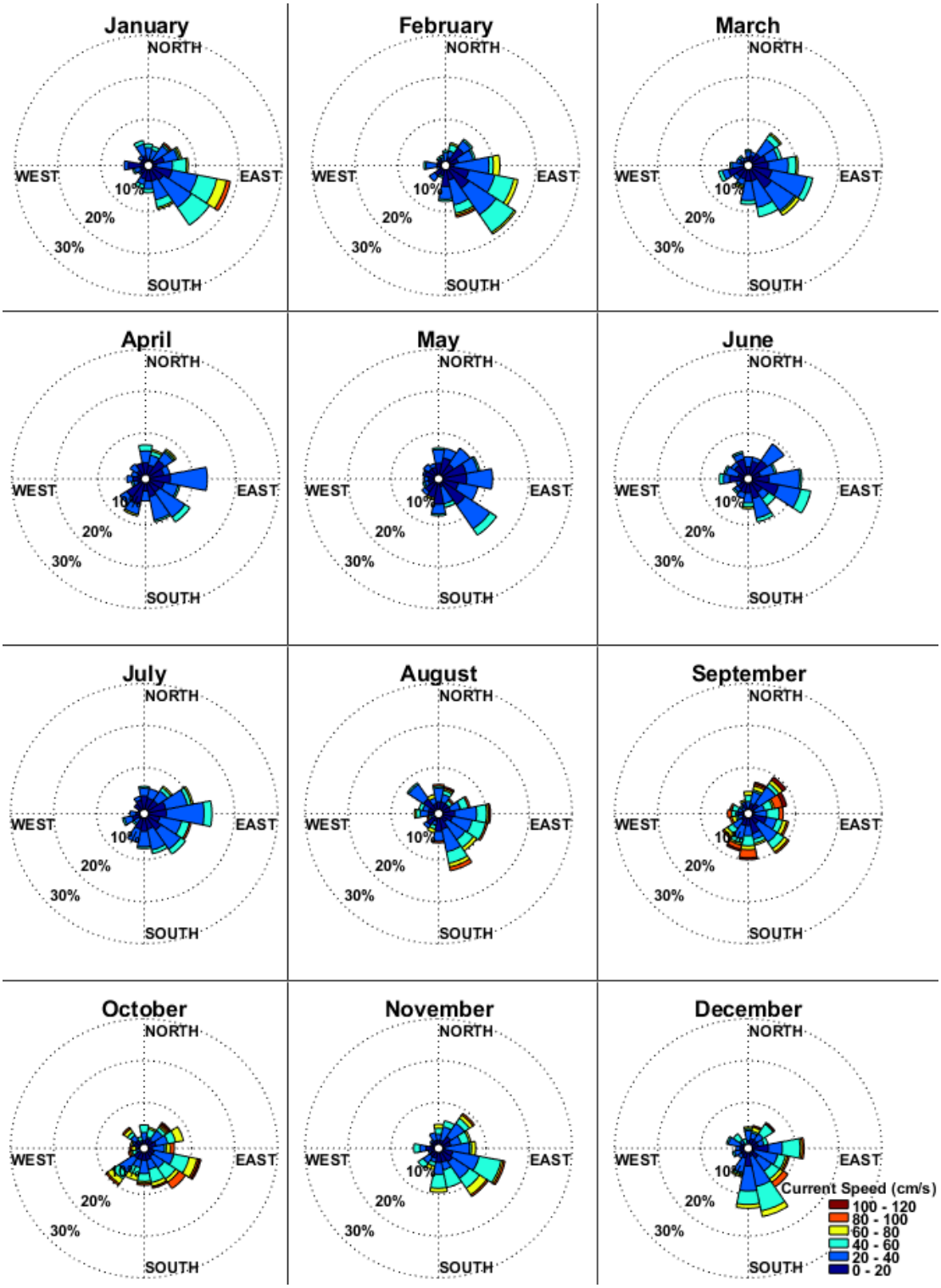

Figure 1-4. Current roses illustrating the distribution of HYCOM surface currents (speed and direction) by month at EL 1157 (model period from 2006-2012); using oceanographic convention (i.e. direction currents are flowing toward).

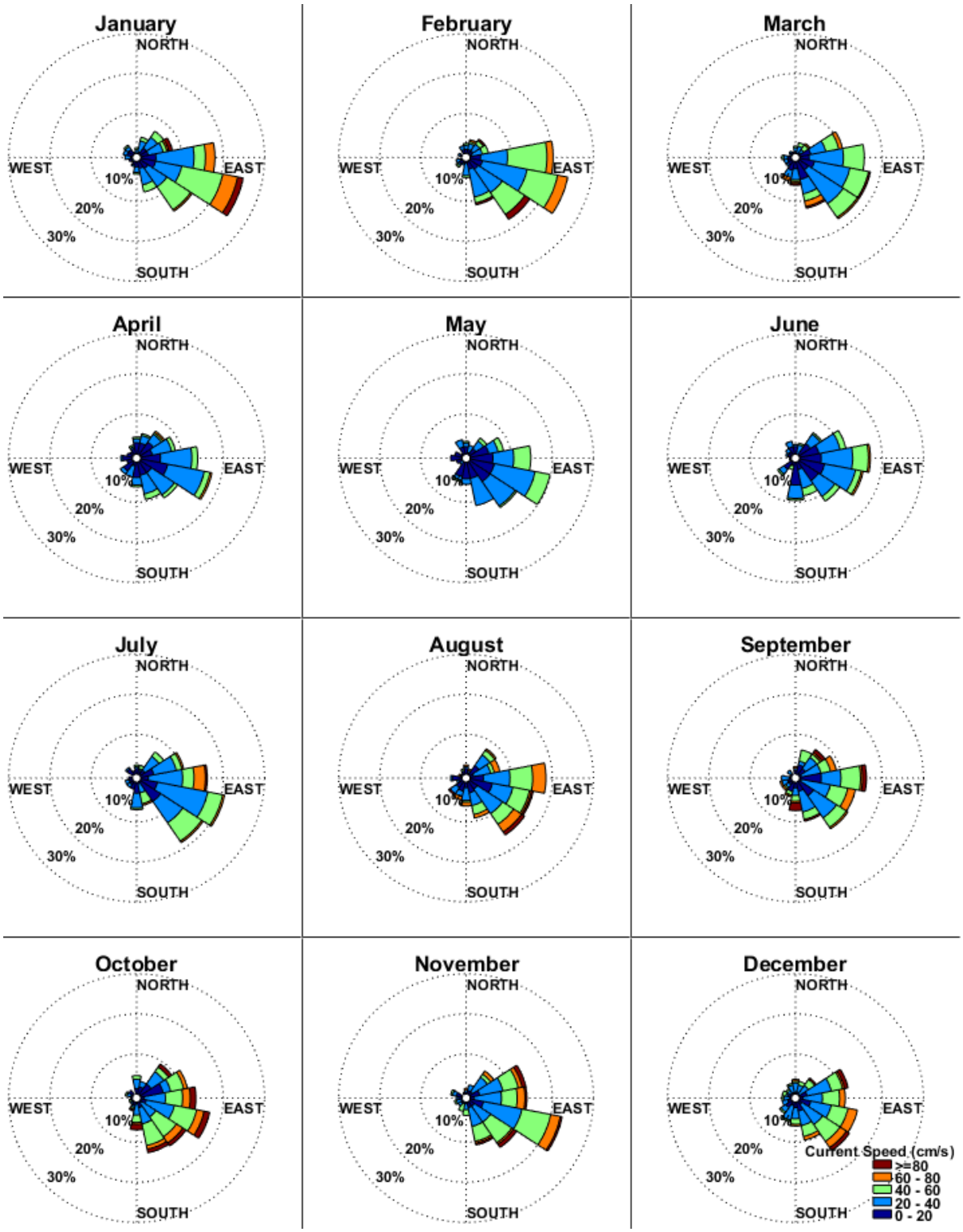

Figure 1-5. Current roses illustrating the distribution of HYCOM surface currents (speed and direction) by month at EL 1158 (model period from 2006-2012); using oceanographic convention (i.e. direction currents are flowing toward).

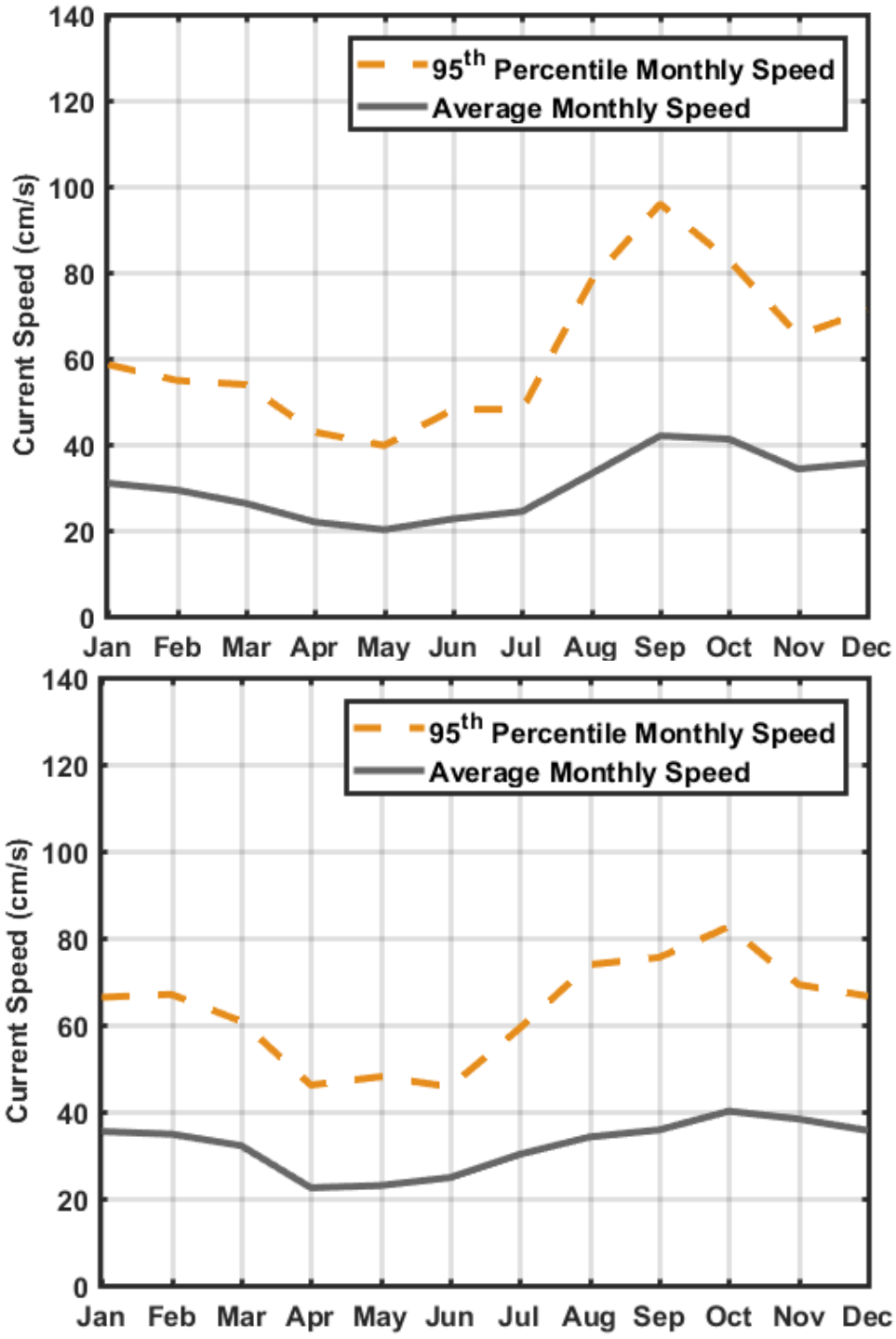

Figure 1-6. Monthly average (grey solid) and 95th percentile (orange dashed) HYCOM surface current speed (cm/s) statistics at EL 1157 (top) and EL 1158 (bottom).

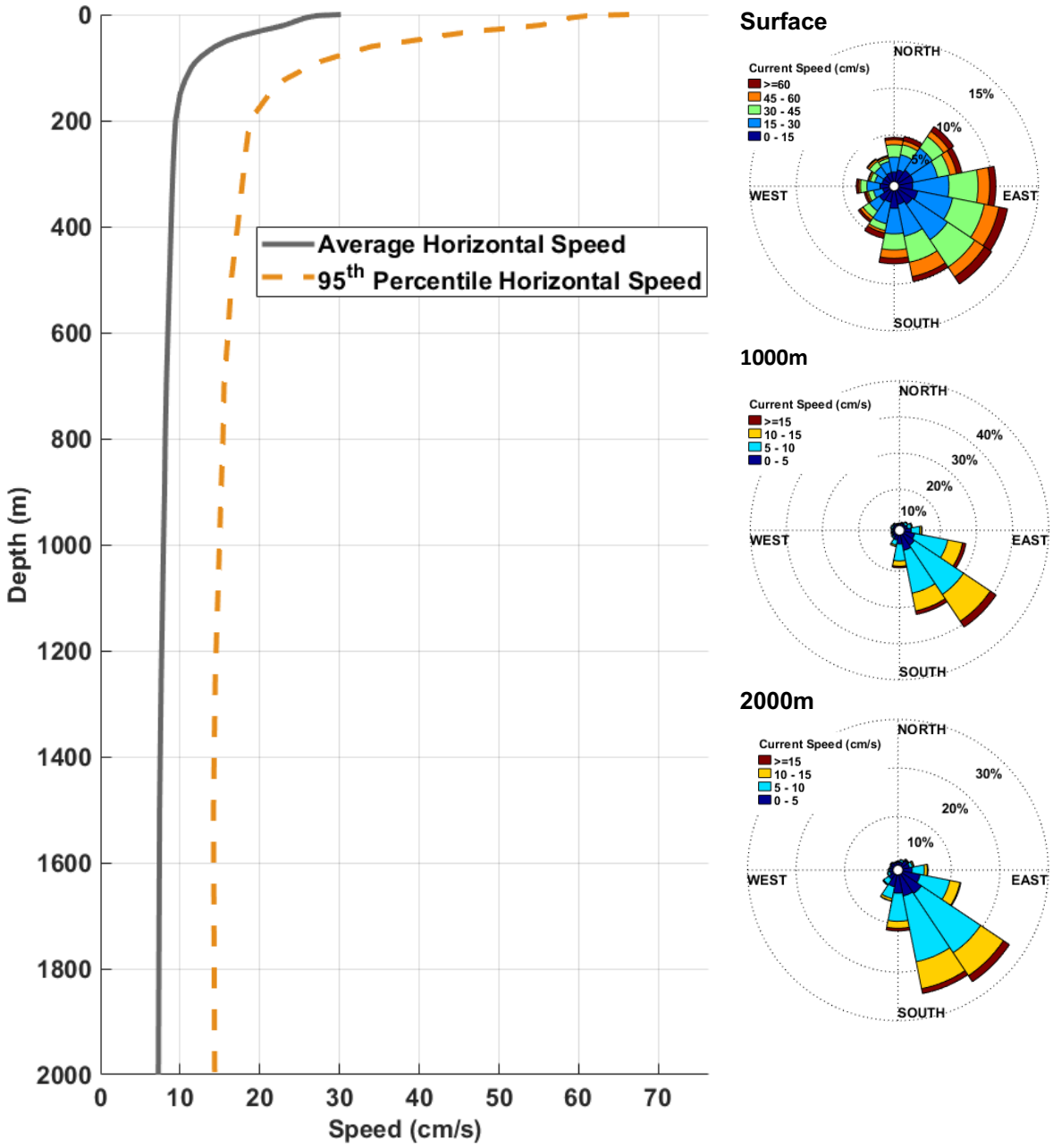

Figure 1-7. Vertical profile of average and 95th percentile horizontal current speed (cm/s) by depth (m) (left) and current roses at multiple depths presented in oceanographic convention (direction currents are flowing toward) (right) at EL 1157; Average current speeds were derived from HYCOM model currents between 2006 and 2012.

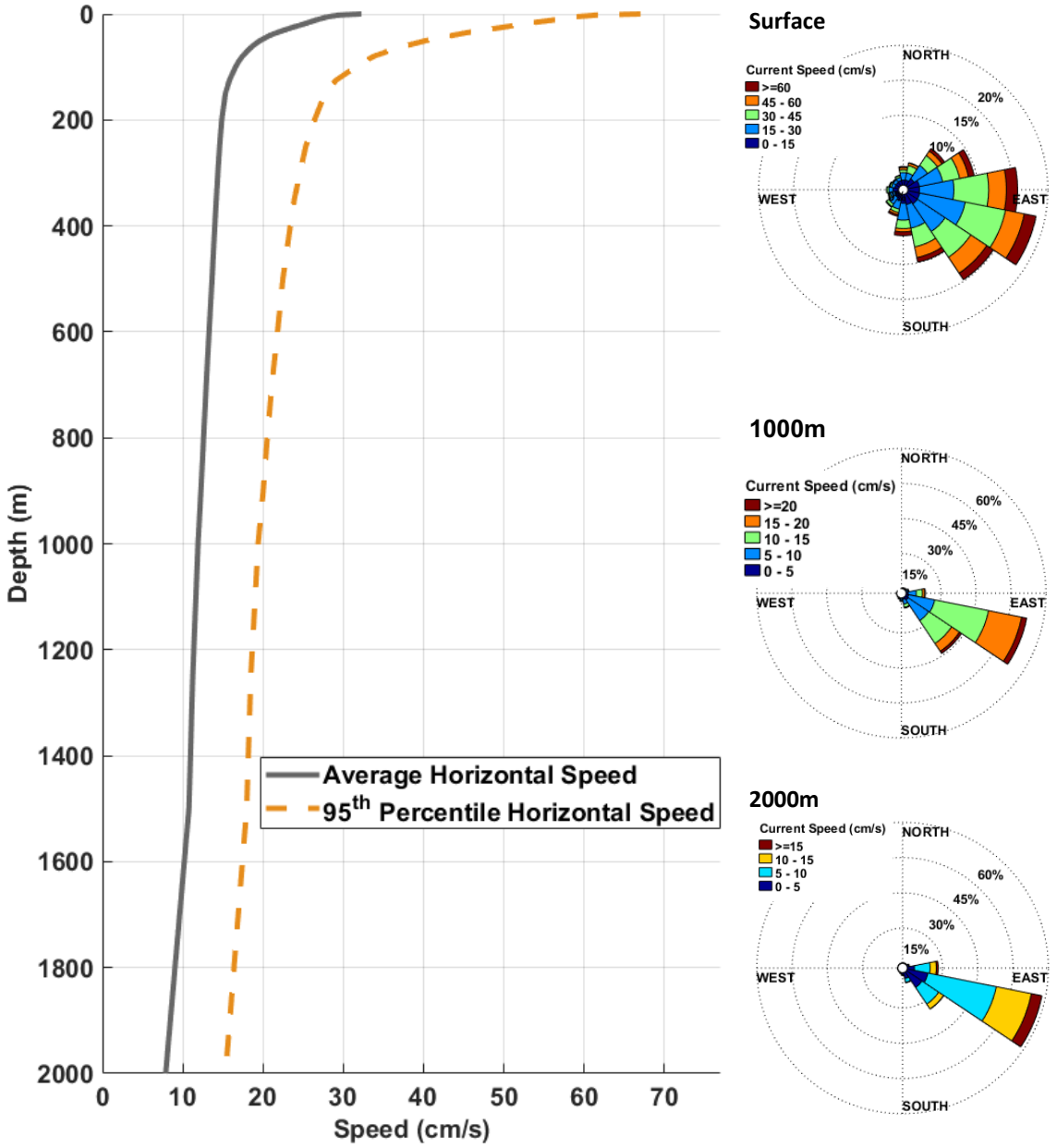

Figure 1-8. Vertical profile of average and 95th percentile horizontal current speed (cm/s) by depth (m) (left) and current roses at multiple depths presented in oceanographic convention (direction currents are flowing toward) (right) at EL 1158; Average current speeds were derived from HYCOM model currents between 2006 and 2012.

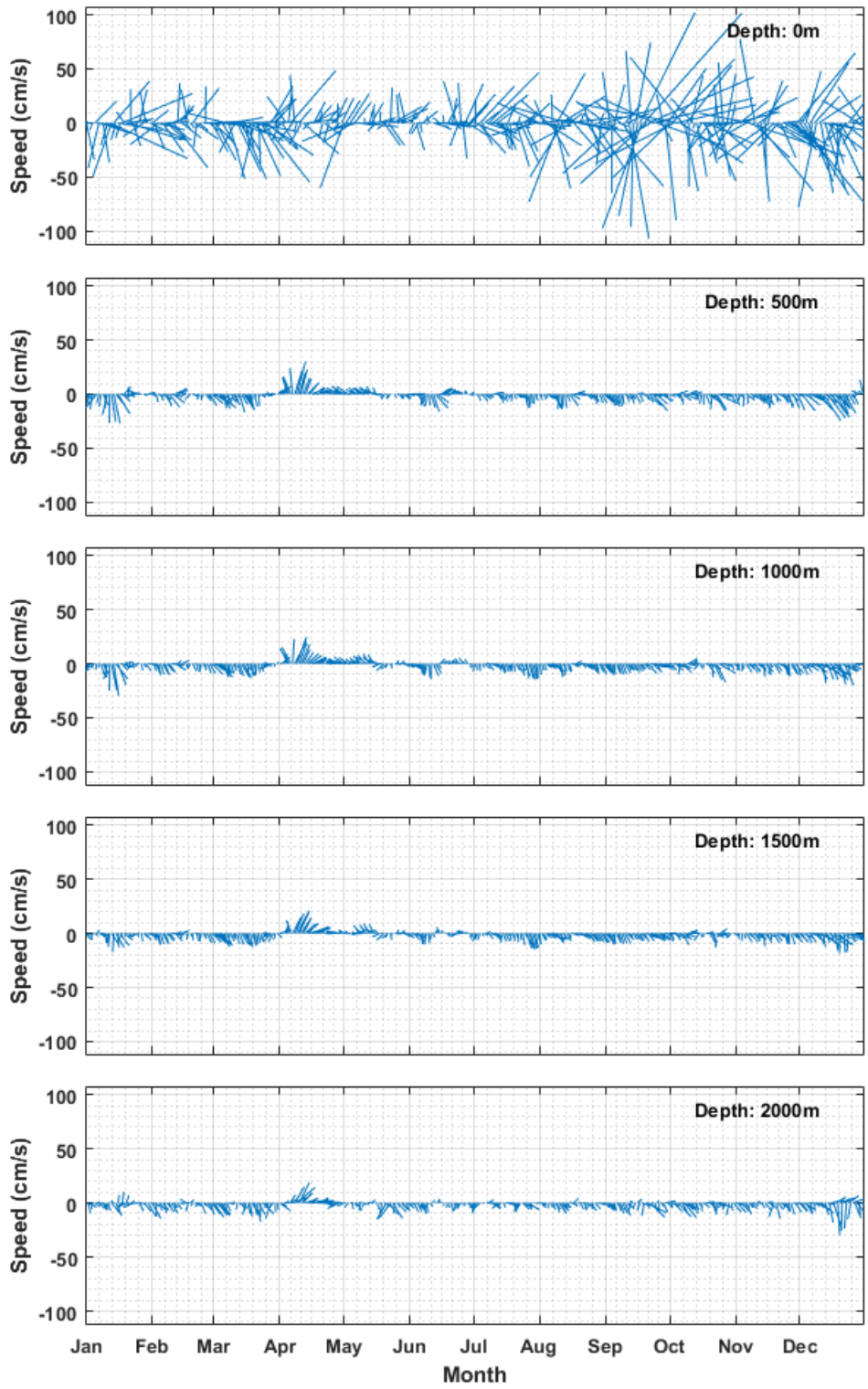

Figure 1-9. Timeseries of HYCOM current speeds (cm/s) at five depths at EL 1157.

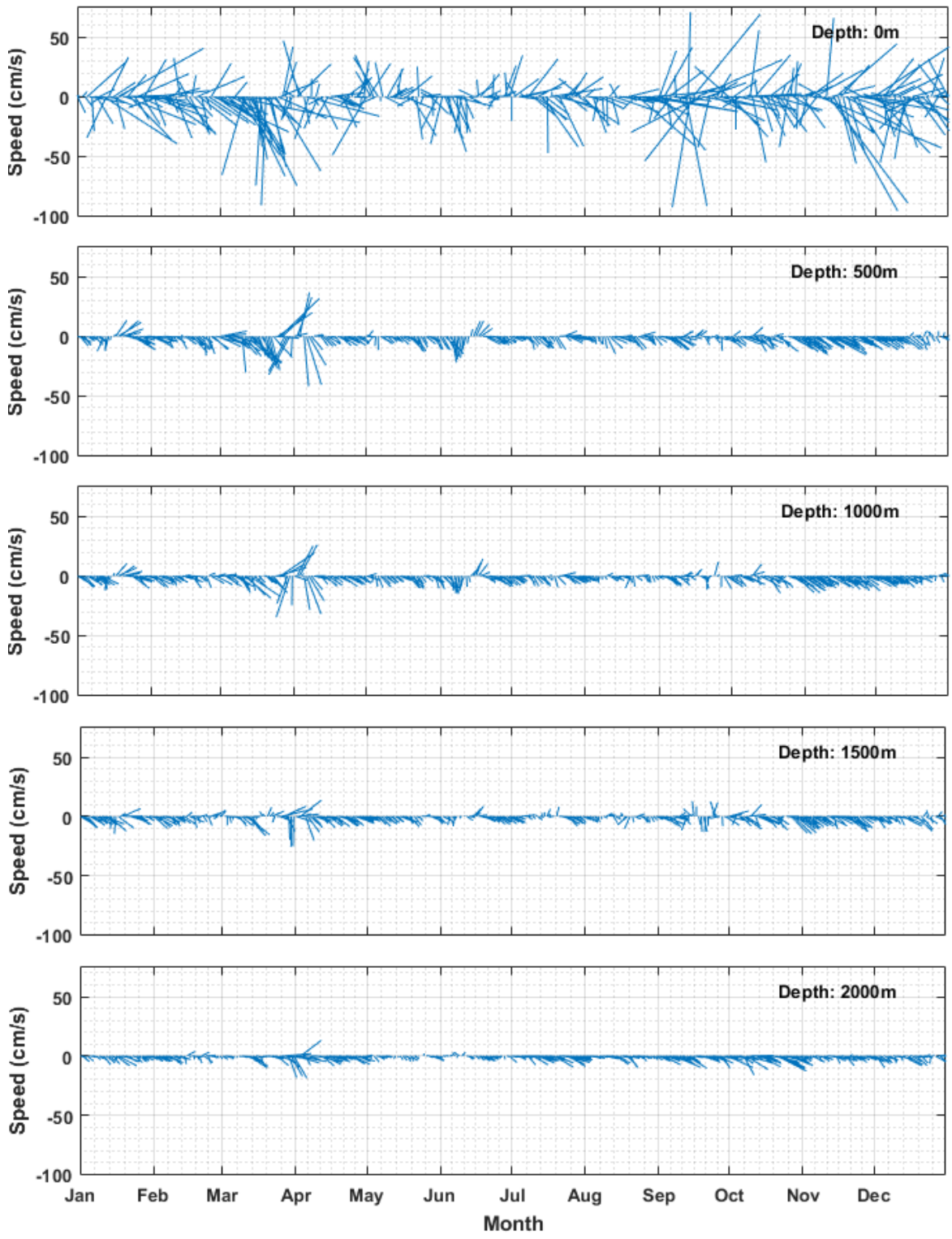

Figure 1-10. Timeseries of HYCOM current speeds (cm/s) at five depths at EL 1158.

2 MODELLING APPROACH

2.1 Modelling Tool – MUDMAP Dispersion Model

Drilling discharge simulations were completed using the RPS MUDMAP modelling system (Spaulding et al., 1994). MUDMAP is a numerical model developed by RPS to predict the near- and far-field transport, dispersion, and bottom deposition of drilling mud and cuttings. In MUDMAP, the equations governing conservation of mass, momentum, buoyancy, and solid particle flux are formulated using integral plume theory, and then solved using a Runge-Kutta numerical integration technique. The model includes three stages: convective descent/ascent, dynamic collapse, and far field dispersion. It allows the transport and dispersion of the release to be modelled through all stages of its movement. The initial dilution and vertical spreading of the release is predicted in the convective descent/ascent process. The far field process predicts the transport and dispersion of the release caused by the ambient current and turbulence fields. In the dynamic collapse process, the release impacts the surface or bottom, or becomes trapped by vertical density gradients in the water column.

MUDMAP is widely used to simulate settling and dispersion of drilling mud and cuttings for offshore environmental impact assessments and follows the same theoretical framework as several other common cuttings models (IOGP, 2016). The equations and solutions in MUDMAP are based on thirty years of research and the model is regularly updated as new scientific research is presented. The system has been applied for discharge operations in both coastal and offshore environments, with excellent agreement among results compared with other industry accepted models, such as the Offshore Operators Committee Mud and Produced Water Discharge Model (Spaulding et al., 1994). Examples of the model validation are provided in Burns et al. (1999), King and McAllister (1997, 1998), and Tetra Tech (2002). Limitations of the MUDMAP model are similar to those that exist for most other cuttings dispersion models (IOGP, 2016), including that it does not account for certain complex process such as aggregation (or degradation) of cuttings as they settle, flocculation, or post-depositional consolidation of cuttings over time. MUDMAP does not account for the resuspension and transport of previously discharged solids; therefore, it provides a conservative estimate of the potential seafloor depositions.

The MUDMAP model output consists of three-dimensional predictions of the movement and shape of the discharge plume, the concentrations of insoluble (i.e., cuttings and mud) discharge components in the water column, and the accumulation of discharged solids on the seabed. The model predicts the transport of solid particles from the time of discharge or release to initial settling on the seabed. With simplifying assumptions, concentrations of hydrocarbons or other pollutants adhered to cuttings can be derived from the seabed loading (Nedwed et al., 2004). The algorithms for the far field and passive diffusion stage are based on a particle based random walk model. More details about MUDMAP are included in Appendix A.

2.2 Mixing Parameters

For discharges near the sea surface, a horizontal dispersion (i.e., mixing) coefficient of 2.0 m^2/s was used to account for the turbulence of the sediment as it was transported from the release site. A vertical dispersion coefficient of 0.001 m^2/s was used to account for the influence of turbulence within the water column. These values were selected, based upon professional judgment and previous experience, to represent typical conditions of the deep marine environment.

2.3 Discharge Schedule

Representative drilling schedules were provided to RPS by BHP to characterize discharges from five planned drilling sections at EL 1157 and EL 1158, respectively (Table 2-1). The first two sections will be drilled using seawater and WBM at both sites. The remainder of the drilling sections will require the use of SBM at both sites. The provided discharge schedule consists of a release of 792 m^3 of drill cuttings and 867 m^3 of drilling fluids (not including 6.9% by mass of synthetic oil that is retained on the cuttings) at each site over the duration of the anticipated drilling campaign. This schedule captures approximately 2 months of work at each simulated location and season, with 10.5 days of active discharge per simulation.

Table 2-1. Proposed drilling program for EL 1157 and EL 1158 (provided by BHP). Each row defines drilling sections beginning at the sediment-water-interface (1) and extending down to the reservoir (5).

Section	Diameter (inches)	Drilling period		Drilling Duration (days)	Discharge Duration (days)	Cuttings Discharge		Drilling Fluid (Mud) Discharge[1]		Mud Type	Release Depth[2]
		Scheduled	Alternative Scheduled			vol (m^3)	rate (m^3/d)	vol (m^3)	rate (m^3/d)		
1	42	Summer	Fall	0.5	0.5	101	201	193	387	WBM	Seafloor
2	26	Summer	Fall	2	2	218	109	674	337	WBM	Seafloor
3	21.5	Summer	Fall	2	2	234	117	6.9% ROC	NA	SBM	Surface
4	16.5	Summer	Fall	2	2	172	86	6.9% ROC	NA	SBM	Surface
5	12.25	Summer	Fall	4	4	67	17	6.9% ROC	NA	SBM	Surface
Total				**10.5**	**10.5**	**792**		**867***			

Notes: 1. Cuttings from sections drilled with SBM were modelled with an additional 6.9% by weight of synthetic oil to account for base fluid that was assumed to be adhered to cuttings
2. Releases were simulated at 5 m above seabed and 10 m below the sea surface
*Does not include 6.9% retained on cuttings (ROC) by mass of synthetic oil

During the initial phase of drilling (the first two sections in Table 2-1), all cuttings and WBM are expected to be released directly to the seabed (assumed discharge was 5 m above the wellhead onto the seafloor). Subsequent sections will be drilled using SBM and cuttings will be returned to the mobile offshore drilling unit (MODU) and cleaned prior to discharge. The direct release of bulk SBM was not expected to occur as part of operational drilling, although for modelling, it was presumed that synthetic oil, a fraction of the drilling fluid (approximately 6.9% by mass of the SBM cuttings), would remain adhered to cuttings drilled with SBM. The release of these combined surface returns (cuttings and adhered SBM) was simulated from a depth of 10 meters below the sea surface at a continuous discharge rate.

The schedule provided by BHP indicated an expected spud date in the summer. Because the drilling schedule may be delayed, a modelling strategy was developed to compare the potential differences in seabed deposits during different offshore conditions for the scheduled and alternative drilling periods. Two (2) deterministic scenarios were performed at the theoretical well location using the MUDMAP dispersion model, each covering a

period of approximately two months (spanning all active drilling stages and time necessary to allow for settling of fine particles):

1. Scenario 1 - scheduled drilling period (Summer; July-August)
2. Scenario 2 - alternative drilling period (Fall; October-November)

As described in Section 1.2, currents in the area are typically to the southeast, but can be variable during portions of the year. RPS performed a qualitative review of the HYCOM time series between 2006-2012, comparing current statistics (speeds and directions) from each year at multiple depths for each modelled season. Current trends for the two model periods during 2012 were in agreement with the overall 7-year trend and were thus deemed suitable as a representative modelling period.

2.4 Discharge Solids Characteristics

To assess the fate of drilling discharges in the marine environment, it is critical to characterize the components of the released materials. The composition of the drilling mud applied will depend on the characteristics of the formation being drilled. This composition is variable and determines the density and weight of the discharged fluid, its toxicity, and the settling velocities of the material released into the water column.

A description of the specific components of the drilling fluids to be used, including the percent solid material and concentration and type of weighting materials, was provided by BHP with the discharge schedule. The discharge solids characteristics of the drilling by-products varies between drilling sections (Table 2-2).

Table 2-2. Bulk density of drilling discharges used for modelling (densities provided by BHP).

Discharged material	Bulk density (ppg)	Bulk density (kg/m^3)	Percent solid by weight	Average SG of solid fraction
WBM cuttings	21.7	2,600	100	2.6
WBM fluids	10.2	1,222	20	3.8
SBM cuttings	22.1	2,650	100	2.65

Particle size data, along with material density, are used to estimate settling velocities for MUDMAP simulations. The size distribution of discharged solids varies as a function of the geology, the type of drilling fluid, and the treatment of cuttings. Particle size distributions (PSD) used for operational drilling simulations are presented in Table 2-3, were broken into six size classes, ranging from coarse sands to fine silt-clays. Additionally, section-specific PSDs are presented, allowing for the simulation of discharges resulting from unique sections separately to more accurately characterize the seabed deposition.

Table 2-3. Particle size distribution for operational modelling simulations.

	6 COARSE SAND	5 MEDIUM SAND	4 FINE SAND	3 V. FINE SAND	2 COARSE-MEDIUM SILT	1 FINE SILTS-CLAYS
Particle diameter (mm)	0.595	0.297	0.149	0.074	0.031	0.005
Cuttings Type, Well Section	**Measured Weight Percent Material**					
WBM, conductor and surface	0.5	1.0	2.0	2.5	10.0	84.0
Barite, conductor and surface	0.5	1.0	2.0	2.5	10.0	84.0
Average PSD for conductor and surface	0.0	0.0	0.1	0.1	11.7	88.1
SBM, intermediate (445 and 311 mm)	0.7	0.8	0.8	2.0	5.9	89.9
SBM, reservoir	0.7	3.8	7.8	10.7	8.7	68.3

Given the absence of local sample data, representative size distributions based on published values from Brandsma and Smith (1999) were used to characterize the WBM fluids released during the top-hole stages (Table 2-4).

Table 2-4. Water based mud (WBM) settling velocities (Brandsma and Smith, 1999).

Size Class	Percent Volume	Settling Velocity	
		(cm/s)	(m/day)
1	7.01	2.74E-03	2.37
2	7.99	6.10E-03	5.27
3	5.00	1.48E-02	12.77
4	10.00	3.00E-02	25.94
5	13.26	4.36E-02	37.66
6	13.26	5.12E-02	44.24
7	19.24	6.40E-02	55.30
8	19.24	8.23E-02	71.10
9	4.00	4.27E-01	368.69
10	1.00	1.12E+00	969.12

Samples from a laser diffraction analysis were provided by Weatherford Laboratories to estimate the PSDs of cuttings resulting from Statoil Canada Ltd. Et al Bay de Verde F-67 well (2014). Samples were taken at different depths corresponding to intermediate and reservoir sections. The conductor and surface sections were also assumed from the intermediate section.

The extent to which discharged drilling fluids and cuttings accumulate on the seabed is largely controlled by the particle settling velocities, which are a function of size and density, and the prevailing currents in the water column, which will transport and disperse particles within the water column. The data from Brandsma and Smith, 1999 has been used to compare the settling characteristics for each of the materials (i.e., cuttings and muds) in the model input. The data can be used to emphasize the different behaviours of discharged materials within the water column. Cuttings, which in general are relatively large and dense, are expected to sink rapidly and mostly accumulate in a thick near-field mound close to the wellhead. By contrast, drilling fluids will remain in suspension far longer and will disperse over greater distances, having a larger influence on the pattern of far field dispersion and thinner deposition on the seabed.

2.5 Thresholds of Concern

2.5.1 Sedimentation Effects and Thresholds

Although sediment deposition is a natural process, the rate of sedimentation is variable, depending on the oceanographic characteristics within the area. Deep sea habitats, like those in the current study, are generally characterized by low-energy currents and slow sediment accumulation rates of approximately 1 – 100 mm per thousand years (Gage and Tyler, 1991; Glover and Smith, 2003). Benthic organisms associated with these environments are generally adapted to tolerate a range of conditions and sedimentation rates. Rapid increases in sedimentation associated with mud and cuttings discharges can have direct and indirect effects on benthic infauna communities in deep sea habitats. Direct effects can include smothering, toxicity exposure, and physical abrasion. Indirect effects include habitat alterations and changes to community assemblages (DOER, 2005). The severity of sedimentation effects on organisms depends on factors including burial depth, burial rate, burial time, species-specific tolerances, the grain size of the deposited sediments, and seasonal timing (Kjeilen-Eilertsen et al., 2004). For example, higher mortality can occur in the summer than in the winter (Smit et al. 2008). Higher mortality has been observed at higher temperatures in mesocosm and lab studies of burial for mussels and gastropods, possibly due to greater oxygen demand at higher temperatures (Chandrasekara and Frid, 1998; Hutchison et al. 2016). However, there is great variability, as taxonomic groups react differently and have varying levels of tolerance to sedimentation. Sessile and attached organisms typically have the lowest tolerance and highest mortality rate during sedimentation events (DOER, 2005; Gates and Jones, 2012).

Observations from previous research conducted on sedimentation and recovery of benthic infauna in Newfoundland, Canada, were used to demonstrate an increased abundance and biomass in some polychaete species and declines in others in the area around the studied drill site. Reduced abundance was observed to extend approximately 1 – 2 km from the drill site for some species (Paine et al., 2014). This aligns with findings from an extensive literature review that documented biological effects (such as changes in benthic community structure) at distances of 200 – 2,000 m from platforms using water-based drilling fluids (Ellis et al., 2012). The range of effects from synthetic-based drilling fluids was found to be somewhat smaller, with detected biological effects from 50 – 1,000 m from the drill site (Ellis et al., 2012).

Specific sedimentation thresholds tested and reported by Smit et al. (2008) indicate that epibenthic, sessile, filter-feeding species cannot survive sediment burial depths over 10 mm. Meanwhile, infauna taxa that are adapted to habitats covered in sediment may escape from burial under 100 mm of sediment or more (Kjeilen-Eilertsen et al., 2004). In a mesocosm and field study, Trannum et al. (2011) observed that 24 mm of water-based drill cuttings lowered oxygen availability and reduced the abundance of macrofauna in the sediment. Overall, Smit et al. (2008) estimated that mortality of 5% of benthic organisms (including mollusks, polychaetes, and crustaceans) would occur at burial depths of 6.3 mm (3.1 – 10.6 mm), and mortality of 50% would occur at burial depths of 54 mm (37 – 79 mm).

Benthic invertebrates are broadly considered to be unaffected by nontoxic sediment burial depths less than 6.5 mm, based on tolerances to burial, oxygen depletion, and change in sediment grain size (Wood, 2018; Kjeilen-

Eilertsen et al., 2004; Smit et al., 2006; 2008). However, some more sensitive species are considered more susceptible to shallower burial depths (1.5 mm), and thus 1.5 mm is suggested as a more conservative predicted no-effect threshold.

Studies on the recovery of benthic infaunal communities post-sedimentation present varying results. The ability of a benthic community to recover after sediment deposition depends on larval settlement, the rate of bioturbation, and sediment mixing by currents (Smit et al., 2008; Trannum et al., 2011). Because many benthic species have drifting pelagic larvae, resettlement can occur within months post-disturbance. Trannum et al. (2011) observed reestablishment of species-rich communities within six months of sedimentation and noted that the most successful colonizers were species in the Spionidae family of polychaete worms. In studies from the North Sea, recolonization of cuttings piles from the edges of the piles occur in 1-5 years (Kjeilen-Eilertsen et al., 2004). Areas with the thickest deposition will likely rely on larval transport and resettlement for recolonization, as survival of buried organisms is unlikely. In areas with lower levels of deposition, reestablishment by surviving organisms that burrow or sift through sediment to feed is possible, as they mix mud and cuttings with native sediments and slowly return habitats to pre-drilling conditions (Smit et al., 2008; Gates and Jones, 2012).

For this study, we model to a resolution of 0.01 mm, but report a minimum deposition threshold of 0.1 mm (presence of negligible sedimentation) and focus on the area of deposition above 1.5 mm and 6.5 mm, which could be considered potential effects thresholds.

2.5.2 Turbidity and TSS Effects and Thresholds

Smit et al. (2006, 2008) described an increase in the concentration of total suspended solids (TSS) and water column turbidity due to the discharge of drilling cuttings and fluids, which could potentially affect pelagic organisms. Particulates in drilling muds come from bentonite clay and barite, which are toxicologically inert, but can be suspended in the water column. Suspended clay particles of less than 0.01 mm diameter settle very slowly and can potentially persist in the water column for weeks or months (Smit et al., 2008).

Increased turbidity decreases the light availability for phytoplankton in the water column (IOGP, 2016). Phytoplankton were negatively affected at concentrations of 10 mg/L bentonite clay or 1,000 mg/L barite, but these concentrations are unlikely to occur in a discharge plume greater than 25 m down-current (IOGP, 2016). In general, drilling fluid and cuttings solids rapidly disperse, dilute, and settle out of the water column, which reduces the risk of adverse effects on water column organisms because exposure to elevated turbidity or TSS is intermittent and brief (IOGP, 2016).

Benthic suspension feeders (e.g., molluscs) are sensitive to mud and cuttings discharges because they are sessile organisms that cannot escape discharge plumes, and fine suspended particles interfere with feeding and growth (DOER 2005; Smit et al. 2008). Filter-feeding zooplankton and algae were also more sensitive, likely due to greater exposure in the water column from drifting with the currents and therefore with portions of the discharge plume that encounter surface currents. Benthic crustaceans and siphon-feeding molluscs were relatively insensitive to suspended particulates, likely because they have evolved to inhabit the benthic boundary layer comprising mobile sediments and water that is naturally highly turbid (Smit et al. 2008). However, the quality of data available to evaluate TSS thresholds are poor, with few laboratory studies on bentonite or barite suspended clays.

Synthetic non-aqueous base fluids are not considered toxic to phytoplankton, zooplankton, and other water column marine organisms (IOGP, 2016). Certain chemicals within synthetic base fluids (primary emulsifier and fluid loss agent) elicited sublethal exposure responses in biomarkers of juvenile pink snapper fish, which suggests that chronic exposure from chemicals leaching out of cuttings piles may have some effect on fish over several days (Bakhtyar and Gagnon, 2012). However, a transient exposure to drilling fluids as they pass through the water column is unlikely to be toxic to mobile pelagic organisms.

3 MODEL RESULTS

The fate of mud and cuttings released from operational drilling activities at EL 1157 and EL 1158 were assessed using deterministic scenarios corresponding to the drilling period and discharge volumes depicted in Table 2-1. One deterministic simulation was performed for operational discharges at each of the two sites during each of the two current regimes, totalling four simulations of operational discharges. MUDMAP was used to model the trajectory of cuttings and fluid particles from operational release simulations and to track the far field dispersion, accounting for the prolonged settling of very fine particles from the water column. Based on the depth at EL 1157 (2,338 m) and EL 1158 (2,047 m), and settling velocities of the finer sediments, several days were required to allow for the majority of particles to reach the seabed.

3.1 Operational Discharges

3.1.1 Predicted Seabed Deposition

The output of each MUDMAP simulation is a predicted concentration grid that estimates the loading to the seabed, associated with each drill section. These grids were aggregated outside of the MUDMAP model to produce maps of cumulative deposition from all discharged sections. Figure 3-1 and Figure 3-2 depict the model-predicted deposition patterns from an aerial view. While the MUDMAP model was used to simulate deposition down to 0.01 mm, Table 3-1 and Figure 3-3 summarize the cumulative areal extent of seabed deposition for operational discharge simulations ≥0.1 mm. Deposition thicknesses were calculated based on mass accumulation on the seabed, sediment bulk density, and the assumption of no voids (i.e., zero porosity) (Table 3-2).

At both locations, fine blankets of mud/cuttings were predicted to be deposited no more than 2.3 km from the drill site, with furthest deposits ≥0.1 mm thick ranging from 1.8 to 2.3 km from the wellhead, depending on the location and season (Table 3-2). The predicted deposition patterns between the modelled summer and fall scenarios were very similar in size, shape, and depositional thickness at both EL 1157 and EL 1158 (Figure 3-1 and Figure 3-2). However, there was seasonal variability in the orientation of deposition at EL 1157, during the summer scenario, based upon different met-ocean conditions. During the first two sections of drilling, which was predicted to discharge approximately 60% of the total mass and of larger size fractions, there was a temporary shift in the currents from southeasterly to southwesterly. During all remaining drilling sections, where the remaining 40% of mass in the smaller size fractions was discharged, the currents returned to their predominant southeasterly direction. This resulted in a broader footprint that extended to the southwest. For both seasons, the deposition of muds and cuttings equal to or exceeding 1.5 mm was predicted to remain within 0.45 km at EL 1157 and 0.58 km at EL 1158 and cover less than 0.12 km^2 in all scenarios (Table 3-1 and Table 3-2). Depositional thicknesses at or above the predicted threshold of 6.5 mm (Smit et al., 2008) were not predicted to occur at either location, with the thickest deposition predicted to be approximately 5.45 mm, during the fall for EL 1157. The low thicknesses of the predicted depositional plumes can be attributed to the deep-water column through which material had to settle at EL 1157 and EL 1158 (2,338 and 2,047 m, respectively), and associated long settling times for the finer silts/clays, which make up majority of the cuttings released at the surface.

When comparing the two drilling periods, the predicted areal extent of depositional thicknesses ≥0.1 for the summer drilling period was slightly larger than the fall drilling period at EL 1157 (Table 3-1). For EL 1158, the fall drilling period was predicted to be slightly larger than the summer drilling period. However, the areas predicted to have depositional thicknesses ≥1.5 mm were nearly the same for all scenarios, with values ranging between 0.11-0.12 km^2. Marginally stronger currents during the fall at EL 1157 and EL 1158 were predicted to transport the cuttings and mud particles further from the discharge site resulting in slightly further travel but allowing for less radial dispersion before settling.

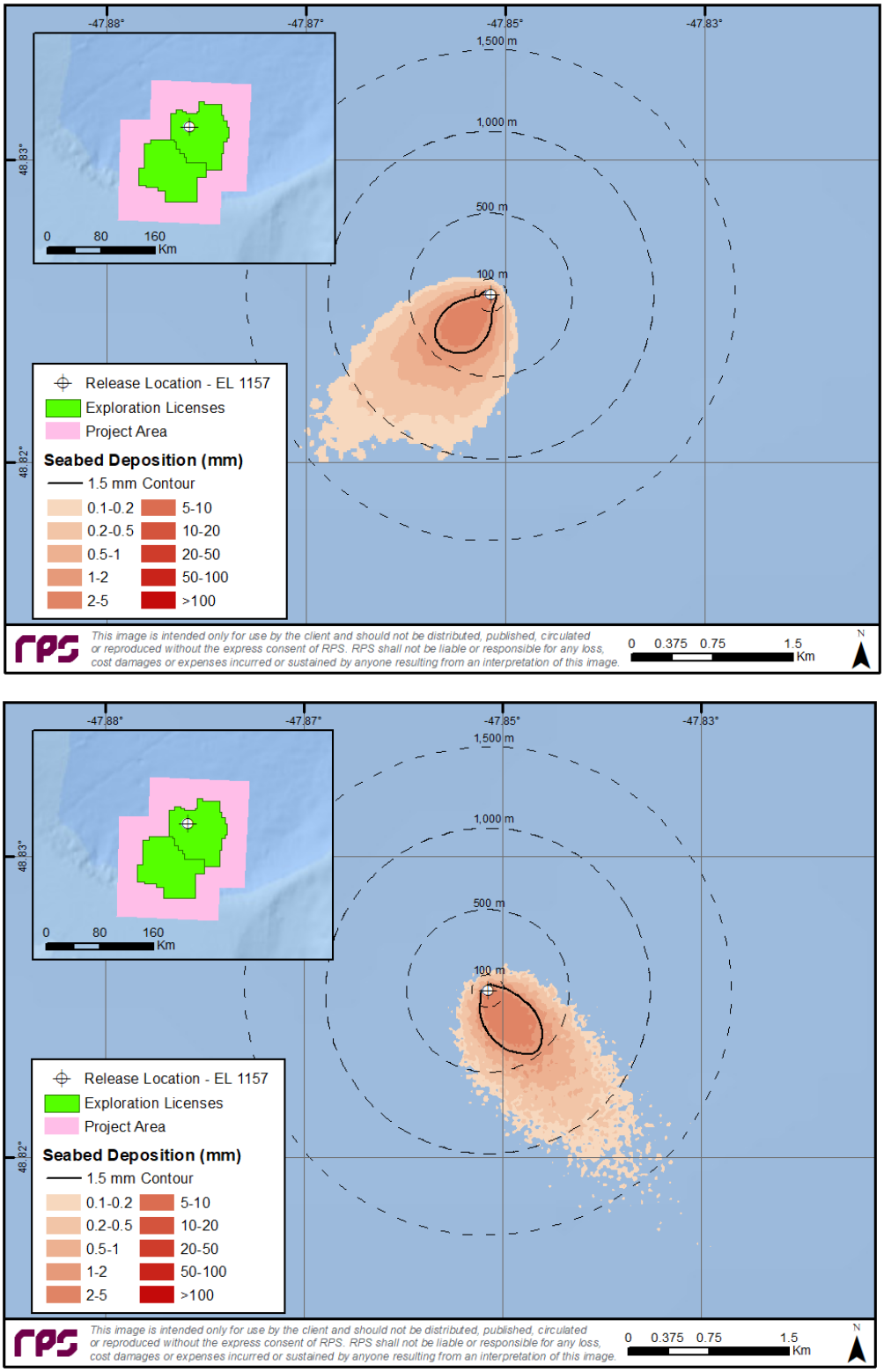

Figure 3-1. Predicted thickness of seabed deposition of discharged mud and cuttings (≥0.1 mm) resulting from all drilling sections during the scheduled Summer (top) drilling period and during the alternative scheduled Fall (bottom) drilling period at EL 1157. The 1.5 mm contour is provided as a solid black line.

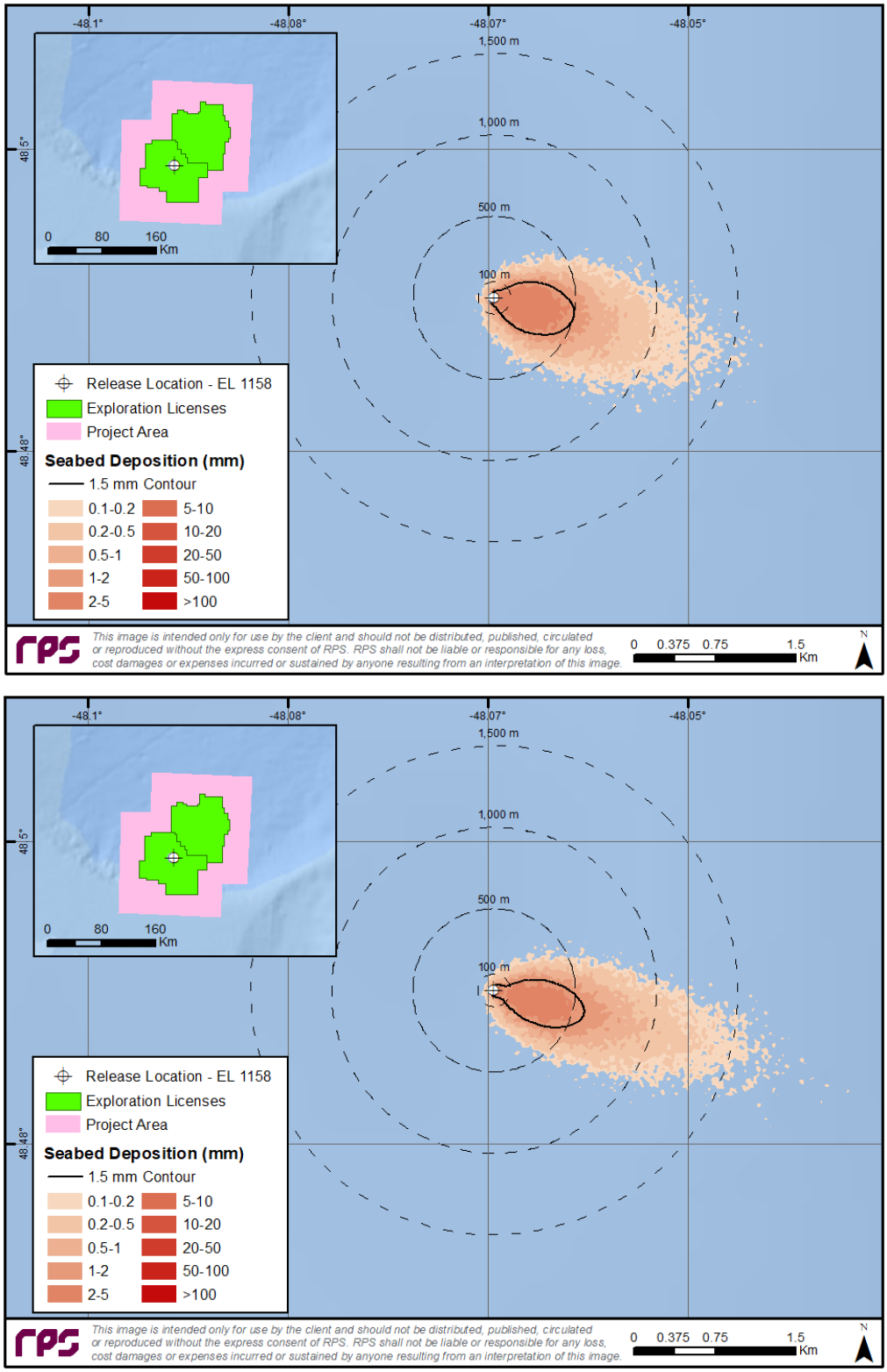

Figure 3-2. Predicted thickness of seabed deposition of discharged mud and cuttings (≥0.1 mm) resulting from all drilling sections during the scheduled summer (top) drilling period and during the alternative scheduled fall (bottom) drilling period at EL 1158. The 1.5 mm contour is provided as a solid black line.

Table 3-1. Areal extent of predicted seabed deposition (by thickness interval) for operational discharge simulations in Summer and Fall.

Deposition Thickness (mm)	Cumulative Area Exceeding (km^2)			
	1157		1158	
	Summer	Fall	Summer	Fall
≥0.1	0.9338	0.8603	0.8471	0.8974
≥0.2	0.6110	0.5680	0.5429	0.6005
≥0.5	0.3266	0.3094	0.3113	0.3253
≥1	0.1783	0.1761	0.1831	0.1874
≥1.5	0.1092	0.1178	0.1241	0.1181
≥2	0.0648	0.0812	0.0867	0.0733
≥5	0.0000	0.0005	0.0000	0.0000
≥6.5	0.0000	0.0000	0.0000	0.0000
Maximum Thickness (mm)	**3.37**	**5.45**	**4.75**	**4.18**

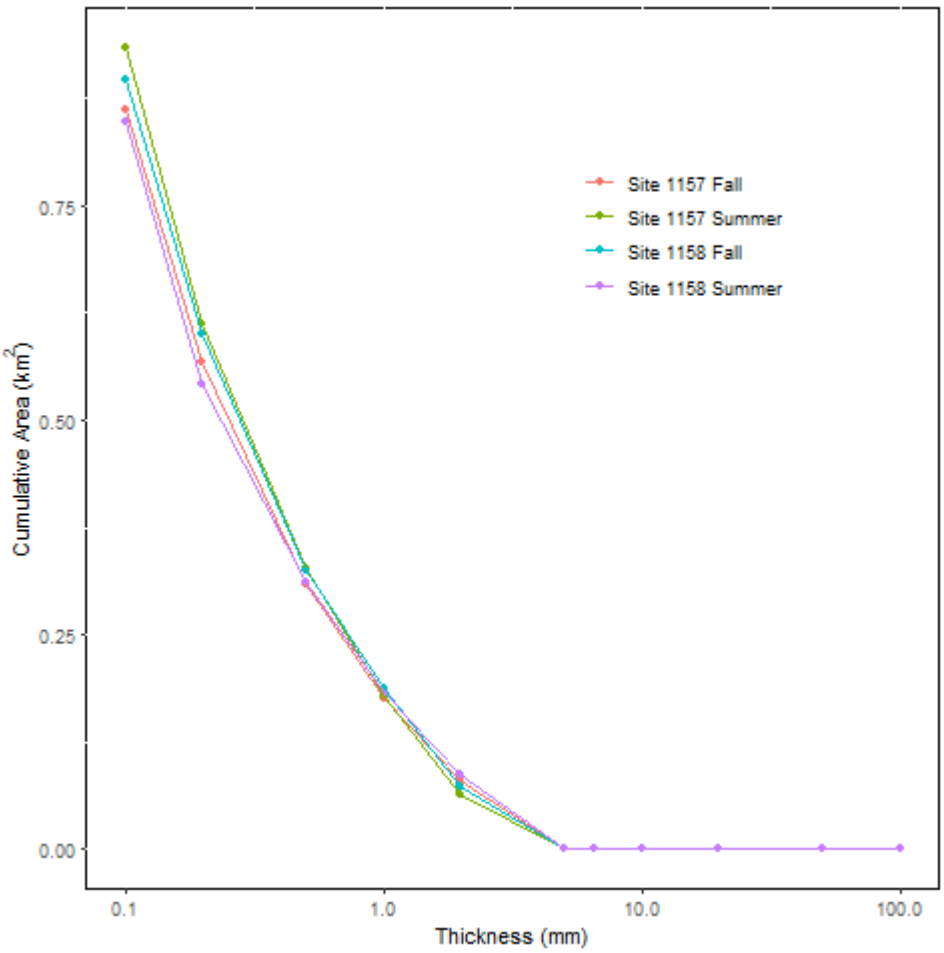

Figure 3-3 Cumulative areal extent of predicted seabed deposition for operational discharge simulations in Scheduled (Summer) and Alternative Scheduled (Fall) drilling periods.

Table 3-2. Maximum distance of thickness contours (distance from release site) predicted for operational discharge simulations.

Deposition Thickness (mm)	Maximum extent from release site (km)			
	1157		1158	
	Cumulative Summer	Cumulative Fall	Cumulative Summer	Cumulative Fall
≥0.1	1.83	2.08	1.86	2.28
≥1.5	0.36	0.45	0.47	0.58
≥6.5	0.00	0.00	0.00	0.00

4 DISCUSSION AND CONCLUSIONS

In each modelled case, the deposition of muds and cuttings from operational discharges onto the seabed was controlled by the settling velocity of particles, the currents within the water column, and the depth of the water column. Modelled operational discharges from EL 1157 (2,338 m) and EL 1158 (2,047 m) were predicted to produce a spatially confined depositional area of up to 5.45 mm thick. The difference in depth between both sites did not influence the seabed deposition patterns, because only the first two sections (released at seabed) contributed to measurable thicknesses on the seafloor. Slow settling velocities associated with the fine silts/clays, which make up the largest fraction of the cuttings drilled with SBM, allowed for greater dispersion before settling out.

Summer simulations (scheduled drilling) for both sites were predicted to have weaker subsurface current regimes with greater directional variability, when compared to the fall simulations. This resulted in slightly more radial footprints for summer simulations, when compared to the more elongated results in the fall simulations. However, each predicted depositional footprint was similar in shape, size, and depositional thickness. Depositional thicknesses at or above 0.1 mm was predicted to extend up to 1.83 km to the southwest at EL 1157 and 1.86 km to the southeast at EL 1158. In total, the area exceeding a depositional thickness of 0.1 mm was predicted to be less than 0.94 km^2 for EL 1157 and 0.85 km^2 for EL 1158.The larger areal extent at EL 1157 was due to the variability of current direction during the summer season. During the first two sections of drilling, which was predicted to discharge approximately 60% of the total mass and of larger size fractions, there was a temporary shift in the currents from southeasterly to southwesterly. During all remaining drilling sections, where the remaining 40% of mass in the smaller size fractions was discharged, the currents returned to their predominant southeasterly direction. This resulted in a broader footprint that extended to the southwest. Depositional thicknesses at or above 1.5 mm were predicted to extend to the southwest up to approximately 0.36 km covering 0.11 km^2 at EL 1157 and to the southeast 0.47 km covering 0.12 km^2 at EL 1158. Maximum depositional thicknesses of 3.37 and 4.75 mm were predicted at EL 1157 and EL 1158, respectively. Again, the reduced distance, areal extent, and thickness predicted at EL 1157 is the result of the currents shifting direction over the course of drilling. Depositional thicknesses at or above 6.5 mm did not occur at either site or for either seasonal scenario.

Fall simulations (alternate drilling) for both sites were characterized by stronger subsurface current regimes, which led to slightly more elongated depositional footprints, when compared to summer scenarios. Depositional thicknesses at or above 0.1 mm were predicted to extend to the southeast for both locations up to approximately 2.08 km at EL 1157 and 2.28 km at EL 1158. In total, the area exceeding a depositional thickness of 0.1 mm was predicted to be less than 0.86 km^2 at EL 1157 and 0.90 km^2 at EL 1158. Depositional thicknesses at or above 1.5 mm were predicted to extend southeast up to approximately 0.45 km covering 0.12 km^2 at EL 1157 and 0.58 km covering 0.12 km^2 at EL 1158. Maximum depositional thicknesses of 5.45 and 4.18 mm were predicted at EL 1157 and EL 1158, respectively. Depositional thicknesses at or above 6.5 mm did not occur at either site or for either seasonal scenario.

The variations within predicted results between simulations were due to three main factors including: 1) settling velocity associated with different release substances, 2) current patterns (i.e. velocity) and 3) release height relative to the seabed. The discharges modelled in this study may be considered representative of other potential discharges in the Project Area, as the depth of the sites (~2,000 m) are similar in depth to other potential sites within the Project Area. This dispersion modelling targeted the most likely drilling window for the Project (July-August), as well as an alternate season (October-November) selected because of its differences from the target season, so the predicted results are applicable outside of this temporal window.

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APPENDIX A: MUDMAP MODEL DESCRIPTION

MUDMAP is a personal computer-based model developed by RPS (Applied Science Associates or ASA at the time of creation) to predict the near and far-field transport, dispersion, and bottom deposition of drill muds and cuttings and produced water (Spaulding et al; 1994). In MUDMAP, the equations governing conservation of mass, momentum, buoyancy, and solid particle flux are formulated using integral plume theory and then solved using a Runge Kutta numerical integration technique. The model includes three stages:

Stage 1: **Convective decent/jet stage** – The first stage determines the initial dilution and spreading of the material in the immediate vicinity of the release location. This is calculated from the discharge velocity, momentum, entrainment and drag forces.

Stage 2: **Dynamic collapse stage** – The second stage determines the spread and dilution of the released material as it either hits the sea surface or sea bottom or becomes trapped by a strong density gradient in the water column. Advection, density differences and density gradients drive the transport of the plume.

Stage 3: **Dispersion stage –** In the final stage the model predicts the transport and dispersion of the discharged material by the local currents. Dispersion of the discharged material will be enhanced with increased current speeds and water depth and with greater variation in current direction over time and depth.

MUDMAP is based on the theoretical approach initially developed by Koh and Chang (1973) and refined and extended by Brandsma and Sauer (1983) and Khondaker (2000) for the convective descent/ascent and dynamic collapse stages. The far-field, passive diffusion stage is based on a particle based random walk model. This is the same random walk model used in RPS' OILMAP spill modelling system (ASA, 1999).

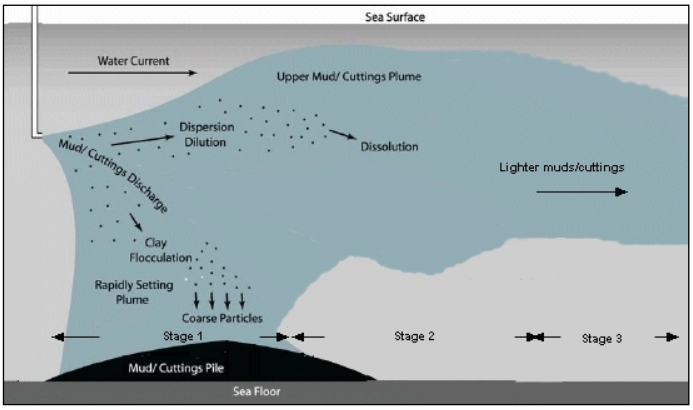

Figure A1. Conceptual diagram depicting the general behavior of cuttings and muds following discharge to the ocean and the three distinct discharge phases (after Neff 2005).

The model's output consists of calculations of the movement and shape of the discharge plume, the concentrations of soluble (i.e. oil in produced water) and insoluble (i.e. cuttings and muds) discharge components in the water column, and the accumulation of discharged solids on the seabed. The model predicts the initial fate of discharged solids, from the time of discharge to initial settling on the seabed As MUDMAP does not account for resuspension and transport of previously discharged solids, it provides a conservative estimate of the potential seafloor concentrations (Neff 2005).

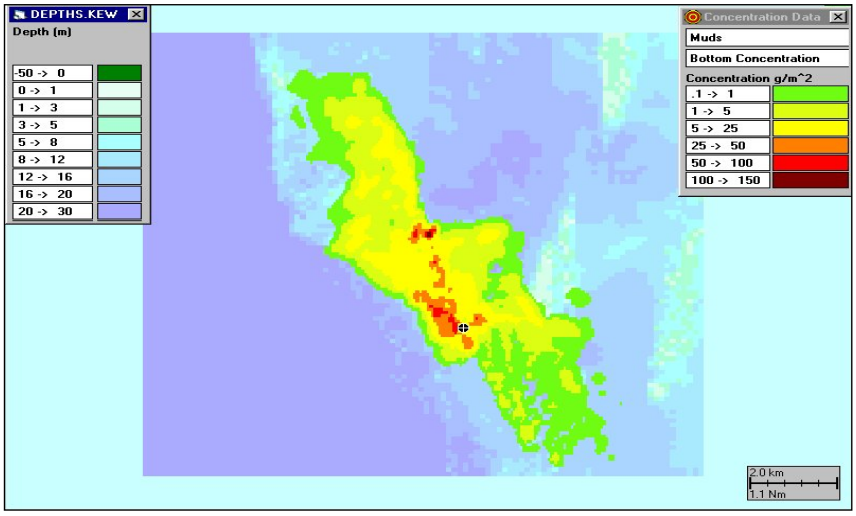

Figure A2 Example MUDMAP bottom concentration output for drilling fluid discharge.

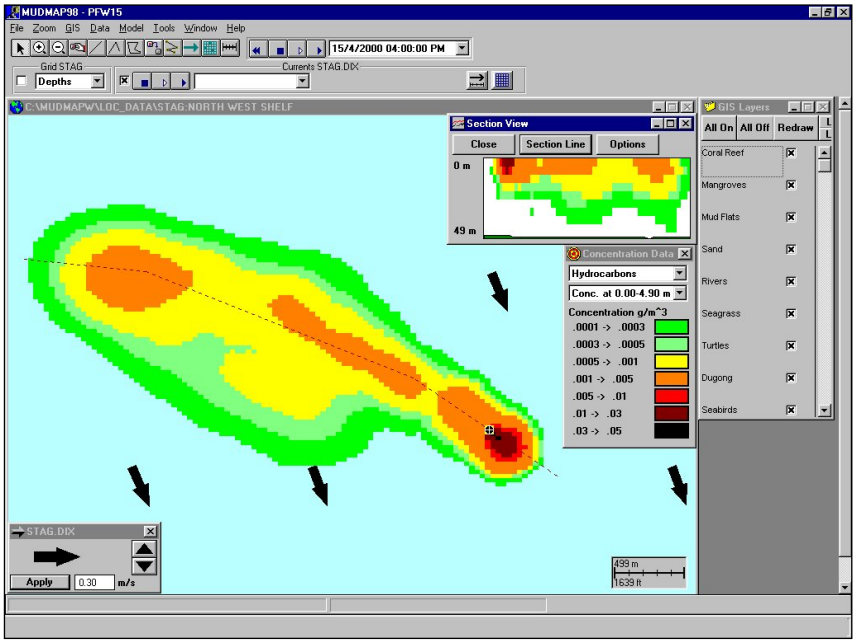

Figure A3. Example MUDMAP water column concentration output for drilling fluid discharge.

MUDMAP uses a color graphics-based user interface and provides an embedded geographic information system, environmental data management tools, and procedures to input data and to animate model output. The system can be readily applied to any location in the world. Application of MUDMAP to predict the transport and deposition of heavy and light drill fluids off Pt. Conception, California and the near-field plume dynamics of a laboratory experiment for a multi-component mud discharged into a uniform flowing, stratified water column are presented in Spaulding et al. (1994). King and McAllister (1997, 1998) present the application and extensive verification of the model for a produced water discharge on Australia's northwest shelf. GEMS (1998) applied the model to assess the dispersion and deposition of drilling cuttings released off the northwest coast of Australia.

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APPENDIX E

Acoustic Modelling Report

2019 BHP Exploration Drilling in the Orphan Basin

Underwater Sound Modelling Report

Submitted to:
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11 December 2019

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Acronyms and Abbreviations

AASM	airgun array source model
AMAR	autonomous multichannel acoustic recorders
ANSI	American National Standards Institute
BELLHOP	beam tracing model for predicting acoustic pressure fields in the ocean
BHP	BHP Canada, acronym derives from Broken Hill Proprietary (original firm in Broken Hill, Australia). Also references the parent company, which is duel listed as BHP Billiton Limited and BHP Billiton Plc.
c	sound speed
cm	centimeter
CNLOPB	Canada Newfoundland Labrador Offshore Petroleum Board
CPA	closest point of approach
CW	continuous wave
Δ	mathematical prefix denoting a change in a quantity; for example Δf is a change in frequency
d	depth
dB	decibel
DP	dynamic positioning
DSV	dive support vessel or drilling support vessel, depending on context
EL	exploratory license (geographic block)
ESRF	Environmental Studies Research Fund
f	frequency
ft	feet
FWRAM	full waveform RAM (range-dependent acoustic model)
g	gram
GB	gigabyte
GDEM	generalized digital environmental model
GI	generated injection airgun
GTI	GeoSpectrum Technologies Inc.
HESS	High Energy Seismic Survey
HF	high frequency (cetacean hearing group)
HP	horsepower
Hz	hertz
in	inch
ISO	International Organization for Standardization
JASCO	Jasco Applied Sciences
kHz	kilohertz
km	kilometer
kts	knots, or nautical-miles-per-hour
kW	kilowatt
λ	acoustic wavelength
L_{100}	spectrum level at 100 Hz (applies as well to other frequencies)
L_E	cumulative sound exposure level (also SEL)
LF	low frequency (cetacean hearing group)

Log_{10}	mathematical function to calculate the base-10 logarithm
L_p	sound pressure level
L_{pk}	peak sound pressure level
m	meter
MF	mid-frequency (cetacean hearing group)
MONM	marine operations noise model
MOODS	master oceanographic observational data
ms	millisecond
µPa	micropascal
mbsf	meters below the seafloor
MODU	mobile offshore drilling unit
m/s	meter per second
MW	mammal weighting (in the context of SEL criteria and exposure)
MW	megawatt (in the context of equipment power ratings)
N×2D or N×2-D	a two-dimensional analysis in range and depth repeated for multiple azimuthal directions
NIOSH	National Institute for Occupational Safety and Health (US)
NOAA	National Oceanic and Atmospheric Administration (US)
NMFS	National Marine Fisheries Service (US)
NOPEC	NOrwegian Petroleum Exploration Consultants International ASA
ONR	Office of Naval Research (US)
ϕ	latitude (in degrees or radians)
P	pressure
PGS	Petroleum Geo-Services
PK	peak sound pressure level
PSD	power spectrum density
psi	pounds-per-square-inch
psu	physical salinity unit (approximately equal to parts-per-thousands in mass)
PTS	permanent threshold shift
PW	phocid in water (hearing group)
r or R	range
R_{nf}	maximum range of the near-field of an array
RAM	range-dependent acoustic model (parabolic equation)
rpm	revolutions-per-minute or rotations-per-minute
Σ	mathematical symbol to denote a summation operator
S	shear or salinity (context dependent)
s	second
SEL	cumulative sound exposure level
SL	source level
SPL	sound pressure level
SRTM	Shuttle Radar Topography Mission; usually means a global database of depth and elevation originally derived from SRTM altimeter data
SSP	sound speed profile
rms	root mean square

θ	azimuthal direction (in degrees or radians)
t or *T*	time or temperature (context dependent)
TGS	TGS-NOPEC Geophysical Company ASA, listed on the Oslo Stock Exchange as TGS, originally an acronym for Tomlinson Geophysical Services Inc.
TTS	temporary threshold shift
UTM	universal transverse Mercator
V	volt (the unit of electric potential) or the symbol for voltage
VSP	vertical seismic profiling
WGS	world geodetic system

Executive Summary

The 2019 Exploration Drilling project, proposed by BHP, includes exploration drilling activities in Exploration Licences (EL) 1157 and 1158 in Orphan Basin, located 370 km east of Newfoundland, Canada (BHP 2019). This project may involve drilling up to 20 exploration wells over the licence term (2019–2028). The project will use a mobile offshore drilling unit (MODU), either a semi-submersible platform or a drillship; either option will be maintained on station by dynamic positioning (DP). Other sound generating equipment will include a vertical seismic profiling (VSP) array and support vessels.

In this report, JASCO Applied Sciences (JASCO) discusses the underwater sounds associated with the proposed project activities by reviewing existing assessments of similar projects located offshore Newfoundland and Nova Scotia. Sound source spectra representative of the planned project activities were estimated based on assessments published in previous studies. The acoustic environment is described and compared to the environmental parameters used in the underwater sound assessments for the Scotian Basin Exploration Drilling Project (hereafter the Scotian Basin Project; Zykov 2016), the Nexen Energy ULC Flemish Pass Exploration Drilling Project (hereafter the Flemish Pass Project; Matthews et al. 2017), and the BP Orphan Basin Exploration Drilling Program (hereafter the BP Orphan Basin Project; Matthews et al. 2018). Underwater acoustic propagation conditions for these three offshore projects are compared to those in EL-1157 and EL-1158, in February and August. Ambient sound levels and various contributors to the soundscape in the area were derived from data measured at two Environmental Studies Research Fund (ESRF) recording stations, near EL-1157 and EL-1158. Anthropogenic contributors to the soundscape (including vessel traffic, previous seismic surveys, and oil and gas extraction activity) and naturally occurring ambient sound contributors (including wind, other environmental phenomena, and fin whales) are discussed. The present study modelled underwater acoustic propagation loss from typical sound sources this type of project. Two seasonal extremes (summer and winter) at two modelled sites in the project area were modelled. It also quantified maximum received levels over depth, in the sound pressure level (SPL) and sound exposure level (SEL) metrics, and estimated SEL threshold distances for four marine mammal hearing groups.

Accurately assessing sound propagating away from the planned project activities depends on the particulars of the equipment and activities. However, because of the similarities in operations and environmental parameters, underwater sound assessments for the Scotian Basin, the Flemish Pass, and the BP Orphan Basin exploration drilling projects help provide a preliminary assessment of likely sound propagation features in the BHP Orphan Basin project. Based on sound monthly averaged speed profiles in EL-1157 and EL-1158, we expect distances to sound thresholds to be shorter in summer (e.g., August) than in winter (e.g., February). The February sound speed profile in both EL-1157 and EL-1158 features a deep surface duct (or half-channel) that results in longer distances than in August. We expected this difference to persist throughout the oceanographic winter months (January–April). Based on the analysis of propagation loss coefficients for drillship and semi-submersible platforms in the BP Orphan Basin Project (Matthews et al. 2018), similar distances to those in Flemish Pass, and those in August in the Scotian Basin are expected in EL-1157 and EL-1158. The propagation loss coefficients for the VSP operations indicate that distances to sound level isopleths in June in EL-1157 and EL-1158 should be similar to those in May in Flemish Pass, and longer than modelled in the Scotian Basin. These distances from VSP operations in EL-1157 and EL-1158 are expected to be shorter than in Flemish Pass and the Scotian Basin.

The modelled acoustic fields were compared against various marine mammal impact criteria defined in terms of peak pressure and 24 hour SEL. For all sources, the ranges to the acoustic thresholds for peak pressure were never longer than 0.28 km. The distances to the peak pressure thresholds were all shorter than 0.06 km. For all the vessel and MODU sources, the peak pressure was well under the thresholds for temporary threshold shift (TTS) and permanent threshold shift (PTS) onset at less than 15 m from the source.

For the distances to the 24 hour SEL impact criteria, the longest distances are from a airgun array and a generic drillship. The longest distance to PTS onset threshold was 0.59 km. This was for the low-frequency cetacean ensonified by for the airgun array at Site B in August. This scenario also had the longest distance to the TTS onset threshold (6.2 km). This scenario (airgun array, Site B, August) also

yielded maximum distances to NFMS criteria (for PTS and TTS onset for phocid pinnipeds) of 0.07 and 0.4 km, respectively.

Most threshold distances for the vessel and MODU sources were much lower than those for the VSP source, although the generic drillship yielded a maximum PTS onset distance of 0.28 km for NMFS (2018) criteria for high-frequency cetaceans at Site A in February and a corresponding maximum TTS onset distance of 5.5 km. In all modelled scenarios, the maximum PTS onset distance never exceeded 0.60 km.

Based on the analysis of important contributors to the ambient soundscape in the region, sound levels associated with the project activities are expected to dominate the soundscape within distances of 10–40 km from the platform, during the course of the activities. VSP operations are expected to contribute to the ambient sound levels to a lesser extend than seismic surveys because of their shorter operational timeframe and lower source levels. The relative contribution to the ambient soundscape will depend on the specifications of the project activities, as well as the possible presence of other simultaneous contributors in the region.

1. Introduction

JASCO Applied Sciences (JASCO) undertook a modelling study for Stantec Consulting Ltd. to predict underwater sound levels associated with the proposed 2019 BHP exploration drilling project in the Orphan Basin, located northeast offshore of Newfoundland. The area of interest spans exploratory license blocks EL-1157 and EL-1158 (BHP 2019).

The project development and operation requires exploratory offshore drilling and vertical seismic profiling (VSP) to be performed. These activities will introduce noise into the water and could disturb marine mammals. At the time of this study, the exact equipment was not finalized. JASCO modelled typical equipment commonly used for such activities.

The following operations/sources were modelled:

- Vertical Seismic Profiling (VSP)
- Drillship
- Semi-Submersible Drilling Platform
- Support Vessel

The goal of this modelling study was to estimate sound pressure level (SPL) of noise introduced into the water by the project activities (i.e., the root-mean-square (rms) pressure level) as a maximum-over-depth metric at varying distances (ranges) and azimuth angles (bearings) from the modelled sources. The sound exposure level (SEL) field for a 24 hour period was also modelled. The SEL field was assessed against the marine mammal impact thresholds outlined in the National Marine Fisheries Service (NMFS 2018) exposure guidelines. The peak pressure field level (PK) was calculated for the VSP, an impulsive source. PK of the VSP was estimated as $\sqrt{2}$ times the rms pressure for the other sources, which are non-impulsive.

The acoustic characteristics of the VSP airgun array were modelled with JASCO's Airgun Array Source Model (AASM; Section 3.1). The source levels of the drillship, semi-submersible, and support vessel were estimated based on a combination of field measurements of vessels typical of each type and the relationship between radiated sound expectation value and power ratings, where field measurements were unavailable.

The propagation loss (i.e., a measure of sound intensity loss through propagation) was modelled with JASCO's Marine Operations Noise Model (MONM; Section 3.2) in the 10 to 25,000 Hz frequency range. Sound propagation was modelled for ranges up to 100 km from each source.

The acoustic field was modelled at two locations (Sites A and B) within the project development area (Figures 1 and 2). Two sound speed profiles in the water column were modelled (February and August; Section 4.1).

For greater accuracy, the SPL and peak pressure fields for the VSP airgun array source were estimated based on full waveform modelling (FWRAM) that provides time-domain representations of the pressure waves generated in the water.

The SEL and peak pressure fields were assessed against the threshold levels for the onset of permanent (PTS) and temporary threshold shifts (TTS) relevant to each marine mammal hearing group using respective auditory weighting functions as per NMFS (2018).

Section 1.1 of this report introduces past studies used for estimating ambient sound levels, comparing environmental parameters, and comparing propagation loss (PL) functions. Background information on underwater sound, the factors influencing sound propagation, ambient sound, and anthropogenic sound are presented in Section 2. Section 3 details the methodology used for predicting the source levels (Section 3.1) and modelling the sound propagation (Section 3.2). Section 4 describes the methods and input parameters for the propagation modelling: the assumed environmental parameters (Section 4.1), ambient sound measurements (Section 4.2), modelling and receiver geometry (4.3), and specifications and derived source levels of the acoustic sources (Section 1.1). Section 4.5 reports on the estimated

sound propagation conditions resulting from the modelling. Environmental Studies Research Fund (ESRF) soundscape measurement statistics are provided in Section 4.6. Section 4 presents the results of the modelling study as sound field contour maps and tables of distances to sound level contours for the SPL fields, and as schematics of threshold contours and tables of safe distances to the specific SEL thresholds. Appendix A explains the signal metrics used to represent underwater acoustic fields. Appendix B has background information about the acoustic impact criteria that were considered. Appendix C provides details of the data collection methods for the 2015–2017 ESRF study.

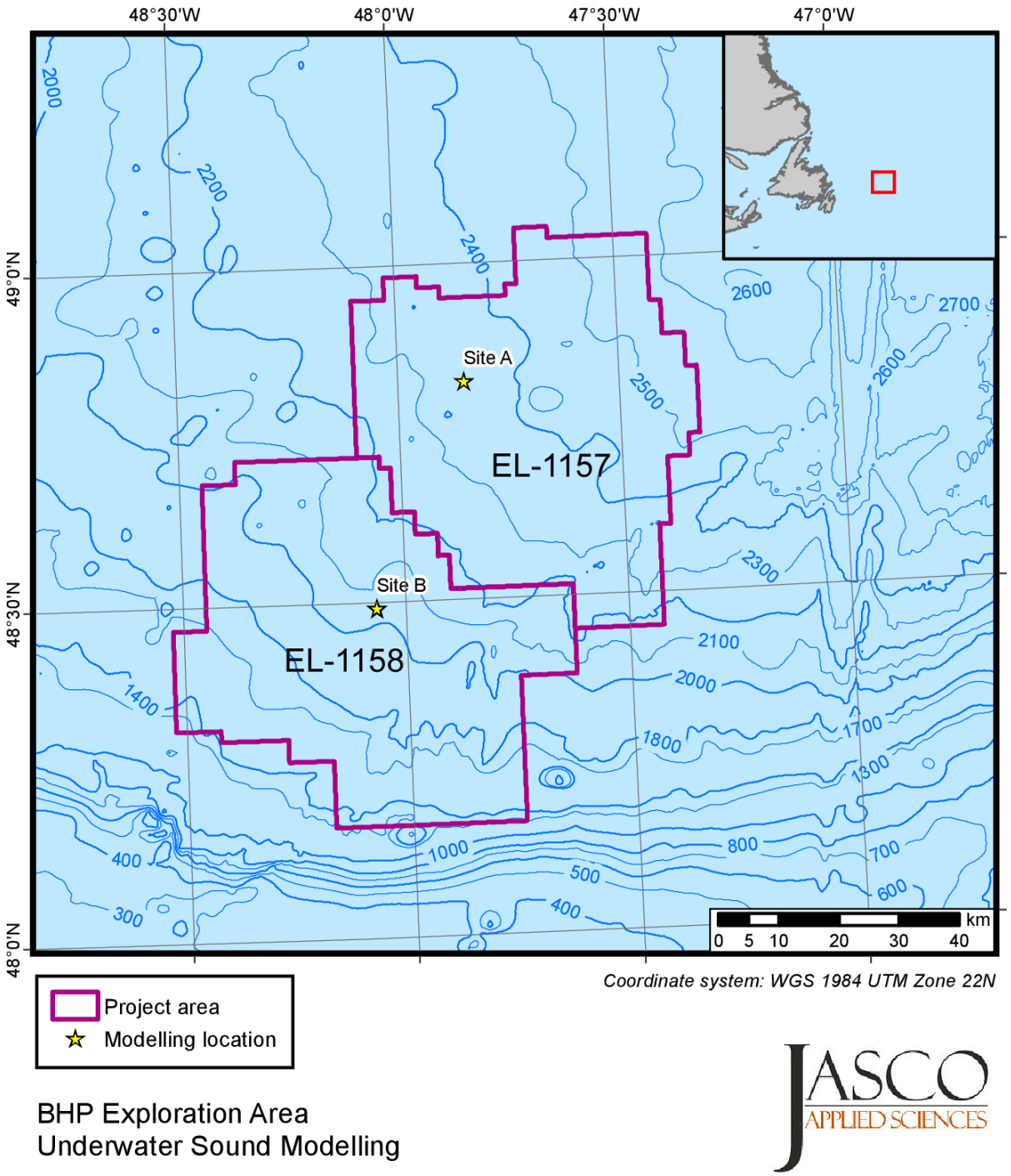


Figure 1. Modelled locations within the BHP exploration drilling project area in the Orphan Basin. Blue contour lines indicate water depth in meters.

1.1. Related Studies

Representative sound source levels as a function of frequency (i.e., source level spectra) for semi-submersible platforms, drillships, VSP arrays, and support vessels have been described in previous JASCO reports. Four recent reports were used in this analysis to derive the best representative sound level spectra for the project (Zykov 2016, Matthews et al. 2017, Quijano et al. 2017).

Three of those studies, Zykov (2016), Matthews et al. (2017), and Matthews et al. 2018 estimated distances to specific sound thresholds for each modelled operation. The environmental parameters used in these studies were compared to those characterizing the project area to assess the pertinence of the estimated distances for the current project. PL functions derived from these results were also compared to those modelled for the current project.

The Environmental Studies Research Fund (ESRF) funded a two-year program aimed at describing the soundscape and the occurrence of marine mammals within the waters off the Canadian Atlantic coast (Delarue et al. 2018, hereafter referred to as the ESRF Study). The ESRF Study area included shallow and deep waters. The area extended from Dawson Canyon off Halifax, NS, to Nain Bank on the Labrador shelf. JASCO deployed 20 acoustic recorders along Canada's east coast for the ESRF Study. The recorders were active for most of 2015–2017. Data from ESRF station 19 (which had two locations in different years) were used in the present study to provide the best available information on the soundscape in the project area (Figure 2). It was first located ~150 km from the project area in ~1280 m water depth (Station 19, 2015–2016 in Figure 2) and later relocated to Sackville Spur at the north end of the Flemish Pass (Station 19, 2016–2017 in Figure 2) in ~1550 m water depth. To summarize the soundscape around the project area, in Section 4.6 we present selected ESRF data that details one-minute sound pressure level (SPL) measurements and their statistical distribution.

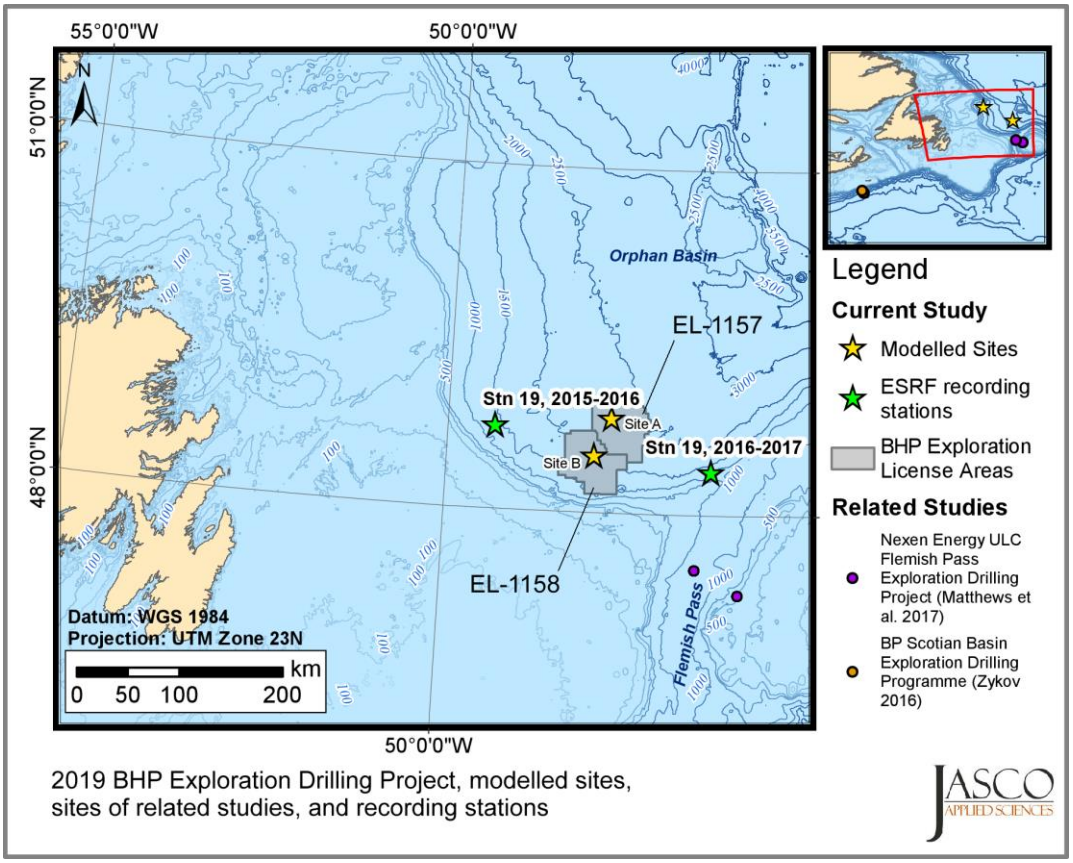


Figure 2. Overview of BHP Exploration Licenses coverage area, the modelled Sites A and B, Environmental Studies Research Fund (ESRF) recording stations, and modelled sites of related studies.

2. Underwater Sound

2.1. Factors Affecting Sound Propagation

Sound propagation in the ocean is a complex process that depends on many factors. Sound levels from an omnidirectional point source in the water column are reduced with range, a process known as geometric spreading. Before sound emanating from a point source reaches the seabed or sea surface boundaries, sound waves propagate in a spherical pattern. In this case, the received levels at a recorder located R distance from the source are $20\times\log(R)$ dB lower than the levels measured at a reference point (1 m from the source). This is known as spherical geometric spreading. Once the sound waves interact with the sea surface and seabed, the spreading becomes cylindrical, with a lower range-dependent decay of $10\times\log(R)$ dB. Spherical and cylindrical spreading factors provide rules of thumb for quickly estimating the expected levels from a given source. For more realistic scenarios, other factors must also be considered related to losses at the seabed and sea surface, frequency spectrum of the source, and environmental parameters (e.g., bathymetry, water sound speed profile, and seabed geoacoustics).

In general, sound levels at short ranges are higher in shallow waters than in deep waters. In deep waters (and at ranges less than a water depth), sound levels are determined by acoustic arrivals from the source and perhaps from energy bouncing off the air-water interface. For shallow environments at the same range, sound levels can increase due to contributions from multiple bounces off the seabed. The opposite situation can also be experienced at far ranges (i.e., several water depths for both deep and shallow waters). In shallow waters, there are substantial losses in acoustic energy due to multiple bounces off the seabed. In deep waters there are fewer interactions of the acoustic wave with the seabed. These general trends must be applied with caution, however, because the ocean waveguide is highly complex.

Along with the environmental parameters (bathymetry, sound speed profile, and seabed geoacoustics), a sound's frequency content plays an important role in how it propagates in the ocean. For example, acoustic energy is attenuated by molecular absorption in seawater. The volumetric sound absorption is quantified by an attenuation coefficient, expressed in units of decibels per kilometre (dB/km). This 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 the frequency (i.e., high frequencies are more affected). 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 can exceed 10 dB, as computed according to the formulae of François and Garrison (1982b, b). Another mechanism of absorption in the water column is scattering, which results from the sound wave interacting with non-homogeneities (such as air bubbles) and with the rough boundaries at the air-sea and sea-seabed interfaces. Acoustic energy loss due to scattering is also frequency-dependent, with more noticeable effects when the scatterer is the same size or larger than the sound wavelength. Sounds at low frequencies, therefore, are less affected by scattering than sounds at high frequencies.

Although lower frequency sounds are less affected by absorption and scattering, there are other mechanisms that have the opposite effect (i.e., favour propagation of higher frequency sounds). For example, propagation through a surface duct only applies to frequencies above a certain cut-off. When sound has strong frequency components above this cut-off, acoustic energy is trapped in the surface channel. This trapped energy does not interact with the seabed, so it propagates to farther ranges. Low-frequency sounds, however, tend to interact with the seabed and are attenuated as they propagate through the seabed sediment.

2.1.1. Sea Surface and Ocean Floor

When sound propagates through the ocean, the sea surface and ocean floor act as boundaries that reflect, absorb, and scatter energy. In computational acoustics, the surface is referred to as a 'pressure-release' interface because it reflects sound with equal amplitude and opposite phase. The reflected direction is equal to the angle of incidence. Thus, if the surface is tilted by wave action, sound energy may be scattered, and the sound is attenuation at the sea surface. This loss resulting from surface roughness

depends on the sound wavelength relative to the size of the surface waves; it becomes more important with increasing frequency.

The ocean floor is a different type of boundary. It is generally modelled as a viscous fluid where a portion of the sound energy is reflected and the remainder is transmitted into the sediment. The amounts of reflection and transmission depend on the angle of incidence, bottom roughness, and the physical properties of the material (e.g., density, grain size, and porosity). Lower density materials, such as clays and silts, allow more sound to penetrate. Hard materials, such as sand and gravel, reflect most of the incident sound. When there are layers of less dense sediment over more dense materials, such as bedrock, the sound can reflect off the lower layers and re-enter the water column. Soft materials, such as clays, can also refract and trap sound, as well as absorb and attenuate it. Thus, seabed geoacoustics are an important environmental component for understanding and predicting acoustic propagation, especially in shallow waters where seabed interactions are frequent.

2.1.2. Bathymetry

At lower frequencies (less than a few kilohertz), acoustic propagation is highly dependent on water depth. In general, the deeper the water, the lower the propagation loss due to interaction with the seafloor. From an acoustic perspective, water depth should be considered in terms of the wavelength of the sound that is being transmitted. For example, when the water is more than several wavelengths in depth, it may be considered “deep” (Buckingham 2005). Shallow water, however, is often arbitrarily defined as that less than 200 m deep (Buckingham 1992) and includes most of the continental shelf regions of the world.

In shallow water, the acoustic energy transmitted from a source likely interacts many times with either or both the sea surface and the seabed, and energy is lost on each interaction. In contrast, these interactions occur less frequently in deeper waters, and the overall acoustic energy levels persist. This is particularly true when the water is sufficiently deep to be defined by an underwater sound speed profile (Section 2.1.3) with a sound channel that prevents acoustic energy from interacting with the surface and seabed, resulting in extended propagation ranges.

2.1.3. Sound Speed Profile

As sound speed changes with depth, the sound refracts toward the depth with the lowest sound speed. This results in sound being trapped in a ‘duct’ and travelling very long distances with minimal attenuation. Conversely, in conditions where the sound speed decreases with depth, sound is refracted toward the seabed and may not reach an intended receiver.

The sound speed changes as a function of the temperature, salinity, and pressure (depth). Colder and fresher water has a lower sound speed. Warmer and saltier water has a higher sound speed. As the water depth increases, the pressure increases the water density slightly, which increases the sound speed (Jensen et al. 2011). These effects combine with environmental forces, such as solar heating, wind mixing, and currents, to constantly affect the sound speed in the upper 500 m of the water column, which has daily variations around typical seasonal means (Figure 3). The ability of a minimum in the sound speed profile to ‘trap’ sound depends on the magnitude of the sound speed change at the minimum, the vertical height of the minimum and the sound’s wavelength. Ducts must be several times larger than the wavelength for effective trapping of sound (Etter 1996). A corollary of this effect is that higher frequencies are refracted more readily by sound speed changes than lower frequencies that have longer wavelengths.

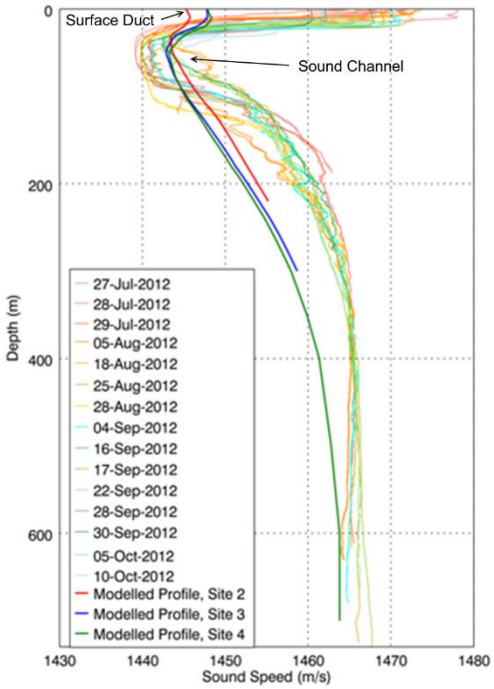


Figure 3. Example of seasonal sound speed profiles from climatology (Modelled Profiles) and actual sound speed profiles measured in situ in Baffin Bay. These profiles show daily variations and features, such as sound channels and surface duct.

2.2. Ambient Sound

The ambient, or background, sound levels that create the ocean soundscape are comprised of many natural and anthropogenic sources (Figure 4). The main environmental sources of sound are wind, precipitation, and sea ice. Wind-generated noise in the ocean is well-described (e.g., Wenz 1962, Ross 1976), and surf noise is known to be an important contributor to near-shore soundscapes (Deane 2000). Sea ice can produce loud sounds that are often the main contributor of acoustic energy in the local soundscape, particularly during ice formation and break up. Precipitation is a frequent noise source, with contributions typically concentrated at frequencies above 500 Hz. At low frequencies (<100 Hz), earthquakes and other geological events contribute to the soundscape.

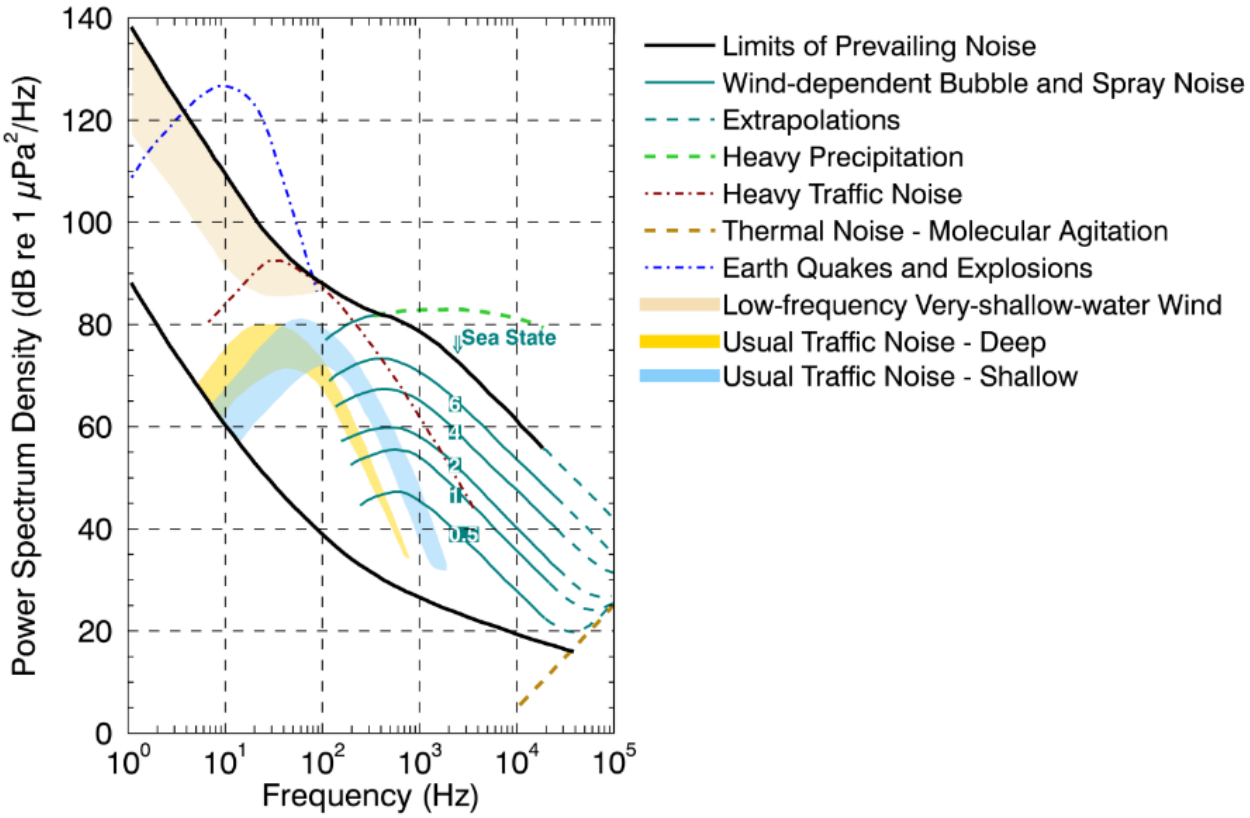


Figure 4. Wenz curves (NRC 2003), describing pressure spectral density levels of marine ambient noise from weather, wind, geologic activity, and commercial shipping, adapted from Wenz (1962).

2.3. Anthropogenic Contributors to the Soundscape

The relative contribution of any sound source to the ocean soundscape depends on factors such as:

- How loud the source is relative to other sounds (e.g., ambient sound);
- The source's frequency spectrum;
- The duration of the sound;
- The characteristics of sound propagation/transmission loss, determined by local environmental parameters (water depth, sound speed profile, and seabed type);
- The depth and distance between a sound source and the receiver or modelling/measurement location; and
- The overlap of the frequency content of the new sounds with the existing sounds in the environment.

Anthropogenic (human-generated) sounds can be a by-product of vessel operations, such as engine sound radiating through vessel hulls and cavitating propulsion systems, or it can be a product of active acoustic data collection with seismic surveys, military sonar, and depth sounding as the main contributors. The contribution of anthropogenic sources to the ocean soundscape has increased from the 1950s to 2010, largely driven by greater maritime shipping traffic (Ross 1976, Andrew et al. 2011). Recent trends suggest that global sound levels or leveling off or potentially decreasing in some areas (Andrew et al. 2011, Miksis-Olds and Nichols 2016). Oil and gas exploration with seismic airguns, marine pile driving and oil and gas production platforms elevate sound levels over radii of 10 to 1000 km when present (Bailey et al. 2010, Miksis-Olds and Nichols 2016, Delarue et al. 2018).The extent of seismic

survey sounds has increased substantially following the expansion of oil and gas exploration into deep water, and seismic sounds can now be detected across ocean basins (Nieukirk et al. 2004).

Seasonality influences the contribution of anthropogenic noise levels to the soundscape. For example, in the project area seismic survey activity and fishing occurs mostly in summer, whereas commercial shipping and oil and gas extraction sounds are present year-round. The activity in winter reduces due to higher average wind speeds and rough surface conditions, which also elevate the natural sound levels. The main anthropogenic contributors to ambient noise in the present study are discussed in the following subsections.

2.3.1. Vessel Traffic Activity

There are several major shipping lanes south of the study area. Vessel tracks fan out after leaving the Gulf of St. Lawrence, resulting in constant traffic on the Scotian Shelf and in areas south of Newfoundland. A few isolated areas of denser vessel traffic off the coast indicate the location of oil and natural gas extraction platforms and the associated transit of support vessels, as well as areas targeted by seismic surveys and potential fishing hotspots (Figure 5). Each vessel that comprises this marine traffic contributes to the ambient underwater sound.

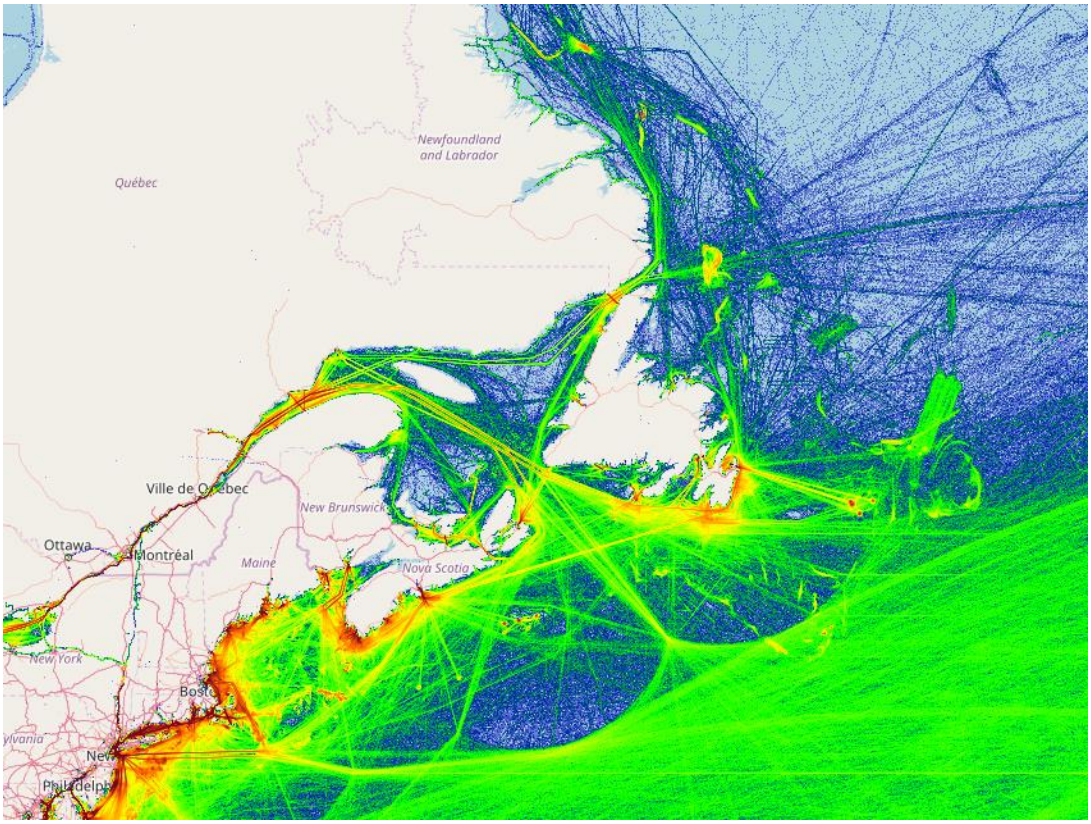


Figure 5. Shipping traffic off the American and Canadian east coast (source: marinetraffic.com; accessed 30 Aug 2017).

2.3.2. Seismic Surveys and Oil and Gas Extraction Activities

Seismic exploration has a long history on Canada's east coast. Increasing in the 1960s, success in both Nova Scotia and Newfoundland in the 1970s and 1980s resulted in an exploration peak in 1983. The next wave of seismic exploration began in 1995 and continued into the 2000s as 3-D work focused on the

Scotian Shelf. In recent years TGS, Petroleum Geo-Services (PGS), Nalcor Energy, and to a lesser extent Shell and BP, have undertaken extensive surveys from Nova Scotia to Labrador.

The influence of such activities is present in the ambient sound levels derived from the ESRF Study data. Nearly 500 000 km were surveyed across areas under the jurisdiction of the Canada Newfoundland Labrador Offshore Petroleum Board (CNLOPB) during the 2015 season (Table 1). Figure 6 shows the extent of the surveys conducted by Multi Klient Invest AS, a joint venture between Nalcor, TGS, and PGS in 2015.

Table 1. Geoscientific programs with fieldwork authorized during 2015–2016 fiscal year in eastern Canadian waters (Source: CNLOPB 2016).

Operator	Program	Region	Distance surveyed (km)
Hibernia Management and Development Company Ltd.	4-D Seismic	Jeanne d'Arc Basin	90 818
Multi Klient Invest	2-D Seismic	Northern Labrador and Northeastern Newfoundland	9 951
Multi Klient Invest	3-D Seismic	Eastern Newfoundland	166 219
Multi Klient Invest	3-D Seismic	Eastern Newfoundland	211 734
Multi Klient Invest	2-D Seismic	Eastern and northeastern Newfoundland	2 483
Multi Klient Invest	2-D Seismic	Southern and southeastern Newfoundland	14 403

Oil and gas extraction activity is increasing on Canada's east coast. For example, exploratory drilling programs were performed Statoil from Nov 2014 to May 2016 in the Flemish Pass (mentioned in Section 4.6) and fall 2015 to summer 2016 by Shell offshore of Nova Scotia. Production platforms are in place in the White-Rose-Hibernia-Hebron developments on the Grand Banks as well as in the Sable and Panuke developments off Nova Scotia (Figure 5). These activities affect the soundscape around them continuously (MacDonnell 2017, Quijano et al. 2017). The distance from the activity where the sounds exceed the ambient background are anywhere from 10–200 km depending on the receiver depth, sound propagation conditions, and the nature of the platform sound signature (Zykov 2016, MacDonnell 2017).

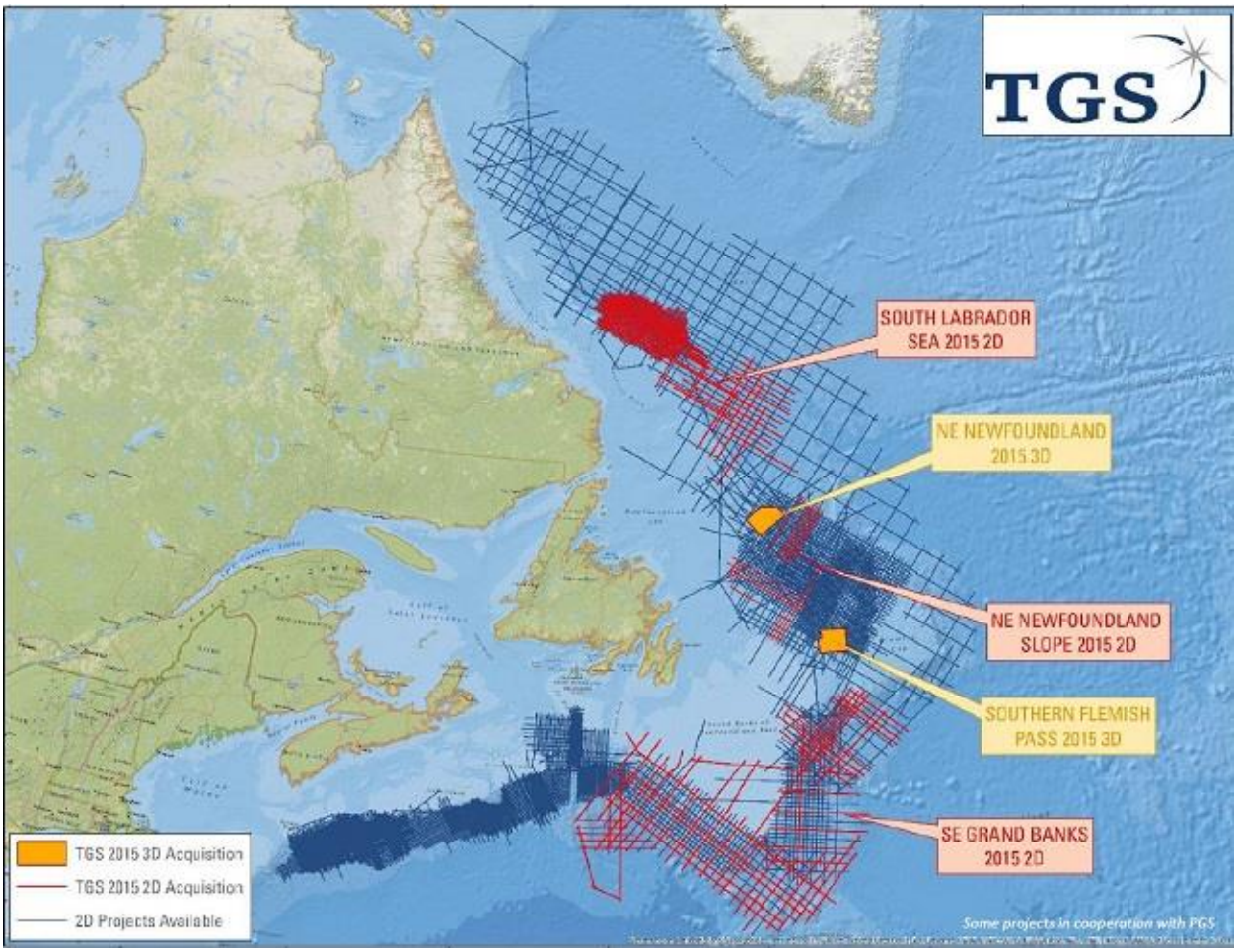


Figure 6. 2015 seismic surveys completed by TGS and PGS and previously available 2-D seismic data in eastern Canadian waters. (Source: Larsen and Ashby 2015).

3. Modelling Methodology

Underwater acoustic fields are predicted in three steps:

1. Underwater acoustic source level (SL) spectrum and directivity beampattern of the noise from each source are modelled.
2. Transmission loss of the water-borne pressure wave at varying range, depth, and bearing around each source location are modelled.
3. Results of the first two steps are combined into a total noise field estimate, as a maximum-over-depth metric, for varying range and bearing from each source to compare to biological impact thresholds.

JASCO can employ various underwater acoustic source spectrum and acoustic wave propagation models. The models employed in this study were selected based on the source characteristics and the required characteristics of the resulting field. These models incorporate parameters that are specific to the modelled sources and the modelled environment.

3.1. Modelling Acoustics Sources

3.1.1. VSP Source: Seismic Airgun Array

The modelled acoustic source for the VSP operation is a conventional airgun array. The source level and directivity of the airgun array were predicted with AASM. This model is based on the physics of the oscillation and radiation of airgun bubbles as described by Ziolkowski (1970). The model solves the set of parallel differential equations that govern bubble oscillations. AASM also accounts for non-linear pressure interactions between airguns, port throttling, bubble damping, and generated injection (GI) airgun behaviour, as discussed by Dragoset (1984), Laws et al. (1990), and Landro (1992). AASM includes four empirical parameters tuned so the model output matches observed airgun behaviour. The model parameters were fit to a large library of empirical airgun data using a "simulated annealing" global optimization algorithm (Černý 1985). These airgun data consist of measured signatures of Bolt 600/B airguns that range in volume from 5 to 185 in^3; the provided sampling rate of the time series was 50 kHz (Racca and Scrimger 1986).

AASM produces a set of notional signatures for each airgun element based on:

- Array spatial layout
- Volume, tow depth, and operating pressure of each airgun
- Interactions between airguns in the array

Notional signatures are the pressure waveforms of the individual airguns at a standard reference distance of 1 m. They account for the interactions between the air bubbles created by adjacent airguns in the array. The signatures are summed with the appropriate phase delays to obtain the far-field source signature of the entire array in the horizontal plane. This far-field[1] array signature is filtered into 1/3-octave passbands 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). It can then be treated as a point source in the far-field.

A seismic array consists of many sources and the point-source assumption is invalid in the near-field where the array elements add incoherently. The maximum extent of the near-field of an array (R_{nf}) is:

$$R_{nf} < \frac{l^2}{4\lambda} \tag{1}$$

where λ is the acoustic wavelength and l is the longest dimension of the array (Lurton 2002, §5.2.4). For example, an airgun array length of $l \approx 16$ m yields a near-field range of 85 m at 2 kHz and 17 m at 100 Hz. Beyond R_{nf}, it is assumed that an array radiates like a directional point source and is treated as such for propagation modelling.

AASM accurately predicts the source level of each complete array as a point source for the purpose of acoustic propagation modelling in the far field; however, the predicted source levels for 0-to-peak (PK) pressure and SEL metrics could be higher than the maximum levels possible during the array operation, even within the array dimensions. AASM accounts for the effects of source depth on bubble interactions, the surface-reflected signal (i.e., surface ghost) is excluded from the far-field source signatures. The propagation models account for surface reflections, a property of the medium rather than the source.

The separations between individual array elements in the horizontal plane create directionality in overall acoustic emissions. Generally, this directivity is prominent mainly at frequencies in the mid-range of several tens to several hundreds of hertz; at lower frequencies, where acoustic wavelengths are much larger than the inter-airgun separation distances, directivity is small. At higher frequencies the pattern of lobes becomes too finely spaced to be resolved and the effective directivity is less.

[1] The far field is the zone where, to an observer, sound originating from a spatially-distributed source appears to radiate from a single point. The distance to the acoustic far-field increases with frequency.

AASM was used to predict the far-field airgun array signature in the frequency range of 10 to 25,000 Hz.

3.1.2. Vessels

Underwater sound that radiates from a vessel is produced mainly by propeller and thruster cavitation. A smaller fraction of the projected emission is produced by internal 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, 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). At higher speeds and under higher propulsion system load, the broadband acoustic output from the cavitation processes on the propeller blades dominates over the other sources of sound on the vessel (Leggat et al. 1981). However, when applying criteria that rely on weighted spectrum, it is important to account for the acoustic energy at higher frequencies.

Another common approach for defining the source levels for vessels is to use field measurements from a similar vessel of the same type (a "surrogate" vessel) while involved in a similar activity. The measured relative spectrum levels are taken unchanged, while the broadband level is adjusted to account for any difference in the total propulsion power between the surrogate vessel and the vessel of interest.

This modelling study applied a hybrid method of vessel source level estimation that involved calculating sound levels from the cavitating propeller and estimations based on the surrogate vessel approach. The resultant source level spectrum for the vessel is the maximum of the values provided by the two methods in each band.

3.1.2.1. Sound Levels from Cavitating Propeller

The sound power from propellers is proportional to the number of blades, the propeller diameter, and the propeller tip speed (Leggat et al. 1981).

Based on an analysis of acoustic data, Ross (1976) provided the following formula for the sound levels from a vessel's propeller, operating in calm, open ocean conditions:

$$L_{100} = 155 + 60\log_{10}(u/25) + 10\log_{10}(B/4)\,, \qquad (2)$$

where L_{100} is the spectrum level at 100 Hz, u is the propeller tip speed (m/s), and B is the number of propeller blades. Equation 2 gives the total energy produced by the propeller cavitation at frequencies between 100 Hz and 10 kHz. This equation is valid for a propeller tip speed between 15 and 50 m/s. The spectrum is assumed to be flat below 100 Hz. Its level is assumed to fall off at a rate of −6 dB per octave above 100 Hz (Figure 7).

Another method of predicting the source level of a propeller was suggested by Brown (1977). For propellers operating in heavily loaded conditions, the formula for the sound spectrum level is:

$$\mathrm{SL}_B = 163 + 40\log_{10} D + 30\log_{10} N + 10\log_{10} B - 20\log_{10} f + 10\log_{10}(A_c/A_D)\,, \qquad (3)$$

where D is the propeller diameter (m), N is the propeller revolution rate per second, B is the number of propeller blades, A_C is the area of the blades covered by cavitation, and A_D is the total propeller disc area. Similar to Ross's approach, the spectrum below 100 Hz is assumed to be flat. Tests with a naval propeller operating at off-design heavily loaded conditions showed that Equation 3 should be used with a value of $\mathrm{A_C}/\mathrm{A_D} = 1$ (Leggat et al. 1981).

If a vessel is equipped with multiple thrusters, the combined source level for a group of thrusters operating together can be estimated using the formula:

$$\mathrm{SL}_{\mathrm{total}} = 10\log_{10}\sum_i 10^{\mathrm{SL}_i/10}\,, \tag{4}$$

where $\mathrm{SL}_{1,\ldots,N}$ are the source levels of individual thrusters. If a vessel is equipped with all the same type of thrusters (the source levels are equal), the combined source level can be estimated using the formula:

$$\mathrm{SL}_N = \mathrm{SL} + 10\log_{10} N\,, \tag{5}$$

where N is the total number of thrusters of the same type.

3.1.2.2. Estimating Source Levels using the "Surrogate" Vessel Approach

The second common approach for defining the source levels for vessels is to use field measurements completed on a similar vessel of the same type ("surrogate" vessel) involved in a similar activity. The measured spectrum is taken unchanged while the broadband source level is adjusted to account for any difference in the total propulsion power between the reference vessel and the vessel of interest. The adjusted broadband source level is calculated as:

$$SL = SL_{ref} + 10\log_{10}\left(P/P_{ref}\right), \tag{6}$$

where SL_{ref} is the broadband source level of the surrogate vessel, and P and P_{ref} are the total propulsion power of the vessel of interest and the surrogate vessel, respectively. The relative source level spectrum of the surrogate vessel is left unchanged.

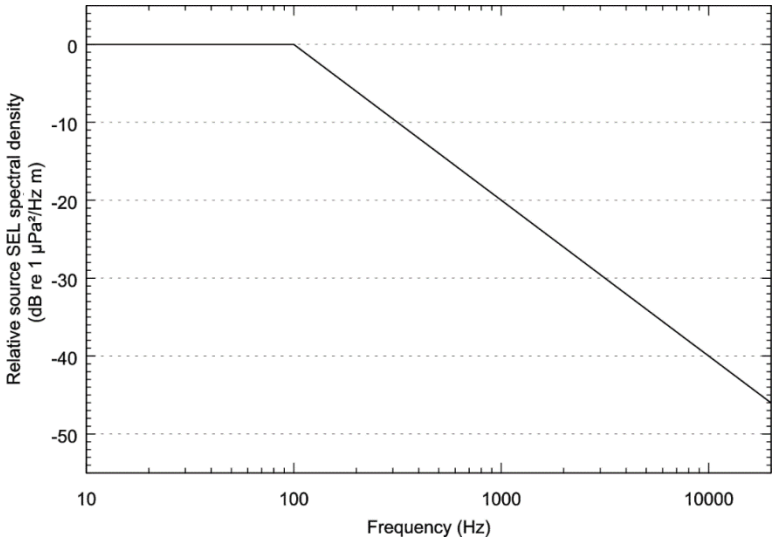


Figure 7. Estimated sound spectrum from a cavitating propeller (Leggat et al. 1981).

3.2. Modelling Sound Propagation

The sound field around a source can be estimated using two approaches: modelling in bands (usually in decidecade bands) and full waveform modelling. In the decidecade band modelling approach, the sound propagation modelling is performed only for the central frequencies of each band. Only 35 individual frequency modelling runs are required for covering the frequency range from 10 Hz to 25 kHz. For the full waveform approach, the propagation modelling has to be performed for individual frequencies with a constant step across the entire modelled frequency range.

The modelling in bands approach is suitable for efficiently modelling a wide frequency range of the SPL field from continuous sound sources and SEL field from both continuous and impulsive sources. The full

waveform approach, which is much more computationally intensive, outputs a synthetic pressure time domain series that allows direct calculation of metrics such as SPL and PK level for impulsive sources.

3.2.1. Energy Propagation Loss Modelling using the Decidecade Band Approach

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 decidecade bands, which are approximately one-third of an octave (base 2) wide and often referred to as 1/3-octave-bands. Each octave represents a doubling in sound frequency. The centre frequency of the *i*th band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{\frac{i}{10}} \tag{7}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the *i*th band are defined as:

$$f_{lo,i} = 10^{\frac{-1}{20}} f_c(i) \quad \text{and} \quad f_{hi,i} = 10^{\frac{1}{20}} f_c(i) \tag{8}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure 8). The acoustic modelling spans from band 1 (f_c (1) = 10 Hz) to band 44 (f_c (44) = 25,000 kHz).

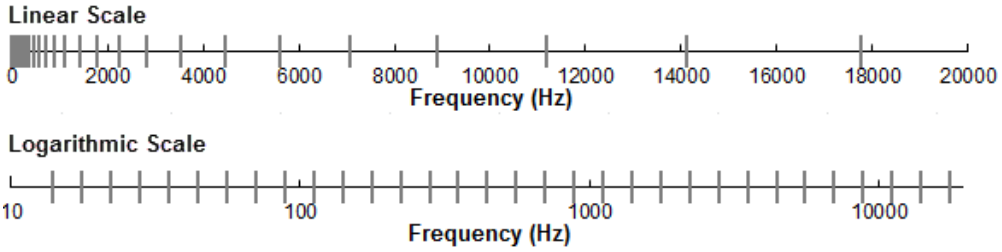


Figure 8. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

3.2.1.1. Propagation Loss Modelling

The propagation of sound through the environment was modeled by predicting the acoustic propagation 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 propagation loss occurs. Propagation 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. Propagation loss depends on the acoustic properties of the ocean and seabed; its value changes with frequency.

If the acoustic energy source level ($L_{S,E}$), expressed in dB re 1 µPa²m²s, and energy propagation loss ($N_{PL,E}$), in units of dB, at a given frequency are known, then the received level ($L_{E,p}$) at a receiver location can be calculated in dB re 1 µPa²s by:

$$L_{E,p}(r) = L_{S,E} - N_{PL,E}(r)\,, \tag{9}$$

where *r* is the range of the receiver from the source.

JASCO's MONM predicts underwater sound propagation (i.e., propagation loss) at frequencies from 10 to 25,000 Hz. MONM employs two underlaying subroutines: MONM-RAM is used for propagating acoustic waves at low frequencies (up to 2000 Hz) and MONM-BELLHOP is used for high frequencies (above 2000 Hz).

MONM-RAM computes acoustic propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the US Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for an elastic 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-RAM accounts for the additional reflection loss at the seabed due to 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-RAM incorporates the following site-specific environmental properties: a modeled area bathymetric grid, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor.

MONM-BELLHOP employs Gaussian beam acoustic ray-trace model (Porter and Liu 1994). This version of MONM accounts for sound attenuation due to energy absorption through ion relaxation and viscosity of water in addition to acoustic attenuation due to reflection at the medium boundaries and internal layers (Fisher and Simmons 1977). The former type of sound attenuation is significant for frequencies higher than 5 kHz and cannot be neglected without noticeably affecting the model results. MONM-BELLHOP incorporates the following site-specific environmental properties: a modeled area bathymetric grid, underwater sound speed as a function of depth, average temperature and salinity in the water column for calculating the sound attenuation due to energy absorption, and geoacoustic properties of the surficial sediments.

The accuracy of MONM's predictions have been validated against experimental data from several sound source verification 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).

The propagation loss values calculated for each individual band are subject to range averaging that replaces frequency averaging (Harrison and Harrison 1995, Siderius and Porter 2006). The range averaging technique allows us to increase the accuracy with which propagation loss function calculated for single frequency matches the band average propagation loss calculated using 1 Hz step frequency propagation loss functions.

3.2.1.2. Summing over Decidecade Bands

In case the source emits acoustic energy that spans across multiple frequency bands, the composite broadband received SEL can be computed by summing the received decidecade band levels (provided in dB units):

$$L_E = 10 \log_{10} \left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}} \right). \quad (10)$$

If frequency weighed SEL is required ($L_{E,\mathrm{MW}}$) for the impact assessment with criteria thresholds (Appendix B), it can be obtained by adding the relative levels (MW) to the equation:

$$L_{E,\mathrm{MW}} = 10 \cdot \log_{10} \sum_{i=1}^{N} 10^{(L_E,i+\mathrm{MW}_i)/10}. \quad (11)$$

3.2.2. Full Waveform Modelling

For impulsive sounds, time-domain representations of the pressure waves generated in the water are required for calculating SPL and PK. The synthetic pressure waveforms can be computed using Full Waveform Rangedependent Acoustic Model (FWRAM), which is a time-domain acoustic model based on the same wide-angle parabolic equation (PE) algorithm as MONM-RAM (Section 3.2.1.1). FWRAM computes synthetic pressure waveforms (Figure 9) for virtual receivers placed at various ranges from the

source and through the water column. The computations occur for range-varying marine acoustic environments, and it takes the same environmental inputs as MONM-RAM (bathymetry, water sound speed profile, and seabed geoacoustic profile). FWRAM computes pressure waveforms via Fourier synthesis of the modelled acoustic transfer function in closely spaced frequency bands. FWRAM employs the array starter method to further increase accuracy of the sound propagation modeling from a spatially distributed source (MacGillivray and Chapman 2012).The FWRAM modelling method requires propagation modelling to be performed at frequencies with constant step across the entire frequency range of interest. The frequency step (Δf) is defined by the necessary length of the time series (t):

$$\Delta f = {}^{1}/_{t}\,. \tag{12}$$

Therefore, to produce a 2 second long time series, the modelling frequency step needs to be 0.5 Hz, and for 0.5 second long time series–2 Hz step.

Full waveform modelling is substantially more computationaly extensive compared to the propagation loss in bands modelling approach. It is performed within a narower frequency band with practical top limit at 2000 Hz and fewer modelling profiles. Because most acoustic energy emmited by a seismic source is below 500 Hz and SPL and PK is calculated on an unweighted field, the exclusion of higher frequencies does not affect the accuracy of the levels in these metrics.

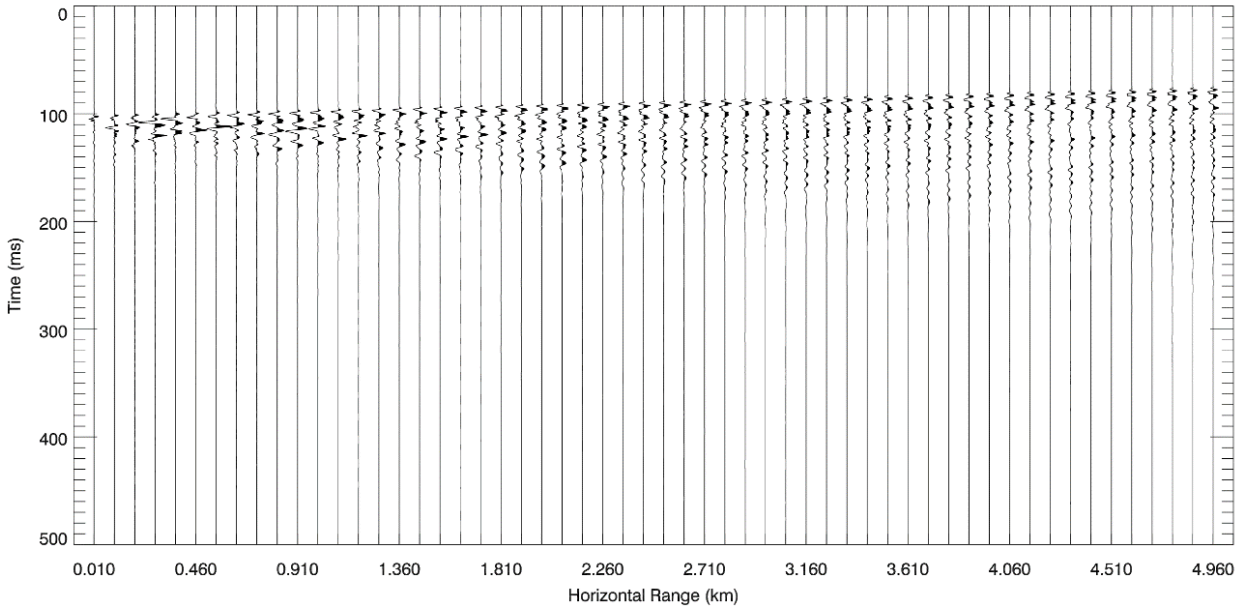


Figure 9. Example of synthetic pressure waveforms computed by FWRAM.

3.2.1. N×2-D Volume Approximation and Maximum-over-depth Sampling

The sound propagation models employed for this project are limited to two-dimensional (2-D) acoustic propagation. The calculations of the acoustic fields in three dimensions is achieved by propagating the acoustic field within 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 10).

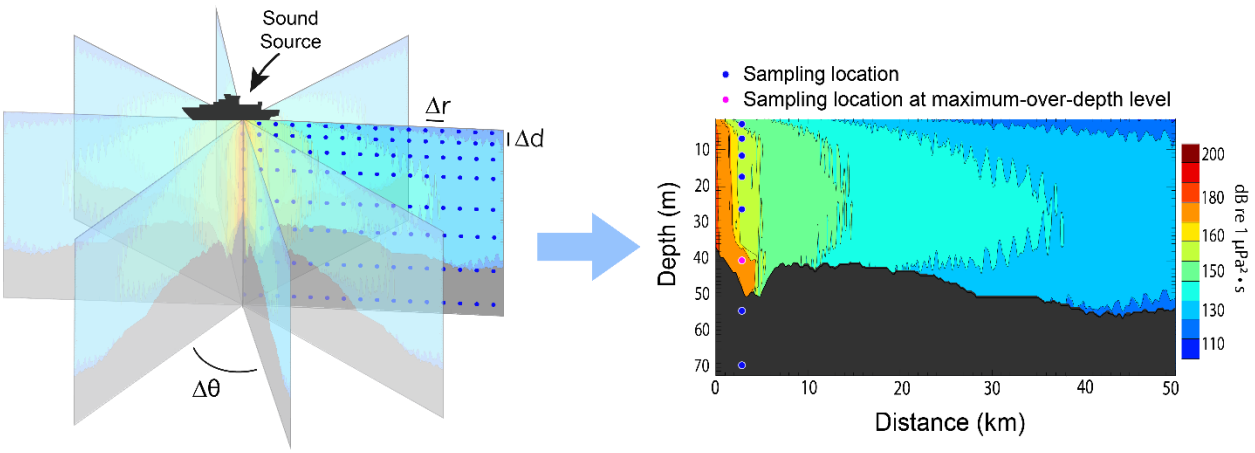


Figure 10. The *N*×2-D and maximum-over-depth modelling approach.

The received sound field within each vertical radial plane is sampled at various ranges from the source, generally with a fixed radial step size (Δr in Figure 10). At each sampling range along the surface, the sound field is sampled at various depths (Δd in Figure 10), with the step size between samples increasing with depth below the surface. The step sizes provide increased coverage near the depth of the source and at depths of interest for the sound speed profile. For deep water areas, sampling is not performed at depths beyond those reachable by marine mammals. The received acoustic levels 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 level. These maximum-over-depth acoustic levels are further used to calculate the ranges to specific thresholds and create acoustic field maps.

3.2.2. Calculating Isopleth Contours and Ranges to Threshold Levels from Acoustic Fields

The output from received level modelling after reducing the vertical dimension using maximum-over-depth rule is a series of data points along radials originating at the source, i.e., in polar coordinates system. The data are interpolated onto a Cartesian grid. The isopleth contours and ranges to specific thresholds are both calculated from the acoustic field grids.

For the threshold level ranges, two distances relative to the source are reported: 1) R_{max}, the maximum range to the given sound level over all azimuths, and 2) $R_{95\%}$, the range to the given sound level after 5% of the farthest points were excluded (see examples in Figure 11).

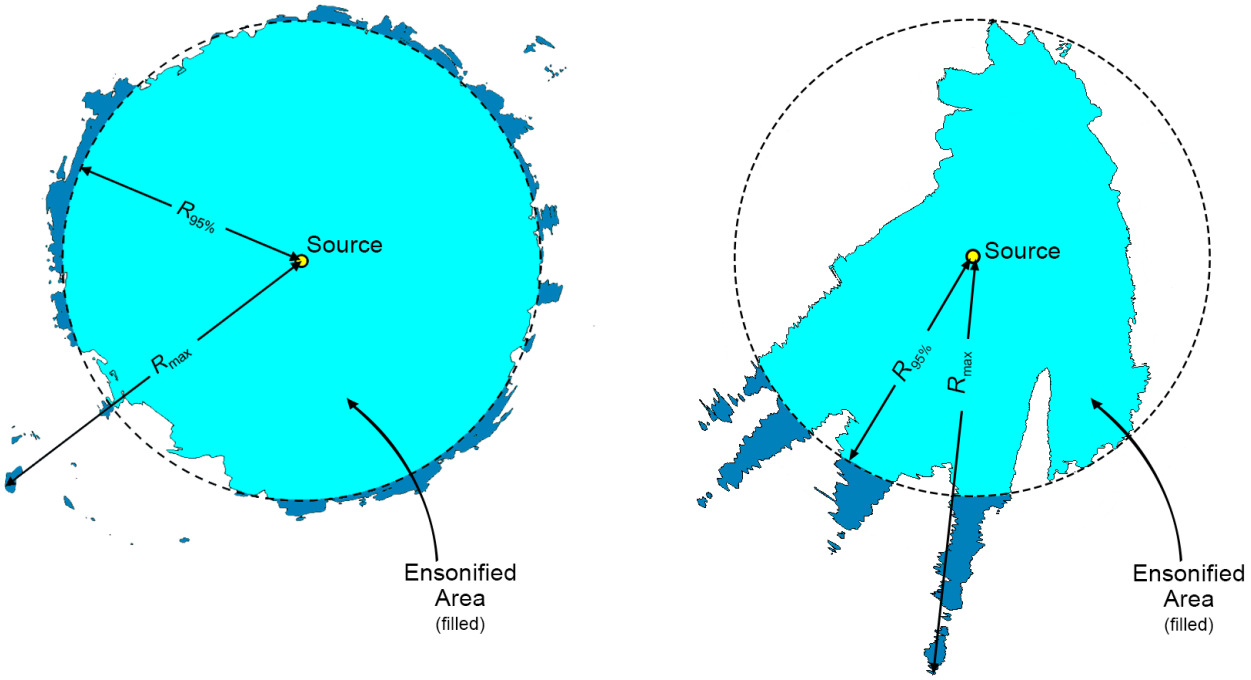


Figure 11. Sample areas ensonified to an arbitrary sound level with R_{max} and $R_{95\%}$ ranges shown for two contrasting scenarios. (a) a largely radially symmetric sound level contour with small protrusions, for which $R_{95\%}$ best represents the ensonified area; and (b) a strongly asymmetric sound level contour with long protrusions, for which R_{max} best represents the ensonified areas in some directions. Light blue indicates the ensonified areas bounded by $R_{95\%}$; darker blue indicates the ensonified areas beyond $R_{95\%}$ that determine R_{max}.

The $R_{95\%}$ is used because sound field footprints are often irregular in shape. In some cases, a sound level contour might have small protrusions or anomalous isolated fringes. This is demonstrated in the image in Figure 11a. In cases such as this, where relatively few points are excluded in any given direction, R_{max} can misrepresent the area of the region exposed to such effects, and $R_{95\%}$ is considered more representative. In strongly asymmetric cases such as shown in Figure 11b, on the other hand, $R_{95\%}$ neglects to account for significant protrusions in the footprint. In such cases R_{max} might better represent the region of effect in specific directions. Cases such as this are usually associated with bathymetric features affecting propagation. The difference between R_{max} and $R_{95\%}$ depends on the source directivity and the non-uniformity of the acoustic environment.

4. Model Parameters

4.1. Environmental Parameters

Two modelled sites were selected, one within each license block (Table 2). The sites are shown in Figure 2. Table 3 provides the location and water depth for sites from the other studies where comparable sources were modelled and that were applied in the current study.

Table 2. Modelled locations and their parameters. Easting and northing are in UTM Zone 22N.

Site	Latitude (N)	Longitude (W)	UTM easting (m)	UTM northing (m)	Water depth (m)
Site A, in EL-1157	48° 49' 33"	47° 51' 04"	731 095	5 412 883	2 341
Site B, in EL-1158	48° 29' 30"	48° 03' 58"	716 751	5 375 120	2 031

Table 3. The coordinates and water depths of modelled sites in related studies used for comparison with the current study.

Site	Latitude (N)	Longitude (W)	UTM easting (m)	UTM northing (m)	Water depth (m)
Zykov (2016)					
A	42° 50' 42.64"	60° 17' 51.44"	720 825 (Zone 20N)	4 747 165 (Zone 20N)	2 790
B	43° 02' 07.76"	60° 26' 05.98"	708 954 (Zone 20N)	4 767 949 (Zone 20N)	2 100
Matthews et al. (2017)					
A	47° 31' 01.23"	46° 43' 09.20"	370 563 (Zone 23N)	5 264 052 (Zone 23N)	1 137
B	47° 18' 13.21"	46° 09' 18.53"	412 678 (Zone 23N)	5 239 558 (Zone 23N)	378
Matthews et al. (2018)					
West Orphan, in EL-1145	50° 31' 49"	49° 40' 44"	168 454 (Zone 23N)	5 608 064 (Zone 23N)	1 376
East Orphan, in EL-1149	49° 22' 26"	47° 02' 08"	352 231 (Zone 23N)	5 471 024 (Zone 23N)	2 774

4.1.1. Bathymetry

Water depths throughout the modelled area were extracted from the SRTM15+ + (v3.0) global bathymetry grid, a 30 arc-second grid (~310 × 460 m at the studied latitude) rendered for the entire globe (Becker et al. 1997, Smith and Sandwell 1997, Rodríguez et al. 2005). Bathymetry for a 437 × 667 km area were extracted and re-gridded, by minimum curvature gridding, onto a Universal Transverse Mercator (UTM) Zone 22 coordinate projection with a regular grid spacing of 200 × 200 m.

The water depth in the Orphan Basin area varies from about 200 m on the continental shelf, west of the modelled sites to >4000 m toward the east. This wider-area bathymetry is seen in the depth contours of Figure 2. Within the modelled project area, the water depths range from 1300 to 2500 m, as can be seen in the greater detail of Figure 1.

4.1.2. Geoacoustics

The geoacoustic seabed properties of surficial layers depend on the sediment type. As the porosity decreases, the compressional sound speed, sediment bulk density, and compressional attenuation increase. For each modelled location, MONM assumes a single geoacoustic profile of the seafloor for the entire modelled area. MONM takes as inputs these geoacoustic properties of the sediments as a function of depth below the seafloor:

- Bulk density (g/cm^3),
- Compressional-wave (or P-wave) sound speed (m/s),
- P-wave attenuation in decibels per wavelength (dB/λ),
- Shear-wave (or S-wave) sound speed (m/s), and
- S-wave attenuation in decibels per wavelength (dB/λ).

On the Grand Banks continental shelf, through the Flemish Pass and in southern Orphan Basin, the shallow sedimentary layers consist of thick grey muds (silt mixed with 10–30% sand and 20–40% clay) with varying amounts of debris and sand bed horizons (Huppertz 2007). The depth (~1100 m) and narrow banks of Flemish Pass trap sediment deposits from the continental shelf. Sediment thickness throughout the project area is >2500 m, but not as deep as the ~4000 m reached in the Flemish Pass (Divins 2007, Géli et al. 2007).

The geoacoustic parameters for the current project were calculated using a sediment grain-shearing model (Buckingham 2005), which computes the acoustic properties of the sediments from porosity and grain-size measurements. The grain size and the porosity variation with depth were estimated based on the expected bottom sediment type. Table 4 presents the full set of geoacoustic parameters used for the acoustic propagation modelling. This set of parameters was used for both sites, as they are in the same geoacoustic regime and relatively close to each other. These are almost the same geoacoustic parameters used in Mathews (2018) for the West Orphan site. The current project used a higher shear speed of 200 m/s, versus 130 m/s for the West Orphan site, but all the other geoacoustic parameters are the same. Although the East Orphan site is closer to the modelled area of the current project, it lies at a greater water depth and has a thicker sediment accumulation over basement, whereas the West Orphan site, though farther away, lies at a similar water depth and has a similar sedimentation history.

Table 4. Geoacoustic model for Sites A and B, which represents a multi-layered sandy bottom. Within each depth range, each parameter varies linearly within the stated range. The compressional wave is the primary wave. The shear wave is the secondary wave.

Depth below seafloor (m)	Material	Density (g/cm^3)	Compressional wave		Shear wave	
			Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
0–5	Silt mixed with sand and clay	1.5–1.7	1525–1585	0.25–0.40	200	3.65
5–50		1.7–2.0	1585–1775	0.40–0.75		
50–500		2.0–2.1	1775–2100	0.75–1.4		
> 500		2.1	2100	1.4		

4.1.3. Sound Speed Profiles

The sound speed profiles for each modelled site were derived from temperature and salinity profiles from the U. Naval Oceanographic Office's *Generalized Digital Environmental Model V 3.0* (GDEM; Teague et al. 1990, Carnes 2009). GDEM provides a climatology data of temperature and salinity for the world's oceans as a latitude-longitude grid with 0.25° spatial resolution, with a temporal resolution of one month, based on global historical observations from the US 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):

$$\begin{aligned} c(z,T,S,\phi) &= 1449.05 + 45.7t - 5.21t^2 - 0.23t^3 \\ &\quad + \left(1.333 - 0.126t + 0.009t^2\right)\left(S - 35\right) + \Delta \\ \Delta &= 16.3Z + 0.18Z^2\,, \quad Z = \frac{z}{1000}\left[1 - 0.0026\cos\left(2\phi\right)\right], \quad t = \frac{T}{10} \end{aligned} \tag{13}$$

where z is water depth (m), T is temperature (°C), S is salinity (psu), and ϕ is latitude (radians).

Twelve mean monthly sound speed profiles (SSP) were calculated based on the data extracted from GDEM database for Sites A and B. February and August were selected as the two profiles that best represent the range of conditions for sound propagation throughout the year (Figures 12 and 13). These figures only show the upper 400 m of the sound speed profiles, and virtually all of the monthly variability occurs in the upper 200 m. Below 200 m, the sound speed profiles all exhibit the same uniform positive pressure-based gradient with increasing depth, essentially independent of seasonality.

The upper portion of these sound speed profiles varies between slightly upward-refracting and isovelocity (November to April) and downward refracting (August to October). A weak sound channel, with a sound speed minimum at ~50–75 m, develops between May and December. In general, the sound emitted in the top 100 m of the water column will tend to refract toward the surface from November to April, and toward the sound speed minimum from May to October. There is only minor temporal variation in the profiles at depths greater than ~100 m. At these depths, the sound speed increases slightly with depth, mainly due to the increase in ambient pressure.

The sound speed profiles for February are typical of a well-mixed cold-ocean environment and are uniformly upward refracting. This allows relatively good deep-water propagation at low-frequencies through repeated surface bounces and minimal bottom interaction. This is also called half-channel propagation. Conversely, the August profiles, exhibit a relatively weak sound channel that will keep most of the long-range propagation between depths of about 30–300 m, with less sound propagating at depths shallower than 30 m, but allowing mid-frequencies to propagate well within the duct.

Figure 14 shows the selected sound speed profiles down to the maximum depth within the modelled area for the current project for Sites A and B in February and August. All months have similar characteristics below 300 m depth. The BP Orphan Basin Project (Matthews et al. 2018) found a similar set of SSPs for the modelled West Orphan site. Being at a similar water depth as the present Sites A and B, and being subjected to the same seasonal oceanographic variations (and shorter-term variations in the form of watermass movements), of which the main driver in this part of the ocean is the Labrador current, flowing north to south, one would expect similar SSP characteristics. In the case of the BP Orphan Basin Project, the study was given a preferred season for drilling activity (the period May to October) and a single SSP was selected (June) that adequately represented conditions in that season.

For the present project, the study parameters specified that two SSPs be selected at each modelled site. These were chosen to exemplify the maximum variation in SSP propagation characteristics over the span of the whole year. These are the August and February profiles. Based on the vertical SSP structure, one expects the surface duct in the February SSP to result in longer propagation ranges for sources and receivers a few tens of meters below the surface, compared to the August SSP. Although the August SSP does exhibit a sound channel with an axis depth of about 50 m, it is weak because the gradient above the axis depth is much steeper than the gradient below the axis, which will promote leakage out of the duct

into the deeper depths and turn many of the upward going acoustic paths back down towards the bottom before they reach the depths nearer the surface. This means that exploratory drilling activities are more likely to appear noisier to the environment in the winter months, and quieter in the summer months, which is better than the other way around, since such work in the North Atlantic is much more likely to be scheduled for summer, if at all possible. The detailed modelling performed in the present study, using these two SSPs, allows one to gauge the magnitude of this contrast in seasonal impact.

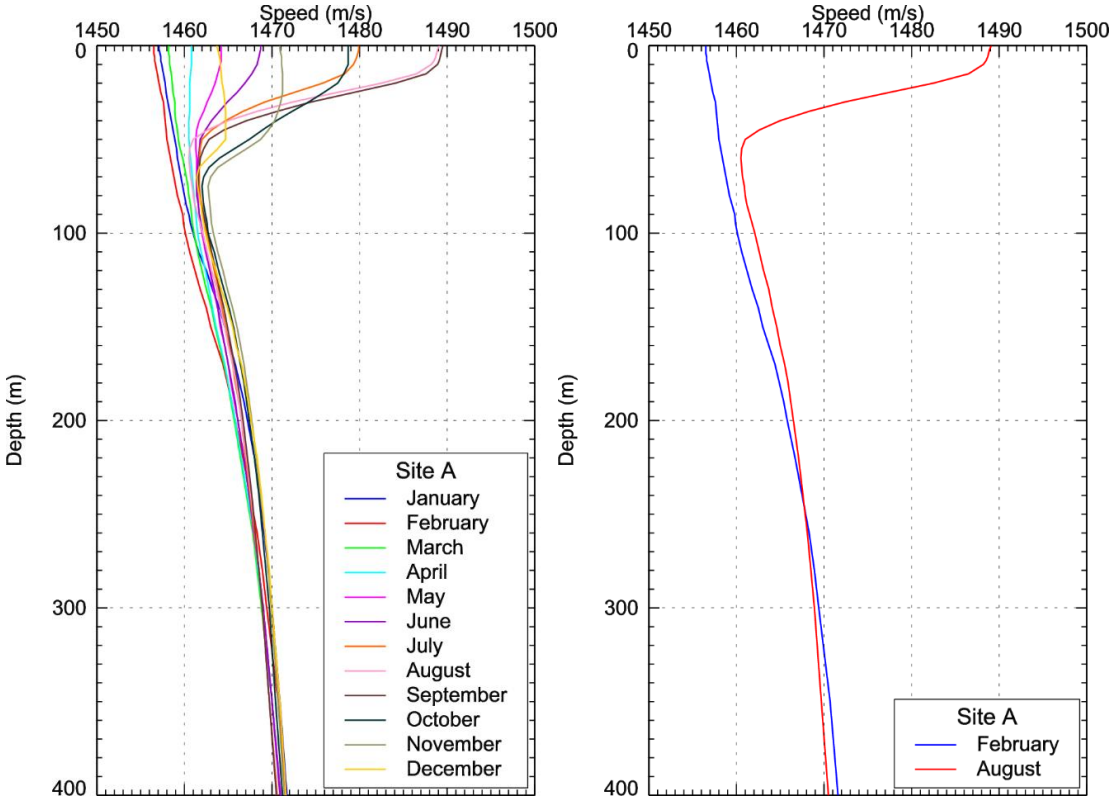


Figure 12. Mean monthly sound speed profiles for Site A (top 400 m only): (left) all twelve months and (right) the two months selected for modelling, which best represent the range in sound propagation conditions over the course of a year. The profiles were derived from data obtained from *GDEM V 3.0* (Teague et al. 1990, Carnes 2009). The full extent of the February and August profiles are shown in Figure 14.

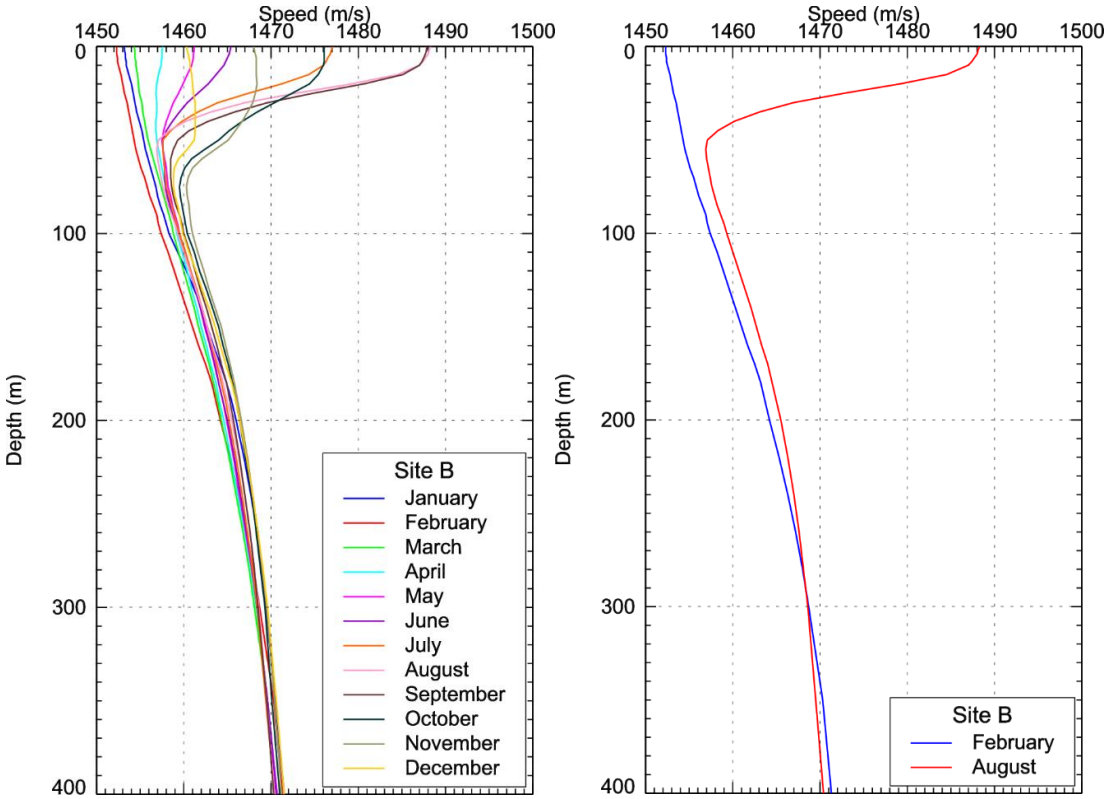


Figure 13. Mean monthly sound speed profiles for Site B (top 400 m only): (left) all twelve months and (right) the two months selected for modelling (February and August), which best represent the range in sound propagation conditions over the course of a year. The profiles were derived from data obtained from *GDEM V 3.0* (Teague et al. 1990, Carnes 2009). The full extent of the February and August profiles are shown in Figure 14.

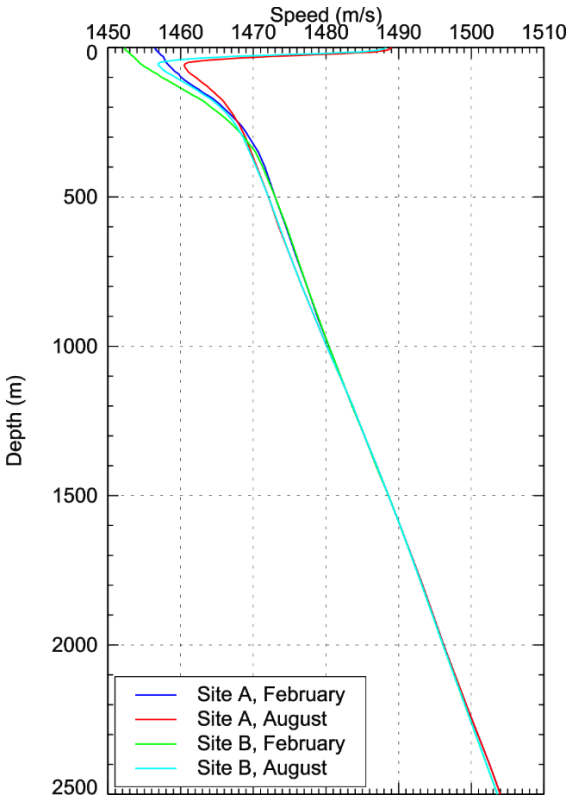


Figure 14. Display of the full water column extent of the sound speed profiles selected for this study (Sites A and B in February and August) that best represent the range in sound propagation conditions over the course of a year.

4.2. Ambient Sound Data Collection

For the ESRF Study, underwater sound was recorded with Autonomous Multichannel Acoustic Recorders (AMARs; Appendix C). AMARs were deployed at 20 locations (see Figures C-1 and C-2) between August 2015 and July 2017 (see Tables C-1 and C-2). Recordings at Station 19, the station closest to the modelling area, were used to derive ambient sound levels for the project. In 2015–2016, Station 19 was located ~120 km west of the present modelled area at ~1280 m water depth (Figure 2). The location was changed in 2016–2017 to Sackville Spur at the north end of the Flemish Pass, which is ~120 km east of the present modelled area in ~1550 m water depth. Both stations used the same mooring configuration (see Figure C-4) with an AMAR suspended about 25 m above the seafloor. A 42AC pistonphone calibrator (G.R.A.S. Sound & Vibration A/S; Figure C-8) was used to verify the sensitivity of systems.

Appendix C provides detailed information about deployment locations and mooring designs (Appendix C.1), the acoustic recorders (Appendix C.3), and recorder calibrations (Appendix C.4). Acoustic data analysis methods are described in Appendix C.5, including methods for identifying periods when seismic surveys and shipping were detectable in the soundscape.

4.3. Geometry and Modelled Volumes

The modelling geometry for each source was selected individually based on the parameters of the source and the required output (Table 5).

Table 5. Modelling geometry for the individual sources.

Source	Metric	N-profiles (azimuthal step)	Horizontal resolution (m)	Maximum distance (km)
Airgun array	SPL	8 (45°)	20	50
	SEL	72 (5°)	20	100
Vessels	SEL and SPL	72 (5°)	20	100
Semi-submersible	SEL and SPL	72 (5°)	20	100

At each sampling location, the sound field was sampled at the following depths:

- 2 m,
- Every 5 m from 5 to 25 m,
- Every 25 m from 50 to 100 m,
- Every 50 m from 150 to 500 m,
- Every 100 m from 600 to 1000 m, and
- Every 200 m from 1200 to 2400 m.

4.4. Acoustic Source Parameters and Modelled Source Levels

4.4.1. Representative VSP Source Airgun Array

The Dual Delta airgun was modelled as the VSP source. It consists of three 250 in^3 volume airguns and three 150 in^3 volume airguns for a total of six airguns and 1200 in^3 volume. Figure 15 presents the array layout, where each set of three airguns is arranged in a vertical equilateral triangle. For the purpose of modeling, the horizontal axis of the array, which goes through the centre of each triangle, was placed at the expected operational depth of 5 m. The Dual Delta 1200 in^3 array was modeled with a firing pressure of 2000 psi.

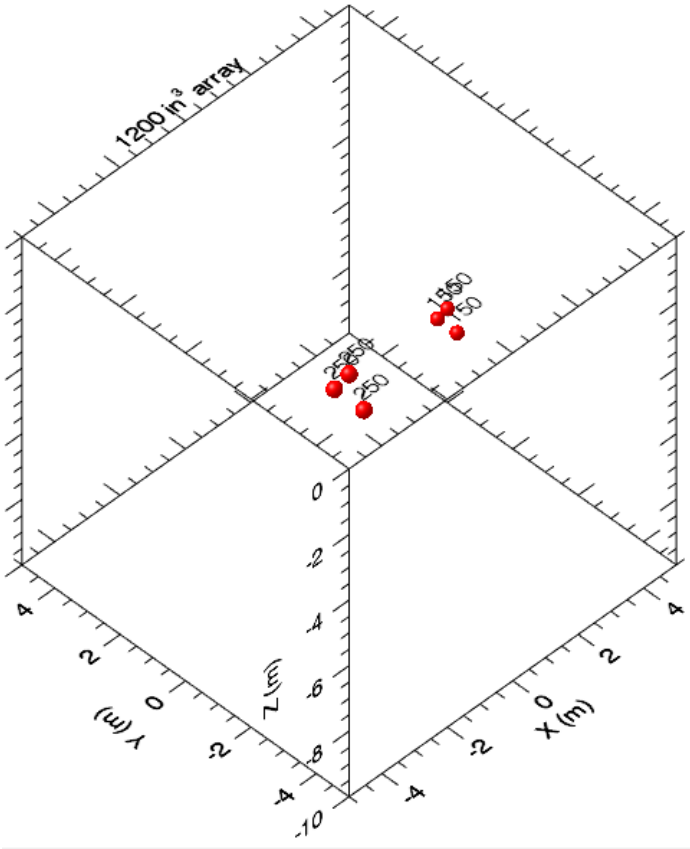


Figure 15. Geometry of the Dual Delta 1200 in³ airgun array. The large spheres represent the 250 in³ airguns and the small spheres represent the 150 in³ airguns

AASM (see Section 3.1) was used to characterize the spectral attributes of the array's composite pressure signature in all directions. The horizontal overpressure signature and corresponding power spectrum level for the Dual Delta 1200 in³ array were computed at frequencies from 10 Hz to 25 kHz. These are shown in Figure 16 for the broadside (perpendicular to the tow direction) and endfire (parallel to the tow direction) directions up to 2 kHz. On far-field horizontally propagating sound, the broadband (10 Hz to 25 kHz) source levels had an SEL of 218.1 dB re 1 µPa² s m broadside and217.5 dB re 1 µPa² s m endfire, and an SPL of 220.4 dB re 1 µPa m broadside and 220.2 dB re 1 µPa m endfire based.

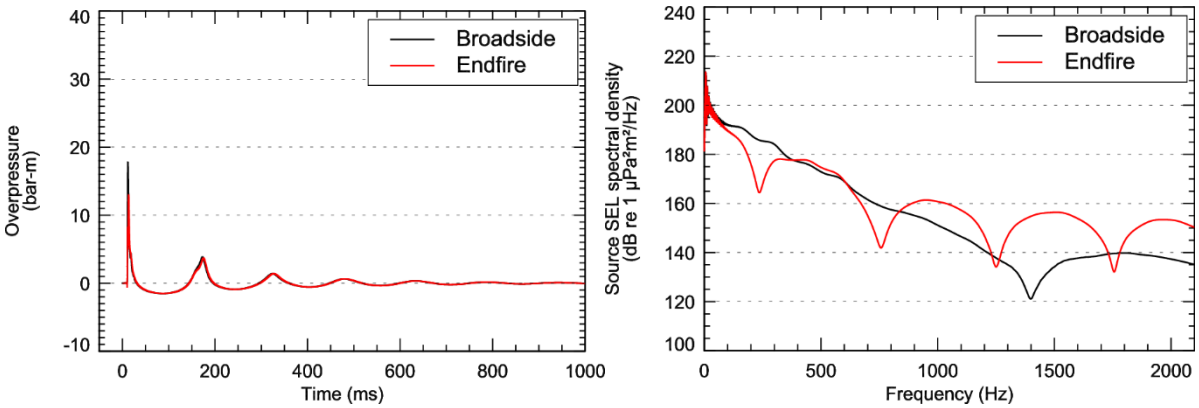


Figure 16. Predicted (a) overpressure signature and (b) power spectrum in the broadside and endfire (horizontal) directions for the Dual Delta 1200 in³ airgun array.

The general trend for the spectral levels is to decrease with increasing frequency. Most of the acoustic wave energy (93%) is contained in frequency bands below 100 Hz. The signatures consist of a strong primary peak related to the initial firing of the airgun, followed by a series of pulses associated with bubble oscillations spaced at about 160 ms. Figure 17 shows the horizontal 1/3-octave-band directivities for the array. In this plot, the arrow indicates the tow direction of the array and the solid black curves indicate SEL source levels in dB re 1 µPa²m²s, as a function of angle in the horizontal plane.

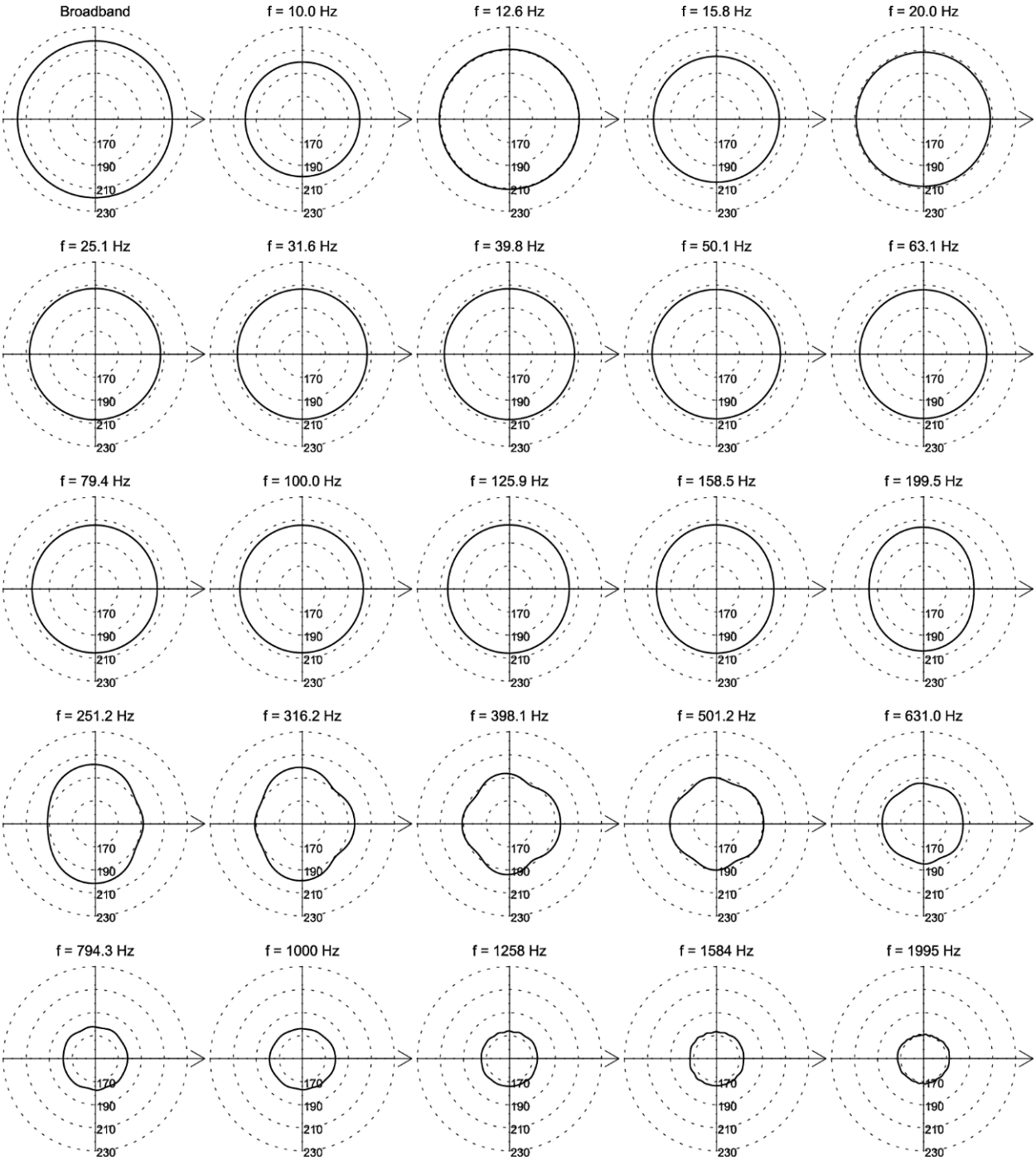


Figure 17. Directionality of predicted horizontal sound exposure level (SEL) source levels (SL; dB re 1 µPa²m²s) in 1/3-octave-bands for the modeled Dual Delta 1200 in³ airgun array, at a 5 m tow depth. The 1/3-octave-band centre frequency is indicated above each plot.

4.4.2. Representative Vessel Sources

Either a drillship or a semi-submersible mobile offshore drilling unit (MODU) could be used in the BHP Orphan Basin exploration drilling project. Both vessel types were modelled, along with the presence of an offshore support vessel. In principle, the total sound field generated underwater includes the sum of the contributions from all the noise sources. Where sources of comparable magnitude consistently operate in close proximity to each other, such as a set of thrusters on a vessel, or a set of airguns in an array, they must be modelled as a combined source. In other cases where the individual sources are typically at varying distances from each other, and where they are usually far enough apart that the more intense zones of potentially harmful sounds of their individual sound fields do not overlap substantially, it is sufficient to model the sources individually. Such cases include multiple support vessels servicing a drilling platform. Modelling these sources individually is always the first step in any such study. If the multiple sources have consistently overlapping zones of potentially harmful sound, it is necessary to take a further step of combined source modelling. This is not typically the case for multiple support vessels and a drilling platform or drilling vessel. In the current study, separately modelling one support vessel along with the drilling platform or drilling vessel accurately assessed the environmental consequences of the complete operation, without jointly modelling a combined sound field of the multiple sources.

The highest sound levels from MODU and vessels while in DP are generated by the propellers. Thus, source levels associated with drill rigs and support vessels are often estimated based on a platform's propulsion system. The specific parameters required as modelling input for each vessel are:

- Thruster depth,
- Propeller diameter,
- Propeller revolutions-per-minute (rpm) at nominal power output,
- Number of blades, and
- Thruster locations on the vessel's hull.

Our modelling assumed that the MODU will use DP to maintain position, as opposed to being anchored at the drill site, because the water depth in the project area is too deep to permit moored drilling operation. Therefore, the thrusters on the MODU will be the main sound source at the site.

The differences between a drillship and a semi-submersible platform include the size, number, and depth of thrusters, and how sound radiates from the auxiliary machinery. Sound radiates through the hull of the drillship into the water, whereas the separation between the platform of the semi-submersible and the water surface prevent the auxiliary machinery sound from propagating into the water. Measurements of either type of rig while using DP are not readily available, but estimates can be made based on related sources. A comparison of source levels derived from available measurements of rigs during drilling operation (using DP) shows that source levels from a semi-submersible are generally lower or equal to levels for a drillship—however, this is because semi-submersibles can be anchored in shallow water, and make far less use of their thrusters for station keeping in that scenario. For the sites in the current study, the water is too deep to permit anchored operations, and both the drillship and the semi-submersible platform will rely on DP thrusters for station keeping operations.

Sound levels are generally lower during drilling operations than during other operations such as maintenance, station keeping during bad weather, or during transits. This is because the mechanical activities specifically involved in drilling do not generate very much sound in the water as compared to the sound generated by a propeller turning in the water at high speed; the tips of the propeller blades push the water with such force that it briefly tears small holes in the water in a process known as propeller cavitation; the water quickly snaps back to refill those little voids of vacuum, making a loud sound for each such event, of which there are a great many in rapid succession, thereby generating intense cavitation noise.

For the drillship sound source, we modelled two scenarios to show the range of possible levels that may occur during the project. The spectrum levels for these two scenarios are compared in Figure 25. The source level measurements for another semi-submersible, the *West Aquarius*, and another drillship, the *Stena IceMAX* (a sister ship to the *Stena Forth*) are also shown in this figure for comparison (Martin et al. 2019).

The drillship must be modelled using two scenarios to provide a balanced assessment of the environmental impact of the vessel's underwater sound emissions. The first scenario shows the environmental impacts that are expected during the periods of operation that are most intense, but still within the scope of typical operations. The second scenario represents statistically average conditions, which will have a lower impact on the environment, and more fairly portray what is happening most of the time. But it is also necessary to assess the impact of the more intense activity episodes, even if they occur less than 5% of the time.

4.4.2.1. Generic Drillship

The first drillship scenario, the generic drillship, represents a higher-end estimate of the levels during drilling operations, without overestimating the possible levels of various infrequent operational states. We estimated the source spectrum of a generic drillship based on the thruster specifications, as outlined in Section 3.1.2. This source level represents a reasonable estimate of the average level over a 24-hour operational period, during which the operational state and sea state may vary greatly.

4.4.2.2. Representative Drillship: Stena Forth

The second drillship scenario uses the measured 95th percentile source spectrum of a representative drillship, the *Stena Forth* (Figure 18). The 95th percentile spectrum is a statistically-derived estimate of the spectrum, giving the level at each frequency such that measurements would only exceed this value 5% of the time. The levels in the second scenario represent a quieter state than maximum expected levels during drilling but are still representative of expected levels during drilling operations.

Figure 18. *Stena Forth* drillship used as a representative sound source for acoustic modelling.

The *Stena Forth* represents the type of rig used for operations that will occur in the deep waters offshore Newfoundland. *Stena Forth* is a harsh environment, dynamically positioned Class 3 drillship capable of drilling in water depths up to 10,000 ft using 18 ¾"–15,000 psi Cameron TL BOP and Cameron Load King Riser. The DP thrusters employ six Rolls Royce UUC-455, variable speed, fixed pitch, 360˚ azimuthing thrusters driven by six ABB ACS6000 5.5 MW water-cooled variable speed drives. The UUC-455 thruster parameters (DNV 2010) are:

- 4.1 m propeller diameter,

- 157 rpm nominal propeller speed, and
- 5500 kW maximum continuous power input.

For modelling, all six thrusters were assumed to operate at nominal speed (i.e., the highest *sustainable* rpm—maximum specifications are higher but were not modelled because they are only used occasionally, for brief periods). The vertical position of the thrusters was 12 m below the sea surface (equal to the draft of the vessel during drilling operations). Figure 19 shows the thruster locations.

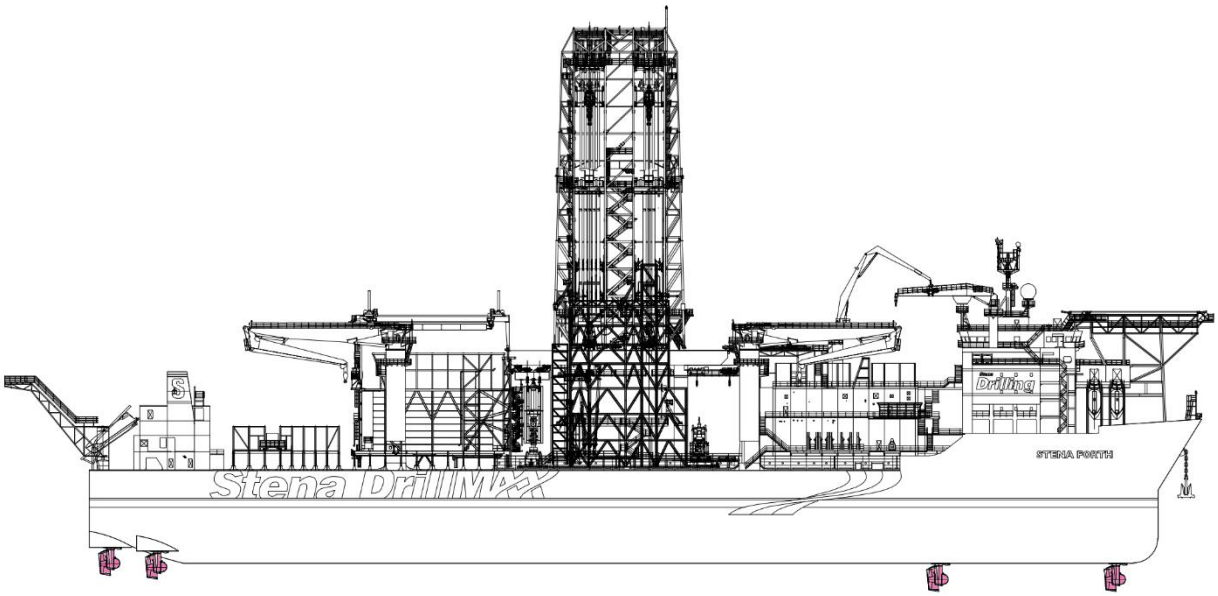


Figure 19. *Stena Forth* equipment profile , with thruster locations shown in red.

4.4.2.3. Representative Semi-submersible Platform: Seadrill West Sirius

The estimates of the semi-submersible platform acoustic source levels and sound spectrum were based on the *Seadrill West Sirius* (Figure 20). *Seadrill West Sirius* is reportedly equipped with eight Rolls-Royce UUC 355 thrusters. The thruster has a fixed-pitch propeller. The parameters for the UUC 355 thruster are:

- 3.5 m propeller diameter,
- 177 rpm nominal propeller speed, and
- 3800 kW maximum continuous power input.

The vertical position of the thrusters below the sea surface during drilling operations is a function of the draft of the vessel, since the thrusters are located at the very bottom, under the deepest floatation element of the structure. The specifications for the *Seadrill West Sirius* give a range of draft during operations between 18–20 m. At the time of this study, it is not known whether the *Seadrill West Sirius* or a different drill rig with a deeper operational draft will be used. For this reason, we assigned the source depth to be 25 m for the semi-submersible platform source modelling.; This also partially accommodated the situation when the semi-submersible platform is not drilling, but station keeping in rough weather and has a deeper draft in those conditions.

As described in Section 3.1.2, a hybrid approach for defining the source levels for the *Seadrill West Sirius* drilling platform was used. For modelling the source level, all eight thrusters (combined maximum power 30,400 kW) were assumed to operate at 50% of maximum power. The source levels and the sound spectrum (Figure 21, red line) for cavitating thrusters were estimated based on the *Seadrill West Sirius* thruster specifications (diameter, and rpm) according to the method described in Section 3.1.2.1, using Equation 6. Table 6 lists the broadband source levels for a single UUC355 thruster operating at 100%, as

well as eight thrusters at 100 and 50%. For the purpose of acoustic propagation modelling, all eight thrusters were assumed to be located at the same spot, i.e., represented by a point source.

Figure 20. *Seadrill West Sirius* semi-submersible platform.

Table 6. Estimated broadband levels for cavitating thrusters used on the *Seadrill West Sirius*.

Source	Power output (% of nominal)	SPL (dB re 1 µPa m)
UUC355	100	187.7
8 × UUC355	100	196.7
8 × UUC355	50	193.7

The source level spectrum calculated for a cavitating propeller was combined with the source levels defined using a surrogate vessel by scaling the surrogate spectrum so that it matches the broadband level of the *Seadrill West Sirius* thruster sound emissions. The surrogate vessel used was another semi-submersible platform, the *Polar Pioneer* (Figure 22). It is reportedly equipped with four Liaan TNCP 105/75–280 rated at 2,400 kW azimuthing. Figure 23 shows the *Polar Pioneer* thruster locations. Although detailed specifications on this thruster are not readily available, JASCO previously obtained field measurements of the *Polar Pioneer* underwater sound spectrum while transiting under DP thruster power at 6.4 kts—with a broadband (10 Hz to 35 kHz) of 196.8 dB re 1 µPa m (Austin and Li 2016) (Figure 25, green line). The shape of the *Polar Pioneer* underwater sound spectrum under transit is a good surrogate for the shape of the *Seadrill West Sirius* underwater sound spectrum under DP drilling operations. That spectrum was scaled in power so that the broadband level of the scaled spectrum matches the broadband level of the *Seadrill West Sirius* DP operations (193.7 dB re 1 µPa m)—i.e., the Polar Pioneer transiting spectrum was reduced by 3.1 dB to become the estimated *Seadrill West Sirius* DP drilling operations spectrum (Figure 21, black line).

Although the thrusters often dominate the noise spectrum, especially in the lower frequency band (below 500 Hz), they are not the only source of sound from the semi-submersible platform operations. There is also machinery noise, which is transmitted through the structure and projected into the water by hull vibrations, albeit not very efficiently in the case of semi-submersibles. JASCO also previously obtained field measurements of the *Polar Pioneer* underwater sound spectrum while drilling under mooring—with a broadband (10 Hz to 35 kHz) SL of 170.1 dB re 1 µPa m (Austin et al. 2018) (Figure 21, blue line). Since the thrusters are not used (very much) during moored operations, these measurements of the *Polar Pioneer* drilling operations are a good surrogate for the machinery noise component of the *Seadrill West*

Sirius DP underwater sound spectrum during drilling operations. As described for this hybrid method, the maximum of the two spectra are taken in each decidecade (or 1/3-octave) band. As can be seen in Figure 21, the thruster noise is higher than the radiated machinery noise in every band.

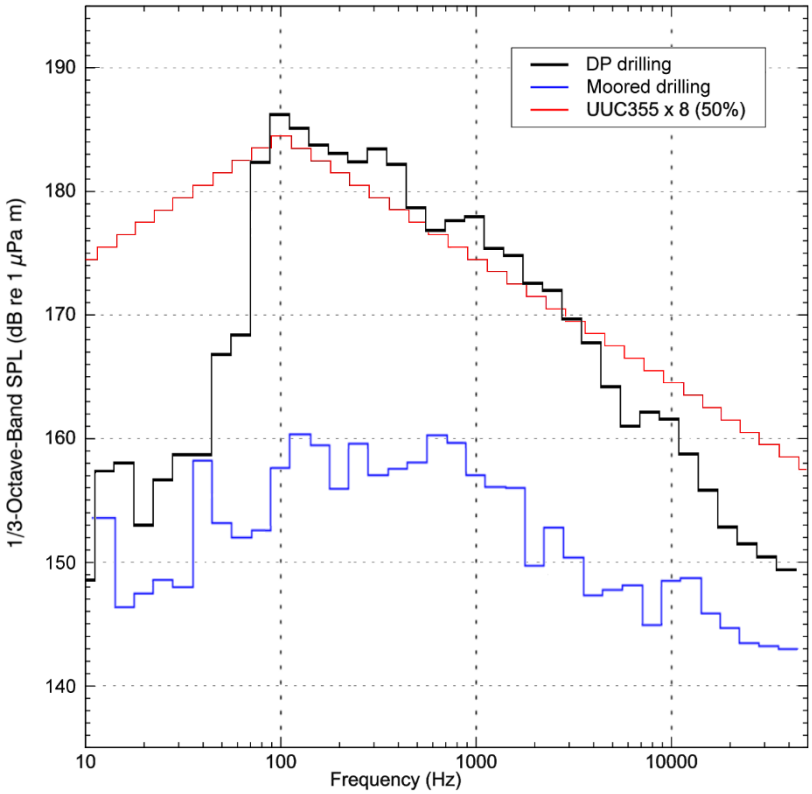


Figure 21. Source level spectrum assumed for the semi-submersible *Seadrill West Sirius* under DP drilling operations (black line). The spectrum for eight UUC355 thrusters operating at 50% capacity (red line) and the moored drilling radiated underwater sound for the surrogate vessel, *Polar Pioneer* (blue line), are also shown.

Our approach to modelling the semi-submersible source spectrum may appear to be overly complex as compared to the approach used in previous studies of the Newfoundland offshore, such as Zykov (2016) and Matthews (2017 and 2019)—these latter ones simply quote the Zykov (2016) results. This previous approach resulted in an overly simplistic estimate of the shape of the modelled spectra: all simply the triangular shape of the red line in Figure 21, merely scaled up or down based on the estimated broadband source level. This was the best that could be done at the time, due to the unavailability of measured band-level spectra for the semi-submersible in DP drilling operations that could be used in those studies. The present modelling has been able to obtain measured band-level spectra from more recent field work, and while the approach of scaling it based on matching the estimated broadband source level must be used, since the exact equipment that will be deployed in the BHP operations was not measured directly, the end result of the estimated band-level spectrum for the semi-submersible under DP drilling operations (Figure 21, black line) has a much more realistic spectral shape. This improves the confidence in the fidelity of the acoustical impact modelling (i.e., the marine mammal frequency weighted, or M-weighted, SEL estimates) that is then based on the spectral shape. We can also be confident that we are not neglecting the impact of the machinery noise at higher frequencies, because the measured band-level spectrum (Figure 21, blue line) is well below the thruster band-level spectrum even at the higher frequencies.

Figure 22. *Polar Pioneer* semi-submersible platform used as a surrogate sound source for acoustic modelling.

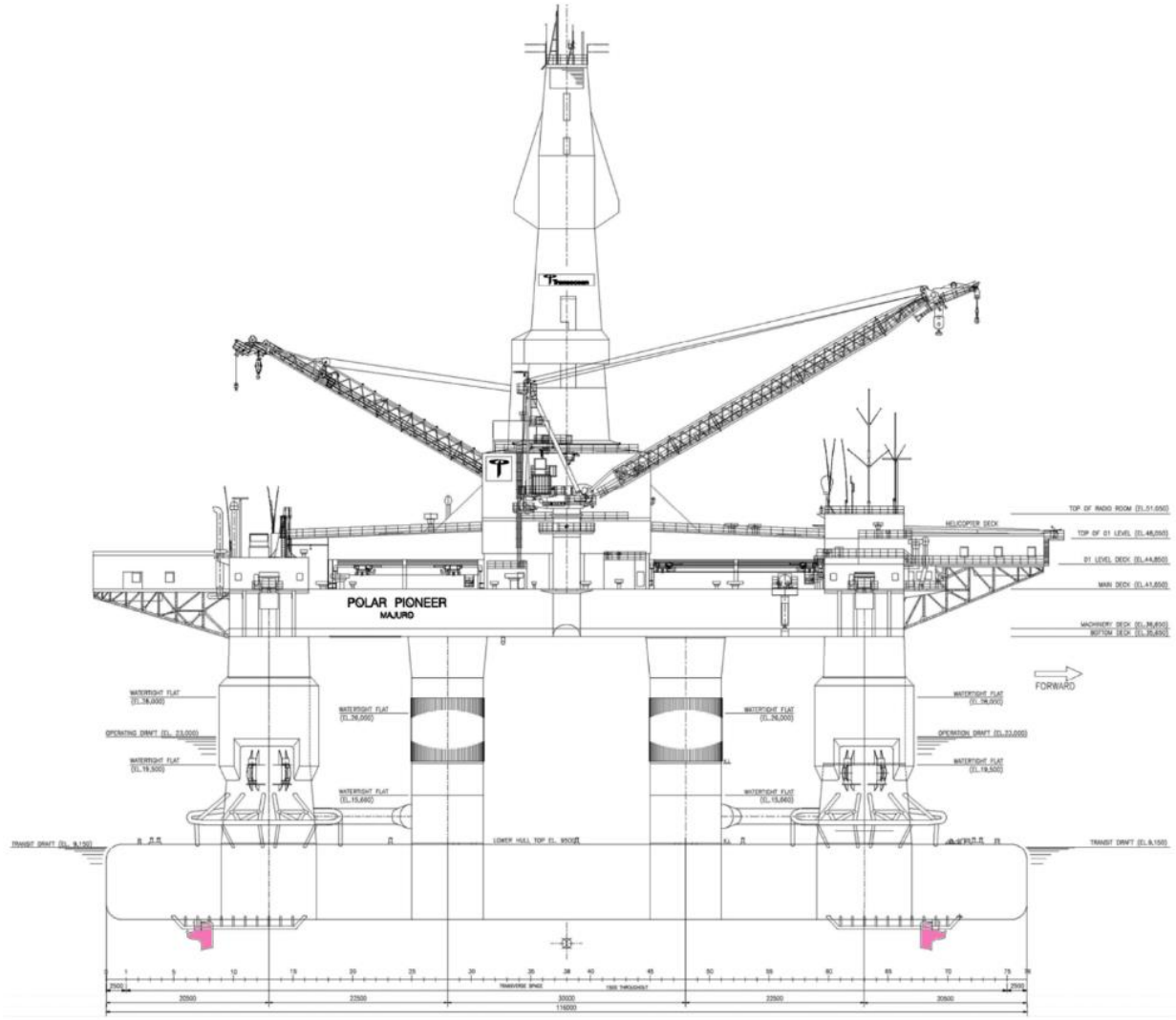


Figure 23. *Polar Pioneer* dimensions with thruster locations shown in red.

4.4.2.4. Representative Support Vessel: DSV Fu Lai

Offshore standby safety vessels are typically ~50–100 m long, 10–20 m wide, with a 3–8 m draft. They are usually fitted with bow and stern thrusters or propellers, and a dynamic positioning system.

For this work we have used the DSV *Fu Lai* (Figure 24) as a representative vessel of this class to simulate the source level spectrum of a typical standby safety vessel. The DSV *Fu Lai* is 107 m long with a total of 12800 HP. Although it is technically a dive support vessel, its acoustic characteristics are primarily a function of its propulsion system, and in this way it is equivalent to more typical offshore supply vessels and drilling support vessels. The main reason for using it as a representative vessel of this class is that source measurements are available for use in this study. The acoustic signature of this vessel (broadband level of 178 dB re 1 µPa m) was recorded by JASCO in dynamic positioning mode at 20–30% power (MacGillivray 2006). For the purpose of the current modelling, a generic version of the source spectrum was derived based on scaling the measured broadband level, so the SL spectrum was less specific to the particular vessel and more representative of the general case. The derived 1/3-octave-band SL spectrum is plotted in Figure 25.

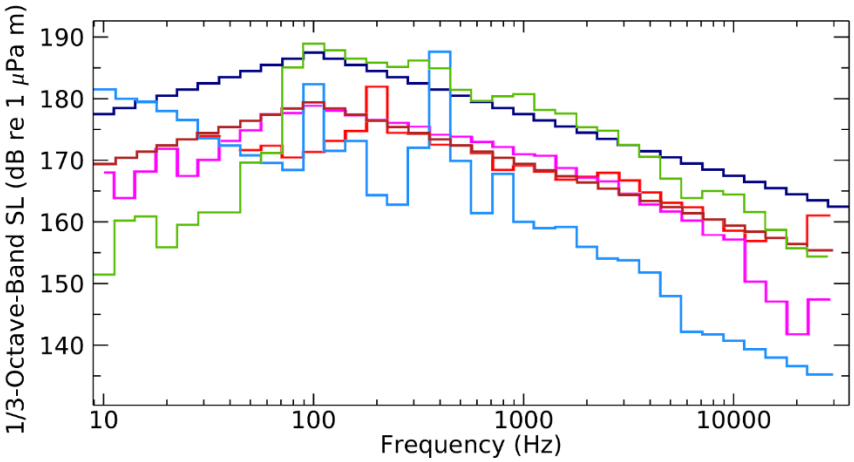
Figure 24. Support vessel *Fu Lai*, used to represent a typical standby safety vessel for acoustic modelling.

4.4.2.5. Summary of Modelled Vessel Source Levels

The general modelling parameters of the four vessel sources and the methods they were derived by are summarized in Table 7 ,and the 1/3-octave-band spectra are shown in Figure 25.

Table 7. Summary of modelled vessel sources.

Source	Method used to obtain spectrum	Method used to obtain broadband SL	Broadband SL (dB re 1 µPa m)	Source depth (m)
Generic drillship	Scaling generic spectrum to broadband SL	Thruster power formula	196.7	12
Drillship *Stena Forth*	Field measurements	Field measurements	189.7	12
Semi-submersible drill rig *Seadrill West Sirius*	Max. of (a) scaling measured DP spectrum to broadband thrusters SL, and (b) measured surrogate moored machinery noise	Thruster power formula	196.7	25
Support vessel *Fu Lai*	Scaling generic spectrum to broadband SL	Field measurements	178	5



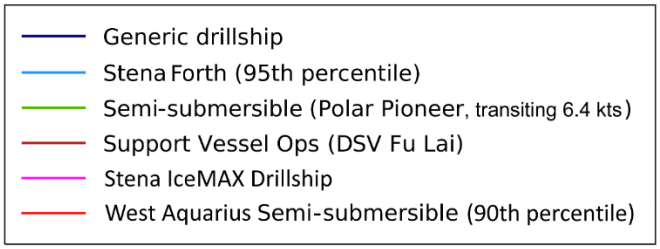


Figure 25. Drilling operations: Comparison of derived 1/3-octave-band source levels between the maximum expected for a generic drill rig, the *Stena Forth* drillship (Kyhn et al. 2014), the surrogate semi-submersible drill rig *Polar Pioneer* (Austin and Li 2016)**,** and the support vessel *Fu Lai*. The source level spectra of another semi-submersible, the *West Aquarius*, and another drillship, the *Stena IceMAX*, are also shown for comparison (Martin et al. 2019). The estimated source spectrum for the semi-submersible *Seadrill West Sirius* that is used in the modelling is effectively the *Polar Pioneer* spectrum shown here reduced by 3.1 dB (Figure 21, black line).

4.5. Sound Propagation

4.5.1. Comparing Acoustic Environments

The sound levels measured at some distance from a source depend mainly on the source-receiver distance, propagation effects of the physical environment, and the sound frequency. Sound propagation is influenced by the bathymetry at and around the sound source, the geoacoustic properties of the seafloor, the variation in sound speed in the water as a function of depth, and the spectral characteristics of the sound source. This section compares the environmental parameters expected within the project area (detailed in Section 4.1, Table 4, and Figures 12–14) to those for the Scotian Basin (Zykov 2016), the Flemish Pass (Matthews et al. 2017), and the BP Orphan Basin (Matthews et al. 2018) Projects.

4.5.1.1. Bathymetry

Modelled sites for the Scotian Basin Project (Zykov 2016) were located off the continental shelf, near the bottom of the slope. The modelled area is characterized by the continental shelf to the northwest of the modelled sites, and relatively flat, deep water (>2000 m) to the southwest, south, and northeast. Sound that reaches the continental shelf is rapidly attenuated between the 200 and 50 m isobaths. Sound levels propagating parallel and away from the shelf can persist for long distances (>100 km).

The bathymetry in Flemish Pass is characterized by a deep channel (~1200 m depth) bounded by the continental shelf (≤200 m depths) to the west and the Flemish Cap (≤200 m depth) to the east. As for the

sound off the Scotia Shelf, sound levels that reaches shallow water is rapidly attenuated, while sound levels propagating along deeper water persist for longer distances (Matthews et al. 2017).

Sound from the planned project activities in EL-1157 and EL-1158 (Figure 2) is expected to be bounded by the continental shelf across the quadrant from south to west of the project area, and to a lesser degree in the northwest and southeast-through-east directions. The sector of the compass bearing north through northeast, however, faces deeper water and gentle downslope in range, which does not offer any bathymetry restrictions to sound propagation in those directions.

4.5.1.2. Geoacoustic Properties

In general, the differences between geoacoustic properties for the project area and the related studies (Zykov 2016, Matthews et al. 2017, Matthews et al. 2018) are not expected to be a major factor influencing differences in sound propagation at the various sites. The profile developed for representing the geoacoustic properties in the project area (Section 4.1.2) is based on the same references and model as those developed for the Flemish Pass Project (Matthews et al. 2017). The water depth being greater in Orphan Basin, the profiles are representative of smaller average grain size than for the shallow site used in the Flemish Pass Project. The Buckingham (2005) grain-shearing model was also used to derived a generic geoacoustic profile for the Scotian Basin Project (Zykov 2016). The expected thick clay layer in this area, off the continental slope, results in similar geoacoustic properties as in Orphan Basin.

4.5.1.3. Underwater Sound Speed Profile

For comparison purposes, the top portion of the mean monthly sound speed profiles for the Scotian Basin Project (Zykov 2016), the Flemish Pass Project (Matthews et al. 2017), and the BP Orphan Basin Project (Matthews et al. 2018) are presented in Figure 26. These may be easily compared with the sound speed profiles for the present Orphan Basin study, shown in Figures 12 and 13.

The sound speed profile from the Scotian Basin Project (Figure 26b) results in more complex propagation effects than expected in the Orphan Basin and the Flemish Pass. In winter, there is a strong sound speed minimum in the top 200 m of the water column that supports long range propagation. Below 200 m, there is a second sound speed minimum that tends to confine sound closer to the seabed where it is attenuated through spreading and absorption. In spring and summer, there is a weaker sub-surface sound channel with a sound speed minimum near 50 m, and a stronger deep sound channel with its minimum below 500 m. In August, the maximum extent of the SPL thresholds of 160 dB re 1 µPa off the Scotia shelf was modelled to 8.44 km for the VSP array at Site B, and extent of the SPL thresholds of 120 dB re 1 µPa in modelled to 61.0 km for the semi-submersible platform (with support vessel) at Site B. In February, the distance for the VSP array at Site B is shorter (3.57 km), while the distance for the semi-submersible platform (with support vessel) at Site B is longer (>150 km).

The seasonal variation in the profiles derived for the Flemish Pass Project (Figure 26c) is more similar to the seasonal variation in the Orphan Basin than in the Scotian Basin. The monthly profiles from January to May are the least downward refracting. Sound is expected to propagate to longer distances during this period. For the Flemish Pass Project, May was selected for modelling since this profile is the least downward refracting during the months that are traditionally most operationally active (May to October). In May, the maximum extent of the SPL threshold of 160 dB re 1 µPa in Flemish Pass was modelled to 6.35 km for the VSP array at the deep site, and the extent of the SPL threshold of 120 dB re 1 µPa was modelled to 47.6 km for the drilling platform at the deep site.

In the Orphan Basin, we expect smaller seasonal variations in propagation conditions than were predicted for the Scotian Basin. Sound propagation in June should be more similar to that modelled in May in Flemish Pass than that in August or February for the Scotian Basin. However, Figures 12 and 13 show that a weak sound channel is present in the Orphan Basin SSPs in the summer months. This feature can be favourable to long-range propagation for some sound sources, depending on the source's depth and frequency content. In all the modelled BP Orphan Basin sites, we expect the profiles for July to November to lead to slightly shorter distances to sound thresholds (for similar sound sources) than in June, since more downward-refracting profiles are expected at that time. Similarly, we expect profiles for December to

April to lead to similar or longer distances than in June, with the June SSP being the most even blend of the two seasonal extremes.

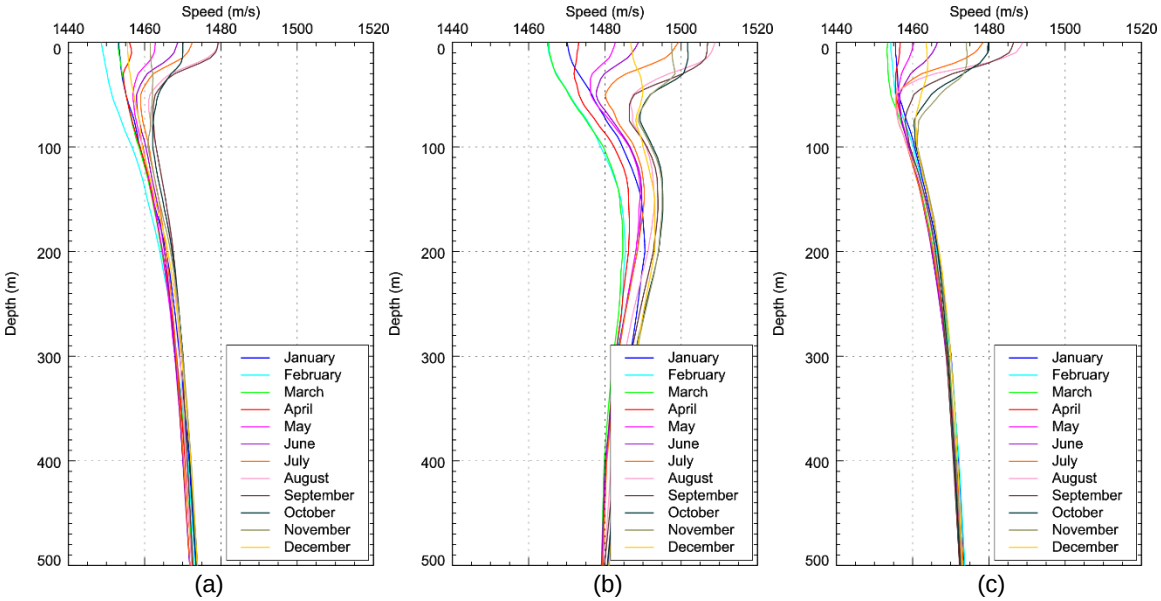


Figure 26. Mean monthly sound speed profiles for the (a) BP Orphan Basin Project, West, in EL-1145, (Matthews 2018), (b) Scotian Basin Project (Zykov 2016), and (c) Flemish Pass Project (Matthews et al. 2017). All profiles were derived from data obtained from *GDEM V 3.0* (Teague et al. 1990, Carnes 2009).

4.5.2. Propagation Loss

Propagation loss (PL) at Orphan Basin Sites in EL-1157 and EL-1158 was quantified using a parabolic equation (PE) numerical treatment (Section 3.2.1.1). The bathymetry (Section 4.1.1), geoacoustics (Section 4.1.2), and historical average February and August sound speed profiles (Section 4.1.3) were used as the environmental basis of this modelling. Broadband PL results representative of each project activity were estimated based on the representative source level spectra and source depth, presented in Section 1.1.

Propagation loss values are not reported separately in this report, but they are combined with the band-level source spectrum values to produce estimates of received levels at various ranges, depths, and azimuth angles. For example, for a receiver at some depth and range away from the semi-submersible at Site A in EL-1157, in the 100 Hz 1/3-octave-band, a PL = 56.4 dB re 1 m and SL = 186.3 dB re 1 µPa m are used together to obtain a received level SPL of 129.9 dB re 1 µPa is predicted at 10 km from the:

$$\mathrm{RL} = \mathrm{SL} - \mathrm{PL} = 186.3 - 56.4 = 129.9 \text{ dB re } 1 \text{ µPa} \quad (14)$$

In the modelling performed for this project, the RL values were also post-processed to yield maximum-over-depth broadband received levels in both the SPL and SEL metrics.

Note that the extent to which these activities could be perceived by, potentially disturb, or potentially injure marine life must consider other factors, such as the hearing sensitivity of species of concerns (e.g., applying frequency filtering based on M-weighting functions). This is all part of the post-processing used to calculate the full acoustic prediction results that are presented in Section 4.

4.6. Ambient Sound in the Project Area

The ambient sound in the project area was estimated based on data from the closest ESRF recording station (see Figure 2)—Station 19, in each of its two locations. Long-term spectral averages along with median band-level time series figures (Figure 27 is an annotated example) provide an overview of the time and frequency evolution in the soundscape. As an illustration of the data display techniques, first consider an example for Station 15. In 2015, ESRF Station 15 recorded seismic survey sounds until November 2015 and beginning again in June 2016. The winter period of 15 Nov 2015 to 1 Jun 2016 was representative of a normal ambient soundscape for this region (Figure 27). DP thrusters from the semi-submersible drilling platform *West Hercules* located 209 km from the recorder were faintly detectable. Fin whale mating choruses were a dominant sound source in the band of 18–25 Hz from November to March.

Power spectral density and 1/3-octave-band distribution plots (Figure 28) can be directly compared to the Wenz plots (Figure 4). In 2015–2016, sound from seismic surveys increased the received sounds levels below 250 Hz for more than 25% of the recording period (Figure 28). Fin whale notes are clearly identifiable as a broad hump around 20 Hz.

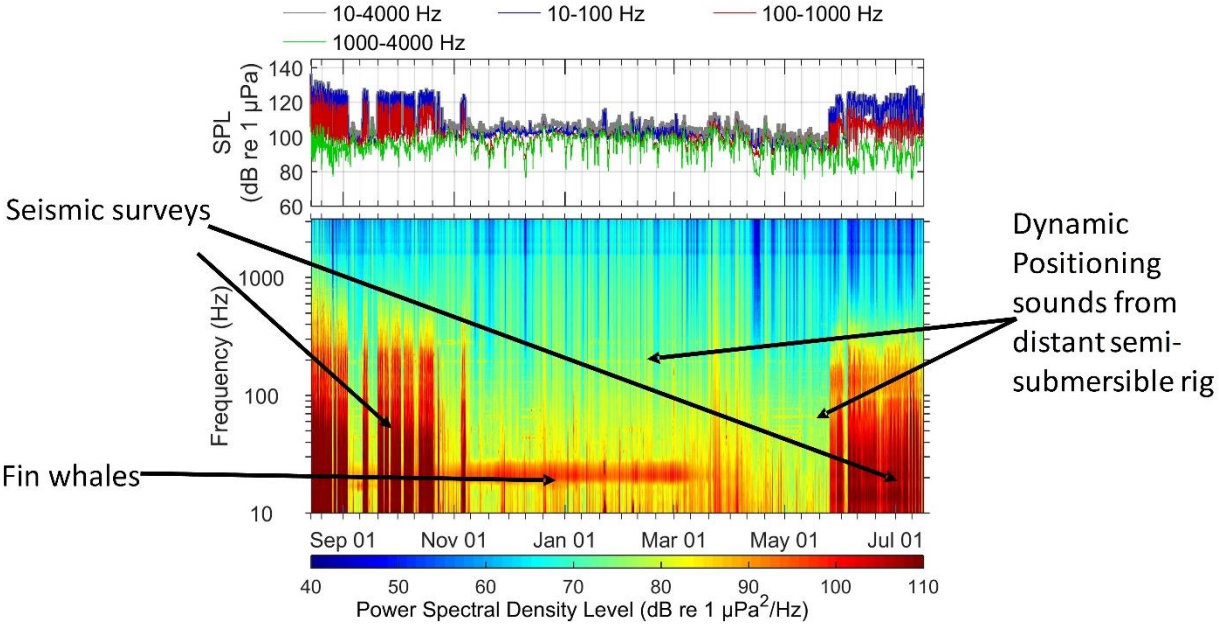


Figure 27. Annotated long-term spectrogram for Station 15, September 2015 to July 2016. The semi-submersible drill-rig West Aquarius was 209 km from the recorder.

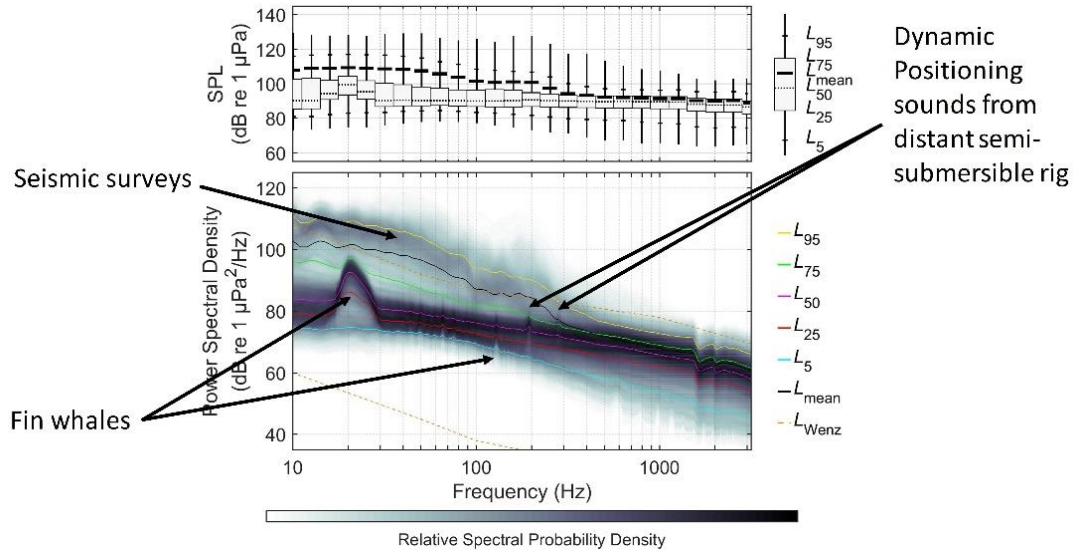


Figure 28. Summary of spectral content of ESRF Station 15. The top figure shows a box-and-whisker plot for the 1/3-octave-band SPL, and bottom shows the power spectral density percentiles and probability density (grayscale) of 1-minute PSD levels compared to the limits of prevailing levels (Wenz 1962). The signatures of seismic surveys, fin whales and distant dynamic positioning thrusters are annotated. The semi-submersible drill-rig West Aquarius was 209 km from the recorder.

Constant but distant sound from dynamic positioning thrusters of the semi-submersible drill rig *West Hercules* (range 209 km) are visible as narrow peaks in the L_5 curve, but those sounds become obscured at times when higher level sounds are present. The sounds from the *West Hercules* did not elevate the total broadband sound levels. There were small nulls in the power spectrum density (PSD) throughout the recording at 1650 and 2000 Hz that were due to destructive interference from reflections off the AMAR Ultra Deep used at this deep location (Figure C-4). These artifacts are far less prominent in the AMAR data than data from most other recorders that have their hydrophones placed directly next to the recorder endcap.

The daily SEL integrates the total sound energy at a receiver location and is believed to be a good predictor of possible temporary threshold shifts in marine life hearing if it is high enough (NMFS 2018). Sound associated with seismic survey activity was the an easily detected contributor to the daily SEL in 2015–2017 (refer to Section 2.3 for information regarding how contribution to soundscape can be quantified). When seismic was present the daily SEL was 10–30 dB higher than daily SEL in the absence of seismic surveys (see Figure 31 in Section 4.6.1). The daily SEL also increased in winter due to both fin whales and increased wind and wave activity.

4.6.1. ESRF Station 19

Station 19 was deployed off the northeastern coast of Newfoundland at slightly different locations in 2015–2016 and 2016–2017. In 2015–2016, it was deployed in southwestern Orphan Basin to obtain baseline data ahead of anticipated oil and gas activity. It was deployed at a depth of 1282 m. In 2016–2017, the station was moved to southeastern Orphan Basin to investigate mammal habitat use after repeated sightings of northern bottlenose whales in the area and due to increased oil and gas interest in the area. It was deployed at a depth of 1547 m.

The maximum and minimum broadband SPL measured in 2015–2016 were 139.5 and 90.6 dB re 1 µPa, respectively (Figure 29). The maximum and minimum broadband SPL measured in 2016–2017 were 157.6 and 95.5 dB re 1 µPa, respectively. The main soundscape features at this station were seismic survey activity from July to October in both years (Figure 31), and fin whale vocalizations. In 2015–2016, the recorder was relatively far from the seismic survey. Sound from the survey was clearly identifiable, but it did not often raise SPL above prevailing levels. In 2016–2017, the adjusted station location was closer

to seismic survey sound, which frequently raised the SPL below 300 Hz to exceed the expected limits of prevailing levels (Figure 30). However, sound levels associated with environmental and mooring conditions at this location also regularly exceeded the limits of prevailing levels.

Fin whale 20 Hz notes were detected as early as September, but they were generally masked by seismic survey sounds until the end of the survey in late October 2015. These notes were the main source of identifiable sound until mid-March 2016 (Figure 29).

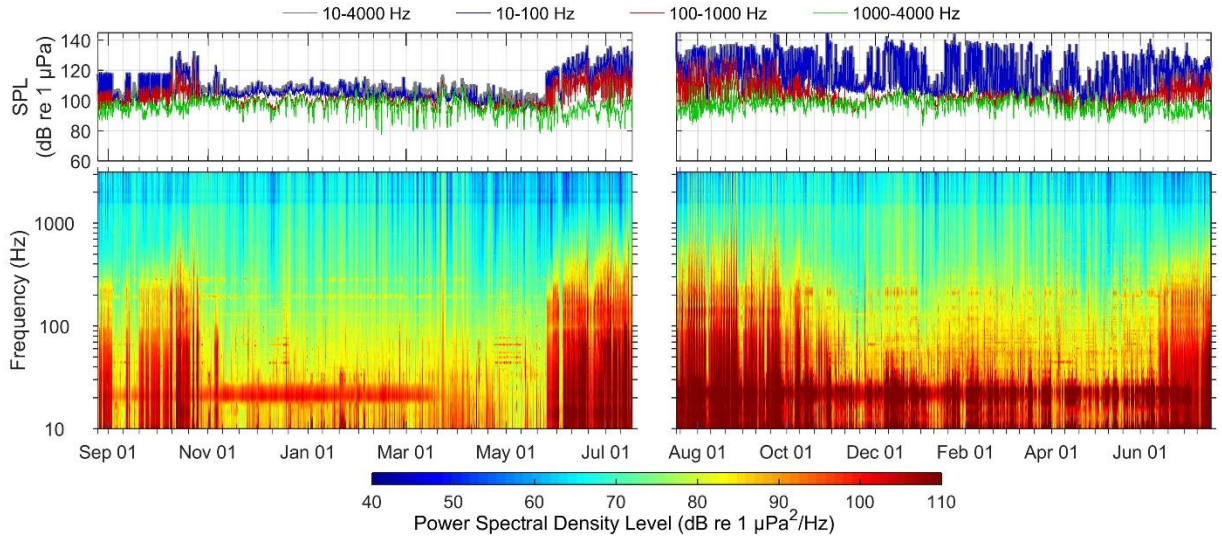


Figure 29. ESRF Station 19: (Top) In-band SPL and (bottom) spectrogram of underwater sound for (left) 2015–2016 and (right) 2016–2017.

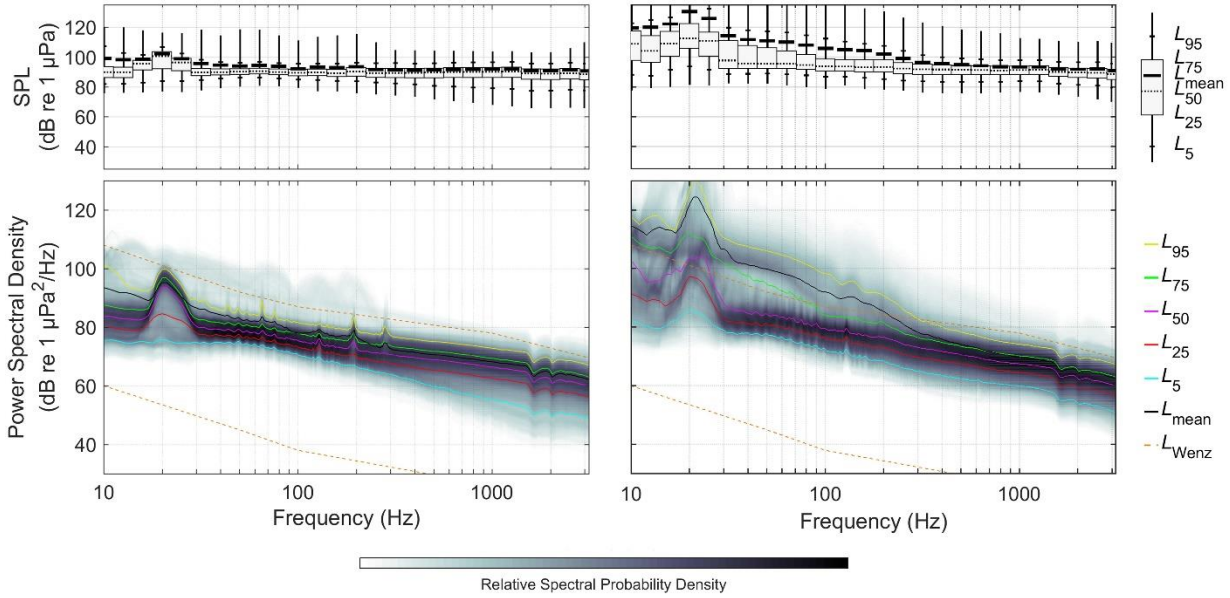


Figure 30. ESRF Station 19: (Top) Exceedance percentiles and mean of 1/3-octave-band SPL and (bottom) exceedance percentiles and probability density (grayscale) of 1-minute PSD levels compared to the limits of prevailing levels (Wenz 1962) for (left) 2015–2016 and (right) 2016–2017.

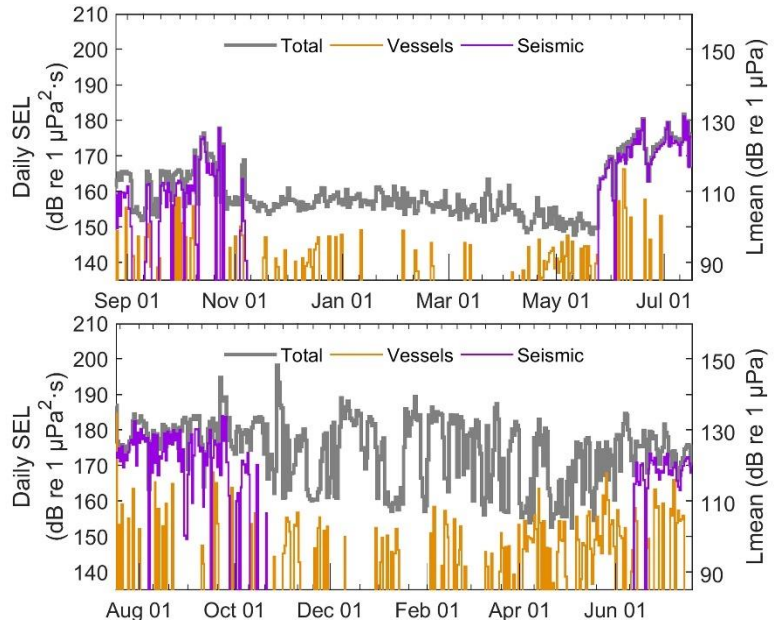


Figure 31. Station 19: Total (grey), vessel (orange), and seismic-associated (purple) daily SEL and equivalent continuous sound levels (L_{eq}) for (top) 2015–2016 and (bottom) 2016–2017.

4.6.2. Dominant Sound Sources 2015–2017

Based on measurements at the ESRF stations, there are three identifiable sources in the Orphan Basin area that have long-term effects on the soundscape. We expect these sources to be present in the foreseeable future. The BHP project's sounds will add to these sources to create the cumulative soundscape in the area. These sources are:

1. *Fin whales*: Fin whales sing from October to March on the Grand Banks. Their constant notes raise the total sound level in the 10–45 Hz band by 5–10 dB in winter across the Grand Banks and Scotian Shelf. Whales near a recorder can temporarily increase the one-minute sound levels to 130 or 140 dB re 1 µPa. We can expect the same contribution by fin whales in future years. The project's sounds will overlap in frequency with fin whale vocalizations; however, the project activities are mostly located off the continental shelf, where the whales are less present.
2. *Shipping and oil and gas extraction platforms*: Shipping, including supply vessels for the project, are generally transient sources that are detectable at any one location over a period of several hours. Near the project sites and existing oil and gas extraction platforms, the sounds from vessels and DP systems are continuously present. We can expect the same contribution from shipping and extraction platforms in near future. The project's activities will mainly add to these sources in the area.
3. *Seismic surveys*: The seismic surveys detected at ESRF Station 19 were over 100 km from the recorders and still a dominant sound source. The peak frequency of sound from seismic source arrays is near 50 Hz (Dragoset 1984). The frequency range increases as a source vessel approaches a measurement location. The measurements reported at Station 19 included energy up to 1 kHz. This sound source is variable in space and time depending on where the seismic source is located. It is expected that 2-D and 3-D seismic surveys will continue off Newfoundland for the foreseeable future each summer. The project will conduct vertical seismic profiles (VSP) to image the well structures. This type of seismic activity is conducted over a much shorter period and with arrays at least half the volume of full-scale seismic surveys. Thus, VSP operations are expected contribute less than seismic surveys., They could still be an important contributor to the soundscape if the activities were to occur in winter, when seismic surveys are absent.

4. *Ambient noise*: Median sound levels increase 3–5 dB in winter due to higher wind speeds and storms. The peak frequency band for wind noise is 200–2000 Hz. See Hildebrand (2009) and Cato (2008) for overview of ocean ambient noise and man-made sound sources.

5. Acoustic Field Modelling Results

5.1. Vertical Seismic Profile Source

Sound propagation from the *Dual Delta* 1200 in^3 airgun array was modelled at Sites A and B. The modelling used two sound speed profiles, February and August, representing the range in sound propagation conditions over the course of a year.

The SEL threshold impact criteria require estimating the SEL over a 24-hour period. For this modelling, it was assumed that the sound source was stationary and operated continuously (at a fixed pulse rate) over the 24 hour period. Over the 24 hours, 225 firings (shots) of the airgun array were modelled at Site A and 363 shots at Site B.

5.1.1. Sound Pressure and Peak Pressure Levels

The SPL and peak pressure for the seismic source were estimated based on the full waveform modelling (see Section 3.2.2). The full-wave modelling was performed along eight transects at each site (Figure 32). The SPL and peak pressure level (PK) were calculated directly from the synthetic pressure waveforms.

The predicted distances to specific received levels were computed from the maximum-over-depth sound fields. Two distances, relative to the source, are reported for each SPL contour (Table 8): (1) R_{max}, the maximum range at which the given sound level was encountered in the modelled SPL maximum-over-depth sound field, and (2) $R_{95\%}$, the maximum range at which the given SPL was encountered after excluding 5% of the farthest such points. Figures 33 and 34 shows coverage maps that portray the SPL field.

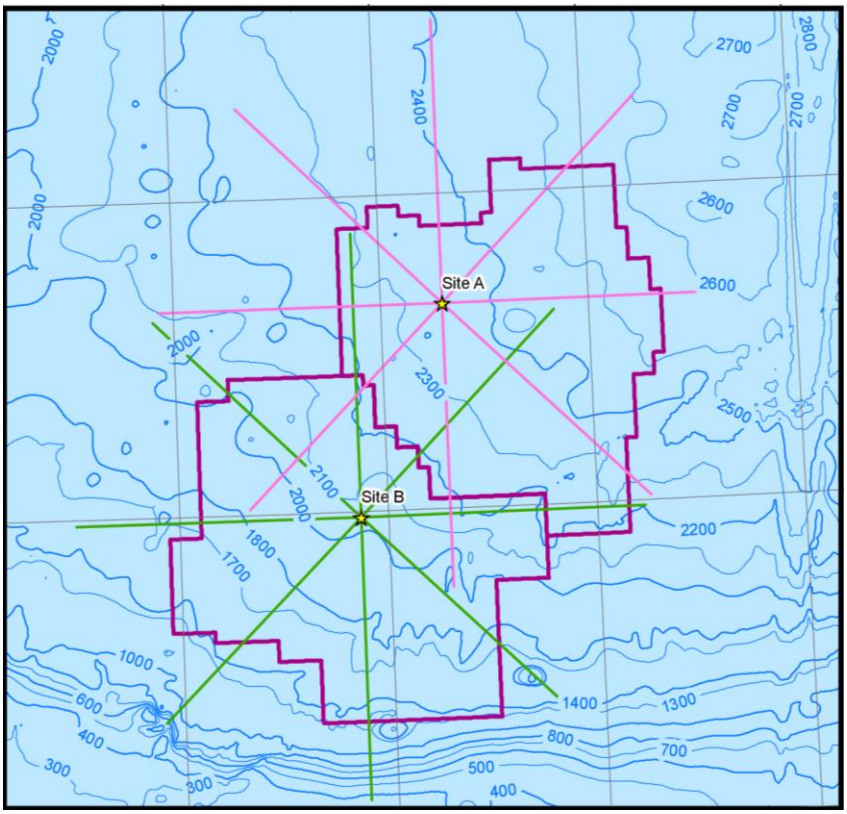


Figure 32. Profiles used for full waveform modelling (Site A pink lines and Site B green lines). Each profile is 50 km long. A total of 225 shots were modelled at Site A and 363 at Site BTable 8. *Dual Delta 1200 in³ airgun array*: Maximum (R_{max}, km) and 95% ($R_{95\%}$, km) horizontal distances from the source to modelled maximum-over-depth SPL contours for each site for February and August propagation conditions.

SPL (dB re 1 µPa)	Site A				Site B			
	February		August		February		August	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
210	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
200	0.07	0.06	0.06	0.06	0.07	0.06	0.06	0.06
190	0.18	0.16	0.18	0.16	0.18	0.16	0.18	0.16
180	0.56	0.49	0.58	0.50	0.56	0.492	0.58	0.50
170	1.80	1.54	1.84	1.57	1.80	1.54	1.86	1.58
160	4.88	4.22	4.88	4.23	7.02	5.87	6.85	5.78
150	15.1	9.29	17.5	14.8	11.3	9.78	17.3	14.3
140	32.4	27.0	32.5	26.8	25.9	22.4	>50.0	29.8
130	>50.0	46.2	>50.0	46.0	>50.0	46.2	>50.0	45.7
120	>50.0	46.2	>50.0	46.2	>50.0	46.2	>50.0	46.2

Table 9 lists the maximum range to the permanent/temporary threshold shift (PTS/TTS) onset thresholds defined for the peak pressure field. The largest estimated distance to threshold is for the high-frequency cetaceans in August: 0.12 km to PTS threshold and 0.28 km to TTS threshold (the results are the same

for Sites A and B); the February estimate is only slightly less. All the other cases have distance to PTS threshold of 40 m or less (and distance to TTS threshold of 60 m or less).

Table 9. *Dual Delta 1200 in³ airgun array*: Maximum horizontal distances in kilometres from the source to PTS- and TTS-onset thresholds defined for the peak pressure field (NMFS 2018) for each site for February and August propagation conditions.

Marine mammal hearing group	PTS-onset					TTS-onset				
	PK (dB re 1 µPa)	Site A		Site B		PK (dB re 1 µPa)	Site A		Site B	
		Feb R_{max} (km)	Aug R_{max} (km)	Feb R_{max} (km)	Aug R_{max} (km)		Feb R_{max} (km)	Aug R_{max} (km)	Feb R_{max} (km)	Aug R_{max} (km)
Low-frequency cetaceans	**219**	0.04	0.04	0.04	0.04	**213**	0.06	0.06	0.06	0.06
Mid-frequency cetaceans	**230**	<0.02	<0.02	<0.02	<0.02	**224**	<0.02	<0.02	<0.02	<0.02
High-frequency cetaceans	**202**	0.12	0.12	0.12	0.12	**196**	0.26	0.28	0.26	0.28
Phocid pinnipeds (underwater)	**218**	0.04	0.04	0.04	0.04	**212**	0.06	0.06	0.06	0.06

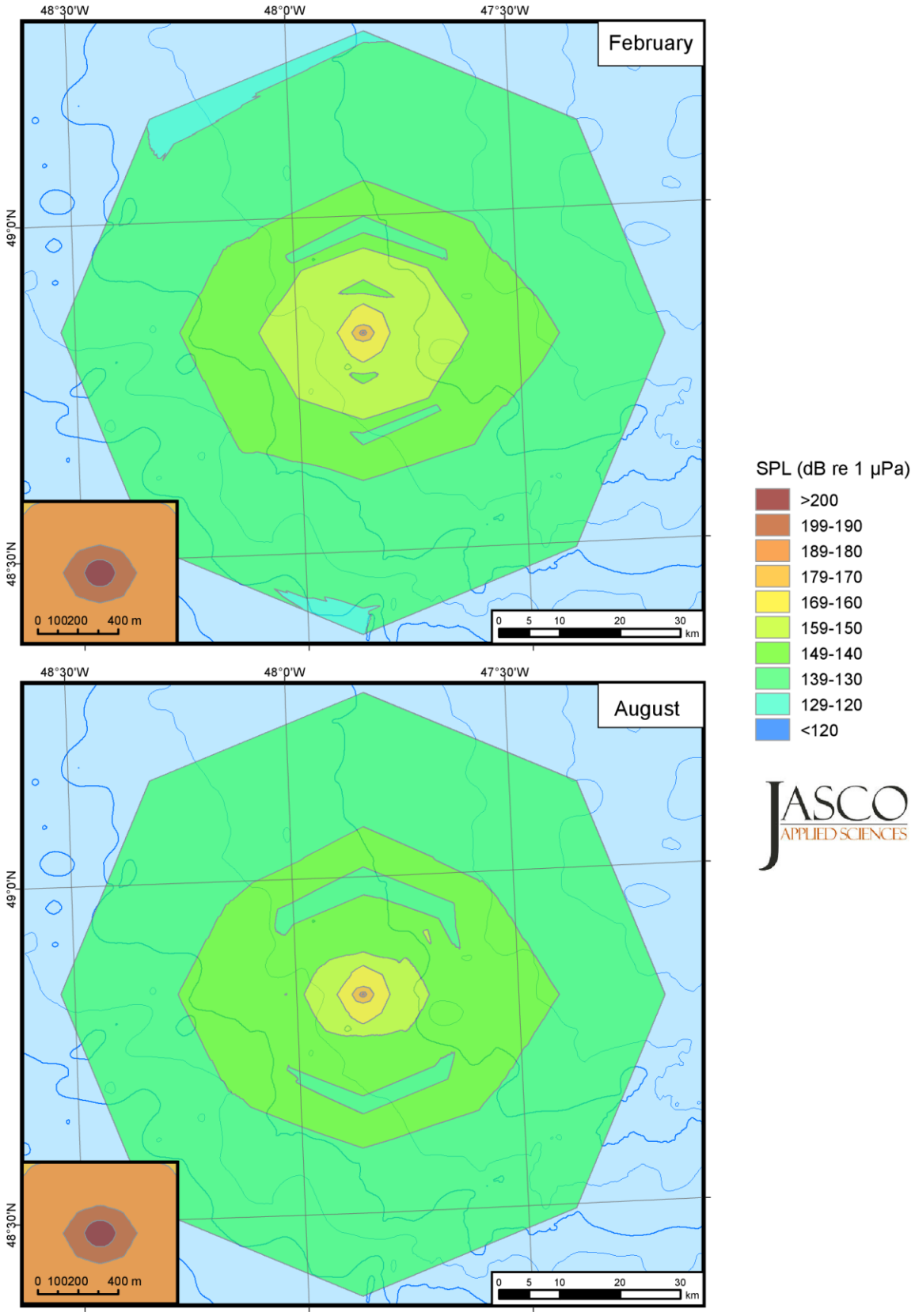


Figure 33. *Site A, Dual Delta 1200 in³ airgun array*: Broadband (10–25,000 Hz) maximum-over-depth SPL field for (top) February and (bottom) August propagation conditions. Blue contours indicate water depth in metres.

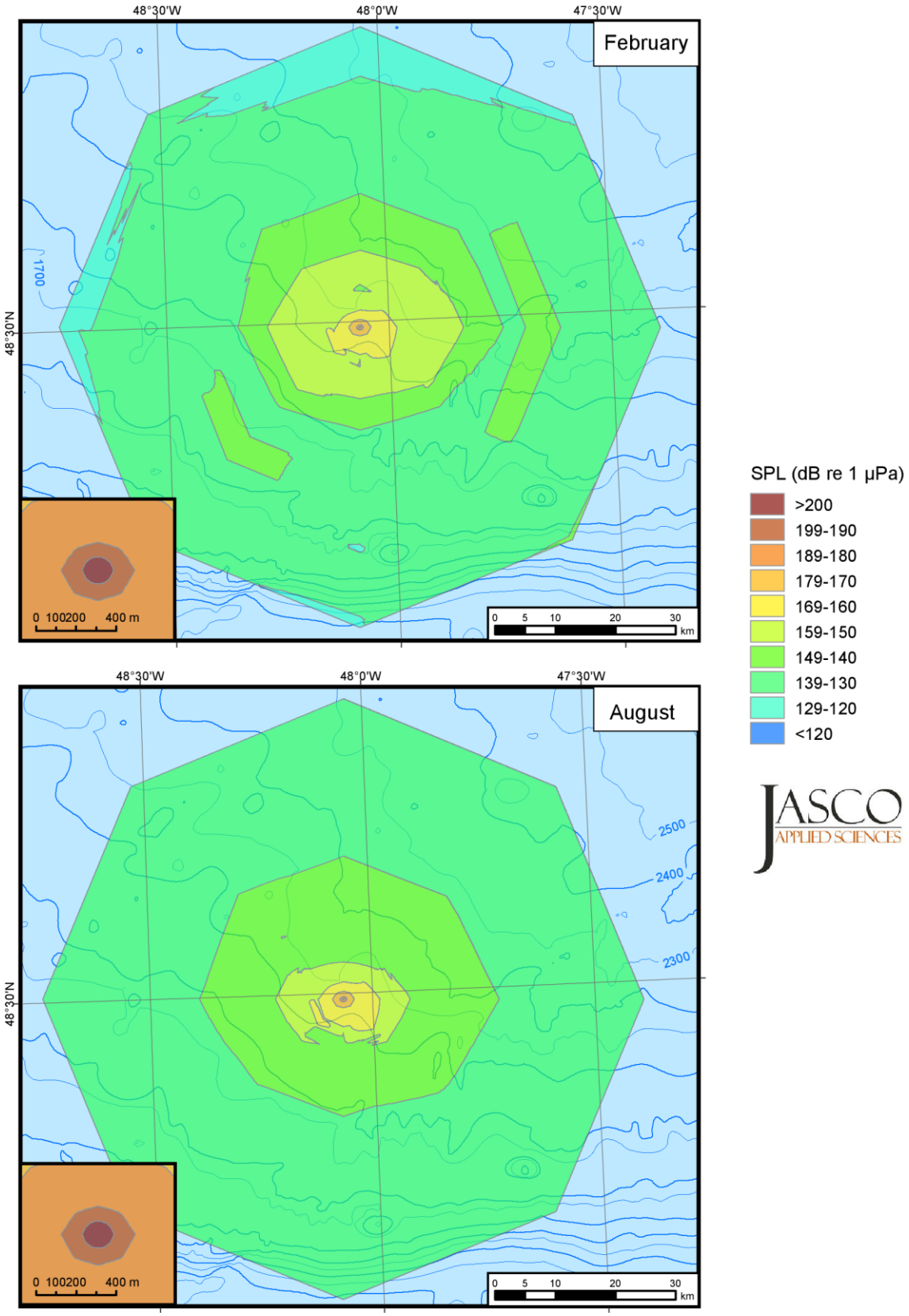


Figure 34. *Site B, Dual Delta 1200 in³ airgun array*: Broadband (10–25,000 Hz) maximum-over-depth SPL field for (top) February and (bottom) August propagation conditions. Blue contours indicate water depth in metres.

Examples of the vertical distribution of the peak pressure and SPL fields for the 1200 in³ seismic array at Site A for the 45° bearing transect are provided in Figures 35 and 36 for the February and August propagation conditions, respectively.

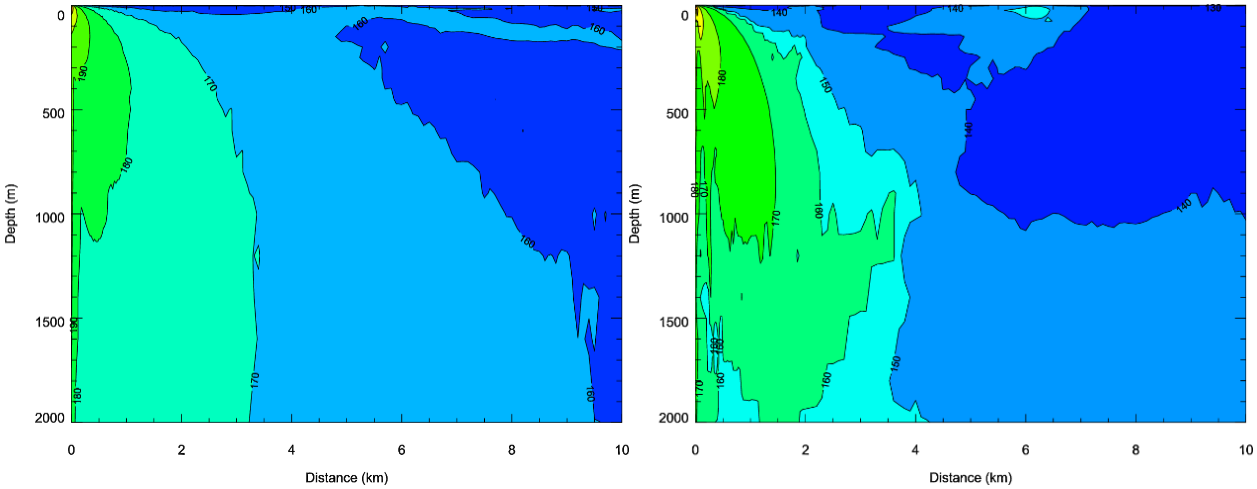


Figure 35. *Dual Delta 1200 in³ airgun array, February propagation conditions*: Vertical slice of the modelled peak pressure (left) and SPL (right) fields at Site A, 45° transect. The contour levels are labelled in dB re 1 µPa.

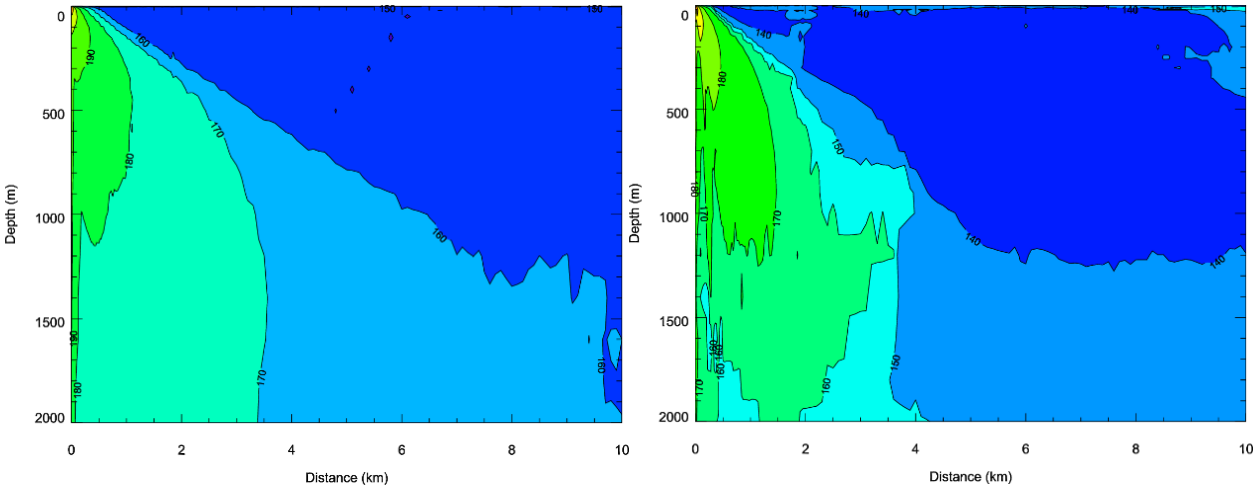


Figure 36. *Dual Delta 1200 in³ airgun array, August propagation conditions*: Vertical slice of the modelled peak pressure (left) and SPL (right) fields at Site A, 45° transect. The contour levels are labelled in dB re 1 µPa.

5.1.2. Sound Exposure Levels

Appendix B provides details of the marine mammal exposure criteria used for this study. These involve M-weighted sound exposure estimates for particular hearing groupings of marine mammals.

Table 10 provides the ranges to specific thresholds based on the M-weighted sound fields. Figures 37 and 38 provide contour maps of the maximum-over-depth 24-hour cumulative SEL, with contours of the distance-to-threshold, zoomed in on the source location. These maps are based on the fields modelled at the Sites A and B for February and August. The VSP source airgun array was modelled to be fired for 225 shots at Site A and 363 shots at Site B in a 24-hour period during the VSP operations.

Table 10. *Dual Delta 1200 in³ airgun array*: Safe distances in kilometres from the source to PTS- and TTS-onset thresholds (NMFS 2018) based on the 24 hour SEL field at each modelled site for February and August propagation conditions.

Marine mammal hearing group	PTS-onset								
	SEL (dB re 1 µPa²s)	Site A				Site B			
		February		August		February		August	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
NMFS (2018)									
Low-frequency cetaceans	183	0.446	0.402	0.455	0.410	0.572	0.512	0.592	0.530
Mid-frequency cetaceans	185	<0.01	<0.01	<0.01	<0.01	0.010	0.010	0.010	0.010
High-frequency cetaceans	155	0.032	0.032	0.032	0.032	0.040	0.036	0.040	0.036
Phocid pinnipeds (underwater)	185	0.054	0.051	0.054	0.051	0.071	0.067	0.071	0.063
Marine mammal hearing group	**TTS-onset**								
	SEL (dB re 1 µPa²s)	**Site A**				**Site B**			
		February		**August**		**February**		**August**	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
NMFS (2018)									
Low-frequency cetaceans	168	2.50	2.24	2.66	2.38	3.18	2.84	6.23	5.70
Mid-frequency cetaceans	170	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
High-frequency cetaceans	140	0.175	0.168	0.170	0.160	0.222	0.212	0.216	0.202
Phocid pinnipeds (underwater)	170	0.324	0.291	0.332	0.295	0.412	0.367	0.434	0.389

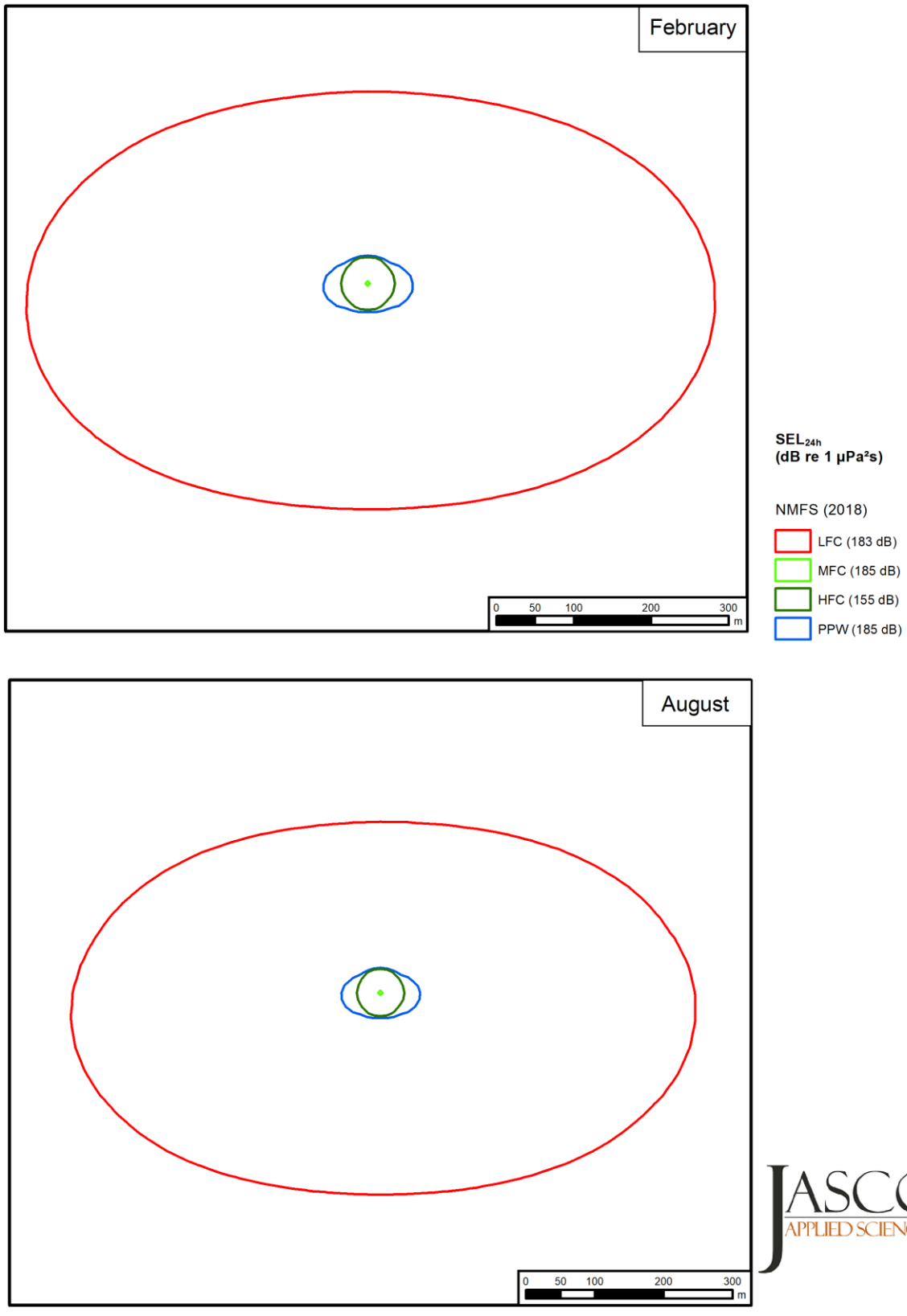


Figure 37. *Site A, Dual Delta 1200 in³ airgun array*: Broadband (10–25,000 Hz) maximum-over-depth M-weighted SEL_{24h} range to PTS threshold for (top) February and (bottom) August propagation conditions.

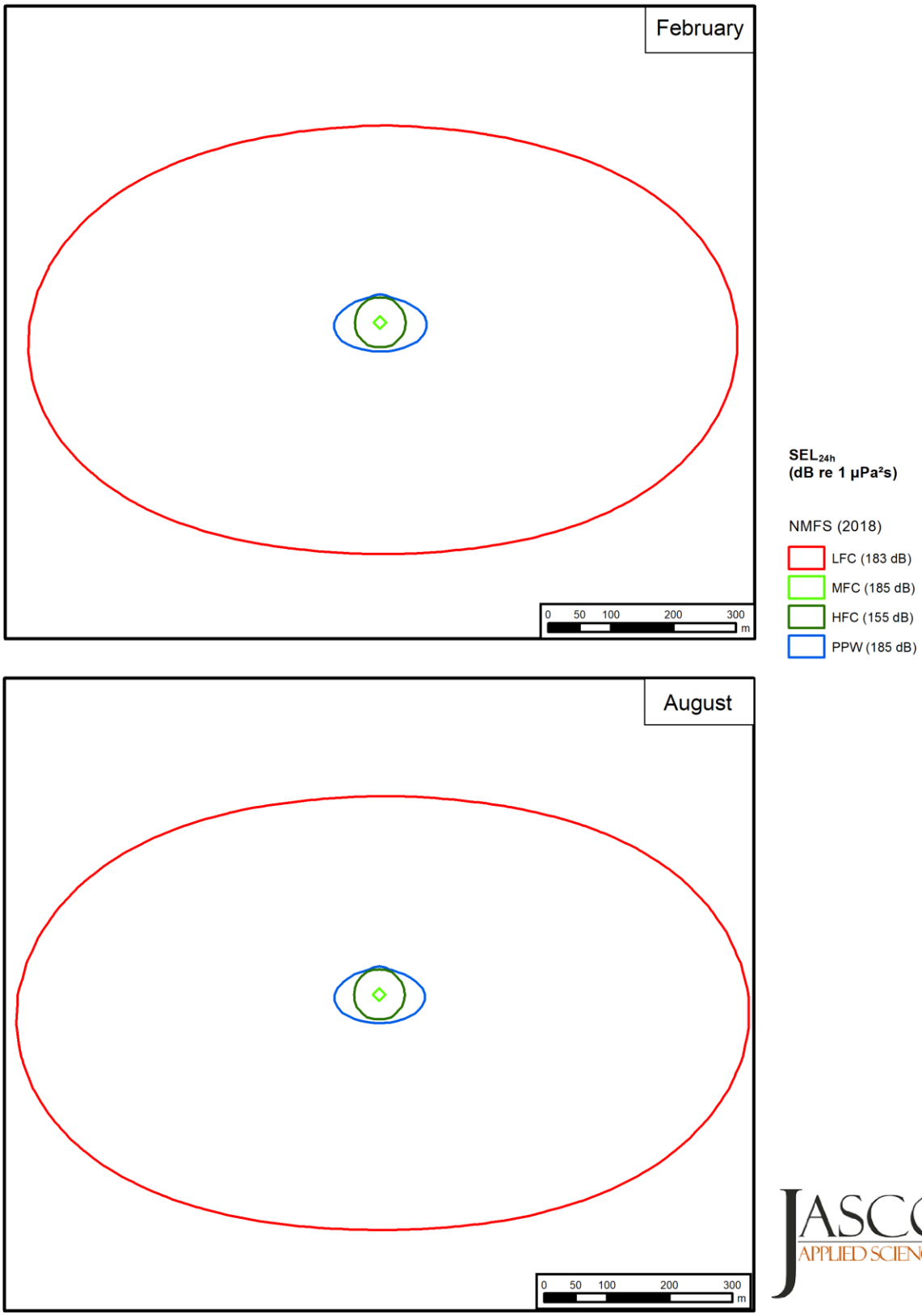


Figure 38. *Site B, Dual Delta 1200 in³ airgun array*: Broadband (10–25,000 Hz) maximum-over-depth M-weighted SEL_{24h} range to PTS threshold for (top) February and (bottom) August propagation conditions.

5.2. Vessels

The vessel operations were modelled at Sites A and B for the propagation conditions of February and August, representing the range in sound propagation conditions over the course of a year. Sound propagation was modelled for the frequency range from 10 to 25,000 Hz along 72 transects at each site up to a range of 100 km from the source. For the simplicity of the interpretation, each vessel was represented by a point source of acoustic energy at a specific source depth.

5.2.1. Sound Pressure Levels

The vessels are non-impulsive noise sources (i.e., continuous wave, or CW). For CW sources, SPL and 1-second SEL are numerically equivalent because the integration time for the purpose of the SEL calculations is taken as constant: 1 second. Therefore, the SPL field for continuous sources can be estimated using a propagation loss modelling approach (Section 3.2.1).

The underwater sound fields predicted by the source level and propagation loss models were sampled such that the received sound level at each point in the horizontal plane was taken to be the maximum value over all modelled depths for that point (see Section 3.2.1). The resultant "maximum-over-depth" SPL fields are presented below in two formats: as tables of distances to sound level thresholds and as contour maps showing the directivity and range to various sound levels.

The predicted distances to specific SPL were computed from the maximum-over-depth sound fields. Two distances relative to the source are reported for each sound level: (1) R_{max}, the maximum range at which the given sound level was encountered in the modelled maximum-over-depth sound field, and (2) $R_{95\%}$, the maximum range at which the given sound level was encountered after excluding 5% of the farthest such points.

The distances to the SPL values from 210 to 120 dB re 1 µPa, in 10 dB steps, are presented in Tables 11–13 for the February and August propagation conditions at each site. The corresponding contour maps of the estimated SPL fields are presented in Figures 39–44.

Table 11. *Generic drillship*: Maximum (R_{max}, km) and 95% ($R_{95\%}$, km) horizontal distances from the source to modelled maximum-over-depth SPL thresholds at each modelled site for February and August propagation conditions.

SPL (dB re 1 µPa)	Site A				Site B			
	February		August		February		August	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
210	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
200	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
190	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
180	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
170	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
160	0.095	0.094	0.092	0.092	0.095	0.094	0.092	0.092
150	0.304	0.297	0.314	0.308	0.305	0.298	0.316	0.308
140	0.983	0.955	1.05	1.02	0.986	0.955	1.06	1.03
130	6.32	6.19	3.38	3.28	6.57	6.37	5.66	5.42
120	53.6	47.7	26.9	17.5	65.0	60.9	26.6	17.4

Table 12. *Representative drillship (Stena Forth)* (95th percentile): Maximum (R_{max}, km) and 95% ($R_{95\%}$, km) horizontal distances from the source to modelled maximum-over-depth SPL thresholds at each modelled site for February and August propagation conditions.

SPL (dB re 1 µPa)	Site A				Site B			
	February		August		February		August	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
210	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
200	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
190	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
180	0.010	0.010	0.014	0.014	0.010	0.010	0.014	0.014
170	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
160	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
150	0.155	0.151	0.160	0.143	0.156	0.151	0.161	0.144
140	0.508	0.495	0.542	0.529	0.512	0.500	0.538	0.523
130	5.49	5.44	2.06	2.01	4.75	4.67	2.06	2.01
120	24.46	23.93	10.31	9.88	30.73	30.1	9.54	8.96

Table 13. *Representative support vessel (DSV Fu Lai) operations*: Maximum (R_{max}, km) and 95% ($R_{95\%}$, km) horizontal distances from the source to modelled maximum-over-depth SPL thresholds at each modelled site for February and August propagation conditions.

SPL (dB re 1 µPa)	Site A				Site B			
	February		August		February		August	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
210	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
200	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
190	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
180	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
170	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
160	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
150	0.103	0.100	0.100	0.100	0.103	0.100	0.100	0.100
140	0.331	0.322	0.332	0.324	0.331	0.323	0.334	0.326
130	1.05	1.02	1.07	1.04	1.05	1.02	1.07	1.04
120	5.56	5.46	3.43	3.34	5.80	5.65	6.05	5.74

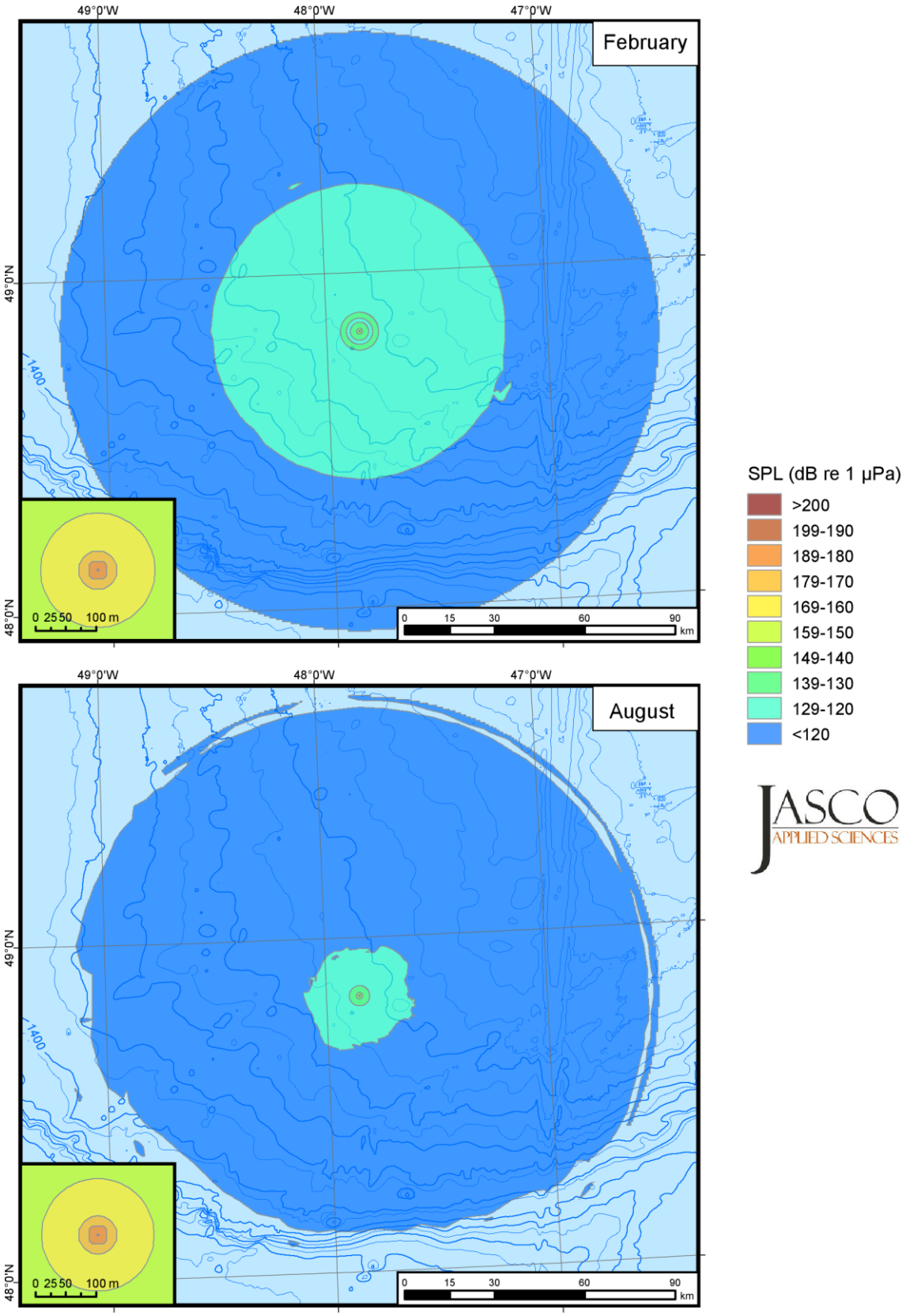


Figure 39. *Site A, Generic drillship*: Broadband (10–25,000 Hz) maximum-over-depth SPL field for February and August propagation conditions. Blue contours indicate water depth in metres.

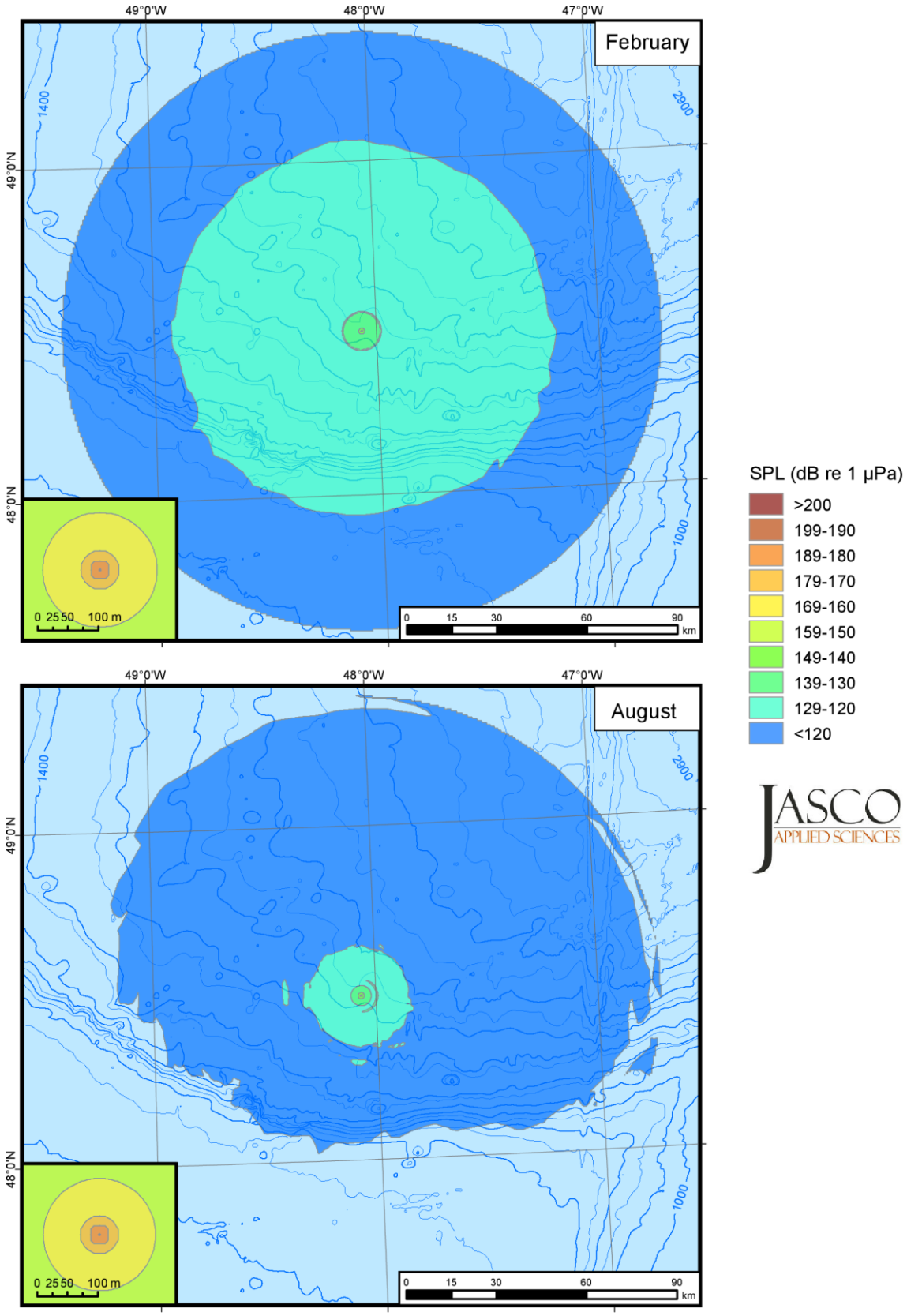


Figure 40. *Site B, Generic drillship*: Broadband (10–25,000 Hz) maximum-over-depth SPL field for February and August propagation conditions. Blue contours indicate water depth in metres.

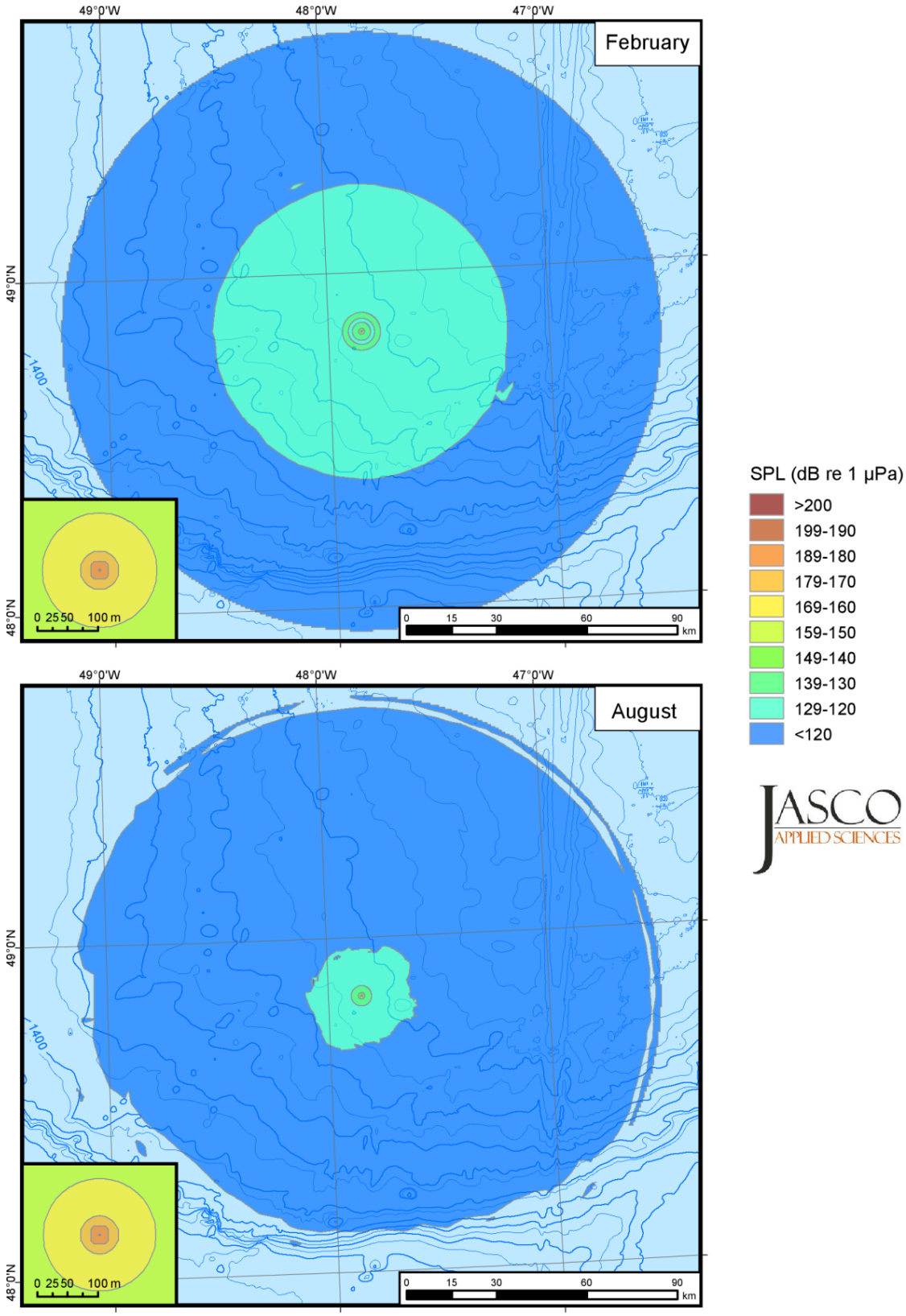


Figure 41. *Site A, representative drillship (Stena Forth) (95th percentile)*: Broadband (10–25,000 Hz) maximum-over-depth SPL field for February and August propagation conditions. Blue contours indicate water depth in metres.

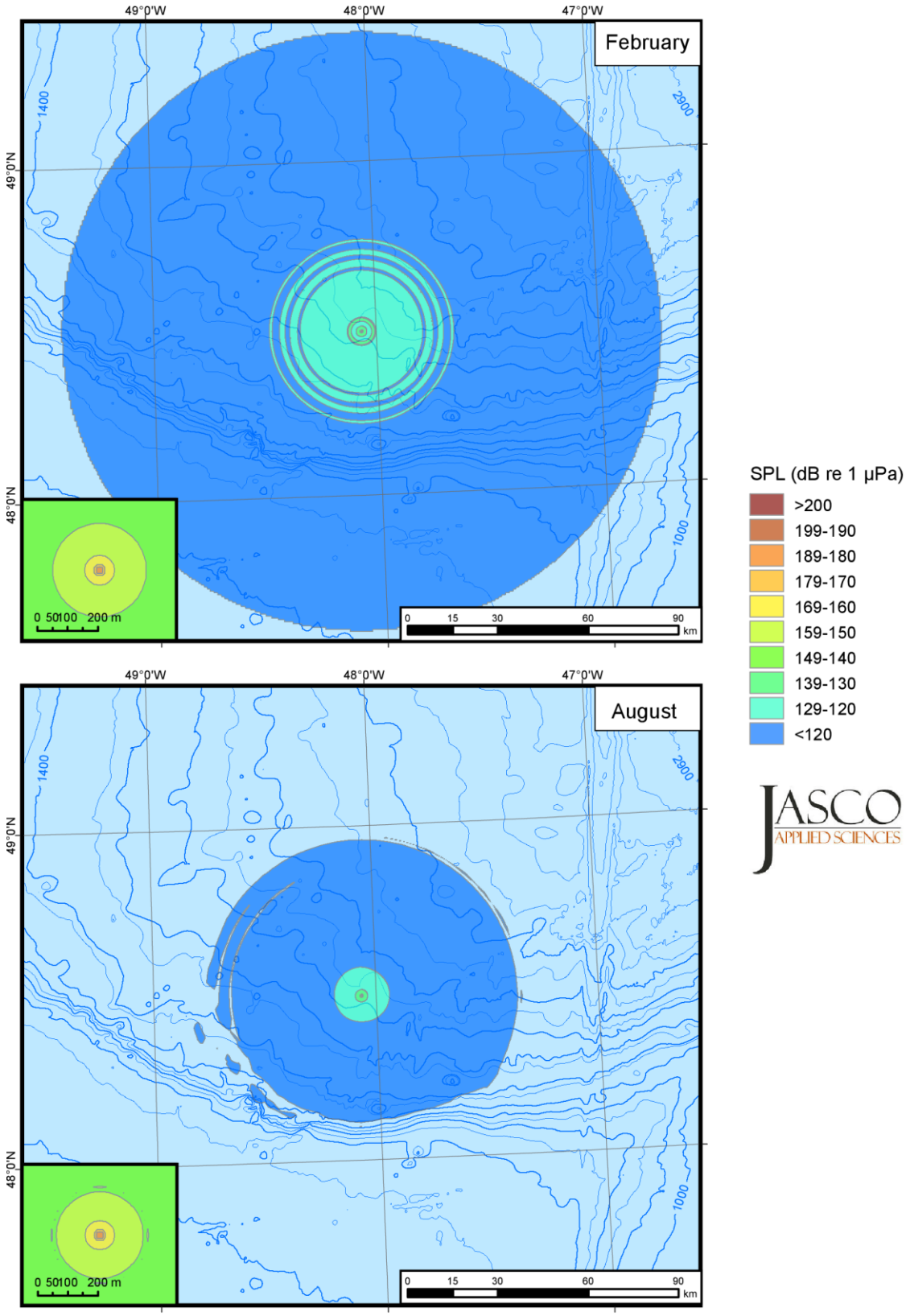


Figure 42. *Site B, representative drillship (Stena Forth) (95th percentile)*: Broadband (10–25,000 Hz) maximum-over-depth SPL field for February and August propagation conditions. Blue contours indicate water depth in metres.

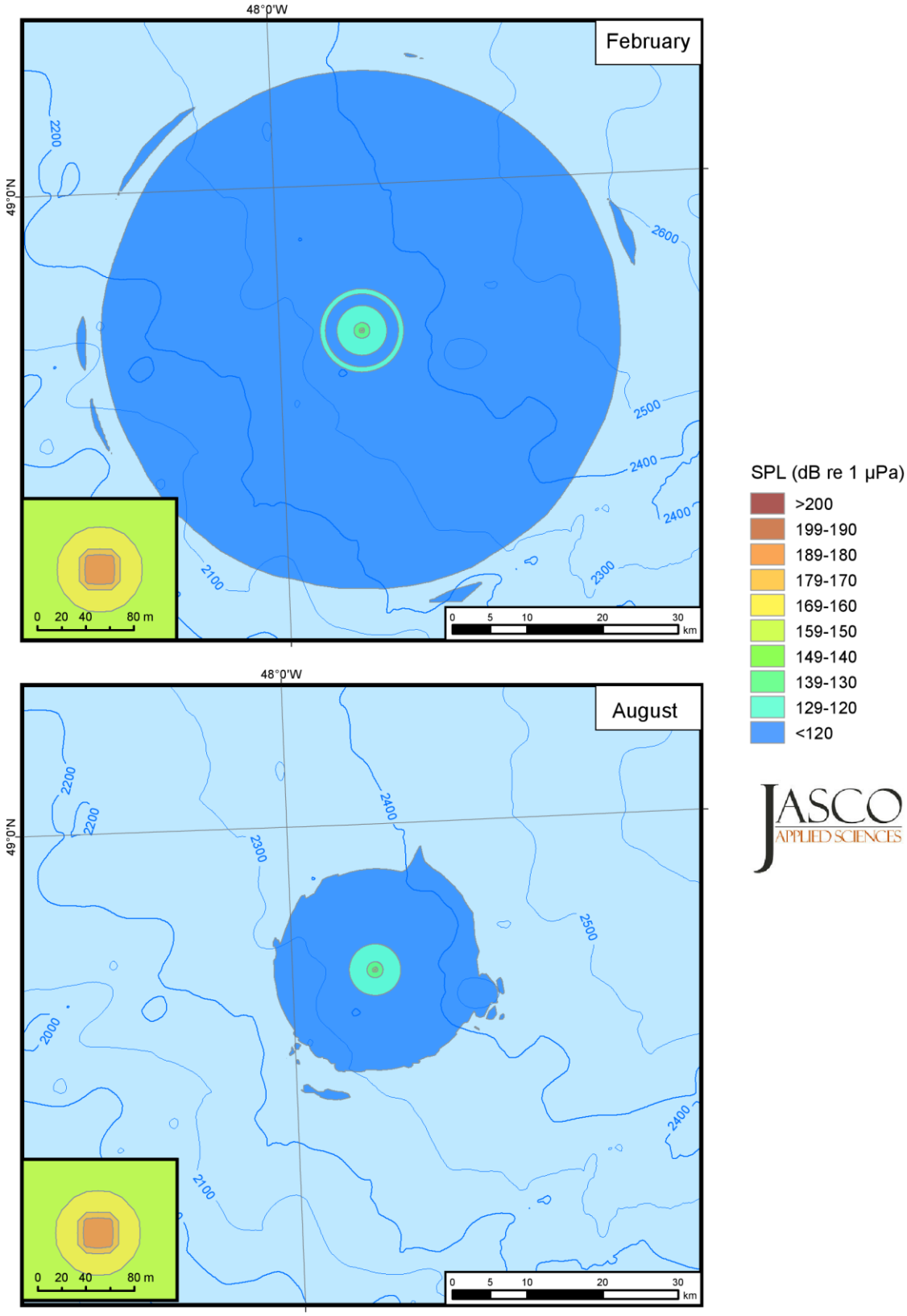


Figure 43. *Site A, representative support vessel (DSV Fu Lai) operations*: Broadband (10–25,000 Hz) maximum-over-depth SPL field for February and August propagation conditions. Blue contours indicate water depth in metres.

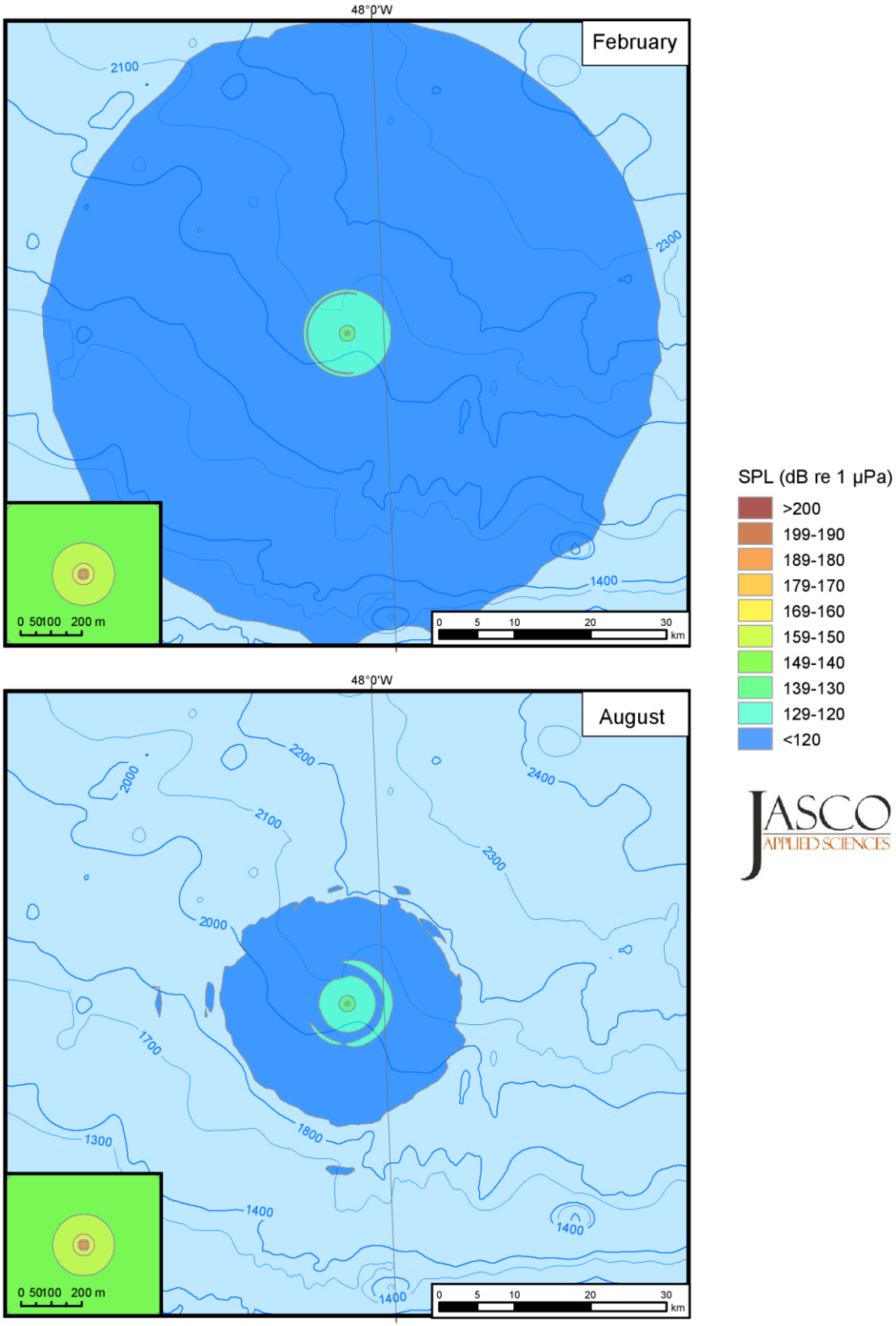


Figure 44. *Site B, representative support vessel (DSV Fu Lai) operations*: Broadband (10–25,000 Hz) maximum-over-depth SPL field for February and August propagation conditions. Blue contours indicate water depth in metres.

5.2.2. Sound Exposure Levels

For the purpose of calculating 24 hour SEL, it was assumed that the vessels were stationary and the source levels did not change with time. So the 24 hour SEL was estimated from the 1-second SEL by adding 49.3 dB, which accounts for the number of seconds in 24 hours—i.e., 86,400 seconds = 24 hours, 10 $\log_{10}$(86,400) = 49.3 dB, and $L_{E,24\mathrm{h}} = L_{E,1\mathrm{s}} + 49.3\ \mathrm{dB}$. The resulting underwater 24 hour SEL fields were sampled such that the received SEL at each point in the horizontal plane was taken to be the maximum value over all modelled depths for that point (see Section 3.2.1). The resultant maximum-over-depth 24 hour SEL fields are presented below in two formats: as tables of maximum distances to specific threshold levels and as contour maps showing the directivity and range to the same threshold levels.

The maximum ranges to the specific TTS- and PTS-onset thresholds were estimated for each marine mammal hearing group using M-weighting functions as defined in NMFS (2018) for non-impulsive noise sources. The calculations were performed for February and August propagation conditions, which represent the range in propagation conditions over the course of a year.

The predicted maximum distances to specific 24 hour SEL marine mammal impact criteria threshold levels were computed from the maximum-over-depth sound fields. Two distances relative to the source are reported for each sound level: (1) $R_{\max}$, the maximum range at which the given threshold level was encountered in the modelled maximum-over-depth sound field, and (2) $R_{95\%}$, the maximum range at which the given threshold level was encountered after excluding 5% of the farthest such points. Tables 14–16 present these results.

Figures 45–50 present contour maps of the predicted maximum distance to these 24 hour SEL threshold levels.

Table 14.*Generic drillship*: Distances (in kilometres from the source) to PTS- and TTS-onset thresholds (NMFS 2018) based on the 24 hour SEL field at each modelled site for February and August propagation conditions.

Marine mammal hearing group	PTS-onset									TTS-onset								
	SEL (dB re 1 µPa²s)	Site A				Site B				SEL (dB re 1 µPa²s)	Site A				Site B			
		February		August		February		August			February		August		February		August	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
NMFS (2018)																		
Low-frequency cetaceans	**199**	0.193	0.190	0.179	0.175	0.193	0.190	0.184	0.180	**179**	5.66	5.58	2.46	2.39	5.23	5.12	2.49	2.42
Mid-frequency cetaceans	**198**	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	**178**	0.216	0.212	0.209	0.202	0.218	0.212	0.209	0.202
High-frequency cetaceans	**173**	0.279	0.272	0.278	0.270	0.283	0.276	0.283	0.276	**153**	5.49	5.35	2.89	2.81	5.07	4.93	3.19	3.11
Phocid pinnipeds (underwater)	**201**	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	**181**	0.553	0.539	0.555	0.541	0.561	0.547	0.556	0.542

Table 15. *Representative drillship (Stena Forth) (95th percentile)*: Distances (in kilometres from the source) to PTS- and TTS-onset thresholds (NMFS 2018) based on the 24 hour SEL field at each modelled site for February and August propagation conditions.

Marine mammal hearing group	PTS-onset									TTS-onset								
	SEL (dB re 1 µPa²s)	Site A				Site B				SEL (dB re 1 µPa²s)	Site A				Site B			
		February		August		February		August			February		August		February		August	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
NMFS (2018)																		
Low-frequency cetaceans	**199**	0.146	0.142	0.139	0.134	0.146	0.142	0.136	0.134	**179**	5.44	5.40	1.96	1.91	4.41	4.35	2.00	1.95
Mid-frequency cetaceans	**198**	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**178**	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
High-frequency cetaceans	**173**	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	**153**	0.166	0.163	0.160	0.155	0.166	0.163	0.158	0.155
Phocid pinnipeds (underwater)	**201**	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	**181**	0.293	0.286	0.276	0.269	0.293	0.286	0.273	0.268

Table 16. *Representative support vessel (DSV Fu Lai) operations:* Distances (in kilometres from the source) to PTS- and TTS-onset thresholds (NMFS 2018) based on the 24 hour SEL field at each modelled site for February and August propagation conditions.

Marine mammal hearing group	PTS-onset									TTS-onset								
	SEL (dB re 1 µPa²s)	Site A				Site B				SEL (dB re 1 µPa²s)	Site A				Site B			
		February		August		February		August			February		August		February		August	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
NMFS (2018)																		
Low-frequency cetaceans	**199**	0.073	0.072	0.073	0.072	0.073	0.072	0.073	0.072	**179**	0.723	0.705	0.779	0.760	0.723	0.704	0.790	0.769
Mid-frequency cetaceans	**198**	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**178**	0.086	0.085	0.086	0.085	0.086	0.085	0.086	0.085
High-frequency cetaceans	**173**	0.114	0.112	0.114	0.112	0.114	0.112	0.114	0.112	**153**	2.10	2.06	1.11	1.08	2.11	2.06	1.13	1.10
Phocid pinnipeds (underwater)	**201**	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	**181**	0.214	0.209	0.204	0.200	0.214	0.210	0.202	0.199

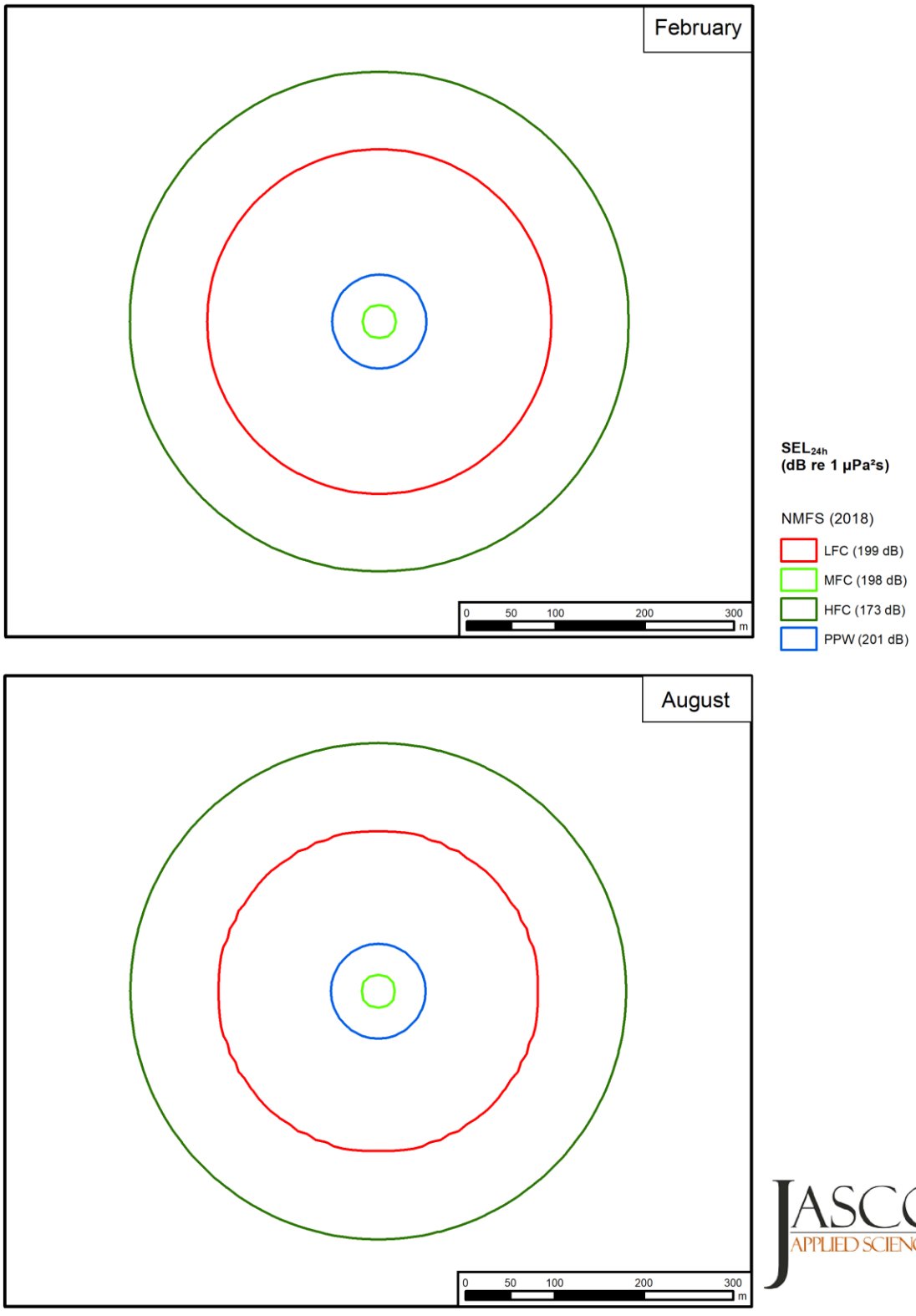


Figure 45. *Site A, Generic drillship*: Broadband (10–25,000 Hz) maximum-over-depth M-weighted SEL_{24h} range to PTS threshold for February and August propagation conditions.

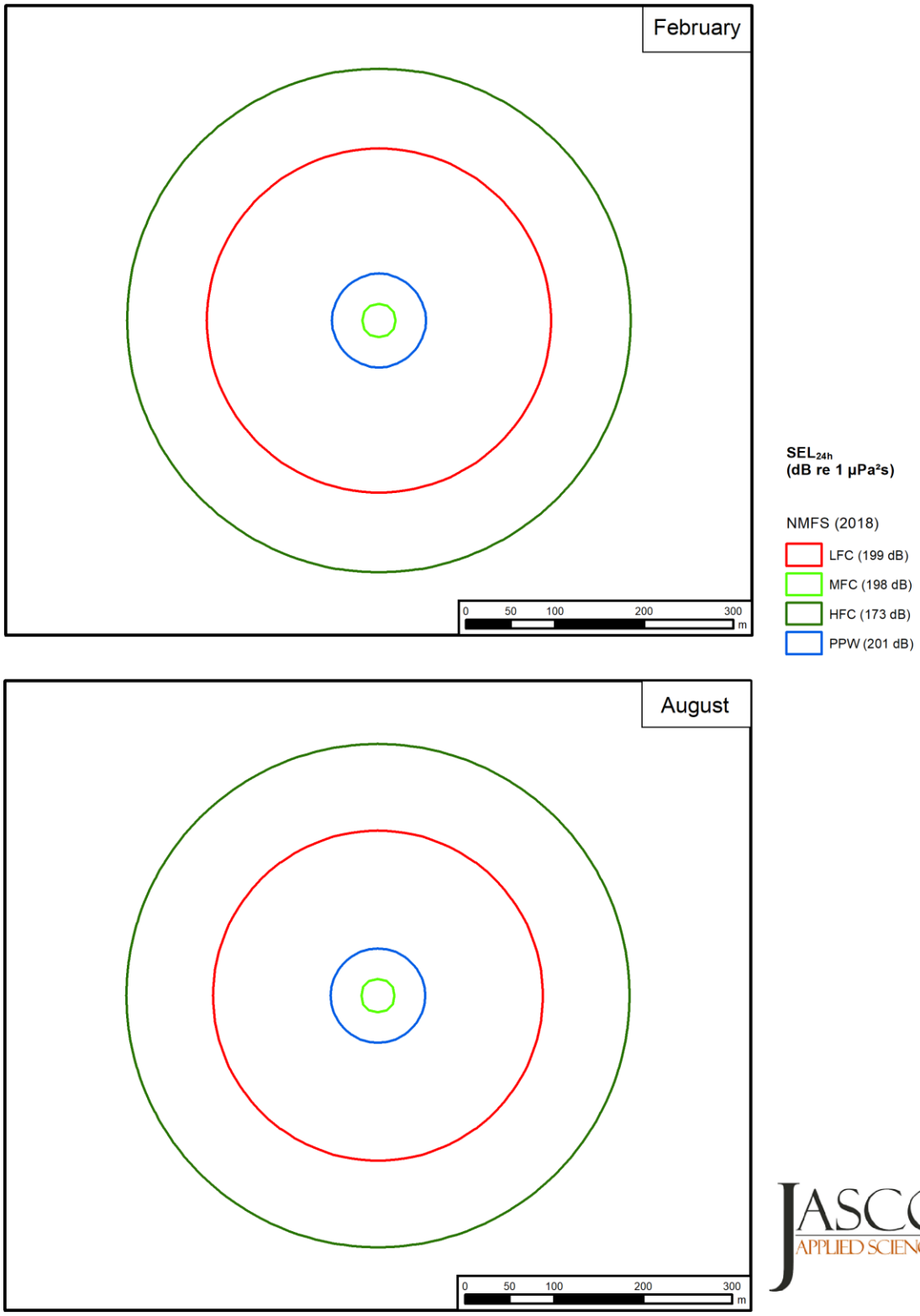


Figure 46. *Site B, Generic drillship*: Broadband (10–25,000 Hz) maximum-over-depth M-weighted SEL_{24h} range to PTS threshold for February and August propagation conditions.

Figure 47. *Site A, representative drillship (Stena Forth) (95th percentile)*: Broadband (10–25,000 Hz) maximum-over-depth M-weighted SEL_{24h} range to PTS threshold for February and August propagation conditions.

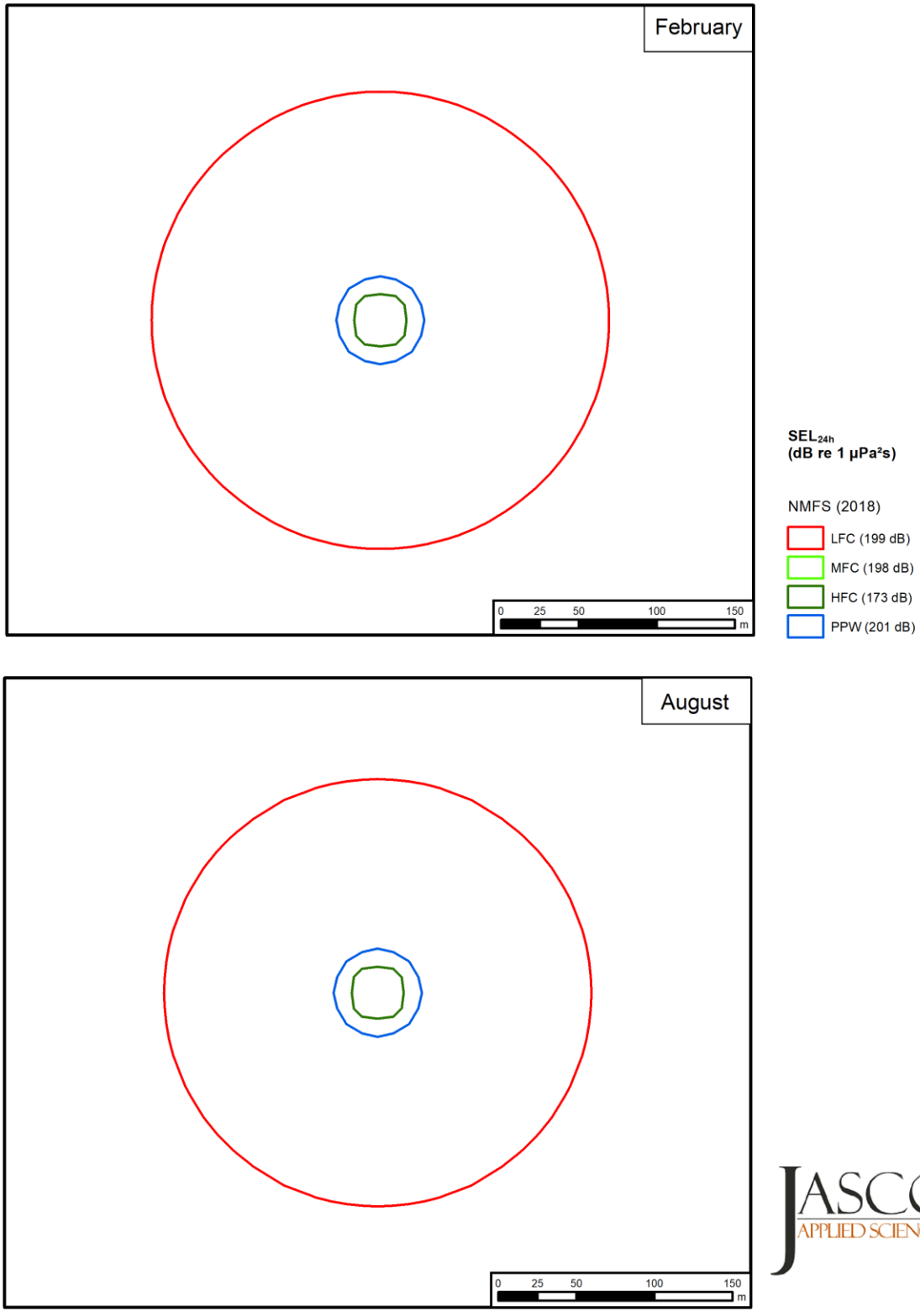


Figure 48. *Site B, representative drillship (Stena Forth) (95th percentile)*: Broadband (10–25,000 Hz) maximum-over-depth M-weighted SEL_{24h} range to PTS threshold for February and August propagation conditions.

Figure 49. *Site A, representative support vessel (DSV Fu Lai) operations*: Broadband (10–25,000 Hz) maximum-over-depth M-weighted SEL_{24h} range to PTS threshold for February and August propagation conditions.

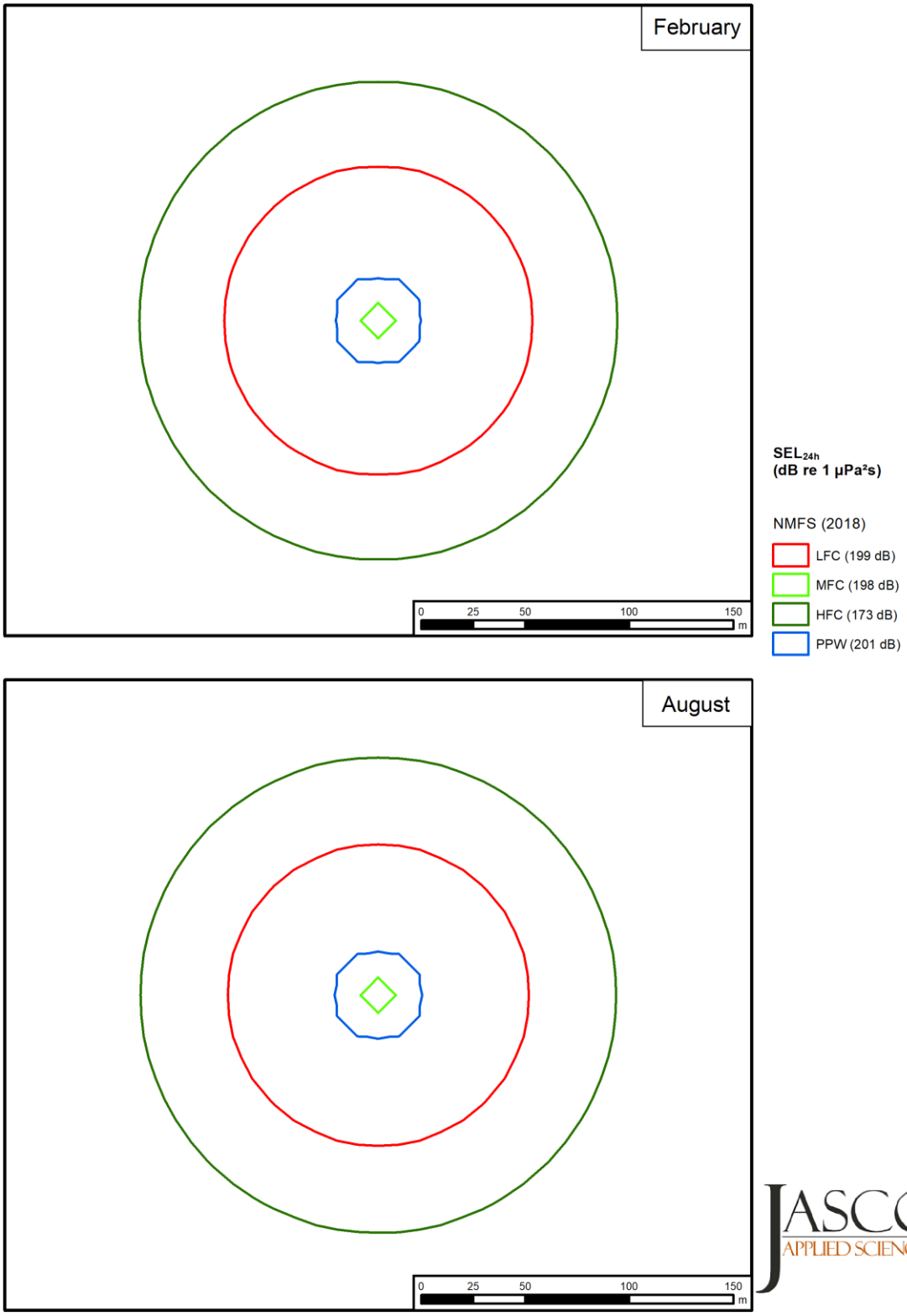


Figure 50. *Site B, representative support vessel (DSV Fu Lai) operations*: Broadband (10–25,000 Hz) maximum-over-depth M-weighted SEL_{24h} range to PTS threshold for February and August propagation conditions.

5.3. Semi-submersible platform

The acoustic field around the semi-submersible drilling platform was modelled at Sites A and B for the propagation conditions of February and August, representing the range in sound propagation conditions over the course of a year. Sound propagation was modelled for the frequency range from 10 to 25,000 Hz along 72 transects (5° regular angular steps) at each site up to a range of 100 km from the source. For the simplicity of the interpretation, each vessel was represented by a point source of acoustic energy at a specific source depth.

5.3.1. Sound Pressure Levels

The underwater sounds radiated by semi-submersible drilling operations are generally non-impulsive (i.e., continuous wave, or CW). For CW sources, SPL and 1-second SEL are numerically equivalent because the integration time for the purpose of the SEL calculations is taken as constant: 1 second. Therefore, the SPL field for continuous sources can be estimated using a propagation loss modelling approach (Section 3.2.1).

The underwater sound fields predicted by the source level and propagation loss models were sampled such that the received sound level at each point in the horizontal plane was taken to be the maximum value over all modelled depths for that point (see Section 3.2.1). The resultant "maximum-over-depth" SPL fields are presented below in two formats: as tables of distances to sound level thresholds and as contour maps showing the directivity and range to various sound levels.

The predicted distances to specific SPL were computed from the maximum-over-depth sound fields. Two distances relative to the source are reported for each sound level: (1) R_{max}, the maximum range at which the given sound level was encountered in the modelled maximum-over-depth sound field, and (2) $R_{95\%}$, the maximum range at which the given sound level was encountered after excluding 5% of the farthest such points.

Table 17. *Representative semi-submersible drilling platform (Seadrill West Sirius)*: Maximum (R_{max}, km) and 95% ($R_{95\%}$, km) horizontal distances from the source to modelled maximum-over-depth SPL thresholds at each modelled site for February and August propagation conditions.

SPL (dB re 1 µPa)	Site A				Site B			
	February		August		February		August	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
210	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
200	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
190	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
180	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
170	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
160	0.100	0.100	0.099	0.095	0.102	0.100	0.099	0.099
150	0.324	0.316	0.328	0.320	0.325	0.316	0.349	0.340
140	1.10	1.07	1.40	1.37	1.12	1.08	1.42	1.38
130	11.9	11.6	4.36	4.24	16.0	15.4	4.21	4.06
120	>100	97.4	36.2	35.7	>100.0	97.4	36.2	34.5

Table 17 presents the distances to the SPL values from 210 to 120 dB re 1 µPa, in 10 dB steps, for the February and August propagation conditions at both sites. Figures 51–56 show vertical slice plots of the SPL field along the 90° and 225° transects from Site A (for February and August, respectively). These transects show the greatest range of variation, with the other azimuth angles (not shown) representing intermediate cases. One shorter range and shallower depth version is also included in the set—for the short range plots, all the azimuth angles generate essentially the same results. The Site B results were essentially the same as Site A. Figures 57–58 present the contour maps of the estimated maximum-over-depth SPL fields for Sites A and B.

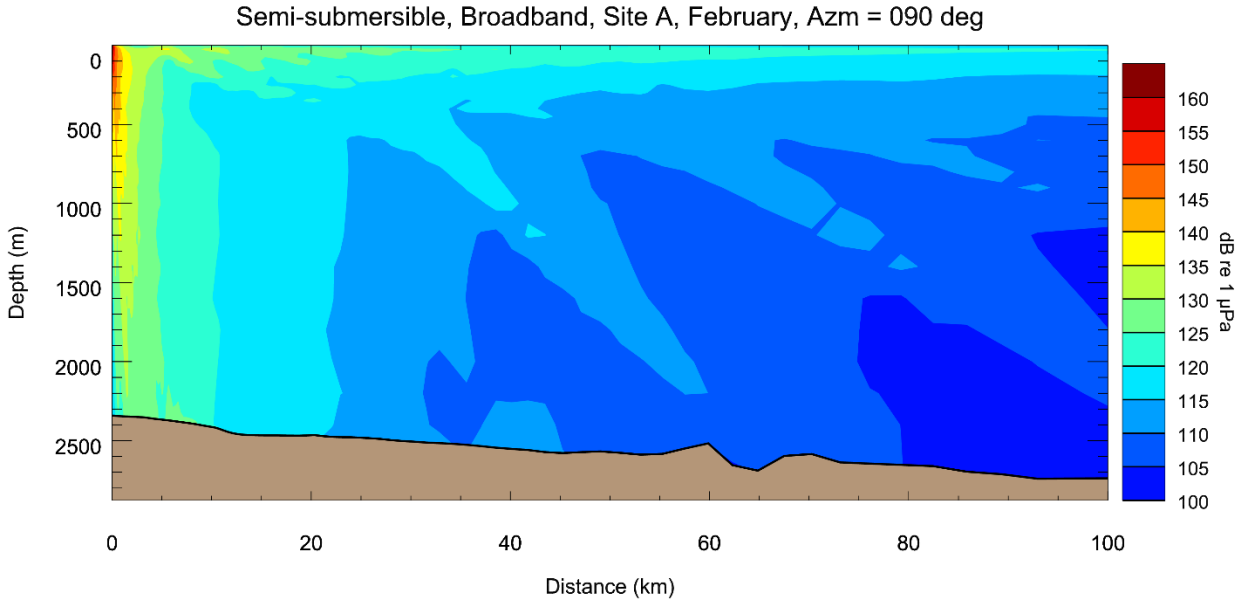


Figure 51. *Site A, representative semi-submersible drilling platform (Seadrill West Sirius)*: Broadband (10–25,000 Hz) vertical SPL field for February along 90° transect.

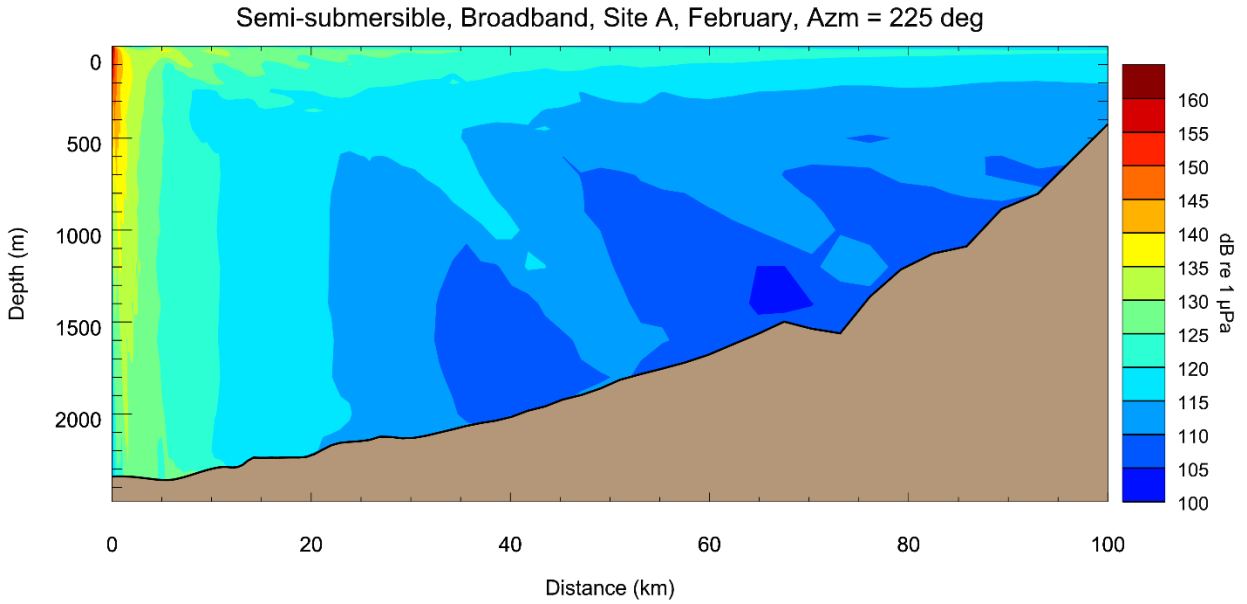


Figure 52. *Site A, representative semi-submersible drilling platform (Seadrill West Sirius)*: Broadband (10–25,000 Hz) vertical SPL field for February along 225° transect.

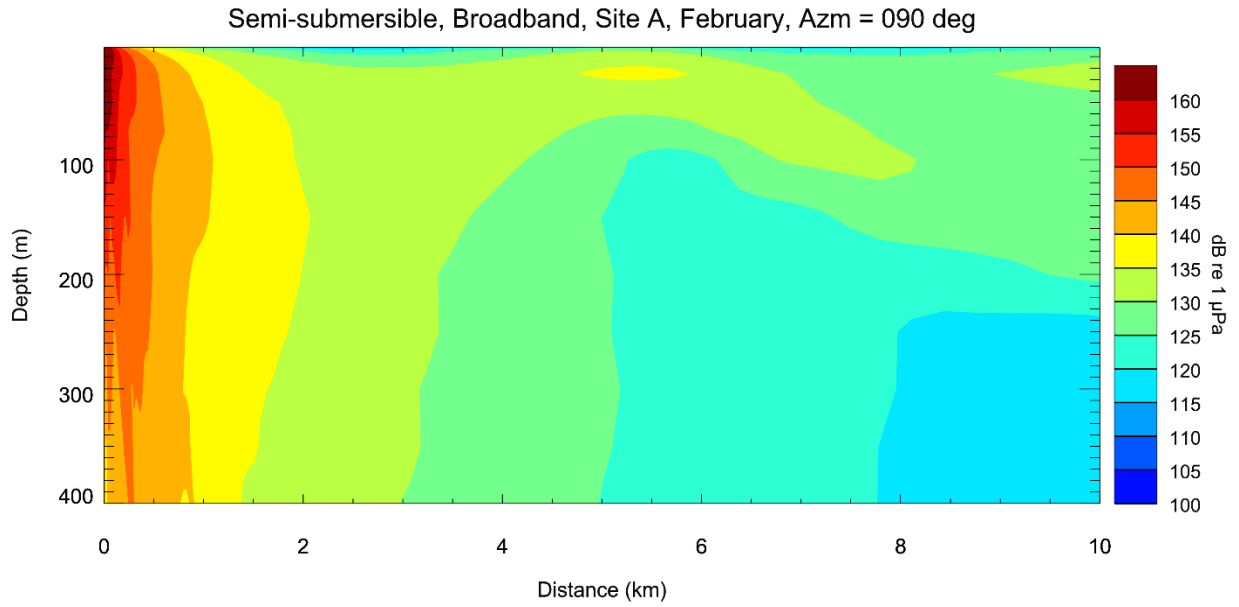


Figure 53. *Site A, representative semi-submersible drilling platform (Seadrill West Sirius)*: Broadband (10–25,000 Hz) vertical SPL field for February along 90° transect, zoomed in on the shorter range and shallower depth.

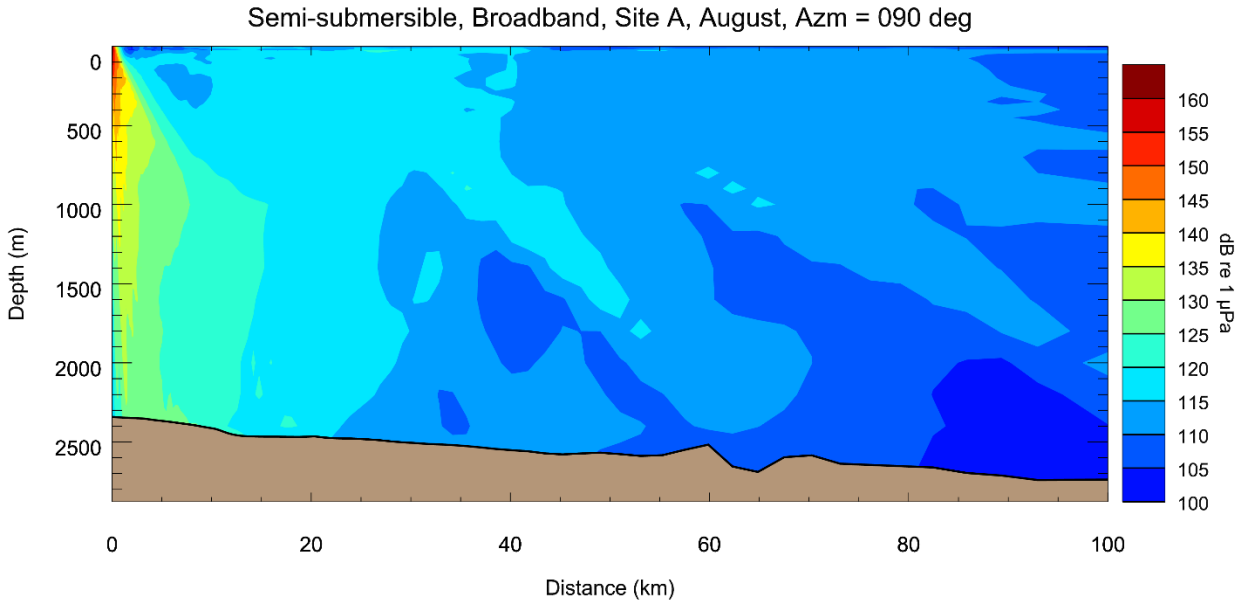


Figure 54. *Site A, representative semi-submersible drilling platform (Seadrill West Sirius)*: Broadband (10–25,000 Hz) vertical SPL field for August along 90° transect.

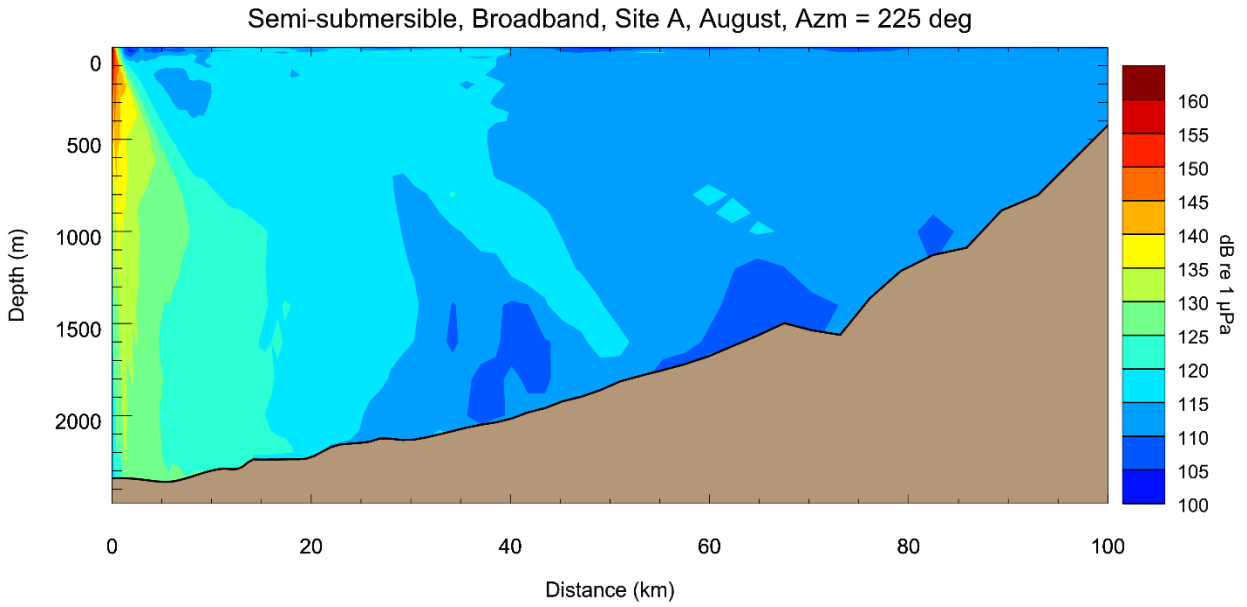


Figure 55. *Site A, representative semi-submersible drilling platform (Seadrill West Sirius)*: Broadband (10–25,000 Hz) vertical SPL field for August along 225° transect.

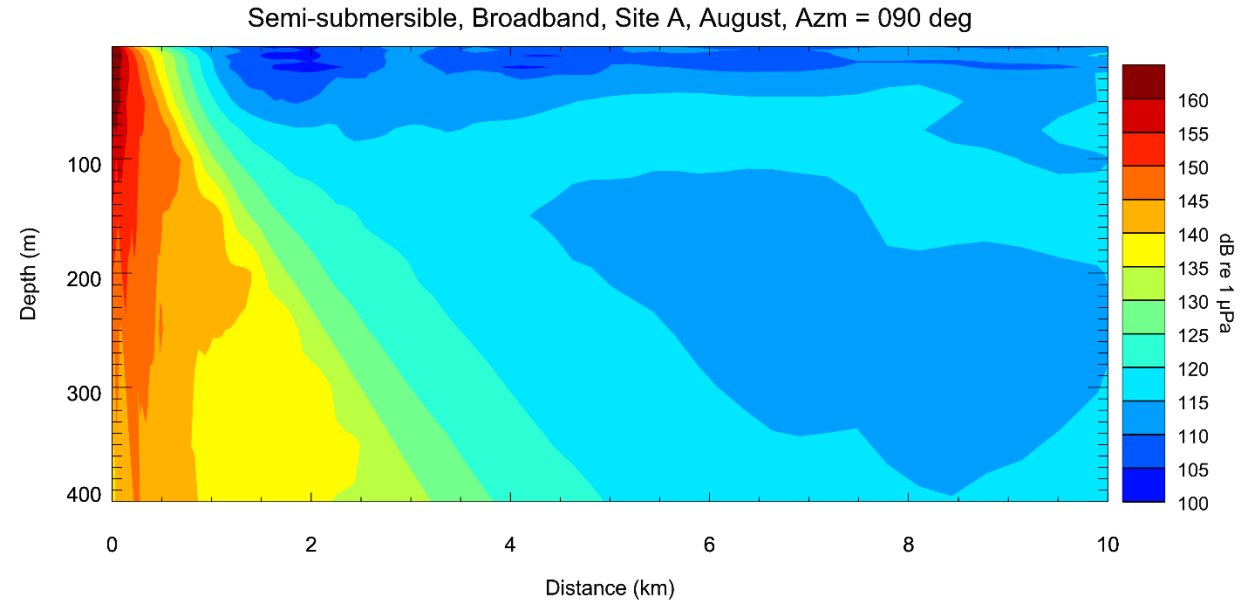


Figure 56. *Site A, representative semi-submersible drilling platform (Seadrill West Sirius)*: Broadband (10–25,000 Hz) vertical SPL field for August along 90° transect, zoomed in on the shorter range and shallower depth.

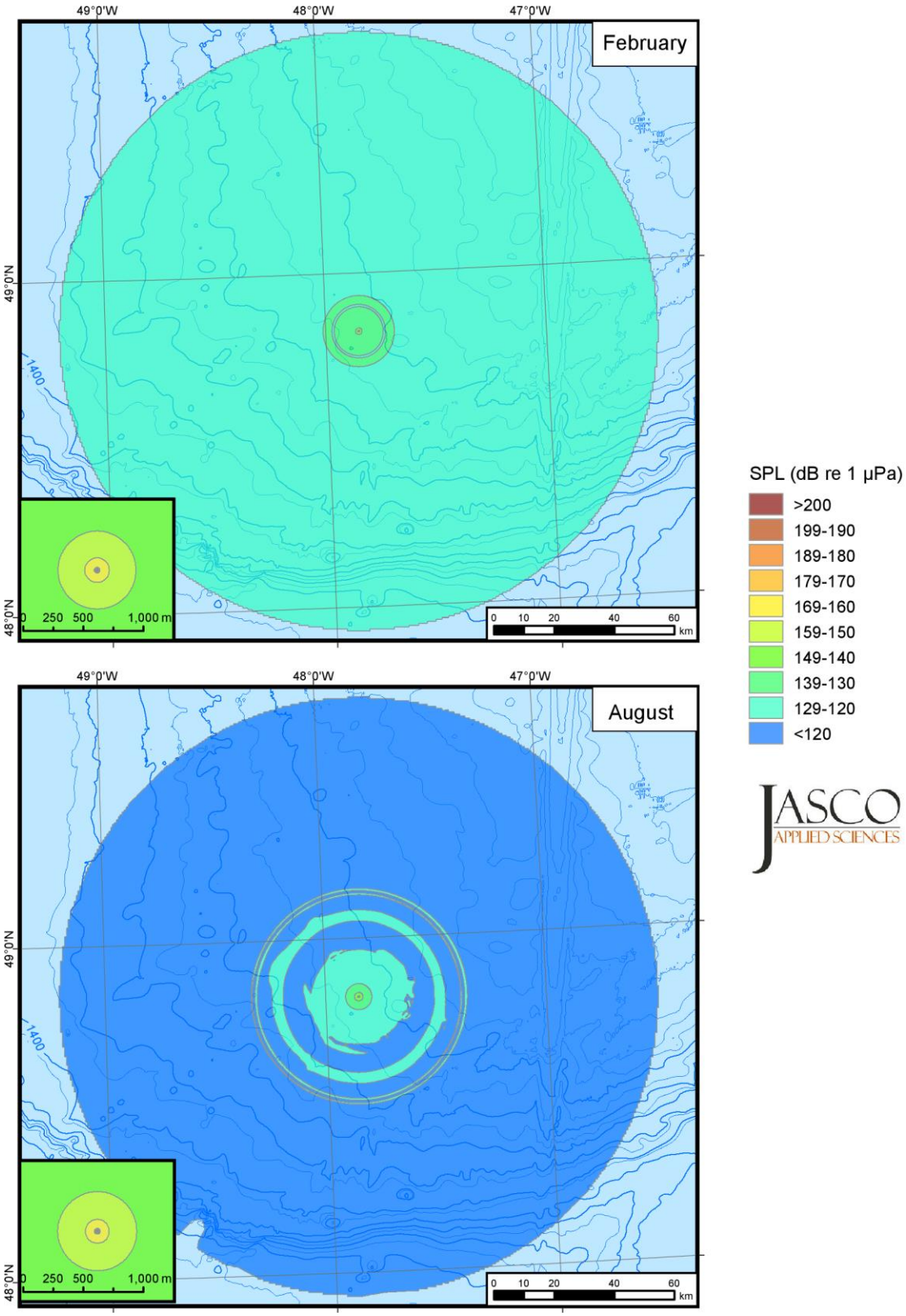


Figure 57. *Site A, representative semi-submersible drilling platform (Seadrill West Sirius)*: Broadband (10–25,000 Hz) maximum-over-depth SPL field for February and August propagation conditions. Blue contours indicate water depth in metres.

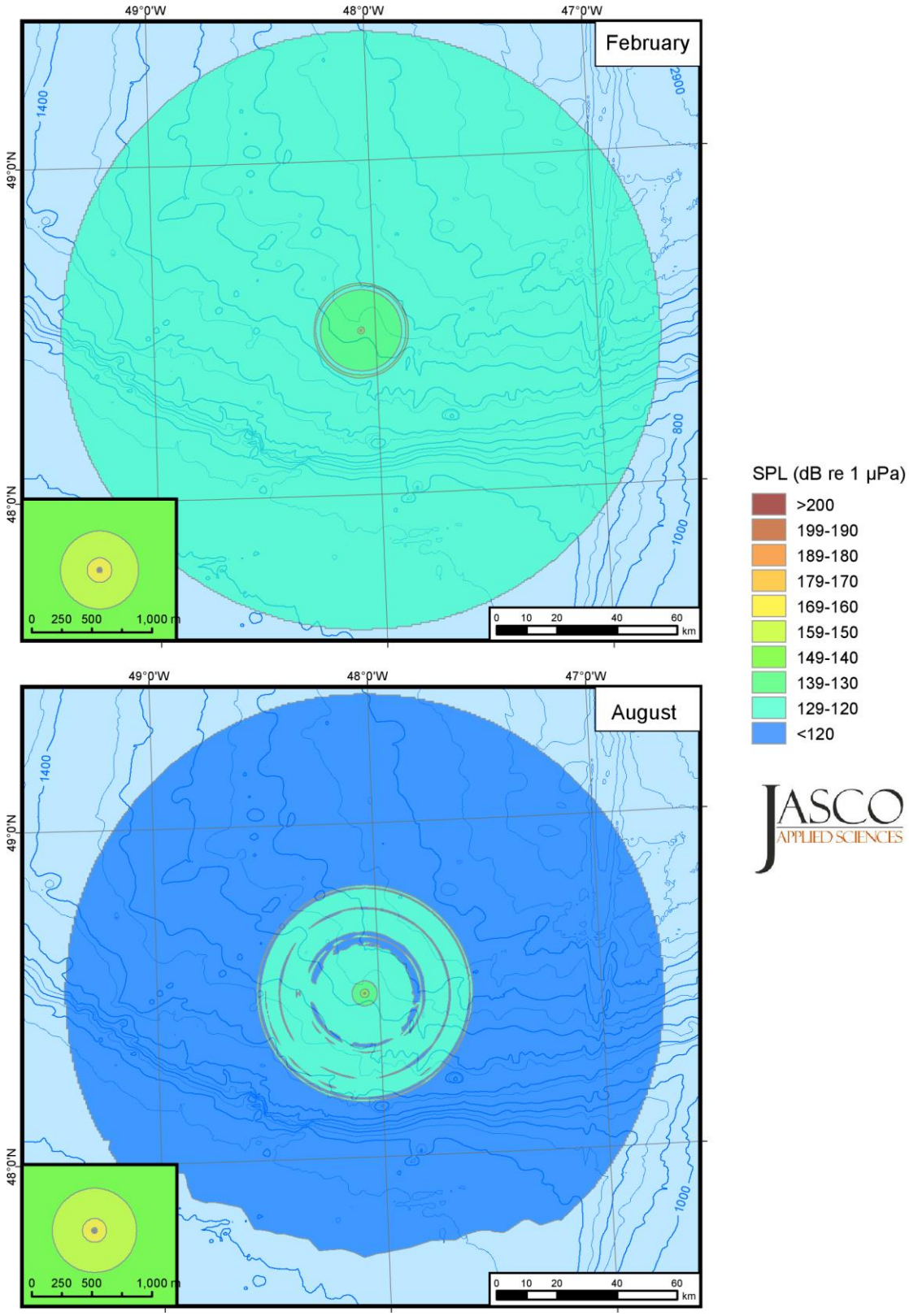


Figure 58. *Site B, representative semi-submersible drilling platform (Seadrill West Sirius)*: Broadband (10–25,000 Hz) maximum-over-depth SPL field for February and August propagation conditions. Blue contours indicate water depth in metres.

5.3.2. Sound Exposure Levels

For the purpose of calculating 24 hour SEL, it was assumed that the vessels were stationary and the source levels did not change with time. So the 24 hour SEL was estimated from the 1-second SEL by adding 49.3 dB, which accounts for the number of seconds in 24 hours—i.e., 86,400 seconds = 24 hours, 10 $\log_{10}$(86,400) = 49.3 dB, and $L_{E,24\mathrm{h}} = L_{E,1\mathrm{s}} + 49.3\ \mathrm{dB}$. The resulting underwater 24 hour SEL fields were sampled such that the received SEL at each point in the horizontal plane was taken to be the maximum value over all modelled depths for that point (see Section 3.2.1). The resultant maximum-over-depth 24 hour SEL fields are presented below in two formats: as a table of maximum distances to specific threshold levels (Table 18) and as contour maps showing the directivity and range to the same threshold levels (Figures 59–60).

Table 18. *Representative semi-submersible drilling platform (Seadrill West Sirius):* Distances (in kilometres from the source) to PTS- and TTS-onset thresholds (2018) based on the 24 hour SEL field at each modelled site for February and August propagation conditions.

Marine mammal hearing group	PTS-onset								
	SEL (dB re 1 µPa²s)	Site A				Site B			
		February		August		February		August	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
NMFS (2018)									
Low-frequency cetaceans	**199**	0.238	0.232	0.210	0.204	0.238	0.232	0.214	0.209
Mid-frequency cetaceans	**198**	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
High-frequency cetaceans	**173**	0.166	0.163	0.155	0.151	0.166	0.163	0.153	0.150
Phocid pinnipeds (underwater)	**201**	0.050	0.050	0.045	0.045	0.051	0.051	0.045	0.045
Marine mammal hearing group	**TTS-onset**								
	SEL (dB re 1 µPa²s)	**Site A**				**Site B**			
		February		**August**		**February**		**August**	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
NMFS (2018)									
Low-frequency cetaceans	**179**	10.8	10.6	3.64	3.54	9.12	8.88	3.32	3.23
Mid-frequency cetaceans	**178**	0.142	0.139	0.142	0.139	0.141	0.139	0.136	0.134
High-frequency cetaceans	**153**	5.24	5.20	2.29	2.23	5.03	3.01	2.63	2.57
Phocid pinnipeds (underwater)	**181**	0.636	0.620	1.04	1.02	0.644	0.626	1.06	1.04

The maximum ranges to the specific TTS- and PTS-onset thresholds were estimated for each marine mammal hearing group using M-weighting functions as defined in NMFS (2018) for non-impulsive noise sources. The calculations were performed for February and August propagation conditions, which represent the range in propagation conditions over the course of a year.

The predicted maximum distances to specific 24-hour SEL marine mammal impact criteria threshold levels were computed from the maximum-over-depth sound fields. Two distances relative to the source are reported for each sound level: (1) R_{max}, the maximum range at which the given threshold level was encountered in the modelled maximum-over-depth sound field, and (2) $R_{95\%}$, the maximum range at which the given threshold level was encountered after excluding 5% of the farthest such points. Table 18

presents these results are presented in. Figures 59–60 present contour maps of the predicted maximum distance to these 24 hour SEL threshold levels.

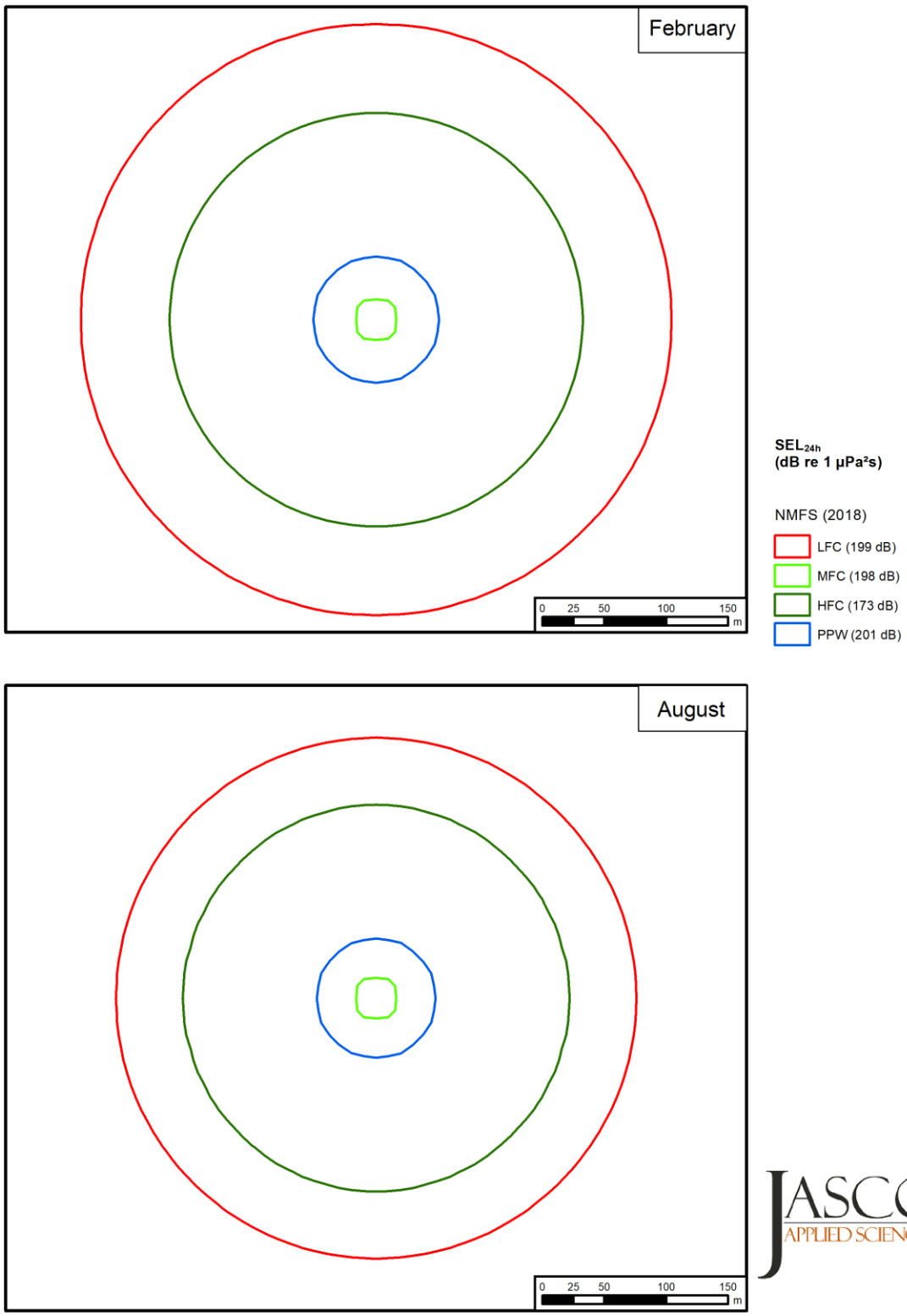


Figure 59. *Site A, representative semi-submersible drilling platform (Seadrill West Sirius)*: Broadband (10–25,000 Hz) maximum-over-depth M-weighted SEL_{24h} range to PTS threshold for February and August propagation conditions.

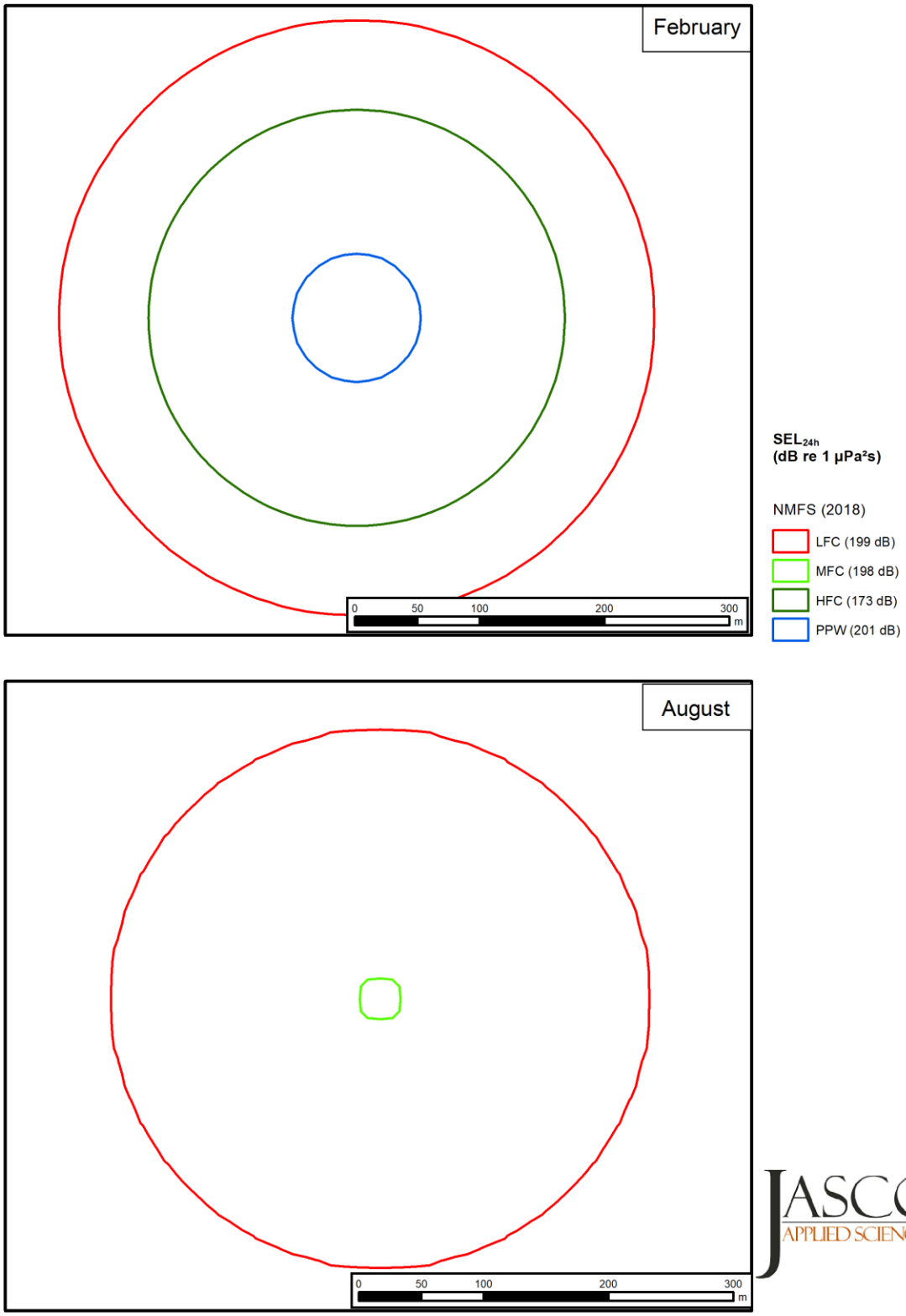


Figure 60. *Site B, representative semi-submersible drilling platform (Seadrill West Sirius)*: Broadband (10–25,000 Hz) maximum-over-depth M-weighted SEL_{24h} range to PTS threshold for February and August propagation conditions.

6. Discussion and Conclusion

In this study, JASCO reviewed sound source parameters representative of the BHP Orphan Basin Exploration Drilling Project. The acoustic environment was compared with related studies near the project area. Source level (SL) spectra were modelled on a 1/3-octave-band basis. Propagation loss was modelled for two seasonal extremes (winter and summer) at two sites in the project area. The maximum received levels over depth, in the SPL and SEL metrics, were quantified. The SEL threshold distances for four marine mammal hearing groups were estimated. This information was compared to the parameters presented in three studies with similar sound source and environmental parameters: the Scotian Basin Exploration Drilling Project (Scotian Basin Project; Zykov 2016), the Nexen Energy ULC Flemish Pass Exploration Drilling Project (Flemish Pass Project; Matthews et al. 2017), and the BP Orphan Basin Exploration Drilling Project (Matthews et al. 2018). Modelled results in these studies help provide a preliminary assessment of sound propagation features in the Orphan Basin. JASCO also identified contributors to the ambient soundscape in the project area. These results help to anticipate the relative contribution of the project activities to the soundscape.

The broadband source levels and the estimated source level spectra associated with the project activities were based on modelling, analysis, and a literature review previously conducted by JASCO. The results in this report are appropriate for typical operational specifications for each activity. The accurate assessment of source levels for this project will depend, however, on the particulars of the equipment and specific planned activities.

Because of the proximity of the sites, the acoustic environment of the BP Orphan Basin Project is most similar to that in the present project. Based on the similarity in acoustic environment, some sound propagation features in the present project area were deducted from these three comparable modelling projects. For example, the sound from the project activities that reaches the continental shelf, to the west and south of the project area, will rapidly attenuate between the 200 and 50 m isobaths. Other bathymetric features are expected to have a minimal influence on sound propagation. Seasonal variations in the sound speed profile will lead to variation in the sound propagation. Longer distances to sound level isopleths are expected in winter than in summer.

The underwater acoustic fields were modelled for two classes of sources: a seismic (VSP) airgun array source, which is impulsive, and four types of vessel sources, which are non-impulsive (i.e., continuous). The propagation conditions were modelled for two months (February and August), which best represented the range in sound propagation conditions over the course of a year. At both sites, the February sound speed profile features a half-channel upward-refracting regime that traps some acoustic energy; however, the moderate velocity gradient still allows a substantial amount of the acoustic energy to escape towards the bottom. The sound speed profile typical for August at each site features a higher sound speed near the surface, creating a weak sound channel with an axis around 50 m in depth, which allows some acoustic energy to be trapped around this depth.

The propagation of sound along different azimuths depends on both the directivity of the source and the topography of the ocean bottom. The topography also determines the spread of the acoustic energy in the vertical dimension. As the water depth increases, the acoustic wave has more space to refract upward without hitting the bottom and losing energy at the bottom interface. As such the propagation loss decreases compared with a constant water depth. Two effects occur for the propagation azimuths (bearings) that decrease water depth, which here are generally to the south and to the west towards the shelf. The decreasing water depth concentrates the acoustic energy within a narrower waveguide, which increases the sound levels. At the same time, the acoustic wave interacts with the bottom more often, losing energy into the sediment. The latter effect prevails, and these propagation azimuths with decreasing water depths have higher propagation losses compared with a constant water depth.

The modelled acoustic fields were compared against various marine mammal impact criteria defined in terms of peak pressure and 24 hour SEL. For all sources, the ranges to the acoustic thresholds defined in terms of peak pressure were never greater than 0.28 km and the distances to the peak pressure thresholds were all less than 0.06 km. For all the vessel and MODU sources, the peak pressure was well under the thresholds for TTS and PTS onset at less than 15 m from the source. It should be noted that the peak pressure signal metric is calculated based on the un-weighted broadband signal, i.e., the

hearing frequency band of specific marine mammals is not accounted for, and M-weighting functions were not applied in this case.

For the distances to the 24 hour SEL impact criteria, the longest distances were from the airgun array and the generic drillship. For the thresholds for PTS onset, the largest distance was 0.59 km, which was for the low-frequency cetacean NFMS (2018) criteria for the airgun array at Site B in August. This scenario also had the longest distance to the threshold for TTS onset (6.2 km). However, almost as far that longest distance, this same scenario (airgun array, Site B, August) yielded a maximum distance to NFMS criteria (for PTS and TTS onset for phocid pinnipeds) of 0.07 and 0.4 km, respectively.

Most of the threshold distances for the vessel and MODU sources were much shorter than those for the VSP source, although the generic drillship yielded a maximum PTS-onset distance of 0.28 km for the high-frequency cetacean NMFS (2018) criteria at Site A in February, and a corresponding maximum TTS-onset distance of 5.5 km. In all modelled scenarios, the maximum PTS onset distance never exceeded 0.60 km. The details can be found in Tables 10–18.

The seasonal differences in sound propagation (Sections 4.1.3 and 4.5.1.3), based on the overall depth gradient structure in the selected SSPs and the azimuthal propagation differences (Section 4.5.1.1) were fairly evident in the SPL coverage maps for the vessels and MODUs (Figures 39–44 and 57–58). They were not apparent in the SPL coverage maps for the VSP (Figures 33–34).

For the question of azimuthal dependence, the VSP was only modelled to 50 km, which is where the azimuthal dependencies start, while the vessel and MODU were modelled to 100 km (Table 5). The 50 km modelling range for the VSP impulsive source was adequate to reach the relevant PTS and TTS levels. Modelling to farther ranges would require longer computer runs of the more resource-intensive FWRAM model; whereas the less resource-intensive MONM model used for the vessel and MODU CW sources could estimate to 100 km without much additional computational effort.

The reason for the lack of apparent seasonal variations in the VSP results is because the dominant frequency components of the broadband pulse are in the lower end of the frequency band, well below 100 Hz, as can be seen in Figure 16b, whereas the SL spectra for the vessels and MODU have dominant frequencies around 100–400 Hz (Figures 21 and 25). Therefore, the wavelengths of the strongest components of the sound were quite different (very roughly 100 versus 10 m, respectively). The longer wavelengths were much less impacted by the details of the top 50 m of the SSP, where the main seasonal differences occur. They were less sensitive to the upper level smaller scale SSP features, as compared to the shorter wavelength sounds, which respond to them quite strongly.

The seasonal difference in the results for the lowest reported SPL of 120 dB re 1 µPa in the case of the semi-submersible is the most apparent, being over 100 km in February, but only about 36 km in August (see Table 17 and Figures 57–58). This long propagation distance was not reported in the previous studies for the region (Scotian Shelf, Flemish Cap, and BP Orphan Basin Projects). The reason that the semi-submersible thruster sounds were modelled at be as high as an SPL of 120 dB re 1 µPa at 100 km from the source in February is mainly because of the strong surface duct (or half-channel) propagation conditions that are present at that time. The previous studies did not consider the February propagation conditions. A smaller effect is due to the deeper source depth of the semi-submersible thrusters, which were modelled at a depth of 25 m, compared to the other sources in the present study, which were modelled at shallower depths.

The two-year-long data set collected for ESRF in 2015–2017 provided information on the ambient soundscape in the Newfoundland Orphan Basin Exploration Drilling Program Area. In general, the ambient sound levels are higher in winter than summer due to fin whale vocalizations, higher winds, and higher sea states. Within distances on the order of 10–40 km from oil and gas platforms, anthropogenic sounds are the dominant sources in the 45–2250 Hz band. The lower but non-negligible sound levels from oil and gas platforms can be measured at distances greater than 40 km. When present, seismic sources can increase the mean monthly sound pressure level by 20 dB or more over large areas.

The estimated broadband source levels associated with the project activities (SEL 218.1 dB re 1 µPa^2·s m for the VSP array, SPL 196.7 dB re 1 µPa m for the semi-submersible and generic drillship, SPL 189.7 dB re 1 µPa m for the *Stena Forth* drillship, and SPL 178 dB re 1 µPa m for the support vessels) were higher than the ambient levels measured in 2015–2017 (mean broadband SPL of 90.6–157.6 dB re

1 µPa at ESRF station 19). Therefore, these activities are expected to contribute to the soundscape in the project area during the course of the activities. VSP operations are expected to raise the ambient sound levels to a lesser extent than seismic surveys because of their shorter operational timeframe and lower source levels. The MODU and associated vessel traffic is like to contribute to the soundscape over a larger area and for longer periods than the VSP operations. The relative contribution to the ambient soundscape will depend on the specifications of the equipment and the project activities, as well as the other simultaneous anthropogenic contributors in the region. For example, if multiple seismic surveys are present during MODU operations, the surveys would be larger contributors to the soundscape than the MODU.

6.1. Depth Dependence

In this section we discuss the received level versus depth, as opposed to the maximum received level over depth, as was discussed above. Figures 35 and 36 show a vertical slice of the PK and SPL sound field for the VSP airgun array source at Site A, for February and August respectively, along a transect line that is halfway between broadside and endfire. These plots do not show much difference between the two SSPs, except in the shallowest depths, because the differences in the SSPs themselves are confined to the shallower depths. Although not plotted separately, there would also be very little variation in such plots along transects of different azimuths, or between the two modelled sites. The VSP array is designed to direct most of its power downward toward the seafloor. This is apparent in the large downward-oriented main-lobe in these plots. These plots portray the variation with depth over the first 10 km in range from the source, to highlight the strongest part of the field. At farther ranges, the maximum-over-depth levels (see the coverage maps in Section 4) generally occur in the top 100 m of the water column, due to the presence of a surface duct (February) or sound channel (August) that favours longer-range propagation at those depths.

The other sources modelled in this report (apart from the VSP array) have omnidirectional beampatterns, where the sound is initially of equal strength in all directions (horizontal azimuth angles and vertical elevation/depression angles), also called isotropic. However, the interaction of the sound with the environment (the SSP gradients, surface reflections, and bottom bathymetric variations) will cause complex variations of the received level in depth and range. This SPL variation in depth and range is illustrated in Figures 51–56, for the semi-submersible source—the other omnidirectional sources would show essentially the same patterns, although the levels for the *Stena Forth* drillship would be uniformly 7 dB lower, and the *Fu Lai* support vessel 19 dB lower. The biggest difference is the seasonal pattern, where the February SSP allows much higher levels of sound to remain in the upper depth layers, due to the surface duct, while in August, the sound channel is able to retain only a low level of sound (around SPL of 120 dB re 1 µPa) to longer ranges.

Detailed tables of the maximum received level in progressive range bins away from each source, and the depth where the maximum occurs, are presented in Appendix D.

Glossary

1/3-octave
One third of an octave. Note: A one-third octave is approximately equal to one decidecade (1/3 oct ≈ 1.003 ddec; ISO 2017).

1/3-octave-band
Frequency band whose bandwidth is one one-third octave. Note: The bandwidth of a one-third octave-band increases with increasing centre frequency.

absorption
The reduction of acoustic pressure amplitude due to acoustic particle motion energy converting to heat in the propagation medium.

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 frequency weighting (auditory weighting function, frequency-weighting function)
The process of band-pass filtering sounds to reduce the importance of inaudible or less-audible frequencies for individual species or groups of species of aquatic mammals (ISO 2017). One example is M-weighting introduced by Southall et al. (2007) to describe “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”.

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.

azimuthing
With reference to thruster propulsion, it is the ability to operationally direct the force of the thruster in a variable azimuthal direction.

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 airguns, 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 kilopascals, which is approximately equal to the atmospheric pressure on Earth at sea level. 1 bar is equal to 10^5 Pa or 10^{11} µPa.

BELLHOP
A beam tracing model for predicting acoustic pressure fields in ocean environments (Porter and Liu 1994).

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 noise.

cetacean
Any animal in the order Cetacea. These are aquatic, mostly marine mammals and include whales, dolphins, and porpoises.

climatology
Historical data pertaining to environmental conditions that have been measured over a long time span and from which statistics have been derived, such as averages and standard deviations.

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 (or simply pressure 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.

decade
Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 2006).

decidecade
One tenth of a decade (ISO 2017). Note: An alternative name for decidecade (symbol ddec) is “one-tenth decade”. A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a “one-third octave”.

decidecade band
Frequency band whose bandwidth is one decidecade. Note: The bandwidth of a decidecade band increases with increasing centre frequency.

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.

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 Fourier transform (FFT)
A computationally efficiently algorithm for computing the discrete Fourier transform.

Fourier transform (or Fourier synthesis)
A mathematical technique which, although it has varied applications, is referenced in the context of this report as a method used in the process of deriving a spectrum estimate from time-series data (or the reverse process, termed the inverse 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.

hearing group
Groups of marine mammal species with similar hearing ranges. Commonly defined functional hearing groups include low-, mid-, and high-frequency cetaceans, pinnipeds in water, and pinnipeds in air.

geoacoustic
Relating to the acoustic properties of the seabed.

hearing threshold
The sound pressure level for any frequency of the hearing group 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 (HF) cetacean
The functional cetacean hearing group that represents those odontocetes (toothed whales) specialized for hearing high frequencies.

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 airguns and impact pile driving.

isobath
A line on a map representing a constant-depth path on the ocean floor.

isopleth
A line on a map connecting points having equal incidence of a specified meteorological or oceanographic feature; in this report, usually a constant maximum-over-depth received level (RL) of sound from one specific source, either of the SPL or SEL metric.

knots
Nautical miles per hour.

linear scale
A scaling method for graphically portraying numerical information such that uniform steps in spacing portray successive addition by a given offset. For example, a linear scale will portray intervals between 10, 20, 30, 40, etc. with a uniform spacing. Contrast with a logarithmic scale.

logarithm
Mathematical term for the value of the exponent (a) relative to a given base (b) that will equal the subject value (c) in the expressions $a = \log_b(c)$ and $c = b^a$.

logarithmic scale
A scaling method for graphically portraying numerical information such that uniform steps in spacing portray successive multiplication by a given factor. For example, a logarithmic scale will portray intervals between 1, 10, 100, 1000, etc. with a uniform spacing. Contrast with a linear scale.

low-frequency (LF) cetacean
The functional cetacean hearing group that represents mysticetes (baleen whales) specialized for hearing low frequencies.

micropascal
Unit of pressure equal to one millionth of a pascal.

mid-frequency (MF) cetacean
The functional cetacean hearing group that represents those odontocetes (toothed whales) specialized for mid-frequency hearing.

M-weighting
An example of auditory frequency weighting (q.v.). See marine mammal auditory weighting functions, Section B.2.2.

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 they use sound for communication. Members of this group include rorquals (Balaenopteridae), right whales (Balaenidae), and grey whales (*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 skulls of toothed whales 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.

otariid pinnipeds in water (OPW)
The functional pinniped hearing group that represents eared seals under water.

parabolic equation method
A computationally efficient solution to the acoustic wave equation that is used to model propagation loss. The parabolic equation approximation omits effects of back-scattered sound, simplifying the computation

of propagation loss. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

particle velocity (particle motion)
The physical speed of a particle in a material moving back and forth in the direction of the pressure wave. Unit: metre per second (m/s). Symbol: *v*.

peak pressure level (PK)
The maximum instantaneous sound pressure level, in a stated frequency band, within a stated period. Also called zero-to-peak pressure level. Unit: decibel (dB).

peak-to-peak pressure level (PK-PK)
The difference between the maximum and minimum instantaneous pressure levels. 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 noise 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.

phocid pinnipeds in water (PPW)
The functional pinniped hearing group that represents true/earless seals under water.

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
Generic term, formally defined as power in W/Hz, but sometimes loosely used to refer to the spectral density of other parameters such as square pressure or time-integrated square pressure.

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).

propagation loss (PL)
The decibel reduction in sound level between an acoustic source and a receiver that results from sound spreading away from the source subject to the influence of the surrounding environment.

range
a horizontal distance, often from a sound source to the location of a receiver; the same range value applies to an underwater sound receiver regardless of its depth in the water.

received level (RL)
The sound level measured (or that would be measured) at a defined location.

rms
root-mean-square.

shear wave
A mechanical vibration wave in which the direction of particle motion is perpendicular to the direction of propagation. Also called secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

signature
Pressure signal generated by a source.

sound
A time-varying pressure disturbance generated by mechanical vibration waves travelling through a fluid medium such as air or water.

sound exposure
Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event. Unit: pascal-squared second ($Pa^2 \cdot s$) (ANSI S1.1-1994 R2004).

sound exposure level (SEL)
A cumulative measure related to the sound energy in one or more pulses. Unit: dB re 1 $\mu Pa^2 \cdot s$. SEL is expressed over the summation period (e.g., per-pulse SEL [for airguns], single-strike SEL [for pile drivers], 24 hour SEL).

sound exposure spectral density
Distribution as a function of frequency of the time-integrated squared sound pressure per unit bandwidth of a sound having a continuous spectrum (ANSI S1.1-1994 R2004). Unit: $\mu Pa^2 \cdot s/Hz$.

sound field
Region containing sound waves (ANSI S1.1-1994 R2004).

sound intensity
Sound energy flowing through a unit area perpendicular to the direction of propagation per unit time.

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^2:

$$L_p = 10 \log_{10}(p^2/p_0^2) = 20 \log_{10}(p/p_0)$$

Unless otherwise stated, SPL refers to the root-mean-square (rms) pressure level. See also 90% sound pressure level and fast-average sound pressure level. Non-rectangular time window functions may be applied during calculation of the rms value, in which case the SPL unit should identify the window type.

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 level measured in the far-field and scaled back to a standard reference distance of 1 metre from the acoustic centre of the source. Unit: dB re 1 µPa·m (pressure level) or dB re 1 $\mu Pa^2 \cdot s \cdot m$ (exposure level).

spectral density level
The decibel level ($10 \cdot \log_{10}$) of the spectral density of a given parameter such as SPL or SEL, for which the units are dB re 1 $\mu Pa^2/Hz$ and dB re 1 $\mu Pa^2 \cdot s/Hz$, respectively.

spectrum
An acoustic signal represented in terms of its power, energy, mean-square sound pressure, or sound exposure distribution with frequency.

standard deviation
a statistical measure of the extent to which a set of data deviates from its mean value.

surface duct
The upper portion of a water column within which the sound speed profile gradient causes sound to refract upward and therefore reflect off the surface resulting in relatively long-range sound propagation with little loss.

temporary threshold shift (TTS)
Temporary loss of hearing sensitivity caused by excessive noise exposure.

transect
a horizontal line on the surface of the earth (or ocean), often to indicate the location for a vertical section plot that portrays the subsurface conditions beneath that line.

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.

wavelength
Distance over which a wave completes one cycle of oscillation. Unit: metre (m). Symbol: λ.

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Appendix A. 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 pulsed sound such as from seismic airguns, 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. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, we follow the American National Standard Institute and International Organization for Standardization definitions and symbols for sound metrics (e.g., ISO 2017, ANSI R2013), but these standards are not always consistent.

The zero-to-peak sound pressure, or peak sound pressure (PK or $L_{p,pk}$; dB re 1 µPa), is the decibel level of the maximum instantaneous acoustic pressure in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$L_{p,\mathrm{pk}} = 10\log_{10}\frac{\max|p^2(t)|}{p_0^2} = 20\log_{10}\frac{\max|p(t)|}{p_0}\ \mathrm{dB} \tag{A-1}$$

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 an acoustic event, it is generally a poor indicator of perceived loudness.

The sound pressure level (SPL or L_p; dB re 1 µPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window (T; s). It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$L_{\mathrm{p}} = 10\log_{10}\left(\frac{1}{T}\int_T g(t)\,p^2(t)\,dt \Big/ p_0^2\right)\ \mathrm{dB} \tag{A-2}$$

where $g(t)$ is an optional time weighting function. In many cases, the start time of the integration is marched forward in small time steps to produce a time-varying SPL function. For short acoustic events, such as sonar pulses and marine mammal vocalizations, it is important to choose an appropriate time window that matches the duration of the signal. For in-air studies, when evaluating the perceived loudness of sounds with rapid amplitude variations in time, the time weighting function $g(t)$ is often set to a decaying exponential function that emphasizes more recent pressure signals. This function mimics the leaky integration nature of mammalian hearing. For example, human-based fast time-weighted SPL ($L_{p,fast}$) applies an exponential function with time constant 125 ms. A related simpler approach used in underwater acoustics sets $g(t)$ to a boxcar (unity amplitude) function of width 125 ms; the results can be referred to as $L_{p,boxcar\ 125ms}$. Another approach, historically used to evaluate SPL of impulsive signals underwater, defines $g(t)$ as a boxcar function with edges set to the times corresponding to 5% and 95% of the cumulative square pressure function encompassing the duration of an impulsive acoustic event. This calculation is applied individually to each impulse signal, and the results have been referred to as 90% SPL ($L_{p,90\%}$).

The sound exposure level (SEL or L_E; dB re 1 µPa²s) is the time-integral of the squared acoustic pressure over a duration (T):

$$L_{\mathrm{E}} = 10\log_{10}\left(\int_T p^2(t)\,dt \Big/ T_0 p_0^2\right)\mathrm{dB} \tag{A-3}$$

where T_0 is a reference time interval of 1 s. SEL continues to increase with time when non-zero pressure signals are present. It is a dose-type measurement, so the integration time applied must be carefully considered for its relevance to impact to the exposed recipients.

SEL can be calculated over a fixed duration, such as the time of a single event or a period with multiple acoustic events. When applied to pulsed sounds, SEL can be calculated by summing the SEL of the N individual pulses. 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:

$$L_{\mathrm{E,N}} = 10 \log_{10} \sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}} \tag{A-4}$$

If applied, the frequency weighting of an acoustic event should be specified, as in the case of M-weighted SEL (e.g., $L_{E,LFC,24h}$; see Appendix B.2) or auditory-weighted SPL ($L_{p,ht}$). The use of fast, slow, or impulse exponential-time-averaging or other time-related characteristics should also be specified.

Appendix B. Marine Mammal Impact Criteria

It has been long recognized that marine mammals can be adversely affected by underwater anthropogenic noise. For example, Payne and Webb (1971) suggest that communication distances of fin whales are reduced by shipping sounds. Subsequently, similar concerns arose regarding effects of other underwater noise sources and the possibility that impulsive sources—primarily airguns used in seismic surveys—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 noise sources (NMFS 1998, ONR 1998, Nedwell and Turnpenny 1998, HESS 1999, Ellison and Stein 1999). In the years since these early workshops, a variety of thresholds have been proposed for both injury and disturbance based on SPL (Appendix B.1) and SEL and peak sound pressure levels (Appendix B.2). The following sections summarize the development of the current thresholds relevant to this study; this remains an active research topic, however.

B.1. Sound Pressure Level

The National Marine Fisheries Service (NMFS) SPL criteria for injury to marine mammals from acoustic exposure were set according to recommendations for cautionary estimates of sound levels leading to onset of permanent hearing threshold shift (PTS). These criteria prescribed injury thresholds of 190 dB re 1 µPa SPL for pinnipeds and 180 dB re 1 µPa SPL for cetaceans, for all types of sound sources except tactical sonar and explosives (NMFS 2018). These injury thresholds are applied to individual noise pulses or instantaneous sound levels and do not consider the overall duration of the noise or its acoustic frequency distribution. Criteria that do not account for exposure duration or noise spectra are generally insufficient on their own for assessing hearing injury.

The NMFS currently uses SPL thresholds for behavioural response of 160 dB re 1 µPa for impulsive sounds and 120 dB re 1 µPa for non-impulsive sounds for all marine mammal species (NMFS 2018), based on observations of mysticetes (Malme et al. 1983, Malme et al. 1984, Richardson et al. 1986, Richardson et al. 1990). As of 2016, NMFS applies these disturbance thresholds as a default, but makes exceptions on a species-specific and sub-population specific basis where warranted.

B.2. Sound Exposure Level and Peak Sound Pressure Level

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 noise exposure criteria. Members of this expert group published a landmark paper (Southall et al. 2007) that suggested assessment methods similar to those applied for humans. It was noted, that the potential for noise to affect animals depends on how well the animals can hear it. Noises are less likely to disturb or injure 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).

The resulting recommendations introduced dual acoustic injury criteria for impulsive sounds that included peak pressure level thresholds and SEL_{24h} thresholds, where the subscripted 24 h refers to the accumulation period for calculating SEL. In order to account for specific sensitivity of different marine mammal hearing groups a set of weighting functions were introduced to be applied during calculation of the SEL (Southall et al. 2007). Subsequent studies resulted in reconsideration of how the weighting functions are defined and the values for the threshold levels (NMFS 2018).

SEL_{24h} is frequency weighted according to one of four Southall et al. (2007) or five (NMFS 2018) marine mammal species hearing groups. Low-, mid- and high-frequency cetaceans (LFC, MFC, and HFC respectively) are groups identified in both publications, whereas Southall et al. (2007) considers pinnipeds

as a single group and NMFS (2018) splits the pinnipeds into two subgroups: phocids, earless or true seals, and otariids, eared seals; the latter are not applicable to the present study. The onset threshold levels for Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS) differ by group and are applied to M-weighted SEL.

B.2.1. NMFS (2018) criteria

B.2.2. Marine Mammal Auditory Weighting Functions

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions. The auditory weighting functions for marine mammals are applied in a similar way as A-weighting for noise level assessments for humans. The new frequency-weighting functions are expressed as:

$$G(f) = K + 10\log_{10}\left[\left(\frac{(f/f_{lo})^{2a}}{\left[1+(f/f_{lo})^{2}\right]^{a}\left[1+(f/f_{hi})^{2}\right]^{b}}\right)\right], \quad \text{(B-1)}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid-, and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively), phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA's technical guidance that assesses noise impacts on marine mammals (NMFS 2016), which was updated two years later after extensive consultations within the scientific community (NMFS 2018). The updates did not affect the content related to either the definitions of M-weighting functions or the threshold values. Table B-1 lists the parameters for the M-weighting functions for each hearing group; Figure B-1 shows the resulting frequency-weighting curves.

Table B-1. Parameters to be used in Equation B-1 to obtain the auditory weighting functions recommended by NMFS (2018).

Functional hearing group	a	b	f_{lo} (Hz)	f_{hi} (Hz)	K (dB)
Low-frequency cetaceans	1.0	2	200	19,000	0.13
Mid-frequency cetaceans	1.6	2	8,800	110,000	1.20
High-frequency cetaceans	1.8	2	12,000	140,000	1.36
Phocid pinnipeds in water	1.0	2	1,900	30,000	0.75
Otariid pinnipeds in water	2.0	2	940	25,000	0.64

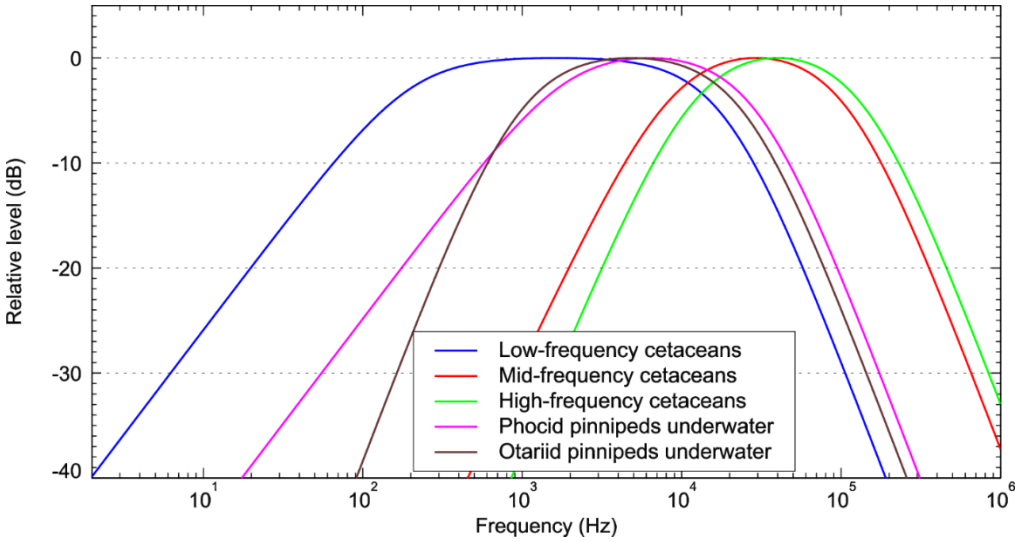

Figure B-1. Auditory weighting functions for the functional marine mammal hearing groups as recommended by NMFS (2018).

B.2.3. Impact Thresholds

Table B-2 lists the PTS-onset threshold levels for each hearing group (NMFS 2018). The threshold levels are defined separately for impulsive sources (e.g., seismic airgun arrays, echosounders) and non-impulsive sources (e.g., vessels). The SEL thresholds are applicable to weighted acoustic fields, while the $L_{p,pk}$ fields are tested against the thresholds without applying the weighting functions.

Table B-2. Onset levels for permanent threshold shift (PTS) for marine mammal hearing groups defined by NMFS (2018).

Marine mammal hearing group	Non-impulsive	Impulsive	
	SEL_w (dB re 1 µPa²s)	**SEL_w (dB re 1 µPa²s)**	**$L_{p,pk}$ (dB re 1 µPa)**
	PTS-onset	PTS-onset	PTS-onset
Low-frequency cetaceans	199	183	219
Mid-frequency cetaceans	198	185	230
High-frequency cetaceans	173	155	202
Phocid pinnipeds underwater	201	185	218
Otariid pinnipeds in water	219	203	232

Appendix C. Data Collection for the ESRF Study

Data from Station 19 in 2015–2016 and 2016–2017 recording period of the ESRF Study were used for comparison purposes for the present study.

C.1. Deployment Locations and Mooring Designs

C.1.1. 2015–2016

Figure C-1 and Table C-1 present the deployment locations for the ESRF 2016–2017 recording period.

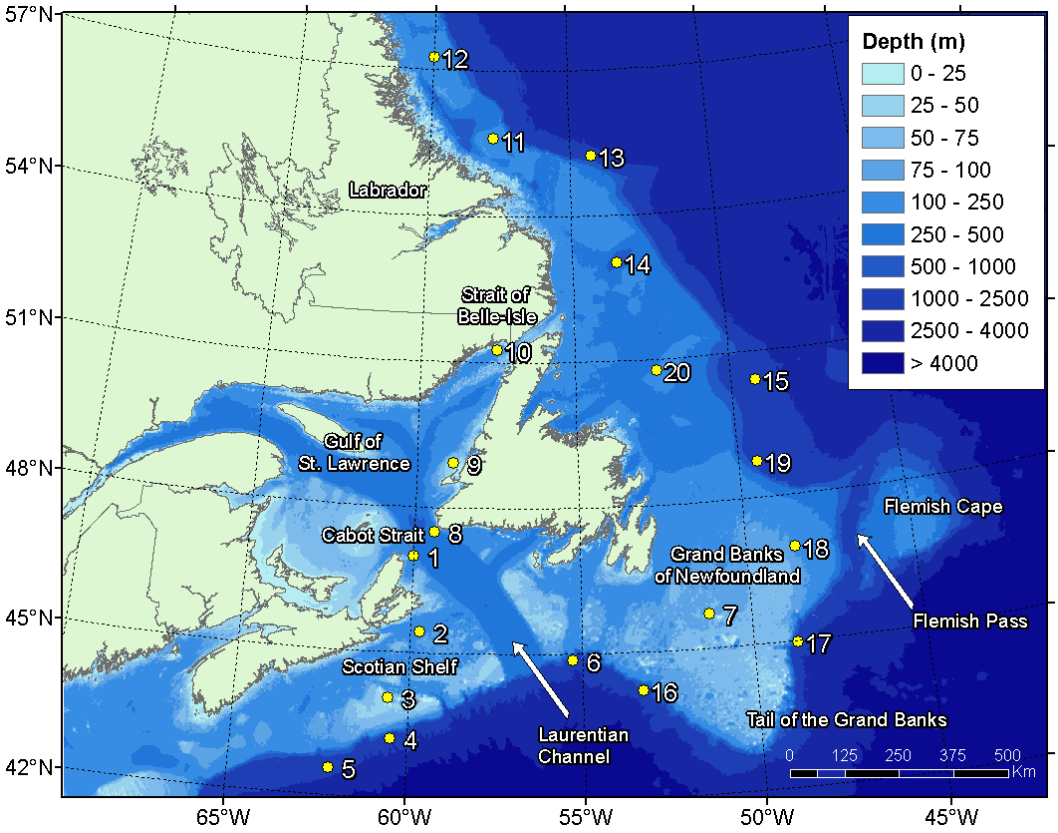

Figure C-1. ESRF Study AMAR deployment locations for the 2015–2016 recording period.

Table C-1. ESRF study operation period, location, and depth of the AMARs deployed for the 2015–2016 recording period.

Station	Latitude	Longitude	Depth (m)	Deployment	Retrieval	Duration (days)
1	46.99134	−60.02403	186	17 Aug 2015	8 Jul 2016	327
2	45.42599	−59.76398	126	18 Aug 2015	21 Jul 2016	339
4	43.21702	−60.49943	1830	19 Aug 2015	22 Jul 2016	339
5	42.54760	−62.17624	2002	19 Aug 2015	23 Jul 2016	340
6	44.85309	−55.27108	1802	22 Aug 2015	20 Jul 2016	334
7	45.70082	−51.23315	78	23 Aug 2015	19 Jul 2016	332
8	47.49307	−59.41325	428	16 Aug 2015	8 Jul 2016	328
9	48.92733	−58.87786	44	16 Aug 2015	26 Apr 2016	255
10	51.26912	−57.53759	121	3 Aug 2015	5 Jul 2016	338
11	55.60300	−57.75040	158	9 Aug 2015	13 Jul 2016	340
12	57.25273	−60.00175	143	10 Aug 2015	13 Jul 2016	339
13	55.22797	−54.19047	1750	8 Aug 2015	11 Jul 2016	339
14	53.01567	−53.46022	582	4 Aug 2015	14 Jul 2016	346
15	50.41327	−49.19638	2000	14 Aug 2015	16 Jul 2016	338
16	44.19230	−53.27441	1602	23 Aug 2015	20 Jul 2016	333
17	44.97141	−48.73373	1282	24 Aug 2015	18 Jul 2016	330
18	46.90877	−48.50418	111	25 Aug 2015	18 Jul 2016	329
19	48.72873	−49.38087	1282	25 Aug 2015	17 Jul 2016	328
20	50.75232	−52.33602	237	13 Aug 2015	15 Jul 2016	338

Four mooring configurations were used because the water depth varied from shallow to very deep across the deployment locations. Stations 3, 7, and 9 were deployed at depth less than 80 m. The AMARs at these three stations were mounted on bottom plates, which prevented motion due to currents (Figure C-2). All other stations were deployed using three variants of suspended mooring designs and recorder housing to account for the effects of increasing depth (Figures C-3, C-4, and C-5). In all deep mooring designs, the AMAR was suspended about 25 m above the seafloor.

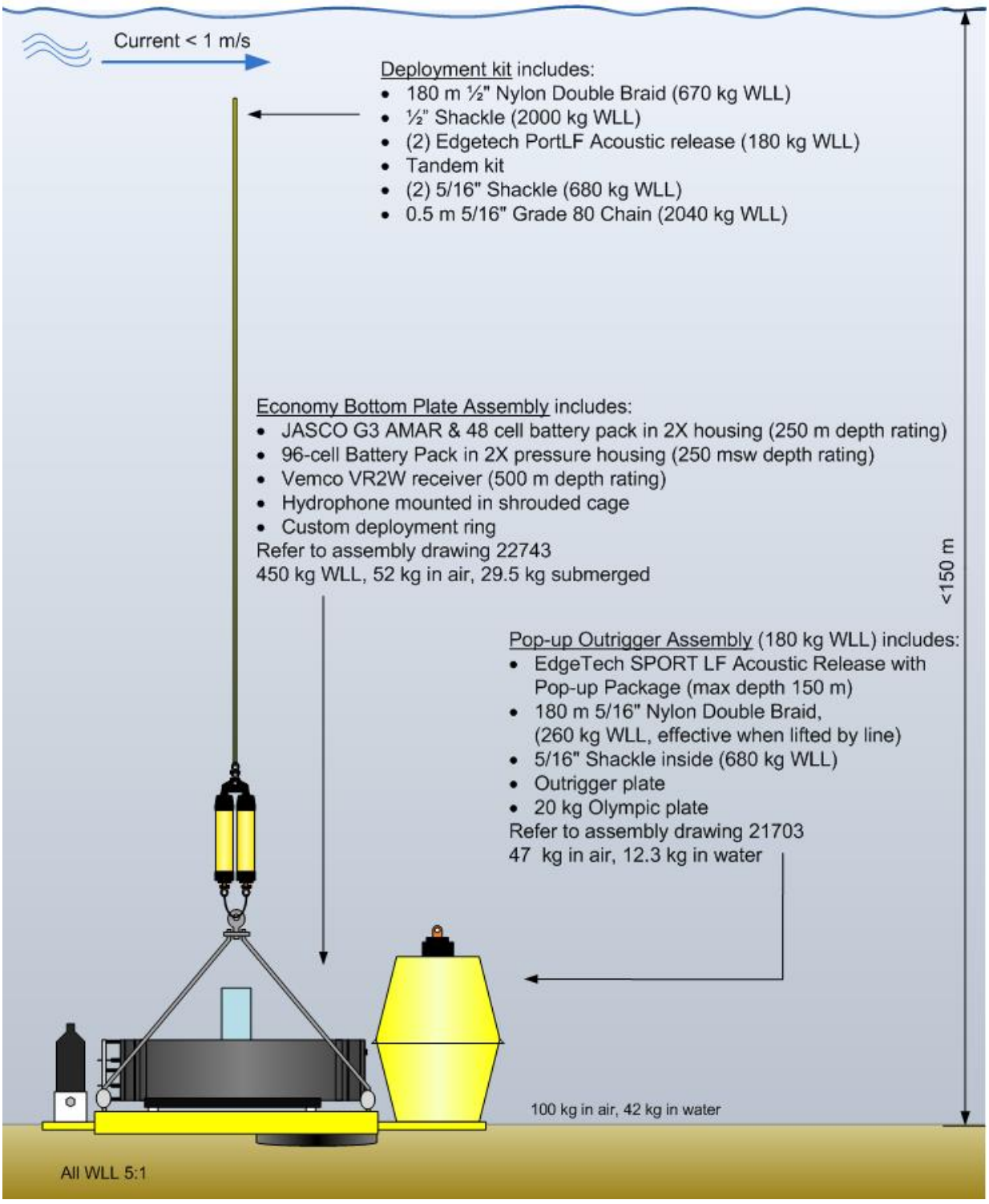

Figure C-2. Shallow mooring design with one PVC-housing AMAR attached to a bottom plate with a pop-up release and a fish logger. This configuration was used at Station 3, 7, and 9.

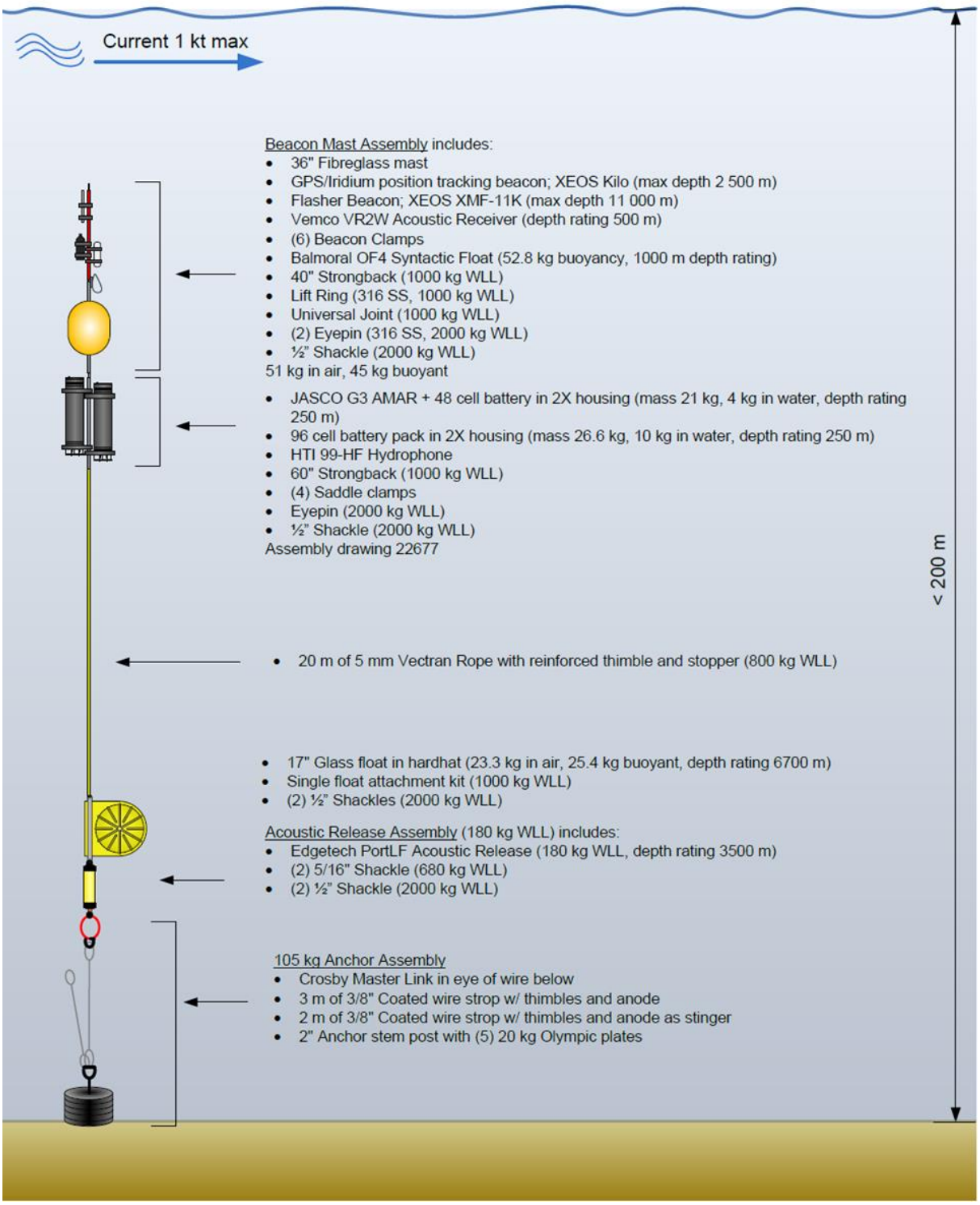

Figure C-3. Shallow mooring design with a PVC-housing AMAR and battery pack attached to an anchor. This configuration was used at used at Station 1, 2, 10, 11, 12, 18, and 20.

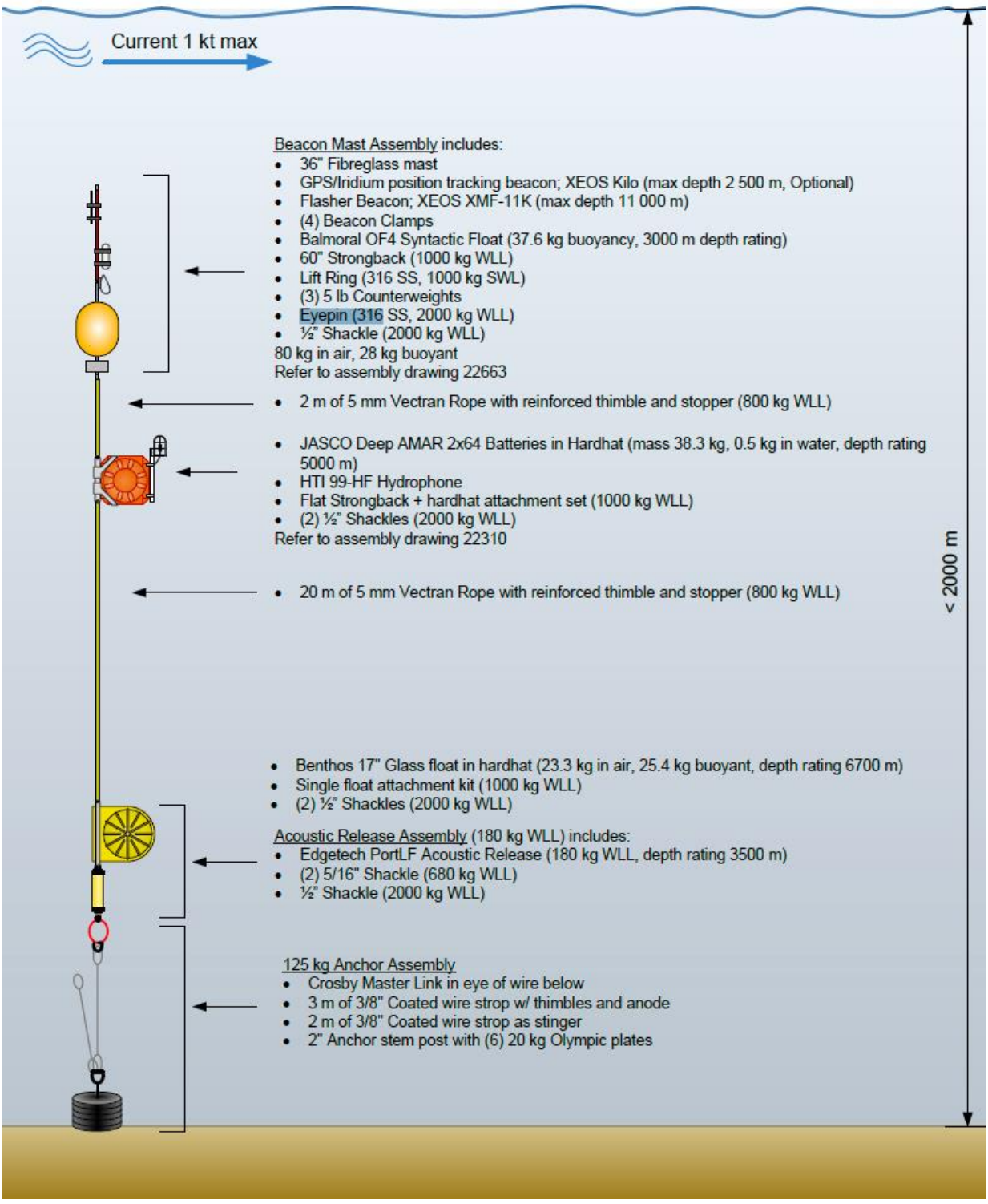

Figure C-4. Deep mooring design with one AMAR ultra-deep (UD) attached to an anchor. This configuration was used at Station 4, 5, 6, 13, 14, 15, 16, 17, and 19.

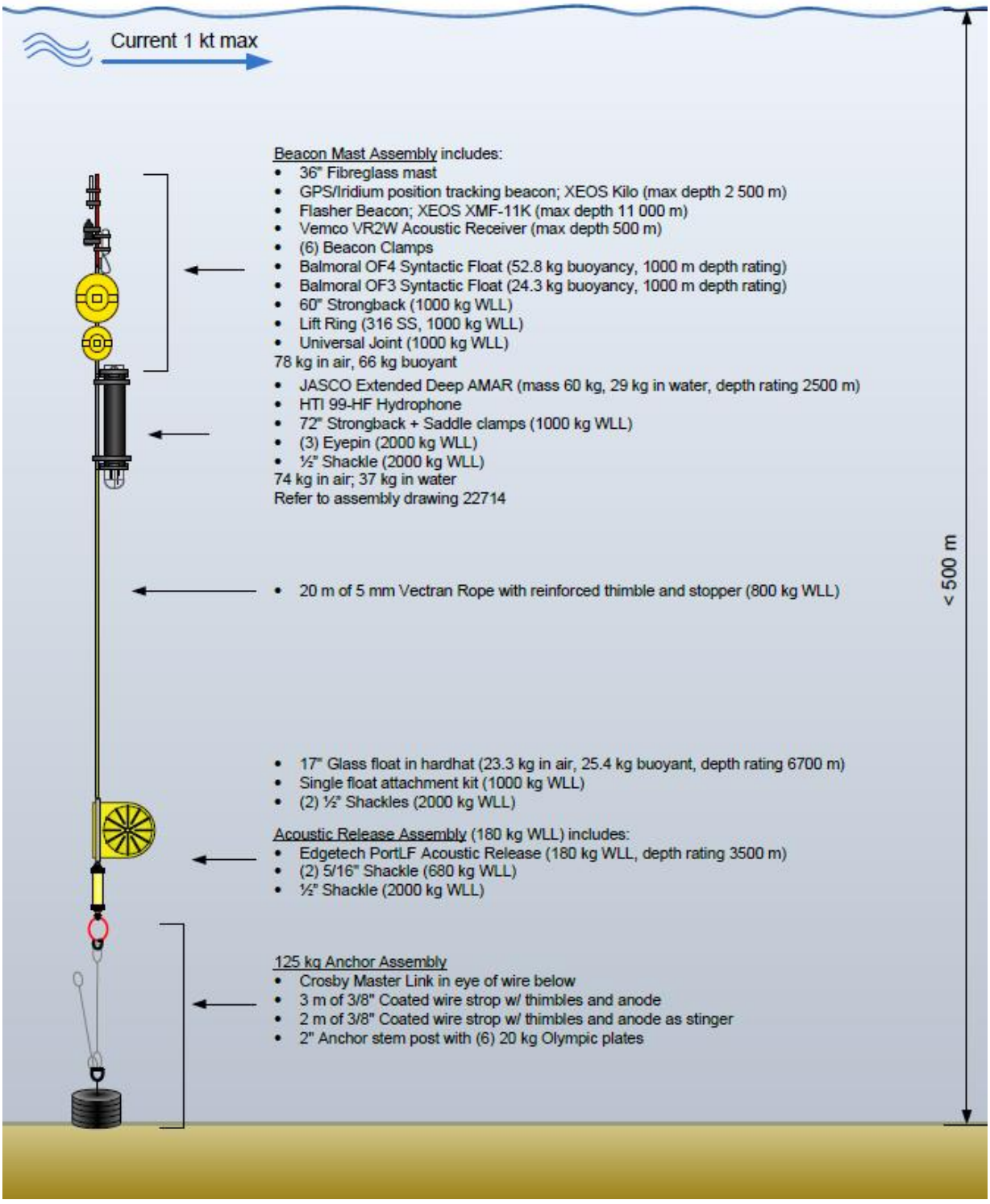

Figure C-5. Deep mooring design with one aluminum-housing AMAR attached to an anchor. This configuration was used at Station 8.

C.2. 2016–2017

Figure C-6 and Table C-2 present the deployment locations for the ESRF 2016–2017 recording period.

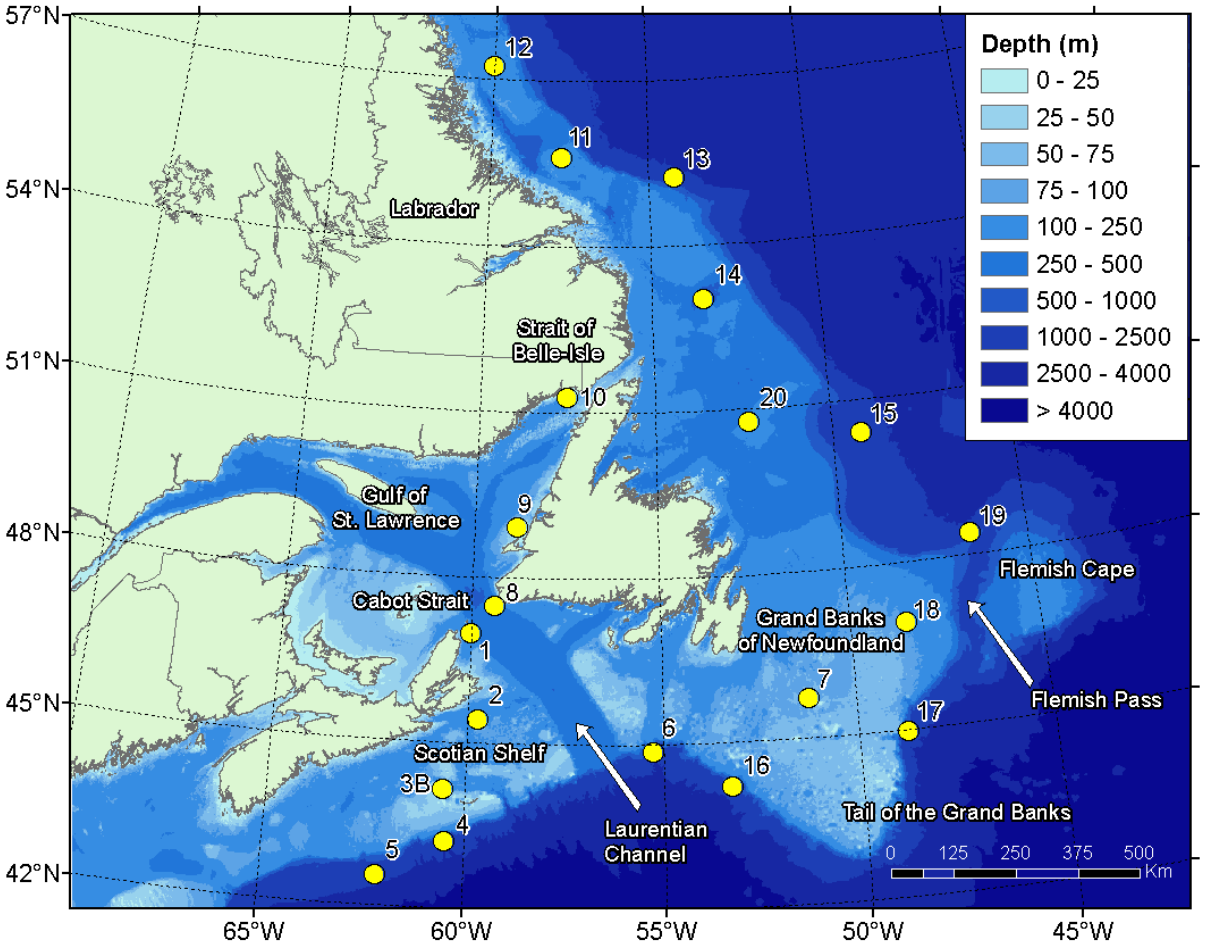

Figure C-6. ESRF Study AMAR deployment locations for the 2016–2017 recording period.

Table C-2. ESRF study deployment locations of each recorder with corresponding mooring designs for the 2016–2017 recording period.

Station ID	Location	Lat (N)	Long (W)	Depth (m)	Mooring design
1	Cape Breton	46° 59.218	060° 01.251	175	151
2	Louisburg Line	45° 25.892	059° 46.351	120	151
3	Sable	44° 08.973	060° 35.76	72	147
4	SW Sable	43° 12.96	060° 30.1	1558	146
5	Deep SW Nova	42° 32.86	062° 10.616	1831	146
6	Mouth Laurentian Ch.	44° 51.126	055° 16.244	1790	146
7	Central Grand Banks	45° 42.127	051° 13.715	76	147
8	North Slope Cabot Strait	47° 29.581	059° 24.743	420	150
9	West NFLD	48° 55.644	058° 52.643	43	147
10	Belle Isle	51° 16.615	057° 32.094	110	151
11	Makkovik Bank	55° 36.303	057° 44.927	150	151
12	Nain Bank	57° 14.911	060° 00.474	142	151
13	Labrador Offshore	55° 13.673	054° 11.407	1700	146
14	S Hamilton Bank	53° 01.244	053° 27.63	551	146
15	W Orphan Knoll	50° 24.667	049° 11.755	1993	146
16	Desbarres Canyon	44° 11.564	053° 16.486	1608	146
17	Lily Canyon	44° 58.066	048° 44.015	1273	146
18	Hibernia	46° 54.708	048° 30.069	214	151
19	Sackville Spur	48° 22.812	046° 31.526	1547	146
20	Funk Island Bank	50° 45.514	052° 19.819	236	151

C.3. Acoustic Recorders

Underwater sound was recorded with Autonomous Multichannel Acoustic Recorders (AMARs; JASCO) (Figure C-7). The recorder configuration used for 2015–2016 and 2016–2017 were similar.

In 2015–2016, each AMAR was fitted with an HTI-99 omnidirectional hydrophone (HTI, Inc., −165 ± 3 dB re 1 V/µPa sensitivity). The AMAR hydrophones were protected by a hydrophone cage, which was covered with a cloth shroud to minimize noise artifacts due to water flow. The AMARs operated on a duty cycle. They recorded at 8000 samples per second (for a recording bandwidth of 10 Hz to 4 kHz) over 11 minutes 18 s and at 250,000 samples per second (for a recording bandwidth of 10 Hz to 125 kHz) over 1 minutes 4 s, for a total cycle of 20 minutes. The low-frequency recording channel had 24-bit resolution with a spectral noise floor of 31 dB re 1 $\mu Pa^2/Hz$ and a nominal ceiling of 171 dB re 1 µPa. The high-frequency recording channel had 16-bit resolution with a spectral noise floor of 32 dB re 1 $\mu Pa^2/Hz$ and a nominal ceiling of 171 dB re 1 µPa. Acoustic data were stored on 1792 GB of internal solid-state flash memory.

In 2016–2017, each AMAR was fitted with an GTI M36-V35-100 omnidirectional hydrophone (GeoSpectrum, Inc., −165 ± 3 dB re 1 V/µPa sensitivity). The AMAR hydrophones were protected by a hydrophone cage, which was covered with a cloth shroud to minimize noise artifacts due to water flow. The AMARs operated on a duty cycle. They recorded at 8000 samples per second (for a recording bandwidth of 10 Hz to 4 kHz) over 11 minutes 18 s and at 250,000 samples per second (for a recording bandwidth of 10 Hz to 125 kHz) over 1 minutes 4 s, for a total cycle of 20 minutes. The low-frequency recording channel had 24-bit resolution with a spectral noise floor of 34 dB re 1 µPa^2/Hz and a nominal ceiling of 164 dB re 1 µPa. The high-frequency recording channel had 16-bit resolution with a spectral noise floor of 33 dB re 1 µPa^2/Hz and a nominal ceiling of 164 dB re 1 µPa. Acoustic data were stored on 1792 GB of internal solid-state flash memory.

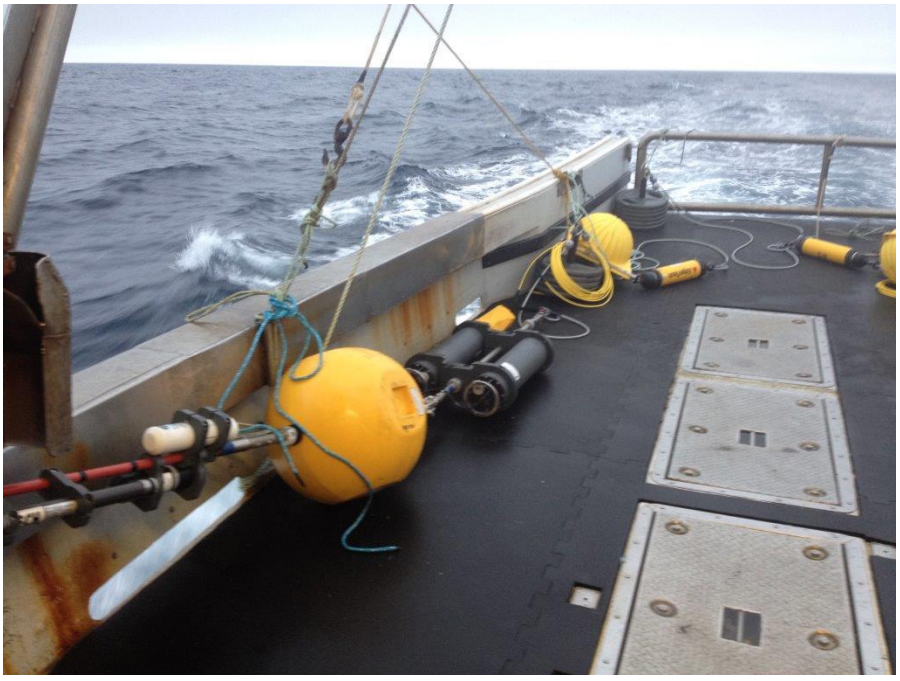

Figure C-7. Mooring set up prior to deployment.

C.4. Recorder Calibrations

A 42AC pistonphone calibrator (G.R.A.S. Sound & Vibration A/S; Figure C-8) was used to verify the sensitivity of the whole recording apparatus—the hydrophone, pre-amplifier, and AMAR. The pressure response of the recording system was verified by placing the pistonphone and its adapter over the hydrophone while the pistonphone produced a known pressure signal on the hydrophone element (a 250 Hz sinusoid at 152.2 dB re 1 µPa). The system sensitivity was measured independently of the software that performed the data analysis. This independently calibrated the analysis software. Calibrations were performed in JASCO's facility before the recorders were shipped. The reading was verified for consistency before data analysis was performed.

Figure C-8. Split view of a G.R.A.S. 42AC pistonphone calibrator with an M15B hydrophone.

C.5. Total Ocean Noise and Time Series Analysis

For the ESRF study, ambient noise levels at the recording stations were examined to document the local baseline underwater sound conditions. Ambient noise levels are presented as:

- Statistical distribution of SPL in each 1/3-octave-band. The boxes of the statistical distributions indicate the first (L_{25}), second (L_{50}), and third (L_{75}) quartiles. The whiskers indicate the maximum and minimum range of the data. The solid line indicates the mean SPL, or L_{mean}, in each 1/3-octave.
- Spectral density level percentiles: Histograms of each frequency bin per 1 minute of data. The L_{eq}, L_5, L_{25}, L_{50}, L_{75}, and L_{95} percentiles are plotted. The L_5 percentile curve is the frequency-dependent level exceeded by 5% of the 1 minute averages. Equivalently, 95% of the 1 minute spectral levels are above the 95th percentile curve.
- Broadband and approximate-decade-band SPL over time for these frequency bands: 10 Hz to 8 kHz, 10–100 Hz, 100 Hz to 1 kHz, and 1–63 kHz.
- Spectrograms: Ambient noise at each station was analyzed by Hamming-windowed fast Fourier transforms (FFTs), with 1 Hz resolution and 50% window overlap. The 120 FFTs performed with these settings are averaged to yield 1 minute average spectra.
- Daily sound exposure levels (SEL): Computed for the total received sound energy and the detected shipping energy. The SEL is the linear sum of the 1 minute SEL. For shipping, the 1 minute SEL values are the linear 1 minute squared SPL values multiplied by the duration, 60 s. For seismic survey pulses, the 1 minute SEL is the linear sum of the per-pulse SEL.

The 50th percentile (median of 1 minute spectral averages) can be compared to the well-known Wenz ambient noise curves (Figure 4), which show the variability of ambient spectral levels off the east coast of Canada as a function of frequency of measurements for a range of weather, vessel traffic, and geologic conditions. The Wenz curve levels are generalized and are used for approximate comparisons only (see Section 2.2).

C.5.1. Vessel Noise Detection

Vessels are detected in two steps:

1. Constant, narrowband tones produced by a vessel's propulsion system and other rotating machinery (Arveson and Vendittis 2000) are detected. These sounds are also referred to as tonals. We detect the tonals as lines in a 0.125 Hz resolution spectrogram of the data.
2. The root-mean-square sound pressure levels (SPL) are assessed for each minute in the 40–315 Hz frequency band, which commonly contains most sound energy produced by mid-sized to large vessels. Background estimates of the shipping band SPL and broadband SPL are then compared to their median values over the 12 hour window, centred on the current time.

Vessel detections are defined by three criteria:

- The SPL in the shipping band is at least 3 dB above the median.
- At least 5 shipping tonals (0.125 Hz bandwidth) are present.
- The SPL in the shipping band is within 8 dB of the broadband SPL (Figure C-9).

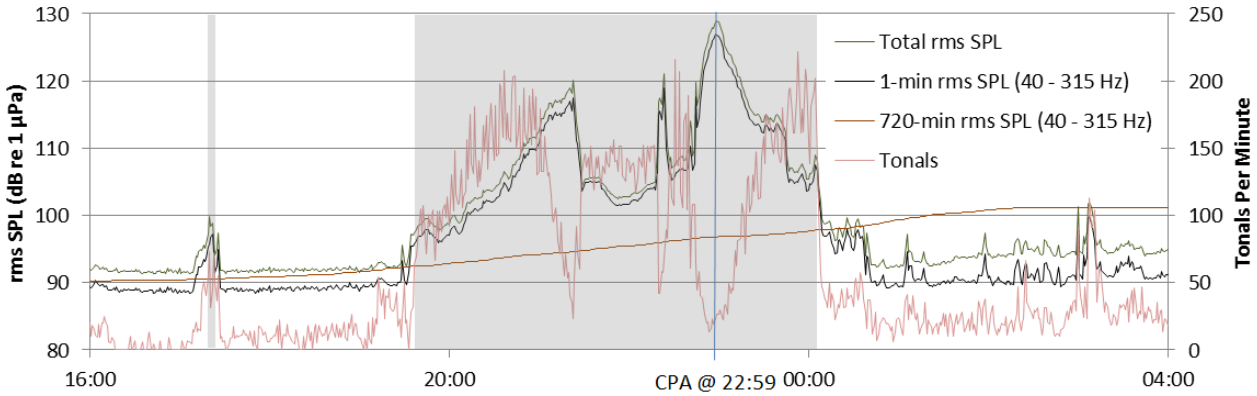

Figure C-9. Example of broadband and 40–315 Hz band SPL, as well as the number of tonals detected per minute as a ship approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the ship's closest point of approach (CPA) at 22:59 because of masking by broadband cavitation noise and due to Doppler shift that affects the tone frequencies.

C.5.2. Seismic Survey Event Detection

Seismic pulse sequences are detected using correlated spectrogram contours. We calculate spectrograms using a 300 s long window with 4 Hz frequency resolution and a 0.05 s time resolution (Reisz window). All frequency bins are normalized by their medians over window the 300 s window. The detection threshold is three times the median value at each frequency. Contours are created by joining the time-frequency bins above threshold in the 7–1000 Hz band using a 5 × 5 bin kernel. Contours 0.2–6 s in duration with a bandwidth of at least 60 Hz are retained for further analysis.

An "event" time series is created by summing the normalized value of the frequency bins in each time step that contained detected contours. The event time series is auto-correlated to look for repeated events. The correlated data space is normalized by its median and a detection threshold of 3 is applied. Peaks larger than their two nearest neighbours are identified and the peaks list is searched for entries with a set repetition interval. The allowed spacing between the minimum and maximum time peaks is 4.8 to 65 s, which captures the normal range of seismic pulse periods. Where at least six regularly spaced peaks occur, the original event time series is searched for all peaks that match the repetition period within a tolerance of 0.25 s. The duration of the 90% SPL window of each peak is determined from the originally sampled time series, and pulses more than 3 s long are rejected.

Appendix D. Tables of Received Level Depth Dependence

This appendix presents detailed tables of received level (RL), in SPL, in progressive range bins away from each source, along eight azimuthal transects, giving the depth at which the maximum RL occurs in each bin, the range at that maximum RL, and the RL at the bottom.

Table 19. Received Level by range bin for Site A, with February SSP, for the VSP Airgun Array.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	169.5	205.2	20	10
0	60	165.7	199.5	40	25
0	100	159.8	193.5	80	50
0	260	159.8	190.0	120	100
0	500	160.6	182.7	280	200
0	1000	158.1	177.4	520	350
0	3000	163.7	171.4	1040	800
0	5000	163.7	163.7	4440	2600
0	10000	158.5	158.5	5600	2600
0	20000	144.3	144.4	10920	1800
0	35000	148.1	148.1	29100	2600
0	50000	137.5	137.5	37800	2600
0		127.5	135.4	51020	75
45	20	169.7	206.6	20	15
45	60	165.8	200.6	40	25
45	100	159.9	194.6	80	50
45	260	160.0	191.1	120	75
45	500	161.5	183.8	280	150
45	1000	160.5	178.4	520	300
45	3000	165.7	172.6	1020	600
45	5000	166.3	166.3	3160	2600
45	10000	146.9	154.8	6160	25
45	20000	153.9	153.9	14340	2600
45	35000	145.4	145.4	30100	2600
45	50000	137.0	137.0	38280	2600
45		128.8	136.4	53679	150
90	20	169.9	208.4	20	10

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
90	60	166.0	202.4	40	20
90	100	160.2	196.2	80	50
90	260	160.1	192.8	120	50
90	500	161.7	185.5	280	150
90	1000	159.3	180.1	520	250
90	3000	168.6	174.3	1020	450
90	5000	167.3	167.3	3060	2600
90	10000	162.7	162.7	8580	2600
90	20000	160.6	160.6	10060	2600
90	35000	148.5	148.5	29920	2600
90	50000	141.1	141.1	39140	2600
90		131.1	140.0	54960	75
135	20	170.1	207.4	20	10
135	60	166.0	201.4	40	25
135	100	160.2	195.4	80	50
135	260	160.2	191.8	120	75
135	500	159.4	184.6	280	150
135	1000	160.8	179.2	520	300
135	3000	168.2	173.4	1020	600
135	5000	166.3	166.3	3260	2600
135	10000	148.1	155.5	6060	15
135	20000	147.8	147.8	10180	2600
135	35000	137.0	145.6	23340	75
135	50000	133.7	138.2	46940	25
135		127.8	137.0	54340	50
180	20	170.1	206.3	20	10
180	60	165.8	200.5	40	25
180	100	160.1	194.5	80	50
180	260	160.0	191.0	120	75
180	500	159.0	183.7	280	200
180	1000	158.3	178.4	520	350
180	3000	167.0	172.5	1020	600
180	5000	164.9	164.9	4460	2600

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
180	10000	158.5	158.5	5580	2600
180	20000	147.3	147.3	10120	2600
180	35000	136.0	143.0	22500	75
180	50000	135.0	137.0	44440	75
180		128.4	133.6	55040	100
225	20	170.1	207.4	20	10
225	60	166.1	201.4	40	25
225	100	160.1	195.4	80	50
225	260	160.1	191.8	120	75
225	500	159.3	184.6	280	150
225	1000	158.5	179.2	520	300
225	3000	167.6	173.3	1020	450
225	5000	165.2	165.2	3359	2600
225	10000	149.0	156.6	6059	25
225	20000	147.9	149.7	13737	2200
225	35000	142.0	145.6	23455	75
225	50000	134.0	138.5	40732	2200
225		129.8	136.1	50790	2200
270	20	169.9	208.3	20	10
270	60	166.0	202.3	40	20
270	100	160.0	196.1	80	50
270	260	160.0	192.7	120	50
270	500	161.0	185.4	280	150
270	1000	158.9	180.1	520	250
270	3000	166.4	174.3	1020	500
270	5000	161.4	164.7	3040	1200
270	10000	148.8	159.3	5920	25
270	20000	148.9	151.3	11740	2000
270	35000	139.8	148.4	26660	2200
270	50000	136.6	140.9	49480	1600
270		129.0	137.7	50160	75
315	20	169.6	206.5	20	15
315	60	165.8	200.6	40	25

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
315	100	159.8	194.6	80	50
315	260	159.5	191.0	120	75
315	500	160.8	183.7	280	150
315	1000	160.5	178.4	520	300
315	3000	167.7	172.4	1020	500
315	5000	162.4	162.9	3020	1400
315	10000	149.0	155.2	6060	25
315	20000	146.9	146.9	10100	2600
315	35000	136.7	143.4	24120	15
315	50000	135.7	136.4	35420	800
315		127.2	135.1	50540	20

Table 20. Received Level by range bin for Site A, with February SSP, for the support vessel.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	128.2	164.1	20	10
0	60	125.8	158.2	40	20
0	100	123.1	151.8	80	50
0	260	121.8	148.7	120	50
0	500	121.4	141.2	280	150
0	1000	122.0	135.9	520	250
0	3000	121.9	130.1	1020	400
0	5000	120.1	121.1	3060	1400
0	10000	119.3	121.4	6040	50
0	20000	114.6	118.3	10620	15
0	35000	107.9	115.1	21060	10
0	50000	105.4	112.0	37060	20
0		103.4	110.5	58400	5
45	20	128.2	164.1	20	10
45	60	125.8	158.2	40	20
45	100	123.1	151.8	80	50
45	260	121.8	148.7	120	50

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
45	500	121.4	141.2	280	150
45	1000	122.0	135.9	520	250
45	3000	121.9	130.1	1020	450
45	5000	120.1	121.0	3020	1200
45	10000	119.0	121.4	6080	50
45	20000	114.6	118.3	11680	75
45	35000	107.8	115.2	21080	10
45	50000	105.4	112.3	37060	20
45		102.8	110.6	52860	10
90	20	128.2	164.1	20	10
90	60	125.8	158.2	40	20
90	100	123.1	151.8	80	50
90	260	121.8	148.7	120	50
90	500	121.3	141.2	280	150
90	1000	121.9	135.9	520	250
90	3000	121.9	130.1	1020	450
90	5000	120.0	121.3	3020	1600
90	10000	119.0	121.4	6040	50
90	20000	114.6	118.2	11700	75
90	35000	107.9	114.8	21100	10
90	50000	106.5	112.2	36140	75
90		103.3	110.7	58180	20
135	20	128.2	164.1	20	10
135	60	125.8	158.2	40	20
135	100	123.1	151.8	80	50
135	260	121.8	148.7	120	50
135	500	121.4	141.2	280	150
135	1000	121.9	135.9	520	250
135	3000	121.9	130.1	1020	450
135	5000	120.0	121.3	3020	1200
135	10000	118.9	121.4	6060	50
135	20000	114.6	118.2	10620	15
135	35000	107.8	114.6	21100	10

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
135	50000	106.9	112.3	37080	20
135		106.0	110.5	58400	5
180	20	128.2	164.1	20	10
180	60	125.8	158.2	40	20
180	100	123.1	151.8	80	50
180	260	121.8	148.7	120	50
180	500	121.4	141.2	280	150
180	1000	122.0	135.9	520	250
180	3000	122.0	130.1	1020	450
180	5000	120.1	121.1	3040	1400
180	10000	118.8	121.4	6040	50
180	20000	114.8	118.2	11720	75
180	35000	108.2	114.9	21100	10
180	50000	105.4	112.2	37060	20
180		107.5	110.5	58400	5
225	20	128.2	164.1	20	10
225	60	125.8	158.2	40	20
225	100	123.1	151.8	80	50
225	260	121.8	148.7	120	50
225	500	121.4	141.2	280	150
225	1000	122.0	135.9	520	250
225	3000	121.9	130.2	1020	450
225	5000	120.1	121.1	3019	1200
225	10000	118.8	121.4	6079	50
225	20000	114.5	118.3	11678	75
225	35000	108.2	115.2	21076	10
225	50000	106.5	112.5	37053	20
225		106.3	111.0	52850	10
270	20	128.2	164.1	20	10
270	60	125.8	158.2	40	20
270	100	123.1	151.8	80	50
270	260	121.8	148.7	120	50
270	500	121.4	141.2	280	150

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
270	1000	121.9	135.9	520	250
270	3000	122.0	130.2	1020	450
270	5000	120.3	120.9	3060	1600
270	10000	119.0	121.4	6060	50
270	20000	114.7	118.1	11680	75
270	35000	108.1	114.7	21160	10
270	50000	105.9	112.5	37060	20
270		104.0	110.7	52860	10
315	20	128.2	164.1	20	10
315	60	125.8	158.2	40	20
315	100	123.1	151.8	80	50
315	260	121.8	148.7	120	50
315	500	121.4	141.2	280	150
315	1000	121.9	135.9	520	250
315	3000	121.9	130.2	1020	450
315	5000	120.1	120.8	3160	1400
315	10000	119.0	121.5	6040	50
315	20000	114.6	118.3	10620	15
315	35000	107.8	114.7	21080	10
315	50000	107.1	112.3	37060	15
315		104.3	110.6	53140	10

Table 21. Received Level by range bin for Site A, with February SSP, for the Generic Drill Ship.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	141.7	172.4	20	10
0	60	138.3	167.3	40	15
0	100	134.7	161.3	80	20
0	260	132.8	157.9	120	25
0	500	130.0	150.7	280	75
0	1000	130.3	145.3	520	150
0	3000	130.4	139.5	1020	250

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	5000	128.4	132.1	4980	15
0	10000	128.3	132.8	5140	15
0	20000	124.2	129.7	10500	15
0	35000	117.8	125.8	21120	20
0	50000	115.8	123.9	36880	15
0		113.4	121.6	53000	15
45	20	141.7	172.4	20	10
45	60	138.3	167.3	40	15
45	100	134.7	161.3	80	20
45	260	132.8	157.9	120	25
45	500	129.9	150.7	280	75
45	1000	130.3	145.3	520	150
45	3000	130.5	139.5	1020	250
45	5000	128.2	132.1	5000	15
45	10000	128.3	132.8	5160	15
45	20000	124.0	129.6	10440	15
45	35000	117.6	125.7	21100	15
45	50000	115.6	123.7	38940	15
45		113.1	122.0	53020	15
90	20	141.7	172.4	20	10
90	60	138.3	167.3	40	15
90	100	134.7	161.3	80	20
90	260	132.8	157.9	120	25
90	500	130.0	150.7	280	75
90	1000	130.3	145.3	520	150
90	3000	130.5	139.5	1020	250
90	5000	128.2	132.4	5000	15
90	10000	128.3	132.7	5140	15
90	20000	123.8	129.5	10440	15
90	35000	117.8	125.7	21080	15
90	50000	116.3	123.8	36900	15
90		113.0	121.6	53080	15
135	20	141.7	172.4	20	10

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
135	60	138.3	167.3	40	15
135	100	134.7	161.3	80	20
135	260	132.9	157.9	120	25
135	500	129.9	150.7	280	75
135	1000	130.3	145.3	520	150
135	3000	130.5	139.5	1020	250
135	5000	128.2	132.1	4980	15
135	10000	128.0	132.6	5120	15
135	20000	123.9	129.4	10400	15
135	35000	117.8	125.7	21260	15
135	50000	117.1	123.9	38940	15
135		115.4	121.6	50700	15
180	20	141.7	172.4	20	10
180	60	138.3	167.3	40	15
180	100	134.7	161.3	80	20
180	260	132.9	157.9	120	25
180	500	129.9	150.7	280	75
180	1000	130.3	145.3	520	150
180	3000	130.5	139.5	1020	250
180	5000	128.2	132.2	4960	15
180	10000	128.1	132.7	5180	15
180	20000	124.2	129.7	10500	15
180	35000	117.9	125.7	21340	15
180	50000	116.6	123.8	39340	15
180		116.9	121.6	50760	15
225	20	141.7	172.4	20	10
225	60	138.4	167.3	40	15
225	100	134.7	161.3	80	20
225	260	132.9	157.9	120	25
225	500	129.9	150.7	280	75
225	1000	130.3	145.3	520	150
225	3000	130.5	139.5	1020	250
225	5000	128.3	132.1	4939	15

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
225	10000	128.1	132.7	5199	15
225	20000	124.0	129.5	10378	15
225	35000	118.6	125.6	21156	20
225	50000	117.0	123.5	38933	15
225		117.0	122.2	53010	10
270	20	141.7	172.4	20	10
270	60	138.3	167.3	40	15
270	100	134.7	161.3	80	20
270	260	132.8	157.9	120	25
270	500	130.0	150.7	280	75
270	1000	130.3	145.3	520	150
270	3000	130.5	139.5	1020	250
270	5000	128.4	132.2	5000	15
270	10000	128.2	132.6	5100	15
270	20000	124.1	129.5	10520	15
270	35000	118.2	125.9	20340	25
270	50000	116.9	123.6	38020	15
270		113.8	122.1	50740	15
315	20	141.7	172.4	20	10
315	60	138.3	167.3	40	15
315	100	134.7	161.3	80	20
315	260	132.8	157.9	120	25
315	500	130.0	150.7	280	75
315	1000	130.3	145.3	520	150
315	3000	130.5	139.5	1020	250
315	5000	128.3	132.2	5000	15
315	10000	128.2	132.7	5140	15
315	20000	123.9	129.4	10500	15
315	35000	117.6	125.8	21280	15
315	50000	116.9	123.8	38980	15
315		113.6	121.9	50680	15

Table 22. Received Level by range bin for Site A, with February SSP, for the *Stena Forth* Drill Ship.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	140.2	167.3	20	5
0	60	135.5	162.3	40	10
0	100	131.6	156.5	80	20
0	260	129.5	152.7	120	50
0	500	125.4	145.2	280	20
0	1000	124.9	139.7	520	200
0	3000	124.4	134.1	1040	250
0	5000	122.6	131.7	4980	15
0	10000	121.8	132.3	5160	15
0	20000	115.6	127.4	10280	15
0	35000	111.3	124.5	28300	25
0	50000	109.5	123.2	37920	10
0		106.5	121.9	58420	10
45	20	140.3	167.3	20	5
45	60	135.6	162.3	40	10
45	100	131.7	156.5	80	20
45	260	129.6	152.7	120	50
45	500	125.4	145.2	280	20
45	1000	125.0	139.7	520	200
45	3000	124.4	134.1	1040	250
45	5000	122.6	131.7	4980	15
45	10000	122.0	132.3	5160	15
45	20000	115.5	127.4	10300	15
45	35000	111.2	123.7	28280	25
45	50000	108.5	123.3	37919	10
45		105.3	121.7	58399	10
90	20	140.3	167.3	20	5
90	60	135.6	162.3	40	10
90	100	131.7	156.5	80	20
90	260	129.5	152.7	120	50
90	500	125.4	145.2	280	20
90	1000	125.0	139.7	520	200

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
90	3000	124.4	134.1	1040	250
90	5000	122.6	132.0	5000	15
90	10000	121.9	132.1	5180	15
90	20000	115.0	127.4	10300	15
90	35000	111.6	124.2	28320	25
90	50000	109.8	123.5	37940	10
90		106.0	122.0	58380	10
135	20	140.3	167.3	20	5
135	60	135.6	162.3	40	10
135	100	131.7	156.5	80	20
135	260	129.6	152.7	120	50
135	500	125.4	145.2	280	20
135	1000	124.9	139.7	520	200
135	3000	124.4	134.1	1040	250
135	5000	122.6	131.8	5000	15
135	10000	121.5	132.2	5180	15
135	20000	115.7	127.4	10320	15
135	35000	111.8	124.1	28340	25
135	50000	110.5	122.9	37900	10
135		110.5	122.0	58420	10
180	20	140.3	167.3	20	5
180	60	135.6	162.3	40	10
180	100	131.7	156.5	80	20
180	260	129.6	152.7	120	50
180	500	125.4	145.2	280	20
180	1000	124.9	139.7	520	200
180	3000	124.4	134.1	1040	250
180	5000	122.6	131.9	5000	15
180	10000	121.5	132.2	5140	15
180	20000	115.9	127.4	10320	15
180	35000	111.3	124.0	28280	25
180	50000	109.0	122.7	38080	15
180		112.4	122.0	53060	15

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
225	20	140.3	167.3	20	5
225	60	135.6	162.3	40	10
225	100	131.7	156.5	80	20
225	260	129.6	152.7	120	50
225	500	125.4	145.2	280	20
225	1000	124.9	139.7	520	200
225	3000	124.5	134.1	1020	400
225	5000	122.7	131.5	4959	15
225	10000	121.3	132.2	5199	15
225	20000	115.9	127.4	10278	15
225	35000	111.9	124.2	22316	75
225	50000	109.6	123.2	37933	10
225		111.9	122.3	58389	10
270	20	140.3	167.3	20	5
270	60	135.6	162.3	40	10
270	100	131.6	156.5	80	20
270	260	129.5	152.7	120	50
270	500	125.5	145.2	280	20
270	1000	124.9	139.7	520	200
270	3000	124.5	134.1	1020	400
270	5000	122.7	131.7	4980	15
270	10000	121.8	132.2	5100	15
270	20000	116.4	127.5	10300	15
270	35000	111.8	123.9	23900	20
270	50000	110.0	123.4	38080	15
270		107.7	121.8	58420	10
315	20	140.3	167.3	20	5
315	60	135.6	162.3	40	10
315	100	131.6	156.5	80	20
315	260	129.5	152.7	120	50
315	500	125.4	145.2	280	20
315	1000	124.9	139.7	520	200
315	3000	124.5	134.1	1020	400

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
315	5000	122.6	131.8	5000	15
315	10000	121.6	132.3	5140	15
315	20000	115.7	127.5	10260	15
315	35000	111.7	123.7	28280	25
315	50000	108.8	123.1	37940	10
315		106.8	121.9	58400	10

Table 23. Received Level by range bin for Site A, with February SSP, for the Semisubmersible Drilling platform.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	119.9	170.6	20	25
0	60	116.2	166.6	40	5
0	100	113.9	161.9	80	10
0	260	116.9	158.7	120	15
0	500	123.7	151.2	280	25
0	1000	124.4	146.2	520	50
0	3000	129.4	140.5	1020	100
0	5000	127.9	135.6	4920	25
0	10000	127.3	136.1	5200	25
0	20000	122.4	133.1	10780	25
0	35000	115.4	130.0	20620	25
0	50000	113.4	126.9	39340	25
0		111.1	125.6	53840	25
45	20	120.0	170.6	20	25
45	60	116.2	166.6	40	5
45	100	113.9	161.9	80	10
45	260	116.8	158.7	120	15
45	500	123.6	151.2	280	25
45	1000	124.4	146.2	520	50
45	3000	129.4	140.5	1020	100
45	5000	127.9	135.7	4960	25
45	10000	127.2	136.1	5480	25

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
45	20000	122.6	132.9	10720	25
45	35000	115.8	129.6	20640	25
45	50000	112.6	126.9	39340	25
45		110.8	125.7	53020	25
90	20	120.0	170.6	20	25
90	60	116.2	166.6	40	5
90	100	113.9	161.9	80	10
90	260	116.9	158.7	120	15
90	500	123.6	151.2	280	25
90	1000	124.4	146.2	520	50
90	3000	129.4	140.5	1020	100
90	5000	127.9	135.7	4940	25
90	10000	127.2	136.1	5160	25
90	20000	122.9	132.9	10720	25
90	35000	115.8	129.5	20060	25
90	50000	114.0	126.7	39320	25
90		111.4	125.4	53860	25
135	20	120.0	170.6	20	25
135	60	116.3	166.6	40	5
135	100	114.0	161.9	80	10
135	260	116.8	158.7	120	15
135	500	123.6	151.2	280	25
135	1000	124.4	146.2	520	50
135	3000	129.4	140.5	1020	100
135	5000	127.8	135.7	5000	25
135	10000	127.1	136.0	5240	25
135	20000	122.4	133.0	10660	25
135	35000	115.3	129.6	20540	25
135	50000	114.4	127.0	38000	25
135		114.4	125.2	53040	25
180	20	120.0	170.6	20	25
180	60	116.3	166.6	40	5
180	100	114.0	161.9	80	10

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
180	260	116.9	158.7	120	15
180	500	123.6	151.2	280	25
180	1000	124.4	146.2	520	50
180	3000	129.4	140.5	1020	100
180	5000	127.9	135.7	4980	25
180	10000	127.0	136.1	5300	25
180	20000	122.1	133.0	10780	25
180	35000	115.8	129.5	20620	25
180	50000	113.3	127.2	39340	25
180		116.4	125.4	53920	25
225	20	120.0	170.6	20	25
225	60	116.3	166.6	40	5
225	100	114.0	161.9	80	10
225	260	116.9	158.7	120	15
225	500	123.7	151.2	280	25
225	1000	124.4	146.2	520	50
225	3000	129.4	140.5	1020	100
225	5000	127.9	135.8	4999	25
225	10000	127.3	136.1	5279	25
225	20000	121.9	133.1	10658	25
225	35000	116.1	129.7	20576	25
225	50000	113.6	126.9	39332	25
225		116.9	125.3	53030	25
270	20	119.9	170.6	20	25
270	60	116.2	166.6	40	5
270	100	113.9	161.9	80	10
270	260	116.8	158.7	120	15
270	500	123.7	151.2	280	25
270	1000	124.4	146.2	520	50
270	3000	129.4	140.5	1020	100
270	5000	128.0	135.7	5000	25
270	10000	127.3	136.0	5160	25
270	20000	121.6	132.8	10540	25

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
270	35000	115.4	129.6	20580	25
270	50000	115.2	127.2	39320	25
270		112.2	125.4	53840	25
315	20	119.9	170.6	20	25
315	60	116.2	166.6	40	5
315	100	113.9	161.9	80	10
315	260	116.9	158.7	120	15
315	500	123.7	151.2	280	25
315	1000	124.4	146.2	520	50
315	3000	129.4	140.5	1020	100
315	5000	127.9	135.7	5000	25
315	10000	127.3	136.1	5280	25
315	20000	121.8	133.0	10760	25
315	35000	115.1	129.5	20120	25
315	50000	115.6	127.1	39360	25
315		113.0	125.2	52980	25

Table 24. Received Level by range bin for Site A, with August SSP, for the VSP Airgun Array.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	169.4	205.1	20	10
0	60	165.6	199.4	40	25
0	100	159.8	193.3	80	50
0	260	159.8	189.9	120	100
0	500	160.7	182.7	280	200
0	1000	158.1	177.4	520	350
0	3000	164.4	171.4	1040	800
0	5000	164.0	164.0	4460	2600
0	10000	157.8	157.8	5600	2600
0	20000	143.7	152.5	10540	10
0	35000	148.2	148.2	29040	2600
0	50000	136.8	136.8	37760	2600

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0		127.1	129.5	50180	20
45	20	169.6	206.5	20	15
45	60	165.8	200.5	40	25
45	100	160.1	194.5	80	50
45	260	160.0	191.0	120	75
45	500	162.0	183.7	280	200
45	1000	160.6	178.4	520	350
45	3000	166.4	172.6	1020	600
45	5000	166.4	166.4	3160	2600
45	10000	152.0	154.0	5780	2200
45	20000	153.1	153.5	10400	10
45	35000	144.7	148.4	21820	10
45	50000	136.4	136.4	35280	2600
45		128.2	132.9	52959	10
90	20	169.8	208.4	20	10
90	60	166.0	202.3	40	20
90	100	160.2	196.1	80	50
90	260	160.1	192.6	120	75
90	500	162.2	185.6	280	150
90	1000	159.6	180.2	520	250
90	3000	168.8	174.4	1020	500
90	5000	167.4	167.4	3060	2600
90	10000	162.7	162.7	8720	2600
90	20000	160.4	160.4	10020	2600
90	35000	148.4	149.3	22300	20
90	50000	141.0	141.0	39120	2600
90		131.8	136.3	55280	10
135	20	170.0	207.3	20	10
135	60	166.0	201.3	40	25
135	100	160.2	195.3	80	50
135	260	160.2	191.8	120	75
135	500	160.7	184.6	280	150
135	1000	160.9	179.3	520	300

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
135	3000	168.4	173.5	1020	600
135	5000	166.5	166.5	3240	2600
135	10000	150.4	154.6	5520	2200
135	20000	147.6	153.8	10620	10
135	35000	136.7	149.7	21740	10
135	50000	135.0	143.0	48940	10
135		126.6	144.4	54360	5
180	20	170.0	206.2	20	10
180	60	165.8	200.4	40	25
180	100	160.1	194.3	80	50
180	260	160.1	190.8	120	75
180	500	159.0	183.6	280	200
180	1000	158.3	178.4	520	350
180	3000	167.0	172.5	1020	600
180	5000	164.8	164.8	3860	2600
180	10000	158.5	158.5	5580	2600
180	20000	146.6	154.5	11240	10
180	35000	138.0	148.7	20820	15
180	50000	132.7	134.7	41260	2200
180		127.5	130.3	59600	1800
225	20	170.0	207.3	20	10
225	60	166.1	201.3	40	25
225	100	160.0	195.2	80	50
225	260	160.1	191.7	120	75
225	500	159.3	184.5	280	150
225	1000	158.6	179.3	520	300
225	3000	167.5	173.4	1020	600
225	5000	166.3	166.3	3299	2600
225	10000	149.6	154.5	5499	2200
225	20000	147.2	155.0	10698	10
225	35000	140.9	149.9	20736	10
225	50000	133.8	138.3	40712	2200
225		127.0	134.5	50710	2200

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
270	20	169.8	208.3	20	10
270	60	166.0	202.2	40	20
270	100	160.0	196.0	80	50
270	260	160.1	192.6	120	75
270	500	161.5	185.5	280	150
270	1000	159.1	180.2	520	250
270	3000	166.7	174.4	1020	500
270	5000	163.5	165.0	3060	1400
270	10000	148.7	158.1	5720	2200
270	20000	148.6	155.1	11780	5
270	35000	139.5	151.2	20160	10
270	50000	136.0	137.4	47420	5
270		129.1	133.8	53140	1800
315	20	169.5	206.5	20	15
315	60	165.7	200.4	40	25
315	100	159.8	194.4	80	50
315	260	159.8	190.9	120	75
315	500	160.8	183.7	280	200
315	1000	160.6	178.4	520	350
315	3000	167.8	172.4	1020	600
315	5000	163.5	163.5	3300	2600
315	10000	149.5	154.7	5800	2200
315	20000	146.4	153.3	10280	10
315	35000	136.2	148.5	20760	20
315	50000	134.4	134.4	43300	2600
315		126.5	132.2	51120	10

Table 25. Received Level by range bin for Site A, with August SSP, for the support vessel.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	128.1	164.1	20	10
0	60	125.7	158.1	40	20

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	100	123.1	151.7	80	50
0	260	121.8	148.3	120	50
0	500	121.4	141.3	280	150
0	1000	122.1	136.1	520	250
0	3000	122.1	130.4	1020	400
0	5000	120.3	121.4	3060	1400
0	10000	119.4	119.4	5920	2400
0	20000	115.0	115.0	10260	2400
0	35000	108.0	109.7	20480	2200
0	50000	105.7	108.8	49280	1600
0		103.2	109.8	52700	1800
45	20	128.1	164.1	20	10
45	60	125.7	158.1	40	20
45	100	123.1	151.7	80	50
45	260	121.8	148.3	120	50
45	500	121.4	141.3	280	150
45	1000	122.1	136.1	520	250
45	3000	122.1	130.3	1020	400
45	5000	120.2	121.2	3020	1200
45	10000	119.1	119.1	5940	2400
45	20000	115.0	115.0	10040	2400
45	35000	108.1	109.8	20160	2400
45	50000	105.7	109.2	45780	1400
45		103.0	110.2	52679	1800
90	20	128.1	164.1	20	10
90	60	125.7	158.1	40	20
90	100	123.1	151.7	80	50
90	260	121.8	148.3	120	50
90	500	121.4	141.3	280	150
90	1000	122.1	136.1	520	250
90	3000	122.0	130.3	1020	400
90	5000	120.1	121.6	3020	1600
90	10000	119.2	119.2	6200	2400

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
90	20000	115.1	115.1	10020	2600
90	35000	107.9	110.3	20260	2400
90	50000	107.0	108.7	49280	1600
90		103.2	111.3	52740	1800
135	20	128.1	164.1	20	10
135	60	125.7	158.1	40	20
135	100	123.1	151.7	80	50
135	260	121.8	148.3	120	50
135	500	121.4	141.3	280	150
135	1000	122.1	136.1	520	250
135	3000	122.1	130.4	1020	400
135	5000	120.3	121.5	3020	1200
135	10000	119.0	119.0	6460	2400
135	20000	115.1	115.1	10020	2400
135	35000	108.1	109.7	20600	2000
135	50000	107.2	109.0	35140	10
135		107.0	109.8	52640	1800
180	20	128.1	164.1	20	10
180	60	125.7	158.1	40	20
180	100	123.1	151.7	80	50
180	260	121.8	148.3	120	50
180	500	121.5	141.3	280	150
180	1000	122.1	136.1	520	250
180	3000	122.1	130.4	1020	400
180	5000	120.2	121.3	3040	1400
180	10000	118.9	118.9	6360	2400
180	20000	115.1	115.1	10120	2400
180	35000	108.3	110.4	20020	2000
180	50000	105.5	109.1	49340	1600
180		106.6	108.9	52800	1800
225	20	128.2	164.1	20	10
225	60	125.8	158.1	40	20
225	100	123.1	151.7	80	50

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
225	260	121.8	148.3	120	50
225	500	121.5	141.3	280	150
225	1000	122.1	136.1	520	250
225	3000	122.1	130.4	1020	400
225	5000	120.3	121.3	3019	1200
225	10000	118.8	118.8	6279	2400
225	20000	115.0	115.0	10018	2400
225	35000	108.3	110.6	23755	10
225	50000	106.5	109.4	49470	1600
225		106.5	106.8	50030	1600
270	20	128.1	164.1	20	10
270	60	125.7	158.1	40	20
270	100	123.1	151.7	80	50
270	260	121.8	148.3	120	50
270	500	121.5	141.3	280	150
270	1000	122.1	136.1	520	250
270	3000	122.1	130.3	1020	400
270	5000	120.4	121.1	3060	1600
270	10000	119.2	119.2	6040	2400
270	20000	115.1	115.1	10120	2400
270	35000	108.3	109.6	20280	2200
270	50000	106.5	108.8	49420	1600
270		104.7	108.1	52660	1800
315	20	128.1	164.1	20	10
315	60	125.7	158.1	40	20
315	100	123.1	151.7	80	50
315	260	121.8	148.3	120	50
315	500	121.5	141.3	280	150
315	1000	122.1	136.1	520	250
315	3000	122.1	130.3	1020	400
315	5000	120.3	121.1	3040	1200
315	10000	119.1	119.1	6000	2400
315	20000	115.0	115.0	10100	2400

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
315	35000	107.8	109.7	34580	5
315	50000	107.6	108.9	49260	1600
315		104.8	108.6	52800	1800

Table 26. Received Level by range bin for Site A, with August SSP, for the Generic Drill Ship.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	141.7	172.4	20	10
0	60	138.4	167.2	40	15
0	100	134.8	161.3	80	25
0	260	133.0	157.6	120	50
0	500	130.1	150.8	280	100
0	1000	130.4	145.8	520	150
0	3000	130.6	140.1	1020	250
0	5000	128.6	131.1	3020	900
0	10000	128.9	128.9	5940	2400
0	20000	125.3	125.3	10300	2400
0	35000	118.5	120.4	20840	2000
0	50000	116.3	120.5	49660	1600
0		114.2	119.3	52740	1800
45	20	141.7	172.4	20	10
45	60	138.4	167.2	40	15
45	100	134.8	161.3	80	25
45	260	133.0	157.6	120	50
45	500	130.0	150.8	280	100
45	1000	130.4	145.8	520	150
45	3000	130.6	140.1	1020	250
45	5000	128.6	131.0	3080	700
45	10000	128.9	128.9	5940	2400
45	20000	125.1	125.1	10080	2400
45	35000	118.2	120.7	20100	2400
45	50000	116.3	120.3	45680	1400

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
45		113.3	119.7	52580	1800
90	20	141.7	172.4	20	10
90	60	138.4	167.2	40	15
90	100	134.8	161.3	80	25
90	260	133.0	157.6	120	50
90	500	130.1	150.8	280	100
90	1000	130.4	145.8	520	150
90	3000	130.6	140.1	1020	250
90	5000	128.5	131.0	3020	800
90	10000	128.9	128.9	6000	2400
90	20000	125.1	125.1	10060	2600
90	35000	118.2	121.1	20520	2400
90	50000	117.2	120.3	45600	1400
90		114.2	120.4	52720	1800
135	20	141.7	172.4	20	10
135	60	138.4	167.2	40	15
135	100	134.8	161.3	80	25
135	260	133.0	157.6	120	50
135	500	130.0	150.8	280	100
135	1000	130.4	145.8	520	150
135	3000	130.6	140.1	1020	250
135	5000	128.6	131.0	3020	800
135	10000	128.8	128.8	6440	2400
135	20000	125.2	125.2	10060	2400
135	35000	118.6	120.5	20300	2200
135	50000	117.8	120.3	45640	1400
135		116.7	119.6	52540	1800
180	20	141.7	172.4	20	10
180	60	138.4	167.2	40	15
180	100	134.8	161.3	80	25
180	260	133.0	157.6	120	50
180	500	130.0	150.8	280	100
180	1000	130.4	145.8	520	150

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
180	3000	130.6	140.1	1020	250
180	5000	128.5	131.0	3020	900
180	10000	128.7	128.7	6340	2400
180	20000	125.4	125.4	10120	2400
180	35000	118.6	121.0	20040	2000
180	50000	117.2	120.6	49540	1600
180		116.6	118.1	52800	1800
225	20	141.8	172.4	20	10
225	60	138.4	167.2	40	15
225	100	134.9	161.3	80	25
225	260	133.0	157.6	120	50
225	500	130.1	150.8	280	100
225	1000	130.4	145.8	520	150
225	3000	130.6	140.1	1020	250
225	5000	128.6	131.0	3039	700
225	10000	128.7	128.7	5859	2400
225	20000	125.3	125.3	10098	2400
225	35000	119.4	121.9	23775	10
225	50000	117.5	120.4	49470	1600
225		117.1	117.1	50710	2000
270	20	141.7	172.4	20	10
270	60	138.4	167.2	40	15
270	100	134.8	161.3	80	25
270	260	133.0	157.6	120	50
270	500	130.1	150.8	280	100
270	1000	130.4	145.8	520	150
270	3000	130.6	140.1	1020	250
270	5000	128.8	131.0	3040	700
270	10000	129.0	129.0	6060	2400
270	20000	125.3	125.3	10160	2400
270	35000	119.1	119.9	22260	2000
270	50000	117.3	120.3	49420	1600
270		114.7	118.0	53120	1800

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
315	20	141.7	172.4	20	10
315	60	138.4	167.2	40	15
315	100	134.8	161.3	80	25
315	260	133.0	157.6	120	50
315	500	130.1	150.8	280	100
315	1000	130.4	145.8	520	150
315	3000	130.6	140.1	1020	250
315	5000	128.5	131.2	3020	800
315	10000	128.9	128.9	5980	2400
315	20000	125.2	125.2	10120	2400
315	35000	118.1	120.7	21260	2200
315	50000	117.2	120.4	45500	1400
315		114.5	118.5	52700	1800

Table 27. Received Level by range bin for Site A, with August SSP, for the *Stena Forth* Drill Ship.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	140.2	167.1	20	10
0	60	135.5	162.3	40	10
0	100	131.6	156.4	80	20
0	260	129.5	152.2	120	10
0	500	125.4	145.5	280	75
0	1000	124.9	140.9	520	150
0	3000	124.4	135.3	1020	300
0	5000	123.2	126.9	3020	500
0	10000	122.1	123.5	5440	900
0	20000	120.7	120.7	10020	2400
0	35000	111.9	116.0	34720	10
0	50000	108.8	117.8	49500	1600
0		108.1	116.8	52820	1800
45	20	140.2	167.1	20	10
45	60	135.5	162.3	40	10

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
45	100	131.6	156.4	80	20
45	260	129.5	152.2	120	10
45	500	125.4	145.5	280	75
45	1000	125.0	140.9	520	150
45	3000	124.3	135.3	1020	300
45	5000	123.2	126.9	3020	500
45	10000	122.1	123.5	5460	900
45	20000	120.9	120.9	10020	2400
45	35000	111.6	115.7	34920	10
45	50000	109.0	117.6	49379	1600
45		106.8	116.2	52660	1800
90	20	140.2	167.1	20	10
90	60	135.5	162.3	40	10
90	100	131.6	156.4	80	20
90	260	129.5	152.2	120	10
90	500	125.4	145.5	280	75
90	1000	125.0	140.9	520	150
90	3000	124.4	135.3	1020	300
90	5000	123.3	126.9	3020	500
90	10000	122.4	123.5	5240	900
90	20000	120.9	120.9	10060	2600
90	35000	111.7	115.3	34980	15
90	50000	111.0	118.0	49560	1600
90		108.0	116.8	52860	1800
135	20	140.2	167.1	20	10
135	60	135.6	162.3	40	10
135	100	131.7	156.4	80	20
135	260	129.6	152.2	120	10
135	500	125.4	145.5	280	75
135	1000	124.9	140.9	520	150
135	3000	124.4	135.3	1020	300
135	5000	123.2	126.9	3020	500
135	10000	122.0	123.5	5480	900

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
135	20000	120.8	120.8	10060	2400
135	35000	111.3	115.9	34680	10
135	50000	110.3	118.5	49420	1600
135		112.3	116.8	52840	1800
180	20	140.2	167.1	20	10
180	60	135.6	162.3	40	10
180	100	131.7	156.4	80	20
180	260	129.6	152.2	120	10
180	500	125.4	145.5	280	75
180	1000	124.9	140.9	520	150
180	3000	124.4	135.3	1020	300
180	5000	123.2	126.9	3020	500
180	10000	122.2	123.5	5480	900
180	20000	120.7	120.7	10020	2400
180	35000	111.7	116.3	34740	10
180	50000	110.0	118.0	49620	1600
180		112.7	115.9	52680	1800
225	20	140.2	167.1	20	10
225	60	135.6	162.3	40	10
225	100	131.7	156.4	80	20
225	260	129.6	152.2	120	10
225	500	125.4	145.5	280	75
225	1000	124.9	140.9	520	150
225	3000	124.4	135.3	1020	300
225	5000	123.3	126.9	3019	500
225	10000	122.0	123.6	5599	900
225	20000	120.3	120.3	10098	2400
225	35000	111.8	116.2	24215	2000
225	50000	110.1	118.6	49530	1600
225		113.9	115.5	50530	1600
270	20	140.2	167.1	20	10
270	60	135.5	162.3	40	10
270	100	131.6	156.4	80	20

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
270	260	129.5	152.2	120	10
270	500	125.5	145.5	280	75
270	1000	124.9	140.9	520	150
270	3000	124.5	135.3	1020	300
270	5000	123.4	126.8	3020	500
270	10000	122.1	123.7	5280	900
270	20000	120.1	120.1	10800	1600
270	35000	112.4	116.3	34760	10
270	50000	110.9	117.9	36680	10
270		109.6	115.6	53120	1800
315	20	140.2	167.1	20	10
315	60	135.5	162.3	40	10
315	100	131.6	156.4	80	20
315	260	129.5	152.2	120	10
315	500	125.4	145.5	280	75
315	1000	124.9	140.9	520	150
315	3000	124.4	135.3	1020	300
315	5000	123.3	126.9	3020	500
315	10000	122.0	123.6	5360	900
315	20000	120.5	120.5	10020	2400
315	35000	112.2	116.5	34480	20
315	50000	111.1	117.5	45440	1400
315		109.5	116.2	52920	1800

Table 28. Received Level by range bin for Site A, with August SSP, for the Semisubmersible Drilling platform.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	120.0	170.8	20	25
0	60	116.2	166.4	40	5
0	100	114.0	161.6	80	10
0	260	117.6	158.2	120	15
0	500	123.4	151.6	280	50

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	1000	124.6	147.1	520	100
0	3000	129.5	142.7	1020	150
0	5000	127.3	133.7	3180	450
0	10000	126.8	128.9	5100	700
0	20000	124.2	124.6	10200	1200
0	35000	116.2	123.9	33620	800
0	50000	114.6	123.9	35400	900
0		111.5	119.7	52860	1800
45	20	120.0	170.8	20	25
45	60	116.2	166.4	40	5
45	100	114.1	161.6	80	10
45	260	117.5	158.2	120	15
45	500	123.3	151.6	280	50
45	1000	124.6	147.1	520	100
45	3000	129.6	142.7	1020	150
45	5000	127.3	133.8	3180	450
45	10000	126.9	129.0	5020	700
45	20000	124.0	124.6	10360	1200
45	35000	116.2	123.5	31980	700
45	50000	113.8	123.7	35360	900
45		111.5	120.3	50040	1600
90	20	120.0	170.8	20	25
90	60	116.2	166.4	40	5
90	100	114.1	161.6	80	10
90	260	117.6	158.2	120	15
90	500	123.3	151.6	280	50
90	1000	124.6	147.1	520	100
90	3000	129.6	142.7	1020	150
90	5000	127.2	133.6	3020	450
90	10000	127.0	129.1	5040	700
90	20000	124.0	124.6	10460	1200
90	35000	116.4	123.6	33620	800
90	50000	115.7	124.2	35300	900

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
90		112.5	121.0	52560	1800
135	20	120.1	170.8	20	25
135	60	116.3	166.4	40	5
135	100	114.1	161.6	80	10
135	260	117.5	158.2	120	15
135	500	123.3	151.6	280	50
135	1000	124.6	147.1	520	100
135	3000	129.6	142.7	1020	150
135	5000	127.2	133.7	3020	450
135	10000	126.9	129.1	5020	700
135	20000	124.0	124.4	10020	1200
135	35000	116.3	123.6	33580	800
135	50000	116.6	123.8	35440	900
135		115.7	120.5	52480	1800
180	20	120.1	170.8	20	25
180	60	116.3	166.4	40	5
180	100	114.1	161.6	80	10
180	260	117.6	158.2	120	15
180	500	123.3	151.6	280	50
180	1000	124.7	147.1	520	100
180	3000	129.6	142.7	1020	150
180	5000	127.2	133.7	3180	450
180	10000	126.7	129.2	5020	700
180	20000	124.2	124.7	10320	1200
180	35000	116.1	123.5	33460	800
180	50000	114.9	123.7	35200	900
180		119.4	119.7	61600	900
225	20	120.1	170.8	20	25
225	60	116.3	166.4	40	5
225	100	114.1	161.6	80	10
225	260	117.6	158.2	120	15
225	500	123.3	151.6	280	50
225	1000	124.6	147.1	520	100

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
225	3000	129.6	142.7	1020	150
225	5000	127.3	133.6	3179	450
225	10000	126.7	129.3	5019	700
225	20000	124.3	124.6	14757	2000
225	35000	117.4	123.8	33573	800
225	50000	115.3	123.5	35453	900
225		119.4	120.3	61488	900
270	20	120.0	170.8	20	25
270	60	116.2	166.4	40	5
270	100	114.0	161.6	80	10
270	260	117.5	158.2	120	15
270	500	123.3	151.6	280	50
270	1000	124.6	147.1	520	100
270	3000	129.6	142.7	1020	150
270	5000	127.4	133.7	3140	450
270	10000	127.1	129.1	5020	700
270	20000	124.7	124.7	10120	2400
270	35000	117.2	123.6	33720	800
270	50000	116.0	123.7	35340	900
270		114.1	119.4	61580	900
315	20	120.0	170.8	20	25
315	60	116.2	166.4	40	5
315	100	114.0	161.6	80	10
315	260	117.6	158.2	120	15
315	500	123.3	151.6	280	50
315	1000	124.6	147.1	520	100
315	3000	129.6	142.7	1020	150
315	5000	127.3	133.7	3020	450
315	10000	126.9	129.0	5040	700
315	20000	124.3	124.6	10580	1000
315	35000	116.4	124.2	31940	700
315	50000	116.4	123.5	35400	900
315		113.3	119.6	61600	900

Table 29. Received Level by range bin for Site B, with February SSP, for the VSP Airgun Array.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	171.5	205.3	20	10
0	60	163.9	199.5	40	25
0	100	159.6	193.6	80	50
0	260	159.5	190.0	120	100
0	500	158.9	182.8	280	200
0	1000	160.4	177.4	520	350
0	3000	160.5	171.6	1040	800
0	5000	152.0	157.1	4720	25
0	10000	151.0	157.9	5640	75
0	20000	141.6	146.0	10080	2000
0	35000	132.5	144.7	24200	2200
0	50000	131.6	137.2	42360	75
0		125.8	133.5	51880	150
45	20	171.6	206.6	20	15
45	60	164.1	200.6	40	25
45	100	159.7	194.7	80	50
45	260	159.6	191.0	120	75
45	500	159.1	183.7	280	150
45	1000	161.0	178.4	520	300
45	3000	161.0	172.7	1020	600
45	5000	153.9	161.6	3040	800
45	10000	152.9	157.6	5020	2000
45	20000	143.8	150.4	10140	2000
45	35000	134.1	144.9	20560	25
45	50000	135.0	138.2	38540	20
45		131.4	135.2	51719	150
90	20	171.6	208.4	20	10
90	60	163.9	202.4	40	20
90	100	159.9	196.2	80	50
90	260	159.8	192.8	120	50

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
90	500	159.6	185.5	280	150
90	1000	161.8	180.2	520	250
90	3000	161.5	174.3	1020	500
90	5000	154.0	165.0	3020	1200
90	10000	154.7	161.9	5040	2000
90	20000	144.7	154.2	10280	2000
90	35000	136.5	147.8	20340	15
90	50000	145.9	145.9	38240	2600
90		133.8	139.6	53540	10
135	20	171.8	207.4	20	10
135	60	164.4	201.4	40	25
135	100	160.2	195.4	80	50
135	260	159.7	191.8	120	75
135	500	159.5	184.6	280	150
135	1000	161.6	179.2	520	300
135	3000	161.5	173.4	1020	600
135	5000	153.4	164.2	4860	2000
135	10000	156.0	164.0	5180	2000
135	20000	143.5	153.8	13440	2000
135	35000	137.8	143.1	21280	50
135	50000	135.8	139.6	40780	1200
135		132.8	145.2	54320	1200
180	20	171.9	206.4	20	10
180	60	163.6	200.5	40	25
180	100	160.2	194.6	80	50
180	260	159.6	190.9	120	75
180	500	159.4	183.7	280	200
180	1000	161.4	178.3	520	300
180	3000	161.1	172.5	1020	600
180	5000	152.2	163.2	3980	2000
180	10000	155.0	155.0	5220	2600
180	20000	143.2	146.5	15740	100
180	35000	137.6	141.5	20020	50

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
180	50000	133.6	145.4	48360	450
180		128.4	135.6	51440	150
225	20	171.8	207.4	20	10
225	60	164.2	201.4	40	25
225	100	160.1	195.4	80	50
225	260	159.7	191.8	120	75
225	500	159.5	184.6	280	150
225	1000	161.5	179.2	520	300
225	3000	161.4	173.5	1020	600
225	5000	153.2	162.9	3200	2000
225	10000	153.5	163.6	5499	2000
225	20000	142.6	149.2	10098	1800
225	35000	138.6	142.9	20576	25
225	50000	135.9	141.3	36973	900
225		132.2	136.2	51370	75
270	20	171.7	208.4	20	10
270	60	164.6	202.3	40	20
270	100	160.0	196.2	80	50
270	260	160.0	192.7	120	50
270	500	159.6	185.4	280	150
270	1000	161.5	180.1	520	250
270	3000	161.5	174.2	1020	450
270	5000	153.3	165.1	3040	1000
270	10000	154.7	160.6	5120	2000
270	20000	148.5	157.4	10320	2000
270	35000	139.6	146.7	20460	20
270	50000	135.5	143.6	42280	1200
270		132.2	140.0	55780	15
315	20	171.6	206.6	20	15
315	60	164.1	200.6	40	25
315	100	159.7	194.6	80	50
315	260	159.6	191.0	120	75
315	500	159.1	183.7	280	150

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
315	1000	161.1	178.4	520	300
315	3000	160.9	172.6	1040	600
315	5000	153.2	158.3	3020	700
315	10000	153.2	157.1	5180	2000
315	20000	144.3	149.4	10020	1800
315	35000	137.9	145.0	22060	2000
315	50000	132.8	137.8	38460	20
315		131.6	136.1	57860	100

Table 30. Received Level by range bin for Site B, with February SSP, for the support vessel.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	129.9	164.1	20	10
0	60	127.4	158.2	40	20
0	100	124.6	151.8	80	50
0	260	123.3	148.7	120	50
0	500	122.8	141.2	280	100
0	1000	123.1	135.9	520	250
0	3000	123.0	130.2	1020	450
0	5000	120.6	122.4	4200	25
0	10000	120.2	122.0	5040	50
0	20000	114.1	118.2	10740	100
0	35000	109.1	115.3	22800	25
0	50000	107.5	113.3	39400	15
0		104.1	111.4	51640	50
45	20	129.9	164.1	20	10
45	60	127.5	158.2	40	20
45	100	124.6	151.8	80	50
45	260	123.3	148.7	120	50
45	500	122.8	141.2	280	150
45	1000	123.1	135.9	520	250
45	3000	123.1	130.0	1020	400

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
45	5000	120.6	122.5	4240	25
45	10000	120.5	122.0	5600	75
45	20000	113.8	118.2	10740	100
45	35000	108.9	115.8	22480	15
45	50000	106.2	113.5	37120	5
45		104.2	111.4	64079	5
90	20	129.8	164.1	20	10
90	60	127.4	158.2	40	20
90	100	124.6	151.8	80	50
90	260	123.3	148.7	120	50
90	500	122.9	141.2	280	150
90	1000	123.2	135.9	520	200
90	3000	123.2	130.2	1020	450
90	5000	120.6	122.5	4200	25
90	10000	120.5	122.0	5580	75
90	20000	114.0	117.9	11320	5
90	35000	110.8	115.5	20980	75
90	50000	112.0	113.1	37120	5
90		106.7	111.5	53580	5
135	20	129.9	164.1	20	10
135	60	127.5	158.2	40	20
135	100	124.6	151.8	80	50
135	260	123.3	148.7	120	50
135	500	122.8	141.2	280	150
135	1000	123.2	135.9	520	200
135	3000	123.2	130.1	1020	450
135	5000	120.7	122.5	4160	25
135	10000	120.4	122.0	5540	75
135	20000	113.6	118.2	10820	100
135	35000	110.3	115.9	22500	15
135	50000	111.4	114.1	37100	5
135		108.5	112.5	51040	15
180	20	129.9	164.1	20	10

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
180	60	127.5	158.2	40	20
180	100	124.6	151.8	80	50
180	260	123.3	148.7	120	50
180	500	122.8	141.2	280	150
180	1000	123.2	135.9	520	200
180	3000	123.2	130.2	1020	450
180	5000	120.7	122.4	4200	25
180	10000	120.5	122.0	5580	75
180	20000	113.4	118.4	15220	5
180	35000	112.1	115.5	20220	50
180	50000	110.3	113.0	44640	50
180		105.4	111.6	52520	25
225	20	129.9	164.1	20	10
225	60	127.5	158.2	40	20
225	100	124.6	151.8	80	50
225	260	123.3	148.7	120	50
225	500	122.8	141.2	280	150
225	1000	123.1	135.9	520	250
225	3000	123.1	130.1	1020	450
225	5000	120.8	122.4	4239	25
225	10000	120.4	122.1	5019	50
225	20000	113.4	118.2	10898	100
225	35000	112.7	115.8	22456	15
225	50000	110.9	113.1	37113	5
225		107.6	111.5	53570	10
270	20	129.9	164.1	20	10
270	60	127.5	158.2	40	20
270	100	124.7	151.8	80	50
270	260	123.3	148.7	120	50
270	500	122.9	141.2	280	100
270	1000	123.1	135.9	520	250
270	3000	123.1	130.1	1020	450
270	5000	120.6	122.5	4160	25

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
270	10000	120.0	122.1	5020	50
270	20000	114.2	118.4	10260	75
270	35000	112.9	116.1	20200	50
270	50000	107.1	112.8	37120	5
270		104.0	111.3	64100	5
315	20	129.9	164.1	20	10
315	60	127.4	158.2	40	20
315	100	124.6	151.8	80	50
315	260	123.3	148.7	120	50
315	500	122.9	141.2	280	150
315	1000	123.1	135.9	520	250
315	3000	123.0	130.2	1020	450
315	5000	120.5	122.6	4160	25
315	10000	120.3	121.9	5540	75
315	20000	113.7	118.1	11480	10
315	35000	108.8	115.8	22440	15
315	50000	107.6	113.4	37120	5
315		107.4	111.3	64100	5

Table 31. Received Level by range bin for Site B, with February SSP, for the Generic Drill Ship.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	143.4	172.4	20	10
0	60	140.0	167.3	40	15
0	100	136.3	161.3	80	20
0	260	134.0	157.9	120	25
0	500	131.3	150.8	280	75
0	1000	131.6	145.3	520	150
0	3000	131.5	139.6	1020	250
0	5000	129.4	133.6	4320	20
0	10000	129.3	132.2	5020	50
0	20000	124.2	129.4	10180	75

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	35000	118.3	126.9	20200	15
0	50000	116.4	124.9	38540	20
0		114.3	122.4	51620	15
45	20	143.4	172.4	20	10
45	60	140.0	167.3	40	15
45	100	136.3	161.3	80	20
45	260	134.0	157.9	120	25
45	500	131.3	150.8	280	75
45	1000	131.6	145.3	520	150
45	3000	131.6	139.5	1020	250
45	5000	129.7	133.7	4180	15
45	10000	129.5	132.2	5180	50
45	20000	123.4	128.9	10220	75
45	35000	118.5	127.0	20300	15
45	50000	116.7	125.5	38460	15
45		113.5	122.6	52819	15
90	20	143.3	172.4	20	10
90	60	139.9	167.3	40	15
90	100	136.3	161.3	80	20
90	260	134.0	157.9	120	25
90	500	131.3	150.8	280	75
90	1000	131.7	145.3	520	150
90	3000	131.7	139.5	1020	250
90	5000	129.6	133.7	4320	20
90	10000	129.6	132.2	5160	50
90	20000	123.4	128.9	10160	75
90	35000	120.2	127.0	20340	15
90	50000	121.8	125.1	38440	15
90		115.6	122.6	53540	15
135	20	143.3	172.4	20	10
135	60	140.0	167.3	40	15
135	100	136.3	161.3	80	20
135	260	134.1	157.9	120	25

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
135	500	131.3	150.8	280	75
135	1000	131.7	145.3	520	150
135	3000	131.7	139.5	1020	200
135	5000	129.6	133.7	4360	20
135	10000	129.6	132.2	5100	50
135	20000	123.2	129.2	10260	75
135	35000	120.7	126.6	20280	15
135	50000	121.0	124.9	38440	15
135		118.0	123.2	51060	15
180	20	143.3	172.4	20	10
180	60	140.0	167.3	40	15
180	100	136.3	161.3	80	20
180	260	134.0	157.9	120	25
180	500	131.3	150.8	280	75
180	1000	131.7	145.3	520	150
180	3000	131.7	139.5	1020	250
180	5000	129.4	133.7	4360	20
180	10000	129.3	132.2	5080	50
180	20000	123.4	129.6	10220	75
180	35000	121.0	127.3	20240	15
180	50000	121.1	124.7	38460	15
180		116.7	122.6	52740	15
225	20	143.3	172.4	20	10
225	60	140.0	167.3	40	15
225	100	136.3	161.3	80	20
225	260	134.0	157.9	120	25
225	500	131.3	150.8	280	75
225	1000	131.6	145.3	520	150
225	3000	131.6	139.5	1020	250
225	5000	129.6	133.7	4339	20
225	10000	129.5	132.2	5159	50
225	20000	123.3	129.3	10278	75
225	35000	122.6	127.0	20276	15

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
225	50000	120.4	124.5	38452	15
225		118.2	123.4	51550	15
270	20	143.4	172.4	20	10
270	60	140.0	167.3	40	15
270	100	136.3	161.3	80	20
270	260	134.1	157.9	120	25
270	500	131.3	150.8	280	75
270	1000	131.6	145.3	520	150
270	3000	131.6	139.6	1020	250
270	5000	129.5	133.6	4200	15
270	10000	129.2	132.1	5040	50
270	20000	124.1	129.3	11020	100
270	35000	123.0	127.4	20280	15
270	50000	118.2	124.7	38440	15
270		114.5	122.5	53660	15
315	20	143.3	172.4	20	10
315	60	140.0	167.3	40	15
315	100	136.3	161.3	80	20
315	260	134.0	157.9	120	25
315	500	131.3	150.8	280	75
315	1000	131.6	145.3	520	150
315	3000	131.5	139.6	1020	250
315	5000	129.4	133.7	4380	20
315	10000	129.3	132.2	5140	50
315	20000	123.6	129.3	10240	75
315	35000	119.0	126.9	20300	15
315	50000	116.9	124.8	38460	15
315		116.8	122.4	51360	20

Table 32. Received Level by range bin for Site B, with February SSP, for the *Stena Forth* Drill Ship.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	142.2	167.3	20	5
0	60	138.1	162.3	40	10
0	100	133.6	156.4	80	20
0	260	130.9	152.7	120	50
0	500	126.1	145.2	280	20
0	1000	126.3	139.8	520	200
0	3000	125.4	134.3	1020	200
0	5000	123.8	132.9	4000	15
0	10000	123.1	130.0	5620	75
0	20000	116.0	127.7	11080	20
0	35000	112.3	125.5	22400	15
0	50000	110.3	123.3	41680	10
0		108.5	121.4	57760	50
45	20	142.2	167.3	20	5
45	60	138.0	162.3	40	10
45	100	133.6	156.4	80	20
45	260	130.9	152.7	120	50
45	500	126.1	145.2	280	20
45	1000	126.2	139.8	520	200
45	3000	125.5	134.3	1020	200
45	5000	123.9	132.9	4040	15
45	10000	123.5	130.1	5020	50
45	20000	116.1	127.5	11040	20
45	35000	112.7	125.7	26460	15
45	50000	109.7	123.3	41680	10
45		105.3	121.4	57759	50
90	20	142.1	167.3	20	5
90	60	137.9	162.3	40	10
90	100	133.5	156.4	80	20
90	260	130.9	152.7	120	50
90	500	126.1	145.2	280	20
90	1000	126.1	139.8	520	200

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
90	3000	125.4	134.3	1020	200
90	5000	124.0	132.9	4060	15
90	10000	123.5	130.2	5640	75
90	20000	116.2	127.5	11080	20
90	35000	114.5	125.6	22380	15
90	50000	115.1	123.4	37760	10
90		109.6	121.5	57760	50
135	20	142.2	167.3	20	5
135	60	138.0	162.3	40	10
135	100	133.6	156.4	80	20
135	260	130.9	152.7	120	50
135	500	126.1	145.2	280	20
135	1000	126.1	139.8	520	200
135	3000	125.4	134.3	1020	200
135	5000	124.0	132.9	4060	15
135	10000	123.4	130.2	5620	75
135	20000	116.6	127.8	11100	20
135	35000	115.2	126.4	22320	15
135	50000	117.6	123.5	41660	10
135		114.4	121.8	57740	50
180	20	142.2	167.3	20	5
180	60	138.0	162.3	40	10
180	100	133.6	156.4	80	20
180	260	130.9	152.7	120	50
180	500	126.1	145.2	280	20
180	1000	126.1	139.8	520	200
180	3000	125.4	134.3	1020	200
180	5000	124.0	132.9	4020	15
180	10000	123.1	130.4	5640	75
180	20000	117.3	128.2	11080	20
180	35000	112.3	125.7	22380	15
180	50000	117.4	123.4	41660	10
180		110.8	121.1	55540	25

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
225	20	142.2	167.3	20	5
225	60	138.0	162.3	40	10
225	100	133.6	156.4	80	20
225	260	130.9	152.7	120	50
225	500	126.1	145.2	280	20
225	1000	126.1	139.8	520	200
225	3000	125.4	134.3	1020	200
225	5000	123.8	132.9	3999	15
225	10000	123.2	130.3	5659	75
225	20000	117.0	128.0	11118	20
225	35000	115.2	126.2	26435	10
225	50000	116.3	123.2	41632	10
225		114.8	121.5	53790	50
270	20	142.2	167.3	20	5
270	60	138.0	162.3	40	10
270	100	133.6	156.4	80	20
270	260	131.0	152.7	120	50
270	500	126.2	145.2	280	20
270	1000	126.3	139.8	520	200
270	3000	125.4	134.4	1020	200
270	5000	123.8	132.9	4060	15
270	10000	122.8	130.1	5660	75
270	20000	117.5	128.5	11080	20
270	35000	114.7	125.8	22600	15
270	50000	111.0	123.3	41660	10
270		109.5	121.4	55560	25
315	20	142.2	167.3	20	5
315	60	138.1	162.3	40	10
315	100	133.6	156.4	80	20
315	260	130.9	152.7	120	50
315	500	126.1	145.2	280	20
315	1000	126.3	139.8	520	200
315	3000	125.4	134.4	1020	200

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
315	5000	123.8	132.9	4060	15
315	10000	123.2	130.1	5620	75
315	20000	116.5	127.8	11020	20
315	35000	111.9	125.8	22380	15
315	50000	110.7	123.4	41720	10
315		110.1	121.2	57760	50

Table 33. Received Level by range bin for Site B, with February SSP, for the Semisubmersible Drilling platform.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	122.1	170.5	20	25
0	60	119.4	166.6	40	5
0	100	116.4	161.9	80	10
0	260	120.8	158.7	120	15
0	500	125.8	151.2	280	25
0	1000	125.9	146.3	520	50
0	3000	130.5	140.5	1020	100
0	5000	128.0	137.0	4620	25
0	10000	128.8	136.0	5060	25
0	20000	121.3	132.4	11420	25
0	35000	116.5	130.1	20180	25
0	50000	115.4	128.3	38420	25
0		112.5	126.3	51500	25
45	20	122.1	170.5	20	25
45	60	119.4	166.6	40	5
45	100	116.4	161.9	80	10
45	260	120.8	158.7	120	15
45	500	125.8	151.2	280	25
45	1000	126.0	146.3	520	50
45	3000	130.6	140.6	1020	100
45	5000	128.4	137.0	4620	25
45	10000	128.9	136.1	5060	25

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
45	20000	120.9	132.2	11540	25
45	35000	116.1	130.0	20180	25
45	50000	113.5	128.3	38460	25
45		111.3	126.3	53660	25
90	20	122.0	170.5	20	25
90	60	119.3	166.6	40	5
90	100	116.3	161.9	80	10
90	260	120.8	158.7	120	15
90	500	125.8	151.2	280	25
90	1000	125.9	146.3	520	50
90	3000	130.6	140.5	1020	100
90	5000	128.4	137.0	3840	25
90	10000	129.0	136.0	5120	25
90	20000	121.3	132.3	11480	25
90	35000	118.7	129.7	21340	25
90	50000	119.9	128.2	38460	25
90		114.0	126.3	53680	25
135	20	122.0	170.5	20	25
135	60	119.4	166.6	40	5
135	100	116.4	161.9	80	10
135	260	120.7	158.7	120	15
135	500	125.8	151.2	280	25
135	1000	126.0	146.3	520	50
135	3000	130.7	140.5	1020	100
135	5000	128.5	137.0	4620	25
135	10000	128.7	136.1	5080	25
135	20000	121.6	132.3	11400	25
135	35000	118.0	130.3	20160	25
135	50000	120.1	128.4	38440	25
135		118.3	126.1	53660	25
180	20	122.0	170.5	20	25
180	60	119.4	166.6	40	5
180	100	116.4	161.9	80	10

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
180	260	120.8	158.7	120	15
180	500	125.8	151.2	280	25
180	1000	125.9	146.3	520	50
180	3000	130.7	140.5	1020	100
180	5000	128.6	137.0	4620	25
180	10000	128.5	136.2	5020	25
180	20000	121.7	132.3	11440	25
180	35000	120.4	130.1	20200	25
180	50000	120.2	128.0	38380	25
180		116.9	126.2	51480	25
225	20	122.1	170.5	20	25
225	60	119.4	166.6	40	5
225	100	116.4	161.9	80	10
225	260	120.8	158.7	120	15
225	500	125.8	151.2	280	25
225	1000	125.9	146.3	520	50
225	3000	130.6	140.5	1020	100
225	5000	128.5	137.1	4639	25
225	10000	128.8	136.0	5039	25
225	20000	121.9	132.2	12398	25
225	35000	120.4	130.2	20156	25
225	50000	119.9	128.0	38532	25
225		118.7	126.8	51650	25
270	20	122.1	170.5	20	25
270	60	119.5	166.6	40	5
270	100	116.5	161.9	80	10
270	260	120.7	158.7	120	15
270	500	125.8	151.2	280	25
270	1000	125.9	146.3	520	50
270	3000	130.6	140.5	1020	100
270	5000	128.3	137.0	4640	25
270	10000	128.3	136.1	5080	25
270	20000	122.1	132.6	10640	25

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
270	35000	120.2	130.2	20160	25
270	50000	114.6	128.1	38460	25
270		111.4	126.3	53660	25
315	20	122.1	170.5	20	25
315	60	119.4	166.6	40	5
315	100	116.4	161.9	80	10
315	260	120.7	158.7	120	15
315	500	125.8	151.2	280	25
315	1000	125.9	146.3	520	50
315	3000	130.5	140.5	1020	100
315	5000	128.0	137.0	4600	25
315	10000	128.7	136.1	5020	25
315	20000	121.7	132.5	11440	25
315	35000	116.4	129.9	20140	25
315	50000	115.9	128.3	38520	25
315		115.8	126.3	51540	25

Table 34. Received Level by range bin for Site B, with August SSP, for the VSP Airgun Array.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	171.4	205.3	20	15
0	60	163.9	199.3	40	25
0	100	159.5	193.3	80	50
0	260	159.4	189.9	120	100
0	500	158.8	182.7	280	200
0	1000	160.5	177.4	520	350
0	3000	160.5	171.5	1040	800
0	5000	151.7	156.4	4520	2000
0	10000	150.7	153.4	8960	10
0	20000	141.0	153.0	10280	10
0	35000	132.1	144.1	24140	2200
0	50000	131.3	132.7	39760	15

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0		125.9	130.6	51080	15
45	20	171.5	206.5	20	15
45	60	164.1	200.5	40	25
45	100	159.6	194.5	80	50
45	260	159.6	190.9	120	75
45	500	159.1	183.7	280	200
45	1000	161.1	178.5	520	350
45	3000	161.0	172.7	1020	600
45	5000	153.7	161.6	3200	2000
45	10000	152.7	158.2	5020	2000
45	20000	142.9	154.3	10320	10
45	35000	134.1	144.0	23200	2200
45	50000	132.9	135.2	36640	2200
45		130.7	130.7	53739	2600
90	20	171.5	208.4	20	10
90	60	163.9	202.3	40	20
90	100	159.9	196.1	80	50
90	260	159.8	192.6	120	75
90	500	159.6	185.6	280	150
90	1000	161.9	180.3	520	250
90	3000	161.6	174.5	1020	500
90	5000	154.0	165.1	3020	1200
90	10000	154.7	162.5	5060	2000
90	20000	144.0	156.5	14140	10
90	35000	136.3	154.4	30580	5
90	50000	145.9	145.9	38240	2600
90		133.5	135.7	53060	1800
135	20	171.6	207.3	20	10
135	60	164.5	201.2	40	25
135	100	160.1	195.3	80	50
135	260	159.8	191.7	120	75
135	500	159.5	184.6	280	150
135	1000	161.7	179.3	520	300

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
135	3000	161.6	173.5	1020	600
135	5000	153.4	164.0	4860	2000
135	10000	156.2	163.8	5180	2000
135	20000	142.4	155.4	10240	10
135	35000	137.5	146.6	30540	10
135	50000	135.2	145.5	47560	5
135		130.1	143.9	50120	10
180	20	171.7	206.3	20	10
180	60	163.7	200.3	40	25
180	100	160.1	194.4	80	50
180	260	159.5	190.8	120	75
180	500	159.4	183.7	280	200
180	1000	161.4	178.3	520	350
180	3000	161.2	172.5	1020	600
180	5000	152.2	163.1	3500	2000
180	10000	154.6	155.0	9540	10
180	20000	142.0	154.4	10080	10
180	35000	136.1	139.5	24260	1800
180	50000	131.7	147.7	40480	10
180		120.6	125.4	51180	150
225	20	171.6	207.3	20	10
225	60	164.5	201.2	40	25
225	100	160.1	195.3	80	50
225	260	159.8	191.7	120	75
225	500	159.5	184.5	280	150
225	1000	161.6	179.3	520	300
225	3000	161.5	173.6	1020	600
225	5000	153.2	163.3	3459	2000
225	10000	153.5	163.4	5499	2000
225	20000	141.3	155.1	10158	5
225	35000	138.7	151.5	28474	10
225	50000	132.7	145.5	44012	5
225		127.6	131.7	50050	600

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
270	20	171.5	208.3	20	10
270	60	164.7	202.2	40	20
270	100	159.9	196.1	80	50
270	260	159.9	192.6	120	75
270	500	159.6	185.5	280	150
270	1000	161.7	180.2	520	250
270	3000	161.6	174.4	1020	450
270	5000	153.5	165.0	3060	1400
270	10000	154.7	160.9	5200	2000
270	20000	147.1	157.7	10700	5
270	35000	138.9	144.8	25400	1800
270	50000	134.4	137.9	36120	1800
270		130.6	130.9	50740	1600
315	20	171.5	206.5	20	15
315	60	164.1	200.4	40	25
315	100	159.6	194.4	80	50
315	260	159.6	190.9	120	75
315	500	159.1	183.7	280	200
315	1000	161.1	178.4	520	350
315	3000	160.9	172.5	1040	600
315	5000	153.0	158.2	3020	2000
315	10000	153.0	156.9	5180	2000
315	20000	143.2	154.2	10760	10
315	35000	137.5	144.5	22080	2000
315	50000	132.1	135.5	36640	2200
315		130.9	131.8	50680	2000

Table 35. Received Level by range bin for Site B, with August SSP, for the support vessel.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	129.8	164.1	20	10
0	60	127.4	158.1	40	20

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	100	124.6	151.7	80	50
0	260	123.3	148.4	120	50
0	500	122.9	141.3	280	150
0	1000	123.3	136.2	520	250
0	3000	123.2	130.3	1020	450
0	5000	120.8	121.7	3060	1400
0	10000	120.5	120.5	5540	2200
0	20000	114.5	114.5	10080	2200
0	35000	109.1	110.0	21020	1600
0	50000	107.0	109.1	45480	1400
0		105.0	108.5	52820	1800
45	20	129.8	164.1	20	10
45	60	127.4	158.1	40	20
45	100	124.6	151.7	80	50
45	260	123.3	148.4	120	50
45	500	122.9	141.3	280	150
45	1000	123.3	136.2	520	250
45	3000	123.3	130.4	1020	400
45	5000	120.9	121.6	3040	1600
45	10000	120.6	120.6	5080	2200
45	20000	114.2	114.2	10040	2200
45	35000	108.8	109.7	20480	2000
45	50000	106.9	110.1	49459	1600
45		104.5	108.9	52899	1800
90	20	129.8	164.1	20	10
90	60	127.4	158.1	40	20
90	100	124.6	151.7	80	50
90	260	123.3	148.4	120	50
90	500	122.9	141.3	280	150
90	1000	123.4	136.2	520	250
90	3000	123.3	130.4	1020	500
90	5000	120.8	121.3	3020	1200
90	10000	120.6	120.6	5180	2200

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
90	20000	114.4	114.4	10240	2200
90	35000	111.4	111.4	22440	2200
90	50000	112.6	112.6	38360	2400
90		106.7	108.8	53040	1800
135	20	129.8	164.1	20	10
135	60	127.4	158.1	40	20
135	100	124.6	151.7	80	50
135	260	123.3	148.4	120	50
135	500	122.9	141.3	280	150
135	1000	123.4	136.2	520	250
135	3000	123.4	130.4	1020	400
135	5000	120.9	121.5	3040	1200
135	10000	120.6	120.6	5180	2200
135	20000	114.2	114.2	10160	2200
135	35000	110.4	112.2	20900	1000
135	50000	111.7	113.1	37260	5
135		107.7	107.7	53940	1000
180	20	129.8	164.1	20	10
180	60	127.4	158.1	40	20
180	100	124.6	151.7	80	50
180	260	123.3	148.4	120	50
180	500	122.9	141.3	280	150
180	1000	123.4	136.2	520	250
180	3000	123.4	130.4	1020	400
180	5000	120.9	121.5	3060	1200
180	10000	120.6	120.6	5100	2000
180	20000	113.8	113.8	10020	2000
180	35000	112.5	112.5	22200	1800
180	50000	109.0	110.3	44580	5
180		94.0	94.0	50560	400
225	20	129.8	164.1	20	10
225	60	127.4	158.1	40	20
225	100	124.6	151.7	80	50

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
225	260	123.3	148.4	120	50
225	500	122.9	141.3	280	150
225	1000	123.3	136.2	520	250
225	3000	123.2	130.3	1020	400
225	5000	121.1	121.6	3039	1600
225	10000	120.6	120.6	5319	2200
225	20000	114.1	114.1	10278	1800
225	35000	112.3	112.3	32914	1600
225	50000	108.2	108.9	47791	5
225		107.4	107.4	50410	600
270	20	129.8	164.1	20	10
270	60	127.4	158.1	40	20
270	100	124.6	151.7	80	50
270	260	123.3	148.4	120	50
270	500	123.0	141.3	280	150
270	1000	123.3	136.2	520	250
270	3000	123.3	130.4	1020	450
270	5000	120.8	121.5	3040	1000
270	10000	120.2	120.2	5080	2200
270	20000	114.4	115.3	13160	1400
270	35000	112.2	112.2	24980	1800
270	50000	106.6	109.0	45500	1400
270		104.0	104.5	51420	1400
315	20	129.8	164.1	20	10
315	60	127.4	158.1	40	20
315	100	124.6	151.7	80	50
315	260	123.3	148.4	120	50
315	500	123.0	141.3	280	150
315	1000	123.3	136.2	520	250
315	3000	123.2	130.3	1020	450
315	5000	120.7	121.4	3060	1200
315	10000	120.6	120.6	5320	2200
315	20000	114.4	114.4	10100	2200

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
315	35000	109.0	109.6	20860	1400
315	50000	107.7	109.9	49440	1600
315		107.8	107.8	50620	2200

Table 36. Received Level by range bin for Site B, with August SSP, for the Generic Drill Ship.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	143.4	172.4	20	10
0	60	140.1	167.2	40	15
0	100	136.4	161.3	80	25
0	260	134.1	157.7	120	50
0	500	131.4	150.9	280	100
0	1000	131.7	145.9	520	150
0	3000	131.7	140.2	1020	250
0	5000	129.9	131.1	3020	800
0	10000	130.0	130.0	5760	2200
0	20000	125.0	125.0	10040	2200
0	35000	119.4	120.4	21060	1600
0	50000	117.3	120.0	45700	1400
0		115.4	118.0	52880	1800
45	20	143.4	172.4	20	10
45	60	140.1	167.2	40	15
45	100	136.4	161.3	80	25
45	260	134.1	157.7	120	50
45	500	131.4	150.9	280	100
45	1000	131.8	145.9	520	150
45	3000	131.8	140.2	1020	300
45	5000	130.2	131.1	3020	800
45	10000	130.2	130.2	5340	2200
45	20000	124.5	124.5	10020	2200
45	35000	119.1	120.2	21260	1800
45	50000	117.0	120.3	49379	1600

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
45		114.3	118.0	53000	1800
90	20	143.4	172.4	20	10
90	60	140.0	167.2	40	15
90	100	136.3	161.3	80	25
90	260	134.1	157.7	120	50
90	500	131.4	150.9	280	100
90	1000	131.8	145.9	520	150
90	3000	131.9	140.2	1020	300
90	5000	130.2	131.0	3020	1000
90	10000	130.3	130.3	5040	2200
90	20000	124.7	124.7	10080	2200
90	35000	121.1	121.9	30560	15
90	50000	122.5	122.5	38320	2400
90		116.6	119.2	53140	1800
135	20	143.4	172.4	20	10
135	60	140.0	167.2	40	15
135	100	136.4	161.3	80	25
135	260	134.2	157.7	120	50
135	500	131.4	150.9	280	100
135	1000	131.8	145.9	520	150
135	3000	131.8	140.1	1020	300
135	5000	130.1	130.9	3040	800
135	10000	130.3	130.3	5160	2200
135	20000	124.5	124.5	10140	2200
135	35000	120.9	122.4	21180	900
135	50000	121.9	123.3	37240	10
135		118.4	118.9	51100	10
180	20	143.4	172.4	20	10
180	60	140.0	167.2	40	15
180	100	136.4	161.3	80	25
180	260	134.1	157.7	120	50
180	500	131.4	150.9	280	100
180	1000	131.8	145.9	520	150

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
180	3000	131.8	140.2	1020	300
180	5000	130.1	131.2	3020	800
180	10000	130.2	130.2	5080	2000
180	20000	124.5	124.8	10380	1400
180	35000	122.3	122.3	22220	1800
180	50000	119.7	123.1	44560	5
180		109.5	110.2	52300	350
225	20	143.4	172.4	20	10
225	60	140.1	167.2	40	15
225	100	136.4	161.3	80	25
225	260	134.1	157.7	120	50
225	500	131.4	150.9	280	100
225	1000	131.8	145.9	520	150
225	3000	131.8	140.2	1020	300
225	5000	130.1	131.0	3019	800
225	10000	130.4	130.4	5299	2200
225	20000	124.6	124.6	10238	2000
225	35000	123.7	123.7	32934	1600
225	50000	120.2	120.5	47751	10
225		118.3	118.3	50430	600
270	20	143.4	172.4	20	10
270	60	140.1	167.2	40	15
270	100	136.4	161.3	80	25
270	260	134.2	157.7	120	50
270	500	131.4	150.9	280	100
270	1000	131.7	145.9	520	150
270	3000	131.7	140.2	1020	250
270	5000	130.1	131.3	3020	1000
270	10000	130.0	130.0	5460	2200
270	20000	125.1	125.7	18200	10
270	35000	124.0	124.0	24940	1800
270	50000	119.1	120.5	45460	1400
270		114.9	115.7	51400	1400

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
315	20	143.4	172.4	20	10
315	60	140.1	167.2	40	15
315	100	136.4	161.3	80	25
315	260	134.1	157.7	120	50
315	500	131.4	150.9	280	100
315	1000	131.7	145.9	520	150
315	3000	131.7	140.2	1020	250
315	5000	130.0	131.2	3020	800
315	10000	130.1	130.1	5340	2200
315	20000	124.5	124.5	10080	2200
315	35000	119.5	120.6	21240	1400
315	50000	118.2	120.4	45380	1400
315		117.5	117.5	50500	2200

Table 37. Received Level by range bin for Site B, with August SSP, for the *Stena Forth* Drill Ship.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	142.1	167.1	20	10
0	60	138.0	162.3	40	10
0	100	133.5	156.3	80	20
0	260	130.8	152.1	120	10
0	500	126.1	145.2	280	75
0	1000	126.3	140.8	520	150
0	3000	125.3	135.6	1060	200
0	5000	124.3	126.9	3020	500
0	10000	122.8	123.9	5060	800
0	20000	119.3	120.4	10500	1400
0	35000	113.5	116.6	32720	20
0	50000	111.3	118.3	45360	1400
0		110.1	114.8	52860	1800
45	20	142.1	167.1	20	10
45	60	137.9	162.3	40	10

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
45	100	133.6	156.3	80	20
45	260	130.9	152.1	120	10
45	500	126.2	145.2	280	75
45	1000	126.2	140.8	520	150
45	3000	125.4	135.6	1060	200
45	5000	124.4	126.9	3020	500
45	10000	123.1	123.9	5060	800
45	20000	118.8	120.8	10460	1400
45	35000	112.4	115.6	34300	15
45	50000	109.3	118.0	49340	1600
45		108.1	115.5	53000	1800
90	20	142.1	167.1	20	10
90	60	137.8	162.3	40	10
90	100	133.5	156.3	80	20
90	260	130.8	152.1	120	10
90	500	126.2	145.2	280	75
90	1000	126.2	140.8	520	150
90	3000	125.3	135.6	1060	200
90	5000	124.4	126.9	3020	500
90	10000	123.0	123.7	5060	800
90	20000	118.6	120.6	11100	1400
90	35000	114.5	117.0	21220	1800
90	50000	115.0	117.3	49500	1600
90		111.0	115.4	53100	1800
135	20	142.1	167.1	20	10
135	60	137.9	162.3	40	10
135	100	133.5	156.3	80	20
135	260	130.8	152.1	120	10
135	500	126.2	145.2	280	75
135	1000	126.1	140.8	520	150
135	3000	125.4	135.6	1060	200
135	5000	124.3	127.0	3020	500
135	10000	123.4	123.7	5040	800

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
135	20000	116.7	121.3	10340	1400
135	35000	113.7	118.0	30560	20
135	50000	118.3	118.3	46100	1600
135		115.5	117.4	51180	5
180	20	142.1	167.1	20	10
180	60	137.9	162.3	40	10
180	100	133.5	156.3	80	20
180	260	130.8	152.1	120	10
180	500	126.1	145.2	280	75
180	1000	126.1	140.8	520	150
180	3000	125.3	135.6	1060	200
180	5000	124.3	126.9	3020	500
180	10000	123.8	123.8	6980	2000
180	20000	115.1	122.5	10200	1400
180	35000	117.9	119.9	20540	1400
180	50000	116.5	120.8	44520	5
180		103.6	104.9	50020	25
225	20	142.1	167.1	20	10
225	60	137.9	162.3	40	10
225	100	133.5	156.3	80	20
225	260	130.8	152.1	120	10
225	500	126.1	145.2	280	75
225	1000	126.2	140.8	520	150
225	3000	125.3	135.6	1060	200
225	5000	124.5	127.0	3019	500
225	10000	123.3	123.8	5059	800
225	20000	115.3	121.3	10058	1400
225	35000	118.7	119.0	28494	10
225	50000	115.6	120.4	47851	10
225		116.3	116.3	50330	600
270	20	142.1	167.1	20	10
270	60	137.9	162.3	40	10
270	100	133.6	156.3	80	20

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
270	260	131.0	152.1	120	10
270	500	126.2	145.2	280	75
270	1000	126.3	140.8	520	150
270	3000	125.3	135.6	1060	200
270	5000	124.4	126.9	3020	500
270	10000	123.1	124.0	5040	800
270	20000	116.8	121.0	10120	1400
270	35000	116.2	118.6	32420	10
270	50000	113.2	117.3	45500	1400
270		110.8	114.1	60520	10
315	20	142.1	167.1	20	10
315	60	138.0	162.3	40	10
315	100	133.5	156.3	80	20
315	260	130.9	152.1	120	10
315	500	126.1	145.2	280	75
315	1000	126.3	140.8	520	150
315	3000	125.3	135.6	1060	200
315	5000	124.3	126.9	3020	500
315	10000	122.9	123.8	5040	800
315	20000	118.4	121.0	10120	1400
315	35000	113.3	117.5	22160	1800
315	50000	111.5	117.7	45420	1400
315		113.3	113.9	85060	1600

Table 38. Received Level by range bin for Site B, with August SSP, for the Semisubmersible Drilling platform.

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	20	122.1	170.8	20	25
0	60	119.5	166.4	40	5
0	100	116.5	161.6	80	10
0	260	121.3	158.2	120	15
0	500	125.0	151.8	280	50
0	1000	127.9	147.3	540	100

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
0	3000	130.7	143.3	1020	150
0	5000	128.6	133.4	3020	450
0	10000	128.3	128.4	5220	700
0	20000	124.3	124.5	10100	1200
0	35000	117.4	124.5	33400	800
0	50000	115.0	124.0	35180	900
0		113.8	120.0	61300	900
45	20	122.1	170.8	20	25
45	60	119.5	166.4	40	5
45	100	116.5	161.6	80	10
45	260	121.2	158.2	120	15
45	500	125.0	151.8	280	50
45	1000	128.2	147.3	540	100
45	3000	130.8	143.3	1020	150
45	5000	128.8	133.2	3120	450
45	10000	128.5	128.6	5120	700
45	20000	124.4	124.4	10060	1000
45	35000	116.5	124.1	31300	700
45	50000	114.7	123.4	35060	900
45		112.5	120.2	61439	900
90	20	122.0	170.8	20	25
90	60	119.4	166.4	40	5
90	100	116.5	161.6	80	10
90	260	121.3	158.2	120	15
90	500	125.1	151.8	280	50
90	1000	128.2	147.3	540	100
90	3000	130.9	143.3	1020	150
90	5000	128.6	133.2	3020	450
90	10000	128.6	128.6	5680	2200
90	20000	124.4	124.4	10260	1600
90	35000	118.3	124.4	33580	800
90	50000	119.3	123.2	35240	900
90		115.4	120.1	61280	900

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
135	20	122.1	170.8	20	25
135	60	119.5	166.4	40	5
135	100	116.5	161.6	80	10
135	260	121.2	158.2	120	15
135	500	125.1	151.8	280	50
135	1000	128.3	147.3	540	100
135	3000	130.9	143.3	1020	150
135	5000	128.7	133.2	3080	450
135	10000	128.3	128.6	5040	700
135	20000	124.3	124.5	10540	1800
135	35000	120.7	124.5	33480	800
135	50000	123.9	123.9	40800	1200
135		120.9	122.1	63200	20
180	20	122.1	170.8	20	25
180	60	119.5	166.4	40	5
180	100	116.5	161.6	80	10
180	260	121.3	158.2	120	15
180	500	125.1	151.8	280	50
180	1000	128.2	147.3	540	100
180	3000	130.9	143.3	1020	150
180	5000	128.8	133.3	3100	450
180	10000	128.2	128.6	5120	700
180	20000	124.0	125.6	10240	1400
180	35000	120.6	124.3	31640	700
180	50000	122.8	124.6	44560	10
180		119.1	120.1	50200	25
225	20	122.1	170.8	20	25
225	60	119.5	166.4	40	5
225	100	116.5	161.6	80	10
225	260	121.2	158.2	120	15
225	500	125.0	151.8	280	50
225	1000	128.0	147.3	540	100
225	3000	130.8	143.3	1020	150

Azimuth (°)	Max range in bin (m)	SPL at bottom (dB re 1 µPa)	Max SPL at depth (dB re 1 µPa)	Range of max RL in bin (m)	Depth of max RL in bin (m)
225	5000	128.7	133.2	3099	450
225	10000	128.3	128.6	5019	700
225	20000	124.2	124.8	10238	1000
225	35000	122.4	124.2	29134	600
225	50000	120.7	122.9	36693	1000
225		121.1	121.2	51650	25
270	20	122.2	170.8	20	25
270	60	119.6	166.4	40	5
270	100	116.6	161.6	80	10
270	260	121.2	158.2	120	15
270	500	125.0	151.8	280	50
270	1000	128.0	147.3	540	100
270	3000	130.8	143.3	1020	150
270	5000	128.4	133.3	3020	450
270	10000	127.8	128.6	5020	700
270	20000	124.4	125.5	14740	1000
270	35000	122.6	124.5	33380	800
270	50000	118.2	123.5	35240	900
270		116.0	120.6	54800	700
315	20	122.1	170.8	20	25
315	60	119.5	166.4	40	5
315	100	116.5	161.6	80	10
315	260	121.2	158.2	120	15
315	500	125.0	151.8	280	50
315	1000	127.9	147.3	540	100
315	3000	130.8	143.3	1020	150
315	5000	128.6	133.2	3020	450
315	10000	128.0	128.8	5040	700
315	20000	124.3	124.4	11600	1000
315	35000	116.8	124.3	31560	700
315	50000	116.4	123.3	35280	900
315		115.6	120.3	61300	900

APPENDIX F

Spill Modelling Analysis Report

Annex A: Oil Spill Trajectory and Fate Assessment: Mitigation Modelling

BHP CANADA
ORPHAN BASIN EXPLORATION DRILLING PROJECT 2019-2028
19-P-204068

Oil Spill Trajectory and Fate Assessment

Oil Spill Risk Assessment
BHP Canada
Orphan Basin Exploration
Drilling Project 2019-2028
19-P-204068
Final
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Document Status

Version	Purpose of document	Authored by	Reviewed by	Approved by	Review date
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Draft	Oil Spill Trajectory and Fate Assessment: Technical Report	LM, ST, JZ, DT, MM, TT, MF, JD, MH	MH	MH	December 6, 2019
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Approval for issue

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Matt Horn 2020-02-07

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EXECUTIVE SUMMARY

Study Summary

Oil spill trajectory and fate modelling was performed to support an Environmental Assessment (EA) for the BHP Canada Exploration Drilling Project 2019-2028 in the Orphan Basin area. Hypothetical releases were modelled at two locations in the Orphan Basin located more than 350 km east-northeast of St. John's, Newfoundland. Two hypothetical subsurface blowout scenarios were developed within the Project Area in the blocks of interest (EL 1157 and EL 1158). Releases were modelled as unmitigated subsurface blowouts of Bay du Nord crude oil (BdN). The subsurface blowouts at each release site were simulated as continuous 30- and 120-day releases, with total simulation times of 160 days. The 120-day releases represent the anticipated time to kill the well by mobilizing a mobile offshore drilling unit (MODU) and drilling a relief well, while the 30-day release represents a conservatively long amount of time to successfully mobilize and implement a capping stack to contain the release. The estimated release rates of hydrocarbons simulated in the subsurface blowout scenario were conservative (i.e., high) based on the current knowledge of the reservoir and other subsurface properties associated with the blowout scenario. An additional near-instantaneous, 3,200 L release of marine diesel batch was modelled for 30 days at a third near shore location, 12 km east of St. John's, along a potential supply vessel route. The modelled batch spill volume evaluated a potential discharge on the surface associated with marine diesel spills that could occur from a rupture of a diesel storage tank.

Study Goals

There were several goals of the modelling study. A stochastic assessment was used to provide an understanding of the probability and minimum time to exposure from unmitigated releases of oil. Separate highly conservative thresholds were investigated for oil on the water surface, concentrations of hydrocarbons in the water column, and oil on shorelines. The goal was to identify the areas that may be susceptible to contamination as well as the associated minimum time to exposure based upon variable environmental conditions (i.e., seasonal and interannual variability was assessed using >100 simulated releases). To conservatively determine the approximate magnitude of potential contamination from a single credible "worst-case" scenario (i.e., with spatially- and temporally-varying concentrations, rather than simply the knowledge of a threshold exceedance), three individual deterministic scenarios were selected from each stochastic simulation to represent 95th percentile maximum potential effects within each environmental compartment. These highly conservative 95th percentile scenarios were identified from the area of surface oil, volume of oil in the water column, and the length of shoreline oiled.

Models

In order to reproduce the dynamic and complex processes associated with deep subsea blowout releases, two models developed and maintained by RPS were used. The near-field model OILMAPDeep was used to characterize the dynamics of the jet and buoyant-plume phases of a subsurface blowout. It contains two sub-models, a plume model and a droplet size model. The plume model predicts the evolution of plume position, geometry, centerline velocity, and oil and gas concentrations until the plume either surfaces or reaches a terminal height, at which point the plume is trapped. The droplet size model was used to characterize the size and distribution of oil droplets, including the associated mass of oil being released at specific water depths, where the oil jet and buoyant plume traps as an intrusion and the droplets rise by buoyancy alone. The output

data defining the nearfield blowout plume from OILMAPDeep was then used to initialize the SIMAP model, which simulated the far-field trajectory, fate, and potential exposure of various environmental compartments within the marine environment following a release.

Geographical Data

Geographical data including habitat mapping and shoreline identification and classification were obtained from multiple data sources. For Canadian areas, province-specific data from the New Brunswick Department of Natural Resources and Nova Scotia Department of Natural Resources were used, as well as high-resolution data covering Canadian shorelines from Environment and Climate Change Canada. For the U.S. shoreline, the U.S. National Oceanic and Atmospheric Administration's Environmental Sensitivity Index and Maine Department of Environmental Protection's Environmental Vulnerability Index were used. Bathymetry was characterized using databases provided by NOAA National Geophysical Data Center and GEBCO (General Bathymetric Chart of the Oceans).

Wind and Currents

Wind data for this study were obtained from the U.S. National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) and Climate Forecast System Version 2 (CFSv2) models. Currents for the North Atlantic region were acquired from the U.S. Navy Global HYCOM (HYbrid Coordinate Ocean Model) circulation model. All data were acquired and used for the period between January 2006 and December 2012. This corresponded with the most recent long term (7 year) reanalysis period, meaning the same code-base (which is updated regularly) was used to drive a hind-cast of the coupled hydrodynamic and wind model. In essence, variability within this dataset would be associated with natural environmental variability and not any changes to the way the met-ocean modelling was conducted.

Stochastic Analysis

A stochastic analysis was conducted for each hypothetical unmitigated subsurface blowout, consisting of 172 individual modelled simulations within each stochastic scenario. Stochastic simulations included continuous unmitigated 30- and 120-day BdN blowouts at both locations (EL 1157 and EL 1158) as well as a small volume release of marine diesel at a near-shore location (12 km) east of St. John's. Each simulation was initialized with a different start date/time between 2006-2012 to sample a range of environmental conditions. The dates and times were selected randomly from within each 14-day interval spanning the entire seven years of data. Results of the stochastic analysis included probability footprints above specified highly conservative socio-economic thresholds for surface, water column, and shoreline contact and minimum time to oil exposure as well as less conservative ecological thresholds that may result in potential effects (i.e., acute mortality) within each environmental compartment.

Socio-economic Thresholds:

- Surface oil average thickness >0.04 µm,
- Subsurface (within the water column) dissolved hydrocarbon concentrations >1.0 µg/L,
- Shore oil average concentration >1.0 g/m^2.

Ecological Thresholds:

- Surface oil average thickness >10 µm,
- Subsurface (within the water column) dissolved hydrocarbon concentrations >1.0 µg/L,
- Shore oil average concentration >100 g/m^2.

Because each set of stochastic simulations spanned seven full years and included the associated seasonal variability, the complete set was referred to as annual summaries. To investigate seasonality, results from stochastic analyses were broken into two seasons depending on the majority of modelled days falling within either ice free conditions (i.e., summer) from May through October or periods with ice-cover (i.e., winter) from November through April.

It is important to note that although large footprints of oil are depicted for stochastic analyses, they are not the expected distribution of oil from any single release. These maps do not provide any information on the quantity of oil in a given area. They simply denote the probability of oil exceeding the specific threshold passing through each grid cell location in the model domain at any point over the entire model duration (i.e., 160 days for the subsurface blowouts), based on the entire ensemble of simulations (172 individual releases). Only probabilities of 1% or greater were included in the map output, as lesser probabilities represent random variability in the set of 172 trajectories. Stochastic maps of water column exposure depict the likelihood that dissolved and total hydrocarbon concentrations are predicted to exceed the identified threshold at any depth within the water column (i.e., vertical maximum). However, these figures do not specify the depth at which this threshold exceedance occurs and do not imply that the entire water column (i.e., from surface to bottom) will experience a concentration above the identified threshold.

Deterministic Analysis

Representative deterministic scenarios (i.e., single trajectory) were identified from each set of stochastic results of subsurface blowouts. Individual scenarios were selected based upon the size of the surface oil footprint, the concentration of dissolved hydrocarbons in the water column, and the length of shoreline contacted with oil, contingent upon the set of highly conservative socio-economic thresholds mentioned above.

The selected cases for deterministic analysis included the identified 95th percentile scenarios for surface oil footprint (by area), water column concentration (by volume), and shoreline oil length predicted to be affected by the subsurface releases at EL 1157 and EL 1158. Additionally, the mass balance information was provided for the 50th percentile scenario for surface oil footprint scenario and the 95th percentile scenarios for the batch releases of marine diesel.

Results

Stochastic results are useful in planning for oil spill response as well as environmental assessments, as they characterize the probability that regions may experience oil exposure above specified thresholds, taking into account the environmental variability that is expected. Many release scenarios were simulated over multiple years to capture the different environmental forcing (e.g., variable wind and current speed and direction) that may be possible. For both release sites, EL 1157 and EL 1158, stochastic analyses were used to demonstrate that the highest potential likelihood (>90%) to exceed thresholds of potential surface oil exposure and water

column contamination by dissolved hydrocarbons primarily occurred to the east, up to 1,400 km from the release site. In essence, prevailing winds and currents were most likely to force released oil to the east, away from Canadian shorelines. Water column probability footprints were smaller than surface oil footprints, where the probability of threshold exceedance decreased as distance from the release site increased. In nearly all stochastic scenarios, lower probabilities of threshold exceedance are predicted for surface and water column oil contamination to the north and south, while generally <25% of releases have the potential to exceed thresholds >100 km to the west of the Project Area.

Due to the predominantly eastward transport of oil and the distance of EL 1157 and 1158 to Canadian shorelines, the average probability of shoreline oiling above the threshold was low (9%), with a maximum probability of 28% for a single shoreline grid cell. The currents in the region, due primarily to the bathymetric steering along the continental shelf, were predicted to further reduce the potential for Canadian shoreline exposure to oil. As the Labrador Current flows southward along the continental shelf, it transports entrained oil parallel to the coast. However, this trend is generally absent in the surface oil predictions, as wind forcing typically transported oil to the east, further out to sea. Oil that does make its way to Canadian shorelines would likely be patchy and discontinuous due to the considerable weathering that would take place over the span of weeks to months. Predicted minimum time to shoreline threshold exceedance is 7-27 days along southeastern Newfoundland. All of the diesel batch spills modelled from a nearshore location (12 km east of St. John's) along a potential supply vessel route were predicted to result in <68 km^2 of surface oil exposure above the socio-economic threshold and no areas of exposure above the ecological threshold. Additionally, 53 km of shoreline was predicted to have exposure to oil above the socio-economic threshold. Due to the small release volume and size of the concentration gridding (150 m by 150 m), predicted concentrations of dissolved or total hydrocarbons in the water column did not register above a recordable threshold. Therefore, no water column exposure above the modelled thresholds was predicted.

For most representative credible "worst-case" deterministic scenarios at EL 1157 and EL 1158, natural degradation processes (evaporation and biological degradation) weathered the majority of oil over the 160-day model simulations. The highly volatile nature and large proportion of lower molecular weight compounds in the BdN oil resulted in large percentages of evaporated (>41%) and degraded (31-43%) oil, accounting for up to 87% of each modelled release over each 160-day simulation. The amount of oil predicted to remain on the water surface or within the water column totaled 2-17%, understanding that entrainment and resurfacing can result in surface and entrained oil "see-sawing" between the two environmental compartments based upon wind/wave conditions on hourly time-scales. Between 3-22% of oil (predominantly persistent surface oil) was predicted to be transported by winds outside the model domain (to the east) over the 160-day simulation. Oil was not tracked beyond the model domain. Shoreline contact made up a very small proportion of released oil for these simulations with a maximum value of <3% of the released oil making contact with the shorelines of Newfoundland, to a lesser extent Labrador, and in some circumstances Sable Island. Oil transported to the sediment was not a major fate pathway for these completely unmitigated offshore subsurface blowouts with <0.01 percent predicted to settle on sediments. Note that all scenarios assume a completely unmitigated release, which is an unlikely situation, as emergency response tactics would typically be employed in the event of a spill within hours to days of the release.

The batch spill releases of 3,200 L marine diesel were predicted to result in silver or colorless sheens (<0.0001 mm) of oil floating on the water surface. Generally, oil was predicted to be transported south and, in some

cases, wrap around the Avalon peninsula towards Saint Lawrence, Newfoundland. However, this small amount of oil was predicted to be at thicknesses below the socio-economic threshold. The 95th percentile shoreline exposure case was predicted to lead to shoreline oil contamination exceeding the socio-economic threshold of 1 g/m^2 on over approximately 1,000 km of shoreline, with the biological threshold never exceeded.

The hypothetical releases modelled in this study are not intended to predict a specific future event, but rather are intended to be used as a tool in environmental assessments and spill contingency planning. The results presented in this document demonstrate that there are a range of potential trajectories and fates that could result if a release of crude oil or a batch spill of marine diesel were to occur at any point throughout the year. The specific trajectories and fates vary greatly for each release based upon the environmental conditions occurring at the time of the release. While each oil release is unique, and uncertainties exist, the results of this modelling study suggest that, if oil were to be released in the Project Area, it has a high likelihood of moving away from shore to the east with less likelihood of shoreline oil exposure. Furthermore, this modelling assumes completely unmitigated releases, which is an unlikely situation because emergency response measures would typically be employed in the event of a spill.

Document Summary

This report includes an introduction describing the region, the modelling approach, the methodology, and finally the predicted modelling results of the study. The model results are summarized in figures and tables in the main body of this document, describing the potential for oil exposure on the water surface, within the water column, and along shorelines. This document is broken down into several sections.

- Section 1 – Introduction
- Section 2 – Background and Scenarios, including description of Regional Area and Project Area, modelling approach with the OILMAPDeep and SIMAP models, scenarios, and uncertainty
- Section 3 – Model Input Data
- Section 4 – Model Results, including both stochastic and deterministic oil trajectory and fate simulations
- Section 5 – Discussion and Conclusions
- Section 6 – References

Appendix A – additional information including a detailed description of the OILMAPDeep and SIMAP models, fate processes, and algorithms used.

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1 INTRODUCTION

RPS conducted trajectory and fate modelling to support an Environmental Assessment for the BHP Canada Exploration Drilling Project 2019-2028 in the Orphan Basin area. Hypothetical blowout releases were modelled at two locations in the Orphan Basin located more than 300 km northeast of St. John's, Newfoundland. Water depth at the proposed drilling sites selected for modelling ranged from 2,000 to 2,400 m. Major currents, including the Labrador Current and its inner and outer branch, influence the circulation and biological productivity in this region.

This modelling was conducted to evaluate hypothetical unmitigated release events associated with exploration drilling in the Orphan Basin within Exploration Licenses (EL) 1157 and 1158. Modelling included large-scale, long-duration, deep-water blowouts of a Bay du Nord light crude oil from the wellhead at the seafloor and a smaller scale surface batch spill of marine diesel. All releases were modelled as completely unmitigated, implying that no response efforts (e.g. subsurface dispersant injection, aerial dispersant application, burning, etc.) were undertaken during the modelled time period. Three-dimensional (3D) oil spill trajectory and fate modelling and analyses were performed to support evaluation of the potential movement and behavior of oil following hypothetical releases into the Northwest Atlantic Ocean near Newfoundland, with the goal to determine the magnitude and extent of potential for surface oil, subsurface contamination, and shoreline oiling. The nearfield OILMAPDeep blowout model and the far-field Spill Impact Model Application Package (SIMAP) oil trajectory, fate, and potential effects model were used. These state-of-the-art models were developed and are maintained by RPS. This report provides a description of the Project Area, modelled hypothetical release scenarios, an overview of the modelling approach, details about the model input data that were used, and a presentation and discussion of the predicted model results.

2 BACKGROUND AND SCENARIOS

2.1 Project Area

Newfoundland is comprised of a series of islands off the east coast of Canada, and along with Labrador forms the easternmost Canadian province. The relatively shallow waters of the continental shelf extend eastward into the Northwest Atlantic Ocean, up to 500 km off the Newfoundland coast. The hypothetical modelled release locations are within the Orphan Basin Exploration Drilling Project Area, located approximately more than 300 km east-northeast of St. John's, Newfoundland (Figure 2-1). Water depth at the proposed drilling sites selected for modelling are 2,338 m for EL 1157 and 2,047 m for EL 1158.This biologically productive region, located north of the Grand Banks of Newfoundland, sits atop substantial petroleum resources, with the Hibernia and White Rose fields approximately 250 km to the southwest. Bathymetry within the Project Area ranges between 1,175 and 2,575 m, however regions within the model domain do exceed 4,500 m deep, in regions such as the Laurentian Basin, Bonnition Basin, and the abyssal plain east of the Flemish Cap. The model domain extends from 42°N to 57°N and 72°W to 28°W, encompassing Canadian, U.S., and International waters. This modelled extent is much larger than the Project Area, as hypothetical releases of oil were to be tracked for long periods of time (160 days).

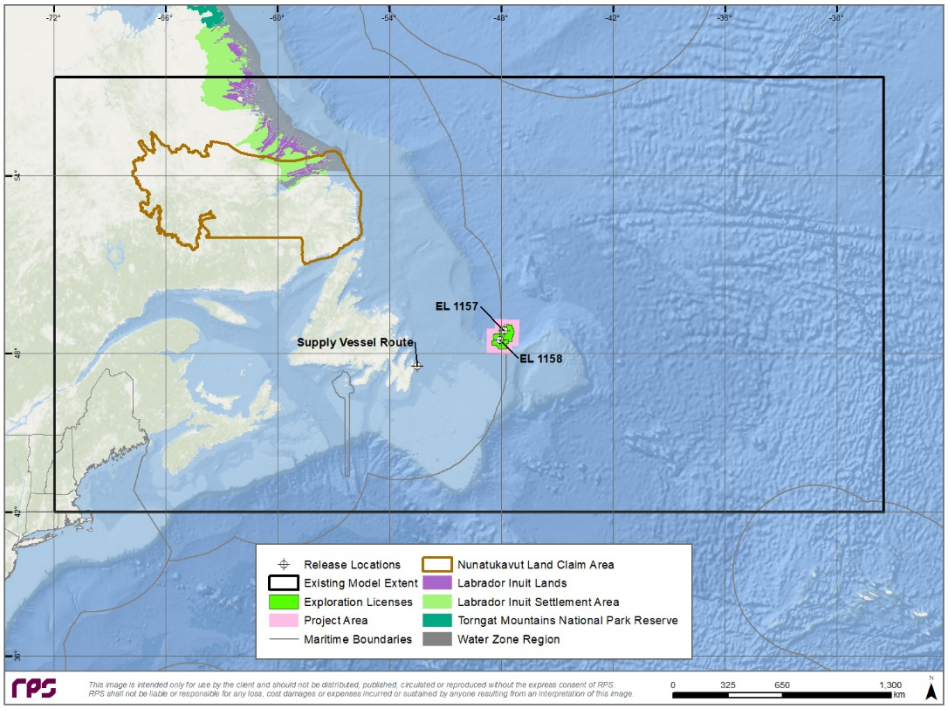

Figure 2-1. Project Area, including the two hypothetical release locations for the subsurface blowouts (EL 1157 and EL 1158) and a point along the potential supply vessel route. The black bounding box represents the modelled extent, while the pink shaded box represents the Project Area.

2.2 Modelling Approach

This modelling study employed a combined stochastic and deterministic approach to determine the potential trajectory and fate of hypothetical hydrocarbon releases from two sites east of Newfoundland (Table 2-1). Stochastic modelling provides a probabilistic view of the likelihood that a given region might be exposed to released hydrocarbons over specified thresholds as well as the minimum time it may take for those threshold exceedances. Because stochastic analyses include >100 simulated releases with different start dates throughout a year and over multiple years, they provide a range of possible trajectories based upon variable environmental conditions. Deterministic analyses provide views of the time-history of individual releases including the spatially- and temporally-varying movement and behavior of released oil from specified individual releases (i.e., representative credible "worst cases"). Deterministic scenarios provide an understanding of the predicted spatial and temporal variability in thicknesses, concentrations, and mass within each environmental compartment. Together, these methods provide a more complete view of the likelihood, timing, and degree or magnitude of potential exposure.

Four blowout release scenarios (two at each site) were modelled for 160-day periods to simulate short (30-day) and long (120-day) duration blowouts. The 120-day releases represent the a conservatively long amount of time anticipated to shut in a well by mobilizing a drilling platform and drilling a relief well, while the 30-day release represents the successful mobilization and implementation of a capping stack to contain the release. The total model duration of 160 days was used to track the trajectory and fate of spilled product as it continued to weather after the release had stopped.

Predicted surface oil thickness, dispersed oil in the water column, and shoreline oil mass exceeding specified thresholds for the full year (i.e., annual) are provided along with seasonal breakdowns associated with variable ice-cover conditions (i.e., summer/ice-free and winter/ice-covered). Individual deterministic trajectories that characterize single release scenarios are also presented associated with representative credible "worst-case" scenarios from each stochastic simulation (i.e., 95th percentile "worst-case" for surface oil, subsurface contamination, and shoreline oiling). Stochastic analysis of hypothetical blowouts were modelled using the physical-chemical properties of BdN or Marine diesel and seven years of variable environmental data, which are discussed further in Section 3. The hypothetical spill sites are located within the Orphan Basin (Figure 2-1). A total of 172 individual oil spill trajectories were modelled for each scenario as unmitigated subsurface releases with randomized start dates/times within each two-week time period making up the seven-years modelled here (Table 2-1). Each stochastic scenario included 79 winter and 93 summer simulations. The duration of each simulation within the stochastic scenarios was 160 days.

In addition to the, a diesel stochastic release (3,200 L) was analyzed to evaluate a potential discharge of marine diesel on the surface associated with a batch spill that could occur from a diesel storage tank at a nearshore location (12 km east of St. John's) along a potential supply vessel route.

In total, 860 individual releases were simulated within this assessment with a goal of capturing environmental variability and resulting differences in the movement and behavior of oil following unmitigated subsurface short- and long-duration releases within each exploration lease as well as a supply vessel route near shore.

Table 2-1. Site and release information used for the stochastic and deterministic approaches.

Modelling Approach	Release Location	Depth of Release	Release Duration	Model Duration	Number of Simulations	Released Product	Release Type	Release Volume
Stochastic and Deterministic*	EL 1157 (48.83°N, 47.85°W)	2,338 m	30 d	160 d	172	BdN	Subsurface Blowout	4,052,506 bbl*
			120 d					15,496,924 bbl*
	EL 1158 (48.49°N, 48.07°W)	2,047 m	30 d					4,050,183 bbl*
			120 d					15,496,430 bbl*
	Nearshore (12 km east of St. John's) (47.55°N, 52.52°W)	Surface	Near Inst.	30 d		Marine Diesel	Surface Batch Spill	3,200 L

*The 95th percentile "worst-case" scenarios for surface, water column, and shoreline were identified from each of the four stochastic scenarios and modelled as three separate deterministic simulations per stochastic scenario. In total, twelve deterministic scenarios were run for the subsurface blowouts at EL 1157 and EL 1158.

2.2.1 Modelling Tools

Hypothetical release scenarios were simulated using the OILMAPDeep blowout model and the SIMAP oil trajectory, fate, and effects model, both developed and maintained by RPS. OILMAPDeep was used to define the near-field dynamics of the subsurface blowout plume, which was then used to initialize the far-field modelling conducted in SIMAP. The near-field plume dynamics are modelled to predict the mass, location, and droplet size distribution of the subsurface oil droplets at the termination (i.e., trap) height, where the oil jet and buoyant oil and gas plume are "trapped" and form an intrusion. The depth of the trap height is dependent upon the environmental conditions, the specific chemical and physical properties of the oil, and other release parameters. Typically, the near-field model considers timescales of seconds and length scales of hundreds of meters, whereas the far-field model considers many days and months (at 30-minute time steps) and length scales of tens, hundreds, and even thousands of kilometers.

OILMAPDeep Model

The OILMAPDeep model incorporates the basic dynamics of a subsurface oil and gas plume and the associated complexities of increased hydrostatic pressure at depths deeper than 200 m. It contains two sub-models, a plume model and a droplet size model. The plume model predicts the evolution of the plume position, geometry, centerline velocity, and oil and gas concentrations until the plume either surfaces or reaches a terminal height (i.e., trap height). During a subsea blowout in deep water, an oil jet and buoyant plume carries oil and gas upwards to a water depth (or depths) where, due to the ambient density gradient in the ocean, the

buoyant plume is arrested, or "trapped" and forms an intrusion (Socolofsky et al. 2011, 2015). Oil droplets are released from the intrusion to the water column above, where they subsequently rise (buoyancy) and are transported by ambient currents. The trap height is typically a few hundred meters above the release depth (Socolofsky et al. 2015). The jet created by the blowout is modelled by considering the momentum of the oil discharge, the density difference between the expanding gas bubbles in the plume and the receiving water, the entrainment of water into the plume, the mixing by turbulence within the plume, the hydrate formation, and the transport by local ambient currents. The droplet size model predicts the size and volume (mass) distribution of the oil droplets in the release at the trap height or at the water surface, which influences trajectory and fate processes, such as oil rise velocity and dissolution.

For oil discharged during a deep-water blowout, the oil droplet size distribution profoundly effects how oil is transported and behaves after the initial release as a buoyant plume. The size of the individual droplets dictates buoyancy, which controls rise rate and the associated length of time that oil will remain within the water column before surfacing. Large oil droplets surface faster than small ones, thus large droplets more quickly generate a floating oil slick, which may be transported by winds and surface currents. Small droplets remain in the water column longer than large droplets (due to less buoyancy and increased drag) and are subjected to subsurface advection-diffusion processes. The small droplets are therefore transported within the water column for a longer period of time. As oil is transported by subsurface currents away from the release location, natural dispersion and degradation of the oil droplets will reduce concentrations within the water column. However, the lower rise velocities associated with smaller oil droplets correspond to longer residence times of oil suspended in the water column, which can increase the dissolution of soluble components and potentially result in larger volumes of water being affected. The surface area to volume ratio of smaller droplets is much larger than that of larger droplets. Therefore, with such a large exchange interface, a larger portion of the soluble fraction of hydrocarbons within the smaller droplets will dissolve into the water column and at a higher rate than that of larger oil droplets. Details of the OILMAPDeep model background theory, inputs, algorithms, and outputs can be found in Appendix A.

SIMAP Model

The SIMAP model is a state-of-the-art oil trajectory, fate, and effects model that was developed by RPS and is constantly being updated/maintained based upon the growing body of field and laboratory data associated with releases of oil in many different environments. The SIMAP model originated from the oil fate sub-model within the Natural Resource Damage Assessment Models for Coastal and Marine Environments (NRDAM/CME). RPS (previously Applied Science Associates) developed the NRDAM/CME in the early 1990s for the U.S. Department of the Interior for use in "type A" Natural Resource Damage Assessment (NRDA) regulations under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). The most recent version of the type A models, the NRDAM/CME (Version 2.4, April 1996) was published as part of the CERCLA type A NRDA Final Rule (Federal Register, May 7, 1996, Vol. 61, No. 89, p. 20559-20614). The technical documentation for the NRDAM/CME is in French et al. (1996). While the NRDAM/CME was developed for simplified NRDAs of small releases in the U.S., SIMAP was further developed to evaluate fate and exposure of both real and hypothetical releases in marine, estuarine, and freshwater environments worldwide. Additions and modifications to SIMAP include increasing model resolution, allowing site-specific input data, incorporating spatially and temporally varying current data, evaluating subsurface releases and

movements of subsurface oil, tracking multiple chemical components of the oil, enabling stochastic modelling, and facilitating analysis of results.

The 3D physical fates model estimates the distribution of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments as both mass and concentration. Because oil contains many chemicals with varying physical and chemical properties, and the environment is spatially and temporally variable, the oil rapidly separates into different environmental compartments through multiple fate processes. Oil fate processes included in SIMAP are spreading (gravitational and by shearing), evaporation, transport, randomized dispersion, emulsification, entrainment (natural and facilitated by dispersant), dissolution of the soluble fraction of oil into the water column, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended sediments, adsorption of soluble and sparingly-soluble aromatics to suspended sediments, sedimentation, and degradation. Oil trajectory and weathering endpoints include surface oil, emulsified oil (mousse), tar balls, suspended oil droplets, oil adhered to particulate matter, dissolved hydrocarbon compounds in the water column and pore water, and oil on and in bottom sediments and shoreline surfaces. Details of the SIMAP model background theory, inputs, algorithms, and outputs can be found in Appendix A.

2.2.2 Stochastic Approach

A stochastic approach was employed to determine the footprint and probability of areas that are at increased risk of oil exposure based upon the variability of meteorological and hydrodynamic conditions that might prevail during and after a release. A stochastic scenario is a statistical analysis of results generated from many (>100) different individual trajectories of the same release scenario, with each trajectory starting at a randomized time from a relatively long-term window. For this project, individual trajectory start dates were selected randomly every 14 days throughout the window of environmental data coverage (2006-2012) to ensure that the data was adequately sampled. This stochastic approach allowed for the same type of release to be analyzed under varying environmental conditions (e.g., summer vs. winter or one year to the next). The results provide the probable behavior of the potential releases based upon this environmental variability.

To reproduce the natural variability of winds and currents, the model requires both spatially- and temporally-varying datasets. Historical observations and models of multiple-year wind and current records were used to perform the simulations within the coinciding time period. These datasets allow for reproduction of the natural variability of the wind and current speeds and directions. Optimally, the minimum time window for stochastic analysis is at least five years, so that various weather patterns from year to year are represented. Seven years of environmental data were used for this modelling study, including 2006-2012. Using wind and current data from throughout this period, a sufficient number of model simulations will adequately sample the variability in wind and current speeds and directions in the region over time and will result in a prediction of the probable oil pathways for releases at the prescribed location.

Stochastic analyses provide two types of information: 1) the areas associated with the probability of oil exposure at some time during or after a release, and 2) the shortest time required for oil above a specified threshold to reach any point within the modelled areas. The left panel of Figure 2-2 depicts four individual trajectories predicted by SIMAP for a generic example scenario. Because these trajectories were started on different dates and times, they experienced different environmental conditions, and thus was transported in different directions. To compute the stochastic results in this study, 172 individual trajectories were overlaid upon one another, like

the four depicted below. The number of times that each given location throughout the modelled domain (i.e., grid cell) was intersected by a trajectory that exceeded the specified threshold was then quantified and used to calculate the probability of oil exposure for each specific location. This process is illustrated by the stacked simulations in the right panel of Figure 2-2. The predicted footprint is the cumulative oil-exposed area for all of the 172 individual releases combined. The color-coding represents a statistical analysis of all the individual trajectories to predict the probability of oil at each point in space, based upon the environmental variability. The footprint of any single release of oil, be it modelled or real, would likely be much smaller than the cumulative footprint of all the simulations used in the stochastic analysis. Similarly, the footprint of oil from any individual release at a single time step (snapshot in time) would be even smaller than the cumulative swept area depicted here.

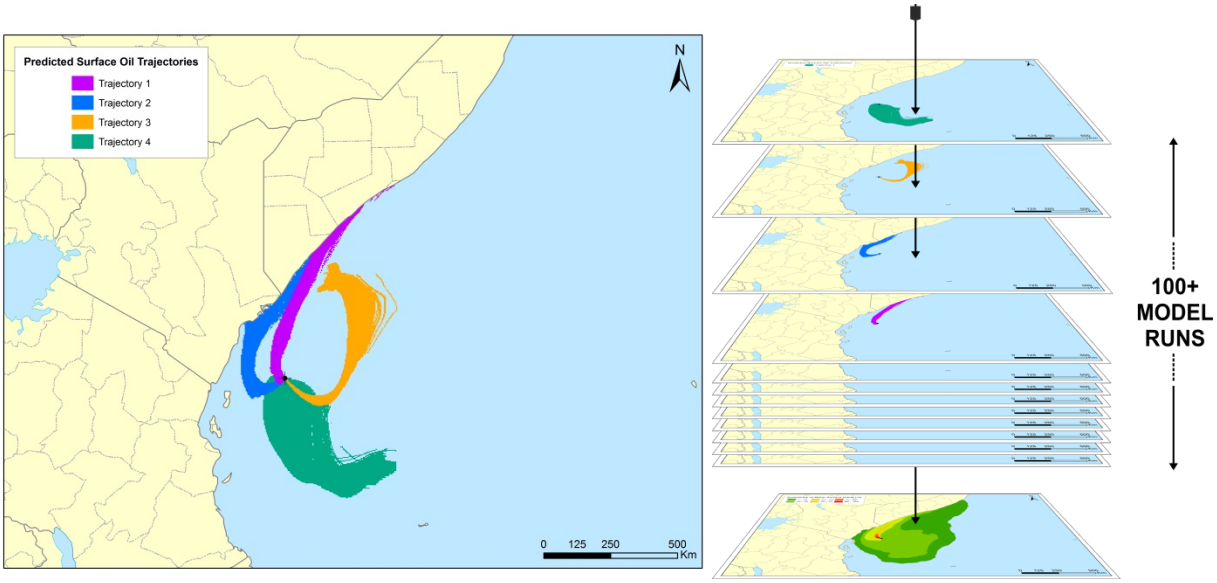

Figure 2-2. Example of four individual release trajectories predicted by SIMAP for a generic release scenario at a generic location simulated with different start dates and therefore environmental conditions. In a stochastic analysis, over one hundred individual trajectories are overlaid (shown as the stacked simulations on the right) and the frequency of threshold exceedance at each location is used to calculate the predicted probability following a release.

The number of individual trajectories and the timeframe of a given stochastic analysis play roles in the spatial extent of the resulting stochastic footprints. More individual simulations may incorporate greater environmental variability, which may result in larger footprints. As the number of trajectories modelled increases, the confidence and resolution of reported probabilities also increase. However, there is a “law of diminishing returns” and thousands of scenarios are not necessary to capture the environmental variability within the system. Annual stochastic model simulations resulted in the largest footprint, encompassing all environmental variability throughout the years. Seasonal footprints may be smaller, encompassing only the environmental variability expected within the smaller time period (e.g., prevailing winds, seasonal patterns, etc.). It is important to note that a single trajectory encounters only a small portion of an overall stochastic probability footprint (i.e.,

an individual trajectory may be less than 10% of an annual stochastic footprint). Maps of probability and minimum time to oil exceeding identified thresholds are provided in Section 4.1.

2.2.3 Thresholds of Interest

In a stochastic analysis, multiple model simulations (over one hundred releases) are overlaid upon one another to create a cumulative footprint of the potential trajectories. When combined with one another, the many individual deterministic footprints can be used to generate an area of probability that describes the potential areas that may be exposed to oil from the entire suite of modelled conditions. To determine the probability or likelihood of potential exposure, specific thresholds for surface oil thickness, oil on shorelines and sediments, and in-water concentrations were required (Table 2-2). Above these conservative socio-economic thresholds, previous studies identified that there is the potential for negative effects to occur. The first set of figures and further analyses for each scenario in this study include the more conservative lower socio-economic thresholds of concern calculated from stochastic results. The use of such conservative thresholds serves as more of a binary “yes/no” question of whether any oil passed through each identified area, as opposed to an ecological threshold that may indicate the potential for acute mortality. The second set of figures includes the less conservative ecological threshold for potential effects. This higher, less conservative stochastic threshold will result in smaller predicted probability footprints for each scenario.

Floating surface oil is expressed as mass per unit area, averaged over a defined (grid cell) area. If the oil is evenly distributed in that area, it would be equivalent to a mean thickness, where 1 micron (µm) corresponds to a layer of oil that has a mass concentration of approximately 1 g/m^2. Surface oil thickness is typically associated with visual appearance by aerial observation for responders (NRC, 1985; Bonn Agreement, 2009, 2011; NOAA, 2016b; Table 2-3). As an example, barely visible sheens may be observed above 0.04 µm and silver sheens correspond with surface oil thickness of approximately 0.3 µm. Crude and heavy fuel oils greater than 1 mm thick typically appear as black oil, while light fuels and diesels that are greater than 1 mm thick may appear brown or reddish. Because of the differences between oils and their degree of weathering, as well as the weather conditions and sea state at the time of observations, floating oil will not always have the same appearance. As oil weathers, it may be observed in the form of scattered floating tar balls and tar mats where currents converge. Typically, oil slicks in the environment would be observed as patchy and discontinuous with a range of visual appearances including silver sheen, rainbow sheen, and metallic areas simultaneously, as a combination of thicknesses may be present (Table 2-3). Thus, a model result presented as average oil mass per unit area or “thickness” is actually a region with patches of oil of varying thickness, which when distributed evenly in the area of interest, would be on average a certain thickness.

Table 2-2. Thresholds used to define areas and volumes exposed above levels of concern.

Threshold Type	Cutoff Threshold*	Rationale/Comments (Socio-economic, Response, Ecological)	Visual Appearance	References
Oil Floating on Water Surface	0.04 g/m^2 (0.04 µm on average over grid cell)	**Socio-economic:** A conservative threshold used in several risk assessments to determine effects on socio-economic resources (e.g., fishing may be prohibited when sheens are visible on the sea surface). Socio-economic resources and uses that would be affected by floating oil include commercial, recreational and subsistence fishing; aquaculture; recreational boating, port concerns such as shipping, recreation, transportation, and military uses; energy production (e.g., power plant intakes, wind farms, offshore oil and gas); water supply intakes; and aesthetics.	Fresh oil at this minimum threshold corresponds to a slick being barely visible or scattered sheen (colorless or silvery/grey), scattered tarballs, or widely scattered patches of thicker oil.	French McCay et al., 2011; French McCay et al., 2012; French McCay, 2016; Lewis, 2007, Bonn Agreement
	10 g/m^2 (10 µm on average over grid cell)	**Ecological:** Mortality of birds on water has been observed at and above this threshold. Sublethal effects on marine mammals, sea turtles, and floating Sargassum communities are of concern.	Fresh oil at this threshold corresponds to a slick being a dark brown or metallic sheen.	French et al., 1996; French McCay, 2009 (based on review of Engelhardt, 1983, Clark, 1984, Geraci and St. Aubin 1988, and Jenssen 1994 on oil effects on aquatic birds and marine mammals); French McCay et al., 2011; French McCay et al., 2012; French McCay, 2016
Shoreline Oil	1.0 g/m^2 (1 µm on average over grid cell)	**Socio-economic/Response:** A conservative threshold used in several risk assessments. This is a threshold for potential effects on socio-economic resource uses, as this amount of oil may trigger the need for shoreline cleanup on amenity beaches and affect shoreline recreation and tourism. Socio-economic resources and uses that would be affected by shoreline oil include recreational beach and shore use, wildlife viewing, nearshore recreational boating, tribal lands and subsistence uses, public parks and protected areas, tourism, coastal dependent businesses, and aesthetics.	May appear as a coat, patches or scattered tar balls, stain	French-McCay et al., 2011; French McCay et al., 2012; French McCay, 2016
	100 g/m^2 (100 µm on average over grid cell)	**Ecological:** This is a screening threshold for potential ecological effects on shoreline flora and fauna, based upon a synthesis of the literature showing that shoreline life has been affected by this degree of oiling. Sublethal effects on epifaunal intertidal invertebrates on hard substrates and on sediments have been observed where oiling exceeds this threshold. Assumed lethal effects threshold for birds on the shoreline.	The oil would appear as opaque/black oil.	French et al., 1996; French McCay, 2009; French McCay et al., 2011; French McCay et al., 2012; French McCay, 2016
In Water Concentration	1.0 ppb (µg/L) of dissolved PAHs; corresponds to ~100 ppb (µg/L) of whole oil (THC) in the water column (soluble PAHs are approximately 1% of the total mass of fresh oil)	Water column effects for both **ecological** and **socio-economic** (e.g., seafood) resources may occur at concentrations exceeding 1 ppb dissolved PAH or 100 ppb whole oil; this threshold is typically used as a screening threshold for potential effects on sensitive organisms.	N/A	Trudel et al. 1989; French-McCay 2004; French McCay 2002; French McCay et al. 2012

*Thresholds used in supporting stochastic results figures. For comparison, a bacterium is 1-10 µm in size, a strand of spider web silk is 3-8 µm, and paper is 70-80 µm thick. Oil averaging 1 g/m^2 is roughly equivalent to 1 µm.

Table 2-3. Oil Appearances based on NOAA JobAid (2016b) and BAOAC.

Code	Description	Layer-Thickness		Concentration	
		microns (µm)	Inches (in.)	m^3 per km^2	bbl/acre
S	Silver Sheen	0.04 - 0.30	1.6×10^{-6} - 1.2×10^{-5}	0.04 - 0.30	1×10^{-3} - 7.8×10^{-3}
R	Rainbow Sheen	0.30 - 5.0	1.2×10^{-5} - 2.0×10^{-4}	0.3 - 5.0	7.8×10^{-3} - 1.28×10^{-1}
M	Metallic Sheen	5.0 - 50	2.0×10^{-4} - 2.0×10^{-3}	5.0 - 50	1.28×10^{-1} - 1.28
T	Transitional Dark (or true) Color	50 - 200	2.0×10^{-3} - 8×10^{-3}	50 - 200	1.28 - 5.1
D	Dark (or true) Color	> 200	> 8×10^{-3}	> 200	> 5.1
E	Emulsified	Thickness range is very similar to that of dark oil.			

* Chart from Bonn Agreement Oil Appearance Code (BAOAC) May 2, 2006, modified by A. Allen

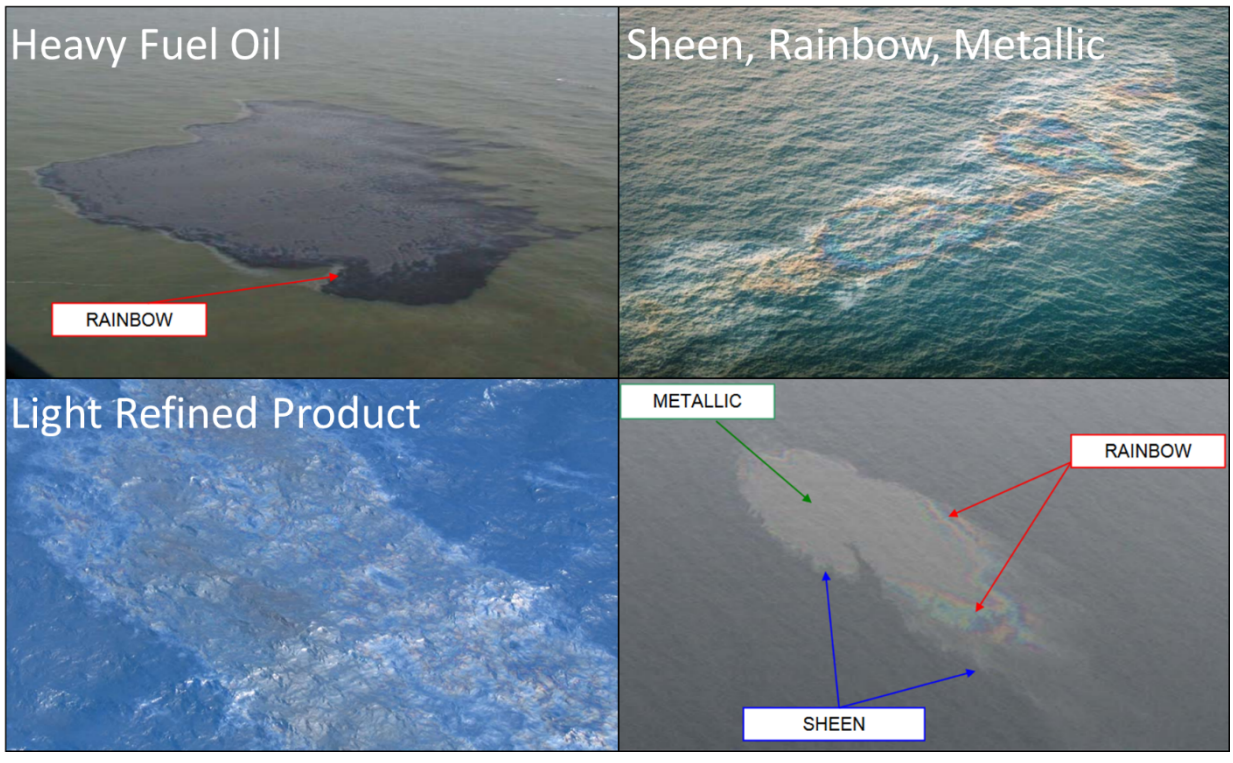

Figure 2-3. Aerial surveillance images of released oil in the environment as examples of different visual appearances based on surface oil thickness and product type (Bonn Agreement, 2011).

2.2.4 Deterministic Approach

Individual trajectories of interest were identified and selected from the stochastic ensemble of results for the deterministic analysis. The deterministic trajectory and fate simulations provided an estimate of the oil's transport and fate through the environment as well as its physical and chemical behavior for a specific set of environmental conditions. While the stochastic analysis provides insight into the probable behavior of oil spills given historic wind and current data for the Project Area, the deterministic analysis provides individual trajectory, oil weathering information, expected concentrations of oil contamination, mass balance, and other information related to a single release at a given location and time.

Each single deterministic simulation within a stochastic analysis represents a specific set of wind and current conditions for the modelled time period. When analyzed together, over one hundred simulations within a stochastic scenario provide a range of expected exposures. The exposures between cases may differ as the trajectory and fate of each individual modelled release is unique. Therefore, the movement and behavior, as well as the resulting areas and magnitudes of predicted contamination for surface, water column, and shoreline oil will be different for each modelled simulation. The 95th percentile "worst-case" exposure for surface, in-water concentration, and shoreline were identified based upon the area, volume, or length of oil that was predicted in each environmental compartment of interest (i.e., water surface area, volume in the water column, or shoreline length).

In addition, a deterministic analysis of a single batch spill release of 3,200 L of marine diesel was modelled at a third near shore location, 12 km east of St. John's, along a potential supply vessel route. The modelled batch spill volume evaluated a potential discharge on the surface associated with marine diesel spills that could occur from a rupture of a diesel storage tank. Similar to the subsurface deterministic scenarios, cases for the 95th percentile exposure for surface, in-water concentration, and shoreline were identified. The 50th percentile for surface exposure was also identified. The simulations include its own spatially and temporally variable trajectory, mass balance, and surface oil thickness reported individually.

The results of each deterministic simulation provides a time history of the fate and weathering of oil over the duration of the release (mass balance), expressed as the percentage of released oil on the water surface, on the shoreline, evaporated, entrained in the water column, and degraded, as well as the portion that was transported outside of the model domain. In addition, cumulative footprints of the individual trajectories over the course of the entire modelled duration will depict the cumulative path of floating surface oil, the mass of oil on shorelines, and the maximum concentrations of dissolved hydrocarbons in the water column at any instant in time. These results are a way to simplify the 4-dimensional nature of 3D model predictions through time with spatially and temporally variable magnitudes and are presented in figures in Section 4.2.

2.3 Modelled Scenarios

Two hypothetical release locations were used for subsurface blowout modelling, representative of EL 1157 and EL 1158 both in the Orphan Basin (Table 2-1 and Table 2-4). A surface batch spill of 3,200 L of marine diesel was also modelled along a potential supply vessel route representative of a release from a diesel storage tank. Scenarios were each modelled separately in a stochastic analysis that included 172 individual model

simulations per location per scenario. This analysis investigated the influence of environmental variability throughout the year over multiple years, on the trajectory and fate of released oil (Table 2-4).

The estimated volume of hydrocarbons released in the subsurface blowout scenarios represent the best technical estimate of the release rates from the wells. In essence, these blowout rates represent credible "worst-case" release volumes given realistic inputs and hypothetical releases.

Table 2-4. Hypothetical subsurface release location, parameters, and stochastic scenario information.

Scenario Parameter	Release Locations of Stochastic Scenarios				
Block/Release Location	EL 1157		EL 1158		Vessel Route
Latitude	48.825889 N		48.491786 N		47.550842 N
Longitude	47.851234 W		48.06617 W		52.522011 W
Water Depth of Release	2,338 m		2,047 m		Surface
Released Product	Bay du Nord (BdN)				Marine Diesel
Gas to Oil Ratio	400 scf/bbl				-
Pipe Diameter	31.12 cm (12.25 in.)				-
Oil Discharge Temperature	85°C				-
Release Duration	30 d	120 d	30 d	120 d	Near-Instantaneous
Release Rate	135,084 bpd	129,141 bpd	135,006 bpd	129,137 bpd	-
Total Released Volume	4,052,506 bbl	15,496,924 bbl	4,050,183 bbl	15,496,430 bbl	3,200 L
Model Duration	160 d				30 d
Number of Simulations within Stochastic Analysis*	172 annual (79 winter & 93 summer) for each scenario				

*A total of 688 individual subsurface releases were modelled within the stochastic analyses, another 172 for surface marine diesel, for a grand total of 860 individual simulations.

Table 2-5. Selected representative deterministic scenarios.

Scenario Parameter	Release Parameters for Representative Deterministic Scenarios															
	30 d Subsurface Release			120 d Subsurface			30 d Subsurface Release			120 d Subsurface			Surface Batch Spill			
Representative Scenario	Surface Oil Exposure Area	Water Column Oil Volume	Shoreline Contact Length	Surface Oil Exposure Area	Water Column Oil Volume	Shoreline Contact Length	Surface Oil Exposure Area	Water Column Oil Volume	Shoreline Contact Length	Surface Oil Exposure Area	Water Column Oil Volume	Shoreline Contact Length	50^{th} % Surface Oil Exposure Area	95^{th} % Surface Oil Exposure Area	95^{th} % Water Column Oil Volume	95^{th} Shoreline Contact Length
Block Release Site	EL 1157						EL 1158						Vessel Route			
Release Type	Subsurface Blowout												Surface Batch Spill			
Water Depth of Release	2,338 m						2,047 m						Surface			
Released Product	Bay du Nord												Marine Diesel			
Release Duration	30 d			120 d			30 d			120 d			Near-Instantaneous			
Release Rate	135,084 bpd			129,141 bpd			135,006 bpd			129,137 bpd			-			
Total Released Volume	4,052,506 bbl			15,496,924 bbl			4,050,183 bbl			15,496,430 bbl			3,200 L			
Model Duration	160 d												30 d			
Modelled Start Date and Season	Nov. 8, 2009 Winter	Oct. 30, 2010 Winter	Mar. 31, 2008 Summer	Jan. 15, 2010 Winter	Jul. 22, 2010 Summer	Nov. 8, 2009 Winter	Apr. 7, 2008 Summer	Dec. 11, 2009 Winter	Apr. 7, 2008 Summer	Jan. 6, 2010 Winter	Sep. 7, 2010 Winter	Dec. 9, 2010 Winter	Apr. 20, 2007 Summer	Nov. 1, 2011 Winter	Oct. 10, 2007 Winter	Mar. 12, 2011 Summer

2.4 Model Uncertainty and Validation

The SIMAP model has been developed over several decades to include past and recent information from laboratory-based experiments and real-world releases to simulate the trajectory and fate of discharged oil. However, there are limits to the complexity of processes that can be modelled, as well as gaps in knowledge regarding the affected environment. Assumptions based on available scientific information and professional judgment were made in the development of the model, which represent a best assessment of the processes and potential exposures that could result from oil releases.

The major sources of uncertainty in the oil fate model are:

- Oil contains thousands of chemicals with differing physical and chemical properties that determine their fate in the environment. The model must, out of necessity, treat the oil as a mixture of a limited number of components, grouping chemicals by physical and chemical properties.
- The fate model contains a series of algorithms that are simplifications of complex physical-chemical processes. These processes are understood to varying degrees.
- The model treats each release as an isolated, singular event and does not account for any potential cumulative exposure from other sources.
- Several physical parameters, including but not limited to, hydrodynamics, water depth, total suspended solids concentration, and wind speed were not sampled extensively throughout the entire modelled domain. However, the data that did exist was sufficient for this type of modelling. When data was lacking, professional judgment and previous experience was used to refine the model inputs.

SIMAP has been validated against many real-world releases including the Deepwater Horizon oil spill, where it was used in the US Government's Natural Resource Damage Assessment. In this specific example, a small portion of the released oil may have sunk as a result of the interaction of released oil with sediments, drilling muds, and other material used in response efforts such as procedures used to seal a leaking well. These are currently areas of active research. While there are additional fate processes that may result in slight differences in the ultimate fate of oil, these processes are known to have relatively lower effects on the total volume of oil in each environmental compartment (on the order of single percentages different, depending on the release and receiving environment) as compared to the fate processes such as entrainment, which are already being modelled. The science and algorithms that may be used to model these processes have not been developed in the scientific community to the point of a consensus or use in modelling. Ongoing research topics currently underway include the formation of marine oil snow (MOS), photo-degradation, droplet size distributions, and other research areas. These and other multi-year research projects are considered for incorporation in modelling nearly constantly. Due to these topics being in the research phase, without scientific consensus, they have not been included in this analysis.

In the unlikely event of an actual release of oil, the trajectory and fate will be strongly determined by the specific environmental conditions, the precise location, and a myriad of details related to the event and specific timeframe of the release. Modelled results are a function of the scenarios simulated and the accuracy of the input data used. The goal of this study was not to forecast every detail that could potentially occur, but to describe a range of possible consequences and exposures of oil releases under various representative release scenarios.

3 MODEL INPUTS DATA

3.1 Oil Characterization

Two hydrocarbon products (BdN and Marine Diesel) were modelled for this hypothetical release study. BdN is a light crude oil that has a low viscosity and a high volatile content (Table 3-1 and Table 3-2). The marine diesel modelled is a standard diesel that also has a low viscosity and high content of soluble hydrocarbons. The low viscosity and high soluble content of these oil products provides conservative approximations of anticipated concentrations in the water following a release, as a relatively large proportion of constituents have the potential to dissolve into the water column, when compared to oils with lower soluble content.

Marine diesel was modelled for the surface batch spill at the supply vessel route location. The marine diesel modelled is a standard diesel (light fuel oil with very little residual fraction) that has a low viscosity and high content of volatile hydrocarbons. Thus, marine diesel is expected to weather (i.e., evaporate) rapidly and be nearly completely on the water surface (Table 3-2). The physical and chemical data used to characterize these oils was provided by BHP Canada, with additional information taken from Environment Canada's oil database (ECCC, 2001).

Table 3-1. Physical properties for the oil products used in the modelling.

Physical Property	BdN Crude Oil	Marine Diesel
Density (g/cm^3)	0.84553 @16°C 0.85800 @0°C	0.83100 @25°C
Viscosity (cP)	5.0 @20°C 53.0 @0°C	2.76 @15°
API Gravity	35.85	38.8
Pour Point (°C)	-9	-50
Interface Tension (dyne/cm)	15.5	27.5
Emulsion Maximum Water Content (%)	72	0

Table 3-2. Fraction of the whole oil comprised of different distillation cuts for the modelled oil product. Note that the total hydrocarbon concentration (THC) is the sum of the aromatic (AR) and aliphatic (AL) groups. Numbers of carbons (C#) in the included compounds are listed.

Distillation Cut[1]	Boiling Point (°C)	Description	BdN	Marine Diesel
AR1	< 180	highly volatile and soluble monoaromatic hydrocarbons (BTEX[2] and MAHs C6-C9)	0.023739	1.93
AR2	180 - 264	semi-volatile and soluble 2-ring aromatics (MAHs and PAHs C10-C12)	0.004166	1.14
AR3	265 - 380	low volatility and solubility 3-ring aromatics (PAHs C13-C18)	0.066998	1.56
AL1	< 180	highly volatile aliphatics (C4-C8)	0.206261	14.46
AL2	180 - 280	semi-volatile aliphatics (C9-C16)	0.160834	47.86
AL3	280 - 380	low volatility aliphatics (C17-C23)	0.168002	30.32
THC1	< 180	total hydrocarbon fraction 1 (sum of AR1 and AL1)	0.230000	16.40
THC2	180 - 280	total hydrocarbon fraction 2 (sum of AR2 and AL2)	0.165000	49.01
THC3	280 - 380	total hydrocarbon fraction 3 (sum of AR3 and AL3)	0.235000	31.89
Residuals	> 380	aromatics ≥ 4 rings and aliphatics > C20 that are neither volatile nor soluble	0.37000	2.70

Numerous data sources and dozens of analyses are used to classify the different chemical and physical characteristics of the oil. As an example, this would include but not be limited to physical testing, distillation studies, weathering studies, measurements of chemicals (e.g. GCMS, PAH, alkanes, saturates, aromatics,

[1] Note that the terms “aromatic” and “aliphatic” are used in a modelling context. “Aromatic” refers to all soluble and volatile hydrocarbons and may include actual aliphatic compounds (by chemical definition) that are soluble. In the modelling context, “aliphatic” refers to insoluble and volatile hydrocarbons. Note that Σ(AR) + Σ(AL) + residuals = Σ(THC) + residual = total hydrocarbon composition

[2] BTEX (benzene, toluene, ethylbenzene, xylene), MAHs (monocylic aromatic hydrocarbons), and PAHs (polycyclic aromatic hydrocarbons) are the more soluble, bioavailable, and potentially toxic components in oil.

resins, asphaltenes, etc.), emulsification studies, degradation studies, etc. All available data is used to classify each oil. When advanced analyses are not available, surrogate oils with more information are used to fill in data gaps and professional judgement and previous experience are used to further refine the oil characterization model inputs.

The “pseudo-component” approach is used to simplify the tracking of thousands of chemicals comprising oil for modelling (Payne et al., 1984; 1987; French et al., 1996; Jones, 1997; Lehr et al., 2000). Chemicals in the oil mixture are grouped by physical-chemical properties, and the resulting component category behaves as if it were a single chemical with characteristics typical of the chemical group. In this component breakdown, aromatic (AR) groups are treated as both soluble (i.e., dissolve into the water column) and volatile (i.e., evaporate to the atmosphere), while the aliphatic (AL) groups are only volatile. The total hydrocarbon concentration (THC) within the boiling range of volatile components is the sum of all AR and AL components. The remainder of the oil is considered to be residual oil, which does not dissolve or volatilize but will degrade over time.

Degradation rates for each component and compartment (surface, upper water column, lower water column, and sediments) were based on biodegradation rates obtained from literature reviews that included estimates for compounds and/or components of crude oil generally (French McCay et al., 2018a: Annex C to Appendix II). For the semi-volatile components, degradation in floating oil would be considerably slower than volatilization. The rates for residual oil are consistent with studies by Zahed et al. (2011) and Atlas and Bragg (2009).

Through the modelled processes, the density and viscosity of the oil tend to increase as the oil weathers. It is possible for the weathered oil, especially in the presence of suspended particulate matter in the water column, to become denser than water and sink. In addition, the oil (including the residual fraction) does continue to degrade over time within the model. In addition, one must consider that the hypothetical long-term releases of oil (many months) continues to add fresh oil, which will increase the total amount of oil through time that will degrade. As time progresses, residual oil is all that remains of the early portions of the release while whole fresh oil continues to be released in later stages. In total, this may appear as though degradation rates are increasing, but it is rather a function of the static degradation rate and the increasing amount of oil (a portion fresh oil) through time.

A recent comprehensive model update with literature review of over a dozen of the most recent studies on oil degradation rates validating the use of modelled SIMAP degradation rates was conducted for work following the Deepwater Horizon Natural Resource Damage Assessment (French et al., 2015) as well as for the United States Bureau of Ocean Energy Management (BOEM) (French McCay et al., 2018b,c).

The long-term weathering and degradability of an oil (including microbial degradation, photo-oxidation, and other processes that may break down compounds or components of oil) may increase the tendency of an oil to sink. These processes are highly dependent upon the type of oil released and the environmental conditions of the receiving environment. A large amount of work is currently being undertaken to develop scientific consensus in this area; however, it is understood that compounds with a boiling temperature >380°C degrade slowly and that these compounds are difficult to measure. The modelled bulk disappearance is quite slow and would conservatively overestimate the effects following a release as oil would remain in the modelled system. The inclusion of compound-specific degradation would increase the degradation and reduce the amount of oil remaining in the model, therefore potentially skewing results towards less effects.

3.2 Geographic and Habitat Data

For geographical reference, SIMAP uses rectilinear grids to designate the location of the shoreline, the water depth (bathymetry), and the shore or habitat type. The grids were generated from a digital shoreline using ESRI geoprocessing and Spatial Analyst Extension tools. The cells were coded for depth and habitat type. Geographical data were obtained from multiple international sources to provide the geographic and environmental information required for modelling (Table 3-3). Habitat data were used to define the bottom type and vegetation found in subtidal areas, areas of extensive mud flats and wetlands, and the shoreline type (e.g., sandy beach, rocky shoreline, etc.).

The SIMAP model used these grids to identify the location of the shoreline and amount of oil that may adhere once oil contacted the shoreline (Figure 3-1). Retention of oil on a shoreline depends on the shoreline type, physical and chemical properties (e.g., viscosity) of the oil, tidal amplitude in estuarine areas, and wave energy. The resolution of the habitat grid was approximately 1.8 km north-south by 2.5 km east-west (0.02225° on each side). Bathymetry data define the water depths within the modelled extent. The General Bathymetric Chart of the Oceans (GEBCO) one arc-minute interval grid was used but was resampled into a grid with the same resolution as the habitat grid (Figure 3-1).

Table 3-3. Sources for habitat, shoreline, and bathymetry data.

Data Type	Data Source	Geographic Location	Reference
Habitat/Shoreline	Environment and Climate Change Canada	Canada	Therrien, A. 2017
	National Oceanic and Atmospheric Administration Environmental Sensitivity Index	United States (except Maine)	NOAA 2016a
	Maine Environmental Vulnerability Index	United States - Maine	MDEP 2016
	New Brunswick Department of Natural Resources	New Brunswick	NBDNR 2013
	Nova Scotia Department of Natural Resources	Nova Scotia	NSDNR 2013
Bathymetry	General Bathymetric Chart of the Oceans Digital Atlas	Global	GEBCO 2003

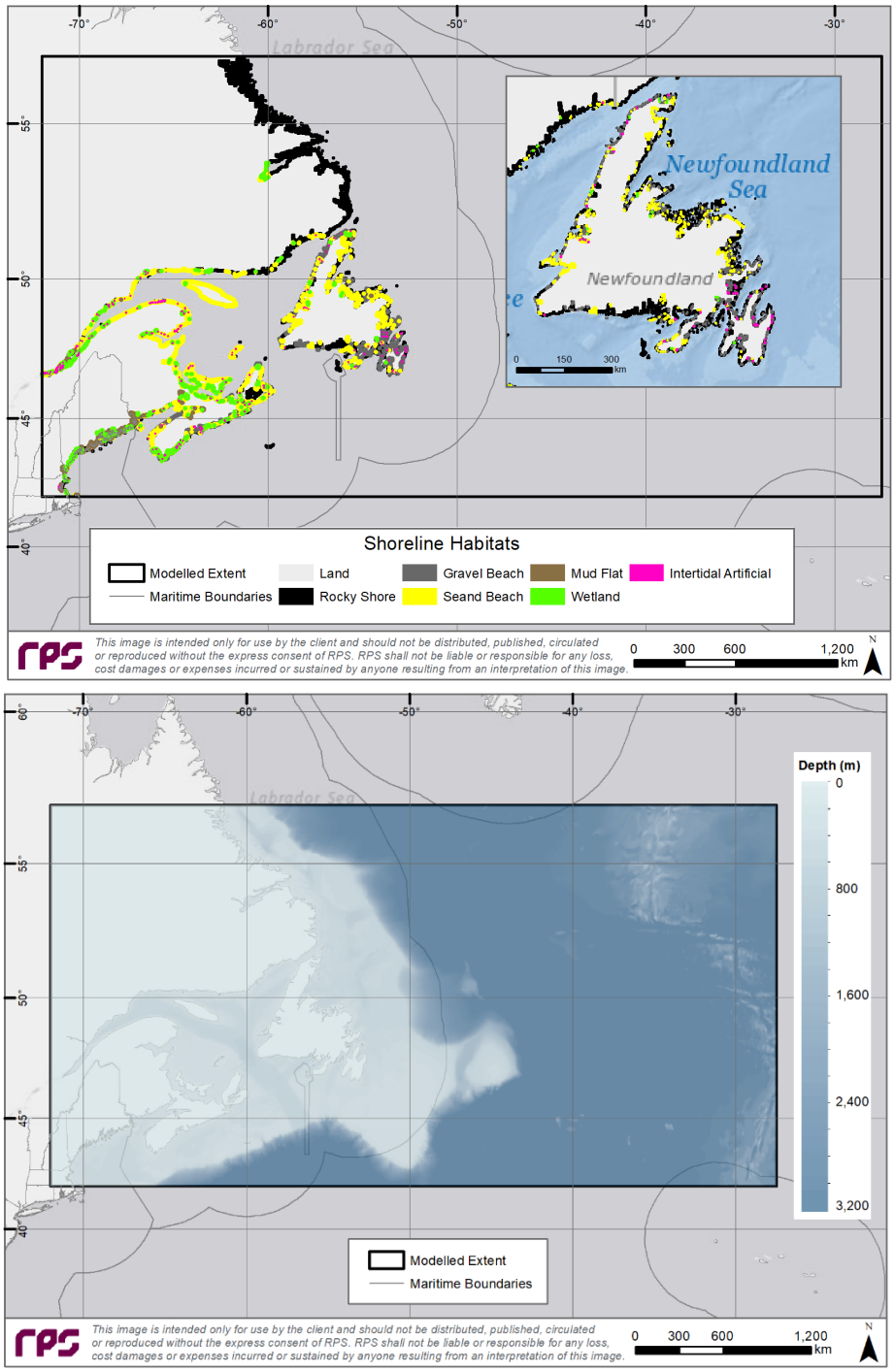

Figure 3-1. Shoreline habitat data (top) and depth (bottom) through modelled domain. The black box represents the modelled extent.

3.3 Ice Cover

Sea-ice is formed in the autumn in the Arctic and sub-Arctic regions of the world. The growth rate of sea-ice depends on surface temperature and the heat flux in the underlying water. The formation and development of sea-ice follows a progression of stages. The exact timing of these stages at any location is not the same from year to year because of subtle differences in climatic conditions. In the Northern Hemisphere during September and October, the air temperature lowers sufficiently to form a thin sheet of ice on the sea surface. The freezing temperature for average ocean seawater with a salinity of 35 parts per thousand (PPT) is about -2°C (NOAA, 2014).

The movement and behavior of released oil is greatly affected by the presence of sea-ice (Figure 3-2). Oil trapped in or under sea-ice will weather more slowly than oil released in open water. Algorithms in SIMAP for modelling the movement and behavior of oil in the presence of sea-ice are based on the percent of ice coverage (also commonly referred to as ice concentration) and an extensive review of the literature (French McCay et al., 2014, French McCay et al., 2016, French McCay et al., 2017a, French McCay et al., 2017b, French McCay et al., 2018a, Wilson et al., 2018). From 0 to ~30% coverage, the sea-ice has no effect on the advection or weathering of surface floating oil. From approximately 30 to 80% ice coverage, oil advection is forced to the right of sea-ice motion in the Northern Hemisphere. Surface oil thickness generally increases due to ice-restricted spreading, and evaporation and entrainment are both reduced by damping/shielding the water surface from wind and waves. Above 80% sea-ice coverage, surface oil moves with the sea-ice, and evaporation and entrainment cease.

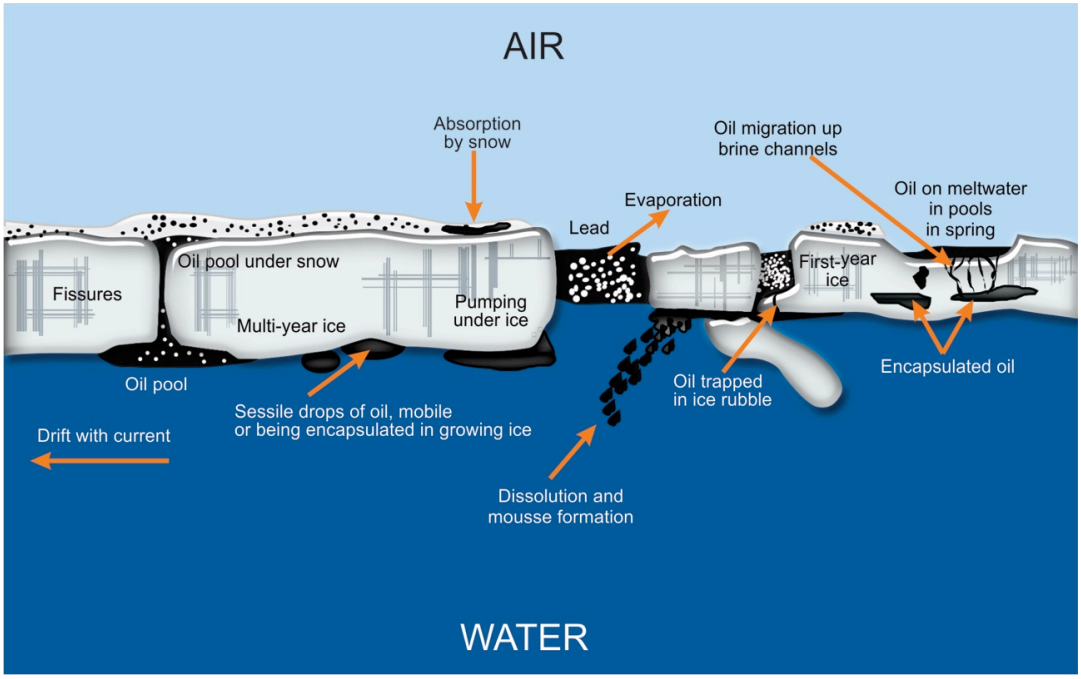

Figure 3-2. Oil and ice interactions at the water surface (RPS 2017, modified by Alan A. Allen from original, DF Dickins Associates Ltd, 2004).

The sea-ice thickness and concentration can vary greatly based upon prevailing weather conditions. If oil is released under sea-ice, water column exposures can be greater, due to the "capping" effect of the ice. Sea-ice cover limits or prevents evaporative losses and could result in substantially greater dissolution of hydrocarbons into the water column.

Sea-ice data used as modelling inputs were obtained from the Canadian Ice Service (CIS; ECCC, 2017) in weekly files spanning from January 2006 to December 2012. These data were in the form of polygon data, with information on total sea-ice concentration and stage of development. For each ice polygon, concentration codes were converted to concentration percentages. Average sea-ice thickness was calculated based on the proportional concentration of the various stages of sea-ice present for each week of the season over seven years. The CIS data provides a range of thicknesses for each sea-ice category and stage of development. In most cases, the mid-point of those ranges was used in the calculation of average sea-ice thickness. If the stage was not identified, but there were concentrations provided, then sea-ice stage was assumed to be first-year medium ice (Table 3-4). The sea-ice data was gridded at a resolution matching the habitat grid (0.02225°). A map depicting percentage of sea-ice coverage and thickness for the first week of February 2008 is presented as an example (Figure 3-3).

Table 3-4. Sea-ice thickness used in the modelling characterized by CIS stage of development.

CIS Sea-Ice Category or Sea-Ice Stage	Concentration	CIS Thickness Range (cm)	Model Applied Thickness (cm)
Ice Free	0%	n/a	n/a
Open Water	30%	n/a	50
Land fast Ice	100%	n/a	assumed full water depth
First year thick ice	Total concentration converted from tenths to percent ice cover	> 120	120
First year medium ice*		70 – 120	95
First year thin ice		30 – 70	50
Young ice		10 – 30	20
Grey white ice		15 – 30	22.5
Grey ice		10 – 15	12.5
New ice		< 10	5
Icebergs		unknown	100

*Default sea-ice stage assumed when none was identified in the data.

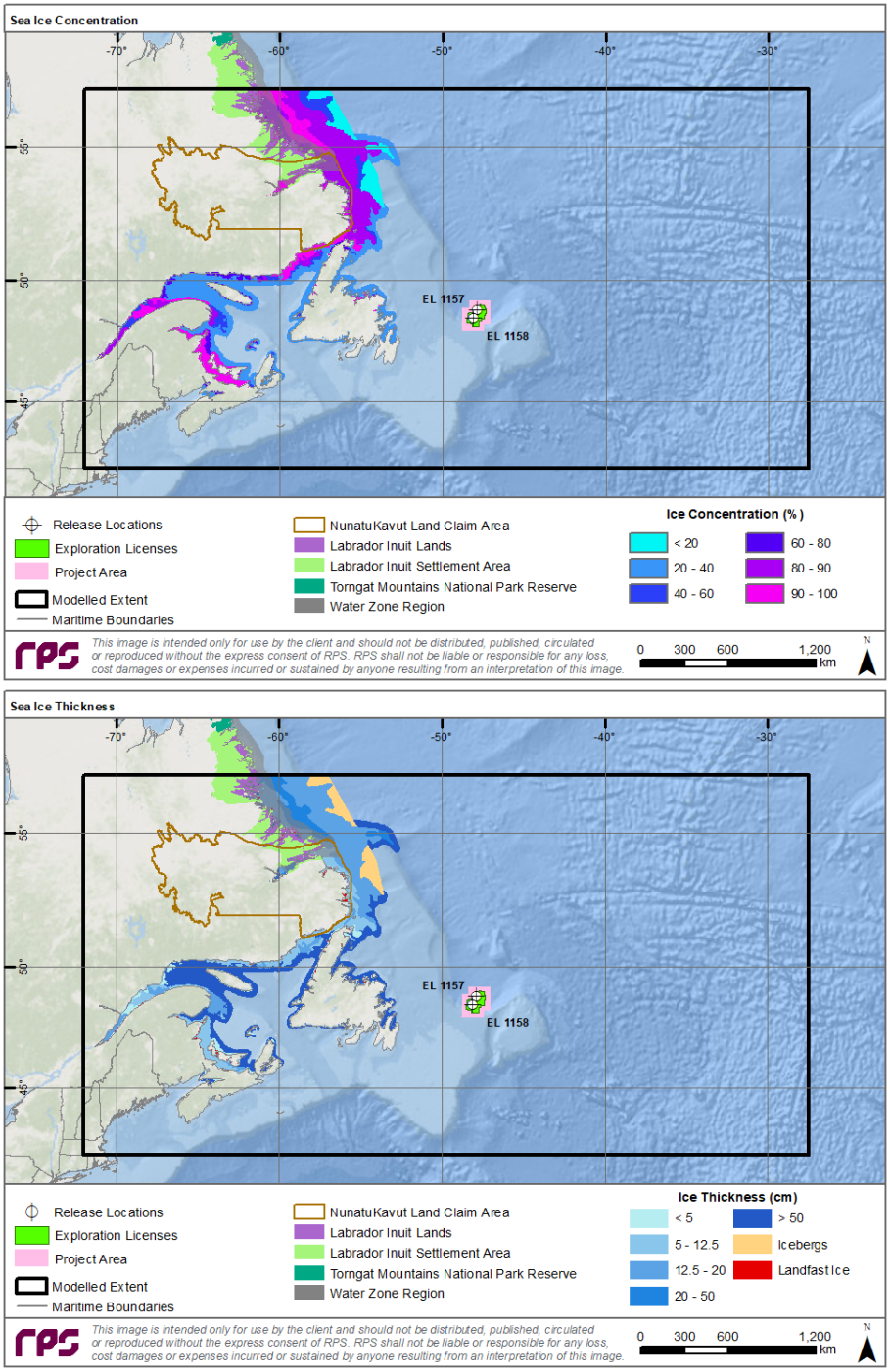

Figure 3-3. Representative percentage sea-ice coverage (top) and corresponding thickness (bottom) for the first week of February 2008.

3.4 Wind Data

Winds are one of the main physical forcing mechanisms of oil transport on the water surface, thus wind speed and direction at the water surface are driving factors of a transport simulation. To effectively model this phenomenon, the wind velocity components data must encompass a large geographic area in order to capture the spatial extent and any spatial variability in potential transport that may occur. The SIMAP model uses time-varying wind speeds and directions over the area for the period which each release was simulated. A multi-year dataset of wind velocity components was used to capture the variability that occurs over the model domain for the multiple years that were modelled (2006-2012). Simulated oil release trajectories using these long-term wind datasets are representative of possible wind conditions at each hypothetical release site. Oil released over long periods of time (e.g., the 120-day blowouts modelled here for 160 days) has the potential to be transported long distances by wind transport.

Wind data for this study were obtained for the entire model domain (Figure 2-1) from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) product for 2006 through 2010 (Saha et al., 2010). Another two years (2011-2012) of wind data were added to the analysis from CFSv2, which uses the same model that was used to create CFSR and thus works as an extension of CFSR (Saha et al., 2014). The CFS was designed and executed as a global, high-resolution, coupled atmosphere-ocean-land surface-sea-ice system to provide the best estimate of the state of these coupled domains (Saha et al., 2010). The CFS includes coupling of atmosphere and ocean, as well as assimilation of satellite radiances. The CFS global atmospheric resolution is ~38 km, with 64 vertical levels extending from the surface to 0.26 hPa. CFS winds are one of the main driving forces in the HYCOM hydrodynamic dataset. The CFS dataset acquired for and used in this study has 0.5-degree horizontal resolution and 6-hourly intervals.

Averaged annual wind data at the EL 1157 and EL 1158 sites are most frequently from the west-southwest direction (Figure 3-4 and Figure 3-5) as part of prevailing Westerlies wind pattern. Due to their proximity to one another, the two sites have similar environmental conditions. These winds would be expected to transport oil generally to the east, away from nearby shorelines and further into the open ocean. Winter season winds are most frequently from the west and northwest with higher velocity than summer season winds, which typically come from the southwest (Figure 3-6 and Figure 3-7). Spring and fall months are more dynamic transitional periods between summer and winter wind regimes. Low pressure systems, tropical, and extra-tropical storms pass through the Grand Banks on a regular basis generating substantial wind speeds for short periods of time. However, winds throughout the year predominantly come from the west, northwest, and southwest, which would force oil further into the open ocean. Monthly average wind speeds varied between 7 and 12 m/s while the 95th percentile wind speed ranged from 13 to 20 m/s throughout the year at both EL 11157 and EL 1158 (Figure 3-8 and Figure 3-9). The highest wind speeds typically occurred during winter months (November-March) and lowest speeds during summer months (June-August). Resulting significant wave heights, induced by winds at the surface of the ocean, are typically highest from November – February, in regions with no ice (C-NLOPB, 2014).

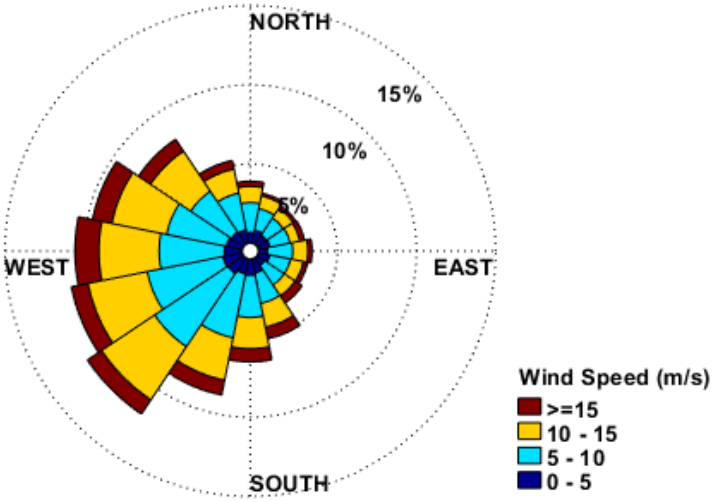

Figure 3-4. Annual CFS wind rose near EL 1157. Wind speeds are presented in m/s, using meteorological convention (i.e., direction wind is coming from).

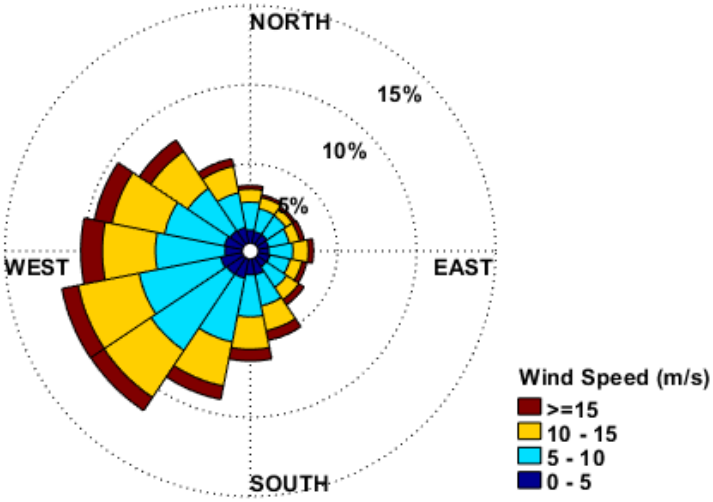

Figure 3-5. Annual CFS wind rose near EL 1158. Wind speeds are presented in m/s, using meteorological convention (i.e., direction wind is coming from).

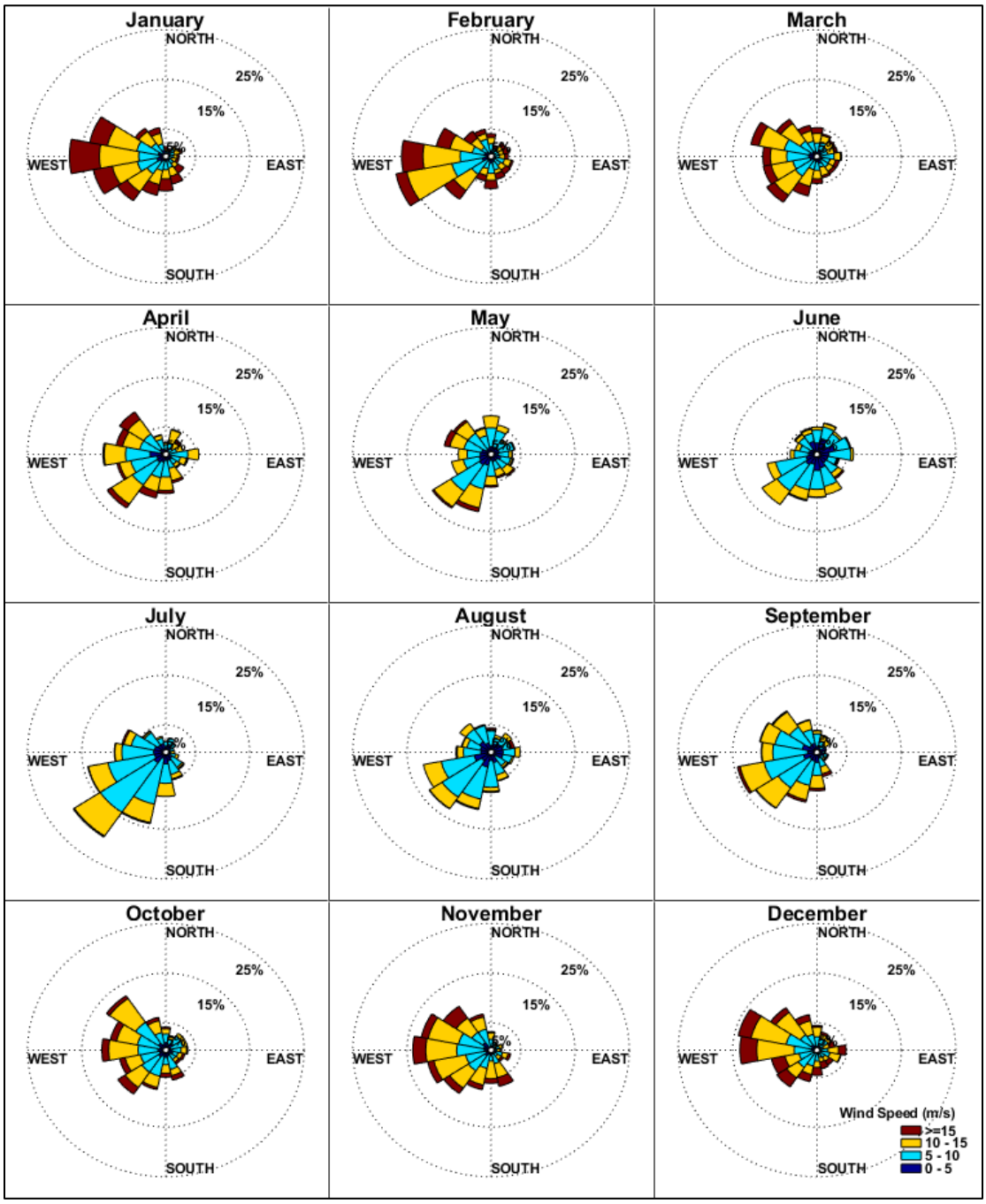

Figure 3-6. Monthly CFS wind rose near EL 1157. Wind speeds are presented in m/s, using meteorological convention (i.e., direction wind is coming from).

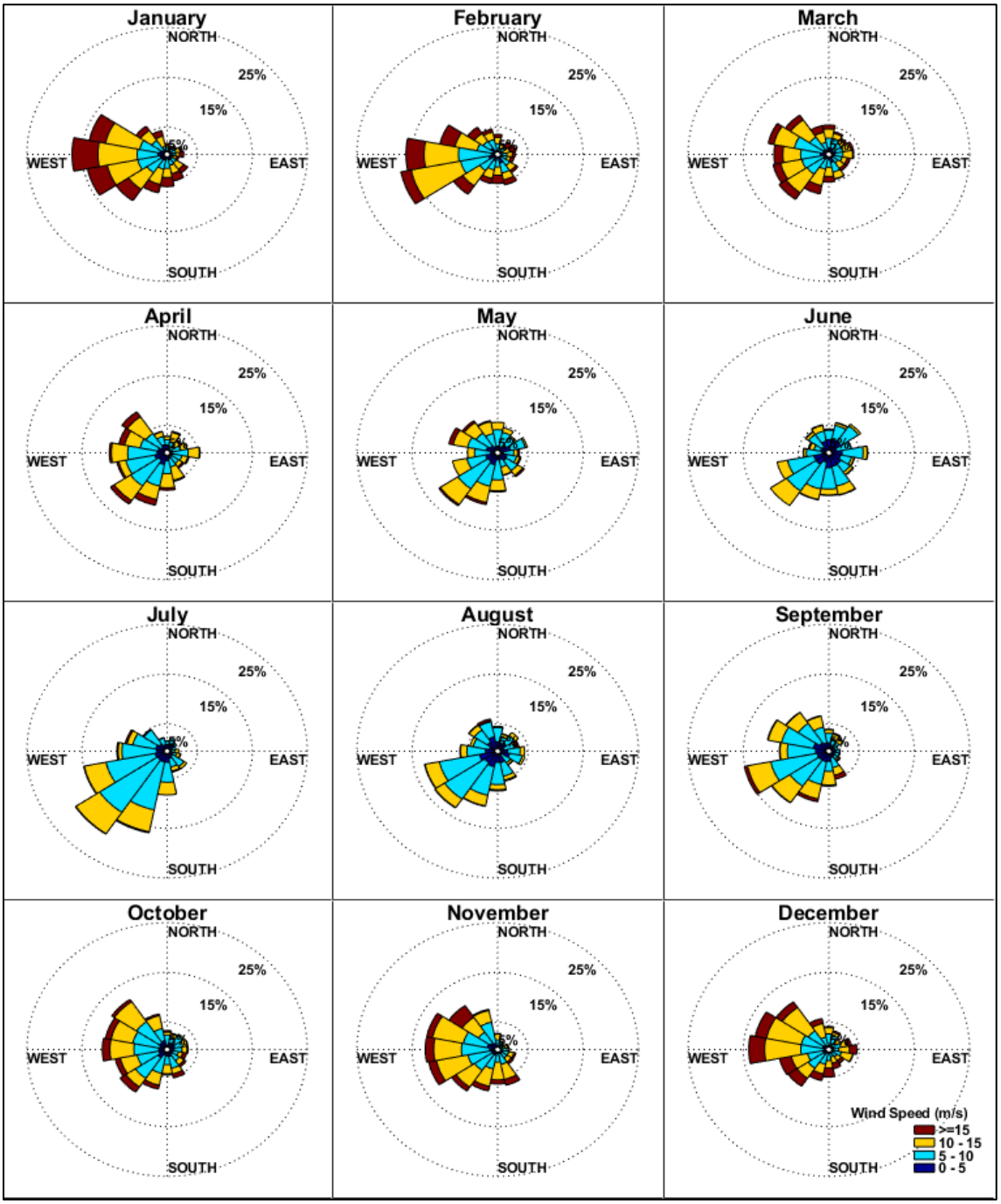

Figure 3-7. Monthly CFS wind rose near the EL 1158. Wind speeds are presented in m/s, using meteorological convention (i.e., direction wind is coming from).

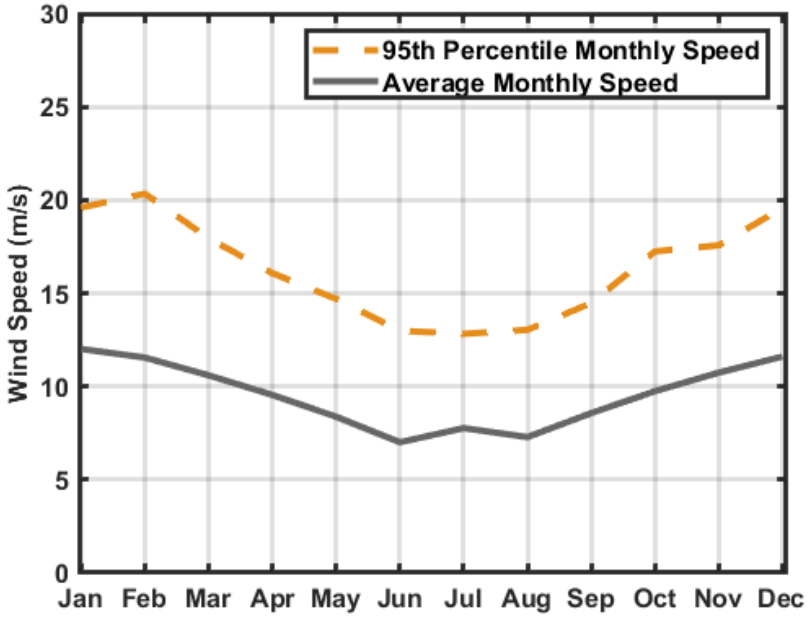

Figure 3-8. Average and 95th percentile monthly wind speeds near EL 1157.

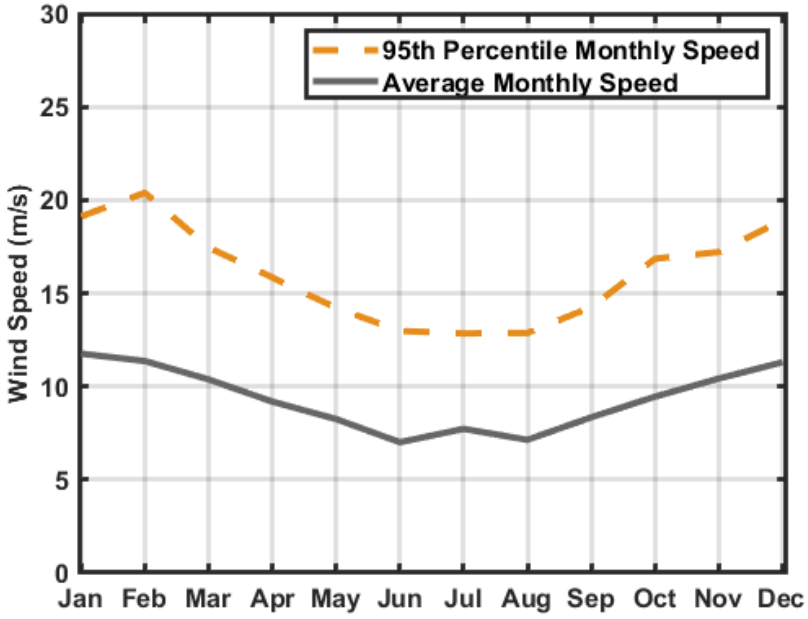

Figure 3-9. Average and 95th percentile monthly wind speeds near EL 1158.

3.5 Currents

The second main forcing factor on oil drift, in addition to winds, is currents. The Labrador Current dominates the large-scale ocean circulation in the Newfoundland region, originating in the Arctic Ocean and flowing south along the coasts of Labrador and Newfoundland (Figure 3-10 and Figure 3-12). This southerly current intensifies as waters funnel through the offshore branch, which follows the Flemish Pass along the 1,000 m contour depth between the Grand Banks and Flemish Cap. To a lesser extent, a portion of the Labrador Current flows through an inshore branch, which follows the Avalon Channel between Newfoundland and the Grand Banks. Over parts of the Grand Banks, currents can be generally weak and flow south (Petrie and Isenor, 1985). Maximum current speeds in the upper 200 m of the water column range from 0.3-2.0 m/s (C-NLOPB, 2014). The strong southerly current dominates the yearly average flow, and winds may only account for approximately 10% of current variability in this region (Petrie and Isenor, 1985). South of the Flemish Pass, the Labrador Current mixes with the North Atlantic Current. The region where these two currents converge is one of the most dynamic oceanographic areas in the world, where extremely energetic and variable frontal systems and eddies are produced on smaller scales on the order of kilometers (Volkov, 2005). Due to these eddies, local transport may advect parcels of water in nearly any direction. Satellite and drifter studies of current dynamics demonstrate this complexity. However, drifting parcels generally move to the south and east (Han and Tang, 1999; Petrie and Anderson, 1983; Richardson, 1983) where they intersect with the North Atlantic Current.

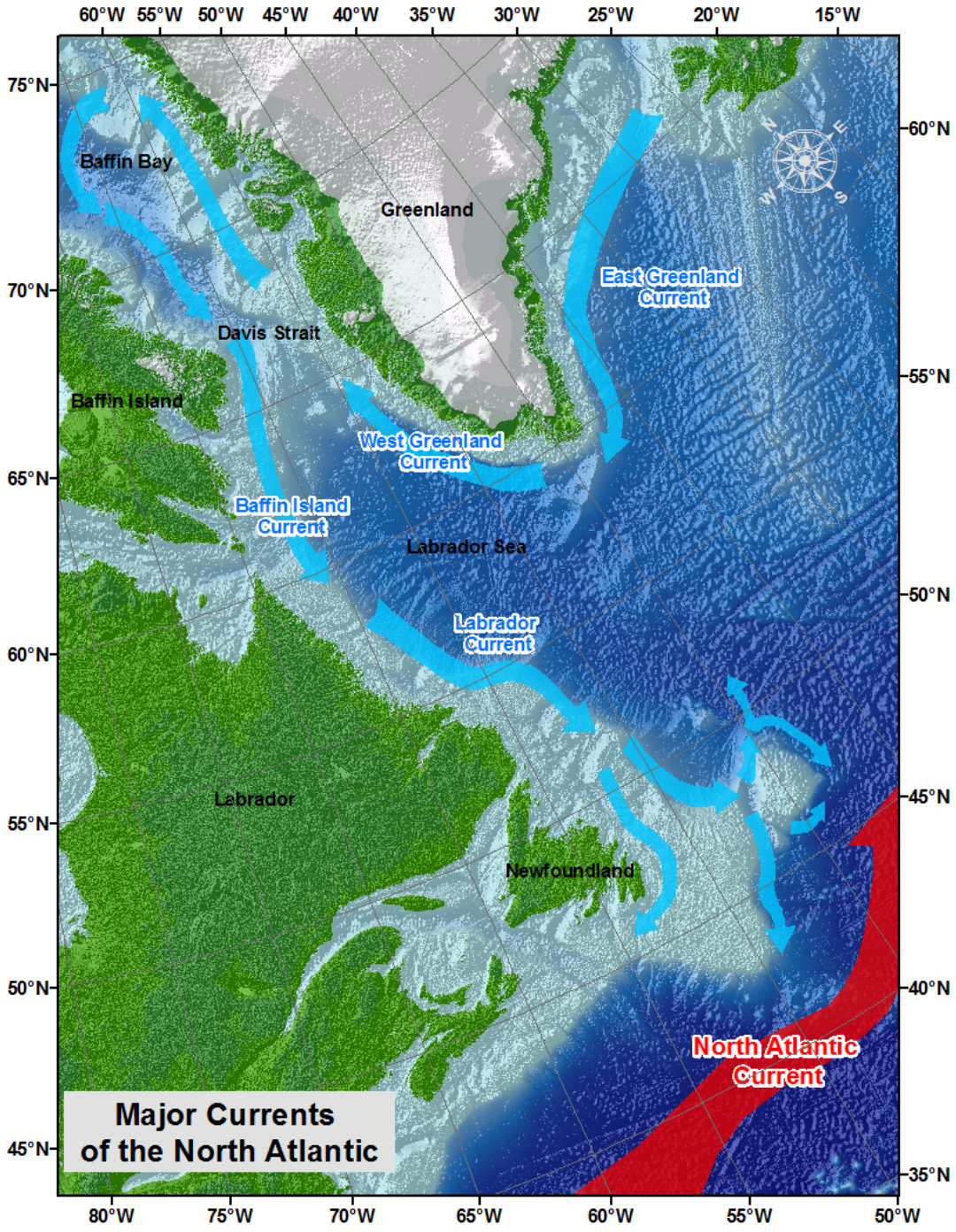

Figure 3-10. Large scale ocean currents in the Newfoundland region (USCG 2009).

Currents for the North Atlantic region were acquired from the HYCOM (HYbrid Coordinate Ocean Model) circulation model. HYCOM is a primitive-equation ocean general circulation model that evolved from the Miami Isopycnic-Coordinate Ocean Model (MICOM) (Halliwell, 2002; Halliwell et al., 1998; Bleck, 2002). HYCOM uses Mercator projections between 78°S and 47°N and a bipolar patch for regions north of 47°N, to avoid computational problems associated with the convergence of the meridians at the pole. The 1/12° equatorial resolution provides gridded ocean data with an average spacing of ~7 km between each point. Several studies demonstrated that at least 1/10° horizontal resolution is required to resolve boundary currents and mesoscale variability in a realistic manner (Hurlburt and Hogan, 2000; Smith and Maltrud, 2000; Chassignet and Garaffo, 2001).

For the energetic eddies at the frontal systems that are of a smaller scale than ~7 km, the HYCOM model would not directly capture these features due to its low resolution (Volkov, 2005). However, from a broader-scale oil trajectory perspective, it is not required to capture these smaller scale features. The movement of water within an eddy is circular by nature, meaning that oil in the eddy would tend to be trapped, circulating within the grid cell. Therefore, while the rate of circulation (i.e., velocity of rotating water body) may be greater than the forward current speed of the eddy, it is irrelevant to the broader scale modelled transport processes. The general ocean circulation (i.e., forward movement of the eddy itself) would be resolved by the average current within the single grid cell, which captures the forward speed of the core of the eddies. In addition, the randomized advection and dispersion account for the variability in currents below the spatial and temporal resolution of each dataset. Because HYCOM does not resolve the trapping of oil in these small-scale features, results of the modelled simulations would tend to include a higher degree of dispersion and would therefore cover larger areas and may be considered more conservative. For eddies that are larger than approximately 14 km in diameter, the HYCOM gridding could capture the circular nature of the circulation in the multiple grid points.

In general, the resolution of underlying forcing data has the potential to influence the results of trajectory and fate simulations. If extremely coarse resolution forcing is used, intricate flow paths may be straightened, and velocities would tend to be closer to the mean. If extremely fine resolution gridding is used, smaller-scale features will be resolved. However, there is a balance and a “law of diminishing returns” when modelling these processes. When higher spatial and temporal resolutions are used, larger amounts of data are required, and the number of modelled time steps must increase. Shorter time steps are required with higher spatial resolution data to account for the distance travelled within each time step, to ensure the spatial scale is resolved (i.e., particles to not jump or skip adjacent grid cells). As the number of cells covering the same domain with higher resolution increases, the amount of time required to model will increase as will the amount of data storage for model outputs.

The HYCOM model leverages data assimilation techniques used in the Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings, 2005). The NCODA system employs a Multi-Variate Optimal Interpolation scheme. This scheme uses model forecasts as a first guess, and then refines estimates from available satellite and in-situ temperature and salinity data that are applied through the water column using a downward projection of surface information (Cooper and Haines, 1996). Its bathymetry is derived from the General Bathymetric Chart of the Oceans (GEBCO; Supporting Volume to the GEBCO Digital Atlas, 2003). Surface forcing is derived from the Navy Operational Global Atmospheric Prediction System (NOGAPS), which includes wind stress, wind speed, heat flux (using bulk formula), and precipitation.

For this study, daily HYCOM current data were obtained for the period of January 2006 through December 2012, for the North Atlantic region (HYCOM, 2016). The data spanned seven years, which encompasses the variability in winds and currents in daily, weekly, seasonal, and inter-annual scales, including calm periods, seasonal variations, and the full range of environmental forcing over the entire period. Because of the bi-weekly randomized sampling within the seven-year modelled period and the 160-day duration of the oil spill models themselves, the range of calm to more energetic periods would be captured in each stochastic analysis. While this subset of hydrodynamic data is not the most recent seven years of data, currents and winds in the study area would be representative of environmental conditions that are likely to be present. Similarly, while there may be questions regarding general circulation during specific time periods, it is important to note that oil spill trajectories are influenced by day to day currents, as opposed to seasonal or annual averages. Average surface current speeds (Figure 3-11 and Figure 3-12) and direction offshore Newfoundland (Figure 3-12) for 2006-2012 in the model domain depict large scale features such as the Labrador Current and the North Atlantic Current as well as bathymetric steering of currents around the Grand Banks and Flemish Cap.

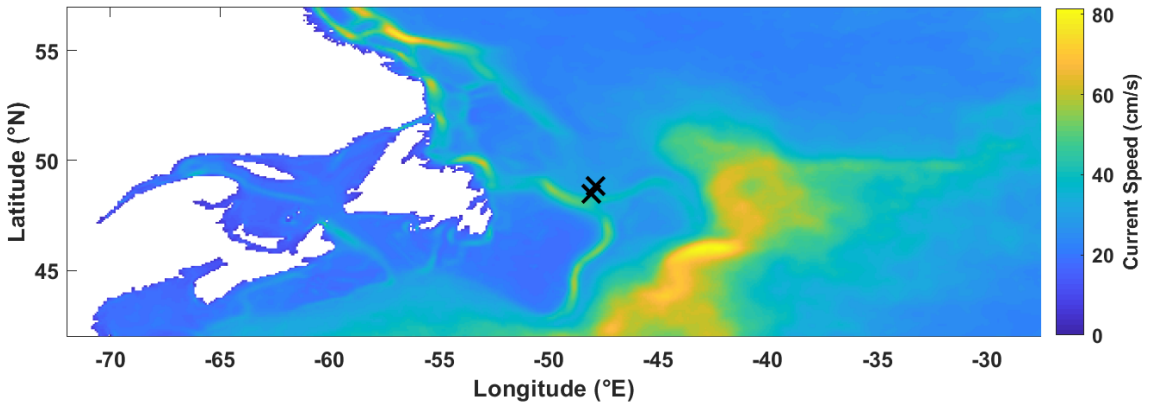

Figure 3-11. Average HYCOM surface current speeds (cm/s) off the coast of Newfoundland from 2006 – 2012. Black crosses represent the well locations.

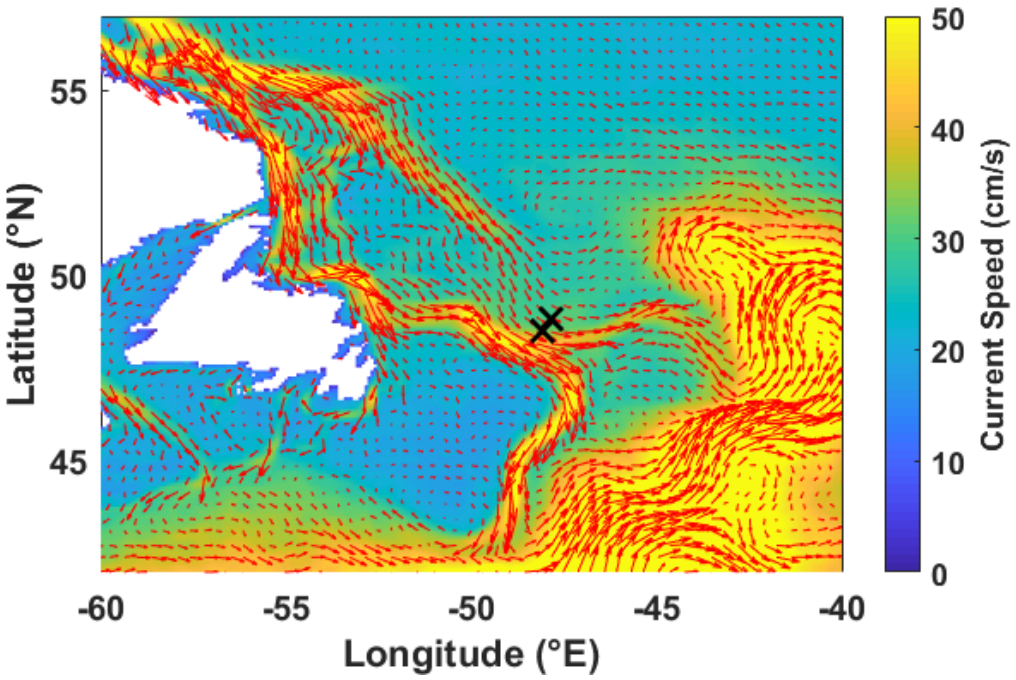

Figure 3-12. Averaged HYCOM surface current speed (cm/s) in color and arrow size, and direction presented as red vectors around the Newfoundland coast, including portions of Labrador (2006-2012). Black crosses represent the well locations.

3.6 Water Temperature & Salinity

Temperature and salinity values throughout the water column influence several oil transport and fate calculations including (but not limited to) density/buoyancy, viscosity, and evaporation (French McCay et al. 2018a). Temperature and salinity data were obtained from the World Ocean Atlas (WOA) 2018 high-resolution dataset, which is compiled and maintained by the U.S. National Oceanographic Data Center (Levitus et al., 2014). The WOA originated from the Climatological Atlas of the World Ocean (Levitus, 1982) and was updated with new data records in 1994, 1998, 2001 (Conkright et al., 2002), 2013, and 2018. These data records consist of observations obtained from various global data management projects. The dataset includes up to 57 depth bins from the sea surface to the seabed and include averaged yearly, seasonally, and monthly data over a global grid with a 1/4° horizontal resolution. At both sites, the temperature sharply decreases as the depth increases, reaching the lowest value at approximately 75 m at EL 1157 (roughly 2.0 °C) and 80 m at EL 1157 (2.8 °C) (Figure 3-13). Below these depths, the temperature increases until a water depth of approximately 325 m. Below 325 m in depth, the temperature at both sites begins to decrease. On the other hand, the salinity and density (represented by salinity and sigma-T plots respectively) of the seawater increase with depth and stabilizes below 325 m at 34.9 psu for salinity and 250 m at 27.7 for density (Figure 3-13).

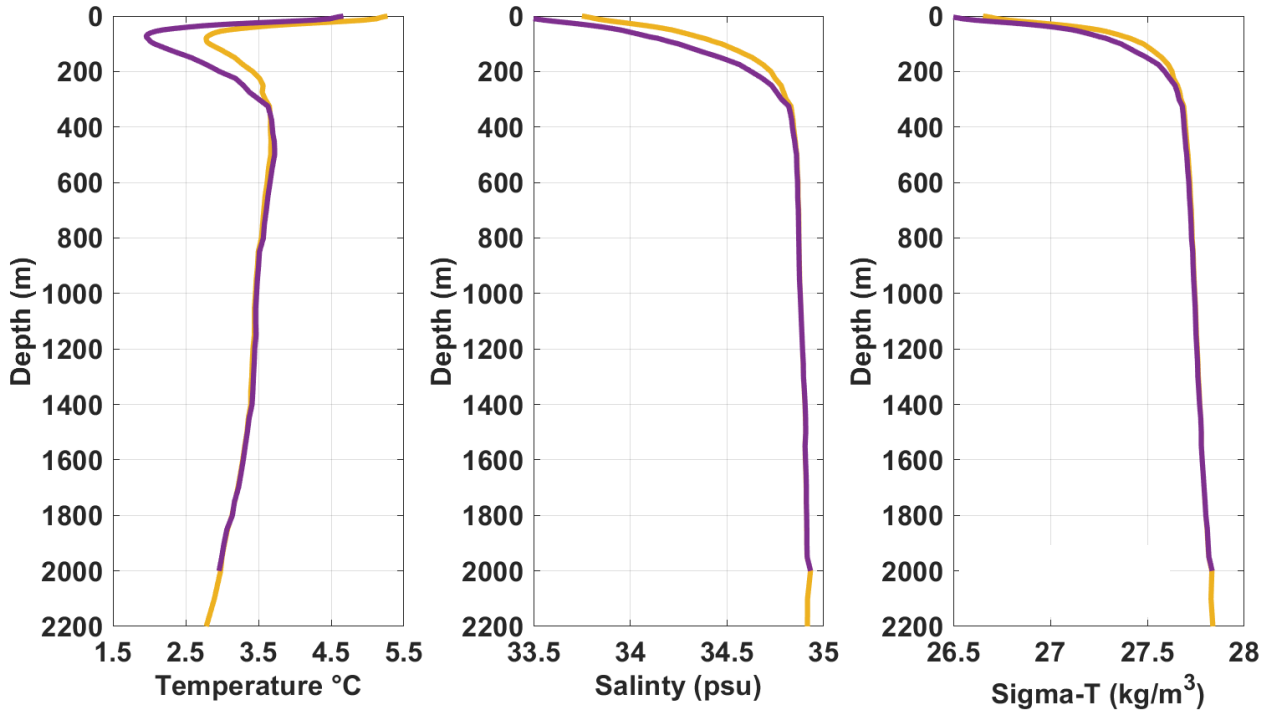

Figure 3-13. Profiles of annual water column temperature (left) and salinity (middle) from WOA18, and the corresponding calculated density (right) represented as sigma-t in the vicinity of the EL 1157 (gold) and EL 1158 (purple) release sites. The density profile was generated based on the temperature and salinity data using equations of state as published by UNESCO, 1981 (EOS – 80).

3.7 Blowout Model Scenario and Results

The nearfield model OILMAPDeep was used to predict the initial droplet size distribution associated with subsurface blowouts of BdN crude oil at two different release locations. Four subsurface blowouts of BdN were evaluated at EL 1157 and 1158 as part of this study, capturing 30- and 120-day releases (Table 2-1). Oil and gas were introduced to the water column near the seafloor to simulate an uncontrolled release from the wellhead frequently referred to as a blowout. The orifice diameter was assumed to be 31.12 cm (12.25 inches) at the seafloor (Table 2-4).

The droplet size model was used to predict the distribution of oil volume (mass) within different size ranges (measured by diameter) in response to the turbulence of the release, the gas content, the water depth, and the properties of the oil. The droplet model predicted the initial droplet size distributions for each scenario as well as the depth or “trap height” in the water column where the droplets would be released to the water column and rise according to their individual buoyancies. These values were then used to generate input files defining the size, mass, and depth of oil droplets entering the water column for use within the SIMAP far-field model.

Initial droplet sizes are primarily a function of the energy of the release, the chemical and physical parameters of the released oil, the gas to oil ratio (GOR), dispersant application, and several other factors. As an example, if the energy of a release or the amount of dispersant added were to increase, or if the viscosity of the released oil were lower, the resulting droplet sizes would be smaller. In the unmitigated scenarios simulated for this study, the oil was assumed to be untreated (i.e., no dispersant used). The energy of the release is a function of the volumetric flow rate and discharge orifice size, with higher energy releases occurring as greater volumes pass through smaller openings more quickly.

The predicted droplet size distribution was represented by seven discrete size bins for each modelled release scenario (Table 3-5). The non-uniform spacing between the droplet size bins is the result of the non-linear functionality of droplet size distribution. Each of the seven bins were determined such that an equal proportion of the released oil by mass (14.29%) was within each bin. Differences in release depth and blowout rate resulted in different droplet size distributions for each of the two modelled release rates.

Oil droplets rise through the water column at rates based on drag, calculated using their diameter (treated as a sphere) and the buoyancy (the density difference between the oil and the water), which varies with changing temperature and salinity by depth (Figure 3-13). Rise times for oil to reach the surface varied between hours to a few days, depending on droplet size and depth of release. Rise time estimates are approximated, based on the initial droplet size, initial droplet density, and bottom water density; neglecting dispersion, dissolution, and degradation (which were tracked within the oil spill model and modified the rise rates). The longest rise times are associated with the smallest droplets.

Table 3-5. Summary of droplet size distribution results for each of two modelled subsurface blowout release sites.

Median Droplet Size in Each of Seven Equal-Mass Bins, by Diameter (µm)			
EL 1157 30-day release of BdN (135,084 bpd)	EL 1157 120-day release of BdN (129,141 bpd)	EL 1158 30-day release of BdN (135,006 bpd)	EL 1158 120-day release of BdN (129,137 bpd)
374	399	359	378
748	797	717	757
1122	1196	1076	1135
1495	1594	1435	1513
1869	1993	1794	1892
2243	2391	2152	2270
2617	2790	2511	2648

4 MODEL RESULTS

4.1 Stochastic Analysis Results

Stochastic analyses characterize results from many tens to hundreds of individual modelled releases. This study included 172 individual subsurface releases modelled for 160 days for each blowout stochastic scenario. Modelled start times were distributed over a period of seven years of environmental data to capture the natural variability in the environment. In total, five stochastic analyses were completed, composed of 860 individual trajectories. Each stochastic analysis was defined by release site and release duration (near-instantaneous, 30 days, or 120 days). The release durations were consistent at each site with short/long subsurface blowouts lasting 30 or 120 days at EL 1157 and EL 1158. These scenarios represent the time required to mobilize and implement a capping stack to contain the release (30-day) or mobilize a drilling platform and drill a relief well (120-day). The near-instantaneous release at the supply vessel route location was modelled for a total of 30 days.

Because ice cover can affect the trajectory and fate of oil, individual model simulations within each stochastic scenario were broken into two groups based upon the specific modelled time period and associated presence or absence of ice cover. Statistics for all 172 releases within a stochastic scenario are referred to as “annual,” as they include all releases in any month over the course of the entire seven-year period. Sea-ice coverage in the region is present in specific regions from November through April, while May through October is mostly ice-free. Modelled releases with the majority of their simulated days (>80 of the 160-day modelled duration) experiencing mostly ice-free periods are referred to as “summer” simulations (93 modelled releases), while those releases with a majority of days experiencing periods with sea-ice coverage are referred to as “winter” simulations (79 modelled releases). Sea-ice coverage very rarely extended far enough offshore to reach within kilometers of the release locations, and when it did, <10% ice coverage was predicted. However, sea ice was present along most of the coastline in winter months, with February typically having the largest expanses of 90-100% sea-ice coverage (Figure 3-3).

The figures presented within this section illustrate the predicted spatial extent of surface floating oil, water column contamination, and shoreline contact above the specified socio-economic and ecological thresholds (Table 2-2). They include both the probabilities and associated minimum times to threshold exceedance for the four hypothetical release scenarios (Table 4-1 and Table 4-3). The probability maps define the area of potential exposure and the associated probability with which sea surface oil, water column contamination, or shoreline oil are expected to exceed the specified thresholds at any point in time throughout each of the 172 simulations with 160-day modelled duration. The colored contours in the stochastic maps specify the probability boundaries for areas that may experience oil at or above the specified thresholds for each release scenario. Darker color contours denote areas that are more likely to exceed the specified threshold, but do *not* denote higher concentrations. Lighter color contours depict regions that are less likely to exceed the specified threshold. Note that the lightest mint-green line represents areas where oil may exceed the specified threshold in only 1% of modelled simulations. In other words, the likelihood that any oil exceeding the identified threshold would leave the area bounded by the mint-green line is <1% out of 172 individual simulations. The area between the 1% contour and the next (10%) has between a 1-10% probability of exceeding the threshold, based upon the environmental variability and given that the modelled release scenario has occurred.

The probabilities of oil exposure were calculated from a statistical analysis of the ensemble of individual trajectories modelled for each release scenario. The fundamental assumption for this modelling was that an unmitigated release occurred. Therefore, probability contours should be interpreted as “In the unlikely event of a release, the probability that any one specific area may experience contamination above the specified threshold is X%.” Stochastic figures do not imply that the entire contoured area would be covered with oil in the event of a single release, nor do they provide any information on the quantity of oil in a given area. Additionally, these figures do not provide the likelihood of a blowout occurring in any given year. Rather, these stochastic figures denote the probability that contamination may exceed identified socio-economic thresholds at any modelled time step (over 160 days), for each point within the modelled domain, assuming a release were to occur at some point in time.

The stochastic maps depicting water column contamination by dissolved hydrocarbon concentrations do not specify the depth at which the threshold exceedance occurs. The maps depict the vertical maximum at any time during or after the release. Thus, images do not imply that the entire water column (i.e., from surface to bottom) will experience a concentration above the threshold, but rather a threshold may be exceeded at a specific depth (typically within a few meters from the surface) in the mapped location.

The minimum time footprints correspond with the associated probability of oil exposure maps. Each figure illustrates the shortest amount of time required (from the initial release) for each point within the footprint to exceed the defined threshold. The time reported is the minimum value for each point considering the entire ensemble of trajectories. Together, probability and minimum time figures can be interpreted to read: “There is X% probability that oil is predicted to exceed the identified threshold at a specific location, and this exceedance could occur in as little as Y days.”

The Exclusive Economic Zones (EEZ) in the North Atlantic, as well as the international border, are depicted on each map to provide context for the spatial extent and potentially affected territorial waters from any potential release (VLIZ, 2014).

All figures depict data where the probability of a region exceeding the threshold is >1%. When comparing annual to seasonal results, the predicted percent exceedance depends on the total number of releases investigated in each subset of releases. Therefore, while only one scenario might be required to exceed the 1% threshold for visualization in seasonal results (79 or 93 modelled simulations), two scenarios would be required to exceed the same threshold in the annual analysis due to a greater number (172 modelled simulations) of modelled releases in the annual set of simulations being analyzed. Figures depicting stochastic results are provided for surface oil thickness >0.04 µm and 10 µm, dissolved hydrocarbon contamination >1 µg/L, and shoreline contact >1 g/m^2 and 100 g/m^2 for annual, summer, and winter scenarios for the two release sites (Figure 4-3 to Figure 4-72).

Due to the small release volume of the batch spill of marine diesel and the size of the concentration gridding (150 m by 150 m), predicted concentrations of dissolved or total hydrocarbons in the water column did not register above a recordable threshold. Therefore, no water column exposure above the modelled thresholds was predicted and figures are therefore not provided.

4.1.1 EL 1157 Results

4.1.1.1 30-day Subsurface Release

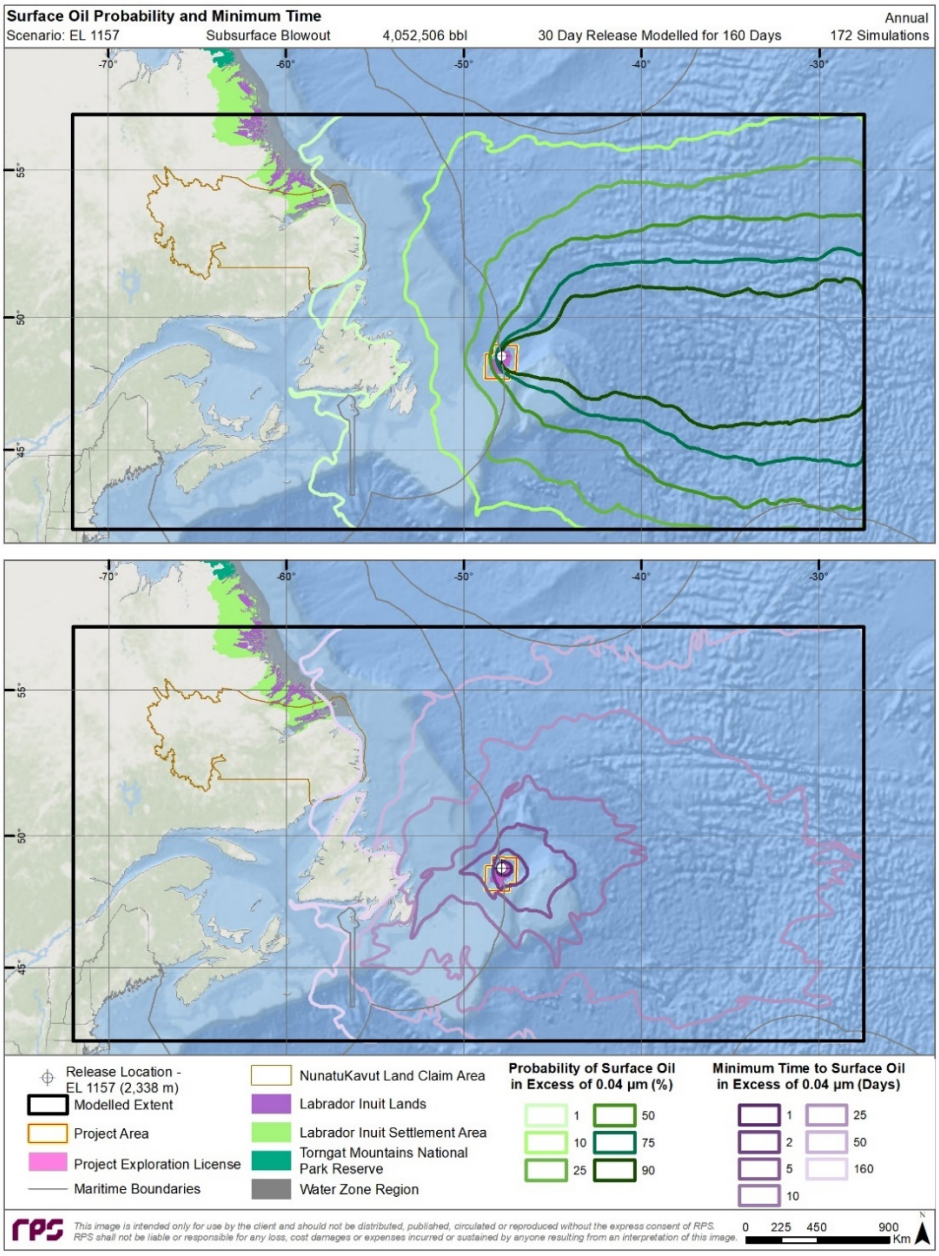

Figure 4-1. Annual probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

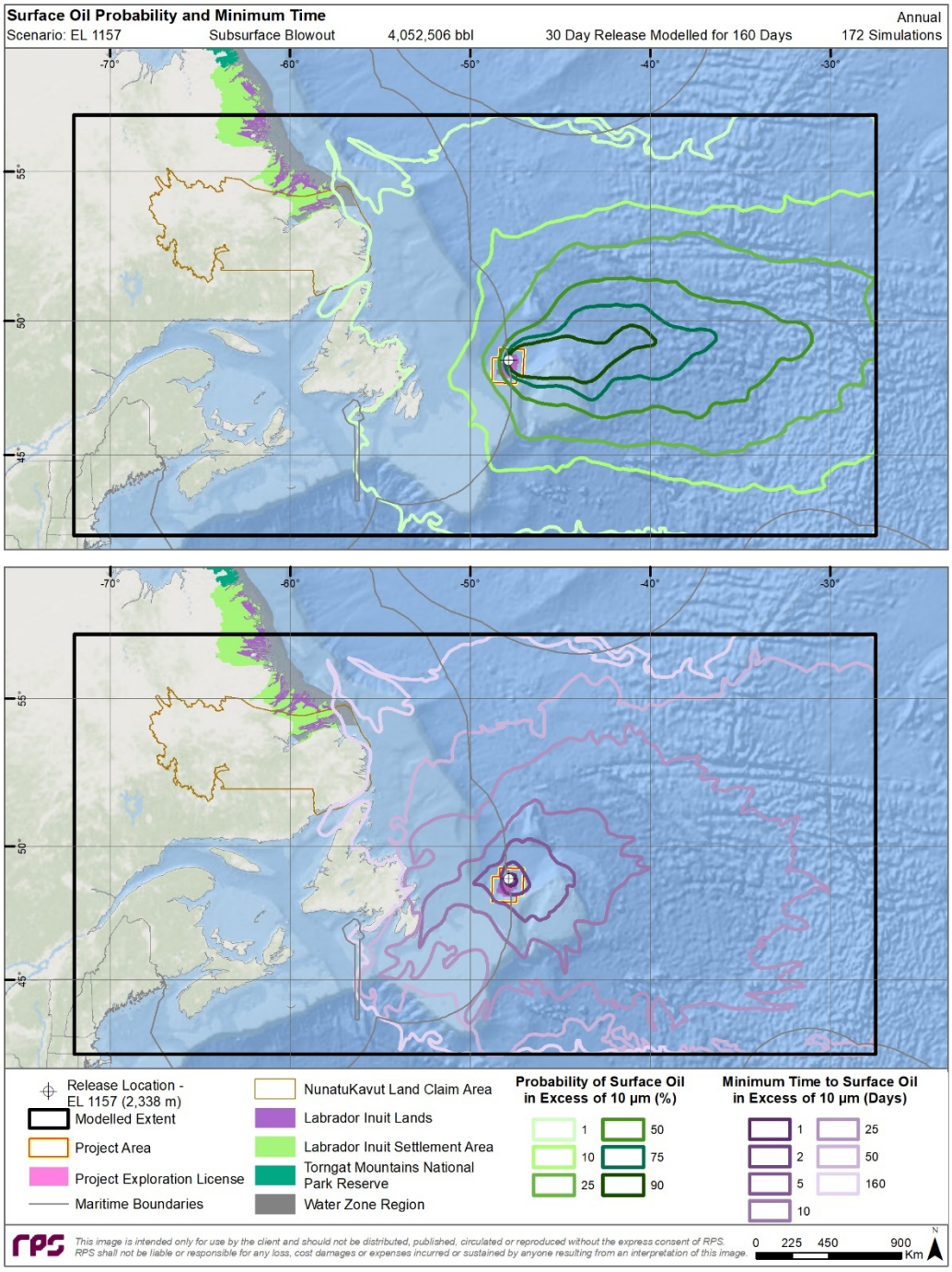

Figure 4-2. Annual probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

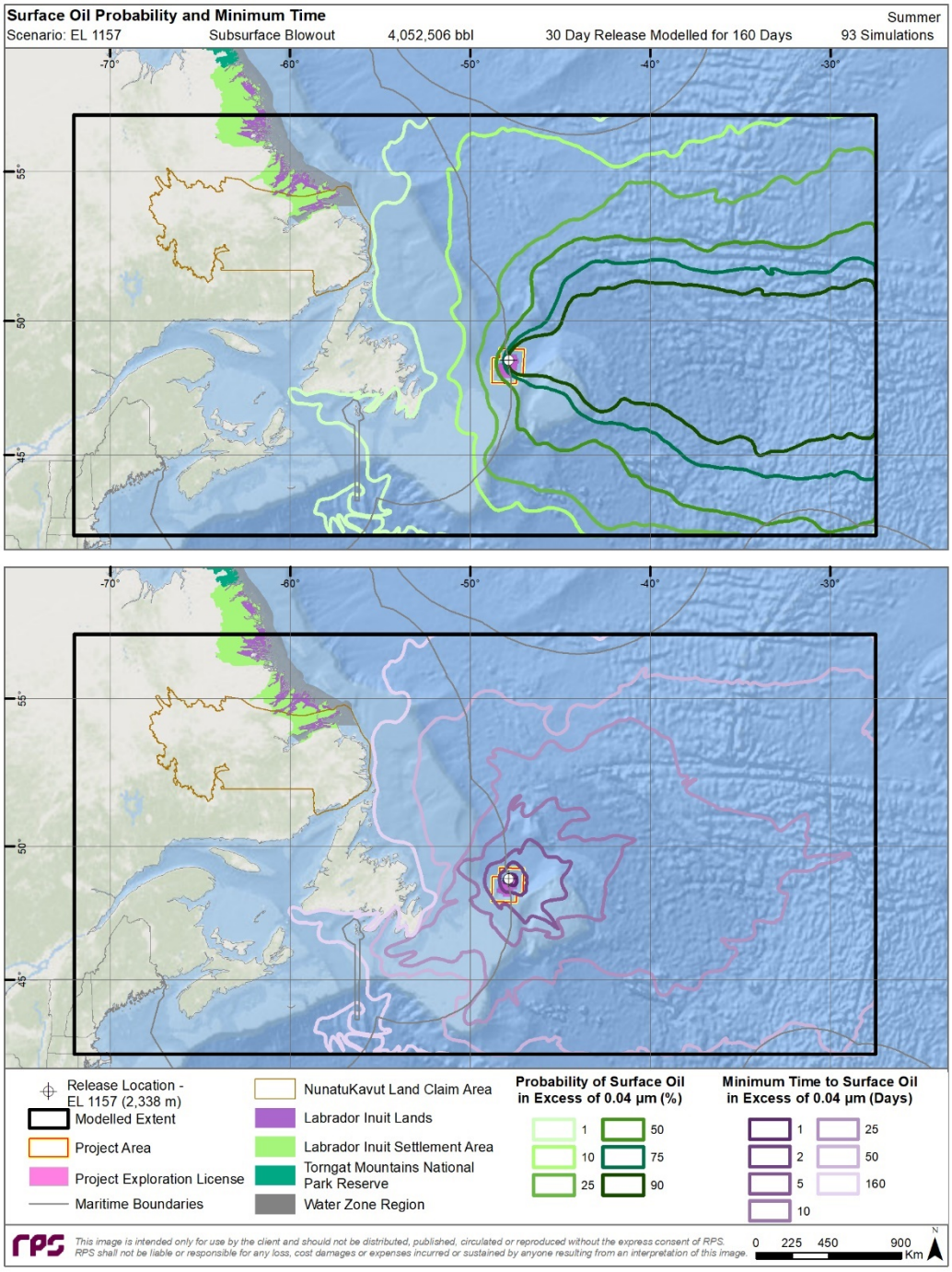

Figure 4-3. Summer probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

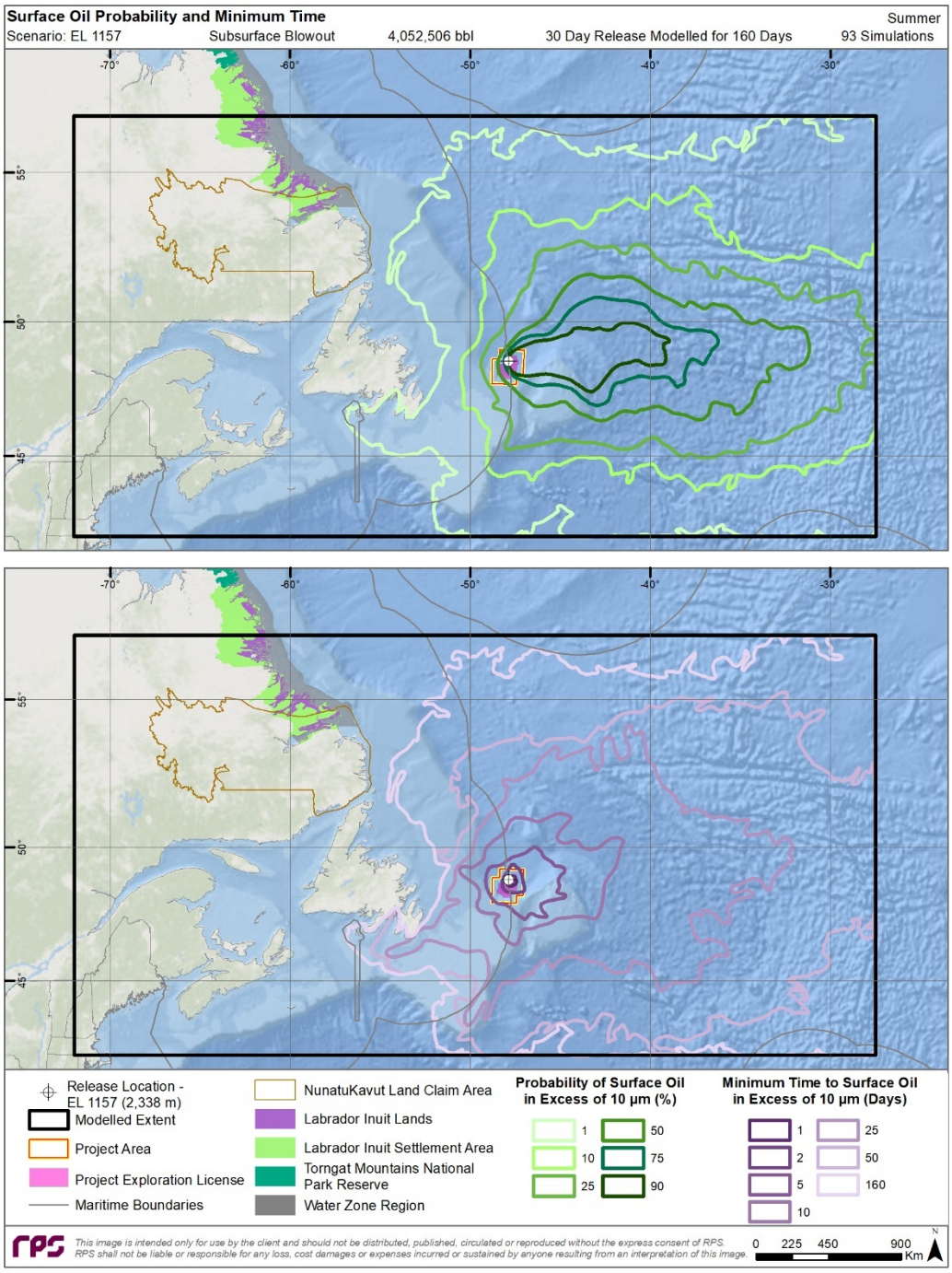

Figure 4-4. Summer probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

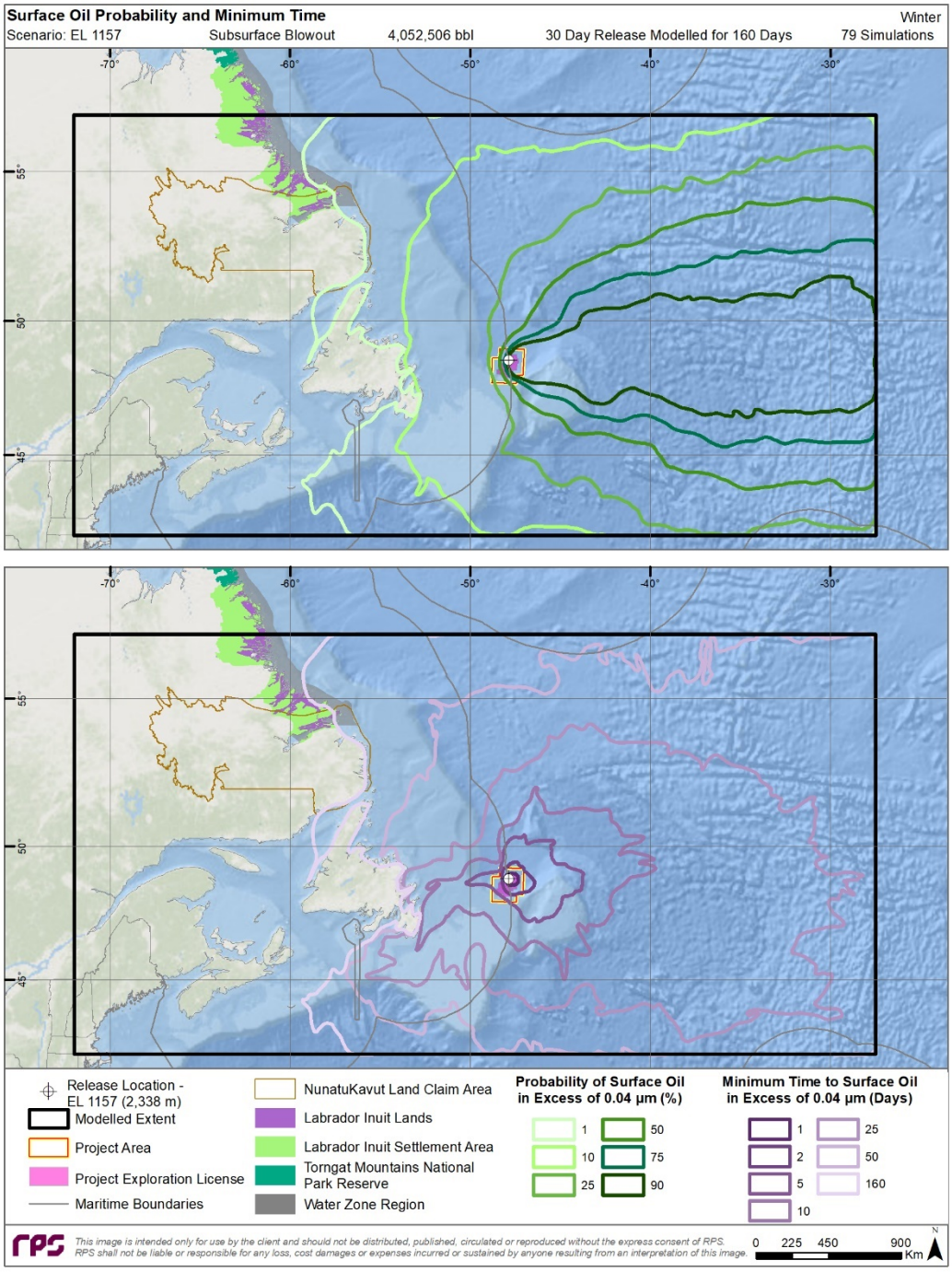

Figure 4-5. Winter probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

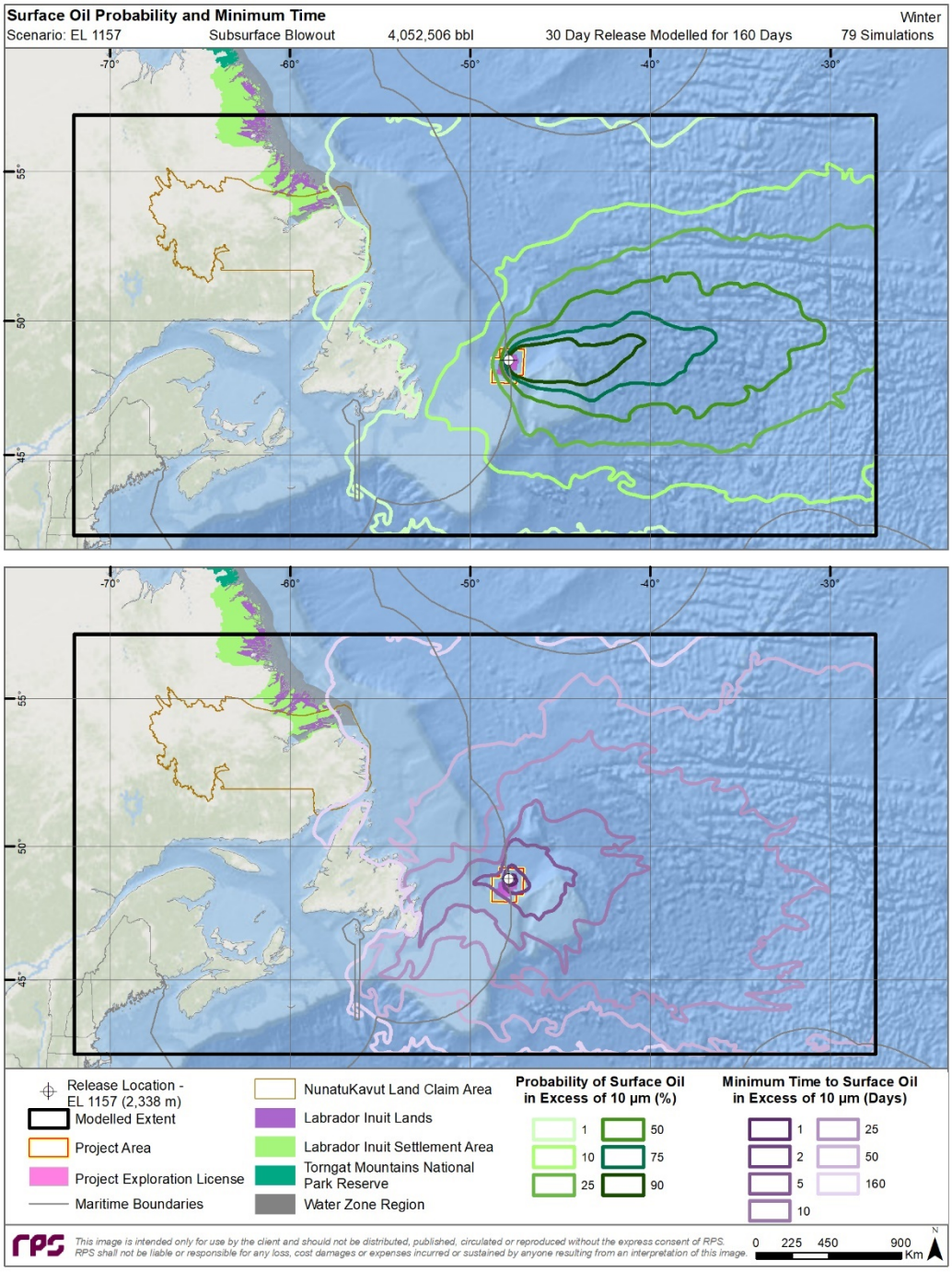

Figure 4-6. Winter probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

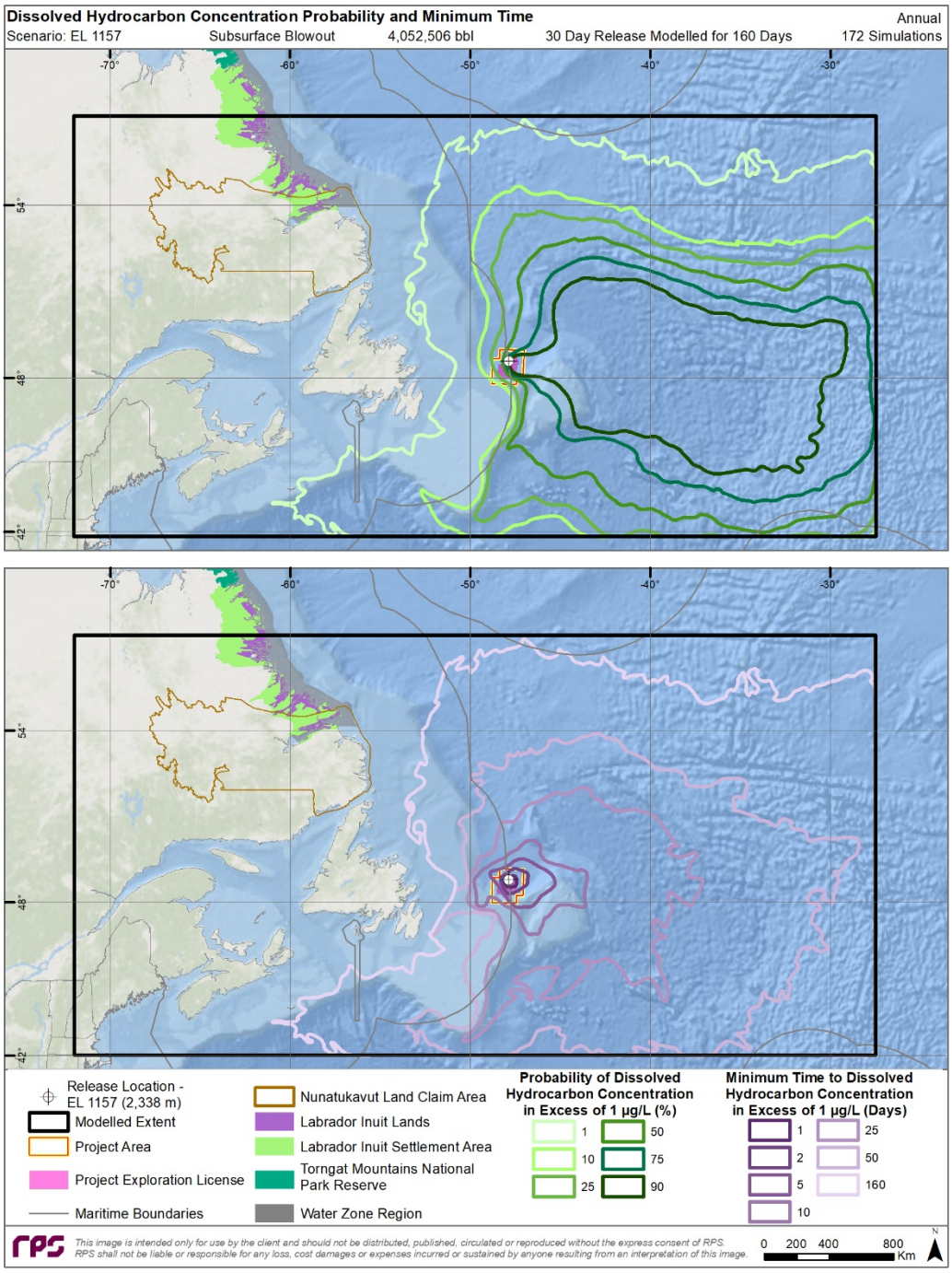

Figure 4-7. Annual probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

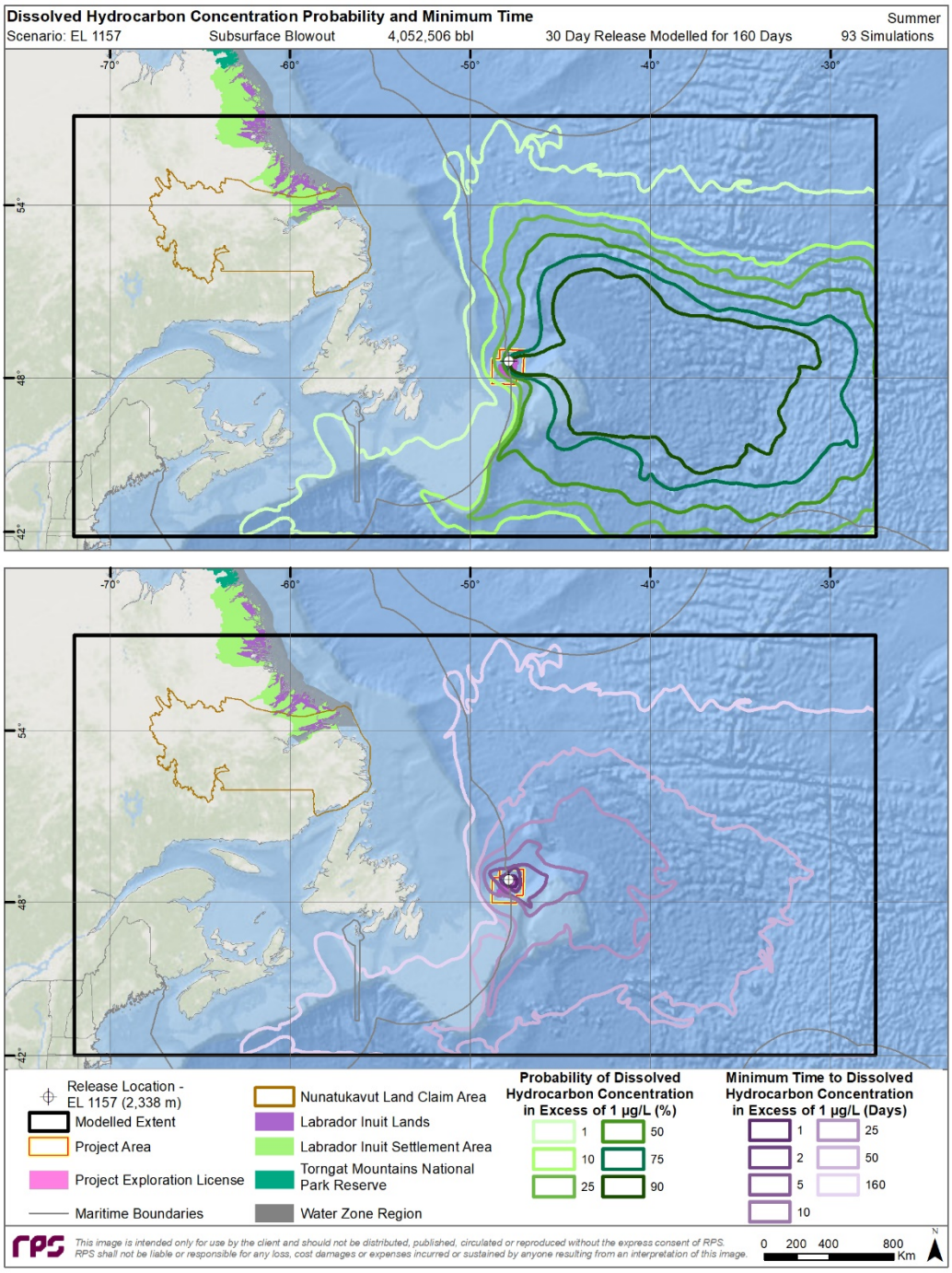

Figure 4-8. Summer probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

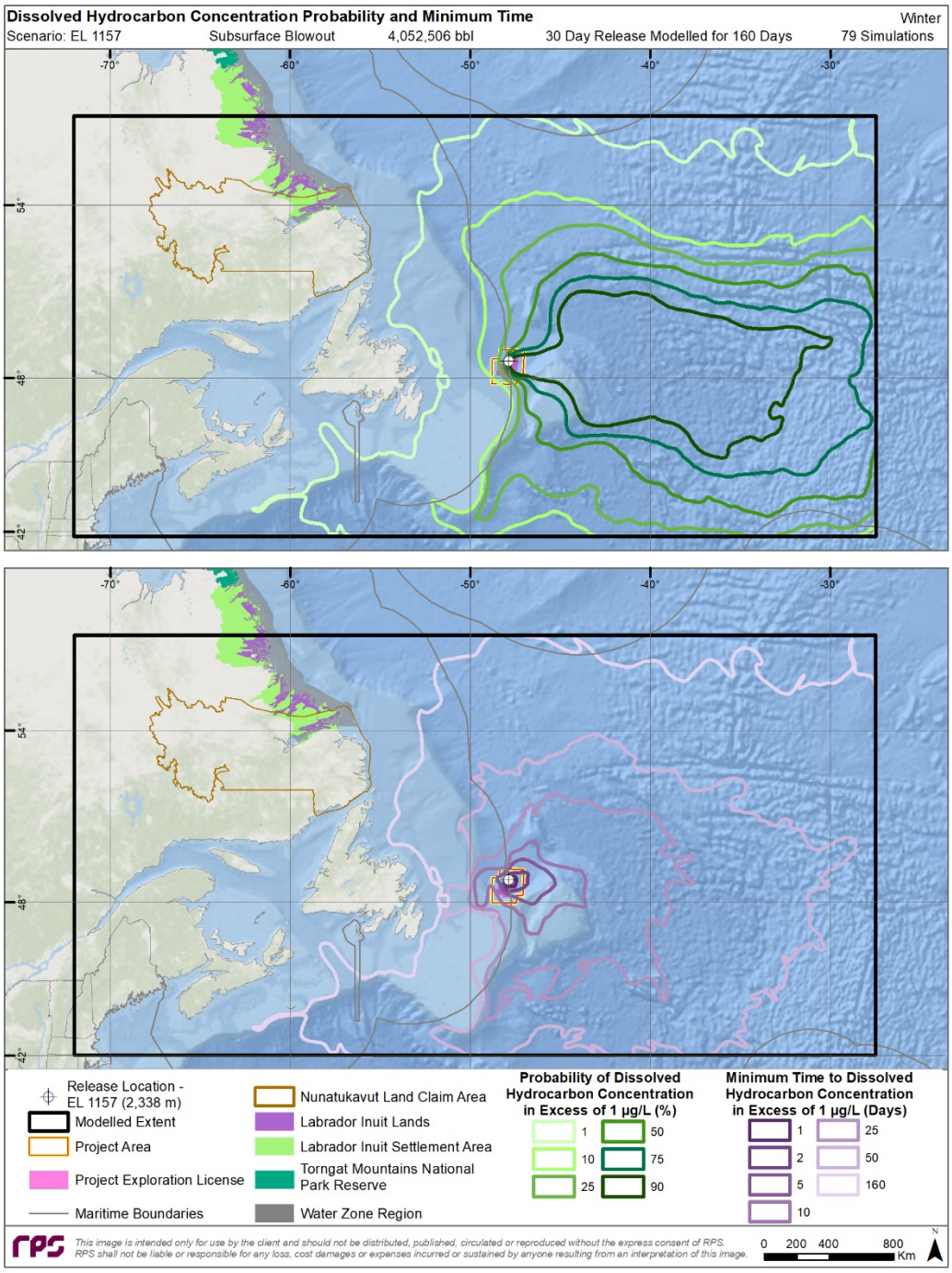

Figure 4-9. Winter probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

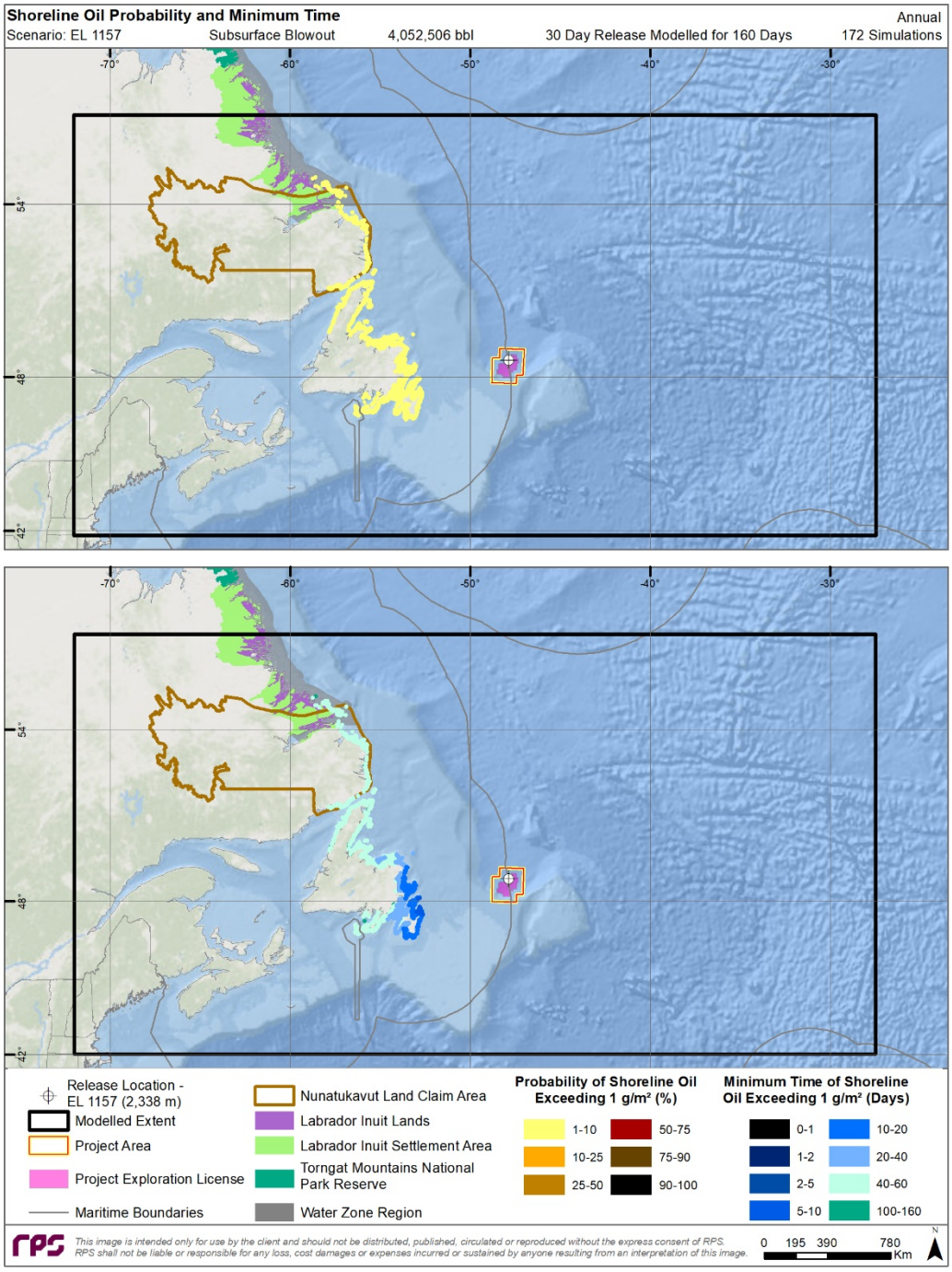

Figure 4-10. Annual probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

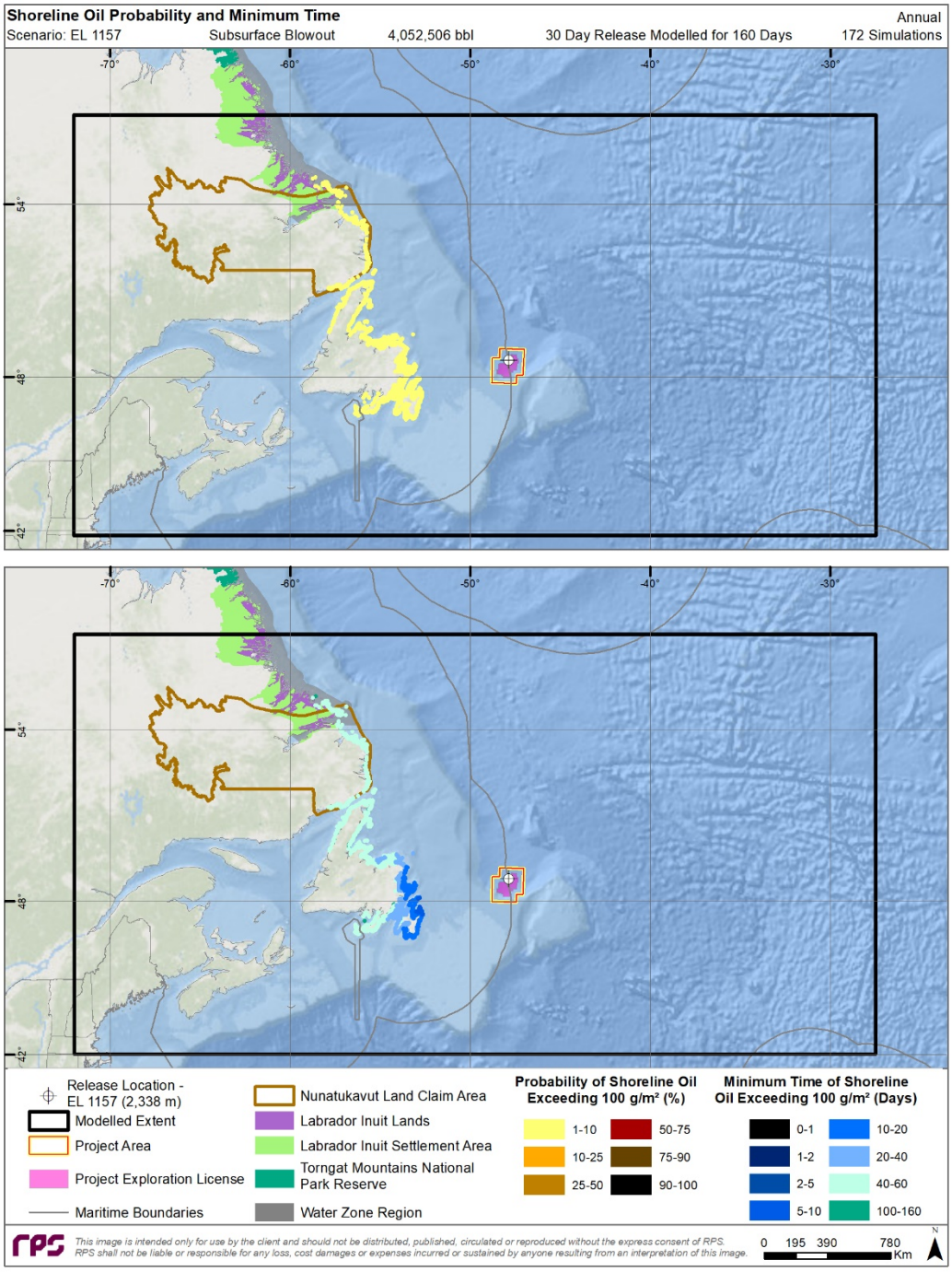

Figure 4-11. Annual probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

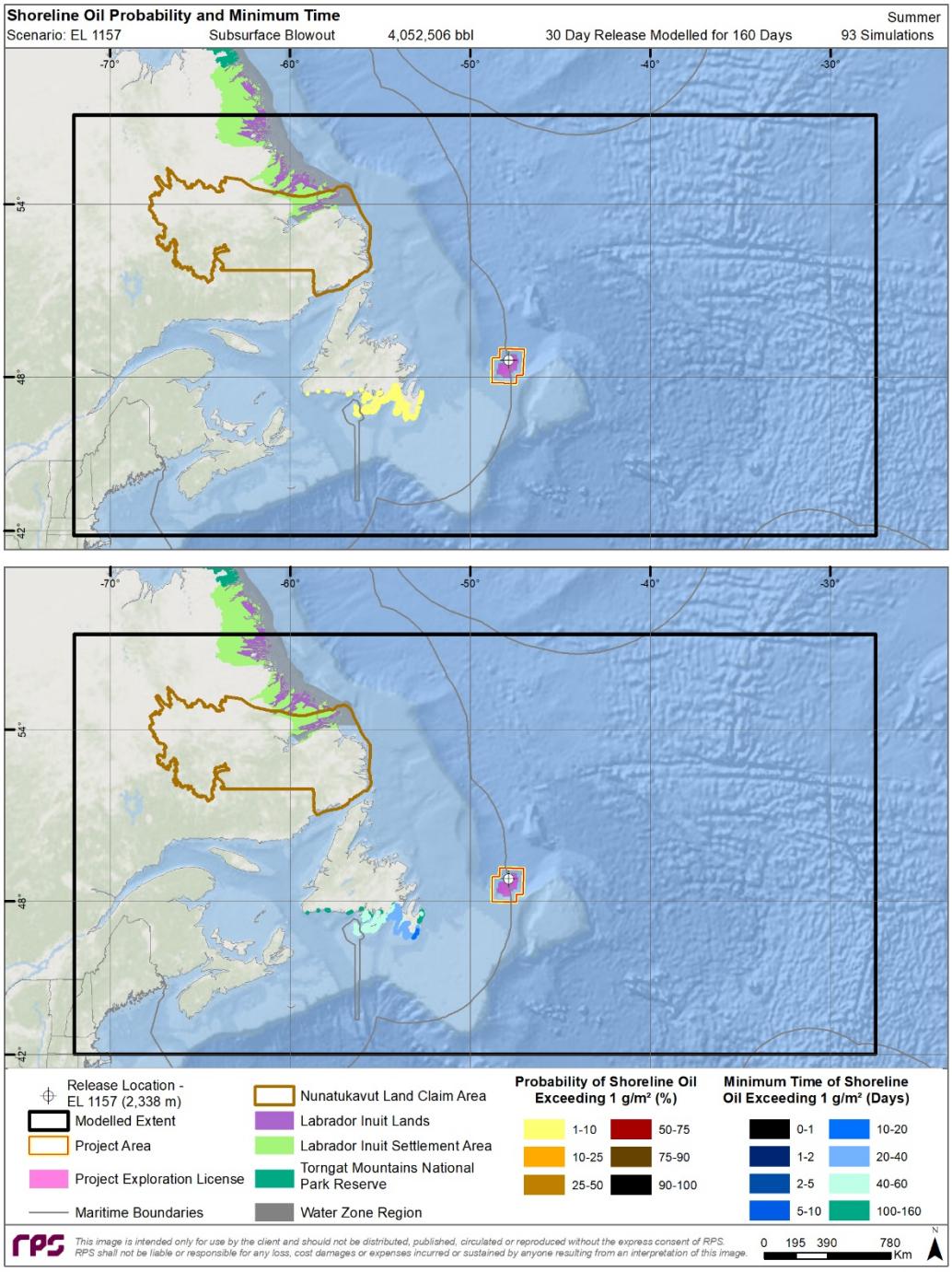

Figure 4-12. Summer probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

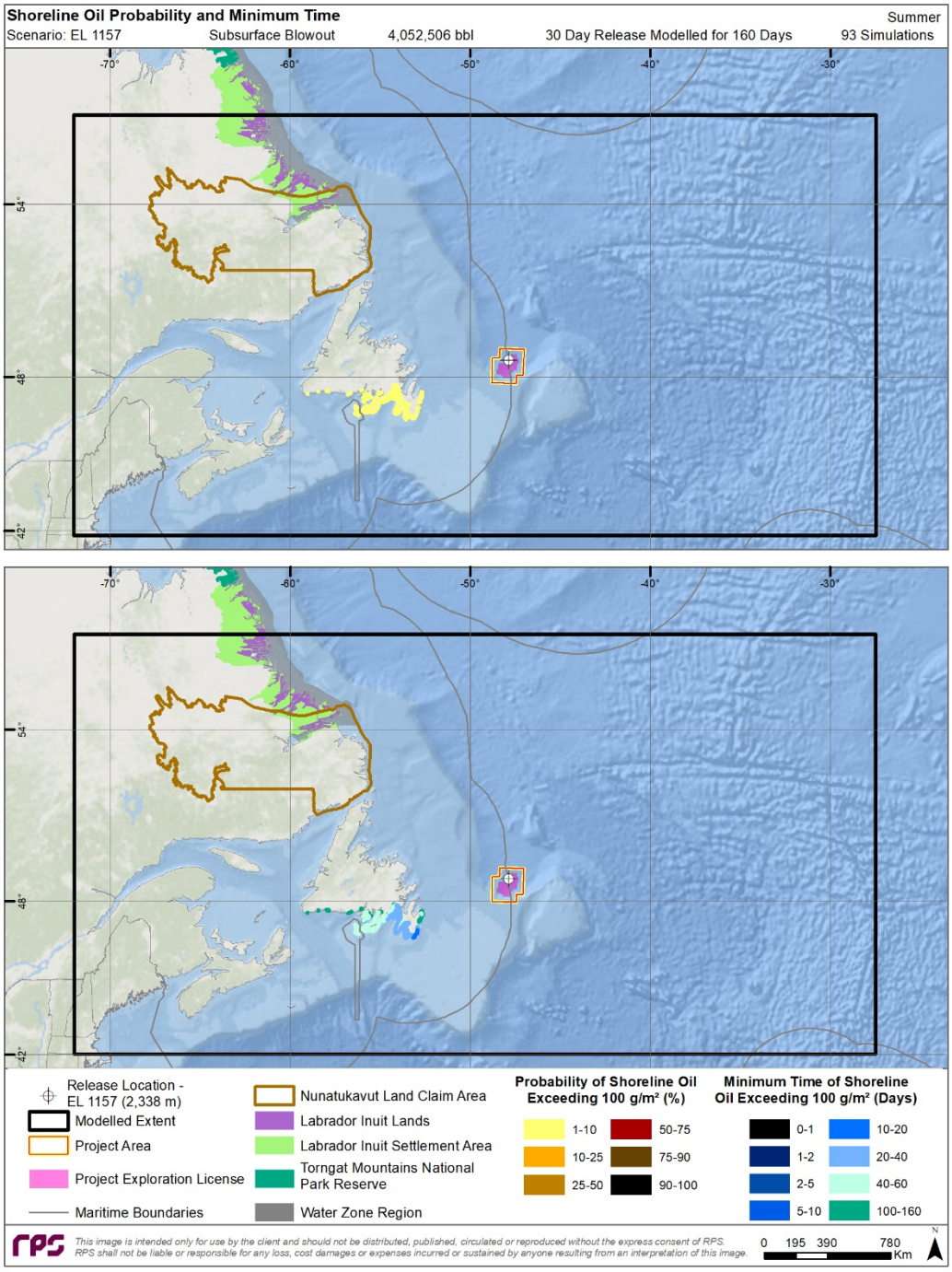

Figure 4-13. Summer probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

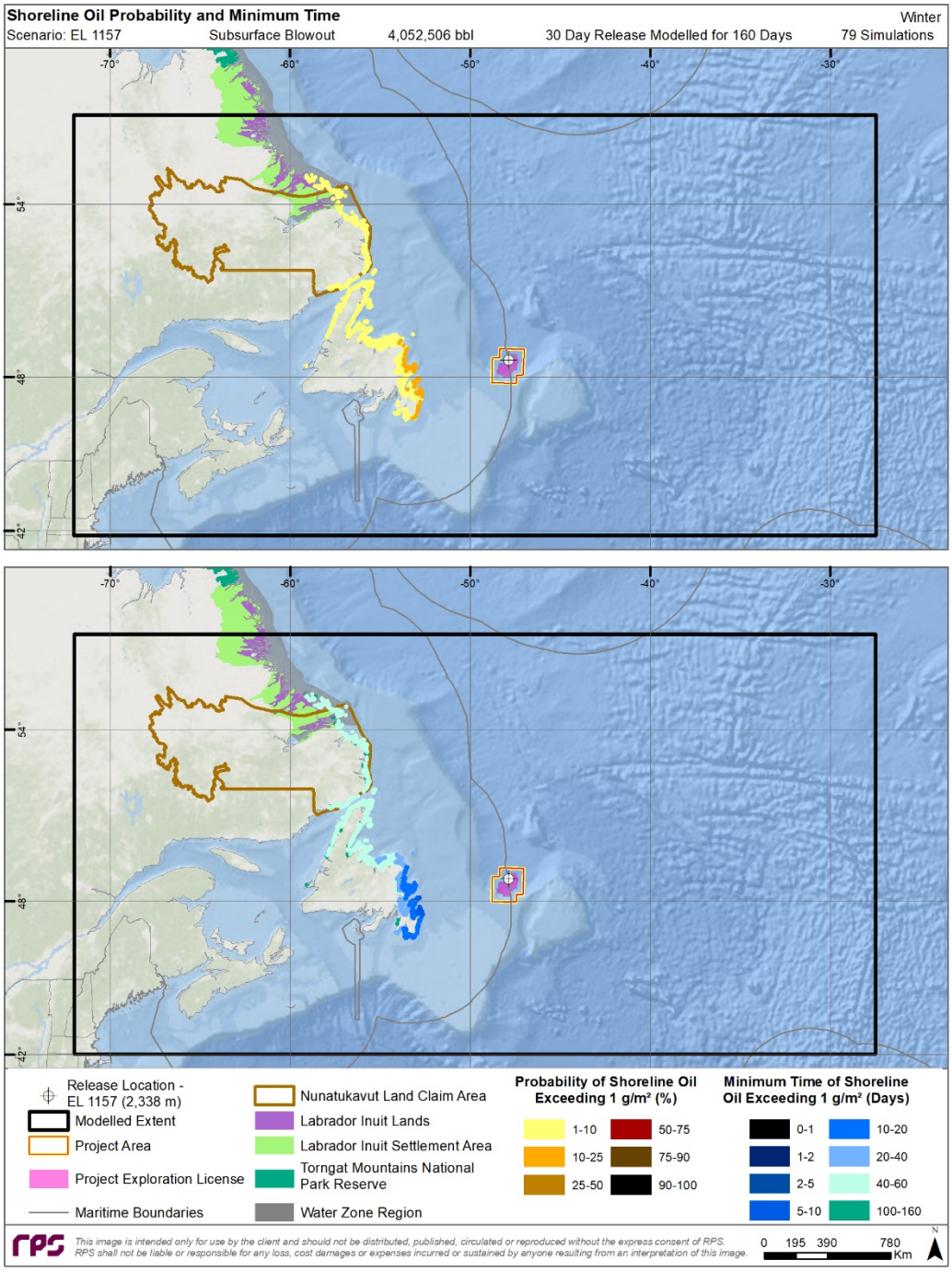

Figure 4-14. Winter probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

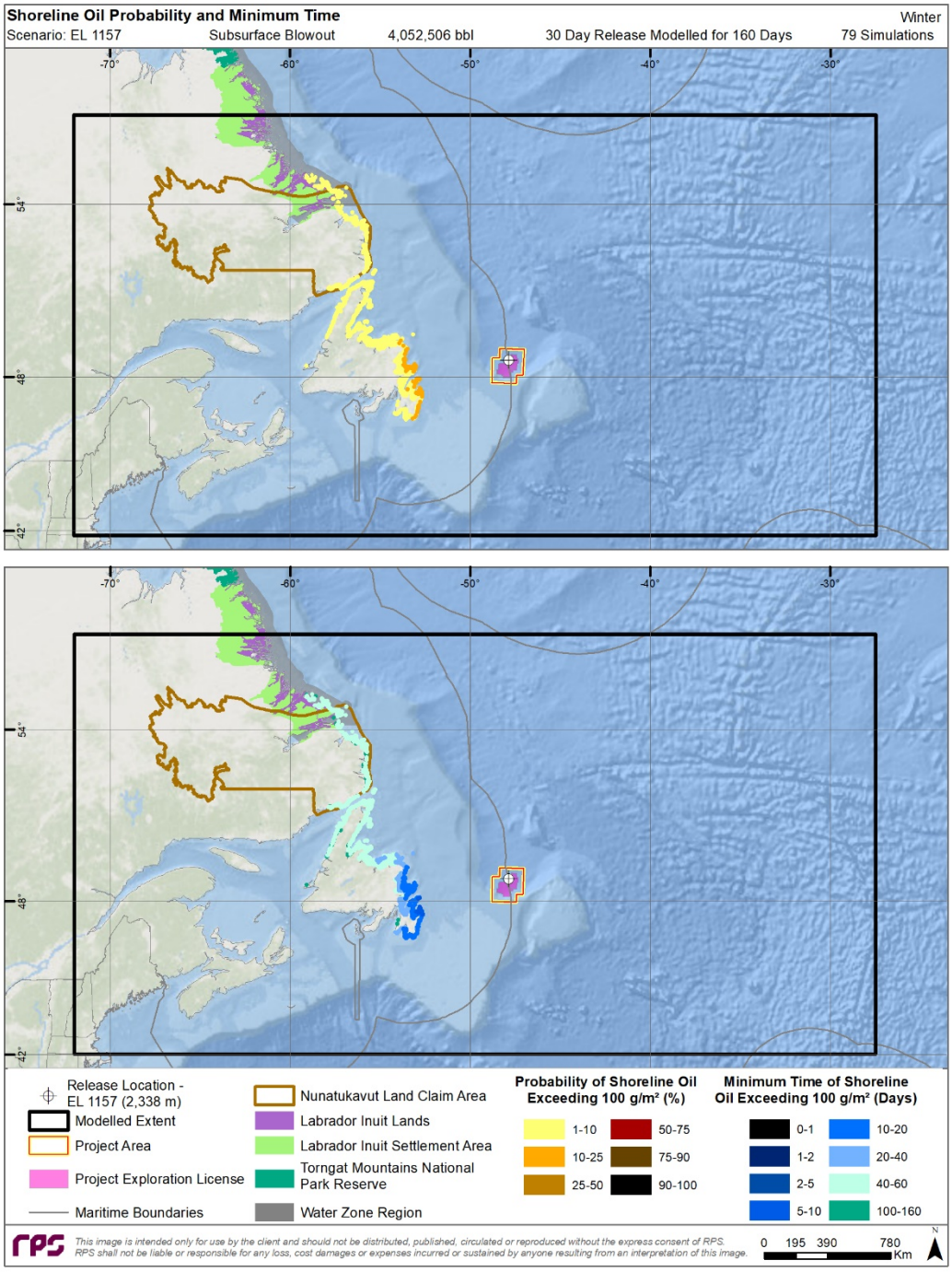

Figure 4-15. Winter probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1157.

4.1.1.2 120-day Subsurface Release

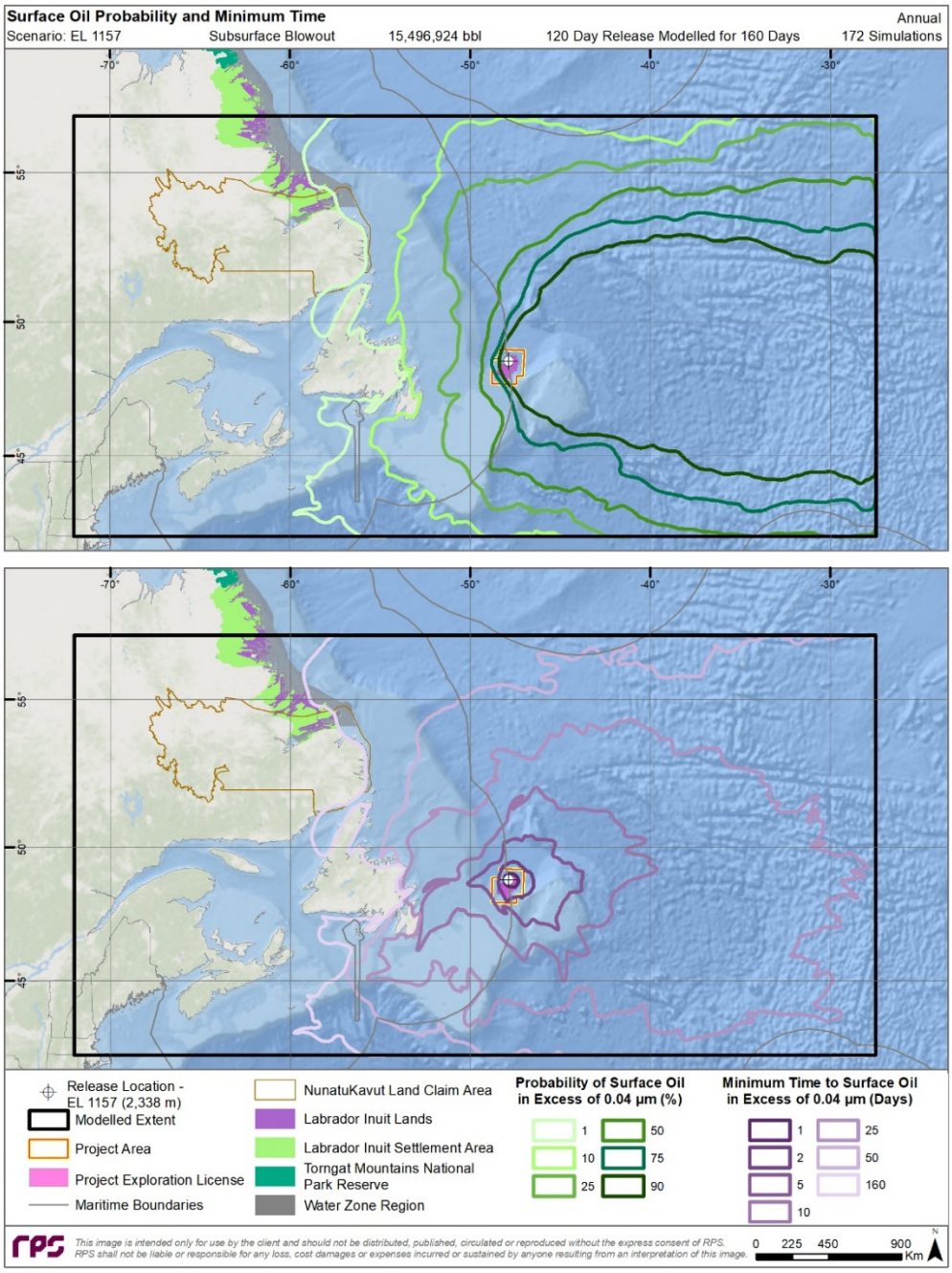

Figure 4-16. Annual probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

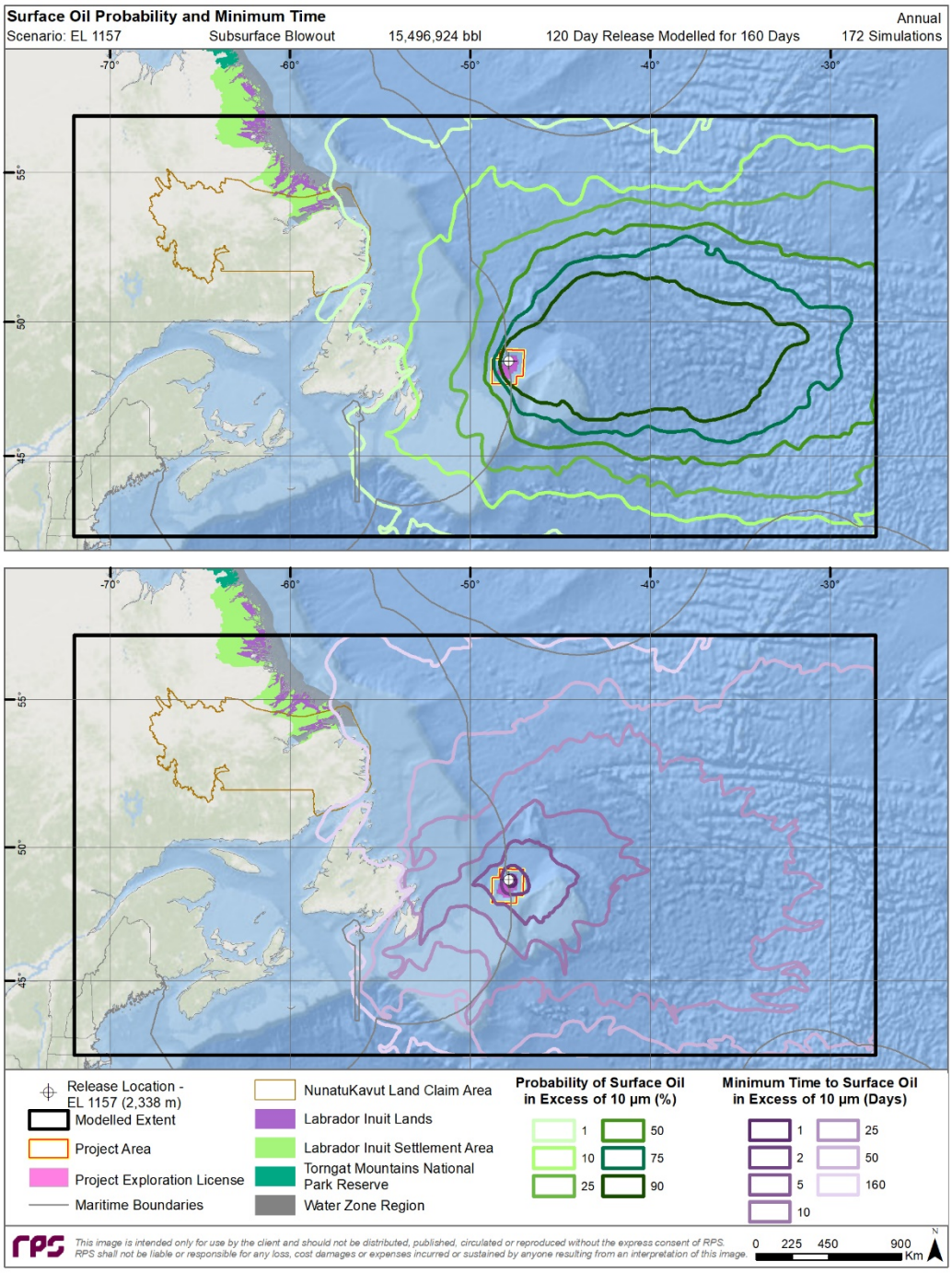

Figure 4-17. Annual probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

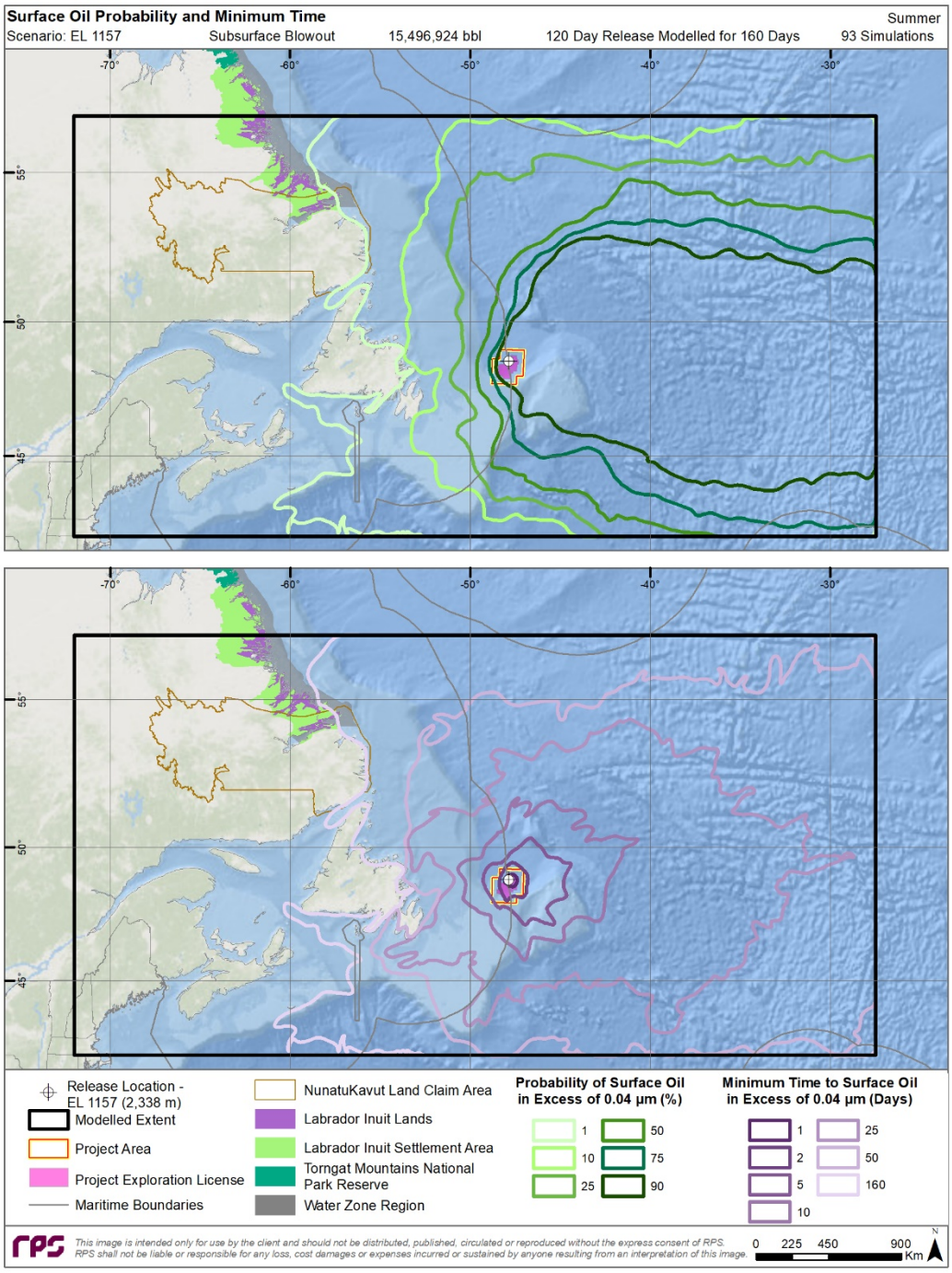

Figure 4-18. Summer probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

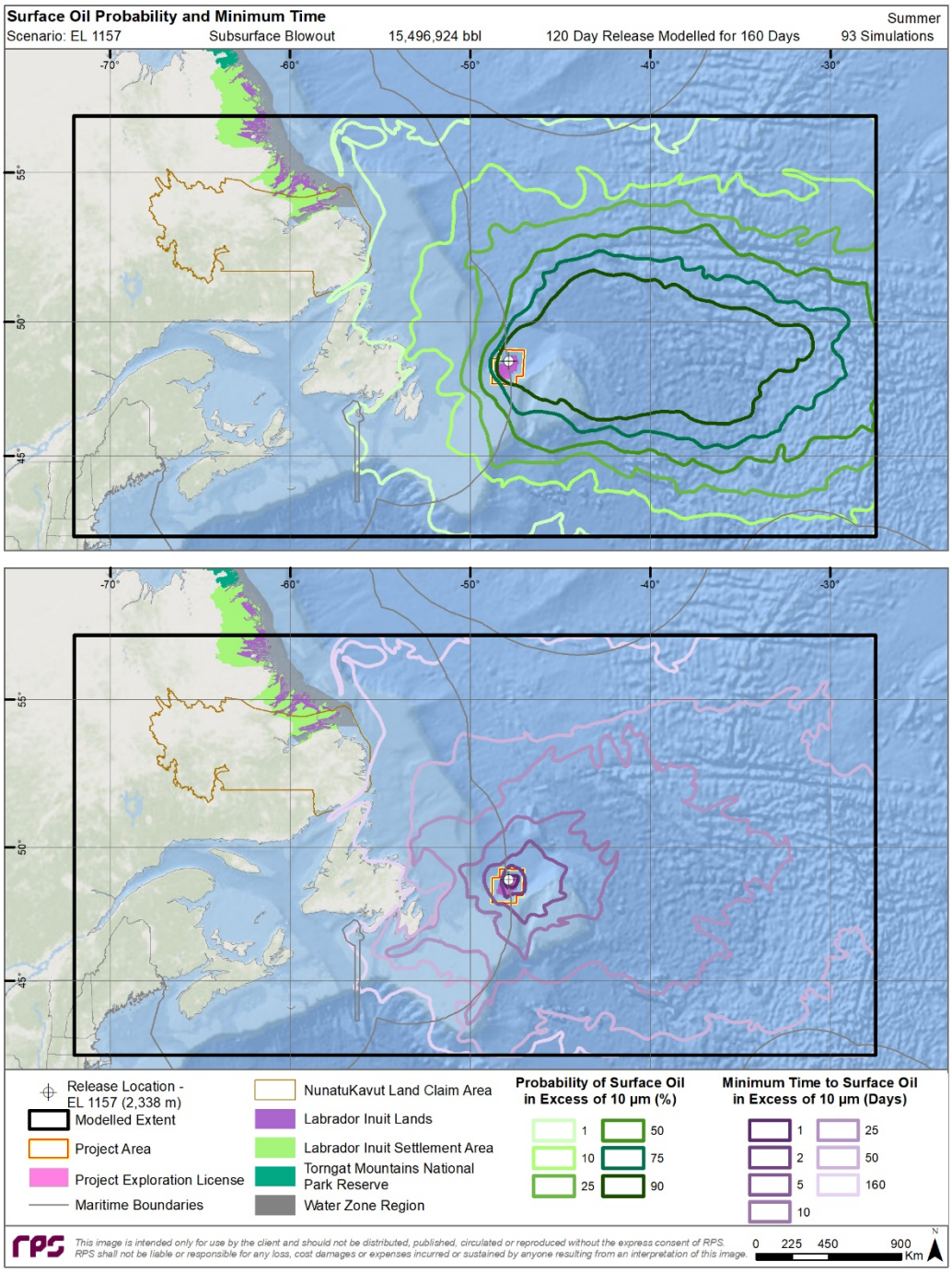

Figure 4-19. Summer probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

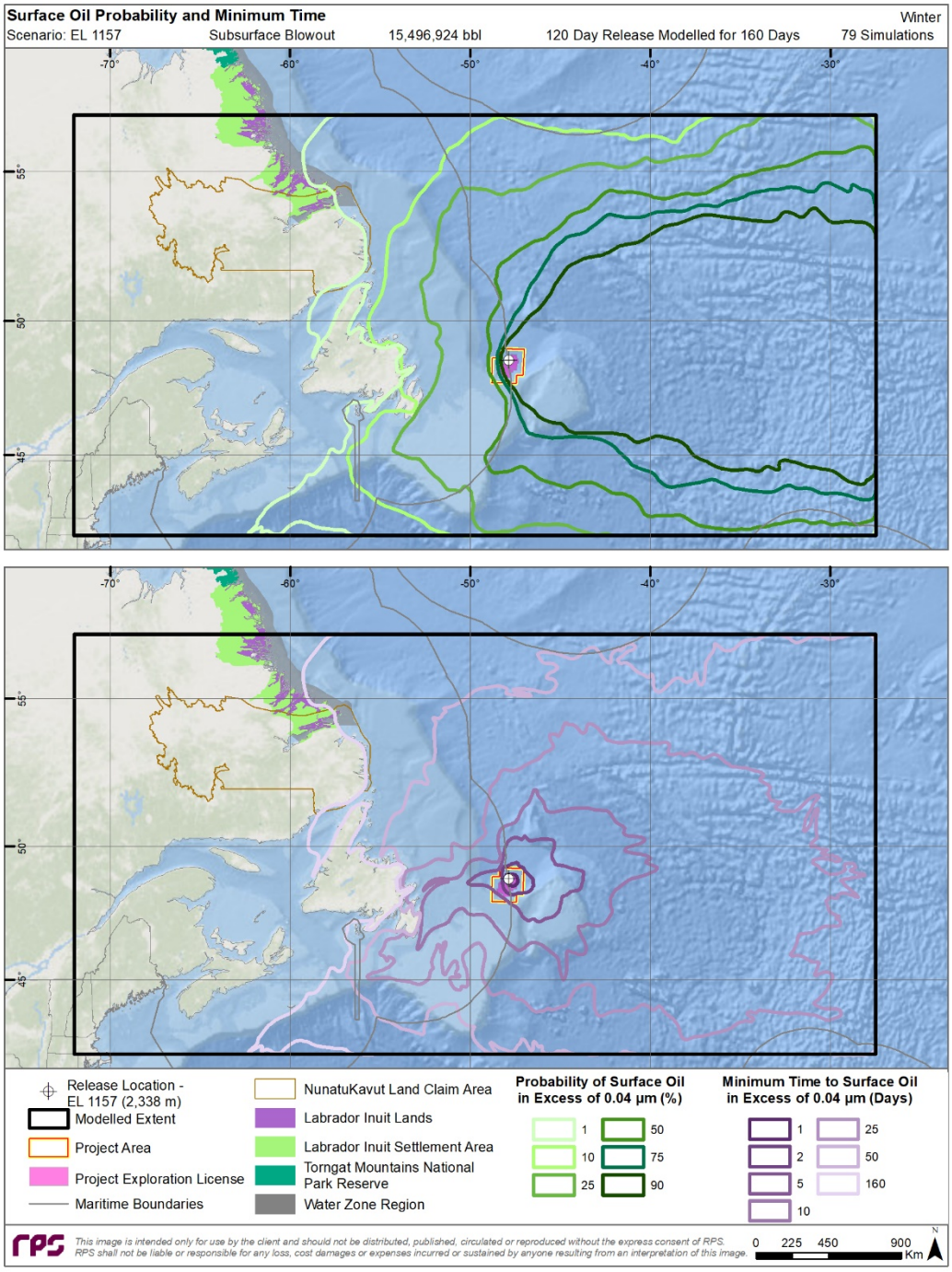

Figure 4-20. Winter probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

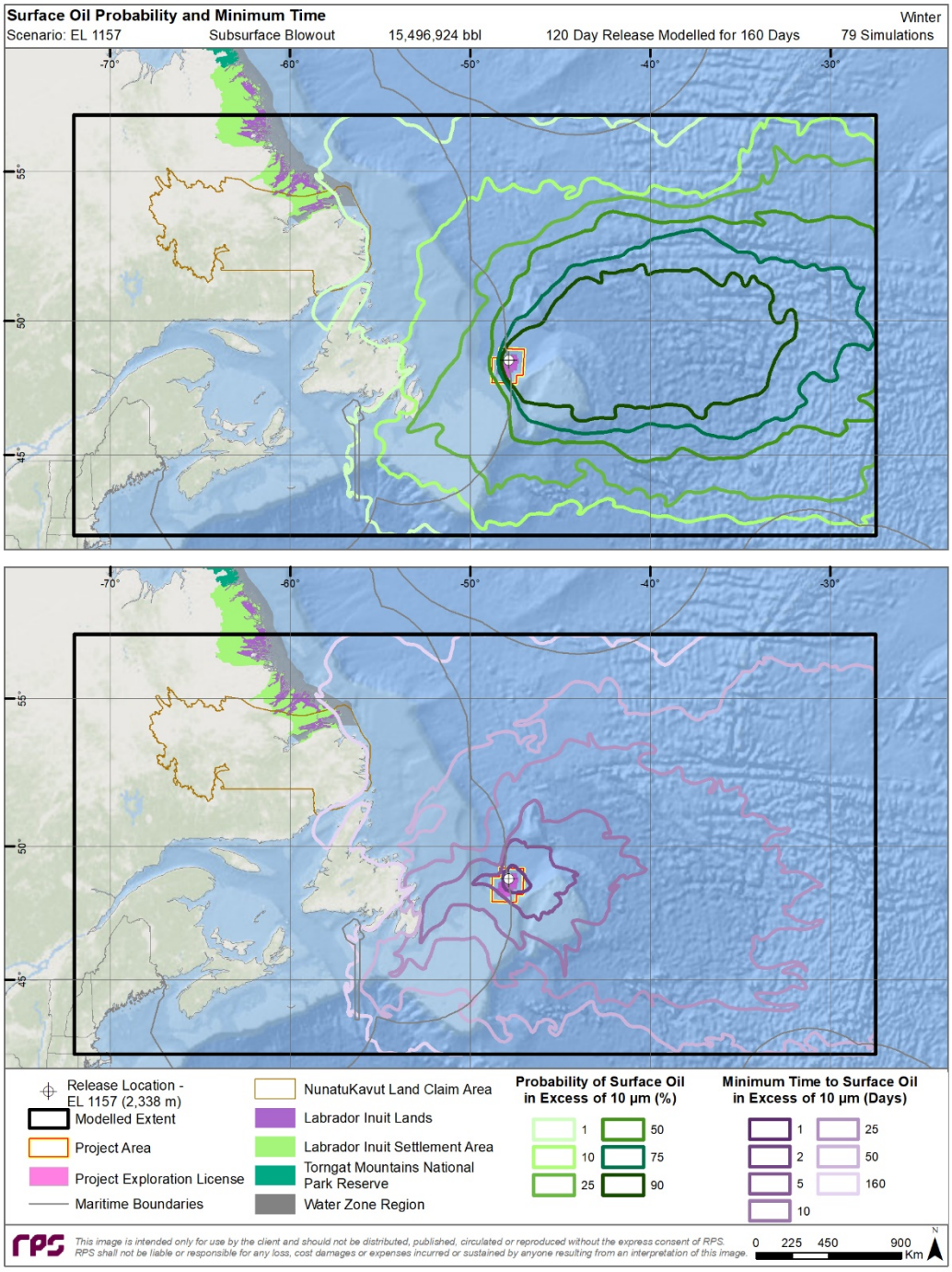

Figure 4-21. Winter probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

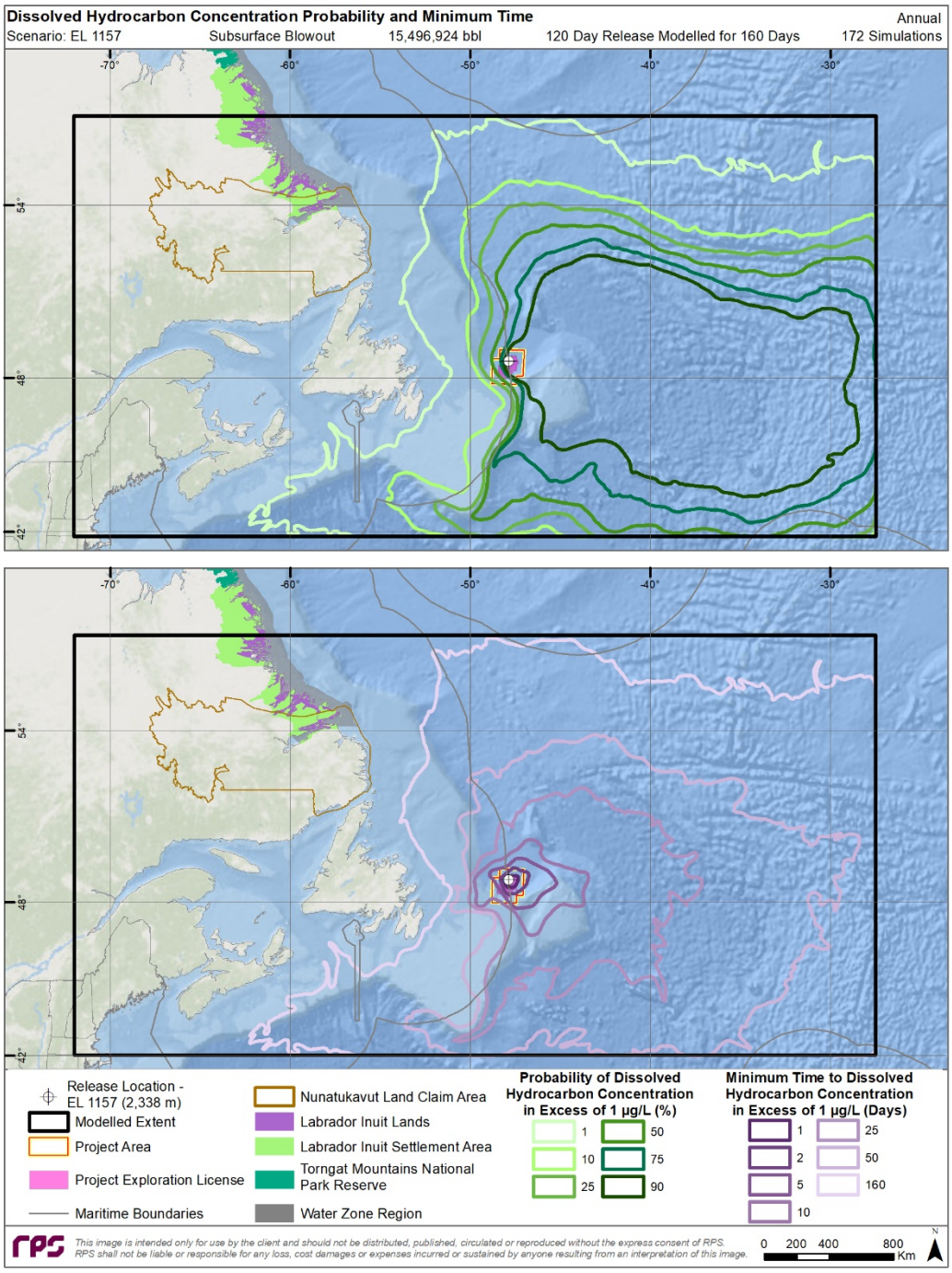

Figure 4-22. Annual probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

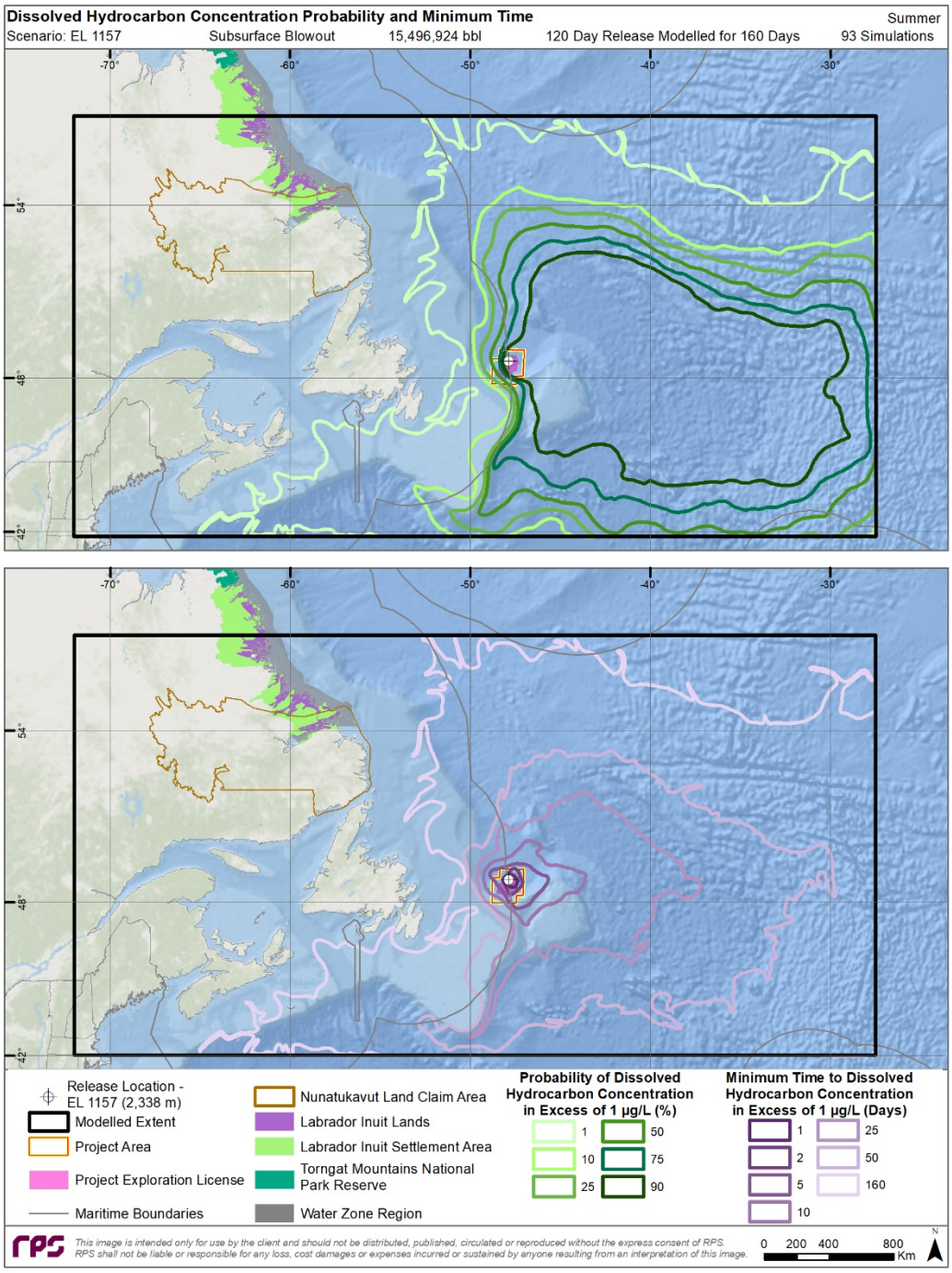

Figure 4-23. Summer probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

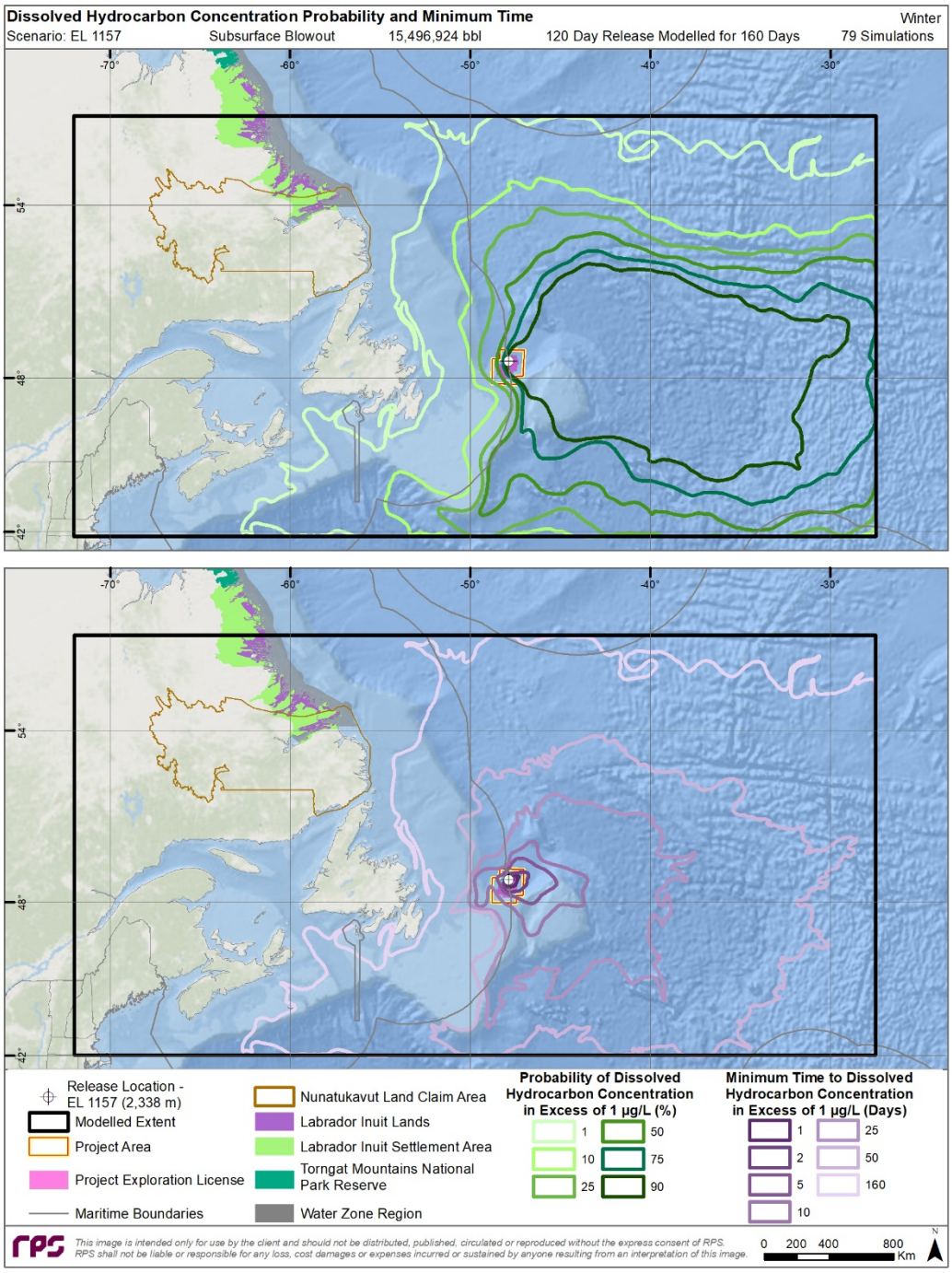

Figure 4-24. Winter probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

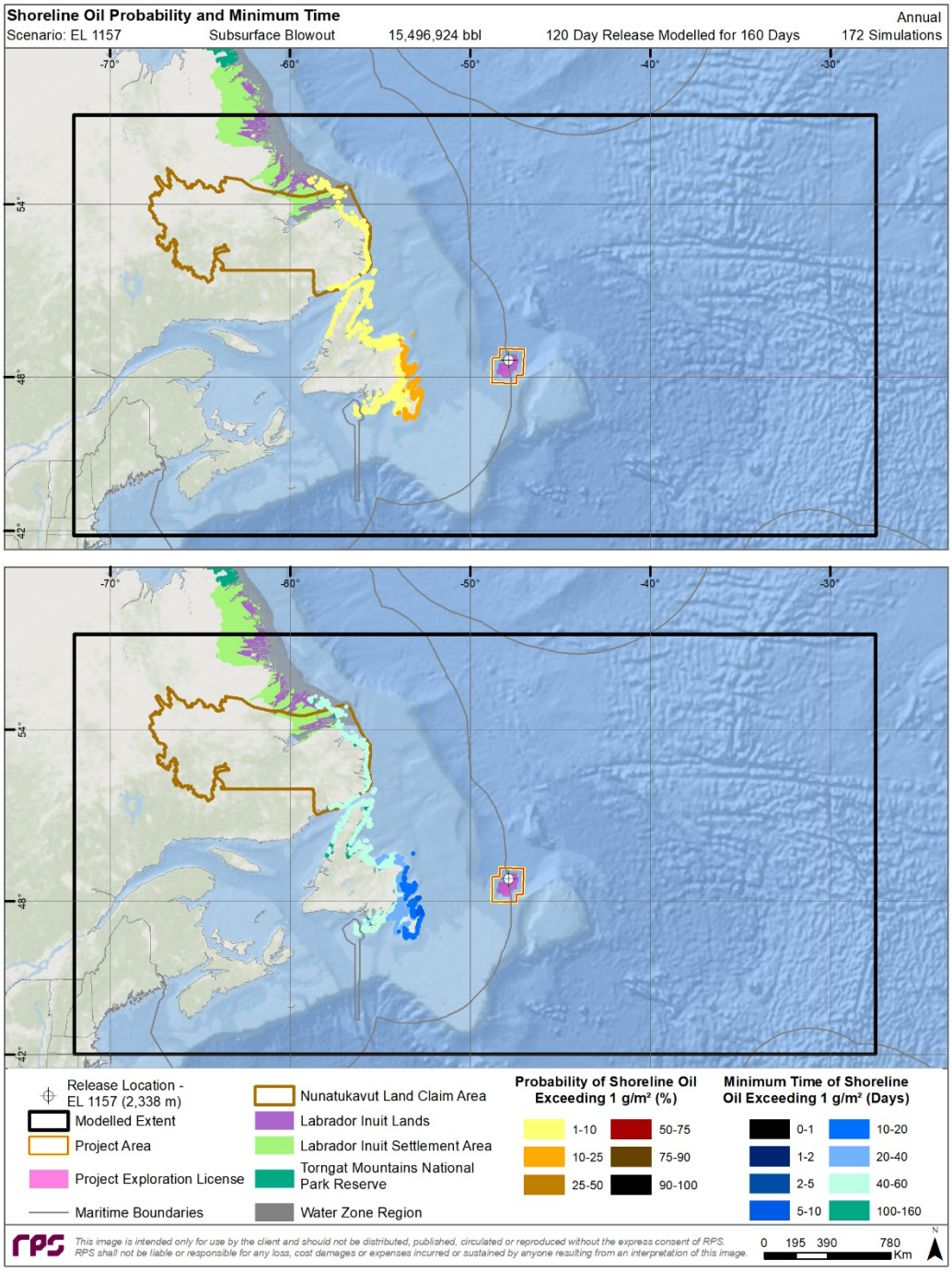

Figure 4-25. Annual probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

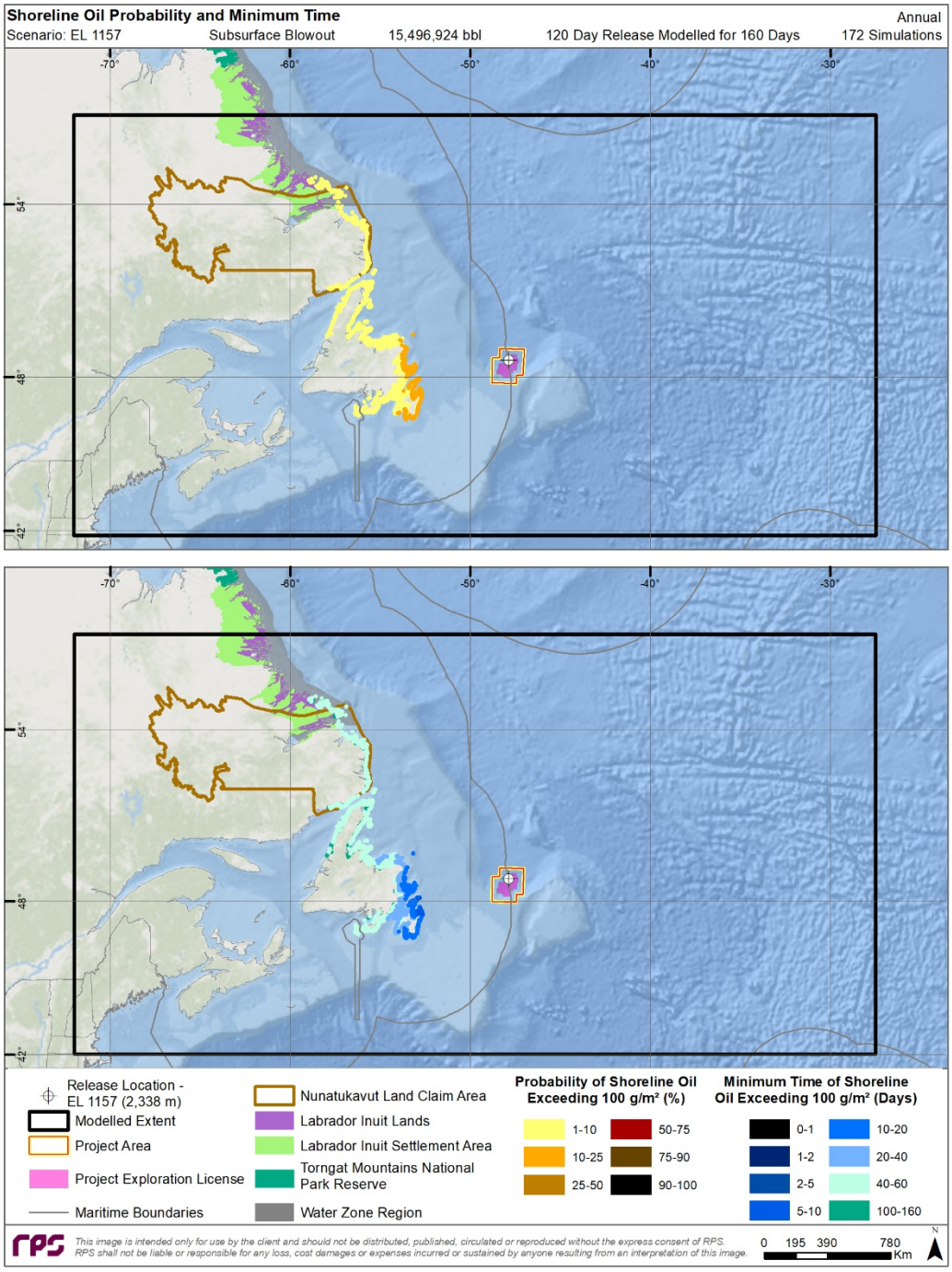

Figure 4-26. Annual probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

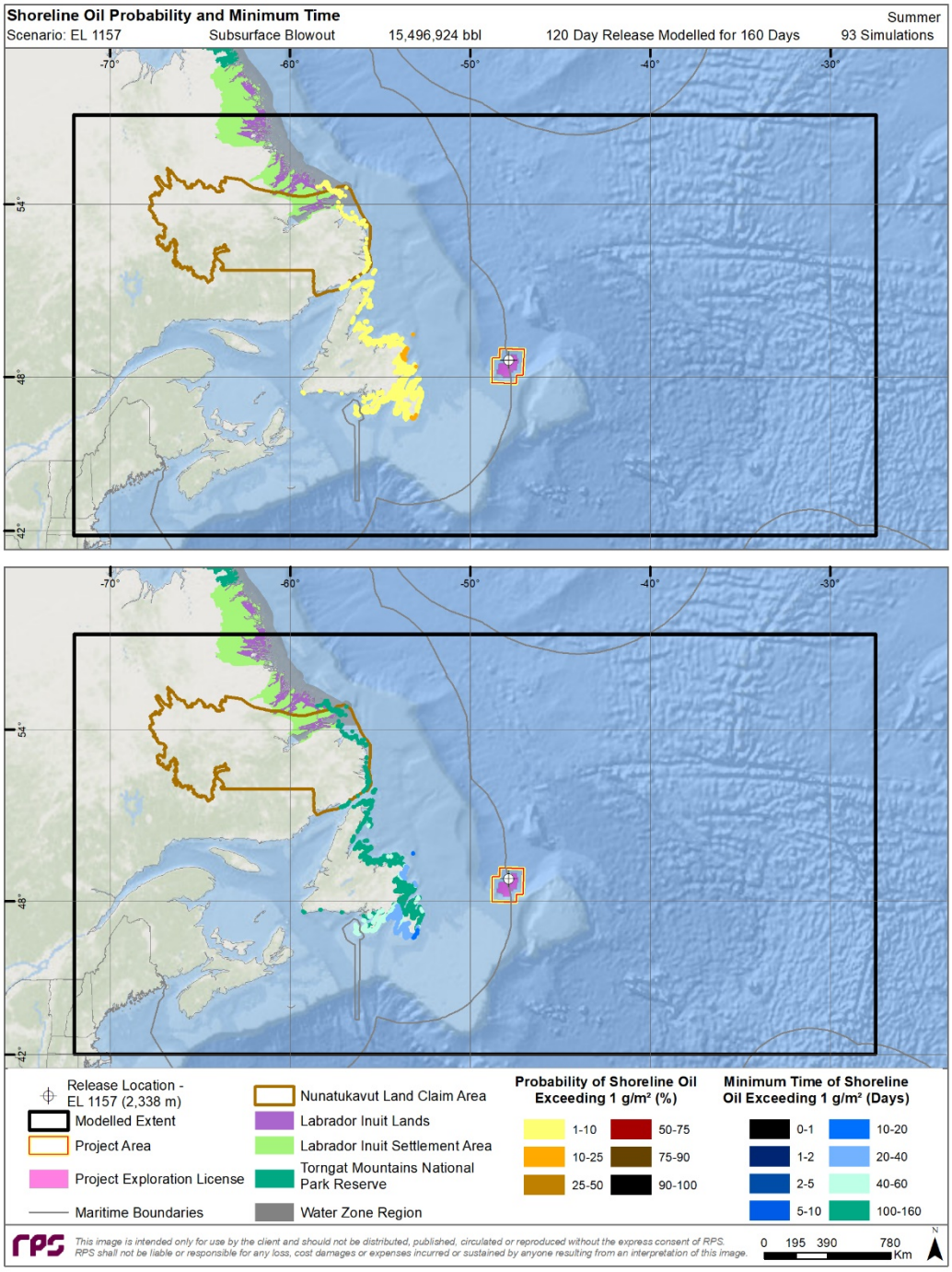

Figure 4-27. Summer probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

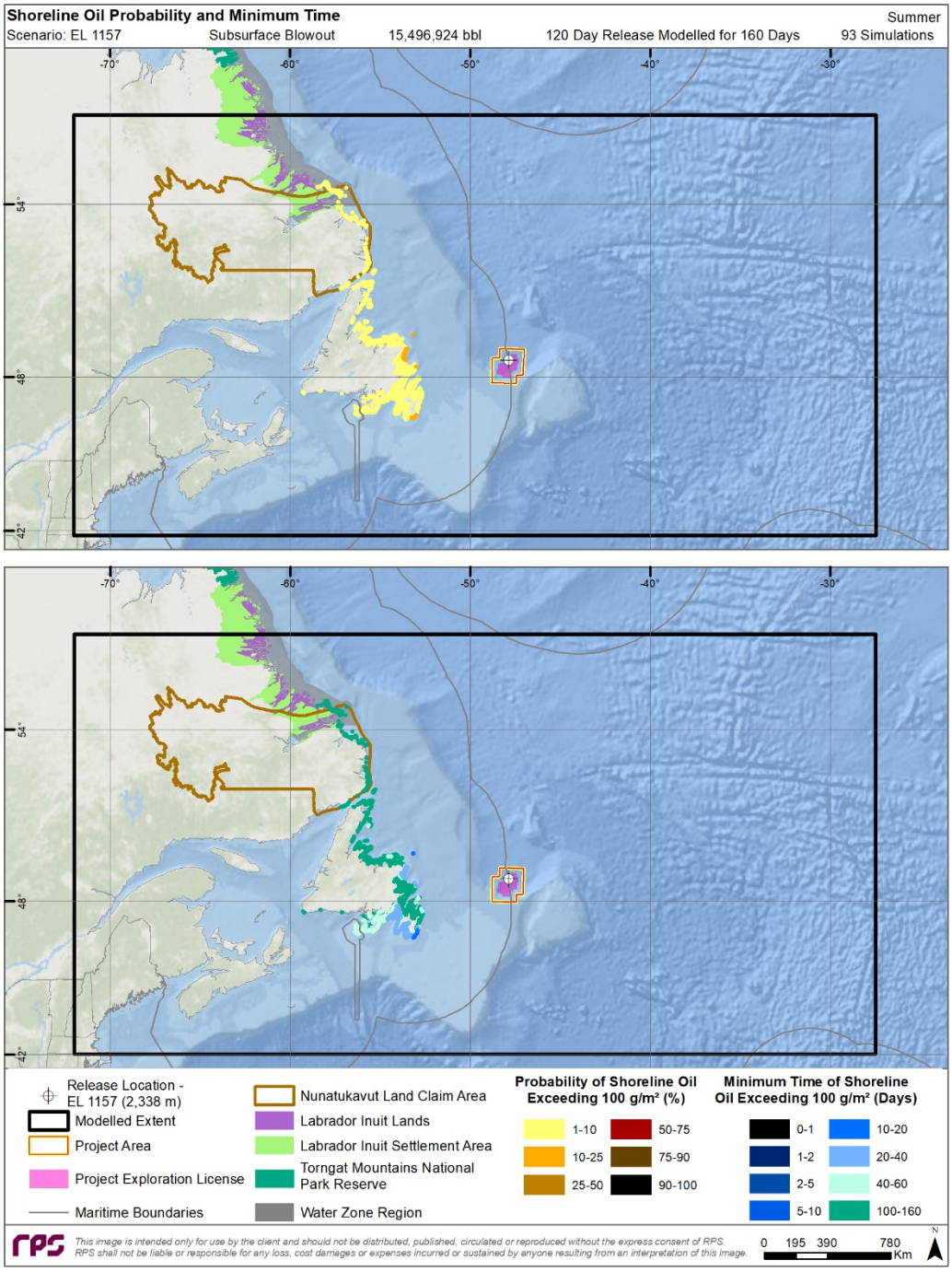

Figure 4-28. Summer probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

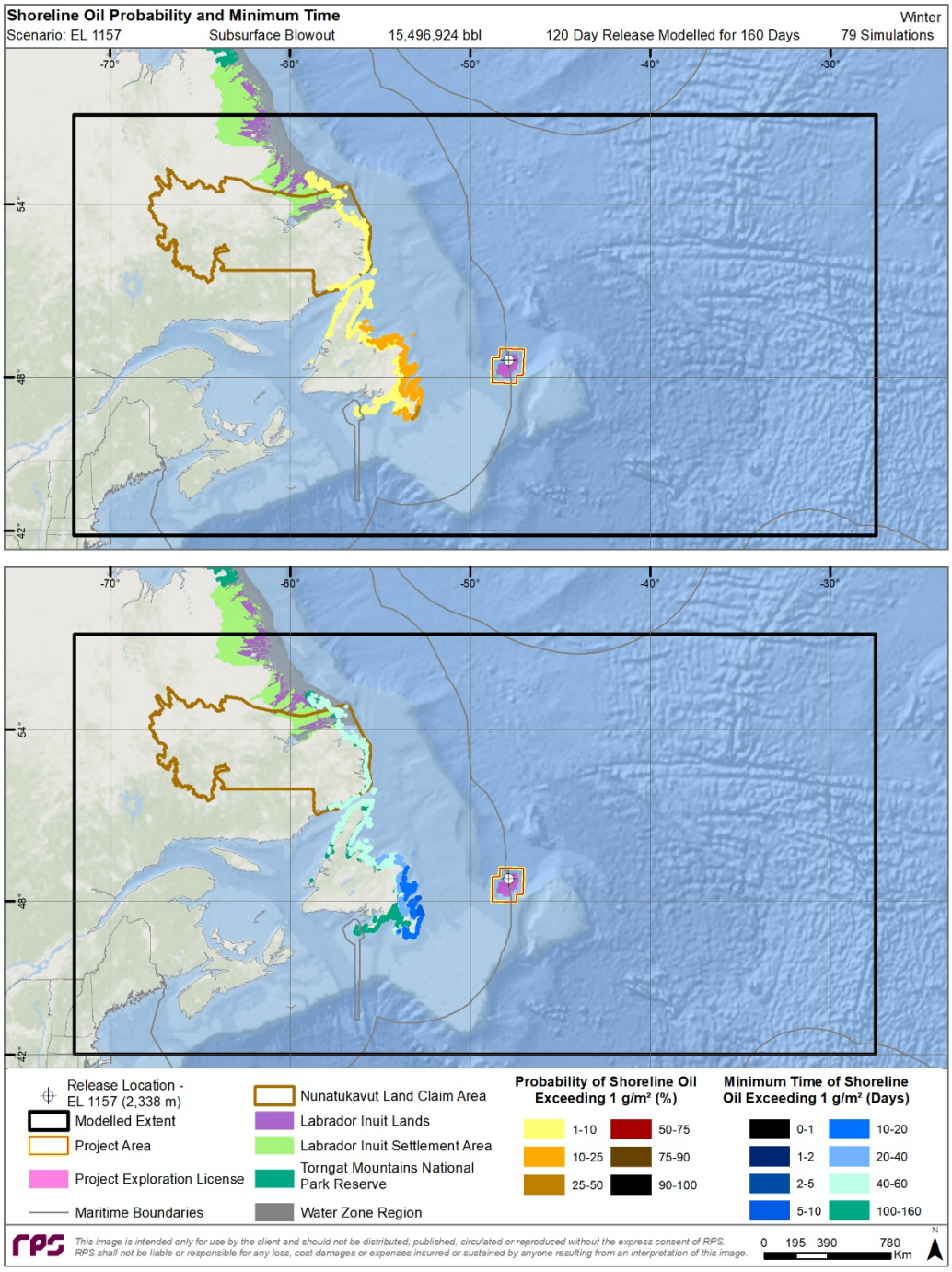

Figure 4-29. Winter probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

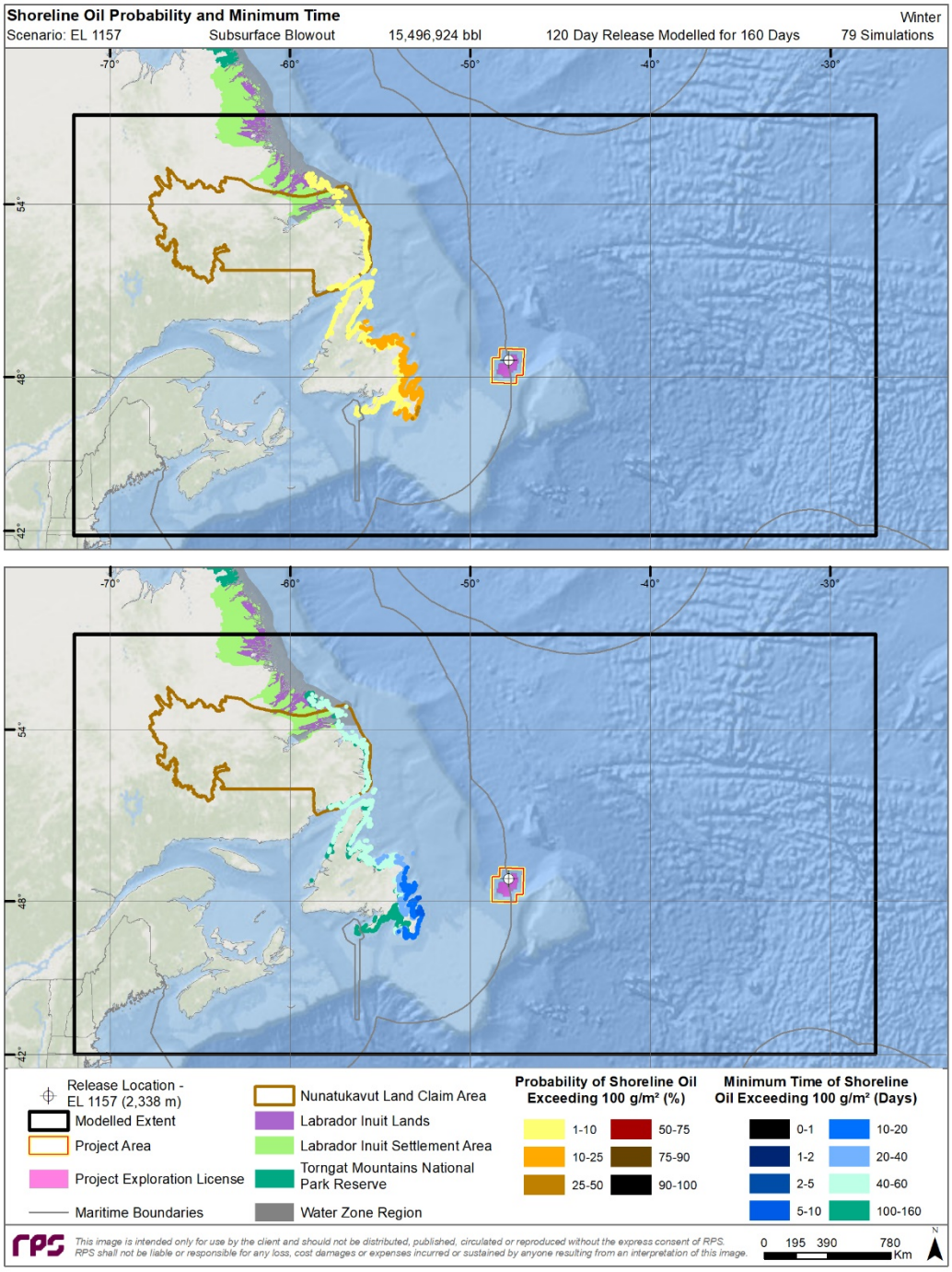

Figure 4-30. Winter probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1157.

4.1.2 EL 1158 Results

4.1.2.1 30-day Subsurface Release

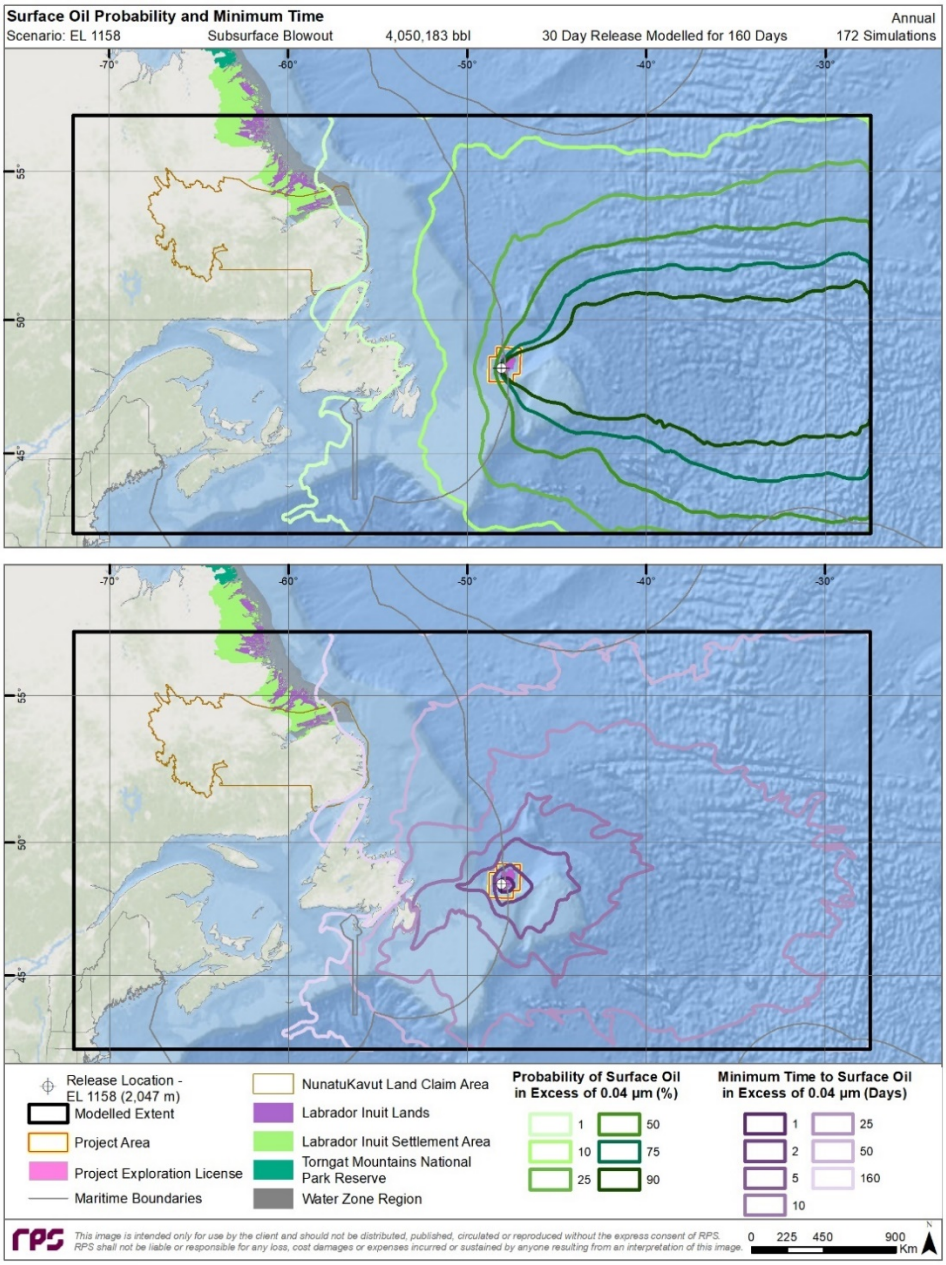

Figure 4-31. Annual probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

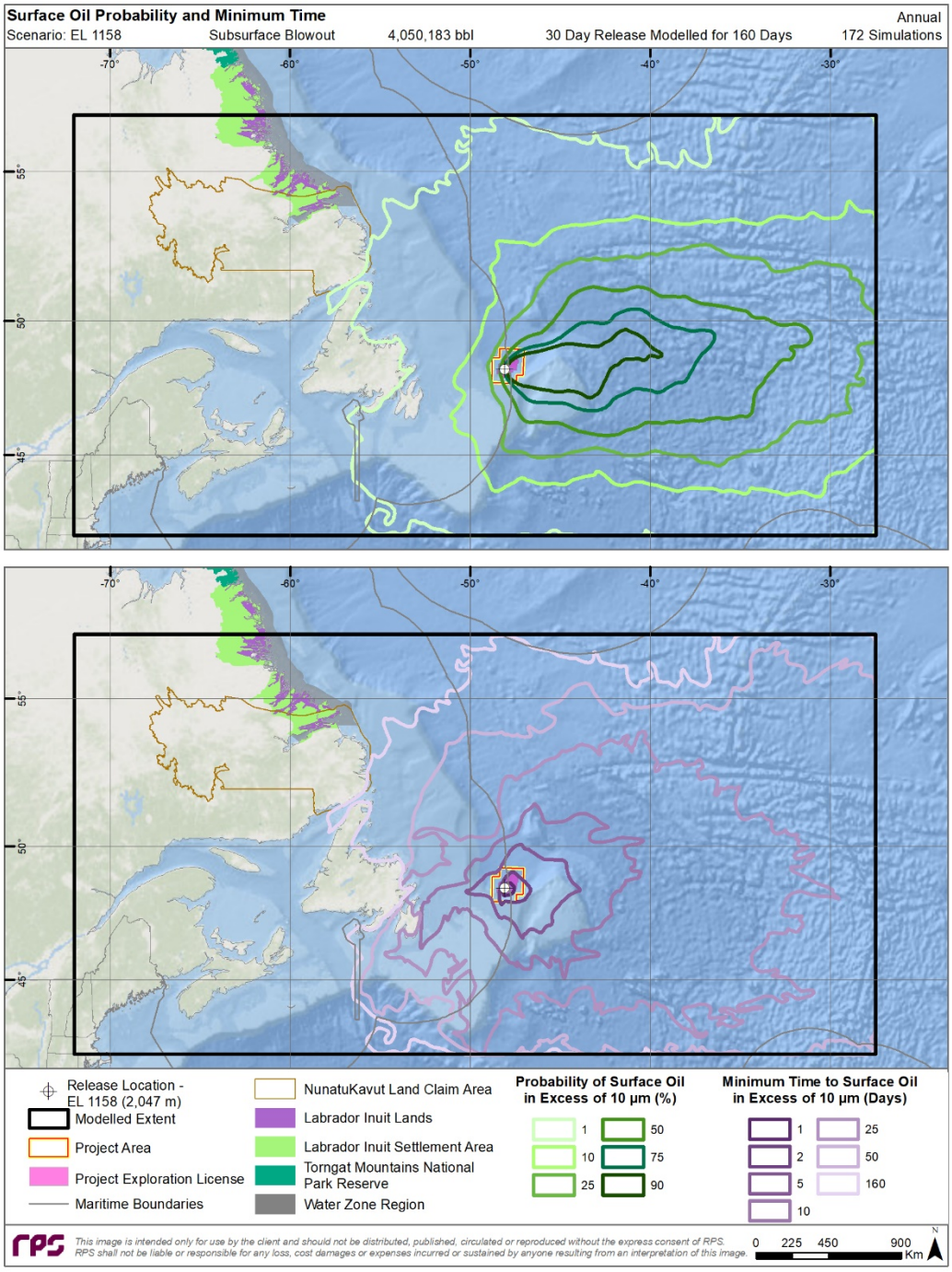

Figure 4-32. Annual probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

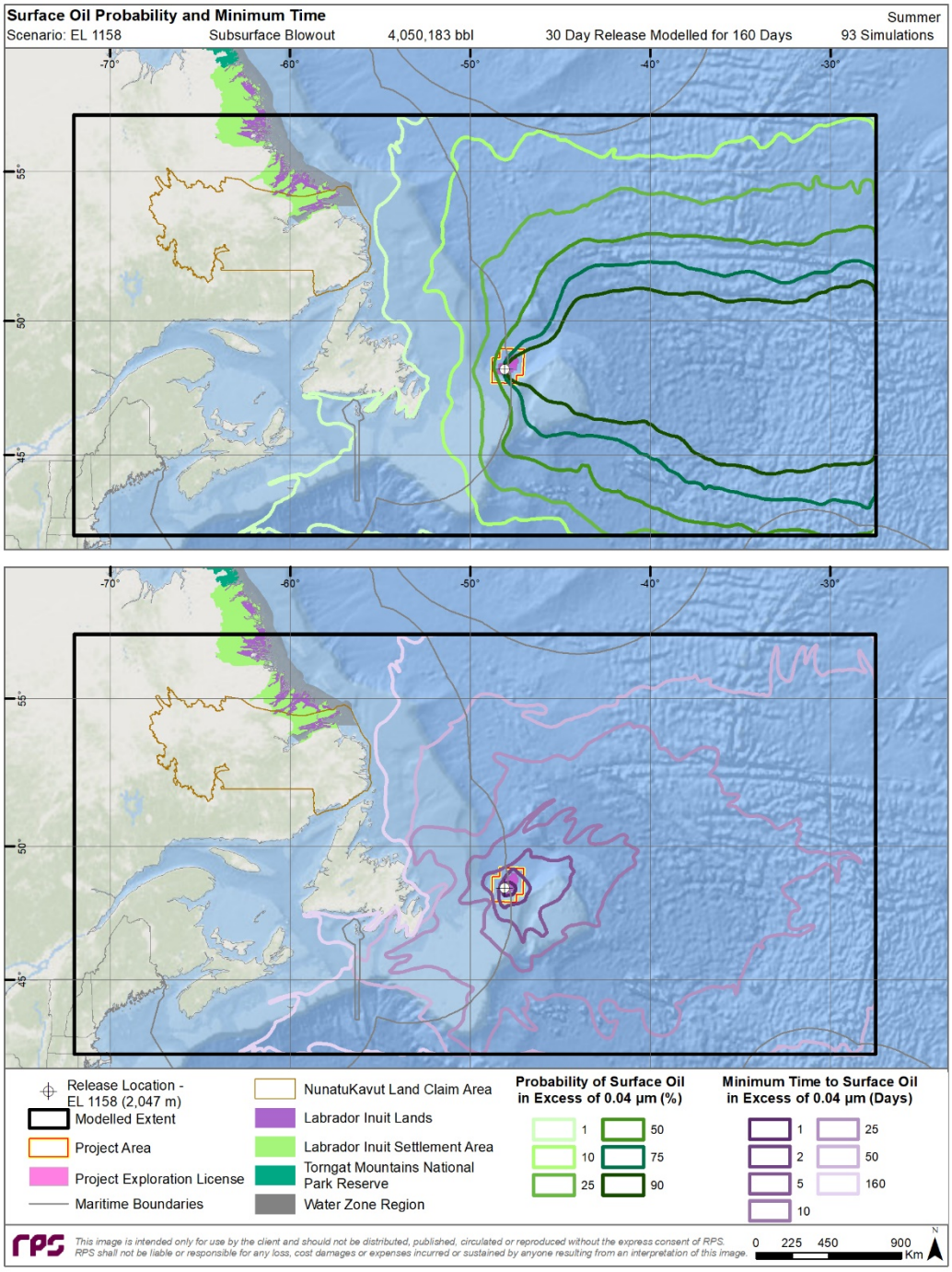

Figure 4-33. Summer probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

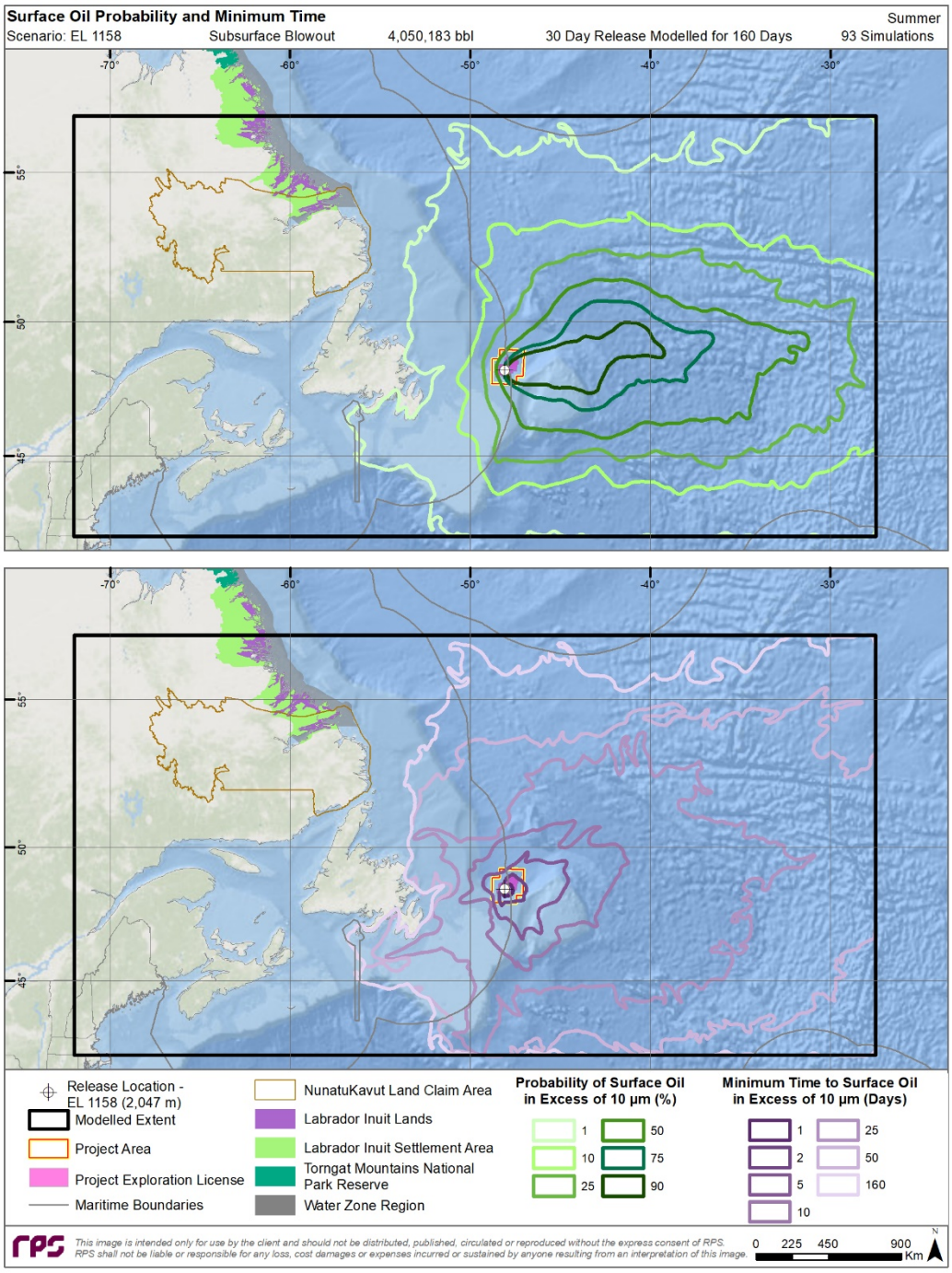

Figure 4-34. Summer probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

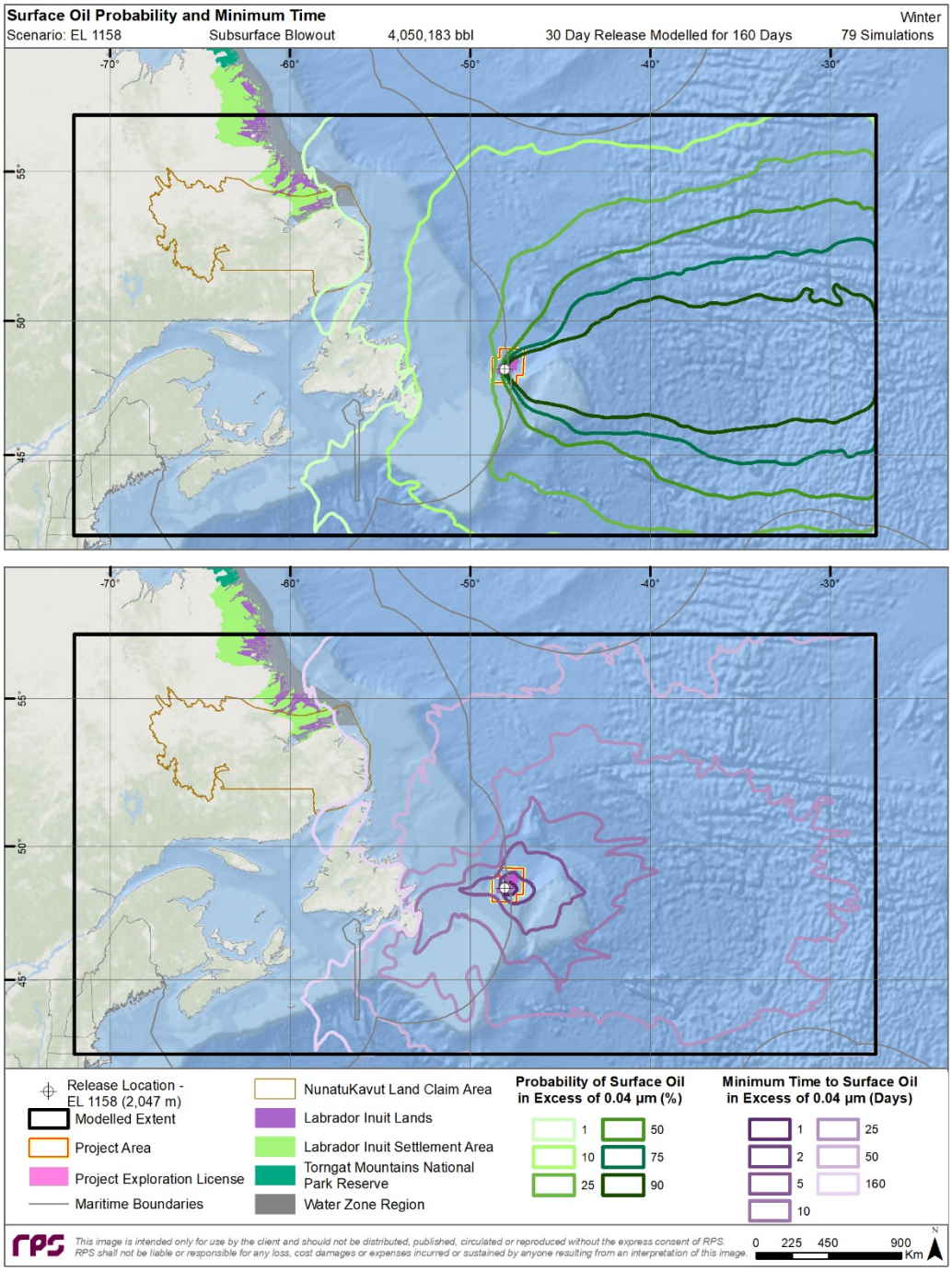

Figure 4-35. Winter probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

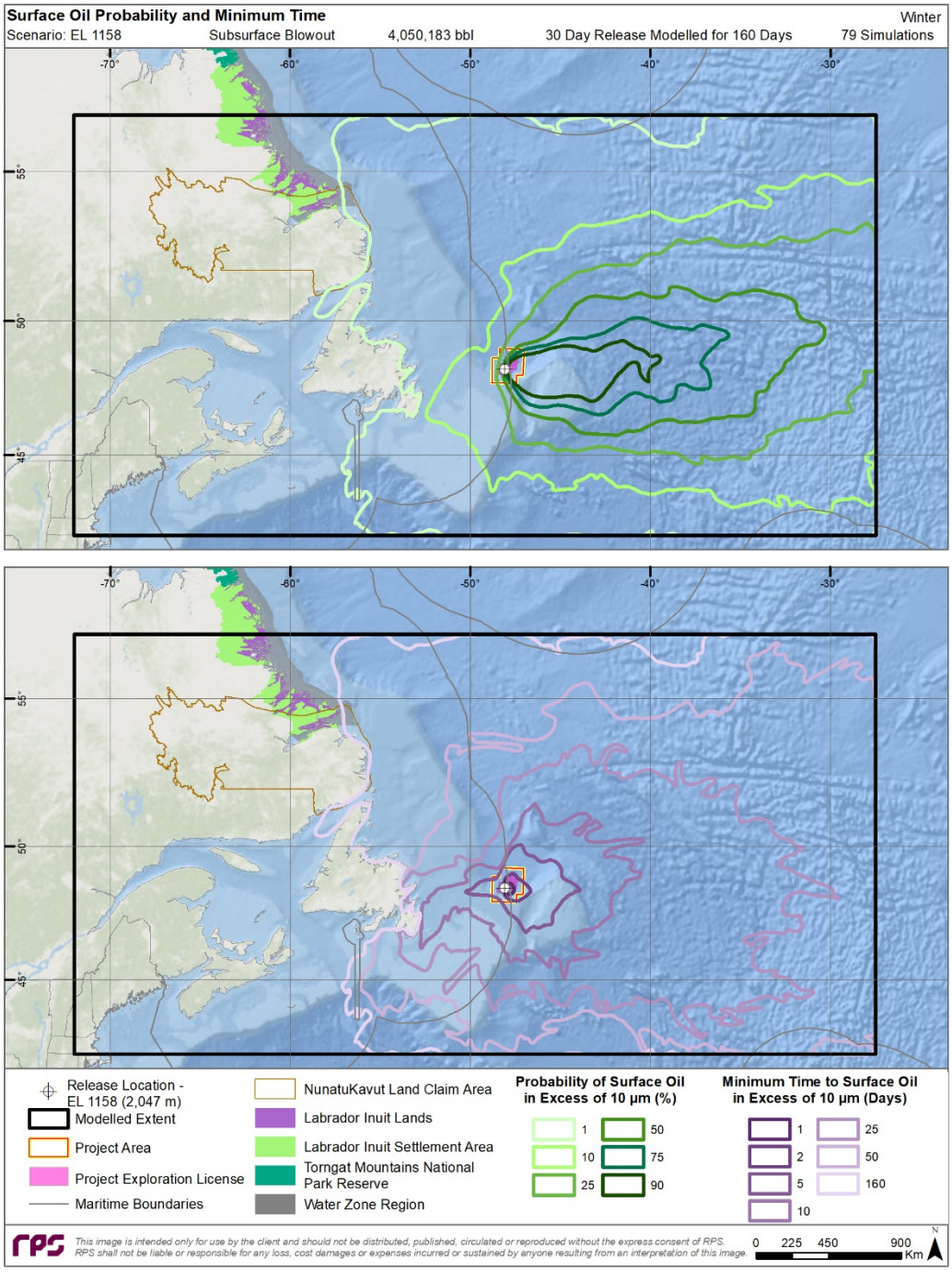

Figure 4-36. Winter probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

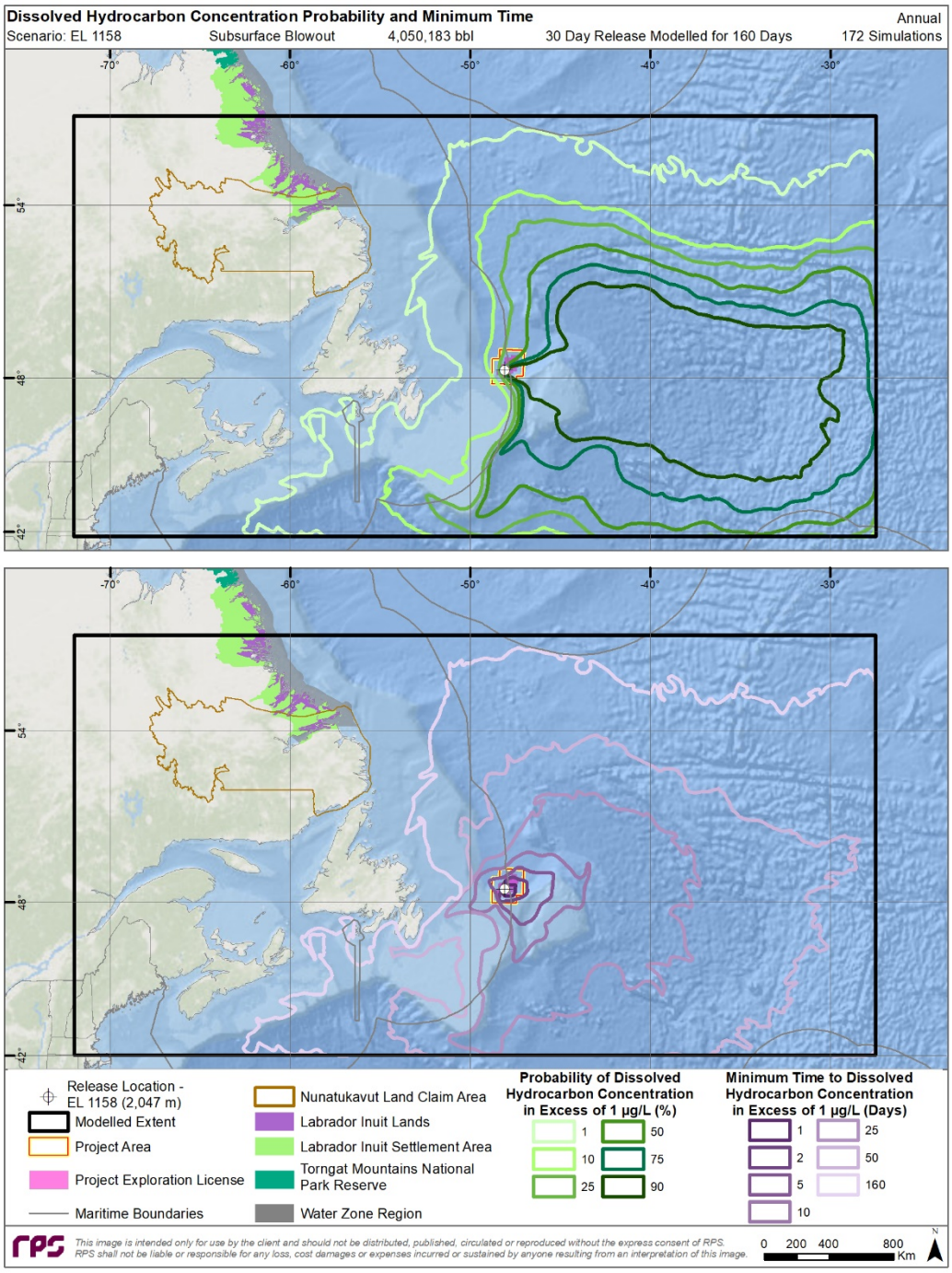

Figure 4-37. Annual probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

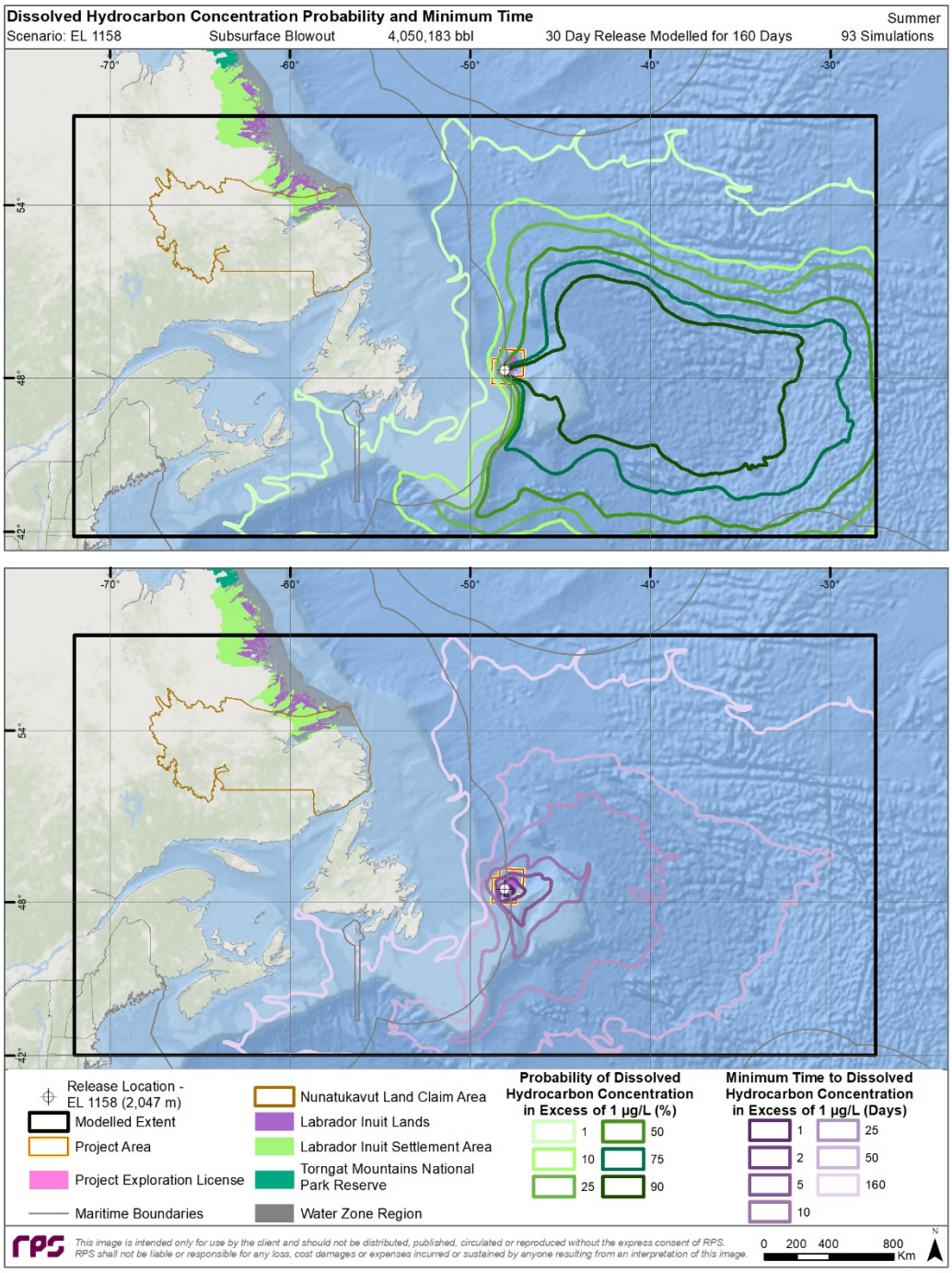

Figure 4-38. Summer probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

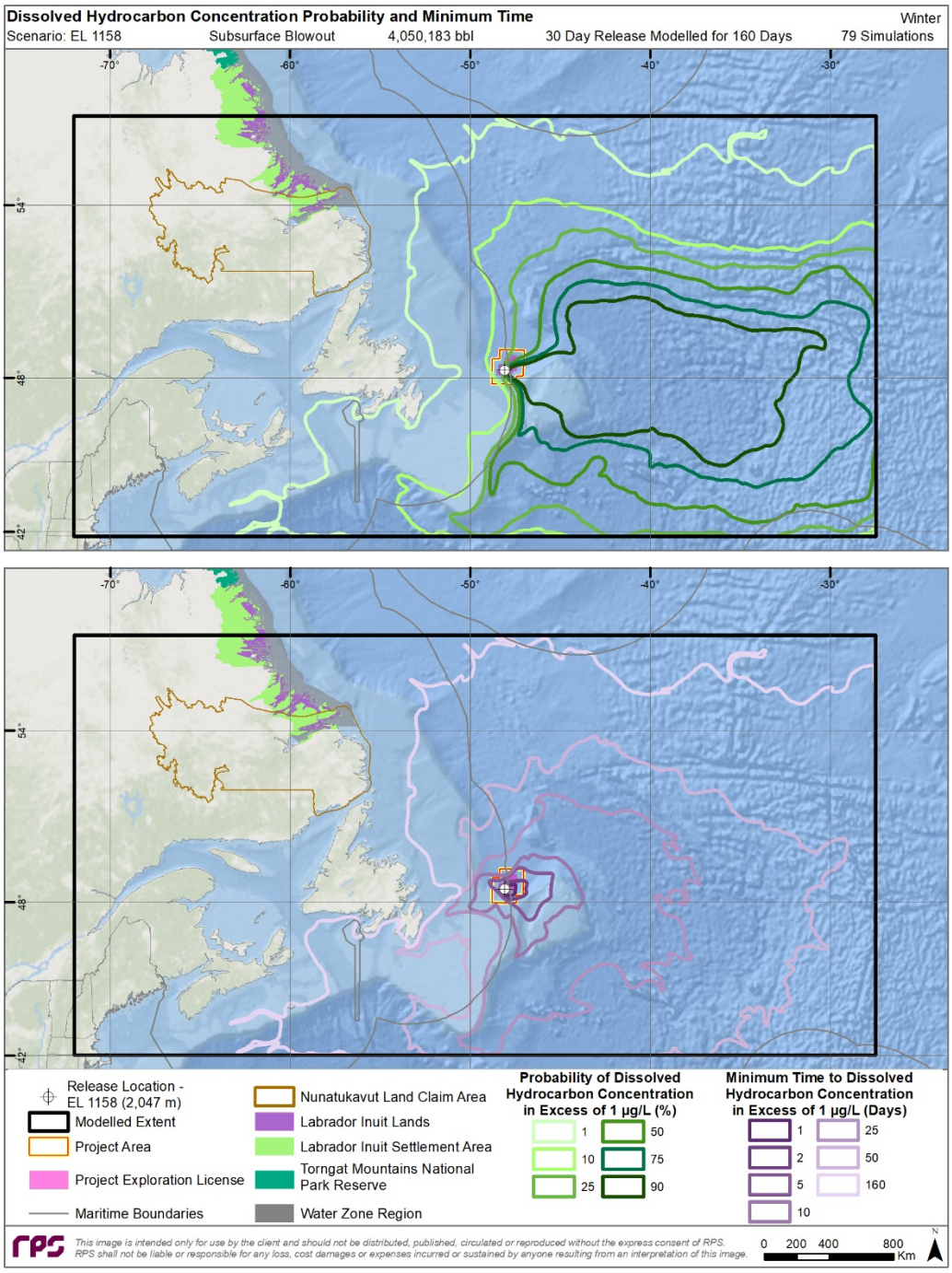

Figure 4-39. Winter probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

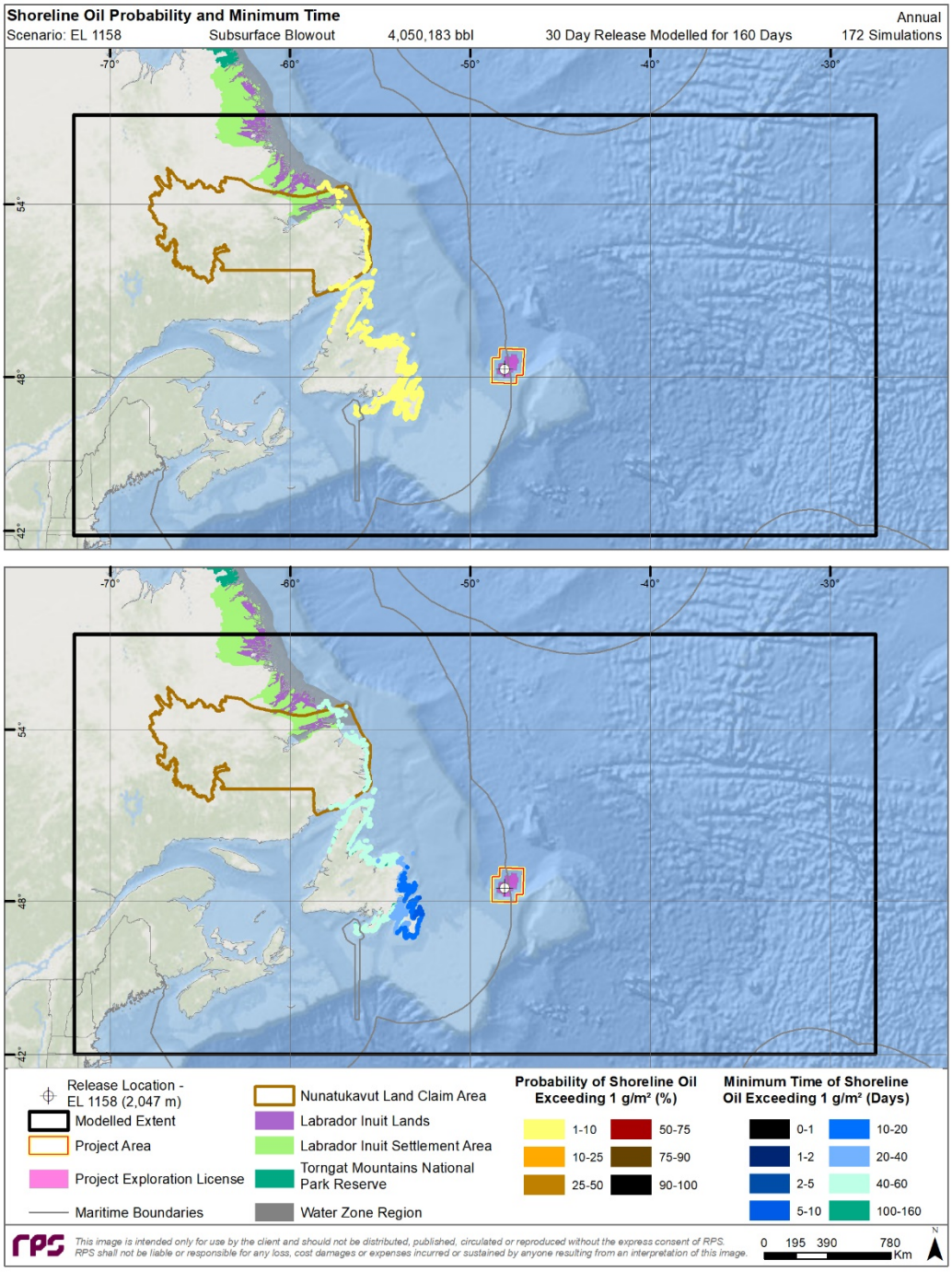

Figure 4-40. Annual probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

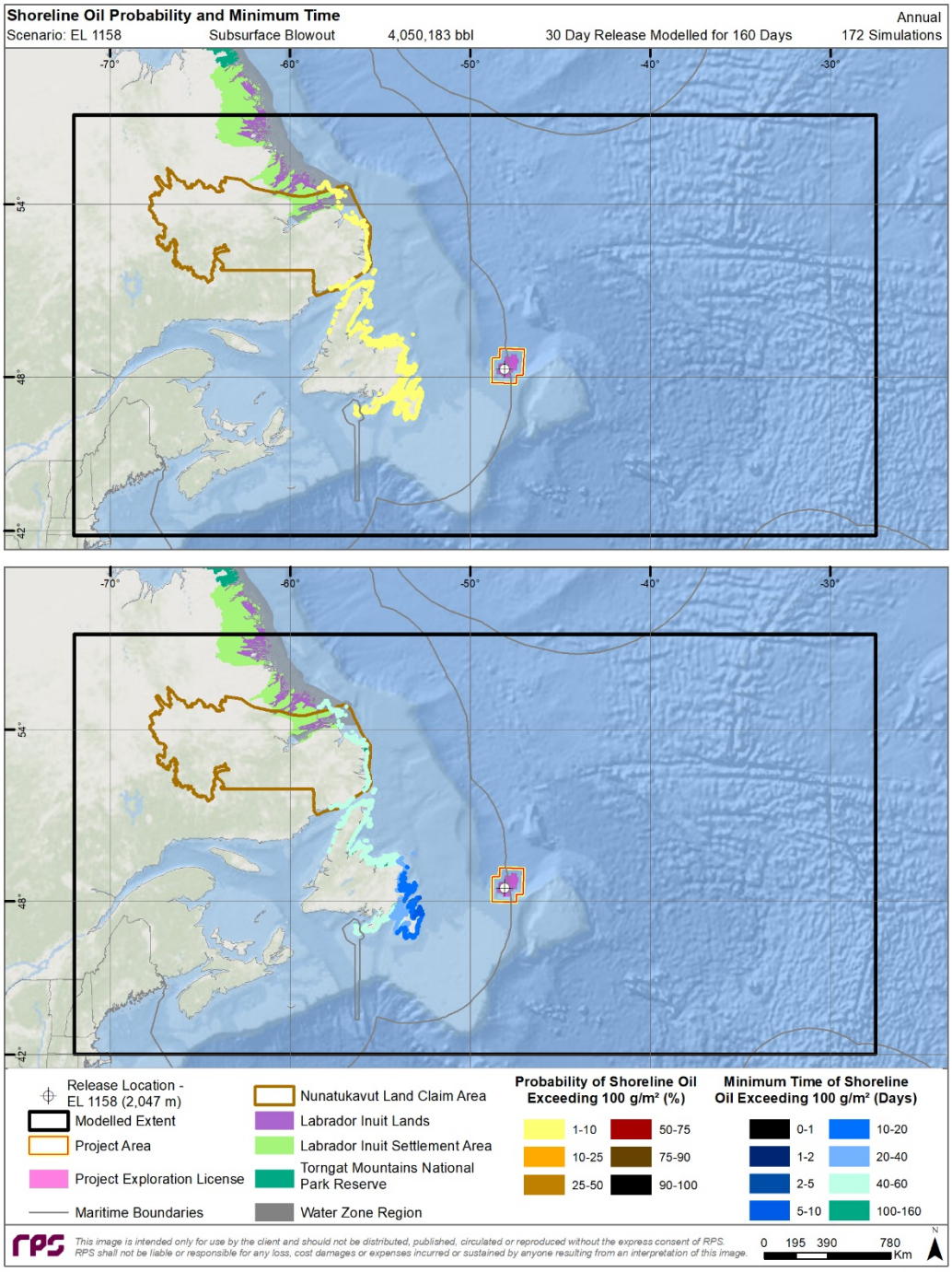

Figure 4-41. Annual probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

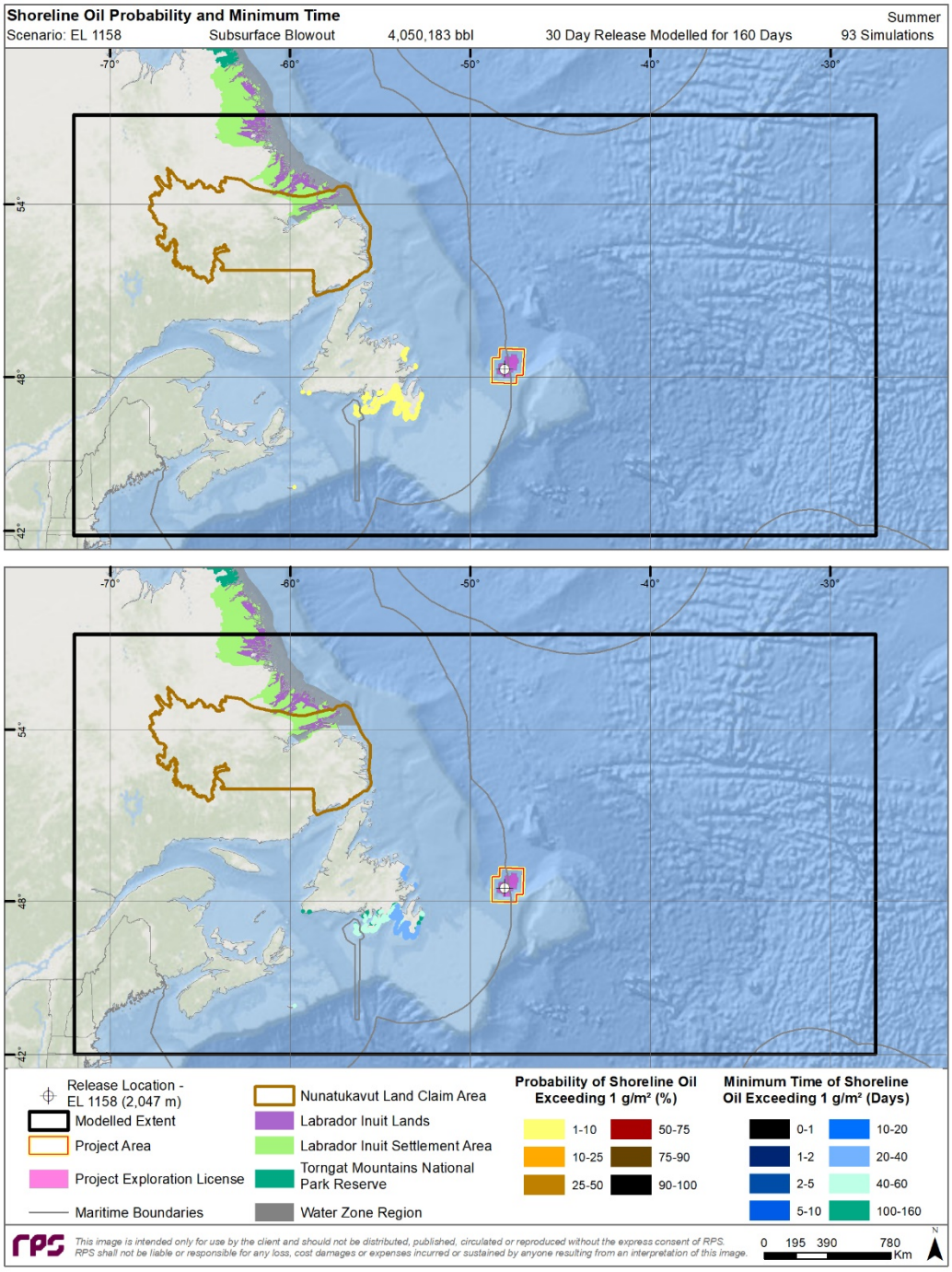

Figure 4-42. Summer probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

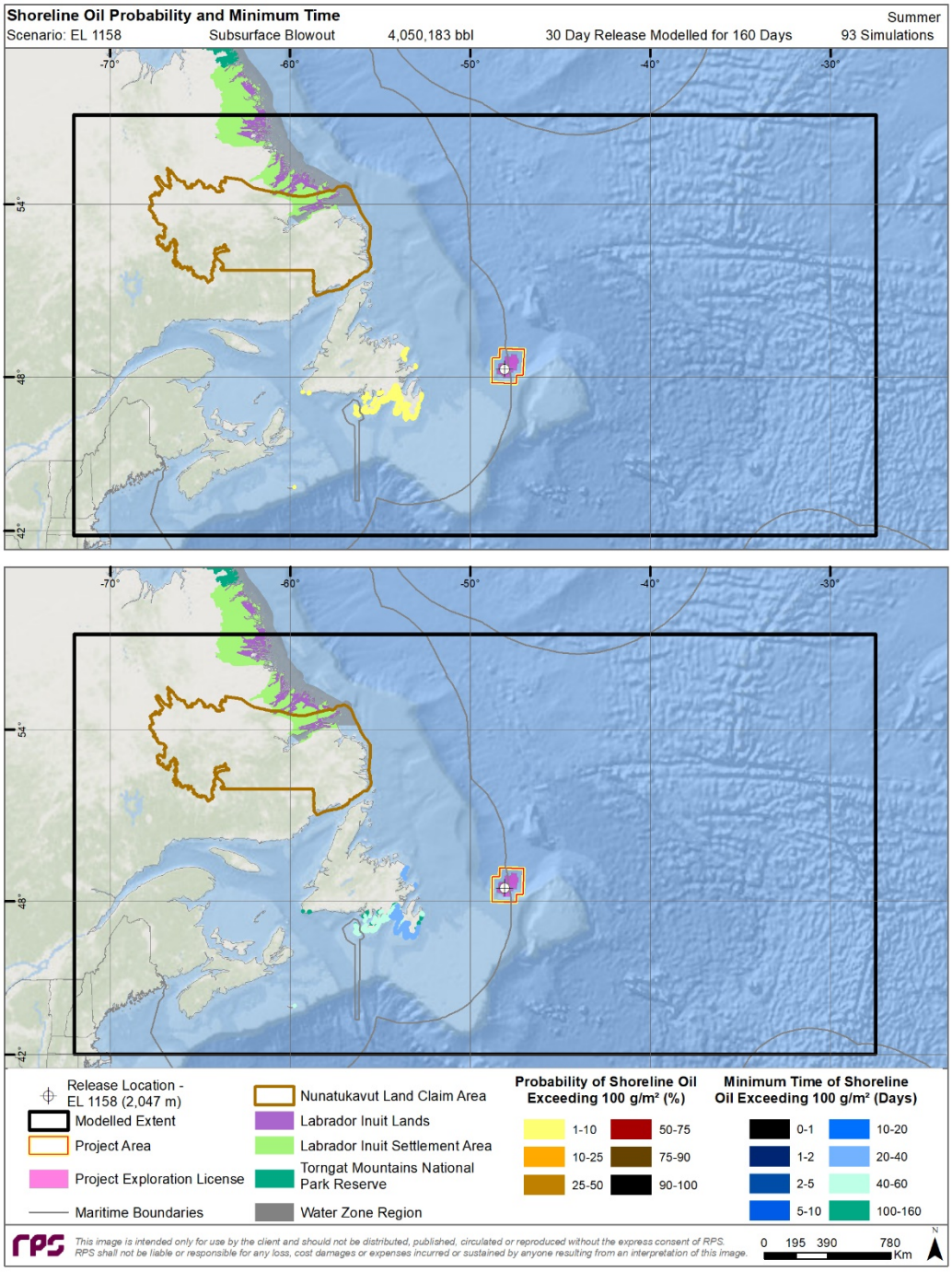

Figure 4-43. Summer probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

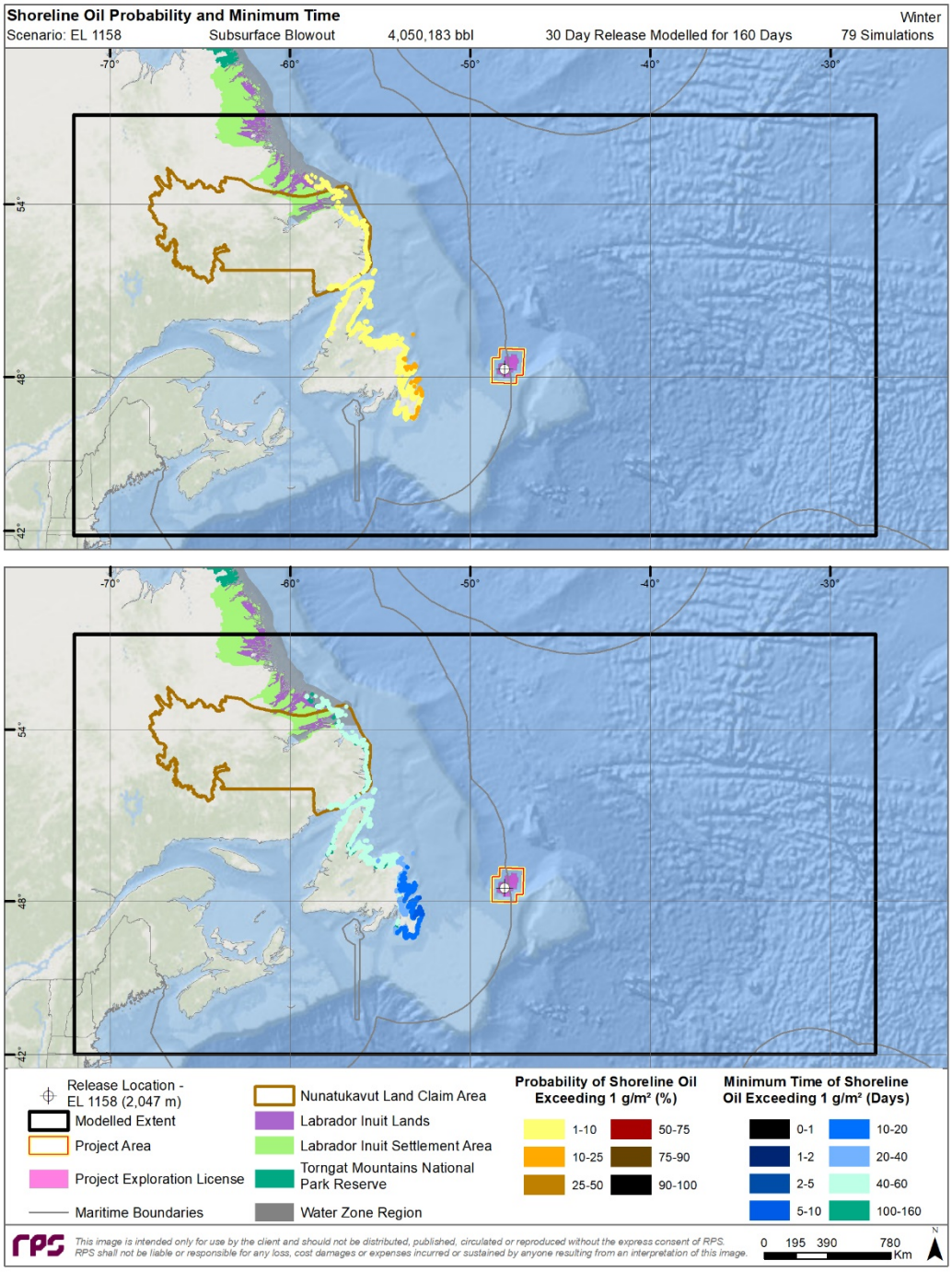

Figure 4-44. Winter probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

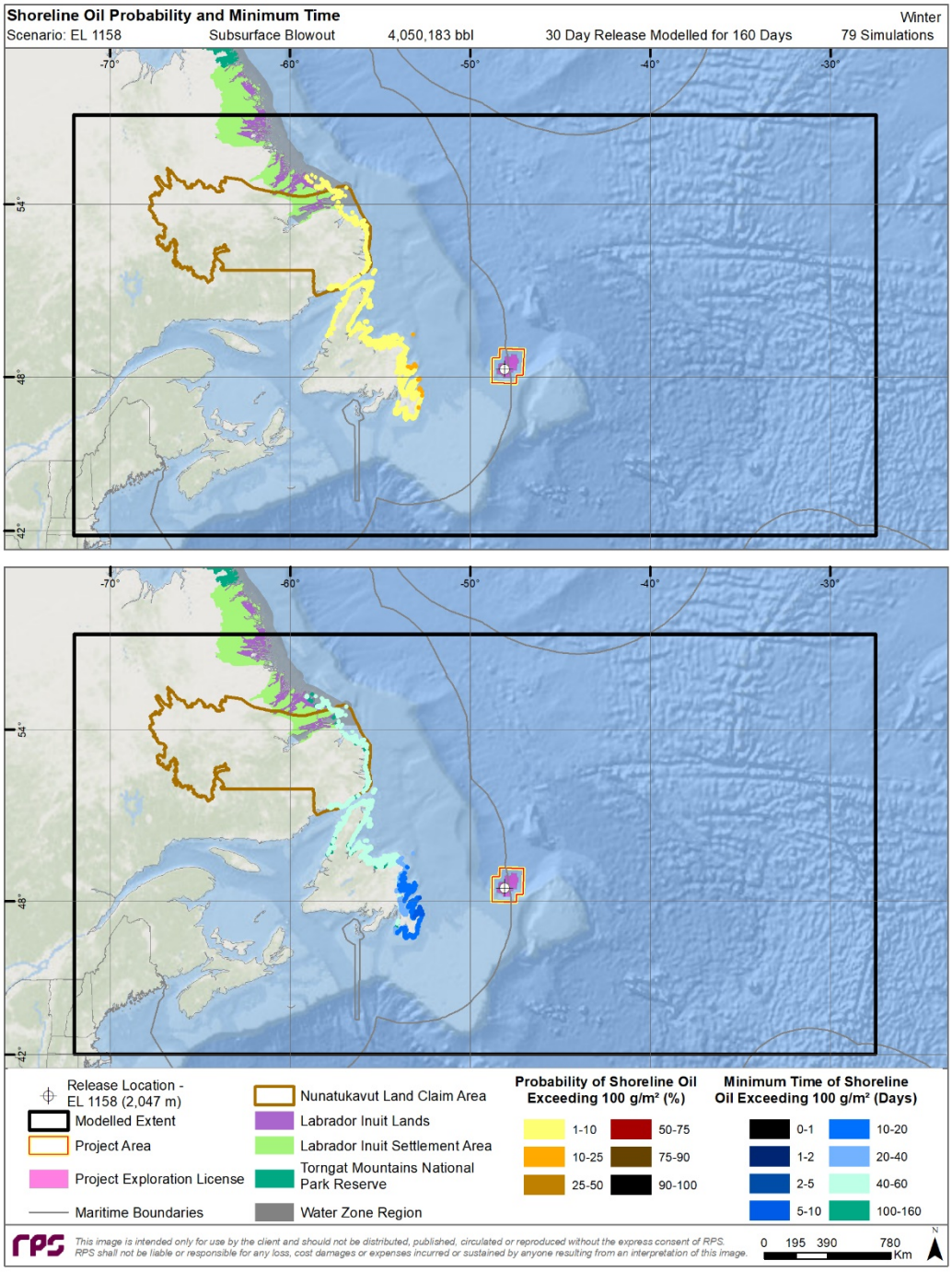

Figure 4-45. Winter probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 30-day subsurface blowout at EL 1158.

4.1.2.2 120-day Subsurface Release

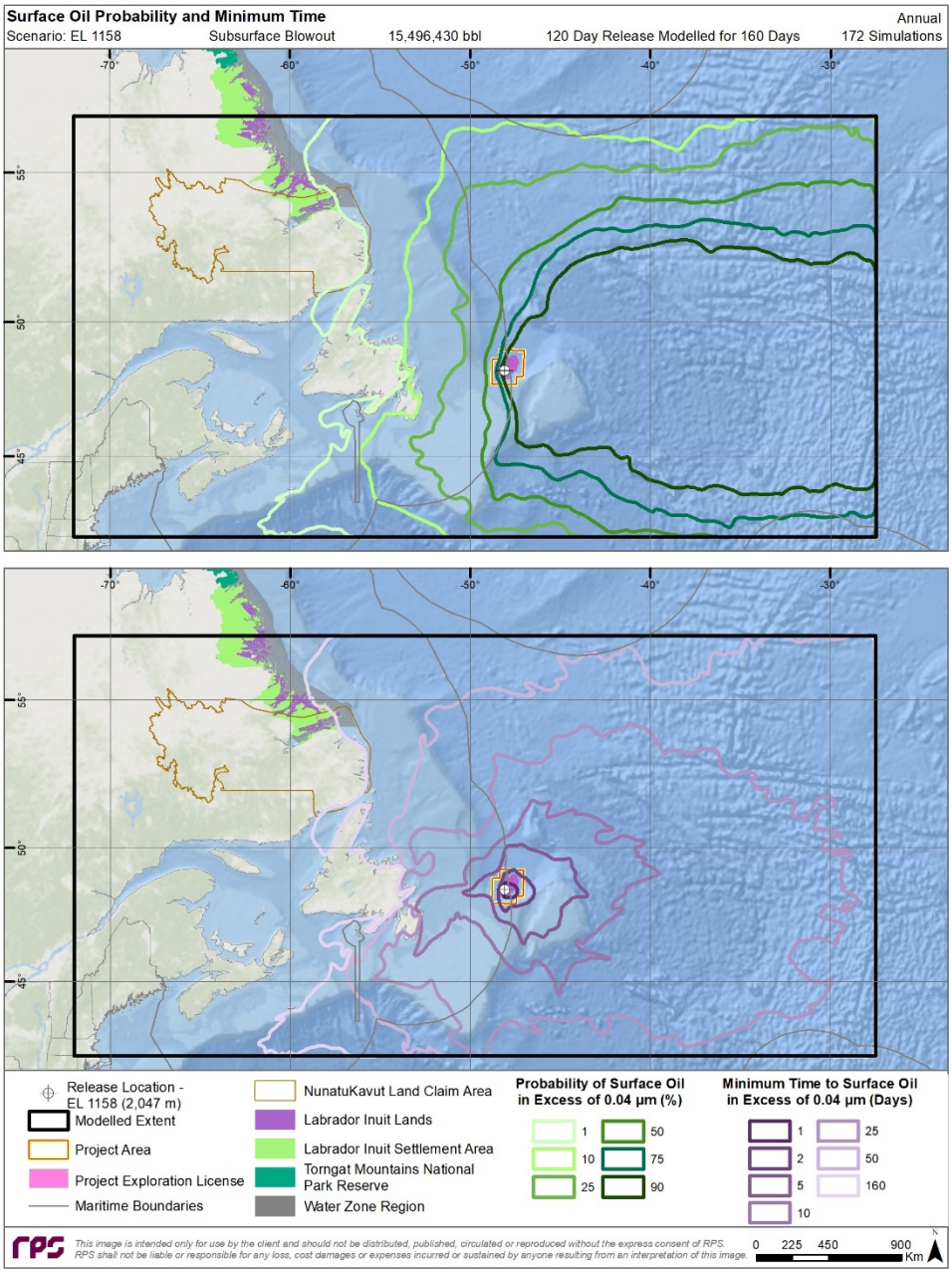

Figure 4-46. Annual probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

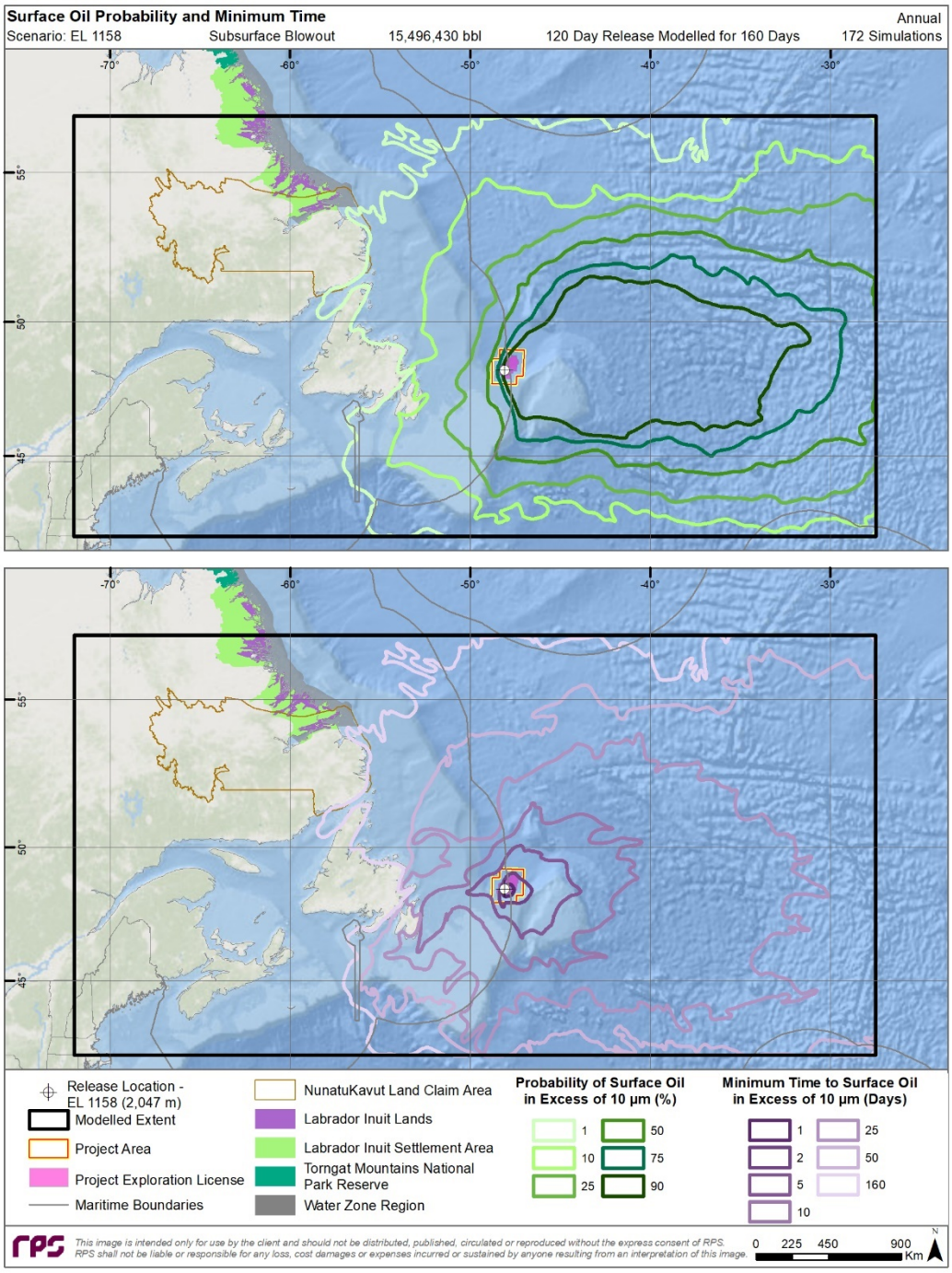

Figure 4-47. Annual probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

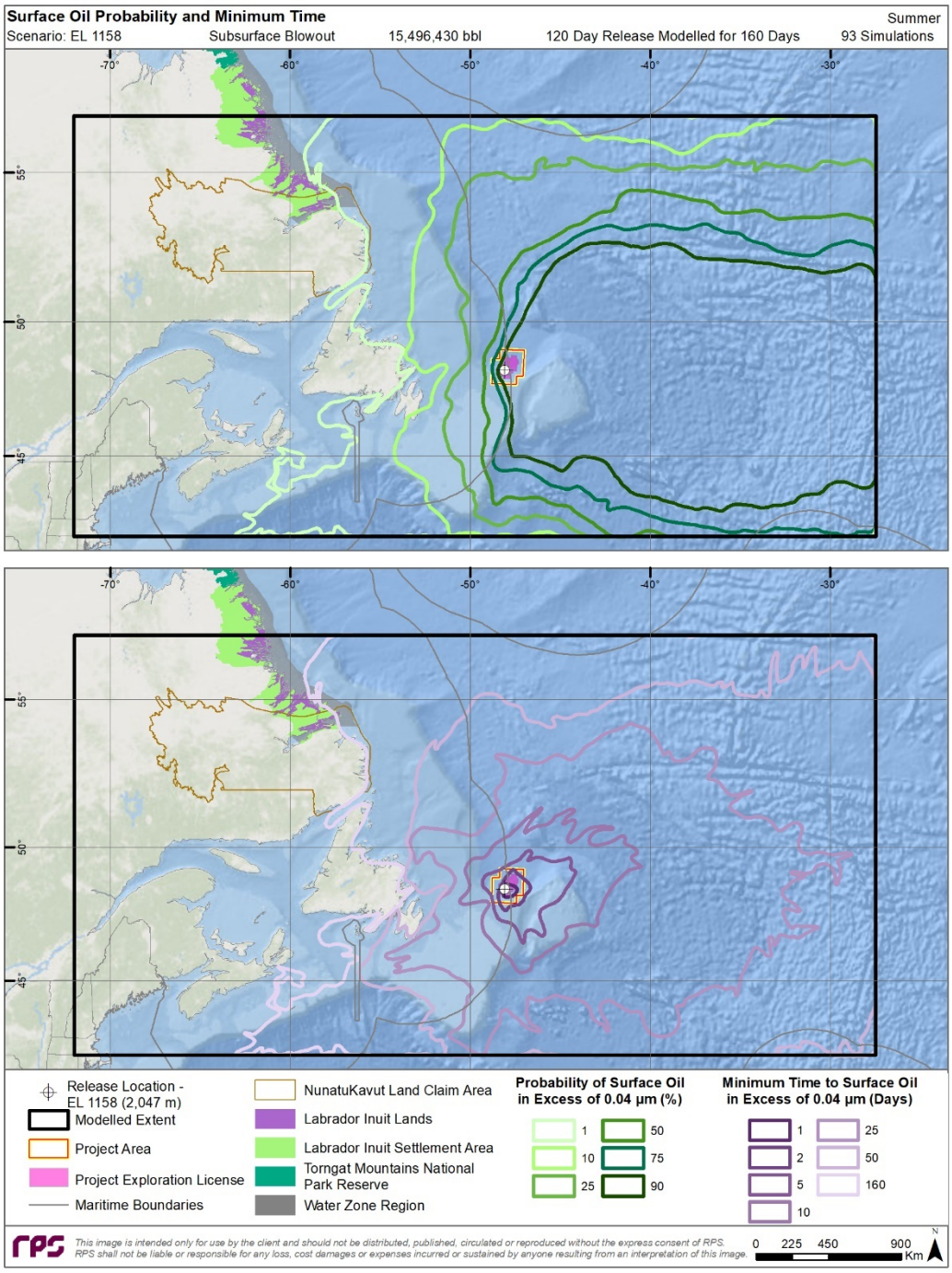

Figure 4-48. Summer probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

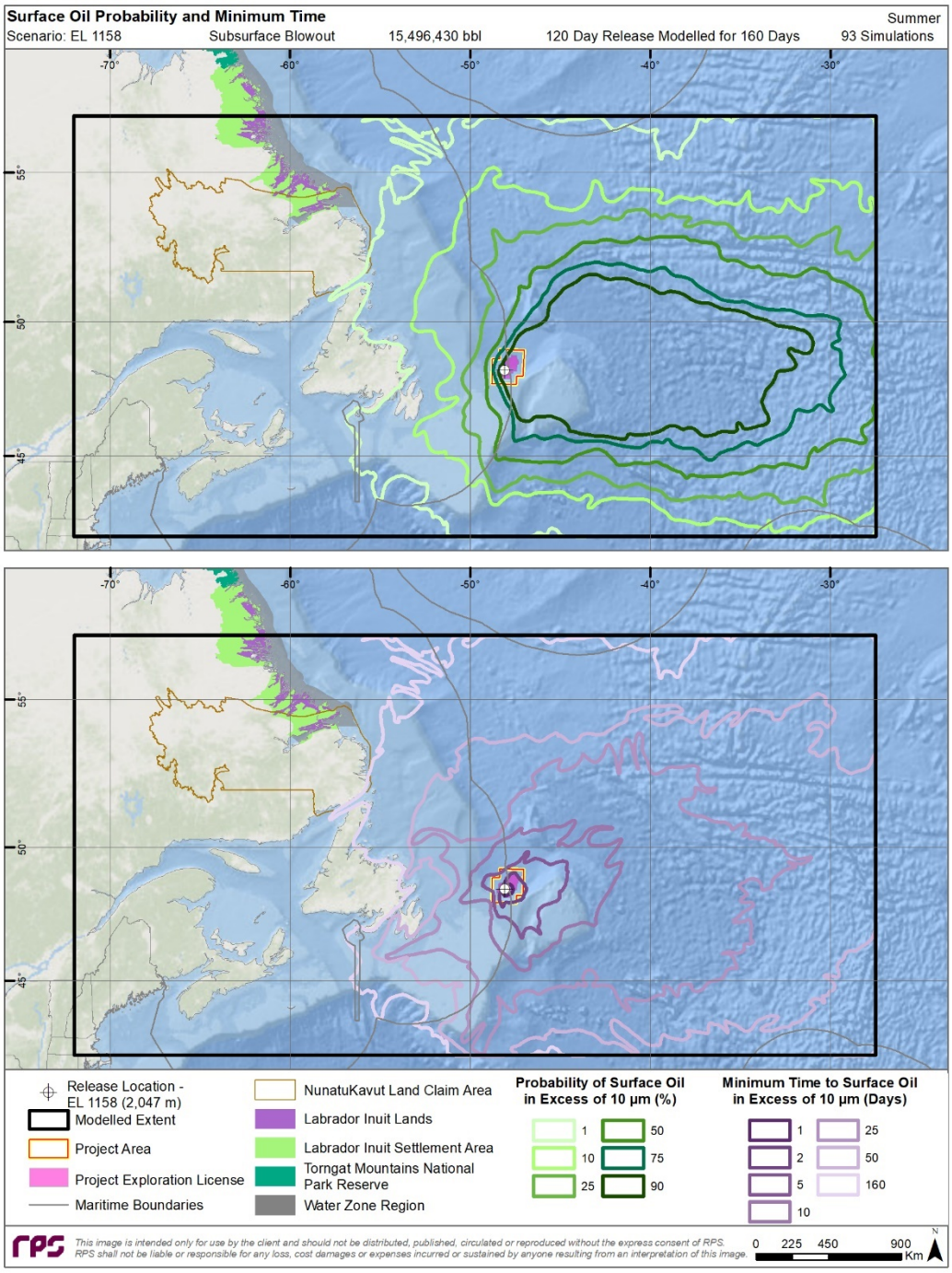

Figure 4-49. Summer probability of surface oil thickness >10 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

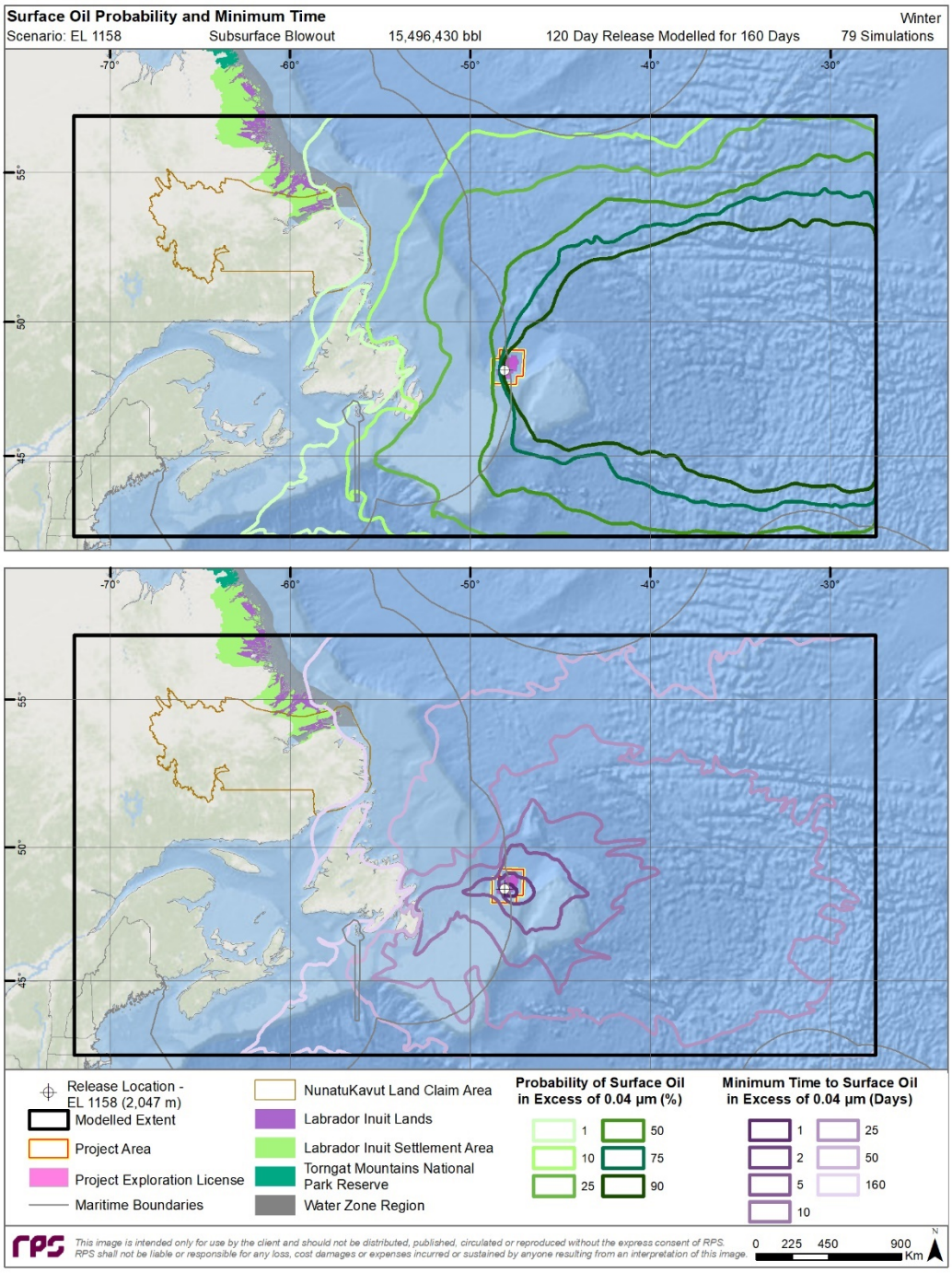

Figure 4-50. Winter probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

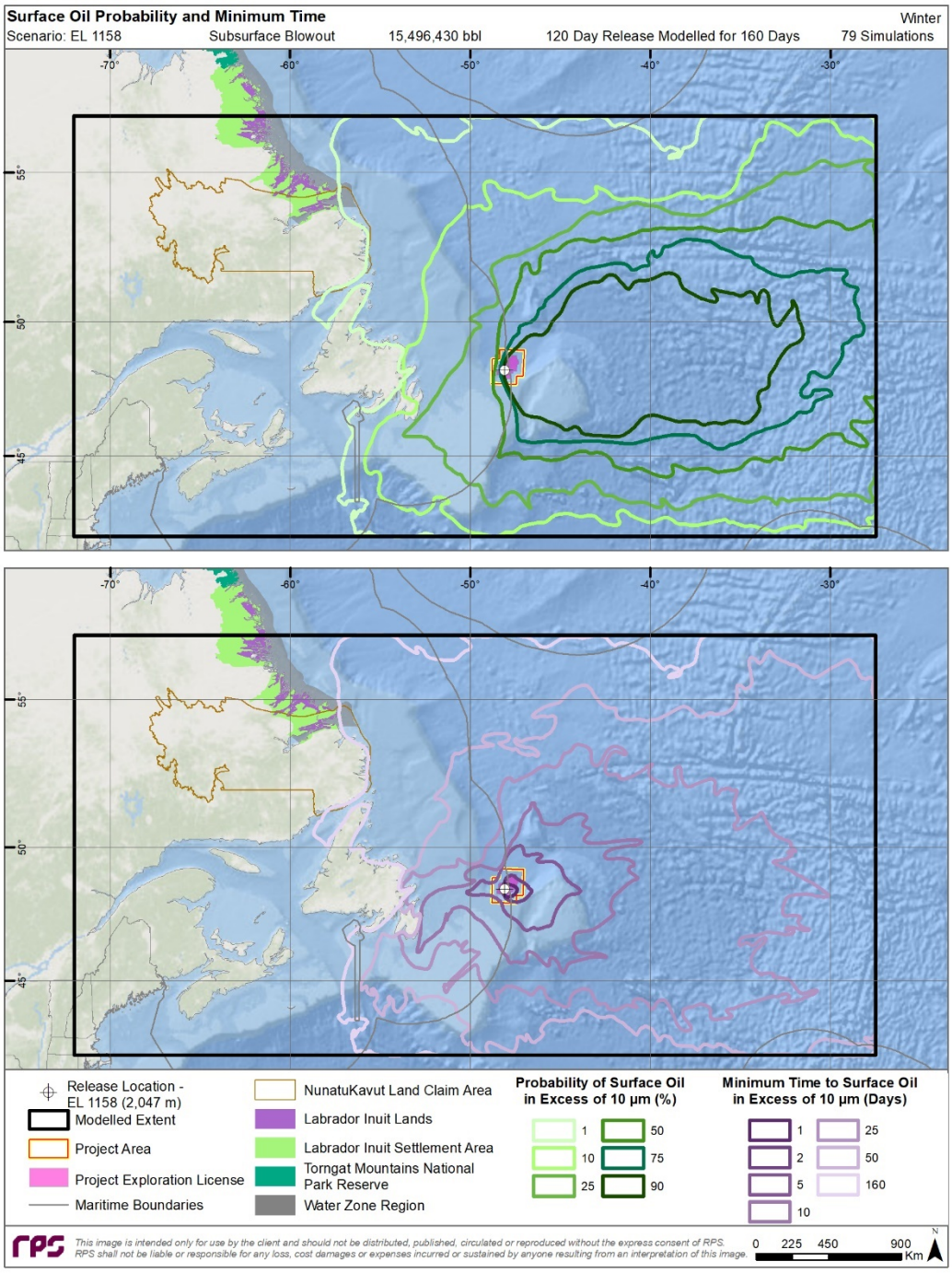

Figure 4-51. Winter probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

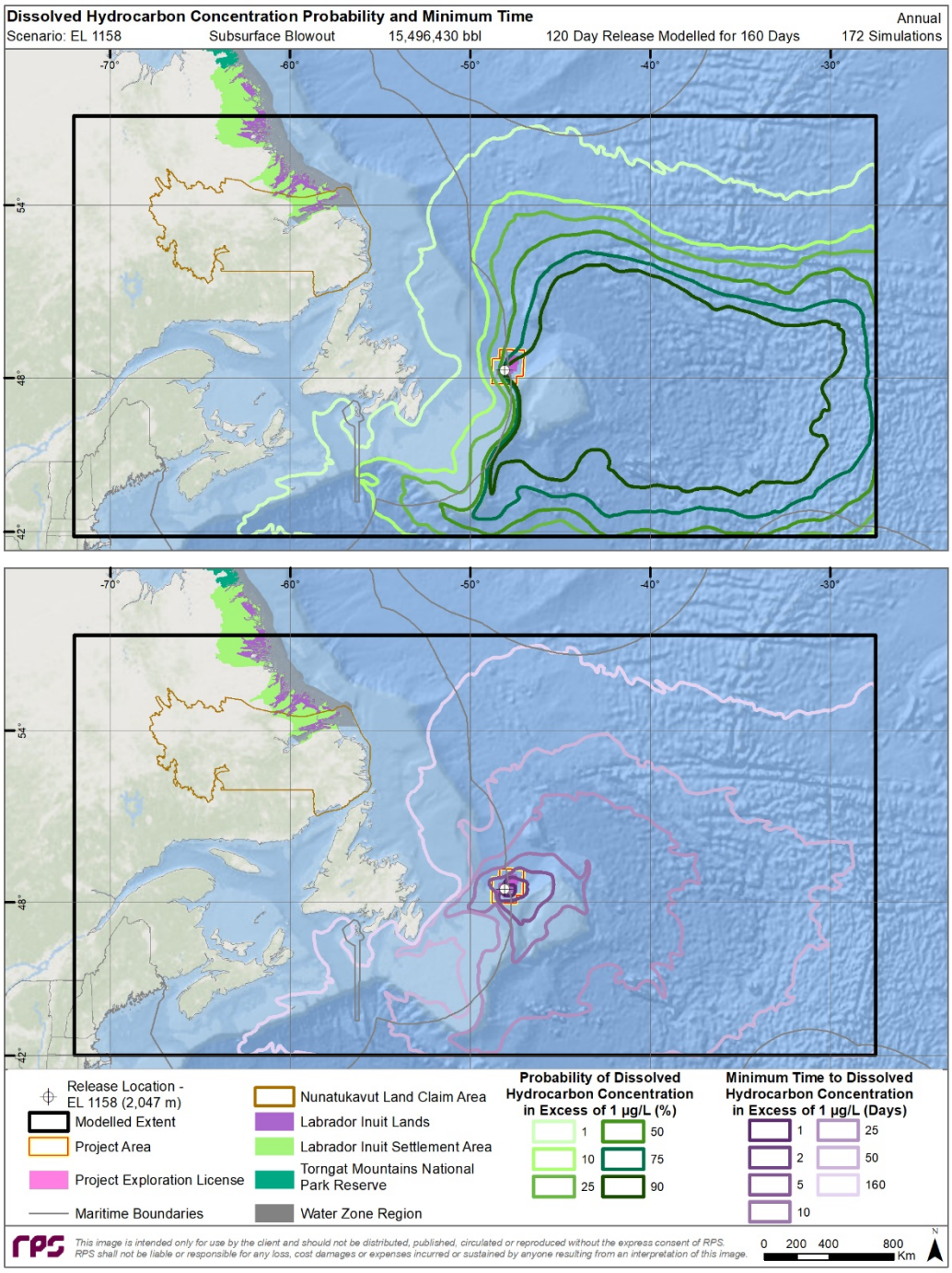

Figure 4-52. Annual probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

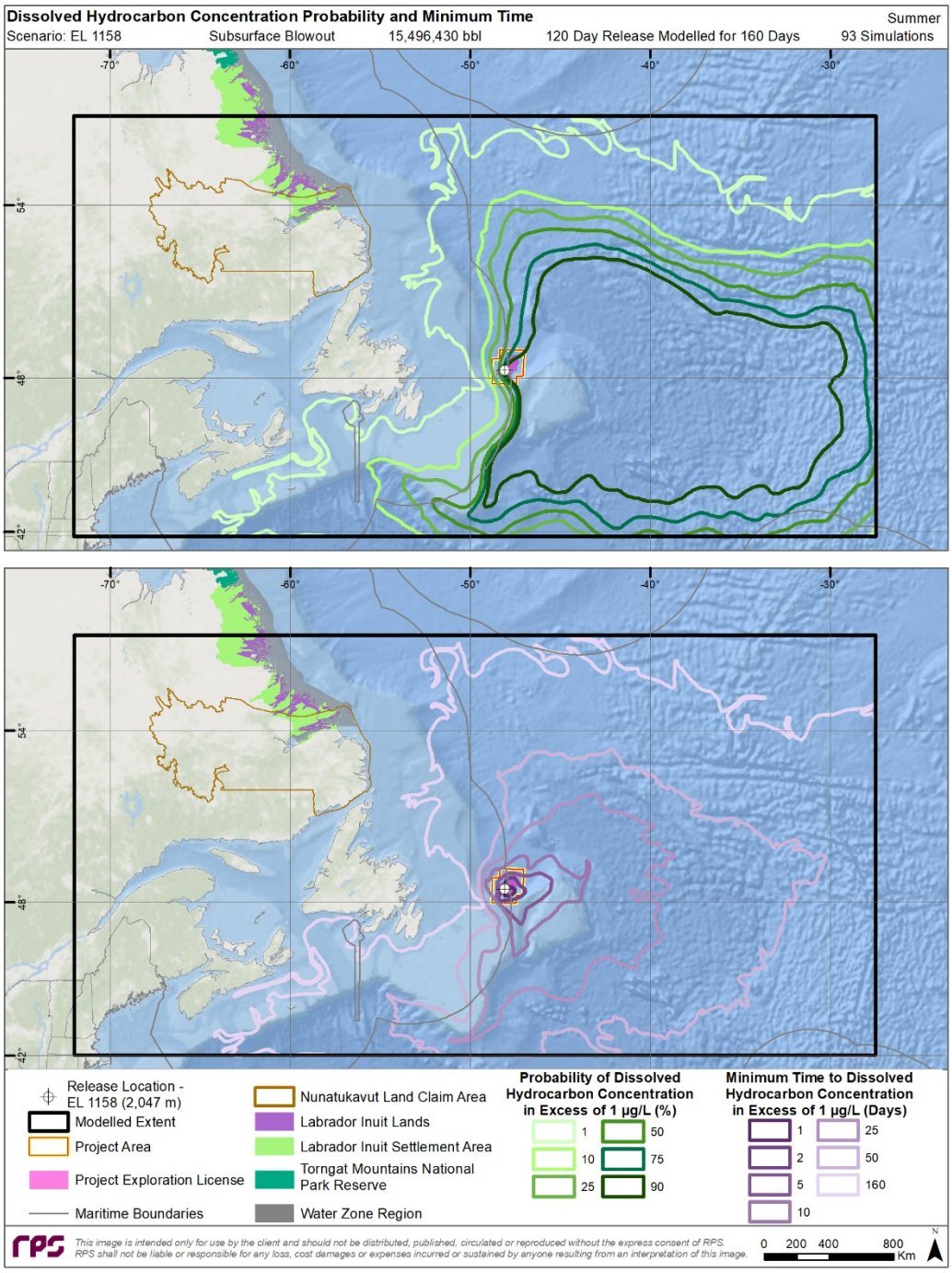

Figure 4-53. Summer probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

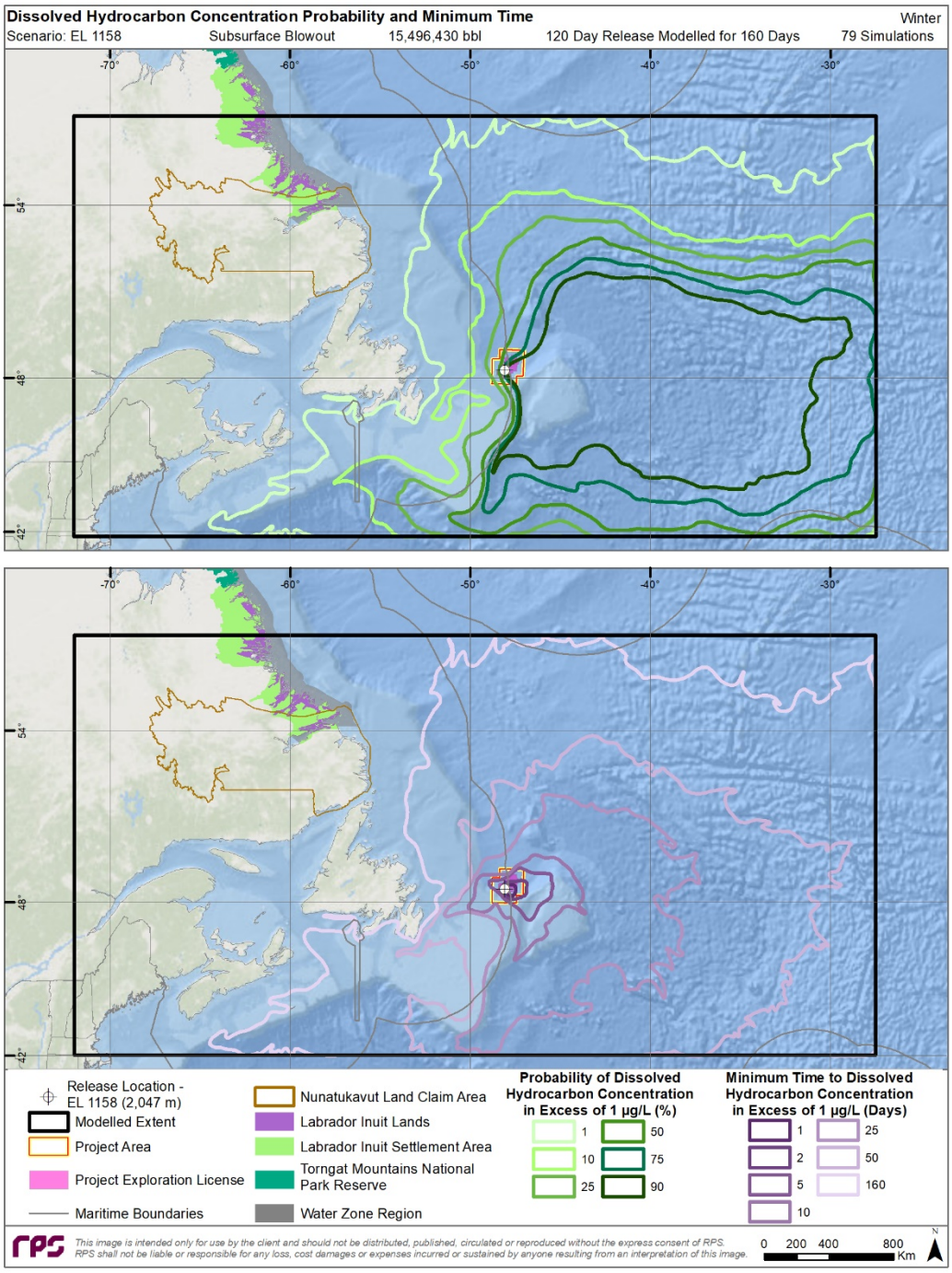

Figure 4-54. Winter probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

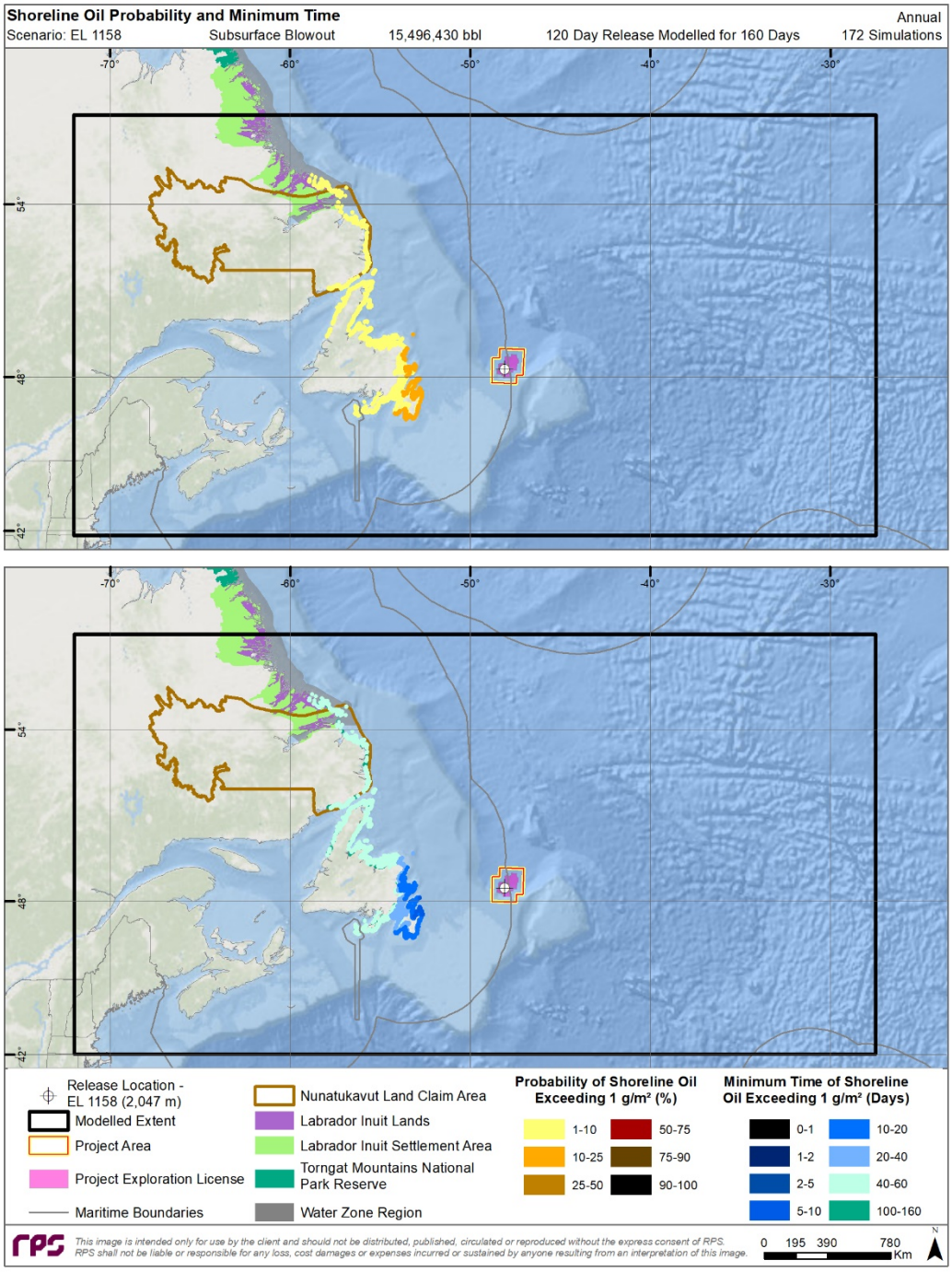

Figure 4-55. Annual probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

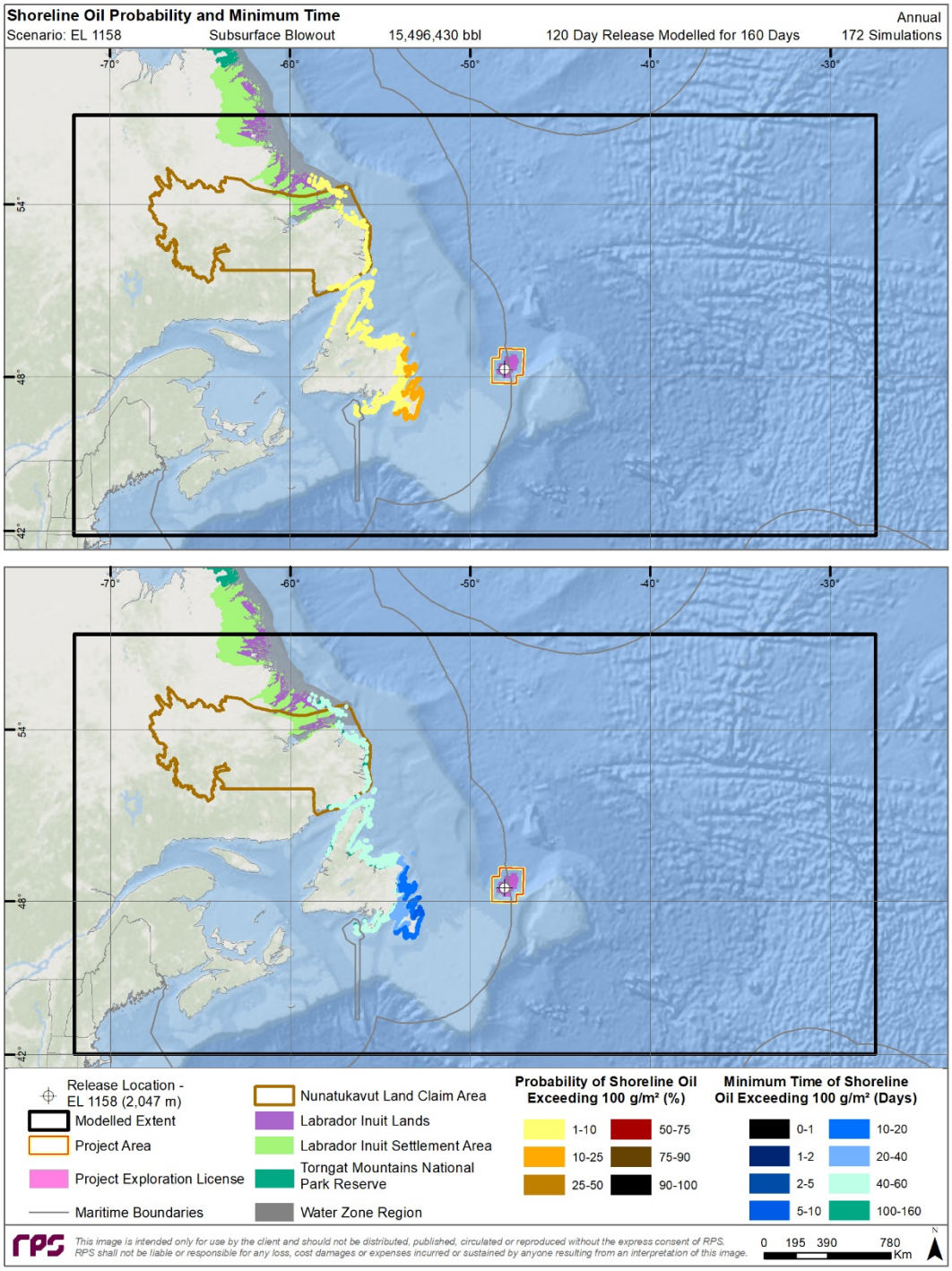

Figure 4-56. Annual probability of shoreline contact >100 g/m² (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

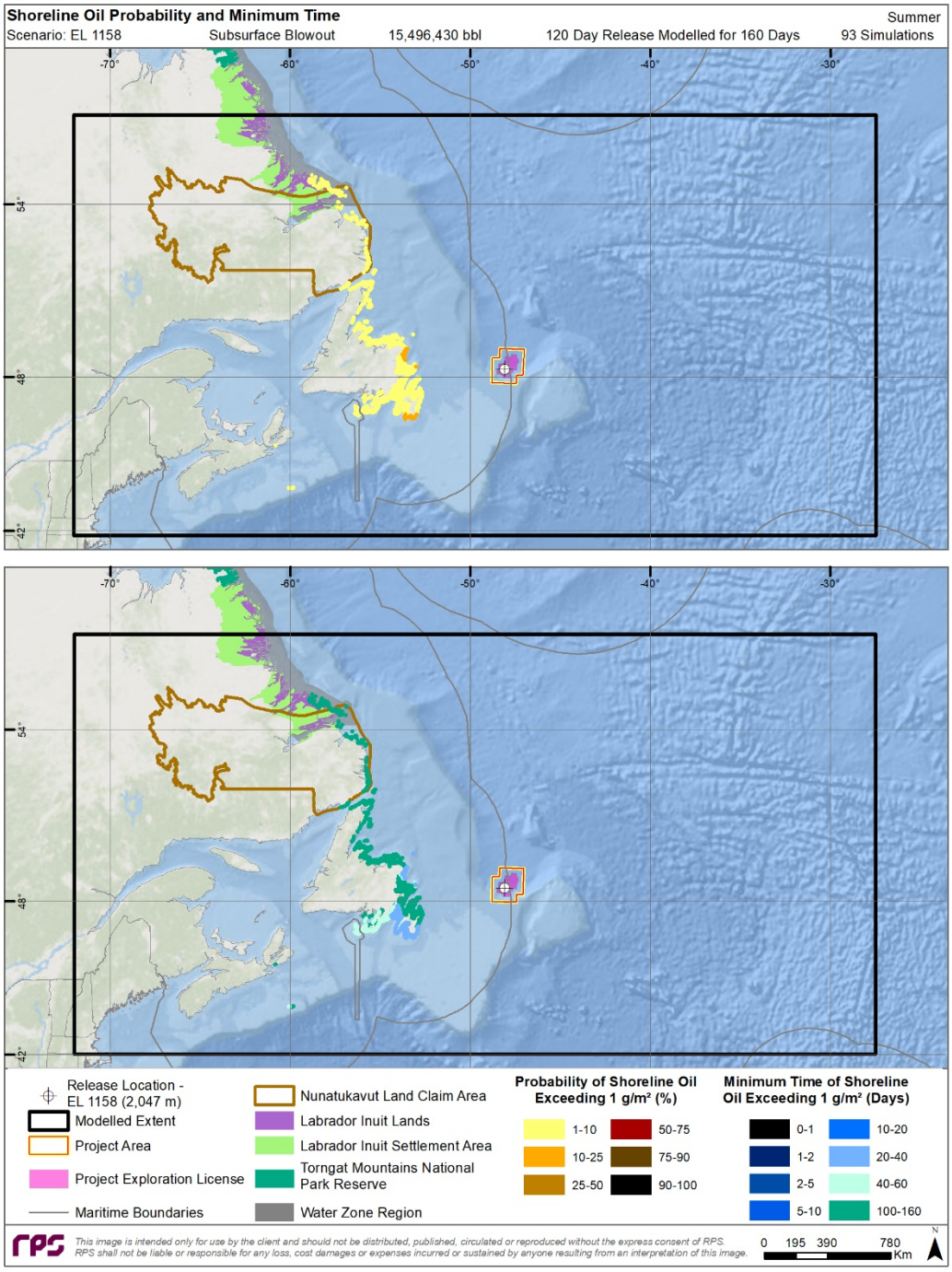

Figure 4-57. Summer probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

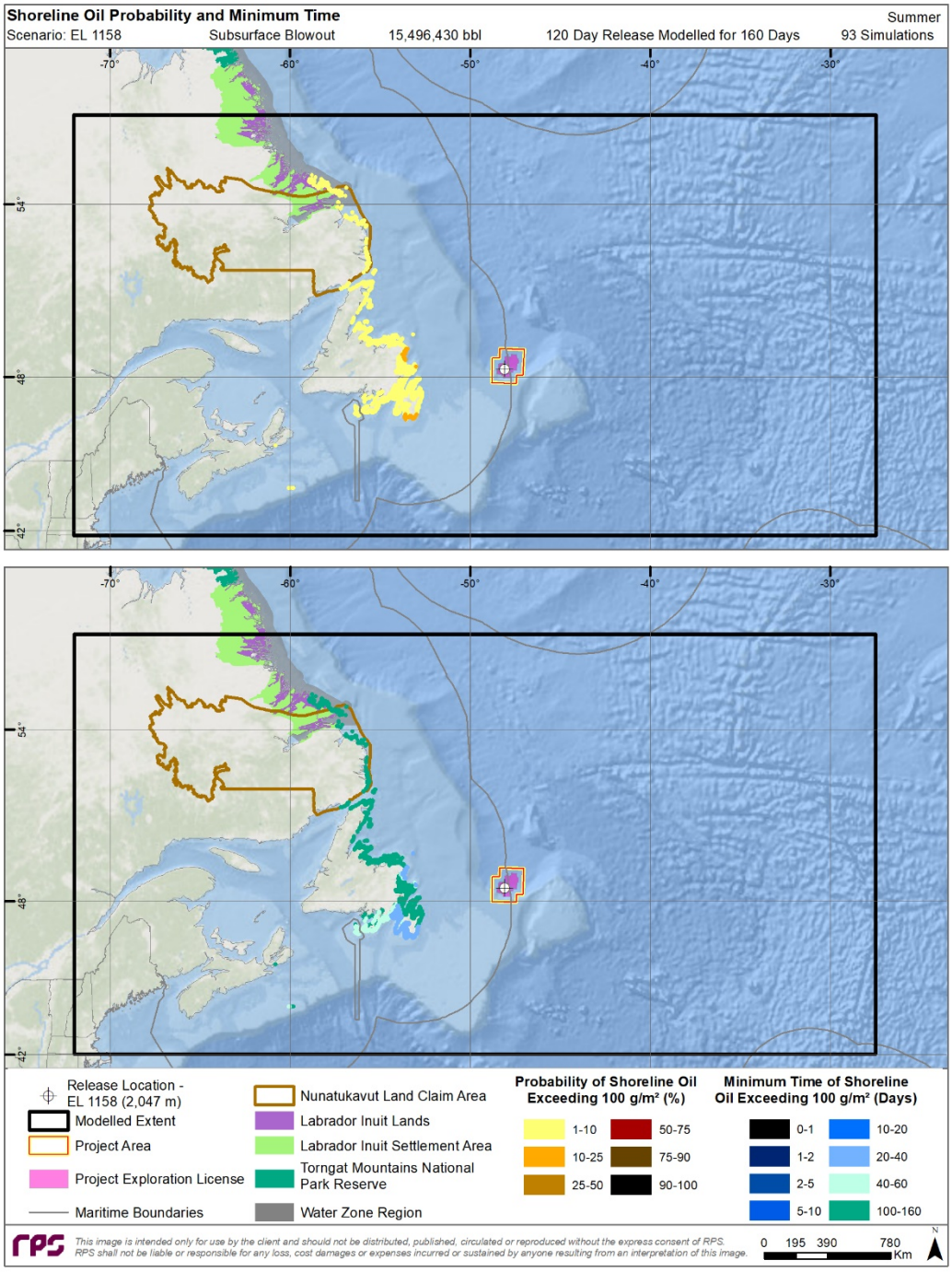

Figure 4-58. Summer probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

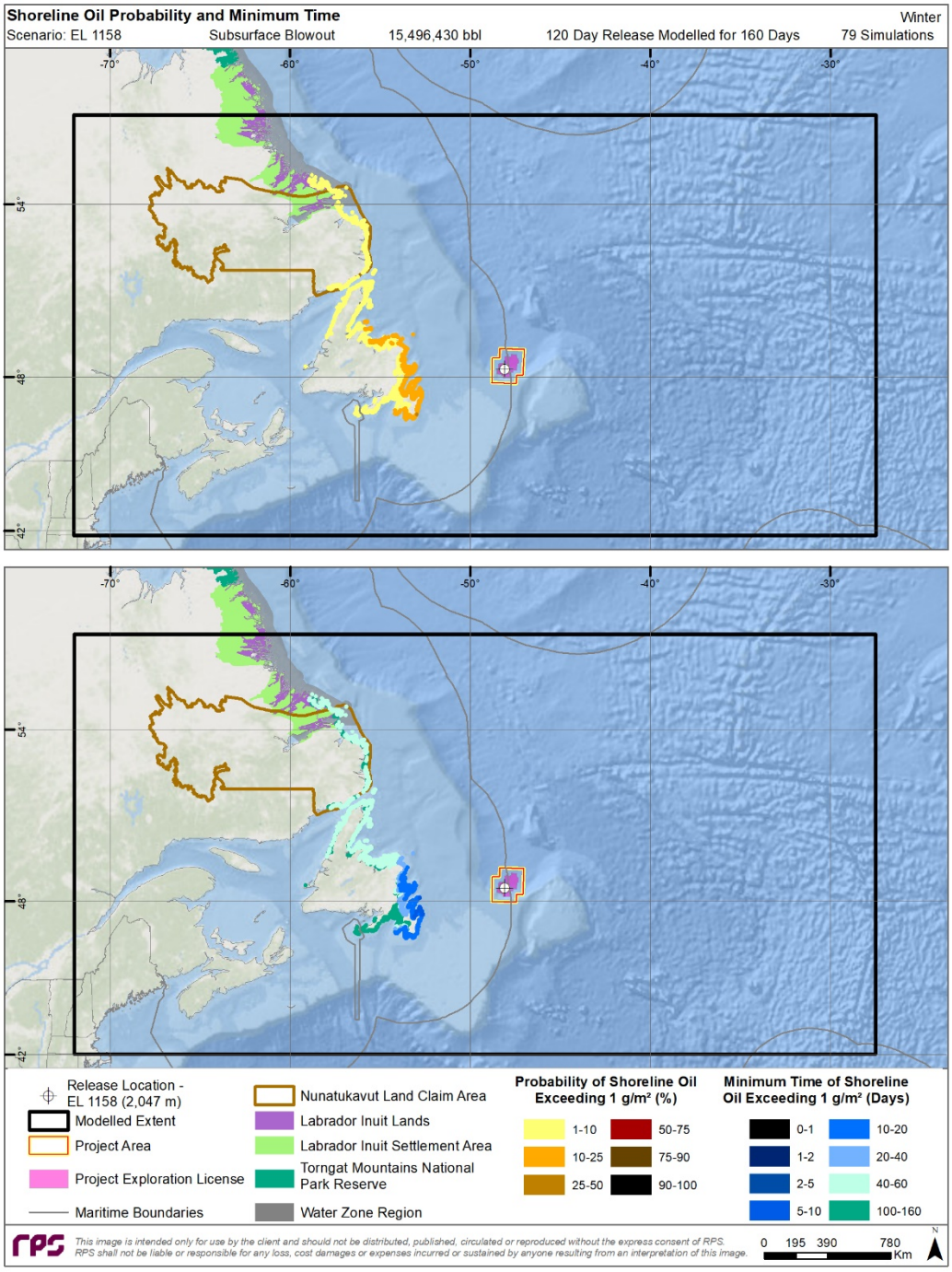

Figure 4-59. Winter probability of socio-economic threshold shoreline contact >1 g/m^2 (top) and minimum time to threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

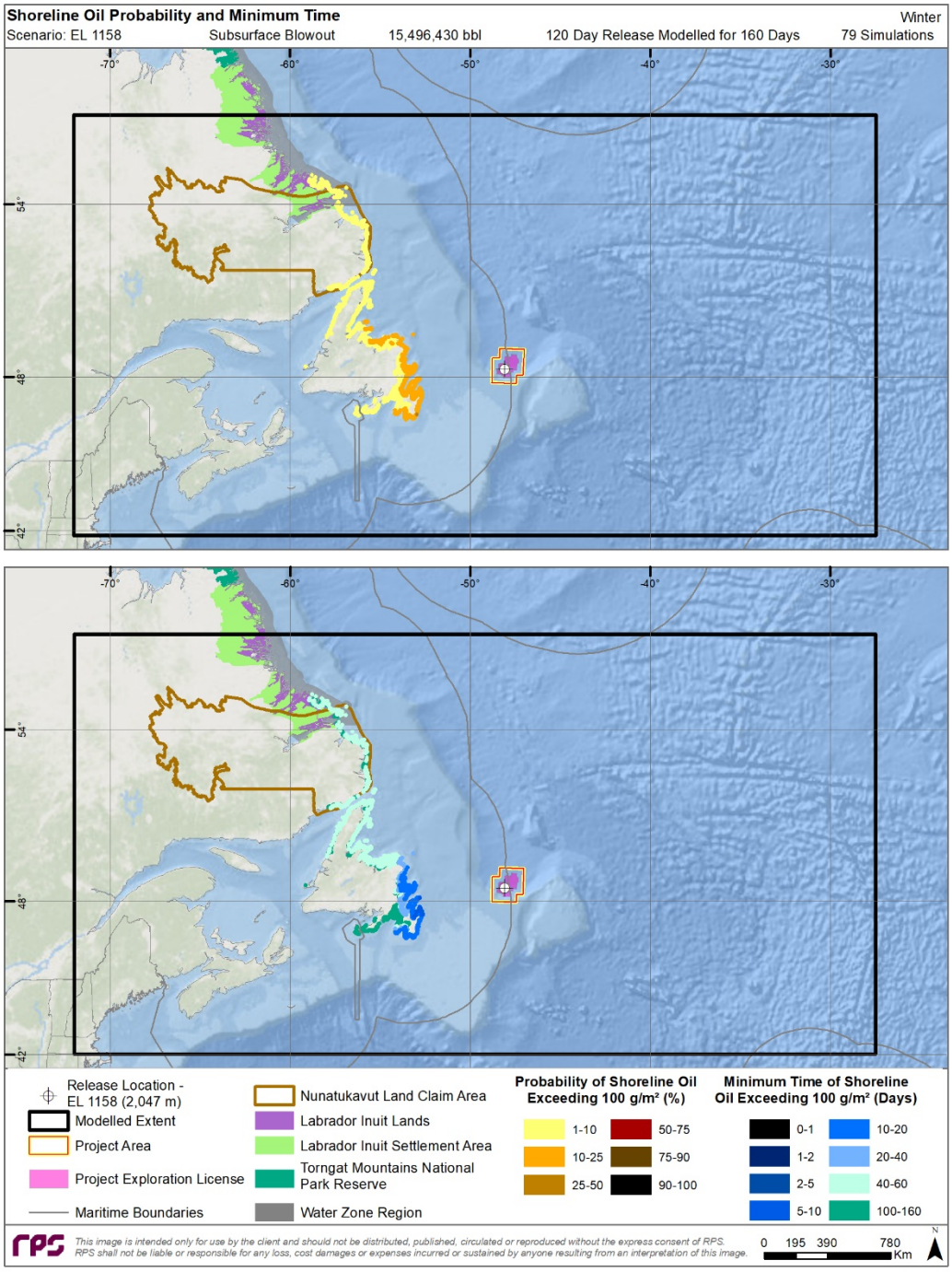

Figure 4-60. Winter probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a 120-day subsurface blowout at EL 1158.

4.1.3 Surface Diesel Batch Spill Results

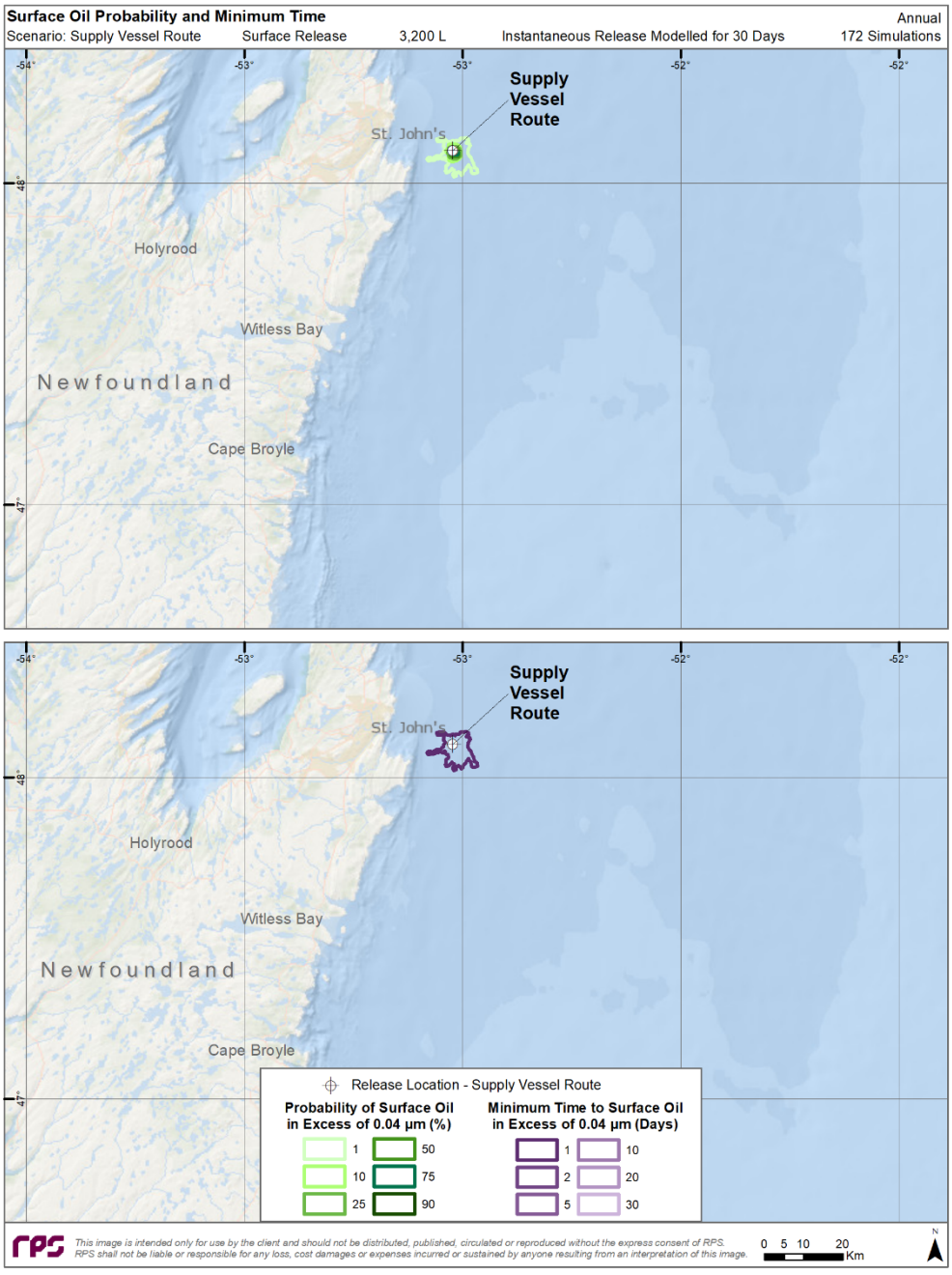

Figure 4-61. Annual probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel (batch spill) release.

Figure 4-62. Annual probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel (batch spill) release.

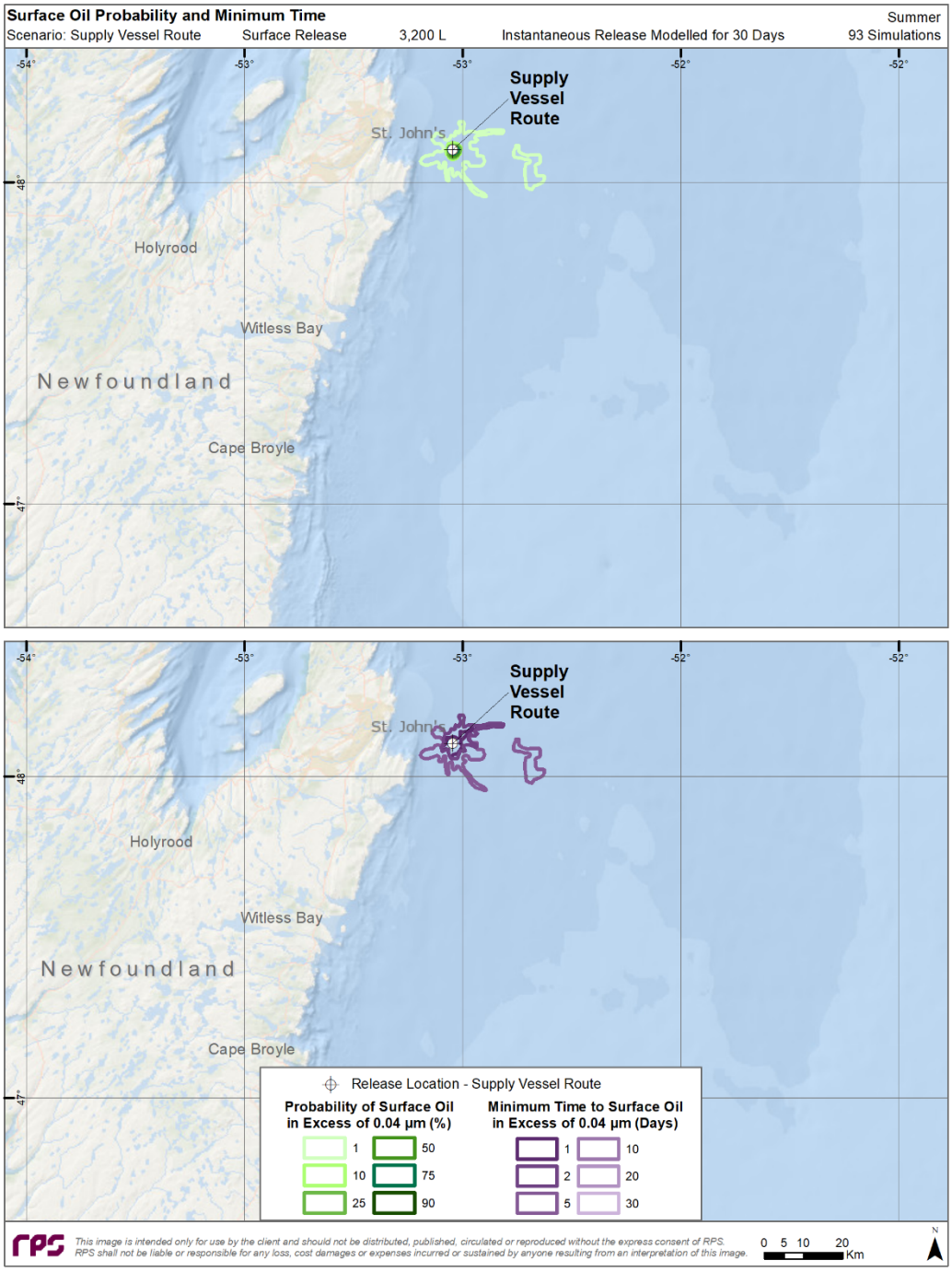

Figure 4-63. Summer probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel release.

Figure 4-64. Summer probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel release.

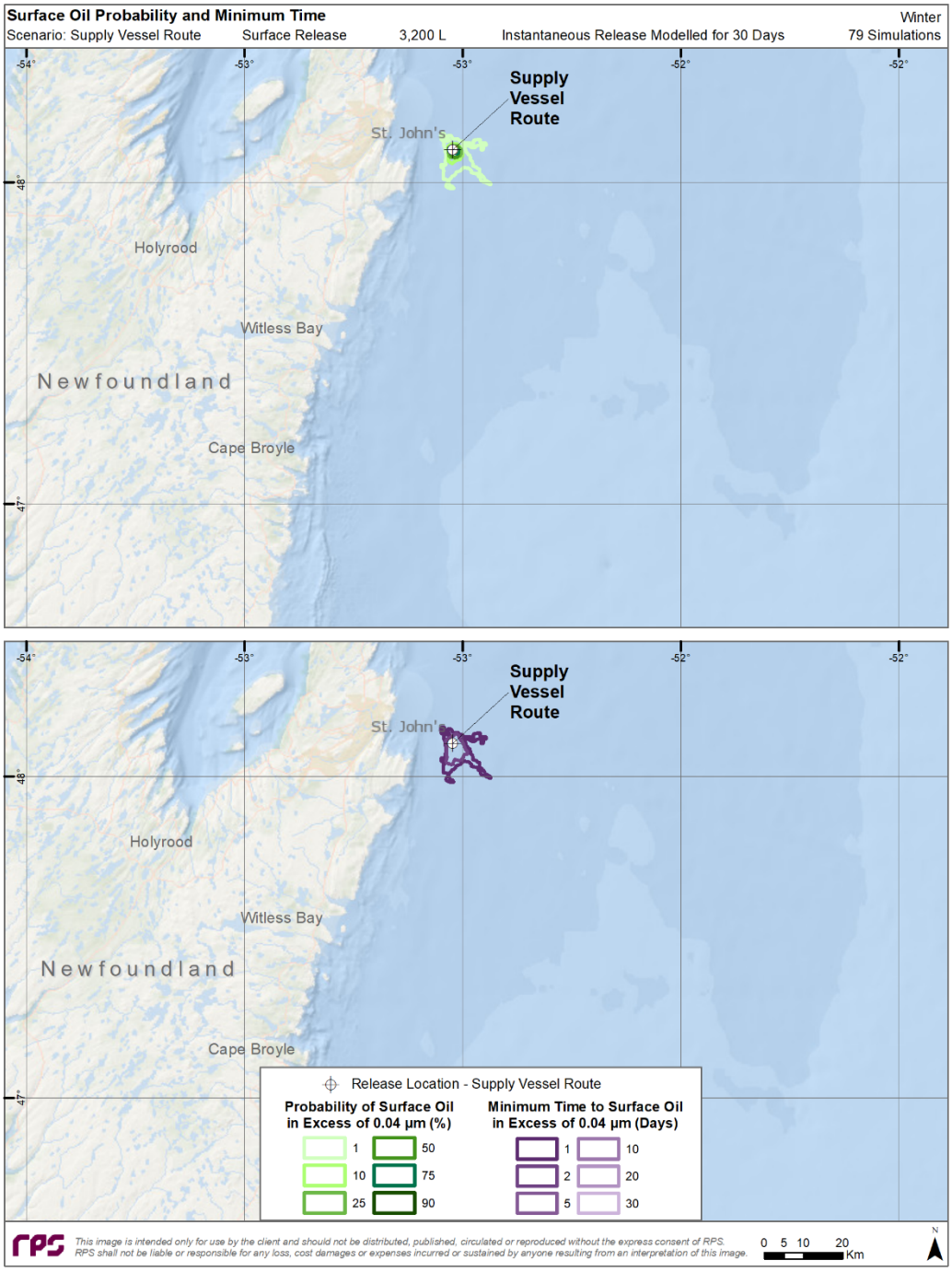

Figure 4-65. Winter probability of surface oil thickness >0.04 µm (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel release.

Figure 4-66. Winter probability of surface oil thickness >10 µm (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel release.

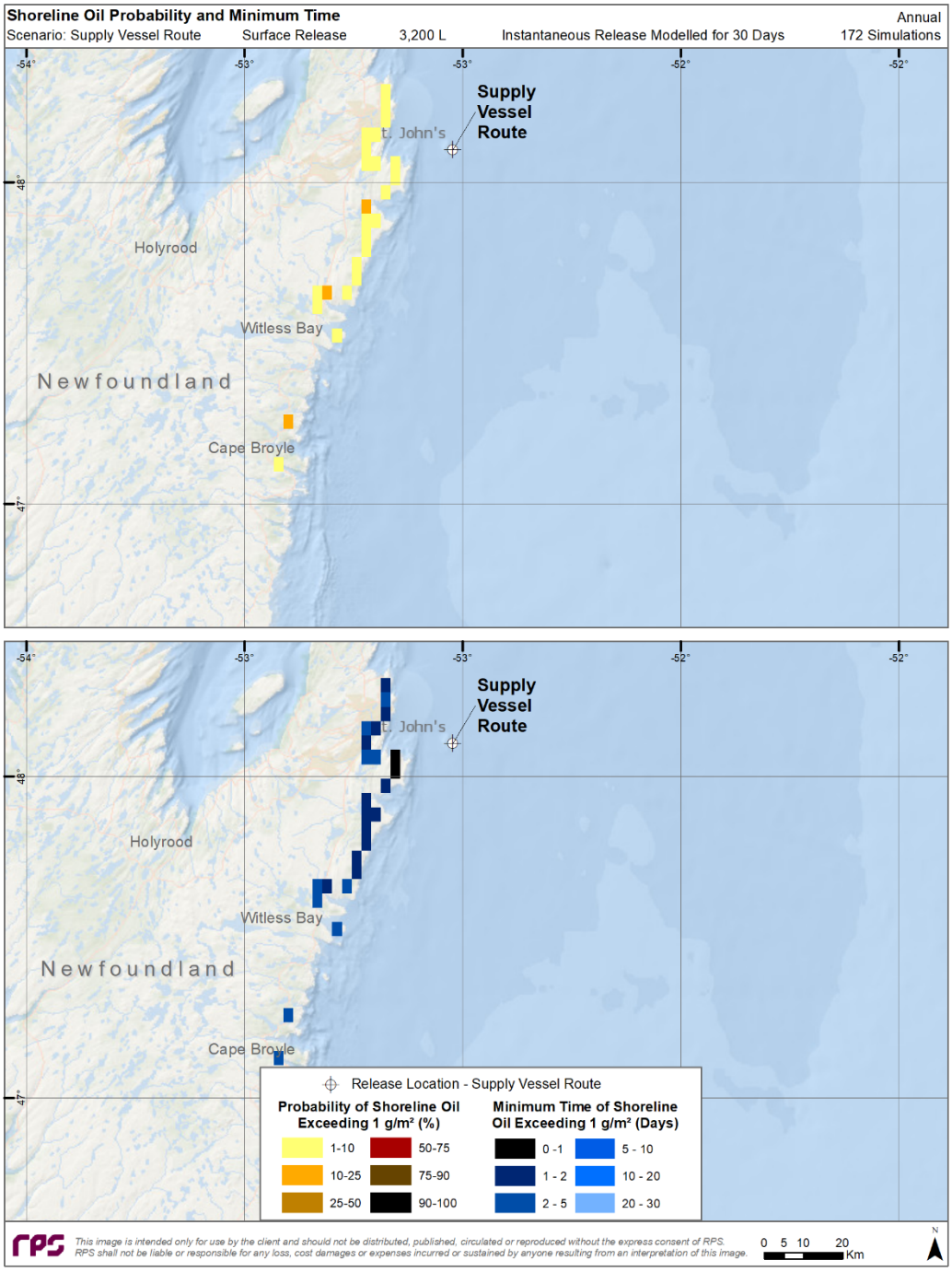

Figure 4-67. Annual probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel (batch spill) release.

Figure 4-68. Annual probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel (batch spill) release.

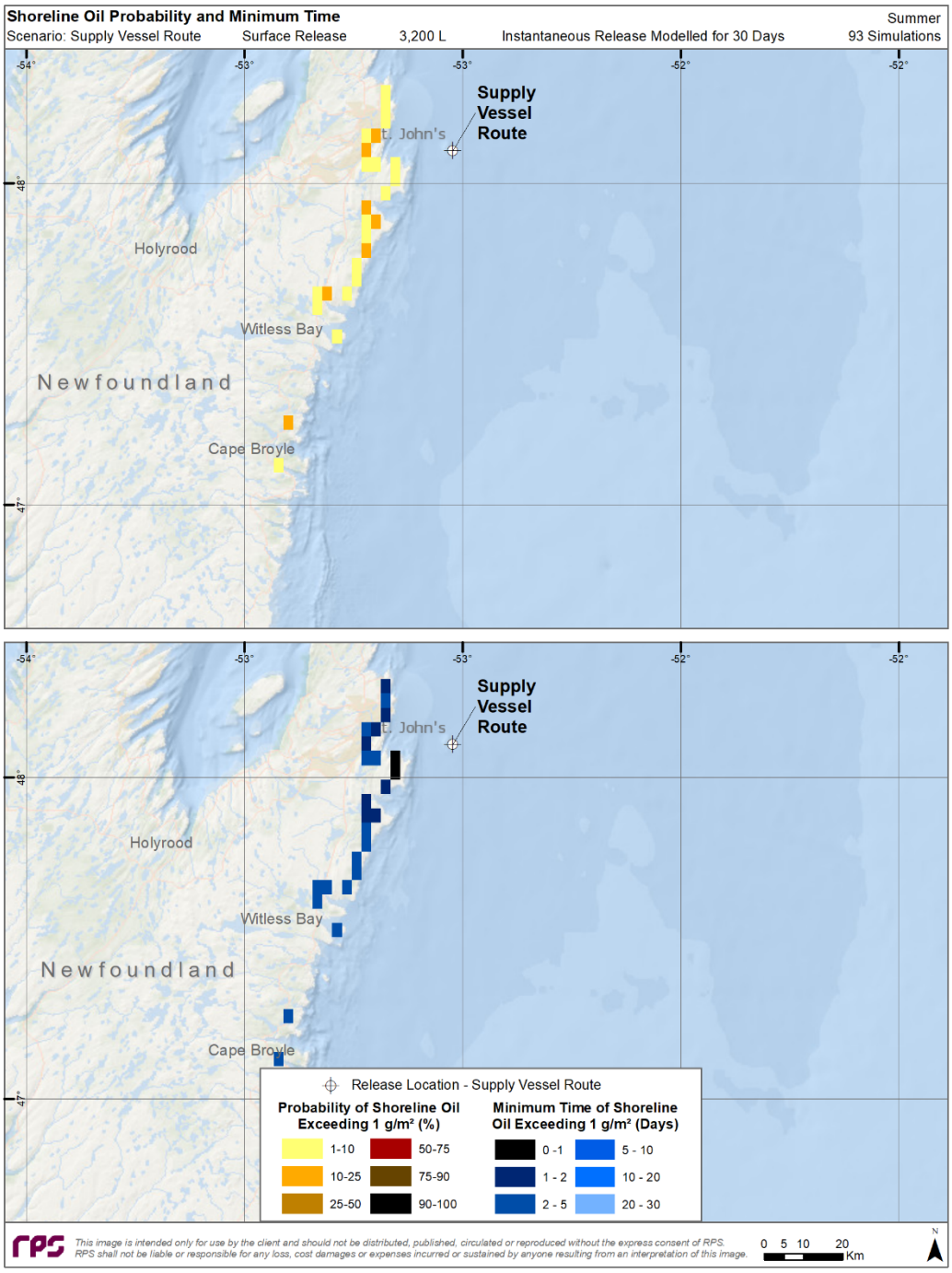

Figure 4-69. Summer probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel release.

Figure 4-70. Summer probability of shoreline contact >100 g/m^2 (top) and minimum time to ecological threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel release.

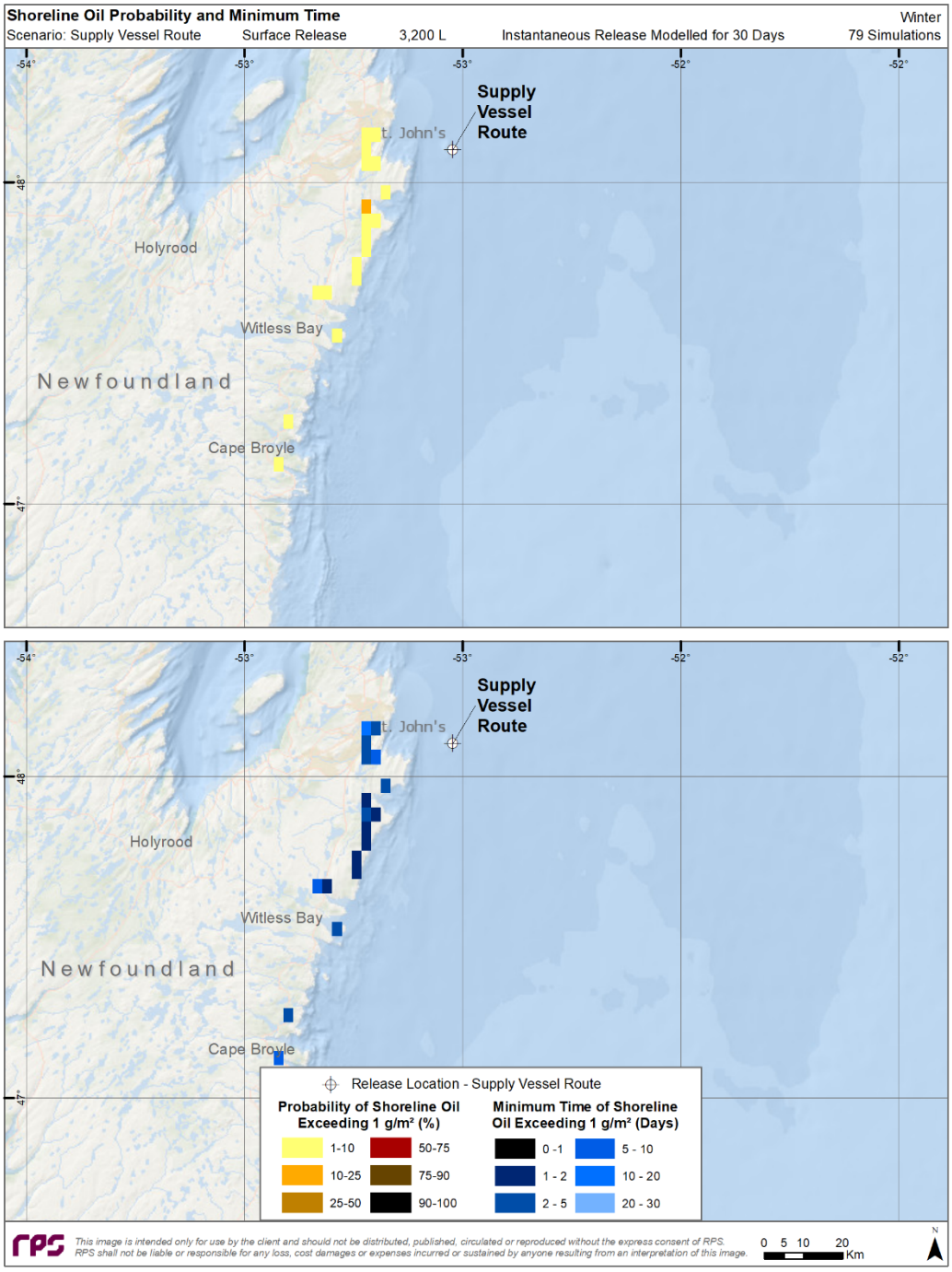

Figure 4-71. Winter probability of shoreline contact >1 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel release.

Figure 4-72. Winter probability of shoreline contact >100 g/m^2 (top) and minimum time to socio-economic threshold exceedance (bottom) predictions resulting from a near-instantaneous surface diesel release.

4.1.4 Summary of Stochastic Results

A total of 172 unique model simulations were conducted for each stochastic analysis at the EL 1157 (2,338 m) and EL 1158 (2,047 m) hypothetical release sites, representing subsurface blowouts in waters offshore of Newfoundland. In addition, another stochastic simulation composed of 172 simulations was modelled to represent batch spill releases of 3,200 L of marine diesel at a third near shore location, 12 km east of St. John's, along a potential supply vessel route. The modelled batch spill volume evaluated a potential discharge on the surface associated with marine diesel spills that could occur from a rupture of a diesel storage tank.

Four blowout release scenarios (two at each site) were modelled for 160-day periods to simulate short (30-day) and long (120-day) duration blowouts. The 120-day releases represent a conservatively long amount of time anticipated time to shut in a well by mobilizing a drilling platform and drilling a relief well, while the 30-day release represents a conservatively long amount of time to successfully mobilize and implement a capping stack to contain the release. The total model duration of 160 days was used to track the trajectory and fate of spilled product as it continued to weather after the release had stopped.

For both release sites, summaries of the BdN stochastic analyses of potential surface oil and water column exposure by dissolved hydrocarbons depict areas to the east of the release sites as having the highest potential likelihood (>90%) to exceed socio-economic and ecological thresholds. The >90% likelihood area typically extended over 1,400 km to the east to the edge of the model domain for the surface oil for both thresholds, but typically fell short of the boundary for the water column contamination with the 50-75% contour line making contact with the easternmost extent. This is the result of persistent fractions of the BdN being emulsified and forming tarballs on the surface. The soluble and volatile fraction making up the water column contamination was more likely to evaporate and degrade over the month or two required for oil to be transported to the easternmost boundary. Predicted water column probability footprints were typically smaller than surface oil footprints, with the probability of threshold exceedance predicted to decrease more rapidly for water column results as distance from the release site increased (Table 4-1). In nearly all stochastic scenarios, lower probabilities of threshold exceedance are predicted for surface and/or water column oil contamination to the north and south. In addition, <25% of the simulated releases were predicted to result in threshold exceedance for the socio-economic thresholds >100 km to the west of the Project Area (Figure 4-1 through Figure 4-9; Figure 4-16 through Figure 4-24; Figure 4-31 through Figure 4-39; Figure 4-46 through Figure 4-54). Due to the weathering of the oil (i.e., emulsification and formation of tarballs) that took place over the week or more required for oil to reach shorelines (which increases viscosity and therefore thickness) as well as the accumulation of oil on shorelines over the 160-day simulations, predicted oil concentrations on the shoreline were typically greater than the ecological threshold of 100 g/m^2. Therefore, the socio-economic and ecological shoreline figures presented in the sections above are extremely similar (Figure 4-10 through Figure 4-15; Figure 4-25 through Figure 4-30; Figure 4-40 through Figure 4-45; Figure 4-55 through Figure 4-60).

Due to the primarily eastward transport of oil from wind and currents, and the distance of the Project Area to the shoreline of Newfoundland, the maximum average probability of Canadian shoreline exposure above the threshold for the four stochastic scenarios was approximately 9% for subsurface blowouts (Table 4-3). As the Labrador current flowed southward along the continental shelf, it was predicted to transport subsurface oil to the south, parallel to the coast (Figure 4-7 through Figure 4-9; Figure 4-22 through Figure 4-24; Figure 4-37

through Figure 4-39; Figure 4-52 through Figure 4-54). However, this trend is generally absent in the surface oil projections as wind forcing was more likely to transport oil to the east (Figure 4-1 through Figure 4-5; Figure 4-16 through Figure 4-20; Figure 4-31 through Figure 4-35; Figure 4-46 through Figure 4-50). Oil that was predicted to make its way to the shoreline of Canada would be patchy and discontinuous due to the considerable amount of weathering and natural dispersion that would take place over the weeks or months that were required for oil to reach shore. The minimum time to shorelines for threshold exceedance was >7 days along the Avalon peninsula and southeastern Newfoundland and >40 days along the northern shores of Newfoundland and southeastern Labrador (Table 4-3, Figure 4-10 through Figure 4-14; Figure 4-25 through Figure 4-29; Figure 4-40 through Figure 4-44; Figure 4-55 through Figure 4-59).

Although minimal, there was some level of seasonal variability in predicted spill behavior. Regardless of release site and duration, the average stochastic probability of shoreline oiling was consistently higher for winter releases than for summer releases (Table 4-3). Similarly, the minimum time to socio-economic shoreline threshold exceedance was approximately three times longer in the summer (22-27 days) than the winter (7 days) (Table 4-3). The lower probability (i.e., 1% and 10%) footprints exceeding both socio-economic and ecological thresholds for surface oil contamination were larger in the winter compared to summer footprints, while the 90% footprints were generally larger in the summer (Table 4-1). This is due to the potential for greater westward transport of surface oil during the winter, associated with dynamic transitional periods, low pressure systems, and tropical and extra-tropical storms, when compared to the summer. As mentioned previously, as surface oil was transported to the east, it was predicted to reach the model domain boundaries in each modelled scenario due to the prevailing westerly winds and Gulf Stream current (Sections 3.4 and 3.5). However, the minimum time for oil to leave the boundary was always >25 days for oil exceeding the highly conservative socio-economic threshold and typically >50 days for oil exceeding the ecological threshold, implying that the oil that left the domain was highly weathered, patchy, and discontinuous.

Due to the similarities in release location, rate, and duration of the scenarios modelled at EL 1157 and EL 1158, the stochastic analysis results were not very different between sites. Both sites had comparable footprints predicted for 90% probability surface oil threshold exceedances (Table 4-1). The 120-day release at EL 1157 resulted in a predicted annual 90% surface oil probability contour exceeding the highly conservative socio-economic threshold with an area of 664,100 km^2, while the 120-day release at EL 1158 resulted in a predicted annual 90% surface oil probability contour with an area of 741,200 km^2 (Table 4-1). Similarities were predicted for footprints of predicted threshold exceedance for water column contamination (Table 4-1). The likelihood of shoreline oiling was very similar between release locations, with a higher potential for shoreline oiling during winter periods, when compared to summer periods (Table 4-3).

Intuitively, the longer release durations led to larger spill volumes. The 30-day spill simulations released 4,052,506 m^3 and 4,050,183 bbl, while 120-day simulations released 15,496,924 and 15,496,430 bbl at EL 1157 and EL 1158, respectively (Table 2-1). Despite the larger spill volumes for the 120-day releases (over four times higher), the size of the predicted stochastic footprints did not increase proportionally. This is due to the same underlying forcing (i.e., winds and currents) transporting different volumes of oil with the same speed and direction. While the overall footprint (down to the 1% contour) does not change to a large extent, the higher probability contours (e.g., 90%) were much larger for the larger volume releases (Table 4-1). At EL 1157, annual stochastic 90% probability footprints of socio-economic threshold exceedance for surface and water column oil increased by 182% and 145%, respectively, from the 30-day to the 120-day release. Similarly, at EL 1158,

annual stochastic 90% probability footprints of socio-economic threshold exceedance for surface and water column oil increased by 176% and 132%, respectively. At both sites, nearly all expansion of footprints for long releases occurred to the east, northeast, and southeast of the release locations with very little expansion of lower probability footprints to the west. In other words, the longer spill duration mainly expanded probability footprints meridionally within the high probability areas east of the release sites. Increased release duration also resulted in more predicted potential for shoreline oiling above the 1% probability of socio-economic threshold exceedance at EL 1157 (2,782 km 30-day vs 4,100 km 120-day) and EL 1158 (2,637 km 30-day vs. 3,944 km 120-day) (Table 4-2). In addition, there were predicted increases in the overall probability of shoreline oiling for the 120-day releases (Table 4-3).

The 3,200 L diesel batch spills modelled from a near-shore location 12 km east of St. John's along a potential supply vessel route were predicted to result in a maximum of 68 km^2 of surface oil exposure above the socio-economic threshold (0.04 µm) and no exposure above the ecological threshold (10 µm) (Table 4-1; Figure 4-61 through Figure 4-66). The largest quantity of surface oil exposure above the socio-economic threshold occurred in the summer season due to calm winds and few waves, resulting in little entrainment and oil remaining on the surface (Table 4-1). The predicted length of shoreline susceptible to contamination above the socio-economic threshold ranged from 32-53 km depending on season with a likelihood of 4-17% (Table 4-2 and Table 4-3; Figure 4-67 through Figure 4-72). There was no shoreline contamination predicted above the ecological threshold for the marine diesel releases. The predicted minimum time to shoreline oil contamination in both the summer and winter seasons was approximately 1 day (Table 4-3; Figure 4-67 through Figure 4-72).

As stated previously, stochastic figures do not imply that the entire contoured area would be covered with oil in the event of a single release, nor do they provide any information on the quantity of oil in each area. Furthermore, the largest-area threshold exceedance footprints from the annual results are not the expected exposure from any single release of oil, but rather areas where there is >1% probability that exposure above the corresponding socio-economic or ecological threshold could occur, based on the combination of either 172 (annual), 93 (summer), or 79 (winter) individual releases analyzed together.

Table 4-1. Summary of threshold exceedances predicted for surface and water column exposure within the modelled domain are provided by season. Predicted areas (km²) are provided for the >1%, 10%, or 90% likelihood of exposure to oil contours.

Stochastic Scenario Parameters				Areas Exceeding Socio-Economic Threshold (km²)			Areas Exceeding Ecological Threshold (km²)		
Component	**Spill Location**	**Release Scenario**	**Probability Contour or Bin***	**Annual**	**Winter (ice cover)**	**Summer (ice-free)**	**Annual**	**Winter (ice cover)**	**Summer (ice-free)**
Surface Oil	EL 1157	30-day release	1%	3,499,000	3,540,000	3,342,000	3,389,000	3,454,000	3,015,000
			10%	2,733,000	2,895,000	2,603,000	1,709,000	1,832,000	1,553,000
			90%	664,100	586,600	746,500	74,790	72,480	103,200
		120-day release	1%	3,547,000	3,580,000	3,546,000	3,372,000	3,421,000	3,248,000
			10%	3,048,000	3,148,000	2,895,000	2,433,000	2,578,000	2,219,000
			90%	1,209,000	1,244,000	1,245,000	510,900	527,300	526,300
	EL 1158	30-day release	1%	3,518,000	3,548,000	3,444,000	3,296,000	3,404,000	3,031,000
			10%	2,782,000	2,930,000	2,650,000	1,711,000	1,834,000	1,626,000
			90%	741,200	645,800	856,000	87,130	94,400	91,100
		120-day release	1%	3,584,000	3,646,000	3,636,000	3,402,000	3,441,000	3,352,000
			10%	3,053,000	3,155,000	2,949,000	2,439,000	2,637,000	2,235,000
			90%	1,310,000	1,310,000	1,400,000	556,500	557,100	583,000
	Vessel Route Location	Instantaneous release	1%	27	31	68	-	-	-
			10%	6	6	5	-	-	-
			90%	<1	<1	<1	-	-	-
Water Column Dissolved Hydrocarbons	EL 1157	30-day release	1%	2,903,000	3,060,000	2,741,000	Ecological threshold is the same value as the socio-economic threshold		
			10%	2,091,000	2,075,000	1,984,000			
			90%	697,200	495,700	595,000			
		120-day release	1%	3,004,000	3,128,000	2,909,000			
			10%	2,271,000	2,290,000	2,125,000			
			90%	1,017,000	799,800	964,000			
	EL 1158	30-day release	1%	2,970,000	3,101,000	2,850,000			
			10%	2,169,000	2,114,000	2,055,000			
			90%	738,000	537,400	605,900			
		120-day release	1%	2,958,000	3,136,000	3,000,000			
			10%	2,227,000	2,333,000	2,174,000			
			90%	978,700	895,700	1,085,000			
	Vessel Route Location	Instantaneous release	1%	-	-	-	-	-	-
			10%	-	-	-	-	-	-
			90%	-	-	-	-	-	-

*Bins are based on stochastic probabilities; for example, 3,733,000 km² of the ocean surface is predicted to exceed the 0.04 µm surface oil threshold in 90% of the 172 modelled simulations from the 30-day release at EL 1157 over the entire 160-day modelled duration.

Table 4-2. Summary of threshold exceedance information predicted for shoreline oil exposure within the modelled domain are provided by season (annual, winter, summer). The predicted length (km) of shoreline susceptible to exposure by oil is provided at 1-5%, 5-15%, and 15-30% contoured intervals.

Stochastic Scenario Parameters				Lengths Exceeding Socio-Economic Threshold (km)			Lengths Exceeding Ecological Threshold (km)		
Component	Spill Location	Release Scenario	Probability Contour or Bin*	Annual	Winter (ice cover)	Summer (ice-free)	Annual	Winter (ice cover)	Summer (ice-free)
Shoreline Oil	EL 1157	30-day release	1 - 5%	2,629	1,943	466	2,626	1,941	463
			5 - 15%	154	1,025	15	150	1,021	15
			15 - 30%	-	-	-	-	-	-
			All Probabilities	2,782	2,968	480	2,776	2,962	478
		120-day release	1 - 5%	2,556	1,574	1,330	2,255	1,546	1,337
			5 - 15%	1,465	1,599	404	1,426	1,587	401
			15 - 30%	79	771	-	81	794	-
			All Probabilities	4,100	3,933	1,734	3,762	3,927	1,738
	EL 1158	30-day release	1 - 5%	2,494	1,915	498	1,937	1,424	498
			5 - 15%	143	942	13	100	839	13
			15 - 30%	-	-	-	-	-	-
			All Probabilities	2,637	2,857	510	2,037	2,263	510
		120-day release	1 - 5%	2,537	1,533	1,200	2,244	1,053	562
			5 - 15%	794	1,619	427	1,296	1,606	429
			15 - 30%	68	653	15	66	641	15
			All Probabilities	3,944	3,805	1,642	3,606	3,300	1,006
	Vessel Route Location	Instantaneous release	1 - 5%	34	23	21	-	-	-
			5 - 15%	19	9	28	-	-	-
			15 - 30%	-	-	4	-	-	-
			All Probabilities	53	32	53	-	-	-

Table 4-3. Shoreline contamination probabilities and minimum time for oil exposure for all shorelines.

All Shorelines							
Threshold	**Spill Location**	**Scenario**	**Scenario Timeframe**	**Probability of Shoreline Oil Contamination (%)**		**Time to Shore (days)**	
				Average	**Maximum**	**Minimum**	**Maximum**
Oil exposure exceeding 1 g/m^2 for all shorelines.	EL 1157	30-day release	Annual	3	9	7	137
			Winter	5	15	7	158
			Summer	4	8	22	157
		120-day release	Annual	6	20	7	147
			Winter	9	28	7	160
			Summer	3	14	22	160
	EL 1158	30-day release	Annual	3	9	7	135
			Winter	5	15	7	156
			Summer	3	8	14	157
		120-day release	Annual	5	21	7	148
			Winter	8	27	7	159
			Summer	4	18	27	160
	Vessel Route Location	Instantaneous release	Annual	5	14	1	17
			Winter	4	11	1	29
			Summer	7	17	1	17
Oil exposure exceeding 100 g/m^2 for all shorelines.	EL 1157	30-day release	Annual	3	9	7	137
			Winter	5	15	7	158
			Summer	4	8	22	157
		120-day release	Annual	6	20	7	147
			Winter	9	28	7	160
			Summer	3	14	22	160
	EL 1158	30-day release	Annual	3	9	7	135
			Winter	5	15	7	156
			Summer	3	8	14	157
		120-day release	Annual	5	21	7	148
			Winter	8	27	7	159
			Summer	4	18	27	160
	Vessel Route Location	Instantaneous release	Annual	-	-	-	-
			Winter	-	-	-	-
			Summer	-	-	-	-

4.2 Deterministic Analysis Results

Individual trajectories of interest were selected from the stochastic ensemble of results for the deterministic analysis. The deterministic trajectory and fate simulations provided an estimate of the transport of oil through the environment as well as its physical and chemical behavior for the specific set of modelled environmental conditions. Representative 95th percentile credible "worst-case" trajectories for surface oil exposure, water column contamination, and contact with shoreline were identified from the stochastic subsurface scenarios for each site modelled and release duration (i.e., 30 vs 120 days). These highly conservative individual cases were selected based upon the size of the surface oil footprint, volume of oil in the water column, and the length of shoreline contacted with oil. Four individual trajectories representative of the 95th percentile for surface, water column, and shoreline exposure, as well as the 50th percentile for surface oil exposure, for the 3,200 L marine diesel batch spill are presented below. This resulted in a total of sixteen individual trajectories (twelve associated with subsurface blowouts of BdN and four associated with the marine diesel batch spill) (Table 2-5).

The following sections (Sections 4.2.1 through 4.2.4) contain figures corresponding to each identified representative case and tables summarizing the areas exceeding specified thresholds. During modelling, components of oil were tracked as floating surface oil, entrained droplets of whole oil, dissolved hydrocarbon constituents, stranded oil on shorelines and sediments, evaporated, degraded, and left the model domain. The figures provided depict the cumulative footprint of all oil predicted to be within a region over the entire modelled duration. Therefore, the depicted footprints are much larger than the amount of oil that would be present in a region at any given time following the release of oil. This concept is illustrated in Figure 4-73 which portrays predicted surface oil thickness at five specific time steps or "snapshots" in time (days 2, 10, 50, 100, and 160) for the 95th percentile surface oil thickness case for the 120-day release at EL 1157. Note the patchy and discontinuous nature of the predicted footprint as the released oil dispersed and thinned over time. Figure 4-74 portrays the cumulative footprint for the exact same simulation. The area covered is much larger, depicting the maximum surface oil thickness that was predicted to occur at each location over the entire modelled time period. The remaining figures in this report will depict cumulative footprints as opposed to "snapshots" at given time steps to provide conservative estimates of potentially affected areas.

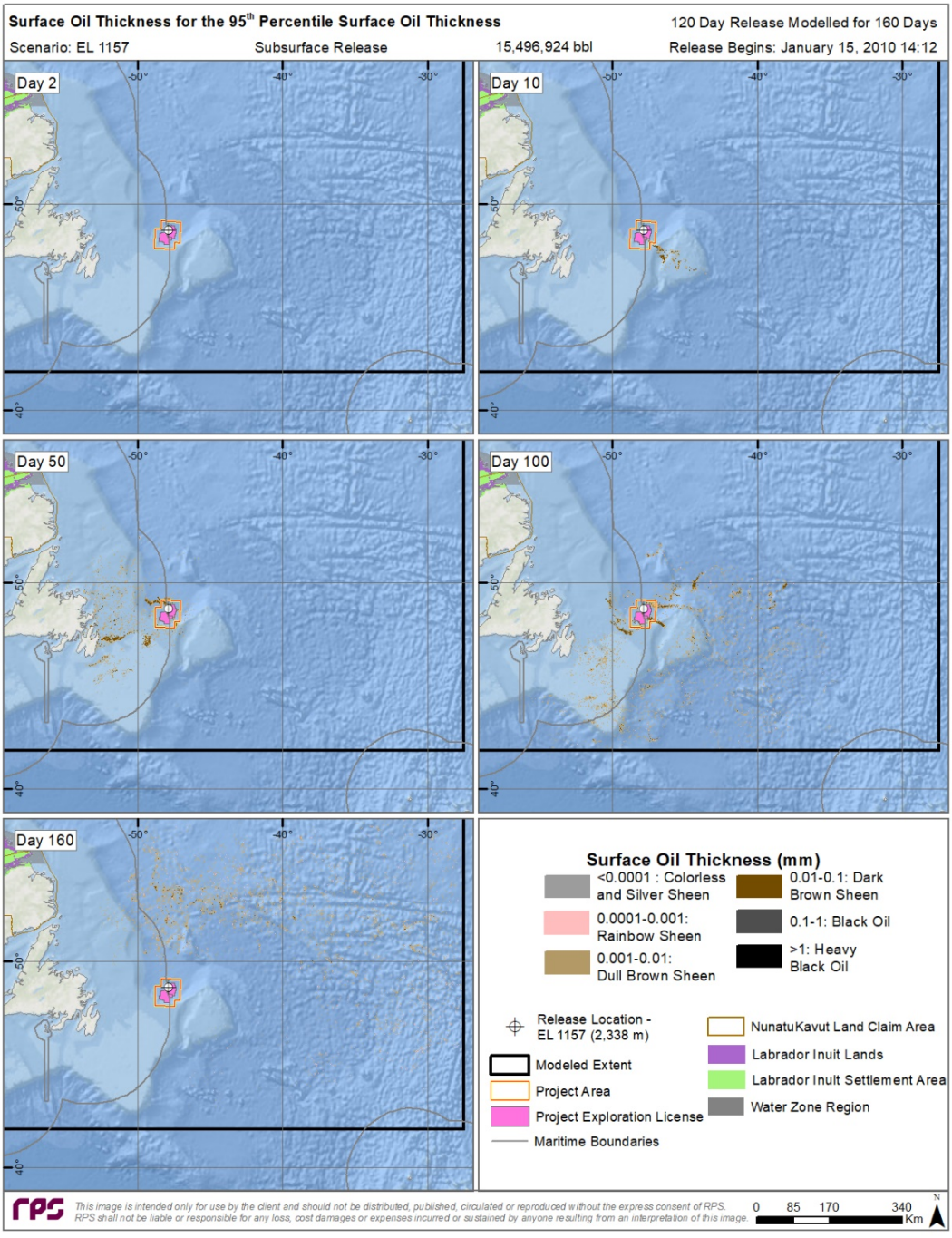

Figure 4-73. Predicted surface oil thickness for the 95th percentile surface oil exposure case for the 120-day release at EL 1157 at days 2, 10, 50, 100, and 160 to illustrate the variation in size of the surface oil footprint over the course of the model duration.

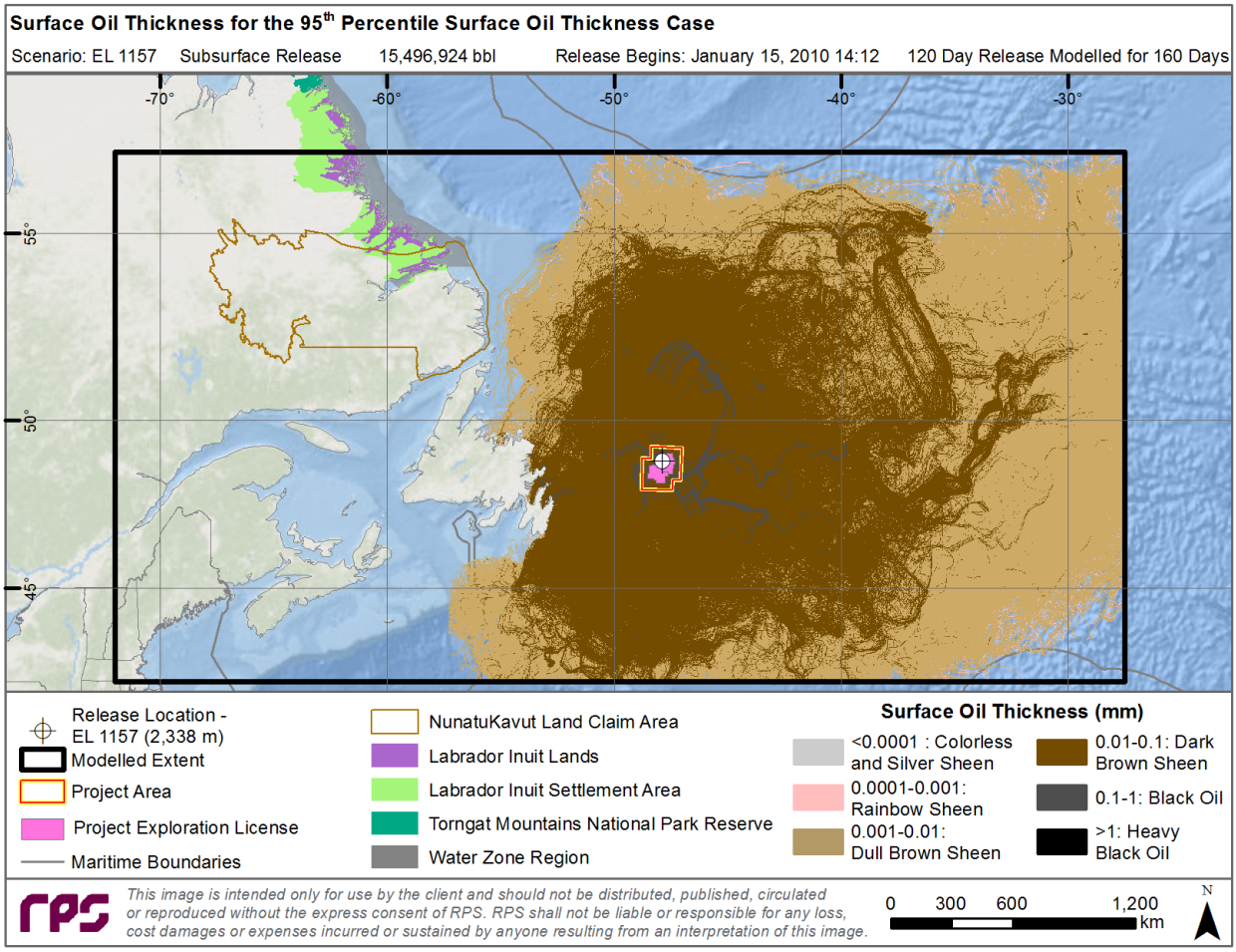

Figure 4-74. Maximum cumulative surface oil thickness for the 95th percentile surface oil exposure case for the 120-day release at EL 1157 to illustrate the much larger size of the cumulative surface oil footprint over the entire model duration, compared to the size of the surface oil footprint on any one day or time step (Figure 4-73).

The types of figures that were used to summarize modelling results are provided, along with brief descriptions of the information that they portray. Note that the thicknesses and concentrations for the modelled blowouts were calculated on a grid with a resolution (i.e., grid cell size) of 1,800 m by 2,500 m, which is equivalent to 0.02 degrees by 0.02 degrees. For concentration grids, vertical binning included 50 m increments over the entire water column.

1. **Mass Balance Plots**: Illustrate the predicted weathering and fate of oil for a specific run over the entire model duration as a fraction of the oil released up to that point. Components of the oil

tracked over time include the amount of oil on the sea surface, the total entrained hydrocarbons in the water column, the amount of oil in contact with the shore or sediments, the amount of oil evaporated into the atmosphere, and the amount of oil degraded (accounts for both photo-oxidation and biodegradation).

2. **Surface Oil Thickness Maps:** Depict the predicted footprint of maximum floating surface oil and the associated oil thicknesses (mm) over all modelled time steps for an individual release simulation. The minimum thickness of surface oil > 0.04 µm is displayed (cumulative over all modelled time steps). Note that floating oil mass is calculated as an average over grid cells, thus in reality, the oil would be patchy and discontinuous and could be thinner or thicker within particular areas of a single grid cell.
3. **Water Column Dissolved Hydrocarbon Concentration (DHC) Maps**: Depict the predicted footprint of the vertical maximum water column concentration of dissolved hydrocarbons over all modelled time steps for an individual release simulation. Dissolved hydrocarbons are the constituents of the oil with the greatest potential to affect water column biota. Only concentrations above 1 µg/L for the representative cases are displayed (Table 2-2).
4. **Water Column Total Hydrocarbon Concentration (THC) Maps:** Depict the predicted footprint of the vertical maximum water column concentration of total hydrocarbons over all modelled time steps for an individual release simulation. Only concentrations above 1 µg/L for the representative cases are displayed (Table 2-2).
5. **Shoreline and Sediment Total Hydrocarbon Concentration (THC) Maps:** Depict the predicted total mass of oil (per unit area as g/m^2) deposited onto the shoreline and on sediments.

Note that for the diesel batch spill scenarios, only mass balance graphs and surface oil thickness maps are provided.

4.2.1 Surface Oil Exposure Cases

Results for the identified 95th percentile (i.e., credible "worst-case") surface oil exposure cases for the 30- and 120-day releases at EL 1157 and 1158 are provided. Note that the modelled release dates for the representative scenarios at each site differed (Table 2-5). Each of the trajectories in the stochastic analysis represented a different start date and associated environmental conditions (e.g., wind and current speed and direction), which resulted in different predicted outcomes. For example, both the 30- and 120-day cases at EL 1157 were representative of winter cases (i.e., start dates in November and January), while the EL 1158 cases were representative of both summer (30-day) and winter (120-day).

Overall predicted surface area exposed to oil > 0.001 mm (dull brown sheens to heavy black oil) was similar between sites and release durations for the selected deterministic cases. Larger surface areas were predicted for the 120-day releases at both sites compared to the 30-day releases (Figure 4-76 and Figure 4-81; Table 4-4). Heavy black oil (> 1 mm) was not predicted in any of the selected deterministic cases due to the natural dispersion as oil rose from the relatively deep release locations and the light and low viscosity BdN crude oil,

which tended to spread rapidly. It is important to note that these scenarios were identified as some of the largest predicted cumulative surface oil footprints (95th percentile) out of all (172) of the 160-day simulations.

Water column concentrations (THC and DHC) were predicted to be of a similar magnitude between sites. Most of the waters with potential elevation in dissolved hydrocarbon concentrations (> 500 µg/L) were within 200 km of the release sites. This was due to the soluble hydrocarbons entering the water column during the initial ascent of the oil to the surface, the rapid dispersion and degradation within the water column, and the rapid rate of evaporation of the soluble fraction (which is also volatile) at the surface, when compared to the slower rate of dissolution. Elevated concentrations in subsurface hydrocarbon contamination at depth were not predicted to cross into shallower waters over the shelf, as subsurface currents follow pressure surfaces (isopycnals), which circulated around the Flemish Cap and southwest along the shelf break (Figure 4-77 and Figure 4-82). Highest concentrations of total hydrocarbons (>15,000 µg/L) were predicted to occur at the release locations with highest levels of contamination to the east and southeast depending on the wind and currents at the time of release (Figure 4-78 and Figure 4-83).

At EL 1157, the 95th percentile surface oil exposure case was predicted to result in shoreline oiling of generally 100-500 g/m^2 (exceeding both the socio-economic and ecological thresholds) along approximately 216 and 1,668 km of Newfoundland and Avalon peninsula coastline for the 30- and 120-day releases, respectively (Table 4-4 and Figure 4-79). At EL 1158, the representative surface oil exposure scenarios are predicted to contaminate roughly 1,000 km of Newfoundland shoreline at concentrations exceeding both the socio-economic and ecological thresholds of 1 and 100 g/m^2. (Table 4-4 and Figure 4-84). Sediment oil contamination was predicted for each representative scenario at both release locations in concentrations generally <0.1 g/m^2, with localized patches of contamination up to 0.5 g/m^2 (Figure 4-79 and Figure 4-84).

At the end of the 160-day simulations of the 95th percentile surface oil exposure for 30- and 120-day releases at the EL 1157 site, large percentages of the oil evaporated (~42-46%) and degraded (33-43%), accounting for >77% of each modelled release. The amount of oil predicted to remain on the water surface was <15% with 3% and less within the water column (Table 4-5). Up to 13% of oil (predominantly persistent surface oil) was predicted to be transported outside of the modelled domain. Shoreline contact made up a very small proportion of releases (<1%) and oil transported to the sediment was not a major fate pathway with <0.1% predicted to settle on sediments (Table 4-5). At the EL 1158 site, 42-46% of oil was predicted to evaporate and 31-42% degrade. Less than 15% was predicted to remain floating on the water surface, 3-22% was transported outside the modelled domain, <3% remained within the water column, and <0.1% settled on sediment. Similar to the cases at EL 1157, shoreline contact made up a small percentage of the released oil (<1%) (Table 4-5).

Frequent cycling of wind and calm events were evident in all surface oil exposure cases, as indicated by “see-sawing” between oil on the surface and entrained oil in the water column (Figure 4-75 and Figure 4-80). During calmer more quiescent periods, oil was predicted to rise to the surface forming slicks, while during periods with wind, surface breaking waves were formed, which resulted in surface oil becoming entrained into the water column.

4.2.1.1 Subsurface Blowouts at EL 1157

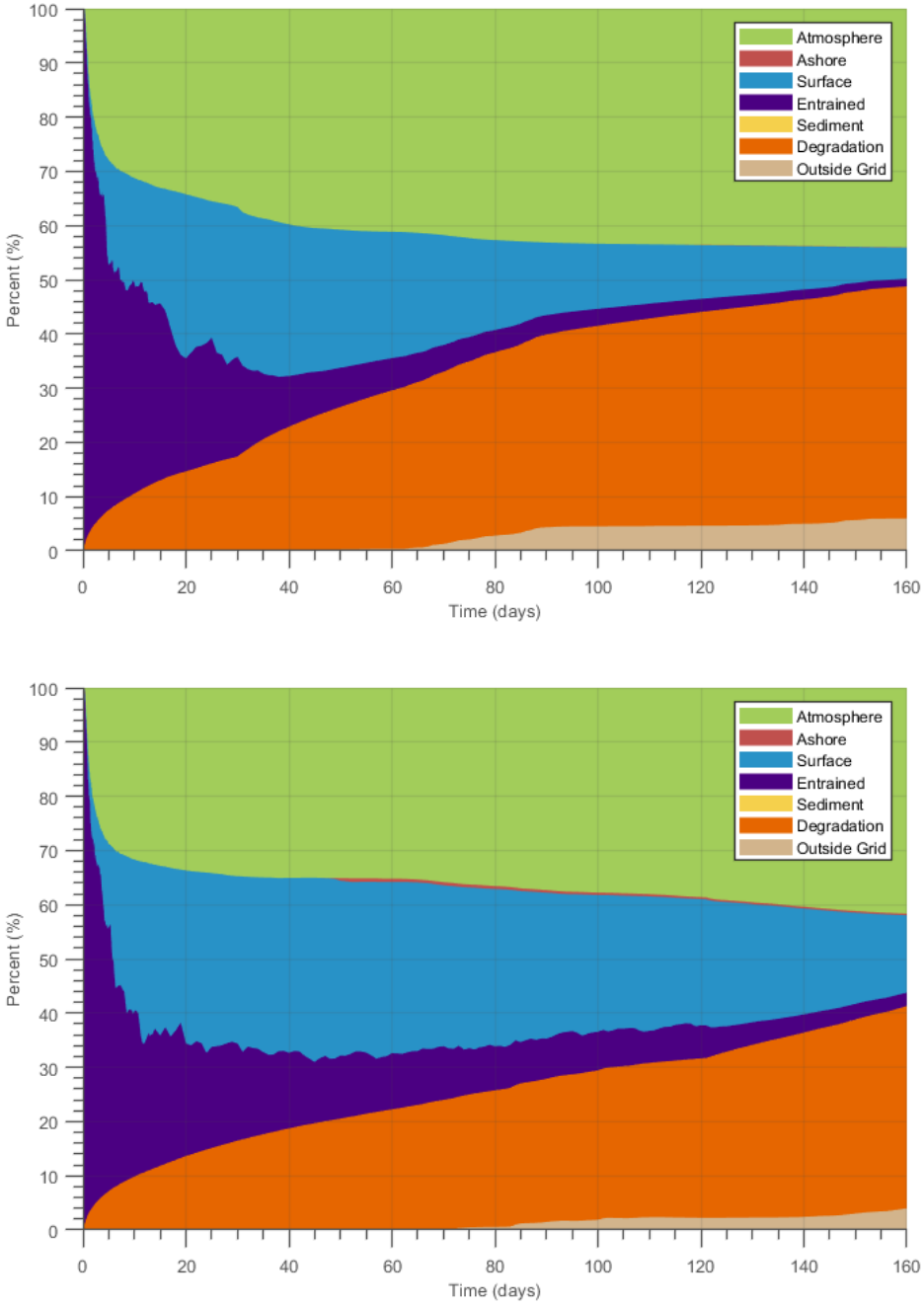

Figure 4-75. Mass balance plots of the 95th percentile surface oil thickness cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

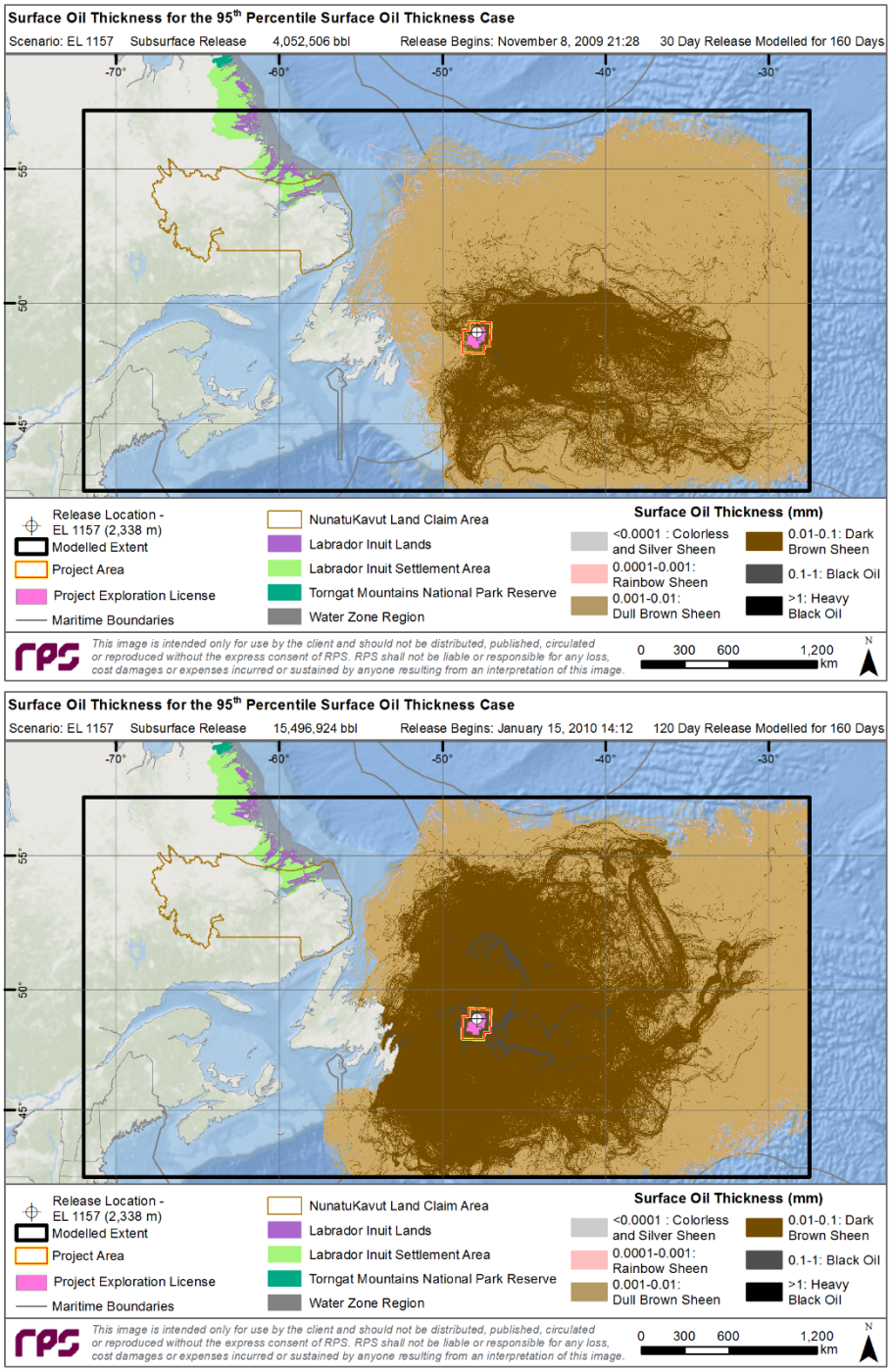

Figure 4-76. Surface oil thickness for the 95th percentile average surface oil thickness cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

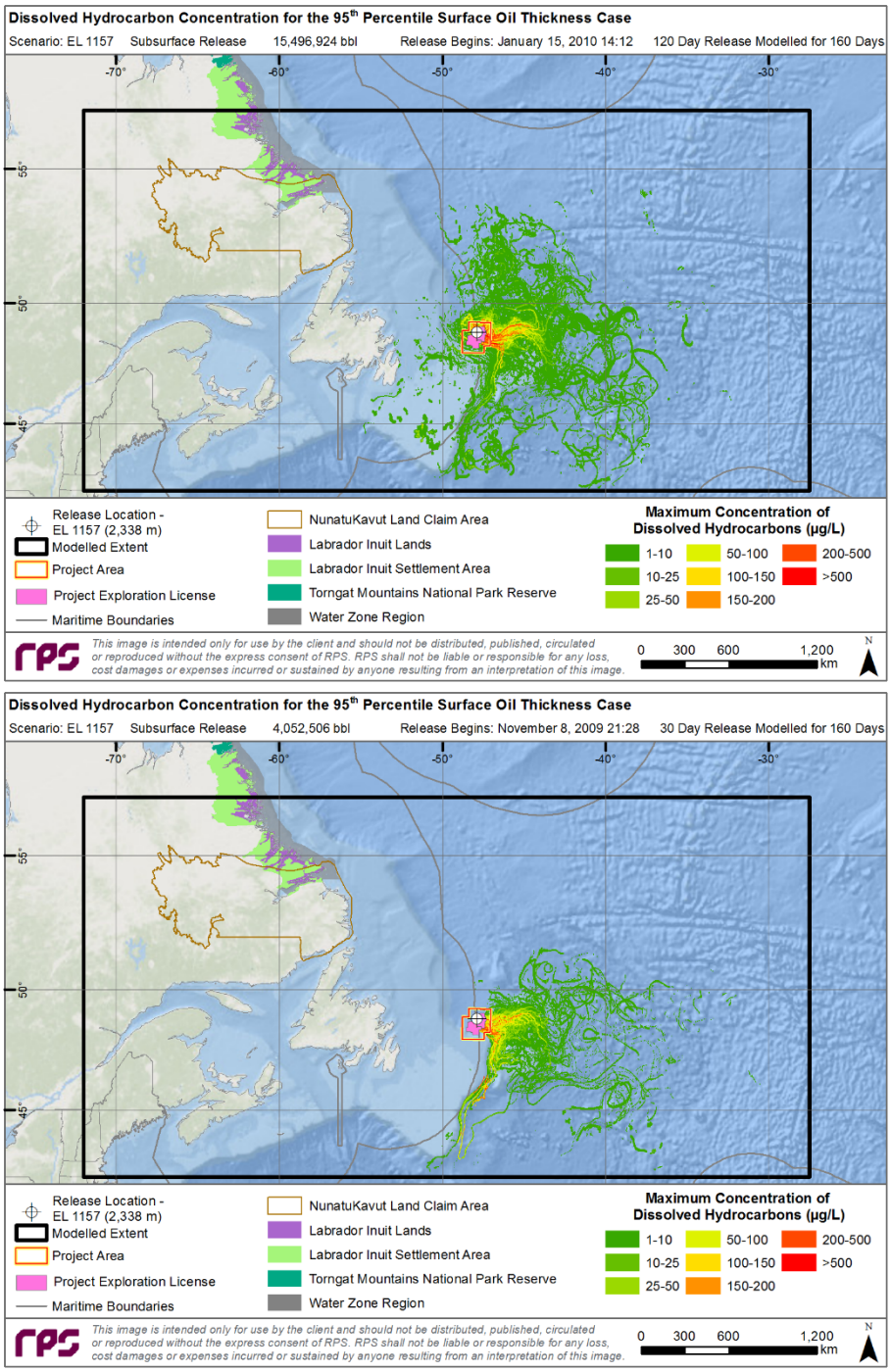

Figure 4-77. Maximum DHC at any depth in the water column for the 95th percentile average surface oil thickness cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

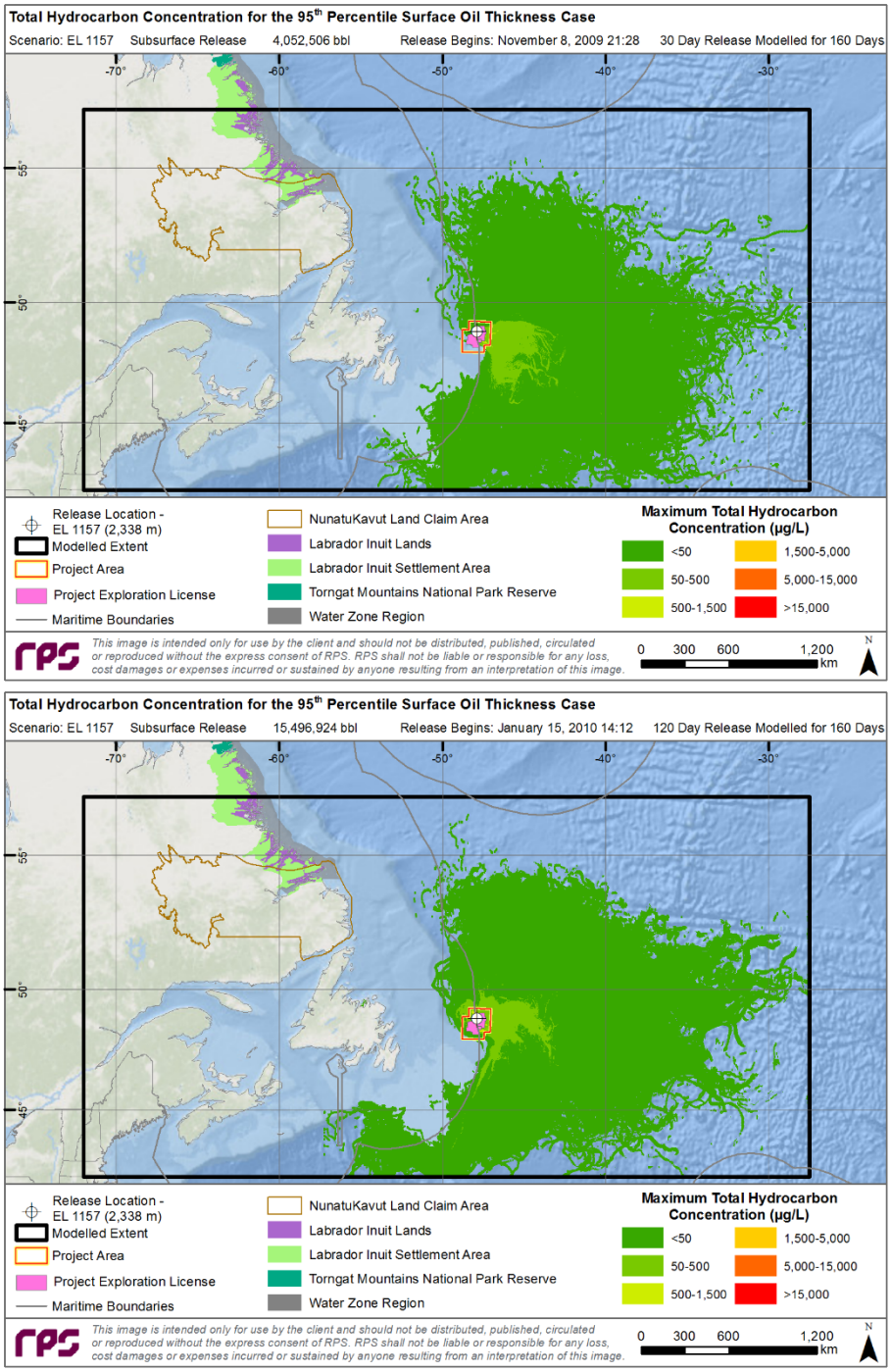

Figure 4-78. Maximum THC at any depth in the water column for the 95th percentile average surface oil thickness cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

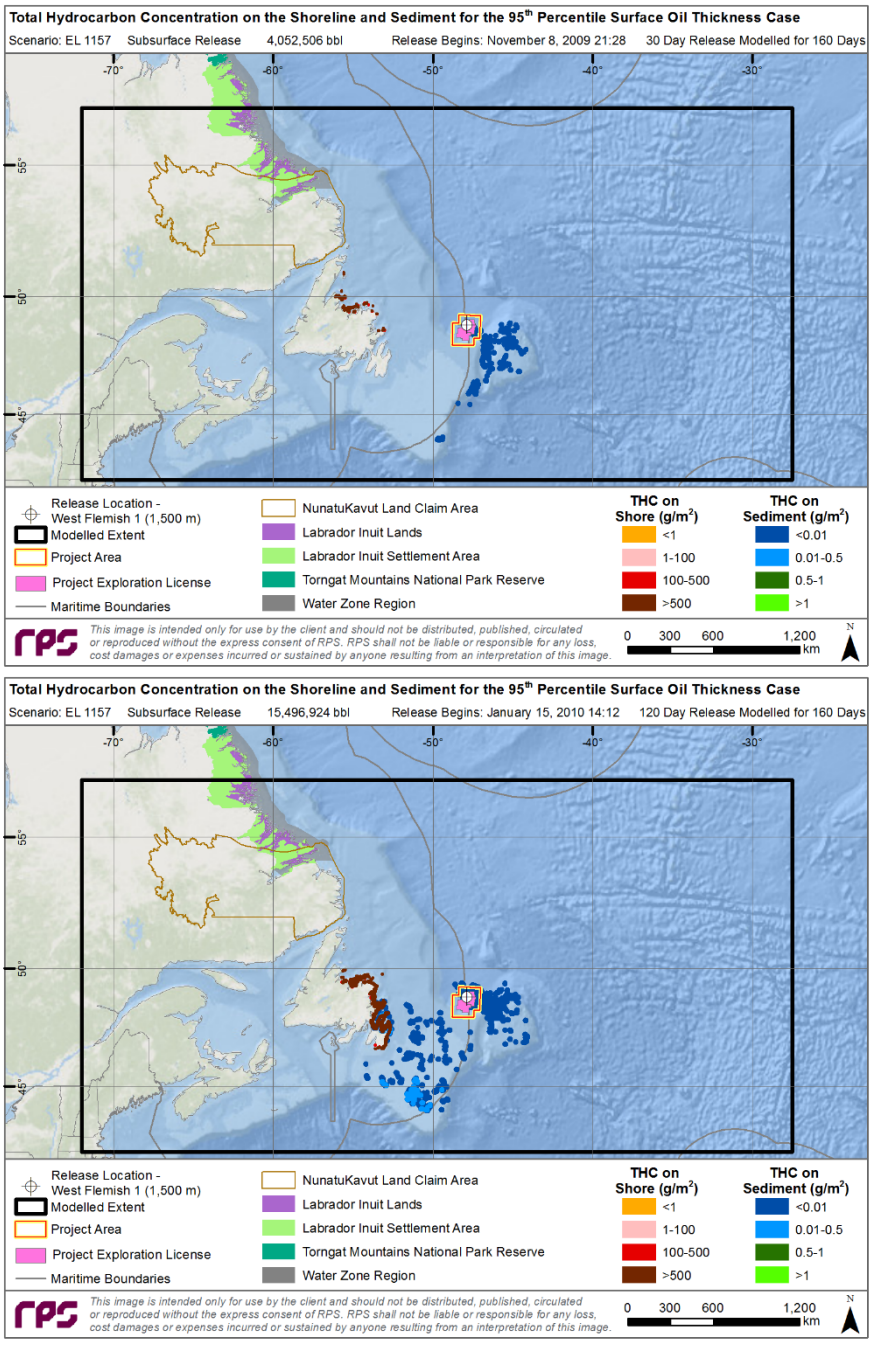

Figure 4-79. THC on the shore and sediment for the 95th percentile average surface oil thickness cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

4.2.1.2 Subsurface Blowouts at EL 1158

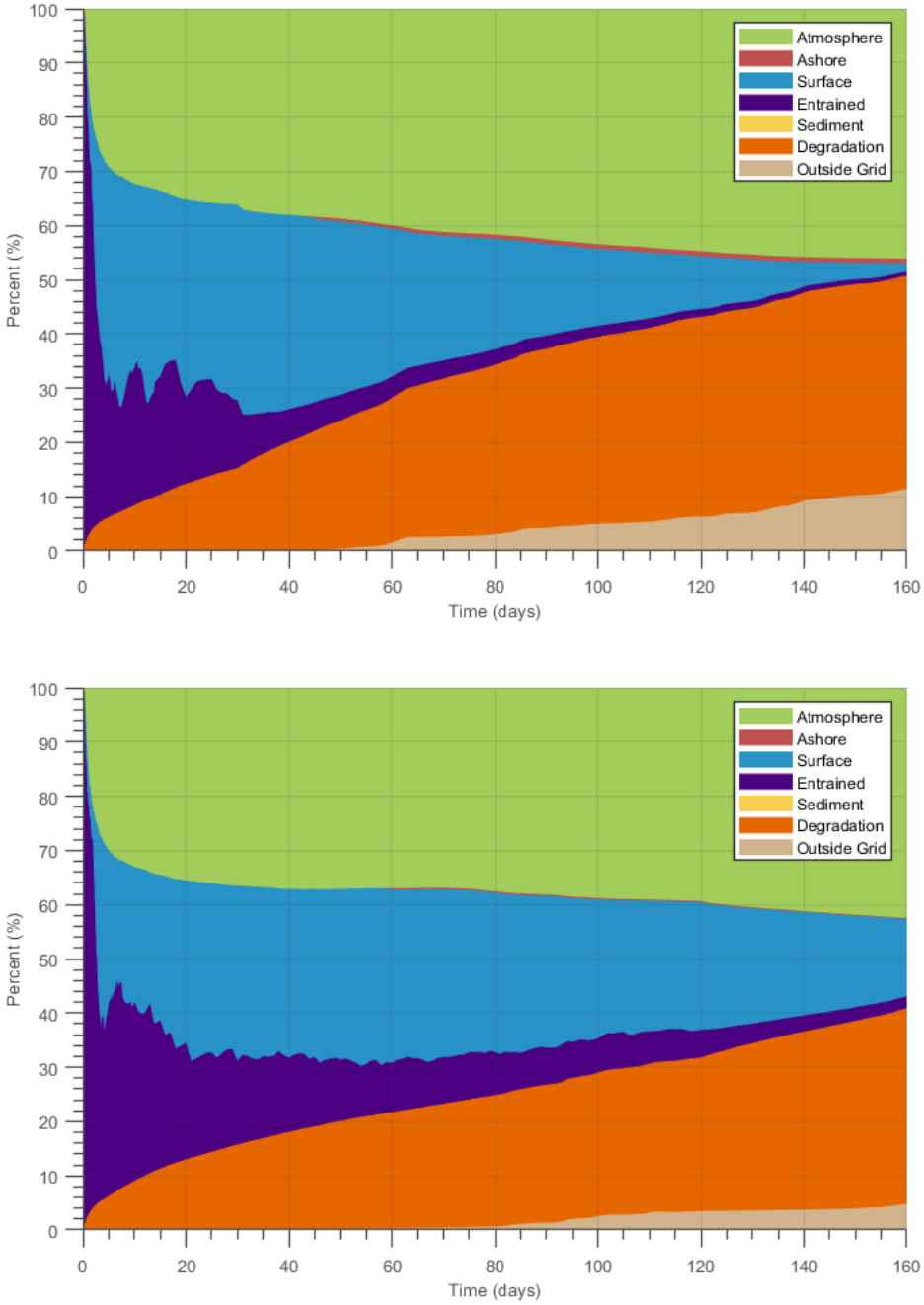

Figure 4-80. Mass balance plots of the 95th percentile surface oil thickness cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

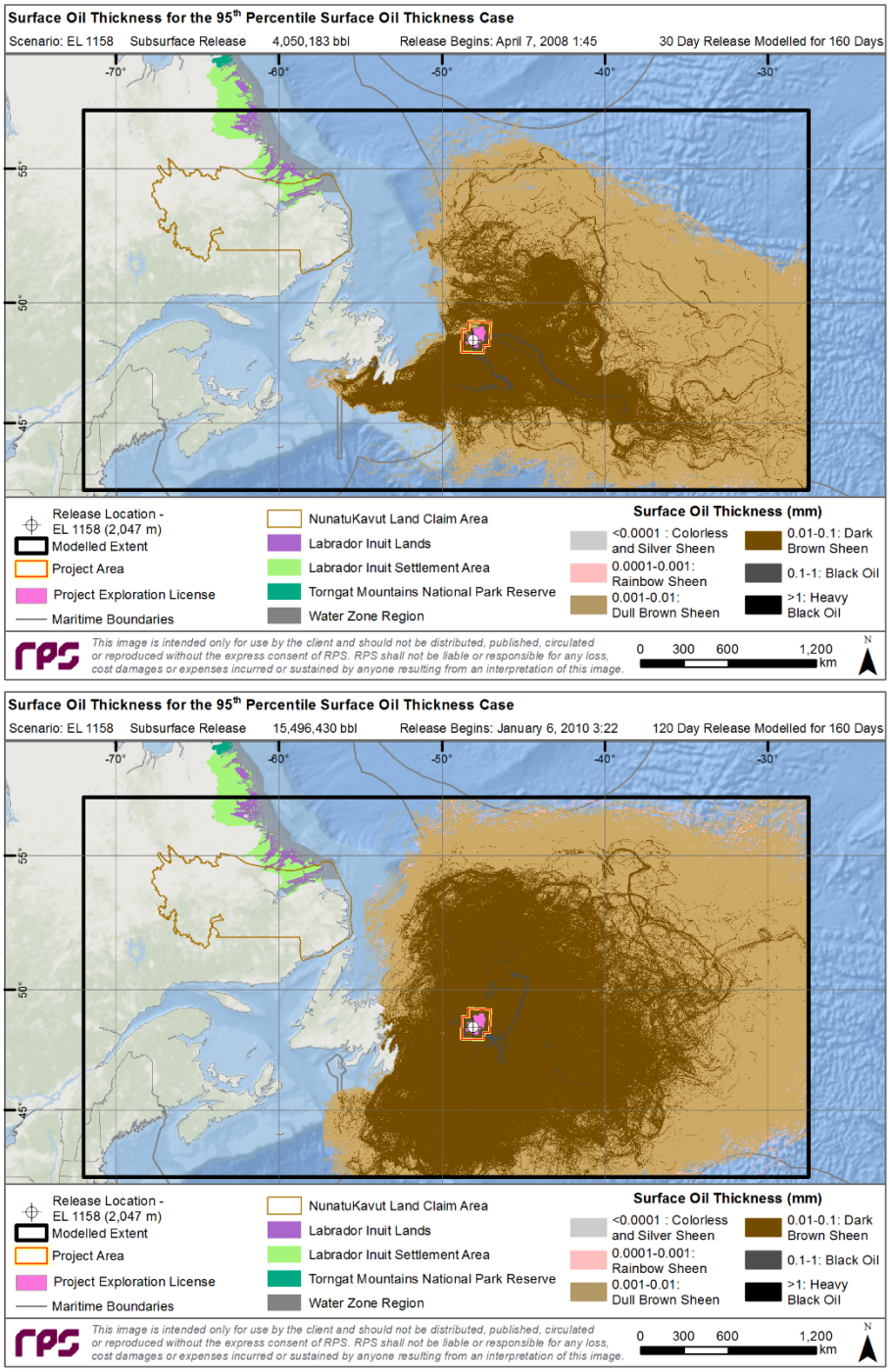

Figure 4-81. Surface oil thickness for the 95th percentile average surface oil thickness cases resulting from 30- (top) and 120-day (bottom) blowouts at the EL 1158.

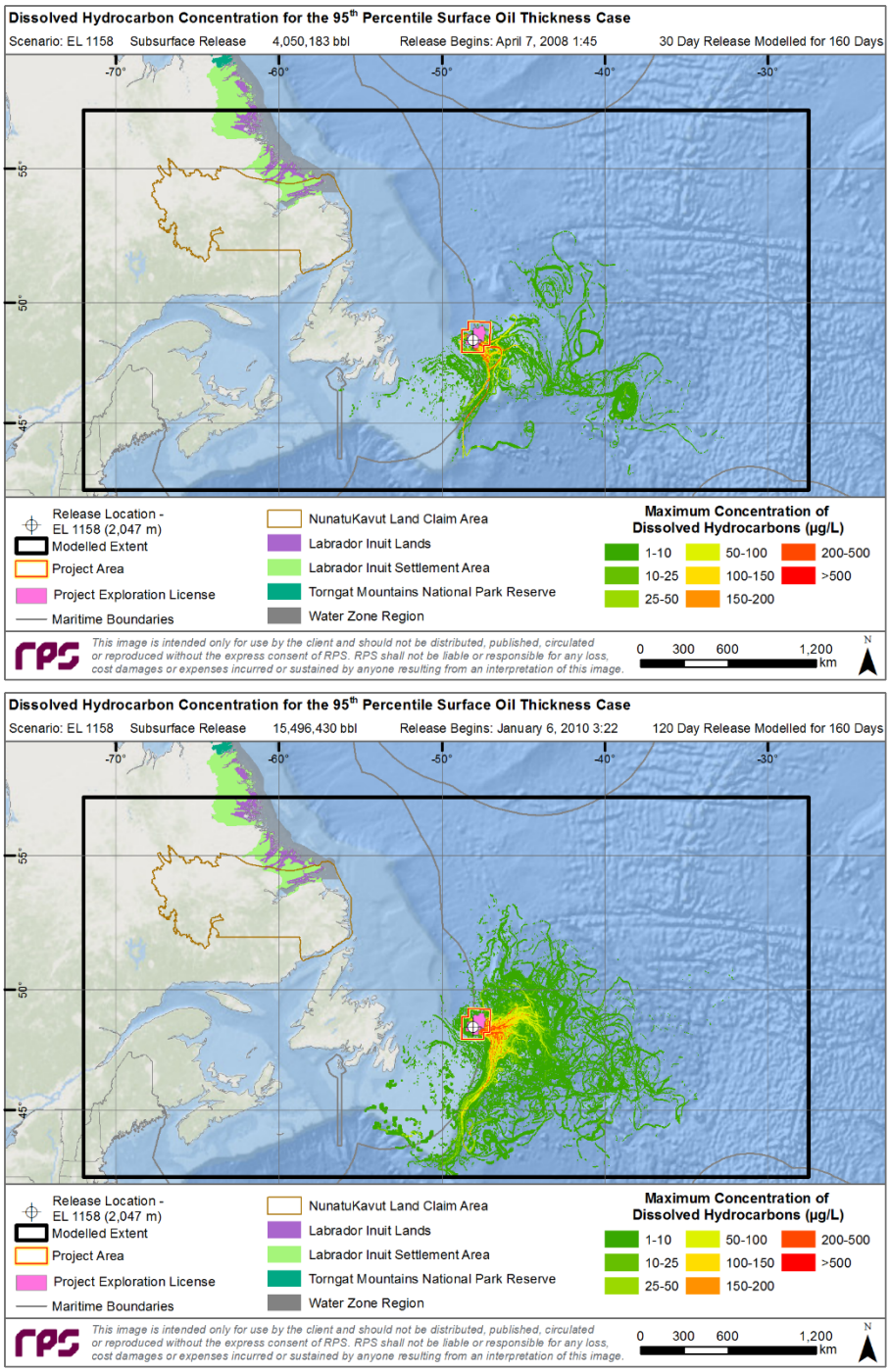

Figure 4-82. Maximum DHC at any depth in the water column for the 95th percentile average surface oil thickness cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

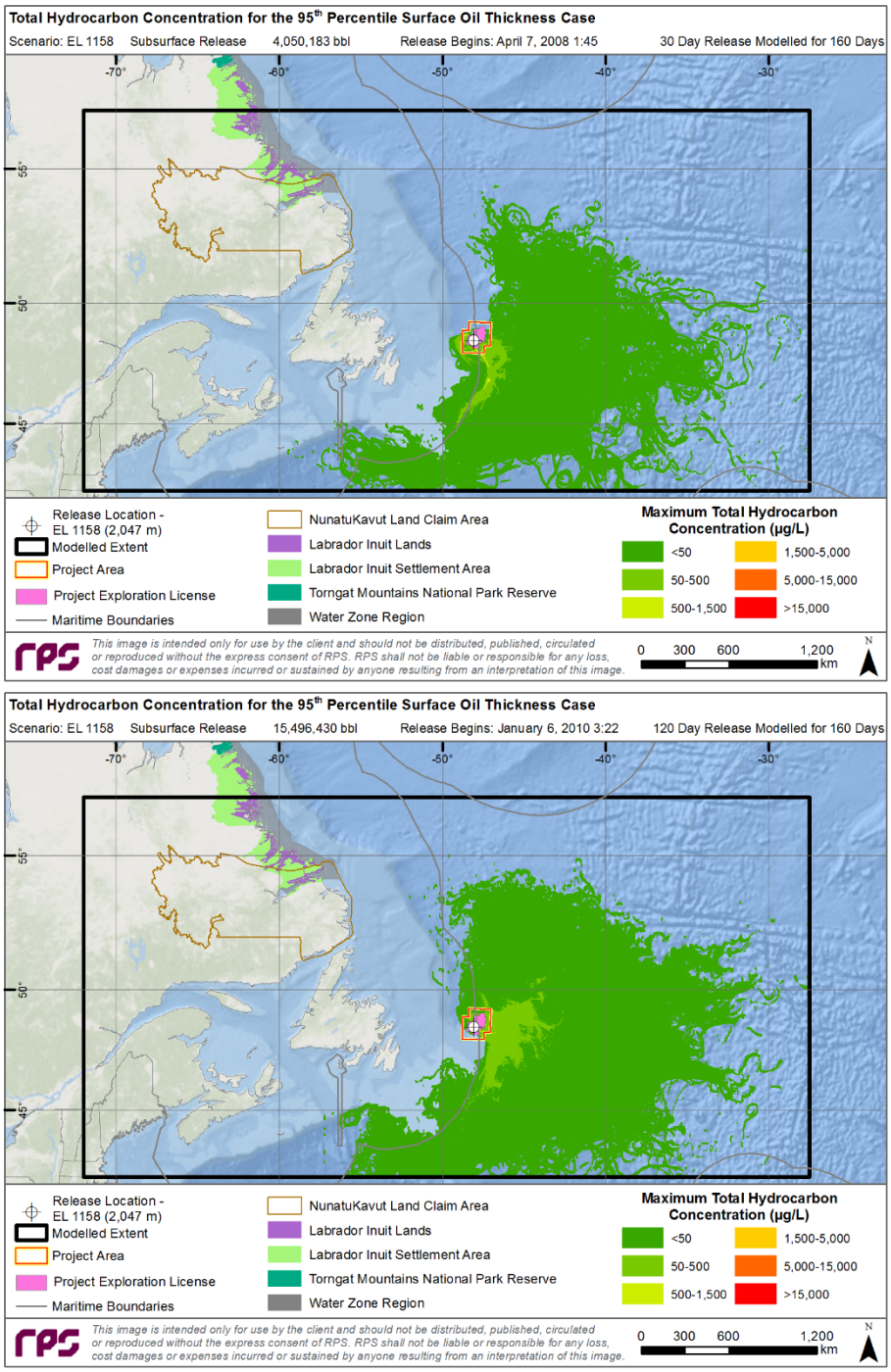

Figure 4-83. Maximum THC at any depth in the water column for the 95th percentile average surface oil thickness cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

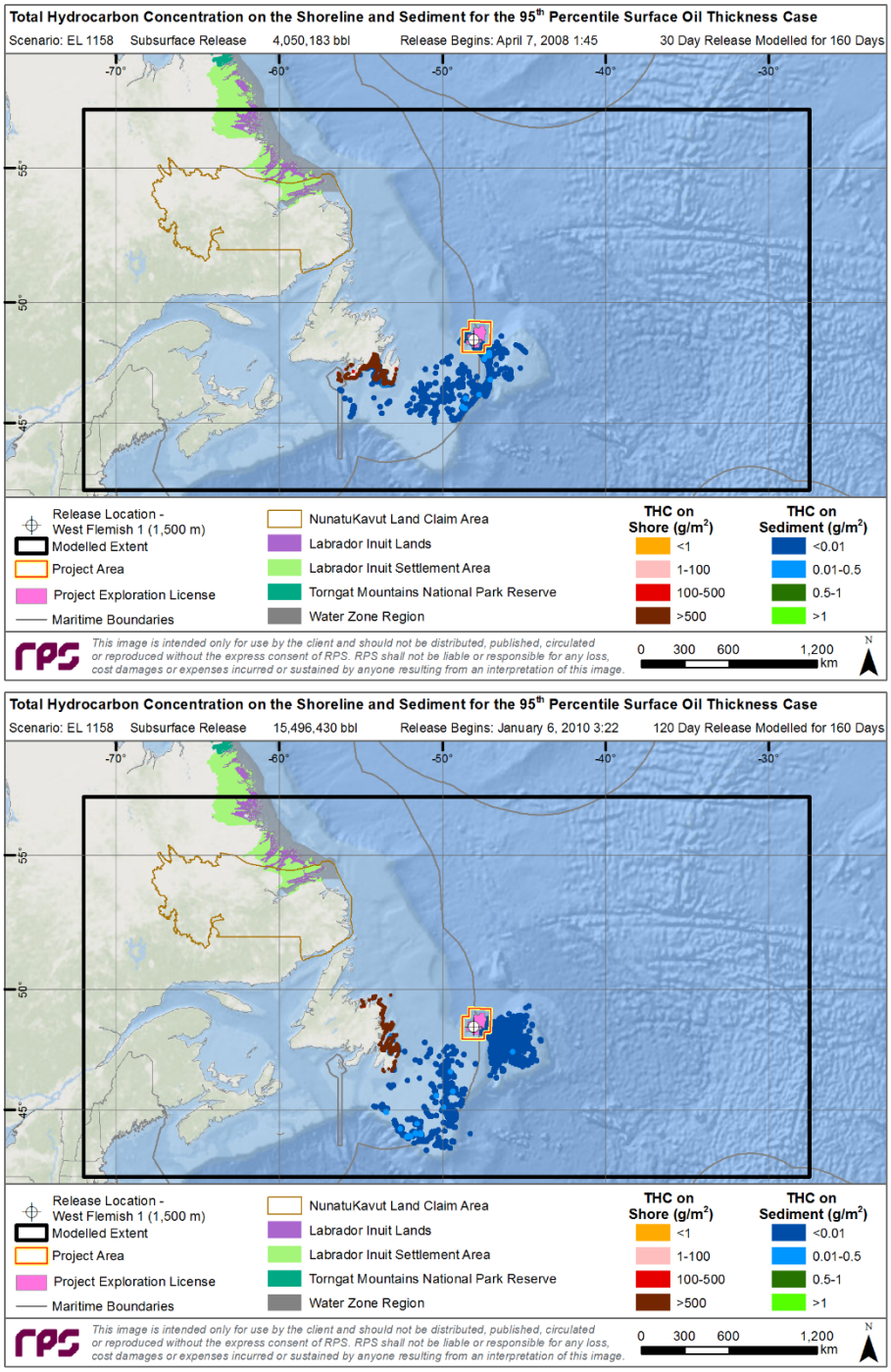

Figure 4-84. THC on the shore and sediment for the 95th percentile average surface oil thickness cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

4.2.2 Water Column Exposure Cases

The results for the identified 95th percentile (i.e., credible "worst-case") water column exposure cases for the short- and long-duration releases at EL 1157 and 1158 are provided in the figures below. Note that the modelled release dates for the representative scenarios at each site differed (Table 2-5). Both the 30- and 120-day cases at EL 1157 were representative of winter with corresponding start dates in October and January. At EL 1158, the cases were also representative of winter with modelled start dates in December (30-day) and September (120-day).

The predicted total surface area and the cumulative footprints of surface area exposed to oil >0.001 mm (dull brown sheens) were generally comparable (i.e., order of magnitude) between sites and release durations for the selected deterministic cases (Table 4-4; Figure 4-86 and Figure 4-91). Due to the larger volume of oil being released, the 120-day releases were also predicted to result in larger areas affected by dark brown sheens (0.01-0.1 mm), when compared to the 30-day releases (Table 4-4; Figure 4-86 and Figure 4-91). Small patchy regions of black oil (0.1 - 1 mm) were predicted all of the selected deterministic scenarios, with discontinuous patches heavy black oil (> 1 mm) predicted for the 120-day release at EL 1157 (Table 4-4).

The high potential for surface oil entering into the water column in these four representative scenarios is the result of high wind speeds in the region, which resulted in surface breaking winds that entrained surface oil into the water column. The formation of persistent emulsions then increased the likelihood that oil would be see-sawing between the surface mixed layer and the surface of the water. Similar to the results from the representative surface oil exposure cases, water column concentrations of THC and DHC were very similar between sites, except for more extensive transport of dissolved hydrocarbons at EL 1158 to the south through the Flemish Pass (Table 4-4; Figure 4-87 and Figure 4-92). Total hydrocarbon concentrations were predicted to be more uniform (low level contamination) than dissolved concentrations. This was due to the rapid dispersion, degradation, and volatilization of soluble constituents, and the rapid transport of surface oil by winds and persistence of the whole oil after it formed emulsions The highest predicted concentrations of total hydrocarbons (up to 5,000 µg/L for the 120-day releases) extended to the east-southeast (Figure 4-88 and Figure 4-93).

The representative cases were predicted to contact shorelines with varying degrees of contamination (Figure 4-89 and Figure 4-94). Between the representative 30- and 120-day releases at both EL 1157 and 1158 between 9 and 4,510 km of shoreline were predicted to be contaminated above the socio-economic threshold (Table 4-4). At EL 1157, both Newfoundland and Labrador shorelines were predicted to be contaminated by oil from the 30-day release, while only northeastern Newfoundland and Avalon peninsula shorelines (Figure 4-89 and Table 4-4). At EL 1158, the 30-day release predicted only small portion of shoreline oil contamination along the northeastern coast of Newfoundland, while the 120-day release resulted in contamination on large stretches of Newfoundland and Labrador shorelines (Figure 4-94 and Table 4-4). Generally, low sediment oil contamination (<0.1 g/m^2) was predicted for the representative runs, with localized patches up to 0.5 g/m^2 predicted from the runs at EL 1158 (Figure 4-89 and Figure 4-94).

At the end of the 160-day simulations for the representative 30- and 120-day releases at the EL 1157 site, large percentages of the oil evaporated (42-45%) and degraded (33-43%), accounting for 77-85% of each modelled release. Up to 11% of oil (predominantly persistent surface oil) was predicted to be transported outside of the modelled domain. The amount of oil predicted to remain on the water surface was up to 9%, with up to 3%

within the water column. Oil transported to the sediment was not a major fate pathway with <0.1% predicted to settle on sediments. Shoreline oil contamination of <3% of the released oil was predicted (Table 4-5). At the EL 1158 site, approximately 43-46% of oil was predicted to evaporate and 36-42% degrade, accounting for 78-88% of each modelled release. The amount of oil predicted to remain on the water surface was between 7% and 9%, <3% remained in the water column, and <0.1% settled on sediment. Shoreline contact was not a major fates pathway with <1% of oil contacting the shoreline. Although <3% of the oil was predicted to remain in the water column at the end of the identified scenarios, these cases were still predicted to experience the highest amount of water column exposure throughout the length of the simulation, and thus resulted in them being the 95th percentile worst-case scenarios (Table 4-5). Frequent cycling of wind and calm events were evident in all water column oil exposure cases, as indicated by “see-sawing” between oil on the surface and entrained oil in the water column (Figure 4-85 and Figure 4-90).

4.2.2.1 Subsurface Blowouts at EL 1157

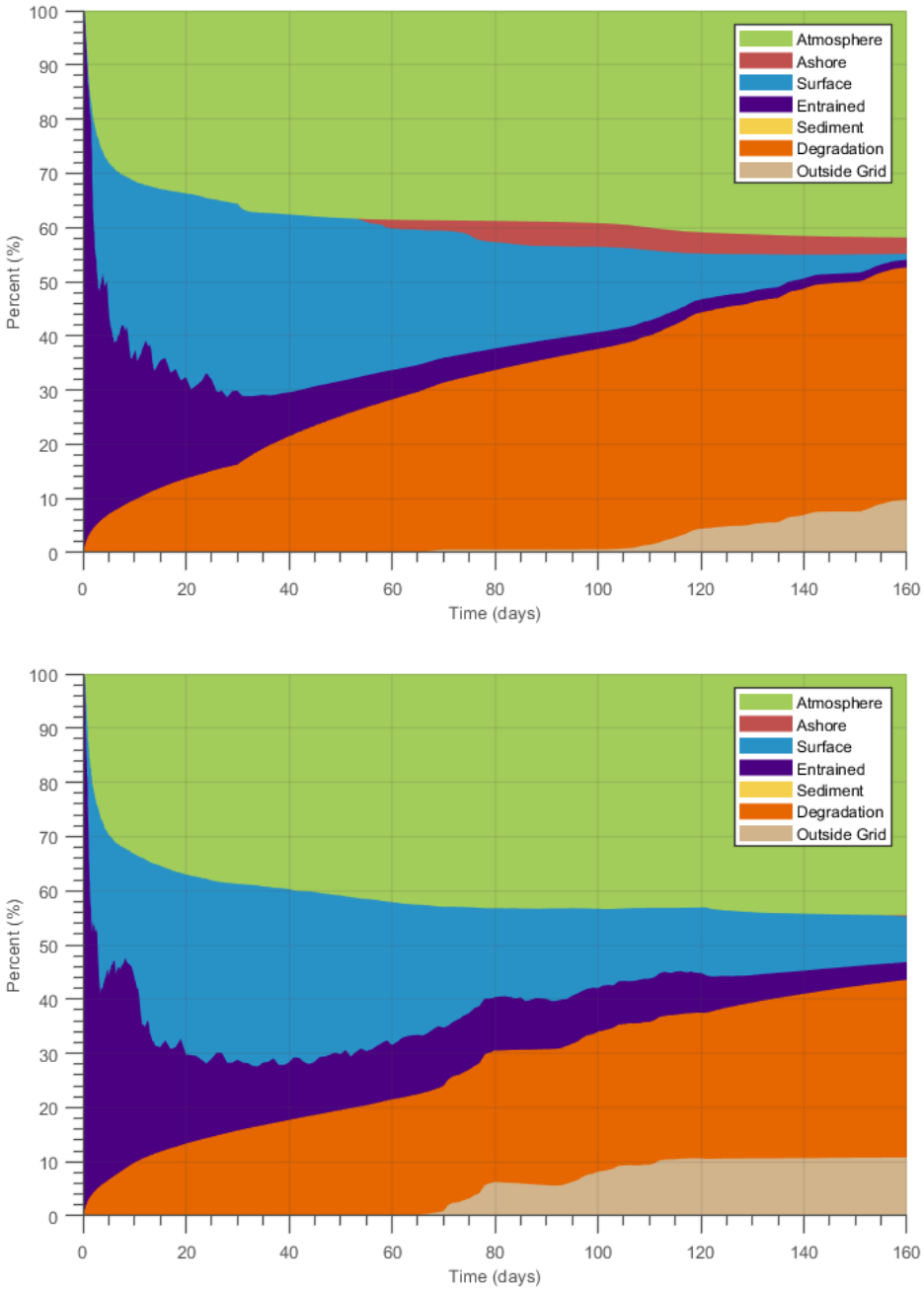

Figure 4-85. Mass balance plots of the 95th percentile water column cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

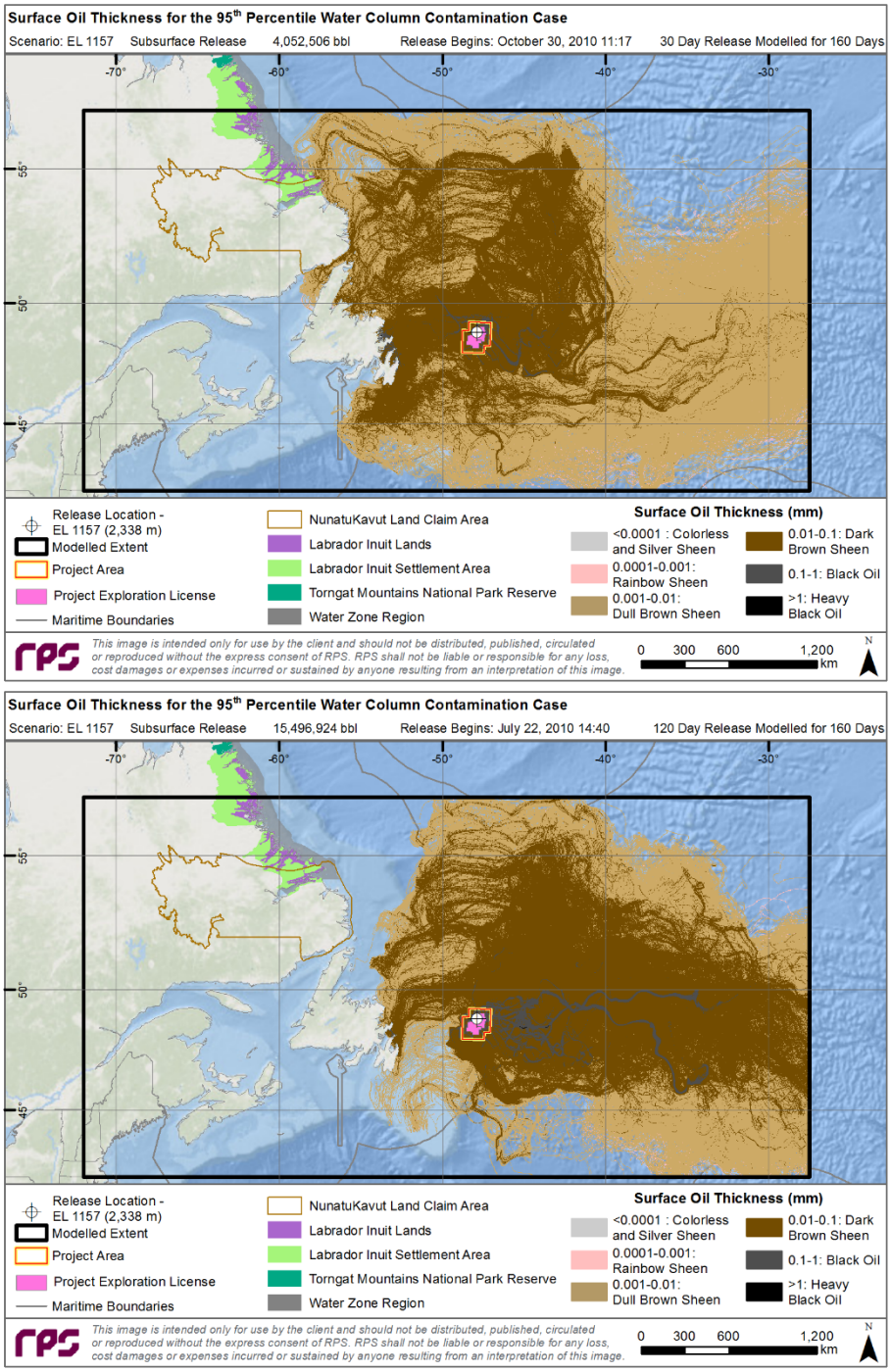

Figure 4-86. Surface oil thickness for the 95th percentile water column cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

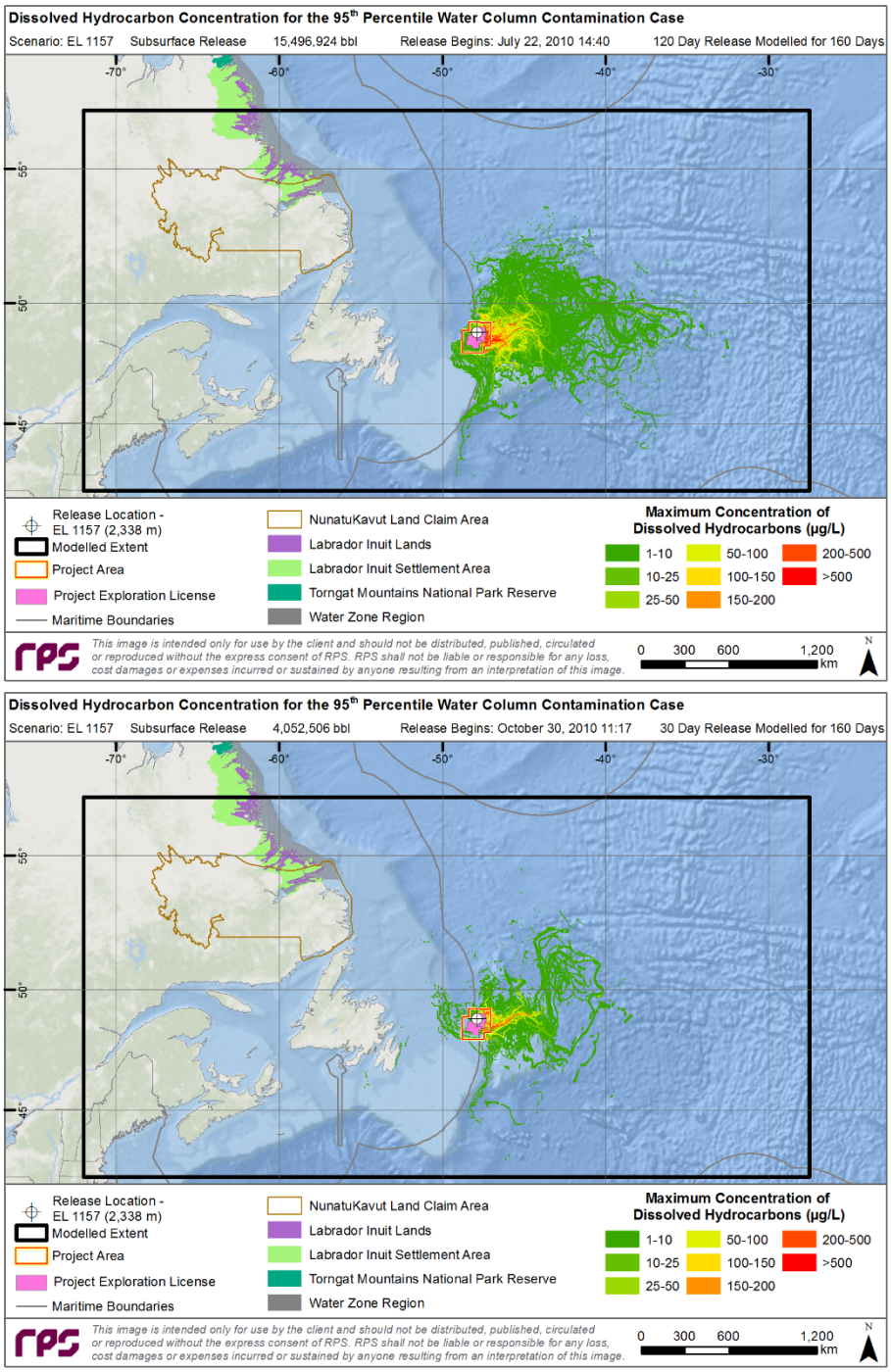

Figure 4-87. Maximum DHC at any depth in the water column for the 95th percentile water column cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

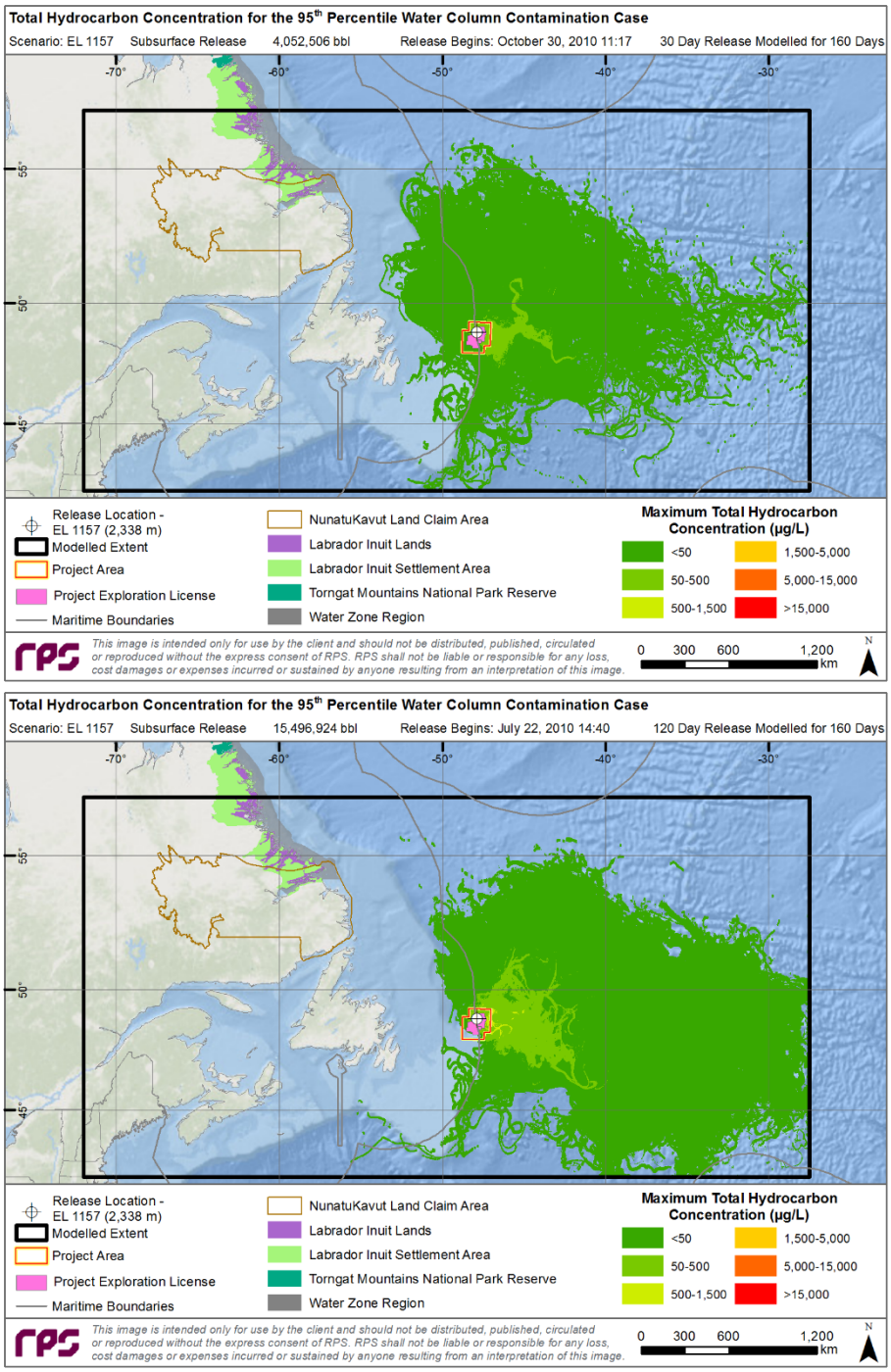

Figure 4-88. Maximum THC at any depth in the water column for the 95th percentile water column cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

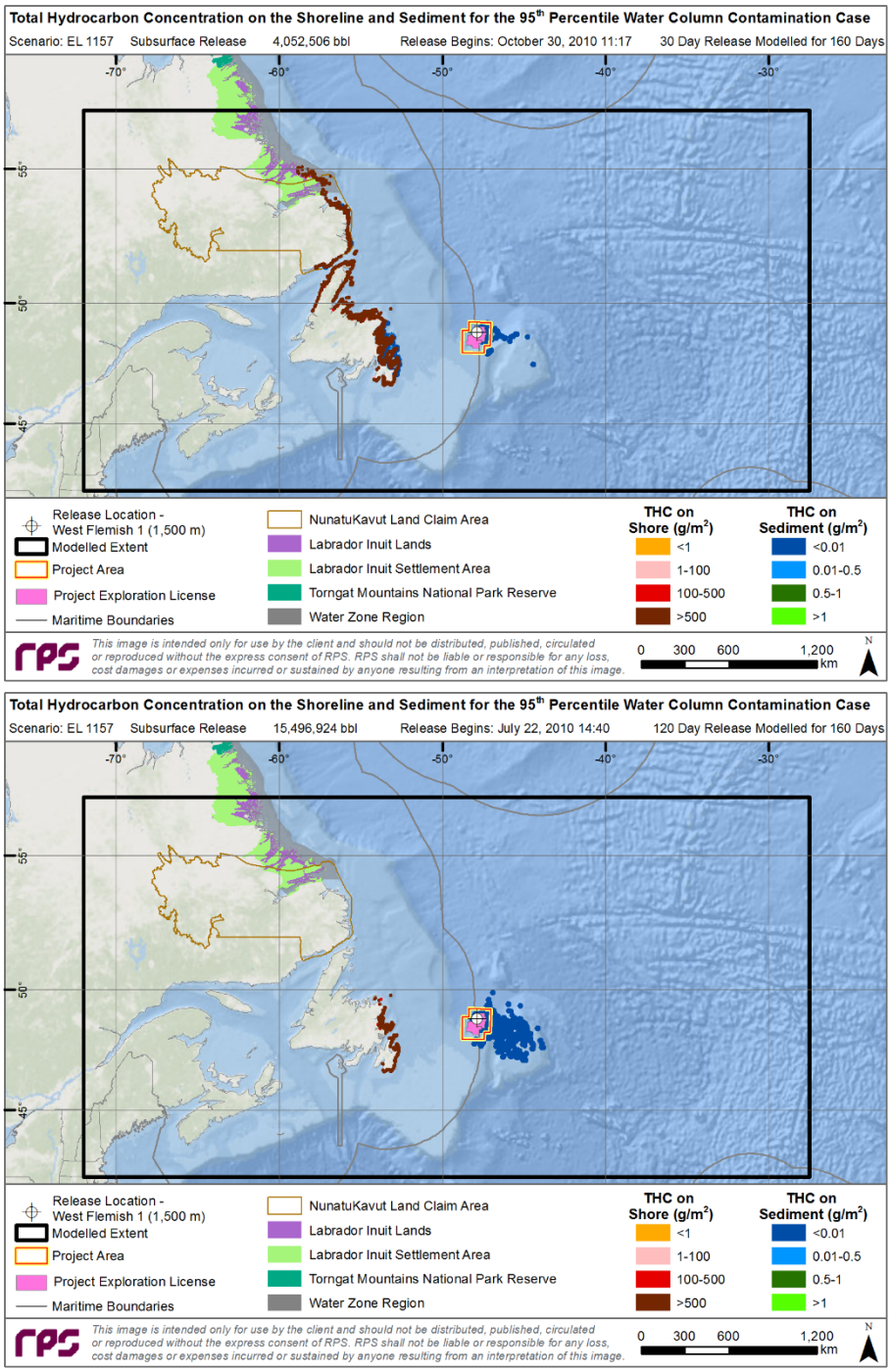

Figure 4-89. THC on the shore and sediment for the 95th percentile water column cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

4.2.2.2 Subsurface Blowouts at EL 1158

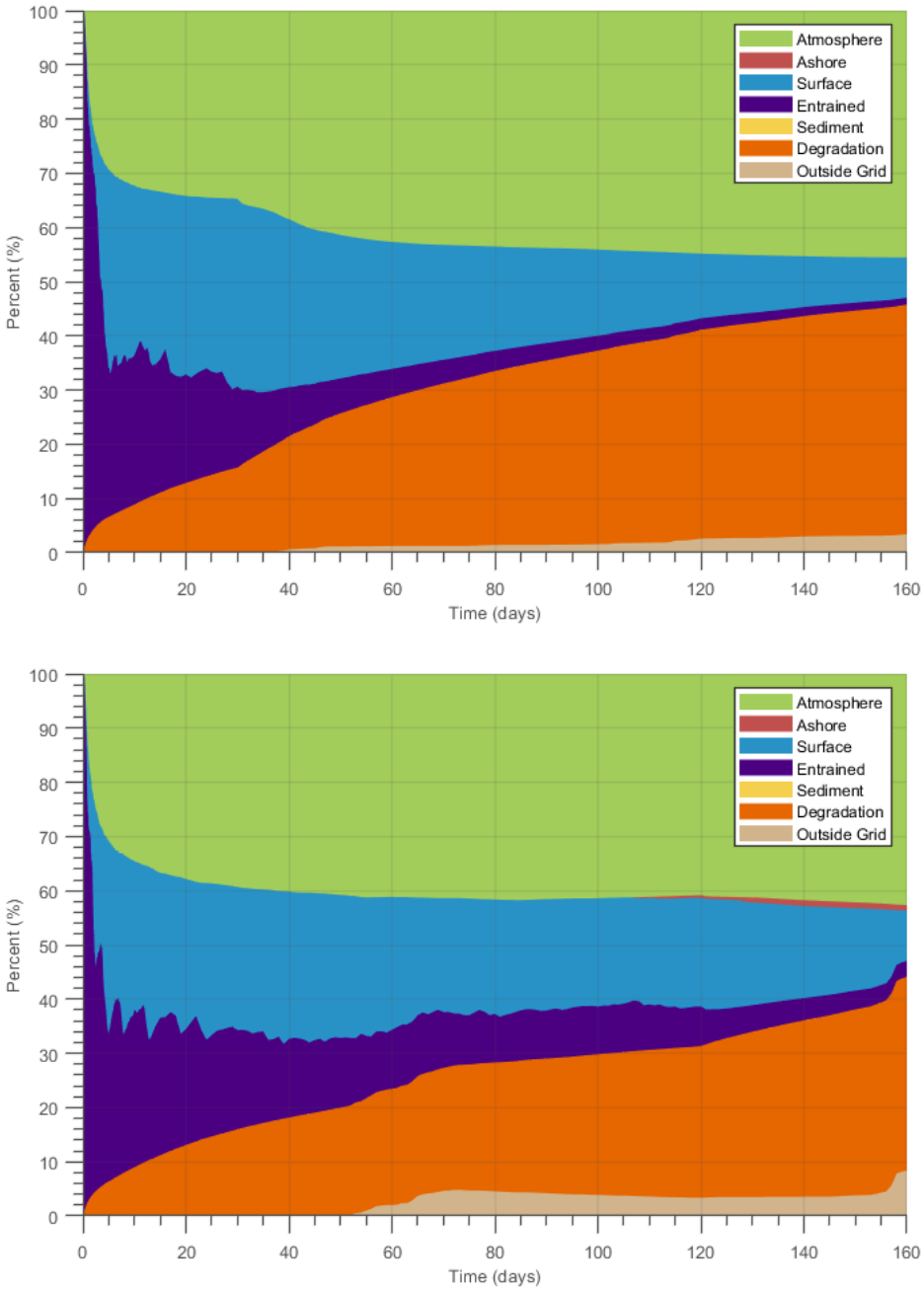

Figure 4-90. Mass balance plots of the 95th percentile water column cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

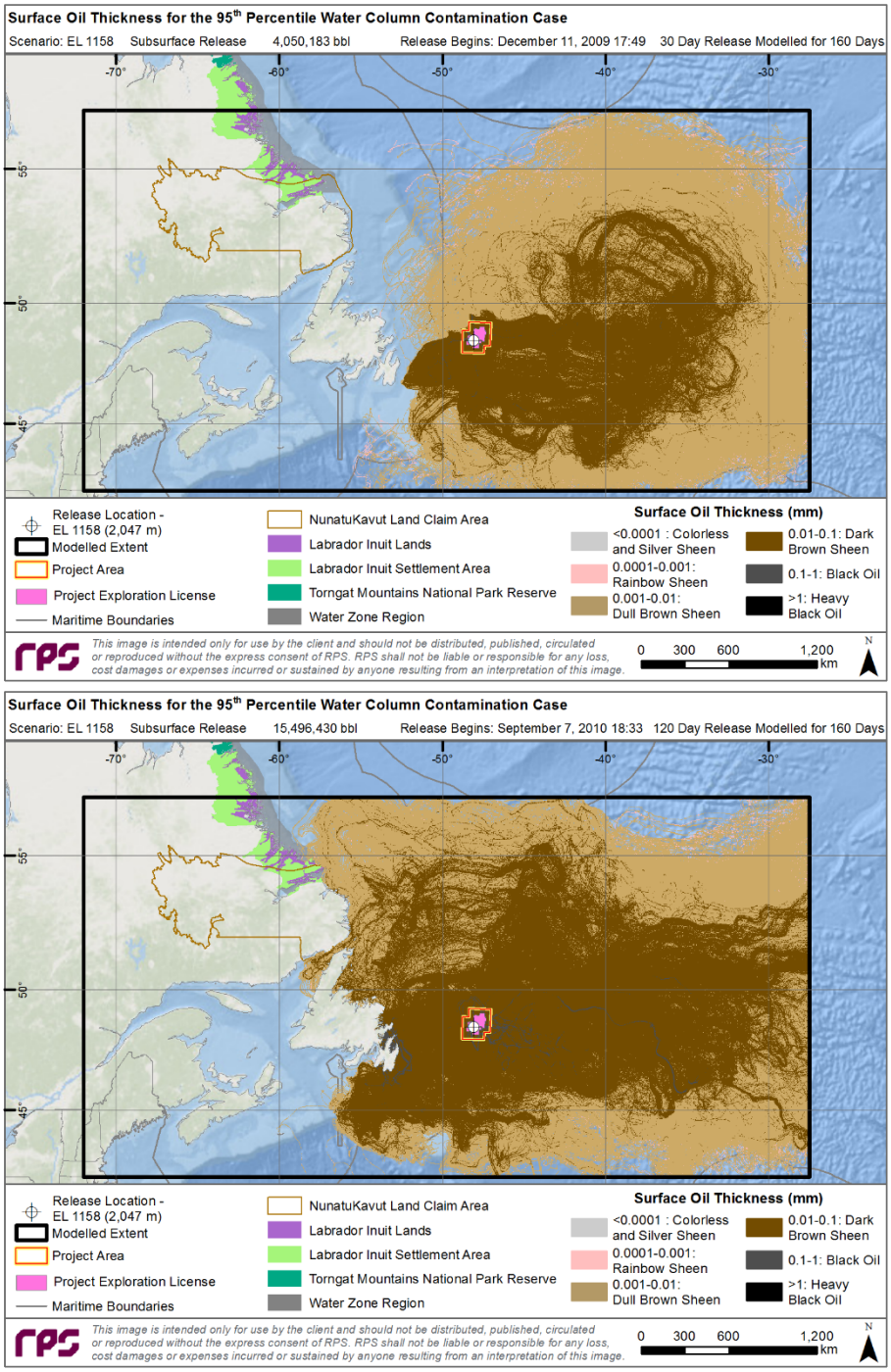

Figure 4-91. Surface oil thickness for the 95th percentile water column cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

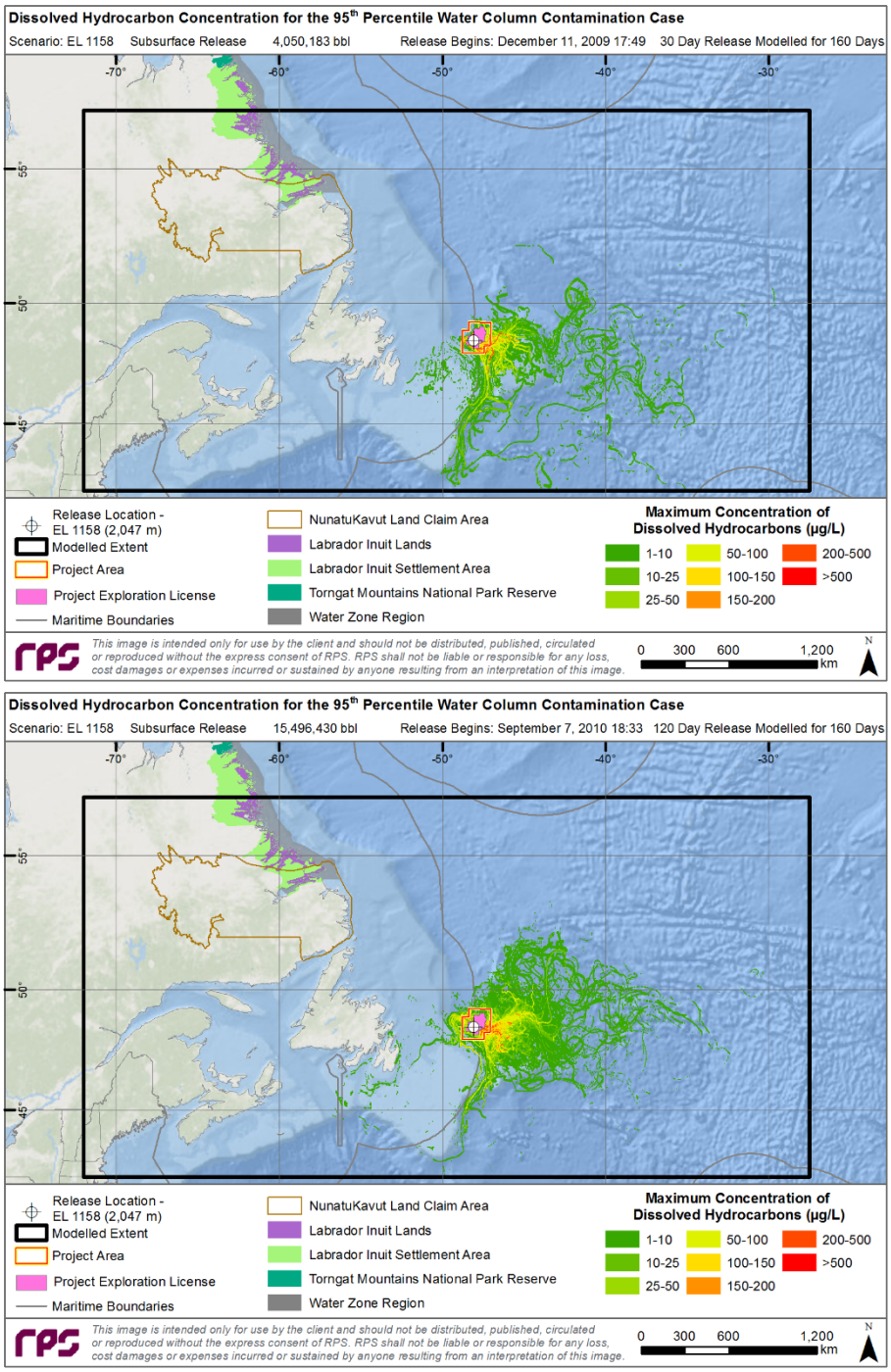

Figure 4-92. Maximum DHC at any depth in the water column for the 95th percentile water column cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

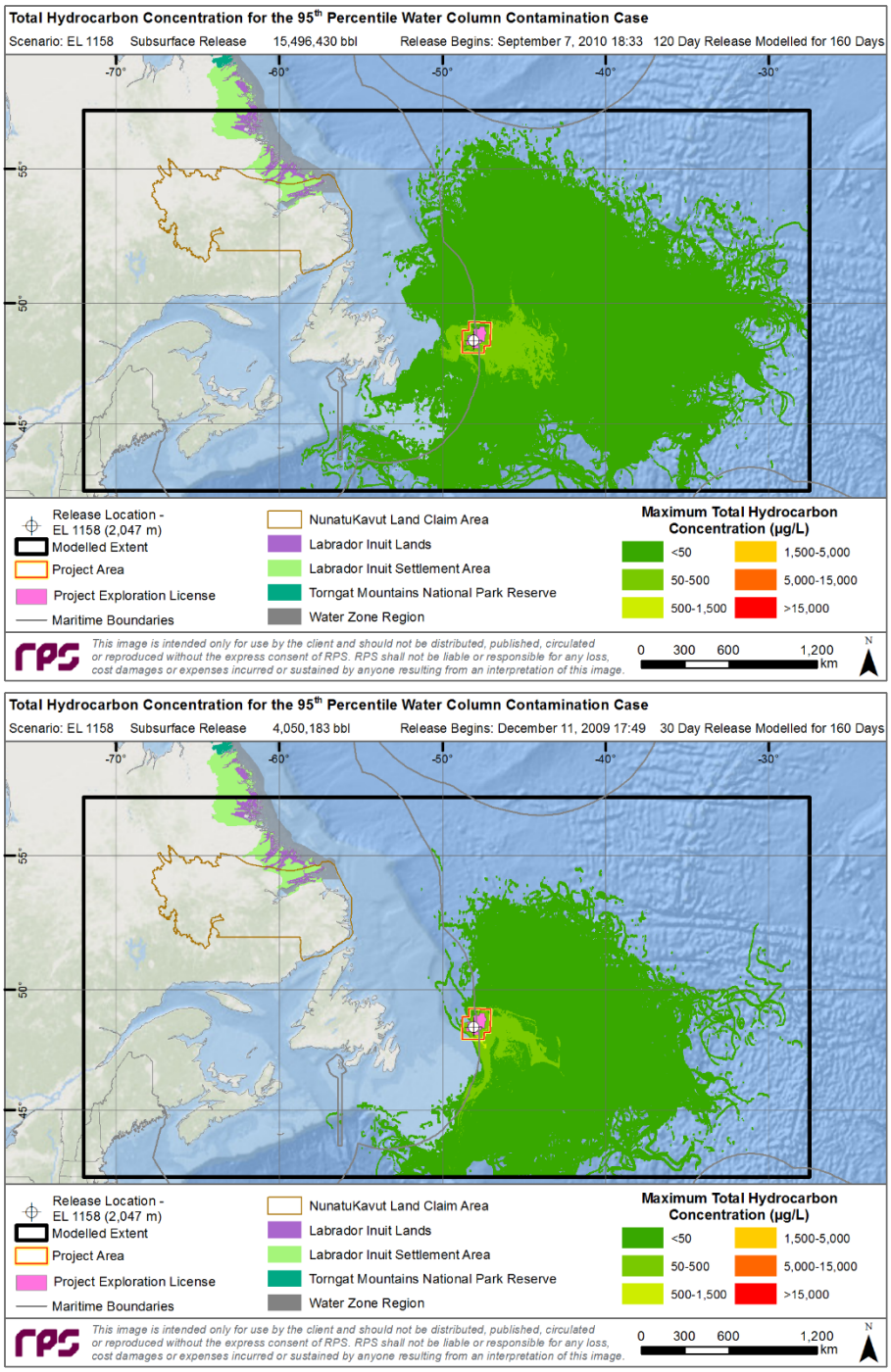

Figure 4-93. Maximum THC at any depth in the water column for the 95th percentile water column cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

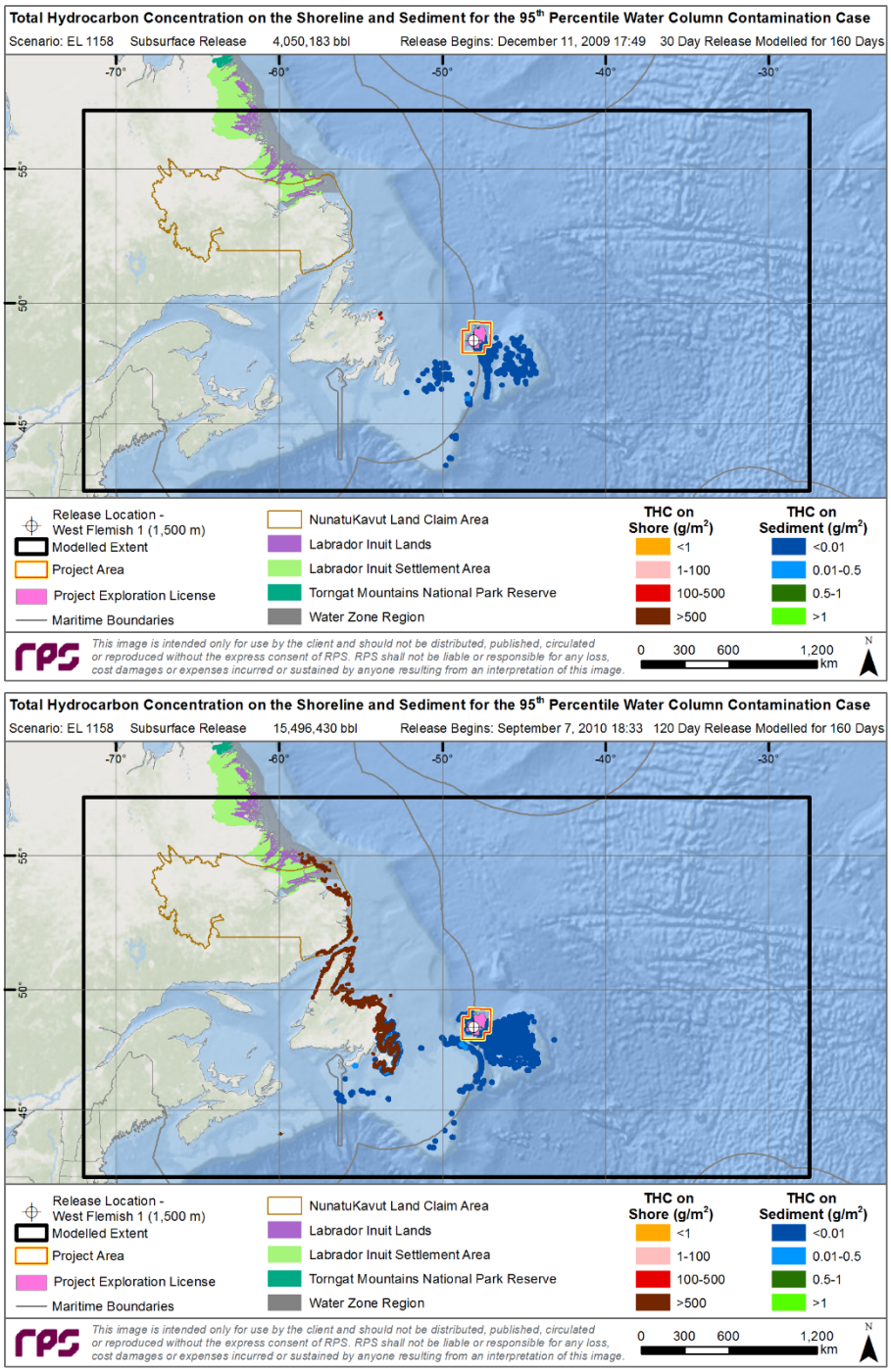

Figure 4-94. THC on the shore and sediment for the 95th percentile water column cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

4.2.3 Shoreline Exposure Cases

The results of the identified 95th percentile (i.e., credible worst-case) cases for shoreline exposure for the short- and long-duration releases at EL 1157 and 1158 are provided below. Note that the modelled release dates for the representative scenarios at each site differed (Table 2-5). For example, the 30-day release cases at both EL 1157 and El 1158 were representative of summer with start dates in March and April, while the 120-day releases were representative of winter with start dates in November and December.

The predicted total surface area and the cumulative footprints of surface area exposed to oil >0.001 mm (dull brown sheens) were generally similar between sites and release durations for the selected deterministic cases (Table 4-4; Figure 4-96 and Figure 4-101). Each of the cases were predicted to result in cumulative surface oil footprints of the same magnitude. The 120-day releases were predicted to result in much larger areas affected by dark brown sheens (0.01-0.1 mm) than the 30-day releases. Although, heavy black oil (> 1 mm) was not noticeably present in any of the selected deterministic scenarios, the potential for socio-economic impacts would be expected within the cumulative oiled region based on surface oil thickness (Table 4-4; Figure 4-96 and Figure 4-101).

Generally, the representative cases modelled at EL 1157 and EL 1158 were comparable with similar volumes of water exposed to DHC (Table 4-4; Figure 4-97 and Figure 4-102). Predicted cumulative THC footprints were larger than DHC, particularly for the 120-day release as the dissolved portion was predicted to disperse, degrade, and volatilize/evaporate. Highest concentrations of total hydrocarbons (>500 µg/mL) were predicted to occur generally within 300 km of the spill sites (Figure 4-98 and Figure 4-103).

The identified representative shoreline exposure cases were predicted to result in 1,241-1,597 km of contaminated shorelines. The releases at both sites resulted in similar lengths of shoreline oiling with the potential for contamination along the coasts of Newfoundland, mostly in excess of 500 g/m^2. The 30-day representative releases were predicted to contact the southern coasts of Newfoundland and the southern coast of the Avalon peninsula (Figure 4-99 and Figure 4-104). However, the 120-day representative releases were predicted to make contact with the northern coasts of Newfoundland and the eastern coasts of the Avalon peninsula (Figure 4-99 and Figure 4-104). In general, the oil that was predicted to reach shorelines was expected to be highly weathered, patchy, and discontinuous, as it would have degraded for well over a week (or more) before contacting shore. Limited sediment contamination of generally <0.1 g/m^2 was predicted to the east and south of the release sites (Figure 4-99 and Figure 4-104). Additionally, there were localized patches of sediment oil up 0.5 g/m^2 predicted from the releases at EL 1157.

At the end of the 160-day simulations of the 95th percentile shoreline exposure for 30- and 120-day releases at the EL 1157 site, large percentages of the oil evaporated (42-44%) and degraded (38-39%), accounting for >79% of each modelled release. The amount of oil predicted to remain on the water surface was 2-14%, with <3% within the water column. Up to 13% of oil (predominantly persistent surface oil) was predicted to be transported outside of the modelled domain. Oil transported to the sediment and shoreline were not major fate pathways with <0.1% predicted to settle on sediments and up to 1.2% was predicted to remain on the shoreline (Table 4-5). At the EL 1158 site, approximately 42-46% of oil was predicted to evaporate and 31-39% degraded, accounting for >72% of each modelled release. The amount of oil predicted to remain on the water surface was 2-3%, 11-22% was transported outside the modelled domain, <2% remained in the water column, and <0.1% settled on sediment. Shoreline contact was not a major fates pathway with ≤1% of the total volume of released

oil making contact with the shoreline (Table 4-5). Frequent cycling of wind and calm events were evident in all shoreline oil exposure cases, as indicated by “see-sawing” between oil on the surface and entrained oil in the water column (Figure 4-95 and Figure 4-100).

4.2.3.1 Subsurface Blowouts at EL 1157

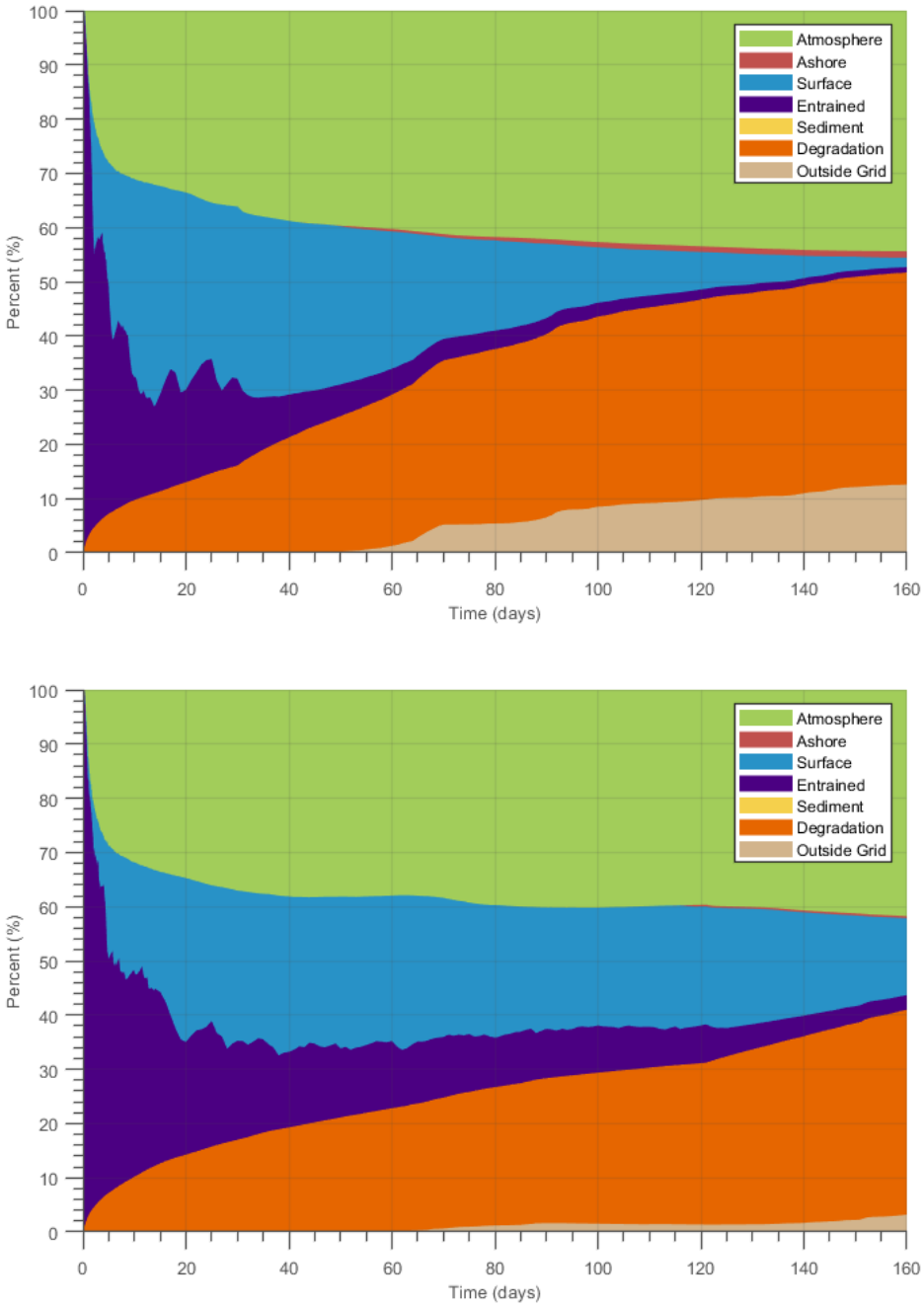

Figure 4-95. Mass balance plots of the 95th percentile shoreline cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

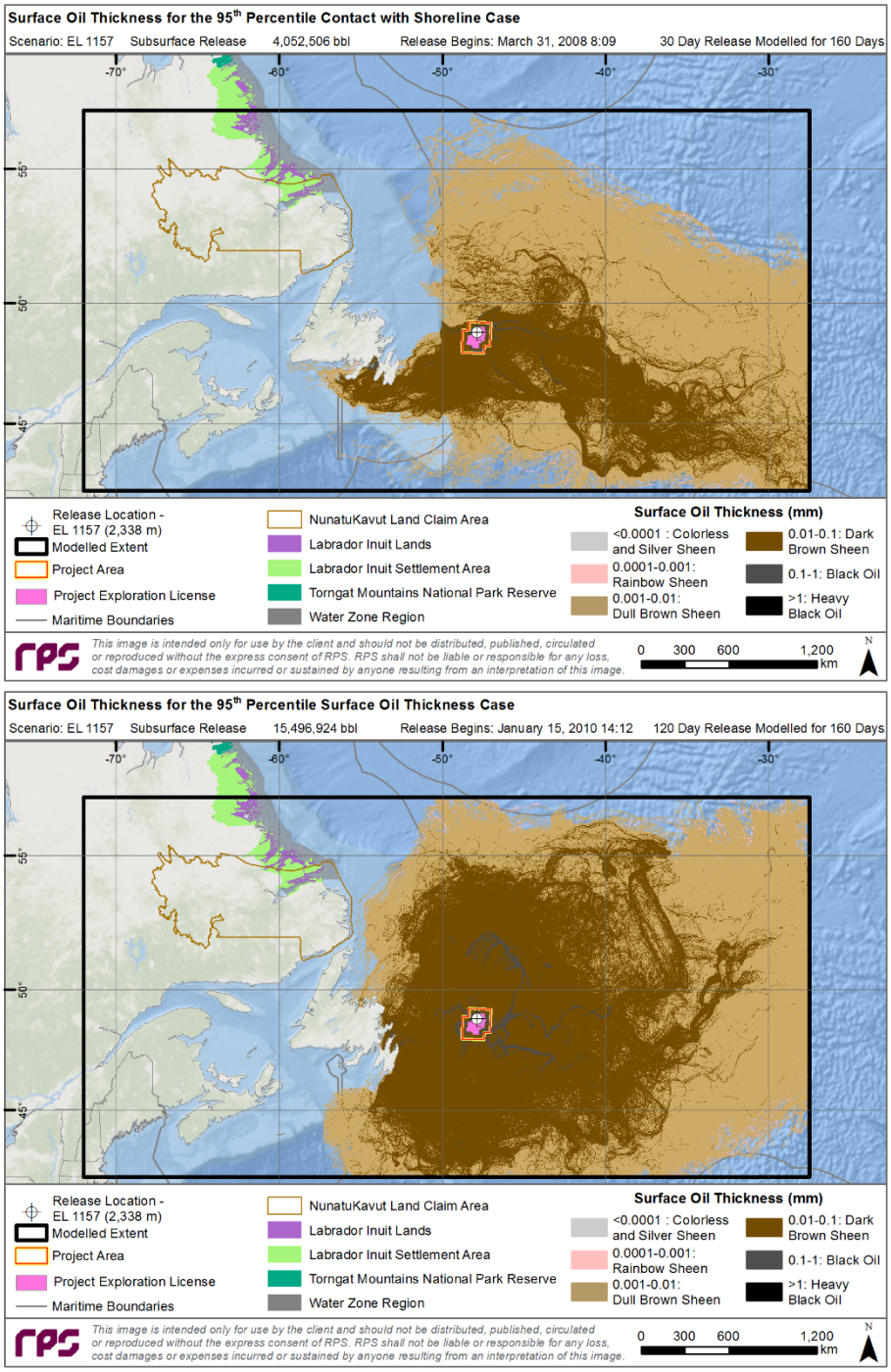

Figure 4-96. Surface oil thickness for the 95th percentile shoreline cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

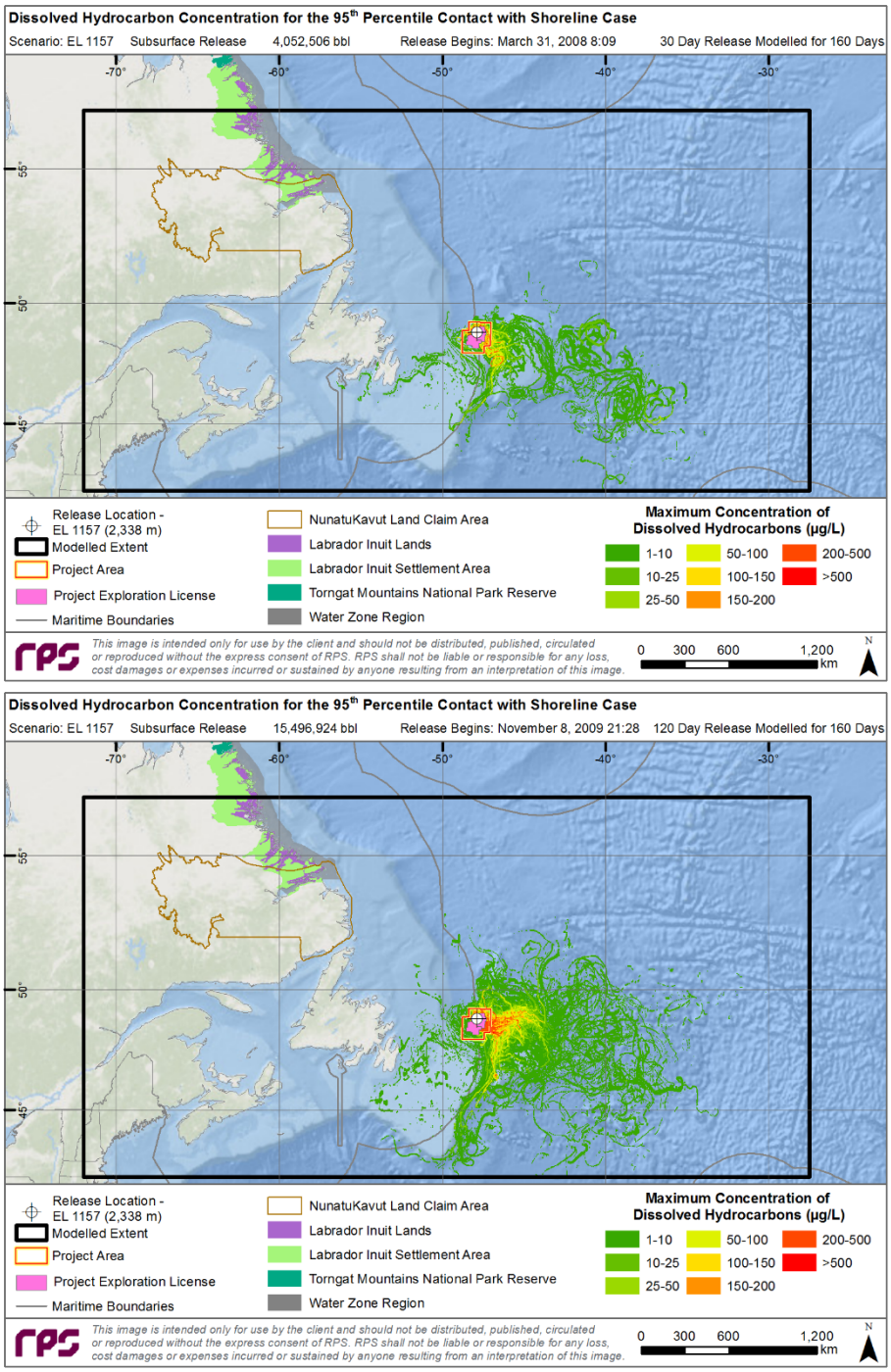

Figure 4-97. Maximum DHC at any depth in the water column for the 95th percentile shoreline cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

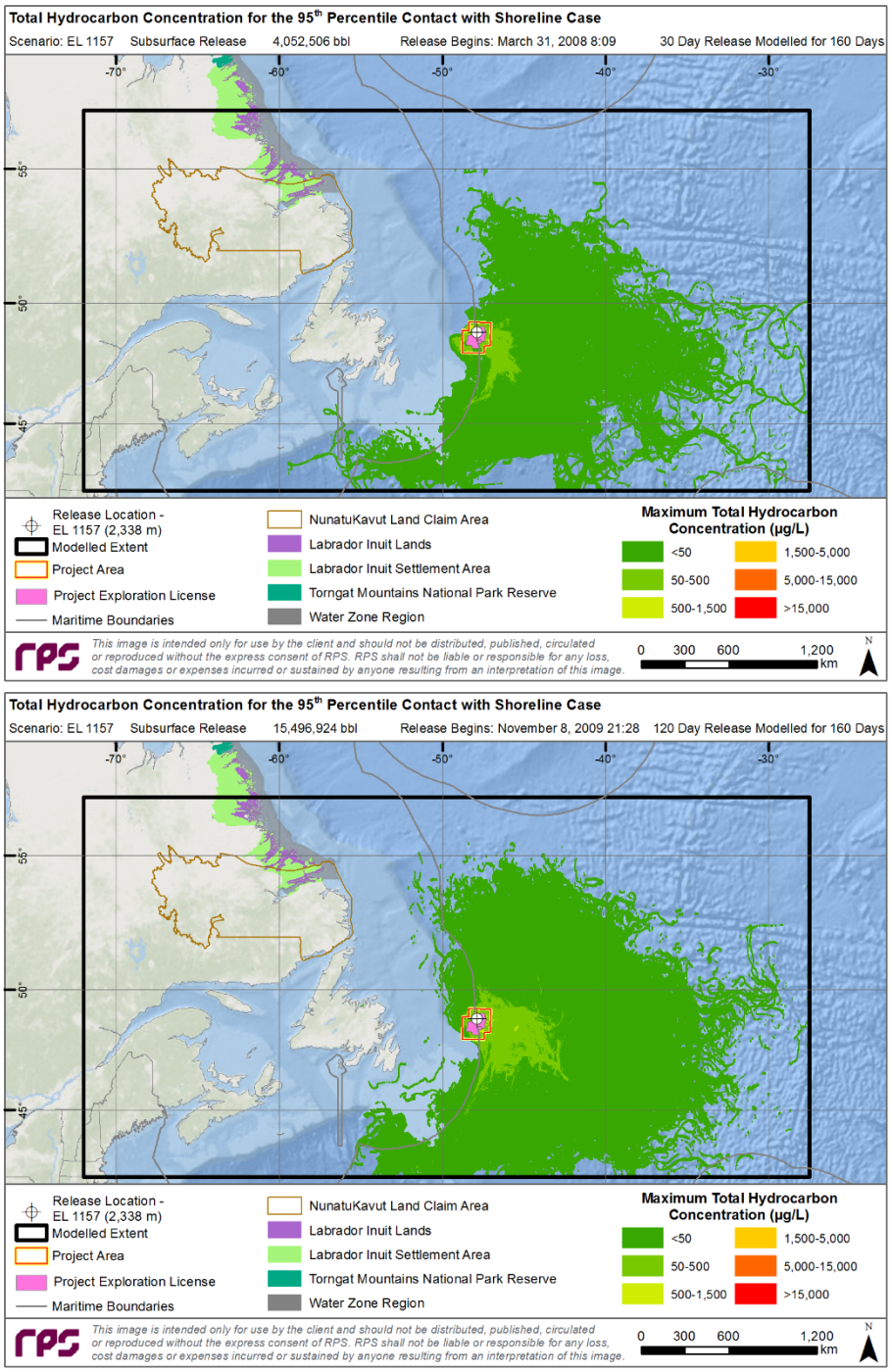

Figure 4-98. Maximum THC at any depth in the water column for the 95th percentile shoreline cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

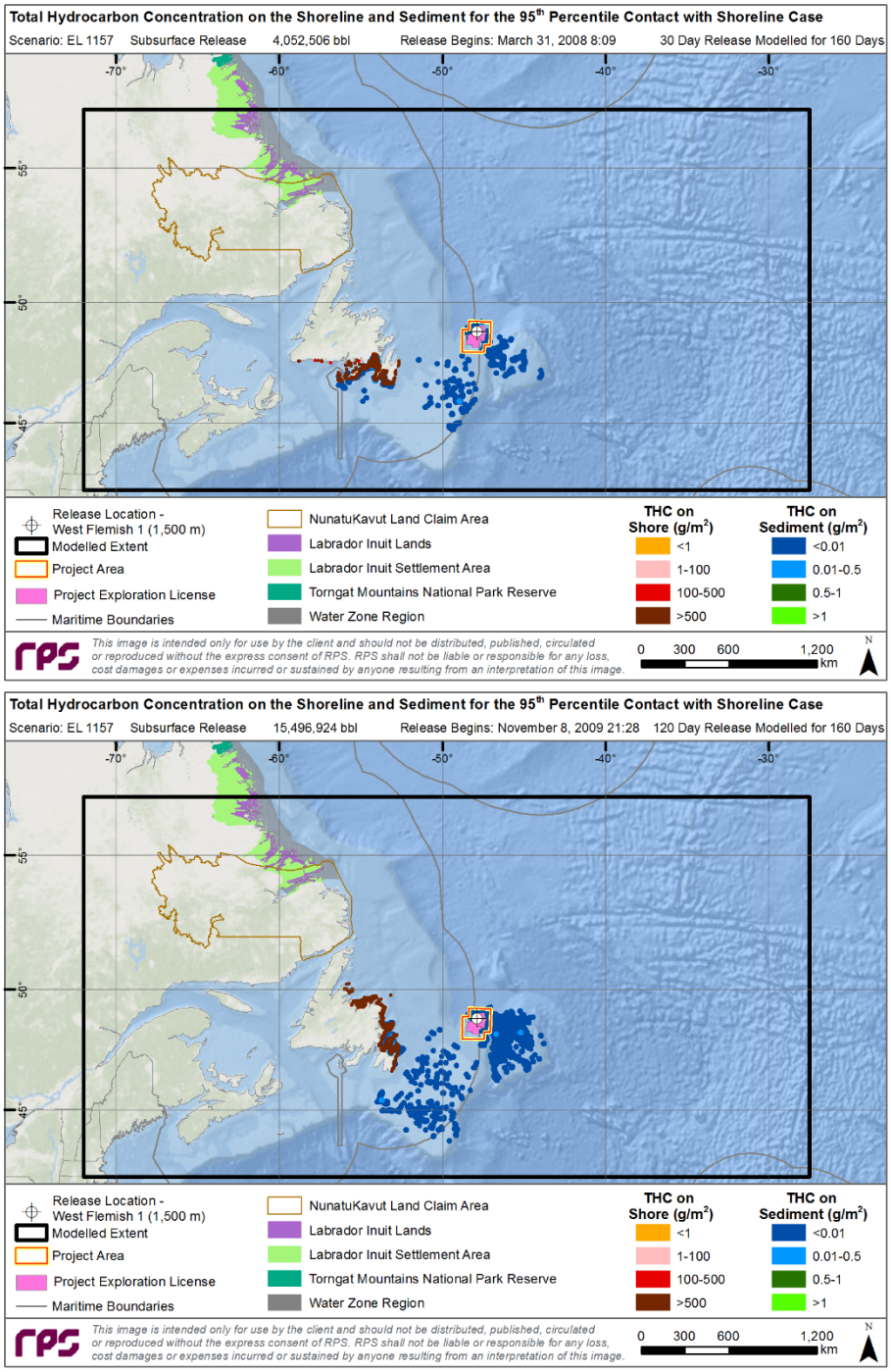

Figure 4-99. THC on the shore and sediment for the 95th percentile shoreline cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1157.

4.2.3.2 Subsurface Blowouts at EL 1158

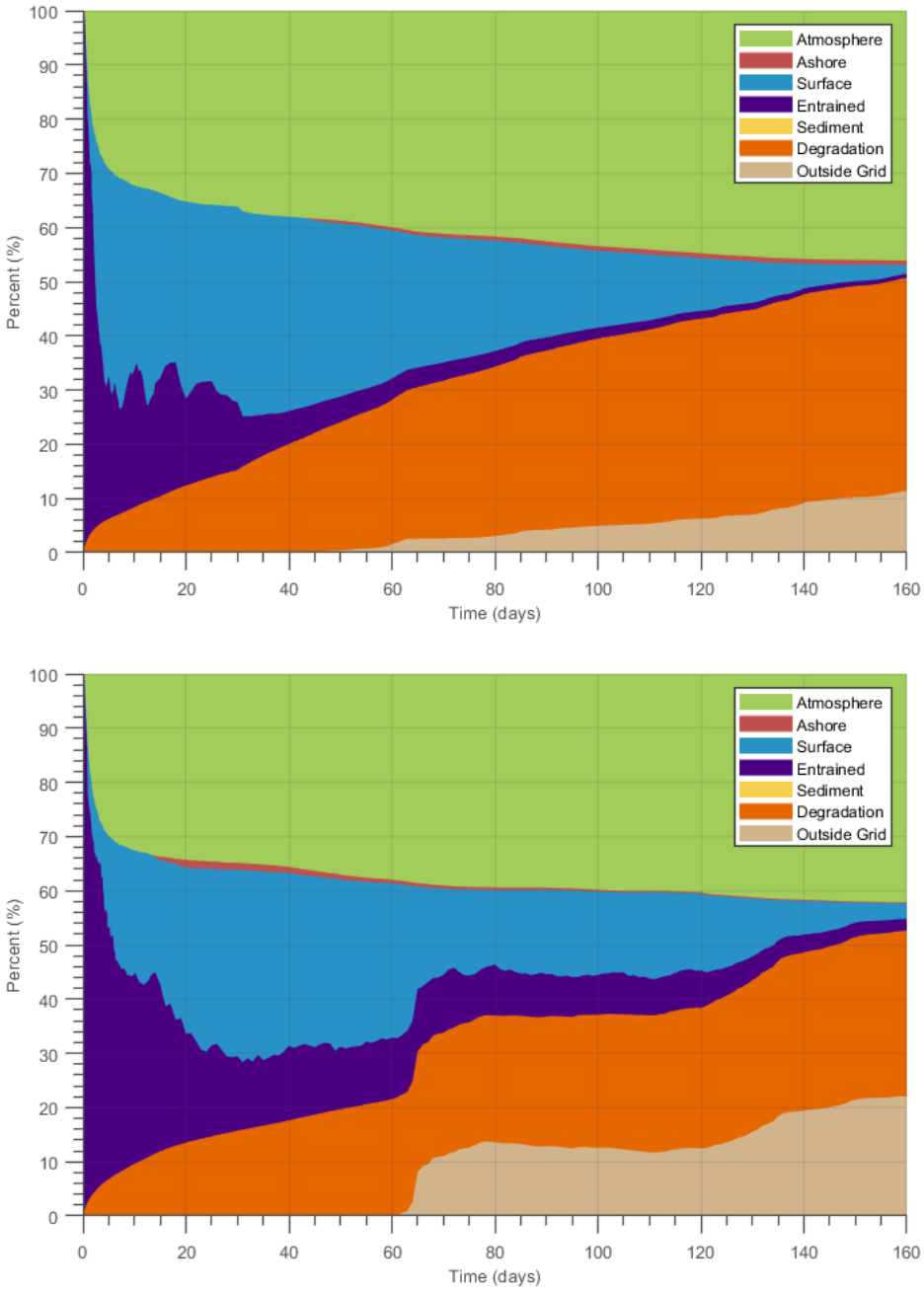

Figure 4-100. Mass balance plots of the 95th percentile shoreline cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

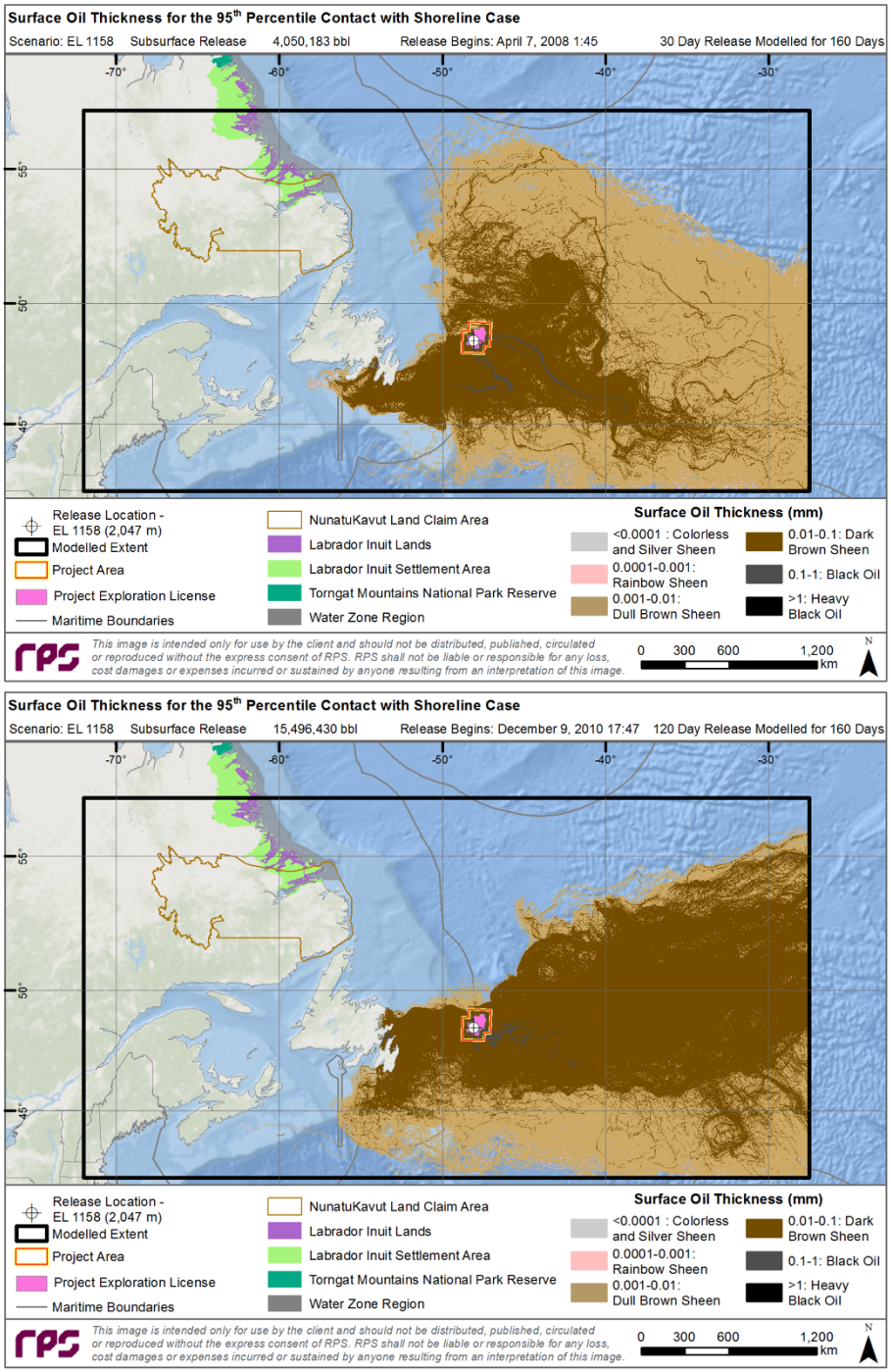

Figure 4-101. Surface oil thickness for the 95th percentile shoreline cases resulting from 30- (top) and 120-day (bottom) blowouts at EL 1158.

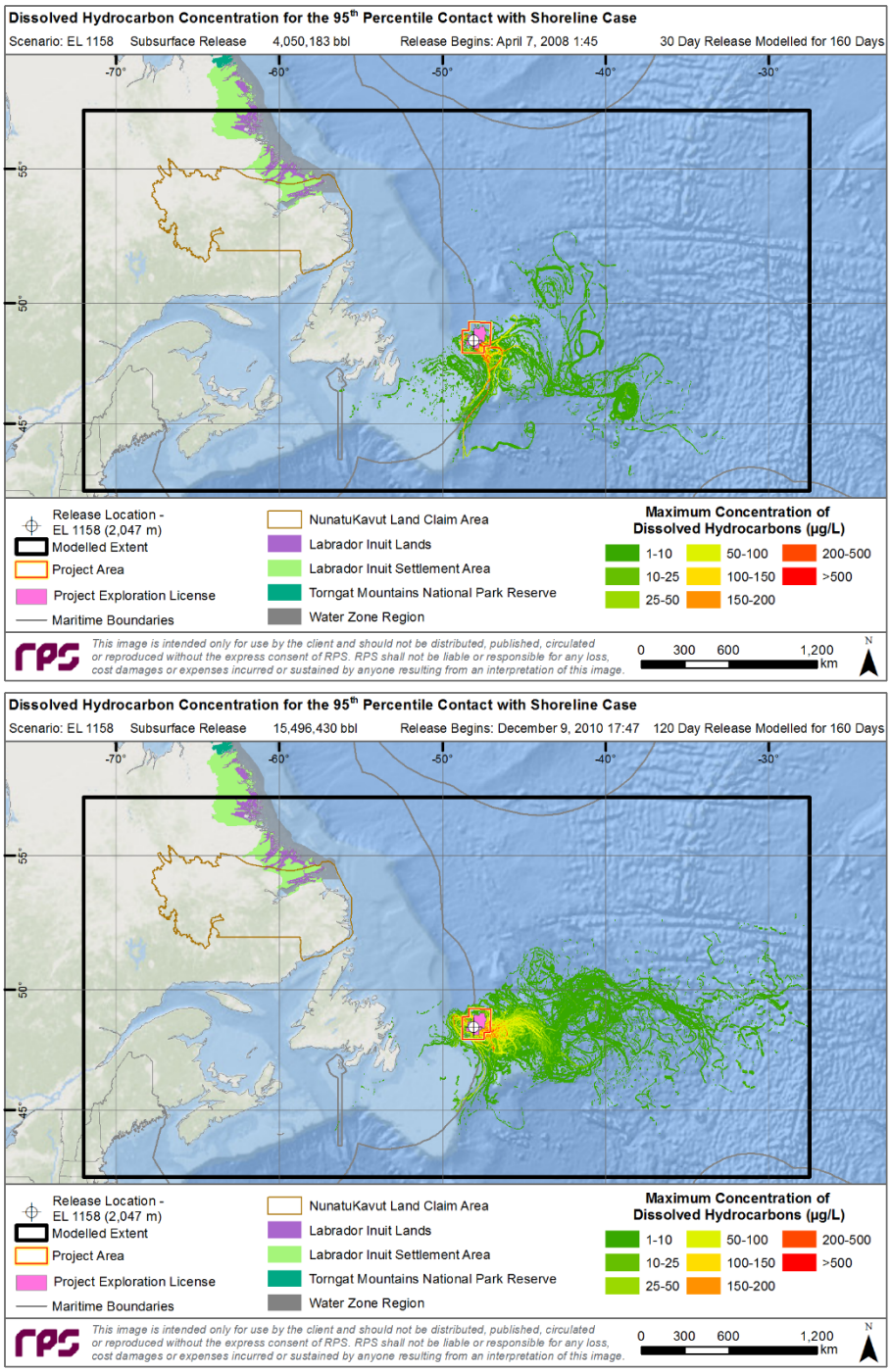

Figure 4-102. Maximum DHC at any depth in the water column for the 95th percentile shoreline cases resulting from 30-day (top) and 120-day (bottom) blowouts at EL 1158.

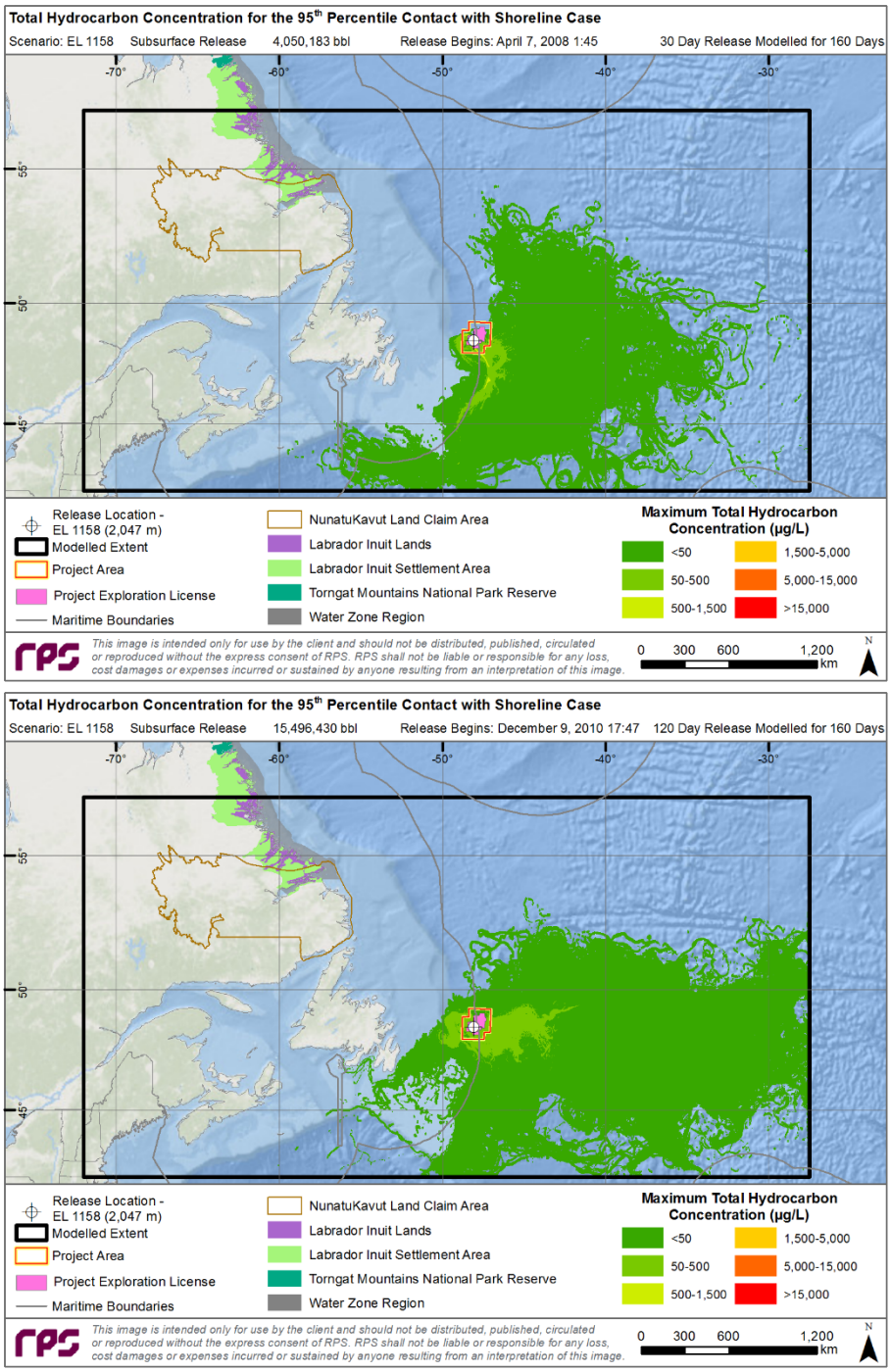

Figure 4-103. Maximum THC at any depth in the water column for the 95th percentile shoreline cases resulting from 30-day (top) and 120-day (bottom) blowouts at EL 1158.

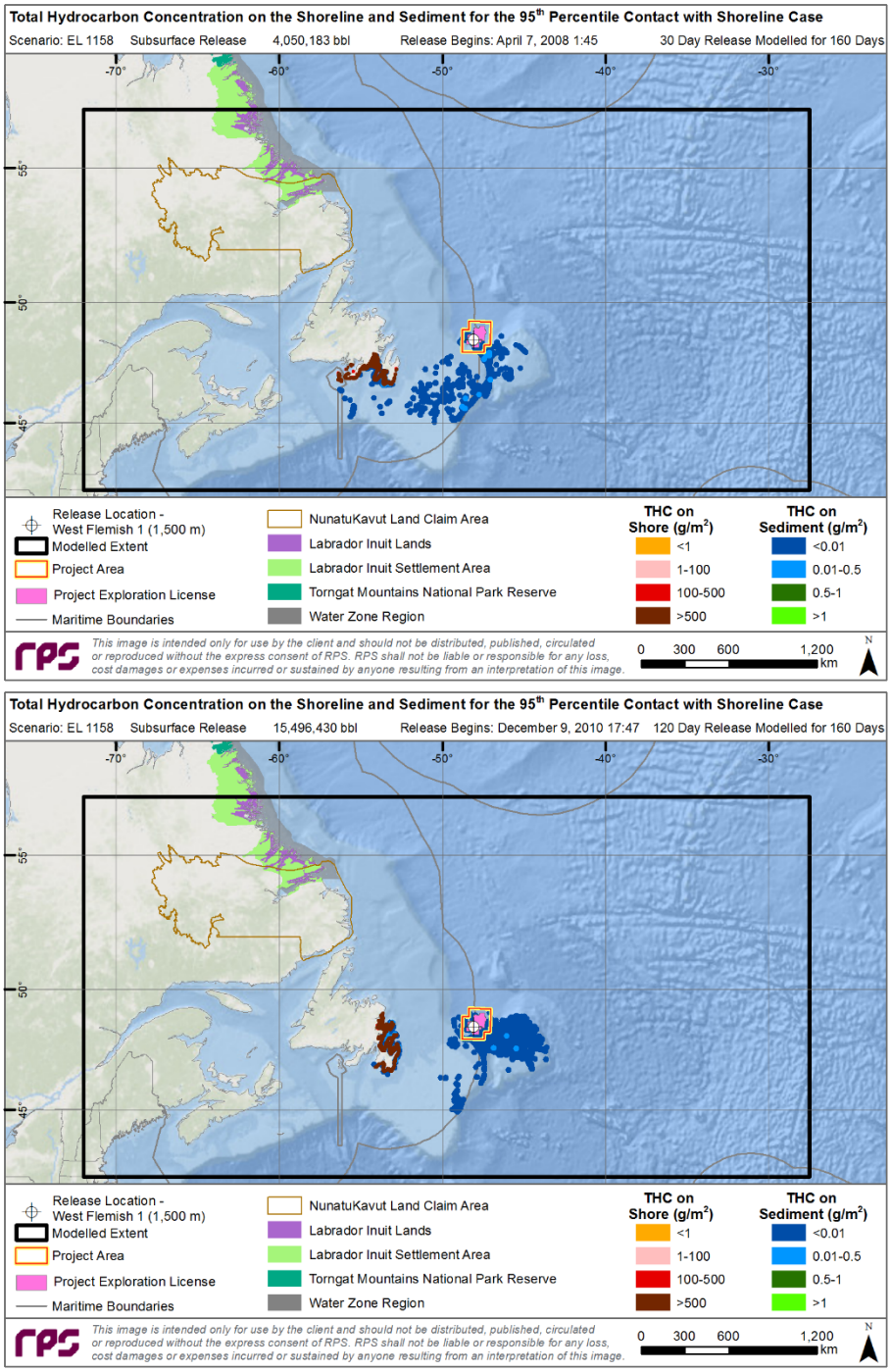

Figure 4-104. THC on the shore and sediment for the 95th percentile shoreline cases resulting from 30-day (top) and 120-day (bottom) blowouts at EL 1158.

4.2.4 Surface Diesel Batch Spill along a Supply Vessel Route

Results for the hypothetical batch spill releases resulting from a nearshore (12 km east of St. John's) release of marine diesel from a diesel storage tank failure are provided. The simulations were comprised of a nearly instantaneous release of 3,200 L of marine diesel at the surface, which was then modelled for 30 days. Mass balance figures include the corresponding 50th percentile surface oil exposure area, 95th percentile surface oil exposure area, 95th percentile water column exposure volume, and 95th percentile shore length exposure area.

The batch spill releases of 3,200 L marine diesel were predicted to result in silver or colorless sheens (<0.0001 mm) of oil floating on the water surface (Figure 4-106). Generally, oil within these representative scenarios was predicted to be transported to the south and in some cases wrap around the Avalon peninsula to the west, towards Saint Lawrence, Newfoundland (Figure 4-106). Note that THC and DHC concentrations in the water column were not predicted for the marine diesel batch spills modelled due to the relatively small volume of diesel oil released on the water surface. Thus, figures of THC and DHC are not presented below.

At the end of the 30-day marine diesel batch spill simulations, 64-80% was predicted to evaporated into the atmosphere, 12-23% degraded, 6-13% remained entrained in the water column, while 0.1% of the released volume was predicted to remain floating on the water surface. No marine diesel was predicted to strand on shorelines or settled on sediments in these representative scenarios other than the 95th percentile shoreline oiling case, which resulted in 1.1% of the release predicted on shore (Figure 4-105 and Table 4-5). The 95th percentile shoreline oiling case was predicted to result in 1,010 km of shoreline oiling above the socio-economic threshold and 9 km above the biological threshold.

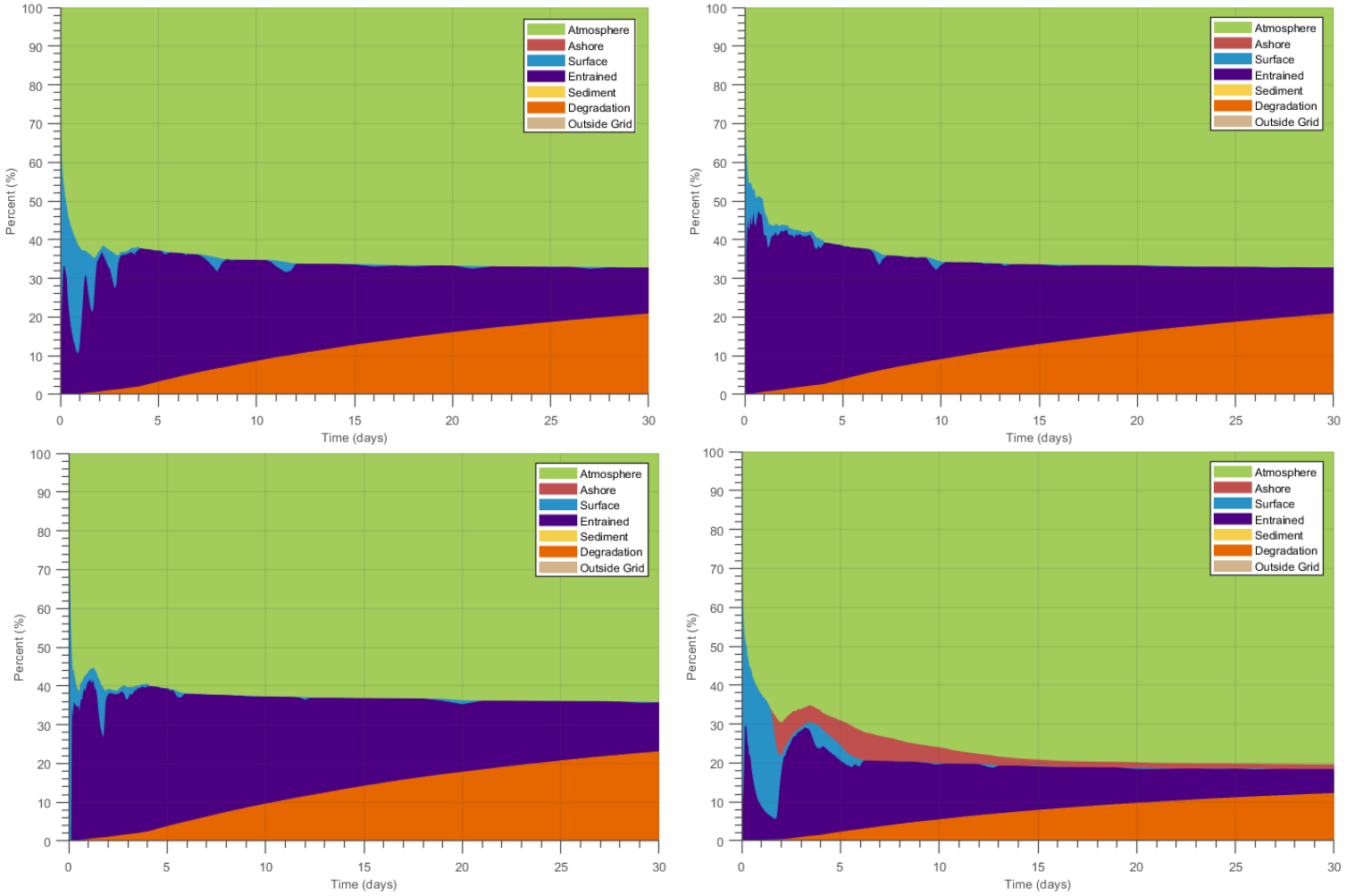

Figure 4-105. Mass balance plots of the Marine Diesel batch spills of 3,200 L along a supply vessel route location corresponding to the 50th percentile surface exposure case (top left), 95th percentile surface exposure case (top right), 95th percentile water column exposure case (bottom left), and the 95th percentile shoreline exposure case (bottom right).

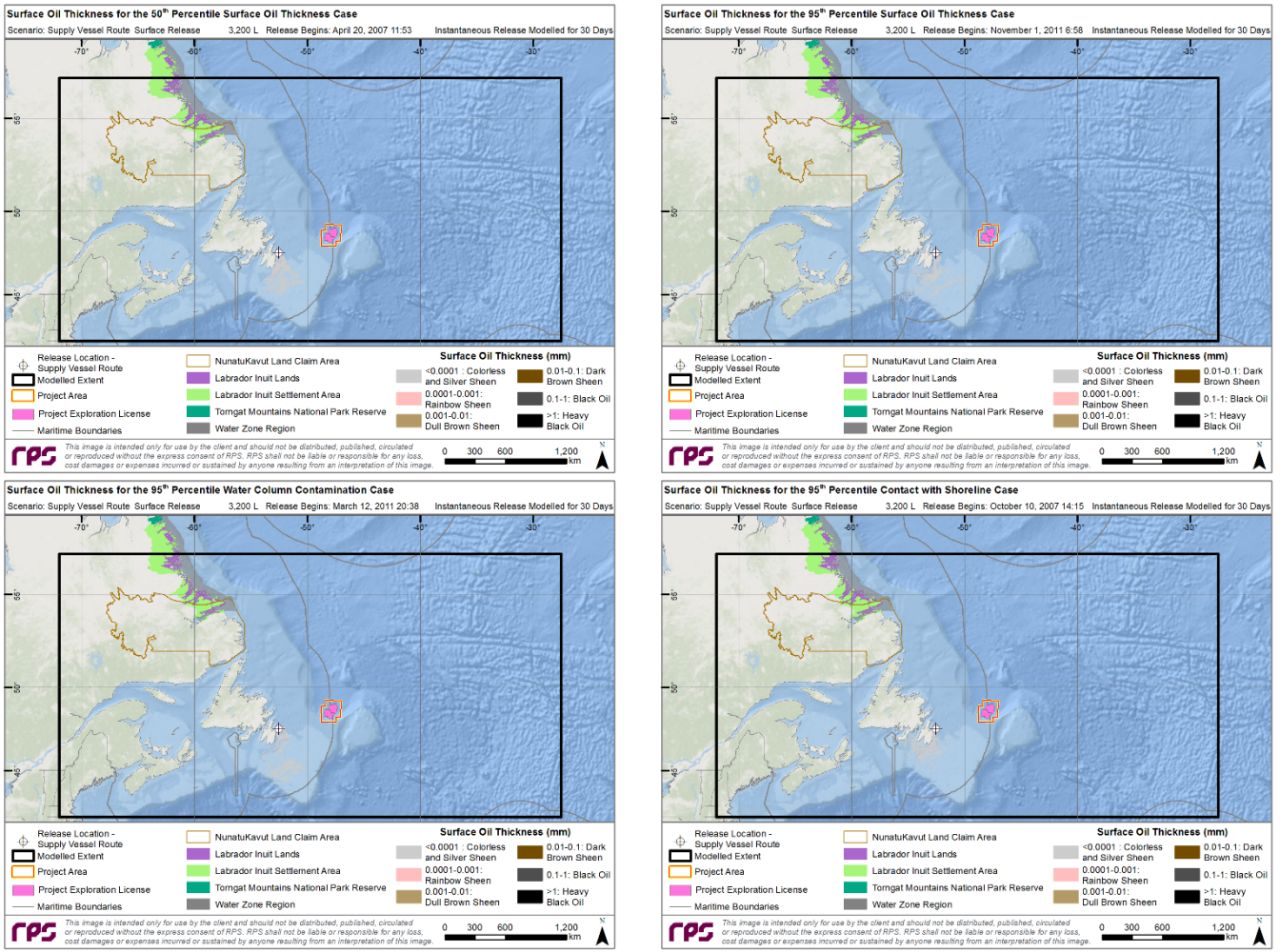

Figure 4-106. Surface oil thickness for the Marine Diesel spills of 3,200 L along a supply vessel route location corresponding to the 50th percentile surface exposure case (top left), 95th percentile surface exposure case (top right), 95th percentile water column exposure case (bottom left), and the 95th percentile shoreline exposure case (bottom right).

4.2.5 Summary of Deterministic Results

4.2.5.1 Representative Cases: Surface, Water Column, and Shoreline Oil

For the representative credible "worst-case" deterministic scenarios at EL 1157 and EL 1158, subsurface oil was predicted to rise through the water column where it surfaced and predominantly was transported to the east and south. In several simulations, oil was predicted to strand on the Newfoundland shoreline, as well as to a lesser extent the southern shores of Labrador and Sable Island. In each scenario, nearly half of the oil was predicted to evaporate, while a third was predicted to degrade by natural processes (Table 4-5). Of the remaining volume of released oil, 2-14% was predicted to remain on the surface, ≤3% remain in the water column, ≤3% stranded on shorelines, and <0.1% settled onto sediments over the course of the 160 day simulations. Because the simulations were so long, between 3 to 22% of the oil (predominantly surface oil as highly weathered emulsifications and tarballs) was predicted to leave the model domain to the east. Note that all scenarios assume a completely unmitigated release, which is an unlikely situation because various emergency response tactics would typically be employed immediately in the event of a spill.

The predicted cumulative surface oil footprints of most of the identified representative cases were centered to the east of the release sites, due to surface oil transport by winds mainly towards the east, with natural dispersion to the north and south. Cumulative maximum surface oil in all cases was predicted to have an average thickness within the range of 0.001–0.1 mm (1 –100 µm), which would appear as discontinuous and patchy brown sheens to dark brown sheens, with thinner features predicted further from the release site (Figure 4-76; Figure 4-81; Figure 4-86; Figure 4-91; Figure 4-96; Figure 4-101). In some cases, patchy black oil (0.1-1 mm) was predicted to occur near the release site as it was transported, primarily to the east, hundreds of kilometers away. The predicted areas of surface oil exposure for the 30- and 120-day 95th percentile cases were similar between sites, with 30-day releases have the potential to affect a total of 2,267,000-2,843,000 km^2 above the socio-economic threshold over 160 days and 120-day releases having the potential to affect a total of 2,311,000-3,185,000 km^2 over 160 days (Table 4-4).

The maximum subsurface water volumes exposed to THC concentrations for the 95th percentile water column cases were predicted to range between 64,070 km^3 and 99,090 km^3 (Table 4-4). Areas of relatively high THC concentration (500-5,000 µg/L) occurred in the Flemish Pass and Flemish Cap region in most scenarios (Figure 4-88 and Figure 4-93). Regions of >500 µg/L dissolved hydrocarbons were predicted to be transported primarily east and southeast of the release site in the 95th percentile cases at EL 1157 and EL 1158. These differences in dissolved hydrocarbon transport were due to the rising oil droplets from the release and the site locations relative to the strong subsurface currents (e.g. Labrador current) moving within the Flemish Pass and along the shelf break. Entrained oil concentrations in surface waters were predicted to vary considerably from day to day as expected from variable wind and wave conditions that control entrainment, mixing, and resurfacing rates.

For the shoreline oil exposure cases, shoreline oil contamination was predicted to range from approximately 9-4,264 km for socio-economic and ecological effects (Table 4-4). In general, most oiling in these scenarios was predicted along the eastern and southern shores of Newfoundland for these representative deterministic simulations, although stochastic results did result in the potential for shoreline oiling from southern Newfoundland up through Labrador. The oil that was predicted to strand along shorelines was generally in the 100 to >500 g/m^2 range (exceeding both the socio-economic and ecological thresholds), but would be patchy,

discontinuous, and generally highly weathered by the time it reached shore. Offshore sediment contamination was much less prevalent and generally occurred at low levels (<0.01 g/m^2) at locations near the release sites and to the south along the continental shelf break, although localized patches of concentrations up to 0.05 g/m^2 were also predicted. The extents of shoreline exposures were generally similar between each release site (Table 4-4; Figure 4-99 and Figure 4-104).

The contrasting results (e.g. areas predicted to be affected and resulting levels of contamination) within the representative deterministic simulations demonstrate the importance of stochastic probability footprints outlining the range of spill outcomes that may result from environmental variability rather than differences in the specific release and site characteristics. In general, stochastic results provided an understanding of the locations that were susceptible to potential effects, while representative deterministic results provided more context with the anticipated magnitude of effects for 95th percentile “worst-case” scenarios.

4.2.5.2 Batch Spills

Smaller scale near-instantaneous batch spills of marine diesel were modelled as an accidental release. Four 3,200 L releases were modelled at a nearshore location 12 km east of St. John’s along a potential supply vessel route and was simulated for thirty days (Table 2-5). The marine diesel used in this scenario was a standard diesel that had a low viscosity and a high aromatic content, which resulted in rapid predicted evaporation during the summertime releases. The marine diesel releases were also predicted to result in a patchy distributions of colorless or silver sheen of oil <0.0001 mm (0.1 µm). Due to the proximity of the modelled spill site to the coastline, the 95th percentile shoreline exposure case was predicted to lead to shoreline oil contamination exceeding the socio-economic threshold of 1 g/m^2 on over approximately 1,000 km of shoreline. The biological threshold was not predicted to be exceeded. The remaining representative scenarios were not predicted to contaminate shorelines.

Table 4-4. Representative deterministic cases and associated areas, lengths, and volumes exceeding specified thresholds for representative trajectories at EL 1157, EL 1158, and a supply vessel route location.

95th Percentile Scenario	Site	Released Volume	Approximate Surface Area exceeding thickness thresholds (km^2)		Approximate Shore Length exceeding mass per unit area thresholds (km)		Approximate Subsurface Volume exceeding THC threshold (km^3)
			Socio-economic (0.04 µm)	Ecologic (10 µm)	Socio-economic (1 g/m^2)	Ecologic (100 g/m^2)	Socio-economic* (1 µg/L)
Subsurface Blowout Releases							
Surface oil exposure case- 30 d	EL 1157	4,052,506 bbl	2,705,000	832,900	226	216	77,010
Water column case- 30 d			2,843,000	1,031,000	4,510	4,384	64,230
Shoreline contact case- 30 d			2,267,000	833,300	1,409	1,358	64,070
Surface oil exposure case- 120 d		15,496,924 bbl	3,037,000	1,616,000	1,668	1,608	78,860
Water column case- 120 d			2,446,000	1,406,000	756	735	86,370
Shoreline contact case- 120 d			2,953,000	1,645,000	1,597	1,547	82,010
Surface oil exposure case- 30 d	EL 1158	4,050,183 bbl	2,322,000	837,400	1,241	1,194	60,290
Water column case- 30 d			2,616,000	1,012,000	9	6	65,470
Shoreline contact case- 30 d			2,322,000	837,400	1,241	1,194	60,290
Surface oil exposure case- 120 d		15,496,430 bbl	3,050,000	1,573,000	1,006	965	76,150
Water column case- 120 d			3,185,000	1,816,000	4,264	4,258	99,090
Shoreline contact case- 120 d			2,311,000	1,433,000	1,478	1,401	79,950
Batch Spill							
Surface Batch Spill 50th % Surface Oil Exposure Area	Vessel Route Location	3,200 L	-	-	-	-	-
Surface Batch Spill 95th % Surface Oil Exposure Area			-	-	-	-	-
Surface Batch Spill 95th % Water Column Oil Volume			-	-	-	-	-
Surface Batch Spill 95th Shoreline Contact Length			-	-	1,010	-	-

*There is only 1 category threshold (socio-economic) for THC –calculated by multiplying the area times the depth of the grid cell.

Table 4-5. Summary of the mass balance information for all representative scenarios. All values represent a percentage (%) of the total amount of released oil at the end of the representative deterministic scenarios.

95th Percentile Scenario	Site	Percent of Total Released Oil (%)						
		Surface	Evaporated	Water Column	Sediment	Ashore	Degraded	Outside Grid
Subsurface Blowout Releases								
Surface oil exposure case- 30 d	EL 1157	5.8	44.0	1.4	<0.1	<0.1	42.8	6.0
Water column case- 30 d		1.2	41.9	1.4	<0.1	3.0	42.9	9.7
Shoreline contact case- 30 d		1.7	44.4	1.0	<0.1	1.2	39.1	12.6
Surface oil exposure case- 120 d		14.3	41.7	2.5	<0.1	0.3	37.3	4.0
Water column case- 120 d		8.5	44.5	3.3	<0.1	0.2	32.8	10.8
Shoreline contact case- 120 d		14.2	41.8	2.7	<0.1	0.4	37.8	3.2
Surface oil exposure case- 30 d	EL 1158	1.6	46.1	0.7	<0.1	0.8	39.3	11.4
Water column case- 30 d		7.4	45.5	1.3	<0.1	<0.1	42.4	3.4
Shoreline contact case- 30 d		1.6	46.1	0.7	<0.1	0.8	39.3	11.4
Surface oil exposure case- 120 d		14.3	42.5	2.2	<0.1	0.1	36.1	4.8
Water column case- 120 d		9.3	42.7	2.9	<0.1	1.0	35.7	8.4
Shoreline contact case- 120 d		2.9	42.1	2.2	<0.1	0.2	30.6	22.1
Batch Spill								
Surface Batch Spill 50th % Surface Oil Exposure Area	Vessel Route Location	<0.1	67.2	11.9	<0.1	0.0	20.9	0.0
Surface Batch Spill 95th % Surface Oil Exposure Area		<0.1	67.2	11.9	<0.1	0.0	21.0	0.0
Surface Batch Spill 95th % Water Column Oil Volume		<0.1	64.2	12.6	<0.1	0.0	23.1	0.0
Surface Batch Spill 95th Shoreline Contact Length		<0.1	80.4	6.2	<0.1	1.1	12.3	0.0

5 DISCUSSION AND CONCLUSIONS

Most surface oil from both release locations was predicted to move eastward because of prevailing westerly winds and the North Atlantic current. The Labrador and North Atlantic currents have steady velocities in the region throughout the year resulting in fairly consistent subsurface oil exposure patterns, but wind speeds increase during the winter months leading to an increase in the probability of shoreline oiling. Based on the results of the stochastic analysis of hundreds of model scenarios, the average probability of shoreline oiling ranged from 3-4% in the summer and 5-9% in the winter. Individual points along shore did have maximum probability of shoreline oil contamination ranging from 8-28%, depending on the scenario. Depending on the time of year and environmental conditions at the time of the release, areas susceptible to shoreline oiling included the entire east coast and much of the west coast of Newfoundland, the Avalon Peninsula, the southern and eastern shores of Labrador and Sable Island. Oil that reached shore was expected to be patchy, discontinuous, and weathered, as it would have taken a minimum of 7 days (and frequently much longer) to reach shore.

Surface exposures above the socio-economic impact threshold were between 2,267,000 and 3,185,000 km^2 for selected deterministic simulations. Subsurface volumes exceeding the THC socio-economic threshold ranged from 60,290 to 99,090 km^3. Shoreline length exceeding mass per unit area thresholds ranged from a mode of 9 up to 4,510 km. In general, most simulated subsurface blowout cases led to predicted surface oil thickness and water column concentrations at or above socio-economic and ecological thresholds for potential impacts in the immediate vicinity and to the east of the release sites. In all representative deterministic cases typically <1% and always <3% of the total volume of released oil was predicted to strand on shorelines after 160 days.

The hypothetical releases modelled in this study are not intended to predict a specific future event, but rather are intended to be used as a tool in environmental assessments and spill contingency planning. The results presented in this document demonstrate that there are a range of potential trajectories and fates that could result if a release of crude oil or a batch spill of marine diesel were to occur at any point throughout the year. The specific trajectories and fates vary greatly for each release based upon the environmental conditions occurring at the time of the release. While each oil release is unique, and uncertainties exist, the results of this modelling study suggest that, if oil were to be released in the Project Area, it has a high likelihood of moving away from shore to the east with less likelihood of shoreline oil exposure. Furthermore, this modelling assumes completely unmitigated releases, which is an unlikely situation because emergency response measures would typically be employed in the event of a spill.

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BHP CANADA
ORPHAN BASIN EXPLORATION DRILLING PROJECT
2019-2028
19-P-204068

Oil Spill Trajectory and Fate Assessment
Appendix A: SIMAP and OILMAPDeep Model Descriptions

Oil Spill Risk Assessment
BHP Canada
Orphan Basin Exploration
Drilling Project 2019-2028
19-P-204068
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1 SIMAP MODEL DESCRIPTION

The analysis was performed using the model system developed by RPS called SIMAP (Spill Impact Model Analysis Package). SIMAP originated from the oil fates and biological effects submodels in the Natural Resource Damage Assessment Models for Coastal and Marine Environments (NRDAM/CME) and Great Lakes Environments (NRDAM/GLE), which ASA developed in the early 1990s for the U.S. Department of the Interior for use in "type A" Natural Resource Damage Assessment (NRDA) regulations under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). The most recent version of the type A models, the NRDAM/CME (Version 2.4, April 1996) was published as part of the CERCLA type A NRDA Final Rule (Federal Register, May 7, 1996, Vol. 61, No. 89, p. 20559-20614). The technical documentation for the NRDAM/CME is in French et al. (1996 a-c). This technical development involved several in-depth peer reviews, as described in the Final Rule.

While the NRDAM/CME and NRDAM/GLE were developed for simplified natural resource damage assessments of small spills in the United States, SIMAP is designed to evaluate fates and effects of both real and hypothetical spills in marine, estuarine and freshwater environments worldwide. Additions and modifications to prepare SIMAP were made to increase model resolution, allow modification and site-specificity of input data, allow incorporation of temporally varying current data, evaluate subsurface releases and movements of subsurface oil, track multiple chemical components of the oil, enable stochastic modelling, and facilitate analysis of results.

Below are brief descriptions of the fates and effects models presented in SIMAP. Detailed descriptions of the algorithms and assumptions in the model are in published papers (French McCay, 2002; 2003; 2004; 2009). The model has been validated with more than 20 case histories, including the *Exxon Valdez* and other large spills (French and Rines, 1997; French McCay, 2003; 2004; French McCay and Rowe, 2004) as well as test spills designed to verify the model (French et al., 1997).

1.1 Physical Fates Model

The three-dimensional physical fates model estimates distribution (as mass and concentrations) of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments. Oil fate processes included are oil spreading (gravitational and by shearing), evaporation, transport, randomized dispersion, emulsification, entrainment (natural and facilitated by dispersant), dissolution, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended sediments, adsorption of soluble and sparingly-soluble aromatics to suspended sediments, sedimentation, and degradation.

Oil is a mixture of hydrocarbons of varying physical, chemical, and toxicological characteristics. In the model, oil is represented by component categories, and the fate of each component is tracked separately. The "pseudo-component" approach (Payne et al., 1984; 1987; French et al., 1996a; Jones, 1997; Lehr et al., 2000) is used, where chemicals in the oil mixture are grouped by physical-chemical properties, and the resulting component category behaves as if it were a single chemical with characteristics typical of the chemical group.

The most toxic components of oil to aquatic organisms are low molecular weight aromatic compounds (monoaromatic and polycyclic aromatic hydrocarbons, MAHs and PAHs), which are both volatile and soluble in water. Their acute toxic effects are caused by non-polar narcosis, where toxicity is related to the octanol-water partition coefficient (K_{ow}), a measure of hydrophobicity. The more hydrophobic the compound, the more toxic it is likely to be. However, as K_{ow} increases, the compound also becomes less soluble in water, and so there is less exposure to aquatic organisms. The toxicity of compounds having $\log(K_{ow})$ values greater than about 5.6 is limited by their very low solubility in water, and consequent low bioavailability to aquatic biota (French McCay, 2002, Di Toro et al., 2000). Thus, the potential for acute effects is the result of a balance between bioavailability (exposure),

toxicity once exposed, and duration of exposure. French McCay (2002) contains a full description of the oil toxicity model in SIMAP, and French McCay (2002) describes the implementation of the toxicity model in SIMAP.

Because of these considerations, the SIMAP fates model focuses on tracking the lower molecular weight aromatic components divided into chemical groups based on volatility, solubility, and hydrophobicity. In the model, the oil is treated as comprising eight components (defined in Table 1). Six of the components (i.e., all but the two non-volatile residual components representing non-volatile aromatics and aliphatics) evaporate at rates specific to the pseudo-component. Solubility is strongly correlated with volatility, and the solubility of aromatics is higher than aliphatics of the same volatility. The MAHs are the most soluble, the 2-ring PAHs are less soluble, and the 3-ring PAHs slightly soluble (Mackay et al., 1992). Both the solubility and toxicity of the non-aromatic hydrocarbons are much less than for the aromatics, and dissolution (and water concentrations) of non-aromatics is safely ignored. Thus, dissolved concentrations are calculated only for each of the three soluble aromatic pseudo-components.

Table 1. Definition of four distillation cuts and the eight pseudo-components in the model (Monoaromatic Hydrocarbons, MAHs; Benzene + Toluene + Ethylbenzene + Xylene, BTEX; Polycyclic Aromatic Hydrocarbons, PAHs).

Characteristic	Volatile and Highly Soluble	Semi-volatile and Soluble	Low Volatility and Slightly Soluble	Residual (non-volatile and very low solubility)
Distillation cut	1	2	3	4
Boiling Point (^{o}C)	< 180	180 - 265	265 - 380	>380
Molecular Weight	50 - 125	125 - 168	152 - 215	> 215
Log(K_{ow})	2.1-3.7	3.7-4.4	3.9-5.6	>5.6
Aliphatic pseudo-components: Number of Carbons	volatile aliphatics: C4 – C10	semi-volatile aliphatics: C10 – C15	low-volatility aliphatics: C15 – C20	non-volatile aliphatics: > C20
Aromatic pseudo-component name: included compounds	MAHs: BTEX, MAHs to C3-benzenes	2 ring PAHs: C4-benzenes, naphthalene, C1-, C2-naphthalenes	3 ring PAHs: C3-, C4-naphthalenes, 3-4 ring PAHs with log(K_{ow}) < 5.6	$\geq$4 ring aromatics: PAHs with log(K_{ow}) > 5.6 (very low solubility)

This number of components provides sufficient accuracy for the evaporation and dissolution calculations, particularly given the time frame (minutes) over which dissolution occurs from small droplets and the rapid resurfacing of large droplets (see discussion above). The alternative of treating oil as a single compound with empirically-derived rates (e.g., Mackay et al., 1980; Stiver and Mackay, 1984) does not provide sufficient accuracy for environmental effects analyses because the effects to water column organisms are caused by MAHs and PAHs, which have specific properties that differ from the other volatile and soluble compounds. The model has been validated both in predicting dissolved concentrations and resulting toxic effects, supporting the adequacy of the use of this number of pseudo-components (French McCay, 2003).

The lower molecular weight aromatics dissolve from the whole oil and are partitioned in the water column and sediments according to equilibrium partitioning theory (French et al., 1996a; French McCay, 2004). The residual fractions in the model are composed of non-volatile and insoluble compounds that remain in the “whole oil” that spreads, is transported on the water surface, strands on shorelines, and disperses into the water column as oil droplets or remains on the surface as tar balls. This is the fraction that composes black oil, mousse, and sheen.

1.2 Oil Fate Model Processes

The schematic in Figure 1 depicts oil fates processes simulated in open water conditions, while the schematic in Figure 2 depicts oil fates processes that are simulated at and near the shoreline. Because oil contains many

chemicals with varying physical-chemical properties, and the environment is spatially and temporally variable, the oil rapidly separates into different phases or parts of the environment:

- Surface oil;
- Emulsified oil (mousse) and tar balls;
- Oil droplets suspended in the water column;
- Oil adhering to suspended particulate matter in the water;
- Dissolved lower molecular weight components (MAHs, PAHs, and other soluble components) in the water column;
- Oil on and in the sediments;
- Dissolved lower molecular weight components (MAHs, PAHs, and other soluble components) in the sediment pore water;
- Oil on and in the shoreline sediments and surfaces.

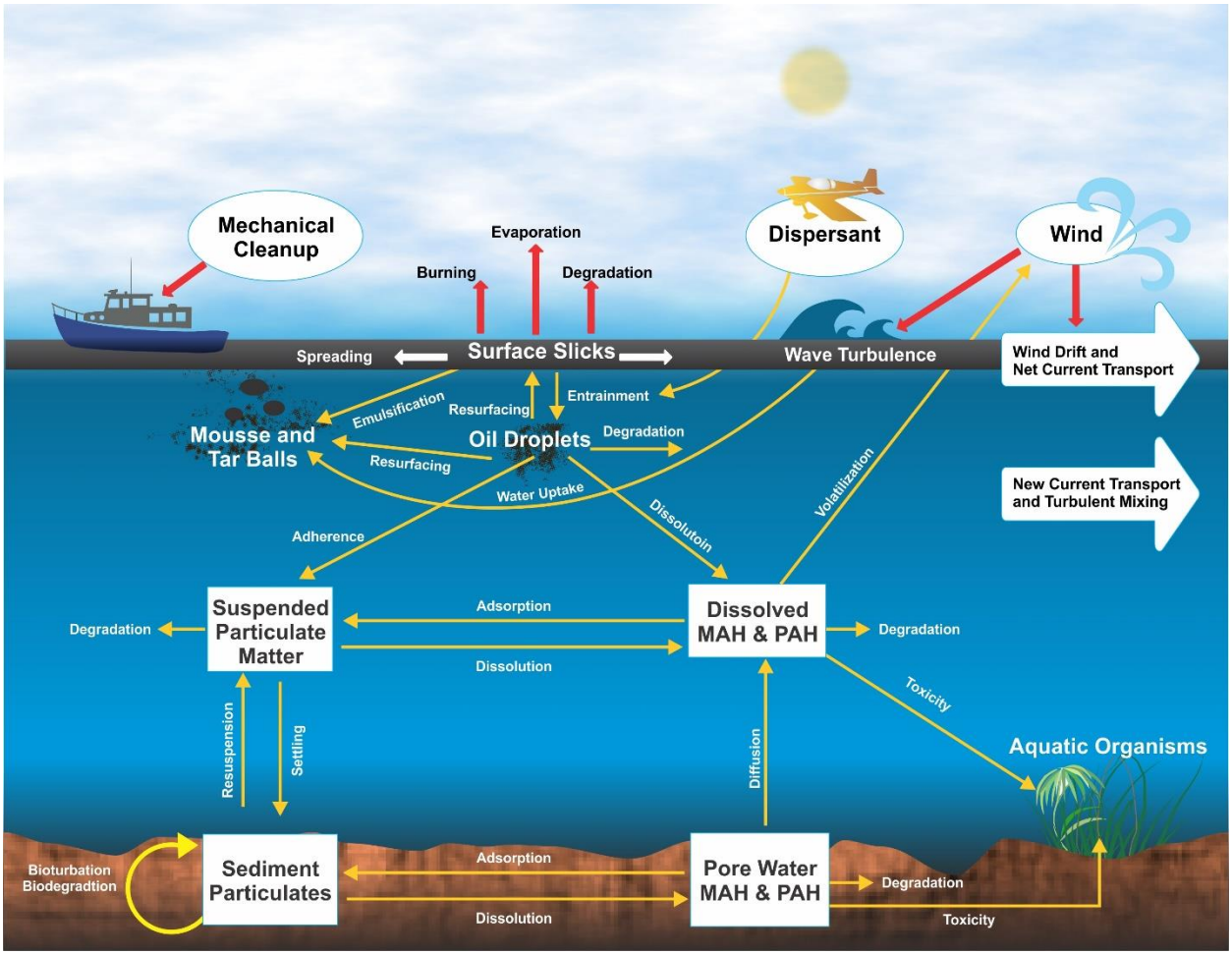

Figure 1. Simulated oil fates processes in open water in the SIMAP model.

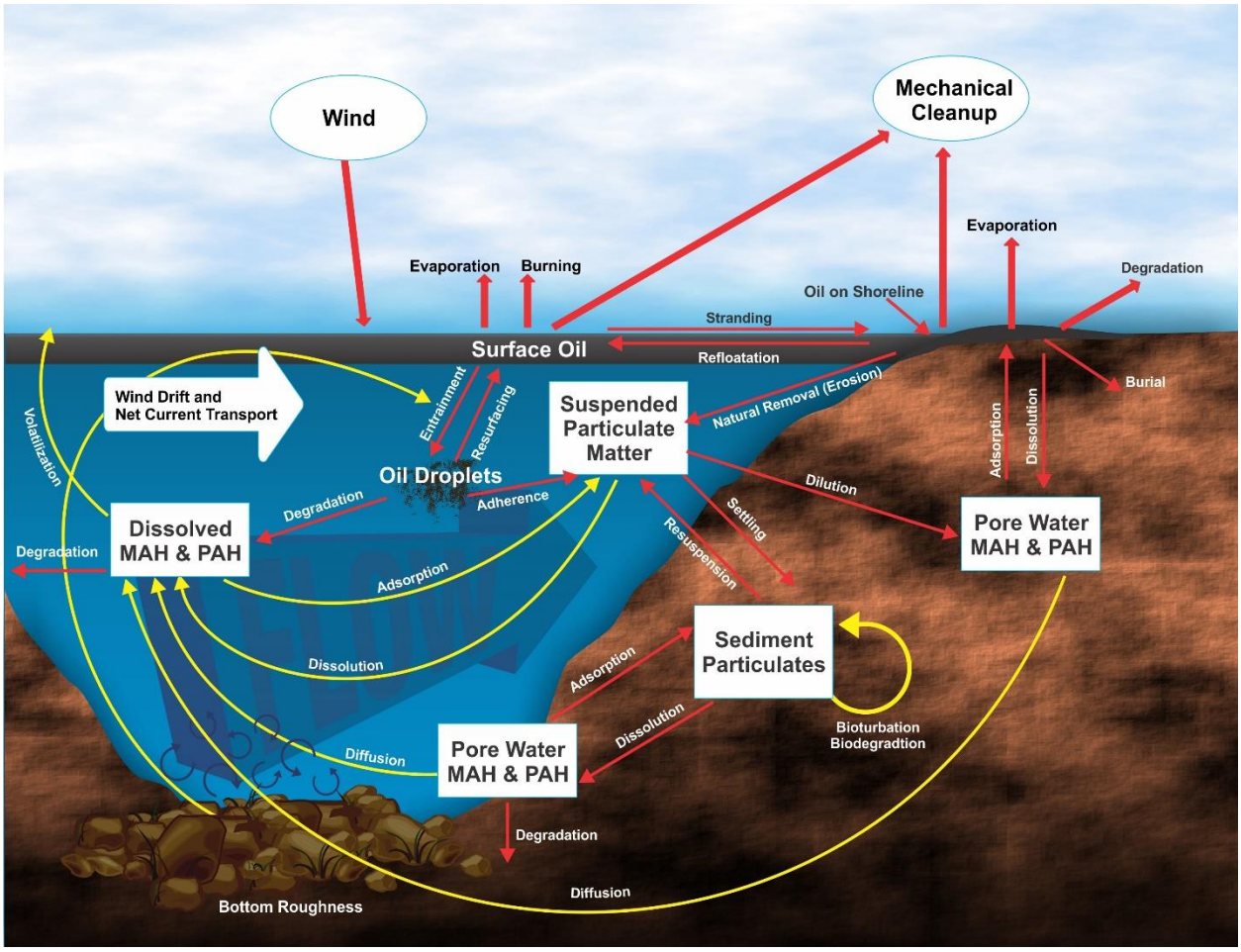

Figure 2. Simulated oil fates processes at the shoreline in the SIMAP model.

The schematics in Figure 1 and Figure 2 represent oil fates processes that are simulated in the model:

- Spreading is the thinning and broadening of surface slicks caused by gravitational forces and surface tension. This occurs rapidly after oil is spilled on the water surface. The rate of spreading is faster if oil viscosity is lower. Viscosity decreases as temperature increases. Viscosity increases as oil emulsifies.
- Transport is the process where oil is carried by currents.
- Turbulent dispersion: Typically there are also “sub-scale” currents (not included in the current data), better known as turbulence that move and mix oil in three dimensions. The process by which turbulence mixes and spreads oil components on the water surface and in the water is called turbulent dispersion.
- Evaporation is the process where volatile components of the oil diffuse from the oil and enter the gaseous phase (atmosphere). Evaporation from surface and shoreline oil increases as the oil surface area, temperature, and wind speed increase. As lighter components evaporate off, the remaining “weathered” oil becomes more viscous.
- Emulsification is the process where water is mixed into the oil, such that the oil makes a matrix with embedded water droplets. The resulting mixture is commonly called mousse. It is technically referred to as a water-in-oil emulsion. The rate of emulsification increases with increasing wind speed and turbulence on the surface of the water. Viscosity increases as oil emulsifies.

- Entrainment is the process where waves break over surface oil and carry it as droplets into the water column. At higher wind speeds, or where currents and bottom roughness induce turbulence, wave heights may reach a threshold where they break. In open waters, waves break beginning at about 12 knots of wind speed and wave breaking increases as wind speed becomes higher. Thus, entrainment becomes increasingly important (higher rate of mass transfer to the water) the higher the wind speed. As turbulence from whatever source increases, the oil droplet sizes become smaller. Application of chemical dispersant increases the entrainment rate of oil and decreases droplet size at a given level of turbulence. Entrainment rate is slower, and droplet size is larger, as oil viscosity increases (by emulsification and evaporation loss of lighter volatile components). The droplet size determines how fast and whether the oil resurfaces.
- Resurfacing of entrained oil rapidly occurs for larger oil droplets. Smaller droplets resurface when the wave turbulence decreases. The smallest droplets do not resurface, as typical turbulence levels in the water keep them in suspension indefinitely. Local winds at the water surface can also prevent oil from surfacing. Resurfaced oil typically forms sheens. In open water where currents are relatively slow, surface slicks are usually blown downwind faster than the underlying water, resurfacing droplets come up behind the leading edge of the oil, effectively spreading the slicks in the down-wind direction.
- Dissolution is the process where water-soluble components diffuse out of the oil into the water. Dissolution rate increases the higher the surface area of the oil relative to its volume. As the surface area to volume ratio is higher for smaller spherical droplets, the smaller the droplets the higher the dissolution rate. The higher the wave turbulence, the smaller the droplets of entrained oil. Dissolution from entrained small droplets is much faster than from surface slicks in the shape of flat plates. The soluble components are also volatile, and evaporation from surface slicks is faster than dissolution into the underlying water. Thus, the processes of evaporation and dissolution are competitive, with evaporation the dominant process for surface oil.
- Volatilization of dissolved components from the water to the atmosphere occurs as they are mixed and diffuse to the water surface boundary and enter the gas phase. Volatilization rate increase with increasing air and water temperature.
- Adsorption of dissolved components to particulate matter in the water occurs because the soluble components are only sparingly so. These compounds (MAHs and PAHs) preferentially adsorb to particulates when the latter are present. The higher the concentration of suspended particulates, the more adsorption. Also, the higher the molecular weight of the compound, the less soluble, and the more the compound adsorbs to particulate matter.
- Adherence is the process where oil droplets combine with particles in the water. If the particles are suspended sediments, the combined oil/suspended sediment agglomerate is heavier than the oil itself and than the water. If turbulence subsides sufficiently, the oil-sediment agglomerates will settle.
- Sedimentation (settling) is the process where oil-sediment agglomerates and particles with adsorbed sparingly-soluble components (MAHs and PAHs) settle to the bottom sediments. Adherence and sedimentation can be an important pathway of oil in near shore areas when waves are strong and subsequently subside. Generally, oil-sediment agglomerates transfer more PAH to the bottom than sediments with PAHs that were adsorbed from the dissolved phase in the water column.
- Resuspension of settled oil-sediment particles and particles with adsorbed sparingly-soluble components (MAHs and PAHs) may occur if current speeds and turbulence exceed threshold values where cohesive forces can be overcome.
- Diffusion is the process where dissolved compounds move from higher to lower concentration areas by the random motion of molecules and microscale turbulence. Dissolved components in bottom and shoreline sediments can diffuse out to the water where concentrations are relatively low. Bioturbation, groundwater

discharge and hyporheic flow of water through stream-bed sediments can greatly increase the rate of diffusion from sediments (see below).

- Dilution occurs when water of lower concentration is mixed into water with higher concentration by turbulence, currents, or shoreline groundwater.
- Bioturbation is the process where animals in the sediments mix the surface sediment layer while burrowing, feeding, or passing water over their gills. In open-water soft-bottom environments, bioturbation effectively mixes the surface sediment layer about 10 cm thick (in non-polluted areas).
- Degradation is the process where oil components are changed either chemically or biologically (biodegradation) to another compound. It includes breakdown to simpler organic carbon compounds by bacteria and other organisms, photo-oxidation by solar energy, and other chemical reactions. Higher temperature and higher light intensity (particularly ultraviolet wavelengths) increase the rate of degradation.
- Floating oil may strand on shorelines and refloat as water levels rise, allowing the oil to move further down current (downstream).

For a spill on the water surface, the gravitational spreading occurs very rapidly (within hours) to a minimum thickness. Thus, the area exposed to evaporation is high relative to the oil volume. Evaporation proceeds faster than dissolution. Thus, most of the volatiles and semi-volatiles evaporate, with a smaller fraction dissolving into the water. Degradation (photo-oxidation and biodegradation) also occurs at a relatively slow rate compared to these processes.

Evaporation is more rapid as the wind speed increases. However, when wind speeds exceed approximately 12 knots (6 m/s) and in open water, white caps begin to form and the breaking waves entrain oil as droplets into the water column. Higher wind speeds (and turbulence) increase entrainment and results in smaller droplet sizes. From Stoke's Law, larger droplets resurface faster and form surface slicks. Thus, a dynamic balance evolves between entrainment and resurfacing. As high-wind events occur, the entrainment rate increases. When the winds subside to less than 12 knots, the larger oil droplets resurface and remain floating. Similar dynamics occur in turbulent streams.

The smallest oil droplets remain entrained in the water column for an indefinite period. Larger oil droplets rise to the surface at varying rates. While the droplets are under water, dissolution of the light and soluble components occurs. Dissolution rate is a function of the surface area available. Thus, most dissolution occurs from droplets, as opposed to from surface slicks, since droplets have a higher surface area to volume ratio, and they are not in contact with the atmosphere (and so the soluble components do not preferentially evaporate as they do from surface oil).

If oil is released or driven underwater, it forms droplets of varying sizes. More turbulent conditions result in smaller droplet sizes. From Stoke's Law, larger droplets rise faster, and surface if the water is shallow. Resurfaced oil behaves as surface oil after gravitational spreading has occurred. The surface oil may be re-entrained. The smallest droplets in most cases remain in the water permanently. As a result of the higher surface area per volume of small droplets, the dissolution rate is much higher from subsurface oil than from floating oil on the water surface.

Because of these interactions, the majority of dissolved constituents (which are of concern because of potential effects on aquatic organisms) are from droplets entrained in the water. For a given spill volume and oil type/composition, with increasing turbulence either at the water surface and/or at the stream bed: there is an increasing amount of oil entrained; the oil is increasingly broken up into smaller droplets; there is more likelihood of the oil remaining entrained rather than resurfacing; the dissolved concentrations will be higher. Entrainment and dissolved concentrations increase with (1) higher wind speed, (2) increased turbulence from other sources of turbulence (waves on a beach, rapids, and waterfalls in rivers, etc.), (3) subsurface releases (especially under higher pressure and turbulence), and (4) application of chemical dispersants. Chemical dispersants both increase

the amount of oil entrained and decrease the oil droplet size. Thus, chemical dispersants increase the dissolution rate of soluble components.

These processes that increase the rate of supply of dissolved constituents are balanced by loss terms in the model: (1) transport (dilution), (2) volatilization from the dissolved phase to the atmosphere, (3) adsorption to suspended particulate material (SPM) and sedimentation, and (4) degradation (photo-oxidation or biologically mediated). Also, other processes slow the entrainment rate: (1) emulsification increases viscosity and slows or eliminates entrainment; (2) adsorption of oil droplets to SPM and settling removes oil from the water; (3) stranding on shorelines removes oil from the water; and (4) mechanical cleanup and burning removes mass from the water surface and shorelines. Thus, the model-predicted concentrations are the resulting balance of all these processes and the best estimates based on our quantitative understanding of the individual processes.

The algorithms used to model these processes are described in French McCay (2004). Lagrangian elements (spillets) are used to simulate the movements of oil components in three dimensions over time. Surface floating oil, subsurface droplets, and dissolved components are tracked in separate spillets. Transport is the sum of advective velocities by currents input to the model, surface wind drift, vertical movement according to buoyancy, and randomized turbulent diffusive velocities in three dimensions. The vertical diffusion coefficient is computed as a function of wind speed in the surface wave-mixed layer. The horizontal and deeper water vertical diffusion coefficients are model inputs.

The oil (whole and as pseudo-components) separates into different phases or parts of the environment, i.e., surface slicks; emulsified oil (mousse) and tar balls; oil droplets suspended in the water column; dissolved lower molecular weight components (MAHs and PAHs) in the water column; oil droplets adhered and hydrocarbons adsorbed to suspended particulate matter in the water; hydrocarbons on and in the sediments; dissolved MAHs and PAHs in the sediment pore water; and hydrocarbons on and in the shoreline sediments and surfaces.

1.3 Oil Fates Algorithms

1.3.1 Transport

Lagrangian particles (spillets) are moved in three dimensions over time. For each model time step, the new vector position of the spillet center is calculated from the old plus the vector sum of east-west, north-south, and vertical components of advective and diffusive velocities:

$$X_t = X_{t-1} + \Delta t \, (U_t + D_t + R_t + W_t)$$

where X_t is the vector position at time t, X_{t-1} is the vector position the previous time step, Δt is the time step, U_t is the sum of all the advective (current) velocity components in three dimensions at time t, D_t is the sum of the randomized diffusive velocities in three dimensions at time t, R_t is the rise or sinking velocity of whole oil droplets in the water column, and W_t is the surface wind transport (“wind drift”). The magnitudes of the components of D_t are scaled by horizontal and vertical diffusion coefficients (Okubo and Ozmidov, 1970; Okubo, 1971). The vertical diffusion coefficient is computed as a function of wind speed in the surface wave-mixed layer (which ranges from centimeter scales in rivers and near lee shorelines to potentially meters in large water bodies away from shore when wind speeds are high), based on Thorpe (1984). R_t is computed by Stokes law, where velocity is related to the difference in density between the particle and the water, and to the particle diameter. The algorithm developed by Youssef and Spaulding (1993) is used for wind transport in the surface wave-mixed layer (W_t, described below).

1.3.2 Shoreline Stranding

The fate of spilled oil that reaches the shoreline depends on characteristics of the oil, the type of shoreline, and the energy environment. The stranding algorithm is based on work by CSE/ASA/BAT (1986), Gundlach (1987), and Reed and Gundlach (1989) in developing the COZOIL model for the U.S. Minerals Management Service. In

SIMAP, deposition occurs when an oil spillet intersects shore surface. Deposition ceases when the volume holding capacity for the shore surface is reached. Subsequent oil coming ashore is not allowed to remain on the shore surface. It is refloated by rising water, and carried away by currents and wind drift. The remaining shoreline oil is then removed exponentially with time. Data for holding capacity and removal rate are taken from CSE/ABA/BAT (1986) and Gundlach (1987), and are a function of oil viscosity and shore type. The algorithm and data are in French et al. (1996a).

1.3.3 Spreading

Spreading determines the areal extent of the surface oil, which in turn influences its rates of evaporation, dissolution, dispersion (entrainment) and photo-oxidation, all of which are functions of surface area. Spreading results from the balance among the forces of gravity, inertia, viscosity, and surface tension (which increases the diameter of each spillet); turbulent diffusion (which spreads the spillets apart); and entrainment followed by resurfacing, which can spatially separate the leading edge of the oil from resurfaced oil transported in a different direction by subsurface currents.

For many years Fay's (1971) three-regime spreading theory was widely used in oil spill models (ASCE, 1996). Mackay et al. (1980; 1982) modified Fay's approach and described the oil as thin and thick slicks. Their approach used an empirical formulation based on Fay's (1971) terminal spreading behavior. They assumed the thick slick feeds the thin slick and that 80-90% of the total slick area is represented by the thin slick. In SIMAP, oil spillets on the water surface increase in diameter according to the spreading algorithm empirically-derived by Mackay et al. (1980; 1982). Sensitivity analyses of this algorithm led to the discovery that the solution was affected by the number of spillets used. Thus, a formulation was derived to normalize the solution under differing numbers of surface spillets (Kolluru et al., 1994). Spreading is stopped when an oil-specific terminal thickness is reached.

1.3.4 Evaporation

The rate of evaporation depends on surface area, thickness, vapor pressure and mass transport coefficient, which in turn are functions of the composition of the oil, wind speed and temperature (Fingas, 1996; 1997; 1998; 1999; Jones, 1997). As oil evaporates its composition changes, affecting its density and viscosity as well as subsequent evaporation. The most volatile hydrocarbons evaporate most rapidly, typically in less than a day and sometimes in under an hour (McAuliffe, 1989). As the oil continues to weather, and particularly if it forms a water-in-oil emulsion, evaporation will be significantly decreased.

The evaporation algorithm in SIMAP is based on accepted evaporation theory, which follows Raoult’s Law that each component will evaporate with a rate proportional to the saturation vapor pressure and mole fraction present for that component. The pseudo-component approach (Payne et al., 1984; French et al., 1996a; Jones, 1997; Lehr et al., 2000) is used, such that each component evaporates according to its mean vapor pressure, solubility, and molecular weight (Table 2-3). The mass transfer coefficient is calculated using the methodology of Mackay and Matsugu (1973), as described in French et al. (1996a).

1.3.5 Entrainment

As oil on the water surface is exposed to wind and waves, or if oil moves into a turbulent area of a stream or river, it is entrained (or dispersed) into the water column. Entrainment is a physical process where globules of oil are transported from the water surface into the water column due to breaking waves or other turbulence. It has been observed that entrained oil is broken into droplets of varying sizes. Smaller droplets spread and diffuse in the water column, while larger ones rise back to the surface.

Entrainment by Breaking Surface Wave Action

In open waters, breaking waves created by the action of wind and waves on the water surface are the primary sources of energy for entrainment. Entrainment is strongly dependant on turbulence and is greater in areas of high wave energy (Delvigne and Sweeney, 1988).

Delvigne and Sweeney (1988), using laboratory and flume experimental observations, developed a relationship for entrainment rate and oil droplet size distribution as a function of turbulent energy level and oil viscosity. Entrained droplets in the water column rise according to Stokes law, where velocity is related to the difference in density between the particle and the water, and to the particle diameter. The data and relationships in Delvigne and Sweeney (1988) are used in SIMAP to calculate mass and particle size distribution of droplets entrained. Particle size decreases with higher turbulent energy level and lower oil viscosity. The natural dispersion particle sizes observed by Delvigne and Sweeney (1988) are confirmed by field observations by Lunel (1993a,b).

Use of chemical dispersants (not modelled in the scenarios examined here) decrease the median particle size, increasing the number of droplets in the <70 µm range (Daling et al., 1990; Lunel, 1993a,b). Particle size distributions for dispersed oil are available for several oils from these studies. When dispersant is applied, the model entrains surface oil, creating subsurface droplets in the appropriate size distribution for dispersant use. The median particle size for permanently dispersed droplets is set at 20 microns, the median size observed by Lunel (1993a,b). The fraction of oil permanently dispersed is set by the assumed dispersant efficiency. The IKU/SINTEF studies provide data on the viscosity range where oils may be dispersed chemically. Typically, dispersants are effective up to about 10,000 cP (Aamo et al., 1993; Daling and Brandvik, 1988; 1991; Daling et al., 1997). In the model, oil is dispersed up to 10,000 cP.

Entrained oil is well mixed in (i.e., mixed uniformly throughout) the wave-mixed zone. Vertical mixing is simulated by random placement of particles within the wave-mixed layer each time step. Settling of particles does not occur in water depths where waves reach the bottom (taken as 1.5 times wave height). Wave height is calculated from wind speed, duration and fetch (distance upwind to land), using the algorithms in CERC (1984). Wave height is on the scale of centimetres in small rivers and streams, and near lee shorelines; whereas it may increase to metres in open waters under windy conditions.

1.3.6 Emulsification (Mousse Formation)

The formation of water-in-oil emulsions, or mousse, depends on oil composition and turbulence level. Emulsified oil can contain as much as 80% water in the form of micrometre-sized droplets dispersed within a continuous phase of oil (Daling and Brandvik, 1988; Fingas et al., 1997). Viscosities are typically much higher than that of the parent oil. The incorporation of water also dramatically increases the oil/water mixture volume.

The Mackay and Zagorski (1982) emulsification scheme is implemented in SIMAP for floating oil. Water content increases exponentially, with the rate related to the square of wind speed and previous water incorporation. Viscosity is a function of water content. The change in viscosity feeds back in the model to the entrainment rate.

1.3.7 Dissolution

Dissolution is the process by which soluble hydrocarbons enter the water from a surface slick or from entrained oil droplets. The lower molecular weight hydrocarbons tend to be both more volatile and more soluble than those of higher molecular weight. For surface slicks, since the partial pressures tend to exceed the solubilities of these lower molecular weight compounds, evaporation accounts for a larger portion of the mass than dissolution (McAuliffe, 1989), except perhaps under ice. Dissolution and evaporation are competitive processes. The dissolved component concentration of hydrocarbons in water under a surface slick shows an initial increase followed by a rapid decrease after some hours due to the evaporative loss of components. Most soluble components are also volatile and direct evaporation (volatilization) from the water column depletes their

concentrations in the water. Dissolution is particularly important where evaporation is low (dispersed oil droplets and ice-covered surfaces). Dissolution can be significant from entrained droplets because of the lack of atmospheric exposure and because of the higher surface area per unit of volume.

The model developed by Mackay and Leinonen (1977) is used in SIMAP for dissolution from a surface slick. The slick (spillet) is treated as a flat plate, with a mass flux (Hines and Maddox, 1985) related to solubility and temperature. It assumes a well-mixed layer with most of the resistance to mass transfer lying in a hypothetical stagnant region close to the oil. For subsurface oil, dissolution is treated as a mass flux across the surface area of a droplet (treated as a sphere) in a calculation analogous to the Mackay and Leinonen (1977) algorithm. The dissolution algorithm was developed in French et al. (1996a).

1.3.8 Volatilization from the Water column

The procedure outlined by Lyman et al. (1982), based on Henry's Law and mass flux (Hines and Maddox, 1985), is followed in the SIMAP fates model. The volatilization depth for dissolved substances is limited to the maximum of one half the wave height. Wave height is computed from the wind speed and fetch (CERC, 1984). The volatilization algorithm was developed in French et al. (1996a).

1.3.9 Adsorption and Sedimentation

Aromatics dissolved in the water column are carried to the sediments primarily by adsorption to suspended particulates, and subsequent settling. The ratio of adsorbed (C_a) to dissolved (C_{dis}) concentrations is computed from standard equilibrium partitioning theory as

$$C_a / C_{dis} = K_{oc} C_{ss}$$

K_{oc} is a dimensionless partition coefficient and C_{ss} is the concentration of suspended particulate matter (SPM) in the water column expressed as mass of particulate per volume of water. As a default, the model uses a mean value of total suspended solids of 10 mg/l (Kullenberg, 1982); alternatively, suspended sediment concentration is specified as model input.

Sedimentation of oil droplets occurs when the specific gravity of oil increases over that of the surrounding water. Several processes may act on entrained oil and surface slicks to increase density: weathering (evaporation, dissolution and emulsification), adhesion or sorption onto suspended particles or detrital material, and incorporation of sediment into oil during interaction with suspended particulates, bottom sediments, and shorelines. Rates of sedimentation depend on the concentration of suspended particulates and the rates of particulate flux into and out of an area. In areas with high suspended particulate concentrations, rapid dispersal and removal of oil is found due to sorption and adhesion (Payne and McNabb, 1984).

Kirstein et al. (1987) and Payne et al. (1987) used a reaction term to characterize the water column interactions of oil and suspended particulates. The reaction term represents the collision of oil droplets and suspended matter, and both oiled and unoiled particulates are accounted for. The model formulation developed by Kirstein et al. (1987) is used to calculate the volume of oil adhered to particles. In the case where the oil mass is larger than the adhered sediment (i.e., the sediment has been incorporated into the oil) the buoyancy of the oil droplet will control its settling or rise rate. The Stoke's law formulation is used to adjust vertical position of these particles. If the mass of adhered droplets is small relative to the mass of the sediment it has adhered to, the sediment settling velocity will control the fate of the combined particulate.

1.3.10 Degradation

Degradation may occur as the result of photolysis, which is a chemical process energized by ultraviolet light from the sun, and by biological (bacterial) breakdown, termed biodegradation. In the model, degradation occurs on the surface slick, deposited oil on the shore, the entrained oil and aromatics in the water column, and oil in the

sediments. A first order decay algorithm is used, with a specified (total) degradation rate for each of surface oil, water column oil and sedimented oil (French et al., 1999).

1.4 Habitat Type

Ecological habitat types (Table 2) are broadly categorized into two zones within SIMAP: shoreline and submerged (or intertidal versus subtidal in estuarine and marine areas, where intertidal habitats are those above spring low water tide level, with subtidal being all water areas below that level). In modelled scenarios, the shoreline habitats may become oiled as surface oil makes contact with these cells. Submerged or subtidal cells are always underwater. Intertidal/shoreline areas may be extensive, such that they are wide enough to be represented by an entire grid cell at the resolution of the grid. These are typically either mud flats or wetlands, and are coded 20 (seaward mudflat), 21 (seaward wetland), 50 (landward mudflat), or 51 (landward wetland). All other intertidal/shoreline habitats are typically much narrower than the size of a grid cell. Thus, these fringing intertidal/shore types (indicated by F in Table 2) have typical (for the region, e.g., French et al., 1996a for estuarine and marine areas) widths associated with them in the model. Boundaries between land and water are fringing habitat types. On the waterside of fringing grid cells, there may be extensive intertidal/shoreline grid cells if the wetlands or mudflats are extensive. Otherwise, subtidal/submerged habitats border the fringing cells.

Table 2. Classification of habitats. seaward (Sw) and landward (Lw) system codes are listed. (fringing types indicated by (F) are only as wide as the intertidal zone or shoreline width where oiling might occur. Others (W = water) are a full grid cell.

Habitat Code (Sw,Lw)	Ecological Habitat	F or W
	Intertidal / Shore	
1,31	Rocky Shore	F
2,32	Gravel Shore	F
3,33	Sand Beach or Shore	F
4,34	Fringing Mud Flat	F
5,35	Fringing Wetland (Emergent or Forested)	F
6,36	Macroalgal Bed	F
7,37	Mollusk Reef	F
8,38	Coral Reef (marine only)	F
	Subtidal / Submerged	
9,39	Rock Bottom	W
10,40	Gravel Bottom	W
11,41	Sand Bottom	W
12,42	Silt-mud Bottom	W
13,43	Wetland (submerged areas)	W
14,44	Macroalgal Bed	W
15,45	Mollusk Reef	W
16,46	Coral Reef (marine only)	W
17,47	Submerged Aquatic Vegetation Bed	W
Intertidal / Shore		
18,48	Man-made, Artificial	F
19,49	Ice Edge	F
20,50	Extensive Mud Flat	W
21,51	Extensive Wetland (Emergent or Forested)	W

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2 OILMAP DEEP MODEL DESCRIPTION

OILMAP Deep was used to characterize the near field blowout conditions for use in the SIMAP model, which characterized the far field effects. OILMAP Deep contains two sub-models, a plume model and a droplet size model. The plume model predicts the evolution of plume position, geometry, centerline velocity, and oil and gas concentrations until the plume either surfaces or reaches a terminal height at which point the plume is trapped (Figure 3). The droplet model predicts the size and volume (mass) distribution of the oil droplets. Provided below is an overview of blowout theory and modelling implementation.

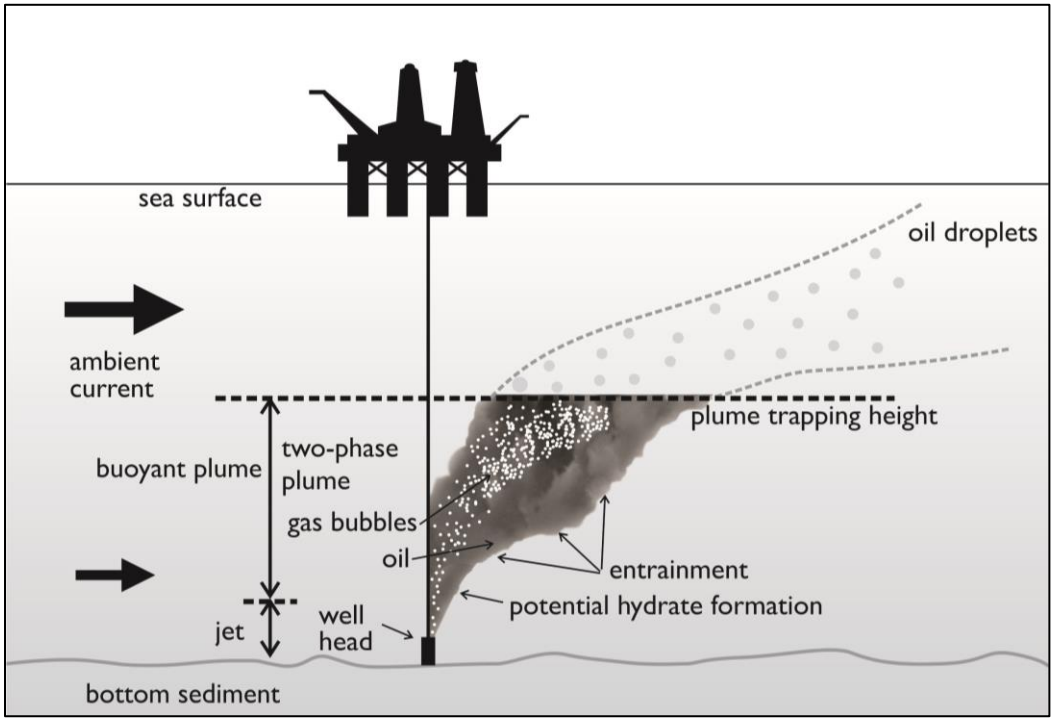

Figure 3. Modelled processes for a subsea blowout in OILMAP Deep.

2.1 Blowout Model Theory

RPS' oil blowout model is based on the work of McDougall (gas plume model, 1978), Fanneløp and Sjøen (1980a, plume/free surface interaction), Spaulding (1982, oil concentration model), Kolluru, (1994, World Oil Spill Model implementation), Spaulding et.al. (2000, hydrate formation) and Zheng et.al. (2002, 2003, gas dissolution). A simplified integral jet theory is employed for the vertical as well as for the horizontal motions of the gas-oil plume. The necessary model parameters defining the rates of entrainment and spreading of the jet are obtained from laboratory studies (Fanneløp and Sjøen 1980a). The gas plume analysis is described in McDougall (1978), Spaulding (1982), and Fanneløp and Sjøen (1980a). The hydrate formation and dissociation is formulated based on a unique equilibrium kinetics model developed by R. Bishnoi and colleagues at the University of Calgary. A brief description of the governing equations used in RPS ASA's blowout model and the solution methodology are described in Spaulding et al., 2000. The core components of this model are conservation of water mass, conservation of oil mass, conservation of momentum, and conservation of buoyancy.

Oil droplet size distribution calculations are based on the methodology presented by Yapa and Zheng (2001a&b) and Chen and Yapa (2007), which uses a maximum diameter calculation and the associated volumetric droplet size distribution. The maximum diameter can is determined using Hinze (1955) and coefficients consistent with Chen and Yapa (2007). The droplet size distribution is defined using a Rosin-Rammler (1933) function.

2.2 Blowout Model Implementation

The results of the near-field blowout model provide information to the far field fates model about the plume (the three-dimensional extent of the mixture of gas/oil/water) and characterization of the initial dispersion/mixing of the oil discharged during the blowout. Key factors in this analysis are the volume flux of oil and gas, gas to oil ratio (GOR), depth, exit flow velocity and environmental water column conditions (the profile of water temperature and density), which affect both the trap height and the potential for hydrate formation. Other factors such as duration of the blowout and ambient currents are also included but are less important.

The OILMAP Deep blowout model implementation is done in two parts; the first is the plume model described in the previous section, based on the McDougall bubble plume model; the second is the oil droplet size distribution and volume fraction calculation. Both are based on the same scenario blowout specifications (e.g., oil type and flow rate, gas oil ratio and depth), but the model predictions are treated separately and do not interact. The two parts of the model predictions only come together at the collapse of the near field plume, at the trap height, where the depth and droplet distribution predictions are used for initialization of the far field particle model simulation.

The blowout plume model solves equations for conservation of water mass, momentum, buoyancy, and gas mass as described in Section 2.1 of the OILMAP Deep Technical Documentation, using integral plume theory. An additional equation for the conservation of oil at the plume centerline is also solved.

The plume model prediction is defined externally by a small set of parameters including:

- Blowout release depth
- Oil discharge rate
- Oil density
- Gas: oil ratio (GOR) at the surface
- Atmospheric pressure
- Ambient seawater density profile
- Plume spreading coefficient
- Entrainment parameter (α)
- Slip velocity of gas bubbles in the oil plume
- Ambient current velocity
- Water column profile of temperature and density

The blowout plume models the evolution of the plume within the water column, solving for the position, radius, velocity and oil and gas concentrations along the centerline. The blowout droplet model solves for the distribution of mass within droplet sizes associated with the turbulence of the release. Typically, the near-field model is on the timescale of seconds and length scale of hundreds of meters, where the far-field model is on the scales of hours/days and kilometers. The details of the near field modelling that are passed along to the far field model include the distribution of the release mass in different droplet sizes at the appropriate initial position in the water column.

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BHP CANADA
ORPHAN BASIN EXPLORATION DRILLING PROJECT 2019-2028: ANNEX A
19-P-204068

Oil Spill Trajectory and Fate Assessment: Mitigation Modelling

Oil Spill Risk Assessment
BHP Canada
Orphan Basin Exploration
Drilling Project 2019-2028
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EXECUTIVE SUMMARY

Study Summary

The RPS Technical Report: BHP Canada Orphan Basin Exploration Drilling Project 2019-2028 (Horn et al., 2019) was prepared for BHP Canada to summarize the potential consequences of short (30 day) and long (120) subsurface blowouts that were completely unmitigated within Exploration Licenses EL 1157 and EL 1158. This work (Annex A) includes additional analyses that investigate the potential effects of mitigation activities, commonly referred to as response options. Mitigated scenarios include subsea dispersant injection (SSDI) at the well head, installation of a capping stack, surface dispersant application (through aerial and vessel distribution), in-situ burning of oil on the water surface, and implementation of a relief well. Multiple weather conditions were also considered in this modelling exercise. Primarily, each set of simulations had a different start date and time, which resulted in different environmental parameters (e.g., winds, currents, waves, temperature, etc.). The prevalence of fog and poor weather conditions that may hamper response activities were considered.

A summary of mitigation options is provided, as well as results and conclusions from the investigation. Representative deterministic scenario results include mass balance information, and cumulative maximum footprints of surface oil thickness, in water concentration, and shoreline and sediment mass per unit area. A summary of the results and conclusions are also provided. Results of this investigation are used to compare mitigated release scenarios to the previously modelled unmitigated release scenarios in a Spill Impact Mitigation Assessment (SIMA).

For each simulated release, response actions were predicted to reduce the surface areas and shore lengths predicted to exceed the identified thresholds of concern. Subsurface volumes exceeding the THC threshold were more variable between unmitigated and response mitigated scenarios. In response mitigated release scenarios, more oil was predicted to be within the water column due to the effective SSDI and aerial/vessel dispersant application. Because of the effects of dispersant application, two of the largest changes in mass balance were the amount evaporated and the amount degraded within the water column. Burning and collection were simulated to remove surface oil. However, due to the dispersant effectiveness, which reduced the total amount of surface oil, and due to the large amount of time that winds, currents, and waves exceeded the effectiveness thresholds, burning and recovery were not predicted to be effective in these simulations.

Document Summary

This annex includes an introduction describing the region, the modelling approach, the methodology, and finally the predicted modelling results of the study. While this document is stand-alone, please refer to the RPS Technical Report: BHP Canada Orphan Basin Exploration Drilling Project 2019-2028 (Horn et al., 2019) for full descriptions of the modelling tools and inputs. The model results from this assessment are summarized in figures and tables in the main body of this document, describing the potential for oil exposure on the water surface, within the water column, and along shorelines. This document is broken down into several sections.

- Section 1 – Introduction
- Section 2 – Modelling Approach and Inputs
- Section 3 – Mitigation Response Results
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Figure 3-38. Scenario 4: Maximum THC at any depth in the water column for the 95th percentile average shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158. 51

Figure 3-39. Scenario 4: THC on the shore and sediment for the 95th percentile average shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157. 52

Figure 3-40. Scenario 4: THC on the shore and sediment for the 95th percentile average shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158. 53

1 INTRODUCTION

RPS conducted trajectory and fate modelling to support the development of an Environmental Impact Statement for the BHP Canada Exploration Drilling Project 2019-2028 in the Orphan Basin area. Hypothetical blowout releases were modelled at two locations in the Orphan Basin located more than 350 km northeast of St. John's, Newfoundland. Water depth at the proposed drilling sites selected for modelling ranged from 2,000 to 2,400 m. Major currents, including the Labrador Current and its inner and outer branch, influence the circulation and biological productivity in this region. The RPS Technical Report: BHP Canada Orphan Basin Exploration Drilling Project 2019-2028 (Horn et al., 2019) was prepared for BHP Canada to summarize the potential consequences of short (30 day) and long (120) subsurface blowouts that were completely unmitigated within Exploration Licenses EL 1157 and EL 1158 (Figure 1-1).

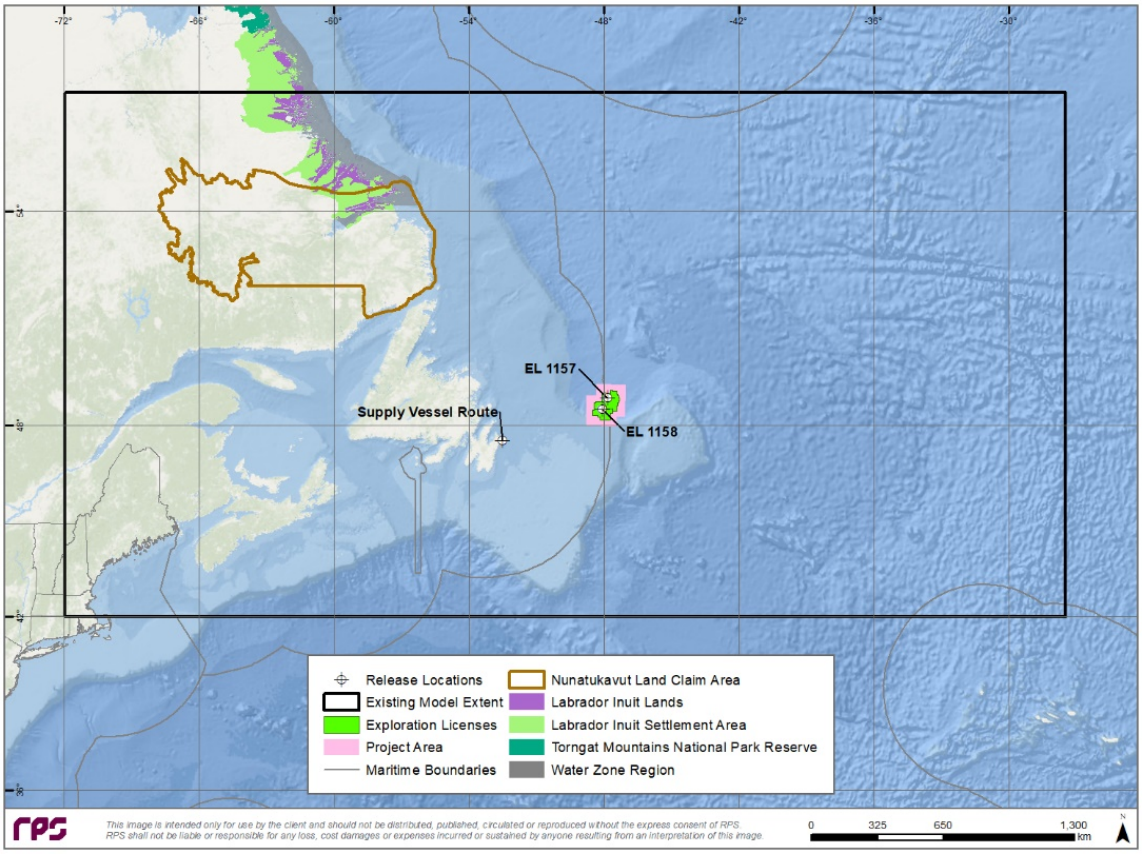

Figure 1-1. Project Area, including the two hypothetical release locations for the subsurface blowouts (EL 1157 and EL 1158) and the potential supply route vessel location. The black bounding box represents the modelled extent, while the pink shaded box represents the Project Area.

This work (Annex A) includes additional analyses that investigate the potential effects of mitigation activities, commonly referred to as response options at the same release locations using the same modelling approach and release parameters (Horn et al., 2019). The nearfield OILMAPDeep blowout model and the far-field Spill Impact Model Application Package (SIMAP) oil trajectory, fate, and potential effects model were used. These state-of-the-art models were developed and are maintained by RPS. Horn et al., 2019 provides a description of the Project Area, modelled hypothetical unmitigated release scenarios, a detailed overview of the modelling approach, details about the model input data that were used, and a presentation and discussion of the predicted model results.

In the event of an oil release, there are several response options available to responders that would act to contain, collect, remove, or disperse a release. Typically, these include booming, burning, collection (e.g. skimming), and dispersant application. In the offshore areas of Newfoundland, the primary methods of response to an oil spill that have been proposed would include subsea dispersant injection (SSDI) at the well head followed by the installation of a capping stack, surface dispersant application (through aerial and vessel distribution), and in-situ burning from the oil surface. Given the distance from shore and typical environmental conditions, booming is likely to be impractical. Mitigated scenarios in this Annex include subsea dispersant injection (SSDI) at the well head followed by the installation of a capping stack, surface dispersant application (through aerial and vessel distribution), in-situ burning from the oil surface, and implementation of a relief well.

When responding to a release of oil, one of the most critical factors impacting the effectiveness of containment and cleanup operations is timing. Typically, the faster a response is initiated and underway, the lower the potential is for consequences, as a result of reduced oil volume in the environment and a smaller extent over which oil has traveled. This study addresses the effects that a number of different oil spill response strategies, timings, and poor weather conditions would have on the ultimate trajectory and fate of hypothetical releases.

2 MODELLING APPROACH AND INPUTS

2.1 Modelling Tools

Hypothetical release scenarios were simulated using the near-field OILMAPDeep blowout model and the far-field SIMAP oil trajectory, fate, and effects model, both developed and maintained by RPS. OILMAPDeep was used to define the near-field dynamics of the subsurface blowout plume, which was then used to initialize the far-field modelling conducted in SIMAP.

The OILMAPDeep model is used to characterize the near-field plume dynamics to predict the mass, location, and droplet size distribution of the subsurface oil droplets at the termination (i.e., trap) height, where the oil jet and buoyant oil and gas plume are “trapped” and form an intrusion. The depth of the trap height is dependent upon the environmental conditions, the specific chemical and physical properties of the oil, and other release parameters. The OILMAPDeep model does consider the effects of SSDI and its impact on droplet size distribution (i.e., the addition of SSDI tends to result in smaller droplet sizes). Typically, the near-field model considers timescales of seconds and length scales of hundreds of meters, whereas the far-field model considers many days and months (at 1 to 30-minute time steps) and length scales of tens, hundreds, and even thousands of kilometers.

SIMAP is a state-of-the-art oil trajectory, fate, and effects model that was developed by RPS and is constantly being updated/maintained based upon the growing body of field and laboratory data associated with releases of oil in many different environments. The 3D physical fates model estimates the distribution of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments as both mass and concentration. Because oil contains many chemicals with varying physical and chemical properties, and the environment is spatially and temporally variable, the oil rapidly separates into different environmental compartments through multiple fate processes. Oil fate processes included in SIMAP are spreading (gravitational and by shearing), evaporation, transport, randomized dispersion, emulsification, entrainment (natural and facilitated by dispersant), dissolution of the soluble fraction of oil into the water column, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended sediments, adsorption of soluble and sparingly-soluble aromatics to suspended sediments, sedimentation, and degradation. SIMAP does consider the effects of surface and subsurface dispersant addition, and various containment and collection options including burning. Oil trajectory and weathering endpoints include surface oil, emulsified oil (mousse), tar balls, suspended oil droplets, oil adhered to particulate matter, dissolved hydrocarbon compounds in the water column and pore water, and oil on and in bottom sediments and shoreline surfaces.

Detailed descriptions of the OILMAPDeep and SIMAP models can be found in Appendix A of Horn et al., 2019.

2.2 Response Scenarios

Four individual response mitigated scenarios were simulated at both EL 1157 and EL 1158 (a total of eight simulations):

- Scenario 1: 95th percentile surface oil case (30-day release)
- Scenario 2: 95th percentile surface oil case (30-day release) with limitations to response options
- Scenario 3: 95th percentile surface oil case (120-day release)
- Scenario 4: 95th percentile shoreline case (30-day release)

These scenarios reference the identified 95th percentile "worst case" representative scenarios for surface and shoreline oiling presented in Horn et al., 2019. These base cases have the same underlying inputs, but have different release dates and times which result in very different predicted trajectories and fates.

The 30-day releases are representative of the conservatively long amount of time anticipated to successfully mobilize and implement a capping stack to contain the release. The 120-day release is representative of the conservatively long amount of time anticipated to kill the well (i.e. stop the blowout), by mobilizing a drilling rig and drilling a relief well (i.e., the implementation of a capping stack was unsuccessful). Detailed descriptions of the simulated response equipment, efficiencies, and associated thresholds for containment and collection are provided below in Section 2.2.1.

2.2.1 Response Equipment

A list of the response equipment that would be available in the event of a release at the EL 1157 and EL 1158 sites in the Orphan Basin was provided to RPS by BHP Canada. Each type of response, assumptions, and associated timings (Table 2-1), are summarized below. These response options assume that permission to apply dispersants had been granted.

- **Subsea Dispersant Injection (SSDI):** The equipment for SSDI is extremely specialized and typically located at response facilities that may be in different regions or countries. Given the necessary time to mobilize equipment and transit to the release site, the initiation of SSDI was assumed to begin at Day 15, and assumed that debris clearance would have already been completed. The modelling assumed that 75% of the discharged oil would have been treated with a dispersant-to-oil-ratio (DOR) of 1:100.
- **Capping Stack Installations:** The modelled release at EL 1157 and 1158 would require a capping stack. The capping stack was assumed to be installed 30 days after the spill, a conservatively long period of time.
- **Aerial Surface Dispersant Application:** The response aircraft were assumed to begin surface aerial dispersant application on Day 2, at a rate of 183 bbl per hour, with a targeted DOR of 1:20. The modelling assumed a 30% reduction in application due to the prevalent fog conditions year-round (i.e., flights were not allowed every third day).
- **Vessel Surface Dispersant Application:** A vessel fitted with spray arms would be used to apply dispersant at the water surface. It was assumed to have unlimited access to dispersant with no need to return to port daily. Vessel surface dispersant application was assumed to arrive on scene on Day 2. It was assumed that the vessel could spray up to 6 m^3 of dispersant per day with a DOR of 1:20.

- **Vessel Marine Recovery:** Vessels assisting in mechanical recovery of oil (i.e., skimming and booming operations) would arrive and begin operations on Day 4. It was assumed that they would recover 10 m^3 of oil per day.
- **In-Situ Burning:** Vessel based burning applications would include a total of four burning operations and were assumed to use project vessels and assistance from other vessels of opportunity (VOO). The modelling assumed two burns per day, with a removal of 200 bbl per burn. Burning would be limited to a 3 NM buffer around the well head, to account for the necessary thickness of oil required for ignition. Burning from both vessels would begin on Day 6. Note that in-situ burning would be limited by oil encounter rate, sea surface conditions (i.e., wind speed and wave height), and visibility.
- **Relief Well:** After 120-days of an active subsurface blowout, the modelled release at EL 1157 and EL 1158 would cease due to successful drilling of a relief well, which would kill the subsurface blowout. effectively ceasing uncontrolled flow.

Table 2-1. Timing of response options at EL 1157 and 1158 for the 95th percentile 30-day surface oil case. Shading indicates when the response option is operational. Aerial dispersants were grounded every 3rd day to account for fog.

Scenario 1 - Response Equipment							
Time	Capping Stack	SSDI	Aerial Dispersant*	Vessel Dispersant	Vessel Marine Recovery	In-Situ Burning Vessel 1	In-Situ Burning Vessel 2
Day 1							
Day 2							
Day 3			Fog				
Day 4							
Day 5							
Day 6			Fog				
Day 7							
Day 8							
Day 9			Fog				
Day 10							
Day 11							
Day 12			Fog				
Day 13							
Day 14							
Day 15			Fog				
Day 16							
Day 17							
Day 18			Fog				
Day 19							
Day 20							
Day 21			Fog				
Day 22							
Day 23							
Day 24			Fog				
Day 25							
Day 26							
Day 27			Fog				
Day 28							
Day 29							
Day 30			Fog				
Day 31							
Day 32							
Day 33			Fog			Oil too thin	Oil too thin
Day 34							
Day 35			Dispersant no longer effective (>5 days weathering)	Dispersant no longer effective (>5 days weathering)			

Table 2-2. Timing of response options at EL 1157 and 1158 for the 95th percentile 30-day surface oil case with limitations to response options. Shading indicates when the response option is operational. Aerial dispersants were grounded every 3rd day to account for fog.

Scenario 2 - Response Equipment							
Time	Capping Stack	SSDI	Aerial Dispersant	Vessel Dispersant	Vessel Marine Recovery	In-Situ Burning Vessel 1	In-Situ Burning Vessel 2
Day 1							
Day 2							
Day 3			Fog				
Day 4							
Day 5							
Day 6			Fog				
Day 7							
Day 8			Response efforts halted (e.g. weather, equipment failure, etc.)				
Day 9			Response efforts halted (e.g. weather, equipment failure, etc.)				
Day 10			Response efforts halted (e.g. weather, equipment failure, etc.)				
Day 11							
Day 12			Fog				
Day 13							
Day 14							
Day 15			Fog				
Day 16							
Day 17			Response efforts halted (e.g. weather, equipment failure, etc.)				
Day 18			Response efforts halted (e.g. weather, equipment failure, etc.)				
Day 19			Response efforts halted (e.g. weather, equipment failure, etc.)				
Day 20							
Day 21			Fog				
Day 22							
Day 23							
Day 24			Fog				
Day 25							
Day 26			Response efforts halted (e.g. weather, equipment failure, etc.)				
Day 27			Response efforts halted (e.g. weather, equipment failure, etc.)				
Day 28			Response efforts halted (e.g. weather, equipment failure, etc.)				
Day 29							
Day 30			Fog				
Day 31							
Day 32							
Day 33			Fog			Oil too thin	Oil too thin
Day 34							
Day 35			Dispersant no longer effective (>5 days weathering)	Dispersant no longer effective (>5 days weathering)			

Table 2-3. Timing of response options at EL 1157 and 1158 for the 95th percentile 120-day surface oil case, representing an unsuccessful implementation of a capping stack. Shading indicates when the response option is operational. Aerial dispersants were grounded every 3rd day to account for fog.

Scenario 3 - Response Equipment								
Time	Relief Well	Capping Stack	SSDI	Aerial Dispersant	Vessel Dispersant	Vessel Marine Recovery	In-Situ Burning Vessel 1	In-Situ Burning Vessel 2
Day 1								
Day 2								
Day 3				Fog				
Day 4								
Day 5								
Day 6				Fog				
Day 7								
Day 8								
Day 9				Fog				
Day 10								
Day 11								
Day 12				Fog				
Day 13								
Day 14								
Day 15				Fog				
Day 16								
Day 17								
Day 18				Fog				
Day 19								
Day 20								
Day 21		Unsuccessful		Fog				
…	Repeat 3-day operational cycle (Day 19-21)							
Day 115								
Day 116								
Day 117				Fog				
Day 118								
Day 119								
Day 120	Kill Well			Fog				
Day 121								
Day 122								
Day 123				Fog			Oil too thin	Oil too thin
Day 124								
Day 125				Dispersant no longer effective (>5 days weathering)	Dispersant no longer effective (>5 days weathering)			

Table 2-4. Timing of response options at EL 1157 and 1158 for the 95th percentile 30-day shoreline oil case. Shading indicates when the response option is operational. Aerial dispersants were grounded every 3rd day to account for fog.

Scenario 4 - Response Equipment							
Time	Capping Stack	SSDI	Aerial Dispersant	Vessel Dispersant	Vessel Marine Recovery	In-Situ Burning Vessel 1	In-Situ Burning Vessel 2
Day 1							
Day 2							
Day 3			Fog				
Day 4							
Day 5							
Day 6			Fog				
Day 7							
Day 8							
Day 9			Fog				
Day 10							
Day 11							
Day 12			Fog				
Day 13							
Day 14							
Day 15			Fog				
Day 16							
Day 17							
Day 18			Fog				
Day 19							
Day 20							
Day 21			Fog				
Day 22							
Day 23							
Day 24			Fog				
Day 25							
Day 26							
Day 27			Fog				
Day 28							
Day 29							
Day 30			Fog				
Day 31							
Day 32							
Day 33			Fog			Oil too thin	Oil too thin
Day 34							
Day 35			Dispersant no longer effective (>5 days weathering)	Dispersant no longer effective (>5 days weathering)			

2.2.2 Modelled Response in SIMAP

This study addressed the effects of multiple response options with different response timings on the ultimate trajectory and fate of hypothetical releases. To capture the potential variability in predicted trajectory and fate of released oil, an assortment of response options were modelled with specific timings for initial response and assumptions of efficiency/effectiveness. Results from modelled response mitigated scenarios were then compared to previously modelled unmitigated releases.

Surface response actions such as aerial and vessel dispersant application and in-situ burning are modelled in SIMAP based on assumptions of location, timing, physical thresholds for operation (e.g., below certain wave heights and wind speeds), equipment efficiency, dispersant application (e.g. amount, DOR, and percent treated), and burning rates. A summary of response options, thresholds, scenarios, and daylight hours used in the modelling are provided in Table 2-5 and Table 2-6. The modelled results were used to evaluate the effect of a range of response option effectiveness implemented at multiple timings over the course of a release, allowing for comparisons between the unmitigated and response mitigated scenarios.

Table 2-5. Modelled response options and thresholds used in response mitigation scenarios

Response Option	Response Target	Modelled Threshold			
		Wind (m/s)	Currents (kts)	Waves (m)	Surface Oil Thickness (µm)
SSDI	Well Head	n/a	n/a	n/a	n/a
Capping Stack	Well Head	n/a	n/a	n/a	n/a
Aerial Dispersant	Water Surface	16	n/a	n/a	13
Surface Vessel Dispersant	Water Surface	16	n/a	1	13
In-Situ Burning	Water Surface	10.3	1	1.5	13

Table 2-6. Daylight hours for the response mitigated cases

Scenario	Release Location/Duration	Release Date	Sunrise	Sunset	Daylight Hours
1 & 2 – 95th Percentile Surface Oil Case	EL 1157 30-day	8 November 2009	7:09	16:43	9 hours 33 minutes
	EL 1158 30-day	7 April 2008	6:39	19:52	13 hours 13 minutes
3 - 95th Percentile Surface Oil Case	EL 1157 120-day	15 January 2010	8:00	16:45	8 hours 44 minutes
	EL 1158 120-day	11 December 2009	7:54	16:17	8 hours 22 minutes
4 – 95th Percentile Shoreline Case	EL 1157 30-day	31 March 2008	6:27	19:40	13 hours 13 minutes
	EL 1158 30-day	7 April 2008	6:39	19:52	13 hours 13 minutes

Every oil spill is unique. Similarly, the response to each release event is unique. The location of the release, volume of oil spilled, environment into which oil enters, and the environmental conditions at the time of the release all play significant roles in determining the ultimate trajectory and fate of oil, as well as the effectiveness of response and cleanup operations. For response options that targeted the water surface, efforts were focused on the areas identified to contain the greatest amount (i.e., thickest) of surface oil. In the SIMAP model, thresholds operate by effectively shutting off specific collection or containment potential when conditions at each location in space and time exceed the identified thresholds. As an example, if wave height exceeds 1 m at a specific location, the surface vessel dispersant at that location will not function at that location (i.e. point in space and time) in the model until the conditions improve and wave height falls below 1 m. Note that while a threshold could be exceeded at one location within the model domain at a given time, thus preventing effective response there, the threshold may not be exceeded at another location, where a successful response would still take place within the model. Response efforts at the water surface were limited to daylight hours (Table 2-6), as effective operations are less likely during the darkness of night.

The nearfield model OILMAPDeep was used to predict the initial droplet size distribution associated with subsurface blowouts of BdN crude oil at two different release locations (Horn et al., 2019). Subsurface blowouts of BdN were evaluated at EL 1157 and 1158 considering a number of variables including release location and depth, oil type, gas-to-oil ratio, release volume, orifice diameter, and several others. While the previous study investigated both the unmitigated 30- and 120-day releases, this study investigated response mitigated blowouts, where SSDI was applied at depth.

The droplet size model was used to predict the distribution of oil volume (mass) within different size ranges (measured by diameter) in response to the turbulence of the release, the gas content, the water depth, and the properties of the oil. The droplet model predicted the initial droplet size distributions for each scenario as well as the depth or “trap height” in the water column where the droplets would be released to the water column and rise according to their individual buoyancies. These values were then used to generate input files defining the size, mass, and depth of oil droplets entering the water column for use within the SIMAP far-field model.

The predicted droplet size distribution was represented by seven discrete size bins for each modelled release scenario (Table 2-7). The non-uniform spacing between the droplet size bins is the result of the non-linear functionality of droplet size distribution. Each of the seven bins were determined such that an equal proportion of the released oil by mass (14.29%) was within each bin. Differences in release depth and blowout rate resulted in different droplet size distributions for each of the two modelled release rates. In addition, the response mitigated droplet size distribution is provided, highlight that the SSDI will tend to shift the droplet size distribution towards smaller diameter particles. These smaller particles are more likely to disperse more effectively throughout the water column and will have reduced rise velocities through the water column. Table 2-7 lists the droplet size distributions for each of the unmitigated and response mitigated releases (30- and 120-day) at both sites. In some cases, SSDI reduces the mean diameter of the oil droplets by and order of magnitude.

Table 2-7. Summary of droplet size distribution results for each of two modelled subsurface blowout release sites.

Median Droplet Size in Each of Seven Equal-Mass Bins, by Diameter (µm)			
Unmitigated		**Response Mitigated**	
EL 1157 30-day release (135,084 bpd)	**EL 1157 120-day release (129,141 bpd)**	**EL 1157 30-day release (135,084 bpd)**	**EL 1157 120-day release (129,141 bpd)**
374	399	43	54
748	797	82	68
1122	1196	91	96
1495	1594	836	954
1869	1993	1588	1549
2243	2391	1877	2390
2617	2790	2591	2584
EL 1158 30-day release (135,006 bpd)	**EL 1158 120-day release (129,137 bpd)**	**EL 1158 30-day release (135,006 bpd)**	**EL 1158 120-day release (129,137 bpd)**
359	378	39	49
717	757	82	68
1076	1135	93	90
1435	1513	701	899
1794	1892	1303	1300
2152	2270	1695	2162
2511	2648	2320	2513

Oil droplets rise through the water column at rates based on drag, calculated using their diameter (treated as a sphere) and the buoyancy (the density difference between the oil and the water), which varies with changing temperature and salinity by depth (see Horn et al., 2019 for details). Rise times for oil to reach the surface varied between hours to a few days, depending on droplet size and depth of release. Rise time estimates are approximated, based on the initial droplet size, initial droplet density, and bottom water density; neglecting dispersion, dissolution, and degradation (which were tracked within the oil spill model and modified the rise rates). The longest rise times are associated with the smallest droplets. Droplets that are less than ~100 microns could potentially stay entrained permanently.

3 RESPONSE MITIGATED RESULTS

Summary figures have been prepared in the same fashion as the previous work (Horn et al., 2019) to illustrate the differences between unmitigated and response mitigated spill results. In addition, tables summarizing the areas exceeding specified thresholds have also been generated. During each modelled simulation, components of oil were tracked as floating surface oil, entrained droplets of whole oil, dissolved hydrocarbon constituents, stranded oil on shorelines and sediments, evaporated, degraded, and left the model domain. The figures provided depict the maximum cumulative footprint of all oil predicted to be within a region over the entire modelled duration. Essentially, each grid cell represents the highest value (thickness, concentration, or mass) that was ever predicted at any point throughout the entire simulation. Therefore, each image grossly overestimates the footprint for each simulation at any single point in time.

The types of figures that were used to summarize modelling results are provided, along with brief descriptions of the information that they portray. Note that the thicknesses and concentrations for the modelled blowouts were calculated on a grid with a resolution (i.e., grid cell size) of 1,800 m by 2,500 m, which is equivalent to 0.02 degrees by 0.02 degrees. For concentration grids, vertical binning included 50 m increments over the entire water column.

1. **Mass Balance Plots**: Illustrate the predicted weathering and fate of oil for a specific run over the entire model duration as a fraction of the oil released up to that point. Components of the oil tracked over time include the amount of oil on the sea surface, the total entrained hydrocarbons in the water column, the amount of oil in contact with the shore or sediments, the amount of oil evaporated into the atmosphere, the amount of oil degraded (accounts for both photo-oxidation and biodegradation), and the amount cleaned (accounts for mechanical removal and in-situ burning).
2. **Surface Oil Thickness Maps:** Depict the predicted footprint of maximum floating surface oil and the associated oil thicknesses (mm) over all modelled time steps for an individual release simulation. The minimum thickness of surface oil >0.04 µm is displayed (cumulative over all modelled time steps). Note that floating oil mass is calculated as an average over grid cells, thus in reality, the oil would be patchy and discontinuous and could be thinner or thicker within particular areas of a single grid cell.
3. **Water Column Dissolved Hydrocarbon Concentration (DHC) Maps**: Depict the predicted footprint of the vertical maximum water column concentration of dissolved hydrocarbons over all modelled time steps for an individual release simulation. Dissolved hydrocarbons are the constituents of the oil with the greatest potential to affect water column biota. Only concentrations >1 µg/L for the representative cases are displayed.
4. **Water Column Total Hydrocarbon Concentration (THC) Maps:** Depict the predicted footprint of the vertical maximum water column concentration of total hydrocarbons over all modelled time steps for an individual release simulation. Only concentrations >1 µg/L for the representative cases are displayed.
5. **Shoreline and Sediment Total Hydrocarbon Concentration (THC) Maps:** Depict the predicted total mass of oil (per unit area as g/m^2) deposited onto the shoreline and on sediments.

3.1 Scenario 1: 30-day Surface Oil Cases

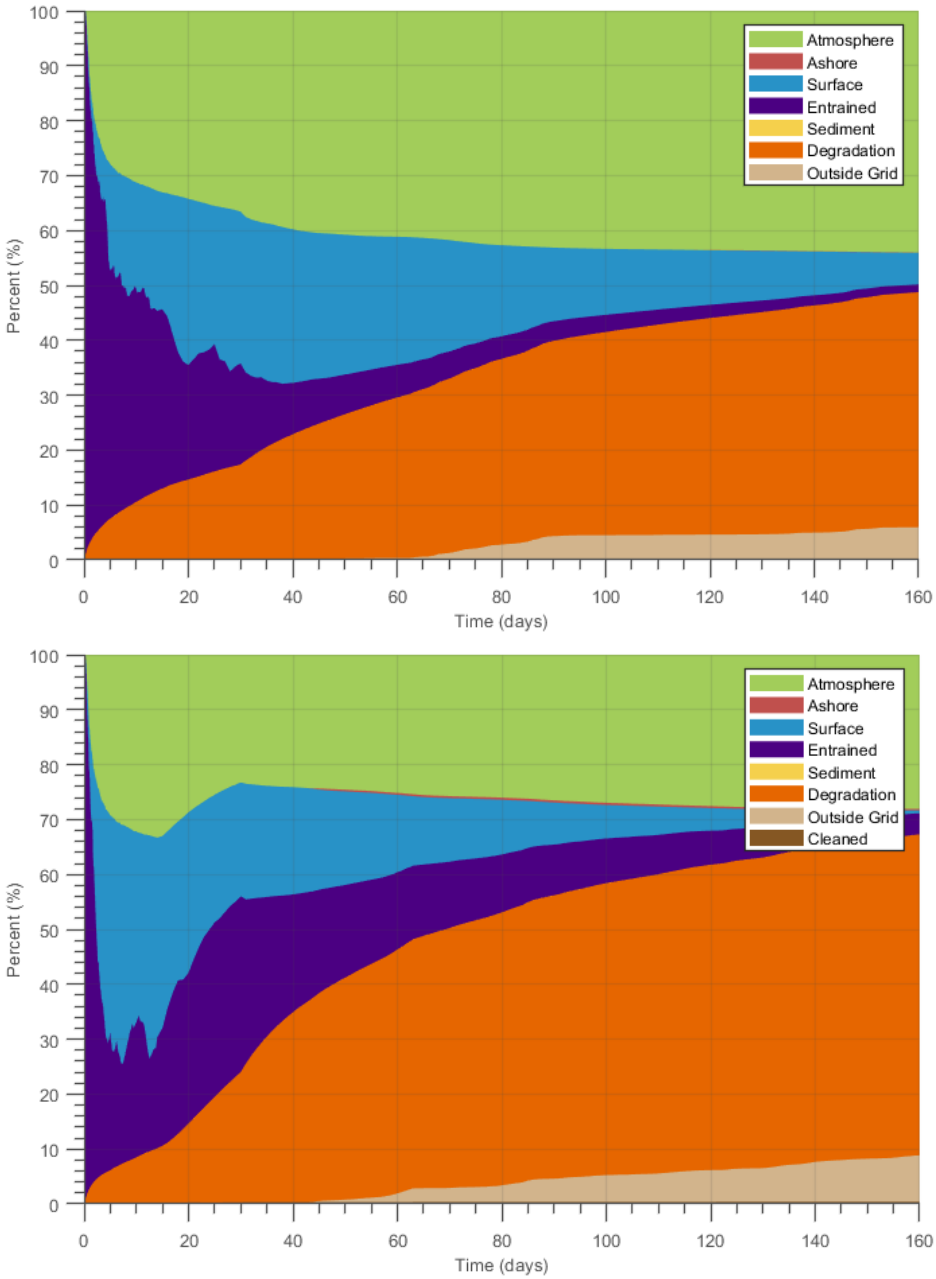

Figure 3-1. Scenario 1: Mass balance plots of the 95th percentile surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

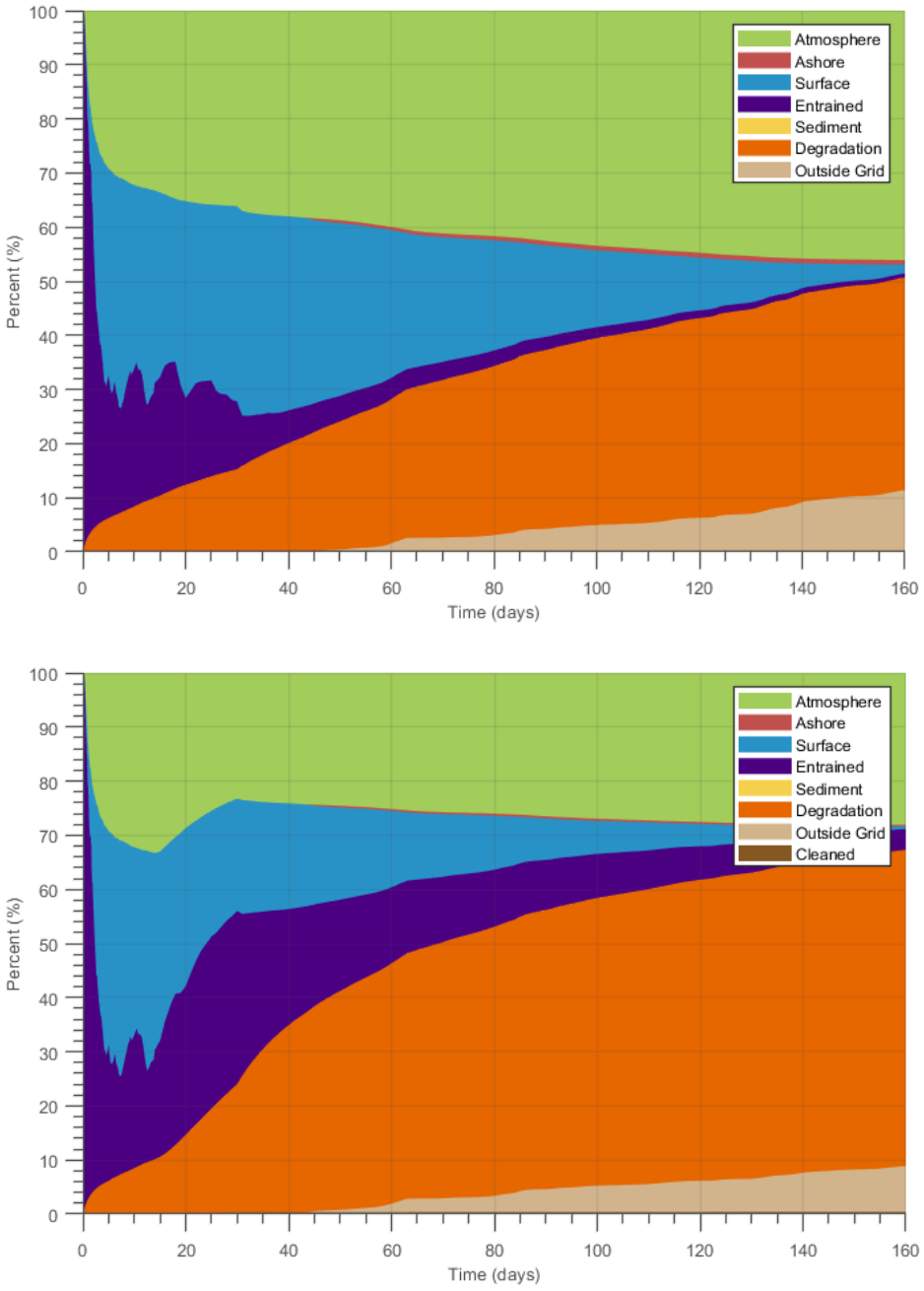

Figure 3-2. Scenario 1: Mass balance plots of the 95th percentile surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

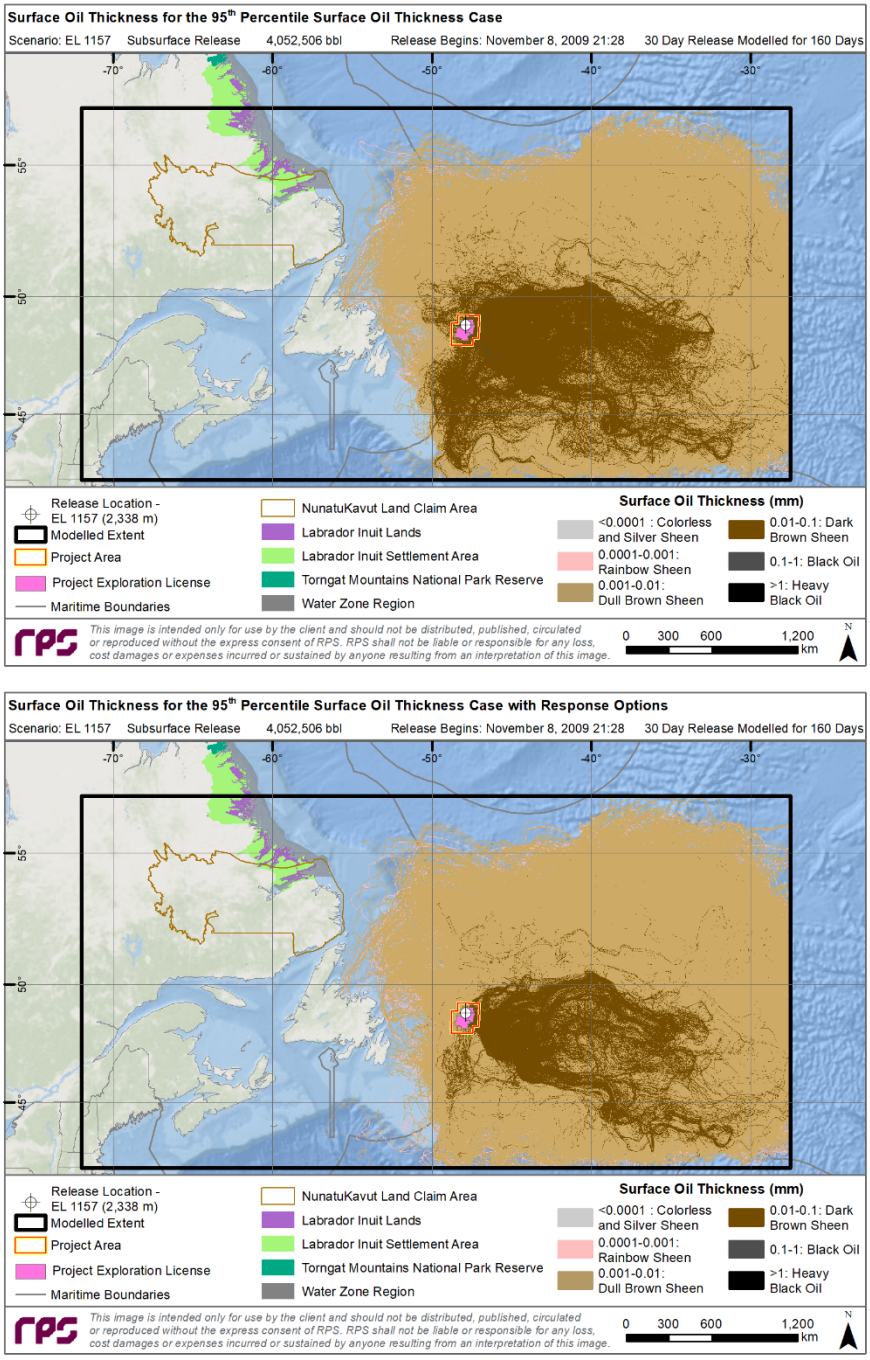

Figure 3-3. Scenario 1: Surface oil thickness for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

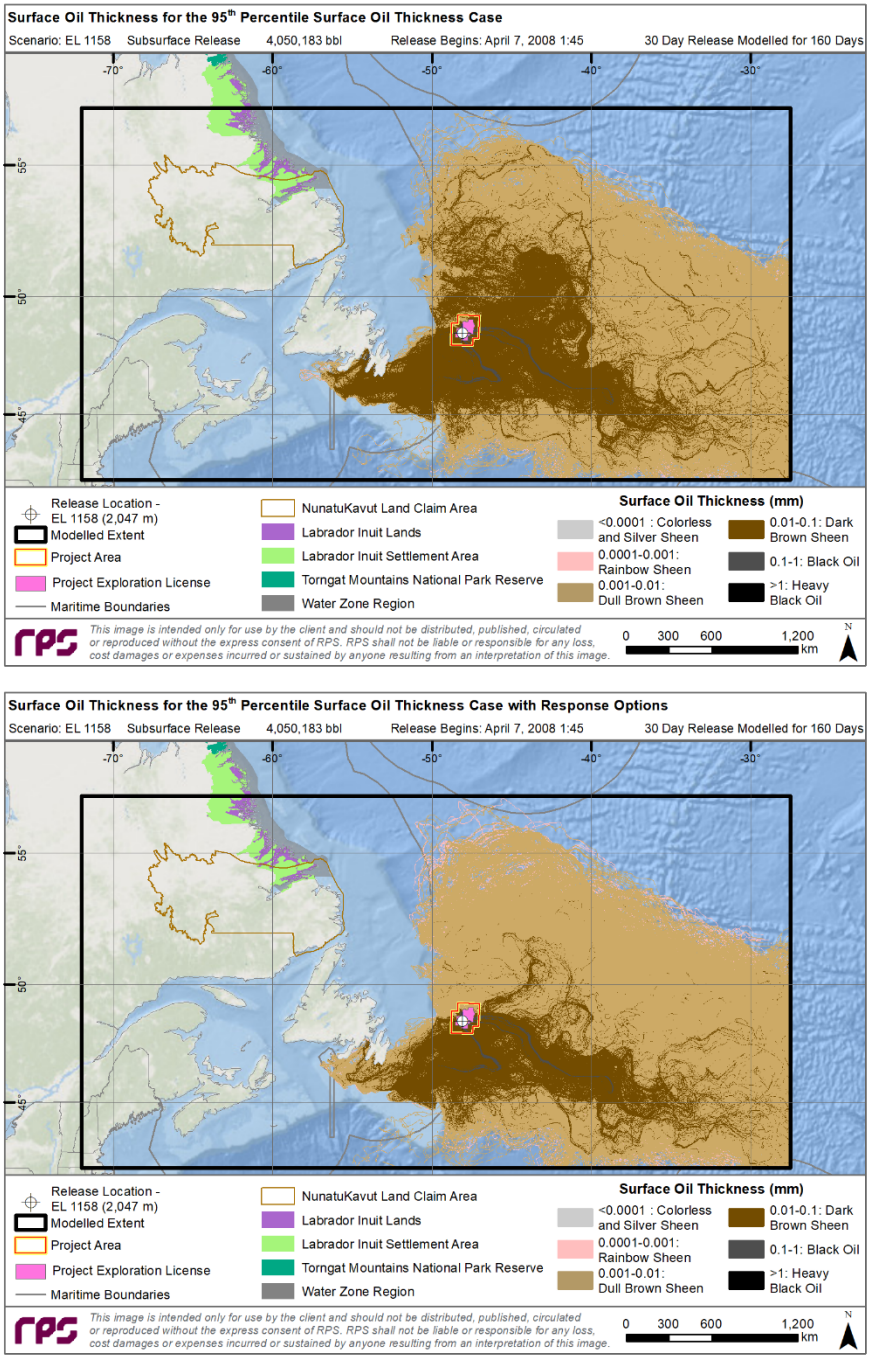

Figure 3-4. Scenario 1: Surface oil thickness for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

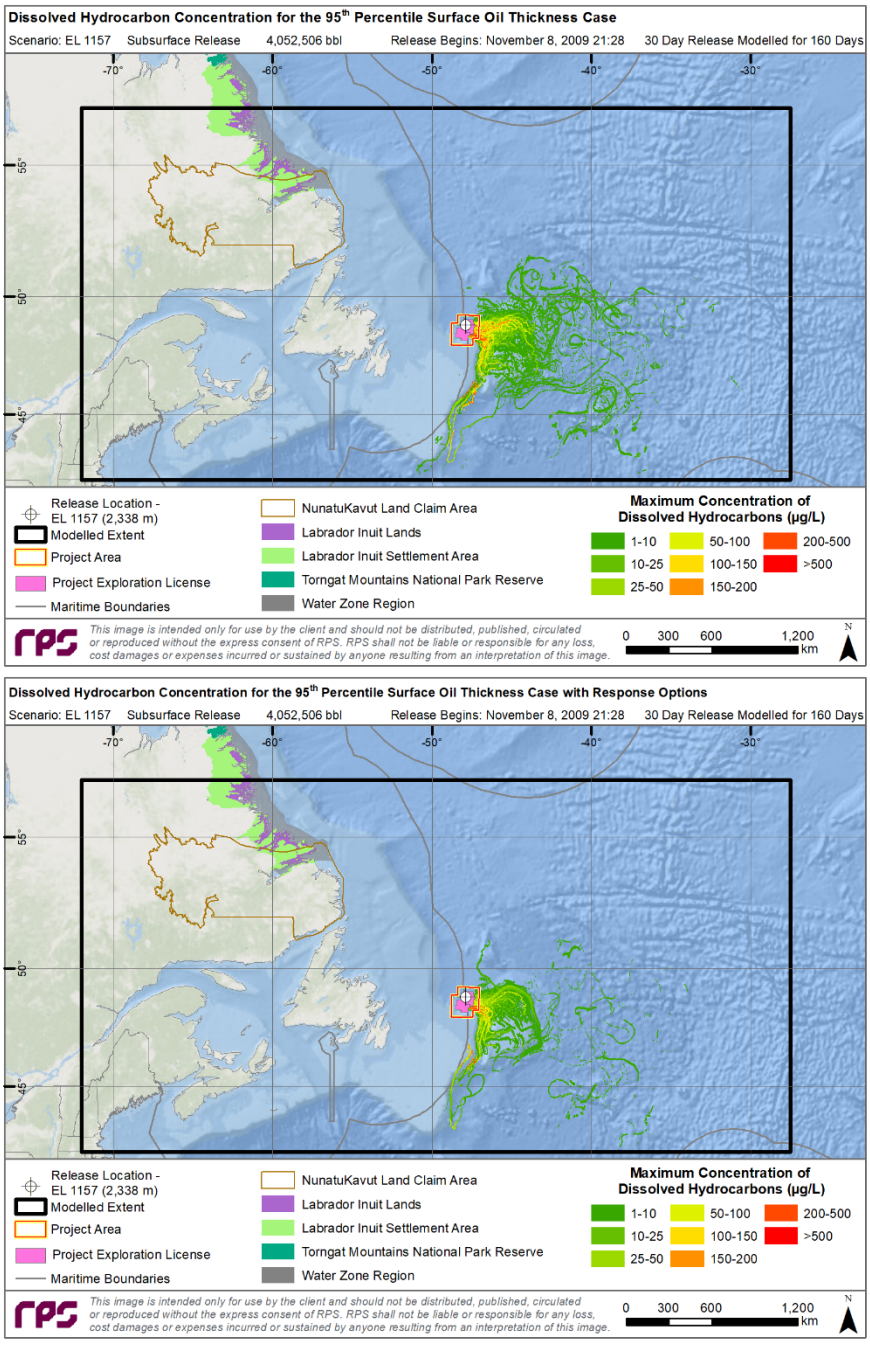

Figure 3-5. Scenario 1: Maximum DHC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

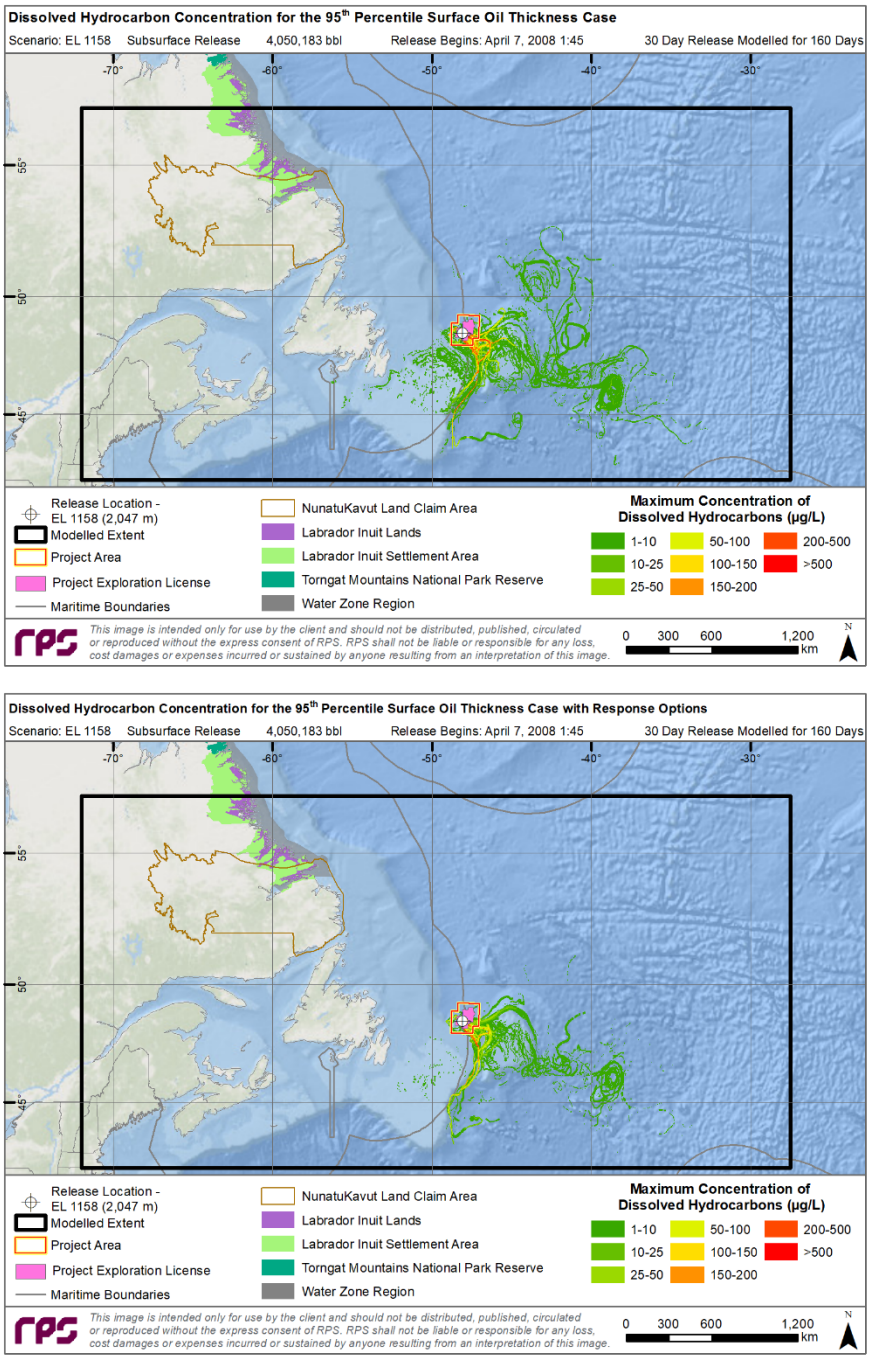

Figure 3-6. Scenario 1: Maximum DHC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

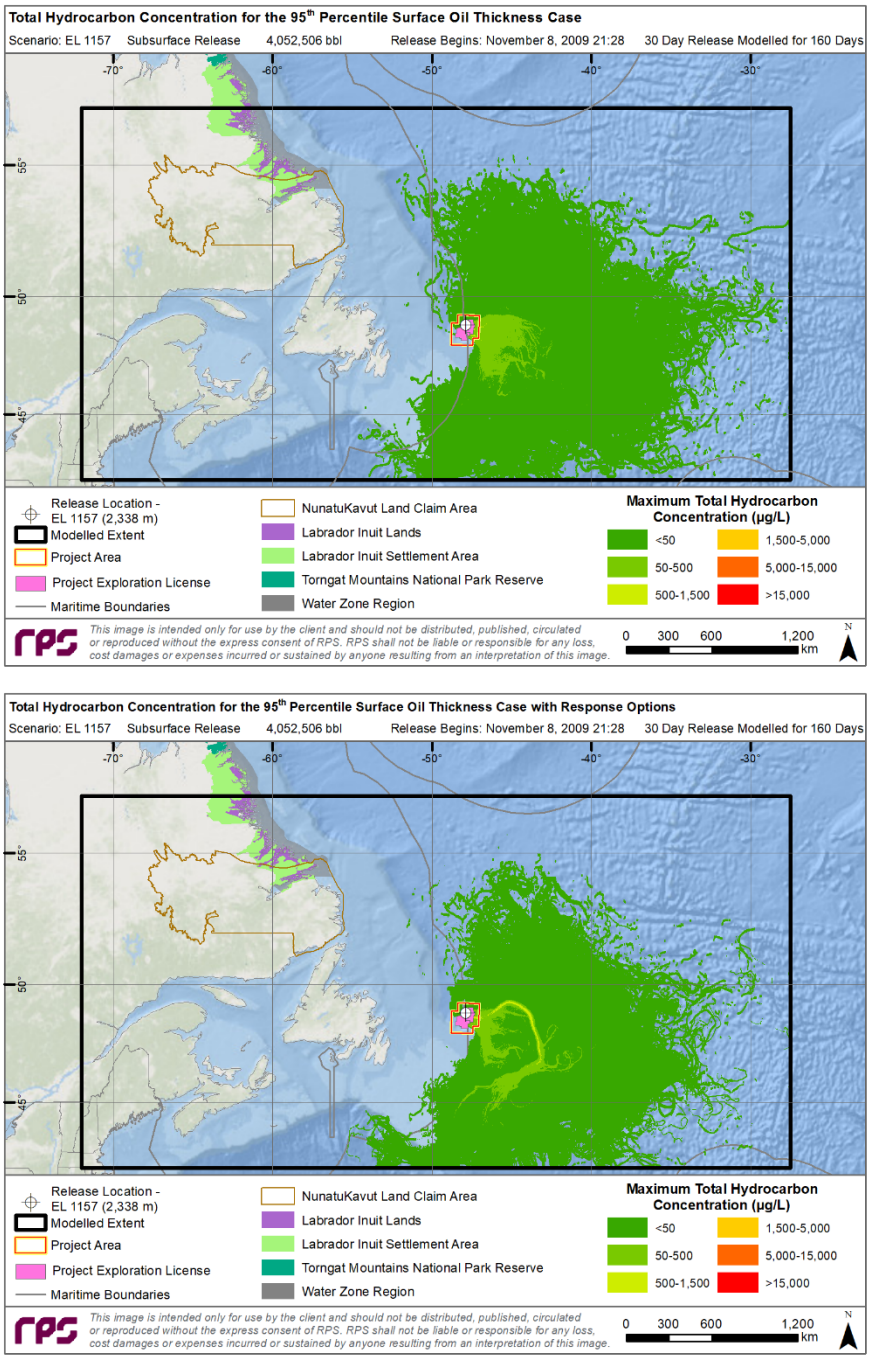

Figure 3-7. Scenario 1: Maximum THC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

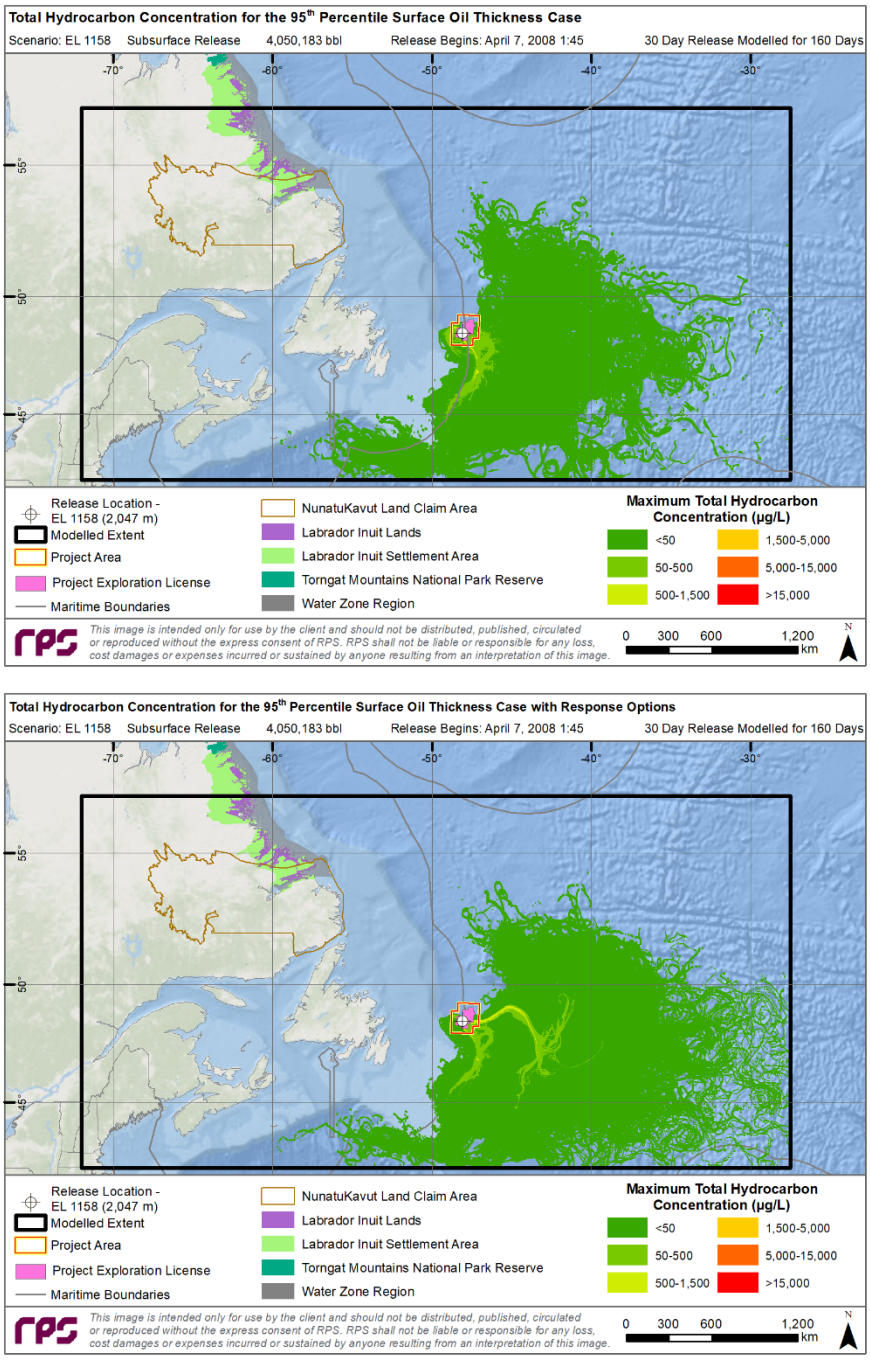

Figure 3-8. Scenario 1: Maximum THC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

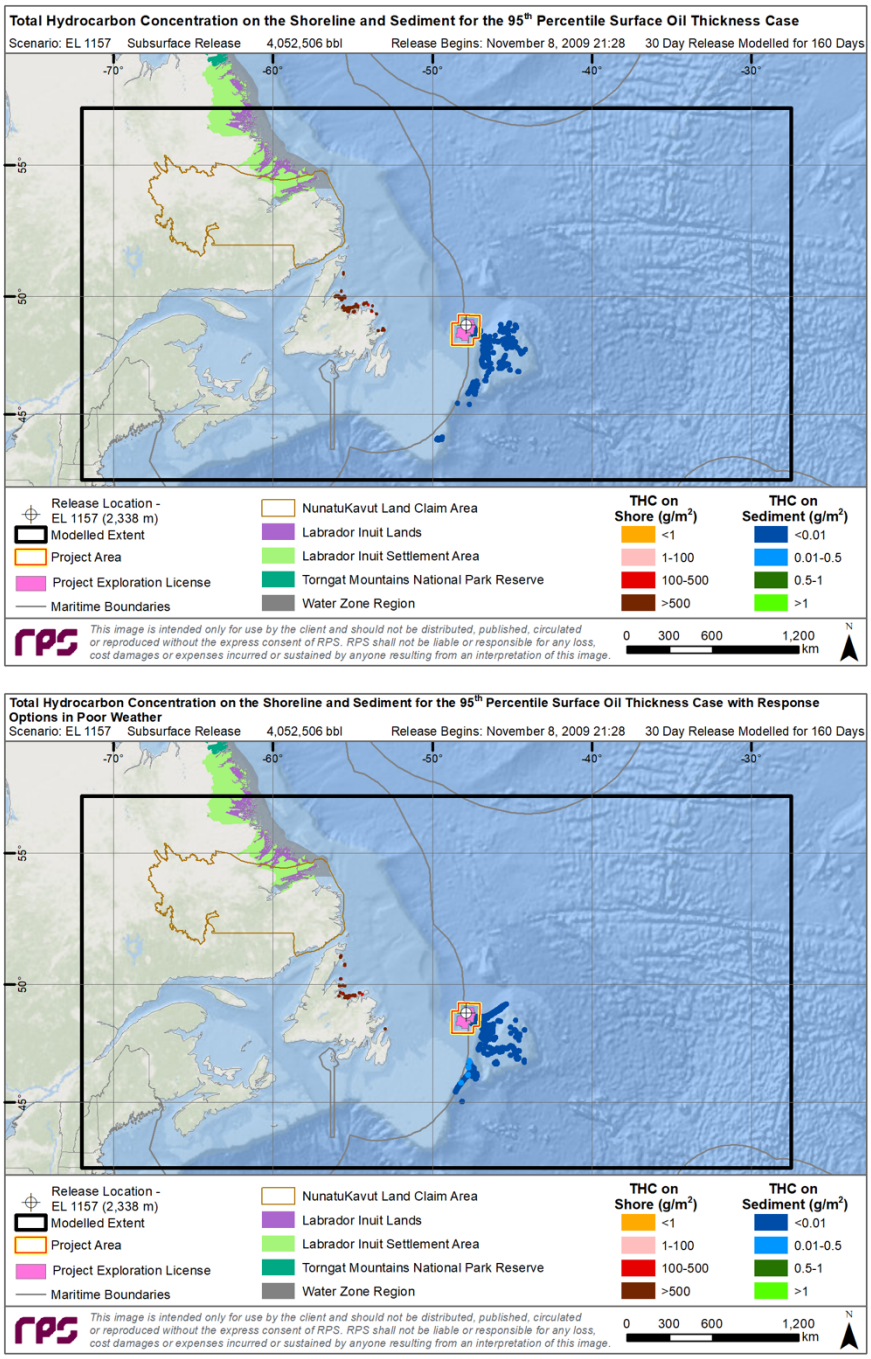

Figure 3-9. Scenario 1: THC on the shore and sediment for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

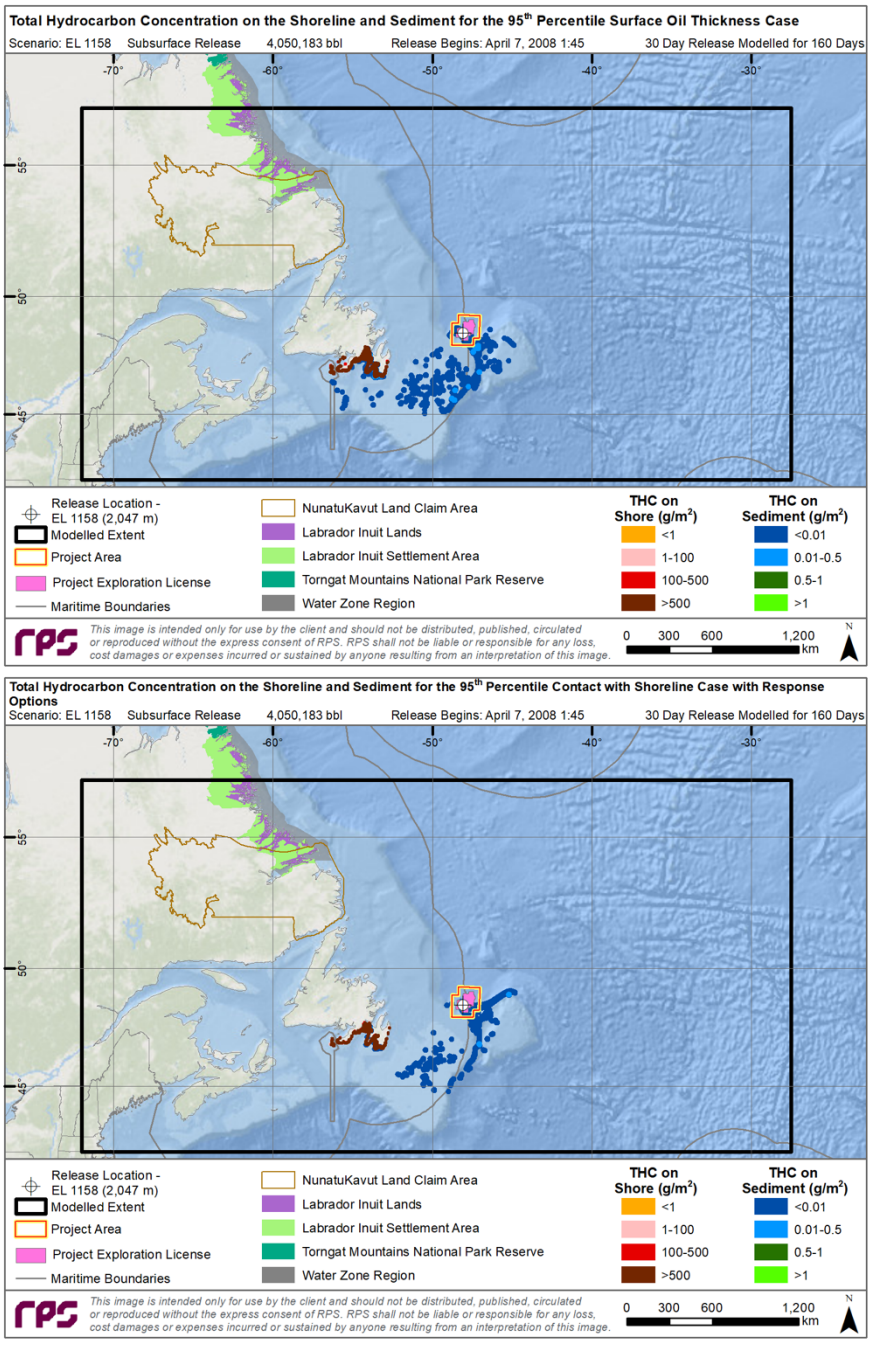

Figure 3-10. Scenario 1: THC on the shore and sediment for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

3.2 Scenario 2: 30-day Surface Oil Cases With Limited Response

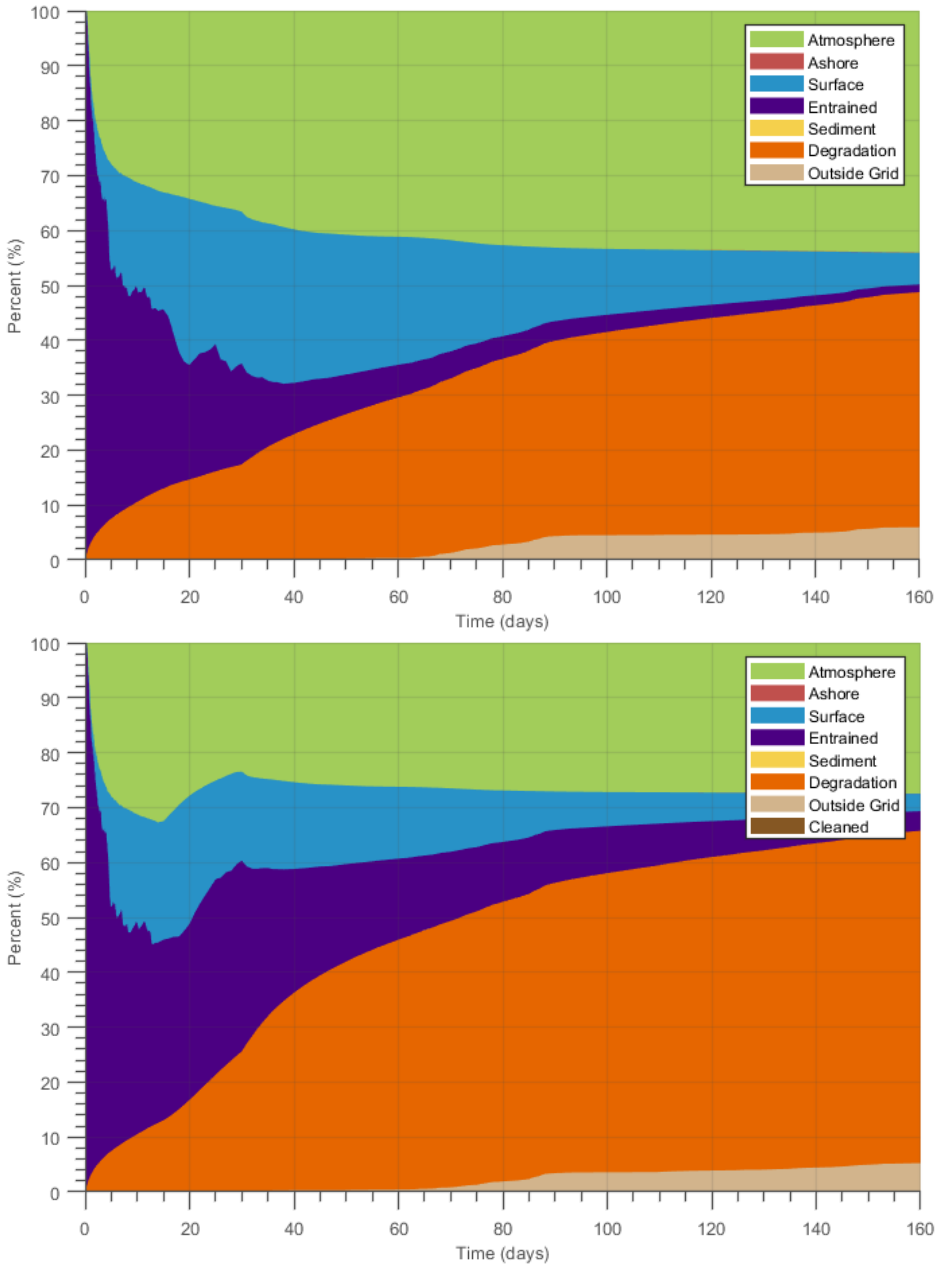

Figure 3-11. Scenario 2: Mass balance plots of the 95th percentile surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157 with limited response.

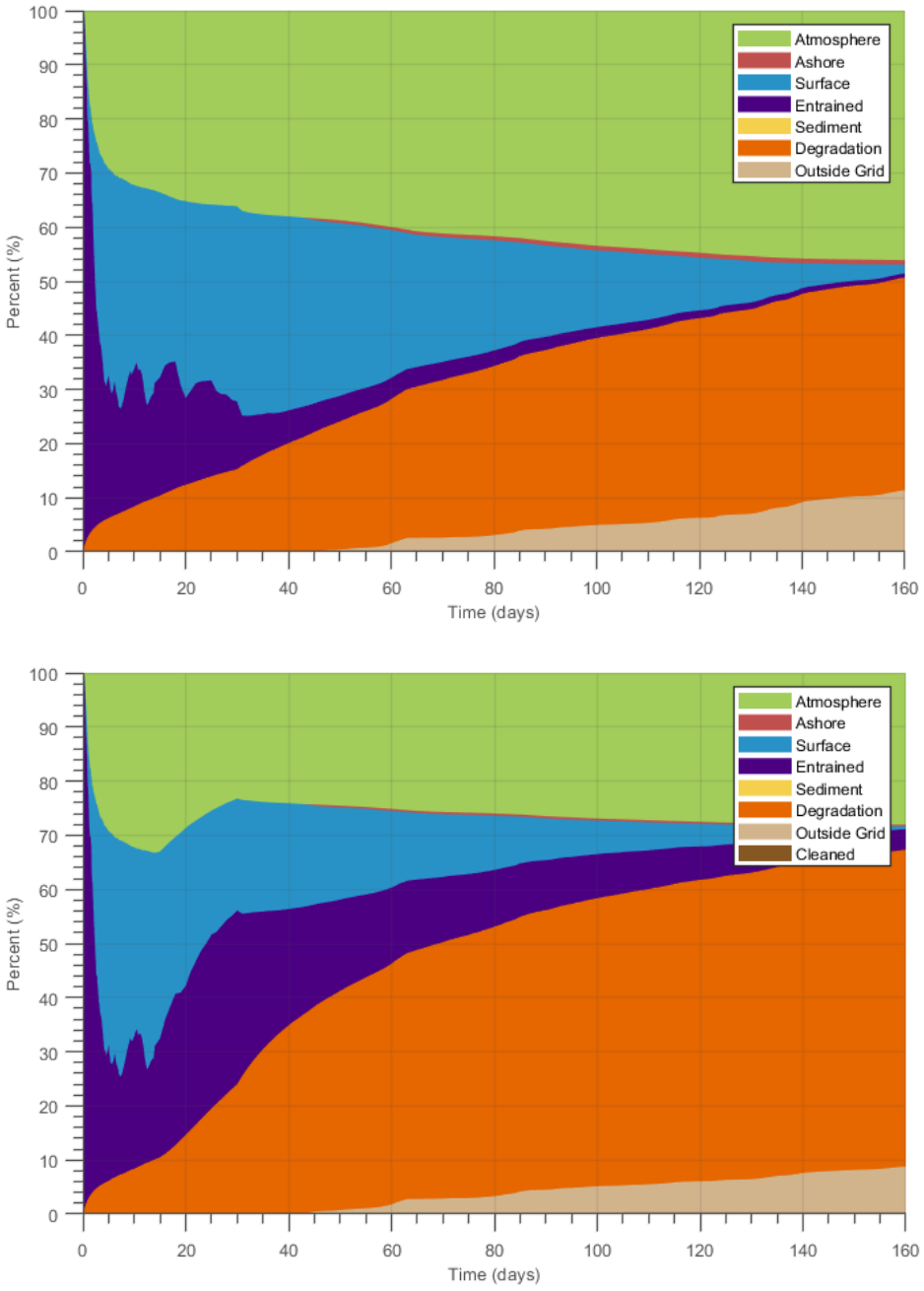

Figure 3-12. Scenario 2: Mass balance plots of the 95th percentile surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158 with limited response.

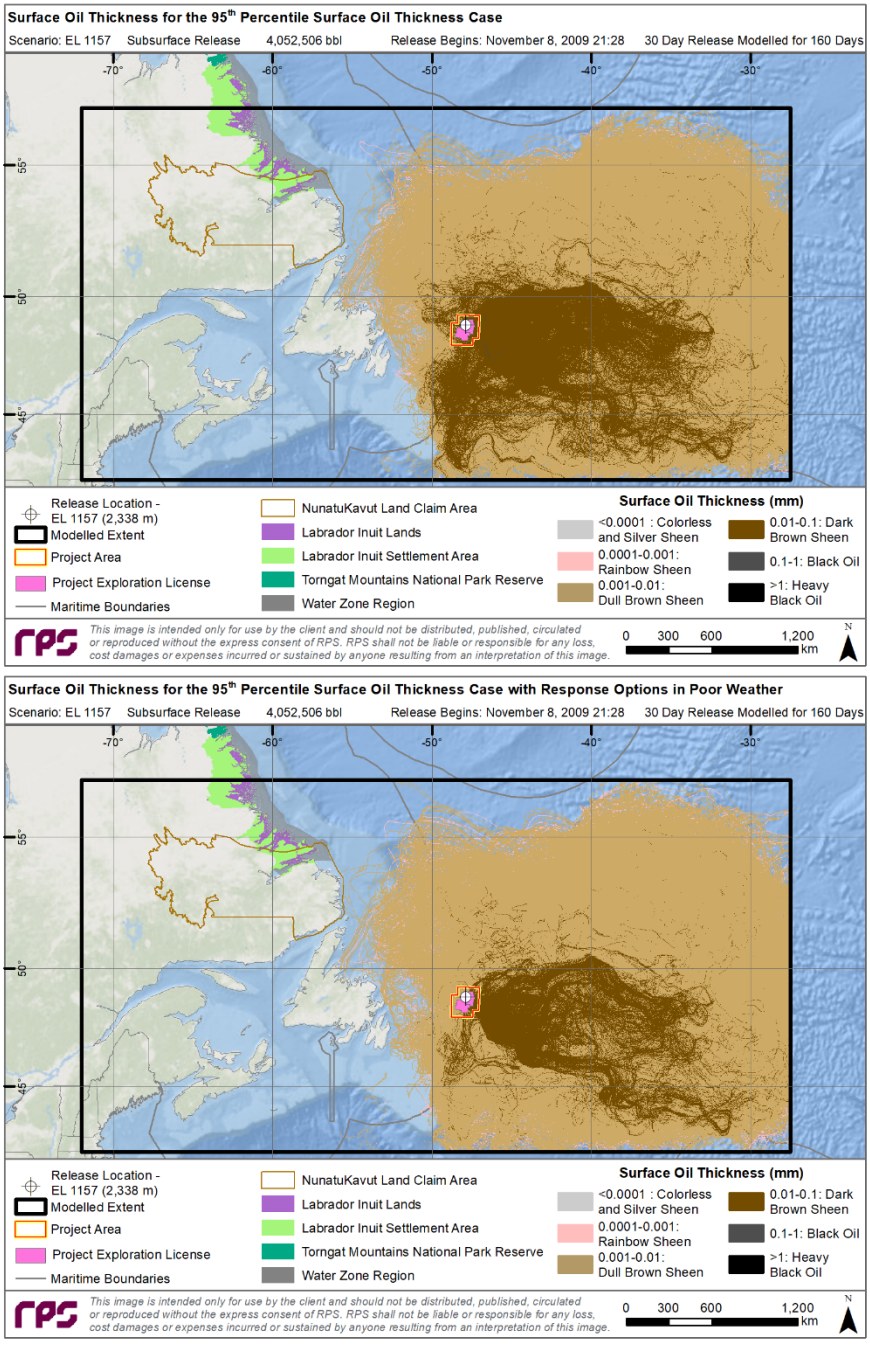

Figure 3-13. Scenario 2: Surface oil thickness for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157 with limited response.

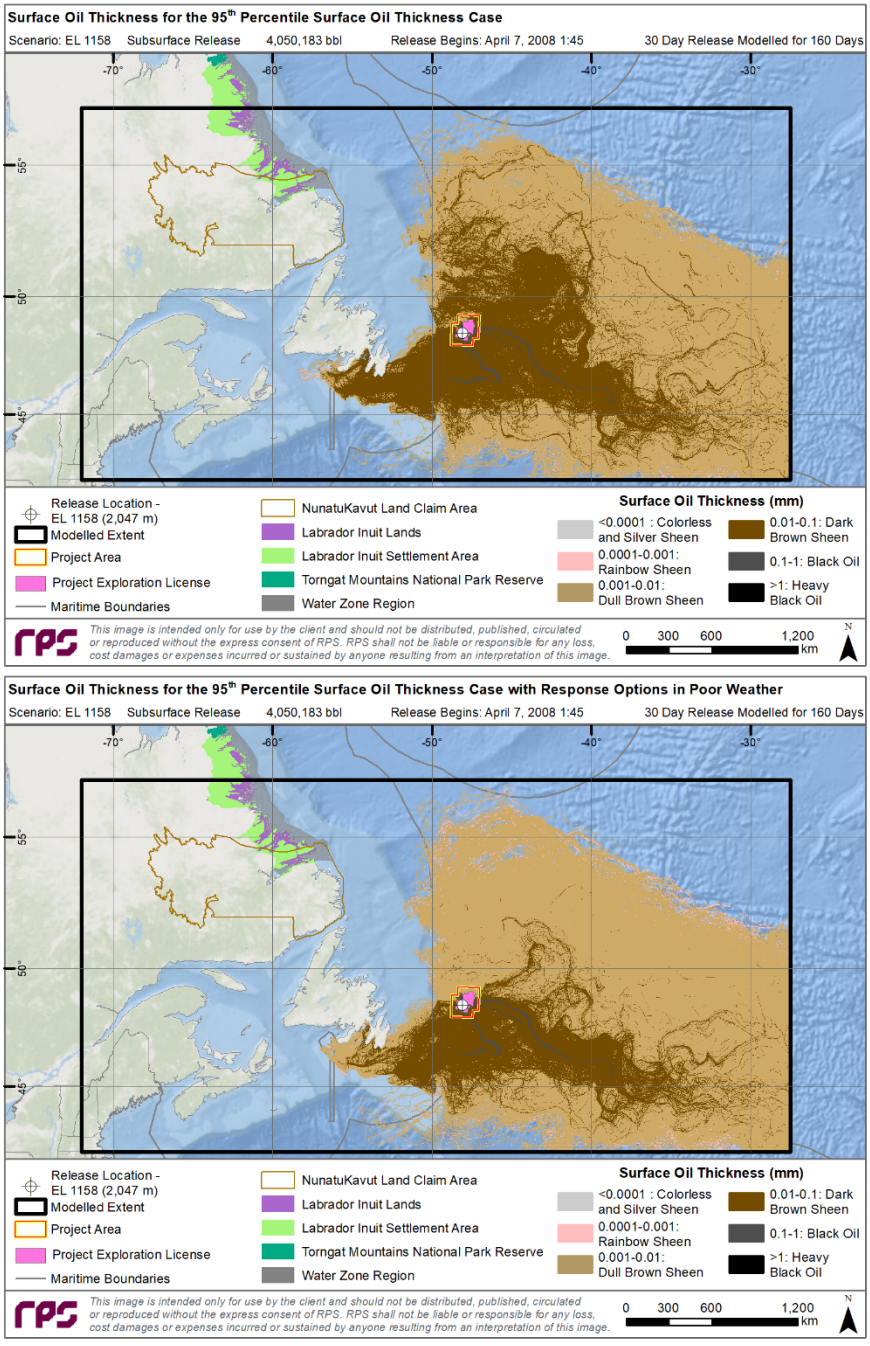

Figure 3-14. Scenario 2: Surface oil thickness for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158 with limited response.

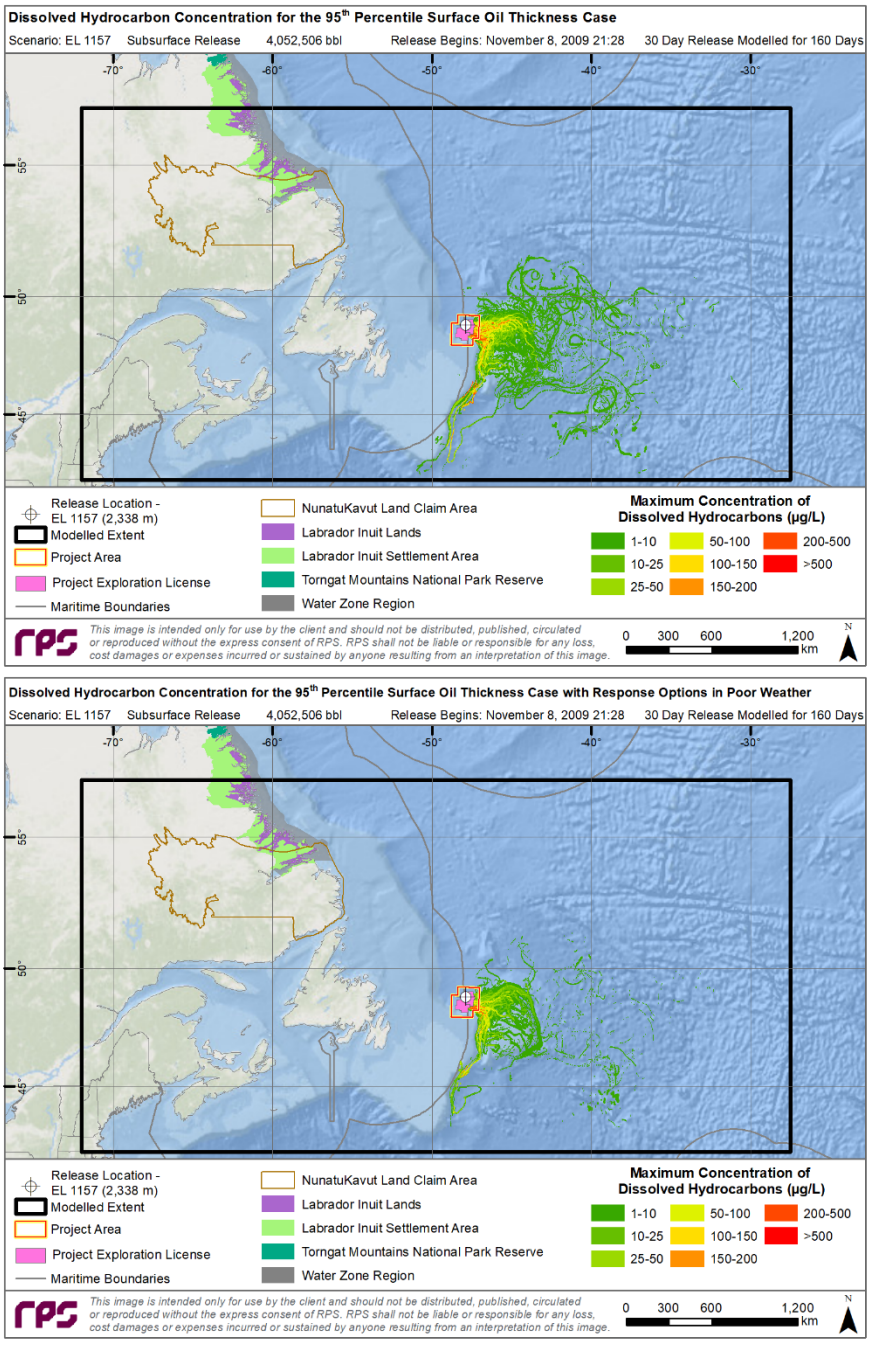

Figure 3-15. Scenario 2: Maximum DHC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

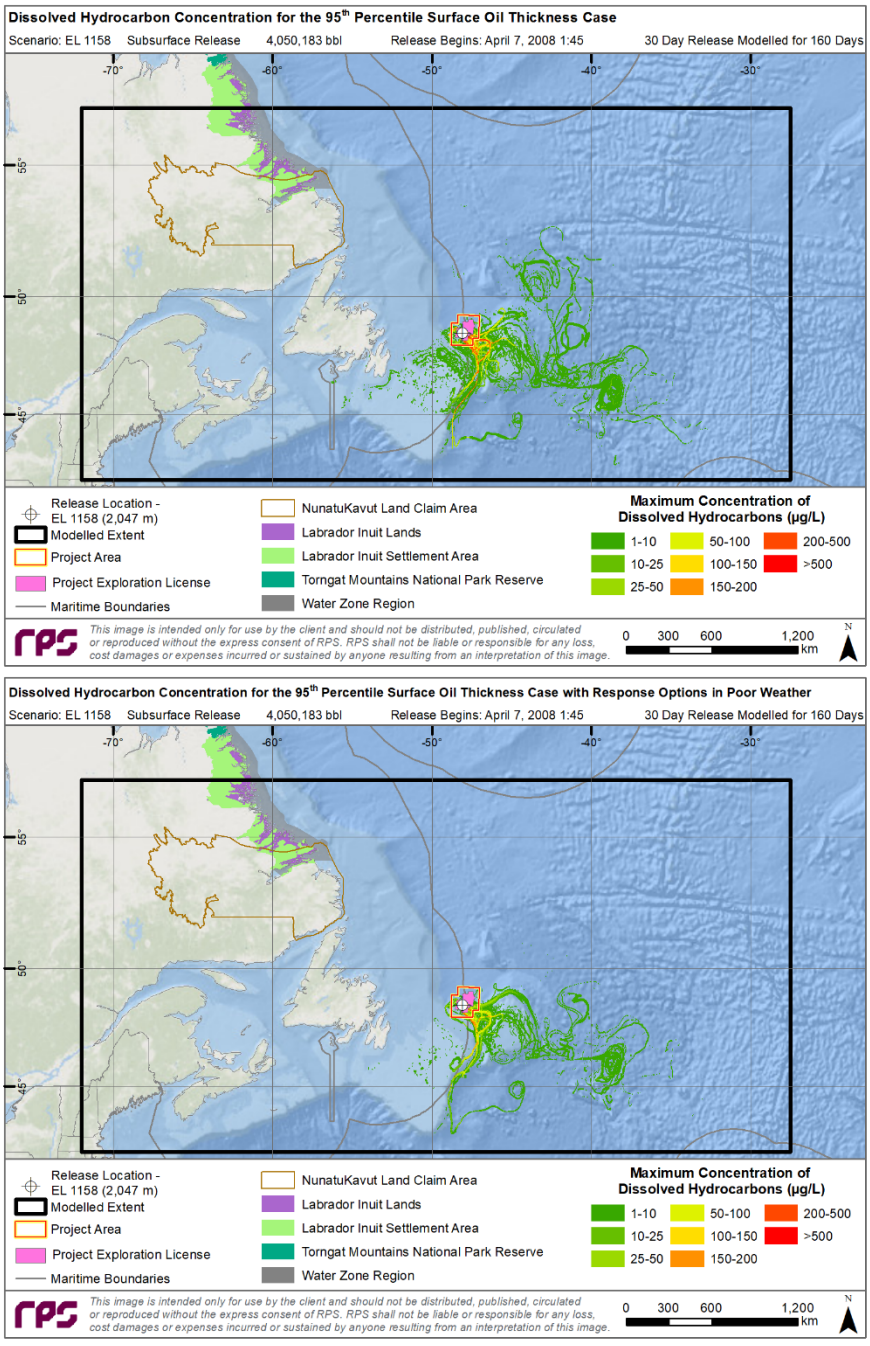

Figure 3-16. Scenario 2: Maximum DHC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

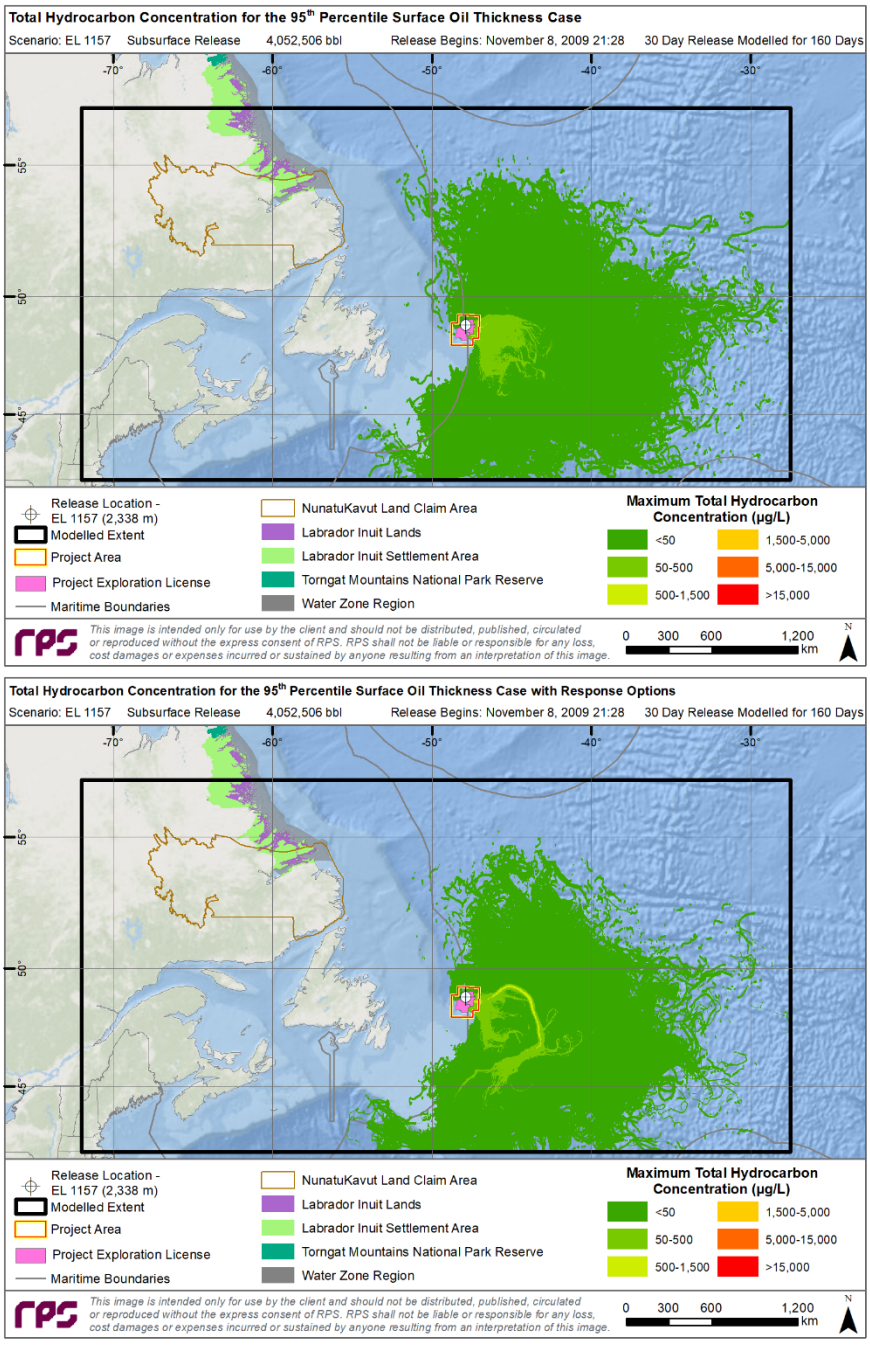

Figure 3-17. Scenario 2: Maximum THC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

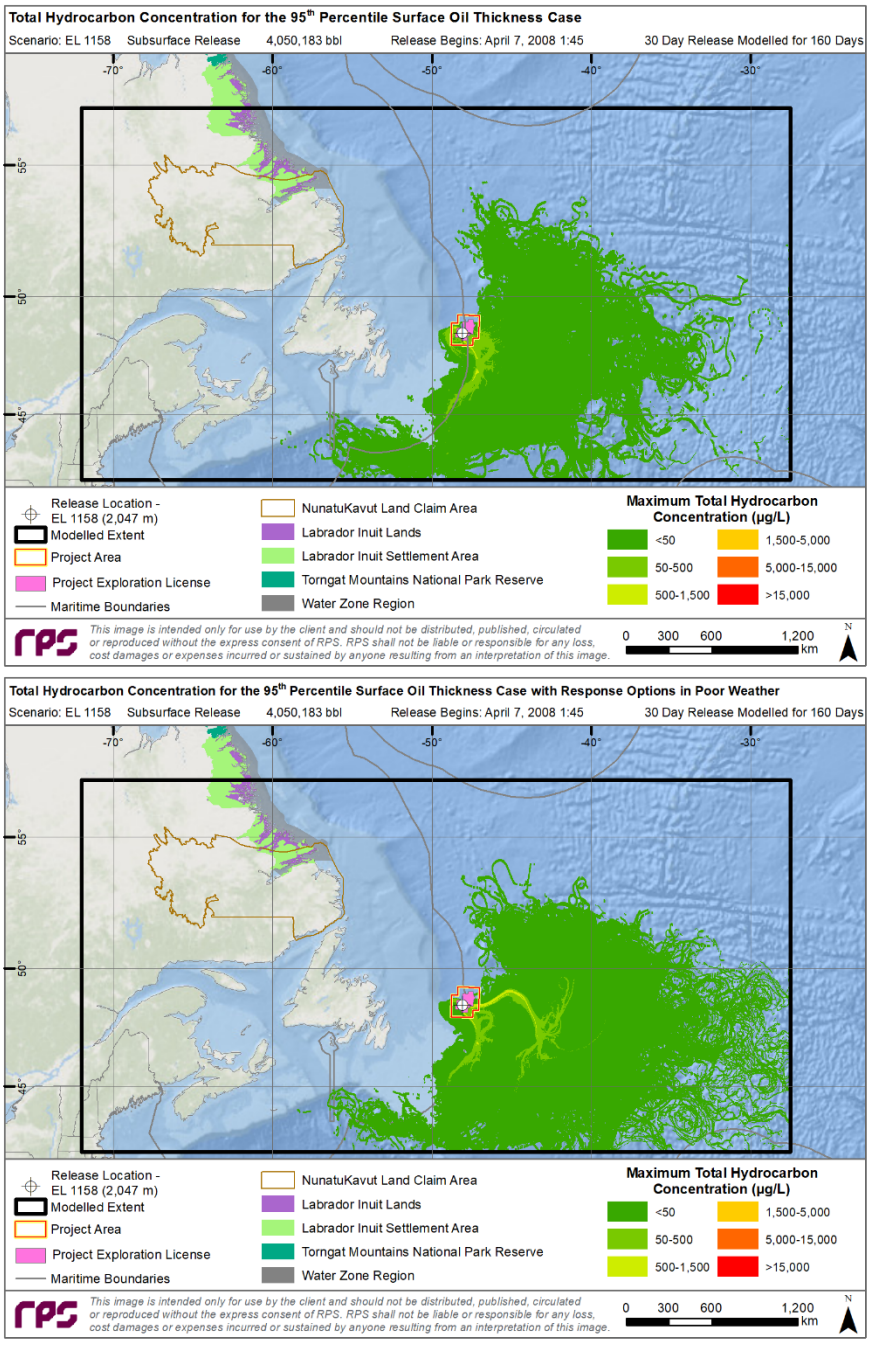

Figure 3-18. Scenario 2: Maximum THC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

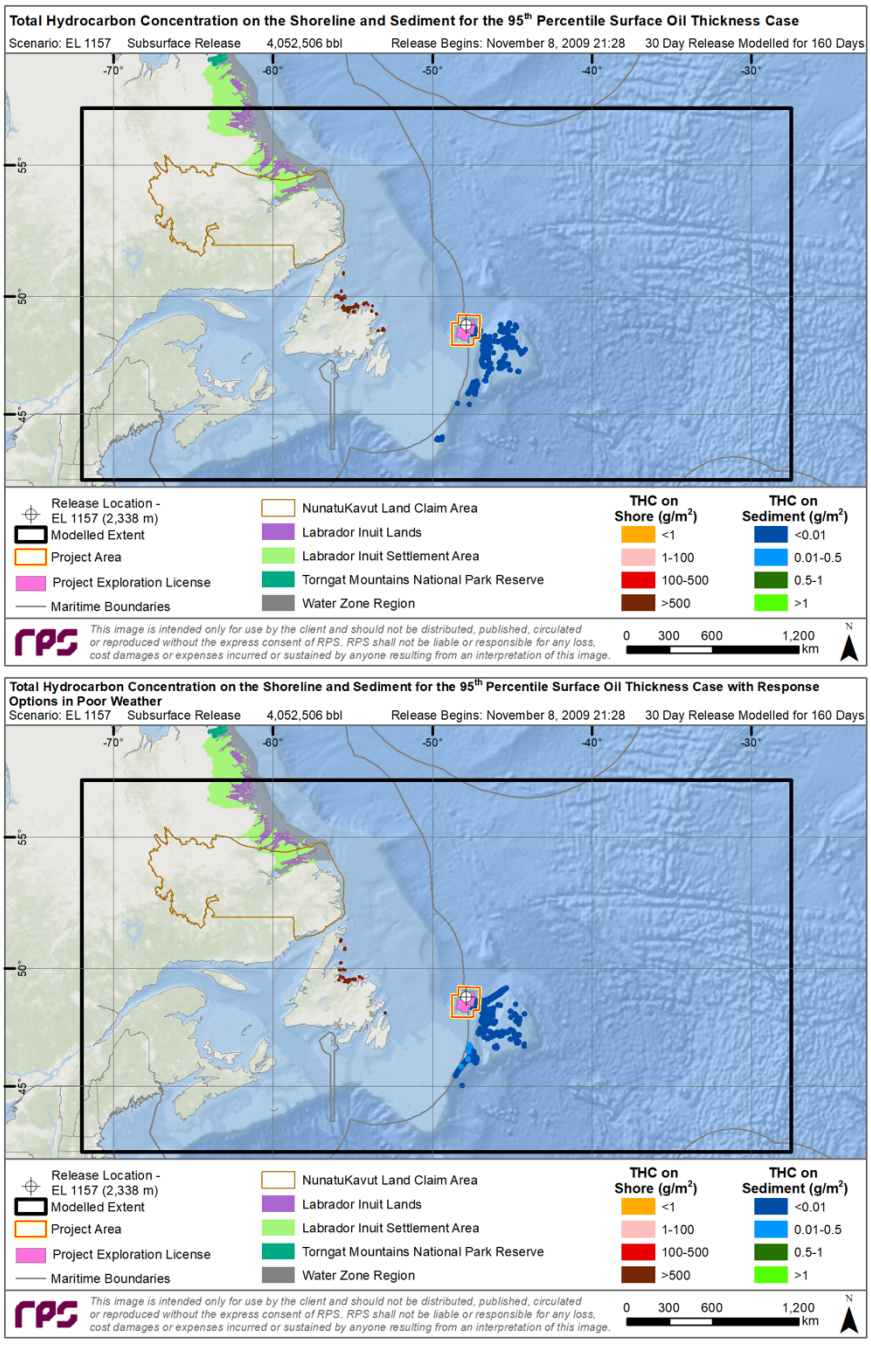

Figure 3-19. Scenario 2: THC on the shore and sediment for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

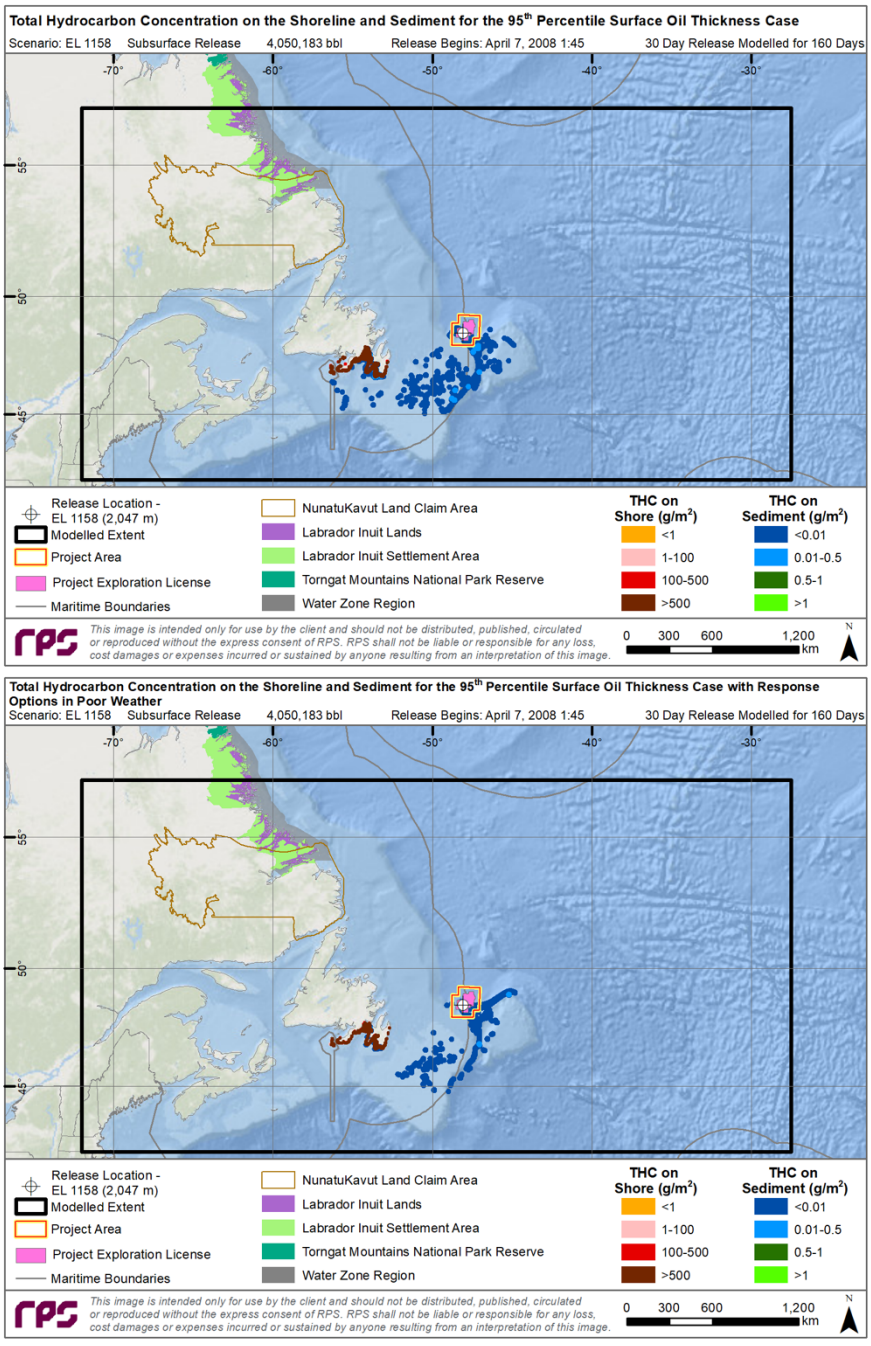

Figure 3-20. Scenario 2: THC on the shore and sediment for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

3.3 Scenario 3: 120-day Surface Oil Cases

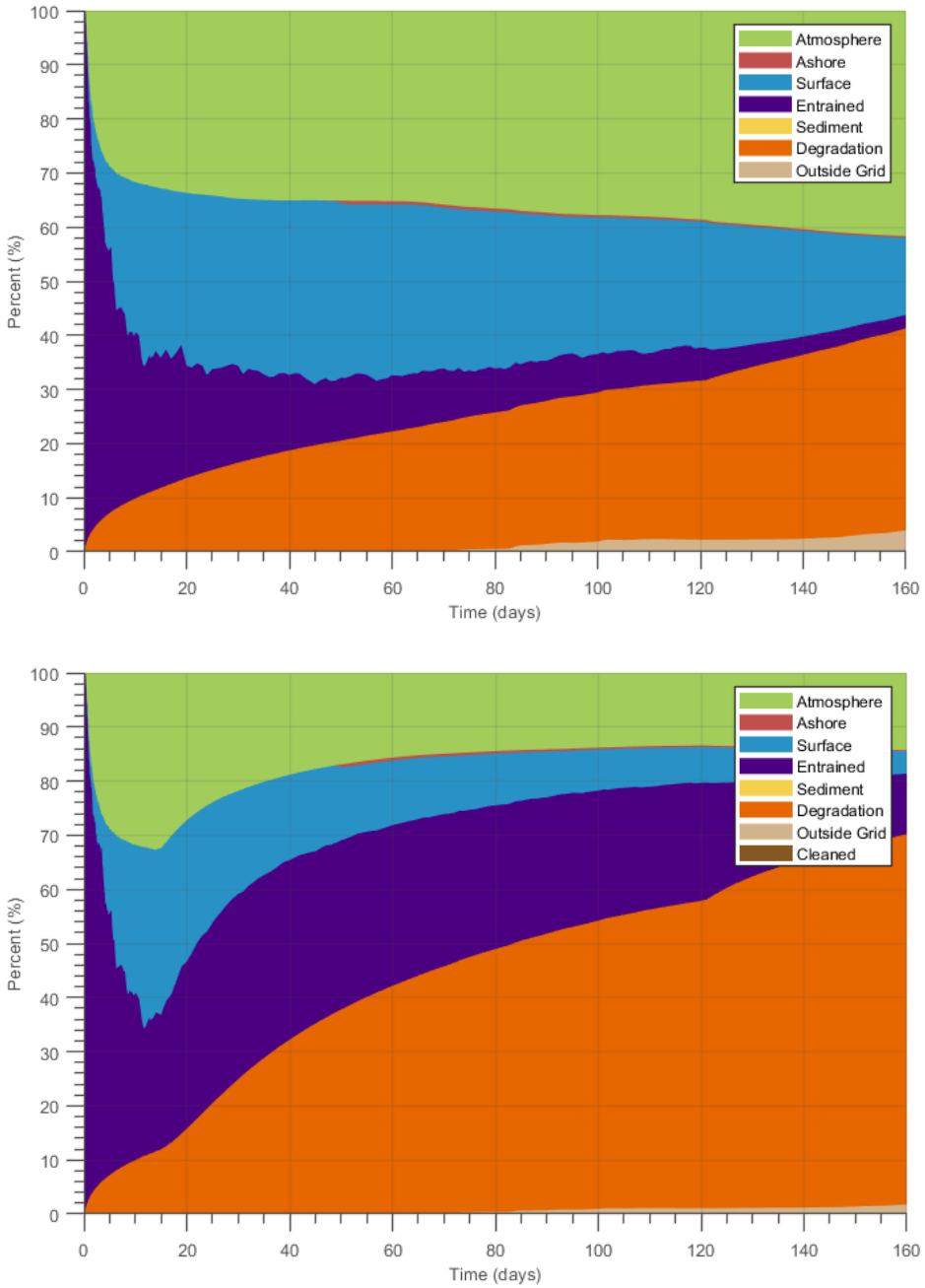

Figure 3-21. Scenario 3: Mass balance plots of the 95th percentile surface oil thickness case for an unmitigated (top) and mitigated (bottom) 120-day blowout at EL 1157.

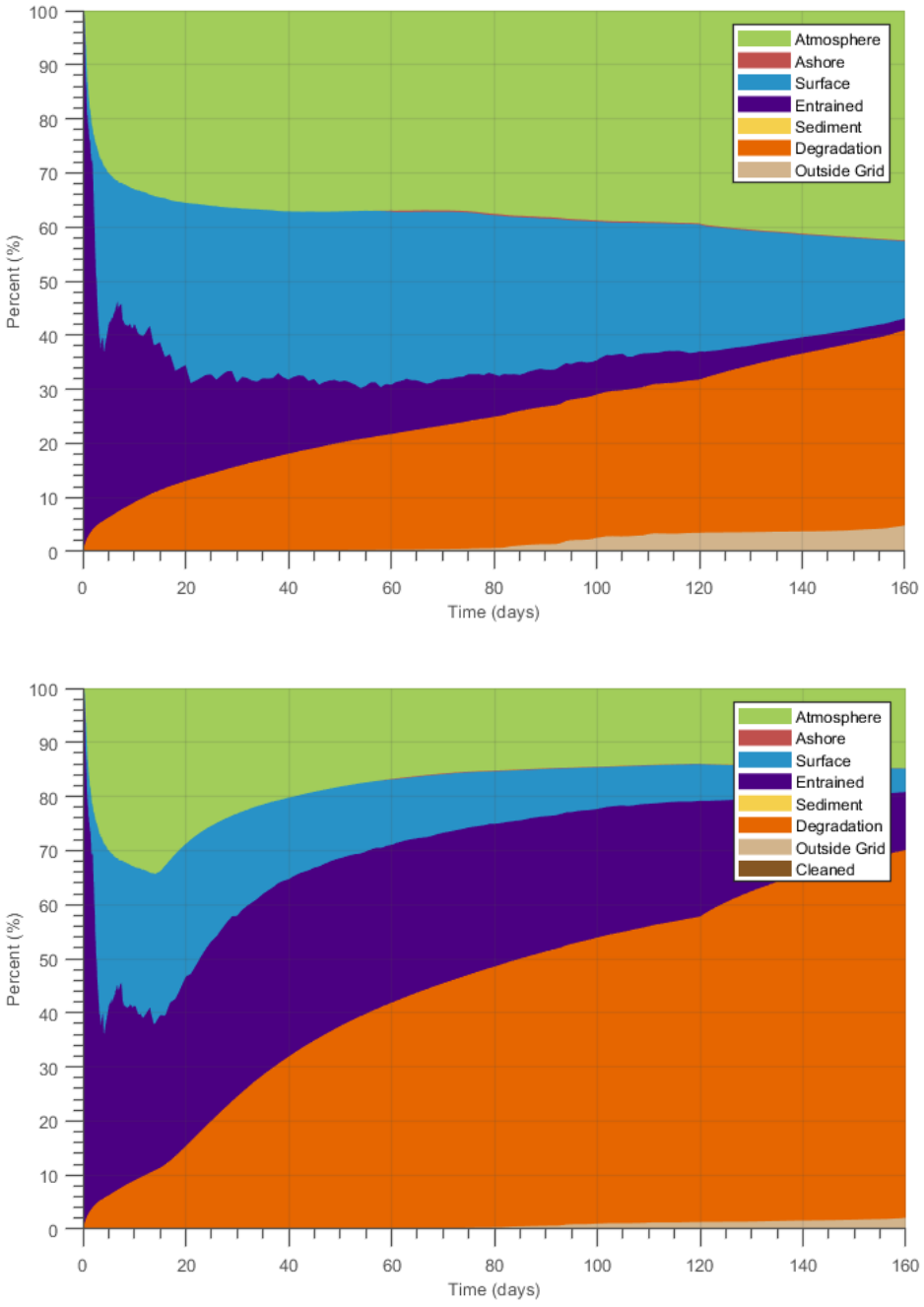

Figure 3-22. Scenario 3: Mass balance plots of the 95th percentile surface oil thickness case for an unmitigated (top) and mitigated (bottom) 120-day blowout at EL 1158.

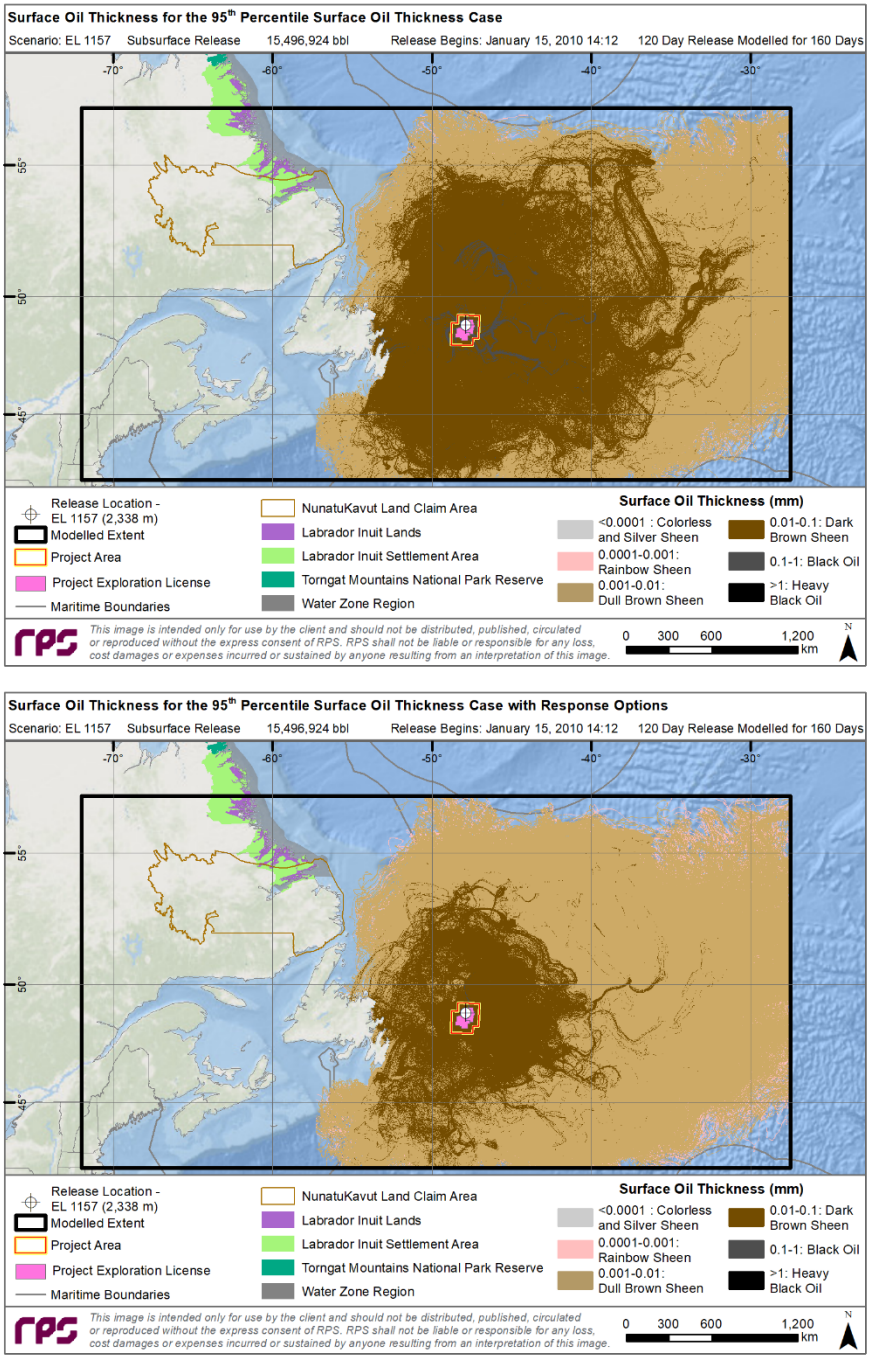

Figure 3-23. Scenario 3: Surface oil thickness for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 120-day blowout at EL 1157.

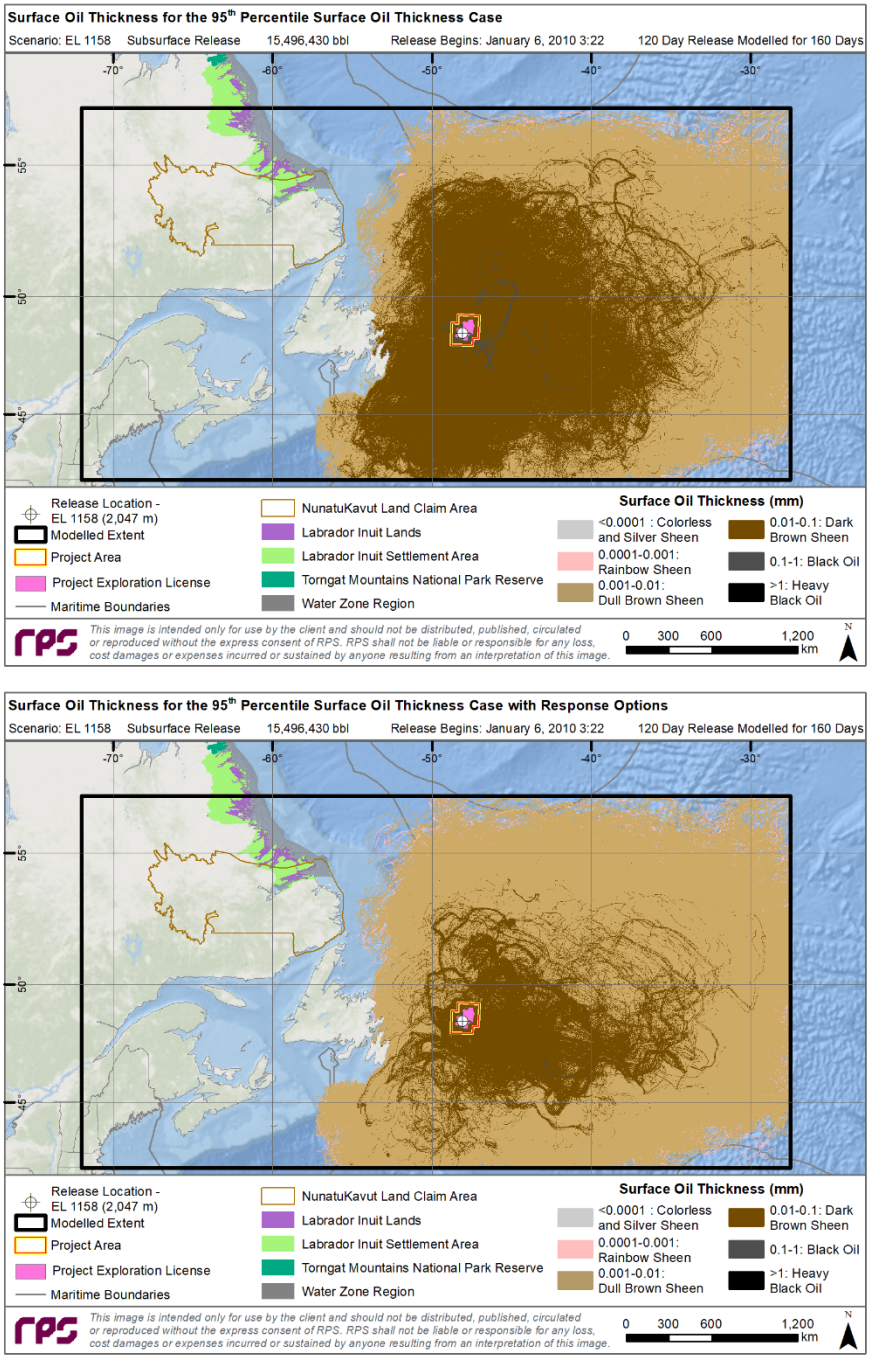

Figure 3-24. Scenario 3: Surface oil thickness for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 120-day blowout at EL 1158.

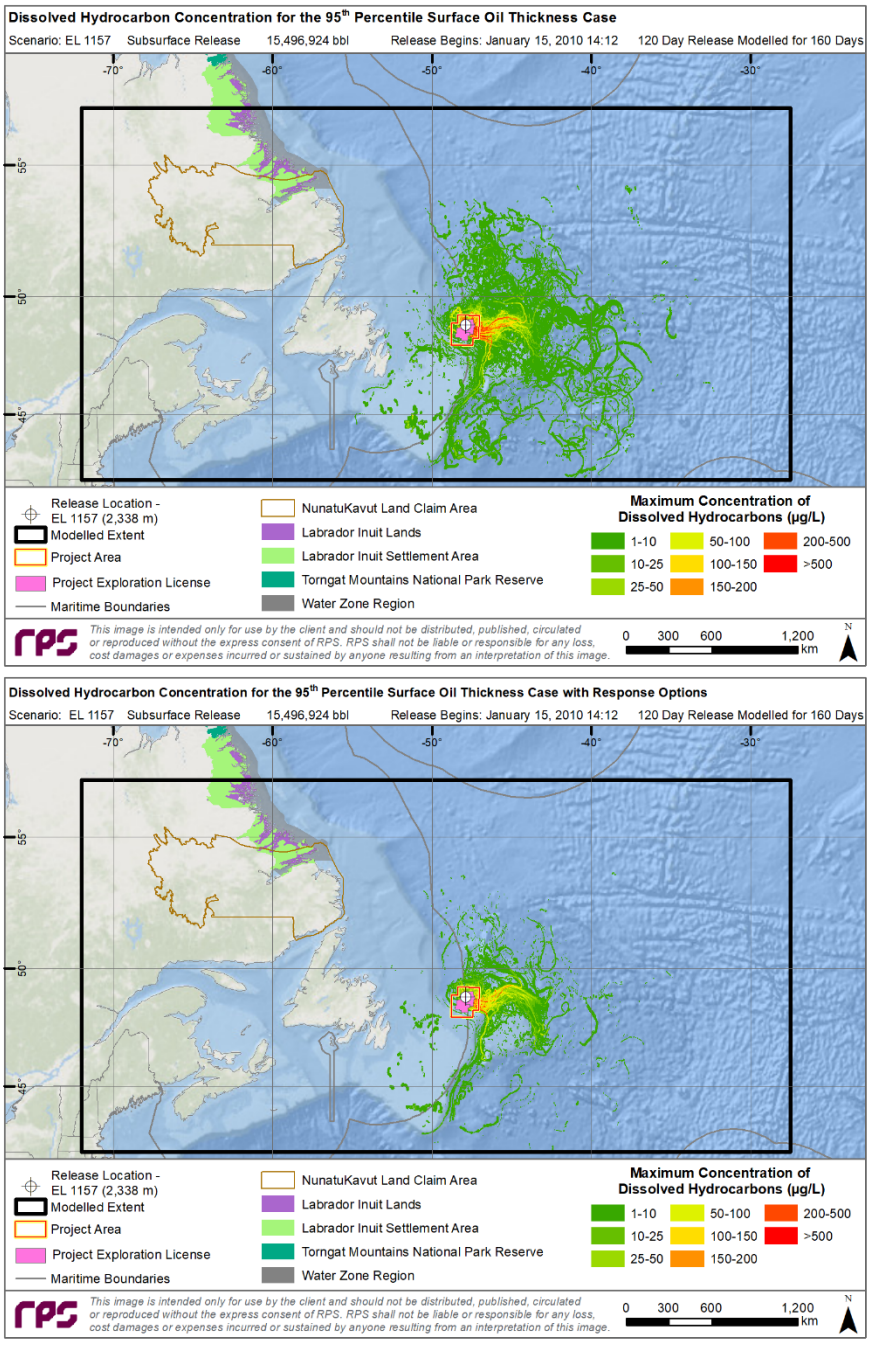

Figure 3-25. Scenario 3: Maximum DHC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 120-day blowout at EL 1157.

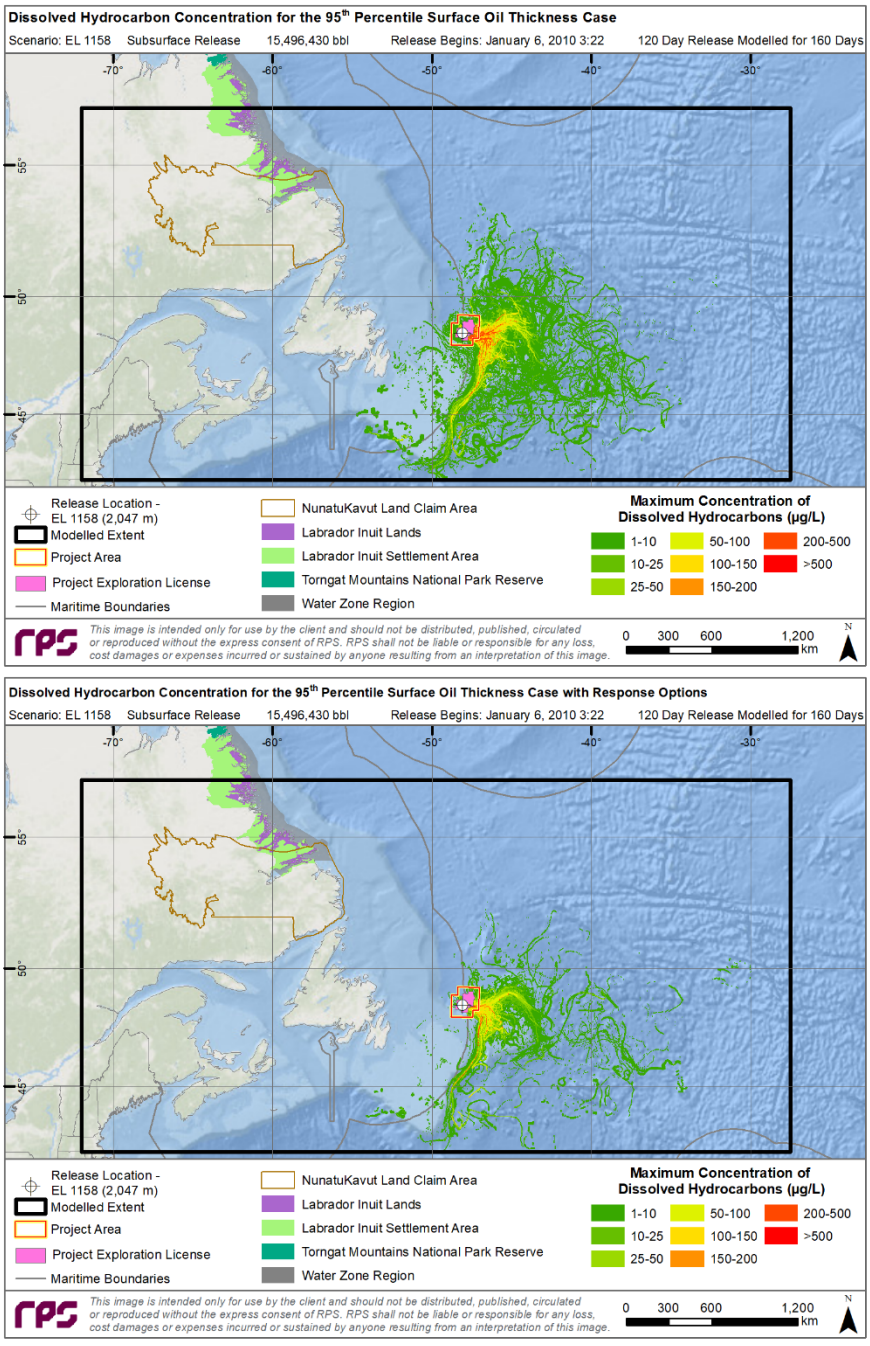

Figure 3-26. Scenario 3: Maximum DHC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

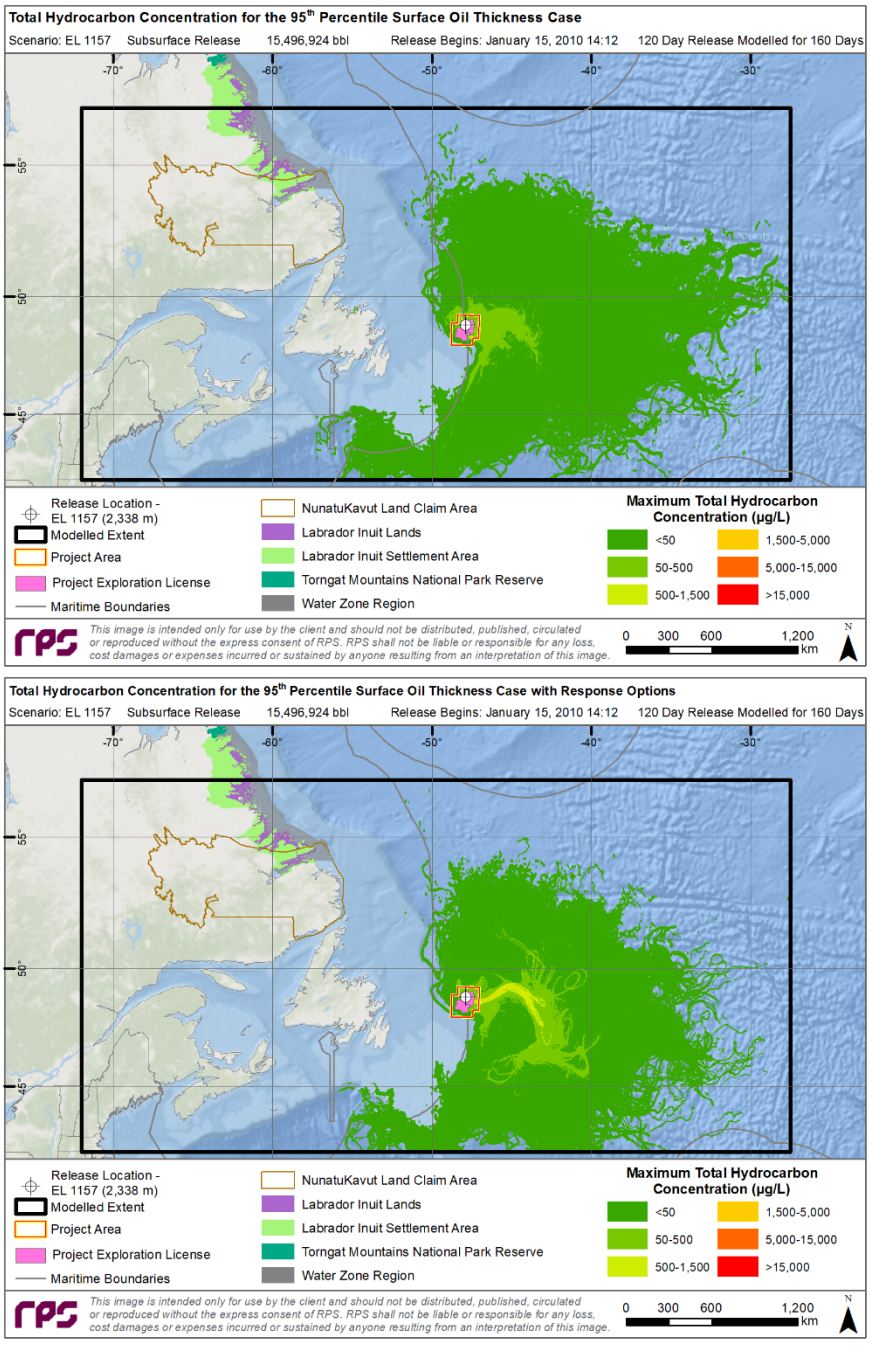

Figure 3-27. Scenario 3: Maximum THC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 120-day blowout at EL 1157.

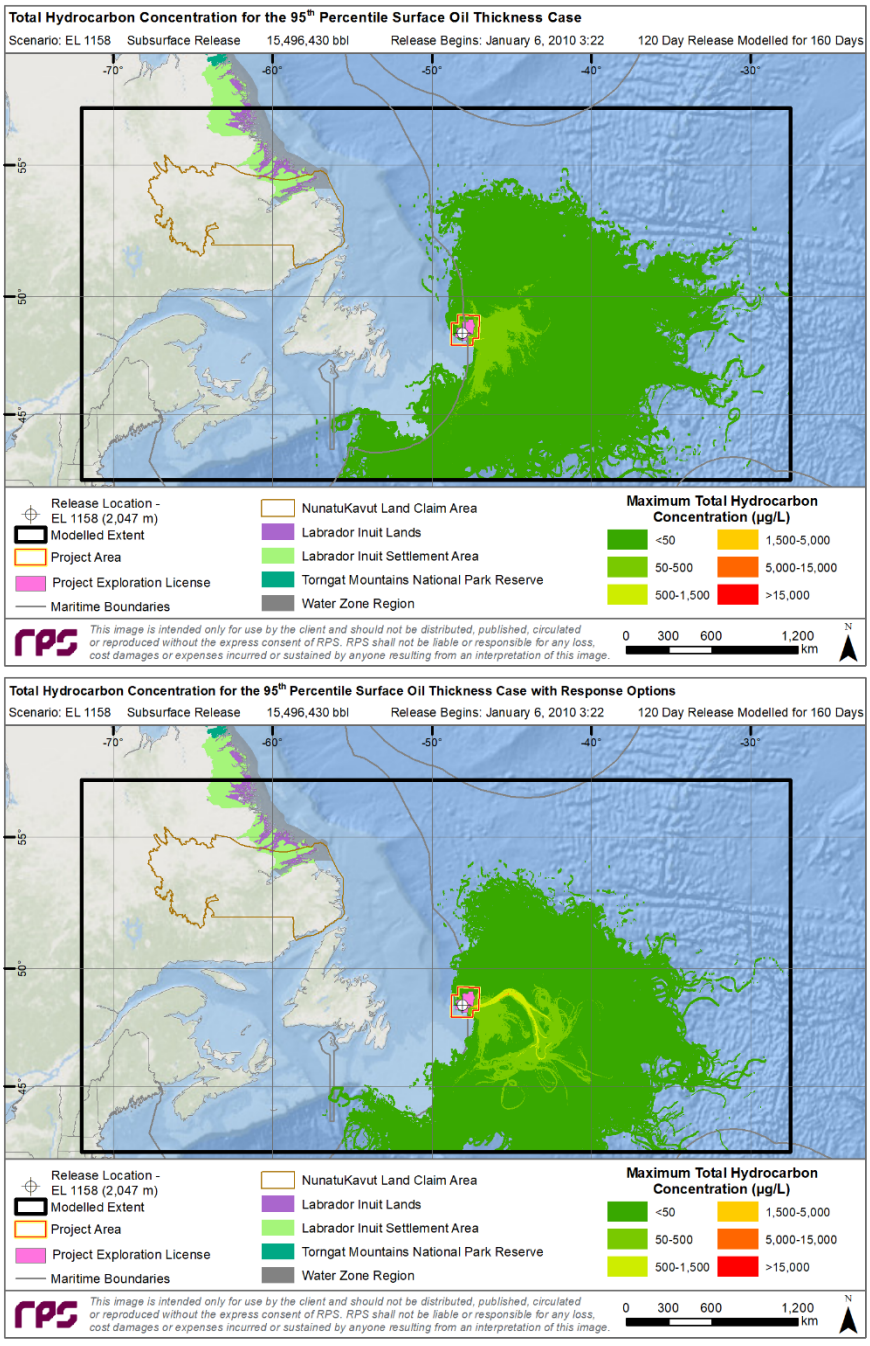

Figure 3-28. Scenario 3: Maximum THC at any depth in the water column for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 120-day blowout at EL 1158.

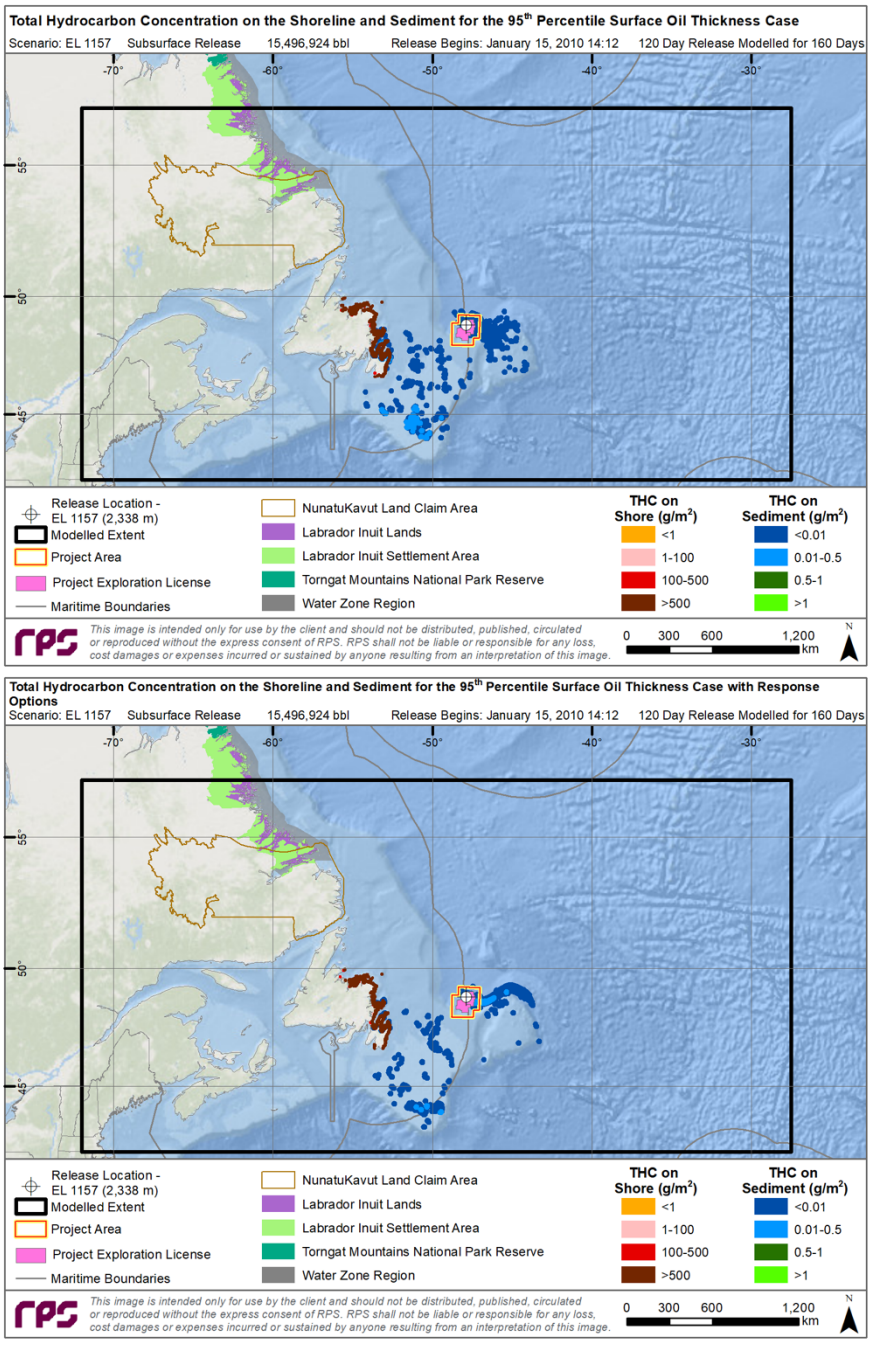

Figure 3-29. Scenario 3: THC on the shore and sediment for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 120-day blowout at EL 1157.

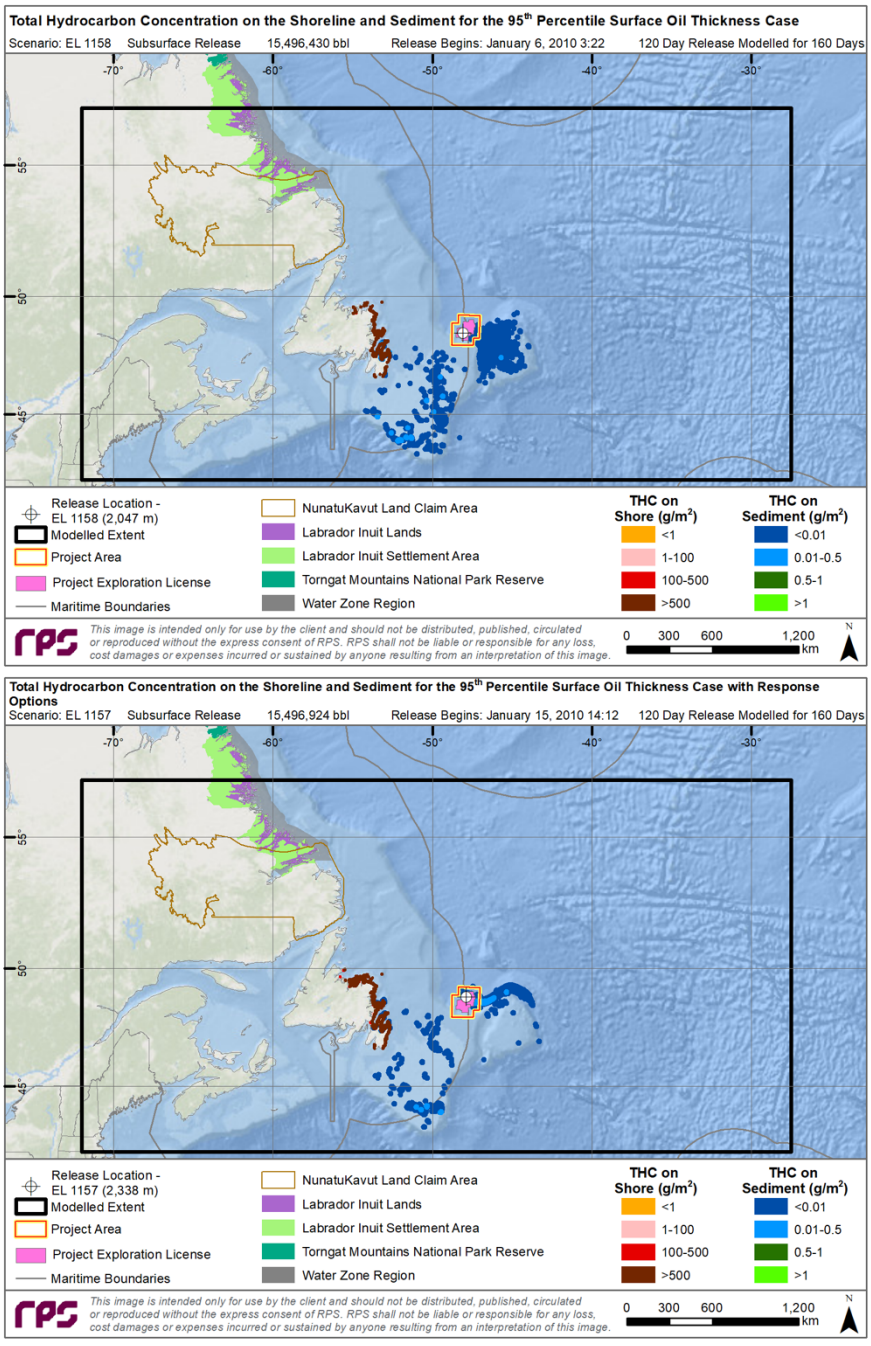

Figure 3-30. Scenario 3: THC on the shore and sediment for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 120-day blowout at EL 1158.

3.4 Scenario 4: 30-day Shoreline Cases

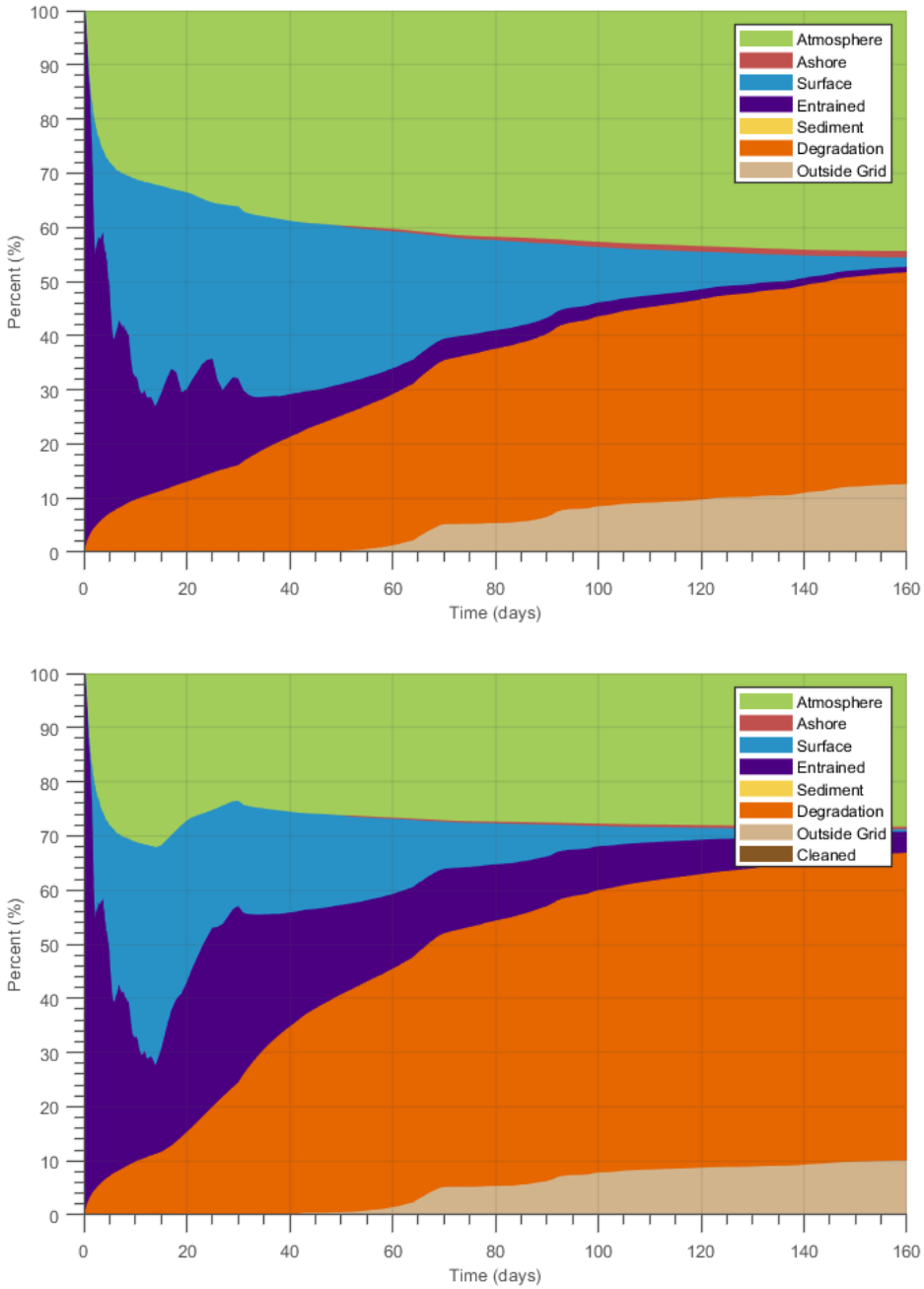

Figure 3-31. Scenario 4: Mass balance plots of the 95th percentile shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

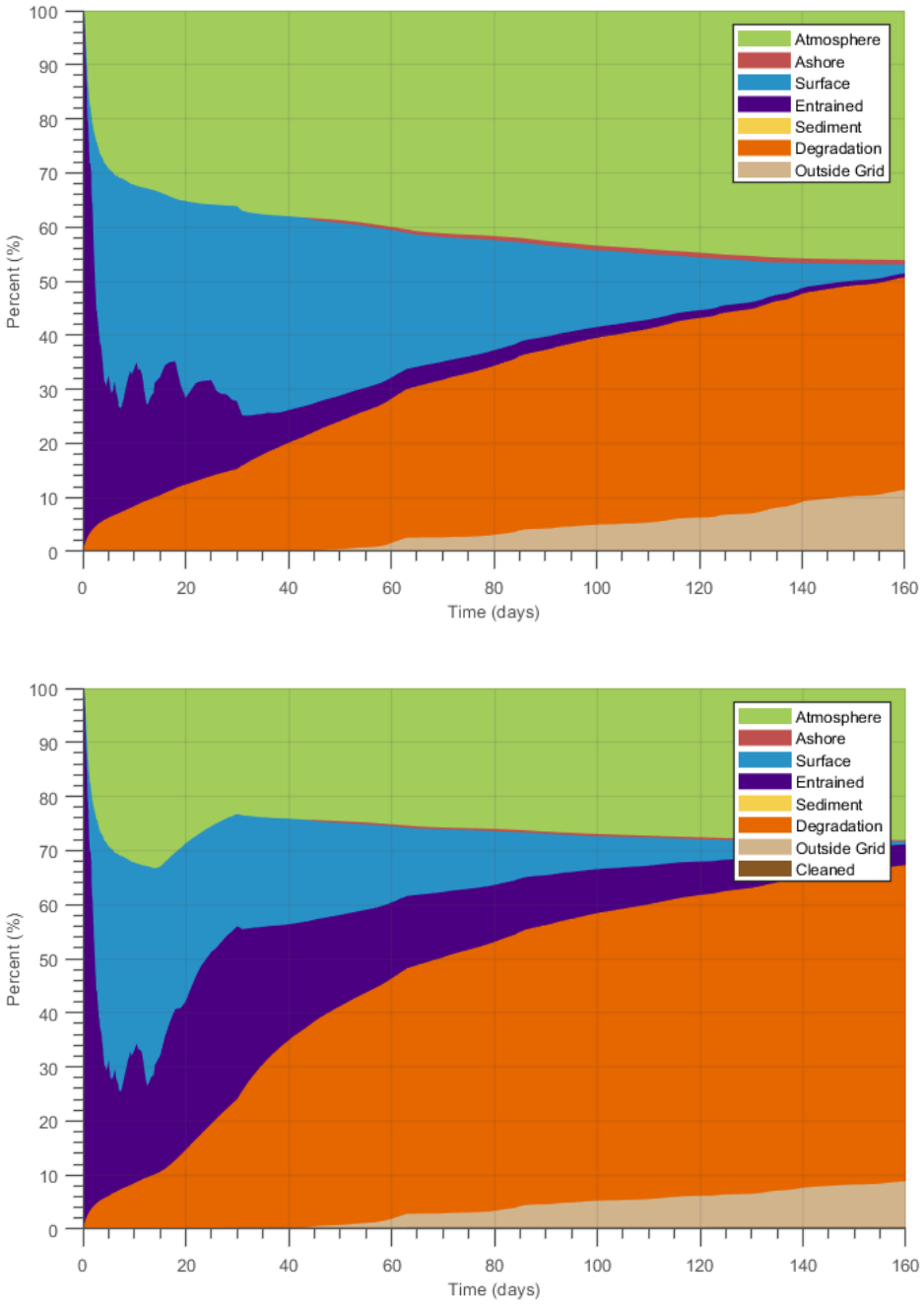

Figure 3-32. Scenario 4: Mass balance plots of the 95th percentile shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

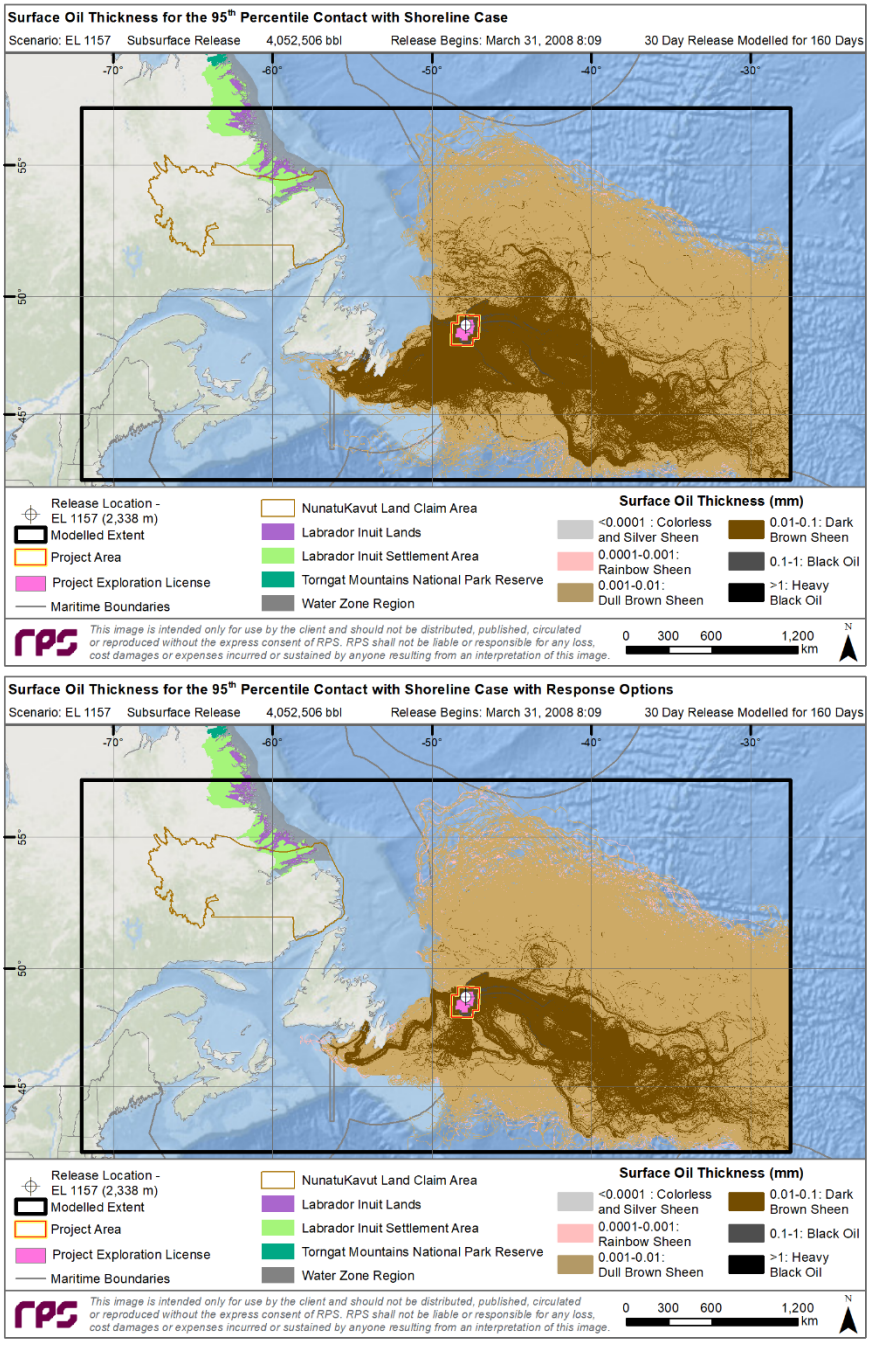

Figure 3-33. Scenario 4: Surface oil thickness for the 95th percentile average shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

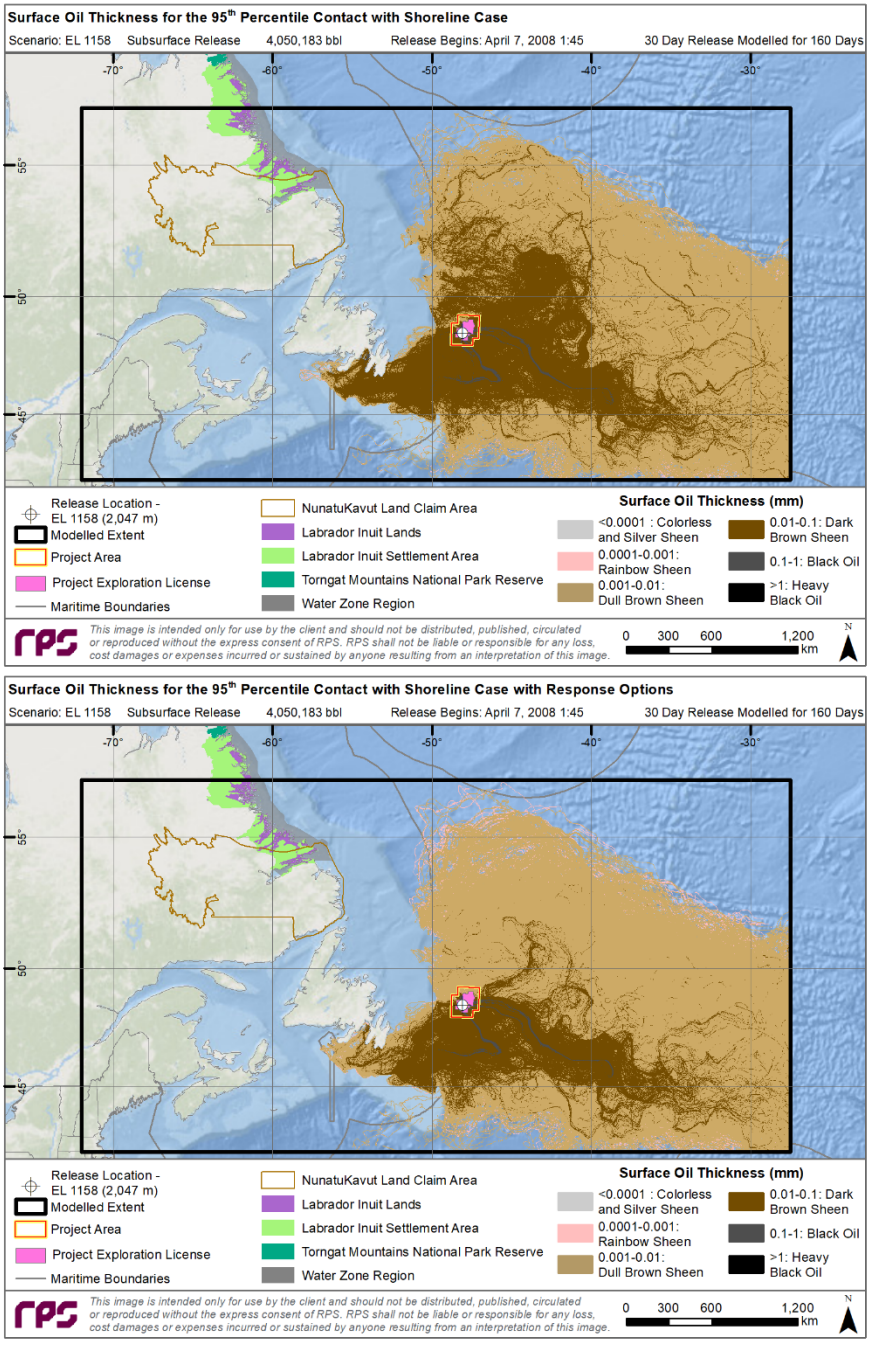

Figure 3-34. Scenario 4: Surface oil thickness for the 95th percentile average surface oil thickness case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

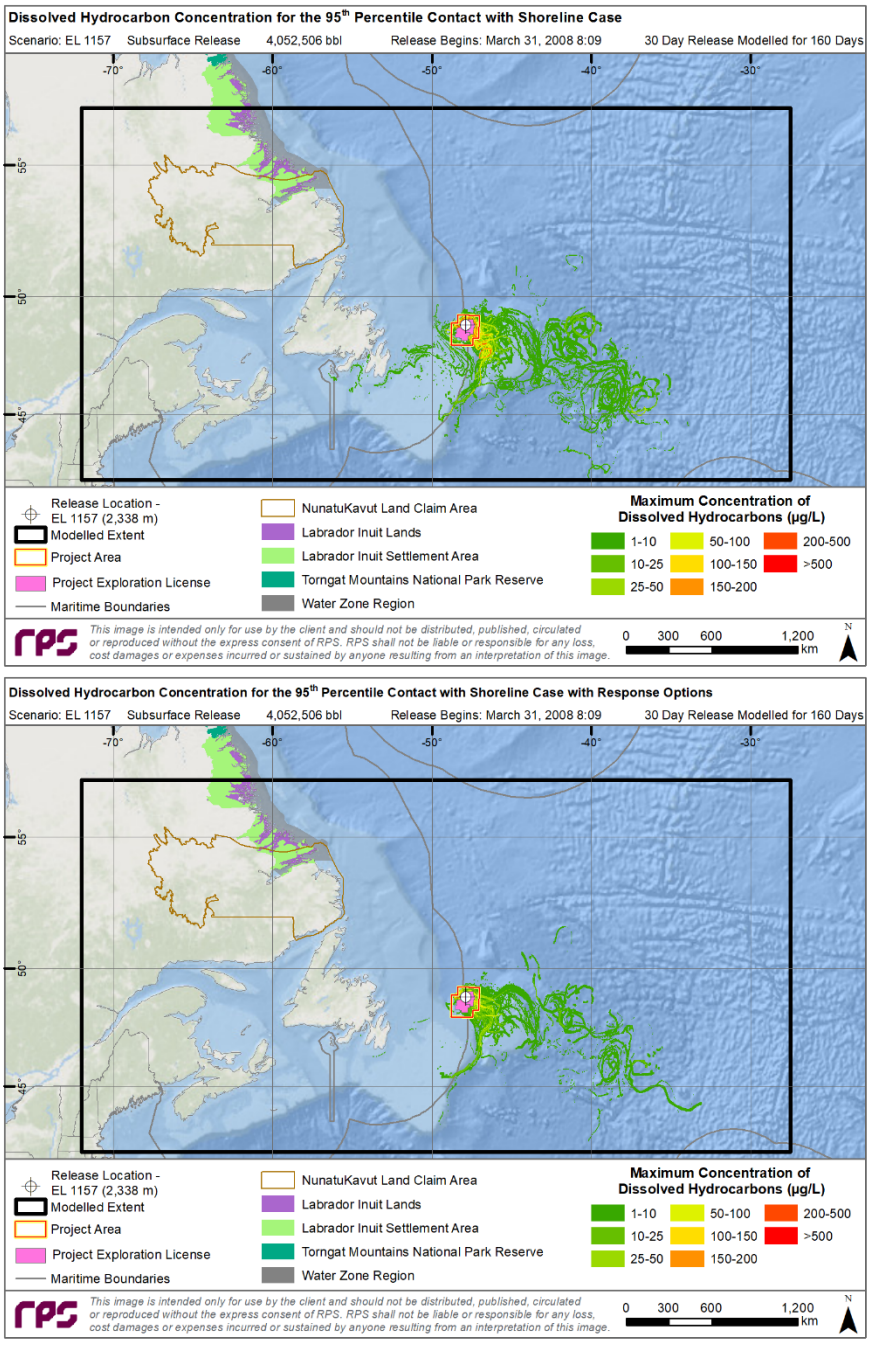

Figure 3-35. Scenario 4: Maximum DHC at any depth in the water column for the 95th percentile average shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

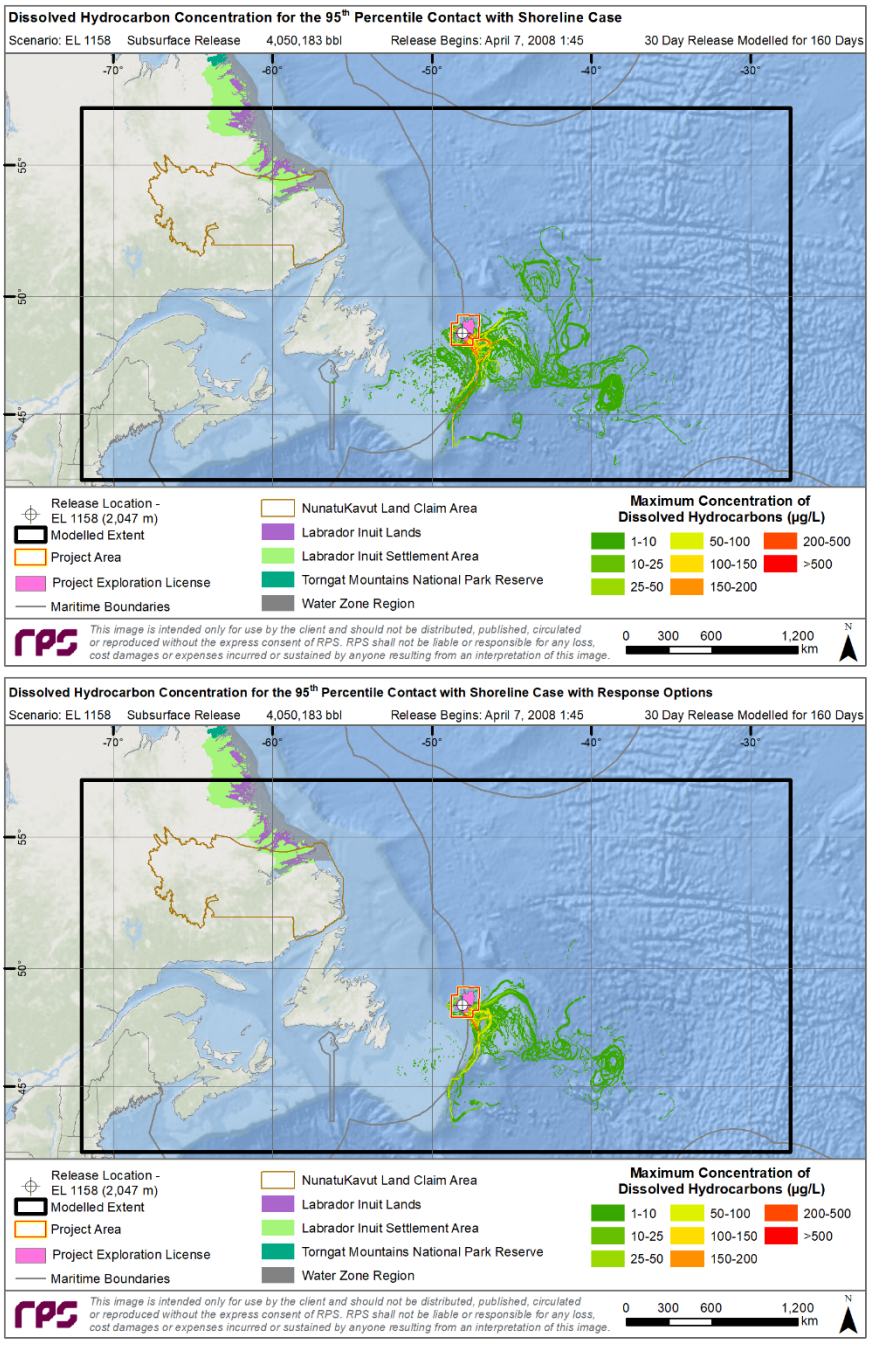

Figure 3-36. Scenario 4: Maximum DHC at any depth in the water column for the 95th percentile average shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

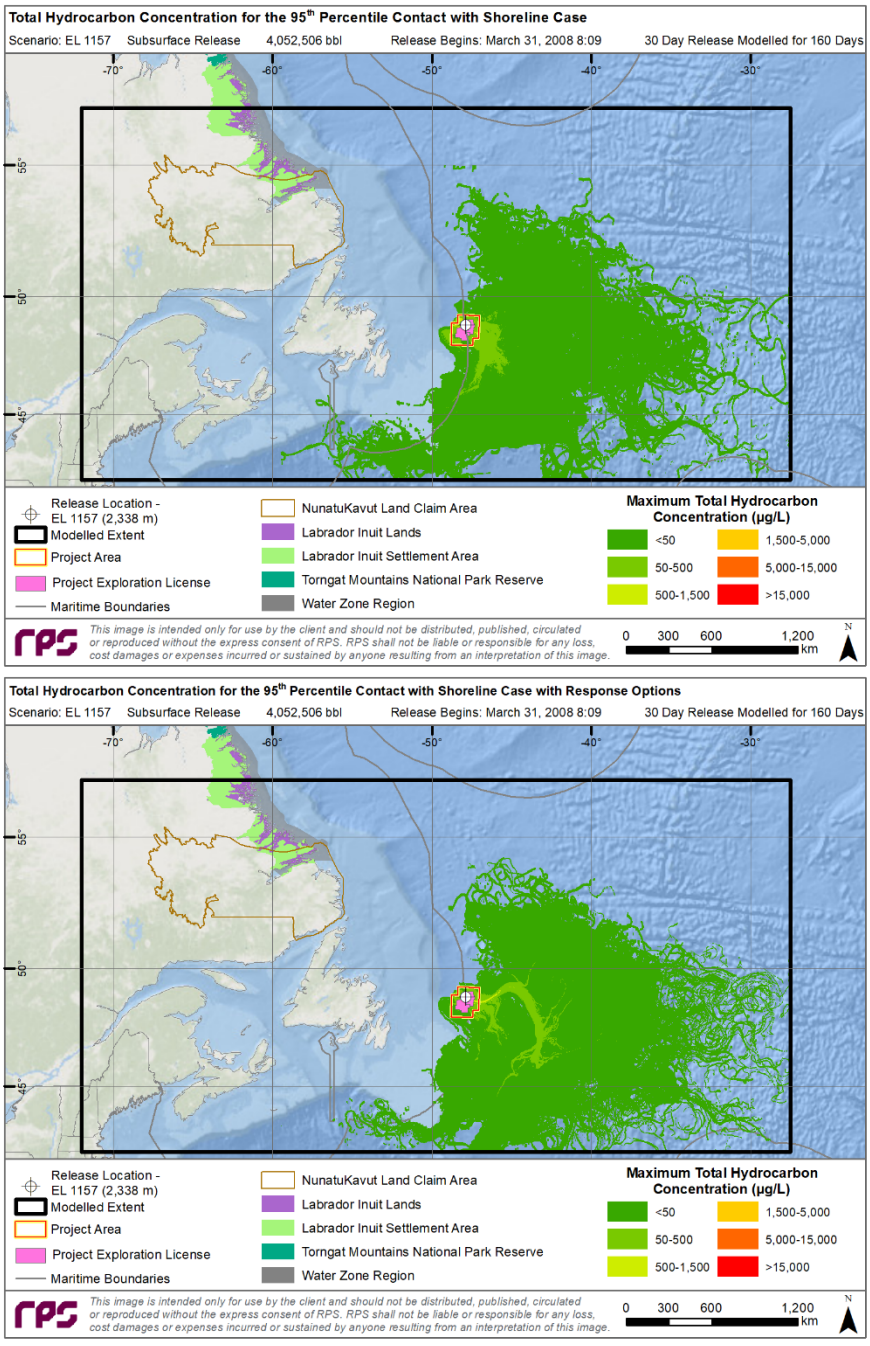

Figure 3-37. Scenario 4: Maximum THC at any depth in the water column for the 95th percentile average shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

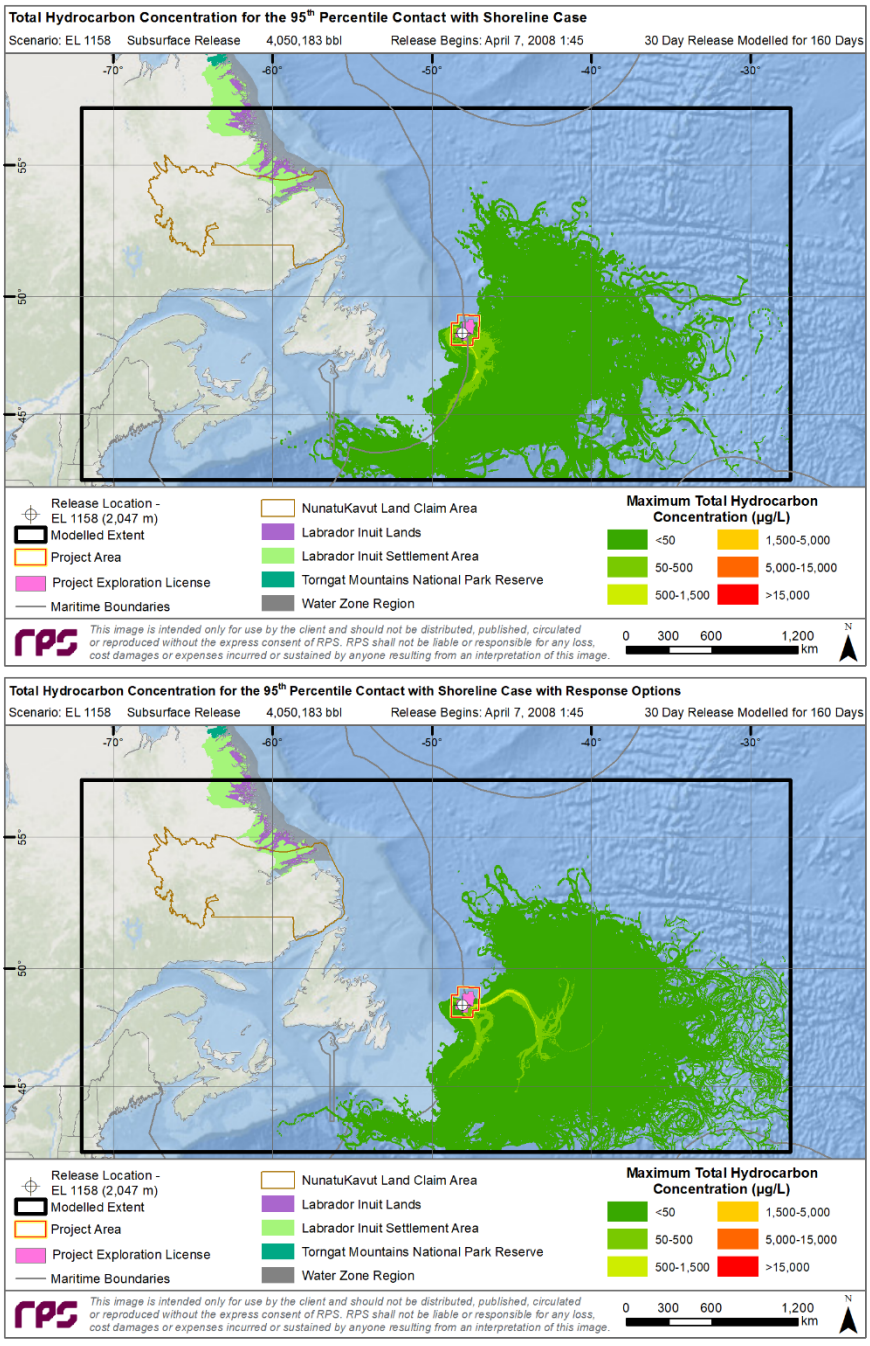

Figure 3-38. Scenario 4: Maximum THC at any depth in the water column for the 95th percentile average shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

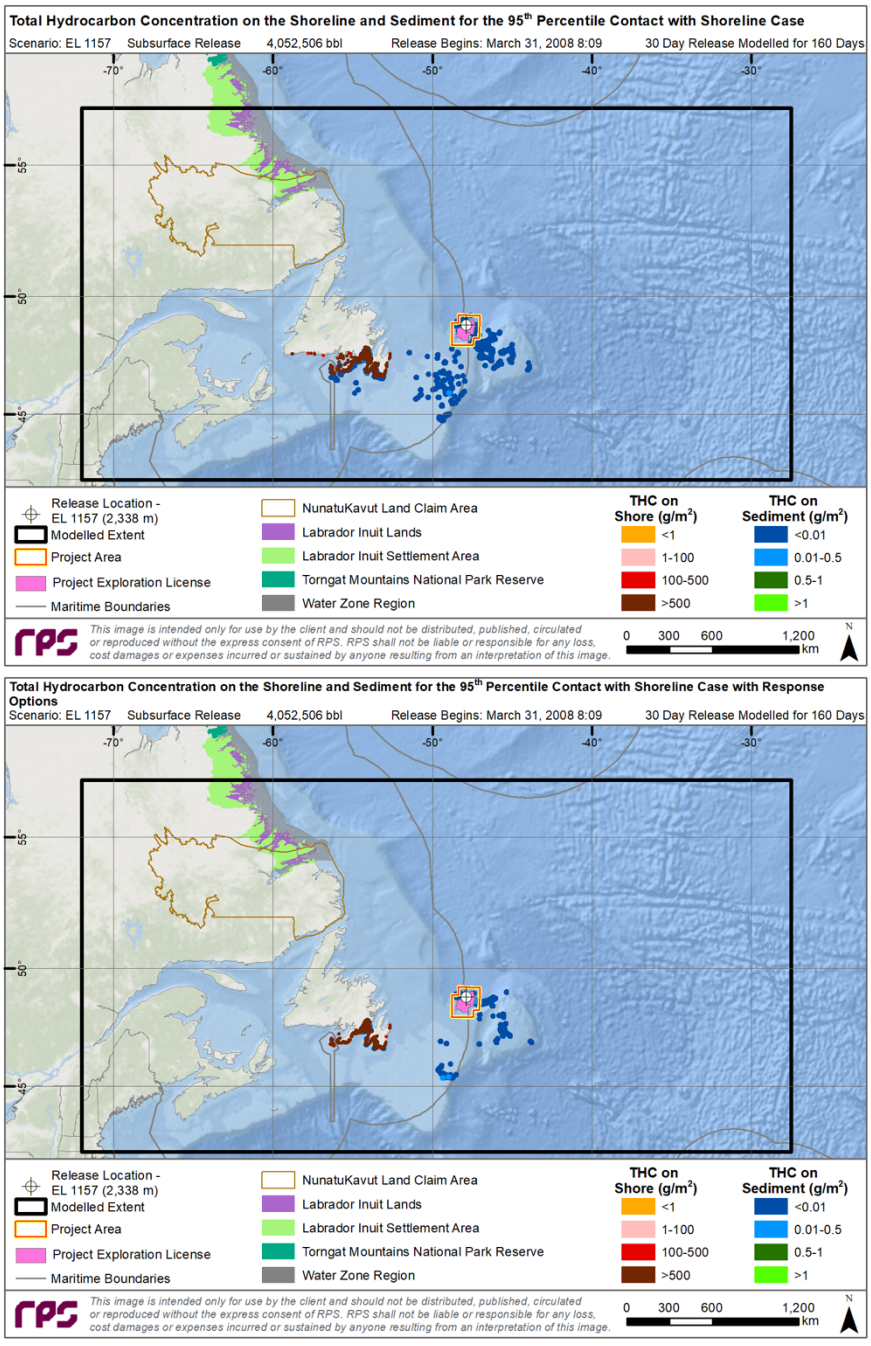

Figure 3-39. Scenario 4: THC on the shore and sediment for the 95th percentile average shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1157.

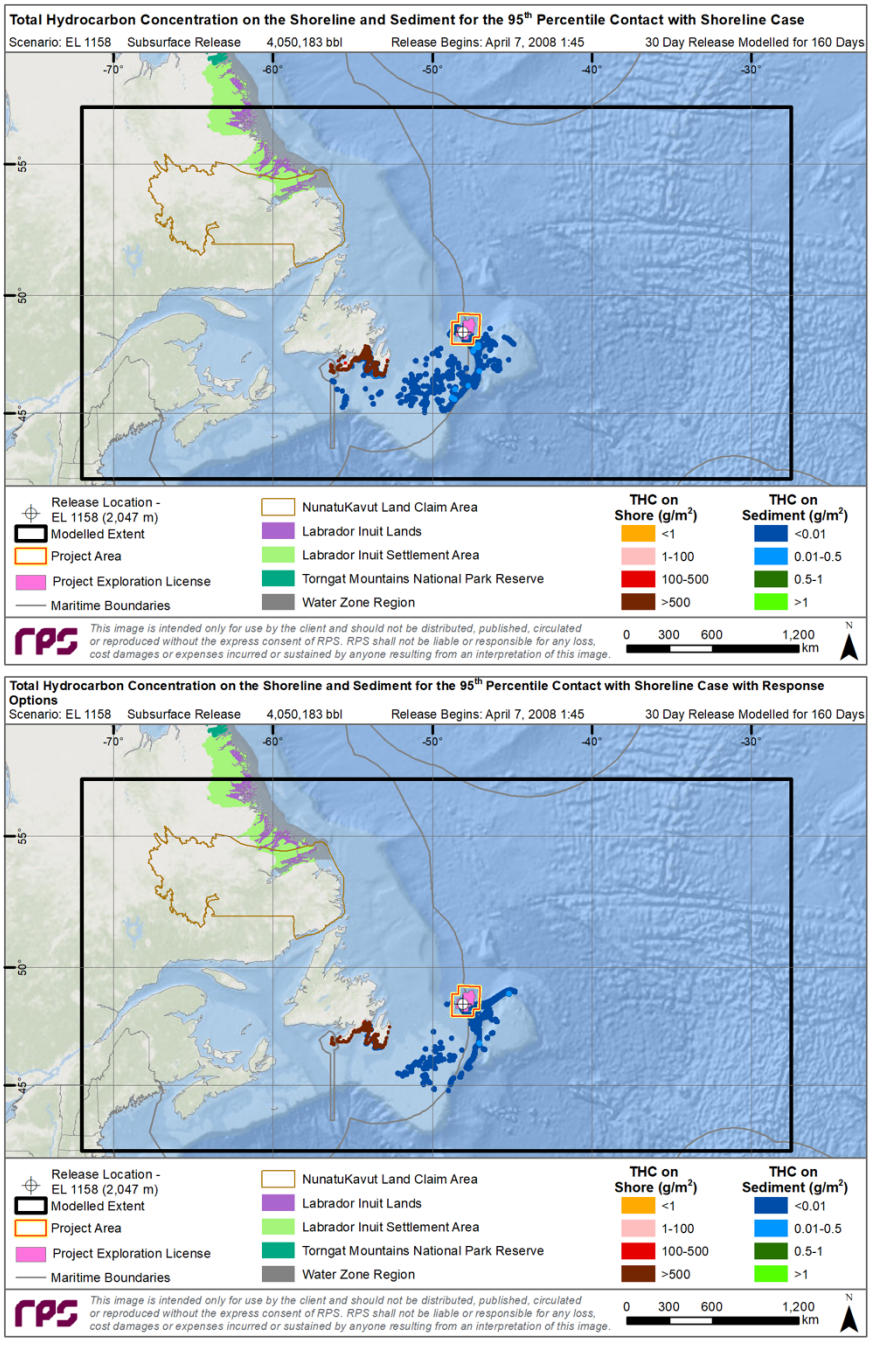

Figure 3-40. Scenario 4: THC on the shore and sediment for the 95th percentile average shoreline case for an unmitigated (top) and mitigated (bottom) 30-day blowout at EL 1158.

4 SUMMARY OF RESULTS & CONCLUSIONS

To analyze the potential effectiveness of response options on releases of crude oil, results of the unmitigated release modelling conducted in Horn et al., 2019 were compared to the identical scenarios with response options added. Several socio-economic and ecological thresholds of concern were investigated to compare the exposure of water surface areas, shoreline lengths, and water column volumes. These thresholds were identical to those used in the previous study (Table 2-2 of Horn et al., 2019). The areas, lengths, and volumes of predicted exposure were compared between the unmitigated scenarios and the modelled response mitigated scenarios to determine the predicted effectiveness that response options would have on the ultimate trajectory and fate of released oil. Results are provided as the maximum cumulative footprint of potentially affected areas, lengths, and volumes that would exceed each threshold over the entire course of each 160-day simulation.

For each simulated release at EL 1157 and EL 1158, response actions were predicted to reduce the surface areas exceeding the identified thresholds (Table 4-1). While the surface areas exceeding ecological thresholds were predicted to be reduced by approximately 35%, the reduction in the highly conservative socio-economic threshold (i.e., first sign of a barely visible sheen) was only 1-4%. The mass of oil on the surface was between 1-10% lower in the response mitigated cases (Table 4-2). Therefore, while there was a reduction in the total amount of oil on the surface, the thickness was still predicted to exceed the socio-economic threshold and with the same environmental forcing was therefore predicted to result in very similar footprints.

With regard to lengths of shoreline oiled, reductions of 11-62% were predicted for response mitigated scenarios for both socio-economic and ecological thresholds (Table 4-1). The lengths of affected shoreline were nearly identical between socio-economic and ecological thresholds for each simulation, because oil that was predicted to strand was almost always at levels above the ecological threshold. In general, the mass of oil on the shoreline was comparable between unmitigated and response mitigated scenarios with differences of only 0-0.7% of the total mass of released oil (Table 4-2).

Subsurface volumes exceeding the THC threshold were more variable between unmitigated and response mitigated scenarios. This was the result of two competing general trends. In unmitigated release scenarios, more oil was predicted to be on the surface, which would ultimately entrain into the upper water column by surface breaking waves (in most cases after being transported great distances) (Table 4-2). Thus, water column exposure was high in the surface mixed layer, resulting in large volumes of water predicted to be affected (Table 4-1). In response mitigated release scenarios, more oil was predicted to be within the water column (2-9% higher amount of the total release volume in the response mitigated cases), the result of effective SSDI and aerial/vessel dispersant application. In some cases, this increased the amount of oil in the water column was predicted to be in localized areas (e.g. within a few kilometers of the release location), which actually resulted in smaller volumes of water column affected by higher concentrations of hydrocarbons. In other cases, surface and vessel dispersant application was quite effective and could increase the amount of surface oil entraining and affecting the surface mixed layer (following surface transport) great distances from the release location, which added to the deeper subsurface exposure from SSDI, and resulted in higher volumes affected.

Table 4-1. Representative deterministic cases and associated areas, lengths, and volumes exceeding specified thresholds for representative trajectories at EL 1157 and EL 1158.

Scenario	Site	Approximate Surface Area exceeding thickness thresholds (km^2)		Approximate Shore Length exceeding mass per unit area thresholds (km)		Approximate Subsurface Volume exceeding THC threshold (km^3)
		Socio-economic (0.04 µm)	Ecologic (10 µm)	Socio-economic (1 g/m^2)	Ecologic (100 g/m^2)	Socio-economic* (1 µg/L)
Scenario 1: Unmitigated Surface oil case - 30 d	EL 1157	2,705,000	832,900	226	216	77,010
Scenario 1: Mitigated Surface oil case - 30 d		2,667,000	535,200	105	98	66,970
Scenario 2: Unmitigated Surface oil case - 30 d		2,705,000	832,900	226	216	77,010
Scenario 2: Mitigated Surface oil case - 30 d with limited response		2,672,000	536,600	105	98	67,080
Scenario 3: Unmitigated Surface oil case - 120 d		3,037,000	1,616,000	1,668	1,608	78,860
Scenario 3: Mitigated Surface oil case - 120 d		3,001,000	729,900	1,478	1,426	70,990
Scenario 4: Unmitigated Shoreline case - 30 d		2,267,000	833,300	1,409	1,358	64,070
Scenario 4: Mitigated Shoreline case - 30 d		2,179,000	569,300	965	929	67,060
Scenario 1: Unmitigated Surface oil case - 30 d	EL 1158	2,322,000	837,400	1,241	1194	60,290
Scenario 1: Mitigated Surface oil case - 30 d		2,276,000	549,600	794	749	73,370
Scenario 2: Unmitigated Surface oil case - 30 d		2,322,000	837,400	1,241	1,2194	60,290
Scenario 2: Mitigated Surface oil case - 30 d with limited response		2,306,000	536,100	794	749	75,020
Scenario 3: Unmitigated Surface oil case - 120 d		3,050,000	1,573,000	1,006	965	76,150
Scenario 3: Mitigated Surface oil case - 120 d		3,044,000	741,000	602	562	66,800
Scenario 4: Unmitigated Shoreline case - 30 d		2,322,000	837,400	1,241	1,194	60,290
Scenario 4: Mitigated Shoreline case - 30 d		2,276,000	549,600	794	749	73,370

Table 4-2. Summary of the mass balance information for all mitigated/unmitigated representative scenarios. All values represent a percentage (%) of the total amount of released oil at the end of the representative deterministic scenarios.

Scenario	Site	Percent of Total Released Oil (%)							
		Surface	Evaporated	Water Column	Sediment	Ashore	Degraded	Cleaned	Outside Grid
Scenario 1: Unmitigated Surface oil case - 30 d	EL 1157	5.8	44.0	1.4	<0.1	<0.1	42.8	NA	6.0
Scenario 1: Mitigated Surface oil case - 30 d		3.2	27.5	3.5	<0.1	<0.1	60.5	<0.1	5.2
Scenario 2: Unmitigated Surface oil case- 30 d		5.8	44.0	1.4	<0.1	<0.1	42.8	NA	6.0
Scenario 2: Mitigated Surface oil case - 30 d with limited response		3.2	27.5	3.6	<0.1	<0.1	60.5	<0.1	5.2
Scenario 3: Unmitigated Surface oil case - 120 d		14.3	41.7	2.5	<0.1	0.3	37.3	NA	4.0
Scenario 3: Mitigated Surface oil case - 120 d		4.1	14.3	11.2	<0.1	0.2	68.4	<0.1	1.7
Scenario 4: Unmitigated Shoreline case - 30 d		1.7	44.4	1.0	<0.1	1.2	39.1	NA	12.6
Scenario 4: Mitigated Shoreline case - 30 d		0.5	28.3	3.9	<0.1	0.5	56.8	0.3	9.8
Scenario 1: Unmitigated Surface oil case - 30 d	EL 1158	1.6	46.1	0.7	<0.1	0.8	39.3	NA	11.4
Scenario 1: Mitigated Surface oil case - 30 d		0.5	28.1	3.8	<0.1	0.3	58.5	0.4	8.4
Scenario 2: Unmitigated Surface oil case - 30 d		1.6	46.1	0.7	<0.1	0.8	39.3	NA	11.4
Scenario 2: Mitigated Surface oil case - 30 d with limited response		0.6	28.0	3.8	<0.1	0.3	58.5	0.3	8.5
Scenario 3: Unmitigated Surface oil case - 120 d		14.3	42.5	2.2	<0.1	0.1	36.1	NA	4.8
Scenario 3: Mitigated Surface oil case - 120 d		4.3	14.8	10.7	<0.1	0.1	68.0	<0.1	2.1
Scenario 4: Unmitigated Shoreline case - 30 d		1.6	46.1	0.7	<0.1	0.8	39.3	NA	11.4
Scenario 4: Mitigated Shoreline case - 30 d		0.6	28.1	3.8	<0.1	0.3	58.5	0.4	8.4

Because of the effects of dispersant application, two of the largest changes in mass balance are the amount evaporated and the around degraded within the water column. Dispersant addition did increase the amount of oil in the water column, which reduced the amount on the surface and reduced evaporation by 16-28% of the total release (Table 4-2). Because this oil was dispersed within the water column, natural degradation was predicted to increase, accounting for an additional 18-32% of the total release.

Burning and collection were simulated to remove surface oil. However, due to the dispersant effectiveness, which reduced the total amount of surface oil, and due to the large amount of time that winds, currents, and waves exceeded the effectiveness thresholds, burning and recovery were not effective in these simulations. In total, less than 1% of the release was predicted to be removed by in-situ burning and vessel recovery in all modelled mitigated scenarios (Table 4-2).

Multiple weather conditions were also considered in this modelling exercise. Primarily, each set of simulations had a different start date and time, which resulted in different environmental parameters (e.g., winds, currents, waves, temperature, etc.). The prevalence of fog was considered and thus, response options did consider reduced effectiveness (e.g., no aerial dispersant application every 3rd day). In addition, Scenario 2 considered numerous events that resulted in limited response (e.g. poor weather conditions, equipment failure, etc.) that occurred roughly every week and would prevent response activities at the surface (Table 2-2). However, very few differences were predicted between Scenario 1 (the same release) and Scenario 2 (with the artificial forced shut down of surface activities). In essence, the region already had enough conditions that exceeded the effective response thresholds (Table 2-5) and thereby reduced removal, even without the artificial assumption of the limited response and the forced cessation of response activities in Scenario 2.

This analysis has demonstrated that computational spill modelling can effectively highlight differences in the predicted trajectory and fate of oil between unmitigated and response mitigated scenarios. The effects are most noticeable when comparing surface areas of water, shorelines lengths, and volumes of water predicted to experience socio-economic and ecological threshold exceedances. As expected, the unmitigated release scenarios were predicted to result in the largest footprints of surface oil (Table 4-1). Similarly, the exposure of areas that were predicted to be impacted by thicker or higher concentrations of oil were much smaller than the exposure of areas that were anticipated to exceed the lower thresholds in both mitigated and unmitigated scenarios. Furthermore, less shoreline was predicted to be contacted by oil in the response mitigated scenarios, when compared to the unmitigated scenarios. This study has identified that SSDI appears to be the main driver in differences between the simulated unmitigated and response mitigated scenarios. SSDI effectively reduces the amount of oil on the surface and thus stranding on shorelines, as well as reducing the total amount of oil predicted to evaporate to the atmosphere. Dispersants effectively disperse oil within the water column, which can increase the volume of water above specified thresholds and can result in much higher concentrations within the water column, when compared to unmitigated scenarios. With the larger amount of dispersed oil within the water column, natural degradation is much higher in the response mitigated scenarios.

Should response effectiveness, weather conditions, or timing be improved, or fog conditions were less frequent than modelled, progressively smaller regions of surface oil contamination would be predicted to be affected. The additions of response options were predicted to both decrease the amount of oil on the surface and increase the amount of oil entrained in the water column, leading to higher quantities of oil predicted to degrade in the water column.

The hypothetical releases modelled in this study are not intended to predict a specific future event, but rather are intended to be used as a tool in environmental assessments and spill contingency planning. The results presented in this document demonstrate that there are a range of potential trajectories and fates that could result if a release of crude oil was allowed to progress completely unmitigated versus when emergency response activities a undertaken. The specific trajectories and fates vary greatly for each release based upon the environmental conditions occurring at the time of the release. While each oil release is unique, and uncertainties exist, the results of this modelling study suggest that, if oil were to be released in the Project Area, an effective emergency response can reduce the amount of oil on the surface, in the atmosphere, and stranding on shorelines.

5 REFERENCES

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APPENDIX G

Species Names

Table G.1 Common and Scientific Species Names

Common Name	Scientific Name
Fish Species	
Abyssal grenadier	*Coryphaenoides armatus*
Acadian redfish	*Sebastes fasciatus*
Albacore tuna	*Thunnus alalunga*
Alewife (or Gaspereau)	*Alosa pseudoharengus*
American eel	*Anguilla rostrata*
American plaice	*Hippoglossoides platessoides*
Arctic cod	*Boreogadus saida*
Atlantic bluefin tuna	Thunnus thynnus
Atlantic cod	*Gadus morhua*
Atlantic halibut	*Hippoglossus hippoglossus*
Atlantic herring	*Clupea harengus*
Atlantic salmon	Salmo salar
Atlantic wolffish	*Anarhichas lupus*
Baird's slickhead	*Alepocephalus bairdii*
Barndoor skate	Dipturus laevis
Barracudinas	Paralepididae (F)
Basking shark	Cetorhinus maximus
Bigeye tuna	*Thunnus obesus*
Black dogfish	*Centroscyllium fabricii*
Black swallower	*Chiasmodon niger*
Blacktail netdevil	*Linophryne coronata*
Blue hake	*Antimora rostrata*
Blue shark	*Prionace glauca*
Boa dragonfish	*Stomias boa boa*
Capelin	*Mallotus villosus*
Carapine grenadier	*Coryphaenoides carapinus*
Chimaera rabbitfish	*Hydrolagus affinis*
Common lumpfish	*Cyclopterus lumpus*
Cusk	Brosme brosme
Daggertooths	Anotopteridae (F)
Deepsea cat shark	*Apristurus profundorum*
Deep-sea smelt	*Bathylagus* sp.
Deep-sea spiny eels	Notacanthidae (F)
Deepwater redfish	*Sebastes mentella*
Eelpouts	Zoarcidae (F)
Glacier lanternfish	*Benthosema glaciale*

Common Name	Scientific Name
Goiter blacksmelt	*Bathylagus euryops*
Greenland halibut	*Reinhardtius hippoglossoides*
Greenland manefish	*Caristius fasciatus*
Greenland shark	*Somniosus microcephalus*
Haddock	Melanogrammus aeglefinus
Jensen's skate	*Amblyraja jenseni*
Lanternfishes	Myctophidae (F)
Little skate	*Leucoraja erinacea*
Longnose eel	*Synaphobranchus kaupii*
Marlin spike	*Nezumia bairdii*
Mirror lanternfish	*Lampadena speculigera*
Northern wolffish	*Anarhichas denticulatus*
Ocean sunfish	*Mola mola*
Porbeagle	*Lamna nasus*
Portuguese dogfish	*Centroscymnus coelolepis*
Ray-finned fishes	Actinopterygii (C)
Redfish	*Sebastes* sp.
Rockling	*Gaidropsarus* sp.
Roughhead grenadier	*Macrourus berglax*
Roughnose grenadier	*Trachyrincus murrayi*
Roundnose grenadier	*Coryphaenoides rupestris*
Sand Lance	*Ammodytes dubius*
Shortfin mako	*Isurus oxyrinchus*
Shortnose loosejaw	*Malacosteus niger*
Short-rod anglerfish	*Microlophichthys microlophus*
Silver hake	*Merluccius bilinearis*
Silver smelt	*Argentina silus*
Slender snipe-eel	*Nemichthys scolopaceus*
Slickhead	*Alepocephalus* sp.
Slickheads	Alepocephalidae (F)
Sloane's viperfish	*Chauliodus sloani*
Smooth skate	*Malacoraja senta*
Snubnosed spiny eel	*Notacanthus chemnitzii*
Spiny dogfish	*Squalus acanthias*
Spinytail skate	*Bathyraja spinicauda*
Spotted wolffish	*Anarhichas minor*
Stareater	*Astronesthes* sp.
Stout sawpalate	*Serrivomer beanii*
Straightline dragonfish	*Borostomias antarcticus*

Common Name	Scientific Name
Swordfish	*Xiphias gladius*
Thorny skate	*Amblyraja radiata*
Thorny skate	*Raja radiata*
Threebeard rockling	*Gaidropsarus ensis*
Unnamed Anglerfish	*Dolopichthys allector*
Whalehead dreamer	*Lophodolos acanthognathus*
White hake	*Urophycis tenuis*
White shark	*Carcharodon carcharias*
Winter Skate	*Leucoraja ocellata*
Witch flounder	*Glyptocephalus cynoglossus*
Invertebrates	
Amphipod	*Themisto libellula*
Bamboo coral	*Keratoisis ornata*
Basket star	*Gorgonocephalus* sp.
Bivalve	*Cuspidaria* sp.
Bivalve	*Cylichna* sp.
Bivalve	*Dentalium* sp.
Bivalve	*Nucula* sp.
Bivalve	*Nuculana* sp.
Black coral	*Bathypathes patula*
Black coral	*Stauropathes arctica*
Brittle star	*Ophiura sarsi*
Broccoli coral	*Duva florida*
Copepod	*Calanus finmarchicus*
Copepod	*Calanus glacialis*
Copepod	*Calanus hyperboreus*
Copepod	*Metridia* sp.
Copepod	*Microcalanus* sp.
Copepod	*Oithona atlantica*
Copepod	*Oithona similis*
Copepod	*Pseudocalanus spp.*
Copepod	*Scolecithricella minor*
Daisy brittle star	*Ophiopholis aculeata*
Deep-water shrimp	*Acanthephyra pelagica*
Deep-water shrimp	*Pasiphaea tarda*
Friendly Blade Shrimp	*Spirontocaris lilljeborgii*
Gastropod	*Aporrhais occidentalis*
Geodid sponge	*Geodia* sp.
Glass sponge	*Asconema* sp.

Common Name	Scientific Name
Gorgonian	*Acanella arbuscula*
Gorgonian	*Acanthogorgnia armata*
Gorgonian	*Anthothela grandiflora*
Gorgonian	*Chrysogorgia* spp.
Gorgonian	*Keratoisis grayi*
Gorgonian	*Paragorgia arborea*
Gorgonian	*Paramuricea* spp.
Gorgonian	*Radicipes gracilis,*
Green sea urchin	*Strongylocentrotus droebachiensis*
Grooveback Shrimp	*Parapasiphae sulcatifrons*
Lamp shell	*Terebratulina sp.*
Lion's Mane Jellyfish	*Cyanea capillata*
Long arm star	*Luidia ciliaris*
Malacostraca	*Stereomastis sculpta*
Moon Jellyfish	*Aurelia aurita*
Mud star	*Ctenodiscus crispatus*
Northern cushion star	*Pentaceraster cumingi*
Northern shortfin squid	*Illex illecebrosus*
Northern shrimp	*Pandalus borealis*
Norwegian Shrimp	*Nephrops norvegicus*
Octopus	*Bathypolypus arcticus*
Pink Glass Shrimp	*Pandalus montagui*
Polymastid sponge	*Polymastia* spp.
Rigid cushion star	*Hippasteria phrygiana*
Salp	*Cyclosalpa pinnata*
Salp	*Pegea bicaudata*
Salp	*Pegea confoederata*
Salp	*Pegea socia*
Salp	*Salpa cylindrica*
Salp	*Salpa maxima*
Sand sifting star	*Astropecten polyacanthus*
Sars Shrimp	*Sabinea sarsii*
Sea mouse	*Aphrodita* sp.
Sea pen	*Anthoptilum grandiflorum*
Sea pen	*Distichoptilum gracile*
Sea pen	*Funiculina quadrangularis*
Sea pen	*Halipteris finmarchica*
Sea pen	*Pennatula grandis*
Sea pen	*Pennatula phosporea*

Common Name	Scientific Name
Sea pen	*Protoptilum carpenteri*
Sea pen	*Umbellula lindahli*
Sea star	*Ceramaster granularis*
Sea star	*Henricia sp.*
Sea star	*Novodinia americana*
Sea strawberry	*Gersemia rubiformis*
Sea urchin	*Phormosoma placenta*
Shrimp	*Acanthephyra pelagica*
Shrimp	*Atlantopandalus propinqvus*
Shrimp	*Gennadas* sp.
Shrimp	*Lebbeus polaris*
Shrimp	*Pasiphaea* sp.
Shrimp	*Sergestes arcticus*
Shrimp	*Sergia robusta*
Snow crab	*Chionoecetes opilio*
Soft coral	*Capnella florida*
Soft coral	*Heteropolypus* cf. *insolitus*
Soft coral	*Neptheid* spp.
Sponge	*Radiella hemisphaerica*
Squid	*Gonatus fabricii*
Squid	*Histioteuthis bonnellii*
Squid	*Histioteuthis reversa*
Squid	*Histioteuthis* sp.
Squid	*Onychoteuthis banksii*
Squid	*Semirossia* sp.
Stony coral	*Dasmosmilia lymani*
Stony coral	*Flabellum alabastrum*
Stony coral	*Flabellum macandrewi*
Stony coral	*Javania cailleti*
Stony coral	*Vaughanella margarita*
Sunstar	*Crossaster papposus*
Toad crab	*Hyas coarctatus*
Toad crab	*Hyas* sp.
Tube-dwelling anemone	*Cerianthus* sp.
Tunicate	*Boltenia* sp.
Whelk	*Buccinum* sp.
Whelk	*Neptunea sp.*
Plants, Macroalgae, and Phytoplankton	
Phytoplankton	*Phaeocystis spp.*

Common Name	Scientific Name
Eelgrass	*Zostera marina*
Coralline algae	*Leptophylum laeve*
Oarweed (kelp)	*Laminaria digitata*
Winged kelp	*Alaria esculenta*
Kelp	*Saccharina longicruris*
Coriander Kelp	*Agarum clathratum*
Sour weed	*Desmarestia viridis*
Sea sorrel	*Desmarestia aculeata*
Dulse	*Palmaria* sp.
Red algae	*Ptilota* sp.
Red algae	*Phycodrys* sp.
Red algae	*Membranoptera* sp.
Lobster horns (red algae)	*Polysiphonia* sp.
Coralline red algae	*Lithothamnion lemoineae*
Coralline red algae	*Lithothamnion* sp.
Coralline red algae	*Clathromorphum compactum*
Coralline red algae	*Clathromorphum circumscriptum*
Geniculate coralline red algae	*Corallina* sp.
Bacteria	
Bacteria	*Alcanivorax* sp.
Bacteria	*Alteromonas* sp.
Bacteria	*Cycloclasticus* sp.
Bacteria	*Glaciecola* sp.
Bacteria	*Oleiphilus* sp.
Bacteria	*Oleispira s*p.
Bacteria	*Planomicrobium* sp.
Bacteria	*Pseudoalteromonas* sp.
Bacteria	*Thalassolituus* sp.
Marine Birds	
African Penguin	*Spheniscus demersus*
Arctic Tern	*Sterna paradisaea*
Atlantic Puffin	*Fratercula arctica*
Band-rumped Storm-petrel	*Oceanodroma [Hydrobates] castro*
Bermuda Petrel	*Pterodroma cahow*
Black Guillemot	*Cepphus grylle*
Black-headed Gull	*Chroicocephalus ridibundus*
Black-legged Kittiwake	*Rissa tridactyla*
Caspian Tern	*Hydroprogne caspia*
Common Murre (or Turr)	*Uria aalge*

Common Name	Scientific Name
Common Tern	*Sterna hirundo*
Cory's Shearwater	*Calonectris borealis*
Desertas (Bugio) Petrel	*Pterodroma deserta*
Double-crested Cormorant	*Phalacrocorax auritus*
Dovekie	*Alle alle*
Fea's Petrel	*Pterodroma feae*
Glaucous Gull	*Larus hyperboreus*
Great Black-backed Gull	*Larus marinus*
Great Cormorant	*Phalacrocorax carbo*
Great Shearwater	*Ardenna gravis*
Great Skua	*Stercorarius skua*
Herring Gull	*Larus argentatus*
Iceland Gull	*Larus glaucoides*
Ivory Gull	*Pagophila eburnea*
Leach's Storm-Petrel	*Oceanodroma leucorhoa [Hydrobates leucorhous]*
Lesser Black-backed Gull	*Larus fuscus*
Long-tailed Jaeger	*Stercorarius longicaudus*
Manx Shearwater	*Puffinus puffinus*
Mew Gull	*Larus canus*
Northern Fulmar	*Fulmarus glacialis*
Northern Gannet	*Morus bassanus*
Parasitic Jaeger	*Stercorarius parasiticus*
Pomarine Jaeger	*Stercorarius pomarinus*
Razorbill	*Alca torda*
Red Phalarope	*Phalaropus fulicarius*
Red-necked Phalarope	*Phalaropus lobatus*
Ring-billed Gull	*Larus delawarensis*
Ross's Gull	*Rhodostethia rosea*
Sabine's Gull	*Xema sabini*
Sooty Shearwater	*Ardenna grisea*
South Polar Skua	*Stercorarius maccormicki*
Thick-billed Murre	*Uria lomvia*
White-tailed Tropicbird	*Phaethon lepturus*
Wilson's Storm-Petrel	*Oceanites oceanicus*
Zino's Petrel	*Pterodroma madeira*
Waterfowl and Divers	
American Black Duck	*Anas rubripes*
American Wigeon	*Mareca americana*
Barrow's Goldeneye	*Bucephala islandica*

Common Name	Scientific Name
Black Scoter	*Melanitta americana*
Blue-winged Teal	*Spatula discors*
Bufflehead	*Bucephala albeola*
Canada Goose	*Branta canadensis*
Common Eider	*Somateria mollissima*
Common Goldeneye	*Bucephala clangula*
Common Loon	*Gavia immer*
Common Merganser	*Mergus merganser*
Eurasian Wigeon	*Mareca penelope*
Gadwall	*Anas strepera*
Greater Scaup	*Aythya marila*
Green-winged Teal	*Anas crecca*
Harlequin Duck	*Histrionicus histrionicus*
Hooded Merganser	*Lophodytes cucullatus*
King Eider	*Somateria spectabilis*
Lesser Scaup	*Aythya affinis*
Long-tailed Duck	*Clangula hyemalis*
Mallard	*Anas platyrhynchos*
Northern Pintail	*Anas acuta*
Northern Shoveler	*Spatula clypeata*
Pied-billed Grebe	*Podilymbus podiceps*
Red-breasted Merganser	*Mergus serrator*
Red-necked Grebe	*Podiceps grisegena*
Red-throated Loon	*Gavia stellata*
Ring-necked Duck	*Aythya collaris*
Surf Scoter	*Melanitta perspicillata*
Tufted Duck	*Aythya fuligula*
White-winged Scoter	*Melanitta fusca*
Wood Duck	*Aix sponsa*
Shorebirds	
American Golden-Plover	*Pluvialis dominica*
Baird's Sandpiper	*Calidris bairdii*
Black-bellied Plover	*Pluvialis squatarola*
Buff-breasted Sandpiper	*Calidris subruficollis*
Dunlin	*Calidris alpina*
Greater Yellowlegs	*Tringa melanoleuca*
Hudsonian Godwit	*Limosa haemastica*
Killdeer	*Charadrius vociferus*
Least Sandpiper	*Calidris minutilla*

Common Name	Scientific Name
Lesser Yellowlegs	*Tringa flavipes*
Pectoral Sandpiper	*Calidris melanotos*
Piping Plover	*Charadrius melodus*
Purple Sandpiper	*Calidris maritima*
Red Knot	*Calidris canutus rufa*
Ruddy Turnstone	*Arenaria interpres*
Sanderling	*Calidris alba*
Semipalmated Plover	*Charadrius semipalmatus*
Semipalmated Sandpiper	*Calidris pusilla*
Short-billed Dowitcher	*Limnodromus griseus*
Solitary Sandpiper	*Tringa solitaria*
Spotted Sandpiper	*Actitis macularius*
Whimbrel	*Numenius phaeopus*
White-rumped Sandpiper	*Calidris fuscicollis*
Willet	*Tringa semipalmata*
Wilson's Snipe	*Gallinago delicata*
Landbirds	
Bank Swallow	*Riparia riparia*
Barn Swallow	*Hirundo rustica*
Bobolink	*Dolichonyx oryzivorus*
Canada Goose	*Branta canadensis*
Chimney Swift	*Chaetura pelagica*
Common Nighthawk	*Chordeiles minor*
Common Redpoll	*Acanthis flammea*
Gray-cheeked Thrush	Catharus minimus minimus
Lincoln’s Sparrow	*Melospiza lincolnii*
Mourning Dove	*Zenaida macroura*
Newfoundland Red Crossbill	*Loxia curvirostra percna*
Olive-sided Flycatcher	*Contopus cooperi*
Osprey	*Pandion haliaetus*
Ovenbird	*Seiurus aurocapilla*
Peregrine Falcon	*Falco peregrinus*
Rock Ptarmigan	*Lagopus muta*
Ruffed Grouse	*Bonasa umbellus*
Rusty Blackbird	*Euphagus carolinus*
Short-eared Owl	*Asio flammeus*
Snow Bunting	*Plectrophenax nivalis*
Spruce Grouse	*Falcipennis canadensis*
Tree Swallow	*Tachycineta bicolor*

Common Name	Scientific Name
Warblers	*Parulidae (F)*
Willow Ptarmigan	*Lagopus lagopus*
Marine Mammals	
Mysticetes (Baleen Whales)	
Blue Whale	*Balaenoptera musculus*
Fin Whale	*B. physalus*
Sei Whale	*B. borealis*
Humpback Whale	*Megaptera novaeangliae*
Common Minke Whale	*B. acutorostrata*
North Atlantic Right Whale	*Eubalaena glacialis*
Bowhead Whale	*Balaena mysticetus*
Odontocetes (Toothed Whales)	
Sperm Whale	*Physeter macrocephalus*
Pygmy sperm whale	*Kogia breviceps*
Northern Bottlenose Whale	*Hyperoodon ampullatus*
Sowerby's Beaked Whale	*Mesoplodon bidens*
Cuvier's Beaked Whale	*Ziphius cavirostris*
Killer Whale	*Orcinus orca*
False Killer Whale	*Pseudorca crassidens*
Long-finned Pilot Whale	*Globicephala melas*
White-beaked Dolphin	*Lagenorhynchus albirostris*
Atlantic White-sided Dolphin	*L. acutus*
Common Dolphin (Short-beaked)	*Delphinus delphis*
Risso's Dolphin	*Grampus griseus*
Common Bottlenose Dolphin	*Tursiops truncatus*
Atlantic Spotted Dolphin	*Stenella frontalis*
Spinner Dolphin	*S. longirostris*
Striped Dolphin	*S. coeruleoalba*
Harbour Porpoise	*Phocoena*
Beluga Whale	*Delphinapterus leucas*
Narwhal	*Monodon monoceros*
Phocids (Seals)	
Harbour Seal	*Phoca vitulina concolor*
Harp Seal	*Pagophilus groenlandicus*
Hooded Seal	*Cystophora cristata*
Grey Seal	*Halichoerus grypus*
Ringed Seal	*Pusa hispida*
Bearded Seal	*Erignathus barbatus*
Sea Turtles	

Common Name	Scientific Name
Leatherback Sea Turtle	*Dermochelys coriacea*
Loggerhead Sea Turtle	*Caretta caretta*
Green Sea Turtle	*Chelonia mydas*
Kemp's Ridley Sea Turtle	*Lepidochelys kempii*
Taxonomic Groups: C – Class, F – Family	