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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

Statoil Canada Ltd. Flemish Pass Exploration Drilling Program

December 23, 2016

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 key 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

Environmental assessment (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 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.

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

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

A key objective of CEAA 2012 is to promote communication and cooperation with Aboriginal peoples which includes First Nations, Inuit and Métis. The proponent is expected to engage with potentially affected groups, beginning as early as possible in the project planning process.

The proponent shall provide potentially affected groups with opportunities to learn about the project and its potential effects and to make their concerns known about the project's potential effects and discuss measures to mitigate those effects. The proponent is strongly encouraged to work with potentially affected groups to establish an engagement approach. The proponent will make reasonable efforts to integrate Aboriginal traditional knowledge into the assessment of environmental effects. For more information on incorporating Aboriginal traditional knowledge, refer to Part 1, Section 4.2.2 of these guidelines.

In order to fulfill the Crown's constitutional obligations to consult with potentially impacted groups, the Agency integrates its legal obligation for consultation and accommodation in the EA process. The information gathered by the proponent during its engagement with groups helps to contribute to the Crown's understanding of any potential adverse impacts on potential or established Aboriginal or treaty rights protected under section 35 of the *Constitution Act*, *1982* ("section 35 Aboriginal rights") including title and related interests, and the effectiveness of measures proposed to avoid or minimize those impacts.

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 August 8, 2016 Statoil Canada Ltd., the proponent of the Flemish Pass Exploration Drilling Program 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 Units designed for year-round operations for the drilling, testing and abandonment of up to thirty exploration wells within exploration licences operated by Statoil Canada Ltd. (1139, 1140, 1141 and 1142), including consideration of any proposed safety exclusion zones. Drilling may occur in various water depths under consideration, with various types of drilling units, and with multiple drilling units operating simultaneously;
- vertical seismic profiling surveys and in-water works (e.g. wellsite surveys) to support the specific exploration wells under consideration, but excluding surveys potentially required to support

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

- the loading, refuelling and operation of marine support vessels (i.e. for re-supply and transfer of materials, fuel, and equipment and on-site safety during drilling activities and transport between the supply base and Mobile Offshore Drilling Unit(s)) and helicopter support (i.e. for crew transport and delivery of light supplies and equipment) including transportation to the Mobile Offshore Drilling Unit.

Note: If the proponent becomes the operator of additional exploration licenses within the Flemish Pass 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 6.3 (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 valued components.

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 is encouraged to consult relevant Agency policy and guidance[2] on topics to be addressed in the EIS, and to liaise with the Agency during the planning and development of the EIS. The proponent is also encouraged to consult relevant guidance from other federal departments.

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.

[2] Visit the Canadian Environmental Assessment Agency website: www.ceaa-acee.gc.ca/default.asp?lang=En&n=F1F30EEF-1

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 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 entitled "Considering Aboriginal traditional knowledge in environmental assessments conducted under the *Canadian Environmental Assessment Act, 2012*".

4.2.3. Existing information

In preparing the EIS, the proponent can use 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). When relying on existing information to support the effects assessment, the proponent will provide a rationale to support the use of the information in relation to the specific 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. In such circumstances, the proponent will clearly describe potential or known data or knowledge gaps, and describe how such gaps have been addressed in the assessment of the project.

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 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.

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 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 Aboriginal traditional 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 could 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 could 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). 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.

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
- 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 within the EIS is preferred. For example, the EIS may make reference to 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 contents 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 versions 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 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.

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 valued component, 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 setting 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 and resource 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 significant areas, fishery closure areas, vulnerable marine ecosystems, and habitats of federally or provincially listed species at risk and other sensitive areas;
- description of local and Indigenous communities; and
- traditional territories and/or consultation areas, treaty lands, and 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, or land zoning; 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[3] 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 following procedural steps for addressing alternative means:

- Identify the alternative means to carry out the project.
- Identify the effects of each technically and economically feasible alternative means.
- Select the approach for the analysis of alternative means (i.e. identify a preferred means or bring forward alternative means).
- Assess the environmental effects of the alternative means.

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);

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

- 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.

The *Offshore Waste Treatment Guidelines*[4] 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*[5] 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

[4] 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

[5] 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

shall conduct an environmental effects analysis at the same level of detail for each of the various options available (alternative means) within the EIS.

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 and UTM coordinates of the proposed exploration licences (1139, 1140, 1141 and 1142);
- 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 Units and/or drill ships and their operations (drilling, testing, abandonment) in locations and water depths under consideration;
- the size and types of vessels that will be used including navigation activities (i.e. routes, number and frequency of trips) and icebreaking activities (time of year, frequency, duration, expected start and end dates);
- 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;
- reagent requirements and uses (e.g. volumes, storage, types);
- petroleum products (e.g. source, volume, storage);
- 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 modeling;
- the management or disposal of wastes (e.g. type and constituents of waste, quantity, treatment and method of disposal) including:
    - ✓ drilling muds, drill solids;
    - ✓ bilge and ballast water;
    - ✓ deck drainage;
    - ✓ cooling 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, 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);
- waste disposal (types of waste, methods of disposal, quantity); and
- components requiring construction or modification at the supply base(s) under consideration.

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.

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 and/or drill ships, including:
  - ✓ drilling at various water depths and in locations under consideration
  - ✓ well flow testing
  - ✓ waste management
  - ✓ water management
- vertical seismic profile surveys;

- 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

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:

- 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 section 35 rights, including title and related interests, in respect of the Crown's duty to consult, and where appropriate, accommodate Aboriginal peoples.

With respect to the effects of changes to the environment on Aboriginal peoples as per paragraph 5(1)(c) of CEAA 2012, the assessment requirements are outlined in sections 6.1.8 and 6.3.7 below. With respect to potential adverse impacts of the project on potential or established section 35 rights, including title and related interests, the EIS will document for the groups identified in Section 5.1 below (or in subsequent correspondence from the Agency):

- potential or established section 35 rights[6], including title and related interests, when this information is directly provided by a group to the proponent, the Agency or is available through public records, including:
  - ✓ geographical extent, nature, frequency and timing 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 section 35 rights, including title and related interests. This assessment is to be based on a comparison of the exercise of the identified rights, title and related interests between the predicted future conditions with the project and the predicted future conditions without the project. Include the perspectives of potentially impacted groups where these were provided to the proponent by the groups;
- measures identified to accommodate potential adverse impacts of the project on the potential or established section 35 rights, including title and related interests. These measures will be written as specific commitments that clearly describe how the proponent intends to implement them, and may go beyond mitigation measures that are developed to address potential adverse environmental effects;
- potential adverse impacts on potential or established section 35 rights, including title and related interests that have not been fully mitigated or accommodated as part of the EA and associated engagement with Indigenous groups. The proponent will also take into account the potential adverse impacts that may result from the residual and cumulative environmental effects. Include the perspectives of potentially affected groups where these were provided to the proponent by the groups.

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 section 35 rights, including title and related interests. However, there may be distinctions between the adverse impacts on potential or established section 35 rights, including title and related interests 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.

In terms of gathering views from potentially affected groups with respect to both environmental effects of the project and the potential adverse impacts of the project on potential or established section 35 rights, including title and related interests, the EIS will document:

- VCs suggested by groups for inclusion in the EIS, whether they were included, and the rationale for any exclusions;

[6] The 2011 *Updated Guidelines for Federal Officials to Fulfill the Duty to Consult (the Guidelines)* defines Aboriginal rights 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 (Van de Peet). 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 (*Powley*). Generally, these rights are fact and site specific. For greater certainty, the Guidelines also define Aboriginal title as an Aboriginal right. Visit the Indigenous and Northern Affairs Canada website at: http://www.aadnc-aandc.gc.ca/eng/1100100014664/1100100014675

- specific suggestions raised by each group for mitigating the effects of changes to the environment on Aboriginal peoples or accommodating potential adverse impacts of the project on potential or established section 35 rights, including title and related interests;
- views expressed by each group on the effectiveness of the mitigation or accommodation measures;
- from the proponent's perspective, any potential cultural, social and/or economic impacts or benefits to each group identified that may arise as a result of the project. Include the perspectives of potentially affected groups where these were provided to the proponent by the groups;
- any other comments, specific issues and concerns raised by potentially affected groups and how they were responded to or addressed;
- changes made to the project design and implementation directly as a result of discussions with potentially affected groups;
- where and how Aboriginal traditional knowledge was incorporated into the environmental effects assessment (including methodology, baseline conditions and effects analysis for all VCs) and the consideration of potential adverse impacts on potential or established section 35 rights, including title and related interests, and related mitigation measures; and
- any additional issues and concerns raised by potentially affected groups in relation to the environmental effects assessment and the potential adverse impacts of the project on potential or established section 35 rights, including title and related interests.

The Agency recommends the proponent create a tracking table of key issues raised by each group, including the concerns raised related to the project, proposed mitigation measures, and where appropriate, a reference to the proponent's analysis in the EIS. Information provided related to potential adverse impacts on potential or established section 35 rights will be considered by the Crown in meeting its common law duty to consult obligations as set out in the *Updated Guidelines for Federal Officials to Fulfill the Duty to Consult* (2011).

5.1. Indigenous groups and engagement activities

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);
- any future planned engagement activities; and
- how engagement activities by the proponent allowed groups to understand the project and evaluate its effects on their communities, activities, potential or established section 35 rights, including title and related interests.

In preparing the EIS, the proponent will ensure that groups have access to timely and relevant information on the project and how the project may adversely impact them. 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.

The proponent will ensure that views of groups are recorded and that groups are provided with opportunities to validate the interpretation of their views. The proponent will keep detailed tracking records of its engagement activities, recording all interactions with groups, the issues raised by each group and how the proponent addressed the concerns raised. The proponent will share these records with the Agency.

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:

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

The groups referenced above may change as more is understood about the environmental effects or potential impacts on rights 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 with 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 a group not listed above, the proponent shall provide that information to the Agency at the earliest opportunity.

6. EFFECTS ASSESSMENT

6.1. 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.

6.1.1. 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 areas 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 (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOCs), hydrogen sulfide (H_2S) and any other potentially toxic air pollutants;

- identify and quantify existing greenhouse gas emissions[7] by individual pollutant measured as kilotonnes of CO_2 equivalent per year in the project study areas;
- direct and indirect sources of air emissions;
- current provincial/territorial/federal limits for greenhouse gas emission targets; and
- information on the variation in weather conditions over the project area using historical records of relevant meteorological parameters, including the following:
  - ✓ precipitation (rain and snow);
  - ✓ air temperature (mean, maximum and minimum temperatures);
  - ✓ wind speed and direction;
  - ✓ freezing spray;
  - ✓ lightning; 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 cyclone activity in the North Atlantic, NOAA's Climate Forecast System Reanalysis (CFSR), and the Canadian Lightning Detection Network.

6.1.2. 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);
- 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, breakup and movement;

[7] 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).

- 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 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 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.

6.1.3. 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 characterisation of seasonal variability;
- a list of any fish or invertebrate species at risk that are known to be present; 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 likely to be affected by the project and their physical characteristics, water and sediment quality. 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.

6.1.4. Migratory birds and their habitat[8]

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.

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:

- 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.

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 Environment and Climate Change Wildlife Division, previous petroleum operations in the area and university or other research programs, if available.

6.1.5. Species at Risk

The EIS will describe federal species at risk and their 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[9];

[8] 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.

[9] Proponents are encouraged to consult COSEWIC's annual report for a listing of the designated wildlife species: http://www.sararegistry.gc.ca/default.asp?lang=En&n=AA7D4CE8-1

- any published studies that describe the regional importance, abundance and distribution of species at risk including management plans, recovery strategies or plans. The existing data must be supplemented by surveys, if required; and
- 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.

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.

6.1.6. 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
- 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.).

6.1.7. 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
- 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.).

6.1.8. Indigenous peoples

With respect to potential effects on Indigenous peoples and the related VCs, baseline information will be provided for ***each group*** identified in Section 5 (Part 2) of these guidelines (and any groups identified after these guidelines are finalized). 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. Baseline information will also 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 and cumulative effects. Baseline information will be sufficient to provide a comprehensive understanding of the current state of each VC.

Baseline information for current use of lands and resources for traditional purposes will focus on the traditional activity (e.g. fishing) and include a characterization of all attributes of the activity that can be affected by environmental change. This includes not only identifying species of importance, but also

assessing the quality and quantity of preferred traditional resources and locations, timing (e.g. seasonality, access restrictions, distance from community), ambient/sensory environment (e.g. noise, air quality, visual landscape, presence of others) and cultural environment (e.g. historical/generational connections, preferred areas). As applicable, specific aspects that will be considered include, but are not limited to:

- current use of lands and resources for traditional purposes, including:
  - ✓ location of traditional territory (including maps where available);
  - ✓ 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 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; and
  - ✓ cultural values associated with the area affected by the project and the traditional uses identified.
- any Project components and a description of any activities (e.g. exclusion zones) that may affect commercial fisheries or other uses;
- human health[10], primarily with respect to potential contamination of food sources;
- location of reserves and communities; and
- physical and cultural heritage[11] (including any site, structure or thing of archaeological, paleontological, historical or architectural significance).

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 from groups, including Aboriginal traditional knowledge, 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.

6.1.9. 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).

[10] The proponent should refer to Health Canada's *Useful Information for Environmental Assessments* document in order to include the appropriate baseline information relevant to human health. This document can be obtained at http://www.publications.gc.ca/site/eng/481782/publication.html

[11] Heritage resources to be considered will include but not be limited to, physical objects (e.g. middens, culturally-modified trees, historic buildings), sites or places (e.g. burial sites, sacred sites, cultural landscapes) and attributes (e.g. language, beliefs).

6.1.9.1. 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:

- Ecologically and Biologically Significant Areas (e.g. The Southeast Shoal and Tail of the Banks, The Northeast Shelf and Slope, Lily Canyon-Carson Canyon and The Virgin Rocks)
- Fishery Closure Areas (e.g. Northwest Atlantic Fisheries Organization Coral Closures, Orphan Knoll Seamount)
- Preliminary Representative Marine Areas (South Grand Bank Area)

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).

6.1.9.2. Human environment

With respect to potential effects on the human environment, non-Indigenous people and the related VCs, 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[12] 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

[12] The proponent should refer to Health Canada's *Useful Information for Environmental Assessments* document in order to include the appropriate baseline information relevant to human health. This document can be obtained at http://www.publications.gc.ca/site/fra/9.700511/publication.html

- 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.

6.2. 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, timing, duration, frequency, ecological and social context, and whether the environmental changes are reversible or irreversible.

The EIS will include stand-alone sections that summarise those changes that may be caused by the project on the components of the environment listed in paragraph 5(1)(a) of CEAA 2012, namely fish and fish habitat, aquatic species and migratory birds.

The EIS will include a stand-alone section that summarises any change the project may cause to the environment that may occur on federal lands or lands outside the province in which the project is to be located (including outside of Canada).

In situations where the project requires one or more federal decisions identified in section 5(2), the EIS will also include a stand-alone section that describes any change that may be caused by the project on the environment that is directly linked or necessarily incidental to these decisions (e.g. changes to commercial fishing).

6.3. 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:

6.3.1. 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, juvenile, rearing and feeding areas), and in relation to availability and significance. 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;
- ✓ 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; environment and species (e.g. corals, plants);
  - ✓ any modifications in migration or local movements during and after project activities (e.g. vertical seismic profiling, drilling);
  - ✓ any modifications and use of habitats by federally or provincially listed fish species;
- 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;
- 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 would be collected during and after drilling operations and how this would be used to verify effects predictions.

6.3.2. Marine plants

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

6.3.3. Marine mammals

- effects on marine mammals, including but not limited to:
  - ✓ mortality and other effects from vessel collisions or disturbance; and
  - ✓ 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, discomfort and behavioural disturbance).

6.3.4. Marine turtles

- effects on marine turtles, including but not limited to:
  - ✓ mortality and other effects from vessel collisions or disturbance; and
  - ✓ 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, discomfort and behavioural disturbance).

6.3.5. 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);
  - ✓ 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 threats, incineration in flares, disruption of normal activities);
  - ✓ exposure to spilled contaminants (e.g. fuel, oils) and operational discharges (e.g. deck drainage, gray 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 or support vessels;
  - ✓ physical harm or mortality from flaring on the drilling unit or other vessel based threats;
  - ✓ 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.

6.3.6. 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;
  - ✓ 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).

6.3.7. Indigenous peoples

With respect to Indigenous peoples, a description and analysis of how changes to the environment caused by the project will affect the following activities exercised by each Indigenous group, as applicable to the proposed project:

- current use of lands and resources for traditional purposes. This assessment will characterize the effects on the use or activity (e.g. fishing) as a result of the underlying changes to the

environment (i.e. how will the activity change if the project proceeds). The underlying changes to the environment will also be described, including, but not limited to:

- ✓ any changes to resources (fish, birds, or other natural resources) used for traditional purposes (e.g. fishing, use of sacred sites);
- ✓ 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;
- ✓ changes related to species important to Indigenous people's current use of resources, including changes to key habitat;
- ✓ any changes or alterations to access into the areas used for traditional purposes and commercial fishing, including implementation of exclusion zones;
- ✓ any changes to the environment that affect 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;
- ✓ consideration of the regional context for traditional use and the value of the project area in that regional context, including alienation of lands from traditional use;
- ✓ 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;
- ✓ an assessment of the potential to return affected areas to pre-project conditions to support traditional practices;

- human health, focusing on effects on health outcomes or risks in consideration of, but not limited to, potential changes in water quality (recreational and cultural uses), availability of country foods (e.g. marine species), and noise exposure. When risks to human health due to changes in one or more of these components are predicted, a complete Human Health Risk Assessment (HHRA) examining all exposure pathways for pollutants of concern may be necessary to adequately characterize potential risks to human health. Where adverse health effects are predicted, any incidental effects such as effects on current use of lands and resources for traditional purposes will also be assessed. 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;
- socio-economic conditions, including, but not limited to:
    - ✓ the use of navigable waters
    - ✓ commercial fishing (e.g. catch rates, exclusion zones, gear damage or loss, well abandonment, marketability of seafood products) and food security
    - ✓ commercial outfitters
    - ✓ recreational use
- 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

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

6.3.8. Other valued components that may be affected as a result of a federal decision[13] or due to effects on federal lands, another province or outside Canada[14]

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 authorisation/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.

6.3.8.1. 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 marine 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);
  - ✓ justify all estimated emissions and emission factors used;
  - ✓ provide the estimation or derivation method, and disclose and describe all assumptions and emission intensity factors used;

[13] sub-section 5(2) of CEAA 2012
[14] paragraph 5(1)(b) of CEAA 2012

- ✓ compare and assess the level of estimated emissions to the regional, provincial and federal emission targets;
- ✓ 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.

6.3.8.2. 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).

6.3.8.3. Special areas

- effects on special areas, including, but not limited to:
  - ✓ use of dispersants, and
  - ✓ change to habitat quality (e.g. noise, light, water, sediment quality).

6.3.8.4. 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);
  - ✓ rural and urban settings that could be affected by routine activities and/or accidents and malfunctions.

6.4. 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 describe mitigation measures in relation to 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 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.

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.

6.5. 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 6.3 above. 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 guidance described in Section 4 of the Agency's Operational Policy Statement, *Determining Whether a Project is Likely to Cause Significant Adverse Environmental Effects under the Canadian Environmental Assessment Act, 2012*[15].

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. 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[16]
- 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.

[15] Visit the Canadian Environmental Assessment Agency's website at: http://www.ceaa-acee.gc.ca/default.asp?lang=En&n=363DF0E1-1

[16] 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.

6.6. Other effects to consider

6.6.1. 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.

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 for each accident and malfunction type and the environmental effects of these scenarios. The EIS will identify the measures to be put in place to prepare, prevent for and respond to all such scenarios (e.g. contingency and emergency procedures). The EIS will also describe the existing mechanisms and arrangements with response organizations for emergency response within the spatial extent of the project.

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 spatial boundaries will identify the areas that could potentially be affected by a worst-case scenario for each accident type.

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 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 burns). 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 the Newfoundland and Labrador offshore. Comparisons with similar settings (e.g. in the Ormen Lange field in Norway and elsewhere) would also be meaningful for deep water drilling where there is very low probability but very high consequences associated with landsliding.

6.6.2. 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) with consideration of predicted climate change effects. These events will be considered in different probability patterns (e.g. 5-year event vs. 100-year event).

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

6.6.3. Cumulative effects assessment

The proponent will identify and assess the project's cumulative effects using the approach described in the Agency's Operational Policy Statement entitled *Addressing Cumulative Environmental Effects under the Canadian Environmental Assessment Act, 2012* and the guide entitled *Technical Guidance for*

Assessing Cumulative Environmental Effects under the Canadian Environmental Assessment Act, 2012[17].

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[18].

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,
  - ✓ Indigenous peoples,
  - ✓ air quality and greenhouse gases, and
  - ✓ human environment.
- Identify and justify the spatial and temporal boundaries for the cumulative effect 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.

[17] Visit the Canadian Environmental Assessment Agency's website at: http://www.ceaa-acee.gc.ca/default.asp?lang=En&n=F1F30EEF-1

[18] These terms are defined in the Canadian Environmental Assessment Agency's *Technical Guidance for Assessing Cumulative Environmental Effects under the Canadian Environmental Assessment Act, 2012*, Draft, December 2014 – http://www.ceaa-acee.gc.ca/default.asp?lang=en&n=B82352FF-1&offset=&toc=hide

- 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. fishing).
- 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 any 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.

7. SUMMARY OF ENVIRONMENTAL EFFECTS ASSESSMENT

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

- potential environmental effects on valued components;
- 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).

8. 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;
- 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.

8.1. 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 exploration 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.

8.2. 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 valued components and the measures and means planned to protect the environment;
- identification of regulatory instruments that include a monitoring program requirement for the valued components;

- 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

Valued Component affected	Area of federal jurisdiction[19] (√)	Project Activity	Potential effects	Proposed mitigation	Residual effect	*Magnitude*	*Geographical Extent*	*Timing*	*Duration*	*Frequency*	*Reversibility*	*Ecological context*	*Other criteria used to determine significance*[20]	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														

[19] 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.

[20] 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.

APPENDIX B

Key Personnel Responsible for EIS Preparation

Statoil Canada Ltd. Flemish Pass Exploration Drilling Project 2018-2028 ExxonMobil Canada Limited Eastern Newfoundland Offshore Exploration Drilling Project 2018-2030 ENVIRONMENTAL IMPACT STATEMENT EIS Study Team	
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ExxonMobil Canada Limited	Robert Stokes, PGeo Hanna Janzen, PEng Kim Coady, MES Janna Kenny, PTech Changyong Zhang, PhD Dewayne Sanders Erik DeMicco, PhD Jay Hartling Laura Bishop, BComm Linda Zimmerman Margot Bruce-O'Connell Miriam Woodfine, PEng Nikole Andres, MREM, BSc Wendy Smith Wolfgang J. Konkel, MSc
EIS Component	**Personnel**
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Chapter 2, Project Description	Elizabeth Way, MSc (Stantec) Colleen Leeder, MSc (Stantec)
Chapter 3, Engagement	Nancy Griffiths, BDEP (Amec FW) Mary Hatherly, LLB, LLM (Amec FW)
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	Marine and Migratory Birds: Maureen Cameron-McMillan, MSc (Amec FW)
	Marine Mammals and Sea Turtles: Andrea Ahrens, MSc (Stantec)
	Special Areas: Nancy Griffiths, BDEP (Amec FW)
Chapter 7, Existing Socioeconomic Environment	Indigenous Communities and Activities: NL, NS, NB, PEI - Christine Jeans, MCIP, LPP (Stantec) QC - Nancy Griffiths, BDEP (Amec FW) QC - Brigitte Masella, MES (Amec FW)
	Fisheries and Other Marine Users: Jeff Janes, MREM (Stantec) Ellen Tracy, BSc (Stantec)
Chapter 8, Marine Fish and Fish Habitat VC	Justin So, MSc (Amec FW) James McCarthy, MSc (Amec FW) Michael Teasdale, MSc (Amec FW)
Chapter 9, Marine and Migratory Birds VC	Maureen Cameron-McMillan, MSc (Amec FW)
Chapter 10, Marine Mammals and Sea Turtles VC	Andrea Ahrens, MSc (Stantec)
Chapter 11, Special Areas VC	Nancy Griffiths, BDEP (Amec FW)
Chapter 12, Indigenous Communities and Activities VC	Steve Bonnell, PhD (Amec FW) Mary Hatherly, LLB, LLM (Amec FW) James McCarthy, MSc (Amec FW) Justin So, MSc (Amec FW)

Statoil Canada Ltd. Flemish Pass Exploration Drilling Project 2018-2028 ExxonMobil Canada Limited Eastern Newfoundland Offshore Exploration Drilling Project 2018-2030 ENVIRONMENTAL IMPACT STATEMENT EIS Study Team	
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Chapter 14, Cumulative Environmental Effects	Steve Bonnell, PhD (Amec FW) Justin So, MSc (Amec FW) Maureen Cameron-McMillan, MSc (Amec FW) Andrea Ahrens, MSc (Stantec) Jeff Janes, MREM (Stantec)
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Chapter 16, EIS Summary and Conclusion	Christine Jeans, MCIP, LPP (Stantec) Jeff Janes, MREM (Stantec) Steve Bonnell, PhD (Amec FW)
EIS Executive Summary / Plain Language Summary	Christine Jeans, MCIP, LPP (Stantec) Hilary Janes, BSc (Stantec) Elizabeth Way, MSc (Stantec) Colleen Leeder, MSc (Stantec) Steve Bonnell, PhD (Amec FW)
GIS and Mapping (All EIS Chapters)	Juanita Abbott, BA (Amec FW) Heather Ward, MSc (Stantec)
Drill Cuttings Modelling	John McClintock, BMath (Amec FW) Trajce Alcinov, MSc (Amec FW) Charlie Bishop, MSc (Amec FW) Karl Lagman, MSc (Amec FW) Patrick Roussel, MEng, MSc (Amec FW)
Oil Spill Modelling	Matt Horn, PhD (RPS)
Underwater Noise Analysis	Bruce Martin, MSc Katie Kowarski, BSc Emily Maxner, MSc

APPENDIX C

Eastern Newfoundland Drilling Noise Assessment: Qualitative Assessment of Radiated Sound Levels and Acoustic Propagation Conditions
(Martin et al. 2017))

Eastern Newfoundland Drilling Noise Assessment

Qualitative Assessment of Radiated Sound Levels and Acoustic Propagation Conditions

Submitted to:
Colleen Leeder
Stantec Consulting Ltd.
Project number: 121413373

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Disclaimer:

The results presented herein are relevant within the specific context described in this report. They could be misinterpreted if not considered in the light of all the information contained in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

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1. Introduction

JASCO Applied Sciences (Canada) (JASCO) provided qualitative predictions of underwater sound levels for the Flemish Pass Exploration Drilling Program (Statoil Canada Ltd.) and the Eastern Newfoundland Offshore Exploration Drilling Project (ExxonMobil Canada Ltd.). The project areas are shown in Figure 1. The areas include existing Statoil and ExxonMobil exploration licence blocks in the Flemish Pass and Jeanne d'Arc Basin region, and is referred to as the Eastern Newfoundland Exploration Drilling Project Area in this report. The sound sources considered in this desktop study include drill rigs (semisubmersibles and drill ships), dynamic positioning (DP) systems, support vessels, and a vertical seismic profiler (VSP). In this desktop study, we consider three locations: Site A, a 300 m deep location at the edge of the Grand Banks; site B, which is 1500 m deep in the Flemish Pass; and Site C, which is 3000 m deep north of Flemish Cap (Figure 1).

This report:

- Provides data on the ambient noise levels in the Eastern Newfoundland Exploration Drilling Project Area,
- Summarizes the environmental parameters in the Eastern Newfoundland Exploration Drilling Project Area,
- Summarizes the expected project source levels, based on client-provided parameters of drill rig DP systems and VSP arrays likely to be used in this Project,
- Compares environmental properties and source levels between the present Project and the Scotian Basin Exploration Drilling Project (Zykov 2016), and
- Concludes by comparing the radii of possible effects to marine life to those reported in the Scotian Basin Exploration Drilling Project (Zykov 2016).

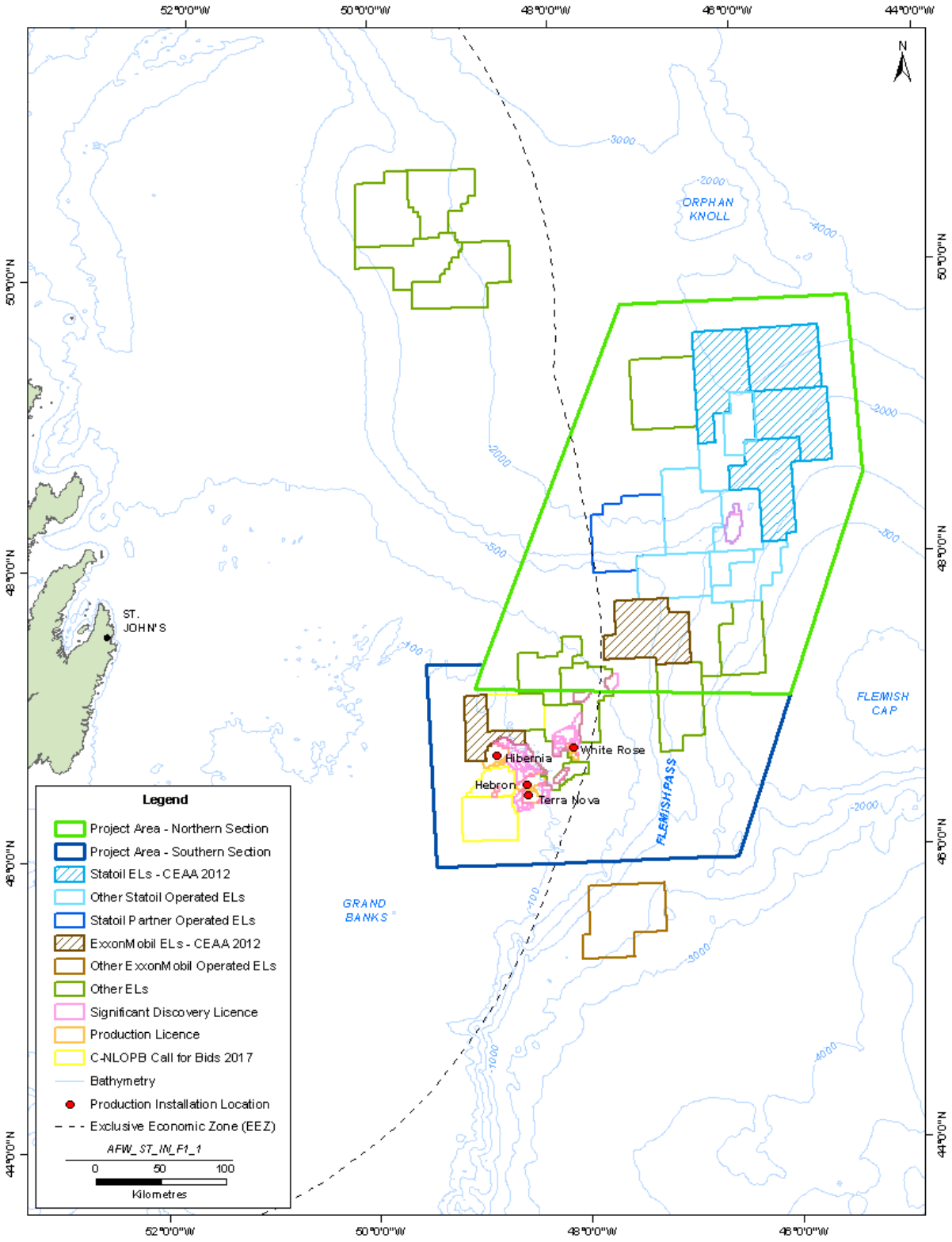


Figure 1. Flemish Pass Exploration Drilling Program and Eastern Newfoundland Exploration Drilling Project Areas (Eastern Newfoundland Exploration Drilling Project Area).

2. Ambient Noise Levels

The impact of sound sources on the ocean soundscape depends on factors such as:

- The source loudness,
- The characteristics of sound propagation, determined by environmental parameters (water depth, sound speed profile, seabed type) and the frequency spectrum of the source,
- The overlap of the frequency content of the new sounds with the existing sounds in the environment.

This section provides an overview of the sound sources in the Project Area. To simplify the discussion of the existing soundscape, we divide the frequency spectrum into five bands. Table 1 provides a classification of known biologic, man-made, natural geologic, and measurement-noise mechanisms as well as the frequency bands associated with their contributions to the soundscape.

Table 1. Typical sound generating mechanisms and their associated frequency bands.

Band name and frequency range	Sound source type			
	Biologic	Man-made	Geologic	Measurement System Noise
Very low frequency: 10–45 Hz (Figure 4)	Fin, blue, Bryde's, Omura's whales	Seismic pulses	Earthquakes	Flow noise, strum
Low frequency: 45–225 Hz (Figure 5)	Fish, baleen whales, pinnipeds	Seismic pulses, large vessels	-	Flow noise, strum
Mid frequency: 225–2250 Hz (Figure 6)	Baleen whales, fish, pinnipeds	Smaller vessels, large vessels at close range, DP	Wind and wave action	-
High frequency: 2250–18000 Hz (Figure 7)	Whistles, sperm whale clicks, baleen song, shrimp	Naval sonar, cavitation bubbles, chains	Sediment movement, rain	-
Very high frequency: >18000 Hz (Figure 8)	Echolocation clicks	Communicating and positioning devices, naval sonar	-	-

"-" symbol means that the corresponding sound source does not have significant energy within the band.

To summarize the soundscapes around the Eastern Newfoundland Exploration Drilling Project Area, we present the distribution of one-minute sound pressure levels from a data collection program conducted by JASCO in 2015-2016. In August 2015, JASCO deployed 20 acoustic recorders along Canada's east coast for the first year of a two-year baseline monitoring program sponsored by the Environmental Sciences Research Fund (ESRF) program. The recorders were retrieved and redeployed in July 2016. Data from six of the recorders are discussed here, as they provide the best available information on the existing sound levels in the Eastern Newfoundland Exploration Drilling Project Area (Figure 2). Stn 18 was in 80 m of water, 35 km from the Hibernia platform in the existing Jeanne D'Arc Basin development area. Data from Stn 7 is presented as an example of a receiver at a location of similar water depth, but far from oil and gas activity. Stns 17 and 19 were in deep water (>1250 m) 200 km south and north of the Flemish Pass respectively. Their data represents the current deep-water soundscape. Stns 4 and 5 are to the southwest of Sable Island. Their data provide examples of the effects of a deep-water drilling rig on the soundscape. Stn 5 was located 13 km from Shell Canada's 2015–2016 Cheshire drilling campaign.

To describe the general characteristics of the soundscape, we present box-and-whisker plots (or boxplots) for each month in each frequency band identified in Table 1. Monthly distributions provide an overview of the range of sound levels and how they change by season. The dominant sound source for each month is indicated by the colour of the boxes. JASCO's experienced analysts identified the dominant sources by inspection of the long-term spectral average figures generated for the ESRF project to identify the sources that would have increased the mean monthly in-band sound pressure level by 3 dB or more from the expected levels in the absence of the source (e.g. Figure 3). A detailed analysis of all detectable sources of sound (e.g. vessels in Figure 3) is beyond the scope of this summary. Section 2.1 discusses the soundscape by frequency band (i.e., the rows of Table 1) and Section 2.2 summarizes the effects of the different sound sources on the soundscape (i.e., the columns of Table 1). In both sections, we will refer to Figure 3 through Figure 8. The boxplots were created from ~2000 one-minute samples collected per month per station. The top and bottom of the boxes show the sound levels exceeded by 25% and 75% of the one minute samples, respectively. The heavy line across the boxes shows the mean monthly sound pressure levels. The lines extending above and below the boxes extend 2 standard deviations from the mean value. The box plots are ordered from north to south.

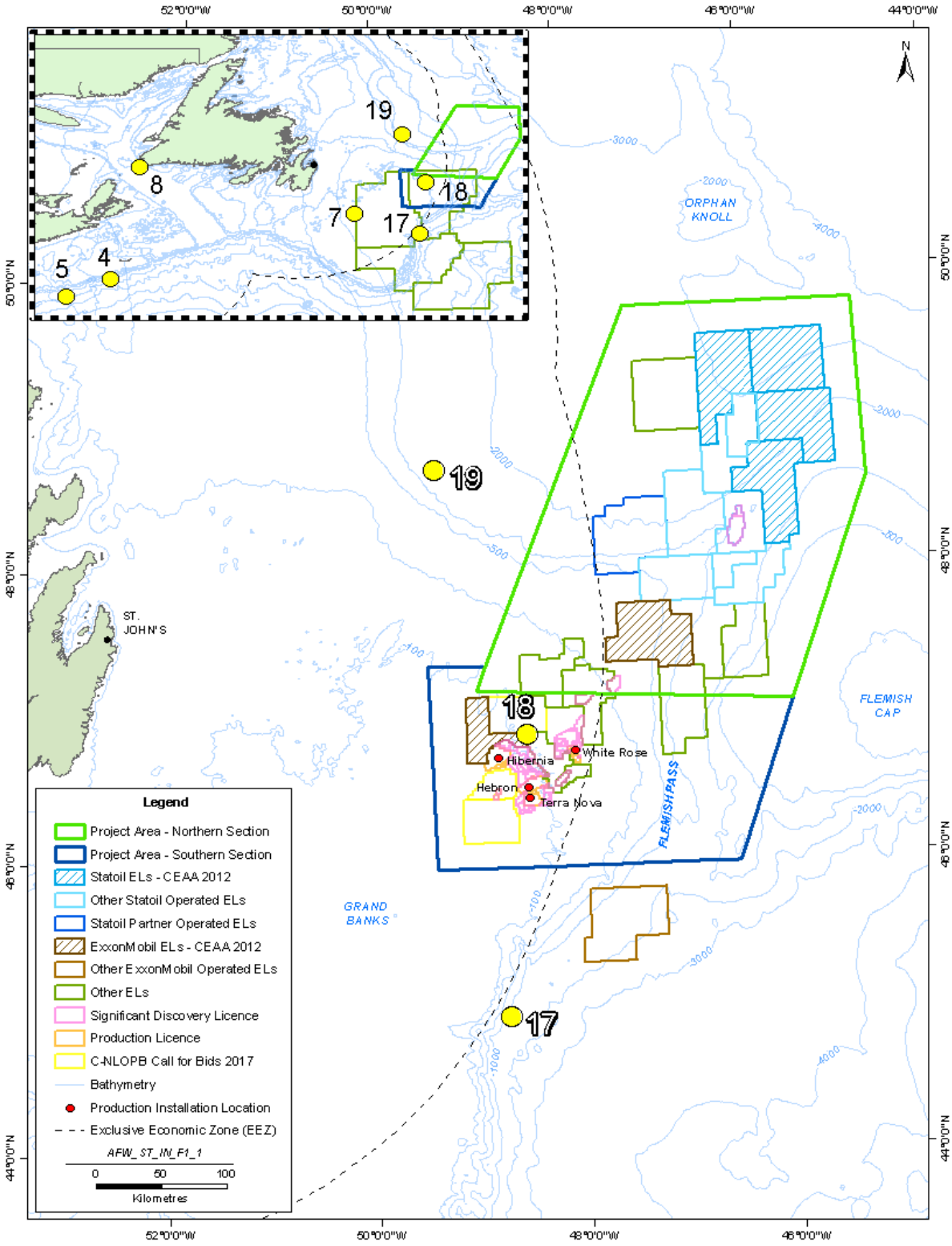


Figure 2. Eastern Newfoundland Exploration Drilling Project Area showing locations of the existing oil production platforms and the JASCO year-long acoustic recorders (yellow dots) deployed as part of an ESRF program. Hebron is expected to produce first oil in December 2017. A zoomed-out view of the Scotian Shelf and Grand Banks is included in the top-left corner for context

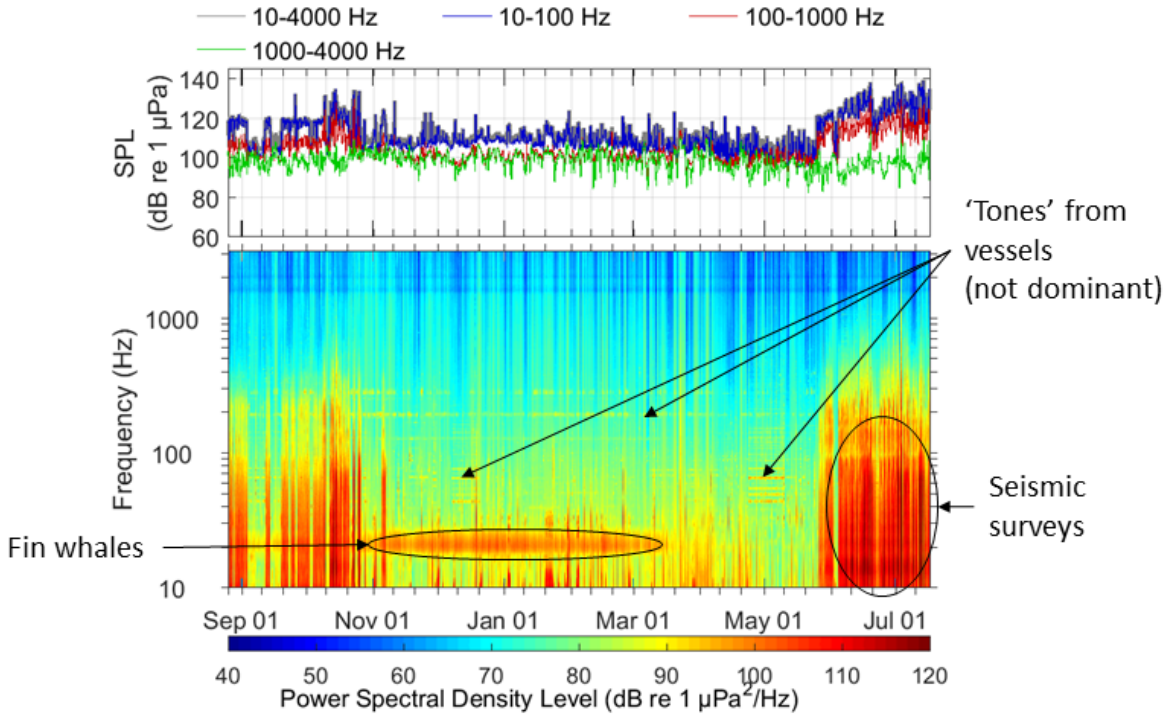


Figure 3. Long-term spectral average from Station 19 showing fin whales and seismic surveys as two dominant sources. Vessels were detectable througout the year, but were not dominant sources in the sense of increasing the per-month sound levels.

2.1. Soundscape by Band

The total sound levels across all bands are referred to as the broadband sound pressure levels (SPL). If a source is identifiable as the dominant source in the monthly broadband sound distributions, then the magnitude of its sounds exceed all other regularly occurring sounds by at least 3–6 dB. In Figure 3, Stn 04 and 17 are good examples of the normal magnitude and distribution of sounds pressure levels in the open ocean. Ambient sound levels are in the range of 100–105 dB re 1 µPa, with levels slightly higher in the winter due to increased wind and wave activity. At Stn 18, the levels are 110–120 dB re 1 µPa continuously, which is due to the platform and support vessel noise from the Hibernia and Hebron oil developments. The effect of the Cheshire well drilling activity at Stn 05 is also obvious by comparison to the nearby Stn 04. The drilling program started in mid October 2015 and continued to mid-March 2016. It was suspended from mid-March until early June after the platform dropped the drill string. The drilling finished at the end of July 2016. Seismic surveys occurred off the Grand Banks in fall 2015, which increased the SPLs at Stn 17 in Sept 2015, and Stn 19 in September and October 2015. Surveys north of the Flemish Pass began again in June of 2016 and resulted in the maximum sound levels presented here of 140 dB re 1 µPa. These values are presented in decibels, which is a logarithmic scale. Thus 140 dB is 10000 times louder than 100 dB.

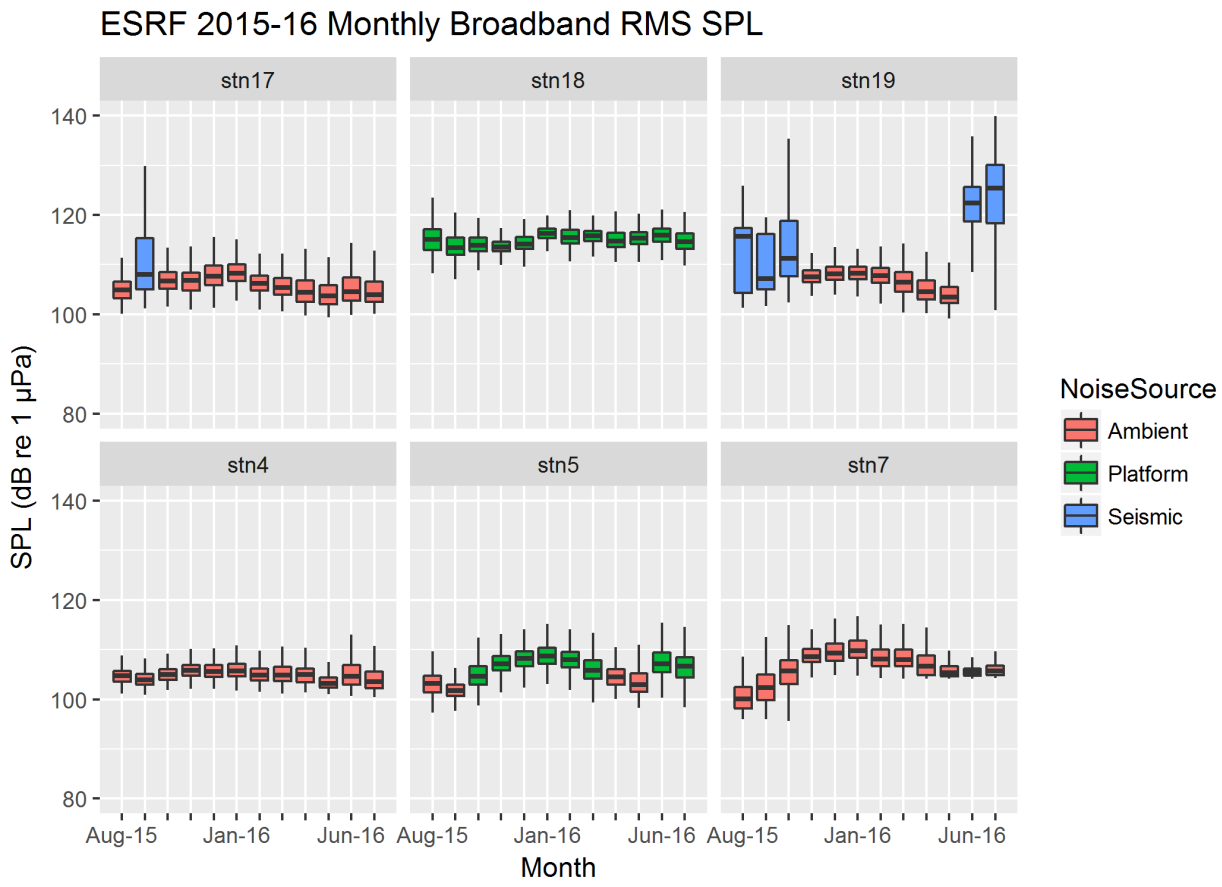


Figure 4. *10–125,000 Hz band*: Distribution of one-minute SPL for selected locations from JASCO's 2015–2016 ESRF data set. Stations 7 and 18 are at <100 m water depth and Stations 4, 5, 17, and 19 are at >1000 m. All measurements were within 10 m of the seabed. Stn 4 and 5 are located off the southwestern Scotian Shelf and represent examples of deep water recordings with and without significant man-made noise sources. Stn 5 is 13 km from Shell's Monteray Jack drilling campaign using the Stena IceMax. Stn 18 is 35 km from the Hibernia platform.

In the very-low frequency band (10–45 Hz, Figure 4), background sound levels in the open ocean are in the range of 90–95 dB re 1 µPa. Fin whales were a dominant noise source for at least four months and up to seven months throughout fall, winter, and spring, which was typical for the ESRF stations that were not ice-covered, especially those over the Scotian Shelf and Grand Banks. North Atlantic fin whales emit a short pulse once every 9–18 seconds from October to March. Seismic survey sounds are a man-made source with high energy levels in this band. They were a major noise source at Stn 19 and 17 in the summer months. The fluctuations in the seismic sound levels were caused by variations of the distance between the seismic survey vessel and the corresponding recorder, as well as by the total number of survey days within each month. Platform and vessel noise were only weakly detectable in this band.

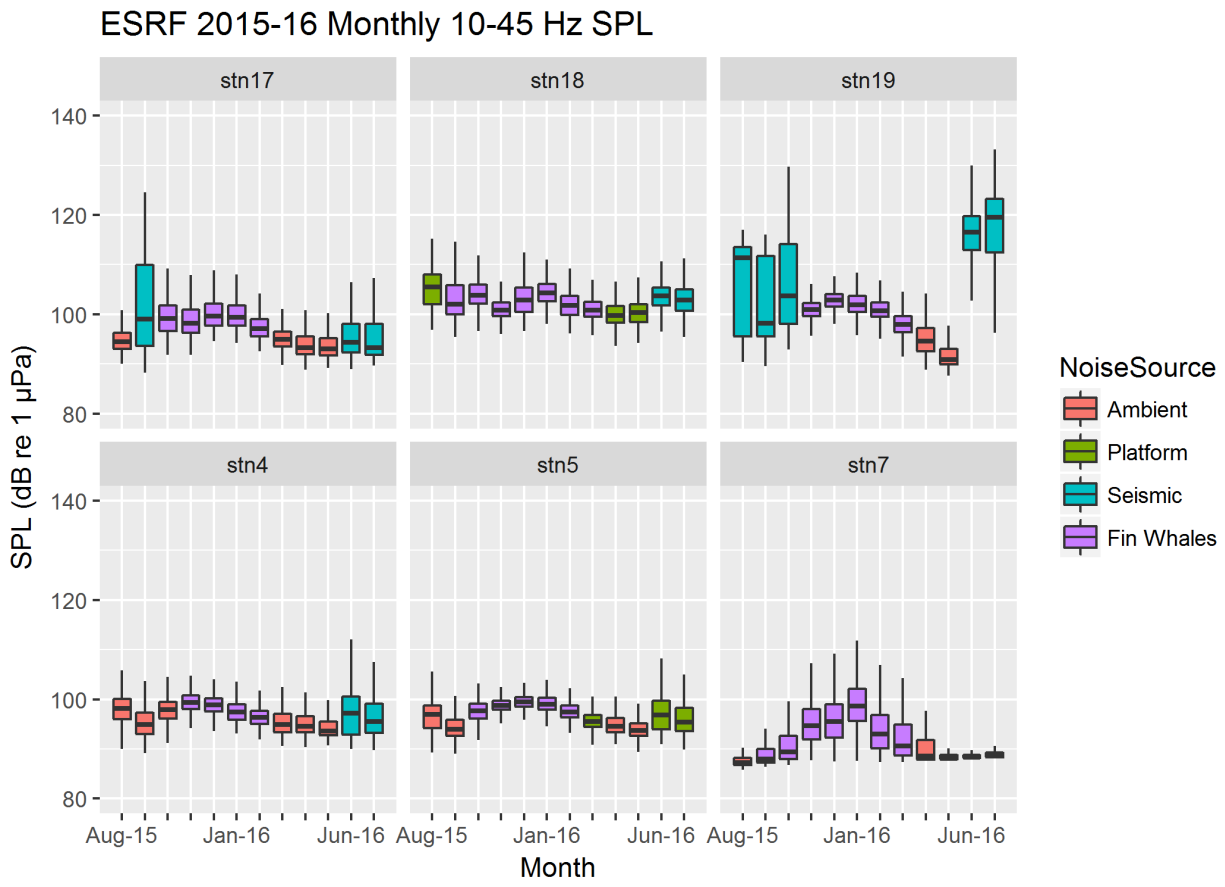


Figure 5. *10–45 Hz band*: Distribution of one-minute SPL for selected locations from JASCO's 2015–2016 ESRF data set. Stations 7 and 18 are at <100 m water depth and Stations 4, 5, 17, and 19 are at >1000 m. All measurements were within 10 m of the seabed. Stn 4 and 5 are located off the southwestern Scotian Shelf and represent examples of deep water recordings with and without significant man-made noise sources. Stn 5 is 13 km from Shell's Monteray Jack drilling campaign using the Stena IceMax. Stn 18 is 35 km from the Hibernia platform.

The low frequency band (45–225 Hz, Figure 5) contained the highest levels of platform noise. At Stn 18, the levels were ~105–115 dB re 1 µPa, nearly the range of the broadband SPL measured at Stn 18. The levels, which varied by small amounts from month-to-month. Stn 05 provides an example of typical platform noise levels for deep-water operations, with the highest levels around 103 dB re 1 µPa during November to February and during June to July. The program occurred from October 2015–July 2016 and was suspended from mid-March to early-June 2016. With respect to platform noise levels representative of operations in shallow water, the sound levels at Stn 18 were ~15 dB and 20 dB higher than those at Stn 7 during winter and summer, respectively. The levels at Stn 18 (35 km from Hibernia) were also considerably higher than those at Stn 05 (13 km from the Cheshire well drilling). This difference is likely due to the presence of three producing platforms near Stn 18 (Figure 2) and the support vessel traffic associated with their activities. Also, the deep waters near Stn 05 result in higher geometric spreading attenuation of the sound compared to the shallow water near Stn 18.

The seismic surveys were again a major source of noise at Stn 17 and Stn 19, although the levels were lower than in the very low frequency band.

Stn 07 shows a wider range of sound levels in the low frequency band in each month compared to the levels from any of the deep stations (17, 19, 04, 05). This is because in the absence of nearby sources of anthropogenic noise, the levels at Stn 07 are mostly driven by underwater noise from wind-driven wave activity, which is significantly higher during winter (November through March).

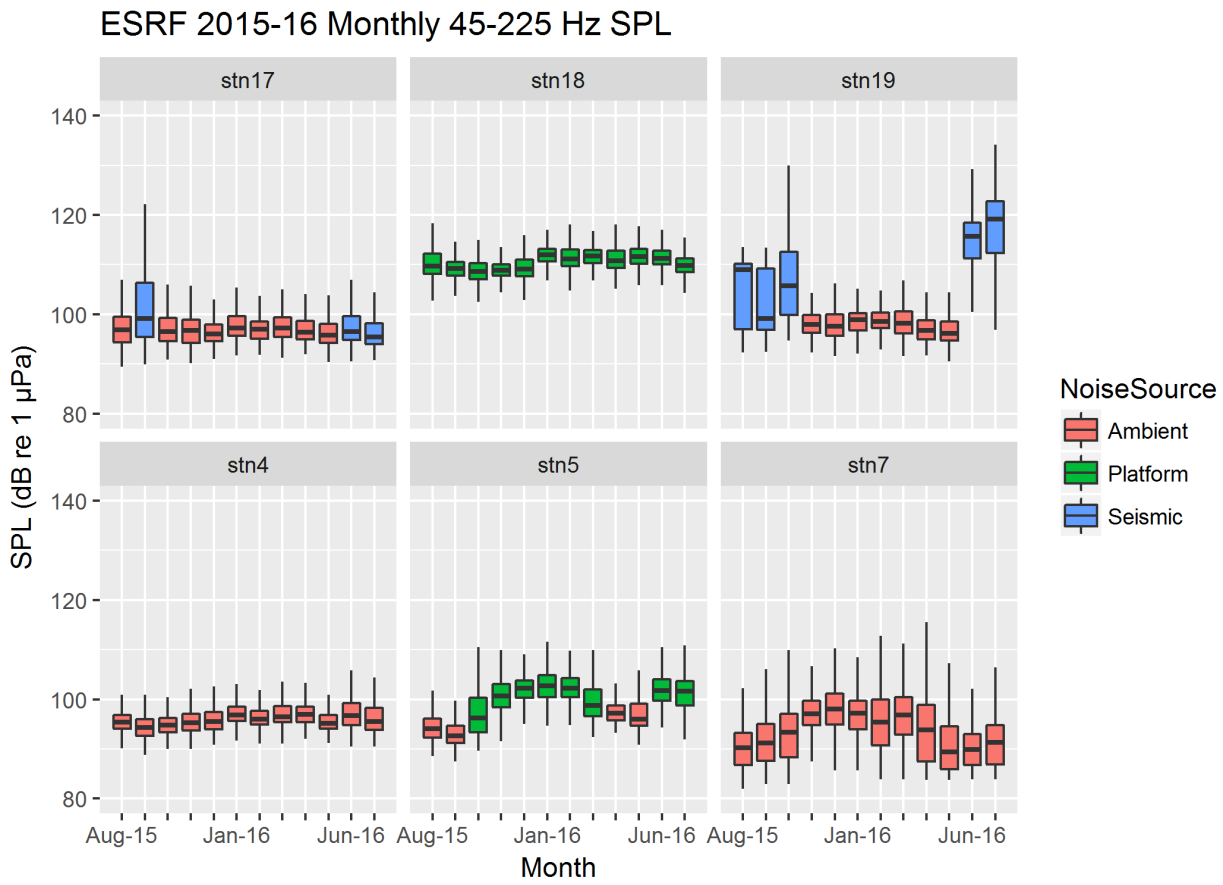


Figure 6. *45–225 Hz band*: Distribution of one-minute SPL for selected locations from JASCO's 2015–2016 ESRF data set. Stations 7 and 18 are at <100 m water depth and Stations 4, 5, 17, and 19 are at >1000 m. All measurements were within 10 m of the seabed. Stn 4 and 5 are located off the southwestern Scotian Shelf and represent examples of deep water recordings with and without significant man-made noise sources. Stn 5 is 13 km from Shell's Monteray Jack drilling campaign using the Stena IceMax. Stn 18 is 35 km from the Hibernia platform.

The mid-frequency band (225–2250 Hz, Figure 6) is the highest band affected by human-related sound sources at the resolution of this analysis. A seismic survey to Stn 19 affected sound levels in June and July. All stations showed a decrease in average sound levels in the summer months due to lower average wind speeds. In the case of Stn 18, the reduced sound levels in this band from the platforms is likely associated with a change in propagation conditions that kept more of the high frequency sounds close to the surface and away from our bottom recorders (see Sections 3.3 and 3.4).

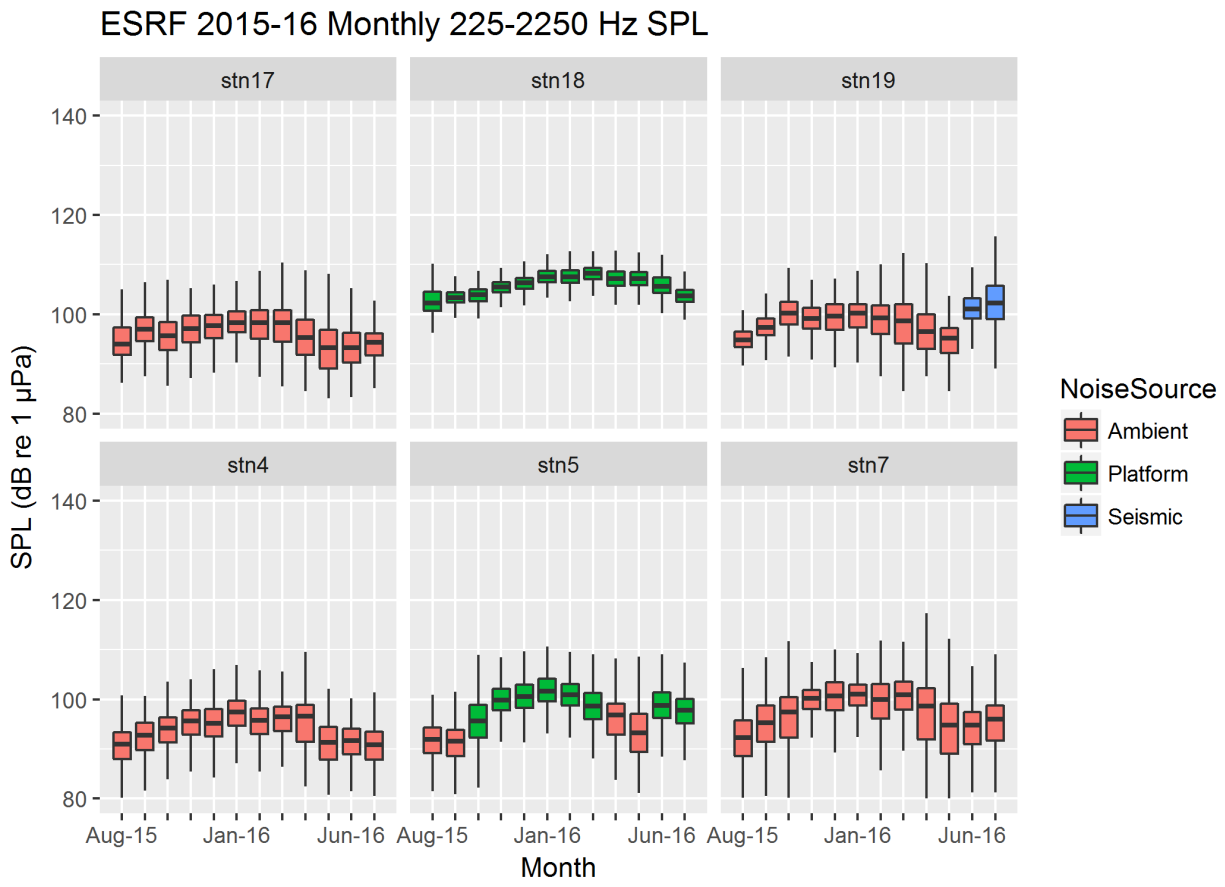


Figure 7. *225–2250 Hz band*: Distribution of one-minute SPL for selected locations from JASCO's 2015–2016 ESRF data set. Stations 7 and 18 are at <100 m water depth and Stations 4, 5, 17, and 19 are at >1000 m. All measurements were within 10 m of the seabed. Stn 4 and 5 are located off the southwestern Scotian Shelf and represent examples of deep water recordings with and without significant man-made noise sources. Stn 5 is 13 km from Shell's Monteray Jack drilling campaign using the Stena IceMax. Stn 18 is 35 km from the Hibernia platform.

In the high frequency band (2250–18000 Hz, Figure 7), all six measurement locations show a cycle of lower sound levels in summer and higher sound levels in winter. The absolute levels and spread of sound levels are similar at all stations.

In the very high frequency band (18000–90000 Hz, Figure 8), the levels shown are known to contain artifacts, caused by hydrophone-self noise frequently exceeding the environmental noise. Higher quality hydrophones were deployed in 2016–2017 to remediate this problem. In our experience, data collected at locations within several kilometres of either a vessel or platform would include energy in both the high-frequency and very high frequency bands.

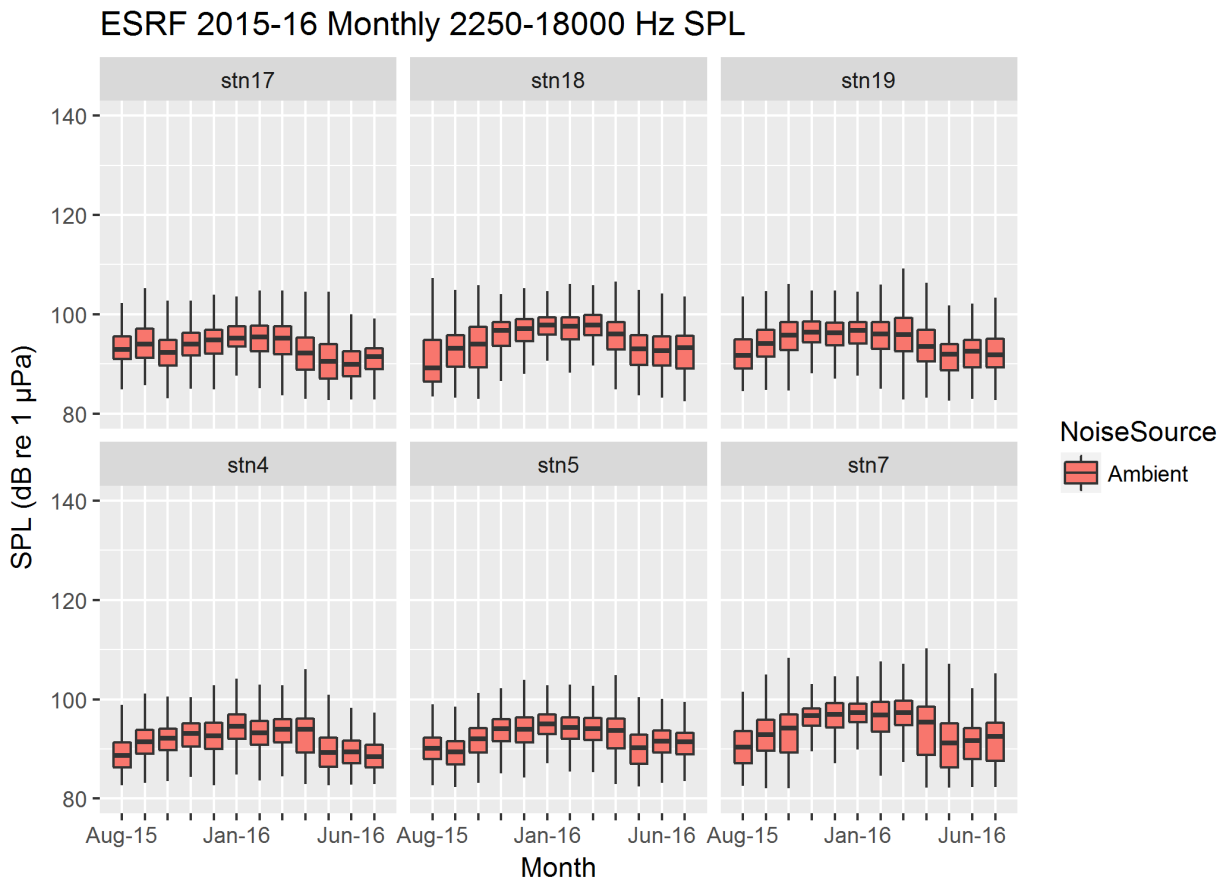


Figure 8. *2250–18000 Hz band*: Distribution of one-minute SPL for selected locations from JASCO's 2015–2016 ESRF data set. Stations 7 and 18 are at <100 m water depth and Stations 4, 5, 17, and 19 are at >1000 m. All measurements were within 10 m of the seabed. Stn 4 and 5 are located off the southwestern Scotian Shelf and represent examples of deep water recordings with and without significant man-made noise sources. Stn 5 is 13 km from Shell's Monteray Jack drilling campaign using the Stena IceMax. Stn 18 is 35 km from the Hibernia platform.

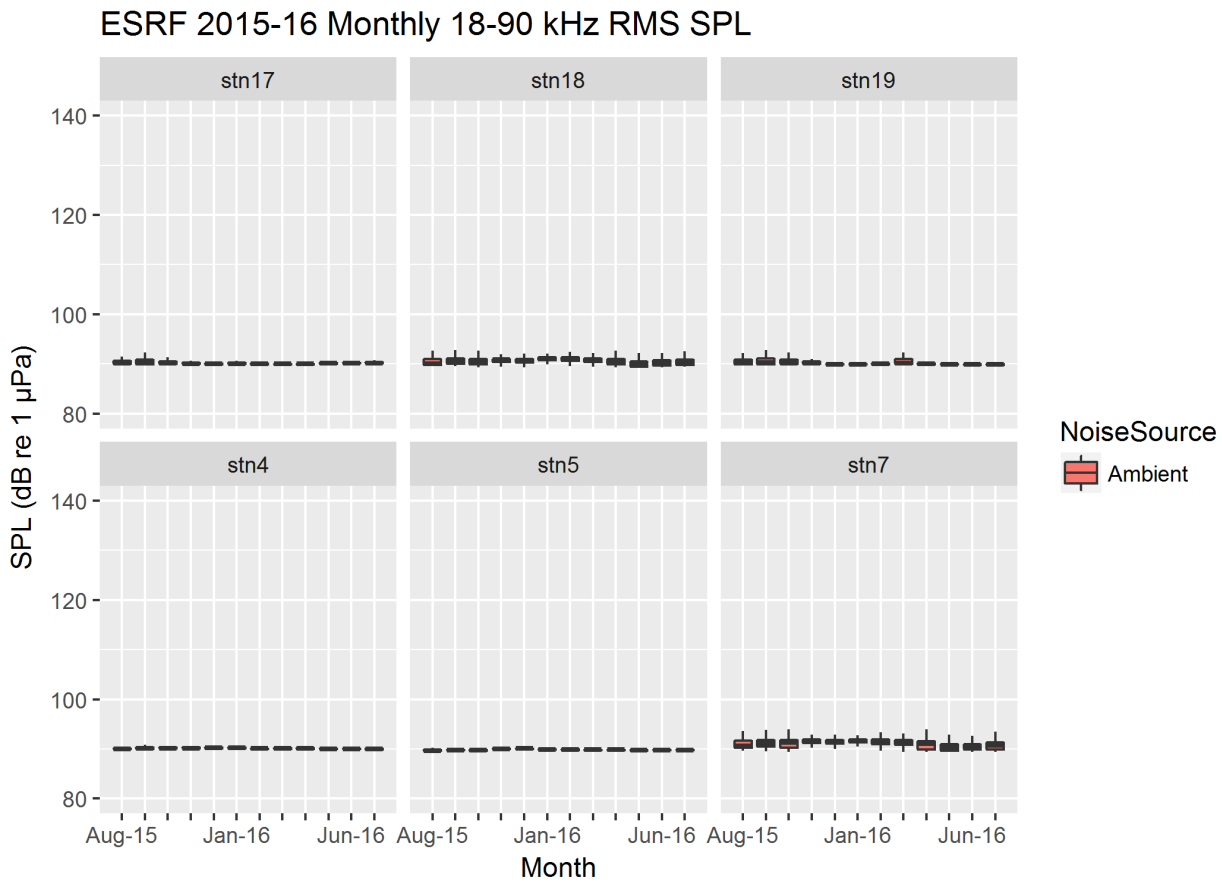


Figure 9. *18000–90,000 Hz band*: Distribution of one-minute SPL for selected locations from JASCO's 2015–2016 ESRF data set. Stations 7 and 18 are at <100 m water depth and Stations 4, 5, 17, and 19 are at >1000 m. All measurements were within 10 m of the seabed. Stn 4 and 5 are located off the southwestern Scotian Shelf and represent examples of deep water recordings with and without significant man-made noise sources. Stn 5 is 13 km from Shell's Monteray Jack drilling campaign using the Stena IceMax. Stn 18 is 35 km from the Hibernia platform.

2.2. Summary of Effects of Sources on the Soundscape

There are four identifiable sources in the Eastern Newfoundland Exploration Drilling Project Area that have long term effects on the soundscape:

1. Fin whales: Fin whales sing from Octoberto March on the Grand Banks. They seem to favour the shallow waters on the Grand Banks compared to the deeper waters off the continental shelf. 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 close to a recorder can temporarily increase the one-minute sound levels to 130 or 140 dB re 1 µPa.
2. Platforms: Oil and gas development and production platforms and their associated support vessels increased the SPL in the band of ~40–225 Hz by 15–20 dB at ranges of 35 km from a collection of 3 platforms in shallow water, and 8–10 dB for a single dynamically positioned drill rig 13 km away in deep water. The sound levels in the band of 225–2250 Hz were elevated 5–10 dB in both locations. The platforms are continuous noise sources that cause permanent elevations in the background sound levels.
3. Seismic Surveys: Seismic surveys are known to be one of the most intense sound sources in the ocean, capable of travelling hundreds to thousands of kilometres (McCauley et al. 2000, Gordon et al. 2003, Nieukirk et al. 2012). The seismic surveys detected at Stn 17 and Stn 19 were over 100 km

from the recorders and still a dominant sound source. Seismic array sound's peak frequency is near 50 Hz (Dragoset 1984), however the frequency range increases as the source vessel gets closer to a measurement location. The measurements reported here included energy up to 1 kHz.

4. Ambient: Median sound levels increase 3–5 dB in the 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.

3. Factors Affecting Sound Propagation

The sound levels measured at some distance from a source depend on the source-receiver distance and propagation effects. 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 noise source. This section details the environmental parameters expected within the Eastern Newfoundland Exploration Drilling Project Area and provides an overview of other propagation effects. Where appropriate, the environmental parameters corresponding to the Scotian Basin Exploration Drilling Project (Zykov 2016) are presented for comparison.

3.1. Bathymetry

Water depths throughout the Eastern Newfoundland Exploration Drilling Project Area were extracted from the SRTM15+ global bathymetry grid, a 30 arc-second grid (~600 × 1800 m at the studied latitude) rendered for the entire globe (Rodríguez et al. 2005). The water depth in the Flemish Pass area varies from 200–300 m in the southwest section (toward the Jeanne D'Arc Basin) to >3000 m northeast of the Flemish Cap (Figure 1). The water depths in the Jeanne D'Arc Basin area range from <80 m on the Grand Banks to more than 2000 m south-east of the Flemish Cap. As explained below, the combined effect of water depth and seabed geoacoustics may strongly influence sound propagation.

3.2. Geoacoustics

When sound propagates through the ocean, the sea surface and ocean floor act as boundaries that reflect, absorb, and scatter the energy. The surface is referred to as a 'pressure-release' interface because the acoustic pressure must be zero. For this to be true, the surface reflects the sound with equal amplitude and opposite phase. The reflected direction is perpendicular to the sea surface, and, therefore, if the surface is tilted by wave action it has a scattering effect that increases with frequency. A hard seabed is a different type of boundary that does not move, so the particle velocity must be zero. Thus, it reflects sound in phase with the incident energy and the pressure doubles. However, most seabeds are not perfect reflectors. Generally, seabeds are modelled as viscous fluids where a portion of the sound energy is reflected and the remainder penetrates the sediment. The amount of reflection and transmission depends on the angle of incidence, bottom roughness, as well as the density and porosity of the material. Less dense materials, such as clays and silts, allow more sound to penetrate. Harder materials like 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 like clays can also refract and trap sound, as well as absorb and attenuate it. Clearly the sea-bed geoacoustics are an important environmental parameter for understanding and predicting acoustic propagation.

On the Grand Banks continental shelf, through the Flemish Pass, and in the 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 shallow depths (~1100 m) and narrow banks of the Flemish Pass trap sediment deposits from the continental shelf. The sediment thickness throughout the Eastern Newfoundland Exploration Drilling Project Area is >2500 m, reaching ~4000 m in Flemish Pass (Divins 2007, Géli et al. 2007).

Three generic geoacoustic profiles were constructed for the region, based on water depth. A thick layer of silt/mud is assumed for all profiles. The average grain size of the silt was assumed to decrease with increasing water depth. Representative grain sizes and porosity were used in the grain-shearing model proposed by Buckingham (2005) to estimate the geoacoustic parameters that would be required by sound propagation models. Tables 2–4 list the geoacoustic parameters derived for numeric modelling.

These profiles are similar to those used in the Scotian Basin Exploraton Drilling Project (Zykov 2016), for which the sound sources were located on the continental slope, where a thick (~600 m) clay deposit is found.

Table 2. *Shallow water (Site A, ~300 m)*: Geoacoustic parameters derived for Eastern Newfoundland Exploration Drilling Project Area.

Depth below seafloor (m)	Material	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation (dB/λ)	S-wave speed (m/s)	S-wave attenuation (dB/λ)
0–5	Silt mixed with sand and clay	1.5–1.7	1560–1650	0.40–0.65	200	3.65
5–50		1.7–2.0	1650–1910	0.65–1.15		
50–500		2.0–2.1	1910–2435	1.15–2.00		
>500		2.1	2435	2.00		

Table 3. *Deep water (Site B, ~1500 m)*: Geoacoustic parameters derived for Eastern Newfoundland Exploration Drilling Project Area.

Depth below seafloor (m)	Material	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation (dB/λ)	S-wave speed (m/s)	S-wave attenuation (dB/λ)
0–5	Silt mixed with sand and clay	1.5–1.7	1525–1585	0.25–0.40	130	3.65
5–50		1.7–2.0	1585–1775	0.40–0.75		
50–500		2.0–2.1	1775–2100	0.75–1.40		
>500		2.1	2100	1.40		

Table 4. *Very deep water (Site C, ~3000 m)*: Geoacoustic parameters derived for Eastern Newfoundland Exploration Drilling Project Area.

Depth below seafloor (m)	Material	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation (dB/λ)	S-wave speed (m/s)	S-wave attenuation (dB/λ)
0–5	Silt mixed with sand and clay	1.5–1.7	1505–1555	0.20–0.30	85	3.65
5–50		1.7–2.0	1555–1700	0.30–0.50		
50–500		2.0–2.1	1700–1920	0.50–1.00		
>500		2.1	1920	1.00		

3.3. Sound Speed Profiles

As a rule of thumb, sound is 'lazy': It wants to travel as the slowest possible speed. When there is a depth variation in the sound speed, the sound will be refracted toward the depth with the lowest sound speed. The sound speed is a function of the temperature, salinity and pressure (depth) and can vary by tens of meters-per-second from the surface to the seabed.

Sound speed profiles in the Eastern Newfoundland Exploration Drilling Project Area were derived from temperature and salinity profiles from the U.S. Naval Oceanographic Office's Generalized Digital Environmental Model V 3.0 (GDEM; Teague et al. 1990, Carnes 2009). GDEM provides an ocean climatology of temperature and salinity for the world's oceans on a latitude-longitude grid with 0.25° resolution, with a temporal resolution of one month, based on global historical observations from the U.S. Navy's Master Oceanographic Observational Data Set (MOODS). The climatology profiles include 78 fixed depth points to a maximum depth of 6800 m (where the ocean is that deep). The GDEM temperature-salinity profiles were converted to sound speed profiles according to Coppens (1981).

Mean monthly sound speed profiles were derived from the GDEM profiles for the entire year for a central location in the Eastern Newfoundland Exploration Drilling Project Area (47°30′ N, 46°30′ W; Figure 9a). For comparison purposes, the mean monthly sound speed profiles for the Scotian Basin Exploration Drilling Project (Zykov 2016) are also presented (Figure 9b).

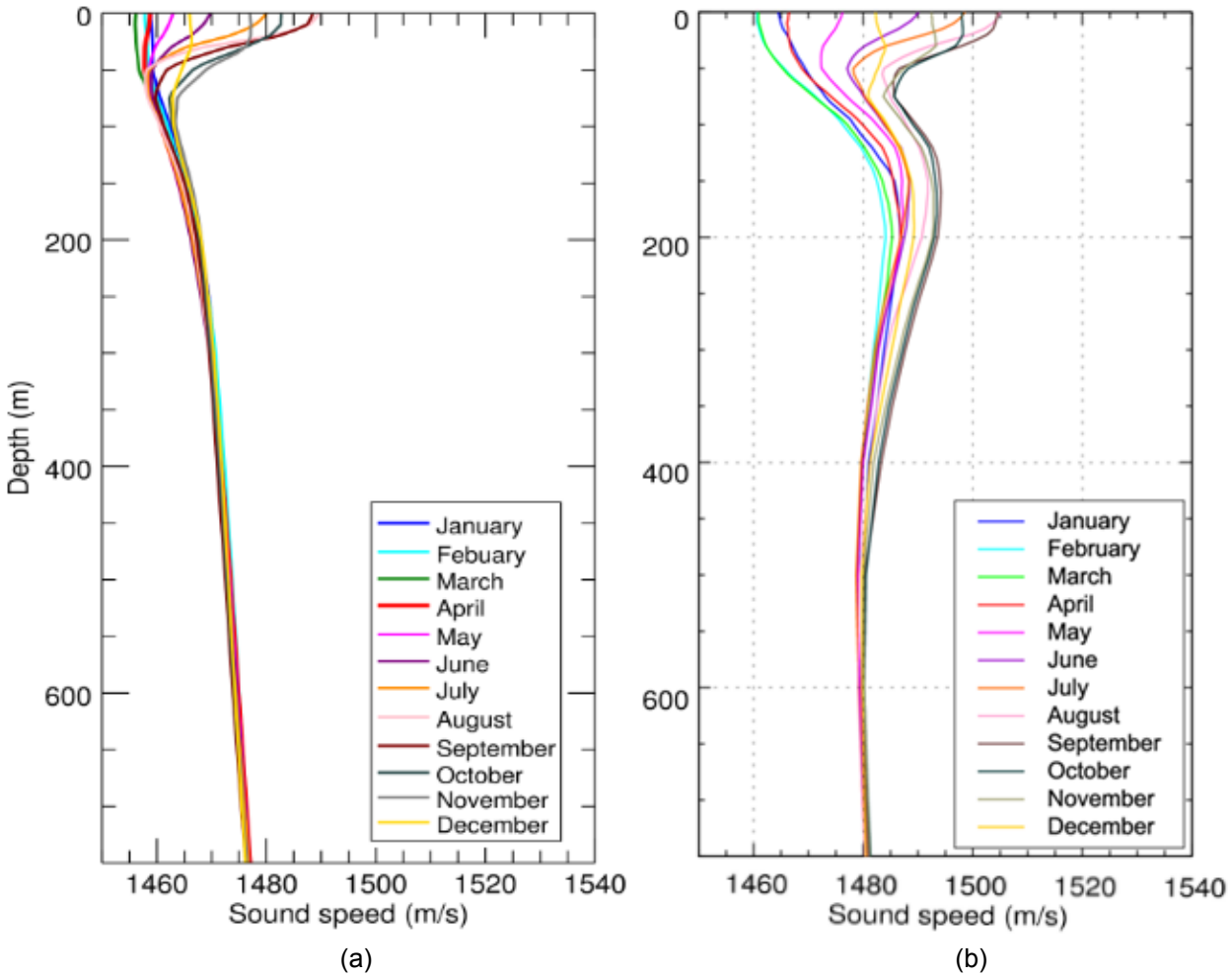


Figure 10. Mean monthly sound speed profiles for the a) Eastern Newfoundland Exploration Drilling Project Area and b) Scotian Basin Exploration Drilling Project (Zykov 2016), derived from data obtained from *GDEM V 3.0* (Teague et al. 1990, Carnes 2009).

The upper portion of the sound speed profile in the Eastern Newfoundland Exploration Drilling Project Area (Figure 9a) varies between isovelocity (January to March) and downward refracting (June to November), down to a depth of ~50–75 m. The sound will tend to refract toward the surface in January-March, but toward the sound speed minimum at 50–75 m in June-November There is little temporal variation in the profiles at depths greater than ~100 m. The sound speed increases slightly with depth, which will refract sound toward the sea surface, promoting long-range sound propagation.

In contrast, the sound speed profile from the Scotian Basin Exploration Drilling program (Figure 9b) results in more complex propagation effects. 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 summer, there is a weaker sub-surface sound speed minimum near 50 m, and a stronger deep sound channel minimum. Thus, the sounds of the Scotian Basin drilling program were expected to be 120 dB re 1 µPa 150 km away in winter, and ~50 km away in summer.

The sound speed profile in the Eastern Newfoundland Exploration Drilling Project Area is weakly upward refracting throughout most of the water column. We expect that the effects of the sound speed profile on sound propagation will be between the two conditions modelled for the Scotian Basin project. In the Eastern Newfoundland Exploration Drilling Project Area, we expect less change in propagation conditions throughout the year than were predicted for the Scotian Basin.

3.4. Propagation Effects

Sound propagation in the ocean is a complex process that depends on several factors. Sound levels from an omnidirectional point source in the water column are reduced with range, a process known as *geometric spreading*. Before the sound emanating from the point source reaches the seabed or sea surface boundaries, waves propagate in a spherical pattern. In this case, the received levels at a recorder located a distance R from the source are $20\log R$ dB lower than the levels measured at 1 m from the source. This is known as spherical geometric spreading. Once the waves interact with the sea surface and seabed, propagation in the form of cylindrical waves takes place, leading to cylindrical geometric spreading with a lower range-dependent decay of $10\log R$ dB. Spherical and cylindrical spreading factors provide rules of thumb for quick assessment of the expected levels from a given source. However, more realistic scenarios must consider other factors related to losses at the seabed and sea surface, source frequency spectrum, and environment.

In general, sound levels at short ranges are higher in shallow waters compared to deep waters. This is because 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, while 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): for shallow waters there are significant losses in acoustic energy due to multiple bounces off the seabed, while for deep waters there are comparatively less interactions of the acoustic wave with the seabed. These general trends must be applied with caution, due to the high complexity of the ocean waveguide.

In addition to the environmental parameters (bathymetry, sound speed profile, and seabed geoacoustics), the frequency content of the sound 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., low frequencies are less 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 distance can exceed 10 dB, as computed according to the formulae of François and Garrison (1982a, 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 lost due to scattering is also frequency-dependent, with most noticeable effect when the scatterer is of the same size or larger than the sound wavelength. Therefore, low frequencies are less affected by scattering compared to sounds at high frequencies.

Despite low frequencies being less affected by absorption and scattering, there are other mechanisms that yield the opposite effect (i.e., supporting propagation of sounds at higher frequencies). 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, on the other hand, tend to interact with the seabed and are attenuated as they propagate through the seabed sediment.

4. Source Levels

4.1. Semisubmersible Platform, Drillship, and Support Vessel

The source levels associated with drill rigs and support vessels can be estimated based on the platform's number of propellers DP thrusters, their diameter, revolution rate, and number of blades. The source spectrum can be estimated based on the generic spectrum suggested by Brown (1977).

For this project, we considered the semisubmersible platforms West Hercules and West Aquarius (Seadrill). Table 5 provides their parameters. At the time of this preliminary study, the nominal propeller speed and the number of blades were unavailable for the Seadrill vessels. The acoustic spectrum of a semisubmersible platform of similar characteristics–SeaDrill's West Sirius–has been previously modelled (Zykov 2016) and can provide a reference of the expected source levels. Based on the similarity in thruster power, propeller diameter, and number of thrusters, it is expected that the West Hercules/West Aquarius will exhibit similar source levels as those from the West Sirius.

If a drillship is required, the Stena Carron is a representative vessel, which has an identical DP system to the Deep Ocean Clarion drillship that was also included in Zykov (2016).

At the time of this preliminary study, the type of support vessel that may be used in the Project was unknown. The estimates of acoustic source levels and sound spectrum for the support vessel were based on the Damen platform supply vessel 3300CD (Zykov 2016). This vessel design has been in service for 5–7 years, including on the Scotian Basin Exploration Drilling Project. It has a similar power plant and thruster configuration to other platform supply vessels. The vessel's specifications are presented in Table 5.

Table 5. Propulsion system specification of semisubmersible drilling units, drillships, and a supply vessel. The specification for units considered in previous studies of similar operations (Zykov 2016) are shown in blue.

Sound source		Propeller diameter (m)	Nominal propeller speed (rpm)	Max. power (kW)	Number of thrusters	Thruster model	Number of blades	Acoustic source depth* (m)
Semisubmersible unit	West Hercules/ West Aquarius	3.5	NA	3500	8	Rolls Royce, specific model N/A	N/A	21.25
	West Sirius	3.5	177	3800	8	UUC355	4	18
Drillship unit	Deep Ocean Clarion (equivalent to Stena Carron)	4.1	157	5500	6	UUC455	4	9.95
Damen platform supply vessel 3300CD	Main thrusters	2.3	250	2000	2	N/A (azimuthal)	4	5
	Bow thrusters	1.7	290	750	2	N/A (tunnel)	4	5

* Draft-1/2 propeller diameter
N/A means the data were "Not Available" at the time of this preliminary study.

Sound spectra and broadband source levels for the Clarion, West Sirius, and Damen units are expected to be representative of the levels for the Eastern Newfoundland Exploration Drilling Project. Figure 10 provides the estimated source spectra of individual thrusters of models UUC335 (West Sirius), UUC455 (Clarion), and the bow/aft thrusters for the Damen. Source levels for acoustic modelling at far ranges (i.e., where multiple thrusters can be approximated as an equivalent single monopole) were obtained by including the total number of thrusters per vessel (Zykov 2016), resulting in the following broadband levels:

- Deep Ocean Clarion drillship: 196.7 dB re 1 µPa @ 1 m,
- West Sirius semi-submersible platform: 196.7 dB re 1 µPa @ 1 m,
- Damen support vessel: 188.6 dB re 1 µPa @ 1 m.

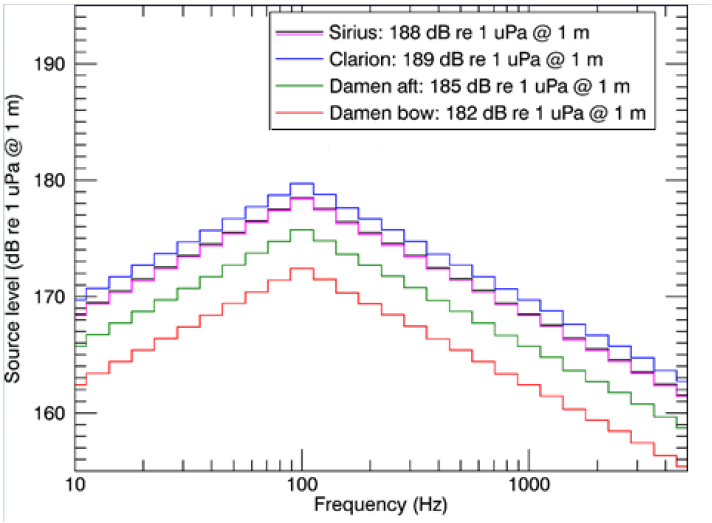


Figure 11. Estimated sound spectra from cavitating propellers of individual thrusters (Zykov 2016). Broadband SPL for each thruster type are provided in the legend.

4.2. VSP Source Array

The activities planned for this operation include Vertical Seismic Profiling (VSP) surveys, which typically use arrays with 3–6 sound source elements with volumes between 150–250 in^3. As a conservative estimate, a 6-element array with 250 in^3 airguns (1500 in^3 total firing volume), such as the Schlumberger's Hypercluster Air Gun Array, was assumed. This array consists of two triangular 3-element airgun clusters, separated 1.7 m, with a central tow depth of 5 m (Figure 11, Table 6).

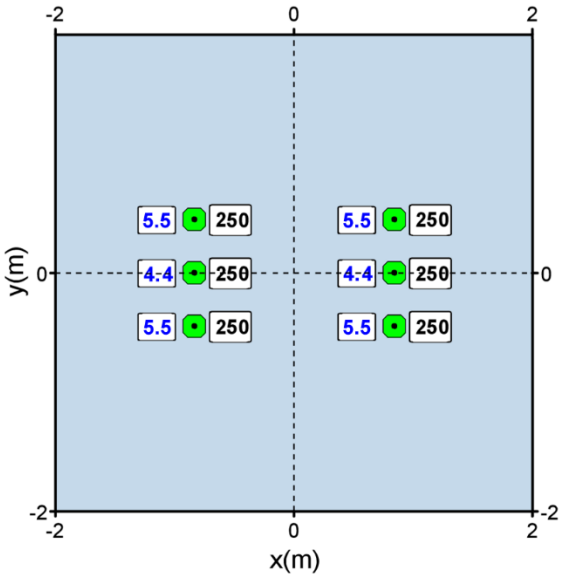


Figure 12. Layout of the modelled airgun array (1500 in^3 total firing volume, 5 m depth), composed of 6 airguns. Labels with black numbers indicate airgun firing volume in cubic inches. The labels with blue numbers indicate the depth of the gun relative to the sea surface.

Table 6. Relative airgun positions within the 1500 in³ airgun array.

Gun	*x* (m)	*y* (m)	*z* (m)	Volume (in^3)
1	0	-0.85	4.4	250
2	-0.445	-0.85	5.5	250
3	0.445	-0.85	5.5	250
4	0	0.85	4.4	250
5	-0.445	0.85	5.5	250
6	0.445	0.85	5.5	250

The source levels and directivity of the airgun array were predicted using JASCO's Airgun Array Source Model (AASM, Appendix A), which accounts for:

- Array layout.
- Volume, tow depth, and firing pressure of each airgun.
- Interactions between different airguns in the array.

The horizontal overpressure signatures and corresponding power spectrum levels for the 1500 in^3 airgun array, at depth of 5 m (to the vertical centre of the gun clusters), are shown in Figure 12 and Table 7 for the broadside (perpendicular to the tow direction) and endfire (parallel to the tow direction) directions. The signatures consist of a strong primary peak related to the initial firing of the airguns, followed by a series of pulses associated with bubble oscillations. Most energy is produced at frequencies below 400 Hz (Figure 12b). The spectrum contains peaks and nulls resulting from interference among airguns in the array, where the frequencies at which they occur depend on the volumes of the airguns and their locations within the array. The horizontal 1/3-octave-band directivities are shown in Figure 13.

For this array, energy is expected to be concentrated in the frequency band 10 to 315 Hz, with broadband SEL of 222.6 dB re 1 µPa^2 @ 1 m (broadside) and 222.4 dB re 1 µPa^2 @ 1 m (endfire).

For comparison purposes, the VSP array used in the Scotian Basin Exploration Drilling Project (Zykov 2016) was the Schlumberger Dual Magnum 2400 in^3 airgun source array at depth 4.5 m. This airgun array consists of four triangular clusters with in-line separations of 2 m; the two external clusters are assemblies of three 250 in³ elements and the two internal clusters are assemblies of three 150 in³ elements. AASM modelling of this 2400 in³ array yielded broadband SEL of 224.7 dB re 1 µPa^2 @ 1 m (broadside) and 224.1 dB re 1 µPa^2 @ 1 m (endfire), with most of its energy in the frequency band 10 to 200 Hz.

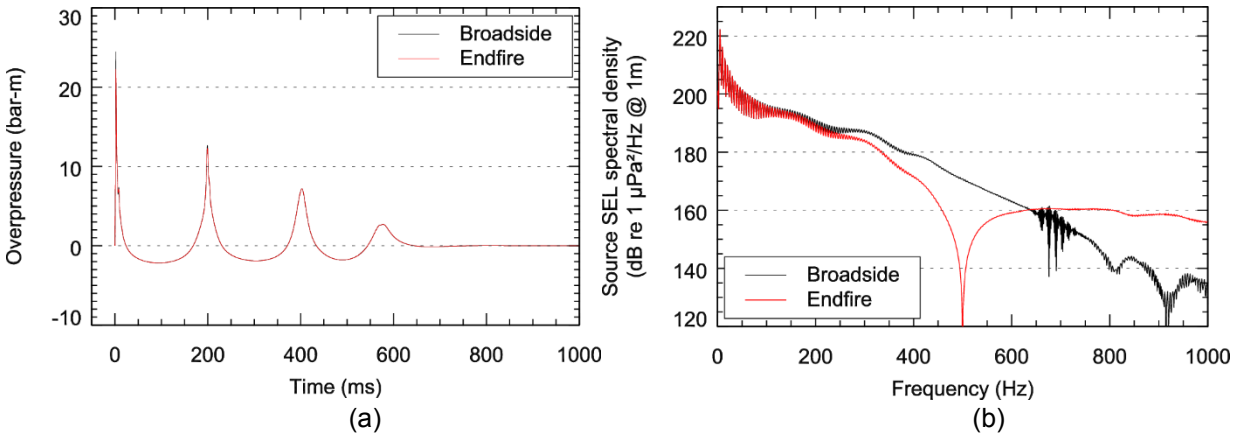


Figure 13. Predicted a) overpressure signature and b) power spectrum in the broadside and endfire (horizontal) directions for the 1500 in^3 array. Surface ghosts (effects of the pulse reflection at the water surface) are not included in these signatures as they are accounted for by the MONM propagation model.

Table 7. Horizontal source level specifications (10–2000 Hz) for the 1500 in^3 seismic airgun array at 5 m depth, computed with AASM in the broadside and endfire directions. Surface ghost effects are not included as they are accounted for by the MONM propagation model.

Direction	Zero-to-peak SPL (dB re 1 µPa @ 1 m)	SEL (dB re 1 µPa^2 @ 1 m)		
		0.01–2 kHz	0.01–1 kHz	1–2 kHz
Broadside	247.8	222.6	222.6	169.5
Endfire	247.0	222.4	222.4	179.2

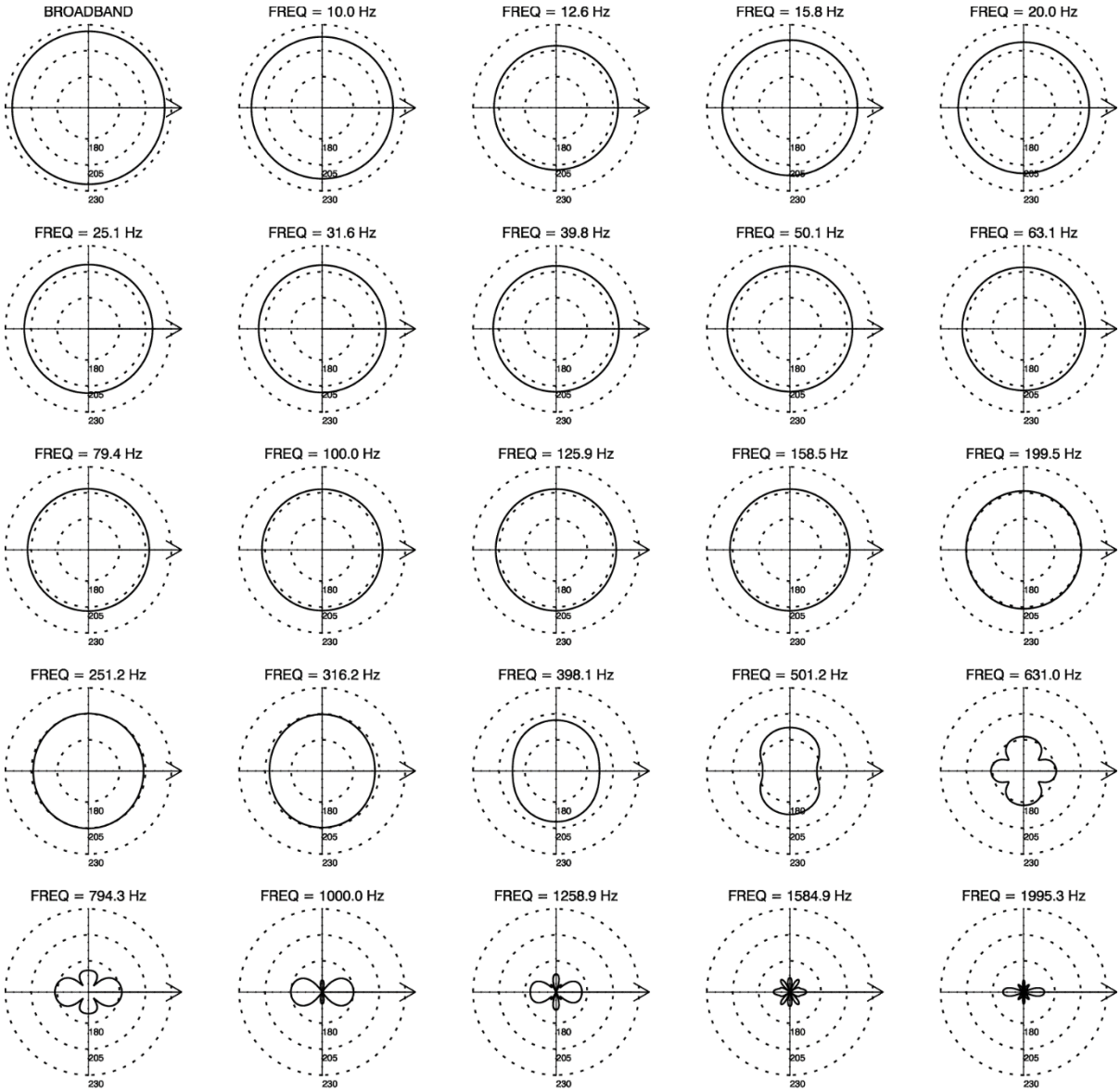


Figure 14. Horizontal directivity of the 1500 in^3 array. Source levels (dB re 1 µPa^2·s) in 1/3-octave-bands. The 1/3-octave-band centre frequencies are indicated above each plot.

5. Conclusion

The year-long data set collected in 2015–2016 provides new information on the ambient soundscape in the Eastern Newfoundland Exploration Drilling Project Area. In general, the ambient sound levels are higher in winter due to fin whales and the effects of higher winds and sea states. Within ranges on the order of 10–40 km from oil and gas platforms, the sounds from the human activities are dominant sound sources for the band of 45–2250 Hz. The effects extend to longer ranges in shallow waters. When present, seismic sources increase the mean monthly sound pressure level by 20 dB or more over large areas.

Accurate assessment of the joint impact of parameters, such as sound speed profile, bathymetry, geoacoustics, and source spectra, can only be achieved by rigourous acoustic propagation modelling. However, the following statements are likely to hold:

- Due to similarities in source levels, seabed geoacoustics, and sound speed profiles, the modelling work previously done at the Scotian Basin (2790 m depth) provides a good reference for the expected sound levels at Sites B and C (1500 and 3000 m depth, respectively) of the current Project. Therefore, distances to thresholds for scenarios involving a drillship/semisubmersible platform with or without a supporting vessel at Sites B and C will be similar to those for the Scotian Basin modelling (Site A from Zykov 2016). The 120 dB re 1 µPa SPL threshold is expected to be reached at maximum distances R_{max} >150 km in winter and R_{max} ~51.6 km in summer.
- Based on the rationale in Section 3.1, for Site A (and in general, for operation sites at shallow water) distances to thresholds corresponding to high levels (e.g., SPL thresholds of 180–190 dB re 1 µPa) are expected to be longer than those modelled for the Scotian Basin Exploration Drilling Project. The opposite would be expected for lower sound level thresholds (e.g., SPL of 120 dB re 1 µPa).
- The most conservative winter sound speed profile for this Project exhibits a weaker surface channel compared to the February profile used in the Scotian Basin modelling. Therefore, the surface channel is not expected to be as conductive to sound, and it will likely yield shorter distances to thresholds.
- Differences in the summer and winter profiles are not as substantial as those in the Scotian Basin area; therefore, distances to thresholds are likely to be more similar in summer and winter in the Eastern Newfoundland Exploration Drilling Project Area than they were at the Scotia Basin site
- Distance to thresholds related to the seismic VSP measurements are likely to be smaller than those from Scotian Basin, due to broadband levels that are ~2 dB lower for this Project's proposed array. This is also based on the observation that both arrays exhibit similar frequency content, with most energy at frequencies < 315 Hz.

Glossary

1/3-octave-band
Non-overlapping passbands that are one-third of an octave wide (where an octave is a doubling of frequency). Three adjacent 1/3-octave-bands comprise one octave. One-third-octave-bands become wider with increasing frequency. Also see octave.

90%-energy time window
The time interval over which the cumulative energy rises from 5% to 95% of the total pulse energy. This interval contains 90% of the total pulse energy. Symbol: T_{90}.

90% sound pressure level (90% SPL)
The root-mean-square sound pressure levels calculated over the 90%-energy time window of a pulse. Used only for pulsed sounds.

absorption
The conversion of acoustic energy into heat, which is captured by insulation.

ambient noise
All-encompassing sound at a given place, usually a composite of sound from many sources near and far (ANSI S1.1-1994 R2004), e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

attenuation
The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium.

azimuth
A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also called bearing.

background noise
Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 R2004). Ambient noise detected, measured, or recorded with a signal is part of the background noise.

bandwidth
The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI/ASA S1.13-2005 R2010).

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.

compressional wave
A mechanical vibration wave in which the direction of particle motion is parallel to the direction of propagation. Also called primary wave or P-wave.

continuous sound
A sound whose sound pressure level remains above ambient sound during the observation period (ANSI/ASA S1.13-2005 R2010). A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decibel (dB)
One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power (ANSI S1.1-1994 R2004).

endfire direction
Parallel to the travel direction of a source. See also broadside direction.

far-field
The zone where, to an observer, sound originating from an array of sources (or a spatially-distributed source) appears t o radiate from a single point. The distance to the acoustic far-field increases with frequency.

fast-average sound pressure level
The time-averaged sound pressure levels calculated over the duration of a pulse (e.g., 90%-energy time window), using the leaky time integrator from Plomp and Bouman (1959) and a time constant of 125 ms. Typically used only for pulsed sounds.

frequency
The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: *f*. 1 Hz is equal to 1 cycle per second.

geoacoustic
Relating to the acoustic properties of the seabed.

hertz (Hz)
A unit of frequency defined as one cycle per second.

hydrophone
An underwater sound pressure transducer. A passive electronic device for recording or listening to underwater sound.

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.

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.

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).

phocid
A common term used to describe all members of the family Phocidae. These true/earless seals are more adapted to in-water life than are otariids, which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves. Phocids are one of the three main groups in the superfamily Pinnipedia; the other two groups are otariids and walrus.

pinniped
A common term used to describe all three groups that form the superfamily Pinnipedia: phocids (true seals or earless seals), otariids (eared seals or fur seals and sea lions), and walrus.

point source
A source that radiates sound as if from a single point (ANSI S1.1-1994 R2004).

power spectrum density
The acoustic signal power per unit frequency as measured at a single frequency. Unit: $\mu Pa^2/Hz$, or $\mu Pa^2 \cdot s$.

power spectral density level
The decibel level ($10\log_{10}$) of the power spectrum density, usually presented in 1 Hz bins. Unit: dB re 1 $\mu Pa^2/Hz$.

pressure, acoustic
The deviation from the ambient hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa). Symbol: *p*.

pressure, hydrostatic
The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid. Unit: pascal (Pa).

received level
The sound level measured at a receiver.

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 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:

$$\mathrm{SPL} = 10\log_{10}\left(p^2 / p_0^2\right) = 20\log_{10}\left(p / p_0\right)$$

Unless otherwise stated, SPL refers to the root-mean-square sound pressure level. See also 90% sound pressure level and fast-average sound pressure level. 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 @ 1 m (sound pressure level) or dB re 1 $\mu Pa^2 \cdot s$ (sound exposure level).

spectrum
An acoustic signal represented in terms of its power (or energy) distribution compared with frequency.

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.

transmission loss (TL)
The decibel reduction in sound level between two stated points that results from sound spreading away from an acoustic source subject to the influence of the surrounding environment. Also called propagation loss.

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

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Appendix A. JASCO's Airgun Array Source Model

The source levels and directivity of the airgun array were predicted with JASCO's Airgun Array Source Model (AASM; MacGillivray 2006). AASM includes both a low-frequency and a high-frequency module for predicting different components of the airgun array spectrum. The low frequency module is based on the physics of oscillation and radiation of airgun bubbles, as originally described by Ziolkowski (1970), that solves the set of parallel differential equations that govern bubble oscillations. Physical effects accounted for in the simulation include pressure interactions between airguns, port throttling, bubble damping, and generator-injector (GI) gun behaviour discussed by Dragoset (1984), Laws et al. (1990), and Landro (1992). A global optimization algorithm tunes free parameters in the model to a large library of airgun source signatures. These airgun data are measurements of the signatures of Bolt 600/B guns ranging in volume from 5 to 185 in^3 (Racca and Scrimger 1986).

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

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

These notional signatures are the pressure waveforms of the individual airguns at a standard reference distance of 1 m; they account for the interactions with the other 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 all directions. This far-field array signature is filtered into 1/3-octave-bands to compute the source levels of the array as a function of frequency band and azimuthal angle in the horizontal plane (at the source depth), after which it is considered to be a directional point source in the far field.

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

$$R_{\mathrm{nf}} < \frac{l^2}{4\lambda} \qquad \text{(A-1)}$$

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

The interactions between individual elements of the array create directionality in the overall acoustic emission. Generally, this directionality is prominent mainly at frequencies in the mid-range between tens of hertz to several hundred hertz. At lower frequencies, with acoustic wavelengths much larger than the inter-airgun separation distances, the directionality is small. At higher frequencies, the pattern of lobes is too finely spaced to be resolved and the effective directivity is less.

APPENDIX D

Marine Mammals and Ambient Sound Sources in the Flemish Pass:
Analaysis from 2014 and 2015 Acoustic Recordings
(Maxner et al. 2017)

Marine Mammals and Sound Sources in the Flemish Pass

Analysis from 2014 and 2015 Acoustic Recordings

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The results presented herein are relevant within the specific context described in this report. They could be misinterpreted if not considered in the light of all the information contained in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

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Executive Summary

An acoustic recorder was deployed in the Flemish Pass from June-October 2014 and from May-September 2015. The data were analyzed to characterize the baseline soundscape, the presence of marine mammals, and characterize the soundscape during Statoil's 2014-2016 drilling program.

Seismic surveys increased baseline sound levels by 10-35 dB throughout the summer months. Drilling operations by the semi-submersible drill rig *West Hercules* generated sound levels similar to those previously reported for the *Stena IceMAX* off Nova Scotia.

Five confirmed species of marine mammals, plus an unknown number of dolphin species (up to six), were detected acoustically. Baleen whale detections were sparse and occurred predominantly in the late summer and early fall, showing pronounced seasonal variations as a result of changes in vocal behavior, migratory movements, or both. Blue whales were detected once in early August and once in early October in 2014, and three times in early September 2015. Only one fin whale call was detected at the beginning of the study period in 2014, but detections increased in early fall 2015. The occurrence of northern bottlenose whales was sporadic throughout the study period in each year and were acoustically active during seismic surveys. In both years, sperm whale calls occurred continuously throughout the recording. Delphinids, which include pilot whales as well as several species of dolphins, were the most broadly detected class. Noise associated with anthropogenic activities, namely seismic surveys, vessel traffic and oil and gas activities, at times restricted or prevented our ability to detected some species.

1. Introduction

The Canadian Atlantic seaboard is home to a wealth of marine life and the site of diverse human activities, including fishing, shipping, and oil and gas activities. To varying degrees, these anthropogenic activities all contribute to the soundscape of the surrounding waters. In 2014 and 2015, Statoil Canada Limited employed a JASCO Applied Sciences (JASCO) acoustic recorder owned by AMEC for opportunistic acoustic recordings at Statoil's 2014-2016 drilling areas off the Canadian Atlantic coast in the Flemish Pass. We present an analysis of these recordings, focusing on the biological (marine mammal) and anthropogenic (seismic surveys, and oil and gas production activities.

1.1. Soniferous Marine Life and Acoustic Monitoring

Passive acoustic monitoring of marine life relies on the monitored species to produce detectable sound. Several marine taxa produce sounds, including all marine mammals as well as some crustaceans (e.g., snapping shrimp; see Au and Banks 1998), and fish (e.g. Nordeide and Kjellsby 1999, Hawkins et al. 2002, Amorim 2006, Erbe et al. 2015). Neither crustaceans, fish spawning aggregations, or fish choruses were present in the acoustic data.

The biological focus of this study was on marine mammals. Twenty-five cetacean and six pinniped species may be found in the study area (Table 1). The presence of pygmy sperm whales is known only from strandings (Measures et al. 2004). Blainville's beaked whales have stranded in Nova Scotia (Mead 1989) and were observed live once near the Gully Canyon (DFO 2016). Gervais' and True's beaked whales may occur in the study area based on habitat characteristics, but have not been sighted or recorded. A bowhead whale sighted in the Bay of Fundy in 2012 is believed to have been a vagrant individual (http://rightwhales.neaq.org/2012/08/11-bowhead-whale-in-bay-of-fundy.html), so detections of this species, if any, would be rare.

Marine mammals are the main biological contributors to the underwater soundscape. For instance, fin whale songs can raise noise levels in the 18–25 Hz band by 5–10 dB over extended time periods (Delarue et al. 2016). Marine mammals, cetaceans in particular, rely almost exclusively on sound for navigating, foraging, breeding, and communicating (Clark 1990, Edds-Walton 1997, Tyack and Clark 2000). Although species differ widely in their vocal behaviour, most can be reasonably expected to produce sounds on a regular basis and passive acoustic monitoring is therefore increasingly preferred as a cost-effective and efficient survey method. Seasonal and sex- or age-biased differences in sound production as well as signal frequency, source level, and directionality all influence the applicability and success rate of acoustic monitoring to some extent and should therefore be considered for each species.

The acoustic signals of some species are poorly known or unknown, which prevents or complicates the acoustic assessment of their occurrence. This is the case for hooded seals, pygmy sperm whales, and True's beaked whales. While the vocal repertoire of most odontocetes in the area is fairly well known, similarities in the spectral features of their signals generally preclude resolving species identity for most detection events. Exceptions include the tonal signals of killer whales and pilot whales and the clicks of sperm whales, beaked whales, and harbour porpoise. In most cases, baleen whale signals can be reliably identified by species.

Table 1. Cetacean and pinniped species known to occur (or possibly occurring) in the study area and their Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and Species at Risk Act (SARA) status.

Species name	Scientific name	COSEWIC status	SARA status
Baleen whales			
Minke whale	*Balaenoptera acutorostrata*	Not at risk	Not listed
Sei whale	*Balaenoptera borealis*	Data deficient	Not listed
Blue whale	*Balaenoptera musculus*	Endangered	Endangered

Fin whale	*Balaenoptera physalus*	Special concern	Special concern
Humpback whale	*Megaptera novaeangliae*	Not at risk	Special concern
North Atlantic right whale	*Eubalaena glacialis*	Endangered	Endangered
Bowhead whale	*Balaena mysticetus*	Special concern	Endangered
Toothed whales			
Short-beaked common dolphin	*Delphinus delphis*	Not at risk	Not listed
Striped dolphin	*Stenella coeruleoalba*	Not at risk	Not listed
White-beaked dolphin	*Lagenorhynchus albirostris*	Not at risk	Not listed
White-sided dolphin	*Lagenorhynchus acutus*	Not at risk	Not listed
Bottlenose dolphin	*Tursiops truncatus*	Not at risk	Not listed
Risso's dolphin	*Grampus griseus*	Not at risk	Not listed
Killer whale	*Orcinus orca*	Special concern	Not listed
Beluga whale	*Delphinapterus leucas*	Endangered[1]	Threatened[1]
Long-finned pilot whale	*Globicephala melas*	Not at risk	Not listed
Harbour porpoise	*Phocoena*	Special concern	Threatened
Pygmy sperm whale	*Kogia breviceps*	Not at risk	Not listed
Sperm whale	*Physeter macrocephalus*	Not at risk	Not listed
Cuvier's beaked whale	*Ziphius cavirostris*	Not at risk	Not listed
Sowerby's beaked whale	*Mesoplodon bidens*	Special concern	Special concern
Northern bottlenose whale	*Hyperoodon ampullatus*	Endangered[2]	Endangered[2]
Blainville's beaked whale	*Mesoplodon densirostris*	Not at risk	Not listed
Gervais beaked whale	*Mesoplodon europaeus*	Not assessed	Not listed
True's beaked whale	*Mesoplodon mirus*	Not at risk	Not listed
Pinnipeds			
Grey seal	*Halichoerus grypus*	Not at risk	Not listed
Ringed seal	*Phoca hispida*	Not at risk	Not listed
Hooded seal	*Cystophora cristata*	Not at risk	Not listed
Bearded seal	*Erignathus barbatus*	Not assessed	Not listed
Harp seal	*Phoca groenlandica*	Not at risk	Not listed
Harbour seal	*Phoca vitulina*	Not at risk	Not listed
Atlantic walrus	*Odobenus rosmarus*	Special concern	Not listed

[1] Status of the Gulf of St. Lawrence population
[2] Status of the Scotian shelf population

1.2. Ambient Sound Levels

The ambient, or background, sound levels that create the ocean soundscape are comprised of many natural and anthropogenic sources (Figure 1). 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). In polar regions, 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.

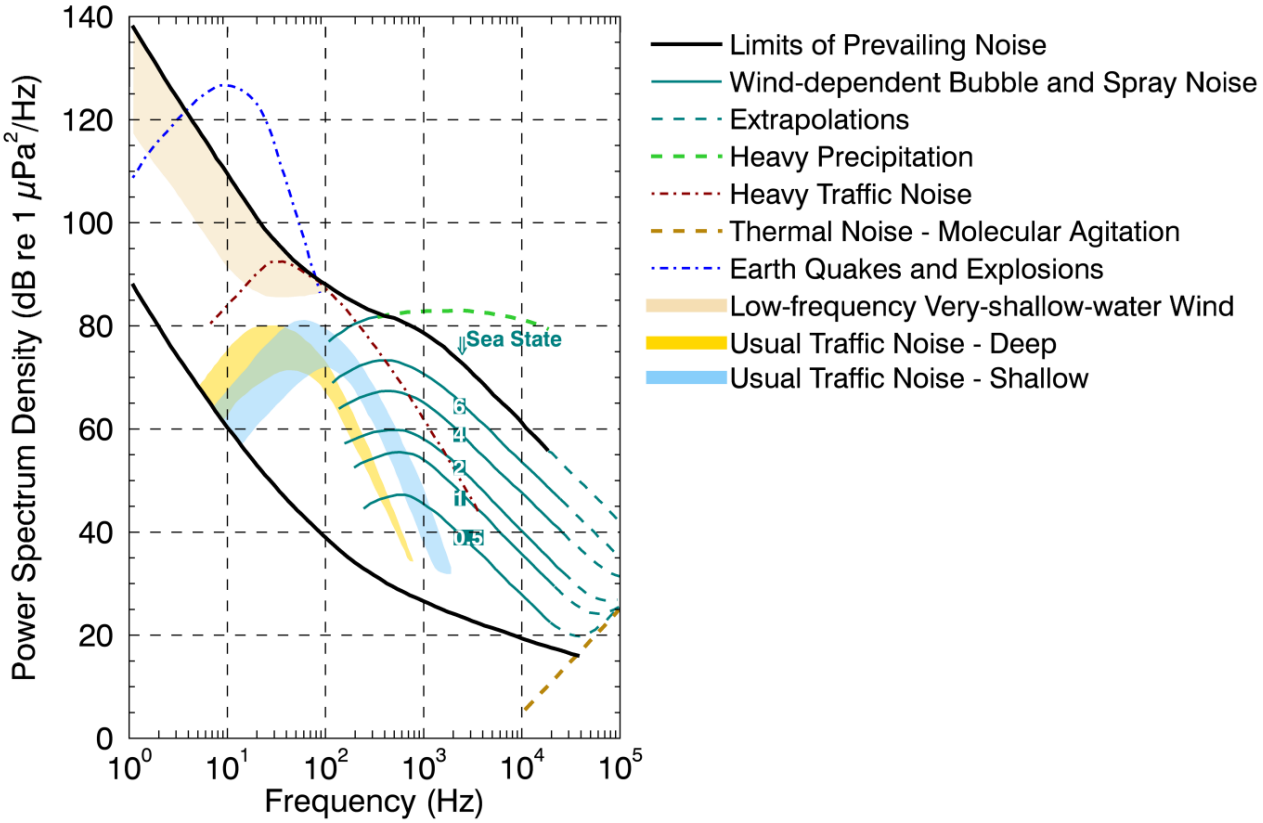


Figure 1. Wenz curves (NRC 2003), describing pressure spectral density levels of marine ambient noise from weather, wind, geologic activity, and commercial shipping, adapted from Wenz (1962).

1.3. Anthropogenic Contributors to the Soundscape

Anthropogenic (human-generated) sound can be a by-product of vessel operations, such as engine noise radiating through vessel hulls and cavitating propulsion systems, or a product of active acoustic data collection with sonar, depth sounding, and seismic surveys. The contribution of anthropogenic sources to the ocean soundscape has increased steadily over the past several decades. The anthropogenic increase is largely driven by greater worldwide amounts of shipping and oil and gas exploration (Hildebrand 2009). Seismic survey sounds have increased significantly following their expansion into deep water, and they can now be detected across ocean basins (Nieukirk et al. 2004). The main anthropogenic contributors to ambient noise in the study area are dynamic positioning vessels and seismic surveys.

1.3.1. Vessel Traffic

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 2).

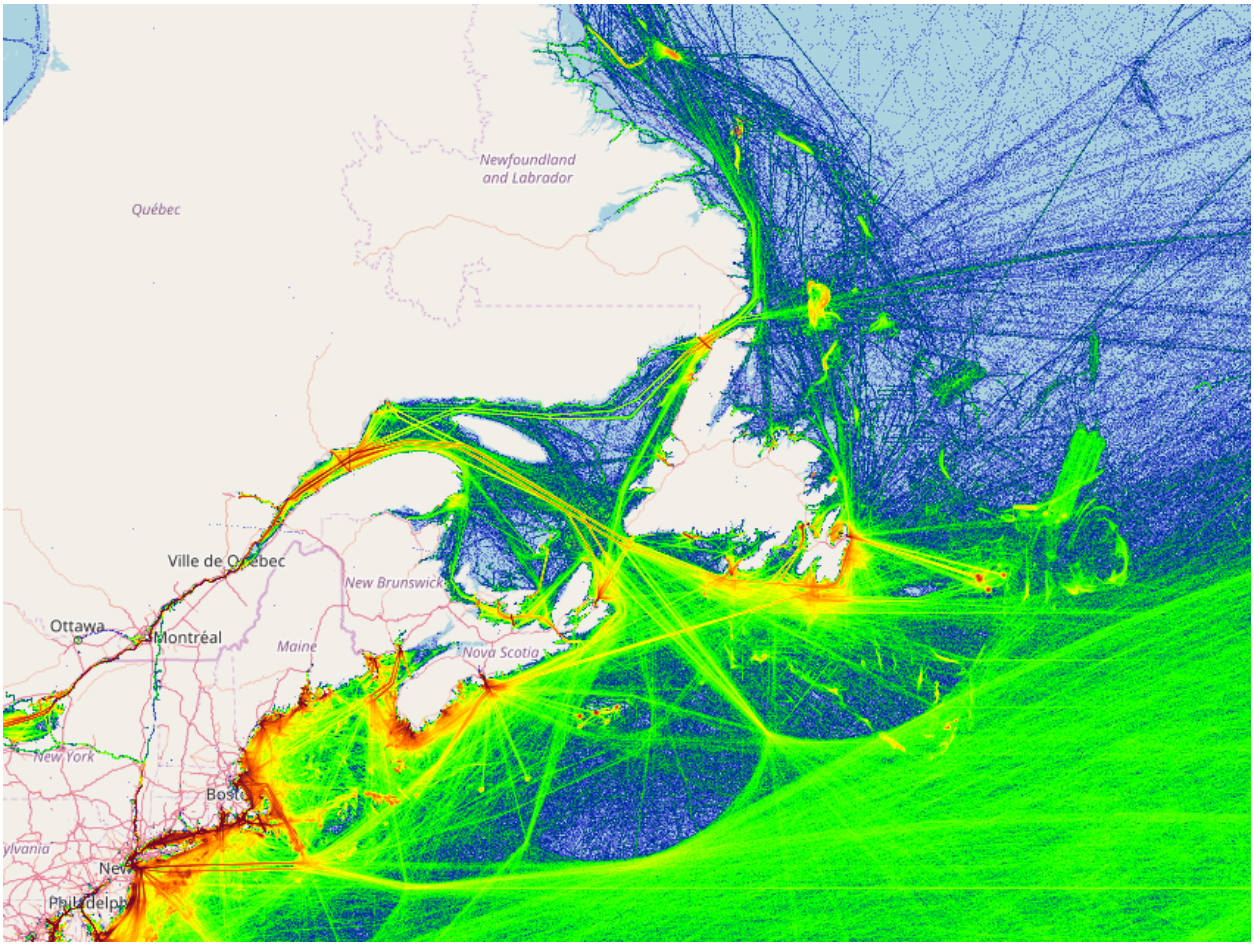


Figure 2. Shipping traffic off the US and Canadian east coast (source: marinetraffic.com; accessed 30 Aug 2017).

1.3.2. Seismic Surveys and Oil and Gas Extraction

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. Nearly 500,000 km were surveyed across areas under the jurisdiction of the Canada Newfoundland Labrador Offshore Petroleum Board (CNLOPB) during the 2015–2016 fiscal year (Table 2). Figure 3 shows the extent of the surveys conducted by MKI, a joint venture between Nalcor, TGP, and PGS in 2015–2016. There were no seismic surveys conducted in 2015–2016 in areas under the jurisdiction of the Canada Nova Scotia Offshore Petroleum Board (CNSOPB).

In addition to the seismic exploration programs the Statoil 2014-2016 drilling program in the Flemish pass contributed to the soundscape from 4 Nov 2014 to 22 May 2016. The Seadrill *West Hercules* semi-submersible drill rig equipped with 8 Rolls-Royce 3,500 kW azimuthing dynamic positioning thrusters was employed for the drilling operations (Figure 4).

Table 2. Geoscientific programs with fieldwork authorized during 2015–2016 fiscal year.(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

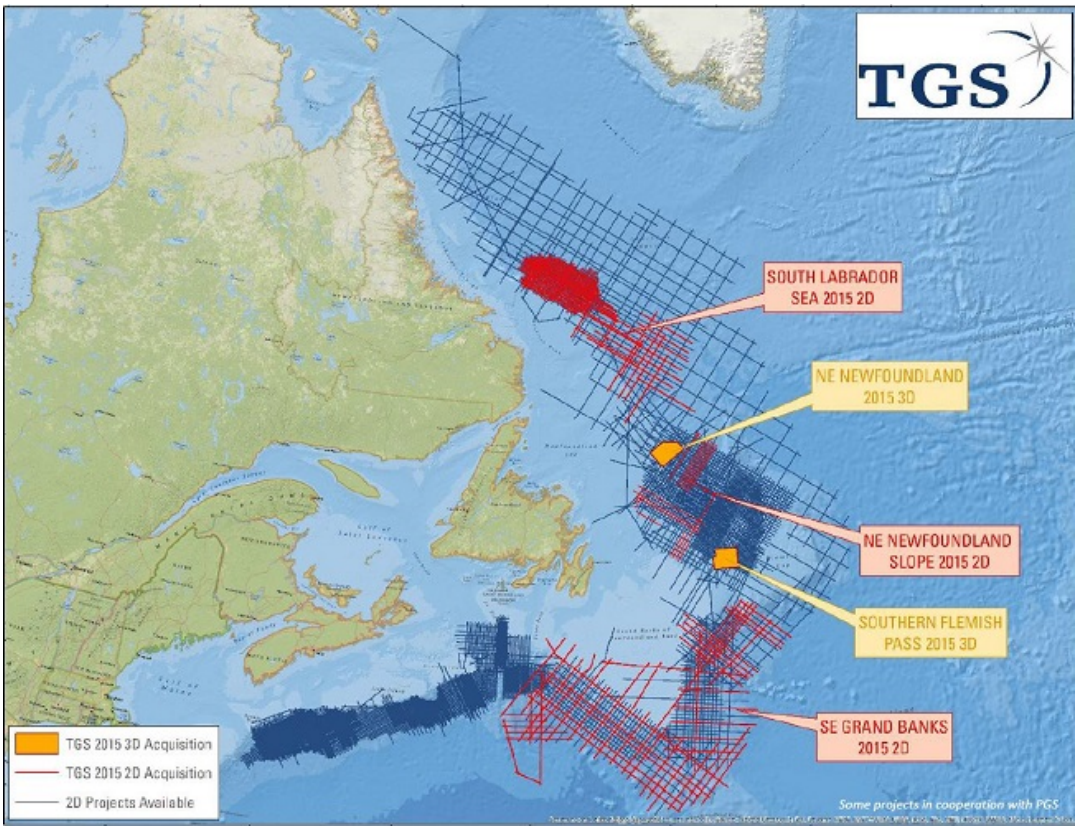


Figure 3. 2015 seismic surveys completed by TGS and PGS and previously available 2-D seismic data in eastern Canadian waters. (Source: Larsen and Ashby 2015; accessed 14 Nov 2016).



Figure 4. Seadrill *West Hercules* semisubmersible drill rig.

2. Methods

2.1. Data Collection

An acoustic recorder (AMAR172) was purchased by AMEC for the Statoil program in 2014 and included in the CM2 current meter mooring. JASCO performed a data download and refurbishment for AMEC prior to the redeployment in 2015.

In August 2015 JASCO deployed an AMAR at Station 19, approximately 230 km north east of the Statoil 2014-2016 drilling area as part of a project sponsored by the Environmental Studies Research Fund (ESRF). These data are included in this report because sounds from the Statiol 2014-2016 drilling program were detected in this data and it serves as a baseline for comparison to the CM2 data.

2.1.1. Mooring Design and Deployment Location

AMEC designed the mooring configuration for a suspended AMAR (Figure 5). The recorded drilling operations was 13.4 km distance to the mooring CM2 (Table 3). The AMAR was deployed twice in the Flemish Pass (CM2 Recorder; Figure 7, Figure 8) from 2 Jun to 9 Oct 2014 and 9 May to 11 Sep 2015 (Table 4). The CM2 deployment recorded the drillilng operations of BdN4 L-76 from 2 May to 11 Sep (Table 3, Figure 8). The AMAR recorded for an average recording duration of four months each year, and was successfully retrieved using an acoustic release.

ESRF Stn 19 mooring (Figure 6, Figure 7) was deployed on 25 August 2015 and retrieved 17 July 2016 in 1280 m of water. The recorder was 209-246 km from the drilling operations until they ceased on 22 May 2016 (Table 3).

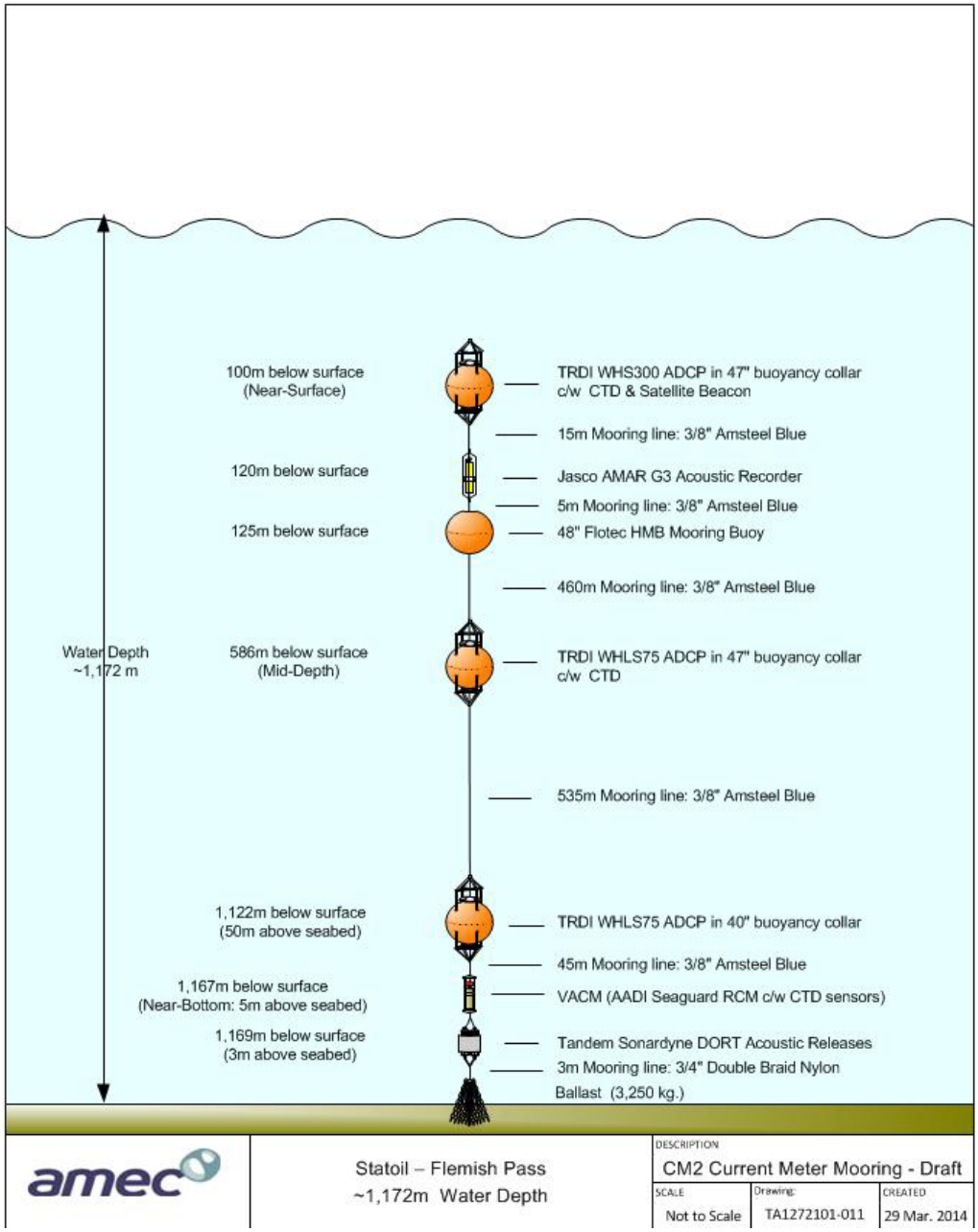


Figure 5. The mooring design used by AMEC.

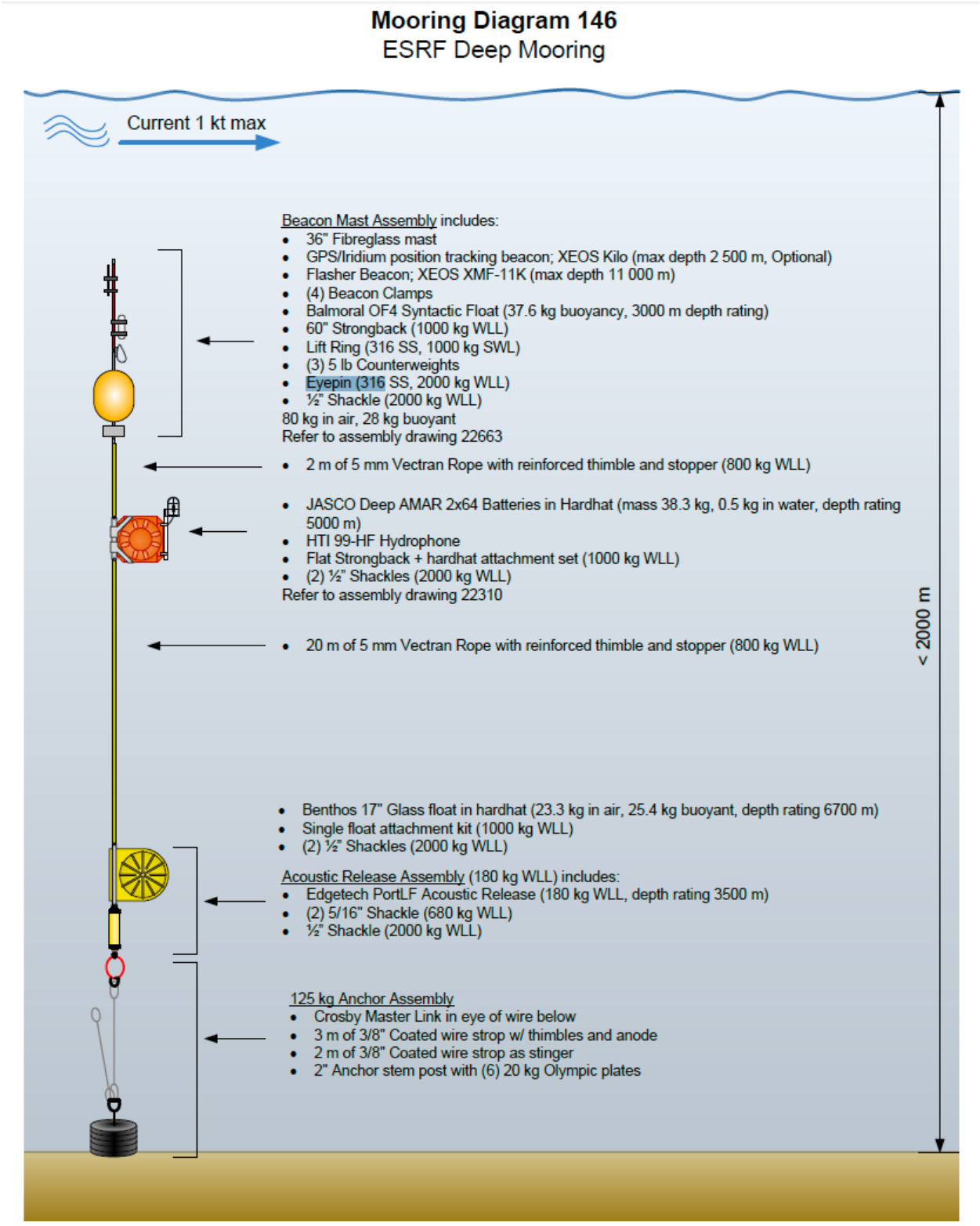


Figure 6. JASCO Mooring 146 employed at ESRF Station 19.

Table 3. The drill rig operation period, location, and distance to the CM2 and Stn19 recorders. Only BdN4 L-76 was recorded at CM2.

Well drilling operation	Rig coordinates (Lat, Long)	Approx. distance to CM2 (km)	Approx. distance to ESRF Stn19 (km)	Operation date
BdN4 L-76	47° 55' 43.9403 N 46° 26' 42.6303 W	13.4	234	2 May to 12 Sep 2015
BdE, B-09	47° 58' 09.8601 N 46° 30' 19.8867 W	Not deployed	230	13–28 Sep 2015 1–31 Dec 2015
Cupids, A-33	49° 02' 08.2606 N 46° 04' 43.9385 W	Not deployed	246	29 Sep - 23 Nov 2015
Fitzroya, A-12	48° 01' 00.1739 N 46° 46' 43.1924 W	Not deployed	209	24–30 Nov 2015
M-62	47° 51' 48.6828 N 46° 25' 19.5067 W	Not deployed	240	31 Mar - 22 May 2016

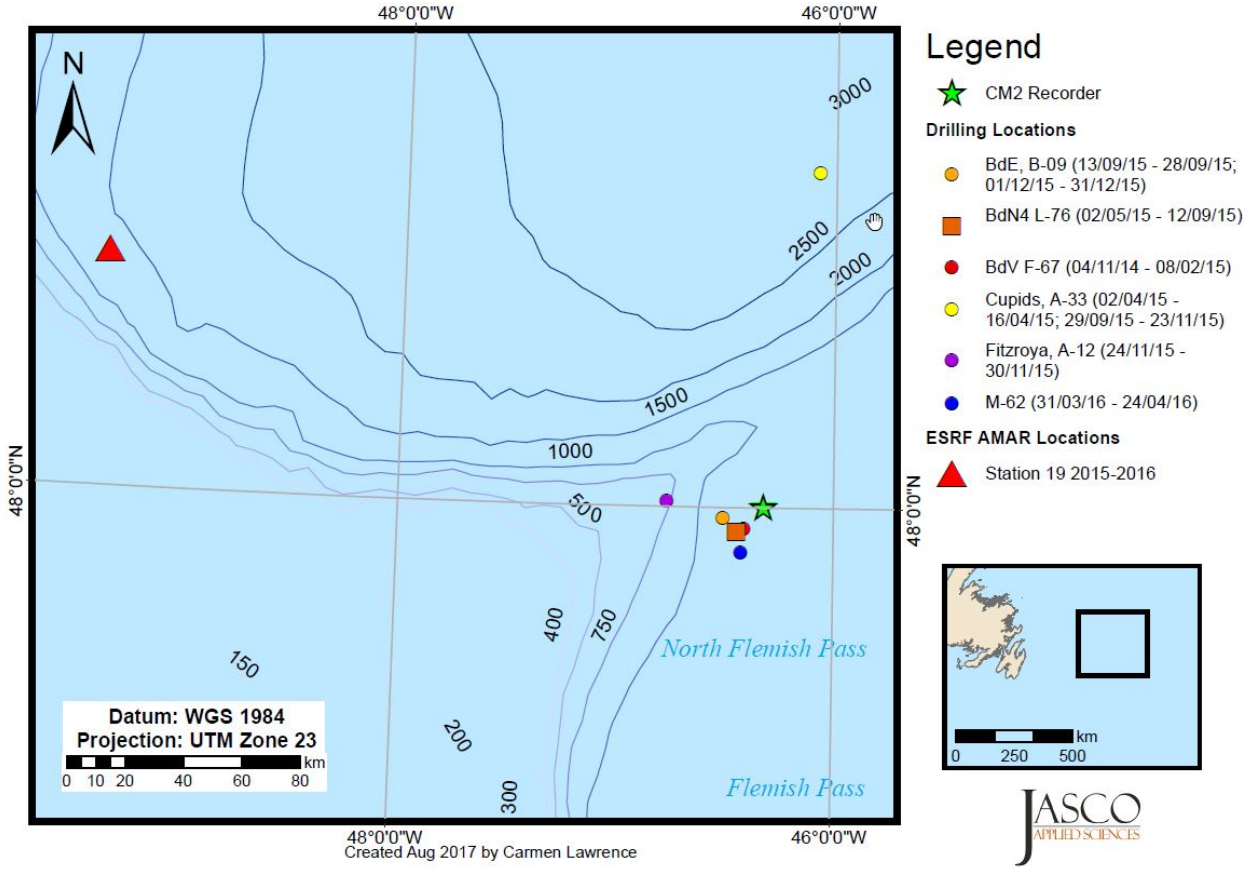


Figure 7. CM2 recorder, ESRF Station 19 recorders, and Statoil 2015-2016 drilling locations off the east cost of Newfoundland.

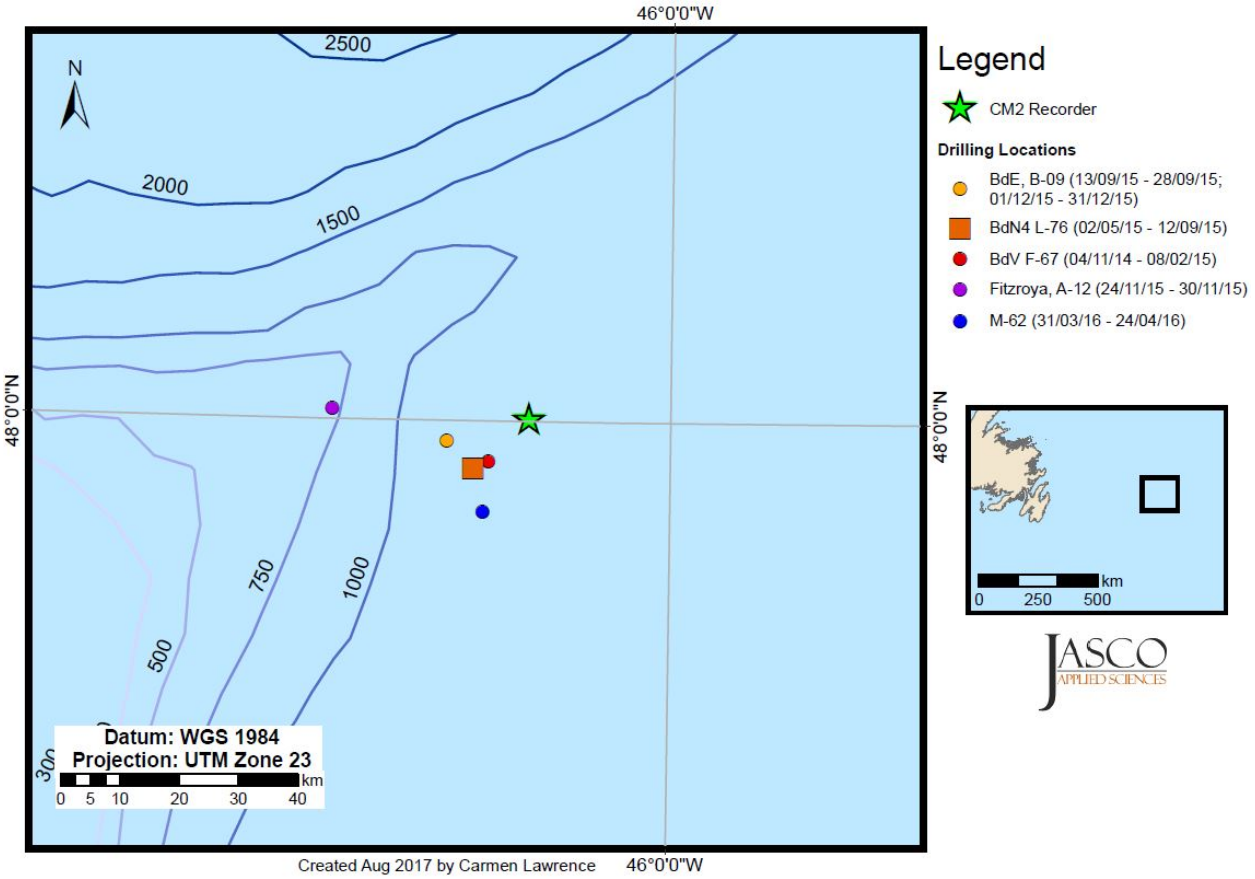


Figure 8. Statoil 2014-2016 drilling sites and CM2 recorder location. The BdN4 L-76 site is highlighted as a square.

Table 4. Operation period, location, and depth of the AMAR deployed in 2014 and 2015 for the Statoil study.

Year	Latitude	Longitude	Depth (m)	Deployment	Retrieval	Duration (days)
2014	44.71155	−63.5874	~1,170	2 Jun 2014	9 Oct 2014	129
2015	49.89104	−47.6597	~1,170	9 May 2015	11 Sep 2015	125

2.1.2. Acoustic Recorders

Underwater sound was recorded with Autonomous Multichannel Acoustic Recorders (AMARs, JASCO). The AMAR on CM2 was fitted with a M8E-35dB omnidirectional hydrophone (GeoSpectrum Technologies Inc.; −164 dB re 1 V/µPa sensitivity). The AMAR hydrophone was 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. The AMAR sampled on a 15 min duty cycle: 680 s at 16 ksps, then 170 s at 128 ksps, and then 50 s of sleep. The 16 ksps recording channel had a 24-bit resolution with no gain resulting in a spectral noise floor of 24 dB re 1 $\mu Pa^2/Hz$ and could resolve a maximum sound pressure level (SPL) of 171 dB re 1 µPa. The 128 ksps data were recorded at 24-bit resolution with no gain resulting in a spectral noise floor of 18 dB re 1 $\mu Pa^2/Hz$ and could resolve a maximum sound pressure level (SPL) of 171 dB re 1 µPa. The spectral noise floor represents the quietest sounds that can be recorded, and is directly comparable to the Wenz ocean noise spectra (Figure 1). Acoustic data were stored on internal solid-state flash memory.

The AMAR deployed at ESRF Station 19 an HTI-99 hydrophone (Hi-tech Industries; -165 dB re 1 V/µPa sensitivity). The AMAR hydrophone was 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. The AMAR sampled on a 20 min duty cycle: 680 s at 8 ksps, then 65 s at 250 ksps, and then 455 s of sleep. The 8 ksps recording channel had a 24-bit resolution with 6 dB gain resulting in a spectral noise floor of 32 dB re 1 μPa^2/Hz and could resolve a maximum sound pressure level (SPL) of 165 dB re 1 µPa. The 250 ksps data were recorded at 16-bit resolution with no gain resulting in a spectral noise floor of 32 dB re 1 μPa^2/Hz and could resolve a maximum sound pressure level (SPL) of 171 dB re 1 µPa

2.1.3. Recorder Calibrations

A 42AC pistonphone calibrator (G.R.A.S. Sound & Vibration A/S; Figure 9) 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.

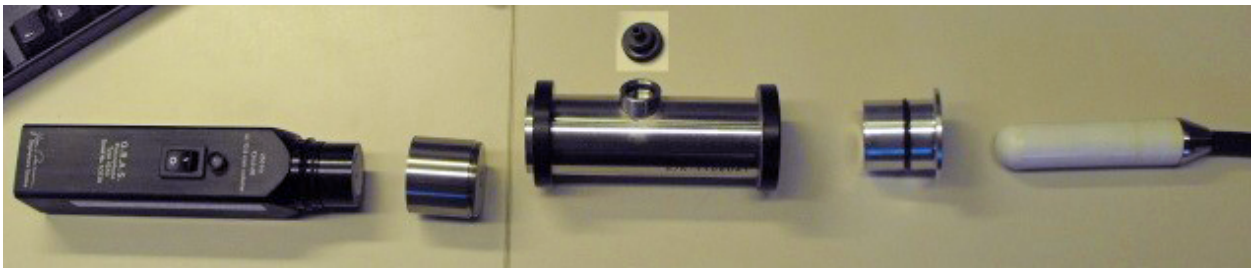


Figure 9. Split view of a G.R.A.S. 42AC pistonphone calibrator with an M15B hydrophone.

2.2. Automated Data Analysis

We use a specialized computing platform for processing acoustic data hundreds of times faster than real-time. The system performs automated analysis of total ocean noise and sounds from vessels, seismic surveys, and (possible) marine mammal calls. Figure 10 outlines the stages of the automated analysis.

We also classify the dominant sound source in each minute of data as "Vessel", "Seismic", or "Ambient". To minimize the influence of anthropogenic sources on ambient sound level estimates, we define ambient levels from individual minutes of data that did not have an anthropogenic detection within one hour on either side of that minute. This results in more accurate estimates of daily sound exposure levels from each source class, cumulative distribution functions of sound pressure levels, and exceedance spectra.

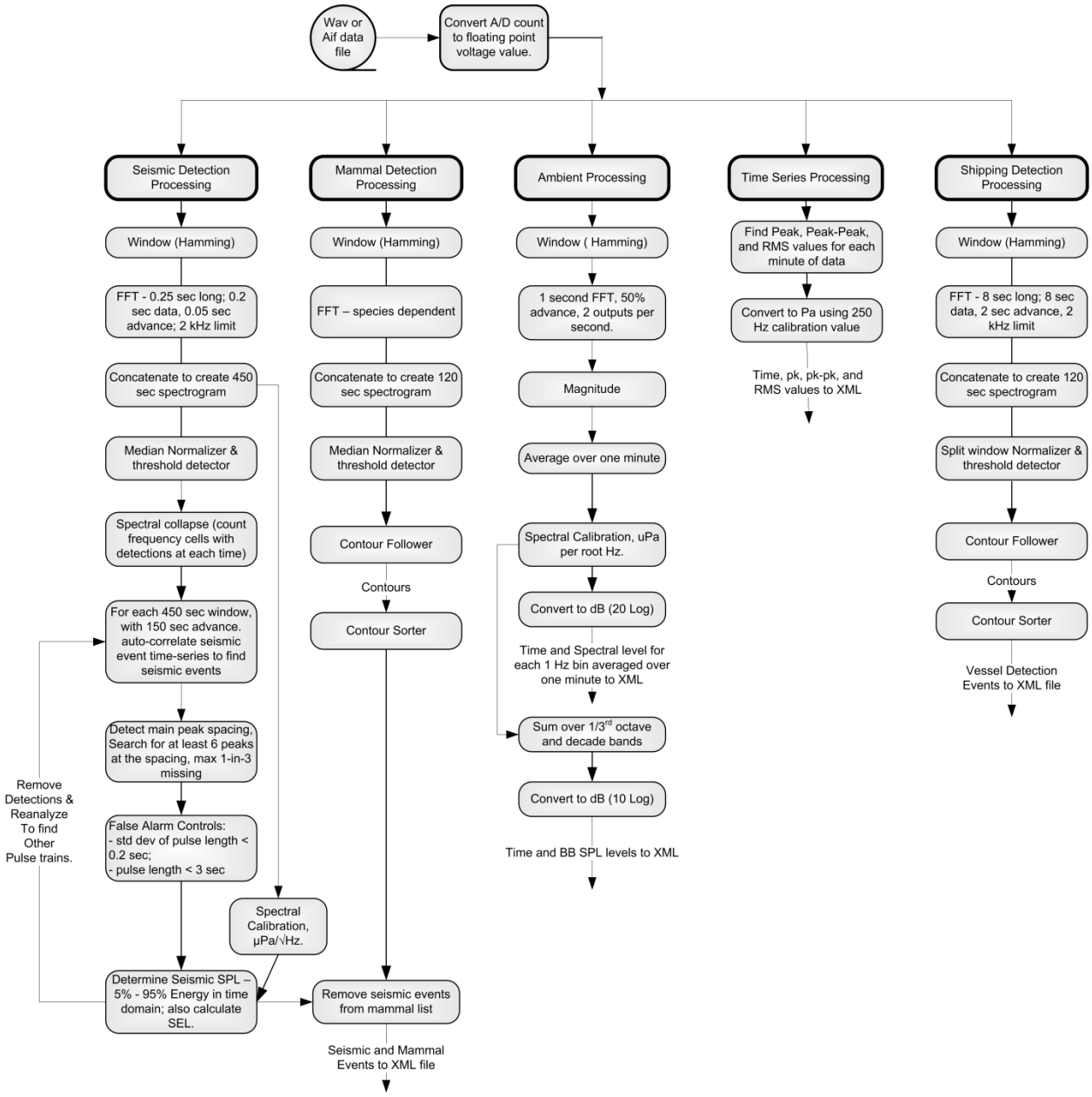


Figure 10. Major stages of the automated acoustic analysis software suite.

2.2.1. Total Ocean Noise and Time Series Analysis

Ambient noise levels at the recording station were examined to document the local baseline underwater sound conditions. In Section 3, 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 min 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 min averages. Equivalently, 95% of the 1 min 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 min 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 min SEL. For shipping, the 1 min SEL values are the linear 1 min squared SPL values multiplied by the duration, 60 s. For seismic survey pulses, the 1 min SEL is the linear sum of the per-pulse SEL.

The 50th percentile (median of 1 min spectral averages) can be compared to the well-known Wenz ambient noise curves (Figure 1), 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 2.2.1.2).

2.2.1.1. *Sound Levels*

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 µPa. Because the perceived loudness of sound, especially impulsive noise 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 noise and its effects on marine life. We provide specific definitions of relevant metrics used in the accompanying report. Where possible we follow the ANSI and ISO standard definitions and symbols for sound metrics, but these standards are not always consistent.

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

$$PK = 10\log_{10}\left[\frac{\max\left(\left|p^2(t)\right|\right)}{p_0^2}\right] . \qquad (1)$$

$L_{p,pk}$ is often included as criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of a noise 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) containing the acoustic event of interest. It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$\mathrm{SPL} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \Big/ p_0^2\right) . \qquad (2)$$

The SPL represents a nominal effective continuous sound over the duration of an acoustic event, such as the emission of one acoustic pulse, a marine mammal vocalization, the passage of a vessel, or over a fixed duration. Because the window length, T, is the divisor, events with similar SEL, but more spread out in time have a lower SPL.

The SEL (dB re 1 µPa²·s) is a measure related to the acoustic energy contained in one or more acoustic events (*N*). The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (*T*):

$$\mathrm{SEL} = 10\log_{10}\left(\int_T p^2(t)dt \Big/ T_0 p_0^2\right) \tag{3}$$

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

SEL can be calculated over periods with multiple events or over a fixed duration. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the *N* individual events:

$$L_{\mathrm{E,N}} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}}\right) . \tag{4}$$

To compute the SPL(T_{90}) and SEL of acoustic events in the presence of high levels of background noise, equations 3 and 4 are modified to subtract the background noise contribution:

$$L_{\mathrm{p90}} = 10\log_{10}\left(\frac{1}{T_{90}}\int_{T_{90}} (p^2(t) - \overline{n^2})dt \Big/ p_0^2\right) \tag{5}$$

$$L_{\mathrm{E}} = 10\log_{10}\left(\int_T (p^2(t) - \overline{n^2})dt \Big/ T_0 p_0^2\right) , \tag{6}$$

where $\overline{n^2}$ is the mean square pressure of the background noise, generally computed by averaging the squared pressure of a temporally-proximal segment of the acoustic recording during which acoustic events are absent (e.g., between pulses).

Because the SPL(T_{90}) and SEL are both computed from the integral of square pressure, these metrics are related by the following expression, which depends only on the duration of the time window *T*:

$$L_{\mathrm{p}} = L_{\mathrm{E}} - 10\log_{10}(T) \tag{7}$$

$$L_{\mathrm{p90}} = L_{\mathrm{E}} - 10\log_{10}(T_{90}) - 0.458 , \tag{8}$$

where the 0.458 dB factor accounts for the 10% of SEL missing from the SPL(T_{90}) integration time window.

Energy equivalent SPL (dB re 1 µPa) denotes the SPL of a stationary (constant amplitude) sound that generates the same SEL as the signal being examined, $p(t)$, over the same period of time, *T*:

$$L_{\mathrm{eq}} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \Big/ p_0^2\right) . \tag{9}$$

The equations for SPL and the energy-equivalent SPL are numerically identical; conceptually, the difference between the two metrics is that the former is typically computed over short periods (typically of one second or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the latter reflects the average SPL of an acoustic signal over times typically of one minute to several hours.

2.2.1.2. *One-Third-Octave-Band Analysis*

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. These values directly compare to the Wenz curves, which represent typical deep ocean sound levels (Figure 1) (Wenz 1962). This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into 1/3-octave-bands, which are one-third of an octave wide; each octave represents a doubling in sound frequency. A very similar measure is to logarithmically divide each frequency decade into 10 passbands, which are commonly misnamed the 1/3-octave-bands rather than deci-decades; we use this naming in the report. The centre frequency of the ith 1/3-octave-band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{i/10}, \tag{10}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith 1/3-octave-band are defined as:

$$f_{lo} = 10^{-1/20} f_c(i) \quad \text{and} \quad f_{hi} = 10^{1/20} f_c(i). \tag{11}$$

The 1/3-octave-bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure 11).

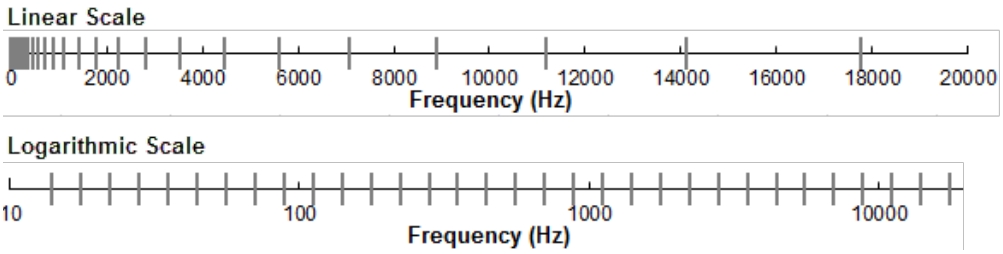


Figure 11. One-third-octave-bands shown on a linear frequency scale and on a logarithmic scale.

The sound pressure level in the ith 1/3-octave-band $(L_b^{(i)})$ is computed from the power spectrum $S(f)$ between f_{lo} and f_{hi}:

$$L_b^{(i)} = 10 \log_{10} \left(\int_{f_{lo}}^{f_{hi}} S(f) df \right). \tag{12}$$

Summing the sound pressure level of all the 1/3-octave-bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{L_b^{(i)}/10}. \tag{13}$$

Figure 12 shows an example of how the 1/3-octave-band sound pressure levels compare to the power spectrum of an ambient noise signal. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum, especially at higher frequencies. 1/3-octave-band analysis is applied to both continuous and impulsive noise sources. For impulsive sources, the 1/3-octave-band SEL is typically reported.

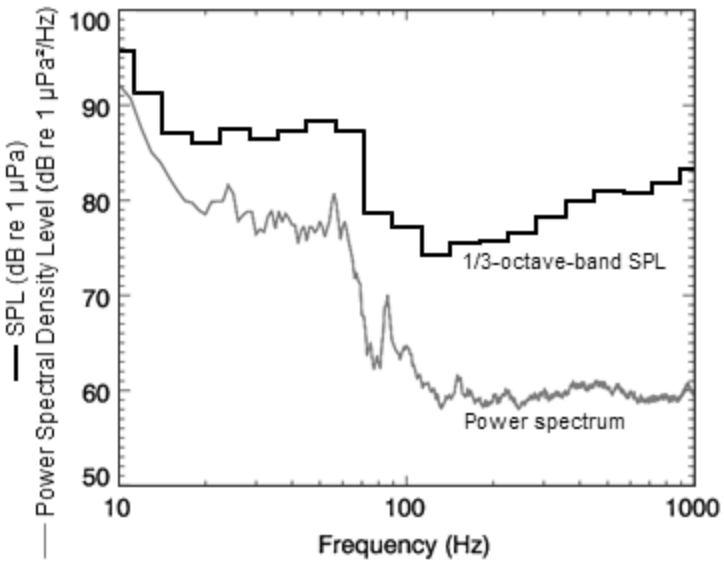


Figure 12. A power spectrum and the corresponding 1/3-octave-band sound pressure levels of example ambient noise shown on a logarithmic frequency scale. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum.

2.2.2. Vessel Noise Detection

Vessels are detected in two steps:

1. Detect constant, narrowband tones produced by a vessel's propulsion system and other rotating machinery (Arveson and Vendittis 2000). 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. Assess the rms SPL for each minute in the 100–315 Hz frequency band. Figure 13 shows an example with a bandwidth of 40–315 Hz, which commonly contains most sound energy produced by mid-sized to large vessels; however, for this study, most of the energy below 100 Hz is likely due to seismic noise. Background estimates of the shipping band SPL and broadband SPL are then compared to their median values over the 12 h 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 3 shipping tonals (0.125 Hz bandwidth) are present.
- The SPL in the shipping band is within 12 dB of the broadband SPL (Figure 13).

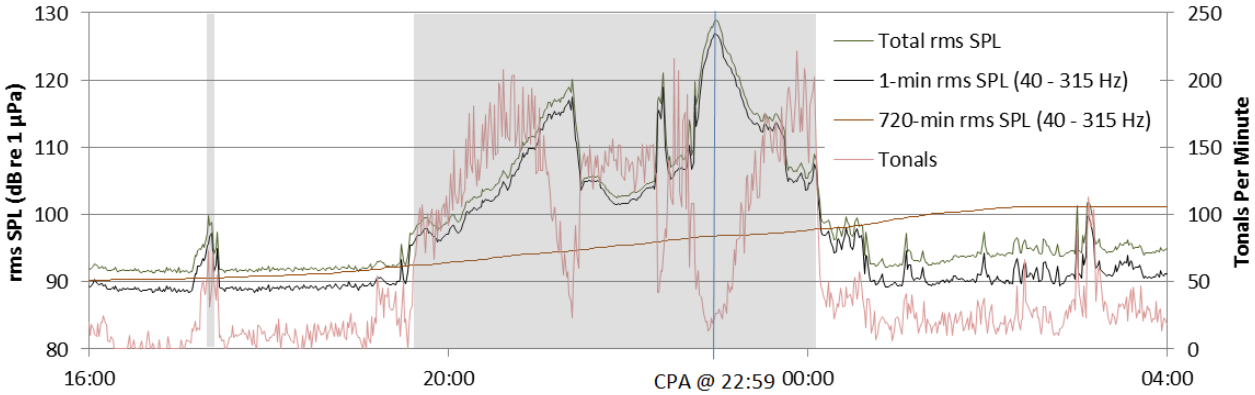


Figure 13. Example of broadband and 40–315 Hz band SPL, as well as the number of tonals detected per minute as a ship approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the ship's closest point of approach (CPA) at 22:59 because of masking by broadband cavitation noise and due to Doppler shift, that affects the tone frequencies.

2.2.3. 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.

2.2.4. Marine Mammal Detection

We apply automated analysis techniques to detect sounds from odontocetes, mysticetes, and pinnipeds in the acoustic data. Targeted signals for odontocetes are echolocation clicks and tonal whistles. Echolocation clicks are high-frequency with impulses ranging from 5 to over 150 kHz (Au et al. 1999, Mohl et al. 2000), while the whistles are commonly between 1 and 20 kHz (Steiner 1981b, Rendell et al. 1999). Baleen whale and pinniped calls are lower in frequency and range predominantly between 15 Hz and 4 kHz (Berchok et al. 2006, Risch et al. 2007). The detectors are applied to the 128 ksps data (audio bandwidth up to 65 kHz for ~2 min of every 15 min).

2.2.4.1. *Click Detection*

We apply an automated click detector/classifier to the high-frequency data to detect clicks from sperm whales, beaked whales, porpoise, and delphinids (Figure 14). This detector/classifier is based on the zero-crossings in the acoustic time series. Zero-crossings are the rapid oscillations of a click's pressure waveform above and below the signal's normal level (e.g., Figure 14). Clicks are detected by the following steps (Figure 14):

1. The raw data is high-pass filtered to remove all energy below 8 kHz. This removes most energy from other sources such as shrimp, vessels, wind, and cetacean tonal calls, while allowing the energy from all marine mammal click types to pass.
2. The filtered samples are summed to create a 0.5 ms rms time series. Most marine mammal clicks have a 0.1–1 ms duration.
3. Possible click events are identified with a Teager-Kaiser energy detector.
4. The maximum peak signal within 1 ms of the detected peak is found in the high-pass filtered data.
5. The high-pass filtered data is searched backwards and forwards to find the time span where the local data maxima are within 12 dB of the maximum peak. The algorithm allows for two zero-crossings to occur where the local peak is not within 12 dB of the maximum before stopping the search. This defines the time window of the detected click.
6. The classification parameters are extracted. The number of zero crossings within the click, the median time separation between zero crossings, and the slope of the change in time separation between zero crossings are computed. The slope parameter helps to identify beaked whale clicks, as beaked whale clicks increase in frequency (upsweep).
7. The Mahalanobis distance between the extracted classification parameters and the templates of known click types is computed. The covariance matrices for the known click types, computed from thousands of manually identified clicks for each species, are stored in an external file. Each click is classified as a type with the minimum Mahalanobis distance, unless none of them are less than the specified distance threshold.

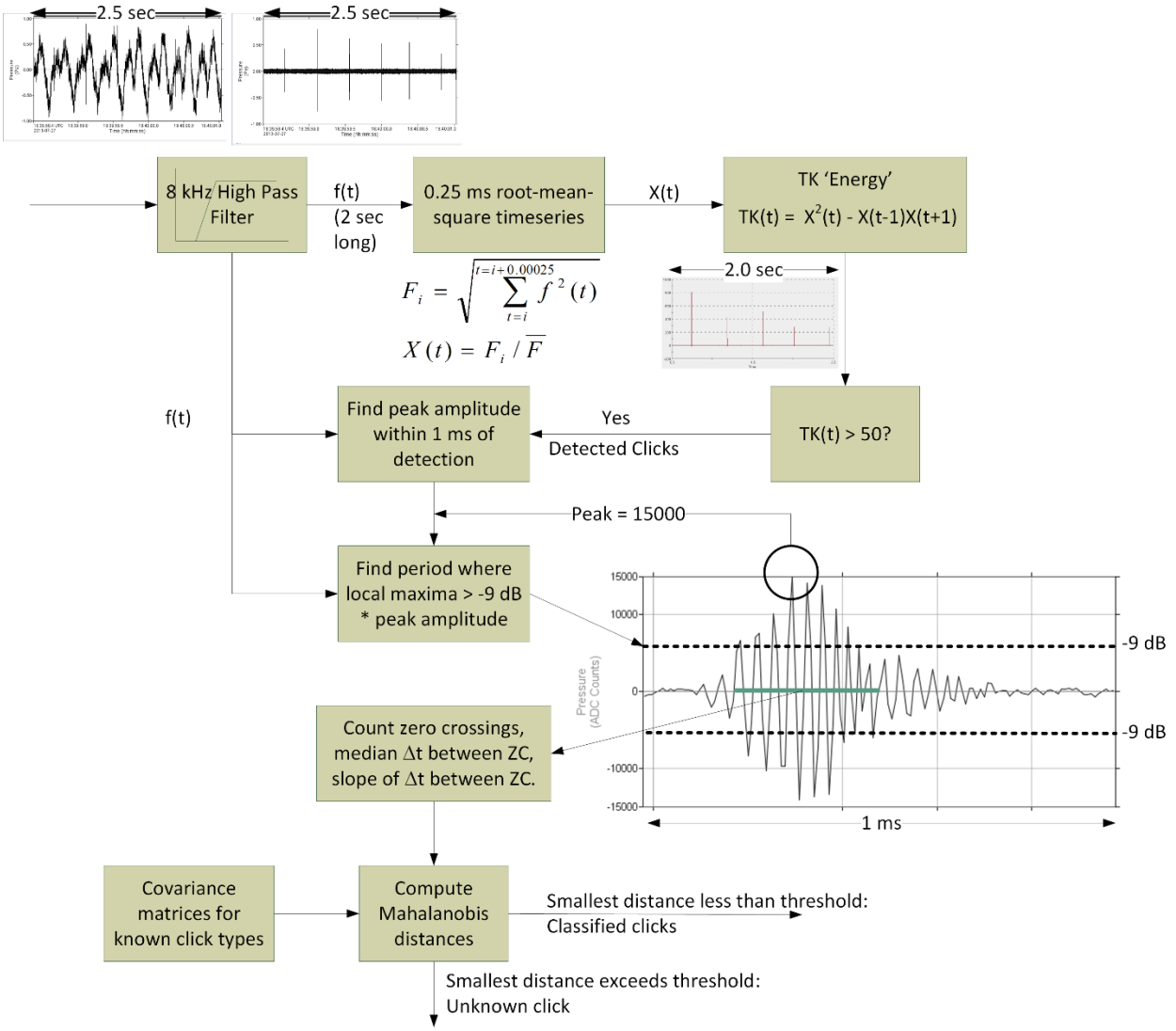


Figure 14. The click detector/classifier and a 1-ms time-series of four click types.

2.2.4.2. *Tonal Call Detection*

The tonal call detector identifies data likely to contain marine mammal moans, songs, and whistles. Tonal calls are detected by the following steps:

1. Spectrograms of the appropriate resolution for each mammal call type that are normalized by the median value in each frequency bin for each detection window (Table 5) are created.
2. Adjacent bins are joined and contours are created via a contour-following algorithm (Figure 15).
3. A call sorting algorithm determines if the contours match the definition of a mammal call type (Table 6).

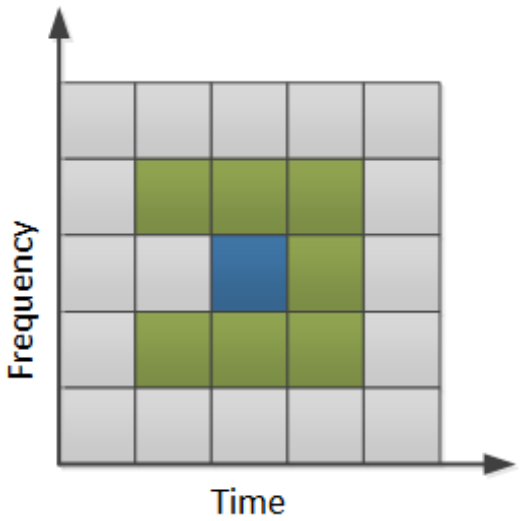


Figure 15. Illustration of the search area used to connect spectrogram bins. The blue square represents a bin of the binary spectrogram equalling 1 and the green squares represent the potential bins it could be connected to. The algorithm advances from left to right so grey cells left of the test cell need not be checked.

Table 5. Fast Fourier Transform and detection window settings used to detect tonal calls of marine mammal species expected in the data. Values are based on JASCO's experience and empirical evaluation on a variety of data sets.

Possible species	Call type	FFT			Detection window (s)	Detection threshold
		Resolution (Hz)	Frame length (s)	Timestep (s)		
Pilot whales	Whistle	16	0.03	0.015	5	3
Dolphin	Whistle	64	0.015	0.005	5	3
Humpback whales	Moan	4	0.2	0.05	5	3
Blue whales	Infrasonic moan	0.125	2	0.5	120	4
Fin whales	20-Hz note	1	0.2	0.05	5	4
Sei whales	Downsweep	3.25	0.2	0.035	5	3.5

Table 6. Call sorter definitions for the tonal calls of cetacean species expected in the area.

Possible species	Call type	Frequency (Hz)	Duration (s)	Bandwidth (Hz)	Other detection parameters
Pilot whales	Whistle	1,000–10,000	0.5–5	>300	Minimum frequency <5,000 Hz
Dolphin	Whistle	4,000–20,000	0.3–3	>700	Maximum instantaneous bandwidth = 5,000 Hz
Humpback whales	Moan	100–700	0.5–5	>50	Maximum instantaneous bandwidth = 200 Hz
Blue whales	Infrasonic moan	15–22	8–30	1–5	Minimum frequency <18 Hz
Sei whales	Downsweep	20–150	0.5–1.7	19–120	Maximum instantaneous bandwidth = 100 Hz Sweep rate = −100 to −6 Hz/s
Fin whales	20 Hz downsweep	8–40	0.3–3	>6	Minimum frequency <17 Hz Sweep rate = −100 to 0 Hz/s

2.2.4.3. *Validation of Automated Detectors*

Automated detectors are often developed and tested with example data files that contain a range of vocalisation types and representative background noise conditions. However, test files normally cannot cover the full range of possible conditions. Therefore, a selection of files must be manually validated to check the detector performance in the specific conditions of each recorder. For each recorder and for each species or call type, a sample of files containing low, medium, and high numbers of detections was reviewed. Files that contained early or late automated detections were primarily selected to help bound the period of occurrence of a species/call type. The automated detector results were checked to evaluate the true presence or absence of each species, as well as vessels and other anthropogenic signals. These validated results were fed to a maximum likelihood estimation (grid search) algorithm that maximised the probability of detection and minimised the number of false alarms using the 'F-score':

$$F = \frac{(1+\beta^2)P * R}{(\beta^2)P + R}; P = \frac{TP}{TP + FP}; R = \frac{TP}{TP + FN}$$

where *TP* (true positive) is the number of correctly detected files, *FP* (false positive) is the number of files that are false detections, and *FN* (false negatives) is the number of files with missed detections. *P* is the classifier's precision, representing the proportion of detected calls that are true positives. A *P* value of 0.9 means that 90% of the detections are correctly classified, but says nothing about whether all calls in the dataset were identified. *R* is the classifier's recall, representing the proportion of calls in the dataset that are detected by the detector. An *R* value of 0.8 means that 80% of all calls in the dataset were detected, but says nothing about how many classifications were wrong. Thus, a perfect detector/classifier would have *P* and *R* values equal to 1. An F-score is a combined measure of *P* and *R* where an F-score of 1 indicates perfect performance–all events are detected with no false alarms. The algorithm determines a classification threshold for each species that maximizes the F-score. Table 7 shows the dependence of the classification threshold on the *β*-parameter and its effect on the precision and recall of the detector and classifier system. *β* is the relative weight between the recall and precision. Here, we have made precision more important than recall as a *β* of 0.5 means the recall has half the weight of the precision.

Table 7. Effects of changing the F-score β-parameter on the classification threshold, precision, and recall for the odontocete clicks.

β	Classification threshold	Precision $P = \frac{TP}{TP + FP}$	Recall $R = \frac{TP}{TP + FN}$	F-score
2	25	0.87	0.95	0.93
0.5	50	0.91	0.91	0.91

Detection time series based on the restrictions above are plotted using JASCO's ADPT software and critically reviewed. Questionable detections based on time of year and location or overlap with the detection period of other species are manually reviewed and removed from the plots if they are found to be false. The detector performance metrics presented in Section 3.4.1 are based on the fully revised and edited results as shown in the detection time series. Detections are also presented as spatial plots showing the number of detections at each station over selected periods.

3. Results

3.1. Total Soundscapes

The objective of this analysis was identification of the sound sources contributing to the recordings at CM2 in 2014 before the start of the Statoil 2014-2016 drilling program and in 2015 during the drilling program. Recordings made 230 km from the drilling program provide contextual information. The main contributors were seismic surveys, fin whales and the *West Hercules* semi-submersible drill rig. This section provides and overview of the measured sound levels. Section 3.2 provides a summary of when vessels were detectable at CM2. Section 3.3 discusses the nature and occurance of the seismic sounds detected at CM2, and 3.4 documents the detections of marine mammals.

Long-term spectral averages along with median band-level time series figures (Figure 16) provide an overview of the time and frequency evolution in the soundscape. In 2014 the soundscape at CM2 was dominated by a relatively close seismic survey. In 2015 CM2 recorded both the *West Hercules* drilling operations and a distant seismic survey. ESRF STN 19 recorded seismic survey sounds until November 2015, and beginning again in June 2016. The winter period of 15 Nov 15 – 1 Jun 16 was representative of a normal ambient soundscape for this region with the *West Hercules* being faintly detectable (Figure 16). Fin whale mating choruses were a dominant sound source in the band of 18-25 Hz from November – March, and were detectable in September and October (Figure 16).

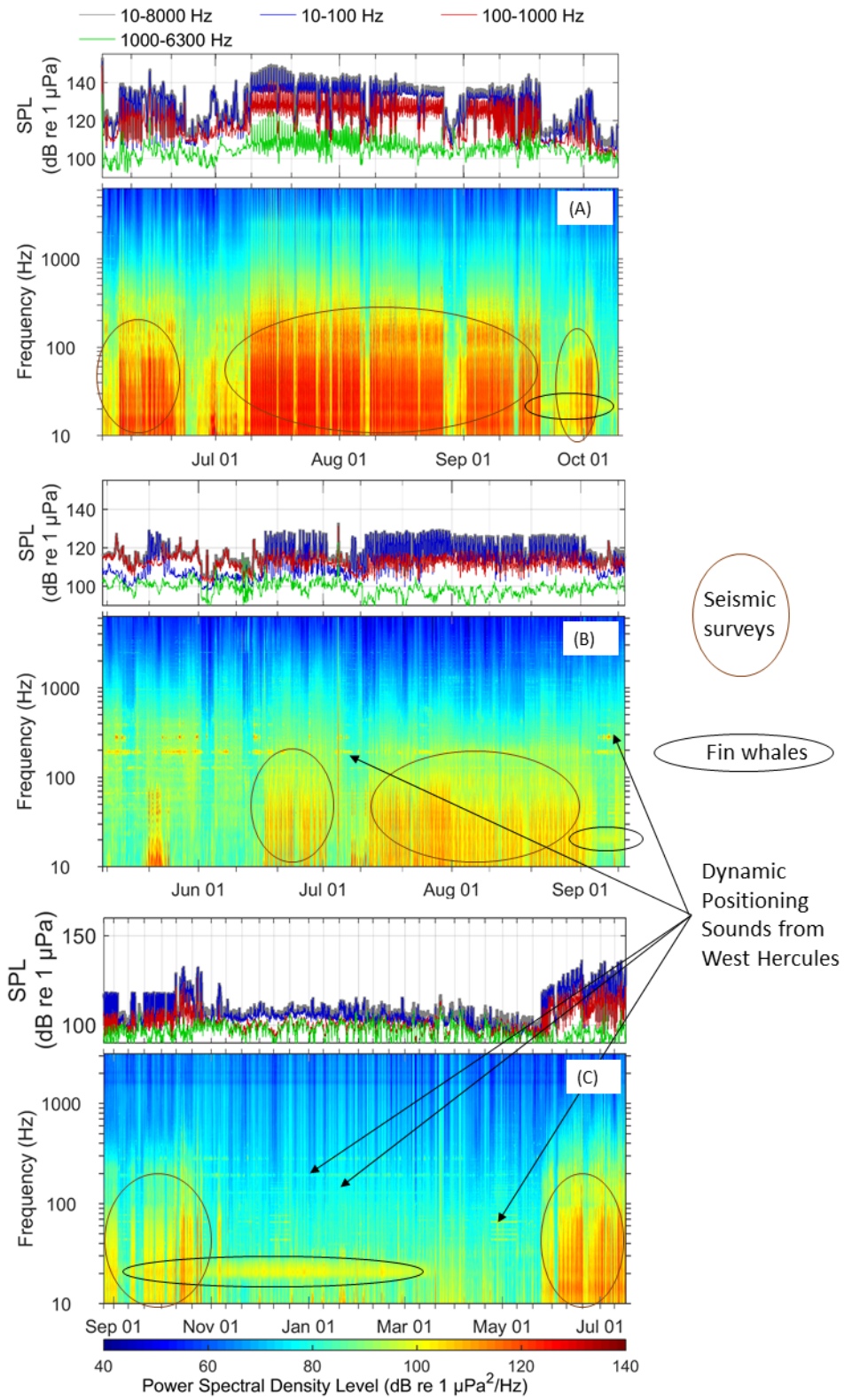


Figure 16. Summary of each recorder's acoustic data. (A) CM2 2014, (B) CM2 2015 and (C) ESRF Stn 19 (Aug 15-Jul 16). For each station the top figure is the median hourly in-band SPL and bottom is the long-term spectral average of the measured sound. On the long-term spectral averages the sounds from seismic surveys, fin whales and the *West Hercules* are annotated.

Band-level box and whisker plots provide a statistical representation of the magnitude of the sound levels recorded (Figure 17). The maximum and minimum broadband SPL measured in 2014 were 165.8 and 104.9 dB re 1 µPa, respectively, and 148.3 and 102.4 dB re 1 µPa in 2015. At ESRF STN 19 the values were 139.5 and 90.5 (Figure 17). The median SPL at ESRF STN 19 of 107.5 dB re 1 µPa is representative of the level measured in most northern deep water ocean locations far from shipping lanes and industrial activity. The seismic survey increased the median levels measured at CM2 to 130 dB re 1 µPa in 2014 and 117 dB re 1 µPa in 2015 (a 10 dB increase in SPL is 10 times louder). In all cases the 10-100 Hz band contained the most energy. This is the band associated with seismic surveys and large shipping. In the winter, it is also associated with fin whale mating choruses.

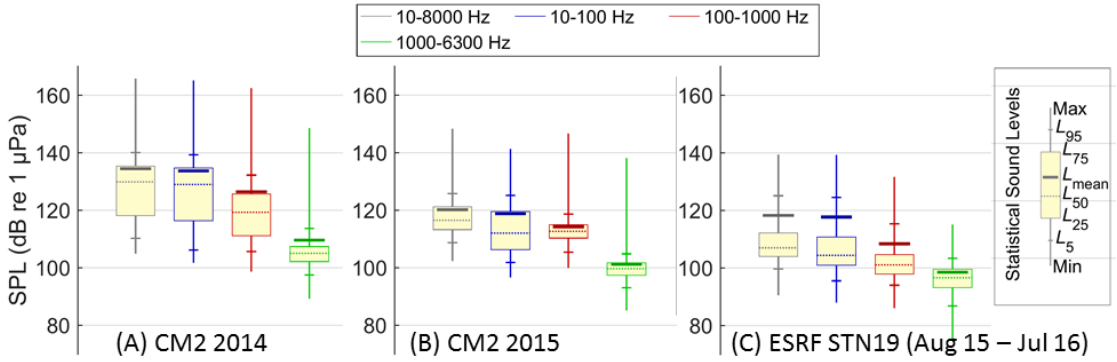


Figure 17. Comparison of the broadband and decade band 1-minute sound pressure levels for (A) CM2 2014, (B) CM2 2015 and (C) ESRF Stn 19 (Aug 15-Jul 16).

Power spectral density and 1/3-octave-band distribution plots (Figure 18) can be directly compared to the Wenz plots (Figure 1) and provide more detailed spectral distribution information than the long-term spectral averages and box-and-whisker plots. In 2014, noise from seismic activity caused the noise between 30 to 250 Hz to exceed the expected limits of prevailing noise for the L_{75} percentile curve, or for 75% of the time (Figure 18). The maximum sound levels were measured during a period of seismic activity. Similarly in 2015, anthropogenic noise between 40–250 Hz L_{50} exceeded expected limits of prevailing noise (Figure 18) (Wenz 1962). These noise levels were likely caused by the thrusters of the drill rig *West Hercules* (see Section 4.1).

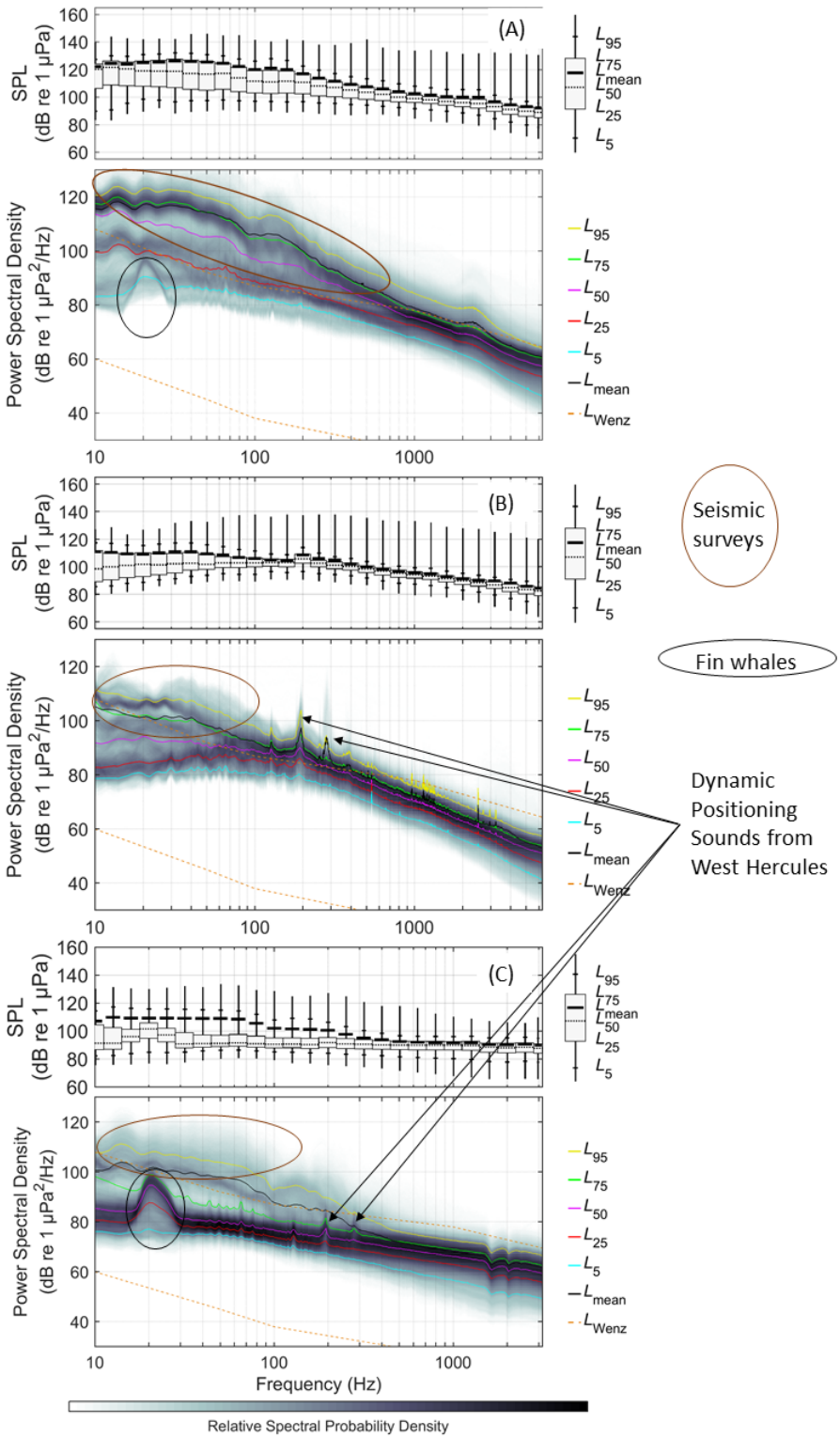


Figure 18. Summary of spectral content of each recorder's acoustic data. (A) CM2 2014, (B) CM2 2015 and (C) ESRF Stn 19. For each station the top figure shows a box-and-whisker plot for the 1/3-octave-band SPLs, and bottom shows the power spectral density percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962). The signatures of seismic surveys, fin whales and the *West Hercules* are annotated.

The daily sound exposure level 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] National Marine Fisheries Service 2016)). Noise associated with a seismic survey was the main contributor to the daily SEL in 2014, which was up to 35 dB higher than daily SEL recorded at ESRF STN 19 in the absence of seismic surveys (Figure 19). At CM2 in 2015 seismic surveys and vessel noise were the main contributors to the daily SEL, which was 10-15 dB higher than the levels measured at ESRF STN 19 without seismic surveys (Figure 19). The daily SEL associated with seismic surveys in 2015 and 2016 were higher at ESRF STN 19 than what was recorded at CM2. The daily SEL at ESRF STN 19 rose in the winter due to both fin whales and increase wind and wave activity (Figure 19, Figure 18).

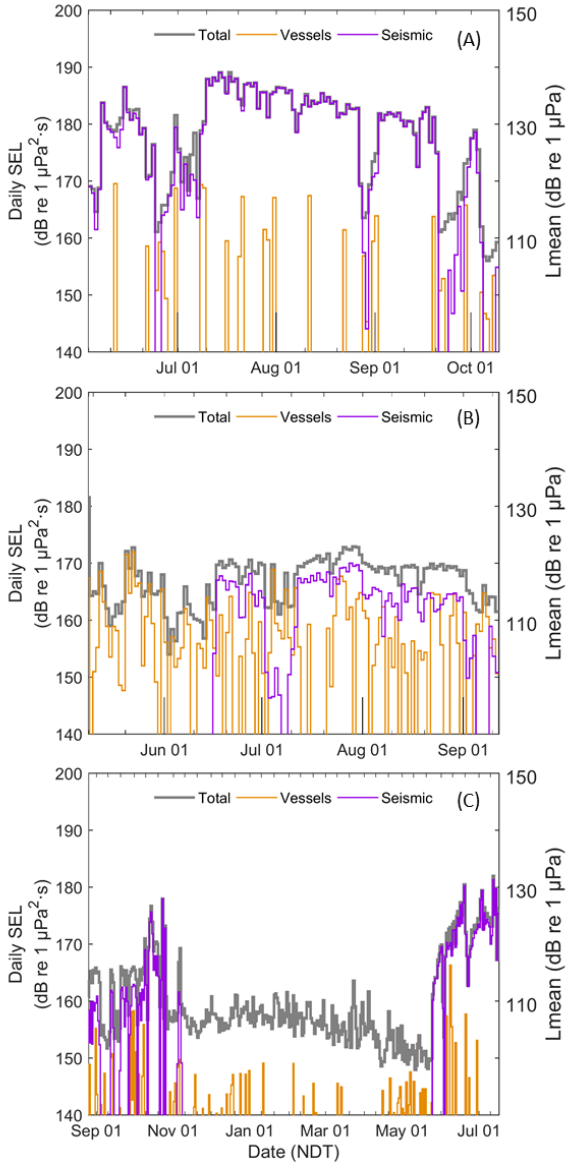


Figure 19. Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{mean}). (A) CM2 2014, (B) CM2 2015 and (C) ESRF Stn 19 (Aug 16 – Jul 16). The detectors described in Sections 2.2.2 and 2.2.3 were used to identify the periods when seismic surveys and vessel were the dominant sound sources. In 2015 there were multiple simultaneous surveys which are difficult for the detector to properly distinguish, leading to less energy assigned to the seismic source than was actually in the water.

3.2. Vessel Detections

Vessels were detected using the automated detection algorithm described in Section 2.2.2. Vessel detections denote closest points of approach (CPA) to the recorder, by hour (Figures 20 and 21). The second year of the study had the most vessel detections, which agrees with the known presence of the vessels supporting the Statiol 2014-2016 drilling program (Figure 21). Note that the shipping detector will not detect the constant energy from the drill rig thrusters.

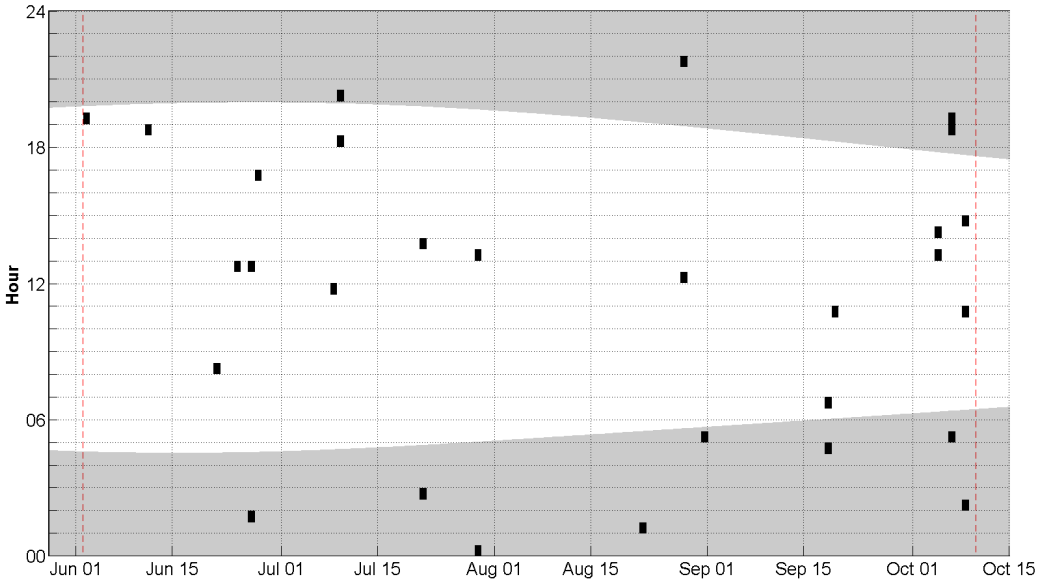


Figure 20. Vessel detections each hour (vertical axis) compared to date (horizontal axis) in the Flemish Pass from 2 Jun to 9 Oct 2014. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

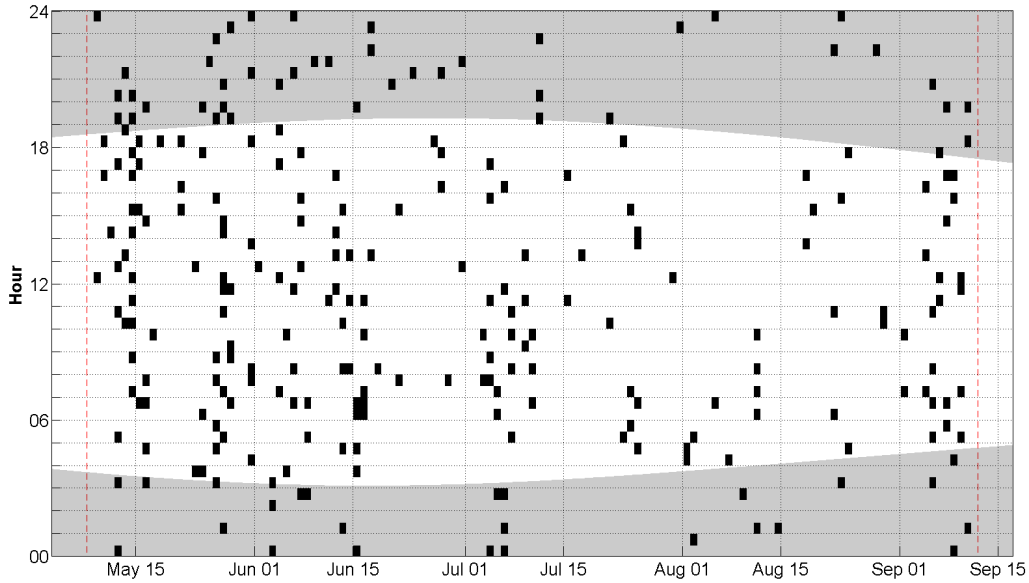


Figure 21. Vessel detections each hour (vertical axis) compared to date (horizontal axis) in the Flemish Pass from 9 May to 11 Sep 2015. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

3.3. Seismic Survey Sounds

Seismic survey sounds were detected using the automated detection algorithm described in Section 2.2.3. In 2014, seismic noise was the main contributor to the total SEL and had more hours with seismic detections (Figure 22) compared to the distant seismic detected in 2015 (Figure 23). Figures 18 and 19 show the effects of the seismic surveys on the mean daily SPL and power spectral densities.

Propagation of airgun signals in deep waters is highly complex, with different frequencies contributing to the received energy at different ranges and depths. Small changes in the range of the source, the sound speed profile, or the source or receiver depth significantly change the sound levels (Figures 24 and 25). Typical 2D and 3D seismic survey generate one impulse every 10-12 seconds. The multiple impulsive arrivals shown in Figure 24 and Figure 25 are the result of the sound reflecting off the seabed and sea surface multiple times. This number of multi-path arrivals increases with distance between the source and receiver. In the case of Figure 25 the arrivals continue for 8 seconds, a pattern JASCO has previously observed in waters 800 m deep off Greenland. The multipath arrivals tend to have lower amplitudes in deeper waters and for environments with softer bottoms.

Notably in 2015, seismic noise was distant and an example of multiple seismic surveys displaying close and distant seismic noise source is shown in Figure 26.

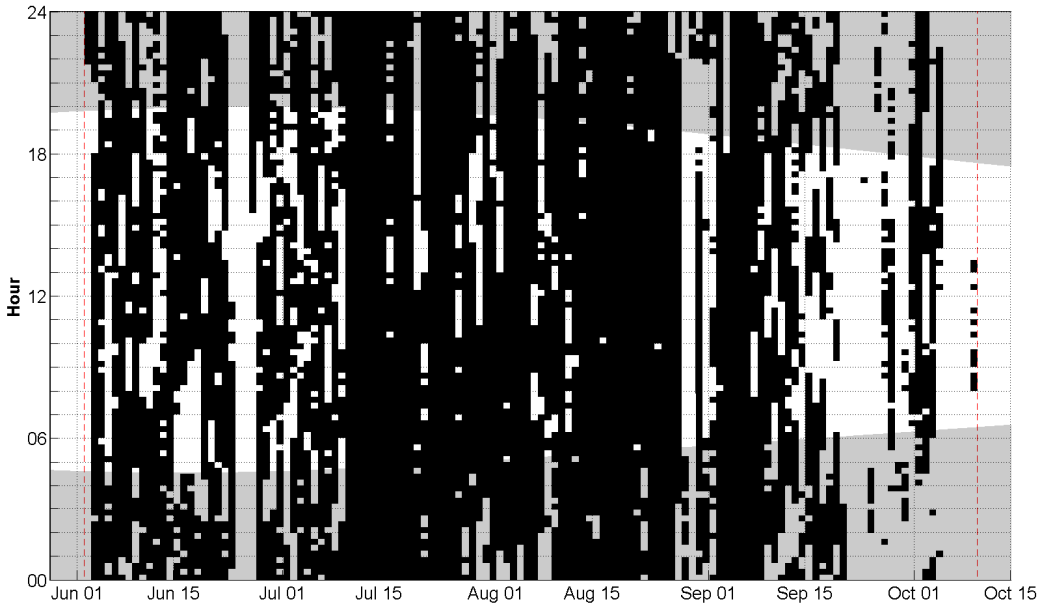


Figure 22. Seismic detections each hour (vertical axis) versus date (horizontal axis) in the Flemish Pass from 2 Jun to 9 Oct 2014. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

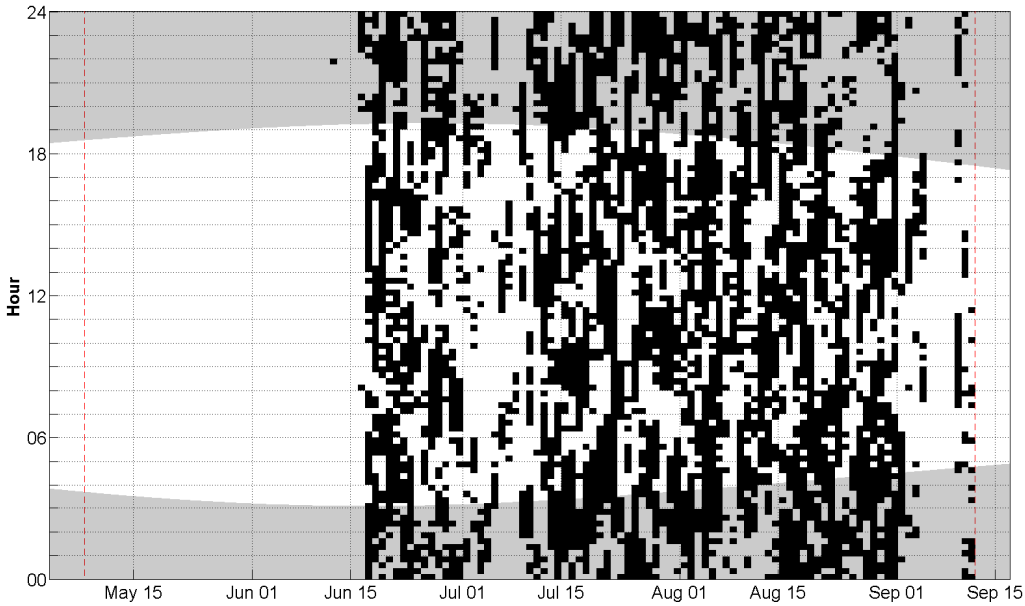


Figure 23. Seismic detections each hour (vertical axis) versus date (horizontal axis) in the Flemish Pass from 9 May to 11 Sep 2015. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

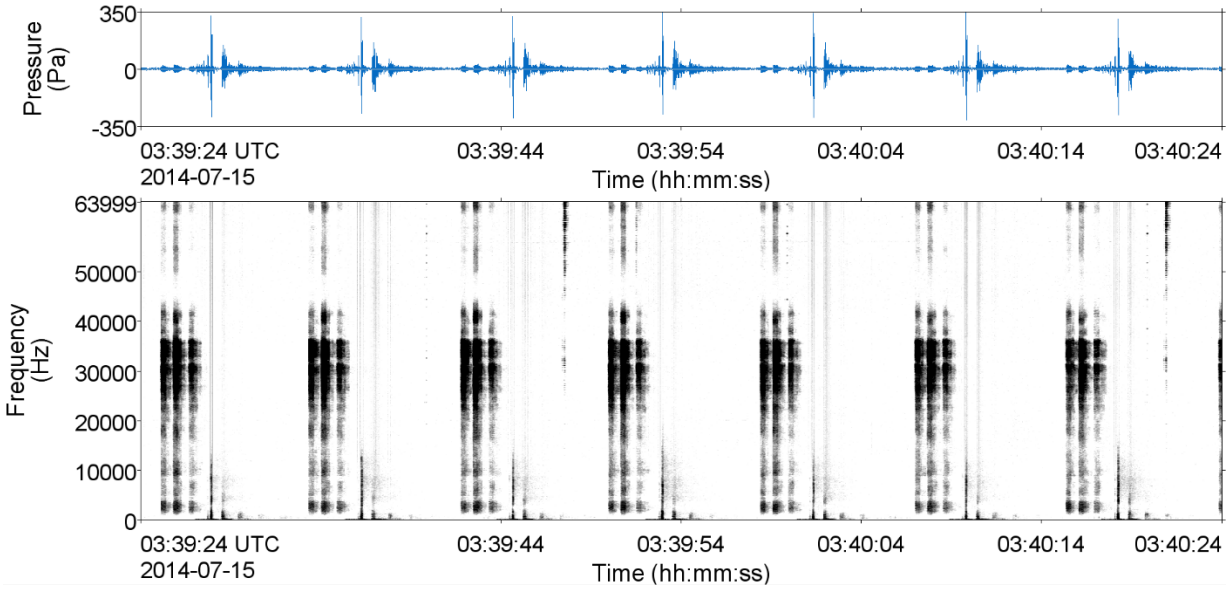


Figure 24. (Top) Pressure signature and (bottom) spectrogram of multibeam seismic pulses from an airgun array on 15 Jul 2014 (2 Hz frequency resolution, 0.128 s frame size, 0.032 s time step, and Hamming window).

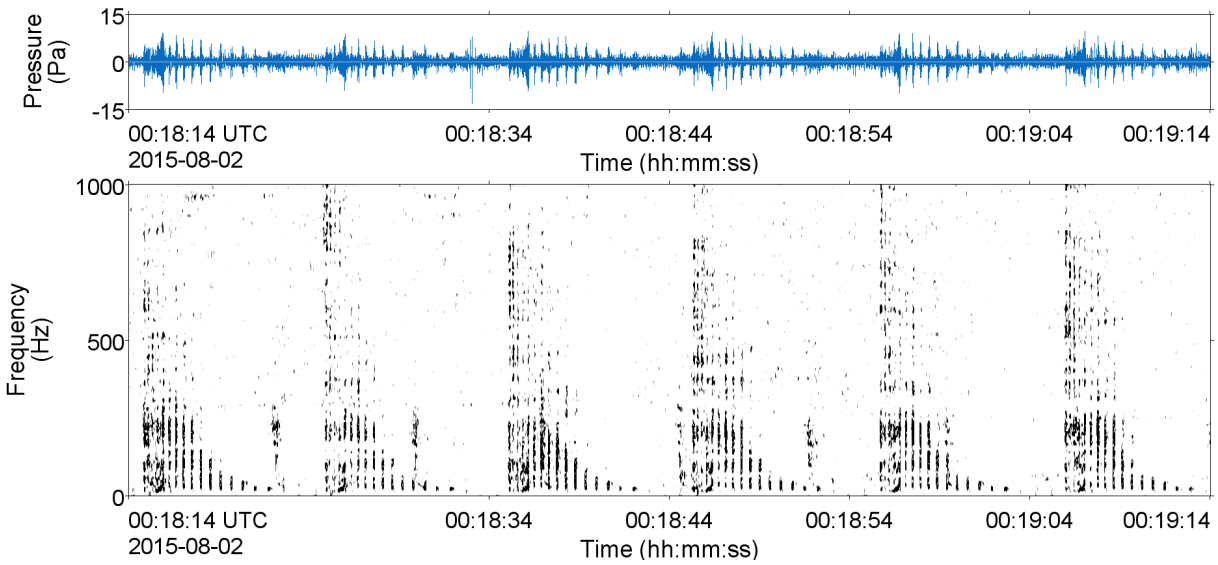


Figure 25. (Top) Pressure signature and (bottom) spectrogram of seismic pulses from an airgun array on 2 Aug 2015 (2 Hz frequency resolution, 0.128 s frame size, 0.032 s time step, and Hamming window).

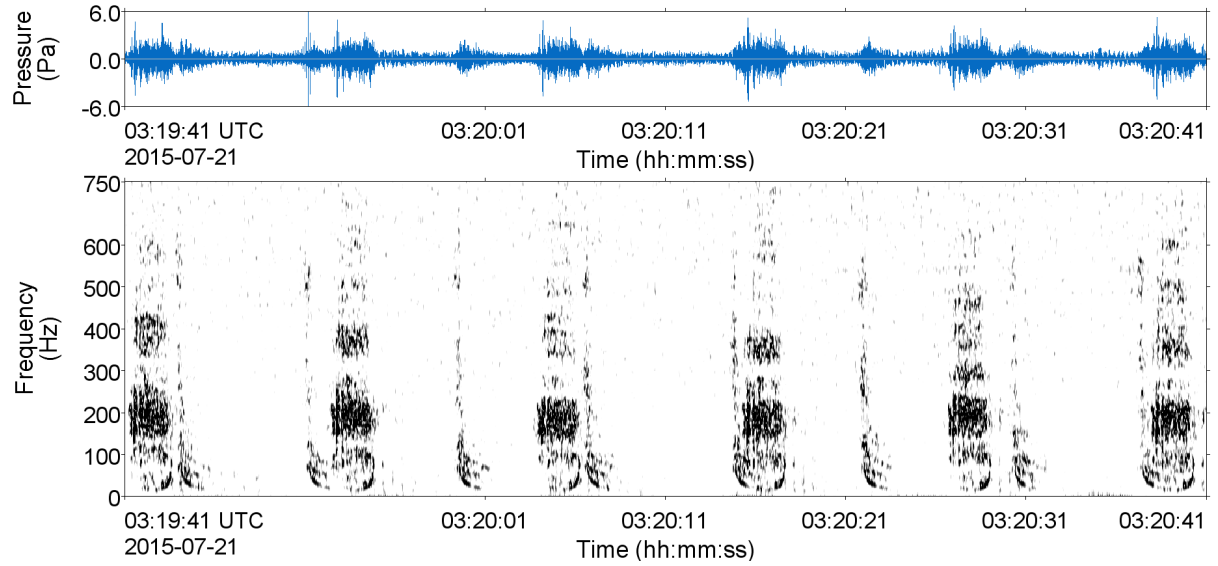


Figure 26. (Top) Pressure signature and (bottom) spectrogram of two seismic surveys on 21 Jul 2015 (2 Hz frequency resolution, 0.128 s frame size, 0.032 s time step, and Hamming window).

3.4. Marine Mammals

The acoustic presence of marine mammals was identified automatically by JASCO's detectors (Section 2.2.4.3), and 5% of the acoustic data was verified by the manual analysis. Detectors and analysts found the 63 kHz acoustic recordings contained sounds from blue, fin, long-finned pilot, northern bottlenose, and sperm whales, as well as dolphins.

3.4.1. Detector Performance

Detector performance varied across species and call types. Except for northern bottlenose whale clicks, pilot whale whistles, and blue whale moans, the detector precision was generally high. It ranged from 0.80 (sperm whales) to 1 (fin whale), indicating that 80 to 100% of files containing calls were correctly detected and classified (Table 8). The lower the precision value, the higher the proportion of non-target signals included in the results. The poor precision for the blue whale moan, pilot whale whistle and northern bottlenose whale click detectors can be attributed to interfering noises consistently falsely triggering the detectors. For pilot whales, false detections were triggered by airgun sounds, vessel noise, and other delphinid whistles. For sperm and northern bottlenose whales, false detections were triggered by airgun sounds, vessel noise (particularly echosounders), and loud delphinid clicks.

Manual validation indicated that detection thresholds were needed for all species identified, except for unknown dolphin/pilot whale clicks (Table 8). These thresholds raised the precision, but lowered the recall values of the detectors. Except for the moderately high-performing dolphin whistle (R = 0.69) and click (R = 0.68) detectors, detector recall values were low to moderate, ranging from 0.13 for fin whales to 0.54 for sperm whales (Table 8). The consistently lower R than P in our detectors reflects the bias of our analysis protocol in favour of precision over recall. A low recall may translate into missing detection events, defined as a string of consecutive files (one or more) with detections of a given species, completely, or missing some files within a detection event. The ultimate effect of a low recall is likely a combination of both scenarios, although the relative contribution of each will depend on species, season, and interfering sound sources at a location. When the primary measure of interest is daily presence of a species, detectors with high precision and lower recall generally provide accurate results with low false alarms.

To compare results across years, the detection count thresholds were calculated using validated detections from both 2014 and 2015. For northern bottlenose, pilot, fin and blue whales, the manual rather than the automated detections will be presented in the following sections.

Table 8. Classification thresholds determined from validating the automated detector outputs. The classification thresholds are the minimum number of detected calls/file required to be confident in that detections are not false alarms. The precision (P), recall (R), and F-score (F) before the threshold is applied (original) and after (threshold) is shown.

File analyzed	Species/call	$P_{original}$	$R_{original}$	Classification threshold	$P_{threshold}$	$R_{threshold}$	$F_{threshold}$
353 files at 2 min 128 ksps	Dolphin whistle	0.90	0.69	1	0.90	0.69	0.85
	Delphinid click	0.79	0.92	40	0.98	0.68	0.90
	Sperm whales	0.55	0.85	17	0.80	0.54	0.73

3.4.2. Odontocetes

3.4.2.1. Northern Bottlenose Whales

The northern bottlenose whale detector was unreliable, as it was falsely triggered by dolphin clicks and high-frequency sperm whale clicks. Therefore, results from manual analysis are presented here and represent a minimum estimate of acoustic occurrence. Clicks classified as northern bottlenose whales had a centroid frequency between 25 and 30 kHz and a smooth upswept contour, ranging in frequency from 20–50 kHz (Figures 27 and 28) (Hooker and Whitehead 2002, Wahlberg et al. 2012).

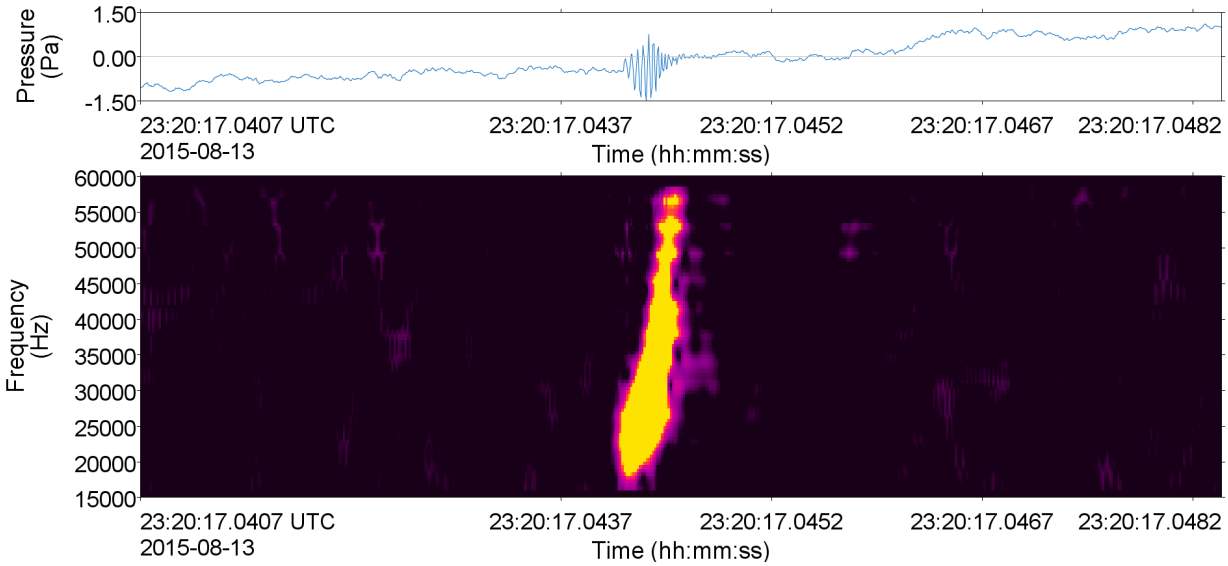


Figure 27. Spectrogram of a northern bottlenose whale click recorded on 13 Aug 2015 (512 Hz frequency resolution, 0.26 ms time window, 0.02 ms time step, Hamming window).

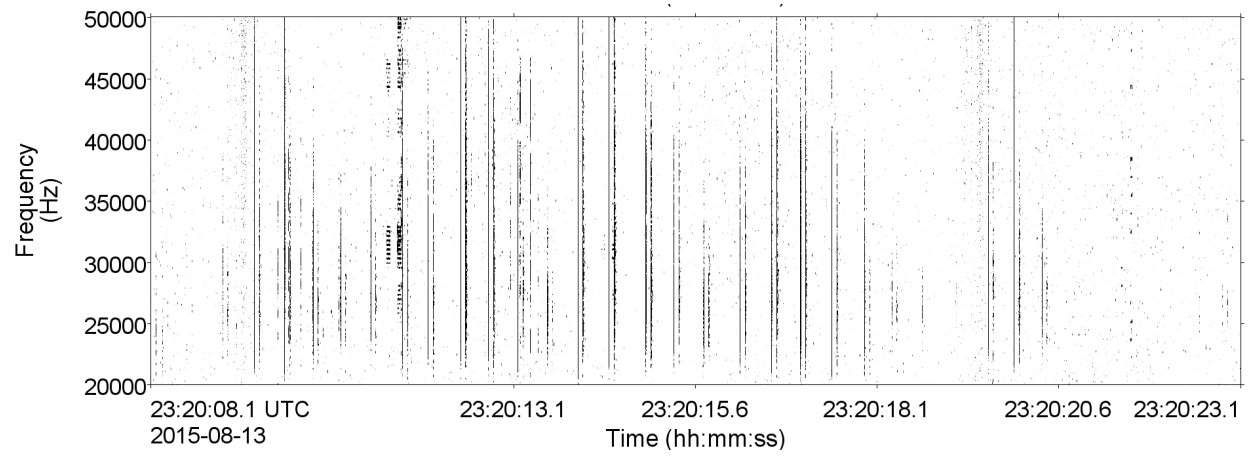


Figure 28. Spectrogram of northern bottlenose whale click trains recorded at 13 Aug 2015 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window). The window length is 15 s.

Northern bottlenose whale clicks were sporadic throughout the recording period in each year. In 2014, detections occurred from mid-June to mid-July. Additionally, there were detections on one day in mid-August and one in late September (Figure 29, Table 9). In 2015, Two detections occurred in June, while 9 days in July contained northern. Detections also occurred on 4–5 days in both August and September (Figure 30, Table 9).

Table 9. Northern bottlenose whales: Summary of manually validated acoustic detections.

Year	Deployment	First detection	Last detection	Record end	Number of days with manual detections
2014	2 Jun	12 Jun	26 Sep	9 Oct	9
2015	9 May	9 Jun	8 Sep	11 Sep	19

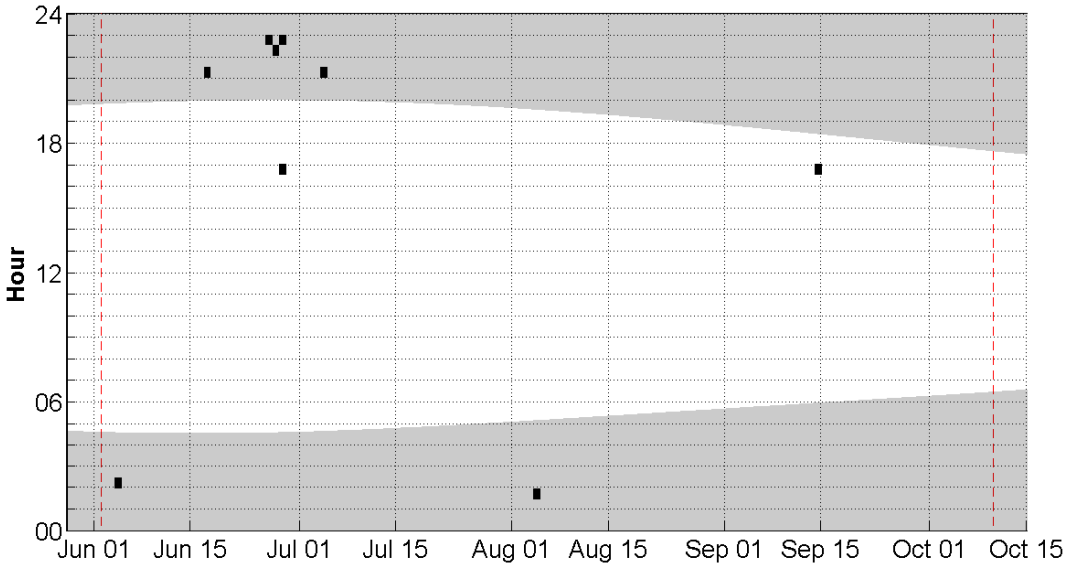


Figure 29. Manual validation of daily and hourly occurrence of northern bottlenose whale clicks recorded in the Flemish Pass from 2 Jun to 9 Oct 2014. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

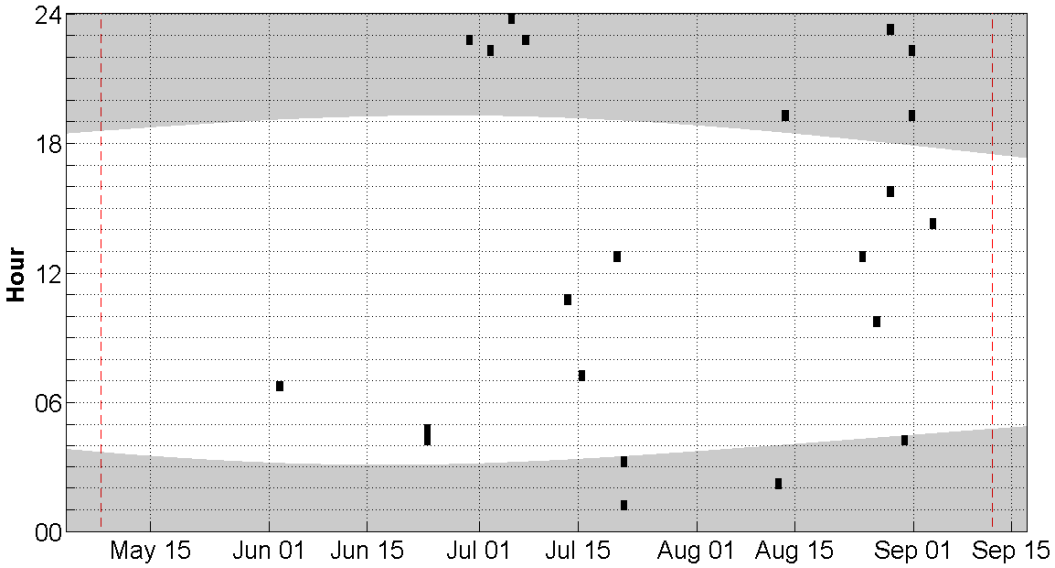


Figure 30. Manual validation of daily and hourly occurrence of northern bottlenose whale clicks recorded in the Flemish Pass from 9 May to 11 Sep 2015. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

3.4.2.2. *Delphinids*

Unlike most odontocetes that are only known to produce clicks, delphinids produce both impulsive (click) and tonal (whistle) sounds that show less species-level specificity than other marine mammal signals and are therefore more difficult to distinguish acoustically. Here, we present results for pilot whales and unidentified dolphins, species groups that can be confidently distinguished based on their tonal signals (Steiner 1981b, Rendell et al. 1999). The tonal calls of pilot whales have energy at frequencies as low as 1.0 kHz and whistles with acoustic energy concentrated below 5–6 kHz. The main energy in tonal calls of unidentified dolphins is greater than 6 kHz. Because of the overlap in spectral features of tonal signals from the different dolphin species expected in the study area (Steiner 1981a) and the expected but unquantified variability of these signals around the few described call types, we were unable to distinguish dolphin calls by species in most cases.

Delphinid clicks show even less species-specificity than tonal signals, partially because of their directionality and the associated degradation of their spectral features when recorded at increasing angles away from the longitudinal axis of the calling animal. The following subsections present pilot whale and dolphin whistle detections, as well as delphinid click detections.

3.4.2.2.1. Pilot Whales

Pilot whale whistles (Figure 31) were distinguished from dolphin whistles based frequency. Detections generally occurred during summer, June to September (Figures 32 and 33). Pilot whale calls were sparsely detected on 10% of the recording days in 2014, and increased to 15% in 2015 (Table 10). The pilot whale detector had a low recall of 32%, reflecting the ability of manual analysts to identify whistles too faint for the automated detector (Table 8). Thus, the results presented here are the manually validated pilot whale whistles.

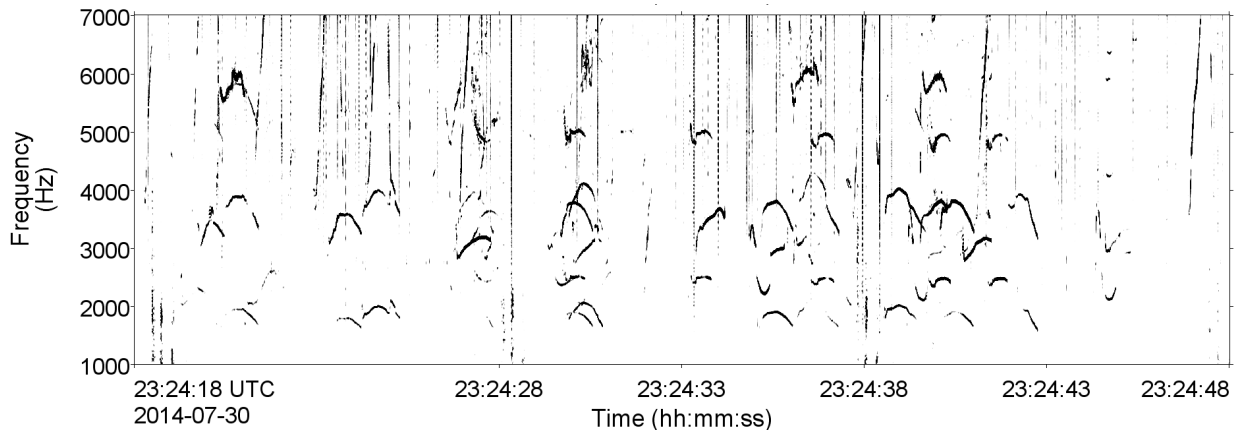


Figure 31. Spectrogram of pilot whale whistles recorded on 30 Jul 2014 (4 Hz frequency resolution, 0.05 s time window, 0.01 s time step, Hamming window). The window length is 30 s.

Table 10. Pilot whales: Summary of manually validated acoustic detections.

Year	Deployment	First detection	Last detection	Record end	Number of days with manual detections
2014	2 Jun	3 Jun	7 Oct	9 Oct	13
2015	9 May	14 May	3 Sep	11 Sep	19

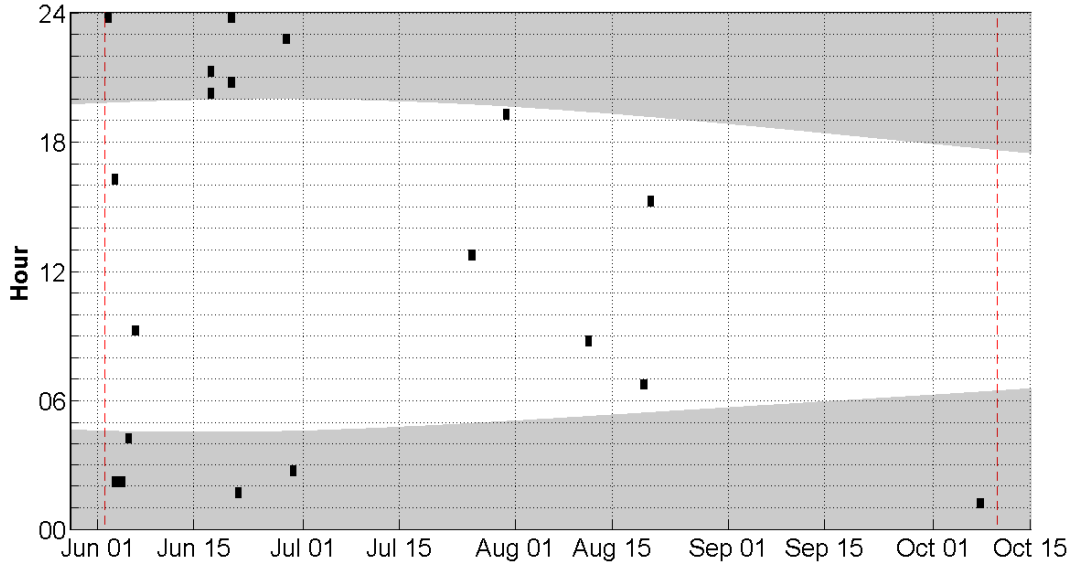


Figure 32. Manual validation of daily and hourly occurrence of pilot whale whistles recorded in the Flemish Pass from 2 Jun to 9 Oct 2014. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

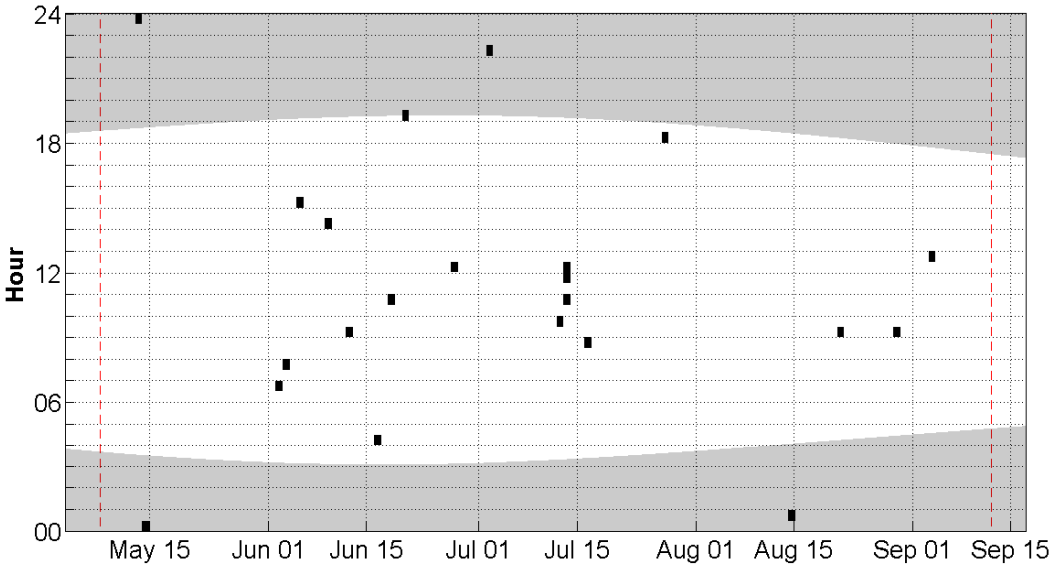


Figure 33. Manual validation of daily and hourly occurrence of pilot whale whistles recorded in the Flemish Pass from 9 May to 11 Sep 2015. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

3.4.2.2.2. Small Dolphins

The detector performed well for small dolphin whistles (Figure 34) and delphinid clicks (Figures 35 and 36, Table 8). Ninety percent of whistle detections and almost 100% of click detections presented here are accurately classified. The whistle results likely include other acoustic signals such a high-frequency components of pilot whale whistles.

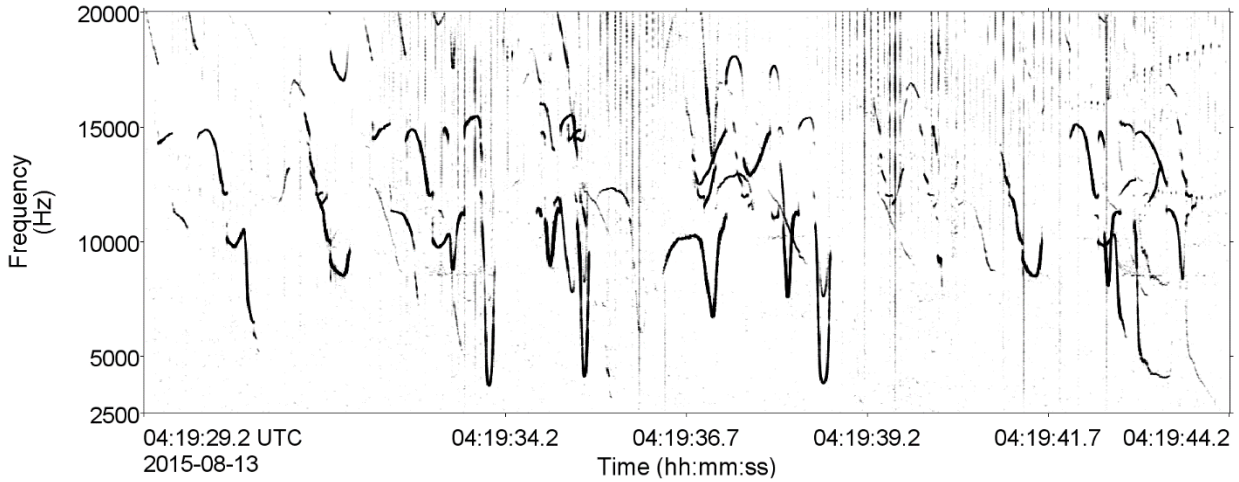


Figure 34. Spectrogram of unidentified dolphin whistles recorded on 13 Aug 2015 (4 Hz frequency resolution, 0.05 s time window, 0.01 s time step, Hamming window). The window length is 15 s.

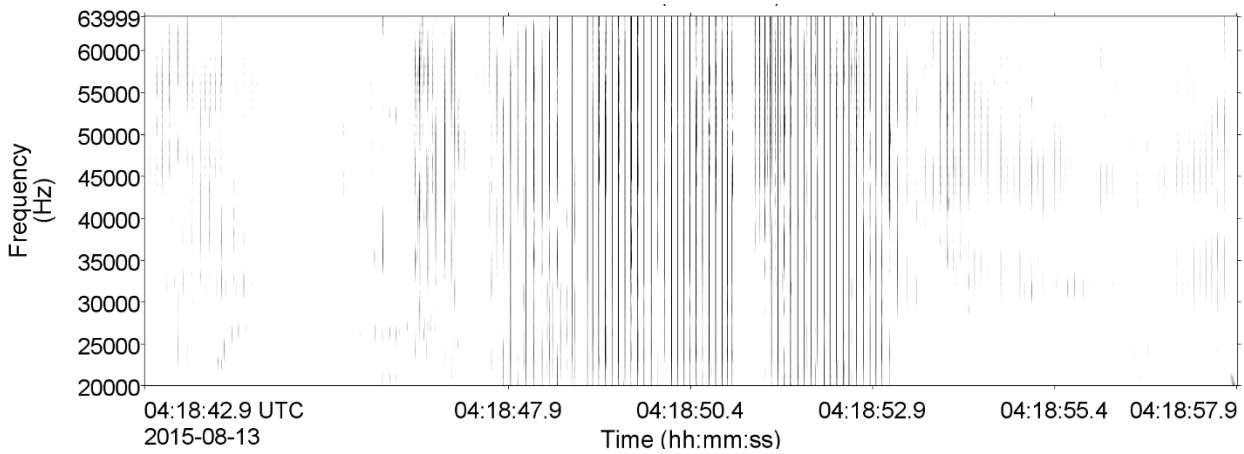


Figure 35. Spectrogram of unidentified dolphin click trains recorded on 13 Aug 2016 (128 Hz frequency resolution, 0.001 s time window, 0.0005 s time step, Hamming window). The window length is 15 s.

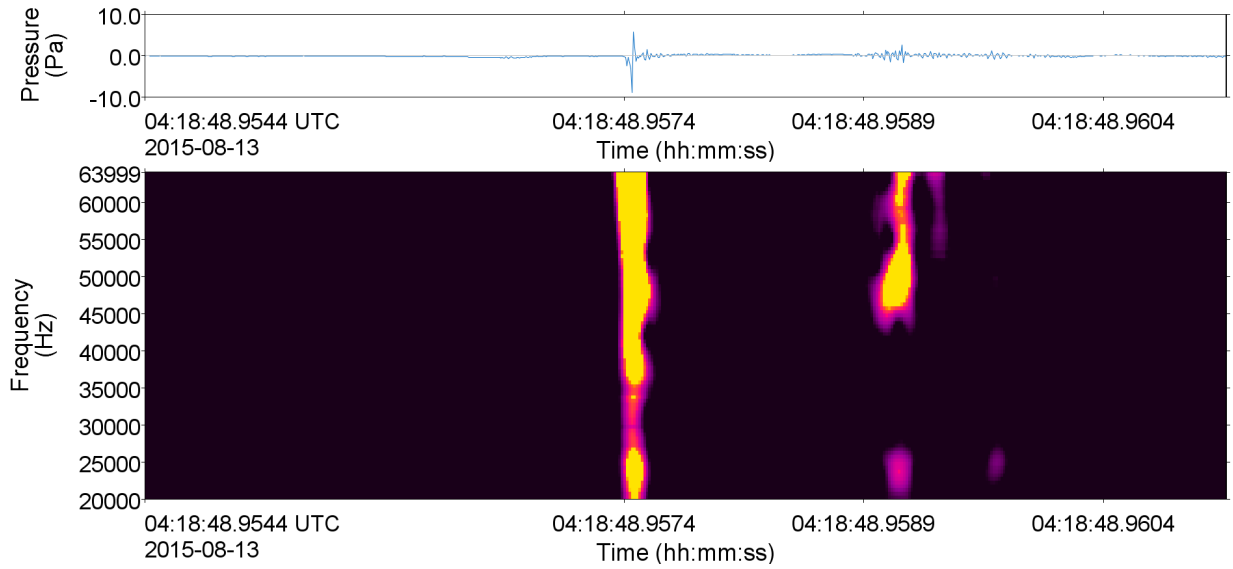


Figure 36. Spectrogram of unidentified dolphin click recorded on 29 Jun 2014 (512 Hz frequency resolution, 0.26 ms time window, 0.02 ms time step, Hamming window).

Clicks and whistles produced by delphinids occurred on ~30% of the recording days (Tables 11 and 12). The number of click detections in 2014 was almost double that of 2015 (Table 11). The opposite is true for whistles detected, as the number of detections in 2015 almost doubles those detected in 2014 (Table 12). Unlike dolphin whistles that were detected throughout the day (Figures 37 and38), delphinid clicks showed a diel pattern, occurring more often at night than in the day (Figures 39 and 40).

Table 11. Delphinid clicks: Summary of automated acoustic detections.

Year	Deployment	First detection	Last detection	Record end	Number of days with manual detections	Number of detections
2014	2 Jun	12 Jun	9 Oct	9 Oct	50	40,852
2015	9 May	9 Jun	10 Sep	11 Sep	36	26,268

Table 12. Dolphin whistles: Summary of automated acoustic detections.

Year	Deployment	First detection	Last detection	Record end	Number of days with manual detections	Number of detections
2014	2 Jun	3 Jun	9 Oct	9 Oct	50	1,598
2015	9 May	14 May	10 Sep	11 Sep	40	2,460

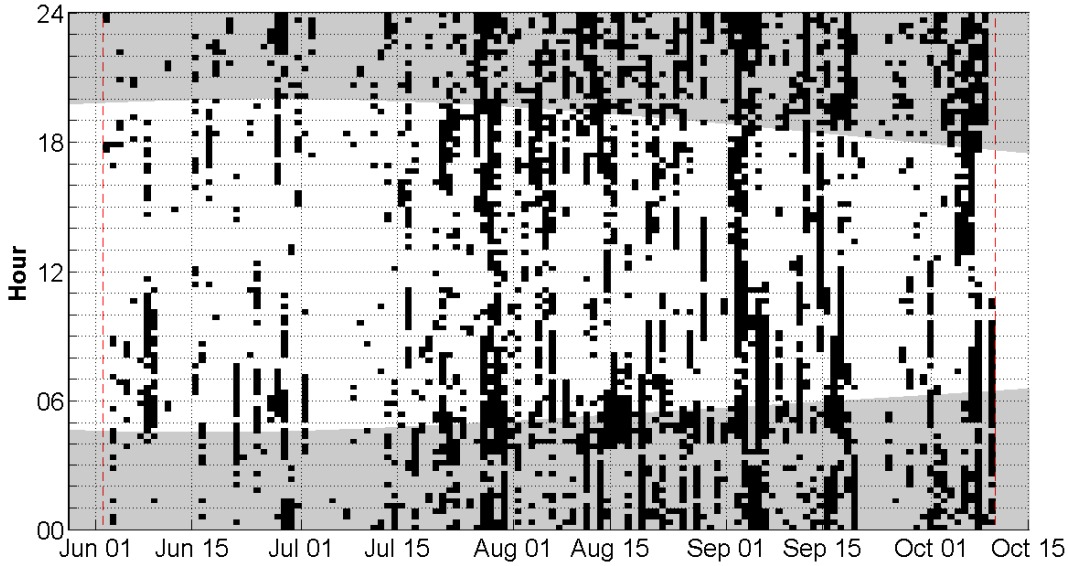


Figure 37. Daily and hourly occurrence of dolphin whistles recorded in the Flemish Pass from 2 Jun to 9 Oct 2014. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

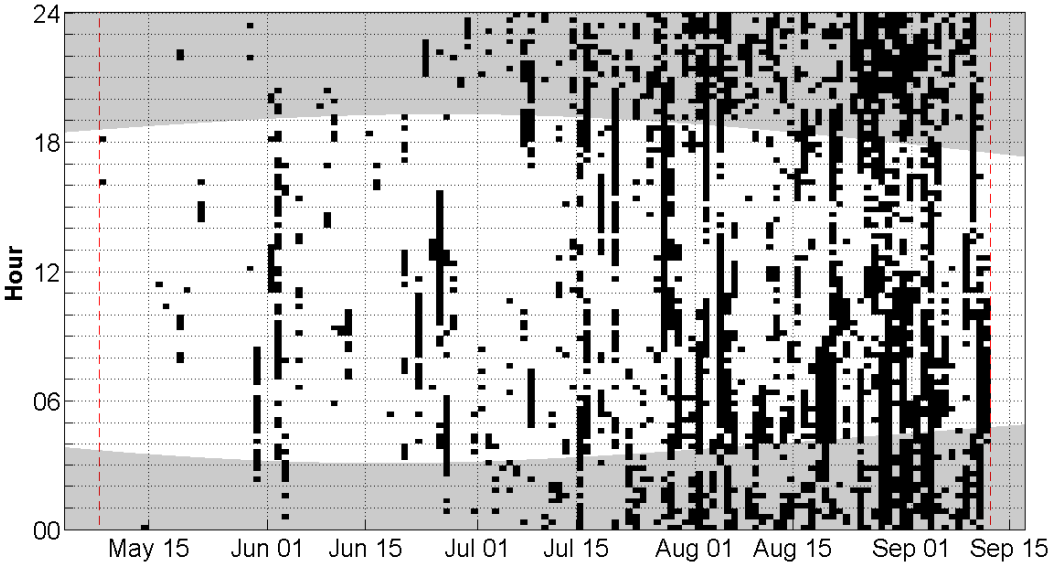


Figure 38. Daily and hourly occurrence of dolphin whistles recorded in the Flemish Pass from 9 May to 11 Sep 2015. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

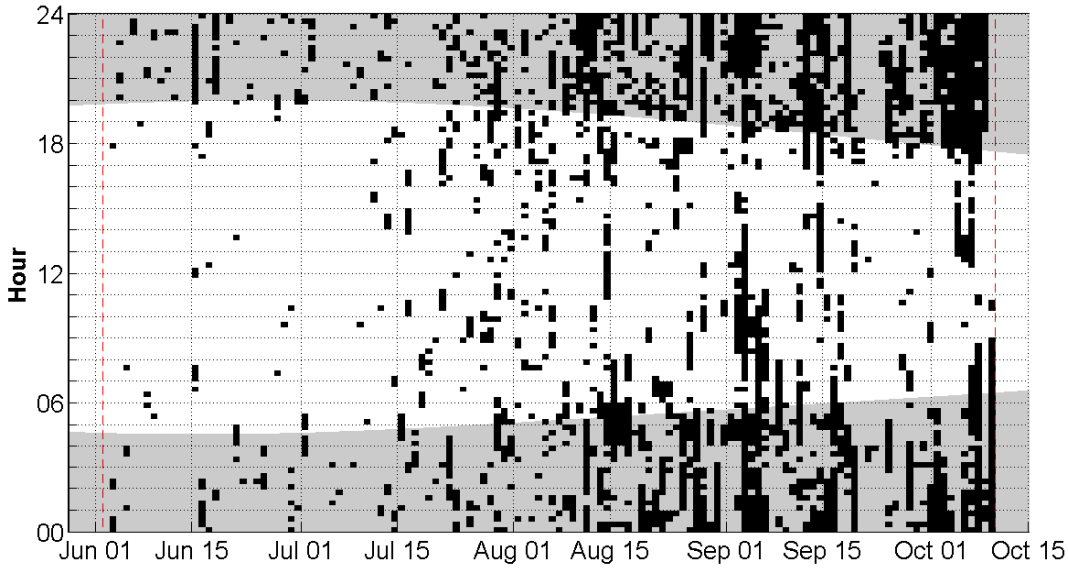


Figure 39. Daily and hourly occurrence of dolphin clicks recorded in the Flemish Pass from 2 Jun to 9 Oct 2014. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

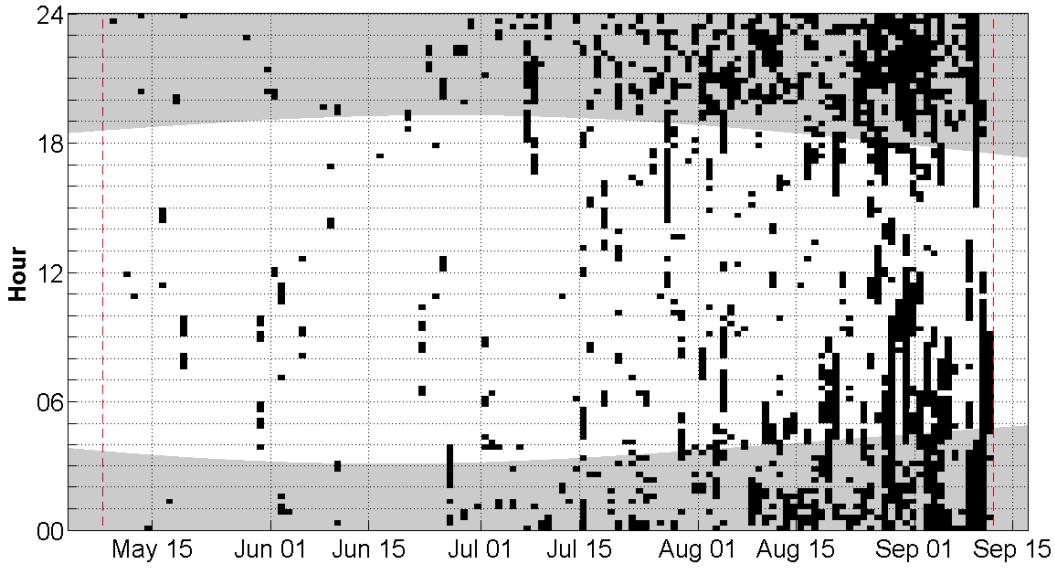


Figure 40. Daily and hourly occurrence of dolphin clicks recorded in the Flemish Pass from 9 May to 11 Sep 2015. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

3.4.2.3. *Sperm Whales*

Sperm whale clicks (Figure 41) were detected consistently throughout the study period in both years (Table 13, Figures 42 and 43). Sperm whale detections were expected in the deep waters of the Flemish Pass along the shelf break. Sperm whale clicks were accurately classified (P = 80%), but the results underestimate the true presence of the species, as the detector missed over 50% of clicks. This could be the result of the high-frequency targeted by the detector (centre frequency ≥8 kHz), whereas most clicks were faint (<8 kHz) or masked by anthropogenic noise.

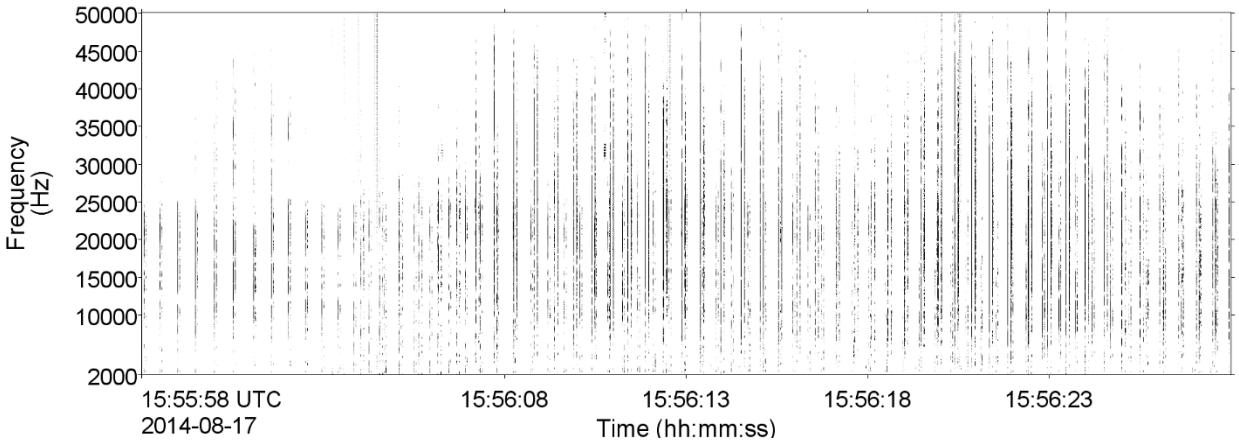


Figure 41. Spectrogram of sperm whale clicks recorded on 17 Aug 2014 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window). The window length is 30 s.

Table 13. Sperm whales: Summary of automated acoustic detections.

Year	Deployment	First detection	Last detection	Record end	Number of days with manual detections	Number of detections
2014	2 Jun	3 Jun	6 Oct	9 Oct	37	6,517
2015	9 May	9 May	10 Sep	11 Sep	37	6,089

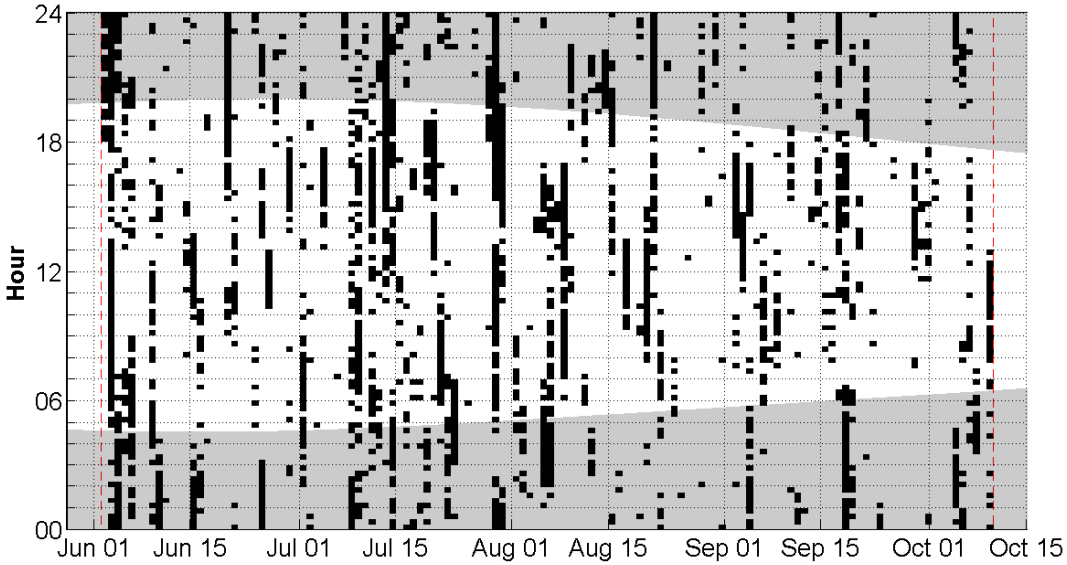


Figure 42. Daily and hourly occurrence of sperm whale clicks recorded in the Flemish Pass from 2 Jun to 9 Oct 2014. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

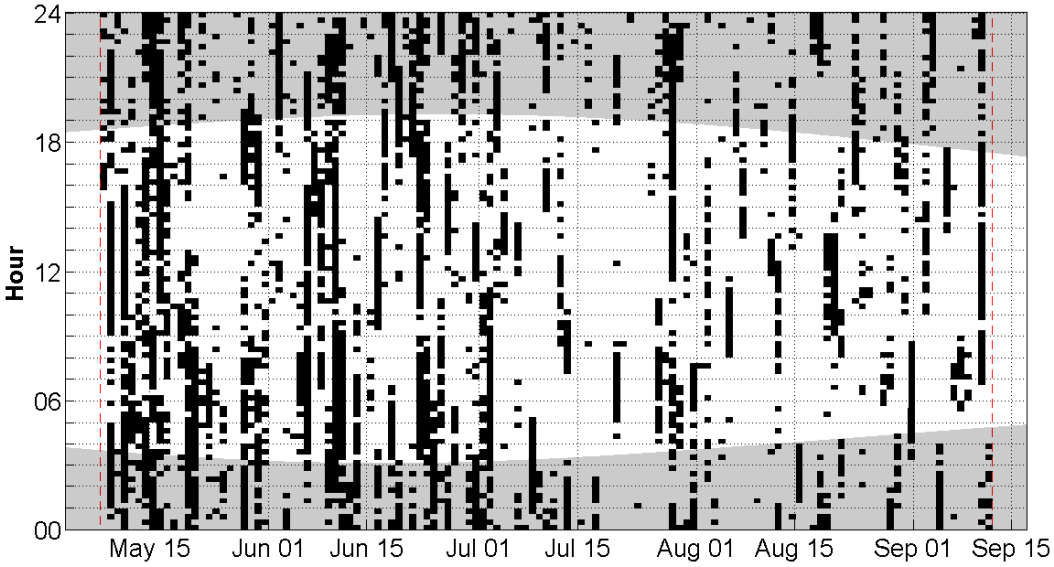


Figure 43. Daily and hourly occurrence of sperm wale clicks recorded in the Flemish Pass from 9 May to 11 Sep 2015. Shaded areas indicate periods of darkness. The red dashed lines indicate AMAR deployment and retrieval dates.

3.4.3. Mysticetes

3.4.3.1. *Blue Whales*

Infrasonic blue whale calls were manually detected in the Flemish Pass in both years of the study (Figure 44) (Mellinger and Clark 2003). This call type is produced in late summer, fall, and winter. Calls were detected on 7 Aug and 2 Oct 2014 (Table 14). While most automated detections occurred in mid-May through mid-June during the 2015 deployment, none of these calls were validated as truly produced by blue whales. Seismic and vessel noise triggered the detector, thus, only manual validated results are presented here. Validated detections occurred on 2 Sep and ended 10 Sep 2015 (Table 14).

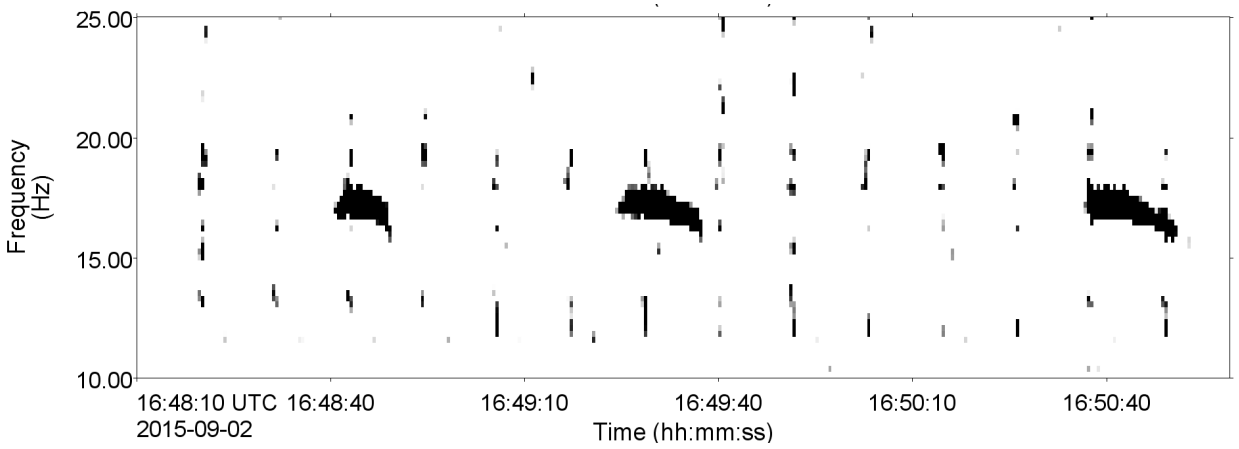


Figure 44. Spectrogram of blue whale infrasonic moans recorded on 2 Sep 2015 (0.4 Hz frequency resolution, 2 s time window, 0.5 s time step, Hamming window).

Table 14. Blue whales: Summary of manually validated acoustic detections.

Year	Deployment	First detection	Last detection	Record end	Number of days with manual detections
2014	2 Jun	7 Aug	2 Oct	9 Oct	2
2015	9 May	2 Sep	10 Sep	11 Sep	3

3.4.3.2. *Fin Whales*

A low number of fin whale calls were manually detected, as the detector was falsely triggered by seismic noise during the study period and some calls were likely masked by these same noises. Fin whale calls were detected on 3 Jun 2014 and occurred sporadically in Aug (22) and Sep (5–8) 2015 (Table 15). The 20-Hz notes detected in late summer to early fall coincided with the beginning of the period associated with song production (Figure 45) (Watkins et al. 1987).

Table 15. Fin whales: Summary of manually validated acoustic detections.

Year	Deployment	First detection	Last detection	Record end	Number of days with manual detections
2014	2 Jun	3 Jun	3 Jun	9 Oct	1
2015	9 May	22 Aug	8 Sep	11 Sep	5

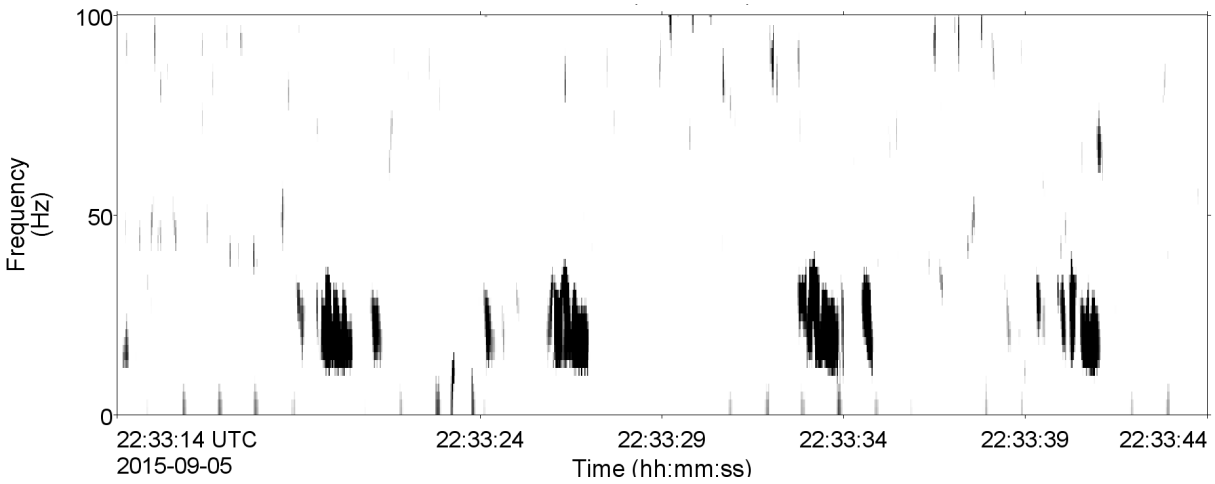


Figure 45. Spectrogram of fin whale 20 Hz notes recorded on 5 Sep 2015 (2 Hz frequency resolution, 0.128 s frame size, 0.032 s time step, and Hamming window).

4. Discussion and Conclusion

4.1. Identifying the Effects of Drilling Operations and Seismic Surveys on the Measured Sound Levels

The data collected at CM2 provide an opportunity to analyze the sounds generated by a semi-submersible drilling operation and seismic surveys. In Figure 46 the mean power spectral density for ESRF STN 19 from 15 Nov 15 – 1 Jun 16 is provided as a baseline for deep water sound levels in the general area of the Flemish Pass. The seismic signature from CM2 in 2014 is 30-35 dB above this baseline up to 100 Hz, and remains 10 dB above the baseline even at 4 kHz. This result is typical for an area within 10-100 km from a seismic survey. A single day's mean power spectral density from 7 Oct 2014 during which there was no seismic surveys or close passes of vessels is also provided. This curve closely follows the baseline, which indicates that ESRF STN 19 is a good proxy for the conditions in the Statoil 2014-2016 drilling area and that differences in recording depth did not affect our ability to compare the measurements.

The period of 25 May – 17 June 2015 was selected as representative of the sounds from the semi-submersible drilling operation in the absence of seismic surveys (see Figure 16). The mean power spectral density for this period exceeds the baseline in the frequency range of 30 – 2000 Hz, with two notable tones at 200 Hz and 290 Hz that were also barely detectable in the baseline (see Figure 16, Figure 18 and Figure 46). A third tone at 120 Hz may be associated with the power generation systems on the semi-submersible drill rig. To further compare the sound levels, a box-and-whisker plot of the decade band SPL from 100-1000 Hz is provided (Figure 47). The mean sound levels from the semi-submersible drill rig were 13 dB above the baseline, while the seismic was 25 dB above baseline in this band.

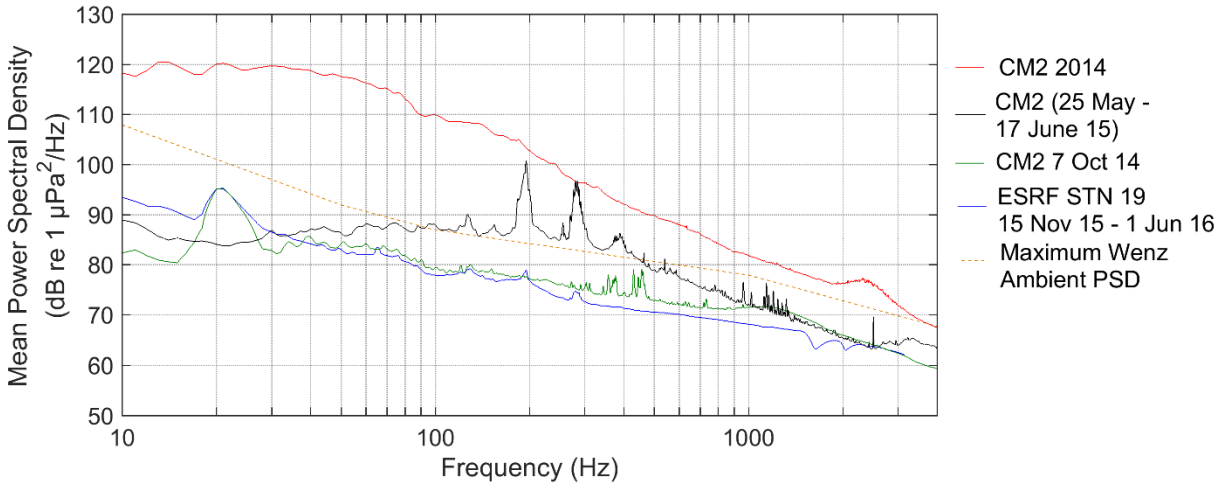


Figure 46. Mean power spectral densities for the complete CM2 2014 data set and three data sets without seismic: CM2 on 7 Oct 14, CM2 2015 for the period of 25 May – 17 Jun 15 and ESRF STN 19 for 15 Nov 15 – 1 Jun 16.

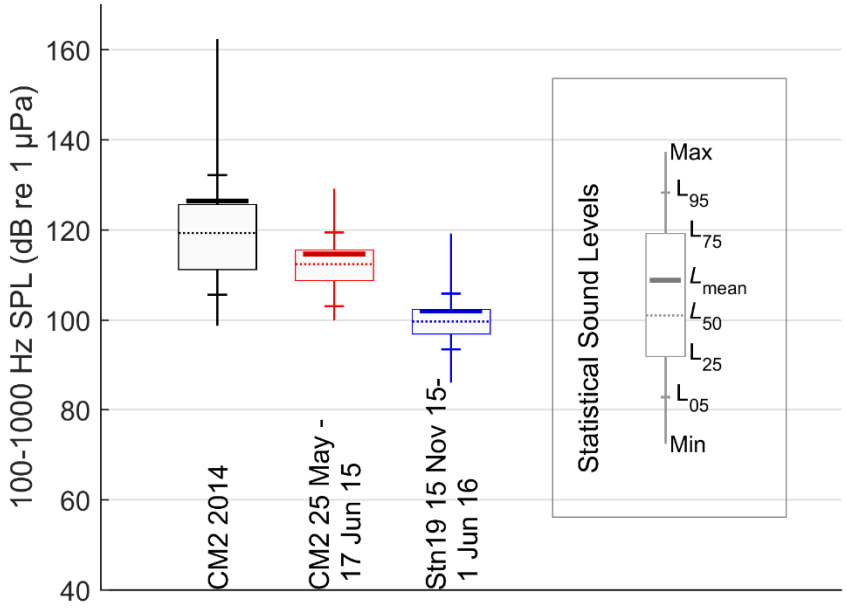


Figure 47. Comparison of the 100-1000 Hz SPLs for all of the CM2 2014 data, CM2 2015 for three weeks without seismic, and ESRF STN 19 without seismic.

JASCO previously measured the sound levels from the Stena IceMax drill ship during Shell Canada's drilling at the Monterey Jack well site (MacDonnell and Martin, 2017). This rig had six Rolls-Royce UUC-505 5,500 kW dynamic positioning thrusters. This rig has a similar shape to it's power spectral density signature, but without the distinct tones at 200 and 290 Hz (Figure 48). The broadband source level of the Stena IceMAX was computed to be 187.7 dB re 1 µPa. Based on the current results and a conservative estimate of the propagation loss differences between the Stena IceMAX measurement and the CM2 location, the *West Hercules* likely has a similar source level. Detailed acoustic modeling could be performed in the future to estimate a more accurate source level if required.

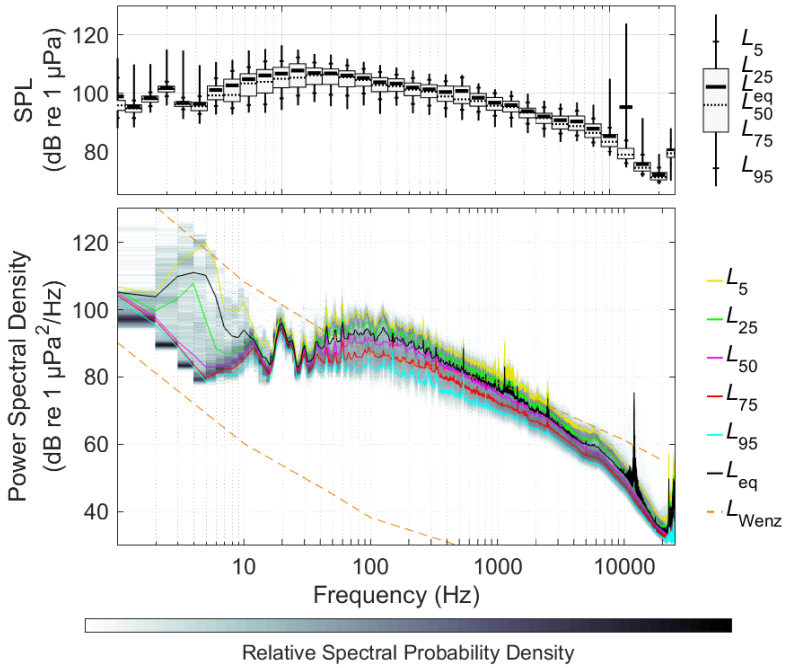


Figure 48 . Power Spectral density plot from 1 day of data collected 2800 m slant range from the Stena IceMAX (MacDonnell and Martin, 2017).

4.2. Marine Mammals

The acoustic detections of marine mammals presented in this report provide an index of acoustic occurrence for each species. They do not represent the number of individuals present at the time of detections. An absence of detections could be the result of an absence of animals, individuals near the acoustic recorders not vocalizing, masking of calls by environmental or anthropogenic noise sources, or a combination of these factors. We compare the acoustic occurrence of each species in the context of noise conditions and their effect on the detectability or masking of calls. Seasonal variations in marine mammal calling behaviour, which may falsely suggest changes in occurrence, are also discussed.

4.2.1. Odontocetes

4.2.1.1. Northern Bottlenose Whales

Two northern bottlenose whale populations occur off eastern Canada (Dalebout et al. 2001): an endangered, well-studied population in the Gully and adjacent canyons (Whitehead et al. 1997, Gowans et al. 2000, Wimmer and Whitehead 2004) and a larger, predominantly unstudied population off the northeast Grand Banks, Labrador, and in the Davis Strait. The boundary between these two populations is unclear (Dalebout et al. 2001). A recent study (ESRF unpublished data) confirmed that northern bottlenose whales are present year-round along the shelf break, particularly north of the Flemish Cape and off the southern Labrador coast.

Detections were infrequent, but they do confirm that northern bottlenose whales are in the Flemish Pass throughout the summer and early fall. Northern bottlenose whale detections occurred simultaneously with seismic surveys. Similarly, the concurrent detections of the northern bottlenose whales and active seismic exploration has been previously noted in the study area (ESRF unpublished data).

4.2.1.2. *Dolphins*

Dolphin whistles were the most prevalent tonal acoustic signals in the data. We could not determine the species due to the limited manual validation performed and the lack of detailed whistle descriptions for the species potentially involved. Based on the results from previous aerial surveys (Lawson and Gosselin 2011), the species likely responsible for most of the detections are white-beaked, white-sided, and short-beaked common dolphins.

The white-beaked dolphin is the northernmost species included in this group (Mercer 1973). Their habitat is characterized by shallow depth and low water temperatures (MacLeod et al. 2007). In eastern Canadian waters they have been observed in winter and spring off Newfoundland and in summer off Labrador (Mercer 1973, Reeves et al. 1998). They are regularly observed in summer in the Strait of Belle Isle (Kingsley and Reeves 1998). White-beaked dolphins were the most abundant dolphin species recorded in the Newfoundland-Labrador strata during the 2007 TNASS aerial surveys (Lawson and Gosselin 2011).

Atlantic white-sided dolphins are known to occur in the study region (Mercer 1973). The northern limit of these species is presumably linked to that of white-beaked dolphins. As white-beaked dolphins retract to the more northern part of the east coast waters, tracking the movement of colder waters, white-sided dolphin likely expand their range to the north in summer. Their abundance was second to that of white-beaked dolphins and common dolphins in the Newfoundland-Labrador and Scotian shelf-Gulf of St. Lawrence strata of the 2007 TNASS surveys, respectively (Lawson and Gosselin 2011).

Short-beaked common dolphins prefer warmer, more saline waters than Atlantic white-sided dolphins, and they tend to inhabit the edge of the continental shelf (Selzer and Payne 1988, Gowans and Whitehead 1995). However, these species often inhabit the same area when an abundance of prey is present. Off eastern Canada, they occur mostly in summer and fall in slope waters of the Scotian Shelf and southern Newfoundland, as well as near prominent bathymetric features such as the Flemish Cape (Jefferson et al. 2009). Common dolphins were by far the most common dolphins sighted in the Scotian Shelf-Gulf of St. Lawrence strata during the 2007 TNASS surveys (Lawson and Gosselin 2011).

It is unlikely, but possible that Risso's, striped, and bottlenose dolphins are present the study area. Their relative contribution to the dolphin acoustic detections is unlikely or very limited.

Click detections followed a strong diel pattern. Detections occurred almost exclusively at night, which reflects the night-time foraging of dolphins that takes advantage of the diel vertical migration of their prey species (Au et al. 2013). Species-specific identification using clicks remains challenging due to the overlap in click characteristics and lack of published description, especially for dolphins.

4.2.1.3. *Pilot Whales*

The range of pilot whales extends in the western North Atlantic from the United States to Greenland (Abend and Smith 1999). Gowans and Whitehead (1995) reported them on the Scotian Slope, and (Sergeant 1962) reported them in Newfoundland waters. The 2007 TNASS surveys estimated the population size for the Scotian Shelf-Gulf of St. Lawrence strata at ~16,000 individuals (Lawson and Gosselin 2011). In a previous study (ESRF unpublished data), acoustic detections were more focused at stations along the continental slope, a known preferred habitat where pilot whales (Payne and Heinemann 1993) forage on long-finned squid (*Lollgo pealei*), among other species (Gannon et al. 1997, Aguilar Soto et al. 2009). In the current study, pilot whales were detected infrequently, suggesting that the animals may be less abundant in this specific region during the summer and early fall, or less vocally active. Because pilot whale calls have tonal components (pulsed calls and whistles) that can be reliably distinguished from dolphin whistles on the basis of frequency, the results presented here are believed to accurately describe the occurrence of this species.

4.2.1.4. *Sperm Whales*

Sperm whales are widely distributed in the Atlantic Ocean, including the present study region. In eastern Canada, they prefer areas near the continental slope although they have been occasionally encountered in shallow areas of the Scotian Shelf (Whitehead et al. 1992). Sperm whales in eastern Canadian waters appear to be exclusively males, with the possible exceptions of areas near the US-Canada border (Reeves and Whitehead 1997). Females remain at lower latitudes year-round, while males migrate between higher latitudes feeding grounds in the summer and lower latitude to breed in winter (Whitehead 2002). In the current study, sperm whales were acoustically detected throughout summer and early fall, in both 2014 and 2015. The almost continuous detections presented here confirm the importance of the Flemish Pass and continental slope area for this species.

4.2.2. Mysticetes

4.2.2.1. *Blue Whales*

Blue whale calls were infrequent, occurring only on two days in the late summer to early fall of 2014 and three days during the beginning of September in 2015. Besides localized, well-studied, summer concentrations, such as the Gulf of St. Lawrence (Sears and Calambokidis 2002), the distribution and movements of endangered blue whales off Atlantic Canada and in the north Atlantic in general remain poorly understood (Reeves et al. 2004). Some of these detections may be from individuals foraging in the Davis Strait in summer and migrating south in fall (Sears and Calambokidis 2002). In most areas of the North Atlantic, peak song detections occur in December and January, with a sharp decline in February and March (Charif and Clark 2000, Clark and Gagnon 2002, Nieukirk et al. 2004). The idnetificaion of blue whale calls is reliable; therefore, some blue whale calls in this area may have been masked by seismic and vessel noise and the detections presented here offer a mininum estimate of acoutic occurence.

4.2.2.2. *Fin Whales*

Previous results (ESRF unpublished data) indicate that the Grand Banks is an important area for fin whales, particularly in fall and winter. Our sparse detections in the early fall are consistent with these results, and with the fin whales' known preference for shelf break and deep water habitats. An ongoing analysis of songs suggest that at least three acoustic populations, characterized by different song structure (Hatch and Clark 2004, Delarue et al. 2009), occur in Canadian waters. One occurs in the Gulf of St. Lawrence, eastern Scotian Shelf and southern Newfoundland; a second is found in the Bay of Fundy, western Scotian Shelf and farther south; the third one prefers areas on the Grand Banks and off Labrador (Delarue et al. 2009; Delarue, unpublished data). Fin whale produce loud sequences of low-frequency notes (~20 Hz) repeated every 9–15 s for hours at a time (Watkins et al. 1987). This calling behaviour translates into a high detection probability. The lack of detections during the study period may not represent the number of individuals in the area, rather some calls may have been masked by seismic noise and various other low-frequency noises.

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APPENDIX E

Trajectory Modelling in Support of the Statoil Exploration Drilling Project
(RPS 2017)

Trajectory Modelling in Support of the Statoil Exploration Drilling Project

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Release	File Name	Date Submitted	Notes
Final	Statoil – RPS Technical Report_20171010.docx	10/10/2017	RPS Draft final version of report following Statoil review
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Draft	Statoil – RPS Technical Report_20170828.docx	08/28/2017	RPS Internal Draft version of report

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Executive Summary

Oil release trajectory and fate modelling were performed to support an Environmental Impact Statement (EIS) for Statoil Canada Ltd. Flemish Pass Exploration Drilling Project. The Project Area includes portions of the easternmost edge the Flemish Pass, as well as the northwestern portion of the Flemish Cap along the Sackville Spur. Modelling was performed at representative sites that were located approximately 300 km east of the Newfoundland Coast, with exploratory drilling anticipated in waters that range in depth from <1,000 m to >3,000 m. Hypothetical continuous unmitigated subsurface blowout scenarios of Bay du Nord crude oil (BdN – a representative crude oil for this region) were developed at two locations including the Eastern Flemish Pass (EPA), and the Northern Flemish Pass (NPA) sites. The water depths are approximately 1,100 m for EPA and 2,700 m for NPA. Unmitigated subsurface blowouts of Bay du Nord (BdN) oil were modelled as continuous releases for 113 days at EPA and 36 days at NPA, which were both simulated for 160 days. The 36-day release represents the successful mobilization and implementation of a capping stack to contain a release, while the 113-day release represents the necessary time to drill a relief well. Modelled release rates and associate volumes varied by location, with the largest release at EPA (15,000 m^3/day totaling 1,695,000 m^3), which was approximately ten times greater than the volume at NPA (4,908 m^3/day totaling 179,280 m^3). These estimated volumes of hydrocarbons released in the subsurface blowout scenarios are conservative (i.e. high) based on the current knowledge of subsurface properties and potential blowout scenarios. These scenarios represent the range of water depths, release rates, and the potential time required to contain a release. In addition, batch spills were modelled as instantaneous unmitigated surface releases of 100 L and 1,000 L of marine diesel at both sites and simulated for 30 days. All releases were modelled without any countermeasures applied (i.e. unmitigtated).

In order to reproduce the dynamic and complex processes associated with deep subsea blowout releases, two models 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 is used to characterize the size and distribution of oil droplets, including the associated mass of oil being released at specific water depths, where the plume became neutrally buoyant. The output data from OILMAPDeep is used to initialize the SIMAP model, which simulates the far-field trajectory, fate, and potential exposure in the marine environment following a release.

Geographical data including habitat mapping and shoreline identification and classification were obtained from multiple data sources. For Canadian areas, data from the New Brunswick Department of Natural Resources and Nova Scotia Department of Natural Resources were used. 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 from the were used. 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 for the period January 2006 through December 2010 for the North Atlantic region. HYCOM is a primitive-equation ocean general circulation model that evolved from the Miami Isopycnic-Coordinate Ocean Model (MICOM). MICOM has become one of the premier ocean circulation models, having been subjected to several validation studies. 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, it is believed that the data that was used is sufficient for this type of modelling. Wind data for this study were obtained from the U.S. National Centers for Environmental Prediction Climate Forecast System Reanalysis (CFSR) model. All data was acquired for the period between 2006 and 2010.

A stochastic analysis was conducted for each release location, consisting of 119 individual model runs per scenario. Each run was initialized with a different start date/time between 2006-2010 to sample a range of environmental conditions. The dates and times were selected randomly from within 14 day intervals spanning the entire five years of data. Results of the stochastic analysis included probability footprints above specified thresholds and minimum time to oil exposure. Because the runs spanned five full years and included all of the associated seasonal variability, the complete set was referred to as annual summaries. To investigate seasonality, individual runs within the stochastic analysis were classified as either summer or winter, depending on whether the majority of the days within the modelled 160-day period had the presence (winter) or absence (summer) of ice cover.

Representative deterministic scenarios (i.e., single trajectory) were identified from each set of stochastic subsurface blowout results. Individual scenarios were selected based upon the size of the surface oil footprint, the mass of oil on shorelines, and the concentration of dissolved hydrocarbons in the water column, based upon a set of highly conservative socio-economic thresholds:

- Surface oil average thickness >0.04 µm
- Shore oil average concentration >1.0 g/m^2
- Subsurface (within the water column) dissolved hydrocarbon concentrations >1.0 µg/L.

The selected scenarios included the identified 95th percentile runs for surface oil footprint, shoreline oil length, and water column contamination identified for each release location. Because there was such limited predicted contact with shorelines, the 98th percentile shoreline oil length scenario was used. In addition to these six deterministic scenarios, four surface releases of marine diesel were modelled as batch spills, including two release volumes (100 L and 1,000 L) at both release locations.

It is important to note that although large footprints of oil contamination 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 given threshold passing through each grid cell location in the model domain over the entire model duration (160 days), based on the entire ensemble of runs (119 individual releases for both locations). Only probabilities of 1% or greater were included in the map output, as lesser probabilities represent random noise in each set of 119 trajectories. Stochastic maps of water column contamination of dissolved hydrocarbons depict the likelihood that concentrations will exceed the identified threshold at any depth within the water column, but do not specify the depth at which this occurs and do not imply that the entire water column (i.e., from surface to bottom) will experience a concentration above the threshold.

Stochastic results are useful in planning for oil spill response, as they characterize the probability that regions may experience contamination above specified thresholds, taking into account the environmental variability that is expected from many potentially-different release scenarios over time. Stochastic footprints for potential surface oil exceeding a thickness of 0.04 µm were between 2,235,000 and 2,751,000 km^2. These footprints depict areas with the highest predicted likelihood of potential oil contamination to the east of the release sites, with a much lower probability (1-10% and 10-25%) for oil to be transported to the west towards Canadian waters. While these areas are quite large, most of this footprint represents a relatively low probability (<10%) of surface oil thickness >0.04 µm. Footprints depicting higher probability contours (90%) yield only a fraction of the total footprint, ranging from 81,630 to 586,600 km^2 depending on the scenario.

Seasonal variations were evaluated yielding different predicted surface oil results for summer versus winter scenarios. Substantially larger surface oil footprints associated with >90% probability contours were predicted for summer scenarios at both sites indicating more coherency in the release, while larger footprints associated with >1% probability occurred during winter scenarios for both sites associated with more extensive and variable transport.

The highest predicted potential (1-2%) for oil to make contact with shorelines exceeding 1 g/m^2 occurred in winter scenarios, with summer conditions typically resulting in substantially less, if any

contact with shorelines after 160 days. For releases at EPA, oil was predicted to reach Sable Island with a low probability (1-2%) during the summer season. During the winter season, oil was predicted to reach the southeastern and northern coasts of Newfoundland. The oil that was predicted to make it to shorelines is expected to be highly weathered, patchy, and discontinuous, as minimum time estimates for first shoreline oil exposure range from approximately 78-158 days, depending on the specific modelled scenario within the stochastic analysis. There was no predicted shoreline contact from the releases at NPA. Modelled oil from these subsurface releases had a higher potential to be transported to the west and southwest prior to surfacing, where surface currents and winds typically carried releases further offshore.

Individual trajectories of interest were identified and selected from the stochastic ensemble of results for deterministic analysis. The identified simulations represented the 95th percentile for exposure area to surface oil, mass of oil in the water column, and length of shoreline contacted. For most representative deterministic scenarios, the amount of oil remaining in surface waters or on sediments at the end of the 160-day simulation was less than 1%. Entrainment into the water column ranged between 7% and 12%. Shoreline contact was minimal for these simulations, where even the 95th percentile shoreline contact case was predicted to have less than 0.001% of the total volume of released oil reaching shore.

The amount of evaporation and degradation was relatively consistent between model runs. Approximately 40 - 45% of the BdN oil releases was predicted to evaporate and another 40-45% to degraded by the end of the 160-day simulation. Most of the variability in the mass balances were associated with the amount of oil found either on the surface or entrained within the water column. There was little to no surface or shoreline oil at the end of the 160-day simulations, while the remaining amount entrained in the water column was predicted to range from 6.5-12%.

Accidental discharges from small volume instantaneous batch spills of marine diesel resulted in little predicted contamination. By the end of the 30-day simulations, 75-78% of the released diesel was predicted to evaporate and 14-17% degrade. A small portion of highly weathered diesel may continue to be transported at the surface or in the water column for some distance. None of the marine diesel batch spills were predicted to reach the shoreline.

It is understood that the hypothetical releases modelled in spill trajectory modelling studies are in no way intended to predict a specific future event. Rather, they are used as a planning tool for use 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 may result following a release of crude oil based upon the environmental variability that may occur over the course of a year or many years. If there were any event such as a subsurface blowout or topside release, it is likely that a different

volume of oil may be released from a different location than modelled here. While it is impossible to know the exact trajectory and fate of an oil releases in the future, inferences may be made from this study.

The goal of the modelling study is to provide probabilities for various potential spill effects (based upon identified thresholds) such as the shortest time to shoreline oiling, maximum oil concentration in the water column, and maximum water surface oiling. Each of those endpoints is then represented by a single highly conservative deterministic model run. The goal of this work is to identify shorelines that have resources that are at risk and to determine how much time is available to protect them. Therefore, very low probability spill events are used to, and then used to identify even lower probability credible "worst case" (i.e. highly conservative subset of all modelled scenarios) as the basis for spill planning and preparedness.

Document Summary

This report includes an introduction describing the region, the modelling approach, the methodology, and finally 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 oil contamination within the water column, on the water surface, and along shorelines. This document is broken down into several sections. Section 1 includes an introduction to the modelling study. Section 2 includes a description of project area, modelling approach with the OILMAPDeep and SIMAP models, scenarios, and uncertainty. Section 3 contains a description of the model input data. Section 4 summarizes the stochastic and deterministic oil trajectory and fate model results. Section 5 summarizes conclusions and discussion points. Section 6 contains the references cited. Additional information may be found in supporting Appendix A, which provides a detailed description of the OILMAPDeep and SIMAP models, fates processes, and algorithms used.

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List of Acronyms and Abbreviations

3D: Three dimensional, referring to the vertical and horizontal, as in x, y, and z directions

AL: Aliphatic portion of the total hydrocarbon, which is modelled as a volatile but insoluble fraction within the SIMAP model and can therefore evaporate.

AR: Aromatic portion of the total hydrocarbon, which is modelled as a volatile and soluble fraction within the SIMAP model and can therefore evaporate and dissolve.

BAOAC: Bonn Agreement Oil Appearance Code

BdN: Bay du Nord crude oil

BTEX: Benzene, toluene, ethylbenzene, and xylene

CERCLA: The U.S. Superfund or Comprehensive Environmental Response, Compensation, and Liability Act of 1980

EIS: Environmental Impact Statements

EPA: Eastern Flemish Pass hypothetical release location

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

MAH: Monocyclic aromatic hydrocarbons (monoaromatic), with only one six carbon ring

MICOM: Miami Isopycnic-Coordinate Ocean Model

NCODA: U.S. Navy Coupled Ocean Data Assimilation

NOAA: U.S. National Oceanic and Atmospheric Administration

NPA: Northern Flemish Pass hypothetical release location

NRC: U.S. National Research Council

NRDA: The U.S. Natural Resource Damage Assessment

NRDAM/CME: Natural Resource Damage Assessment Model for Coastal and Marine Environments

PAH: Polycyclic aromatic hydrocarbons (polyaromatic), with two or more six carbon rings

PPB: Part per billion, as referring to concentration. Roughly equivalent to µg/L

PPM: Part per million, as referring to concentration

SIMAP: Release Impact Model Application Package, a 3D trajectory and fate model developed by RPS

THC: Total hydrocarbon concentrations

UNESCO: United Nations Educational, Scientific, and Cultural Organization

WOA: World Ocean Atlas, a database from NODC NOAA containing observational data of physical and chemical parameters of seawater from many thousands of cruises.

1 Introduction

RPS (previously Applied Science Associates, Inc.) conducted trajectory and fate modelling in support of an Environmental Impact Statement (EIS) for Statoil Canada Ltd. Flemish Pass Exploration Drilling Project. The EIS Project Area is located approximately 300 km east of the Newfoundland coast, overlapping the Grand Banks, Flemish Pass, and the Flemish Cap. Water depths in the Project Area range from <100 m to >4,000 m. Major currents, including the Labrador Current and the Gulf Stream, influence the circulation and biological productivity in this region.

This modelling was conducted to evaluate hypothetical unmitigated release events associated with exploration drilling, including large scale deep-water blowouts of Bay du Nord (BdN) crude oil from the wellhead at the seafloor and smaller scale batch spills of marine diesel at the surface. 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. RPS' nearfield OILMAPDeep blowout model and the far-field Spill Impact Model Application Package (SIMAP) oil trajectory and fate models were used. This report provides a description of the Project Area and modelled scenarios, an overview of the modelling approach, details about the model input data used, and a presentation and discussion of the modelled 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 Statoil Project Area (49-49.5 °N, 45-46.5 °W) contains portions of the Grand Banks, Flemish Pass, and Flemish Cap, in the northwest sector of the Jeanne d'Arc sedimentary rift basin, east of Newfoundland (Figure 2-1). The area is known to contain substantial petroleum resources. This biologically productive region sits atop the Hibernia, White Rose, and Terra Nova oil fields. Bathymetry in the area ranges from less than 100 m over the Grand Bank to greater than 4,500 m deep in the Labrador Basin. The model domain extends as far west as 72° W and east 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 will be tracked for long periods of time (160 days).

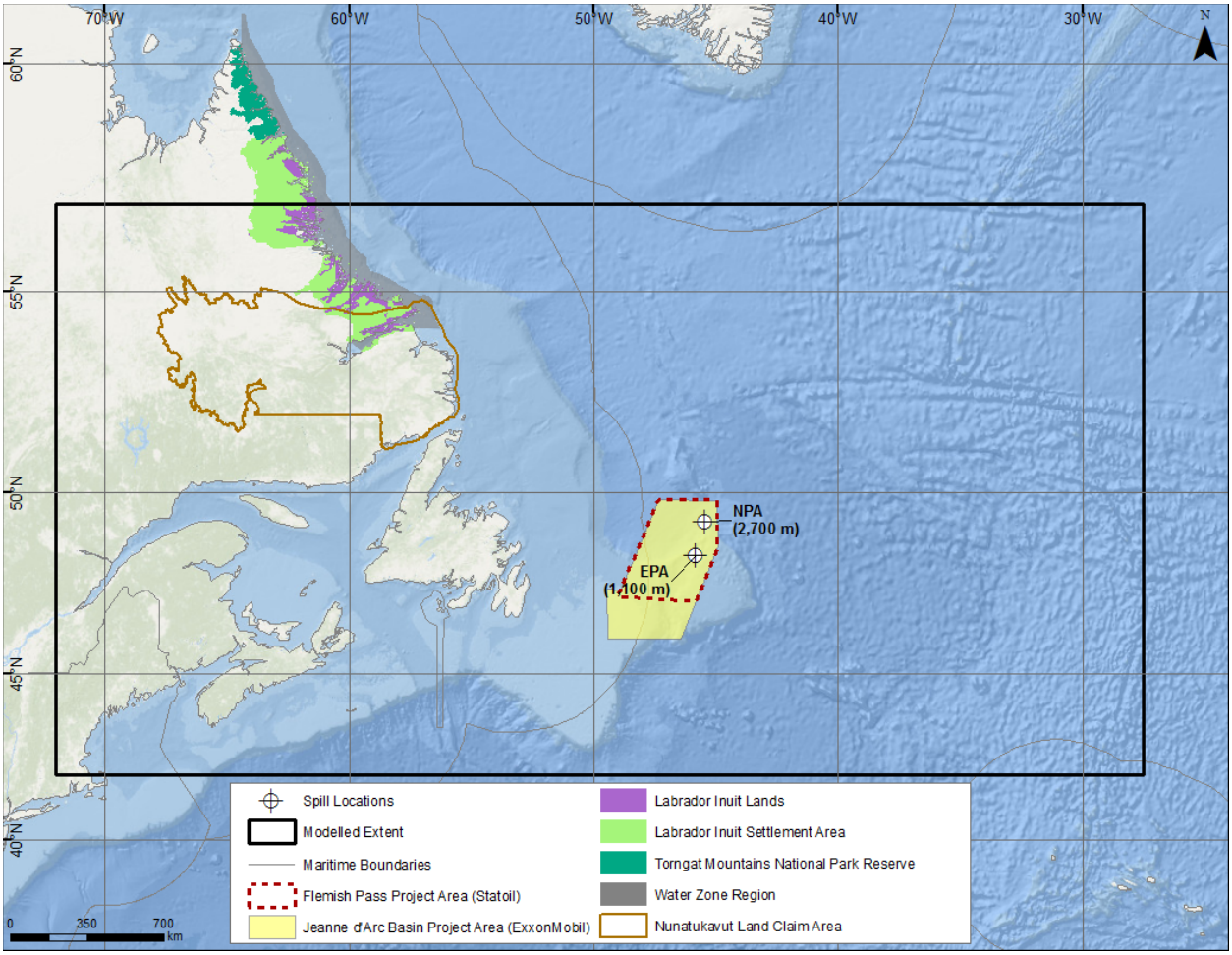


Figure 2- 1. Map of the Project Area, including the two hypothetical release locations and corresponding water depths: Eastern Flemish Pass (EPA) and Northern Flemish Pass (NPA). The black box represents the modelling extent, while the smaller shaded boxes represent the EIS Project Areas.

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 given the range of possible environmental conditions that may occur within and across multiple years. A deterministic analysis provides a view of the time history of the specific movement and behavior of released product from a given (e.g., representative) individual release. Together, these methods provide a more complete view of both the likelihood and degree of potential exposure.

For this report, stochastic information is presented for predicted surface oil thickness, shoreline oil mass, and subsurface contamination for the full year (i.e., annual), and for different seasons with

variable ice-cover conditions (i.e., summer/ice-free and winter/ice-covered). Individual representative deterministic trajectories that characterize single release scenarios are also presented. Stochastic analyses of hypothetical blowouts were modelled at two sites using the physical-chemical properties of the specific oil type that may be released and 5 years of variable environmental data, which are discussed in Section 3. At each location, a total of 119 individual oil release trajectories were modelled throughout the year (55 winter and 64 summer). The duration of each modelled simulation was 160 days. In addition, batch surface spills of marine diesel were analyzed to evaluate potential discharges between surface vessels.

Table 2-1. Site and release information used in the model for the stochastic and deterministic approaches.

Modelling Approach	Spill Location	Depth of Release	Model Duration	Release Duration	Number of Model Runs	Released Product	Release Type	Release Volume
Stochastic and Deterministic	EPA (48.3°N, 45.8°W)	1,100 m	160 Days	113 Days	119	BdN	Subsurface Blowout	1,695,000 Sm^3 (15,000 m^3/day)
	NPA (49.2°N, 45.4° W)	2,700 m		36 Days	119			179,280 Sm^3 (4,980 m^3/day)
Deterministic	EPA (48.3°N, 45.8°W)	Surface	30 Days	Instantaneous	2	Marine Diesel	Batch Spill	100 L & 1,000 L
	NPA (49.2°N, 45.4° W)	Surface		Instantaneous	2			100 L & 1,000 L

2.2.1 Modelling Tools

Hypothetical release scenarios were simulated using the OILMAPDeep blowout model and the SIMAP, oil trajectory and fate model, both developed 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 dynamics of the near-field plume dynamics are modelled to predict the mass, location, and droplet size distribution of the subsurface plume of oil at the termination (i.e., trap) height of the buoyant oil and gas plume, when it becomes diluted enough with surrounding seawater to become neutrally buoyant, based upon the environmental conditions, the specific chemical and physical properties of the oil, and other release parameters. Typically, the near-field model is on the timescale of seconds and length scale of hundreds of meters, whereas the far-field model is on the scale of many hours/days and tens or even hundreds 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, i.e., 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 (i.e., trap height), at which point the plume no longer rises by buoyant forces and the oil contained within the plume escapes to the surrounding water and rises based on the individual buoyancies of the droplets. 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, hydrate formation, and 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 fates processes such as oil rise velocity and dissolution.

For oil discharged during a deep-water blowout, the oil droplet size distribution has a profound effect on how oil is transported and behaves after the initial release as a buoyant plume. The size of the individual droplets dictates buoyancy, which controls the 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 and are subjected to subsurface advection-diffusion processes and are therefore transported for a longer period of time. As oil is transported by subsurface currents away from the release location, natural dispersion of the oil droplets quickly reduces 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. Details of the OILMAPDeep model background theory, inputs, algorithms, and outputs can be found in Appendix A.

SIMAP Model

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 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 fates processes. Oil fate processes included in SIMAP are oil 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 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 to ensure that the data was adequately sampled. This stochastic approach allows 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.

In order 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. Using wind and current data from throughout this long time period, a sufficient number of model runs will adequately sample the variability in the time sequences of wind and current speeds and directions in the region of interest, and will result in a prediction of the probable oil pathways for a release at the prescribed location.

Stochastic analyses provide two types of information: 1) the areas associated with probability of oil exposure at some time during or after a release, and 2) the shortest time required for oil to reach any point within the areas predicted to be exposed above a specified threshold. 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 varying environmental conditions, and thus traveled in different directions. To compute the stochastic results, tens to hundreds of individual trajectories like the four depicted here were overlain and the number of times that each given location throughout the modelled domain was intersected by the different trajectories was used to calculate the probability of oil exposure for each specific location. This process is illustrated by the stacked runs in the right panel of Figure 2- 2. The predicted footprint is the cumulative oil-exposed area for all of the ten to hundreds of 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 be much smaller than the cumulative footprint of all the runs 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.

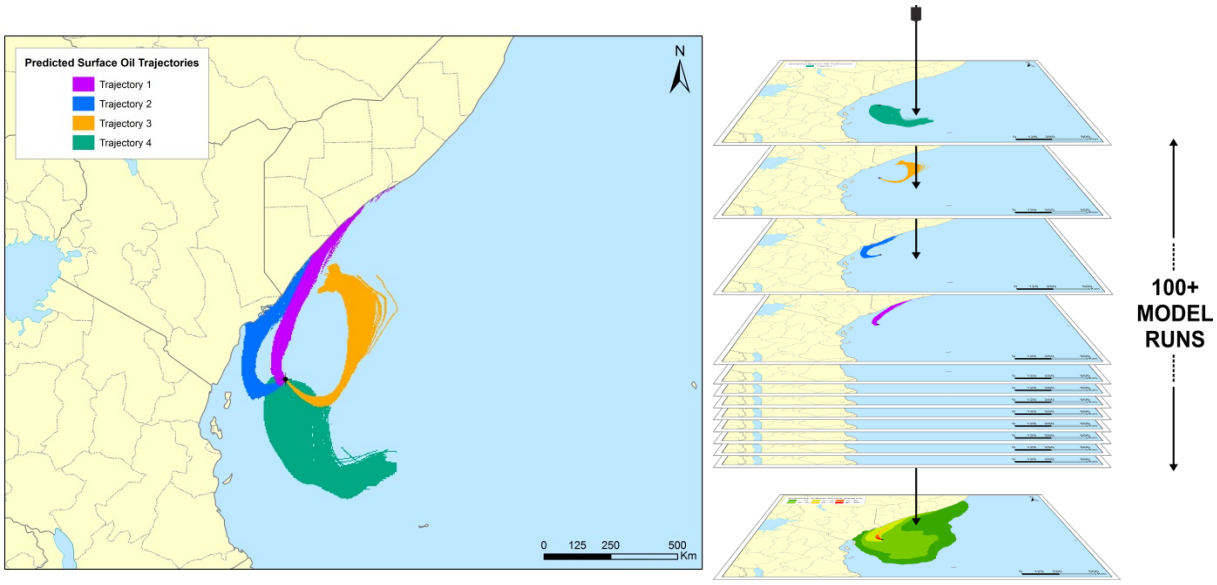


Figure 2- 2. Examples of four individual release trajectories predicted by SIMAP for a generic release scenario simulated with different start dates and therefore environmental conditions. Tens to hundreds of individual trajectories are overlain (shown as the stacked runs on the right) and the frequency of contact with given locations is used to calculate the probability of threshold exceedance during 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 runs 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 increases. Annual footprints result 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 (e.g., 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 runs (10's to 100's of 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 contamination 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 contamination were required (Table 2-2). Above these thresholds, previous studies have identified that there is the potential that negative effects

may occur. Figures and further analyses in this study include the more conservative lower socioeconomic thresholds of concern calculated from stochastic results.

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) of thickness 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, 2016; 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 oils and heavy fuel oils greater than 1 mm thick typically appear as black oil while light fuels and diesels that are greater than 1mm thick may appear brown or reddish. Because of the differences between oils and their degree of weathering, 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 a range of visual appearances including silver sheen, rainbow sheen, and metallic areas simultaneously, as a combination of thicknesses may be present (Figure 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	**Socio-economic:** A conservative threshold used in several risk assessments to determine effects on socioeconomic 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 thickness 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	**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 thickness 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	**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	**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.	May appear as black opaque 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 **socioeconomic** (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 Job Aid (2016) 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

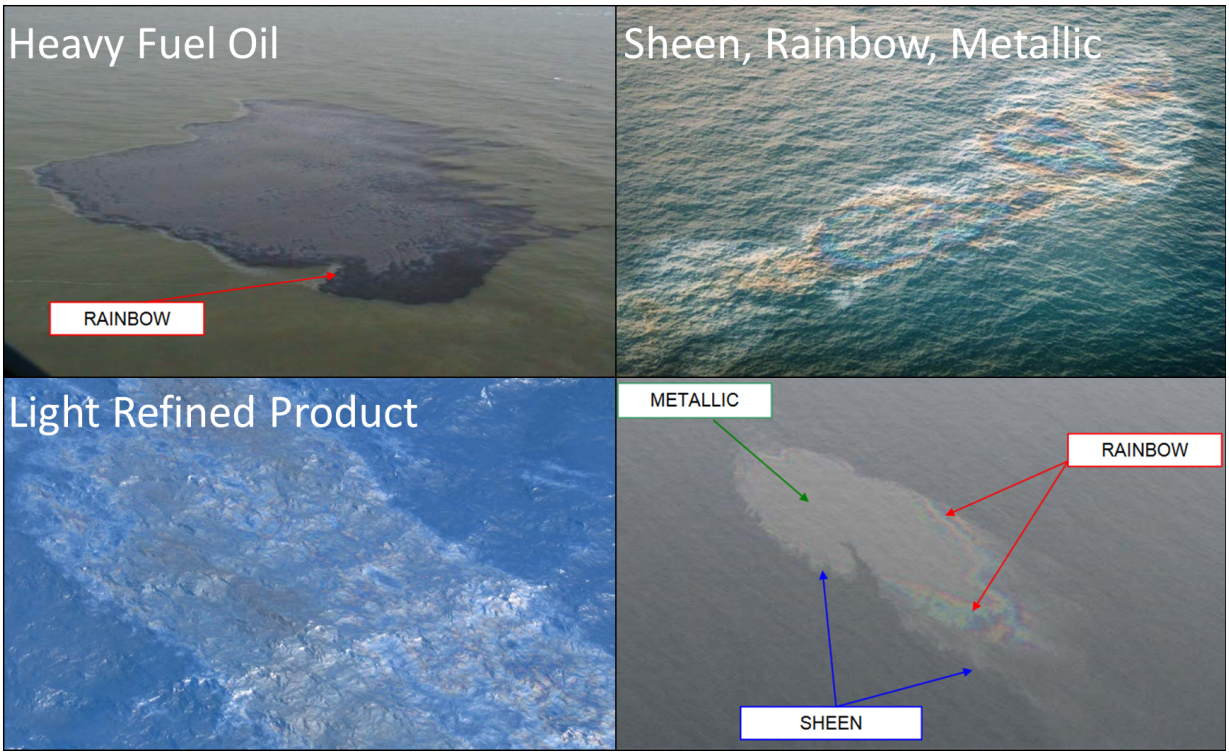


Figure 2- 3. Aerial surveillance images of released oil in the environment as examples of different visual appearances based on surface oil thickness and product type (images from Bonn Agreement, 2011).

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 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 releases given historic wind and current data for the Project Area, the deterministic analysis provides individual trajectory, oil weathering information, expected concentrations or thicknesses of oil contamination, mass balance, or other information related to a single release at a given location and time.

Each single run within a stochastic analysis represents a specific set of wind and current conditions for the modelled time period. When analyzed together, tens to hundreds of stochastic model runs provide a range of expected exposures. The exposures between cases may differ greatly, as the trajectory of each individual modelled release is unique. Therefore, the movement and behavior, as well as the resulting area of surface oil, mass of oil along the shoreline, and mass of oil within the water column, will be different for each modelled simulation. The 95th percentile "worst" case exposures for surface, shoreline, and in-water contamination for each release location were identified based upon the area, length, or mass of oil that was predicted in each environmental compartment of interest (i.e., water surface area, shoreline length, or mass in the water column). In addition, deterministic analyses of batch surface spills of marine diesel at two sites (EPA and NPA) were conducted for small (100 L) and large (1,000 L) spill volumes to evaluate any potential discharges during bunkering operations (i.e. transfer from a vessel) between surface vessels. Scenarios were chosen to occur during the calmest wind-speed period during the summer/ice-free conditions, as they would result in the largest amount of oil on the surface. Each simulation has its own trajectory, mass balance, surface oil thickness, in-water concentration of dissolved hydrocarbons, etc. reported individually.

The results of the deterministic simulations provide 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. 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, mass of shoreline oil, and the maximum concentration of dissolved hydrocarbons in the water column at any instant in time. These results figures are presented in Section 4.2.

2.3 Modelled Scenarios

Two release locations were used for modelling at the Eastern Flemish Pass (EPA) site and Northern Flemish Pass (NPA) sites (Table 2-1; Figure 2- 1). Subsurface blowouts near the seafloor were modelled separately at each location in a stochastic analysis that included 119 individual model runs per location. This analysis investigated the influence of environmental variability, throughout the year over multiple years, on trajectory and fate. Results from stochastic analyses were broken into two seasons depending on the majority of modelled days falling in ice free conditions (summer) from May – October or periods with ice-cover (winter) from November – April. Analysis of representative deterministic scenarios were conducted for individual trajectories that were identified as the 95th percentile for surface oil exposure, contact with shoreline, and water column contamination from blowouts near the seafloor modelled in the stochastic analysis, as well as for instantaneous surface batch spills of marine diesel (Table 2-5).

Table 2-4. Hypothetical subsurface release locations and stochastic scenario information.

Scenario Parameter	Release Locations of Subsurface Blowout Scenarios	
	Eastern Flemish Pass	Northern Flemish Pass
Block	EPA	NPA
Latitude	48° 18' 45.85274	49° 13’ 43.7636
Longitude	45° 49' 41.45009	45° 25’ 5.054
Water Depth of Release	1,100 m	2,700 m
Product	Bay du Nord	Bay du Nord
Release Duration	113 d	36 d
Gas to Oil Ratio	45.9 m^3/m^3	45.9 m^3/m^3
Pipe Diameter	31.1 cm	31.1 cm
Oil Discharge Temperature	79.7°C	
Release Rate	15,000 m^3/d	4,980 m^3/d
Total Released Volume	1,695,000 m^3	179,280 m^3
Model Duration	160 d	
Number of Stochastic Runs	119 annual (55 winter & 64 summer) for each site	

Table 2-5. Selected representative deterministic scenarios.

Scenario Parameter	Release Parameters for Representative Deterministic Scenarios									
	95th Percentile - EPA			95th percentile - NPA			Batch Spills			
Representative Scenario	Surface Oil Exposure Area	Water Column Oil Mass	Shoreline Contact Length	Surface Oil Exposure Area	Water Column Oil Mass	Shoreline Contact Length	100 L	1,000 L	100 L	1,000 L
Release Site	EPA			NPA			EPA		NPA	
Release Type	Subsurface Blowout						Batch Spill			
Depth of Release	1,100 m			2,700 m			Surface			
Released Product	Bay du Nord			Bay du Nord			Marine Diesel			
Release Duration	113 d			36 d			Instantaneous			
Release Rate	15,000 m^3/d			4,980 m^3/d			N/A			
Total Released Volume	1,695,000 m^3			1,695,000 m^3			100 L	1,000 L	100 L	1,000 L
Model Duration	160 d						30 d			
Modelled Start Date and Season	12/19/2009 Winter	7/24/2010 Summer	2/15/2006 Summer	3/14/2010 Summer	1/23/2006 Winter	12/19/2009 Winter	6/15/2009 summer (calmest period identified between 2006-2010)		6/18/2009 summer (calmest period identified between 2006-2010)	

The estimated volumes of hydrocarbons released in the subsurface blowout scenarios (Table 2-4) are conservative (i.e. high) based upon the current knowledge of subsurface properties and potential blowout scenarios. The duration of flowrate was determined by Statoil in consideration of spill response measures to stop the flow of oil such as installation of a capping stack (36 days) and/or drilling a relief well (113 days). Therefore, for effects assessment purposes, to assess potential impacts from these potential losses of well control events, a flow duration of 36 days was used for the 4,980 m^3/day event at NPA, whereas the flow duration of 113 days was used for the 15,000 m^3/day event at EPA.

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 is:

- 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 fates 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 of contamination.
- 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.

In the unlikely event of an actual release of oil, the trajectory, fate, and potential biological exposure will be strongly determined by the specific environmental conditions, the precise locations, 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 scenarios.

3 Model Input Data

3.1 Oil Characterization

Two hydrocarbon products and release sites were modelled for this study including:

1. Bay du Nord (BdN) crude oil at Statoil's NPA and EPA sites, and
2. Marine diesel in the surface vessel transfer batch-release deterministic scenarios.

The physical and chemical data used to characterize these oils was provided by Statoil, with additional assays and measurements by S.L. Ross Environmental Research Ltd. (2016) and Intertek (2016).

BdN is a light crude oil with low viscosity and a high aromatic content (Table 3-1 & 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. The physical and chemical parameters of BdN are similar to those of Hibernia crude oil, which was used in previous studies (SL Ross, 2016; ESTC, 2001) as identified in Statoil's response to the C-NLOPB (Statoil, 2016). These oils would likely behave similarly in the event of a release, with marine diesel being least persistent.

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., 1996a; 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.

Table 3-1. Physical properties for the two oil products used in modelling.

Physical Property	BdN Crude Oil	Marine Diesel
Density (g/cm^3)	0.84553 @16°C 0.85800 @0°C	0.83100 @25°C 0.83089 @16°C
Viscosity (cP)	5.0 @20°C 53.0 @0°C	2.76 @25°C 2.76 @15°C
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 two oil products. Note that the total hydrocarbon concentration (THC) is the sum of the aromatic (AR) and aliphatic (AL) groups. Numbers of carbons in the included compounds are listed.

Distillation Cut[1]	Boiling Point (°C)	Description	BdN Crude Oil	Marine Diesel
AR1	< 180	highly volatile and soluble monoaromatic hydrocarbons (BTEX[1] and MAHs C6-C9)	0.023739	0.019333
AR2	180 - 264	semi-volatile and soluble 2-ring aromatics (MAHs and PAHs C10-C12)	0.004166	0.011410
AR3	265 - 380	low volatility and solubility 3-ring aromatics (PAHs C13-C18)	0.066998	0.015605
AL1	< 180	highly volatile aliphatics (C4-C8)	0.206261	0.144667
AL2	180 - 280	semi-volatile aliphatics (C9-C16)	0.160834	0.478690
AL3	280 - 380	low volatility aliphatics (C17-C23)	0.168002	0.303295
THC1	< 180	total hydrocarbon fraction 1 (sum of AR1 and AL1)	0.230000	0.164000
THC2	180 - 280	total hydrocarbon fraction 2 (sum of AR2 and AL2)	0.165000	0.490100
THC3	280 - 380	total hydrocarbon fraction 3 (sum of AR3 and AL3)	0.235000	0.318900
Residuals	> 380	aromatics ≥ 4 rings and aliphatics > C20 that are neither volatile nor soluble	0.37000	0.02700

[1]Note that the terms “aromatic” and “aliphatic” are used in a modeling context. “Aromatic” refers to all soluble and volatile hydrocarbons and may include actual aliphatic compounds in the chemical sense that are soluble. In the modelling context, “aliphatic” refers to insoluble and volatile hydrocarbons.

[1] 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.

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 and the cells were coded for depth and habitat type. Geographical data were obtained from multiple international sources to provide the geographic and environmental data 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.).

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 2016
	Maine Environmental Vulnerability Index	United States - Maine	MDEP 2016
Bathymetry	General Bathymetric Chart of the Oceans Digital Atlas	global	GEBCO 2003

The model used these grids to identify the location of the shoreline and amount of oil that may adhere once contact with oil was made (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).

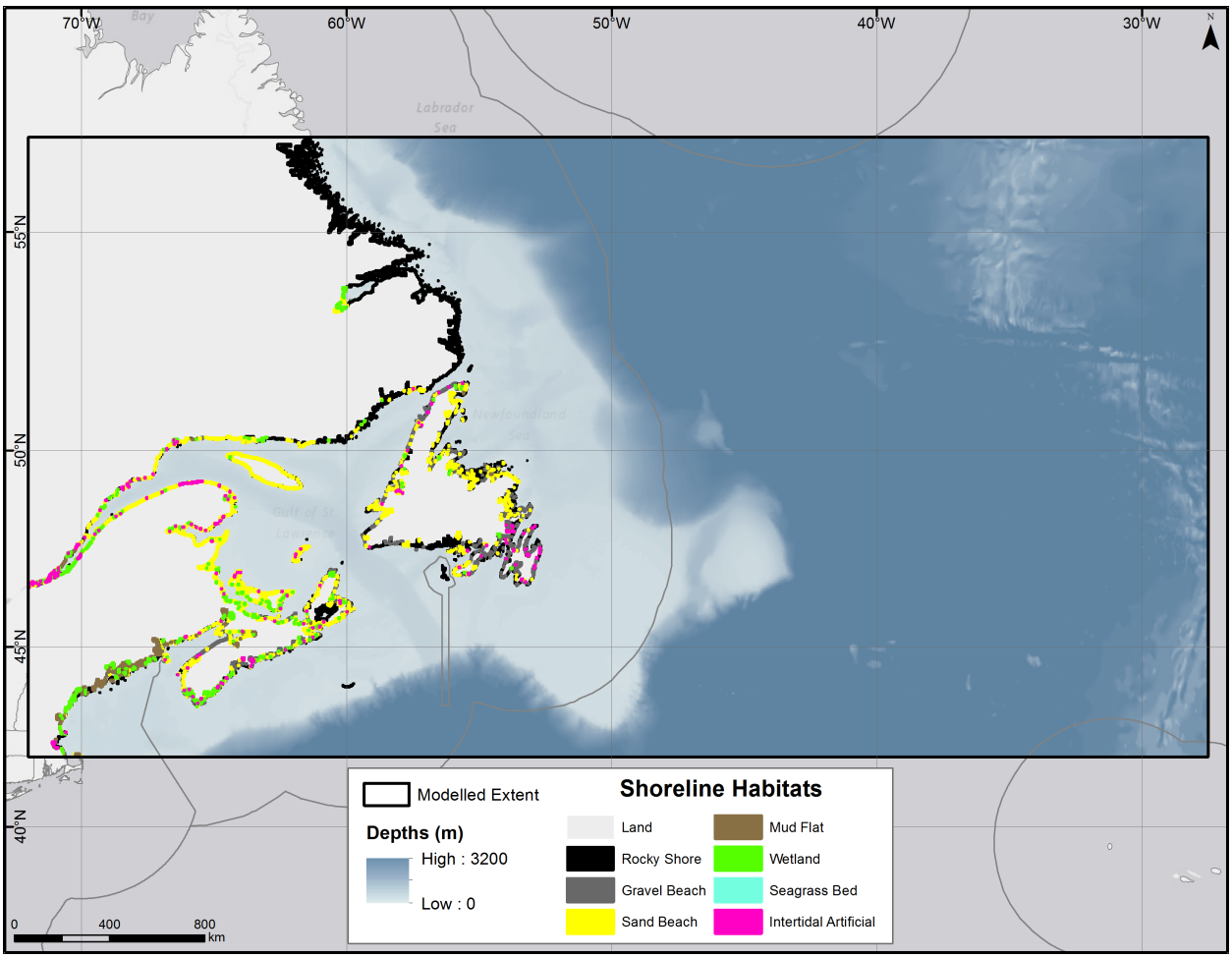


Figure 3-1. Shoreline habitat data and depth throughout the modelled domain. The black box represents the modelled extent.

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. Freezing temperature for average ocean salt water of 35 ppt salinity is about -2°C (NOAA, 2014).

The movement and behavior of released oil is greatly affected by the presence of 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. From 0 to ~30% coverage, the 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 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% ice coverage, surface oil moves with the ice and evaporation and entrainment cease.

The ice thickness and can vary greatly based upon prevailing weather conditions. If oil is released under ice, water column exposures can be greater, due to the "capping" effect of the ice. Ice cover limits or prevents evaporative losses and could result in substantially greater dissolution of hydrocarbons into the water column. Appendix A contains a brief summary of the algorithms implemented in the SIMAP model for oil releases in sea ice conditions.

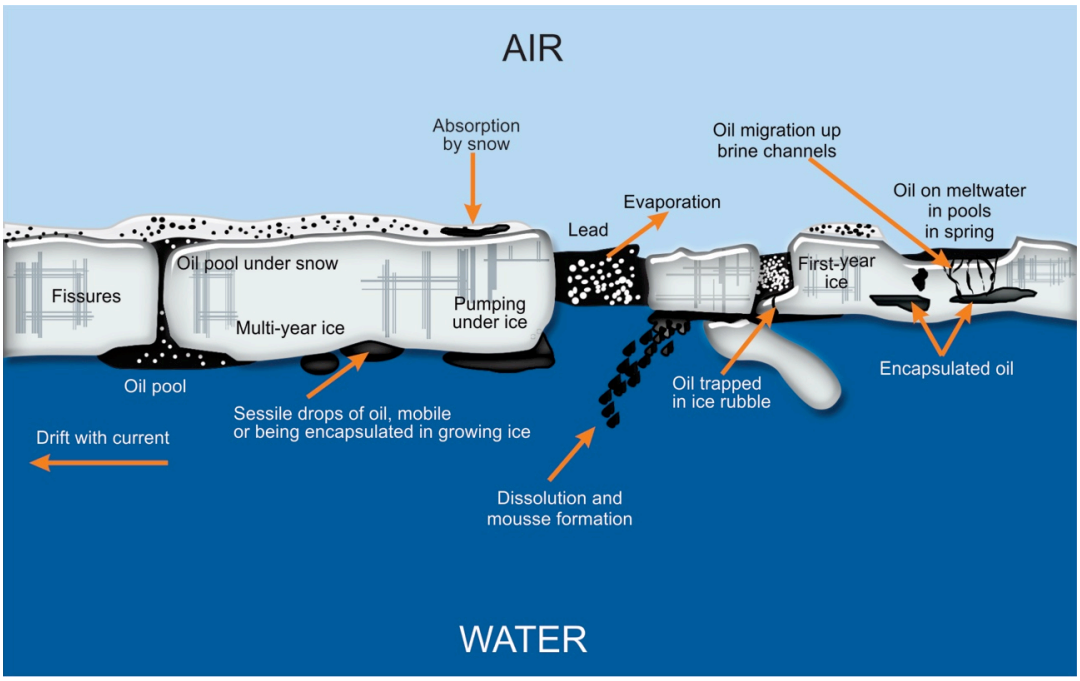


Figure 3-2. Oil and ice interactions at the water surface (Source: RPS 2017, modified from original by Alan A. Allen).

Ice data used as modelling inputs were obtained from the Canadian Ice Service (CIS; ECCC 2017) in weekly files spanning 2006 to 2010. These data were in the form of polygon data, with information on total ice concentration and stage of development. For each ice polygon, concentration codes were converted to concentration percentages. Average ice thickness was calculated based on the proportional concentration of the various stages of ice present for each week of the season over five years. The CIS data provides a range of thicknesses for each ice category and stage of development. In most cases, the mid-point of those ranges was used in the calculation of average 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 ice data was gridded at a resolution matching the habitat grid (0.02225°). A representative map depicting percentage of ice cover and thickness of ice for the first week of February 2010 is presented (Figure 3-3).

Table 3-4. Sea ice thickness used in the modelling characterized by CIS stage of development.

CIS 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
Landfast 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[2]		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

[2] Default sea ice stage assumed when none was defined in the data.

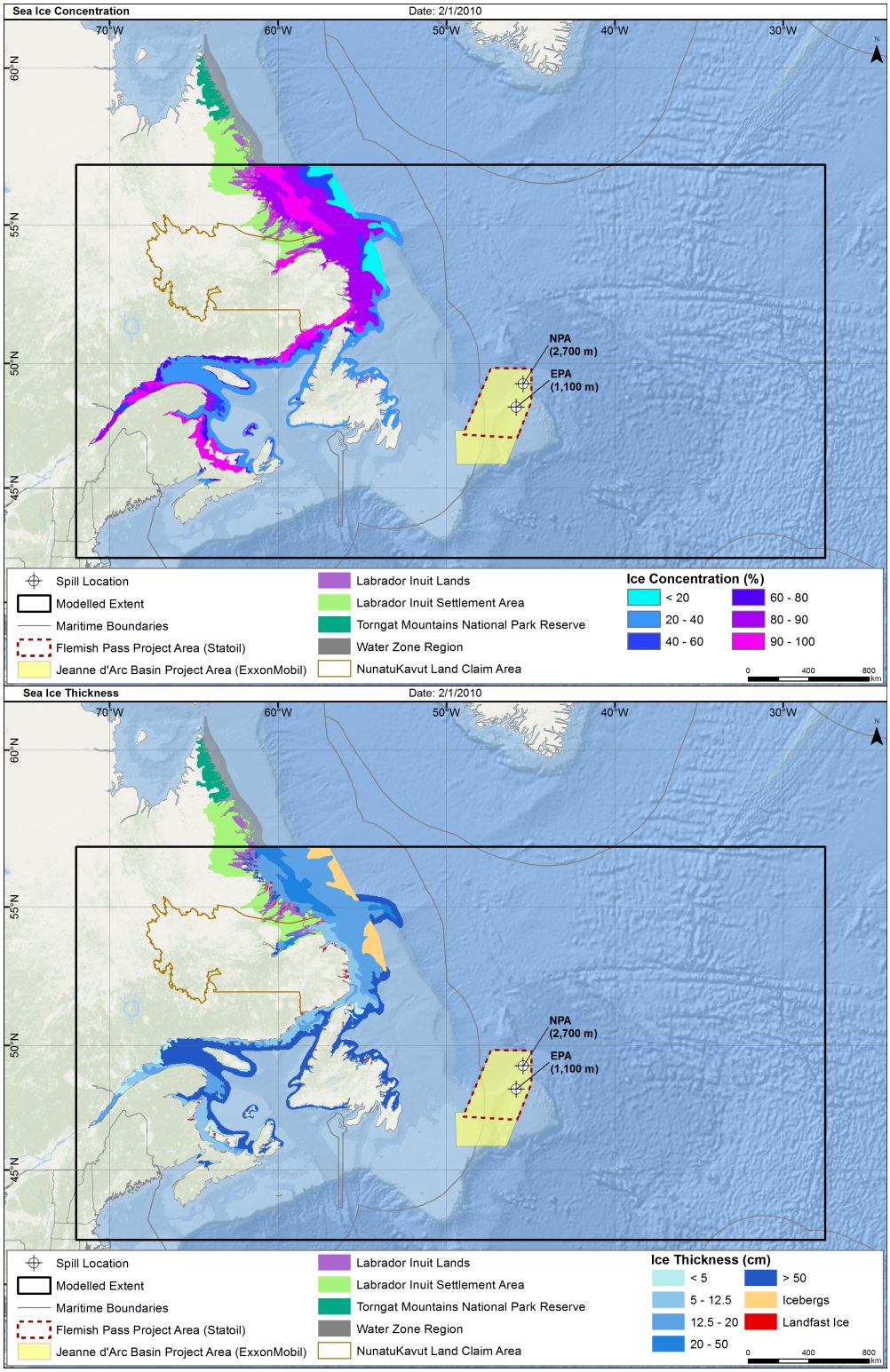


Figure 3-3. Representative percentage ice cover (top) and corresponding thickness (bottom) for the first week of February 2010.

3.4 Wind Data

A multiyear dataset of wind speed and direction oil spill model was used to capture the variability that occurs from year to year. Oil release trajectories simulated using long-term wind datasets are representative of possible wind conditions at the site, assuming the temporal variability is on the timescale of changes in speed and direction. Because winds can change on time scales of minutes to hours, it is best to acquire data at the highest temporal resolution possible (typically every six hours for large global models, or at the very least daily averages). Oil released over long periods of time (e.g., the 113-day blowouts modelled here for 160 days) has the potential to travel long distances by wind transport. To effectively model this, the wind speed and direction data must encompass a large geographic area in order to capture the spatial extent and any spatial variability in potential transport that may occur. Winds may physically transport oil on the water surface, thus wind speed and direction at the water surface may be the driving force between a simulation with limited versus extensive transport. The SIMAP model use time-varying wind speeds and directions for the period over which the release was simulated.

Wind data for this study were obtained from the National Centers for Environmental Prediction Climate Forecast System Reanalysis (CFSR) product for 2006 through 2010. The CFSR 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 CFSR includes coupling of atmosphere and ocean, as well as assimilation of satellite radiances. The CFSR global atmospheric resolution is ~38 km, with 64 vertical levels extending from the surface to 0.26 hPa. CFSR winds were also used as one of the main driving forces in the hydrodynamic dataset used for modelling (see Section 3.5). The CFSR time series acquired for this study was available at 0.5° horizontal resolution at 6-hourly intervals.

Averaged annual wind data at the EPA and NPA sites were most frequently from the west-southwest direction (Figure 3-4). Monthly average wind speeds varied between 7 and 12 m/s throughout the year, with highest speeds occurring during winter months (November – March) and lowest speeds in July (Figure 3-5). These winds would be expected to transport oil generally away from nearby shorelines further into the open ocean.

Winds over the Grand Banks and Flemish Pass are predominantly from the southwest and west throughout the year. Winter season winds are most frequently from the west and northwest with higher velocity than summer season winds, which typically come from the southwest (Statoil, 2016). Spring and autumn months are more dynamic transitional periods between the more consistent 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. Significant wave heights are typically highest from November – February, in regions with no ice (C-NLOPB, 2014).

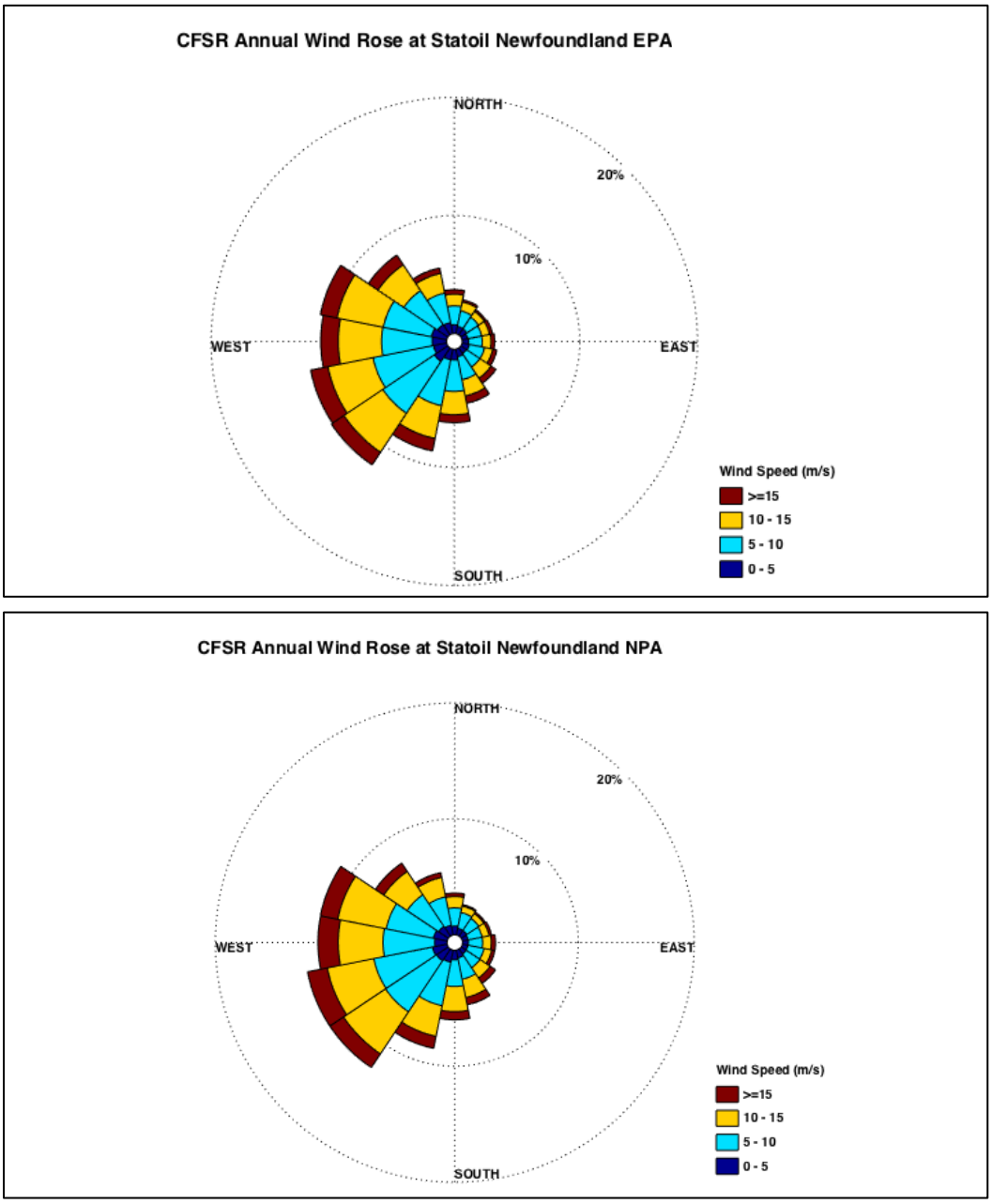


Figure 3-4. Annual CFSR wind rose near the EPA (top) and NPA (bottom) release sites. Wind speeds are presented in m/s, using meteorological convention (i.e., direction wind is coming from).

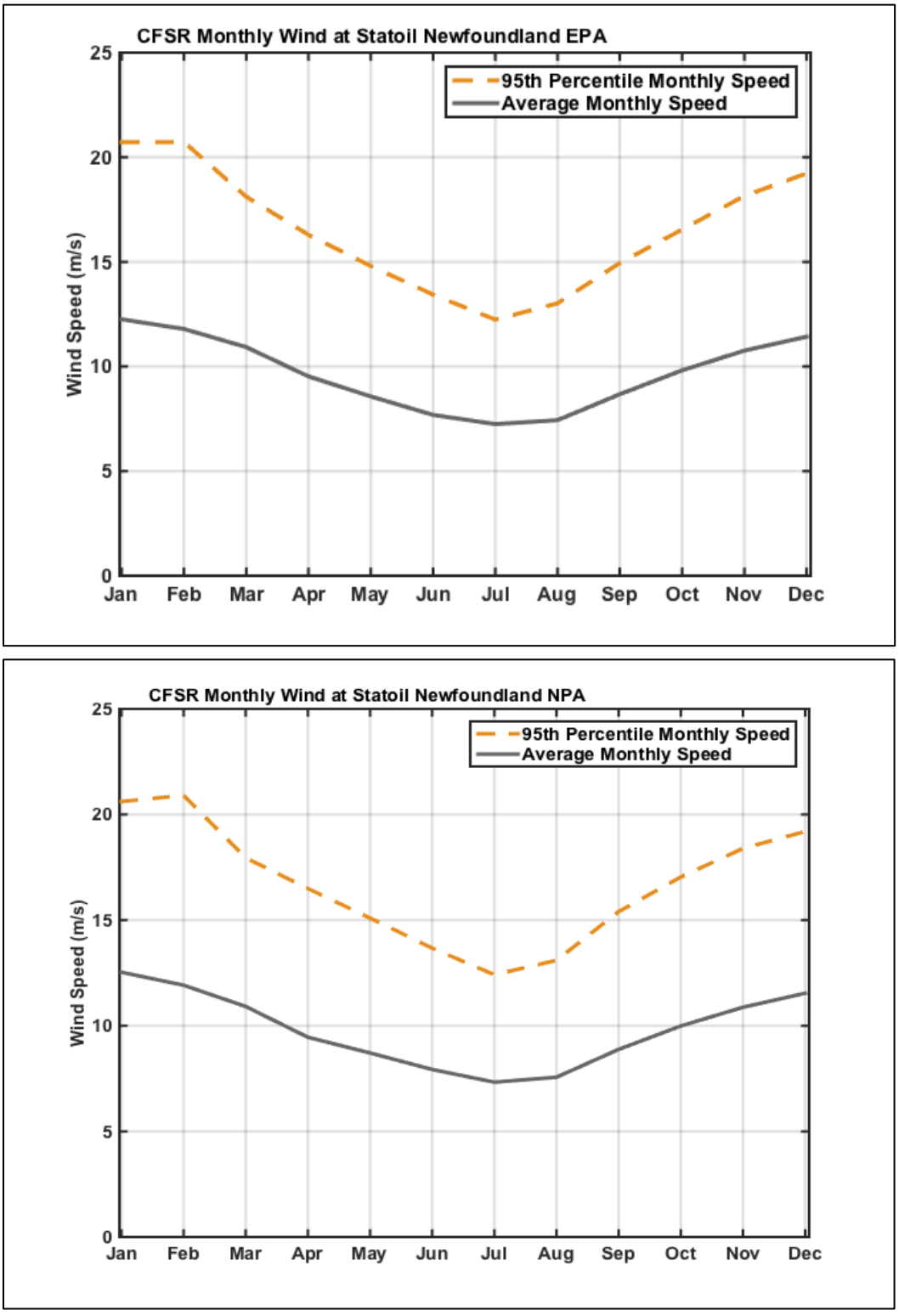


Figure 3-5. **Average and 95th percentile monthly wind speeds near the EPA (top) and NPA (bottom) release sites.**

3.5 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 3-6). 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 (Statoil, 2016). 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.

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). MICOM has become one of the premier ocean circulation models, having been subjected to validation studies (Chassignet et al., 1996; Roberts et al., 1996; Marsh et al., 1996) and used in numerous ocean climate studies (New and Bleck, 1995; New et al., 1995; Hu, 1996; Halliwell, 1997, 1998; Bleck, 1998). The HYCOM global ocean system is a 3D dynamic model that is run each day, providing a 5-day hindcast and 5-day forecast of oceanic currents that works effectively in both deep and shallow waters. Hindcast data were used to validate the accuracy of each run to determine if modelled forcings produce results that match observational data. 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 have 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).

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). Bathymetry is derived from the U.S. Naval Research Laboratory BDB2 dataset. Surface forcing is derived from the Navy Operational Global Atmospheric Prediction System, which includes wind stress, wind speed, heat flux (using bulk formula), and precipitation.

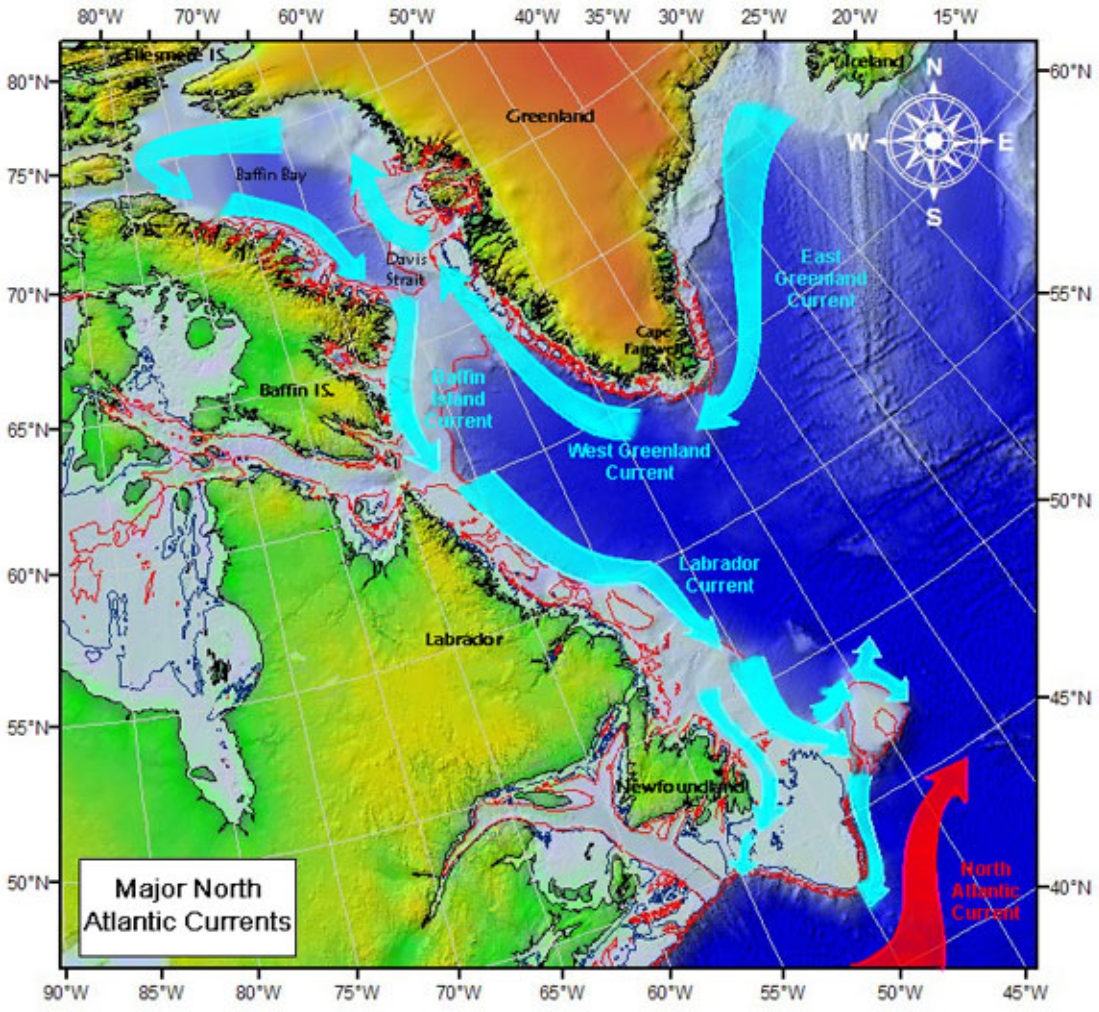


Figure 3-6. Large scale ocean currents in the Newfoundland region (USCG 2009).

For this study, daily current data were obtained for the period January 2006 through December 2010 for the North Atlantic region (HYCOM, 2016). Since the data spanned 5 years, the variability in winds and currents would sample daily, weekly, seasonal, and inter-annual variability, which included calm periods, seasonal storms, and the full range of environmental forcing over the entire time period. Because of the

complete coverage of the bi-weekly randomized sampling within the 5-year modeled period and the 160-day duration of the models themselves, storms occurring during this time period were included in the stochastic analysis. While this subset of data is not the most recent five years of data, currents and winds in the study area are very similar to those from 5-10 years ago and the data used in this study would be representative of environmental conditions present today. Similarly, while there may be questions regarding general circulation during specific time periods, it is important to note that trajectories are influenced by day to day currents, as opposed to averages. Surface forcing is derived from 1-hourly CFSR wind data with a horizontal resolution of 0.3125° and induced wind stress, wind speed, heat flux, and precipitation with bathymetry derived from the GEBCO dataset (HYCOM, 2016). Average surface current speeds (Figure 3-7) and direction offshore Newfoundland (Figure 3-8) in the area from 2006 – 2010 depict larger scale features such as the Labrador current, North Atlantic Current, as well as bathymetric steering of currents around the Grand Banks and Flemish Cap. While these figures depict an average current speed and direction for visual purposes, oil transport was defined by the daily currents throughout each modelled simulation.

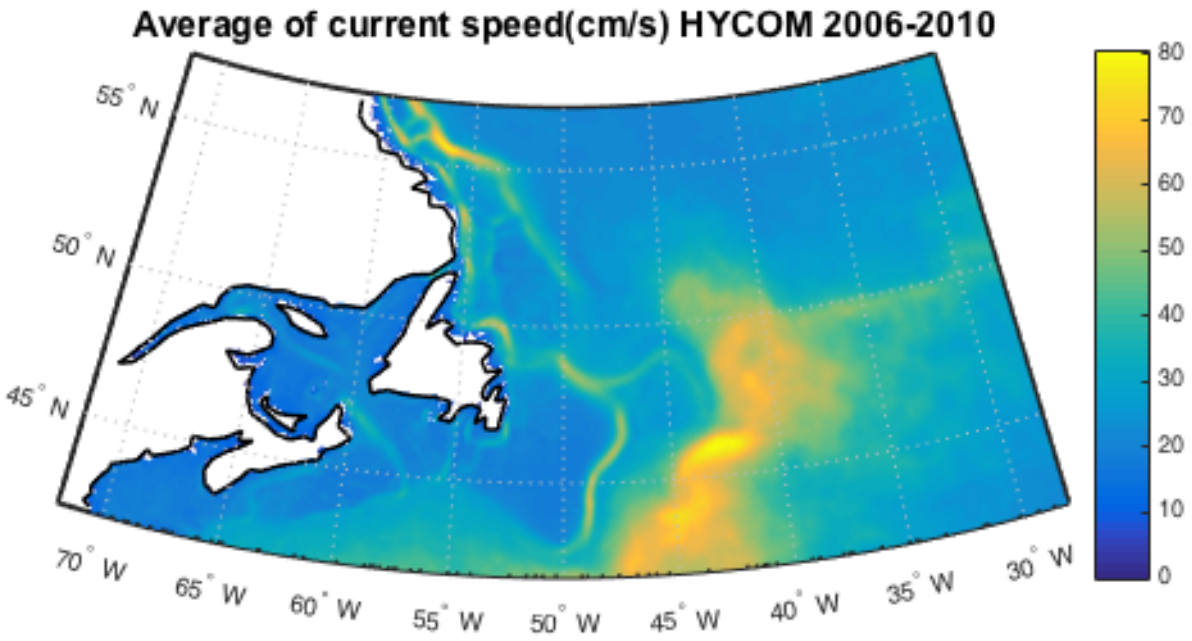


Figure 3-7. Average HYCOM surface current speeds (cm/s) off the coast of Newfoundland from 2006 – 2010.

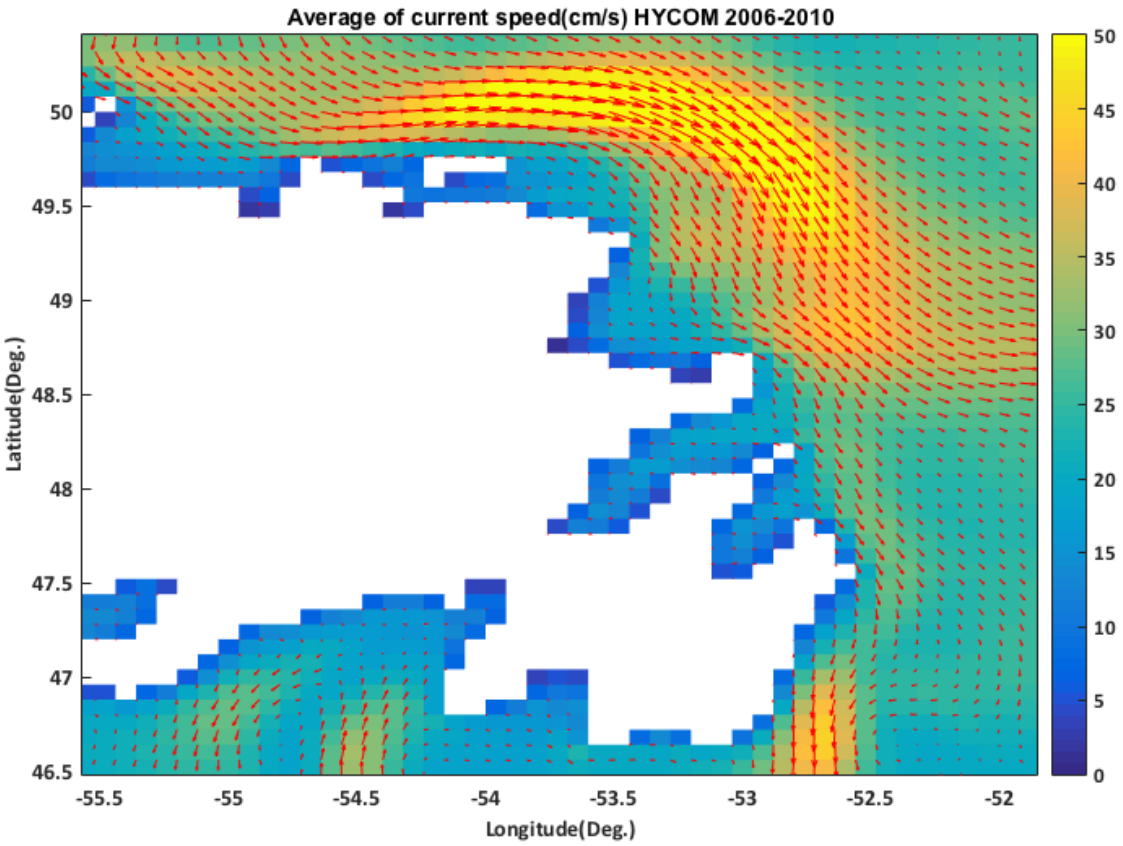


Figure 3-8. Averaged surface current speed (cm/s) in color, and direction presented as red vectors offshore Newfoundland from HYCOM (2006 – 2010).

3.6 Water Temperature & Salinity

Temperature and salinity values throughout the water column influence a number of oil transport and fate calculations. Temperature and salinity data have been obtained from the World Ocean Atlas (WOA) 2013 high-resolution dataset, Version 2, 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., 2001), and 2013. 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.

3.7 Blowout Model Scenarios and Results

The nearfield model OILMAPDeep was used to predict the initial droplet size distribution associated with subsurface blowouts of the hydrocarbon product that was modelled across two different release locations. 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 release depth ranged from 1,100 m to 2,700 m between the two identified release locations. The droplet size model predicts 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 scenarios simulated for this study, the oil was assumed not to be treated with dispersant. 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.

Two subsurface blowout release events were evaluated as part of this study:

(1) Site EPA - 113-day release of BdN, through a 12 ¼ inch orifice at a depth of 1,100 m and rate of 15,000 m^3/d, and
(2) Site NPA - 36-day release of BdN, through a 12 ¼ inch orifice at a depth of 2,700 m and rate of 4,980 m^3/d.

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 volume, duration, and depth of release resulted in different droplet size distributions for each of the two modelled releases.

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 3-9). Rise times for oil to reach the surface varied between minutes to many hours, 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 were associated with the smallest droplets and deepest release depths, with some rise times exceeding a day.

Table 3-5. Summary of droplet size distribution results for each of two modelled subsurface blowout release events.

Median Droplet Size in Each of Seven Equal-Mass Bins, by Diameter (µm)	
Site EPA - BdN Crude Oil (15,000 m^3/d, 113-day release)	**Site NPA - BdN Crude Oil (4,980 m^3/d, 36-day release)**
552	690
1,262	1,577
1,570	1,962
1,891	2,363
2,280	2,849
2,856	3,569
5,021	6,274

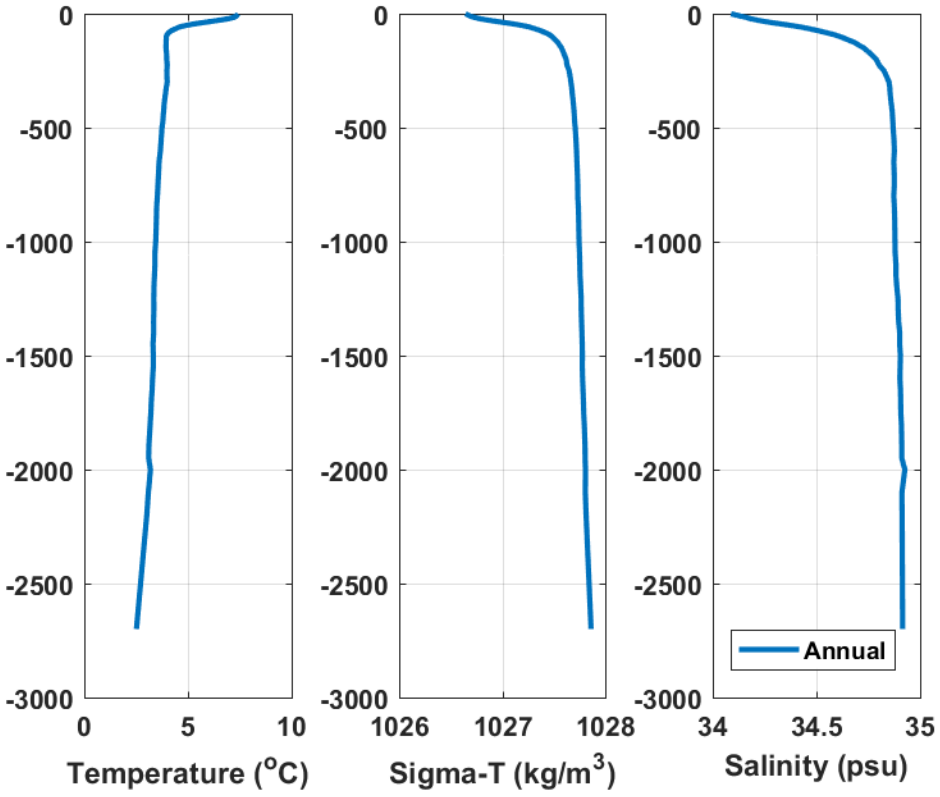


Figure 3-9. Water column profiles of temperature (left), salinity (right) and corresponding density (middle), represented as sigma-t. The density profile was generated based on the temperature and salinity profile using equations of state as published by UNESCO, 1981 (EOS-80).

4 Model Results

This section contains written summaries and analyses of model predicted results. In addition, graphical depictions of surface oil thickness, in water concentrations, and shoreline and sediment contamination have been provided for stochastic and deterministic analyses. Images include both probability and minimum time for specific threshold exceedances (Table 2-2) for stochastic results. Deterministic images include mass balance information, and cumulative footprints of surface oil thickness, in water concentrations, and shoreline and sediment contamination. Full page images are provided in Appendix A.

4.1 Stochastic Analysis Results

Stochastic analyses characterize results from many tens to hundreds of individual modelled releases of BdN crude oil. This study included modelling 119 individual releases over the course of 5 years of environmental data at the EPA and NPA sites to capture the natural variability in the environment. The duration of each model run was 160 days with a continuous 113-day blowout at the EPA site and a 36-day blowout at the NPA site.

Because ice cover can affect the trajectory and fate of oil, individual model runs were separated into two groups based upon the specific time periods modelled that included ice cover or ice-free conditions. Statistics for all 119 releases within a stochastic scenario are referred to as "annual," as they include all releases in any month over the course of the entire five years. Ice cover in the region is present in specific regions from November through April, while May through October is mostly ice-free. Modelled releases that have the majority of their simulated days (≥ 81 of the 160-day modelled duration) experiencing mostly ice-free periods are referred to as "summer" analyses (64 of the modelled releases), while those that have a majority of days experiencing periods with ice cover are referred to as "winter" analyses (55 of the modelled releases). Ice cover very rarely extended far enough offshore to reach the release locations, and when it did, < 10% ice cover was predicted. However, ice was present along most of the coastline in winter months, with February typically having the largest expanses of 90-100% ice cover.

The figures presented in the stochastic modelling results section illustrate the possible spatial extent of surface floating oil, water column concentrations of dissolved hydrocarbons, and shoreline contact including both the probabilities and associated minimum times to threshold exceedance (Table 2-2) for the hypothetical release scenarios. The probability maps define the area of potential exposure and the associated probability with which sea surface oil, shoreline oil, or water column contamination are expected to exceed the specified thresholds at any point of time throughout the 160-day modelled duration. The colored contours in the stochastic maps signify the outer boundary for given percentiles of areas that may experience oil at or above the specified threshold for each release scenario. Darker color contours denote areas that are more likely to exceed the specified threshold, while lighter color contours are less likely. Note that the lightest minty green line represents areas where oil may exceed the specified threshold in only 1% of release simulations. In other words, the likelihood that any oil exceeding the identified threshold would leave the area bounded by the minty green line is <1%. The area between this contour and the next (10%) has between a 1-10% probability of exceeding the threshold, given a release of the modelled scenario has occurred.

The probabilities of oil exposure were calculated from a statistical analysis of the ensemble of individual unmitigated trajectories modelled for each release scenario. The fundamental assumption for this modelling was that a release did occur. 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 of oil exceeding identified 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.

In addition, stochastic maps depicting water column contamination by dissolved hydrocarbon concentrations do not specify the depth at which the threshold exceedance occurred. 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 identified threshold, but rather a concentration may be exceeded at a specific depth (typically within the surface few meters) in the mapped location.

The minimum time footprints correspond with the associated probability of oil exposure map. 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 together to read: "There is a 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 Zone for Canada and the U.S., 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 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 (64 or 55 modelled simulations), two scenarios would be required to exceed the same threshold in the annual analysis (119 modelled simulations), due to the greater number of modelled releases in the annual set of runs being analyzed. Figures depicting stochastic results are provided for surface oil thickness >0.04 µm, dissolved hydrocarbon contamination > 1 µg/L, and shoreline contact > 1 g/m^2 for annual, summer, and winter scenarios for EPA (Figure 4-1 through Figure 4-9) and NPA (Figure 4-10 through Figure 4-18).

4.1.1 EPA Release Site

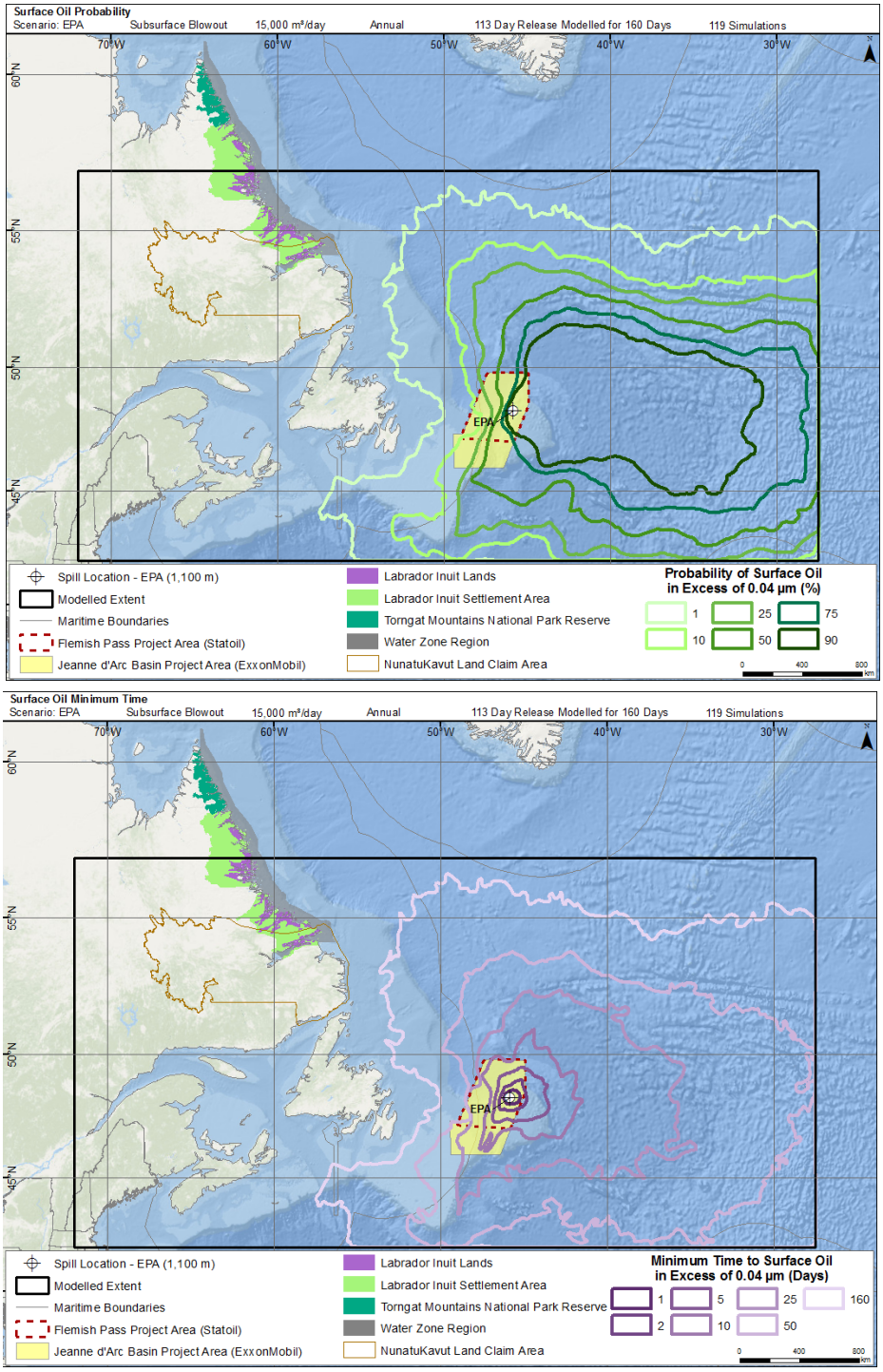


Figure 4-1. Annual probability of average surface oil thickness exceeding 0.04 µm (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the EPA site.

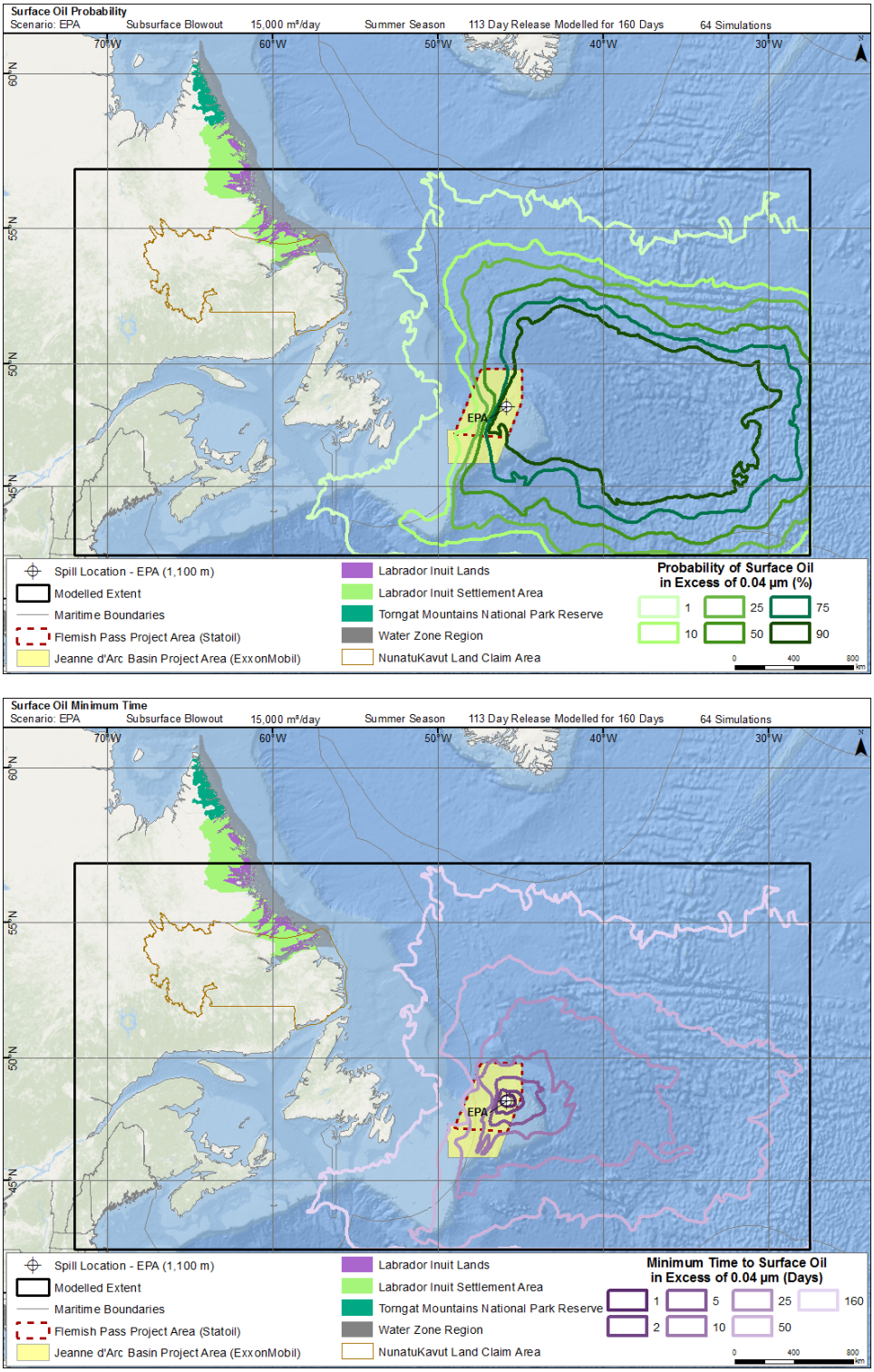


Figure 4-2. Summer probability of average surface oil thickness > 0.04 µm (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the EPA site.

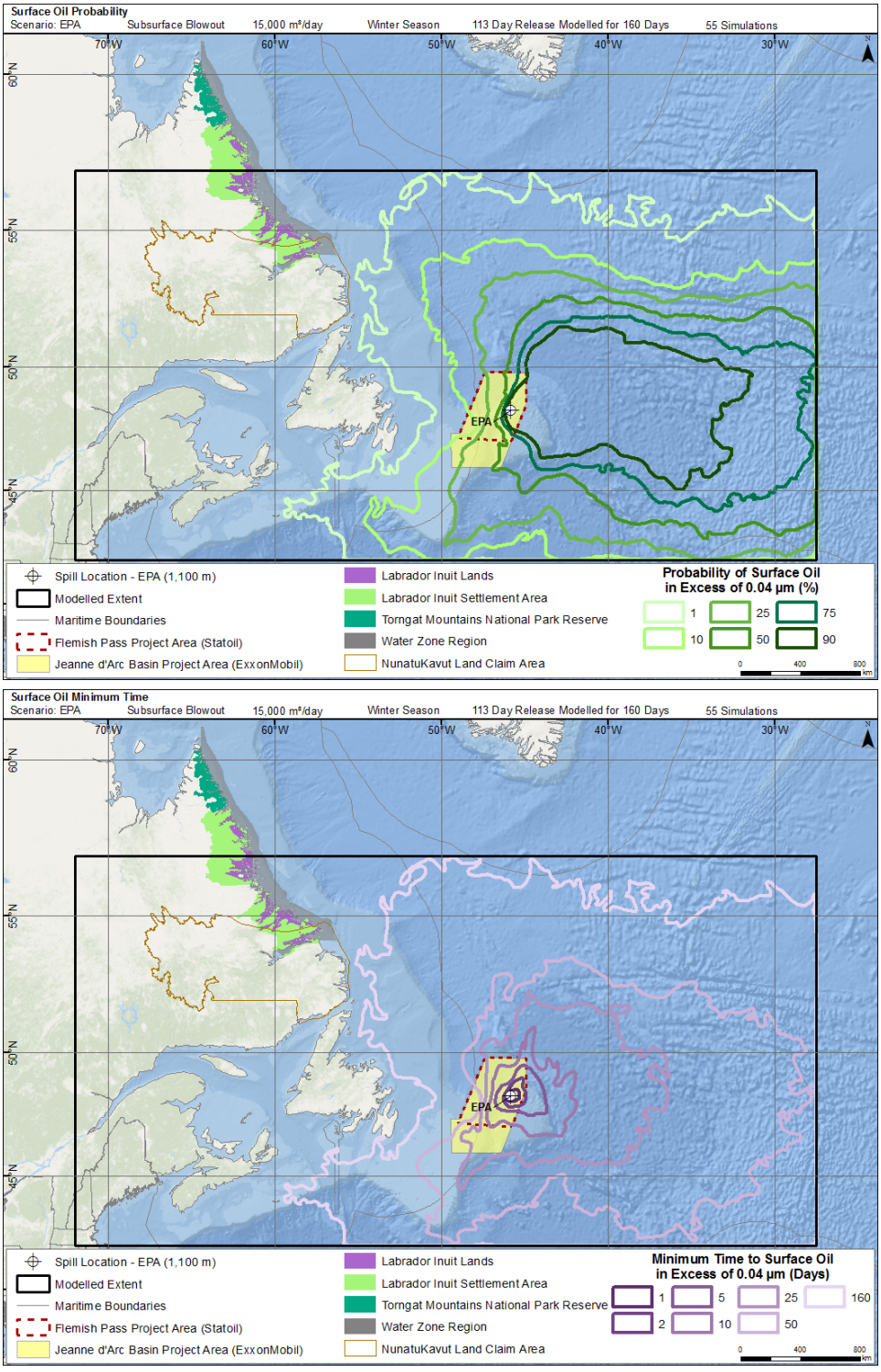


Figure 4-3. Winter probability of average surface oil thickness > 0.04 µm (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the EPA site.

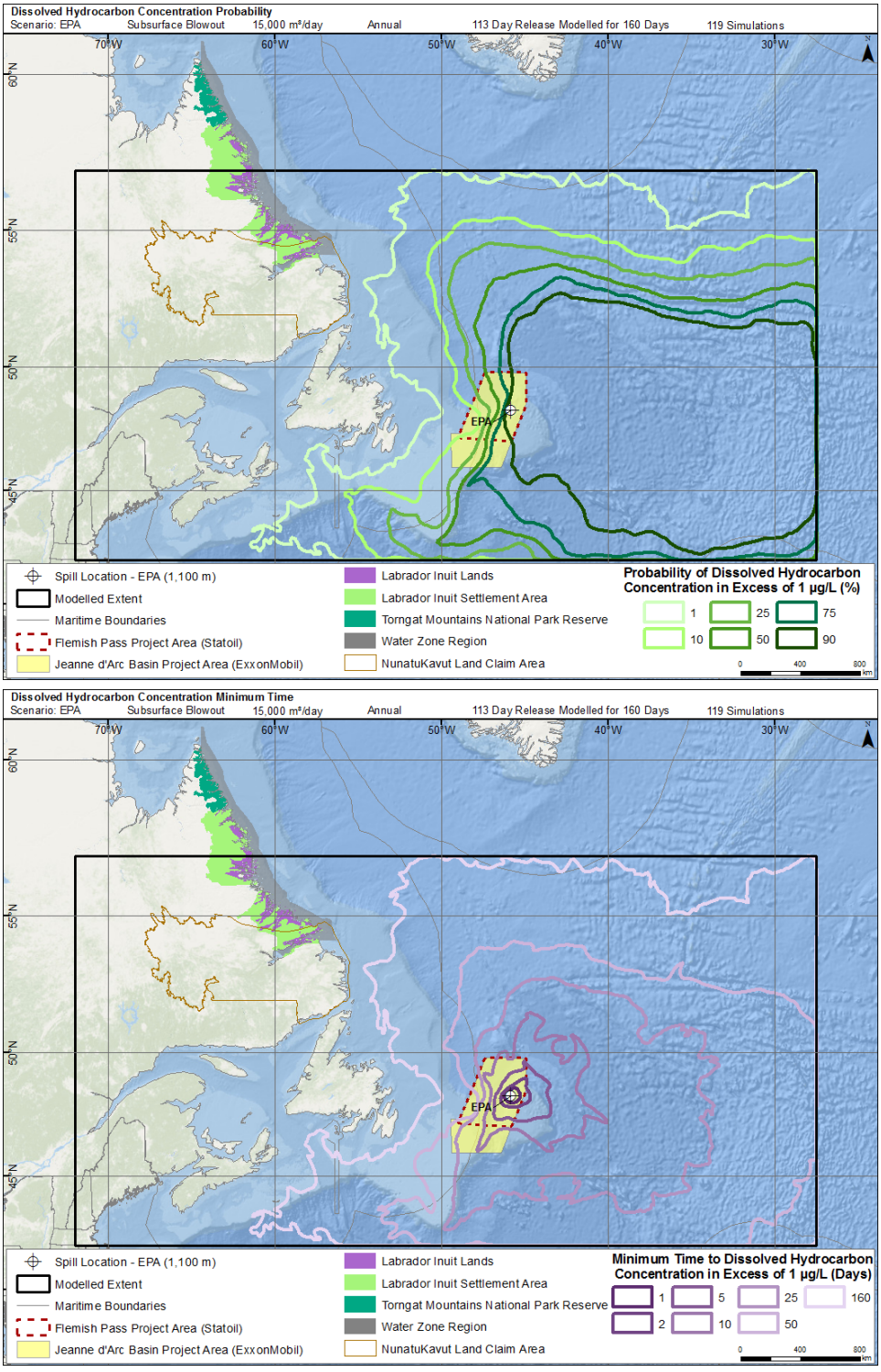


Figure 4-4. Annual probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the EPA site.

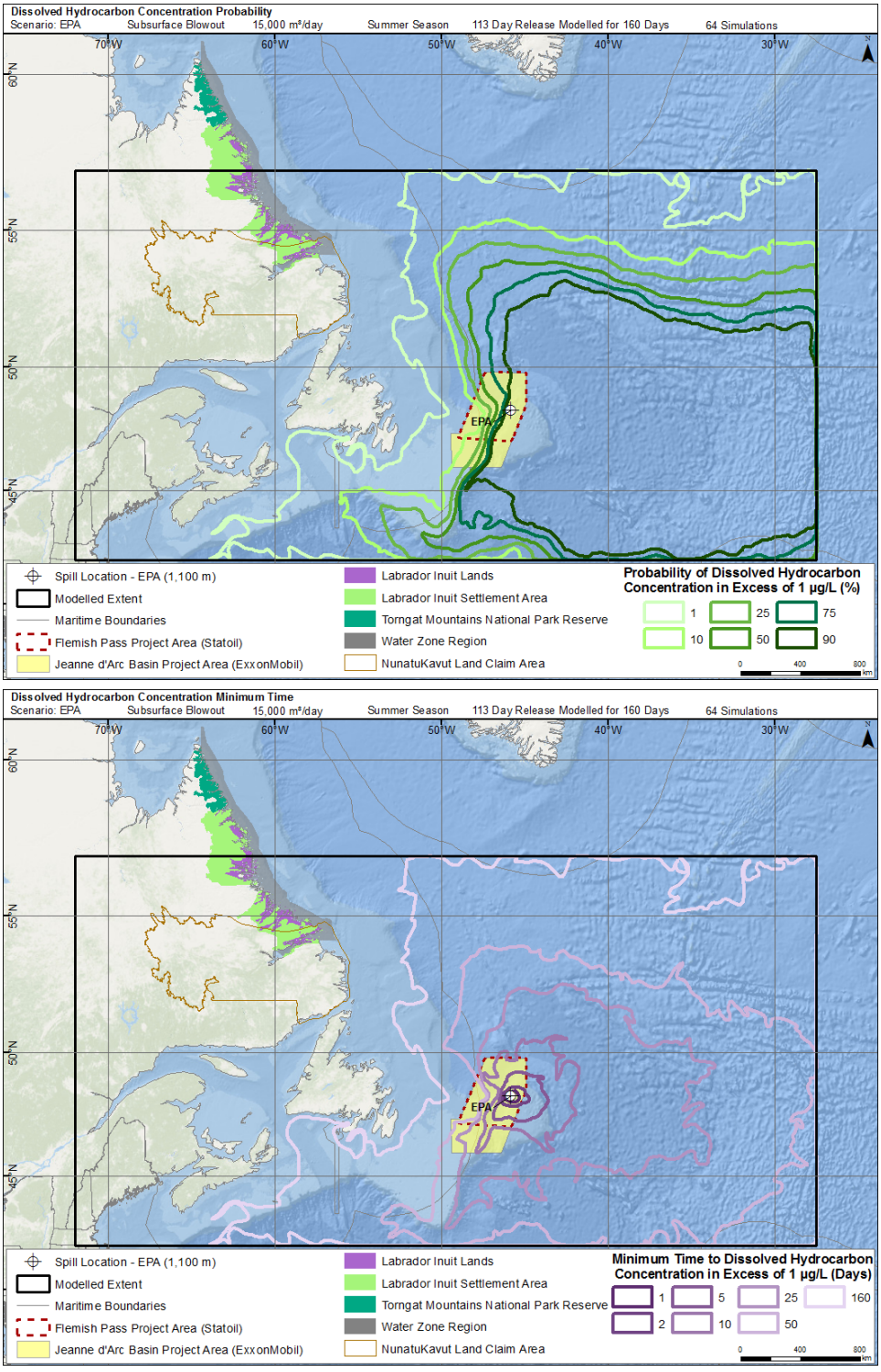


Figure 4-5. Summer probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the EPA site.

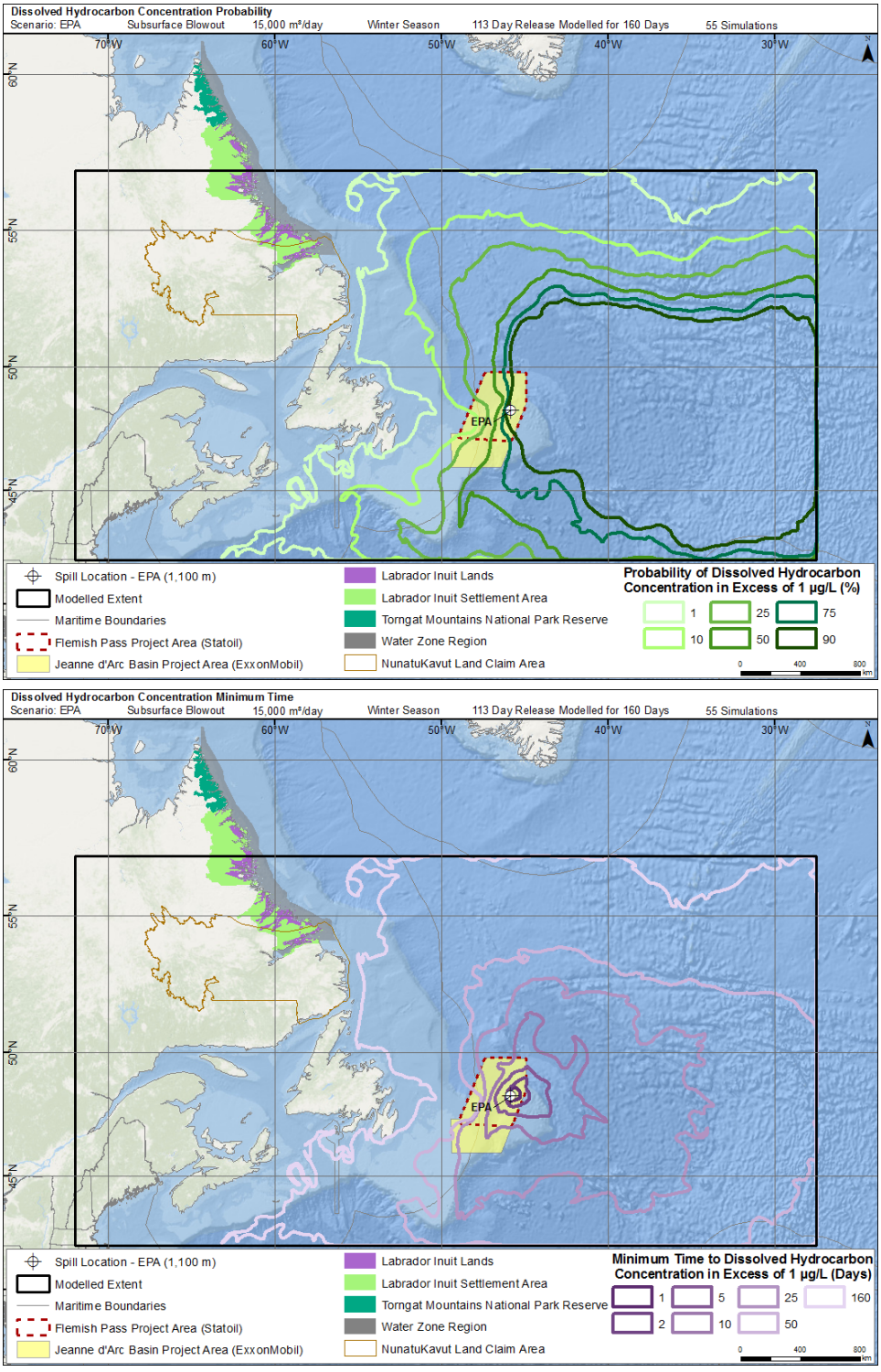


Figure 4-6. Winter probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the EPA site.

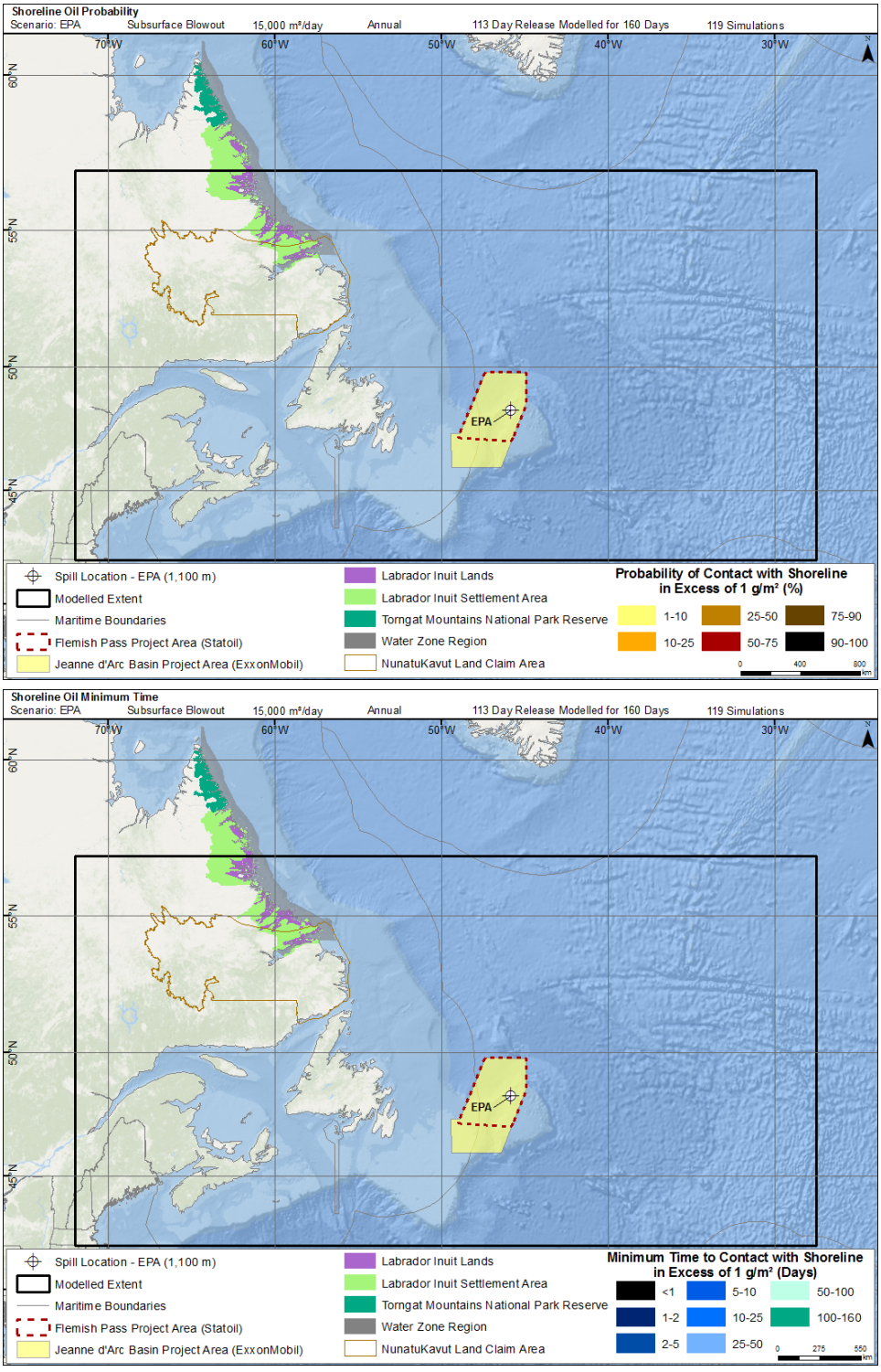


Figure 4-7. Annual probability of shoreline contact > 1 g/m² (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the EPA site.

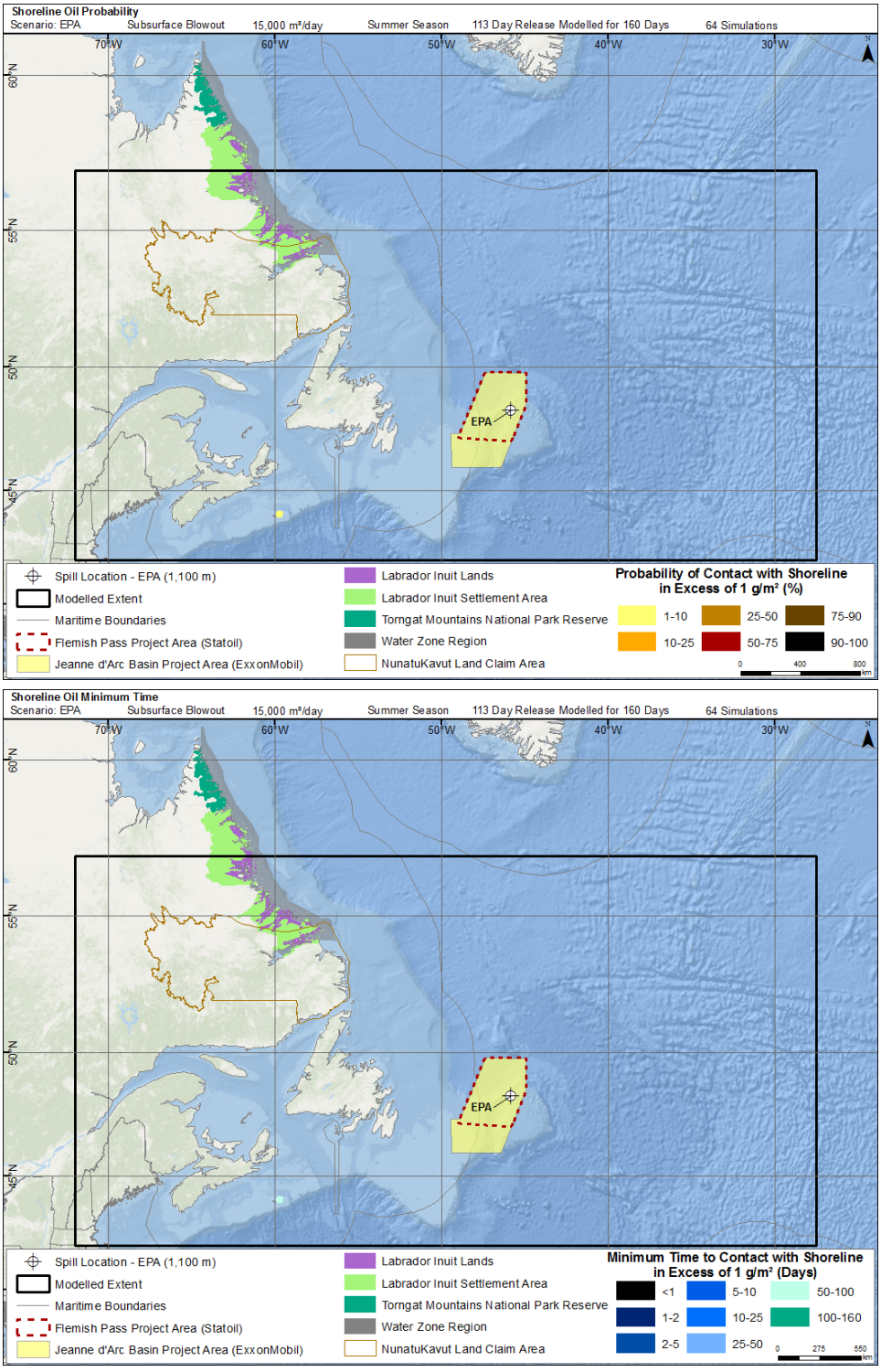


Figure 4-8. Summer probability of shoreline contact > 1 g/m² (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the EPA site.

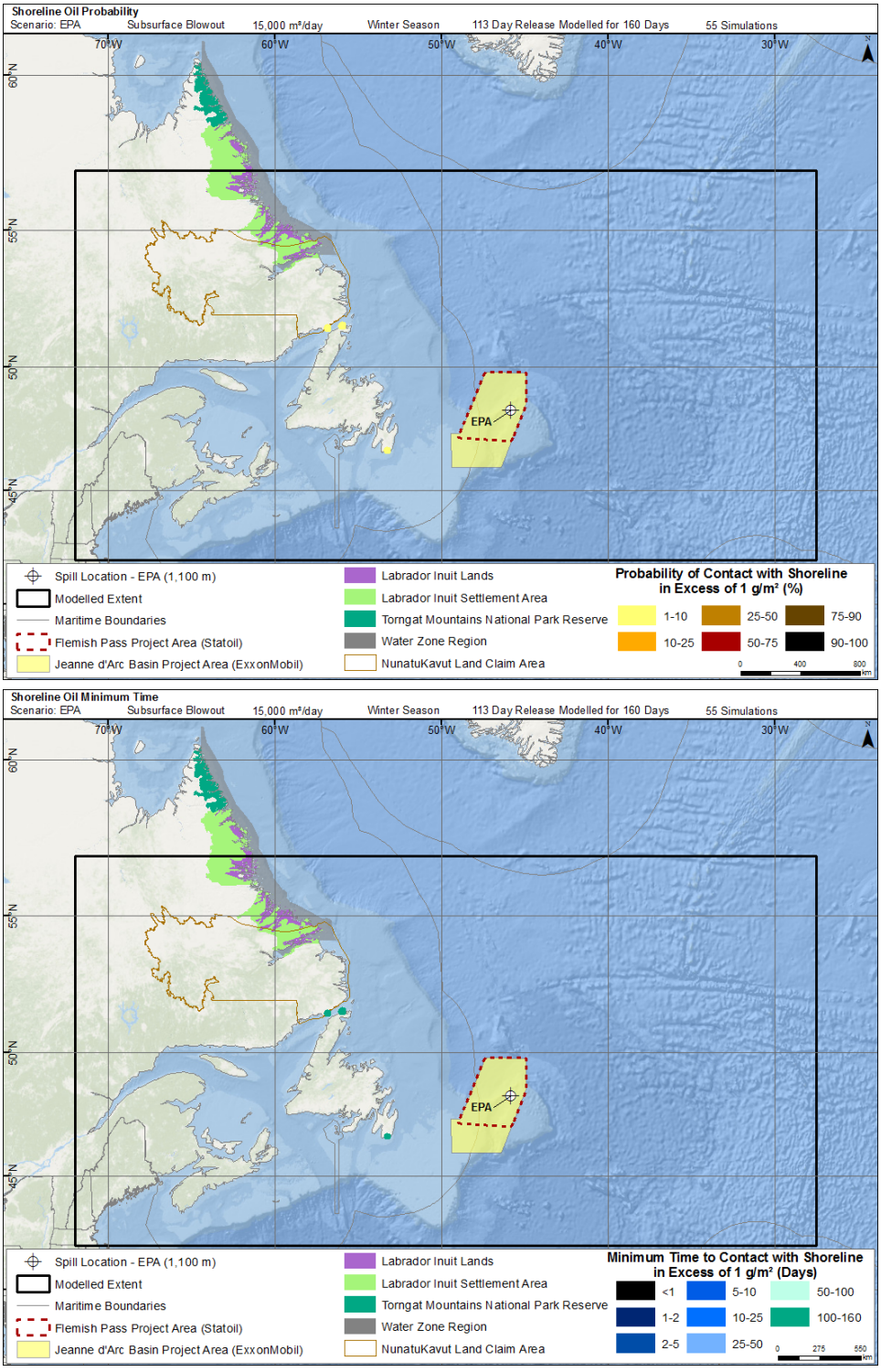


Figure 4-9. Winter probability of shoreline contact > 1 g/m² (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the EPA site.

4.1.2 NPA Release Site

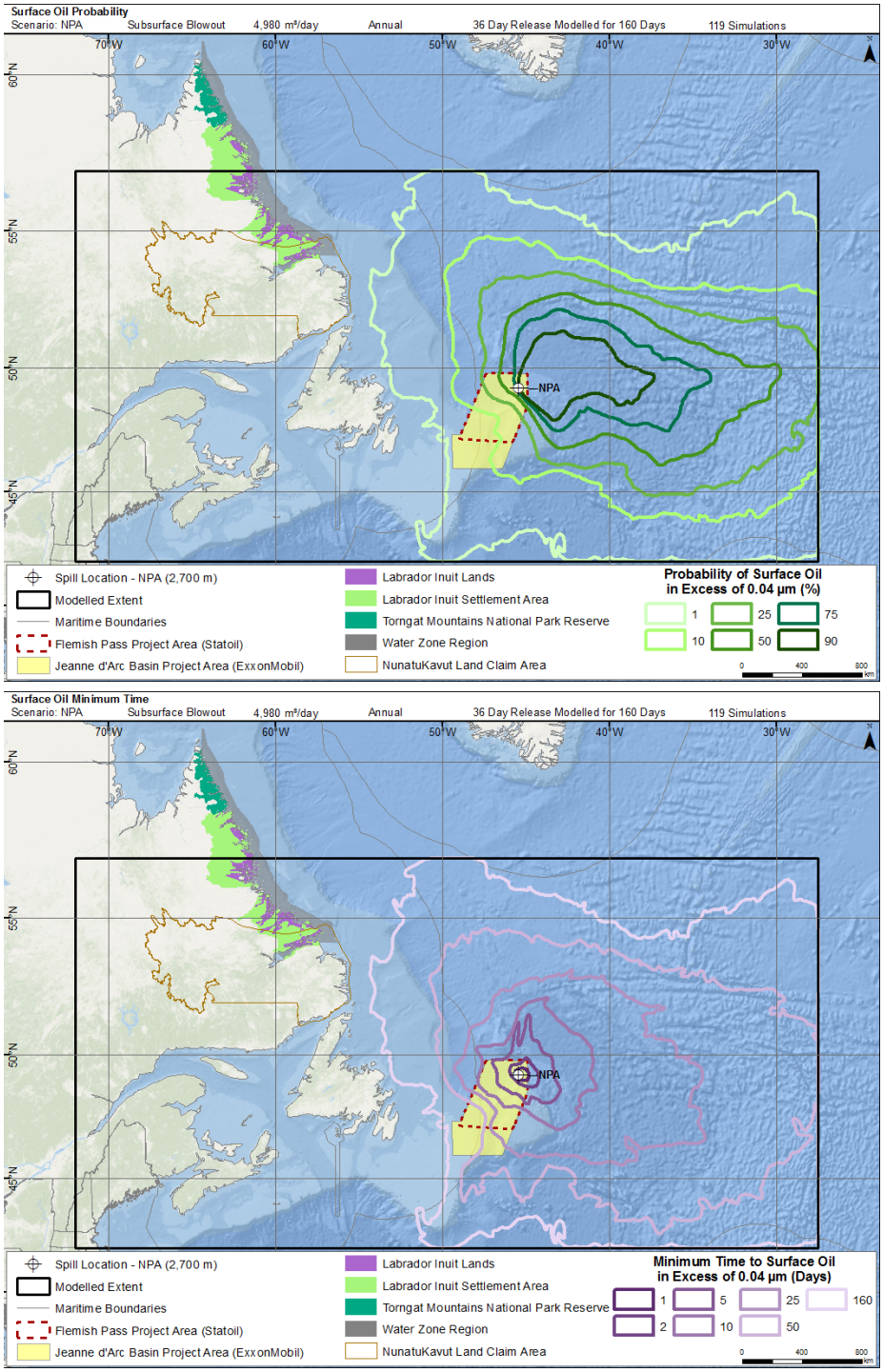


Figure 4-10. Annual probability of average surface oil thickness > 0.04 µm (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the NPA site.

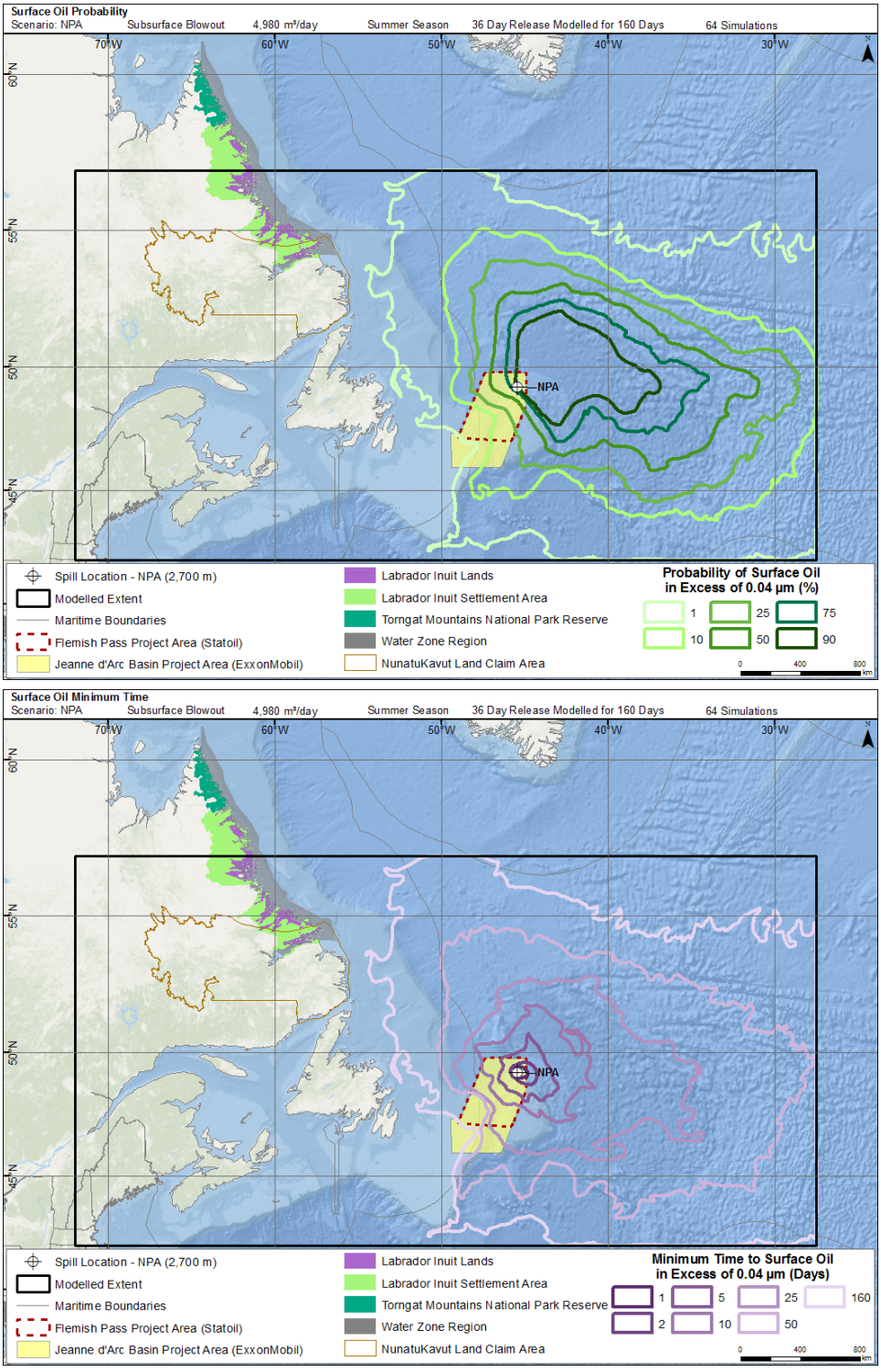


Figure 4-11. Summer probability of average surface oil thickness > 0.04 µm (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the NPA site.

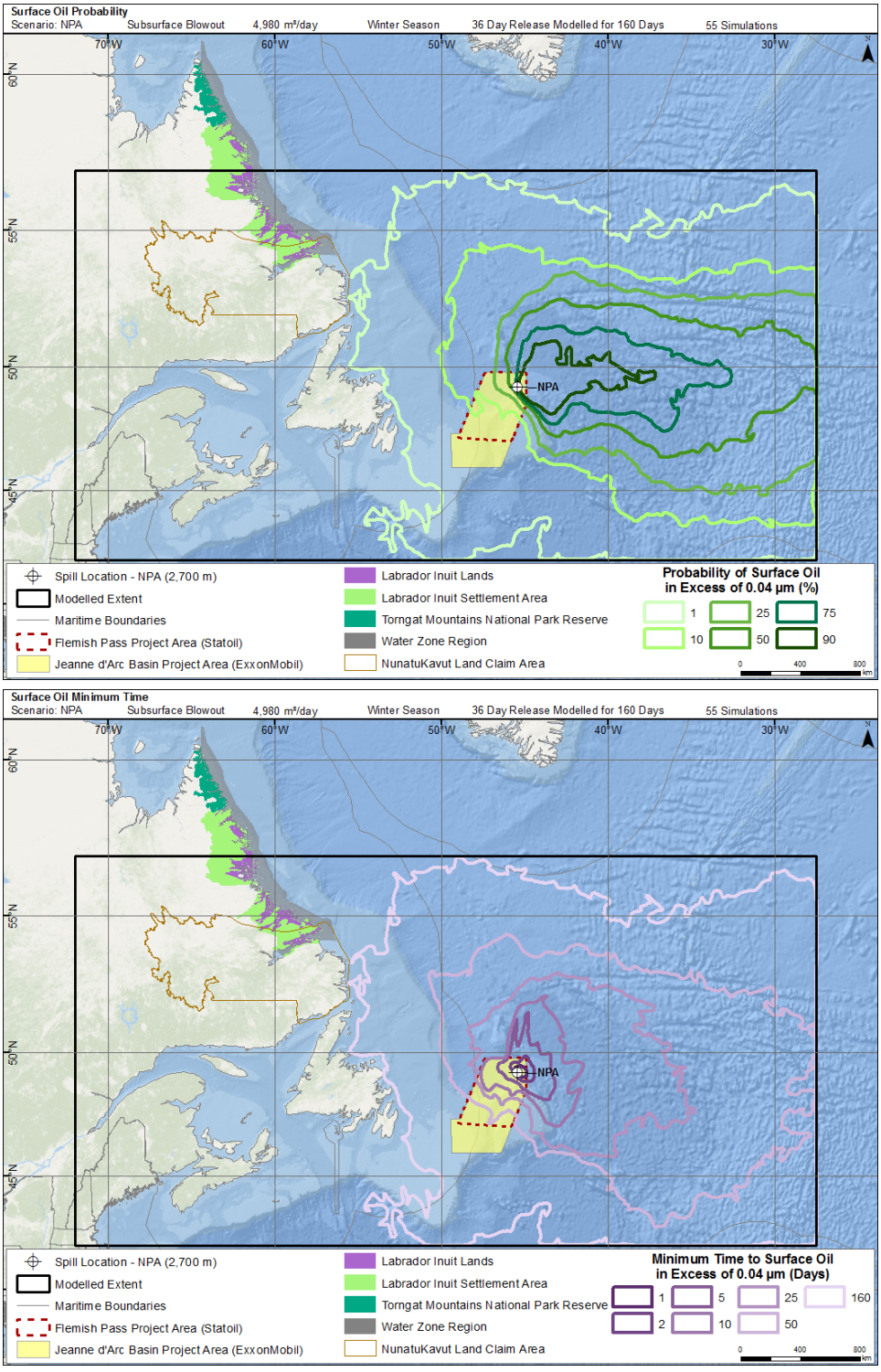


Figure 4-12. Winter probability of average surface oil thickness > 0.04 µm (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the NPA site.

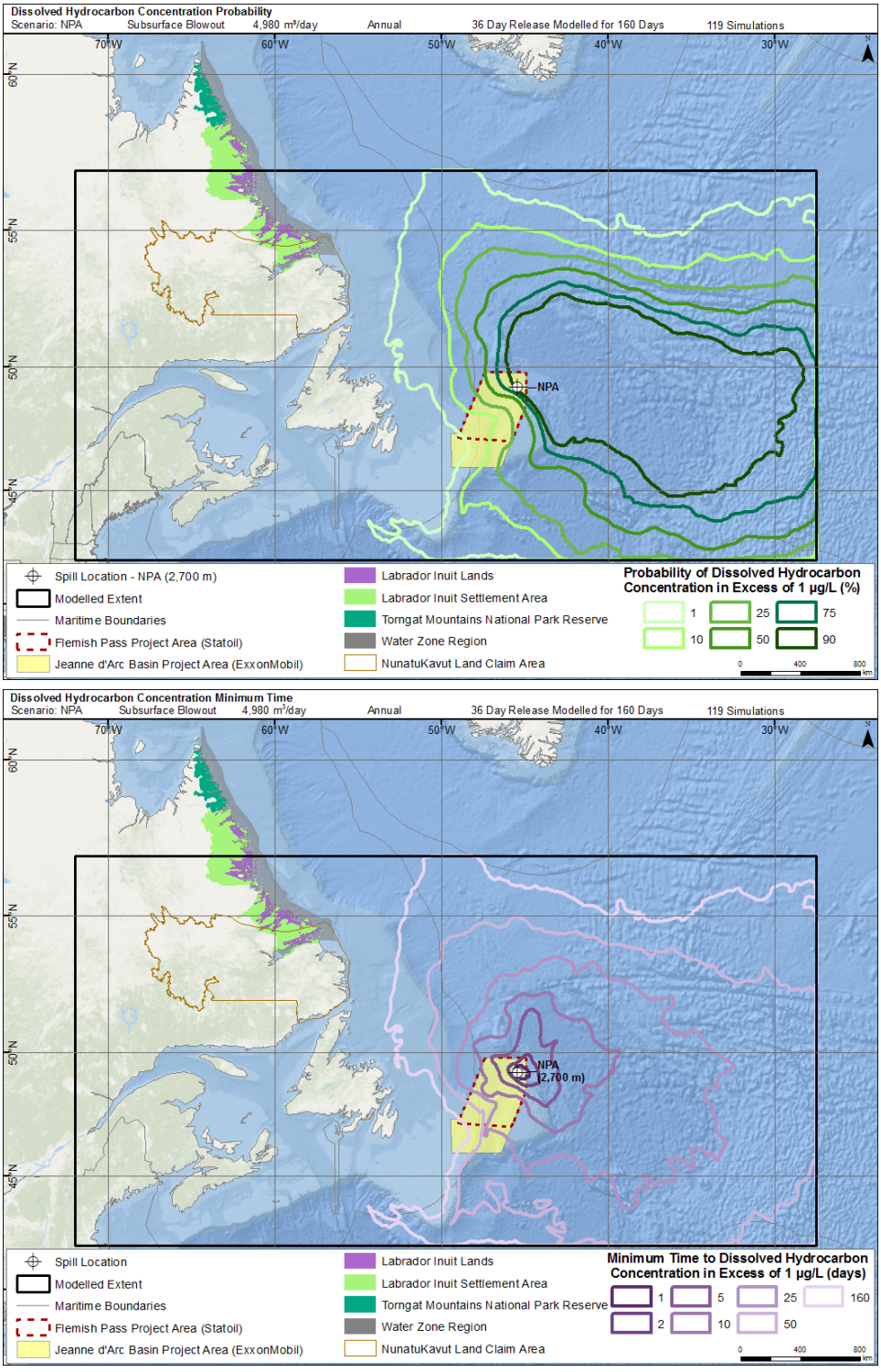


Figure 4-13. Annual probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the NPA site.

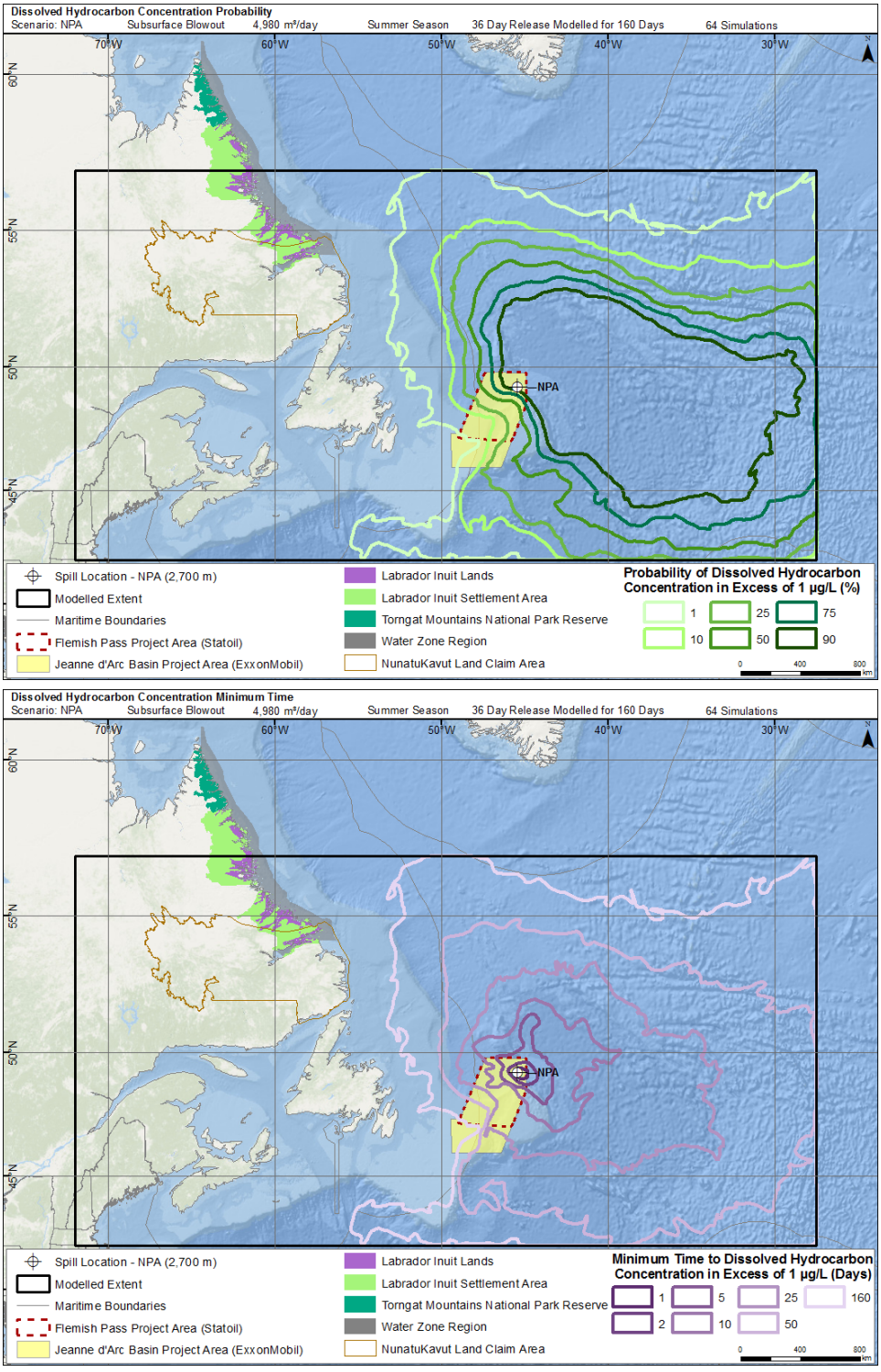


Figure 4-14. Summer probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the NPA site.

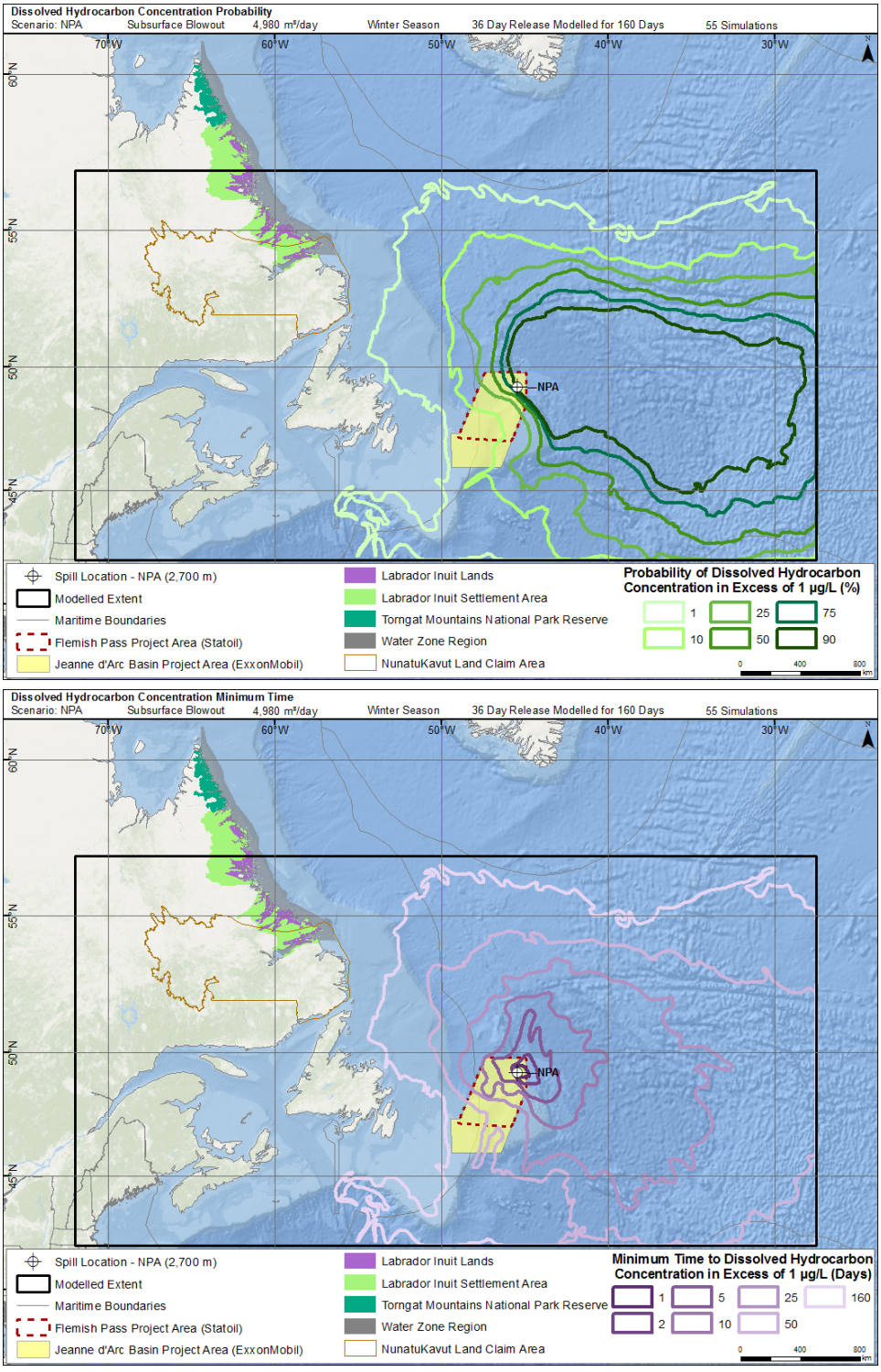


Figure 4-15. Winter probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the NPA site.

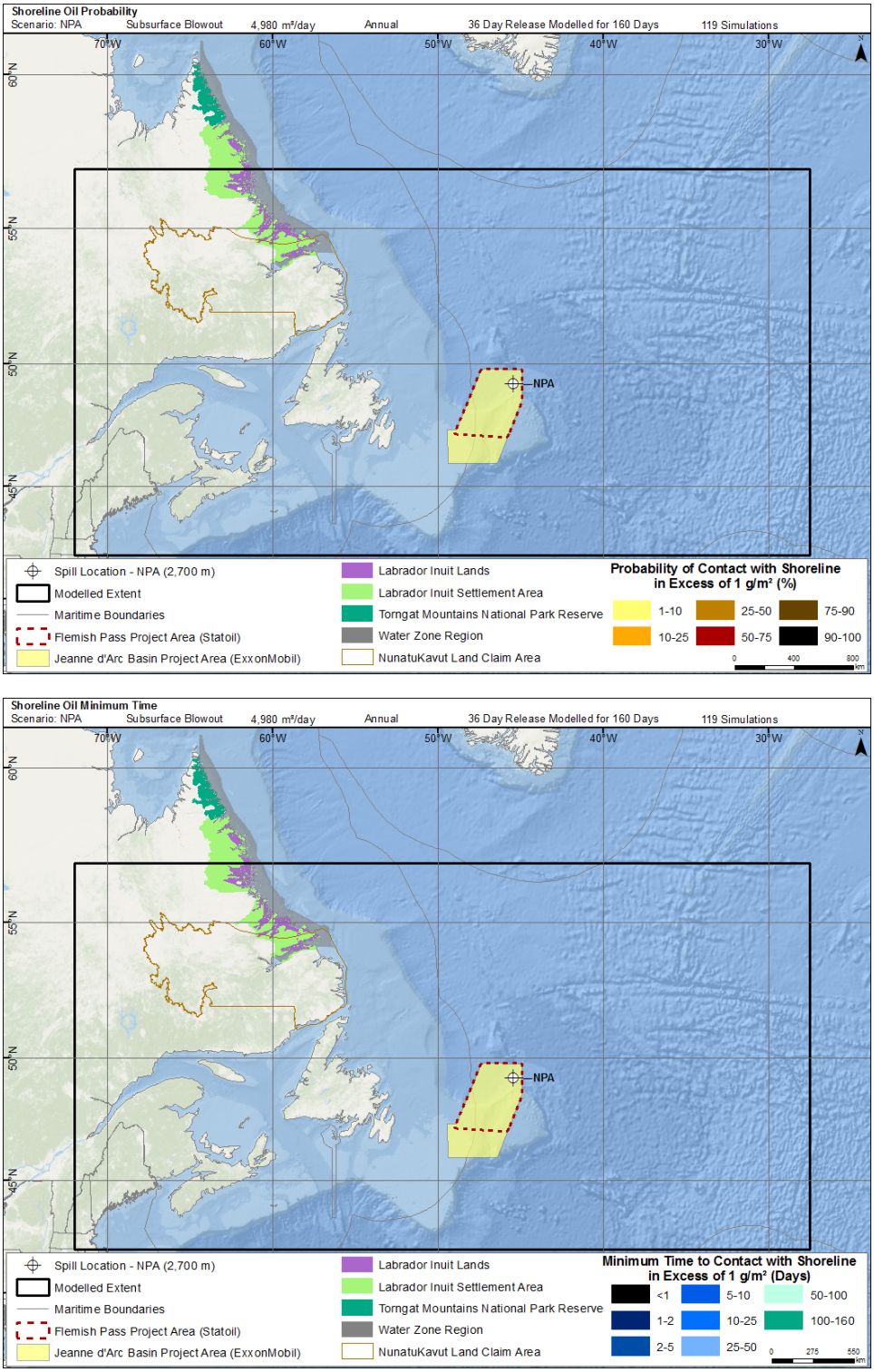


Figure 4-16. Annual probability of shoreline contact > 1 g/m2 (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the NPA site.

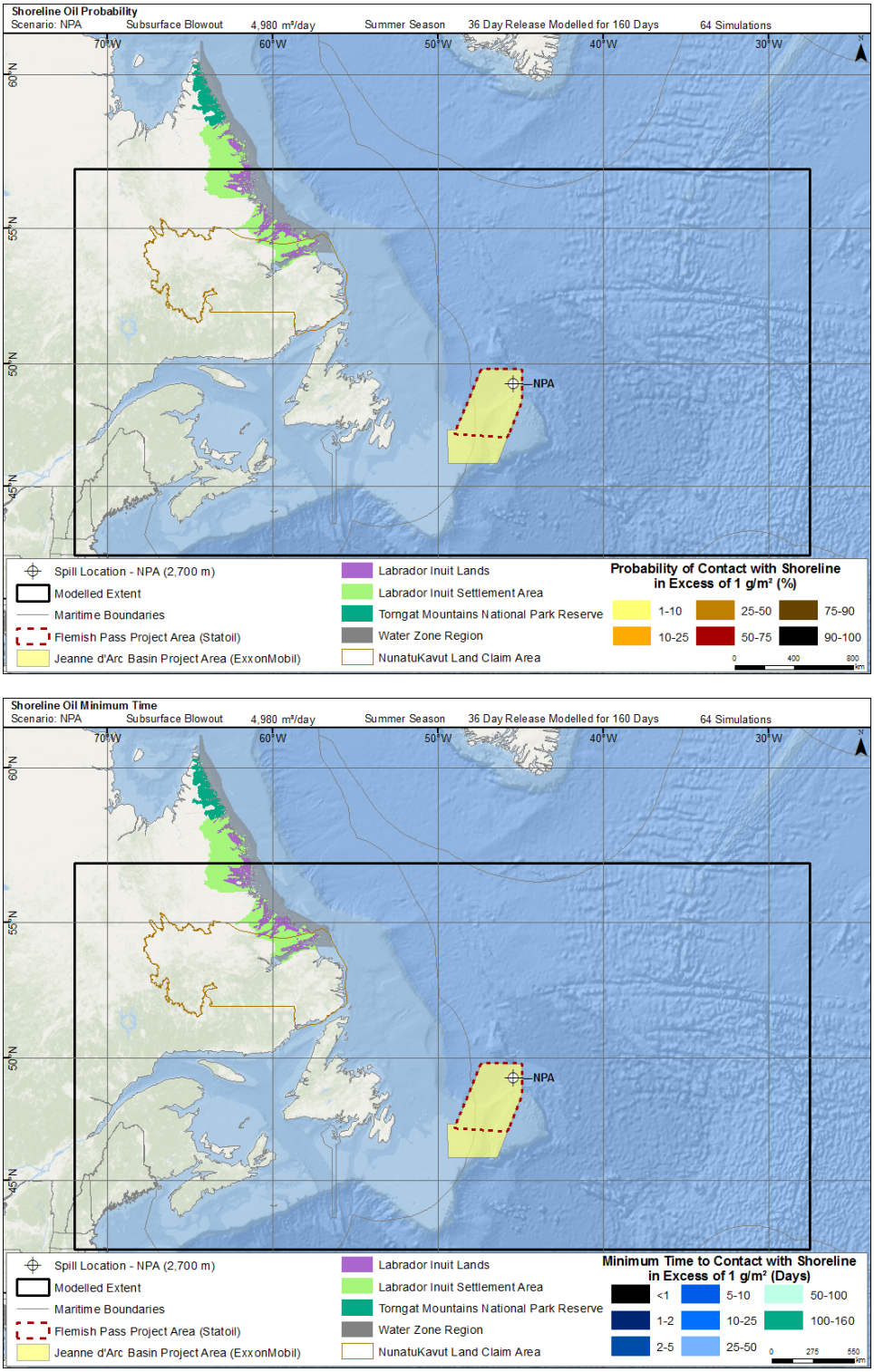


Figure 4-17. Summer probability of shoreline contact > 1 g/m^2 (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the NPA site.

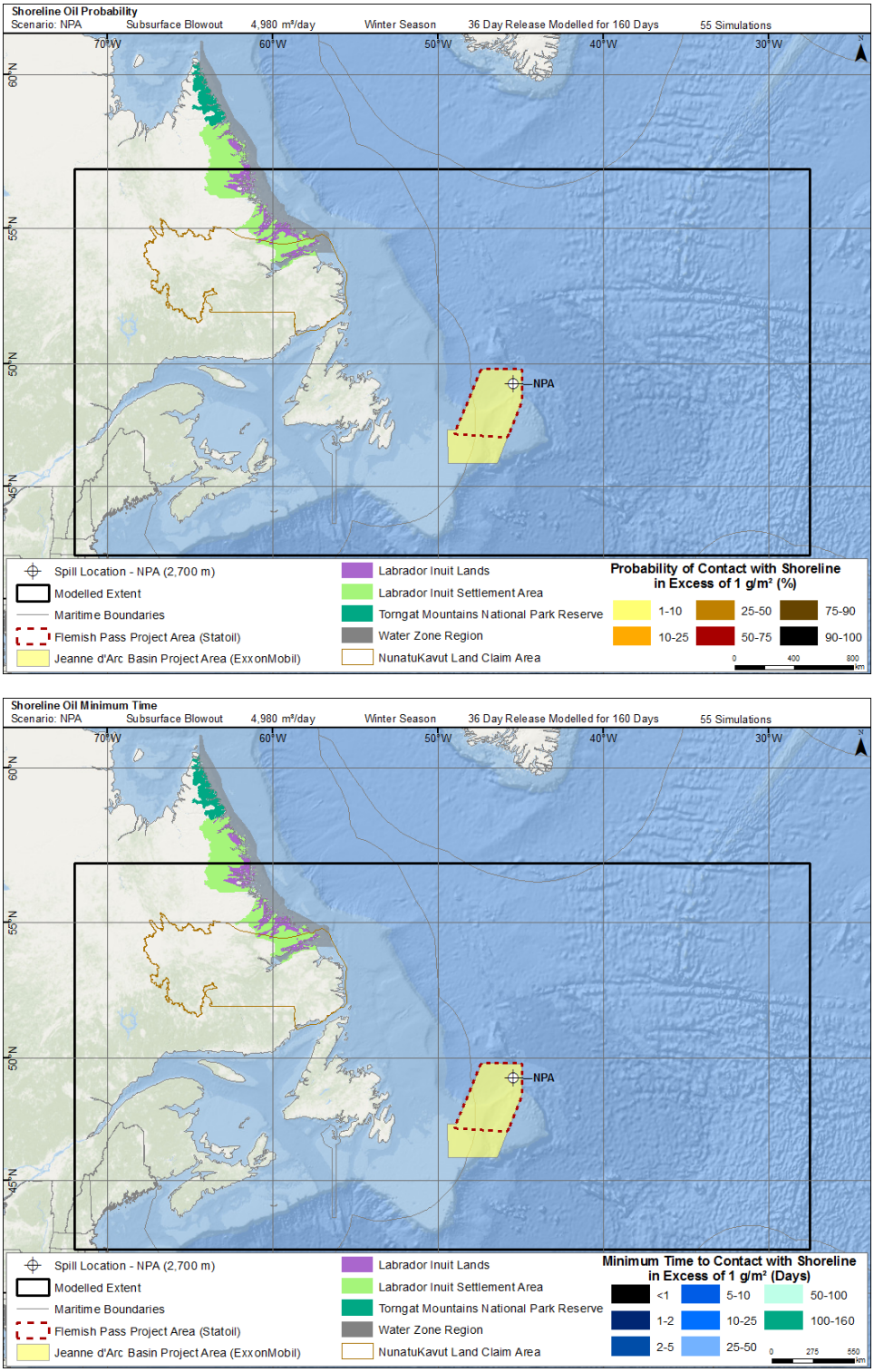


Figure 4-18. Winter probability of shoreline contact > 1 g/m^2 (top) and minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the NPA site - winter results.

4.1.3 Summary of Stochastic Results

A total of 238 individual model runs were conducted for the statistical analysis at the EPA and NPA sites representing subsurface blowouts in deep waters offshore of Newfoundland. The EPA site (1,100 m deep) was modelled as a 113-day release to represent a longer duration response of drilling a relief well and the NPA site (2,700 m) was modelled as a 36-day release to represent a cap-and-stack response scenario. All model run durations were 160 days.

Summaries of the stochastic analyses of potential surface oil exposure and water column contamination by dissolved hydrocarbons depict areas with the highest potential likelihood (>90%) to exceed thresholds to the east of the release sites. Much lower probabilities of threshold exceedance are predicted to the north and south (10-25%), while only 1-10% of releases have the potential to exceed thresholds to locations west of the hypothetical release locations (Figure 4-1 through Figure 4-18). Releases are predicted to have potential effects on Canadian and International waters, but are not expected to reach U.S. territorial waters in the simulated timeframe. In many cases, oil contamination above the identified thresholds was predicted to extend beyond the extent of the modelled domain. In these scenarios, the environmental forcing mechanisms (i.e. wind and currents) and long timeframe modelled (160 days) resulted in the transport of highly weathered oil (>50 days old) outside of the model domain.

The hypothetical release at EPA (see figures in Section 4.1.1) had the largest modelled release volume and a release depth that was much shallower than that of NPA (1,100 m vs. 2,700 m). The EPA release scenario resulted in a larger predicted area with >1% probability of surface oil exceeding 0.04 µm, when compared to NPA. The predicted surface oil footprint >90% for EPA reached a distance approximately 1,100-1,200 km to the east of the release site and was slightly larger in summer than winter (Figure 4-1 through Figure 4-3; Table 4-1). Similarly, the predicted footprint for dissolved hydrocarbons in the water column exceeding 1 µg/L at any depth predominantly extended to the east (Figure 4-4 through Figure 4-7). The predicted area of threshold exceedance for water column contamination was greater than that of the surface oil (Table 4-1). The >90% threshold extended past the easternmost boundary of the model domain and spanned a broader area to the north and south, when compared to surface oil (Figure 4-4 through Figure 4-7). Similar to the surface oil contours, the probability contour for dissolved hydrocarbons >1% was larger for EPA (Figure 4-4 through Figure 4-7), when compared to NPA (Figure 4-13 through Figure 4-17). Of notable interest, there is a slightly higher potential (1-10%) for both surface oil thickness and subsurface hydrocarbon contamination to the south of Newfoundland and east of Nova Scotia during summer months (Figure 4-4 through Figure 4-7 and Figure 4-13 through Figure 4-17). The potential for shoreline impacts are low with <5% probability of oil exceeding 1 g/m^2 making contact with shorelines from the releases at EPA (Figure 4-7 through Figure 4-9). While 35 kilometers of

shoreline were predicted to have approximately 1-2% probability of threshold exceedance during winter runs, only 13 km were predicted during the summer runs (Table 4-1). Most of the shoreline contact for EPA occurs on the southeastern shores of Newfoundland, particularly around the Avalon Peninsula, as well as Sable Island, and portions of the Northern Peninsula and the southeastern shores of Labrador (Figure 4-7 through Figure 4-9).

General findings were very similar for NPA, when compared to EPA. However, the hypothetical unmitigated release at the NPA site (see figures in Section 4.1.2) was deeper, farther offshore, of shorter duration, and had a significantly smaller volume than EPA. Although the areas exceeding 1% for surface oil thickness and in water contamination were very similar between the two release locations, the area exceeding 10% and 90% were much smaller for NPA, when compared to EPA (Table 4-1). As before, a larger probability footprint was predicted for the likelihood of water column contamination, when compared to the probability of surface oil thickness exceedance. For releases at NPA, oil was not predicted to contact the shoreline.

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. The large threshold exceedance footprints in 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 threshold could occur, based on the combination of either 119 (annual), 64 (summer), or 55 (winter) individual releases analyzed together.

The oil that is predicted to make contact with shorelines is expected to be highly weathered, as minimum time estimates for first shoreline oil exposure range from approximately 79-157 days (Figure 4-2). The oil that did make its way to shore would likely be patchy and discontinuous. The subsurface oil is transported by subsurface currents, which have higher potential to transport to the west and southwest prior to surfacing than the surface currents. This subsurface transport, in addition to proximity to the coast, increases the likelihood that over the course of 160 days, oil from a subsurface release may impact a shoreline. However, this “increased likelihood” is relatively unlikely (< 2% for the EPA releases and 0% for the NPA releases; Figure 4-2).

Table 4-1. Predicted areas, volumes, and lengths exceeding the identified thresholds for surface oil thickness, water column concentration, and mass per unit area on shorelines at each NPA and EPA. Areas are displayed by season (annual, winter, summer) and by predicted probability contour. All releases were unmitigated with a constant release rate.

Stochastic Scenario Parameters			Area, Volume, or Length Exceeding Threshold		
Component and Threshold	**Site**	**Probability Contour or Bin**	**Annual Results**	**Winter (ice cover)**	**Summer (ice-free)**
Area (km^2) of Surface Oil > 0.04 µm, on average	EPA	1%	2,792,000	2,751,000	2,507,000
		10%	2,119,000	2,111,000	2,026,000
		90%	586,600	485,800	744,100
	NPA	1%	2,441,000	2,526,000	2,235,000
		10%	1,498,000	1,514,000	1,428,000
		90%	130,600	81,630	178,600
Volume (km^3) of Water Column Dissolved Hydrocarbons > 1 µg/L at some depth within the water column	EPA	1%	2,888,000	2,951,000	2,807,000
		10%	2,437,000	2,532,000	2,374,000
		90%	1,294,000	1,243,000	1,491,000
	NPA	1%	2,516,000	2,522,000	2,479,000
		10%	2,000,000	2,111,000	2,077,000
		90%	705,200	818,700	727,400
Length (km) of Shoreline Oil > 1 g/m^2, on average	EPA	1 - 5%	-	8.3	5
		5 - 15%	-	-	-
		15 - 35%	-	-	-
	NPA	1 - 5%	-	-	-
		5 - 15%	-	-	-
		15 - 35%	-	-	-

Table 4-2. Probability of shoreline contamination and minimum time for predicted oil exposure exceeding 1 g/m^2. All releases were unmitigated with a constant release rate.

Release Site	Scenario Timeframe	Probability of Shoreline Oil Contact (%)	Minimum Time to Shore (days)	Maximum Time to Shore (days)
EPA	Annual	< 1	78.7	157.4
	Winter	1.9	78.7	157.4
	Summer	1.6	78.7	83.7
NPA	Annual	-	-	-
	Winter	-	-	-
	Summer	-	-	-

4.2 Deterministic Analysis Results

Nine individual trajectories of interest were selected from the stochastic ensemble of results for the deterministic analysis (see Table 2-5). 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 trajectories for surface oil exposure, contact with shoreline, and water column contamination of total hydrocarbons were identified from the stochastic scenarios for each site to be modelled. This resulted in two deterministic scenarios for surface oil exposure, and two more for water column contamination. However, a slightly different representative shoreline contact scenario needed to be identified, as predicted oil contact with shoreline was so limited. A single shoreline case was identified for the EPA site, as the 95th percentile case did not have any predicted oil contact with the shoreline. The representative shoreline case represents the 98th percentile by length of shoreline predicted to have contact with oil. In addition, simulations representing 100 and 1,000 L batch spills of marine diesel were modelled separately as near instantaneous release from surface vessels at both sites for a total of four more modelled releases.

The following sections contain figures corresponding to each identified representative case and tables summarizing the areas exceeding specified thresholds. During modelling, components of oil were tracked as entrained droplets of whole oil, dissolved hydrocarbon constituents, floating surface oil, and stranded oil on shorelines. The figures provided in the subsequent sections (Sections 4.2.1 through 4.2.4) 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 4-19, 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 EPA surface oil thickness case. Note the discontinuous nature of the predicted footprint as the released oil spreads and thins over time. Figure 4-20 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.

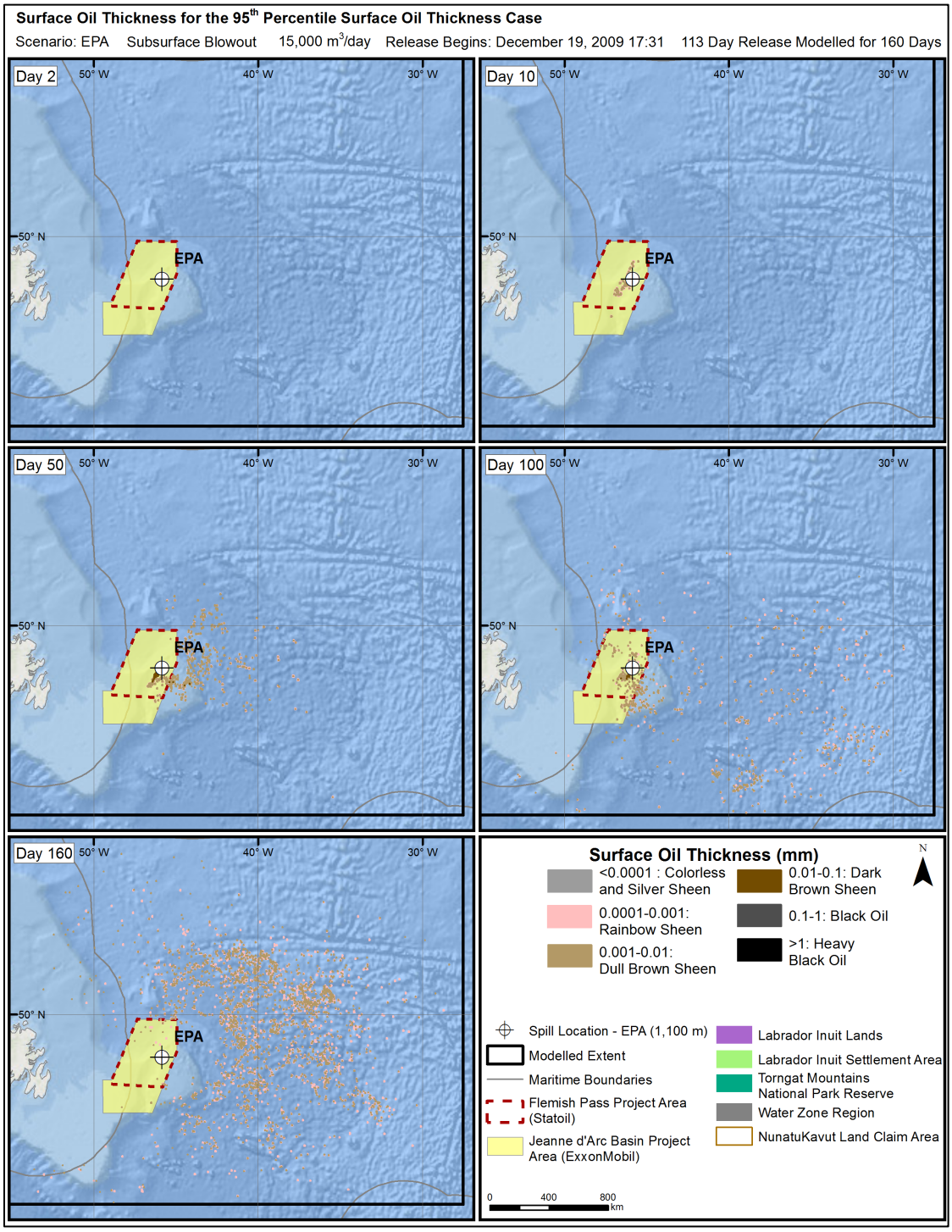


Figure 4-19. Predicted surface oil thickness for the 95th percentile EPA surface oil exposure case at days 2, 10, 50, 100, and 160.

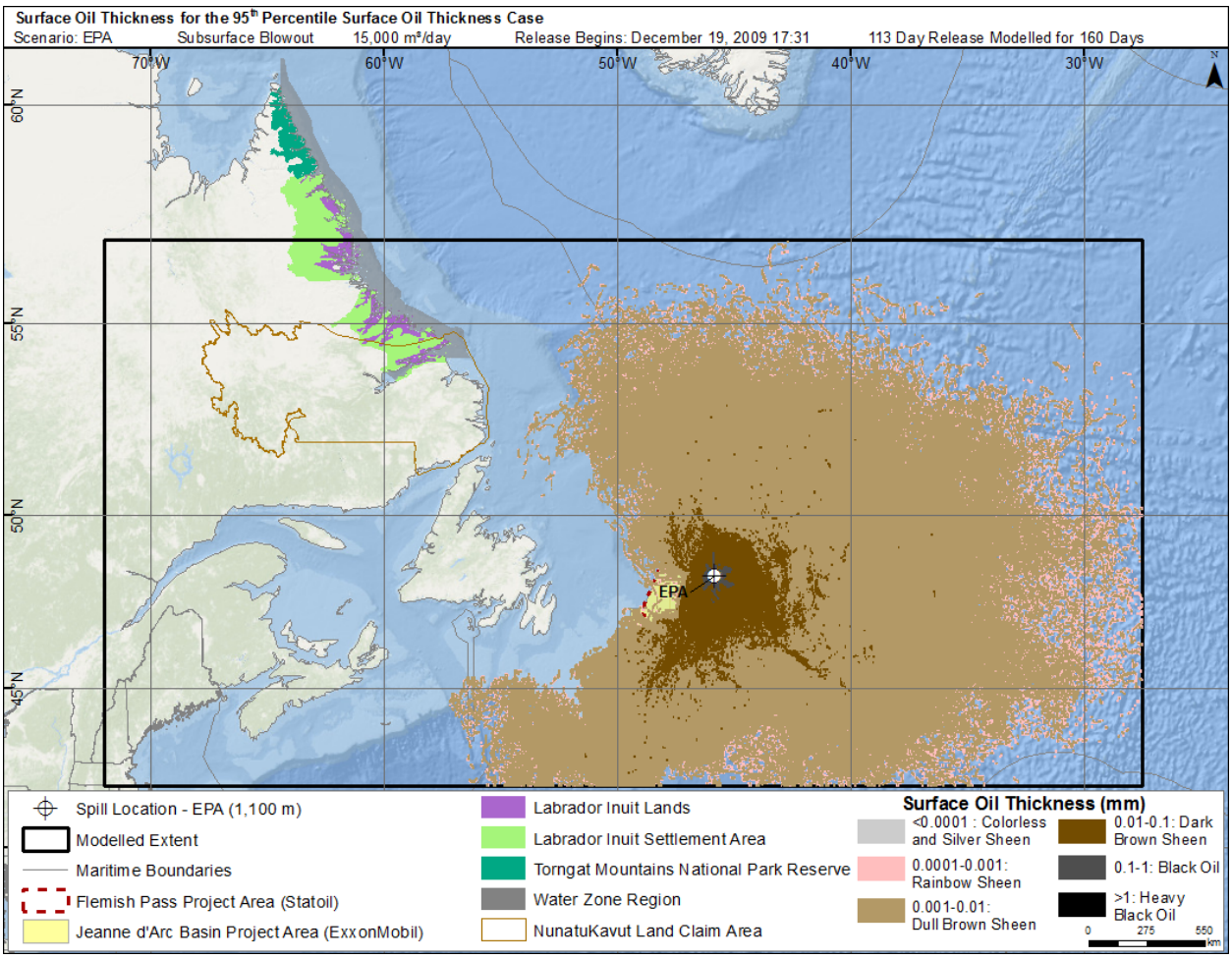


Figure 4-20. Maximum cumulative surface oil thickness for the 95th percentile surface oil exposure case.

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 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 20 m increments.

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, amount of oil in contact with the shore, oil evaporated into the atmosphere, and that which has 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 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 (see Table 2-2). For the marine diesel batch spills, the volumes released were insufficient to produce dissolved hydrocarbon footprints at the gridded resolution used (the dissolved hydrocarbons comprise roughly 1% of total hydrocarbons released). Therefore, total hydrocarbon concentrations in the water column are displayed instead of the dissolved hydrocarbons.
4. **Water Column Total Hydrocarbon Concentration 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 (see Table 2-2).
5. **Shoreline and Sediment Total Hydrocarbon Concentration Maps**: Depict the predicted total mass of oil (per unit area as g/m^2) deposited onto the shoreline and on sediments. For the marine diesel batch spills, the volumes released were insufficient to produce total hydrocarbon concentrations on the shore or sediment. Therefore, these maps are not provided for the marine diesel batch spills.

4.2.1 Surface Oil Exposure Cases

Results for the identified 95th percentile scenarios for floating surface oil exposure > 0.04 µm for the 113-day release at EPA and 36-day release at NPA are provided in the figures below. Note that the modelled release dates for these two scenarios differed, with the EPA release spanning December through May 2009, while the NPA release spanned March through September 2010 (Table 2-5). For both sites, the released oil was predicted to rise rapidly to the surface where it spread, being transported by surface winds and currents where it created discontinuous patchy surface slicks (Figure 4-21 and Figure 4-22). In both scenarios, surface oil was predicted to be thickest closest to the spill site, with maximum thicknesses corresponding to a visual appearance of a dark brown sheen. The majority of the footprint was predicted to have a maximum thickness closer in appearance to a dull brown sheen. While this surface oil was predicted to form some of the largest predicted cumulative footprints over 160 days, note that the maximum amount of released oil on the surface never exceeded 20% (in the first month) but was typically never more than 5-10% of the total mass. The smaller volume release at NPA and the northern location resulted in predicted oil trajectories to the north and east. The larger volume release at EPA and the more southern release location resulted in a much larger cumulative footprint, with larger areas of thicker oil and predicted trajectories to the northeast and the southwest towards the coast of Newfoundland. The majority of the surface expression is predicted to appear as a discontinuous dull brown sheen, with rainbow sheen possible on the outermost edges.

The combined effects of a subsurface release and the entrainment of surface oil into the water column are predicted to result in concentrations of dissolved and total hydrocarbons in the water column that exceed the identified thresholds (Figure 4-21 through Figure 4-24). Due to the larger release volume, the release at EPA was predicted to result in a larger footprint of dissolved hydrocarbon and total hydrocarbon concentrations (THC), when compared to NPA. Neither of the representative surface oil cases was predicted to result in oil contacting shorelines.

At the end of the 160-day simulations, 0-2% of the oil was predicted to remain on the water surface, approximately 42% evaporated into the atmosphere, 7-11% remained entrained within the water column, <0.01% adhered to suspended sediment, 42-43% degraded, 0% made contact with the shore, and 2-4% was transported outside of the model domain (Figure 4-21 and Table 4-4).

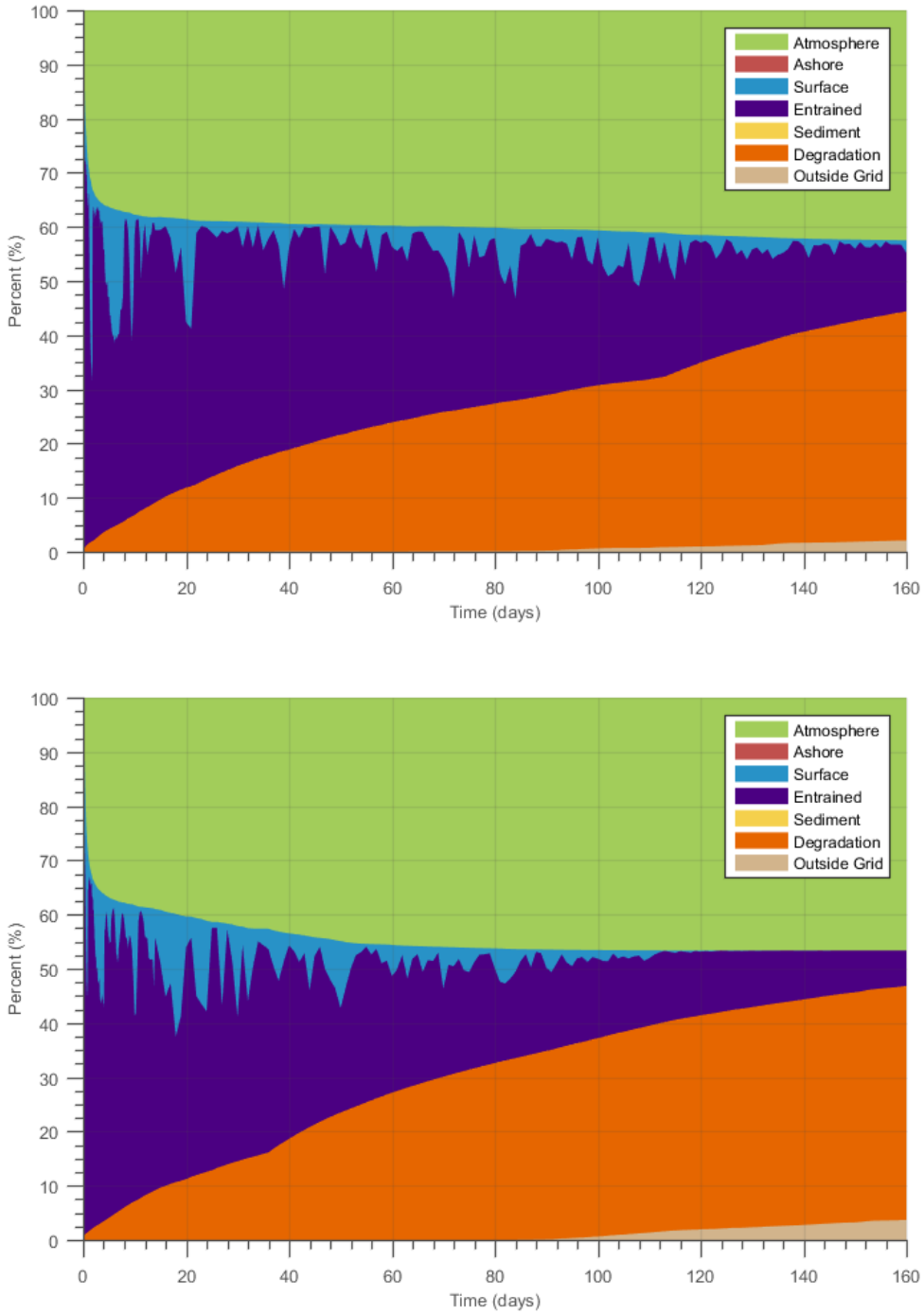


Figure 4-21. Mass balance plots for the 95th percentile surface oil thickness cases at EPA (top) and NPA (bottom).

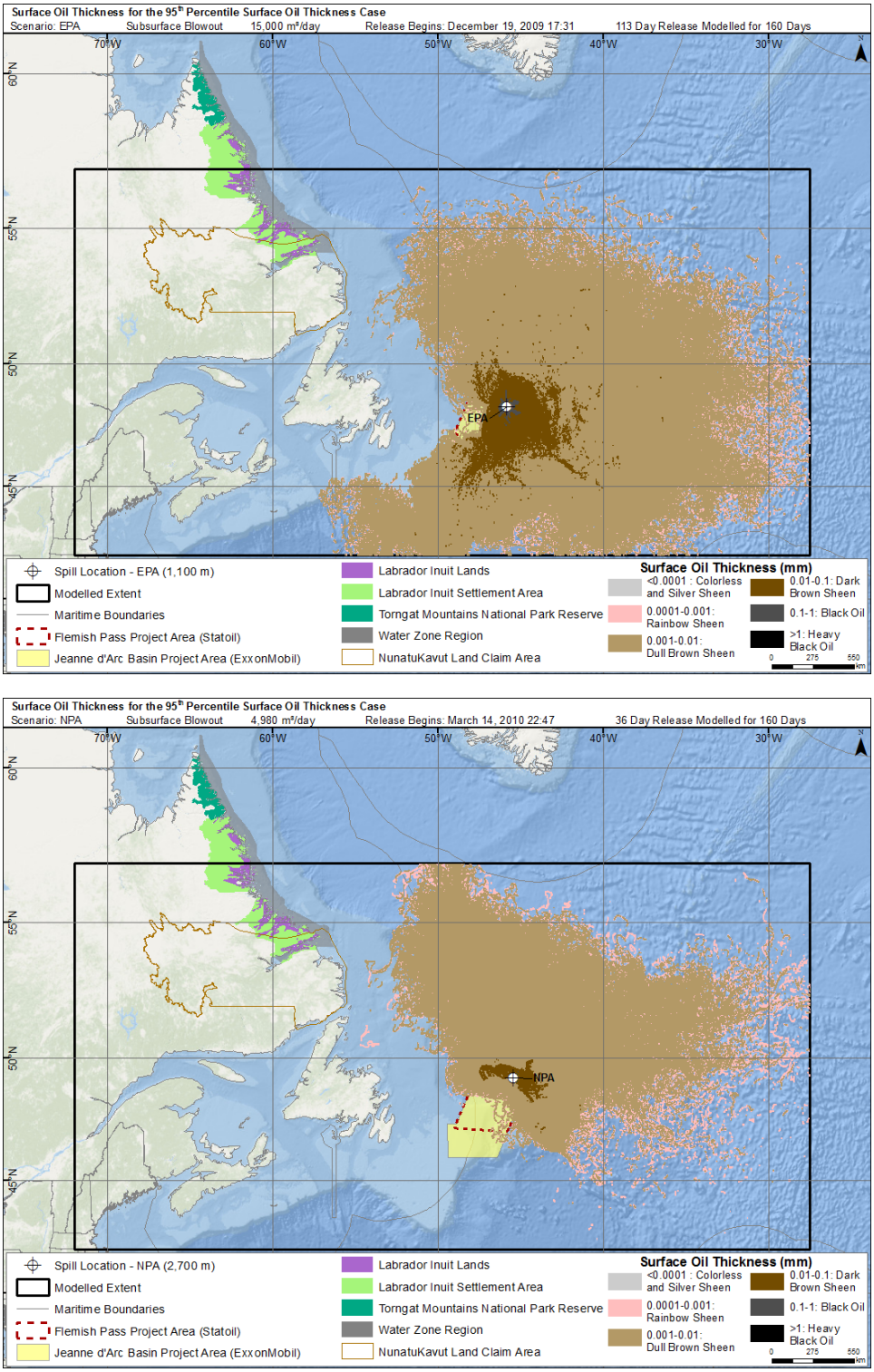


Figure 4-22. Surface oil thickness for the 95th percentile surface oil thickness case at EPA (top) and NPA (bottom).

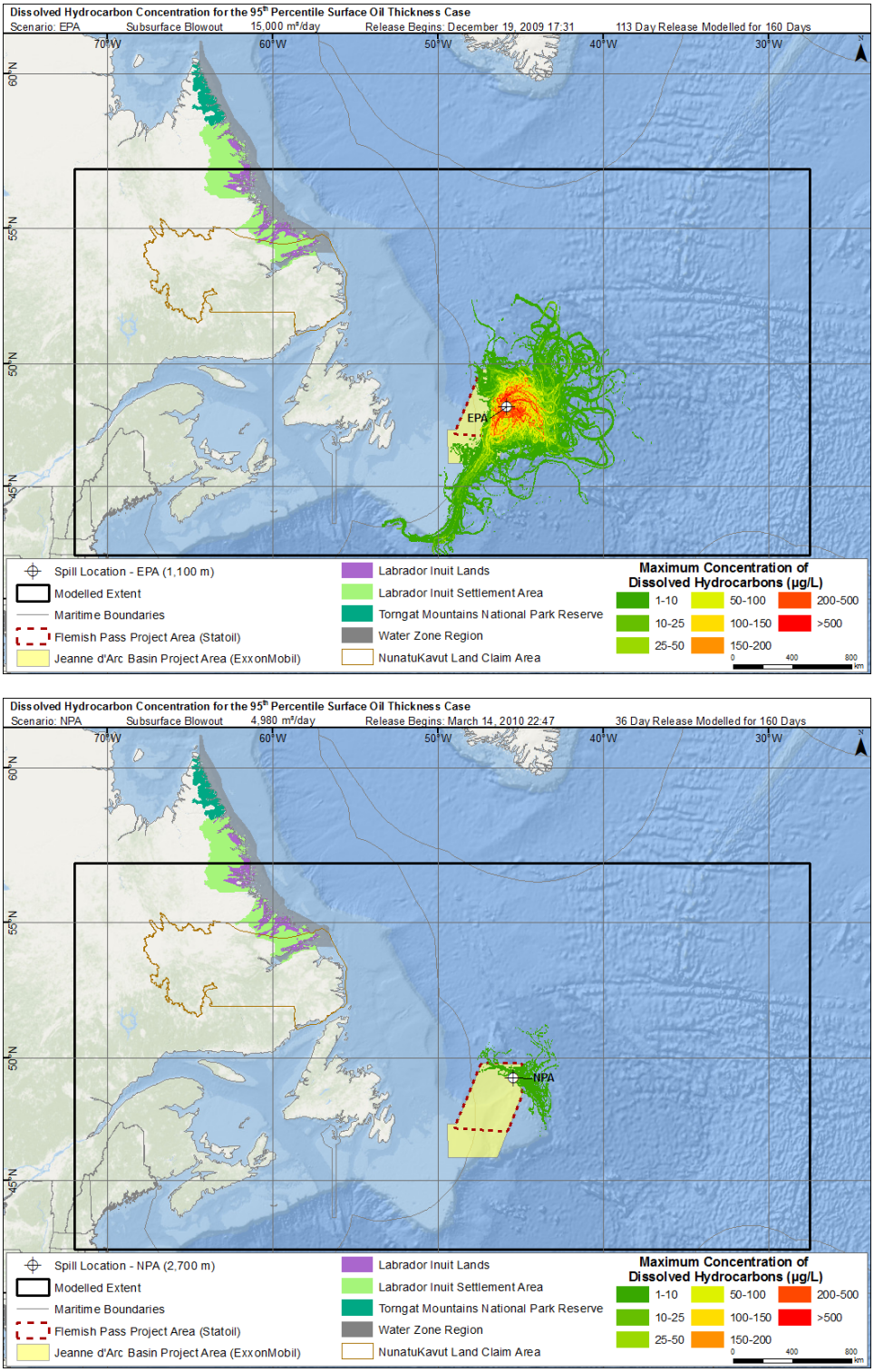


Figure 4-23. Maximum dissolved hydrocarbon concentration at any depth in the water column for the 95th percentile surface oil thickness case for EPA (top) and NPA (bottom).

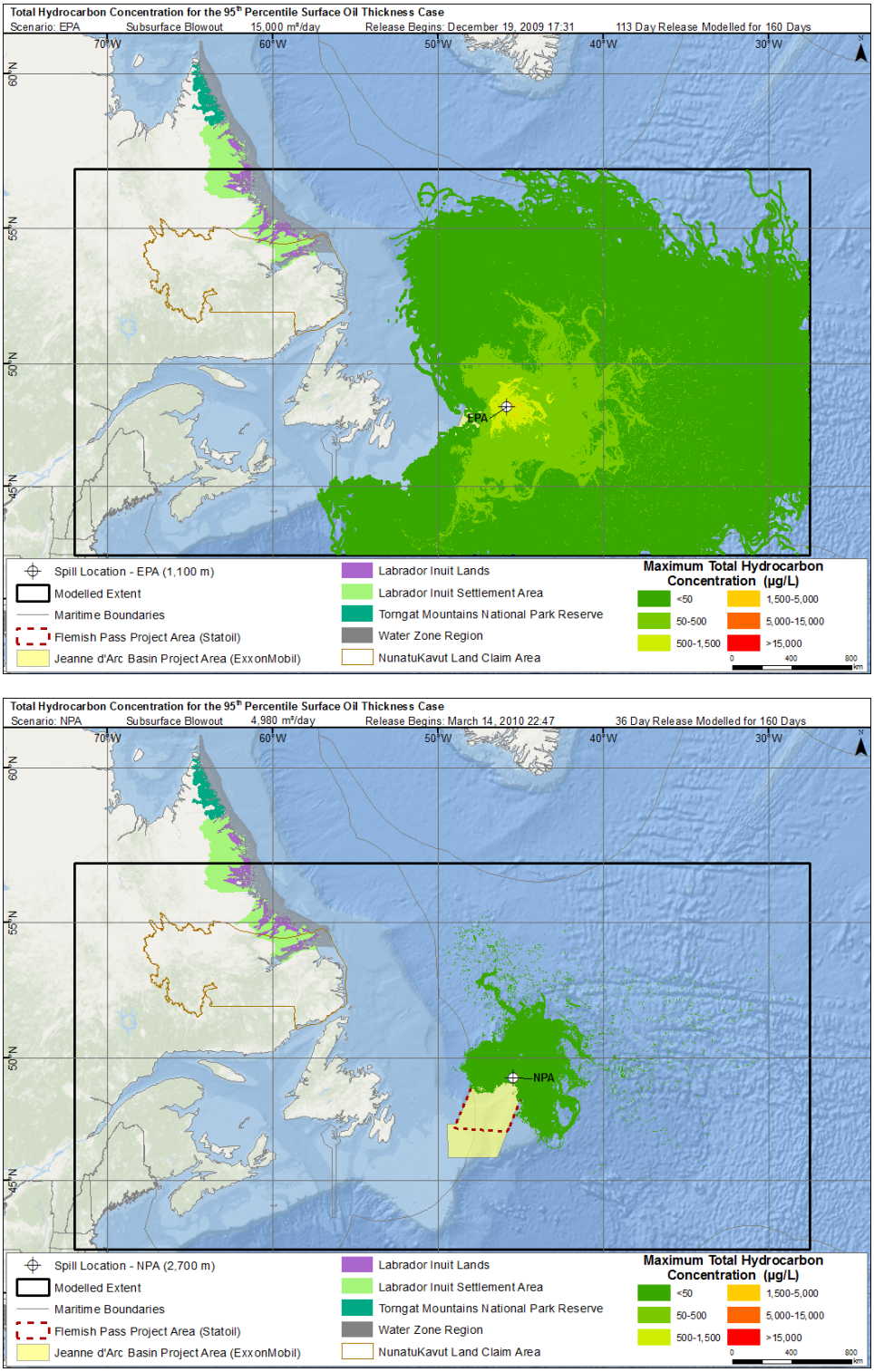


Figure 4-24. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the 95th percentile surface oil thickness case for EPA (top) and NPA (bottom).

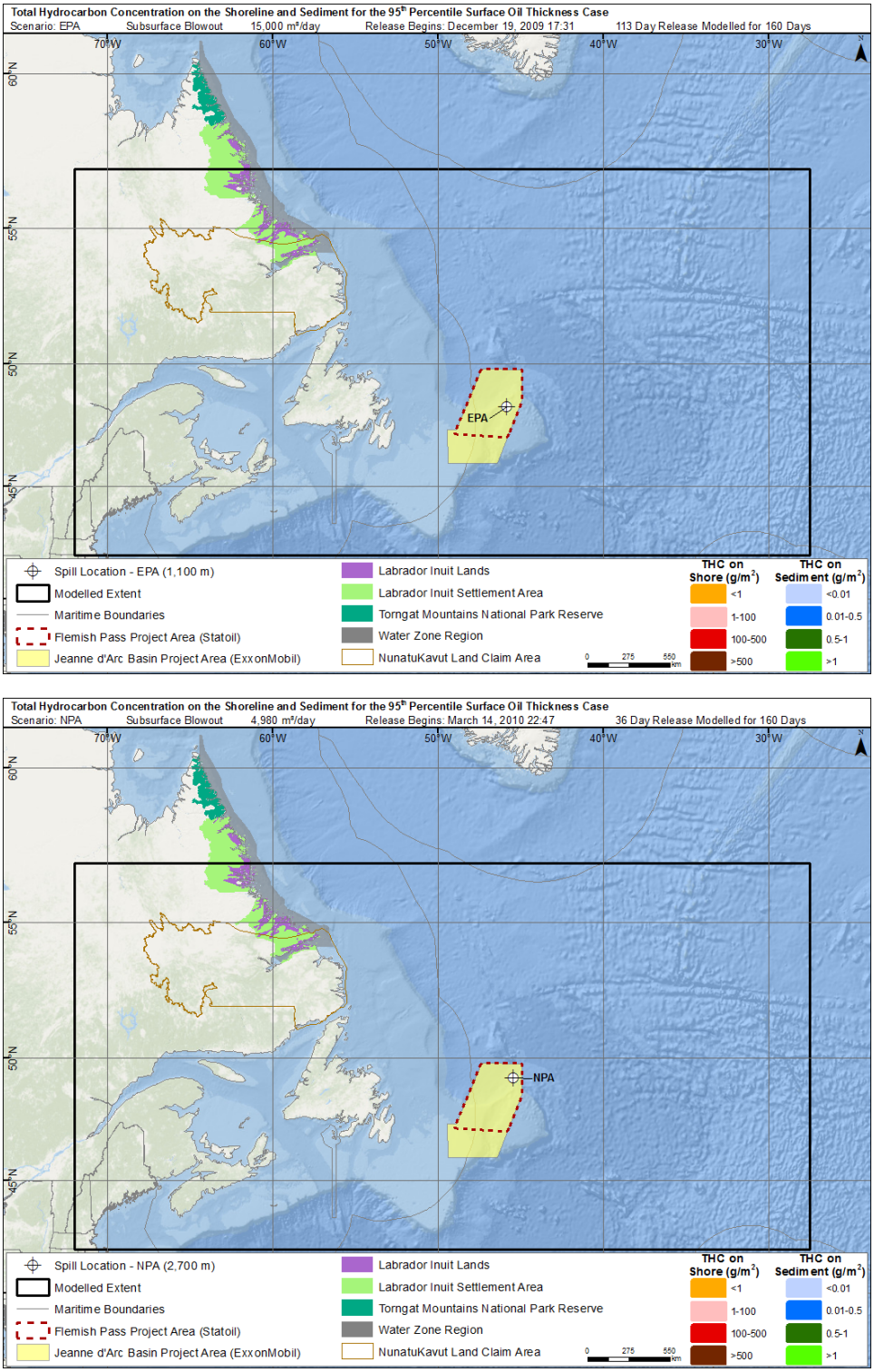


Figure 4-25. Total hydrocarbon concentration (THC) on the shore and sediment for the 95th percentile surface oil thickness case for EPA (top) and NPA (bottom).

4.2.2 Water Column Exposure Cases

Results for the identified 95th percentile water column exposure cases for the 113-day release at EPA and 36-day release at NPA are shown below. Note that the modelled release dates for the two scenarios differed from one another and from the surface cases, with the EPA release spanning July through December 2010, while the NPA release spanned January through June 2006. To reiterate, the combined effects of a subsurface release and the entrainment of surface oil from wind-induced surface breaking waves into the water column was predicted to result in both dissolved and total hydrocarbon concentrations in the water column that exceed the identified thresholds of interest (Figure 4-26, Figure 4-28, and Figure 4-29). Concentrations of dissolved and total hydrocarbons are predicted to be highest around the release site and dissipate as the oil moves away and disperses within the water column. As total hydrocarbons represent the dissolved phase (i.e., soluble fraction making up approximately 1% of the whole oil) plus the particulate phase (i.e., whole oil droplets) within the water column, THC has a much larger footprint than the predicted dissolved phase. The EPA site has higher concentrations and has a larger cumulative footprint, compared to that of the NPA site, due to the larger release volume and duration. The footprints of these predicted concentration exceedances are very similar to the surface oil trajectories, with the largest portion of the oil predicted to move towards the east (Figure 4-28 and Figure 4-29). While the highest concentrations of THC are predicted near the release site at the trap height (see Section 3.7), the majority of the predicted THC concentrations are within tens of meters of the surface. This is due to the majority of the predicted THC being the result of entrained oil from wind-induced surface breaking waves.

There was no shoreline contact from oil released at either site for the 95th percentile water column contamination cases (Figure 4-30 and Table 4-3).

At the end of the 160-day simulations, <1% of the released volume was predicted to remain floating on the water surface, 44-47% evaporated into the atmosphere, 7-12% remained entrained in the water column, <0.01% adhered to suspended sediment, 0% contacted the shore, 40-43% degraded, and 3-4% was transported outside the modelled domain (Figure 4-26 and Table 4-4).

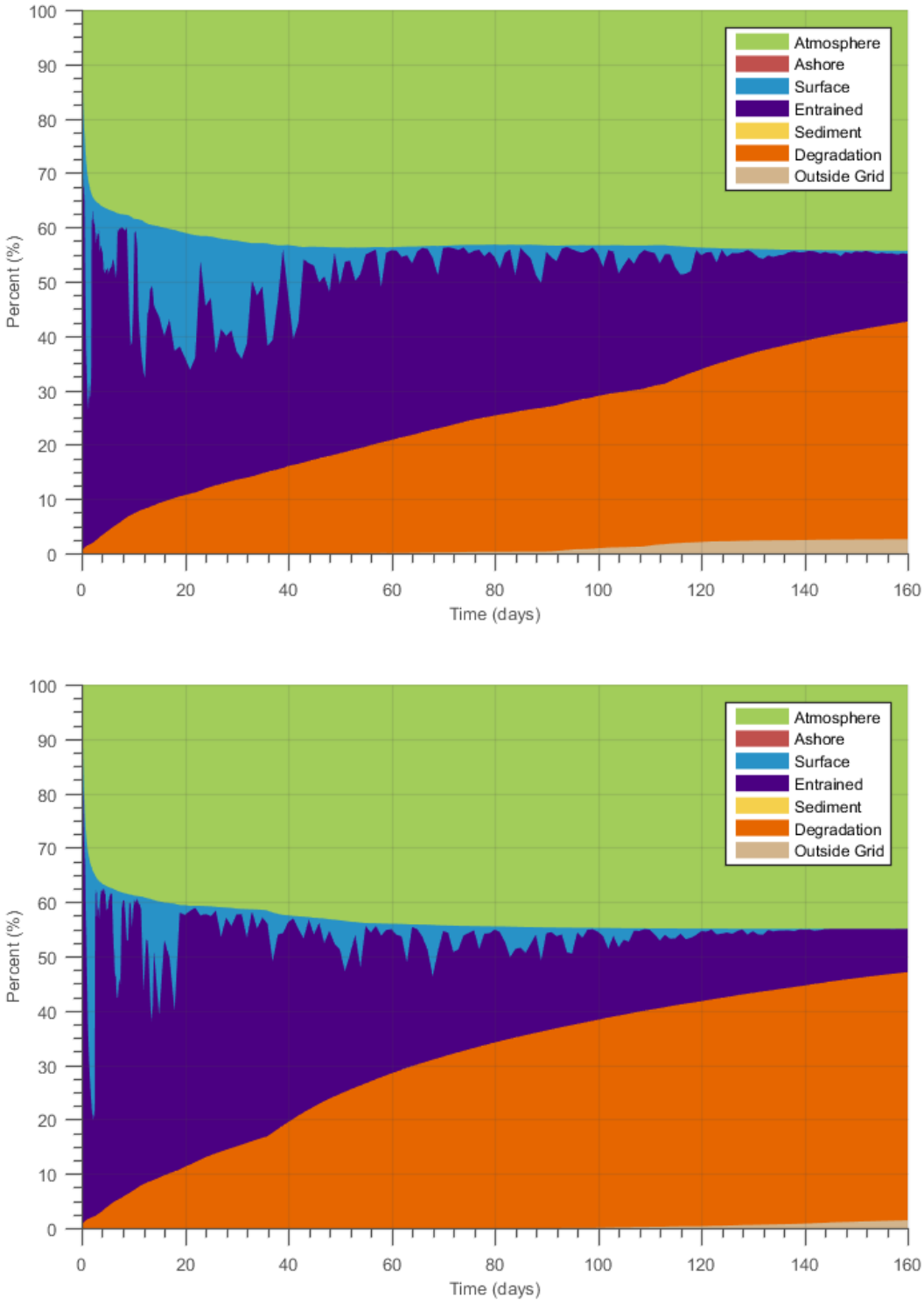


Figure 4-26. Mass balance plots of the 95th percentile water column contamination case for EPA (top) and NPA (bottom).

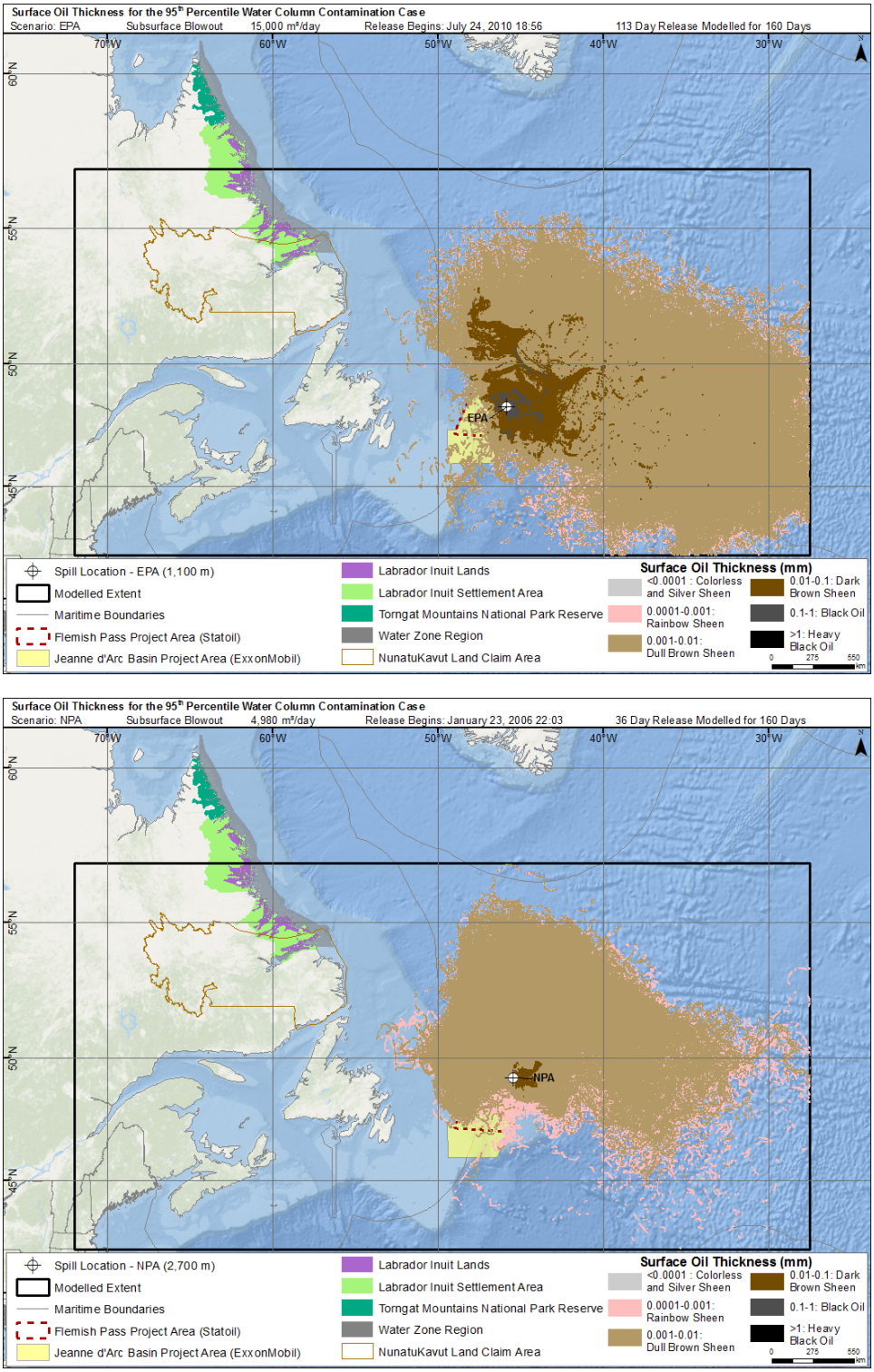


Figure 4-27. Surface oil thickness for the 95th percentile water column contamination case resulting from a subsurface blowout at the EPA site (top) and NPA site (bottom).

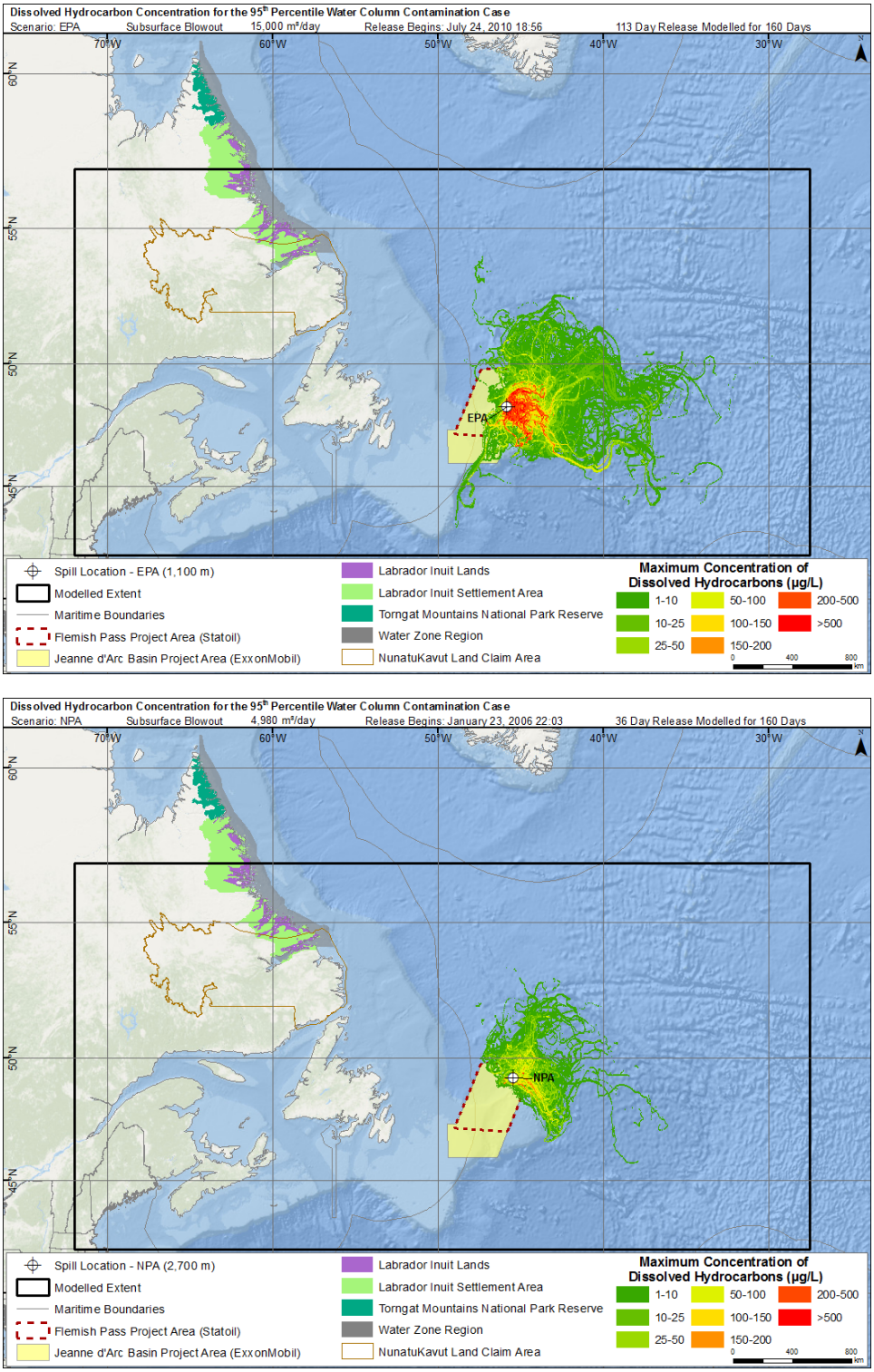


Figure 4-28. Maximum dissolved hydrocarbons at any depth in the water column for the 95th percentile water column contamination case from a subsurface blowout at the EPA site (top) and NPA site (bottom).

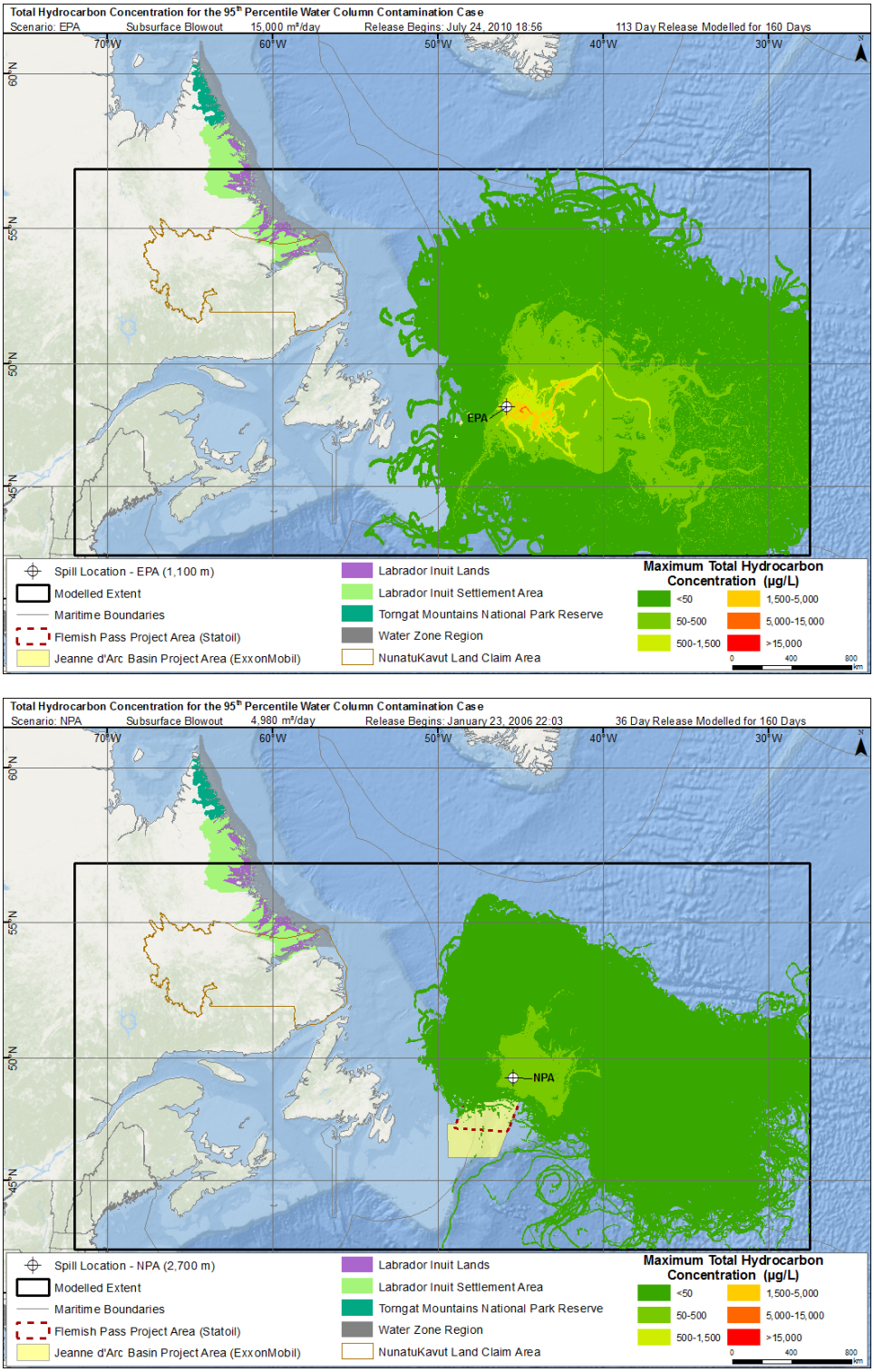


Figure 4-29. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the 95th percentile water column contamination case from a subsurface blowout at the EPA site (top) and NPA site (bottom).

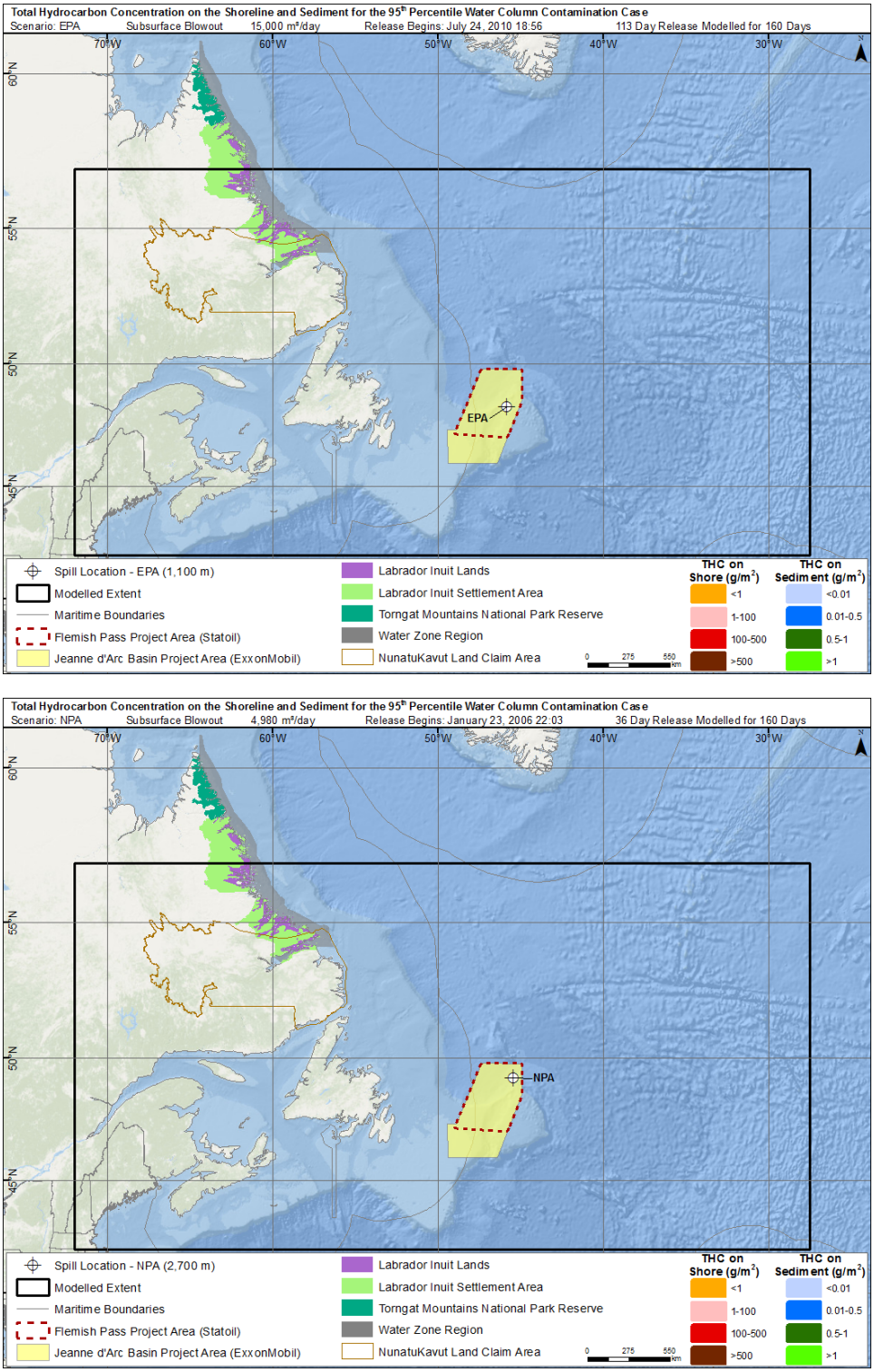


Figure 4-30. Total hydrocarbon concentration (THC) on the shore and sediment for the 95th percentile water column contamination case from a subsurface blowout at the EPA site (top) and NPA site (bottom).

4.2.3 Shoreline Exposure Case

Results for the identified representative shoreline exposure case for the 113-day release at EPA are shown below. Note that because the 95th percentile case did not result in any predicted shoreline exposure, the 98th percentile trajectory was selected as a representative "worst case." The probability of shoreline oil exposure was very low, as less than 1% of the annual scenarios reached the shoreline (Table 4-2). The predicted contact occurred on the Avalon Peninsula and southern shores of Newfoundland near Burgeo (Figure 4-35). However, only a very small portion of the cumulative trajectory was predicted to move in this direction, with only 0.01% of the release volume predicted to make contact with the shoreline (Figure 4-31; Table 4-4). Contact with the shoreline was predicted to occur 116 days into the simulation and would be highly weathered oil. There was no predicted shoreline contact for the 36-day release case at NPA.

Shoreline oil exposure is highly unlikely due to a combination of the forcing parameters transporting surface and entrained oil predominantly to the east. In particular, the predominately westerly winds (Figure 3-4) tend to transport oil offshore. The surface currents are variable (Figure 3-7 and Figure 3-8) and do not continuously transport oil in any one specific direction for significant periods of time. In addition, the release sites are located approximately 500 km offshore. Therefore, there would be a large amount of time required to pass before any oil made its way to shore, at which point evaporation and degradation would have heavily weathered the oil.

In the case of this 98th percentile shoreline exposure scenario, the combination of wind and current conditions resulted in a very small portion of the release making contact with the shoreline. The total hydrocarbon concentration on shore ranged from 100-500 g/m^2, which is above the socioeconomic (1 g/m^2) and ecological (100 g/m^2) thresholds (Table 4-3).

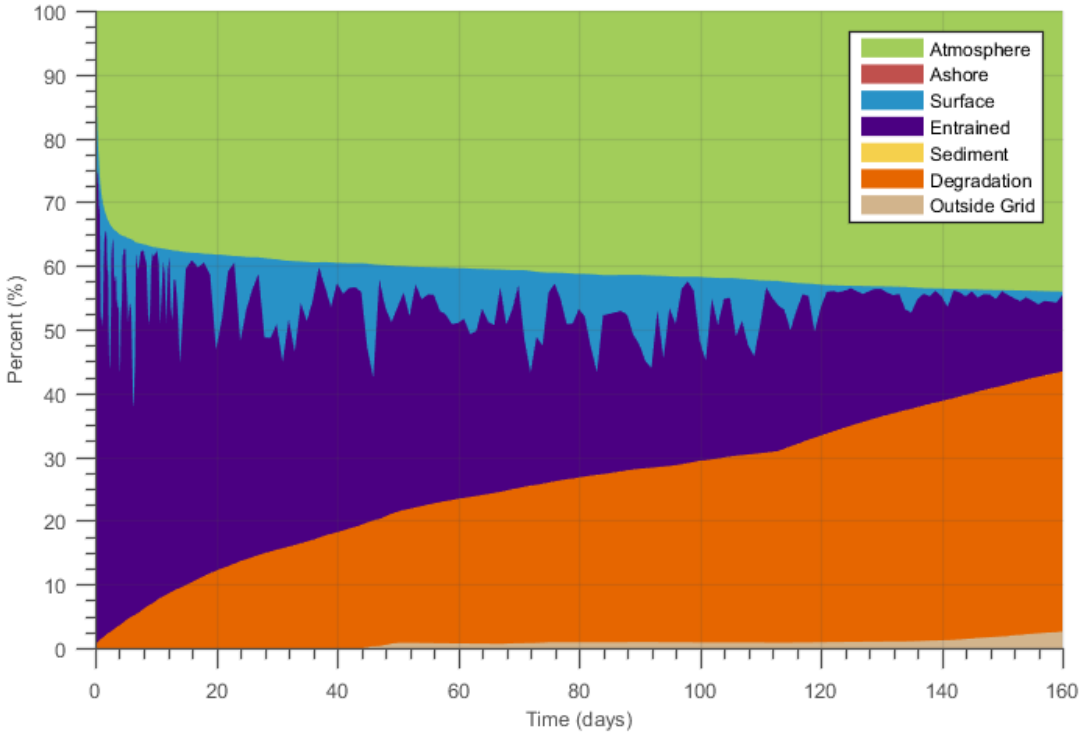


Figure 4-31. Mass balance plot of the 98th percentile contact with shoreline case for EPA.

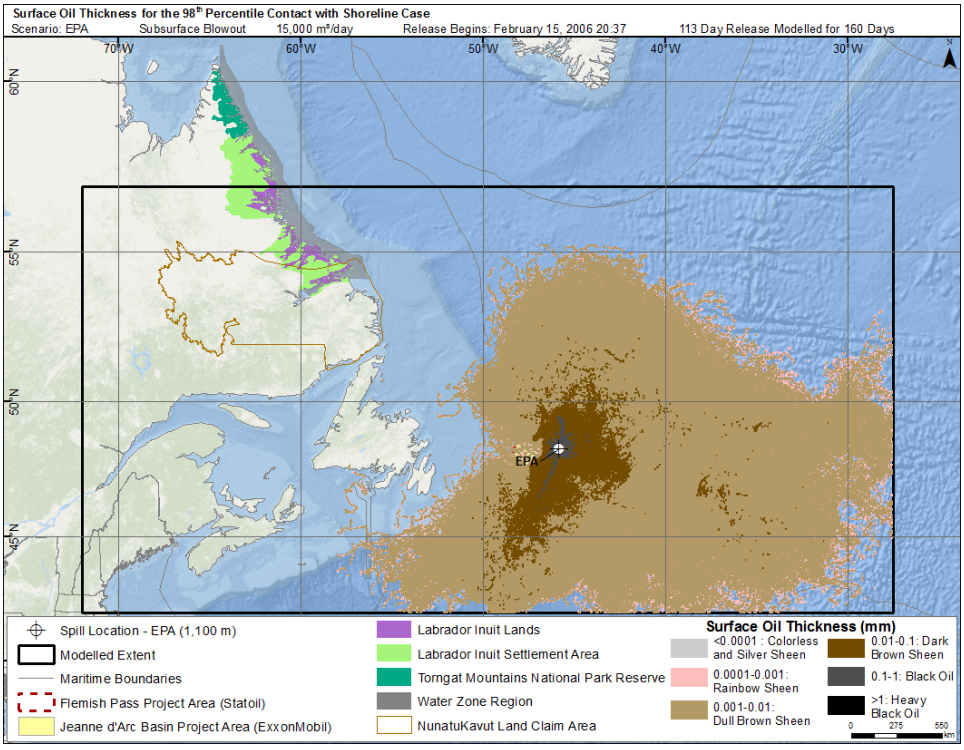


Figure 4-32. Surface oil thickness for the 98th percentile contact with shoreline case for EPA.

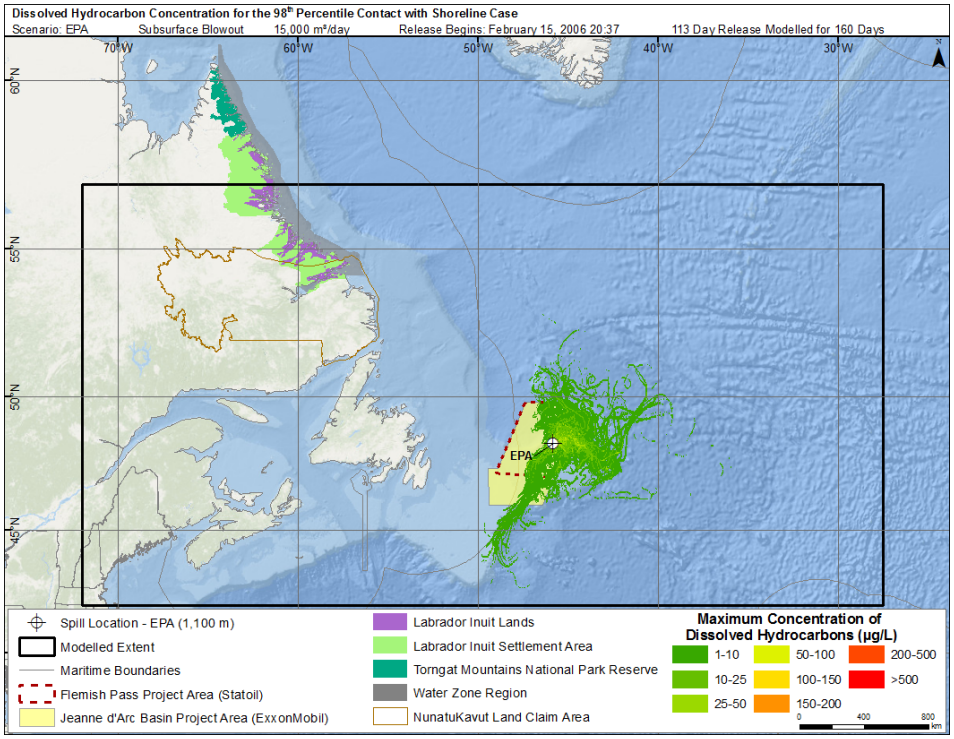


Figure 4-33. Maximum dissolved hydrocarbons at any depth in the water column for the 98th percentile contact with shoreline case for EPA.

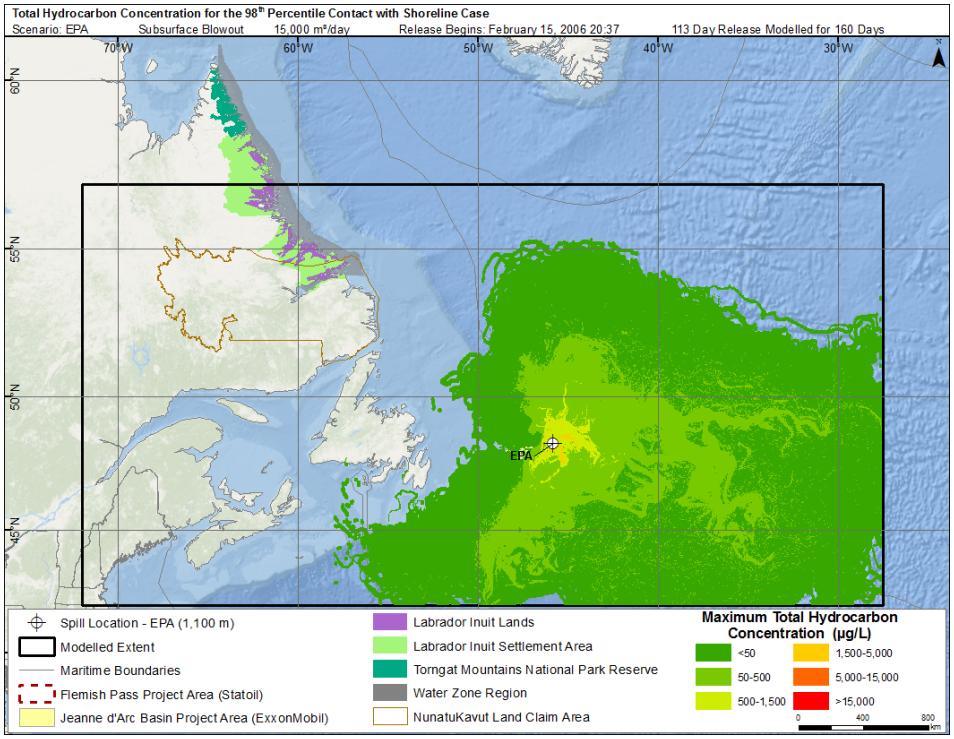


Figure 4-34. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the 98th percentile contact with shoreline case from a subsurface blowout at the EPA site.

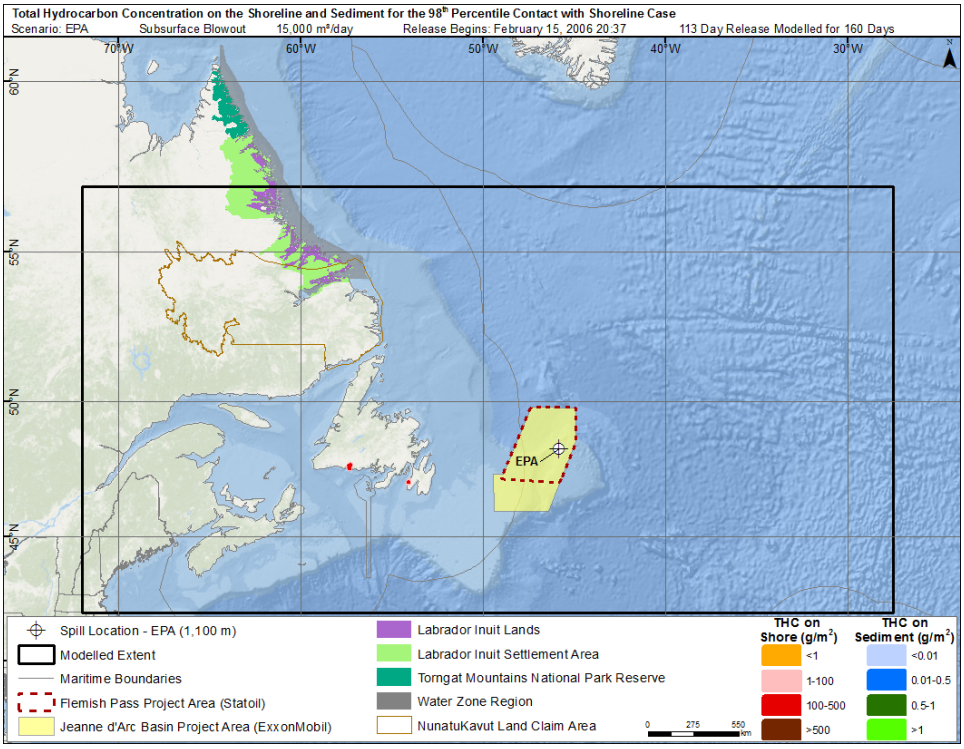


Figure 4-35. Total hydrocarbon concentration (THC) on the shore and sediment for the 98th percentile contact with shoreline case from a subsurface blowout at the EPA site.

4.2.4 Marine Diesel Batch Spills (100 L and 1,000 L)

Results for the marine diesel batch spill scenarios (100 L and 1000 L) at EPA and NPA are provided in the figures below. Small volume releases were modeled to be representative of spills that could occur during bunkering operations (i.e., transfer from a vessel). The scenarios were selected to occur during the calmest wind-speed period during the summer/ice-free conditions, which would result in the largest amount of oil on the water surface. The selected dates were June 15, 2009 at EPA and June 18, 2009 at NPA.

Due to the small release volume and the size of the concentration gridding (1,800 m by 2,500 m), predicted concentrations of dissolved hydrocarbons were not expected at either EPA and NPA and thus figures have not been presented below. Furthermore, concentrations of total hydrocarbons were only predicted for the 1,000 L batch spills at EPA and NPA in the vicinity of the spill site (Figure 4-38 and Figure 4-41). The predicted THC concentrations were within tens of meters of the surface, as they are the result of entrained oil from wind-induced surface breaking waves within the surface mixed layer. For the smaller (100 L) batch spills at EPA and NPA, surface oil spread rapidly with no grid cells exceeding 0.04 µm on average (Figure 4-37 and Figure 4-40). However, the larger volume releases (1,000 L) resulted in predicted surface oil exposure areas ranging from 17 to 22 km^2 (Table 4-3). Neither of the batch spills at EPA or NPA were predicted to result in any oil contacting shorelines.

At the end of the 30-day simulation, <0.1% of the released volume was predicted to remain floating on the water surface, 74-78% evaporated into the atmosphere, 8-9% remained entrained in the water column, 0% adhered to suspended sediment, 0% contacted the shore, 14-17% degraded (Figure 4-36, Figure 4-39, and Table 4-4).

4.2.4.1 EPA Release Site

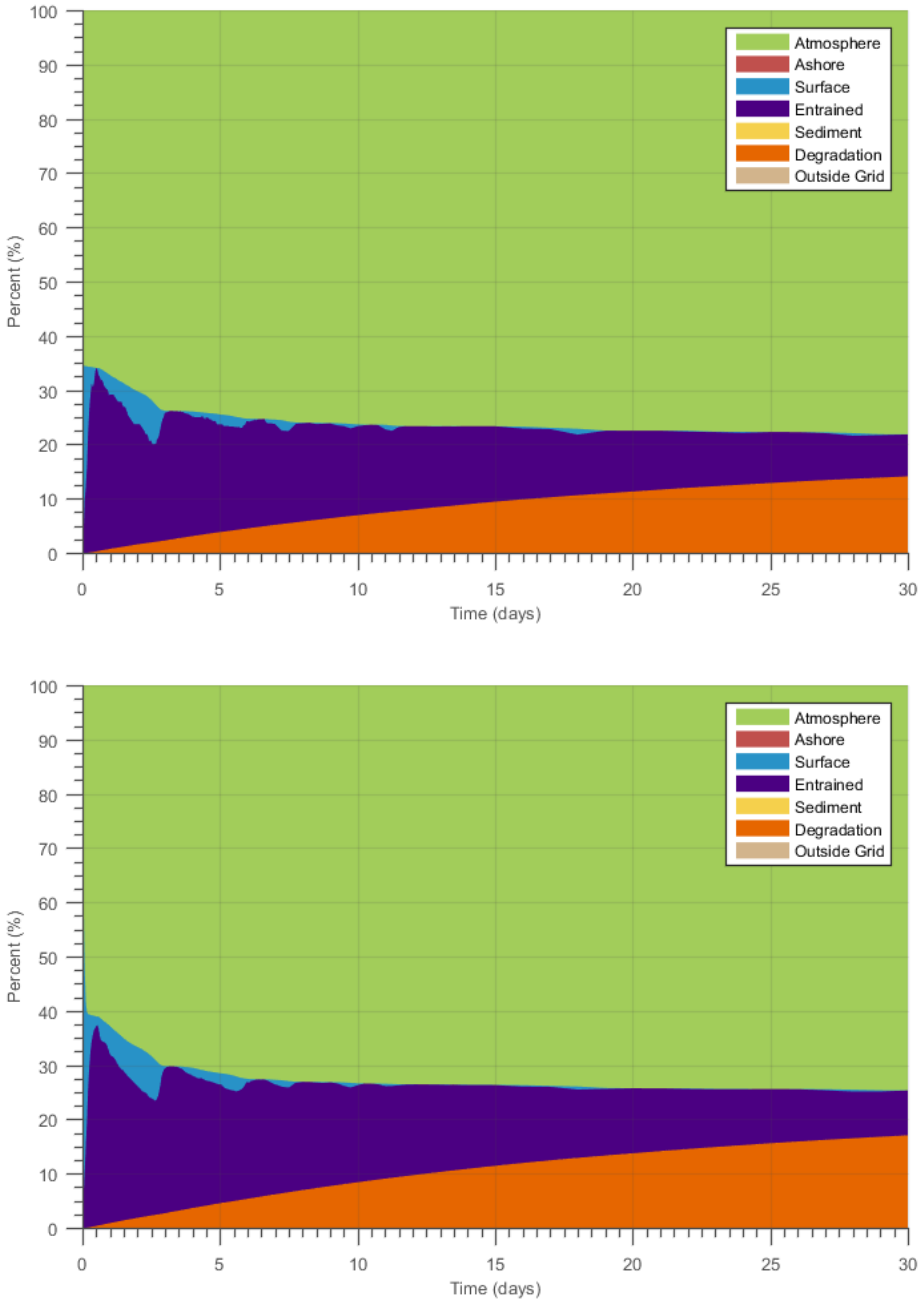


Figure 4-36. Mass balance plots of the EPA release site marine diesel batch spills of 100 L (top) and 1,000 L (bottom).

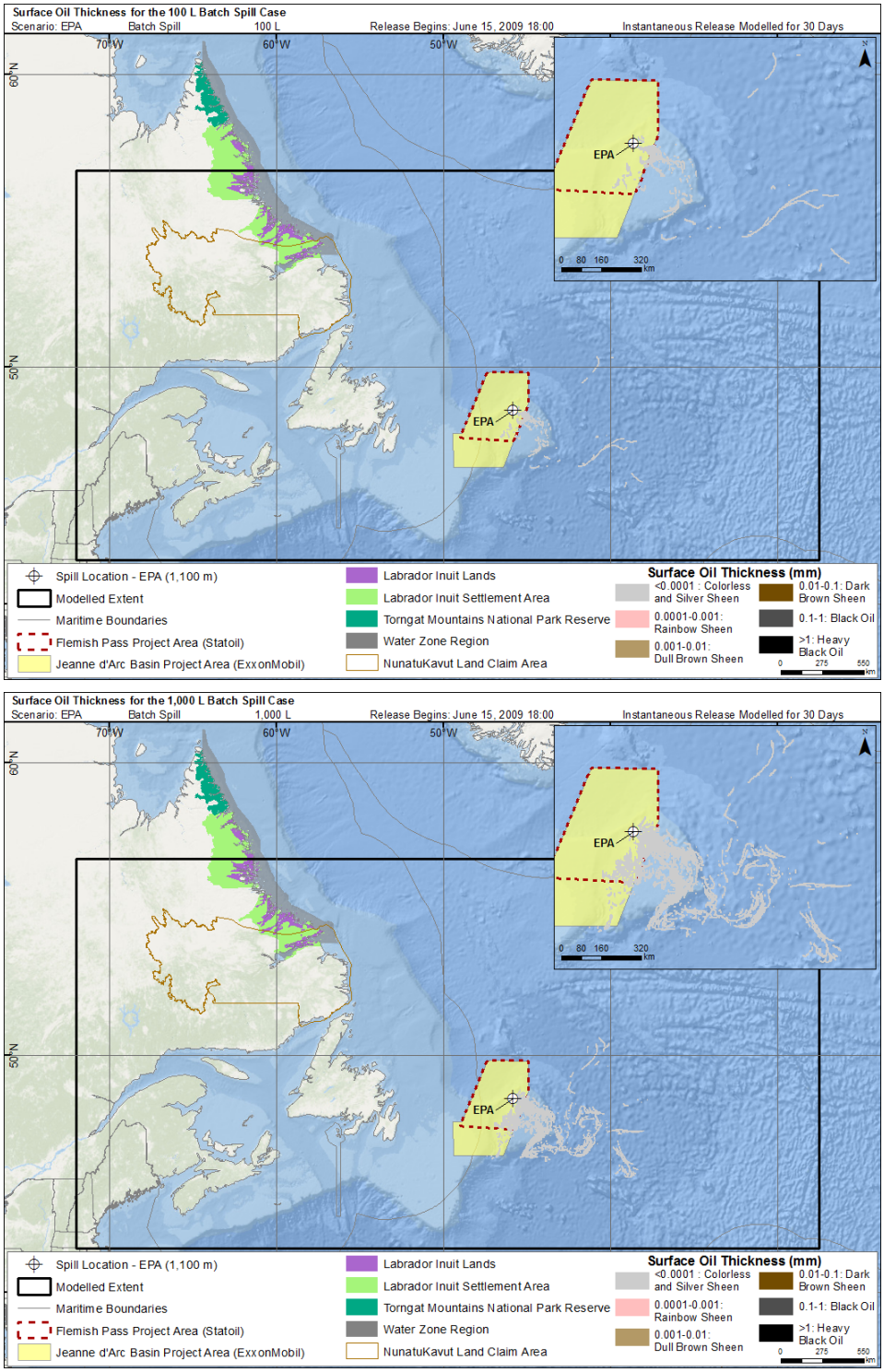


Figure 4-37. Surface oil thickness for the marine diesel batch spills of 100 L (top) and 1,000 L (bottom) at the EPA site. The minimum thickness of surface oil > 0.04 µm is displayed (cumulative over all modelled time steps).

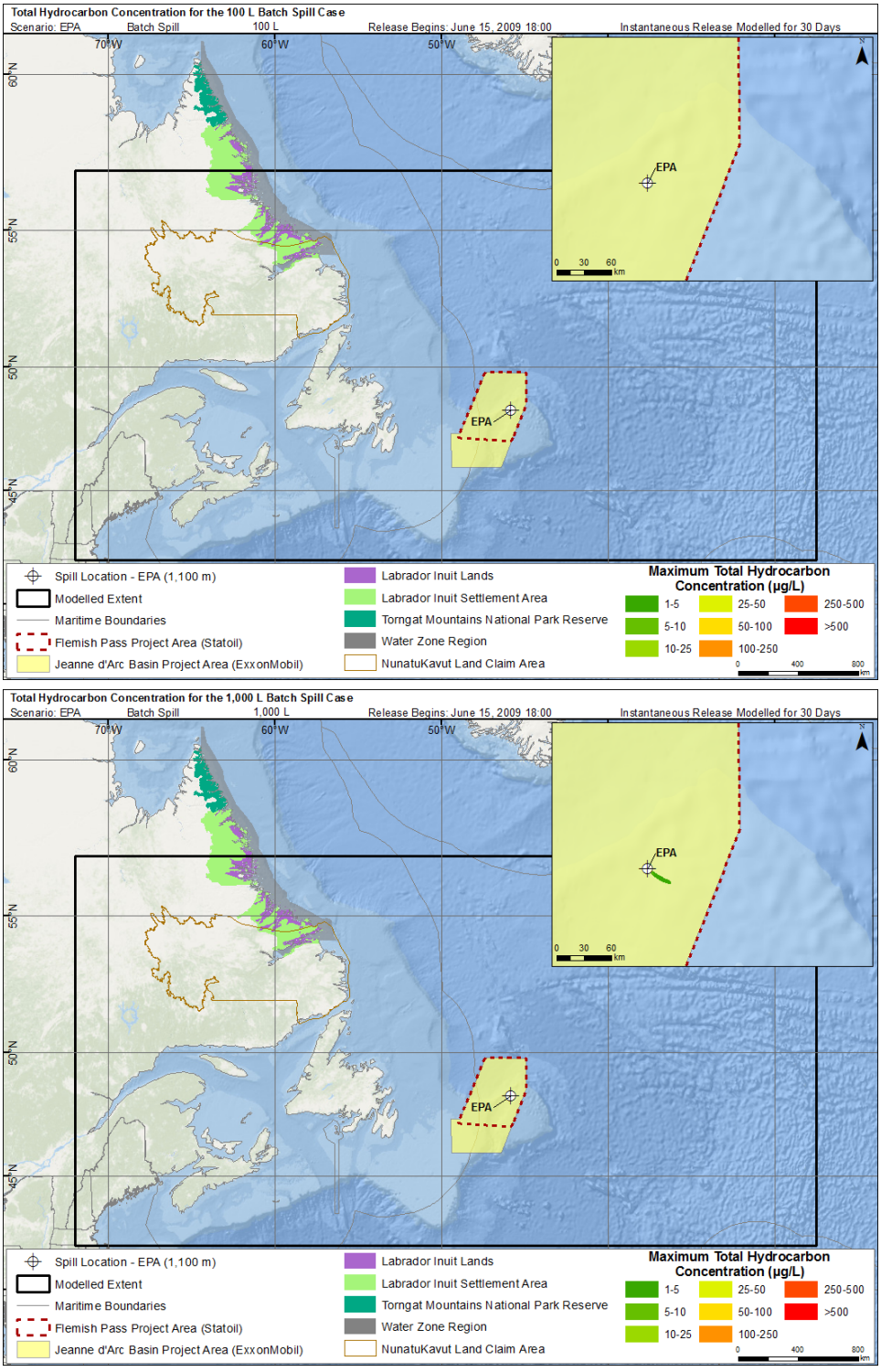


Figure 4-38. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the marine diesel batch spills of 100 L (top) and 1,000 L (bottom) at the EPA site. The minimum threshold of THC > 1 µg/L is displayed (cumulative over all modelled time steps).

4.2.4.2 NPA Release Site

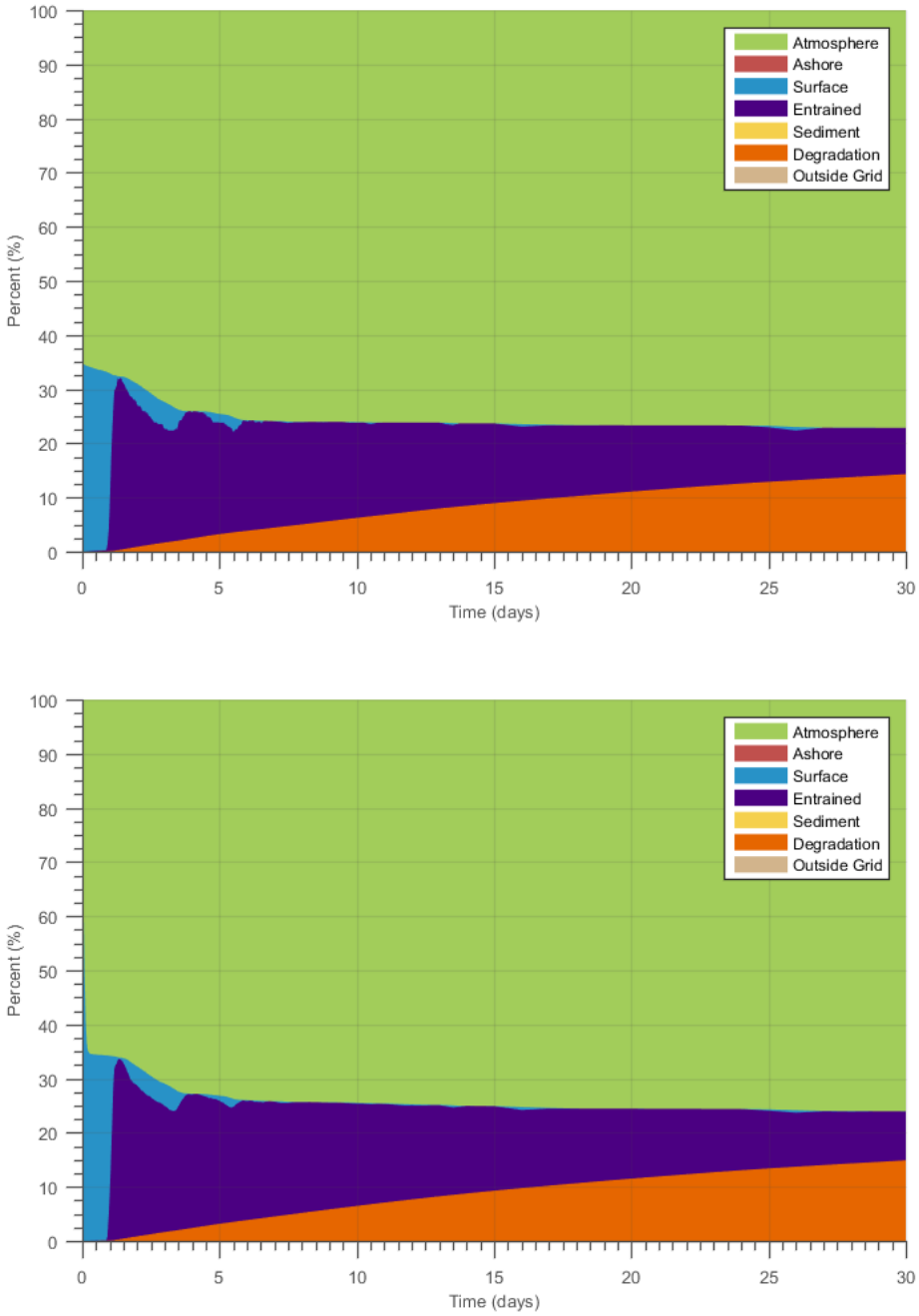


Figure 4-39. Mass balance plots of the NPA release site marine diesel batch spills of 100 L (top) and 1,000 L (bottom).

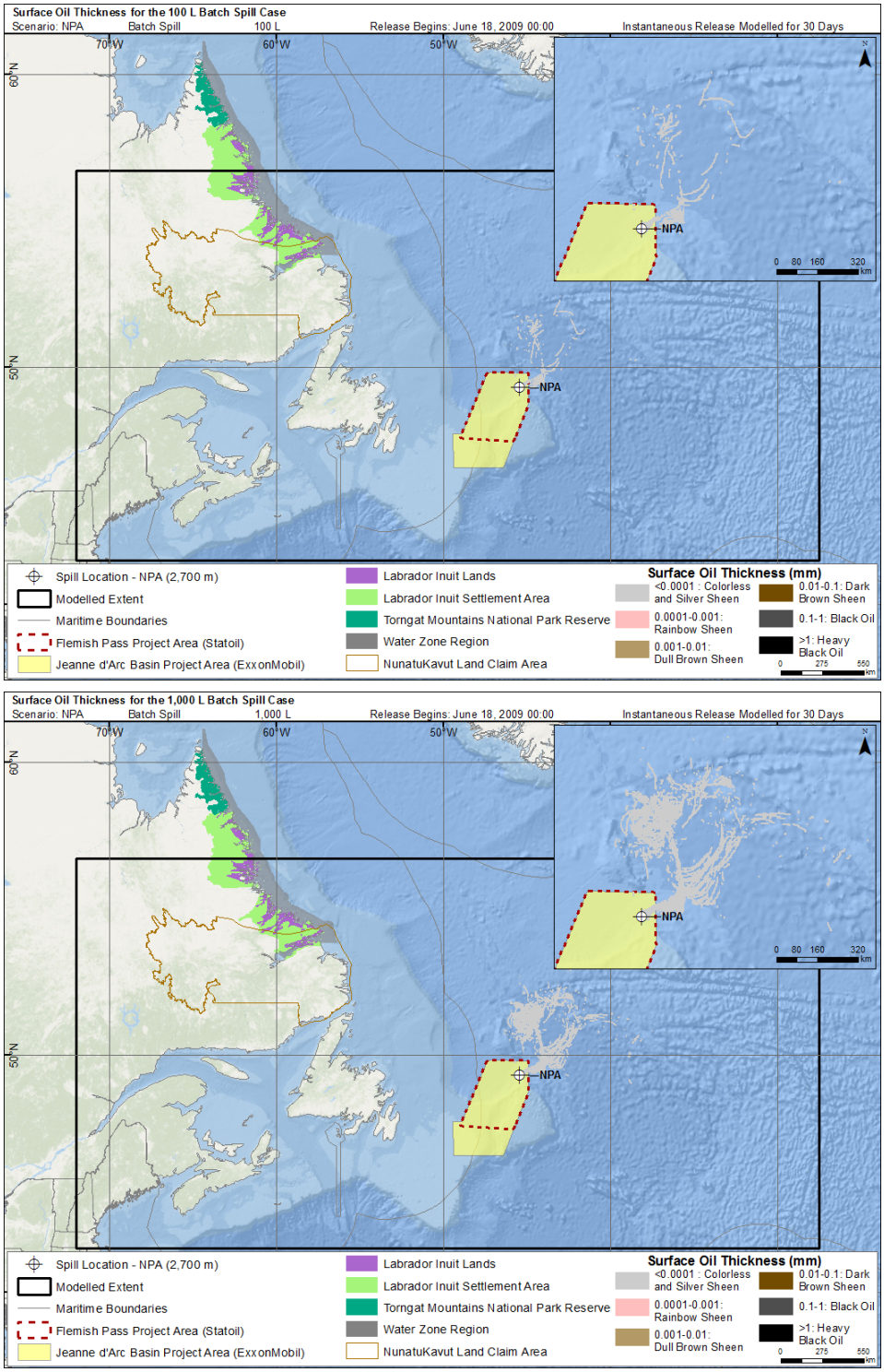


Figure 4-40. Surface oil thickness for the marine diesel batch spills of 100 L (top) and 1,000 L (bottom) at the NPA site. The minimum thickness of surface oil > 0.04 µm is displayed (cumulative over all modelled time steps).

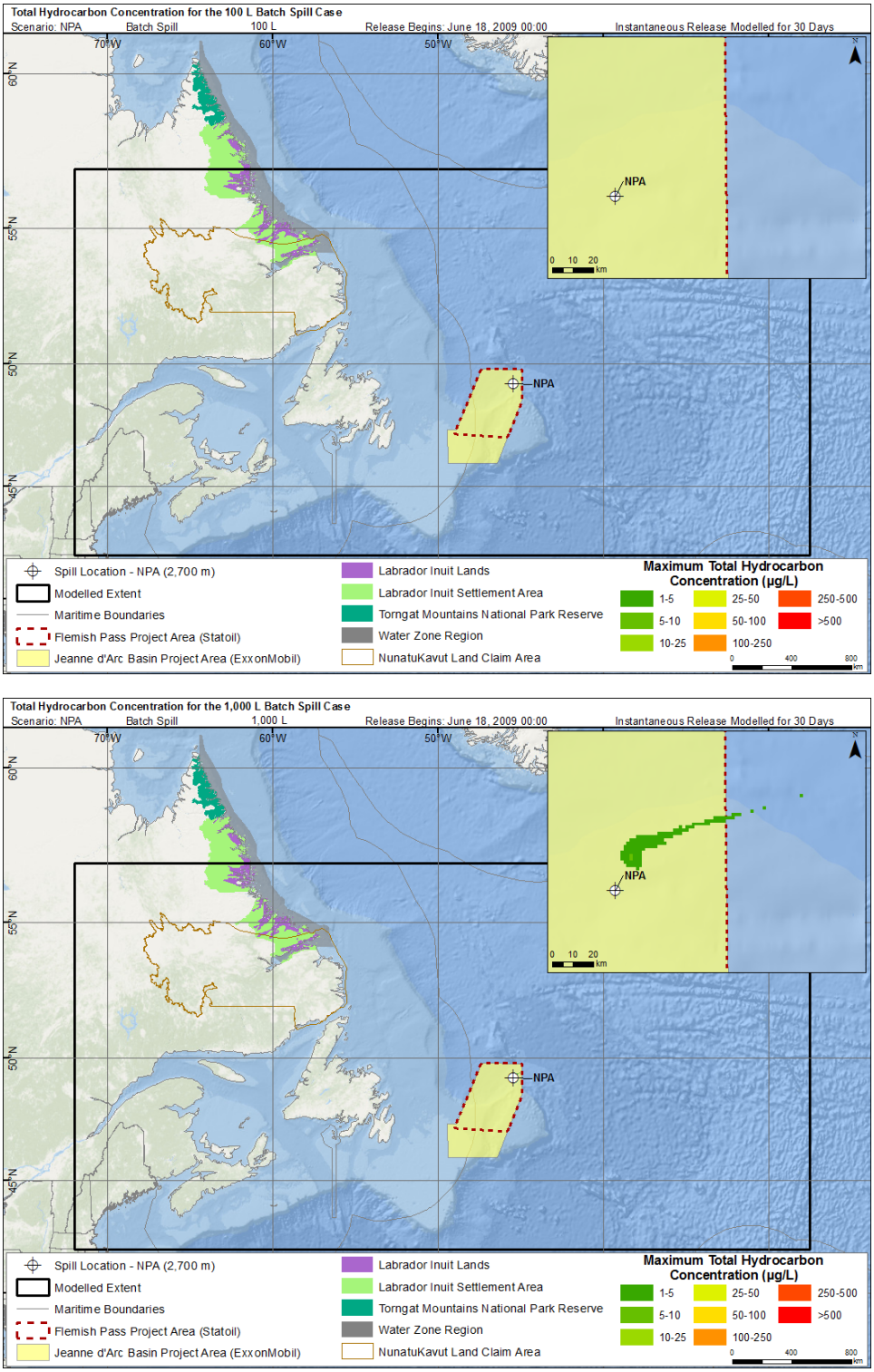


Figure 4-41. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the marine diesel batch spills of 100 L (top) and 1,000 L (bottom) at the NPA site. The minimum threshold of THC > 1 µg/L is displayed (cumulative over all modelled time steps).

4.2.5 Summary of Deterministic Results

4.2.5.1 Representative Cases: Surface, Water Column, and Shoreline Oil

For most representative deterministic scenarios, the amount of oil remaining in surface waters or on sediments at the end of the simulation was less than one percent (Table 4-4; EPA 95th percentile surface was the one exception). This is due to the highly volatile and soluble content of the crude oil product leading to large percentages evaporated (42 – 46%) and degraded (40 – 46%). Entrainment into the water column was predicted to range between 7% and 12%. Shoreline contact was minimal for these simulations, where even the 95th percentile shoreline contact case was predicted to have less than 0.001% of oil reaching shorelines. In all simulations, portions (up to 3.7% of the total released oil) of the oil mass traveled outside the model grid.

The 95th percentile representative surface oil exposure, water column exposure, and shoreline contact cases were identified for both the EPA and NPA sites. The 36-day release at the NPA site did not result in any shoreline oil contamination, thus no representative scenario presented. EPA is the shallower of the two sites (1,100 m), which contributes to larger oil droplets that were predicted to rise to the surface more rapidly than those at the NPA site. Most of the surface oil in both cases was predicted to have an average thickness within the range of 0.001 – 0.01 mm (1 – 10 µm), which would result in a visual appearance that would be a discontinuous or patchy dull brown sheen. Thickest oil was predicted to be located near the release site (0.1 - 1 mm; black oil), with thinner 0.0001 - 0.001 mm (rainbow sheen) extending outward towards the fringes (Figure 4-22). Note that floating oil mass is calculated as an average over grid cells, thus in reality, the oil would be patchy and can be thinner or thicker in particular areas of the grid cell. The area of surface oil exposure for the 95th percentile case at EPA (1,942,00 km^2) is larger than that of the 95th percentile case at NPA (1,038,000 km^2). This is due to a combination of the release location, depth, and release volume modelled.

In all cases, nearly all of the surface oil was predicted to either become entrained, evaporated, degraded, or outside of the grid by the end of the 160-day simulation (Figure 4-21,Table 4-4). The 95th percentile case represents what could be expected from a “worst case scenario” unmitigated blowout, where the environmental conditions would be such to maximize potential exposure. Note that all scenarios assume a completely unmitigated release, which is an unlikely situation to begin with. For surface oil, the NPA 95th percentile case occurred during the summer season (defined as ice-free for more than half the days of the model run), and for EPA occurred in the winter season (having ice for more than half the days of the model run).

The maximum subsurface water volume exposed to THC concentrations for the 95th percentile water column case at the EPA site was larger than that of the 95th percentile case at the NPA site due to the

larger release volume at the EPA spill site. A region of > 500 µg/L dissolved hydrocarbons was predicted to spread primarily east of the release site in the 95th percentile case at EPA. At the NPA site, dissolved hydrocarbon concentrations < 200 µg/L spread to the east of the release site.

Entrained oil concentrations in surface waters were predicted to vary considerably from day to day, as would be expected due to their dependence on variable wind and wave conditions. The amount of entrained oil stopped increasing after the blowout was modelled to cease at 130 days. For the water column simulations, the EPA case occurred during summer months, while the NPA case occurred in the winter.

The 98th percentile shoreline contact case was identified at the EPA site, while there was no case of shoreline contact at the NPA site. Because the EPA site was closer to shore, at a shallower, and released a much larger volume of oil, the site was more likely to have shoreline contact of oil. The 98th percentile case was predicted to have shoreline contact between 100 and 500 g/m^2 around the Avalon Peninsula and the south coast of Newfoundland. The shore length where shoreline contact was predicted to exceed the 1 g/m^2 threshold covered 46 km of coastline. In contrast, shoreline oil comprises an extremely small portion of the total mass of released oil in this case (<0.01% of total), and was only predicted to appear in a detectable quantity after day 116. The 98th percentile case for shoreline contact at EPA occurred during the summer.

4.2.5.2 Marine Diesel Batch Spill

To simulate accidental discharges from operational vessels, two batch spills of marine diesel were modelled as instantaneous surface releases. Two releases of 100 L and 1,000 L were modelled for thirty days (Figure 4-36) at the NPA and EPA sites. The marine diesel is a standard diesel that had a low viscosity and a high aromatic content that was expected to evaporate quickly during the summertime releases.

For the EPA site, the cumulative area of average surface oil thickness > 0.04 µm threshold extended south and southeast of the release site, in a patchy distribution of < 0.0001 mm (0.1 µm) average thickness. For both release volumes, floating oil was predicted to be transported about 1,000 km from the release site over 30 days (Figure 4-37). The trajectory and relatively large distance traveled by the surface oil is due to the strong surface winds in the area. For the smaller volume release (100 L), there was no surface oil exposure exceeding 0.04 µm. However, the larger volume release (1,000 L) resulted in a surface oil exposure area of approximately 17 km^2 (Table 4-3). Furthermore, the smaller release volume does not result in any THC exceeding 1 µg/L. Vertical maximum in-water THC concentrations reach nearly 20 µg/L from the larger volume release in regions directly under the surface slick and extend directly southeast from the release site. Note that for the marine diesel batch spill cases, the

water column contamination was measured as THC, not as dissolved hydrocarbons as in the other deterministic and stochastic scenarios. The reasons behind this were twofold including: 1) the concentration gridding resolution and the 2) small release volumes. Therefore, the predicted concentrations were of dissolved hydrocarbons in the water column (which comprise only approximately 1% of THC) were below the identified thresholds to present in figures.

Both releases resulted in a patchy distribution of very thin < 0.0001 mm (0.1 µm) oil on average (Figure 4-42). The areas where the cumulative average surface oil thickness > 0.04 µm extended approximately 600 km from the NPA release site. The smaller volume release (100 L) did not result in any significant surface oil exposure area exceeding 0.04 µm, while the larger volume release (1,000 L) surface oil exposure area was predicted to be 22 km^2 (Table 4-3). The smaller release volume did not result in any THC concentration exceeding 1 µg/L, while for the larger release volume, low in-water concentrations (1 – 5 µg/L) were predicted to extend northeast of the spill site. Note that surface oil travels northeast initially before becoming entrained and leading to in-water THC concentrations.

Based on the mass balance plots (Figure 4-36 and Figure 4-41), surface oil was nearly immediately (within 30 minutes) entrained in both the 100 L and 1000 L cases at the EPA site due to local winds. Nearly all of the surface oil was evaporated, entrained, or degraded within a week. For both cases, less than 0.05% of oil was predicted to remain on the water surface by the end of the 30-day simulation, with the majority evaporated (75-78%) and the rest degraded (14-17%). No oil from batch spills at the EPA site was predicted to reach shorelines or leave the modelled domain (Table 4-4).

Mass balance results were very similar at the NPA site (Figure 4-41; Table 4-4). In both the 100 L and 1,000 L cases, a small (<0.05%) amount of oil was immediately entrained and nearly 27% the oil immediately evaporated. By the end of the 30-day simulation, no oil remained on the water surface and was either evaporated (76-77%), in the water column (9%), or degraded (14-15%).

Table 4-3. Representative deterministic cases and associated areas, lengths, and volumes exceeding specified thresholds for 95th percentile surface, shoreline, and water column contamination trajectories and small and large volume batch spill trajectories at the NPA and EPA sites.

Scenario Number and Name	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)[3]
			Socioeconomic (0.04 µm)	Ecologic (10 µm)	Socioeconomic (1 g/m^2)	Ecologic (100 g/m^2)	Socioeconomic (1 µg/L)
95th percentile surface oil exposure case	EPA	15,000 m^3/d	1,942,000	95,930	-	-	352,800
95th percentile water column case			1,661,000	115,800	-	-	474,700
95th percentile shoreline contact case			1,984,000	130,500	46	23	58,260
95th percentile surface oil exposure case	NPA	4,980 m^3/d	1,038,000	212,300	-	-	42,460
95th percentile water column case			776,900	5,263	-	-	321,600
95th percentile shoreline contact case			NA	NA	NA	NA	NA
100 L marine diesel batch spill	EPA	100 L	-	-	-	-	-
1,000 L marine diesel batch spill		1,000 L	17.02	-	-	-	-
100 L marine diesel batch spill	NPA	100 L	-	-	-	-	-
1,000 L marine diesel batch spill		1,000 L	21.66	-	-	-	-

[3] There is only 1 category threshold (socioeconomic) for THC –calculated by multiplying the area times the depth of the grid cell.

Table 4-4. Summary of the mass balance information for all representative scenarios. All values represent a percentage of the total amount of released oil.

Summary of Mass Balance Information at the End of the Simulation (Percentage of Released Oil)							
Scenario Information (Site - Condition - Product)	**Surface (%)**	**Evaporated (%)**	**Water Column (%)**	**Sediment (%)**	**Ashore (%)**	**Degraded (%)**	**Outside Grid (%)**
EPA - 95th Shoreline - BdN	0.55	44.05	11.99	0.01	<0.01	40.80	2.61
EPA - 95th Surface - BdN	2.35	42.47	10.77	0.01	0.00	42.29	2.10
EPA - 95th Water Column - BdN	0.60	44.33	12.43	0.01	0.00	40.02	2.62
NPA - 95th Surface - BdN	0.00	46.64	6.54	0.00	0.00	43.13	3.69
NPA - 95th Water Column - BdN	0.00	44.93	7.97	0.00	0.00	45.65	1.44
EPA - 100 L - Marine Diesel	0.00	78.17	7.73	0.00	0.00	14.09	0.00
EPA - 1,000 L - Marine Diesel	0.01	74.68	8.27	0.00	0.00	17.04	0.00
NPA - 100 L - Marine Diesel	0.00	77.13	8.56	0.00	0.00	14.31	0.00
NPA - 1,000 L - Marine Diesel	0.03	76.03	9.04	0.00	0.00	14.90	0.00

5 Discussion and Conclusions

Generally, most surface oil from all release sites was predicted to move eastward due to the prevailing westerly winds. Winds and currents in the Project Area are similar throughout the year, with most notable differences in wind intensity. The increased winds during wintertime conditions enhances surface breaking waves and results in more predicted entrainment of oil, which lowers the likelihood that oil will remain on the surface for extended periods of time. Shoreline contact was not likely from releases at either the EPA or NPA sites, with maximum probabilities of shoreline contact 1-2% at only EPA. Shoreline contact was more likely to occur during winter months, due to the wind speed and direction during this period of time. If shoreline contact was predicted to occur, it would likely be localized to small portions of shoreline, but could span from the Avalon Peninsula and the southeast coast of Newfoundland to the northern shores of Newfoundland, southeastern shores of Labrador and Sable Island, depending on the conditions.

The releases modelled in this study may be considered representative of other potential releases in the Project Area. The depth of release of the EPA and NPA sites (1,100 and 2,700 m, respectively) are within the range of areas present within the Project Area, with many exploration licenses in the 1,000 – 1,500 m depth range.

The hypothetical unmitigated 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 therefore 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 little likelihood of shoreline oil exposure.

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Trajectory Modelling in Support of the Statoil Exploration Drilling Project

Appendix A

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Final Report

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Release	File Name	Date Submitted	Notes
Final	Statoil – RPS Technical Report_20171010_AppendixA.docx	10/10/2017	RPS Draft final version of report following Statoil review

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Summary

This Appendix A is provided as a reference to RPS Technical Report: Trajectory Modelling in Support of the Statoil Exploration Drilling Project. There are no new figures or modifications to those presented in the Technical Report. However, each figure has been provided at a higher resolution filling a full page per image. Stochastic results include predictions of both probability and minimum time to specific threshold exceedances for the EPA and NPA release sites. Deterministic results include mass balance information, and cumulative maximum footprints of surface oil thickness, in water concentration, and shoreline and sediment mass per unit area. Deterministic results have been provided for the 95th percentile surface oil, water column, and shoreline exposure cases. In addition, deterministic results have been provided for 100 and 1,000 L marine diesel batch spills for the EPA and NPA release sites.

In addition to the figure legends, additional release information is contained within a banner at the top of each figure. For stochastic figures, the information includes the type of image displayed (e.g. Surface Oil Probability), release site, type of release (e.g. Subsurface Blowout), release rate, season of release, release duration, model duration, and number of simulations presented. For deterministic figures, the information includes the type of image displayed (e.g. Surface Oil Thickness), release site, type of release, release rate, date and time of release, release duration, and model duration.

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1 Stochastic Analysis Results

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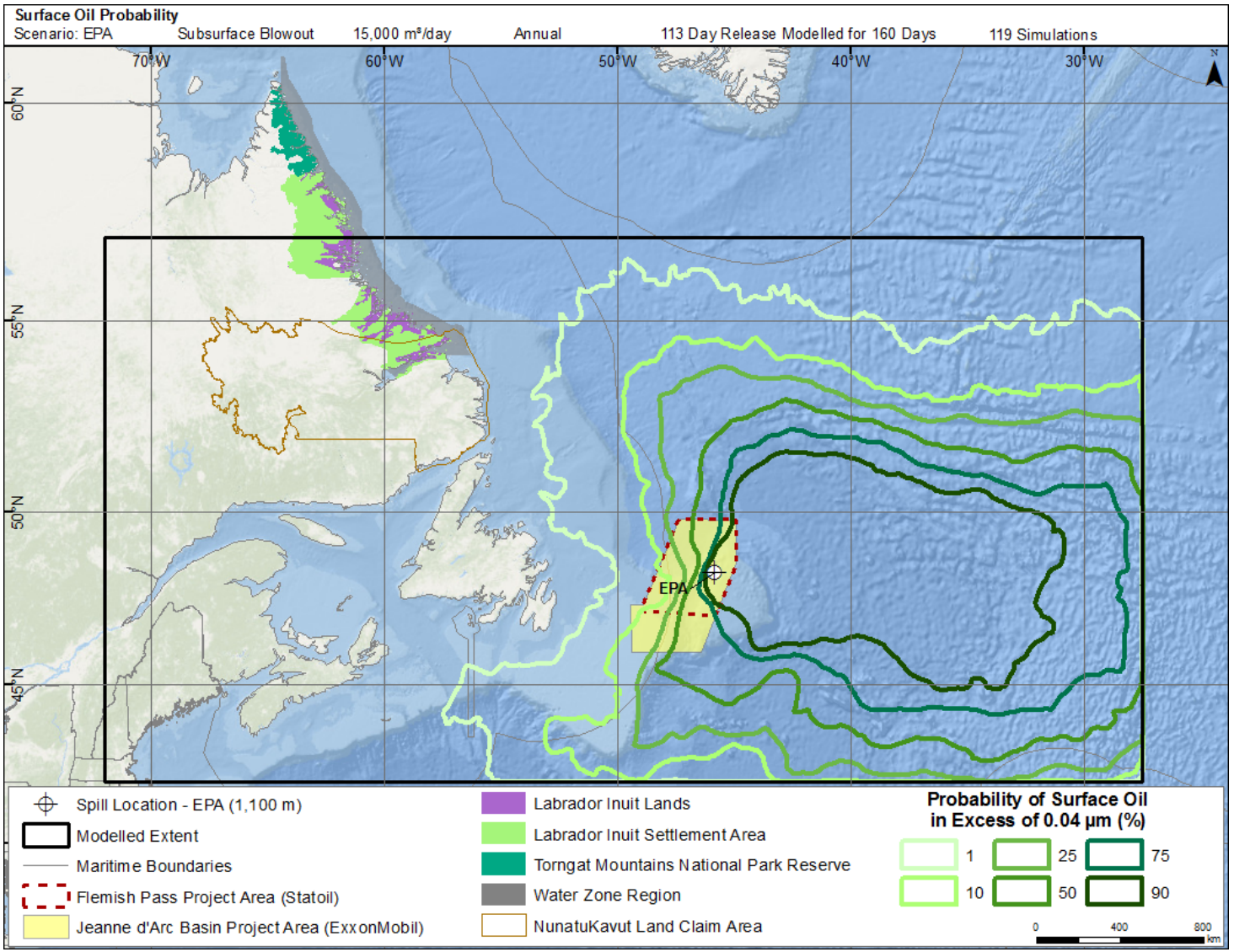


Figure 1-1. Annual probability of average surface oil thickness exceeding 0.04 µm resulting from a subsurface blowout at the EPA site.

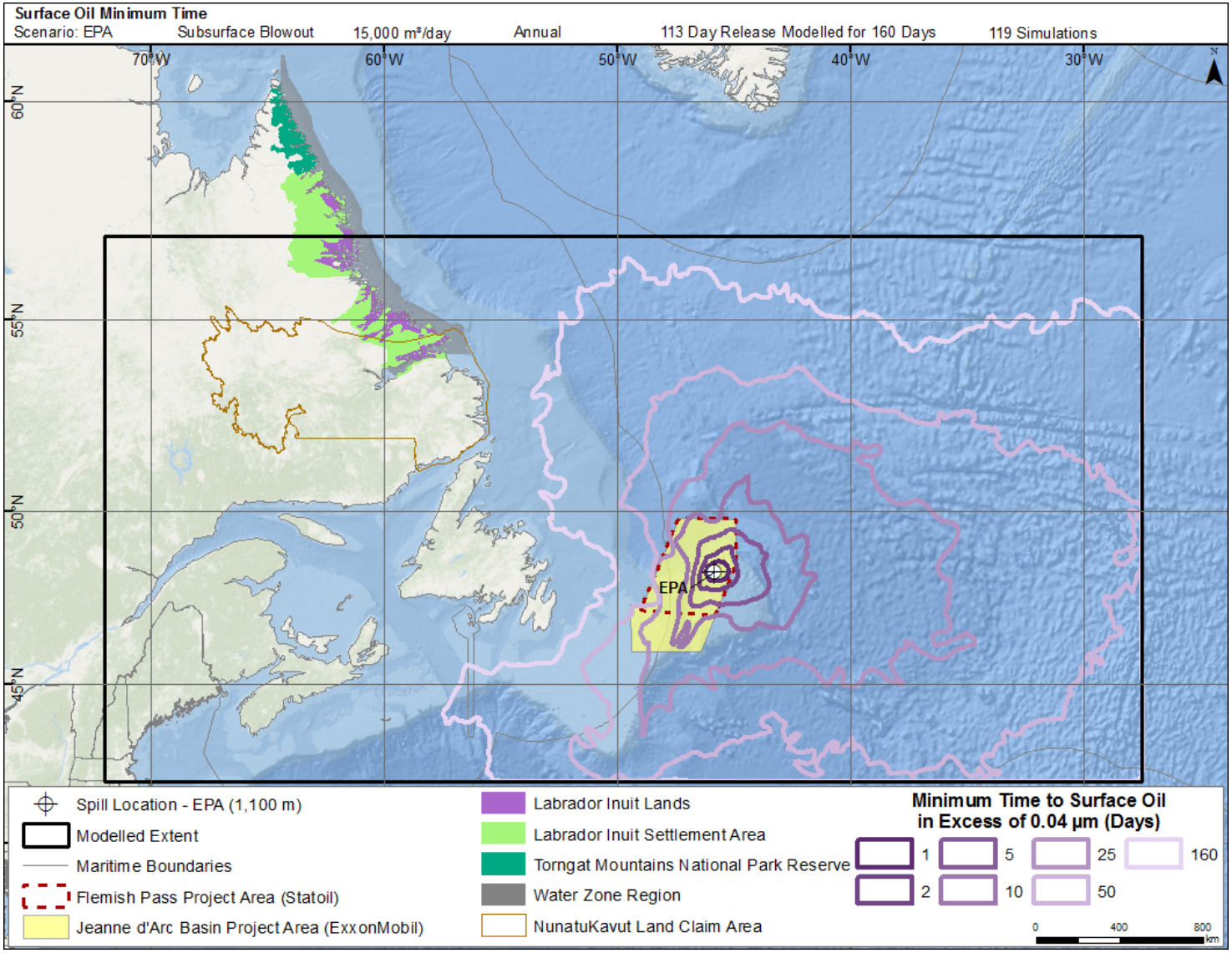


Figure 1-2. Minimum time to threshold exceedance resulting from a subsurface blowout at the EPA site.

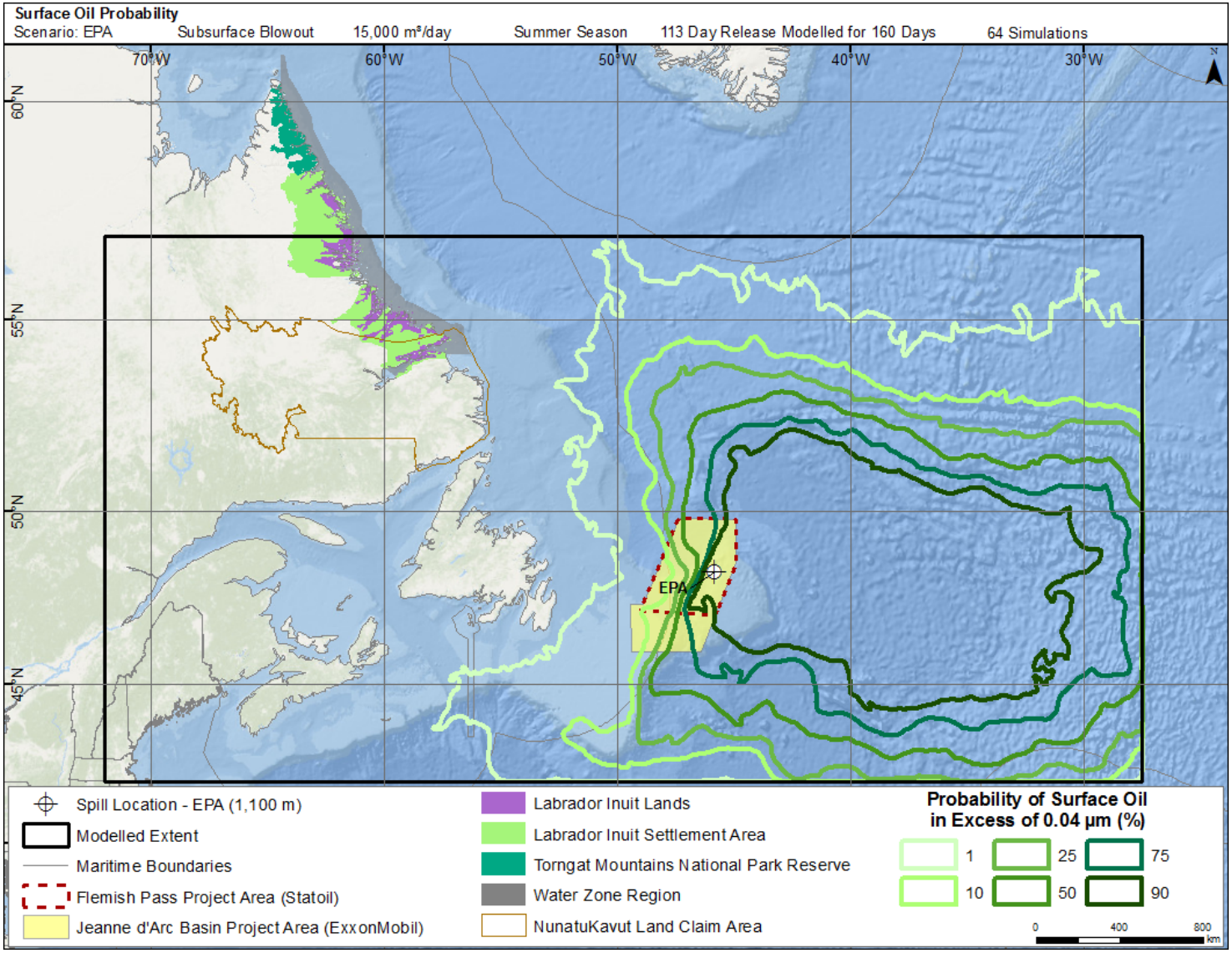


Figure 1-3. Summer probability of average surface oil thickness > 0.04 µm resulting from a subsurface blowout at the EPA site.

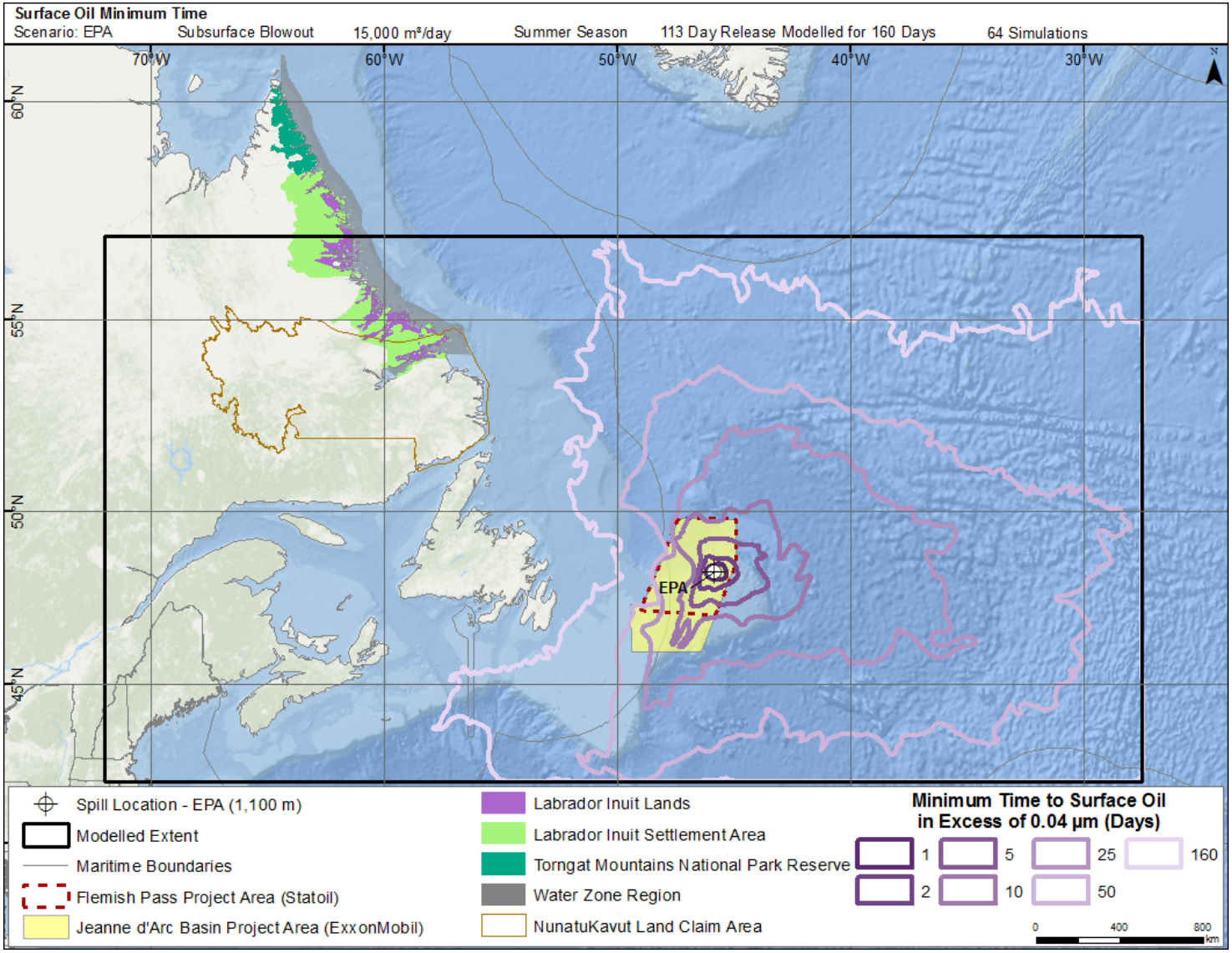


Figure 1-4. Minimum time to threshold exceedance resulting from a subsurface blowout at the EPA site.

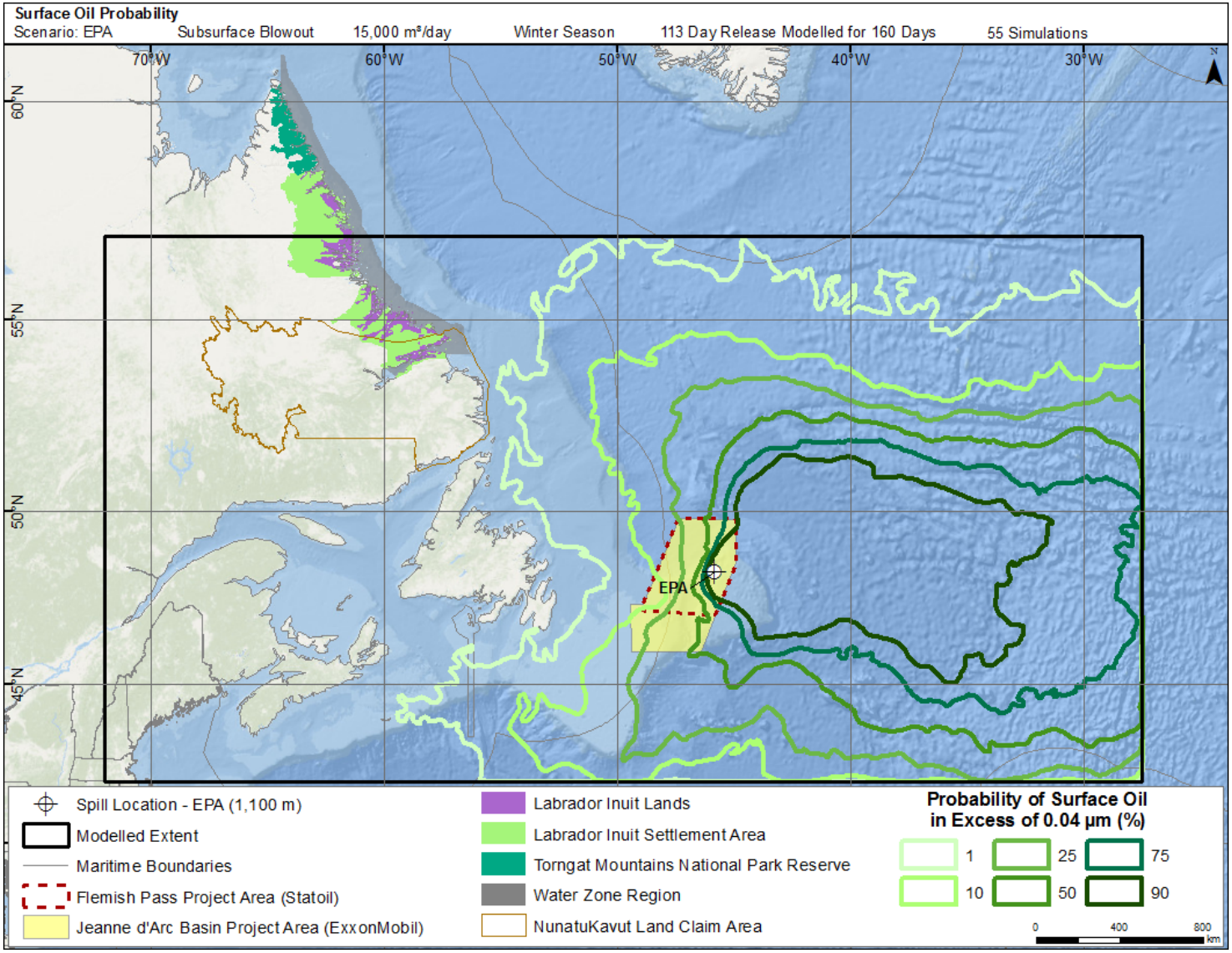


Figure 1-5. Winter probability of average surface oil thickness > 0.04 µm resulting from a subsurface blowout at the EPA site.

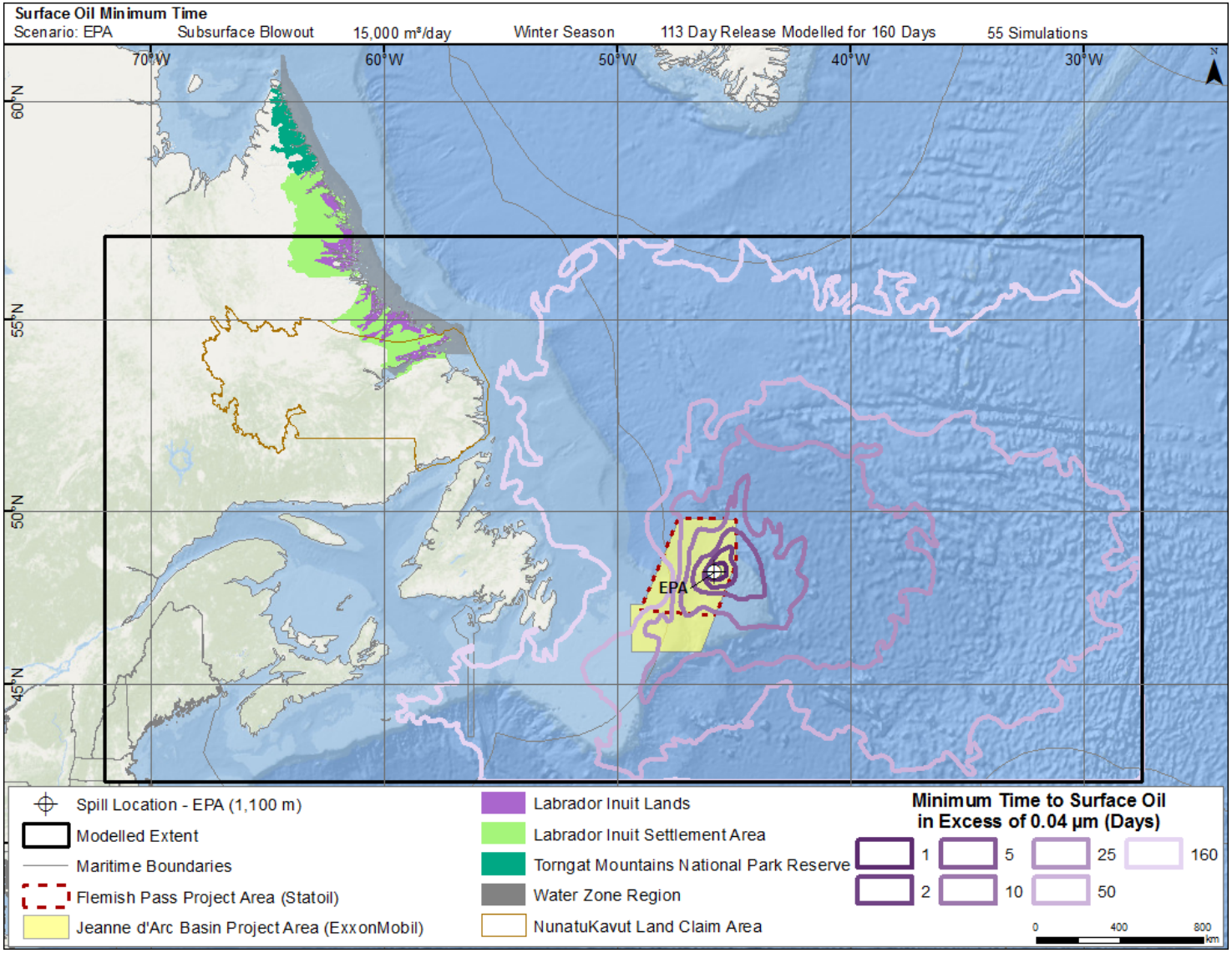


Figure 1-6. Minimum time to threshold exceedance resulting from a subsurface blowout at the EPA site.

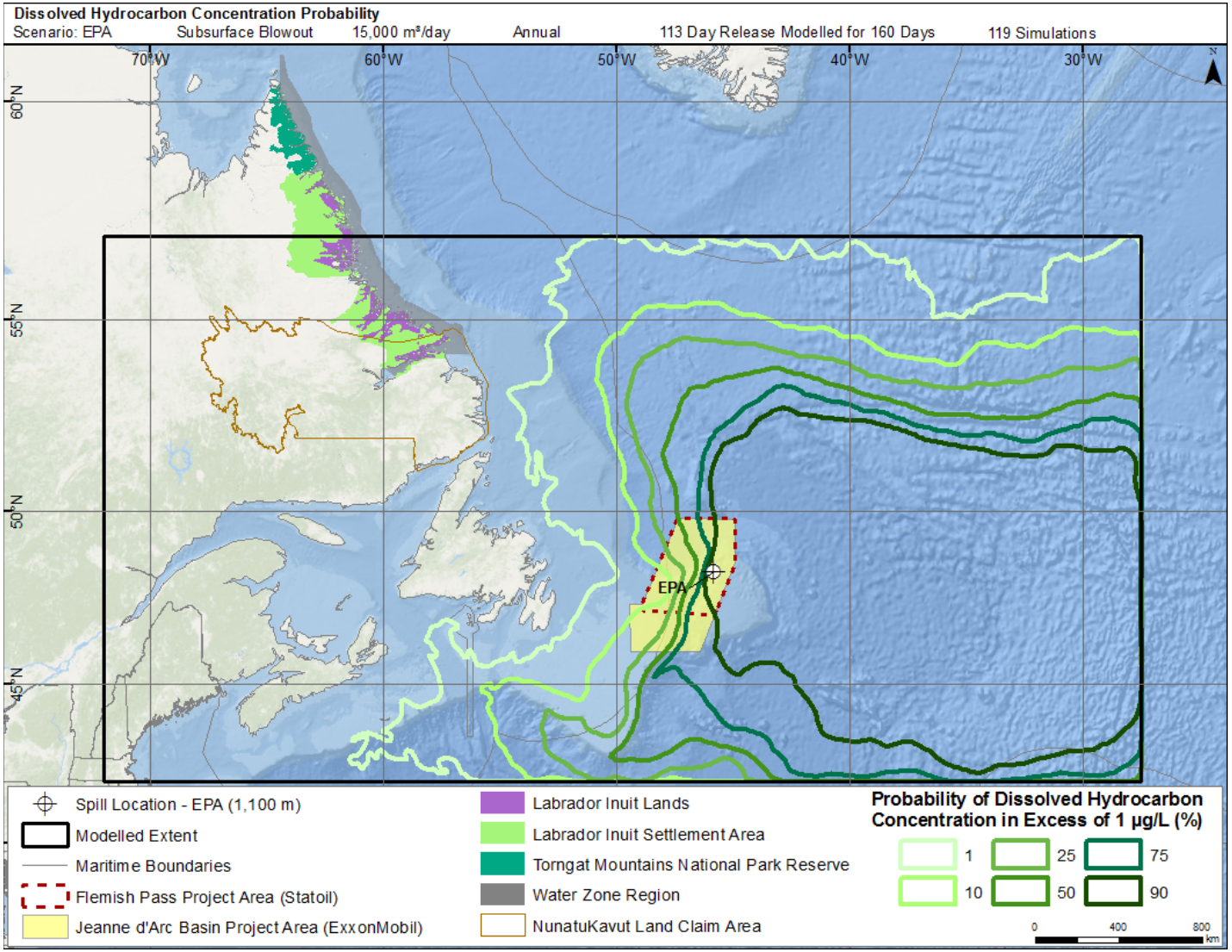


Figure 1-7. Annual probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column resulting from a subsurface blowout at the EPA site.

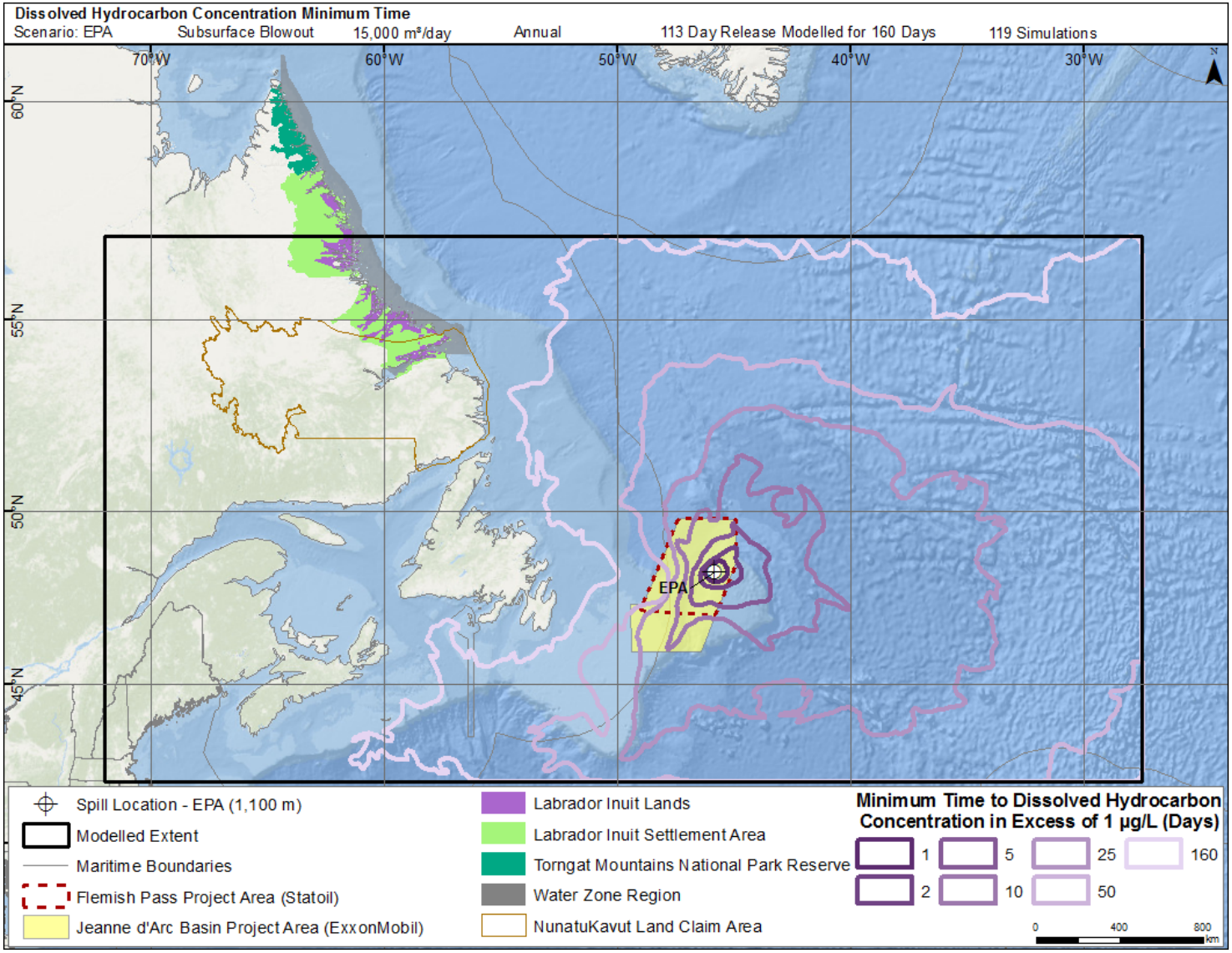


Figure 1-8. Minimum time to threshold exceedance resulting from a subsurface blowout at the EPA site.

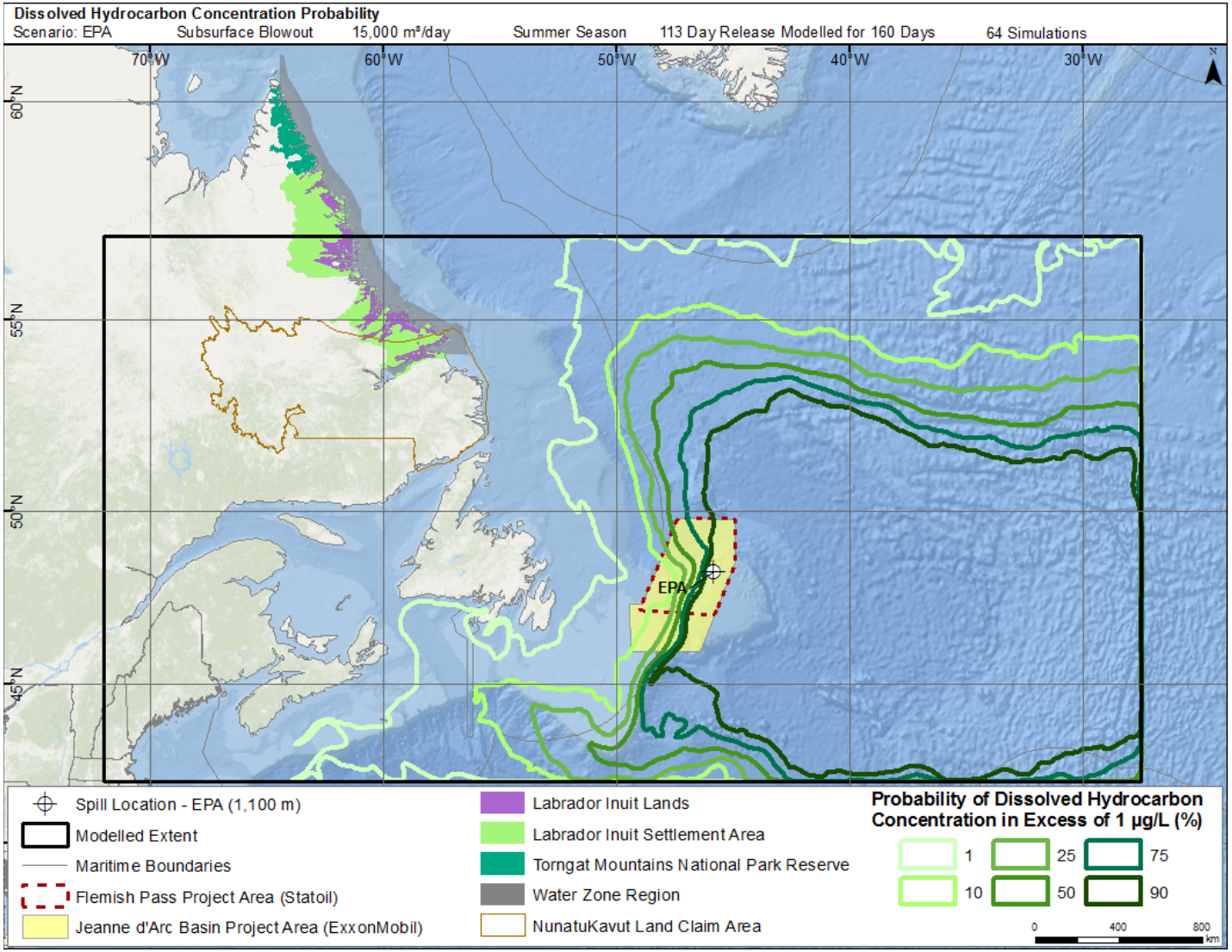


Figure 1-9. Summer probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column resulting from a subsurface blowout at the EPA site.

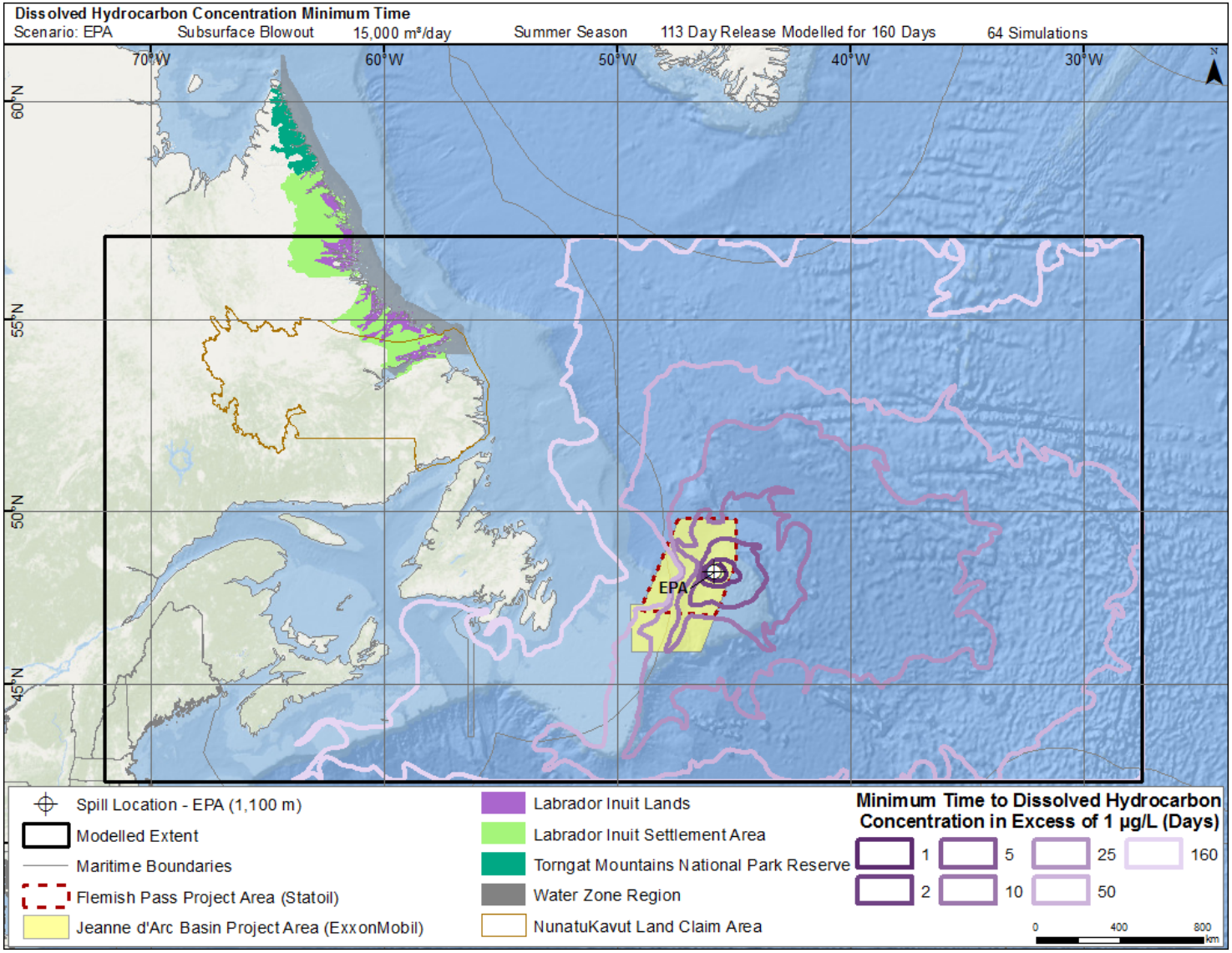


Figure 1-10. Minimum time to threshold exceedance resulting from a subsurface blowout at the EPA site.

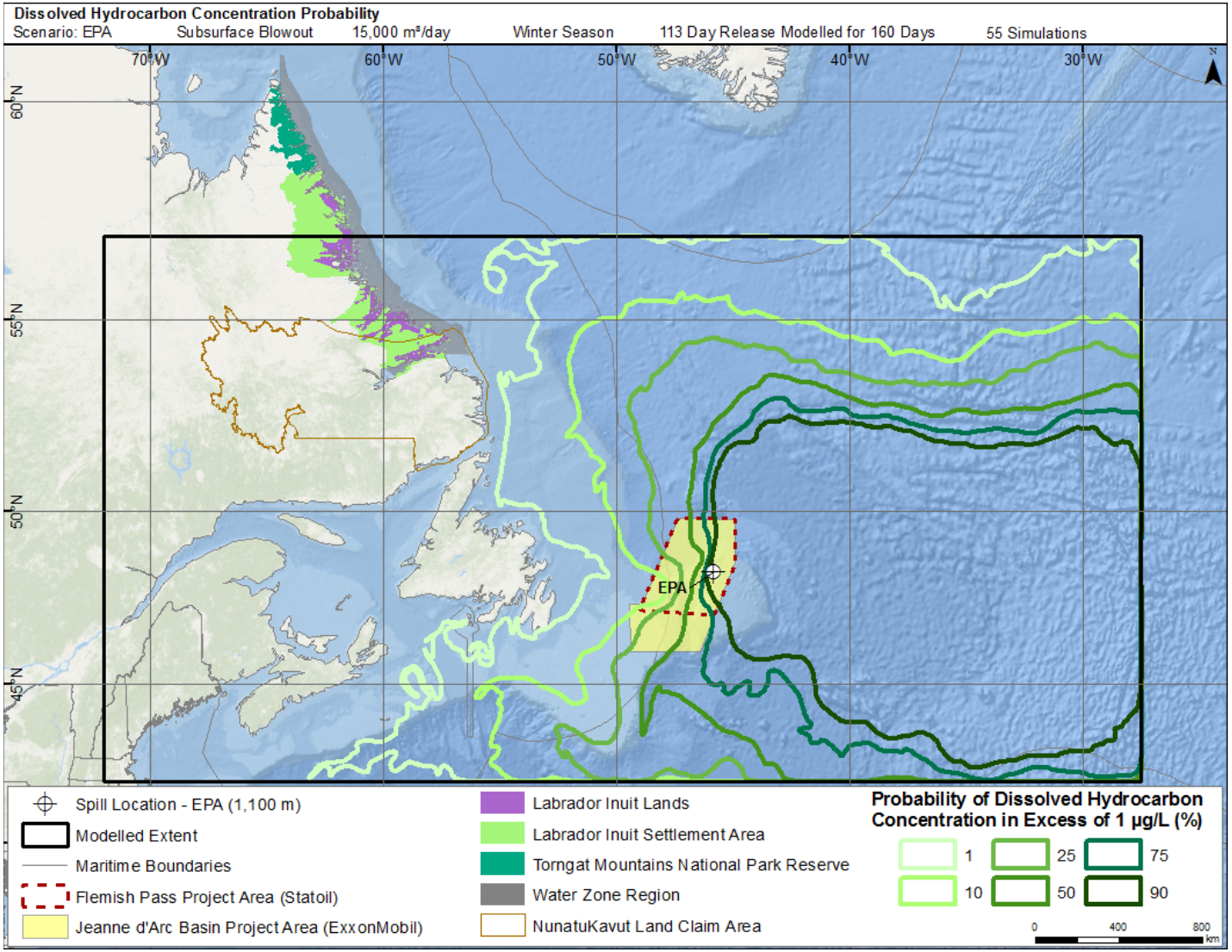


Figure 1-11. Winter probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column resulting from a subsurface blowout at the EPA site.

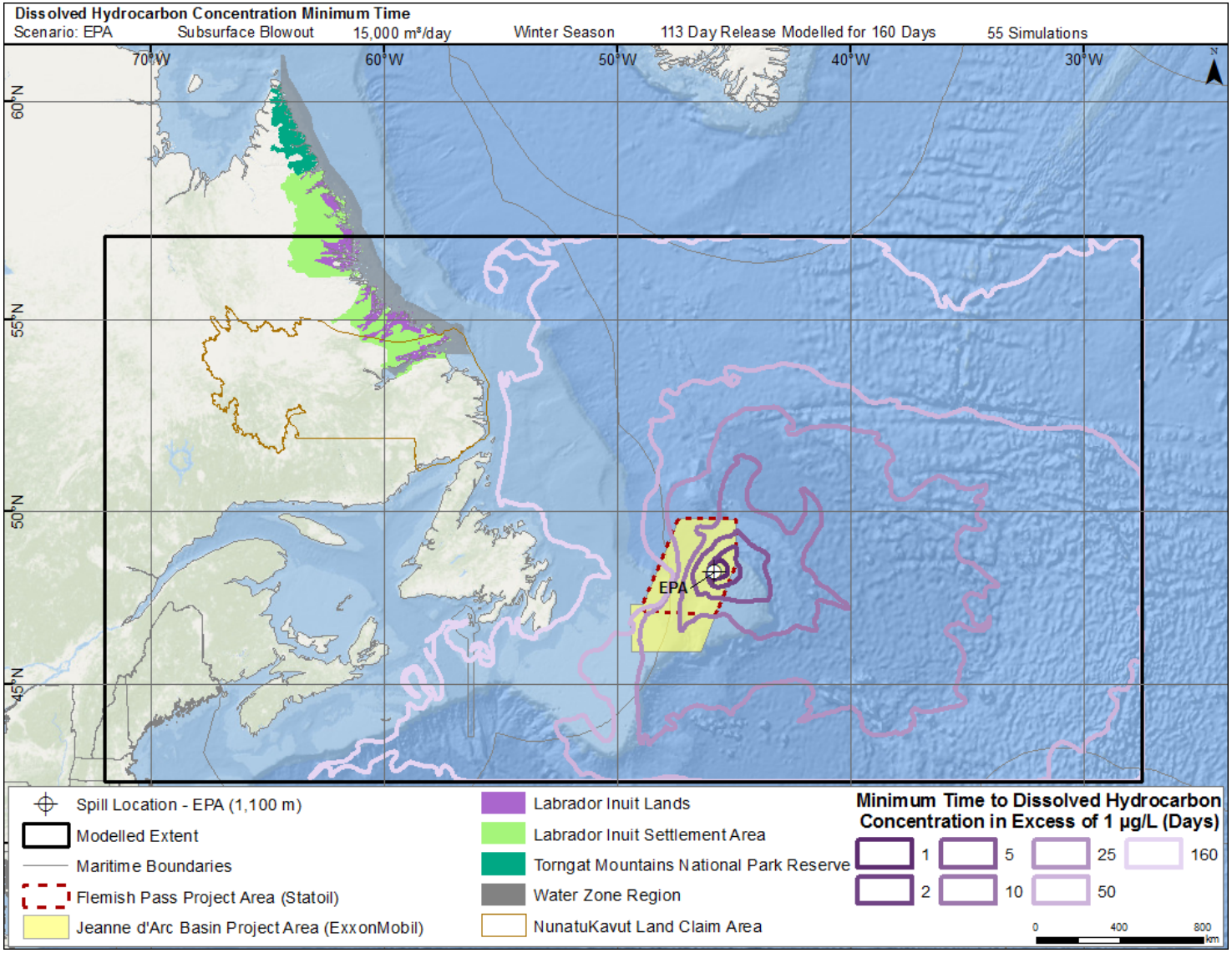


Figure 1-12. Minimum time to threshold exceedance resulting from a subsurface blowout at the EPA site.

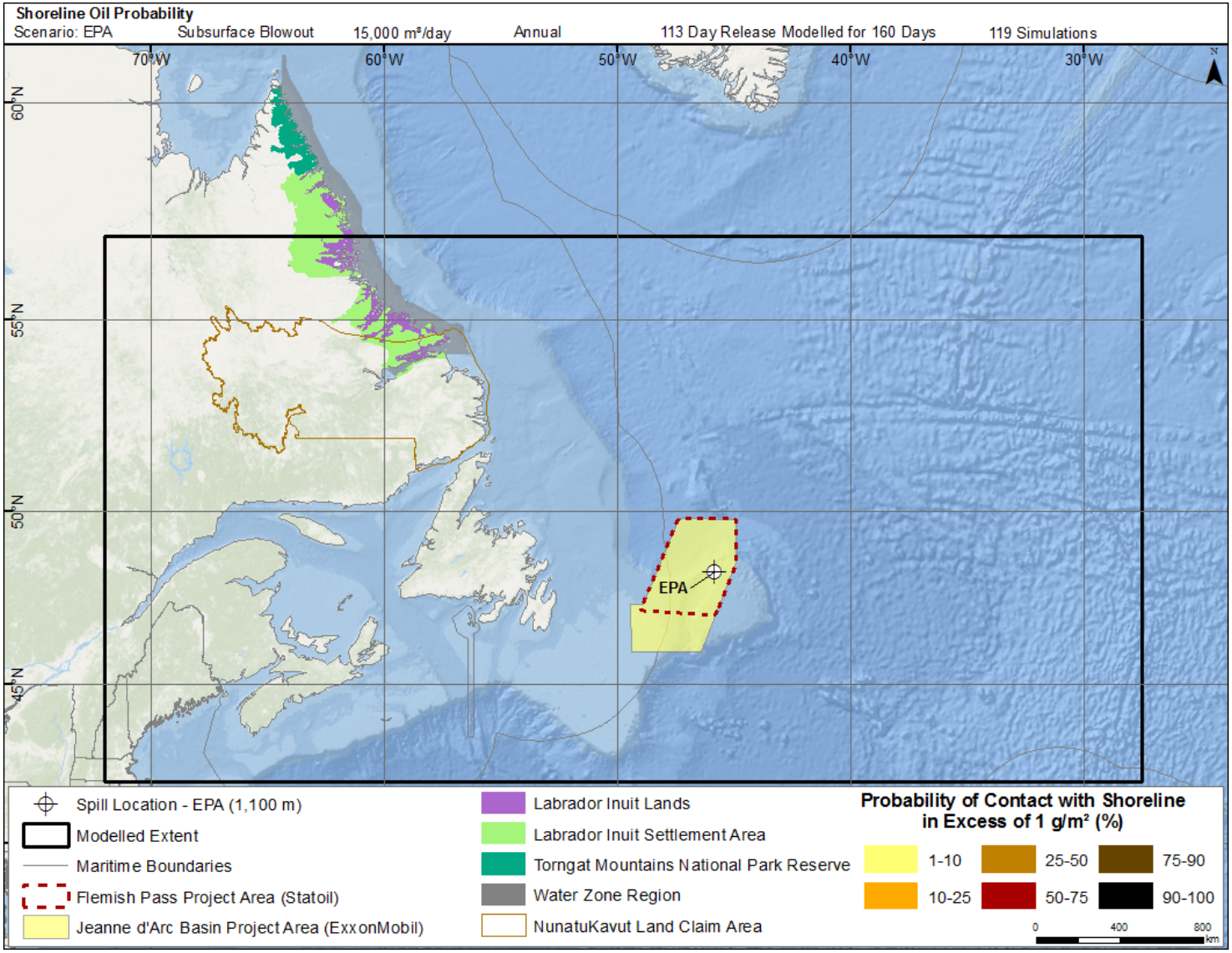


Figure 1-13. Annual probability of shoreline contact > 1 g/m² resulting from a subsurface blowout at the EPA site.

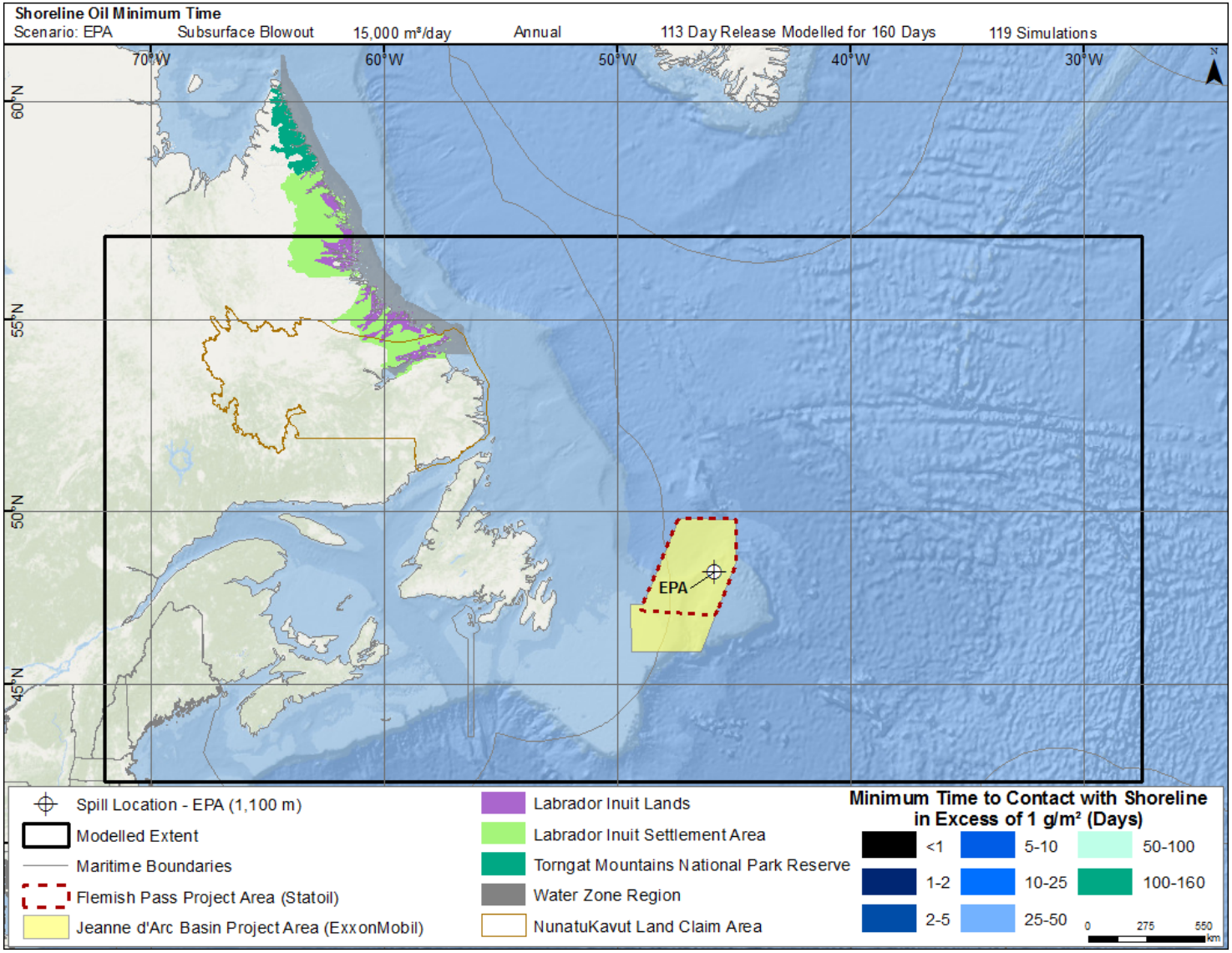


Figure 1-14. Minimum time to threshold exceedance resulting from a subsurface blowout at the EPA site.

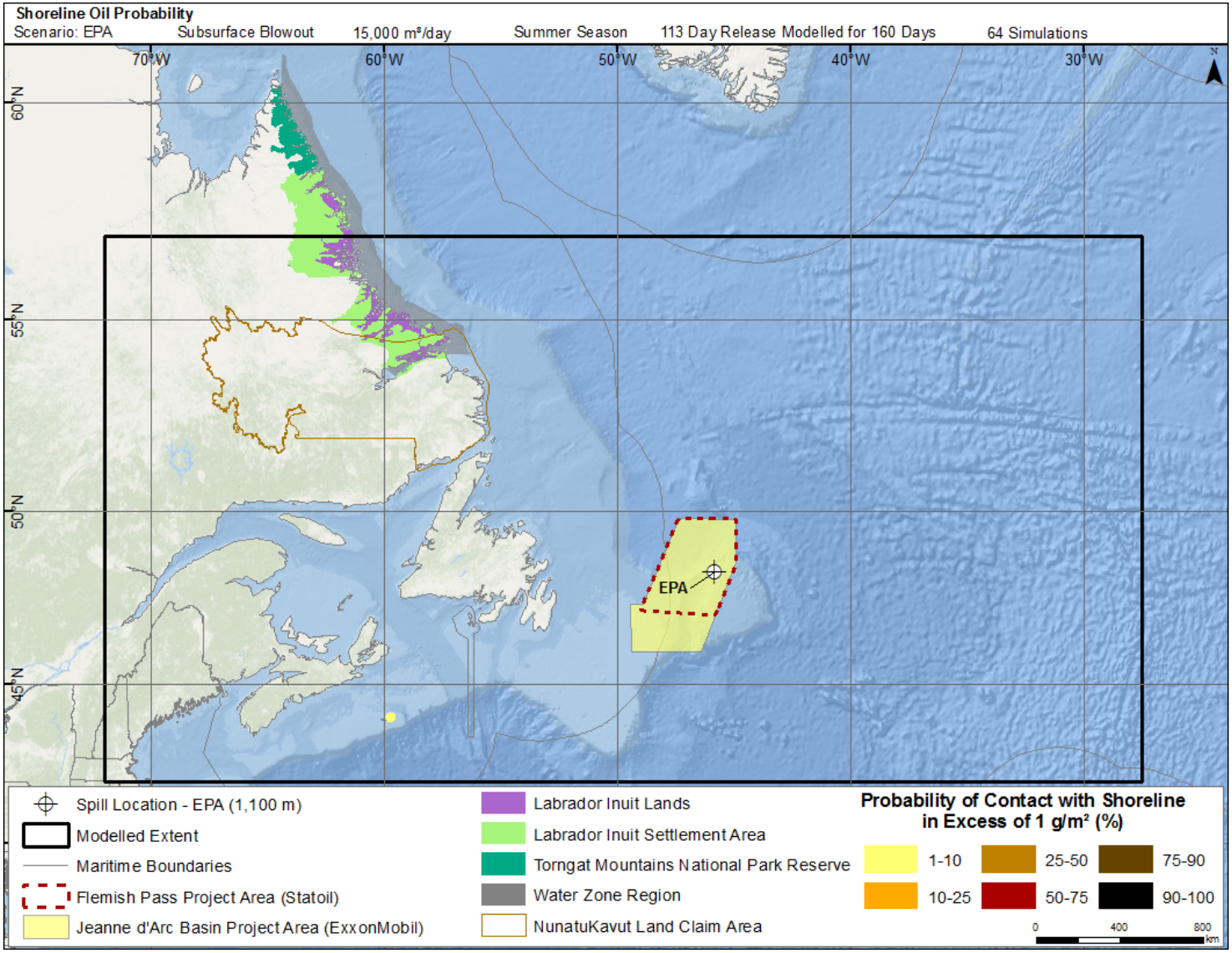


Figure 1-15. Summer probability of shoreline contact > 1 g/m² resulting from a subsurface blowout at the EPA site.

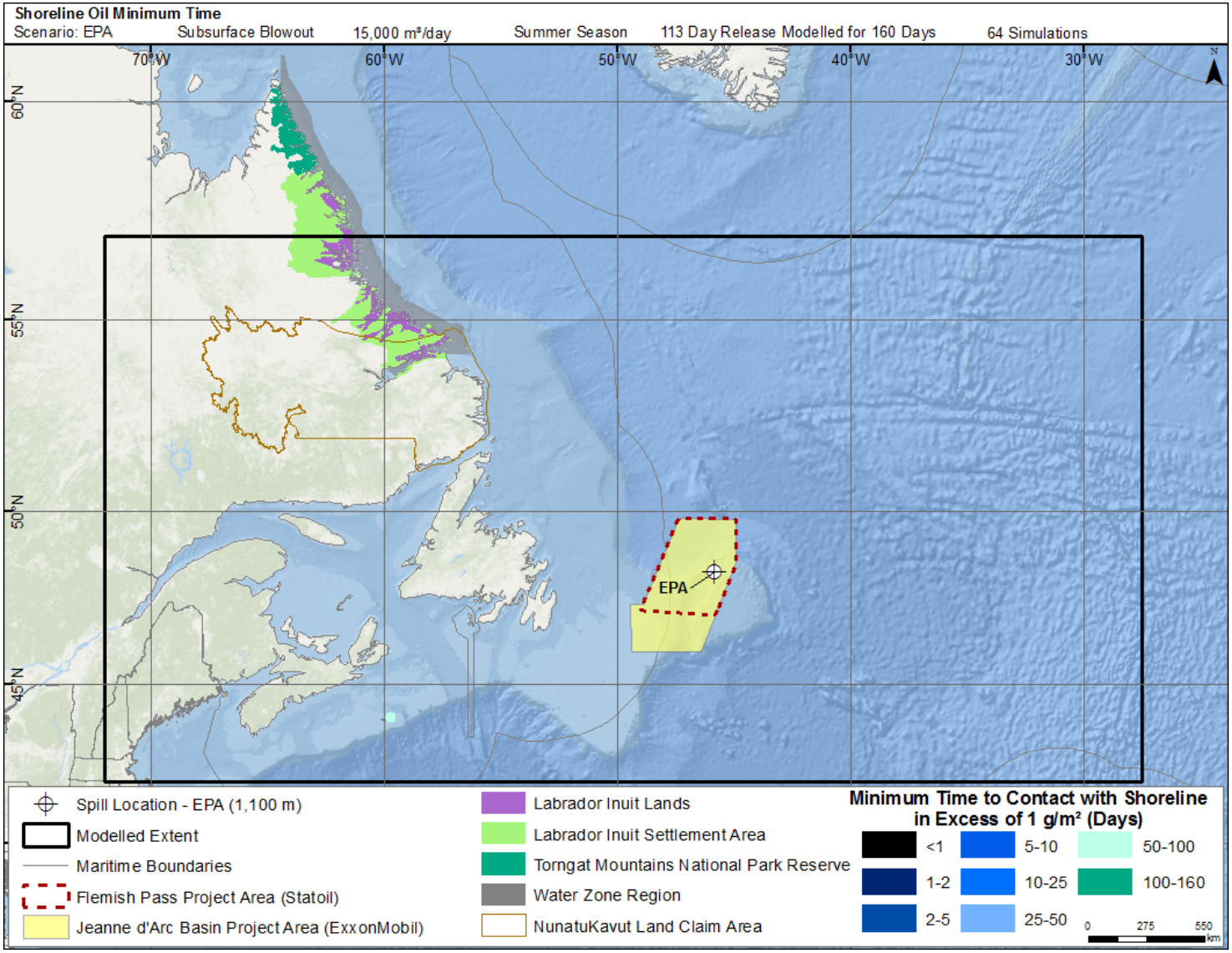


Figure 1-16. Minimum time to threshold exceedance resulting from a subsurface blowout at the EPA site.

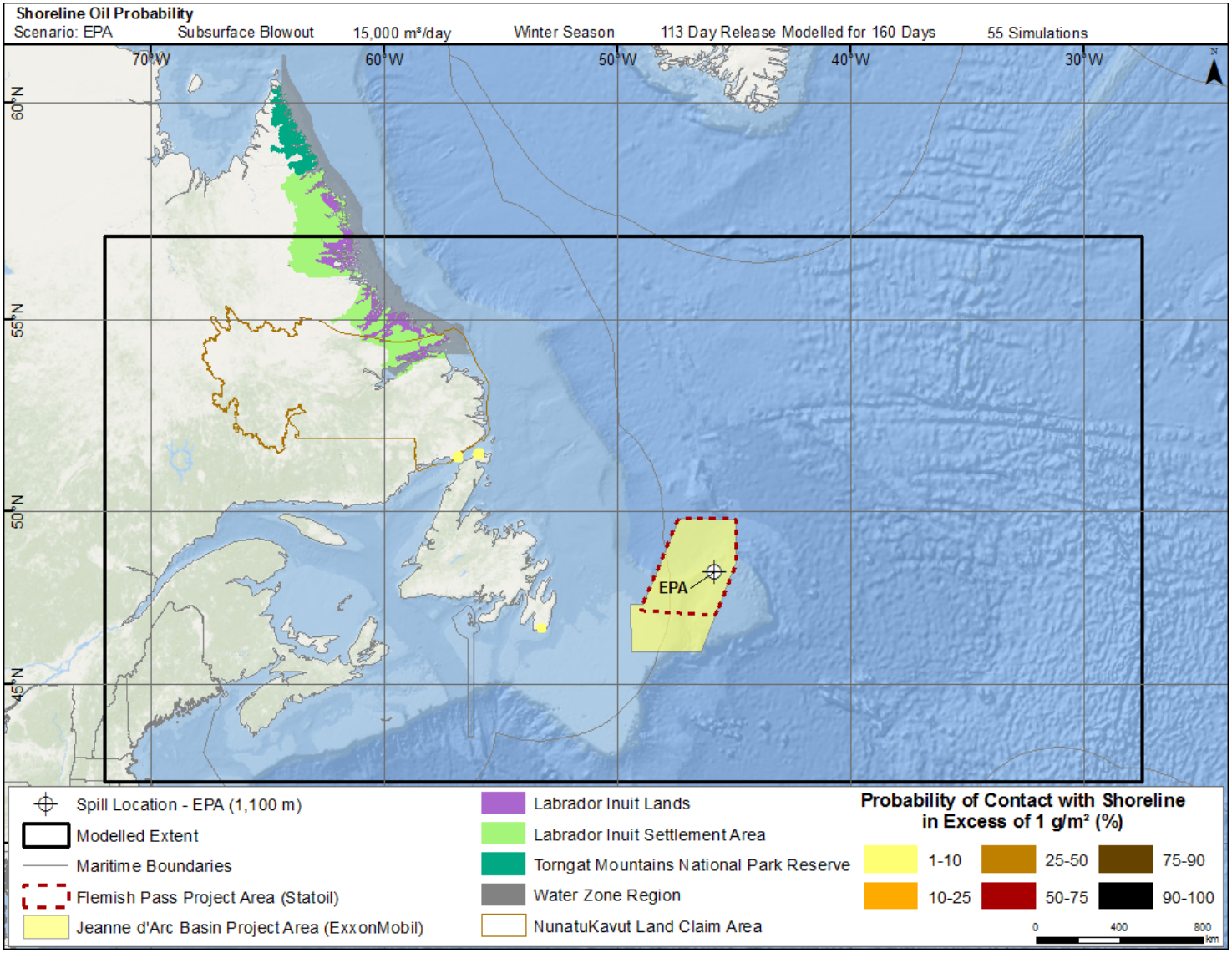


Figure 1-17. Winter probability of shoreline contact > 1 g/m² resulting from a subsurface blowout at the EPA site.

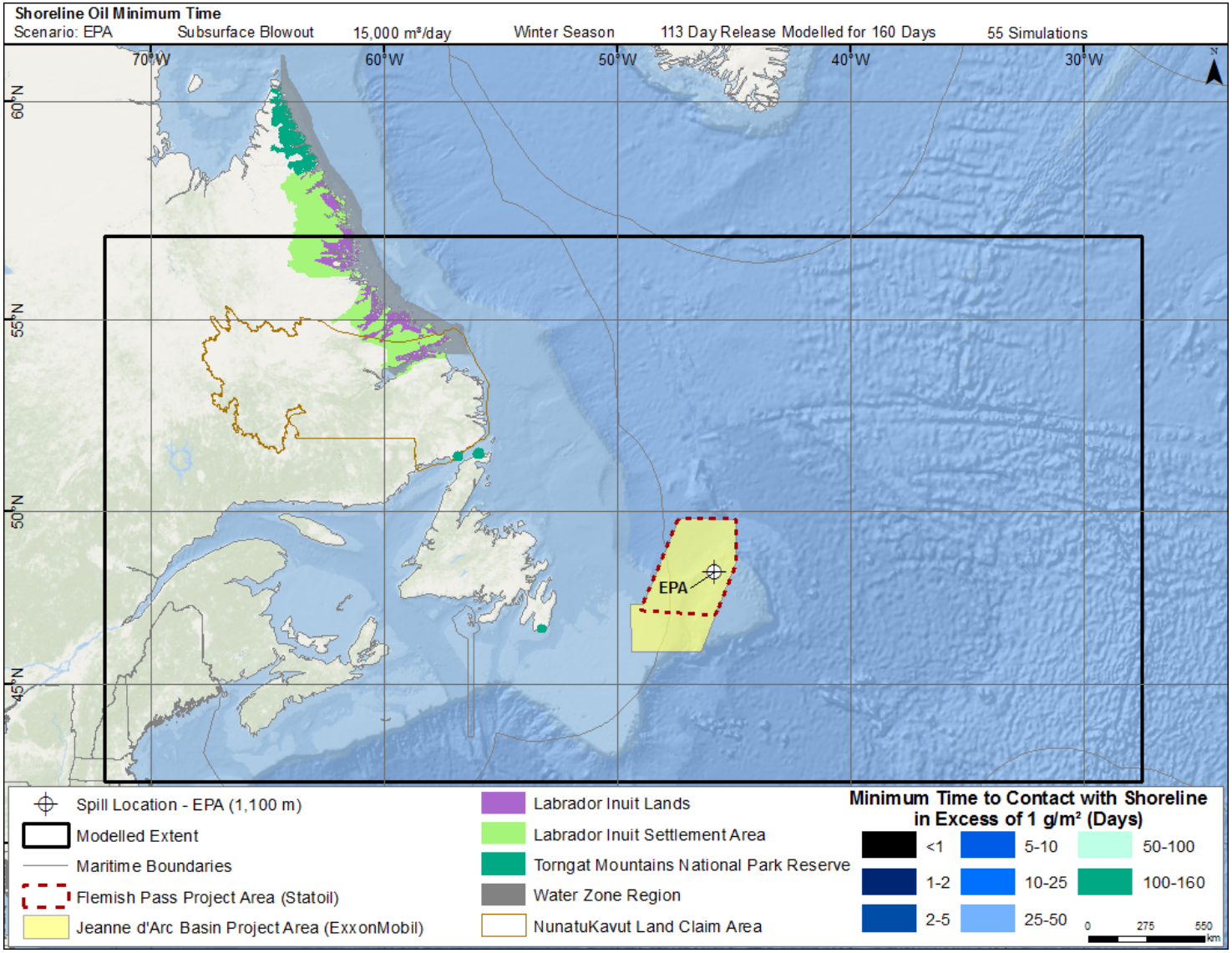


Figure 1-18. Minimum time to threshold exceedance resulting from a subsurface blowout at the EPA site.

1.2 NPA Release Site

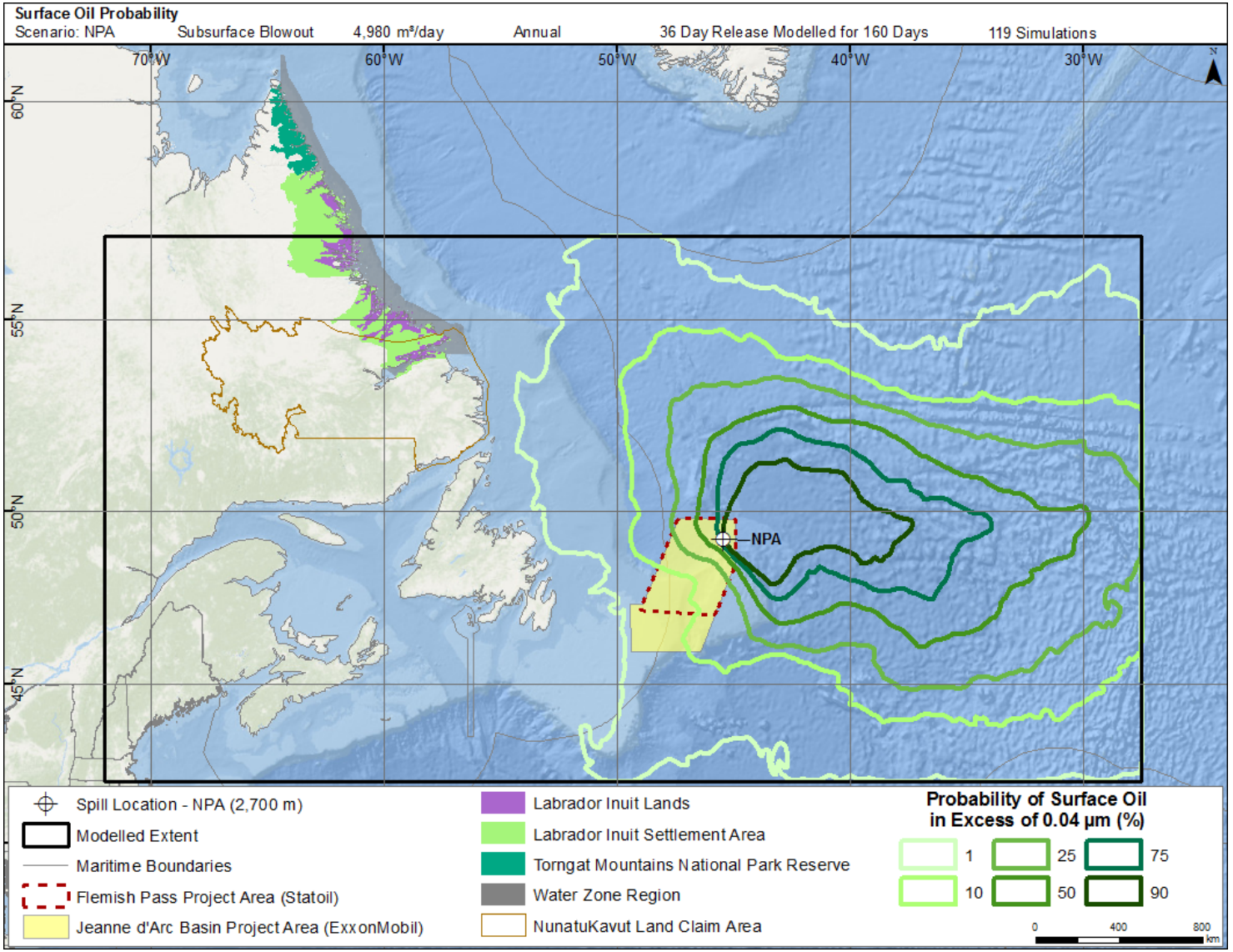


Figure 1-19. Annual probability of average surface oil thickness > 0.04 µm resulting from a subsurface blowout at the NPA site.

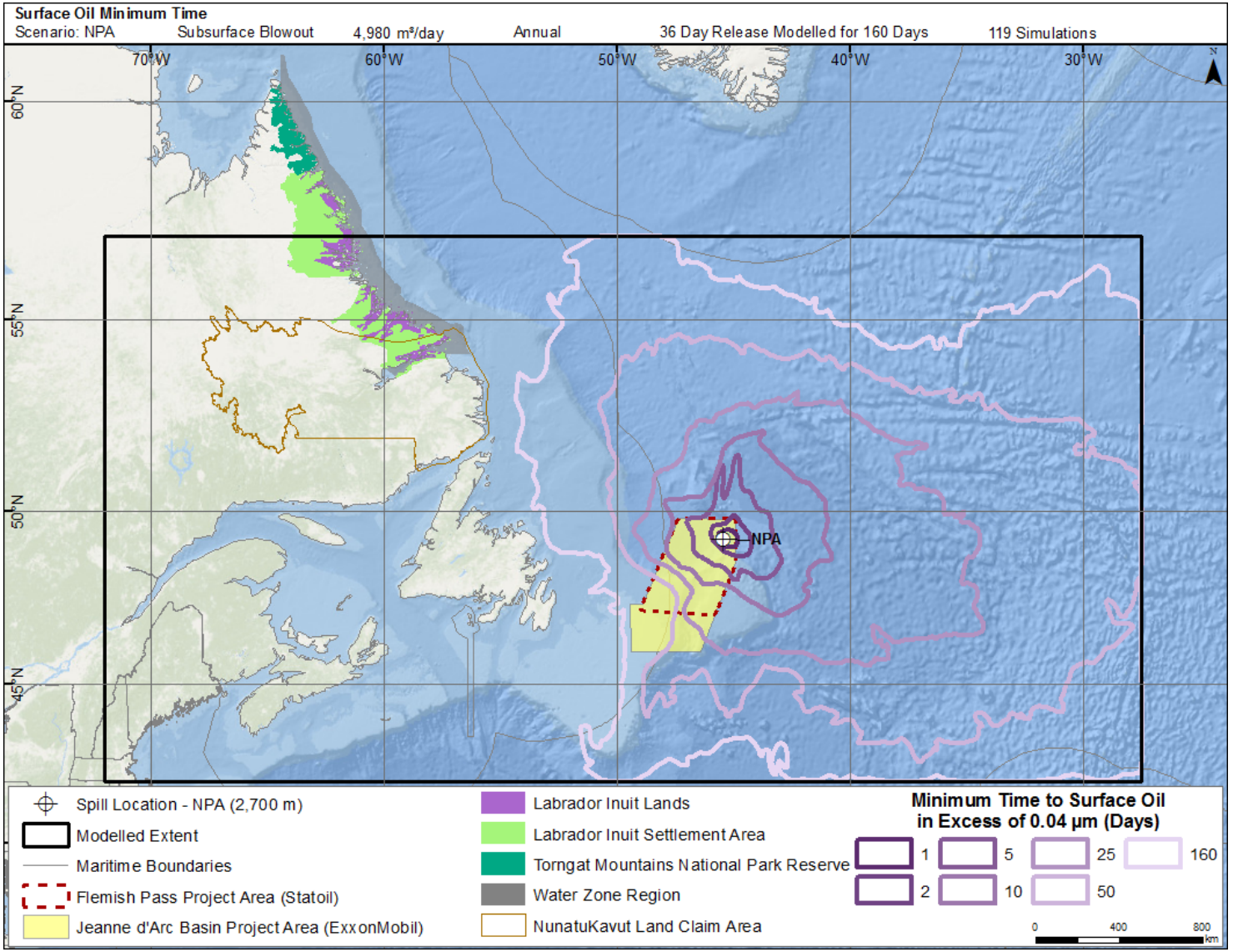


Figure 1-20. Minimum time to threshold exceedance resulting from a subsurface blowout at the NPA site.

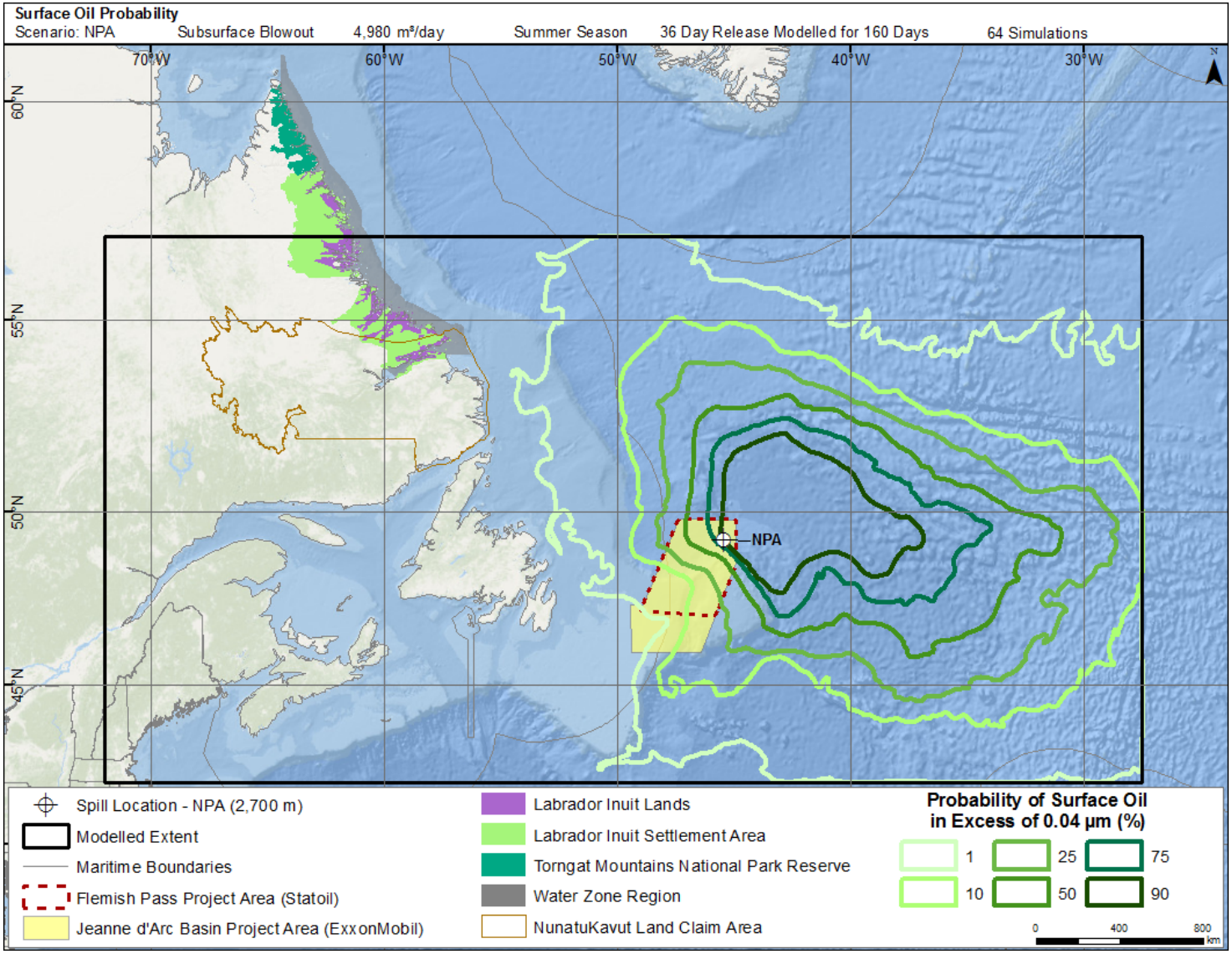


Figure 1-21. Summer probability of average surface oil thickness > 0.04 µm resulting from a subsurface blowout at the NPA site.

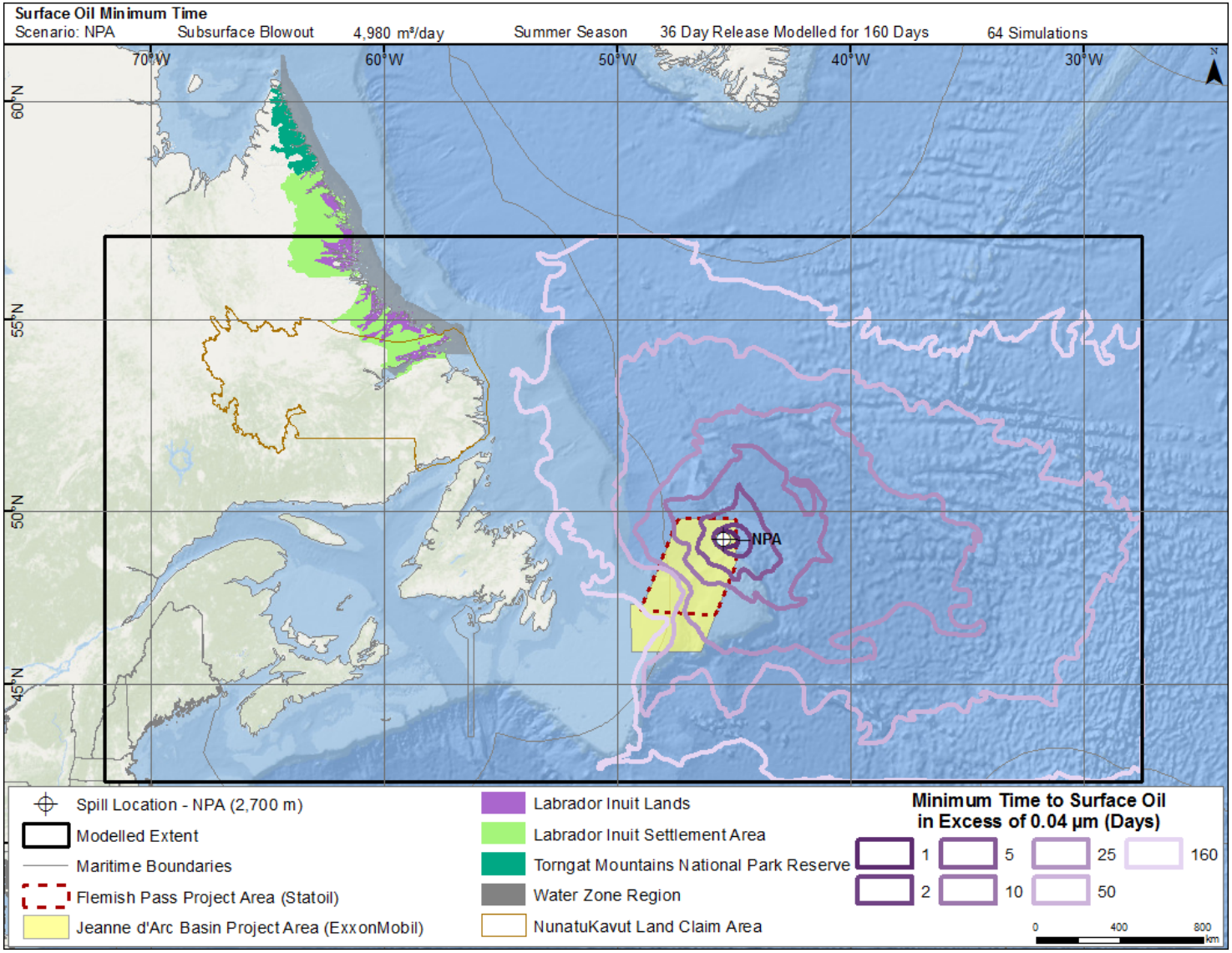


Figure 1-22. Minimum time to threshold exceedance resulting from a subsurface blowout at the NPA site.

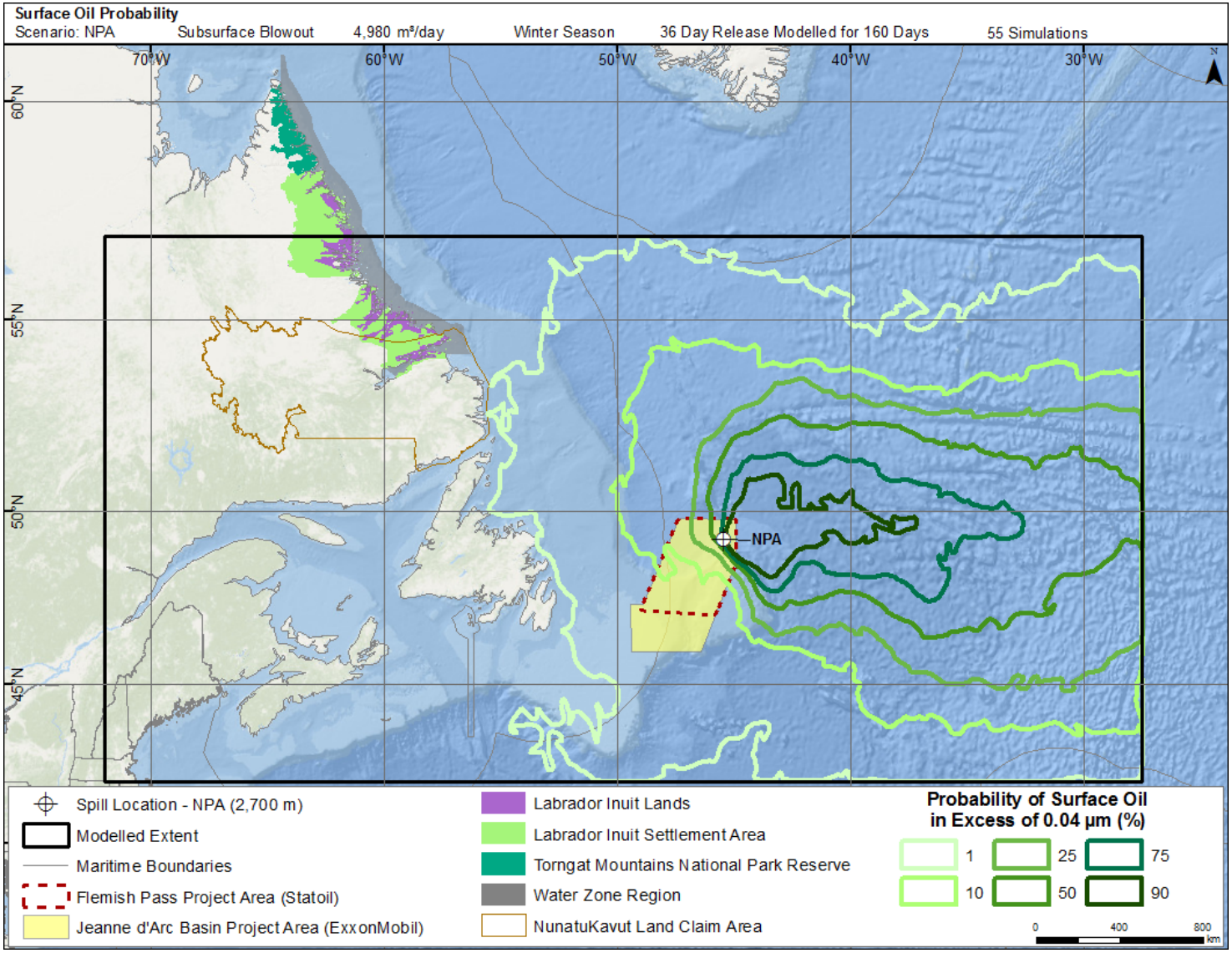


Figure 1-23. Winter probability of average surface oil thickness > 0.04 µm resulting from a subsurface blowout at the NPA site.

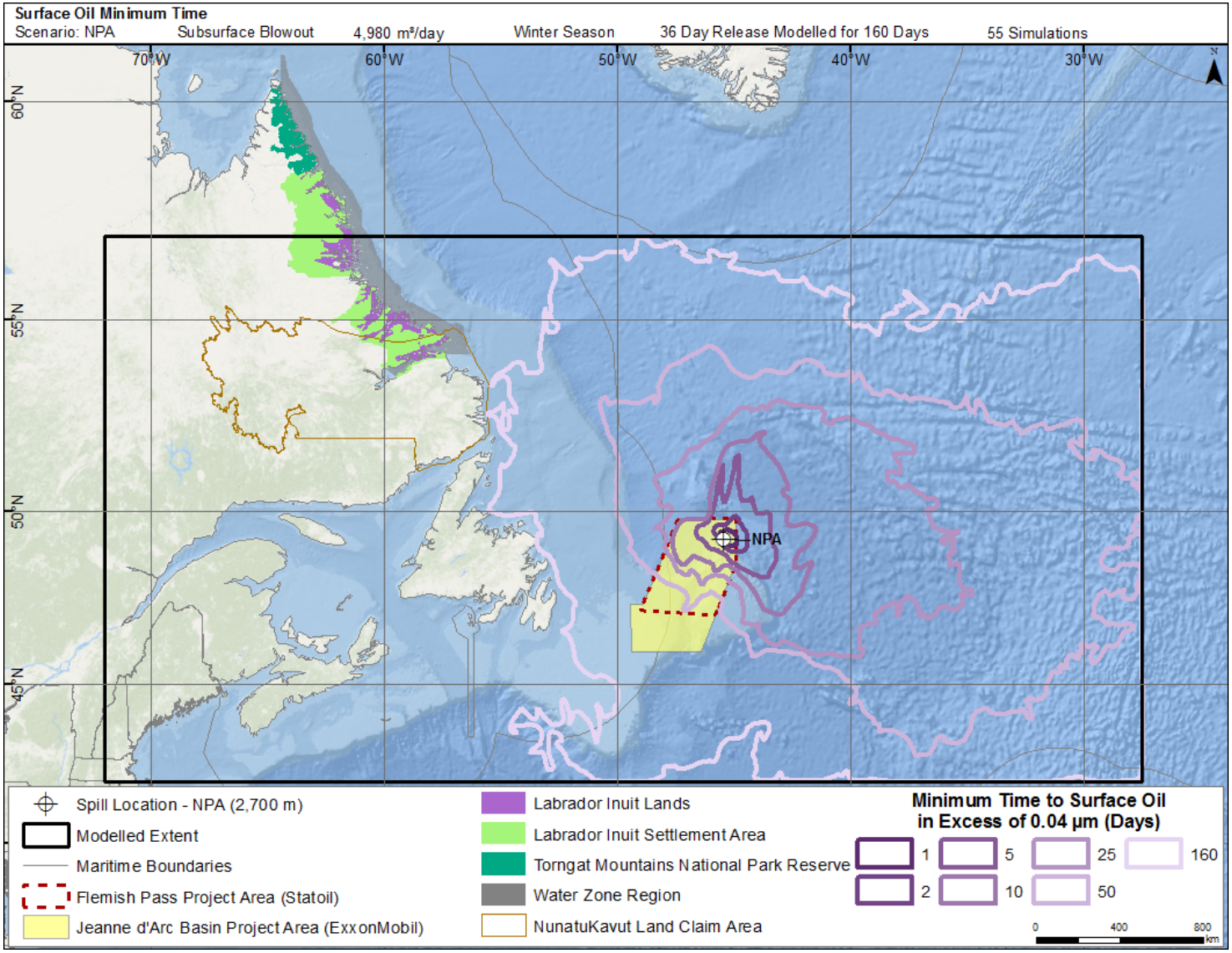


Figure 1-24. Minimum time to threshold exceedance resulting from a subsurface blowout at the NPA site.

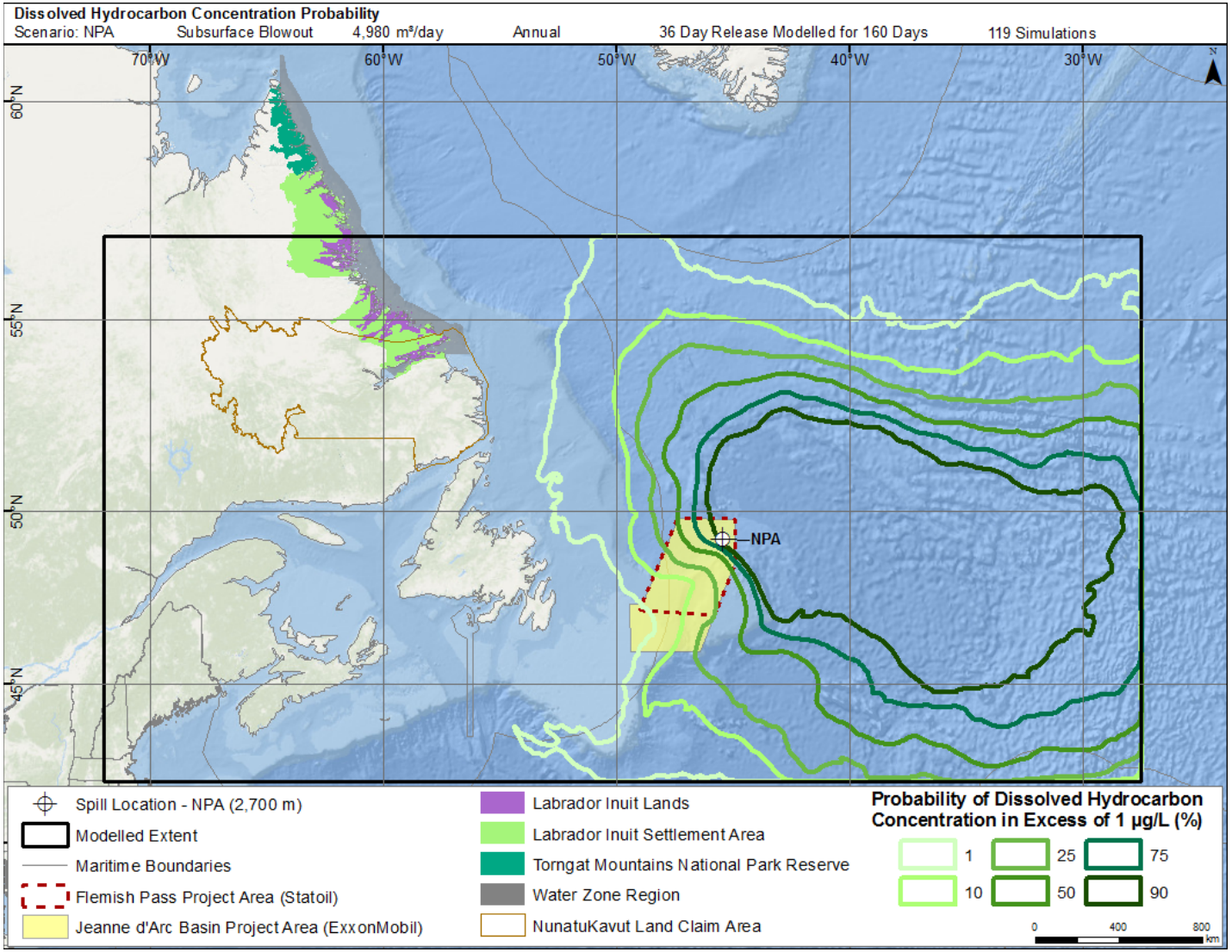


Figure 1-25. Annual probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column resulting from a subsurface blowout at the NPA site.

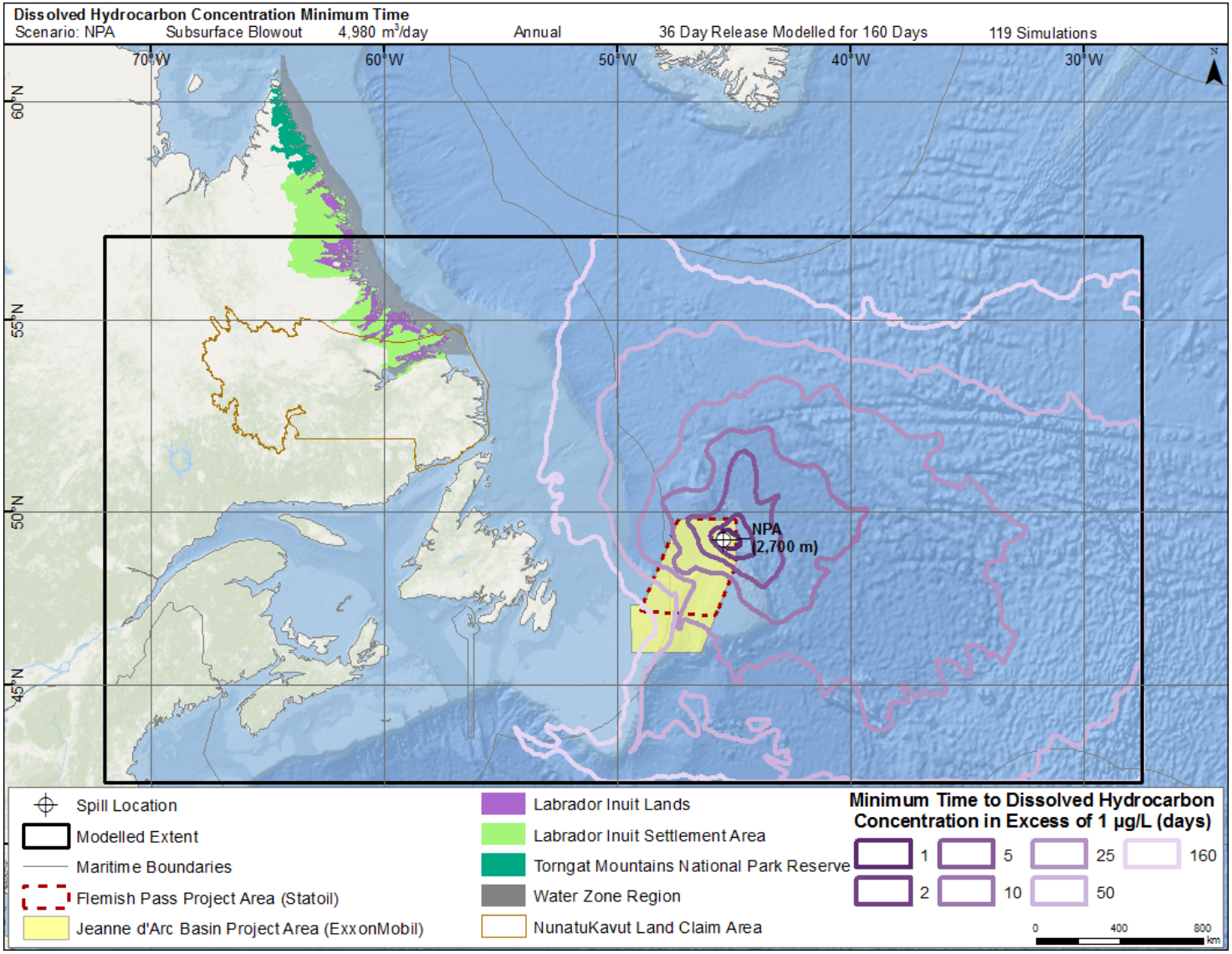


Figure 1-26. Minimum time to threshold exceedance resulting from a subsurface blowout at the NPA site.

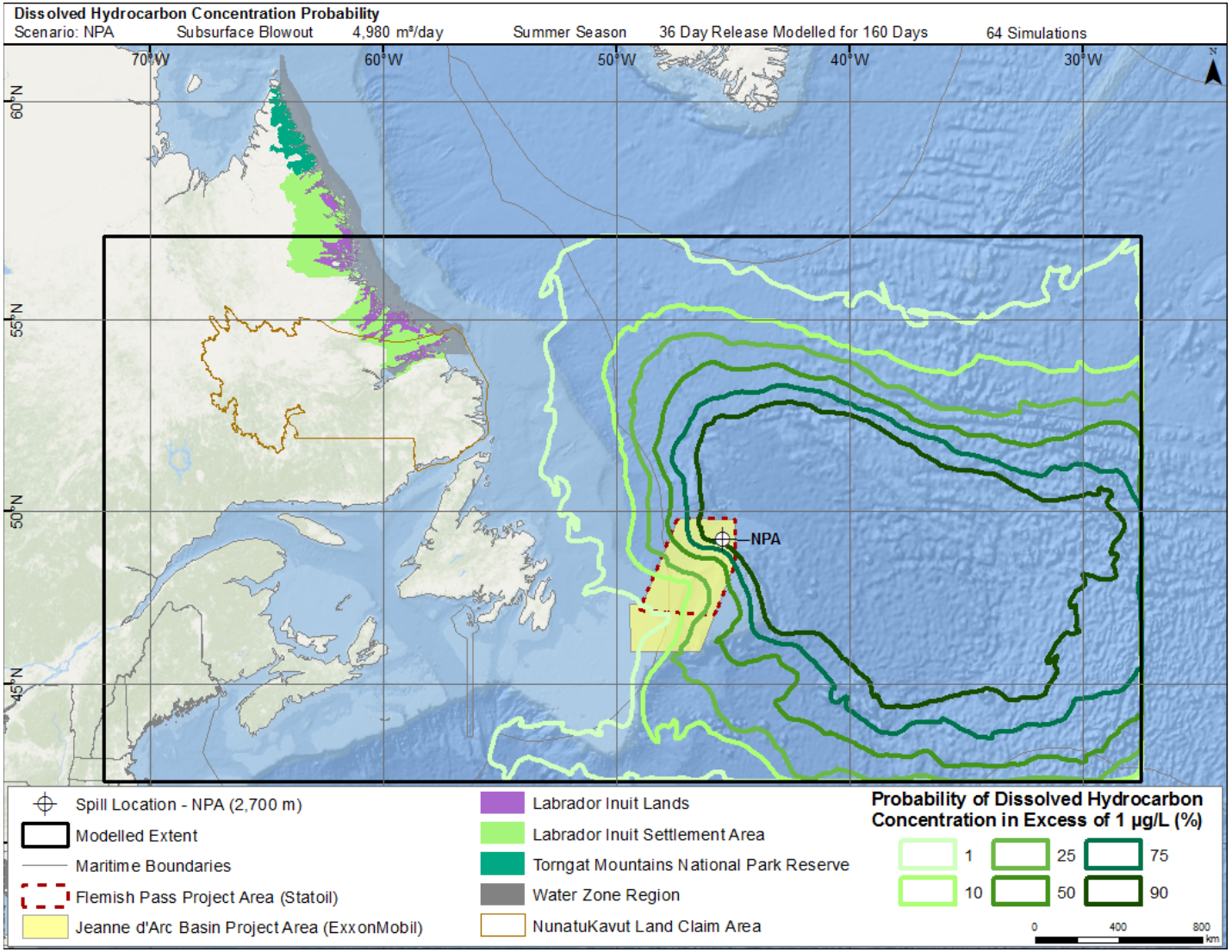


Figure 1-27. Summer probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column resulting from a subsurface blowout at the NPA site.

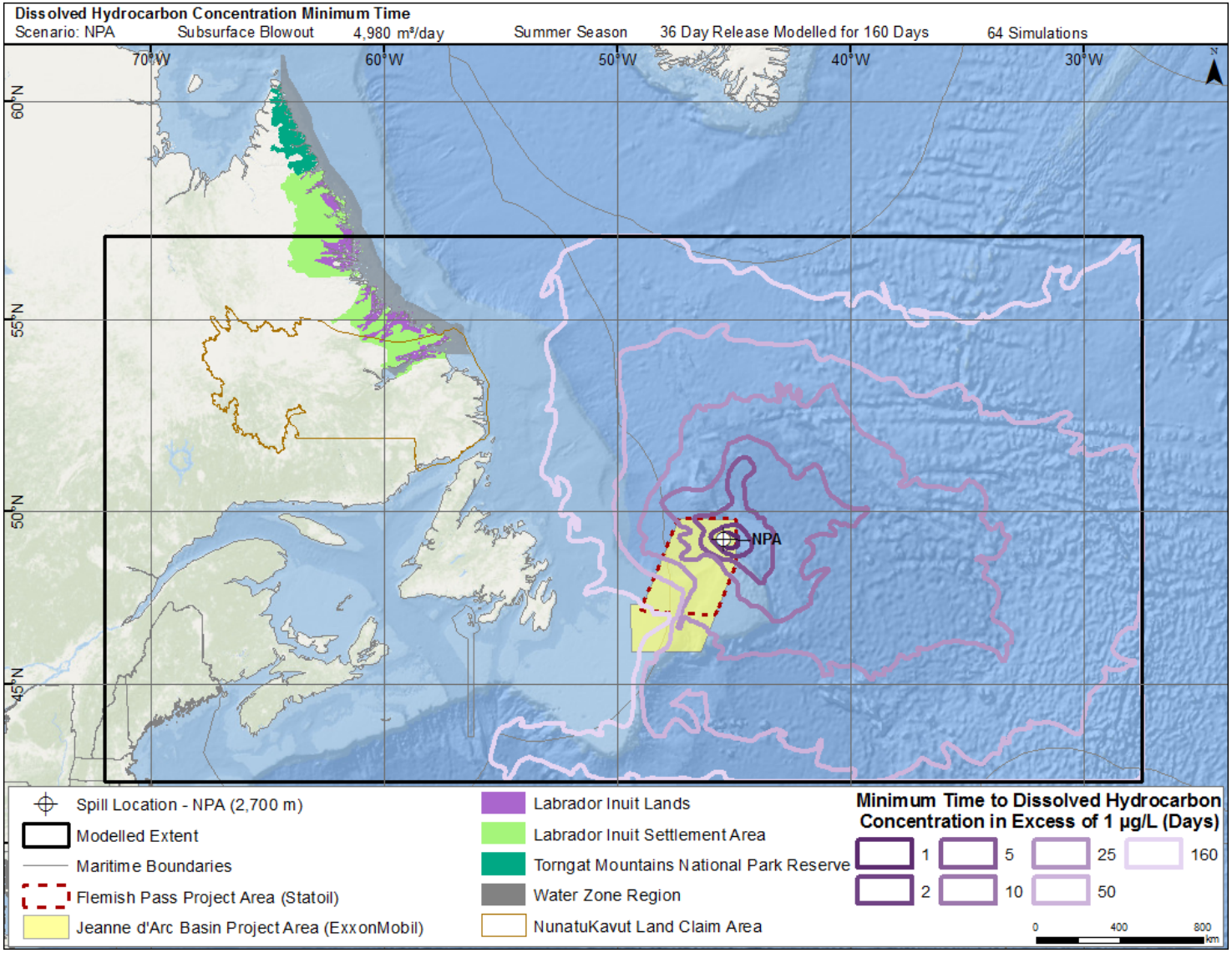


Figure 1-28. Minimum time to threshold exceedance (bottom) resulting from a subsurface blowout at the NPA site.

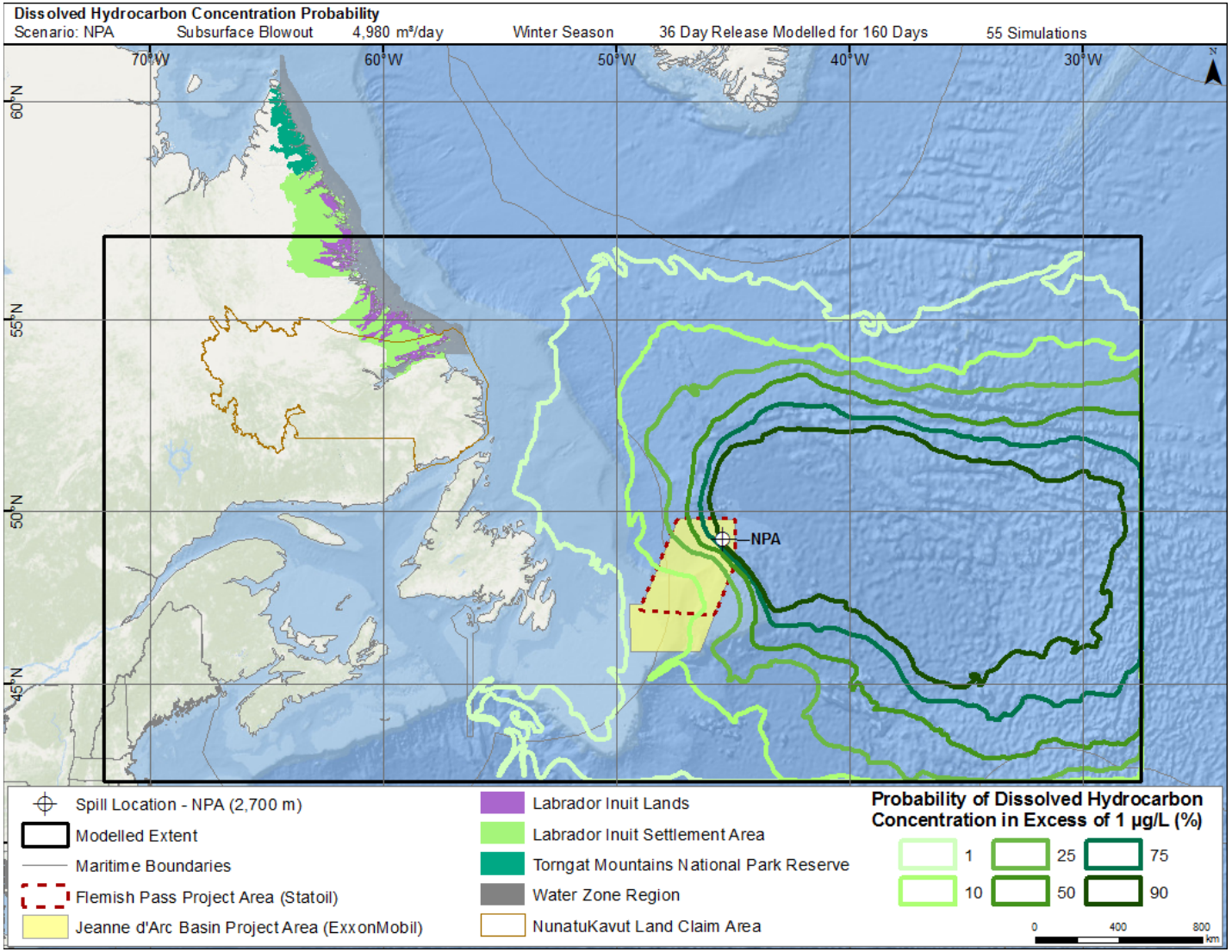


Figure 1-29. Winter probability of dissolved hydrocarbon concentrations > 1 µg/L at some depth in the water column resulting from a subsurface blowout at the NPA site.

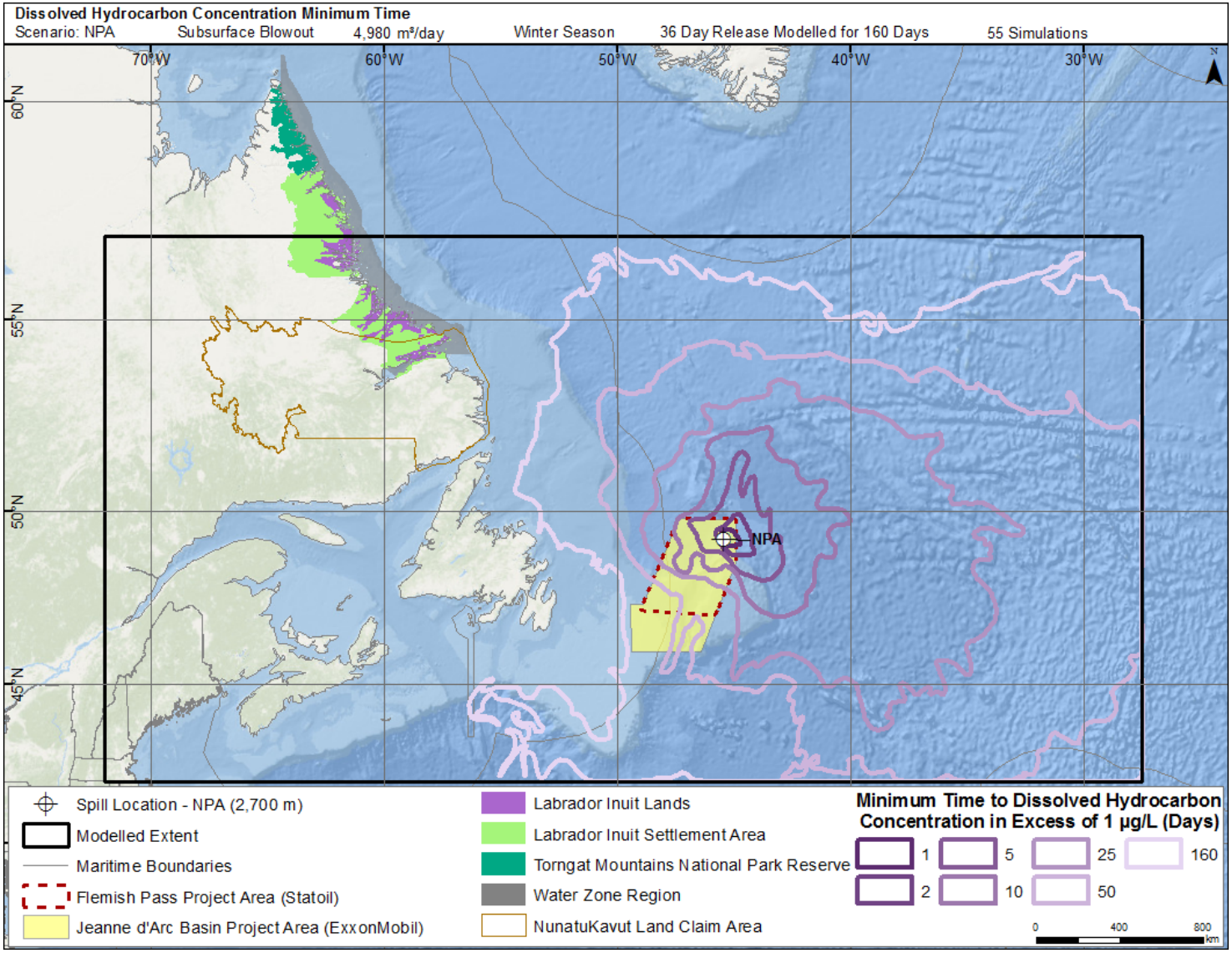


Figure 1-30. Minimum time to threshold exceedance resulting from a subsurface blowout at the NPA site.

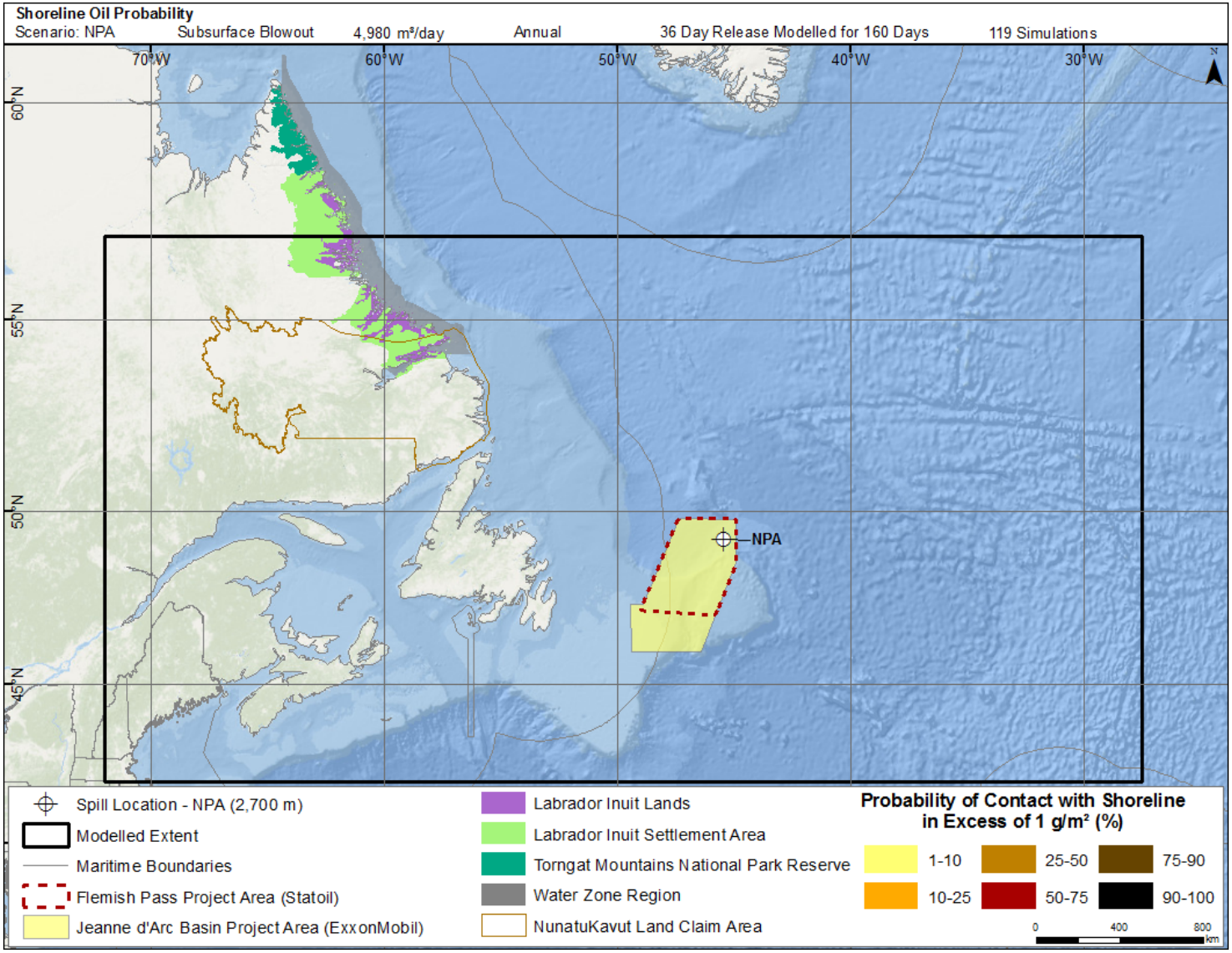


Figure 1-31. Annual probability of shoreline contact > 1 g/m2 resulting from a subsurface blowout at the NPA site.

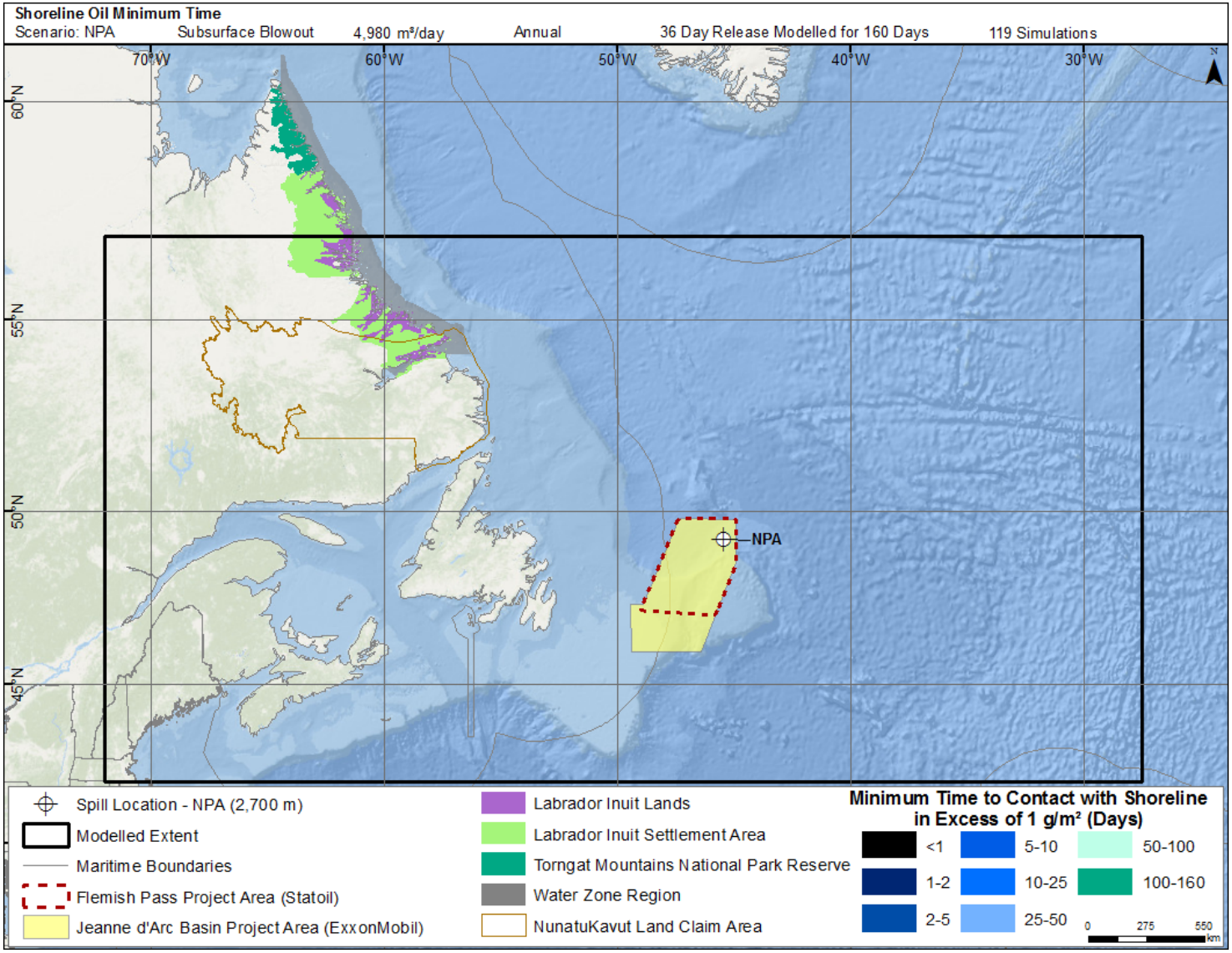


Figure 1-32. Minimum time to threshold exceedance resulting from a subsurface blowout at the NPA site.

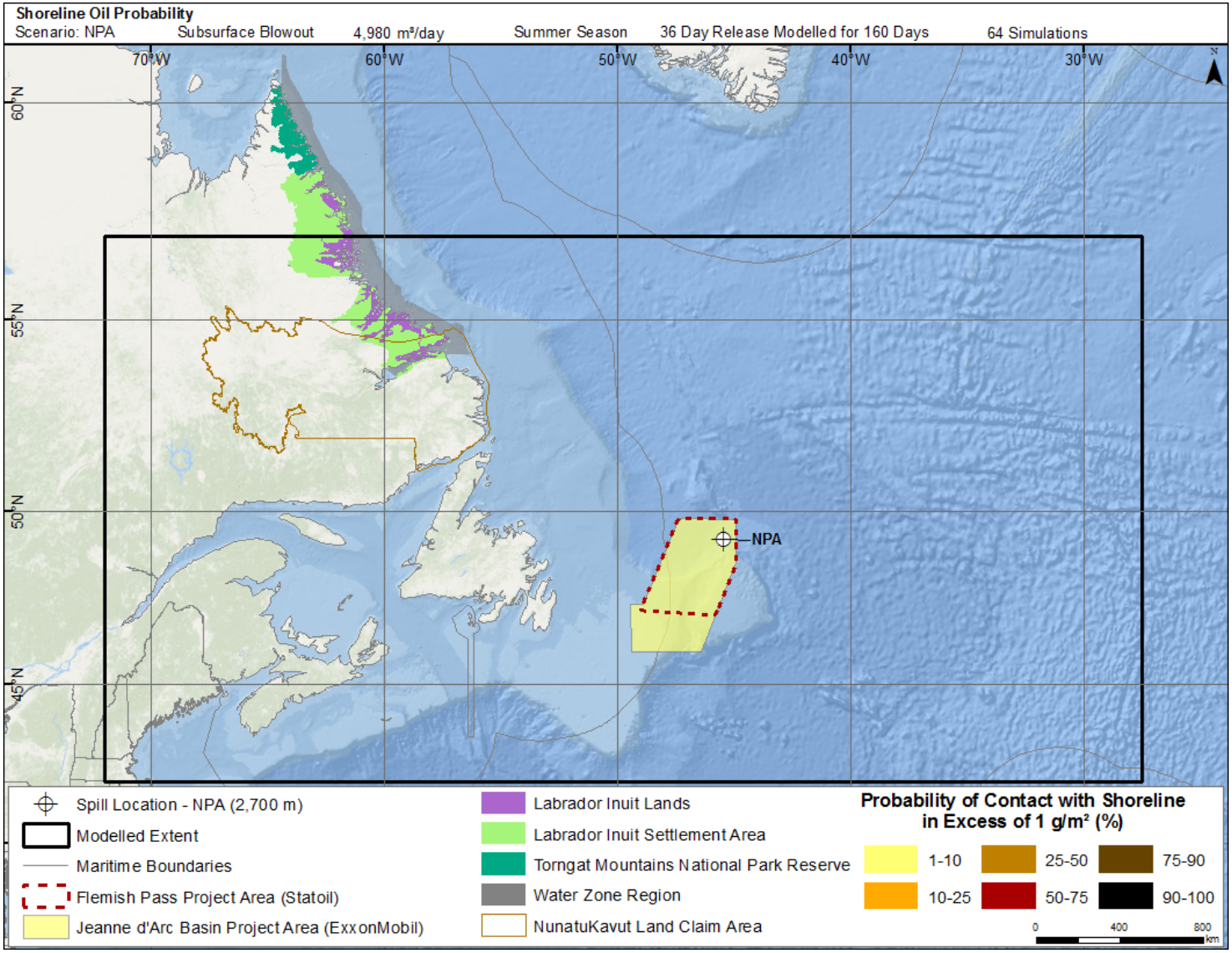


Figure 1-33. Summer probability of shoreline contact > 1 g/m2 resulting from a subsurface blowout at the NPA site.

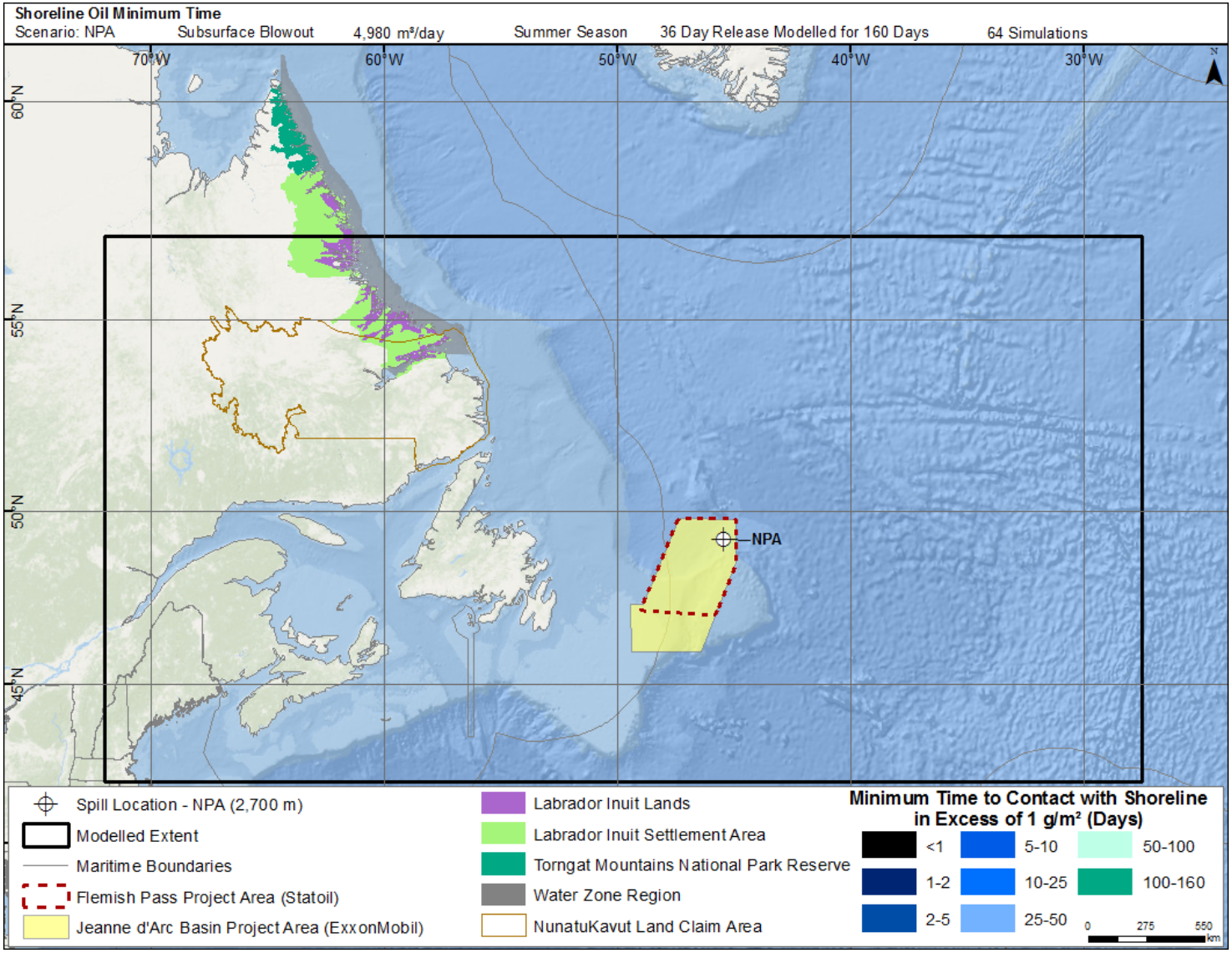


Figure 1-34. Minimum time to threshold exceedance resulting from a subsurface blowout at the NPA site.

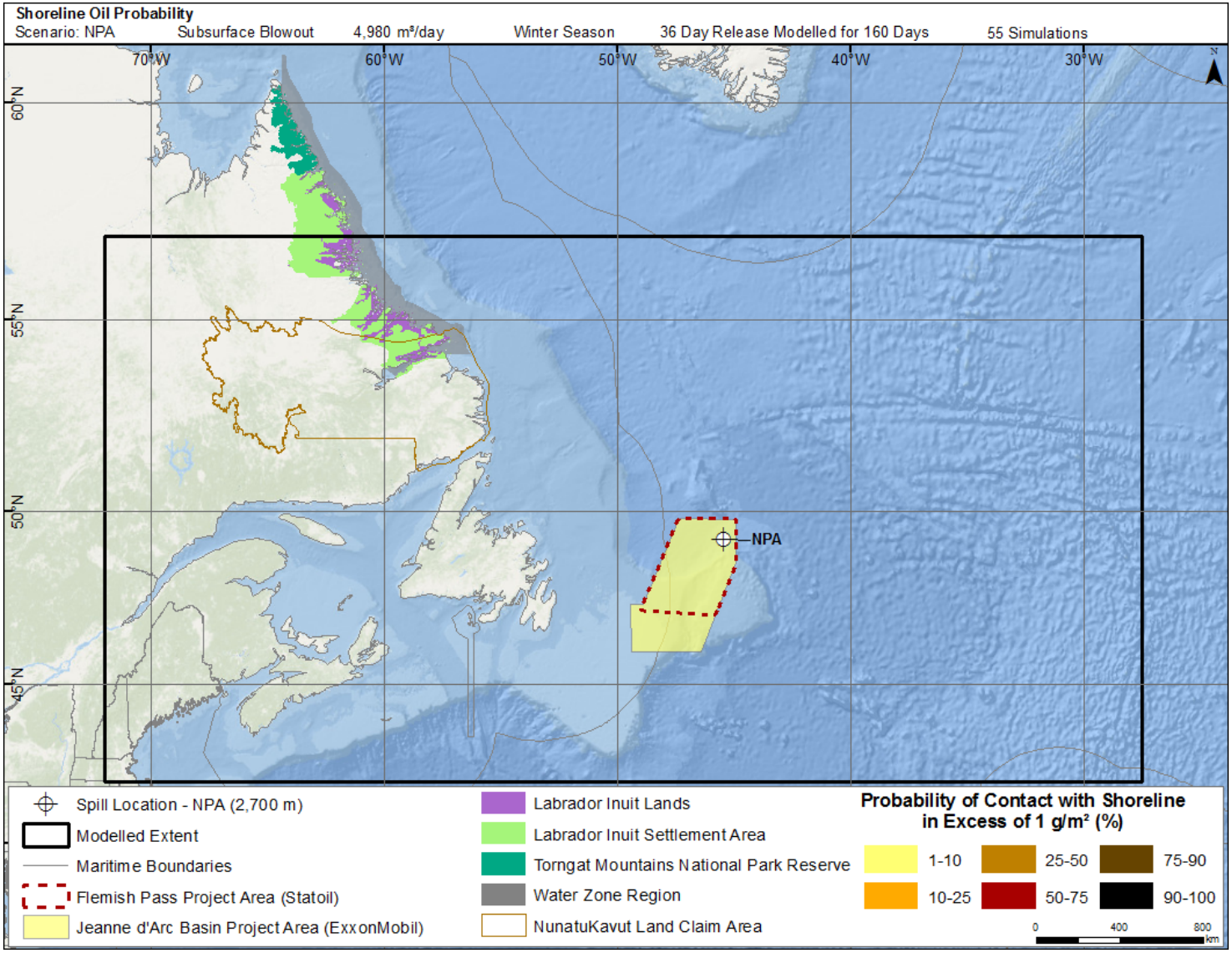


Figure 1-35. Winter probability of shoreline contact > 1 g/m2 resulting from a subsurface blowout at the NPA site - winter results.

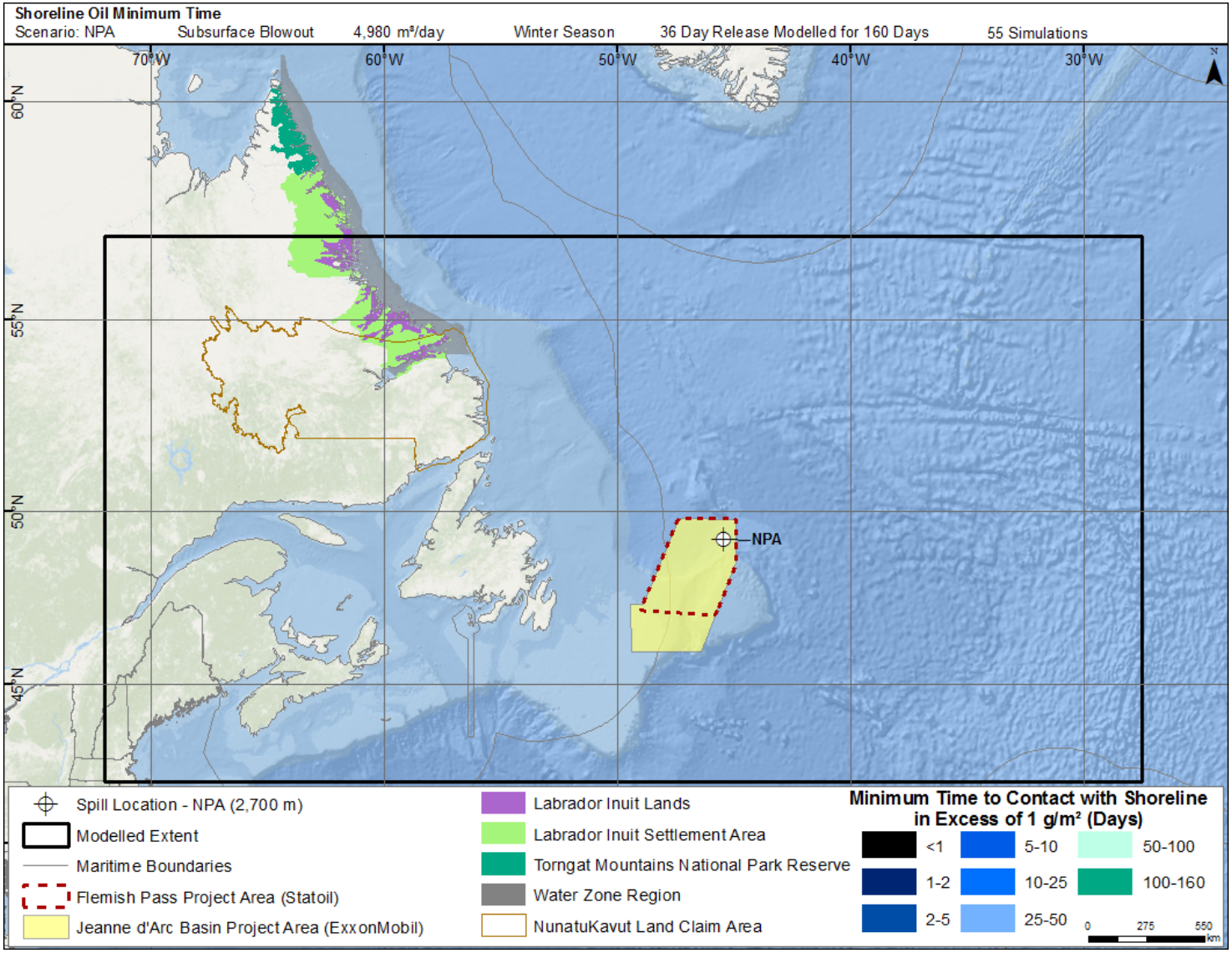


Figure 1-36. Minimum time to threshold exceedance resulting from a subsurface blowout at the NPA site - winter results.

2 Deterministic Analysis Results

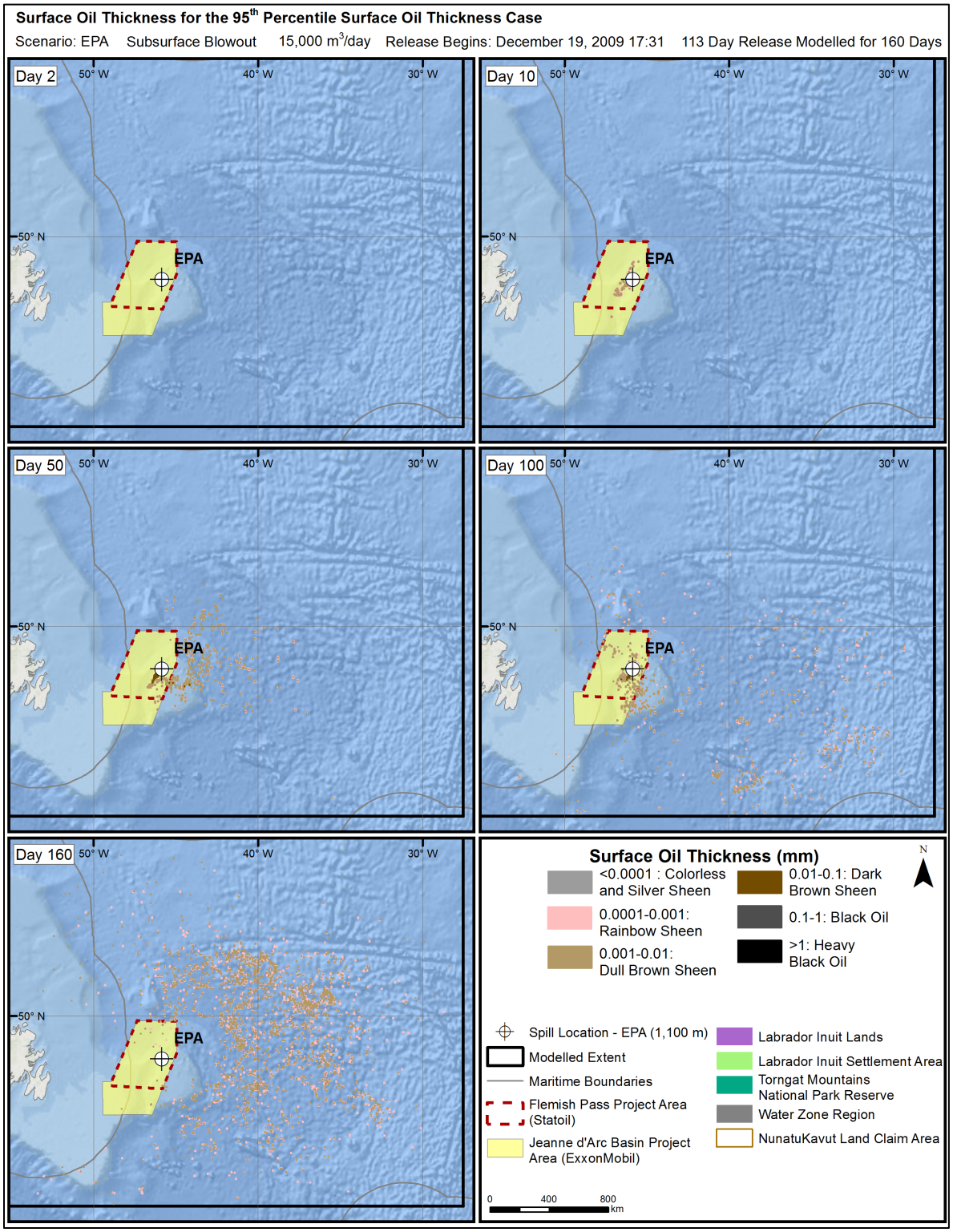


Figure 2-1. Predicted surface oil thickness for the 95th percentile EPA surface oil exposure case at days 2, 10, 50, 100, and 160.

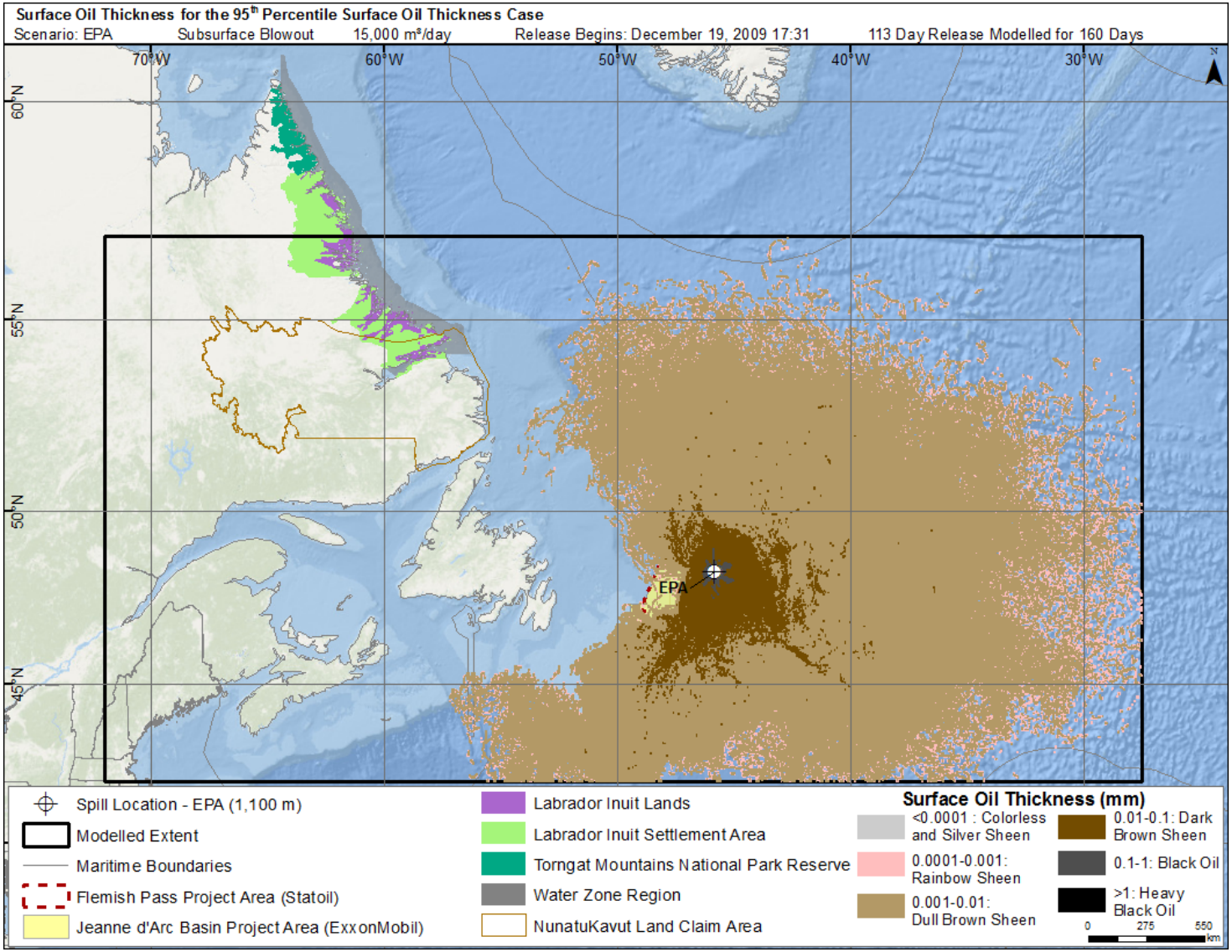


Figure 2-2. Maximum cumulative surface oil thickness for the 95th percentile surface oil exposure case.

2.1 Surface Oil Exposure Cases

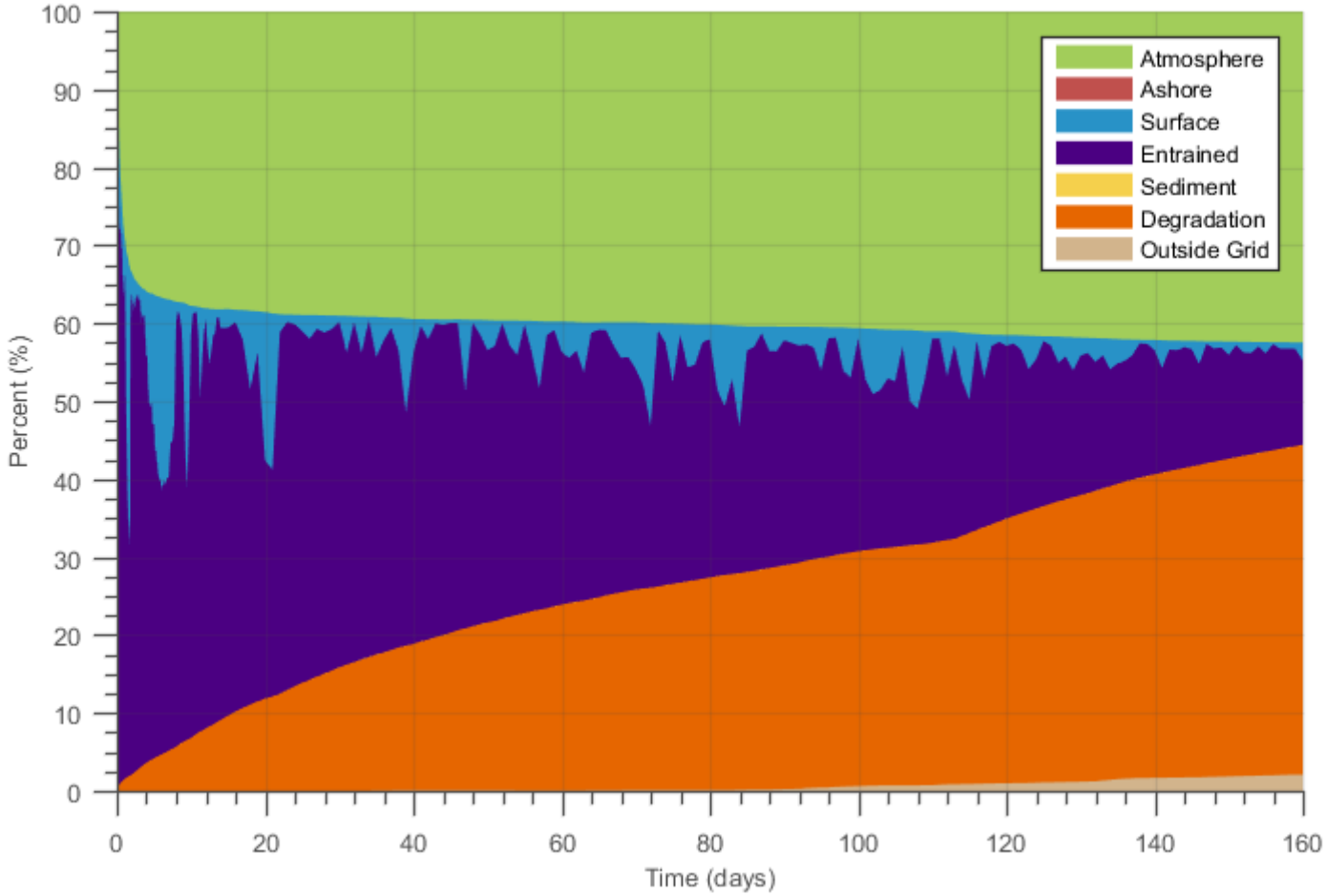


Figure 2-3. Mass balance plots for the 95th percentile surface oil thickness cases at EPA.

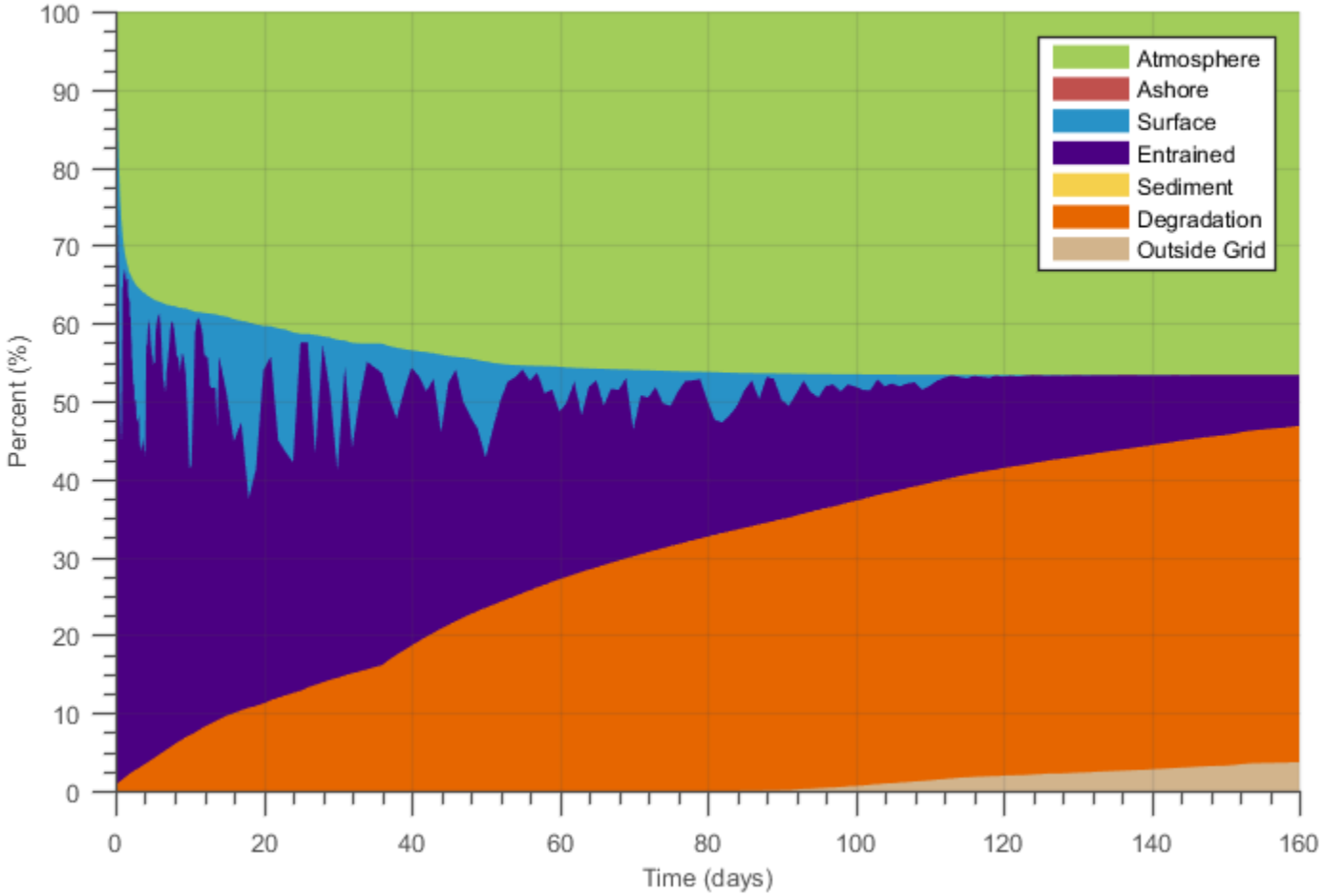


Figure 2-4. Mass balance plots for the 95th percentile surface oil thickness cases at NPA.

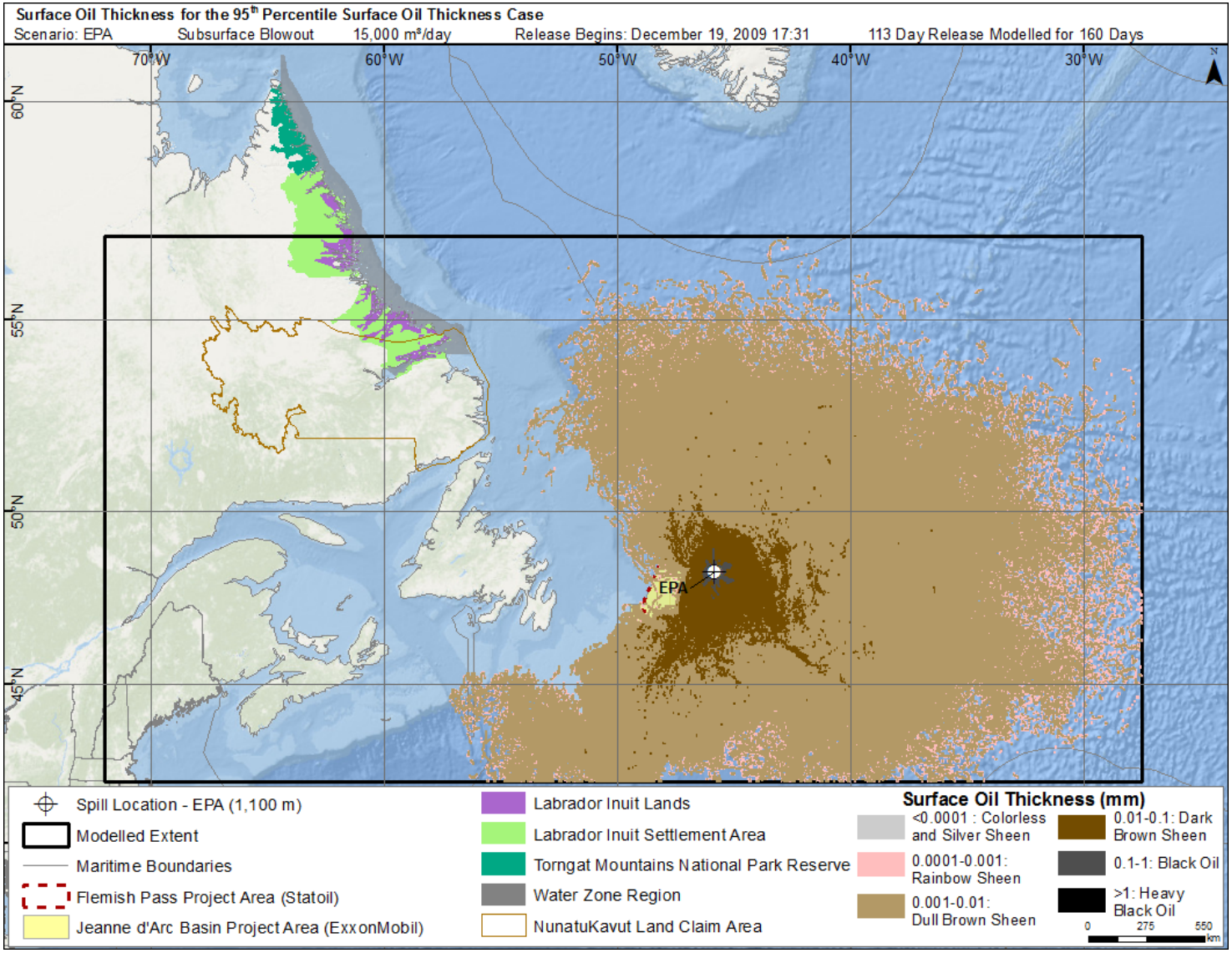


Figure 2-5. Surface oil thickness for the 95th percentile surface oil thickness case at EPA.

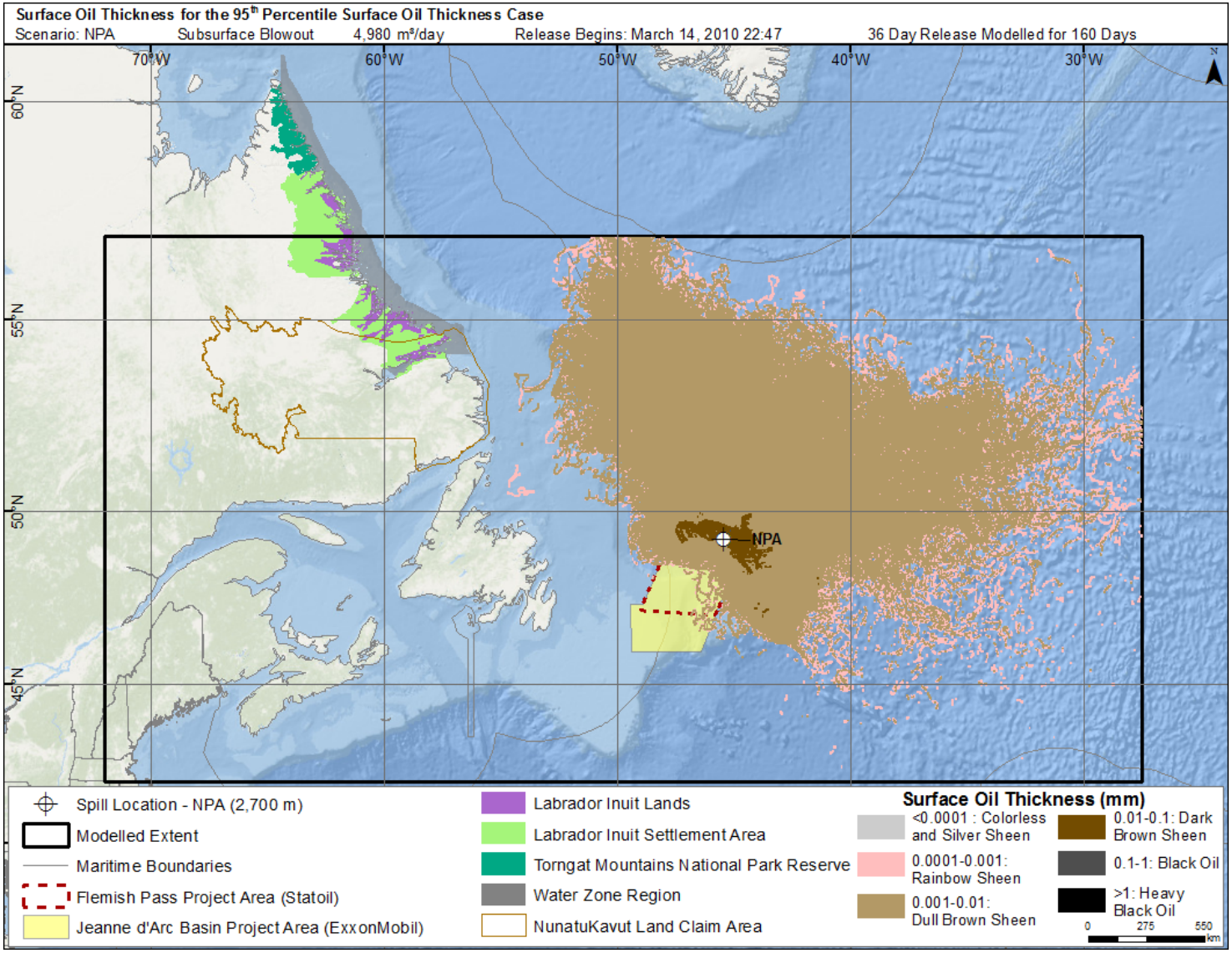


Figure 2-6. Surface oil thickness for the 95th percentile surface oil thickness case at NPA.

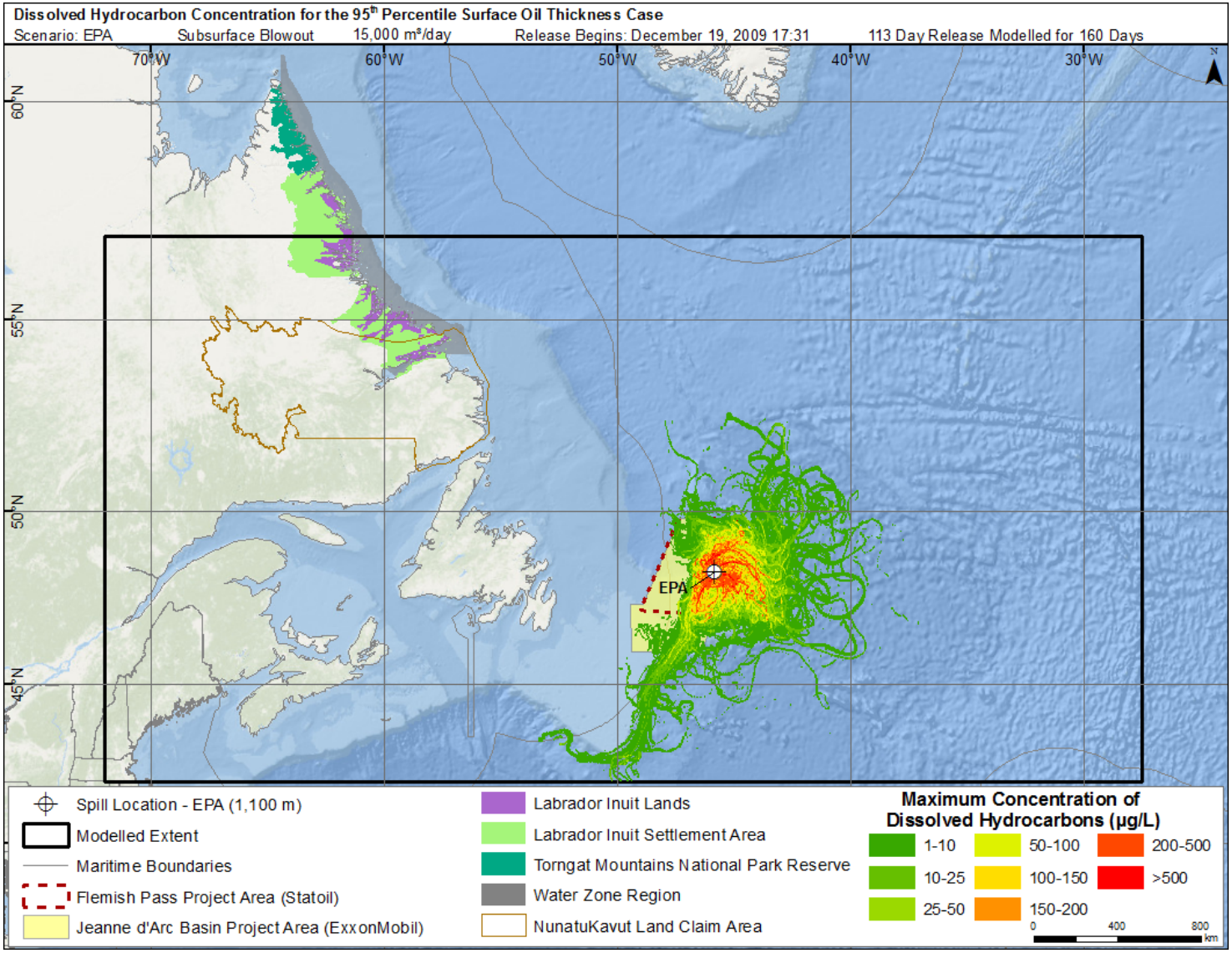


Figure 2-7. Maximum dissolved hydrocarbon concentration at any depth in the water column for the 95th percentile surface oil thickness case for EPA.

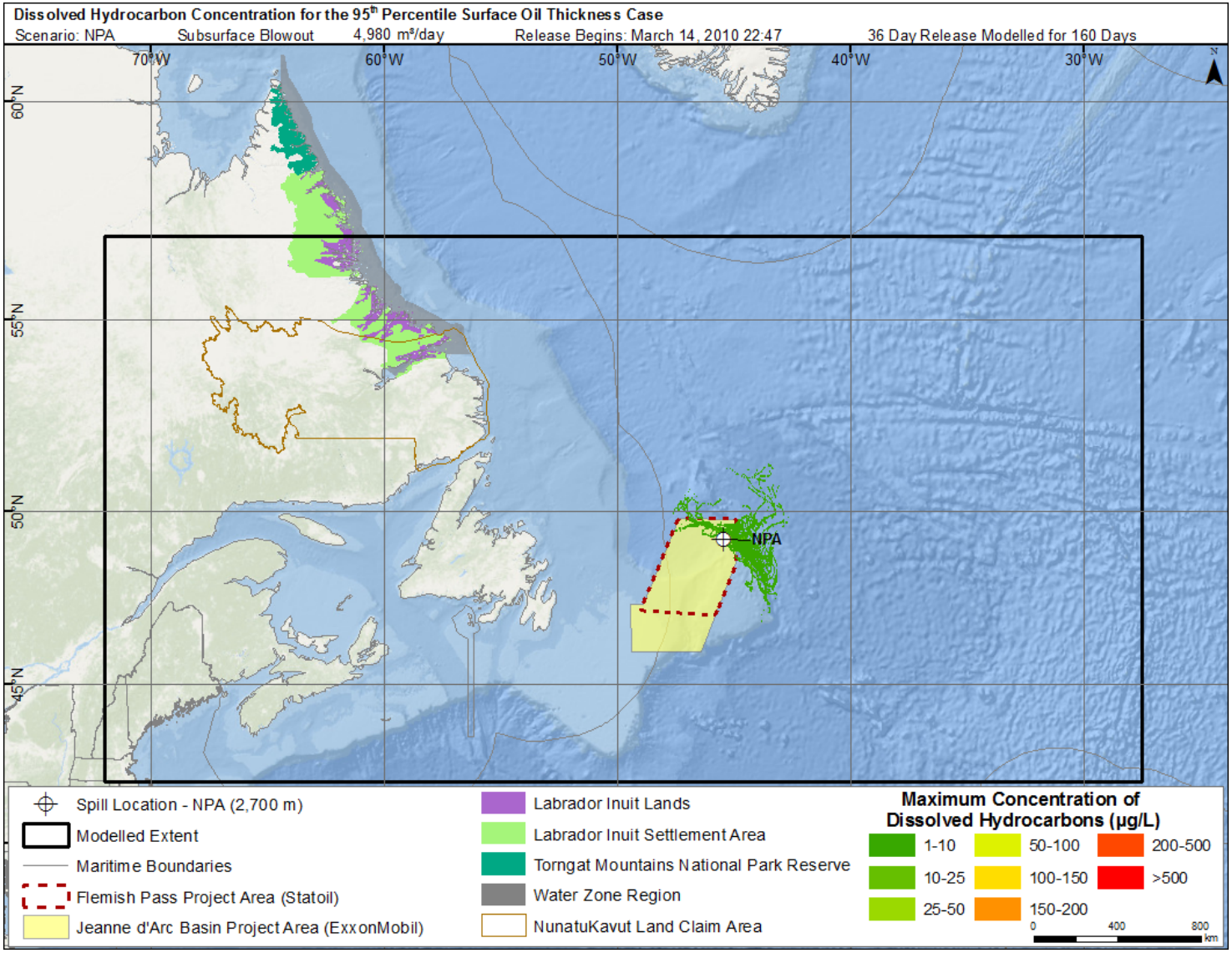


Figure 2-8. Maximum dissolved hydrocarbon concentration at any depth in the water column for the 95th percentile surface oil thickness case for NPA.

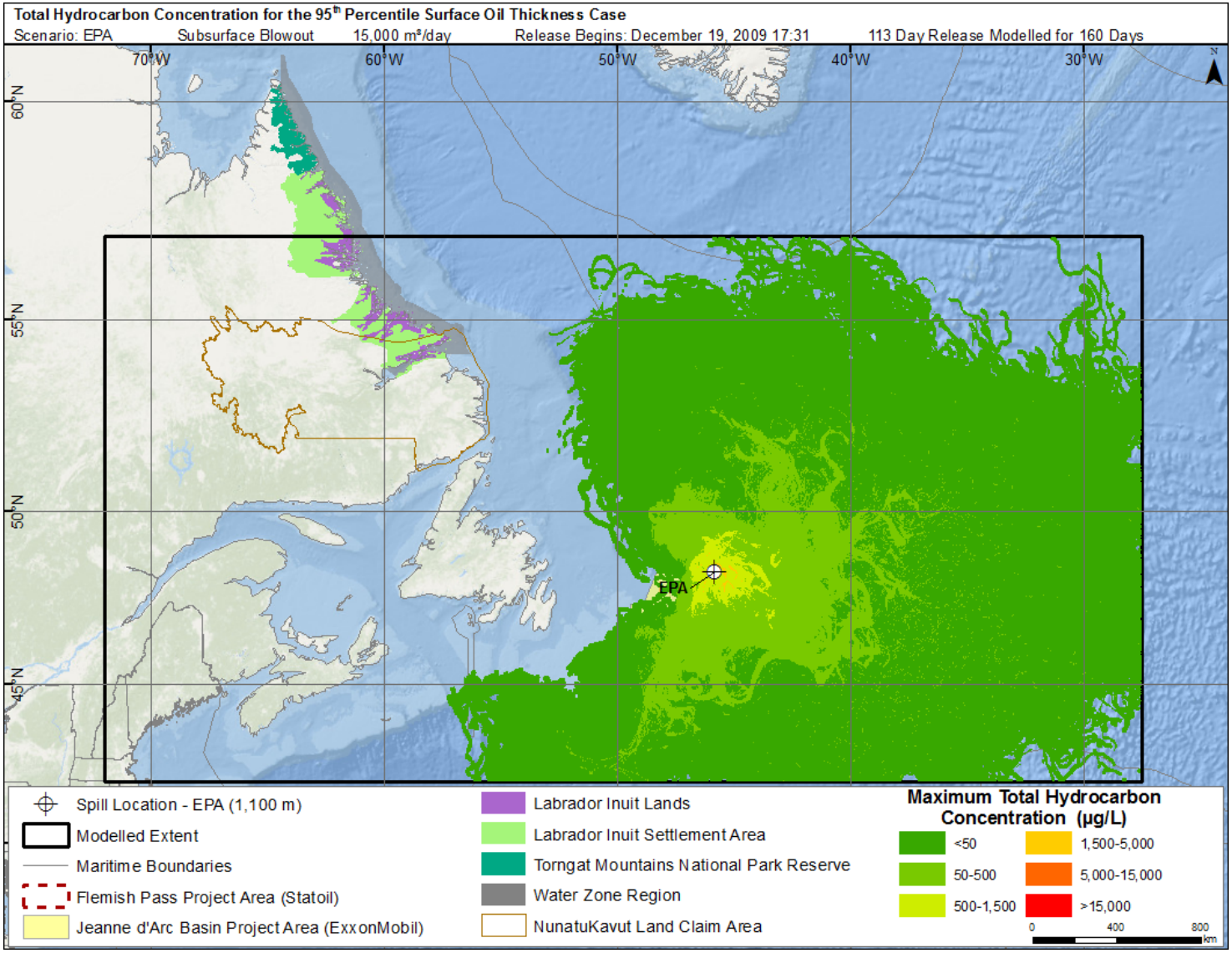


Figure 2-9. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the 95th percentile surface oil thickness case for EPA.

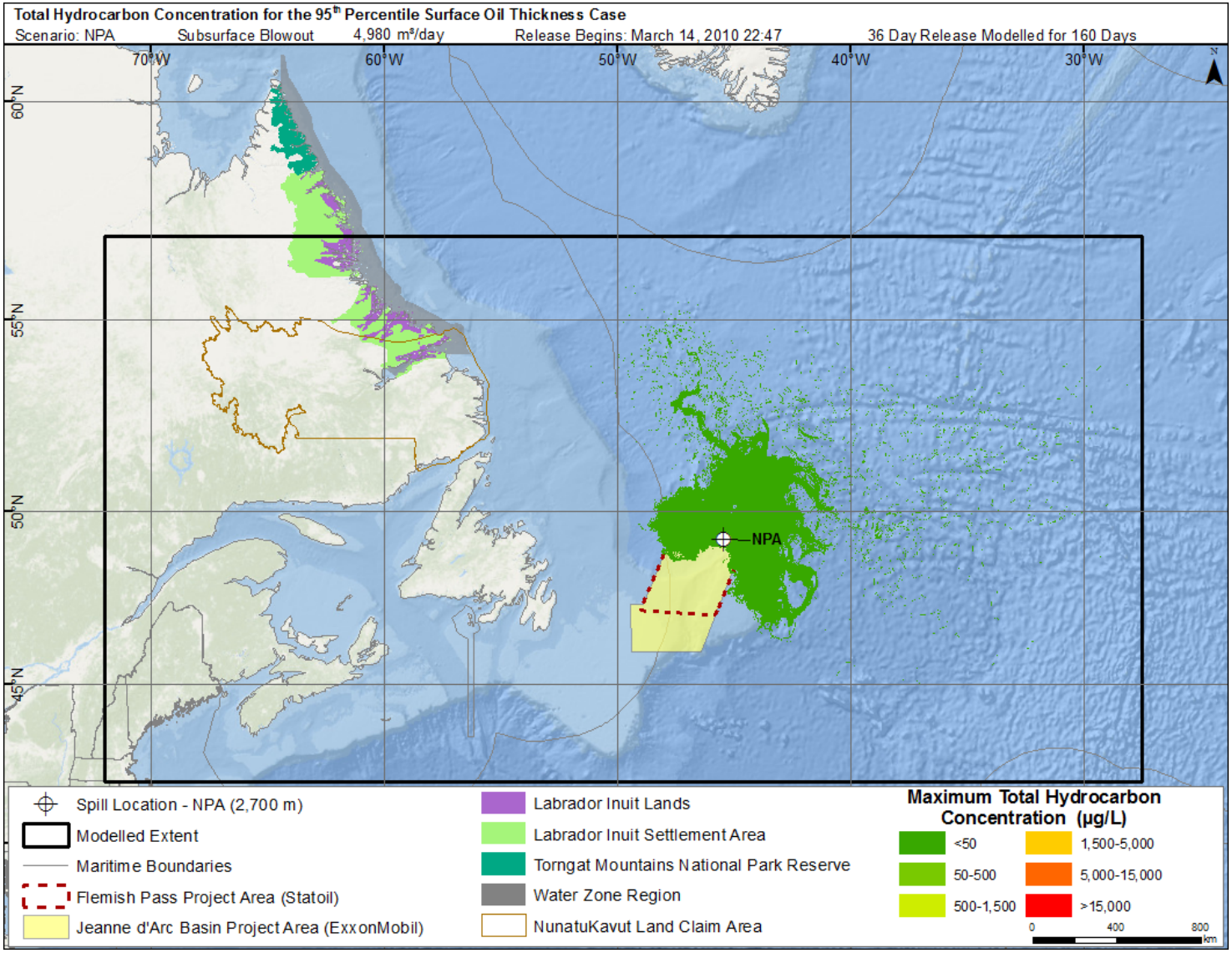


Figure 2-10. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the 95th percentile surface oil thickness case for NPA.

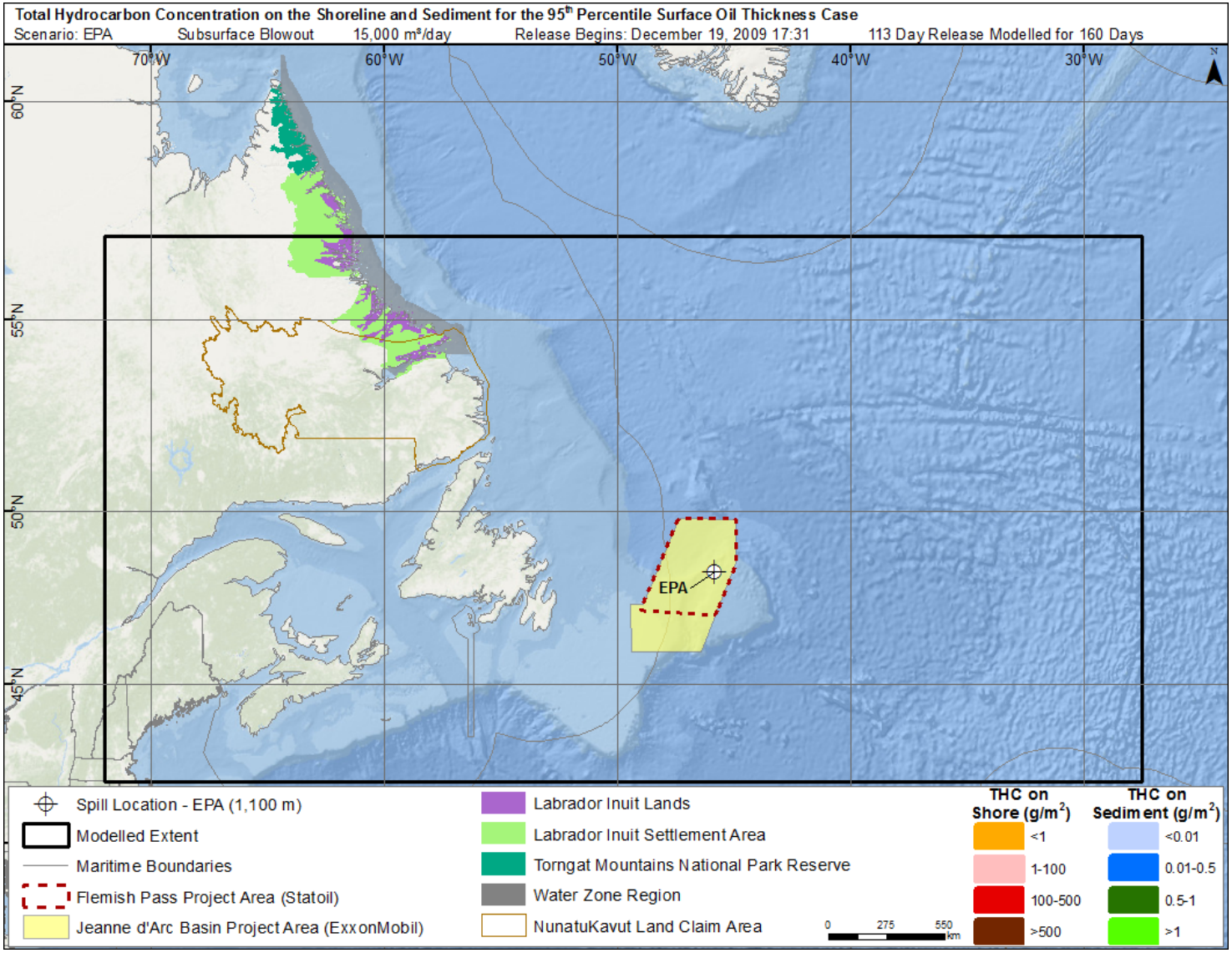


Figure 2-11. Total hydrocarbon concentration (THC) on the shore and sediment for the 95th percentile surface oil thickness case for EPA.

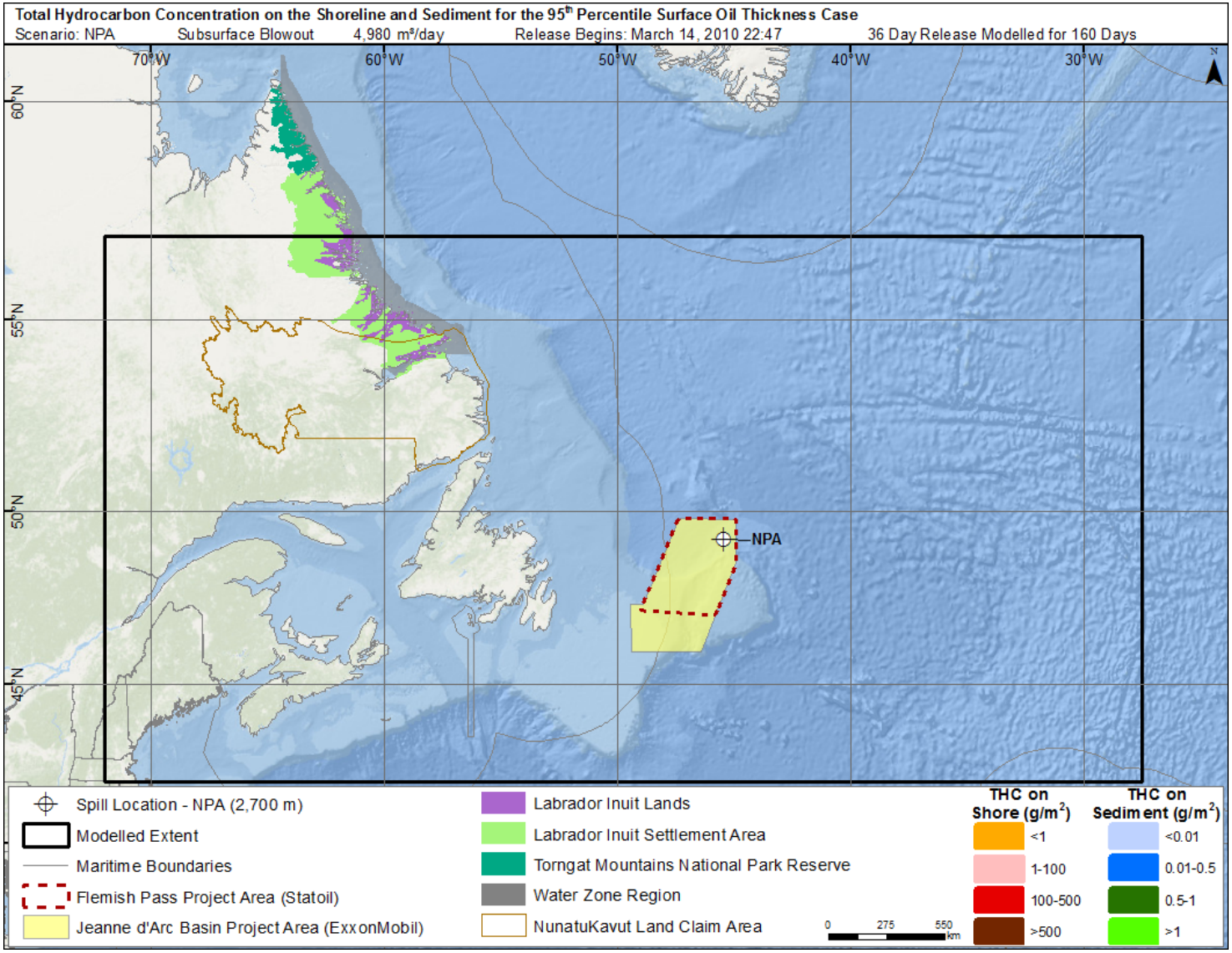


Figure 2-12. Total hydrocarbon concentration (THC) on the shore and sediment for the 95th percentile surface oil thickness case for NPA.

2.2 Water Column Exposure Cases

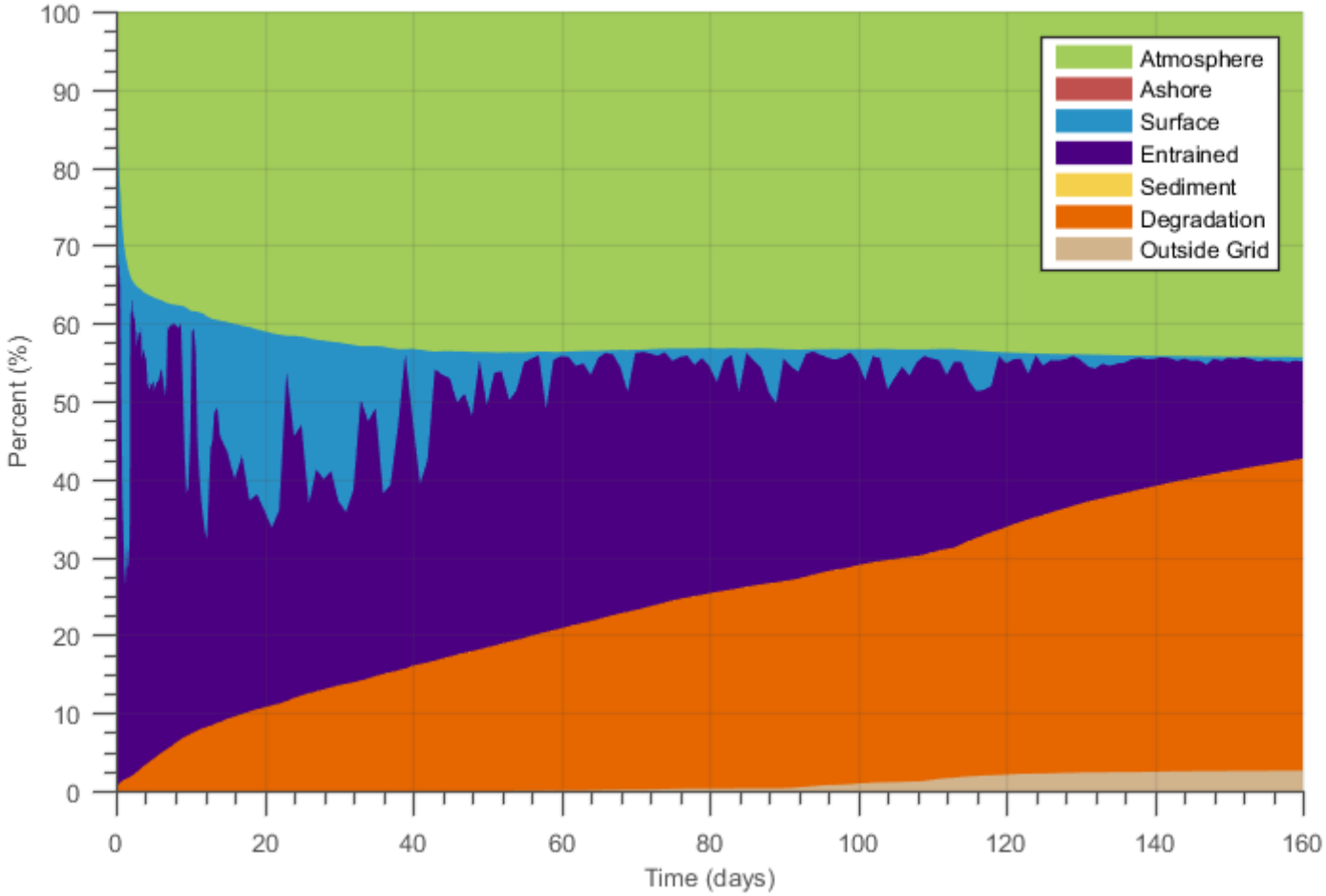


Figure 2-13. Mass balance plots of the 95th percentile water column contamination case for EPA.

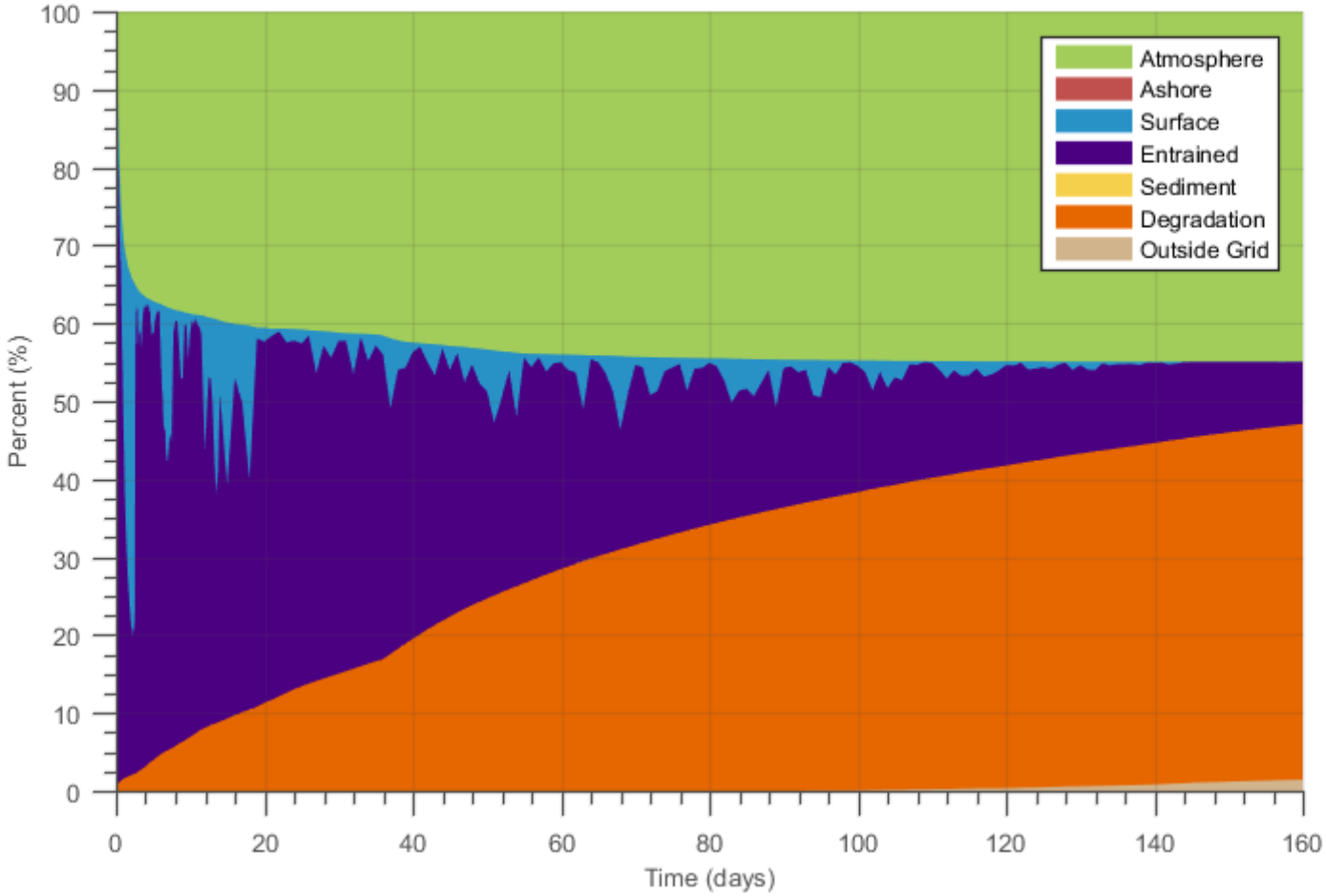


Figure 2-14. Mass balance plots of the 95th percentile water column contamination case for NPA.

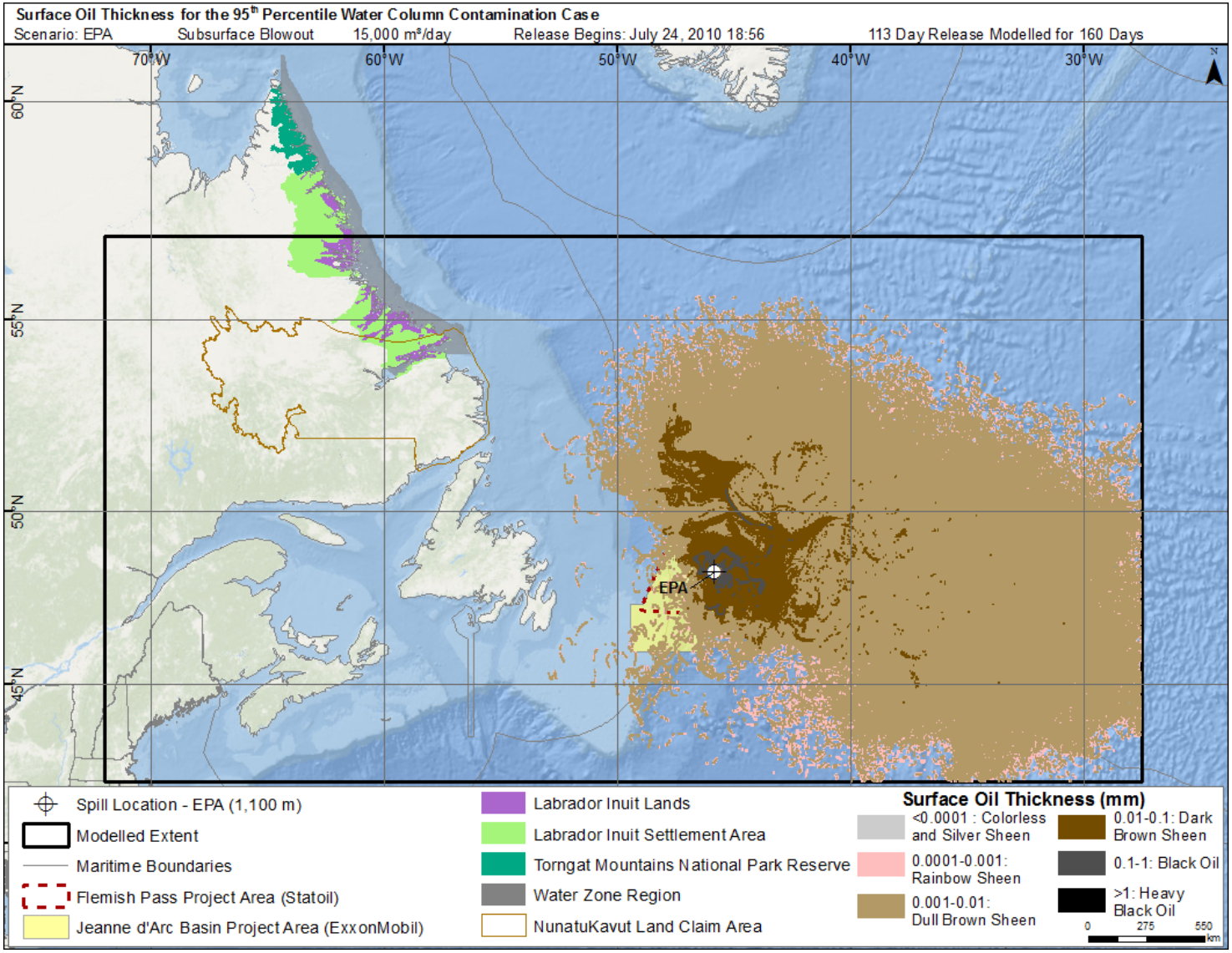


Figure 2-15. Surface oil thickness for the 95th percentile water column contamination case resulting from a subsurface blowout at the EPA site.

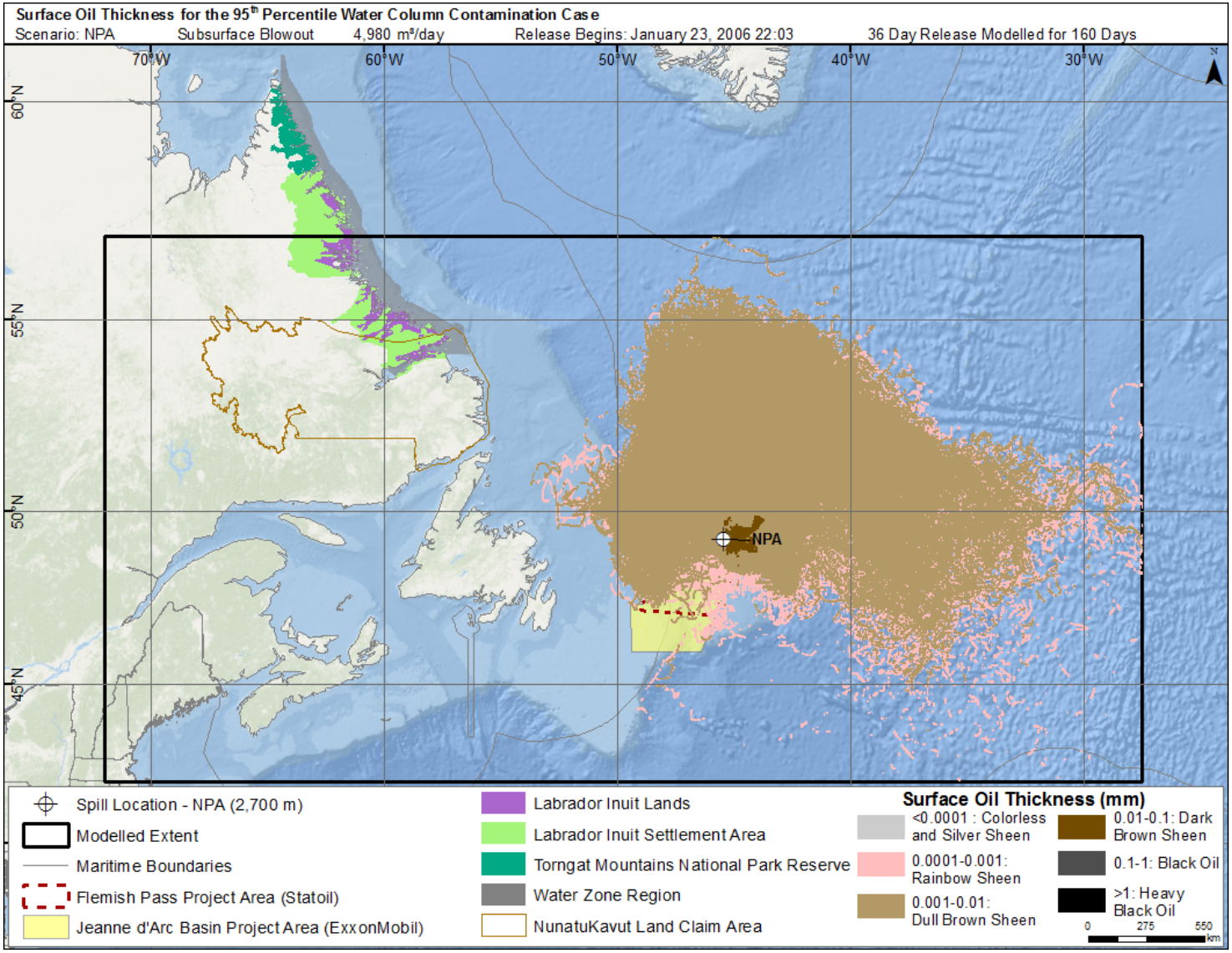


Figure 2-16. Surface oil thickness for the 95th percentile water column contamination case resulting from a subsurface blowout at the NPA site.

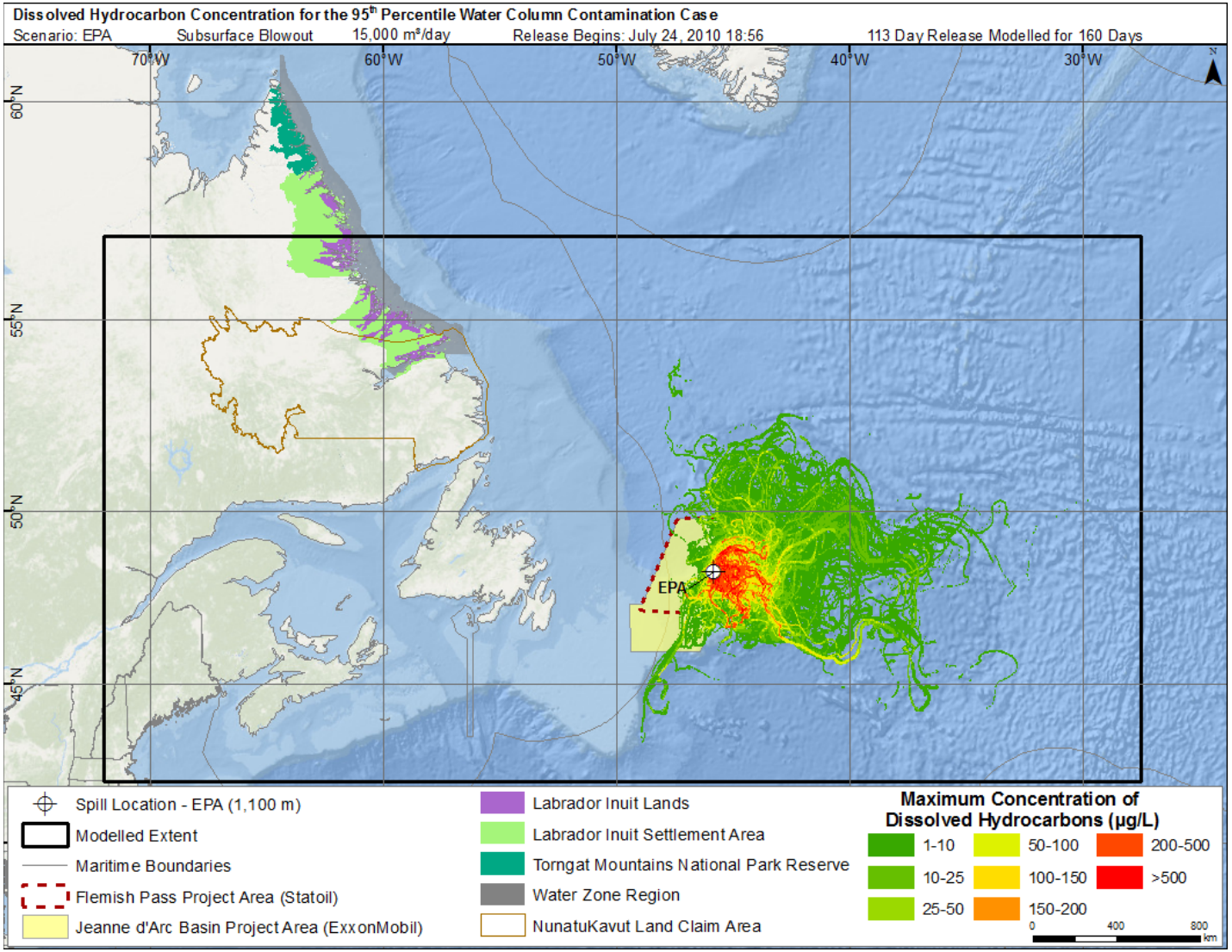


Figure 2-17. Maximum dissolved hydrocarbons at any depth in the water column for the 95th percentile water column contamination case from a subsurface blowout at the EPA site.

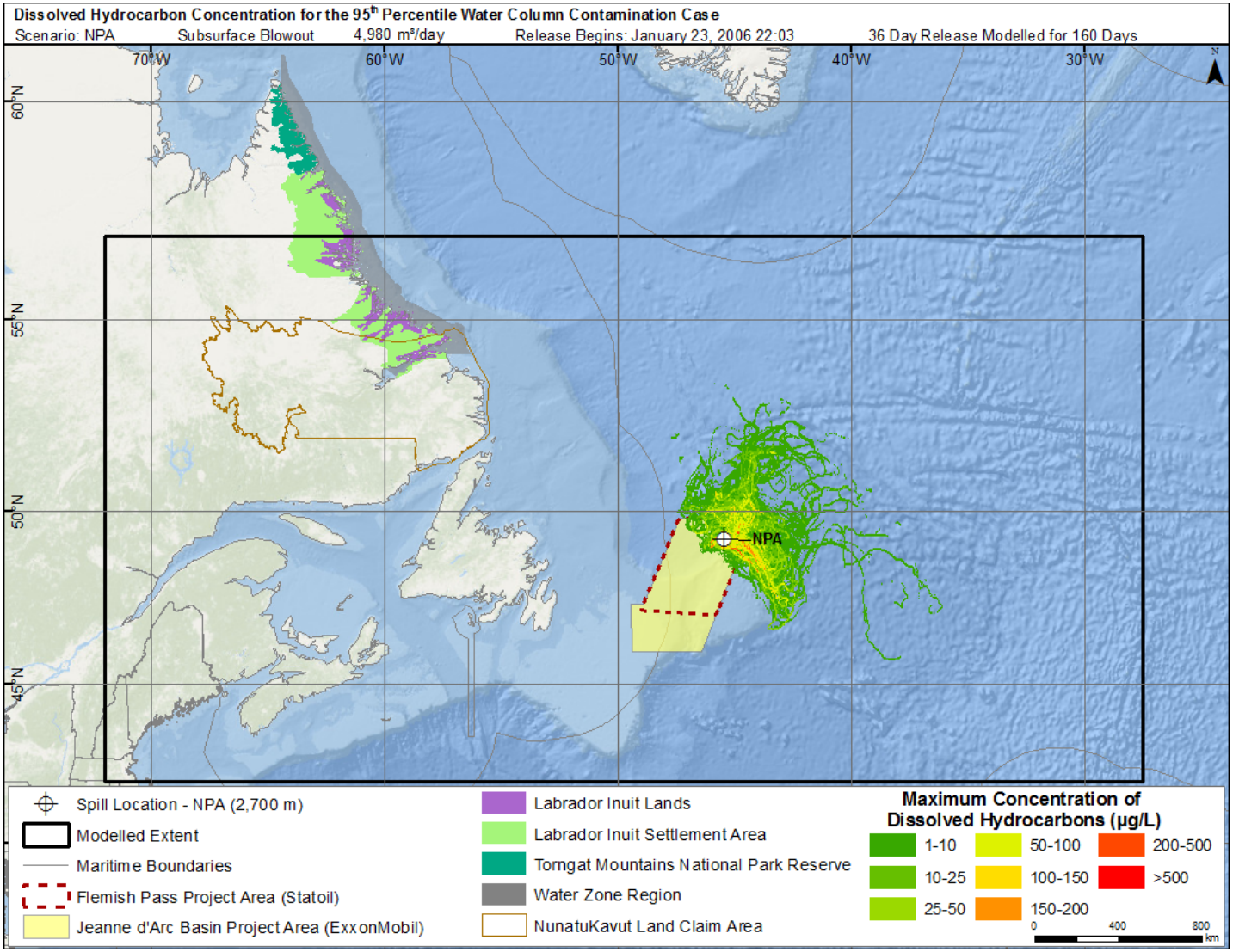


Figure 2-18. Maximum dissolved hydrocarbons at any depth in the water column for the 95th percentile water column contamination case from a subsurface blowout at the NPA site.

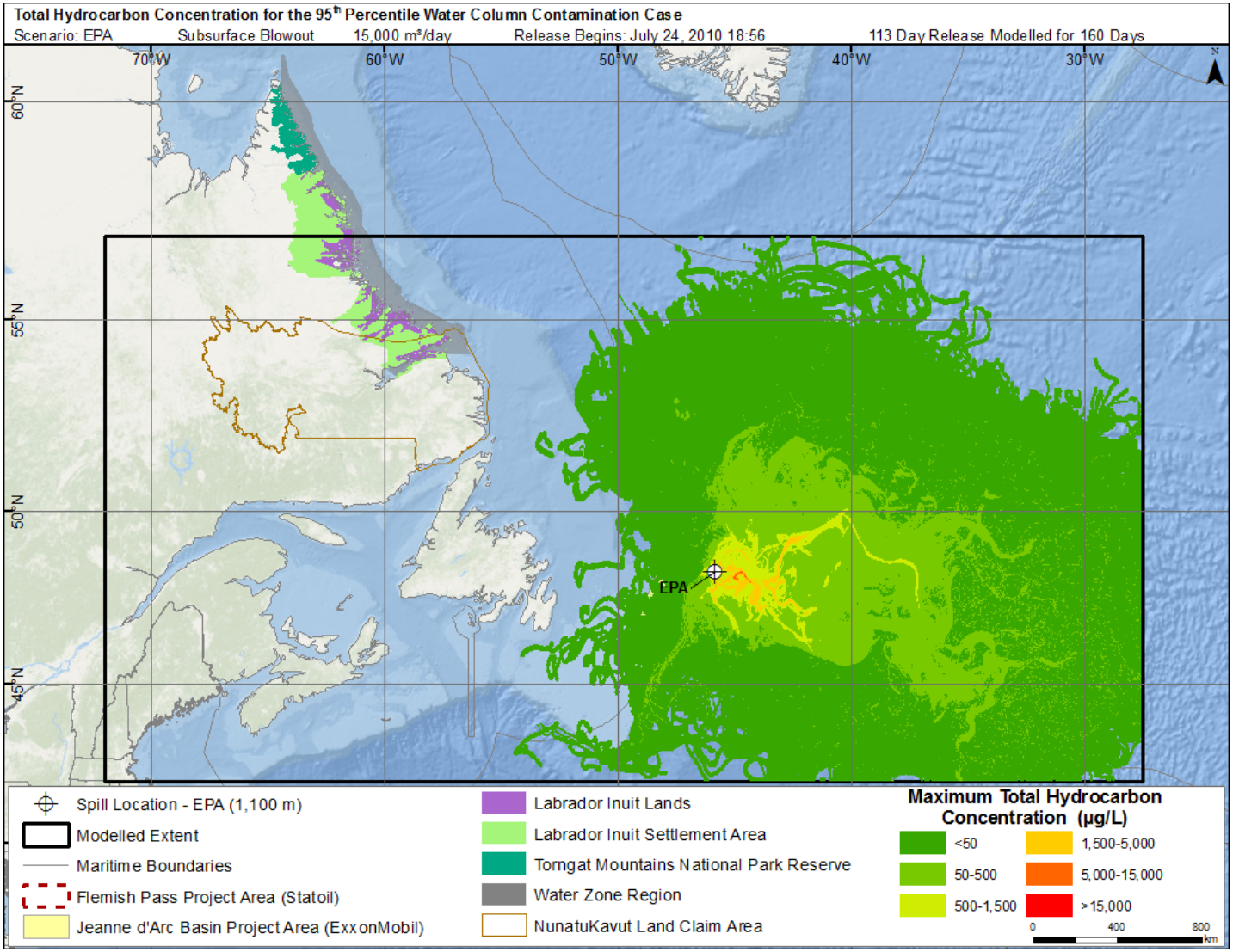


Figure 2-19. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the 95th percentile water column contamination case from a subsurface blowout at the EPA site.

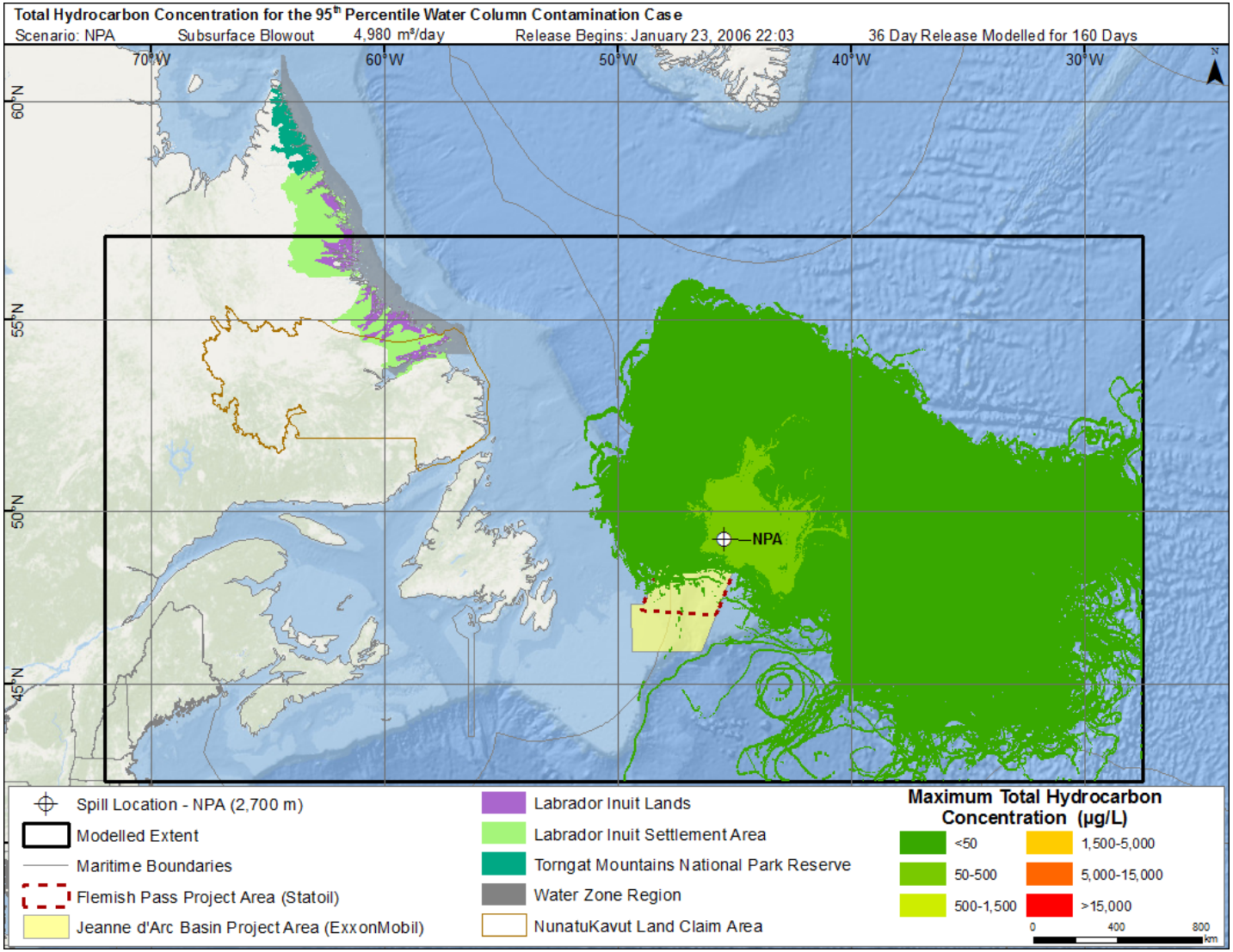


Figure 2-20. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the 95th percentile water column contamination case from a subsurface blowout at the NPA site.

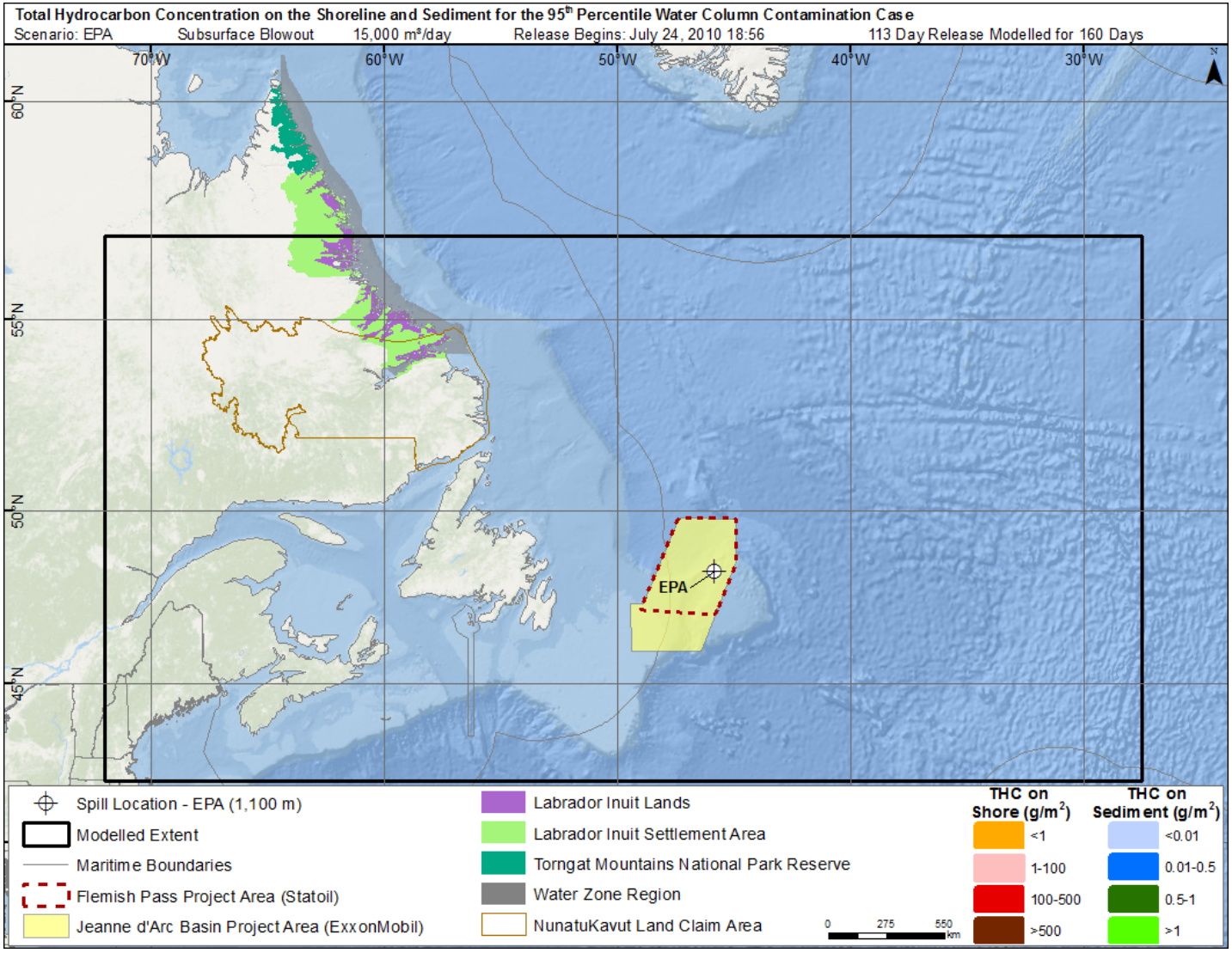


Figure 2-21. Total hydrocarbon concentration (THC) on the shore and sediment for the 95th percentile water column contamination case from a subsurface blowout at the EPA site.

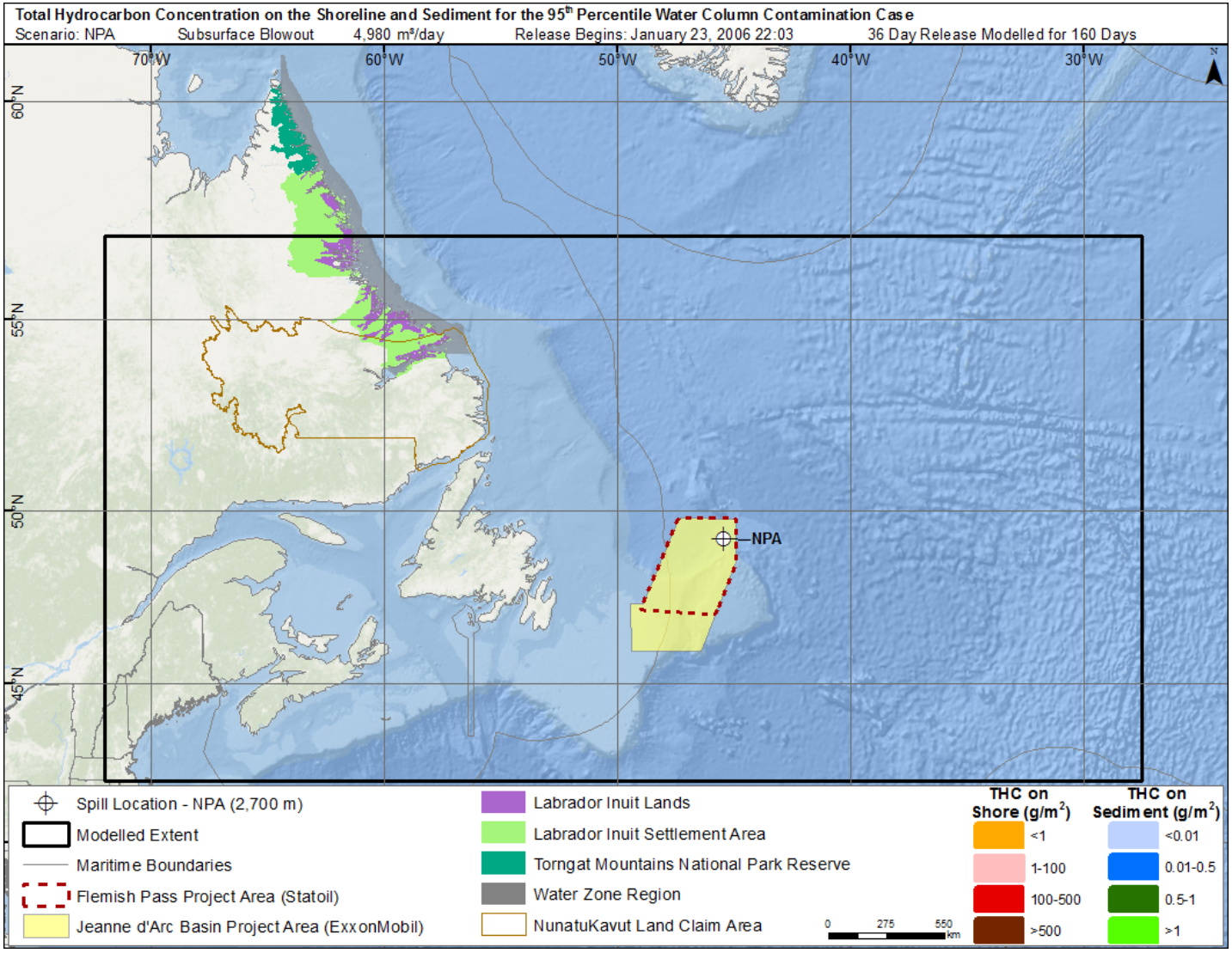


Figure 2-22. Total hydrocarbon concentration (THC) on the shore and sediment for the 95th percentile water column contamination case from a subsurface blowout at the NPA site.

2.3 Shoreline Exposure Case

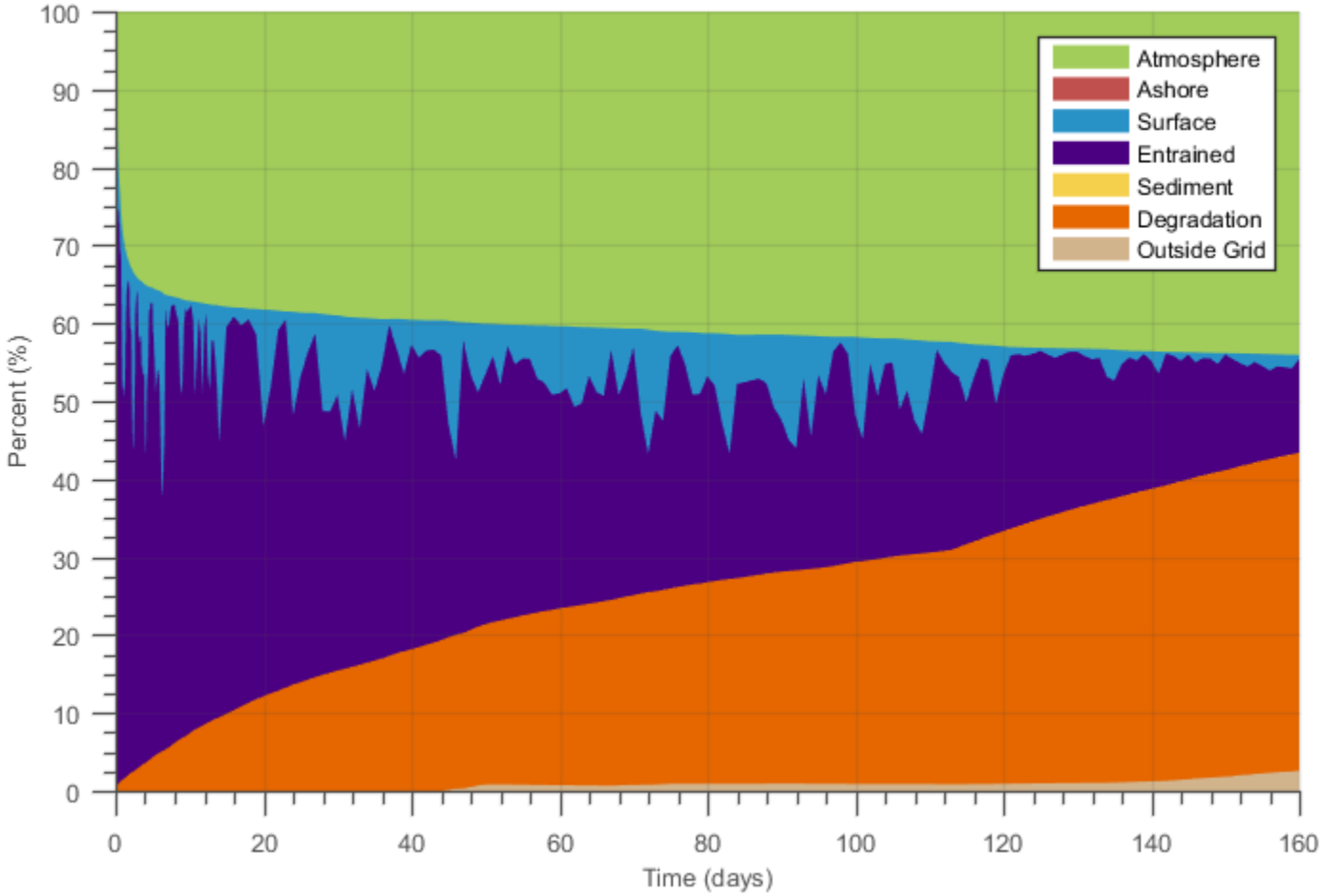


Figure 2-23. Mass balance plot of the 98th percentile contact with shoreline case for EPA.

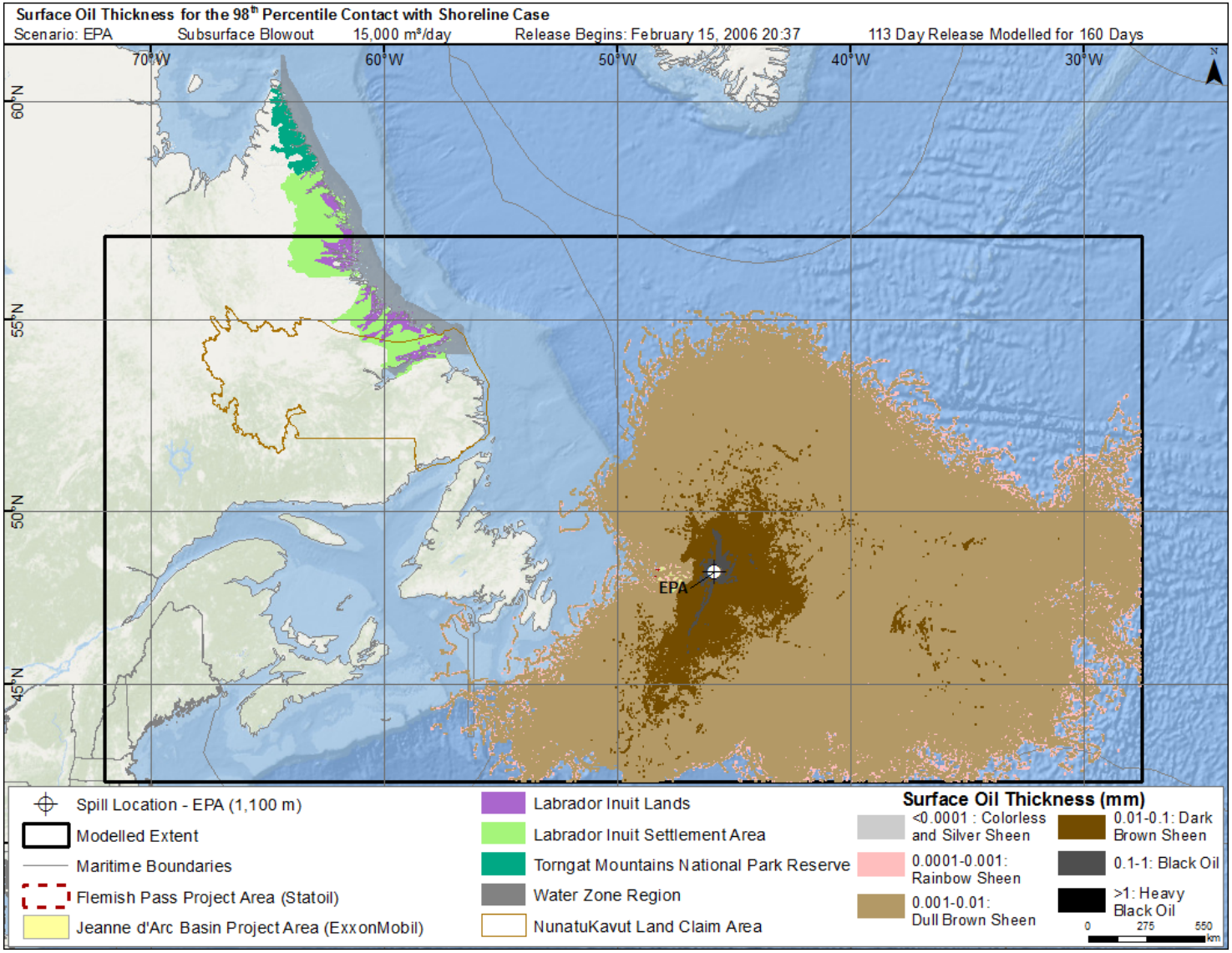


Figure 2-24. Surface oil thickness for the 98th percentile contact with shoreline case for EPA.

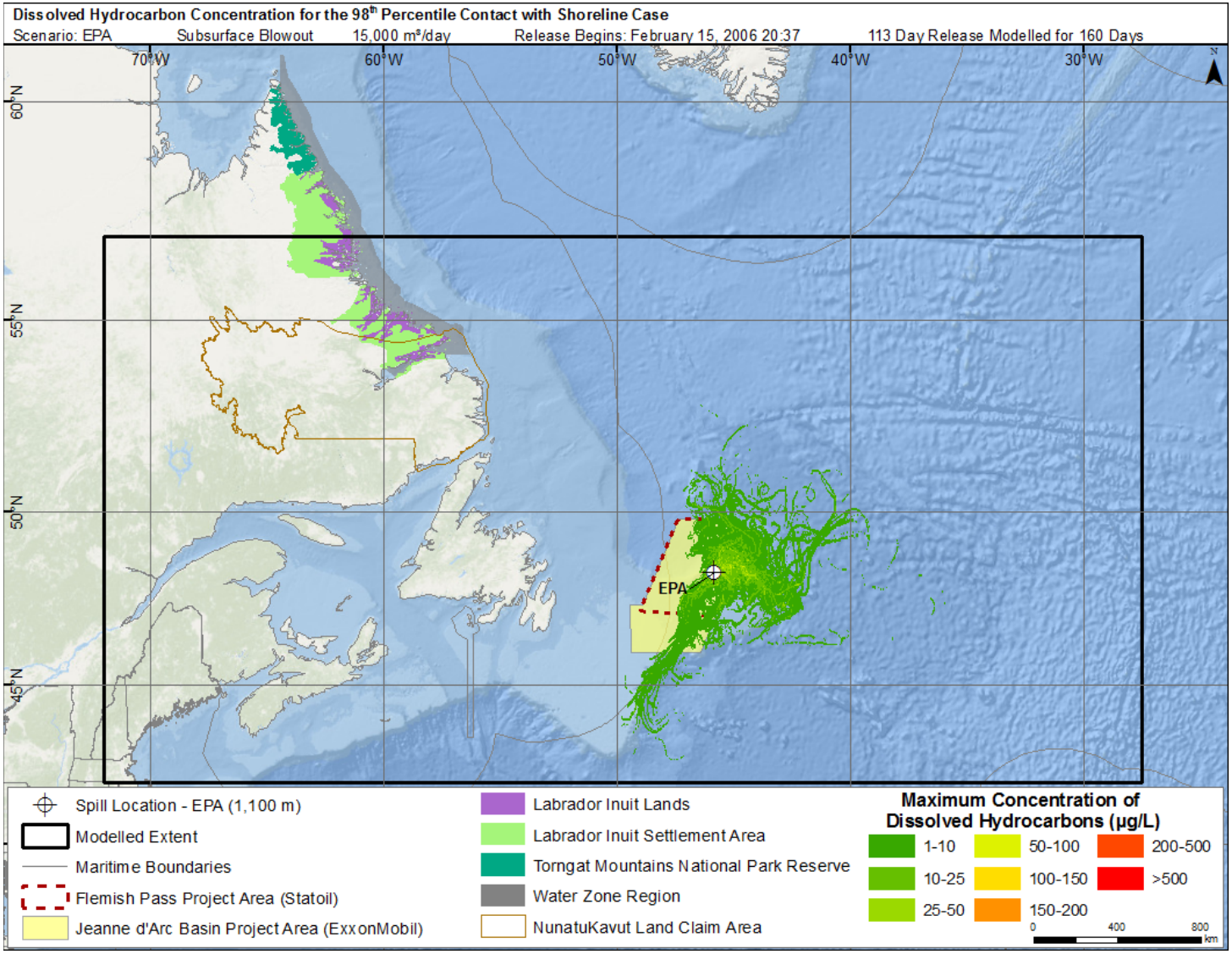


Figure 2-25. Maximum dissolved hydrocarbons at any depth in the water column for the 98th percentile contact with shoreline case for EPA.

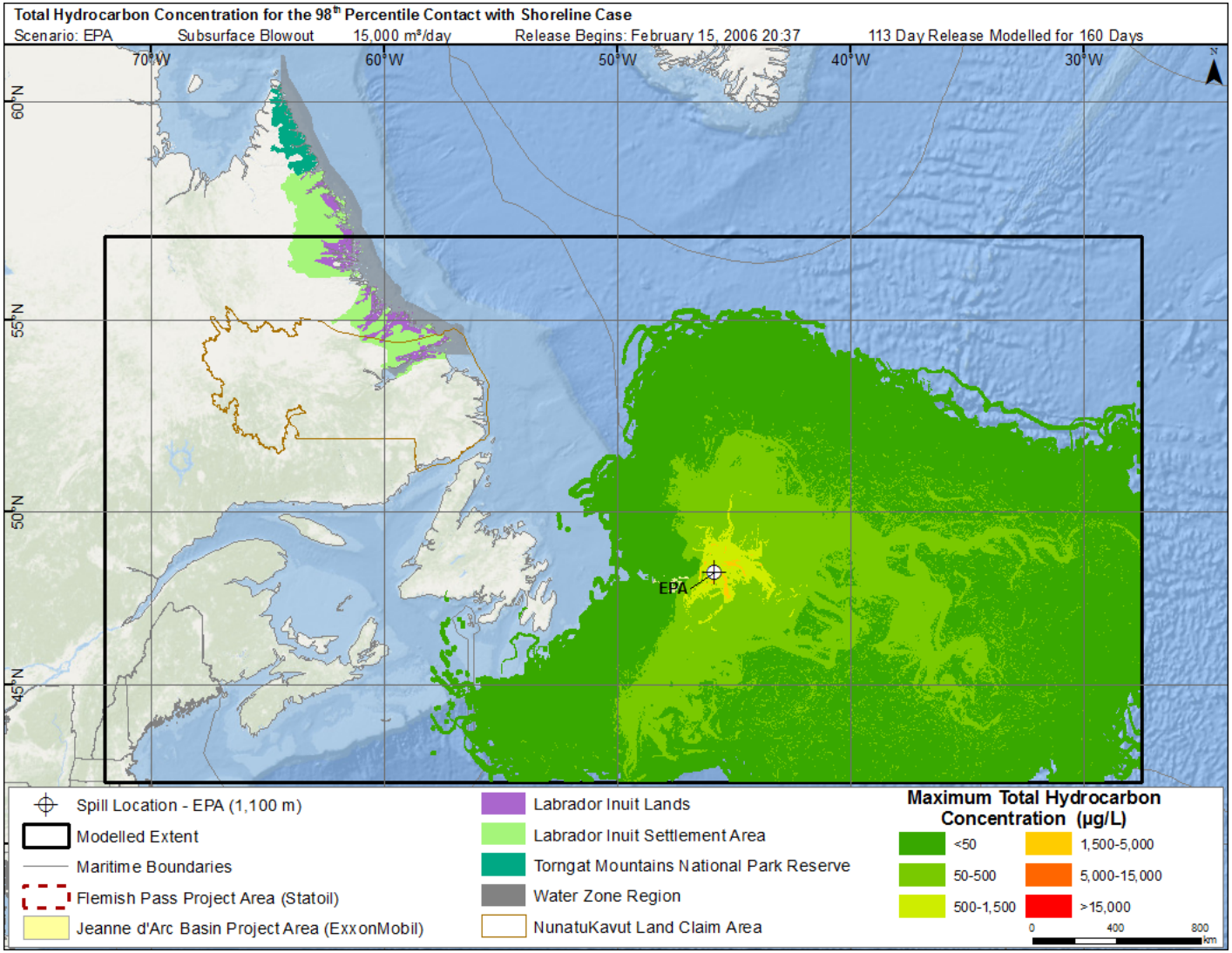


Figure 2-26. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the 98th percentile contact with shoreline case from a subsurface blowout at the EPA site.

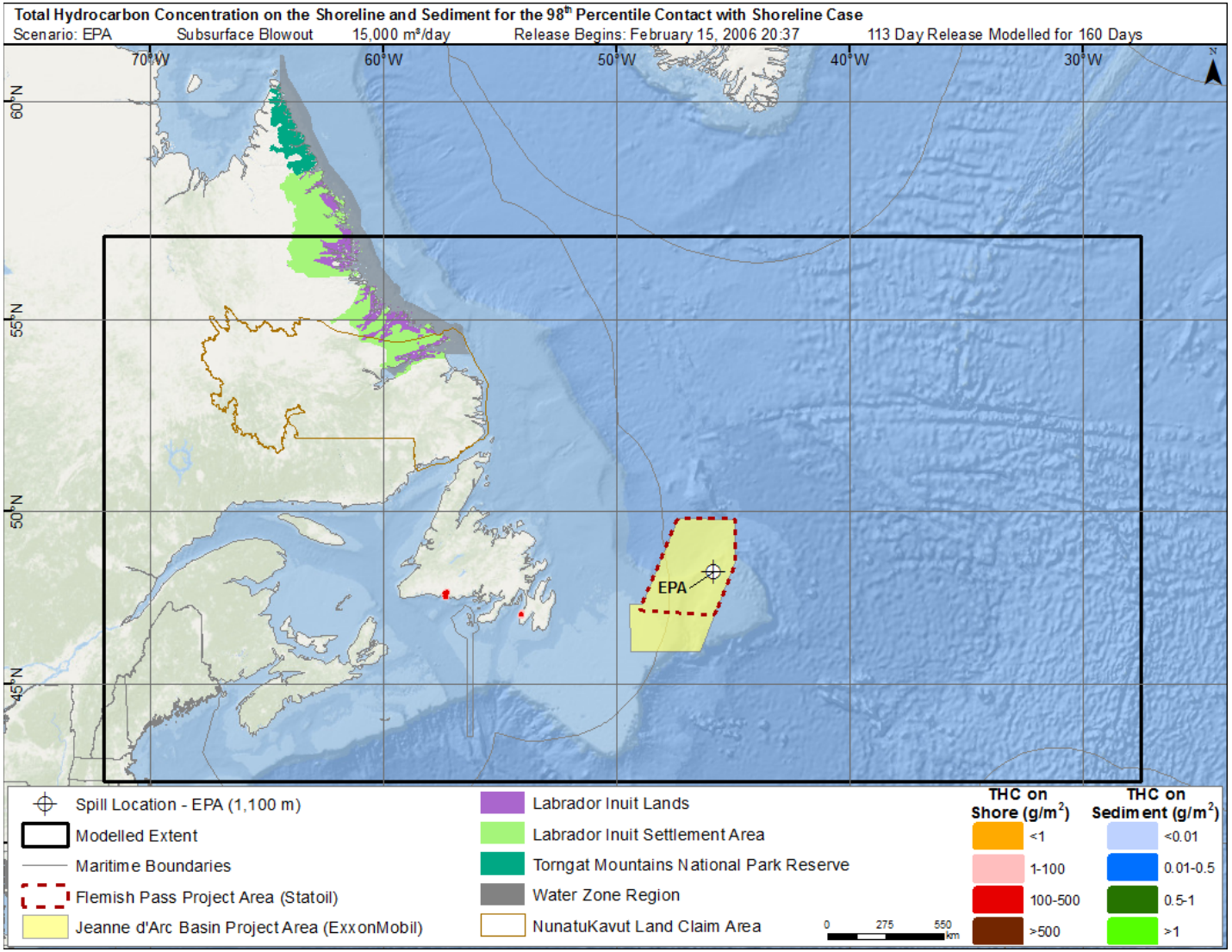


Figure 2-27. Total hydrocarbon concentration (THC) on the shore and sediment for the 98th percentile contact with shoreline case from a subsurface blowout at the EPA site.

2.4 Marine Diesel Batch Spills (100 L and 1,000 L)

2.4.1 EPA Release Site

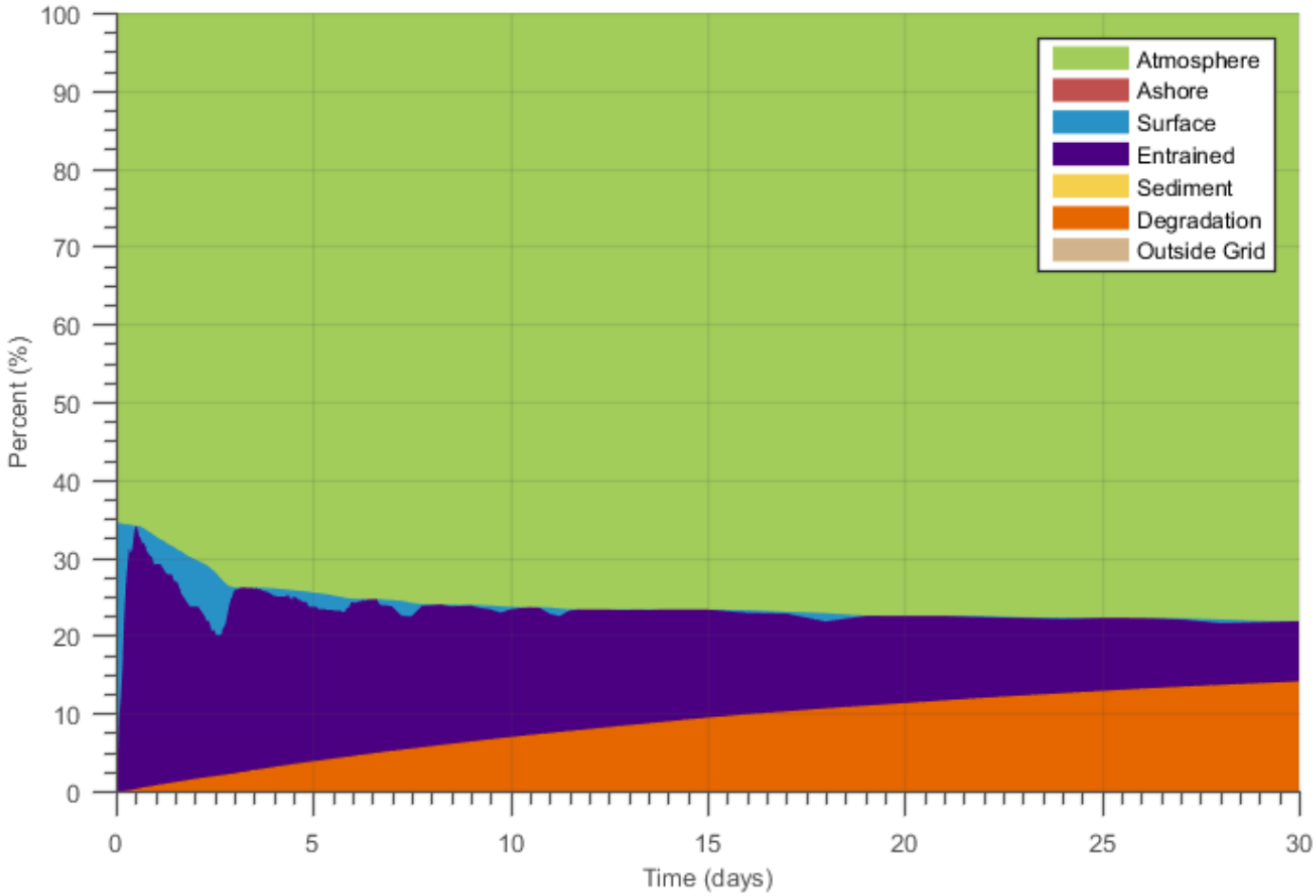


Figure 2-28. Mass balance plots of the EPA release site marine diesel batch spills of 100 L.

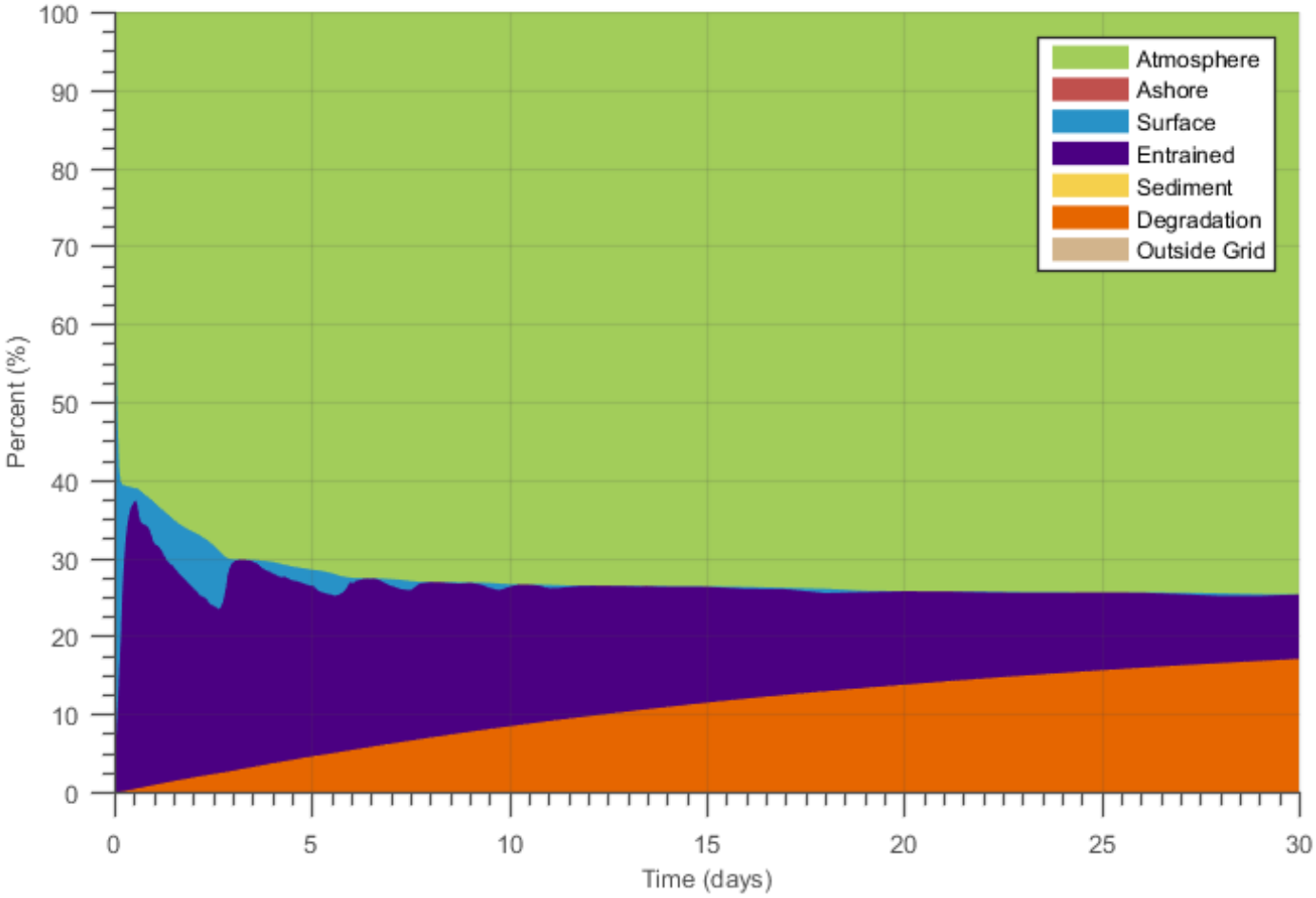


Figure 2-29. Mass balance plots of the EPA release site marine diesel batch spills of 1,000 L.

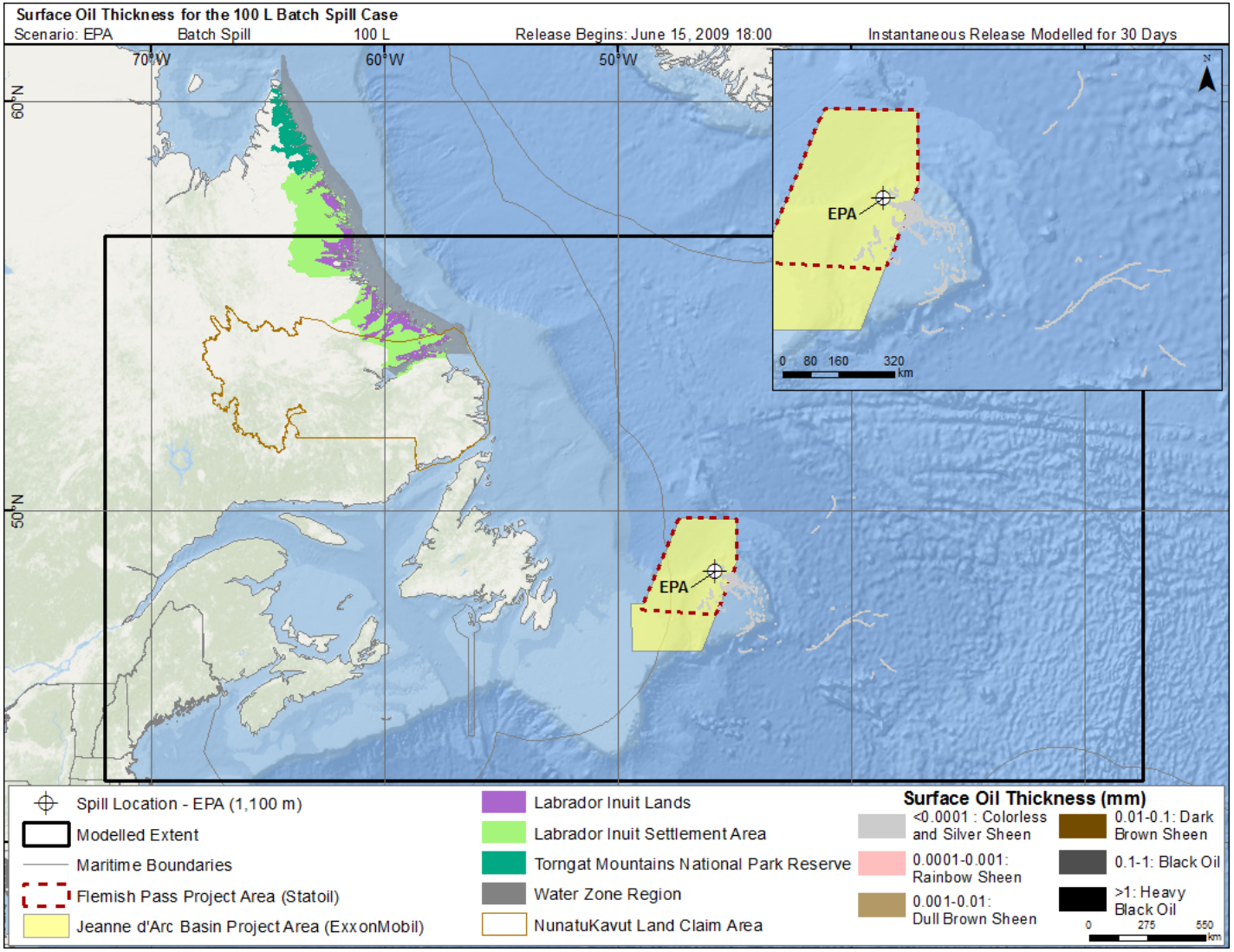


Figure 2-30. Surface oil thickness for the marine diesel batch spills of 100 L at the EPA site. The minimum thickness of surface oil > 0.04 µm is displayed (cumulative over all modelled time steps).

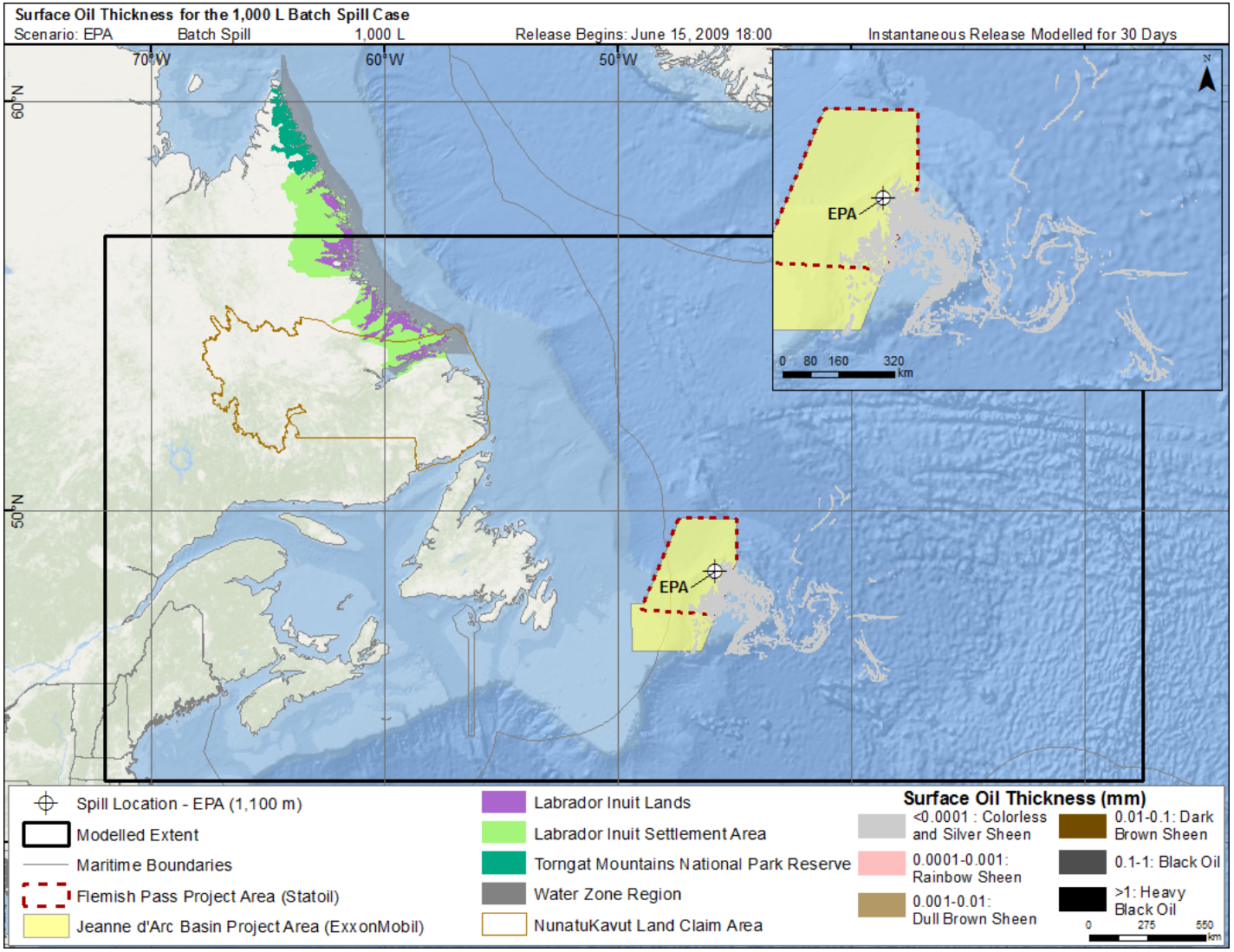


Figure 2-31. Surface oil thickness for the marine diesel batch spills of d 1,000 L at the EPA site. The minimum thickness of surface oil > 0.04 µm is displayed (cumulative over all modelled time steps).

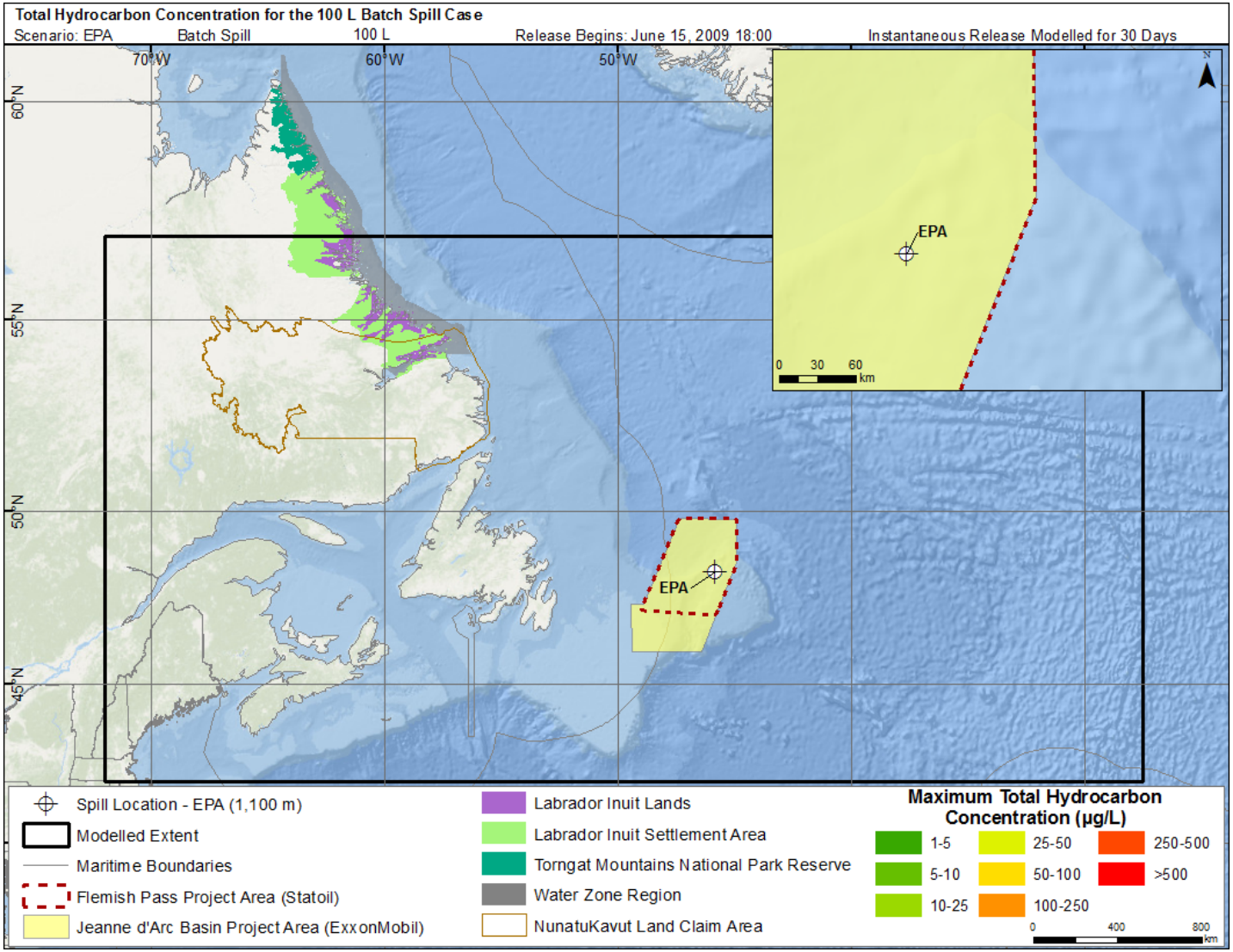


Figure 2-32. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the marine diesel batch spills of 100 L at the EPA site. The minimum threshold of THC > 1 µg/L is displayed (cumulative over all modelled time steps).

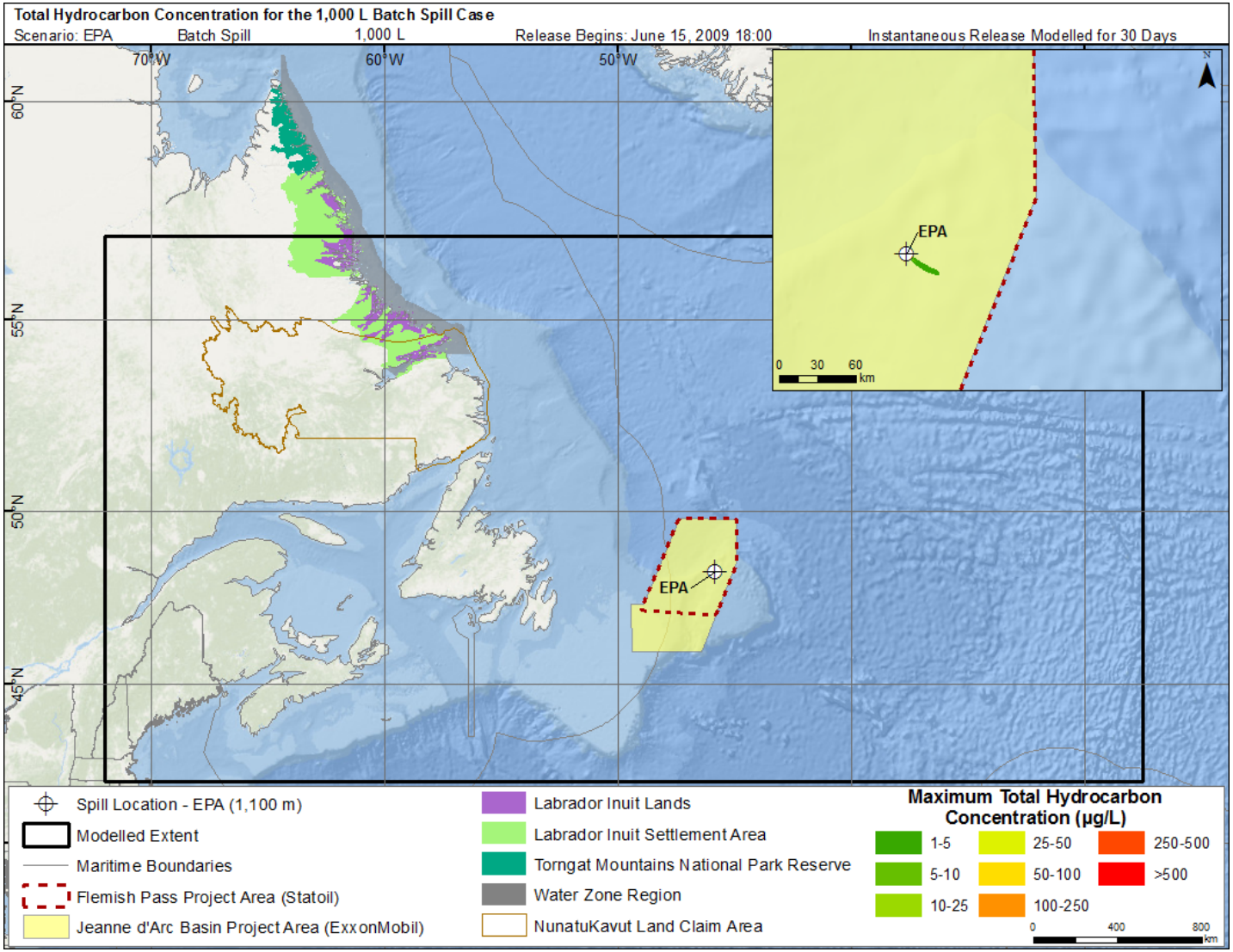


Figure 2-33. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the marine diesel batch spills of 1,000 L at the EPA site. The minimum threshold of THC > 1 µg/L is displayed (cumulative over all modelled time steps).

2.4.2 NPA Release Site

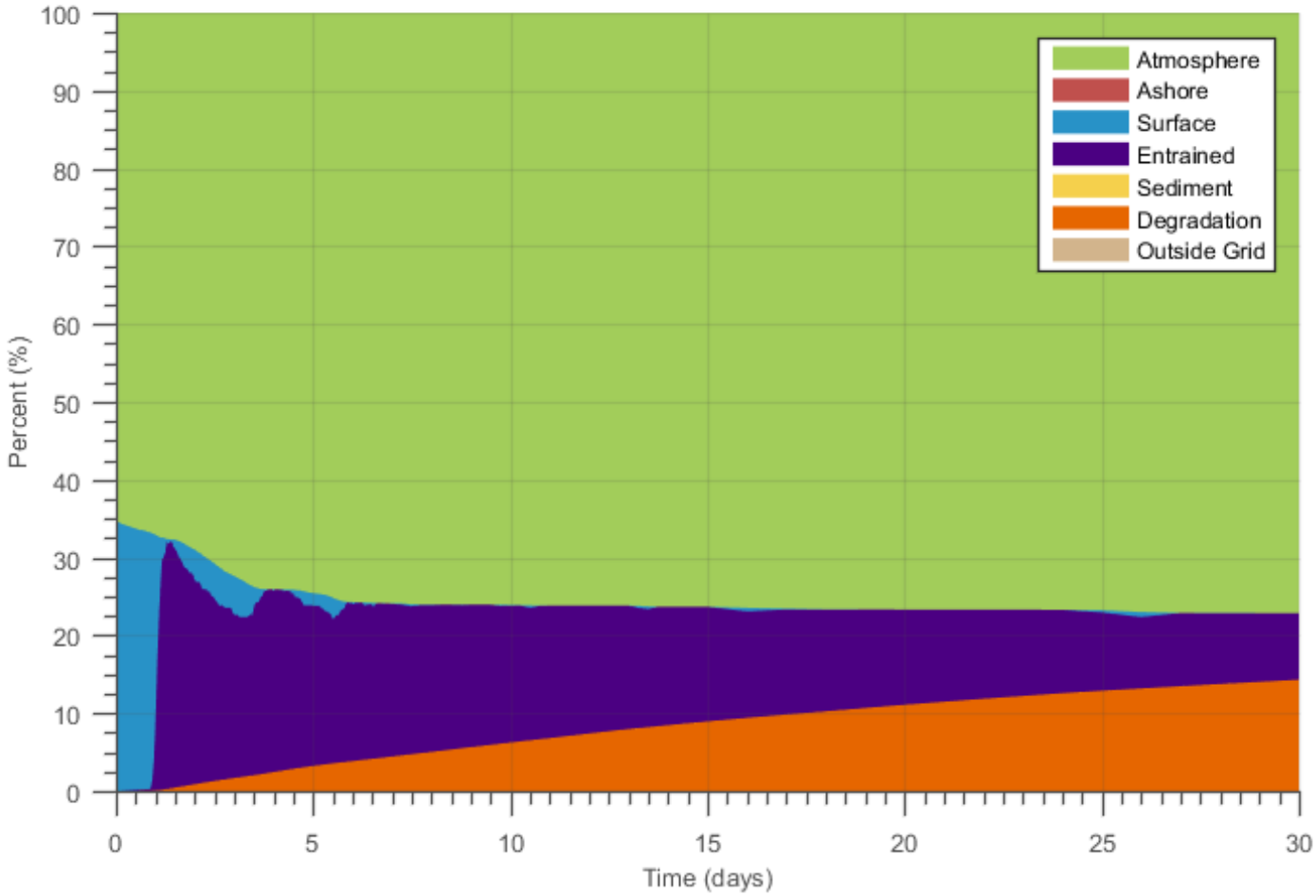


Figure 2-34. Mass balance plots of the NPA release site marine diesel batch spills of 100 L.

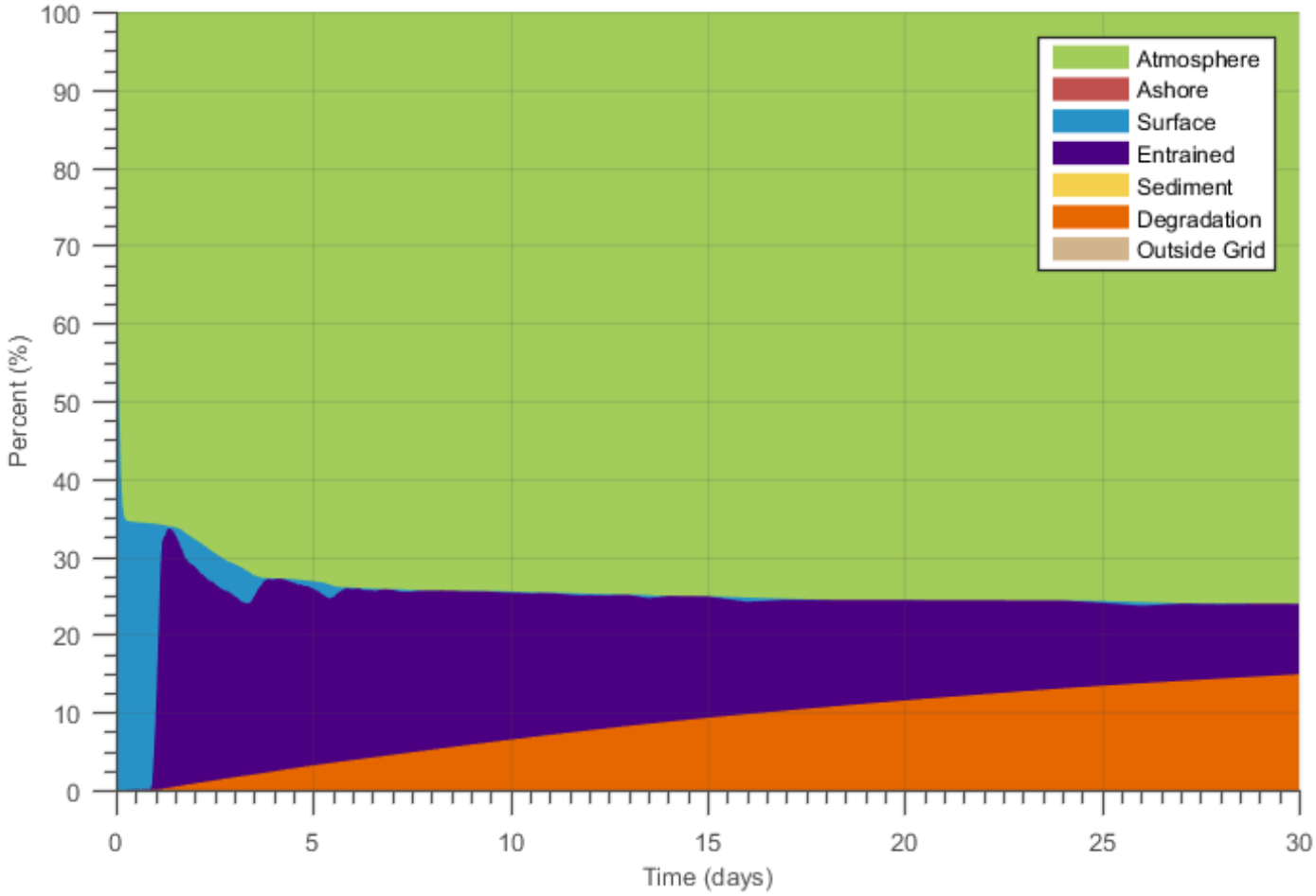


Figure 2-35. Mass balance plots of the NPA release site marine diesel batch spills of 1,000 L.

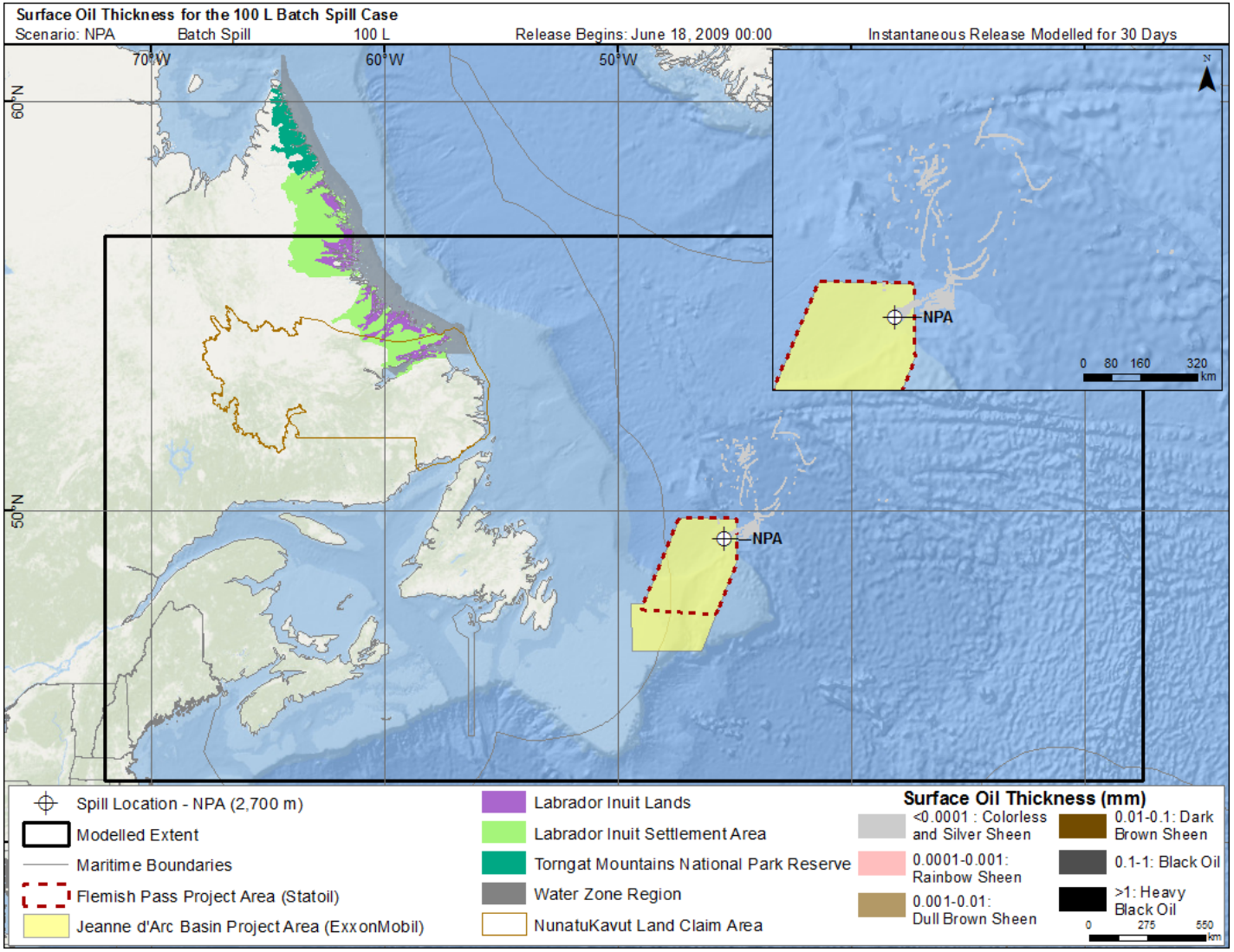


Figure 2-36. Surface oil thickness for the marine diesel batch spills of 100 L at the NPA site. The minimum thickness of surface oil > 0.04 µm is displayed (cumulative over all modelled time steps).

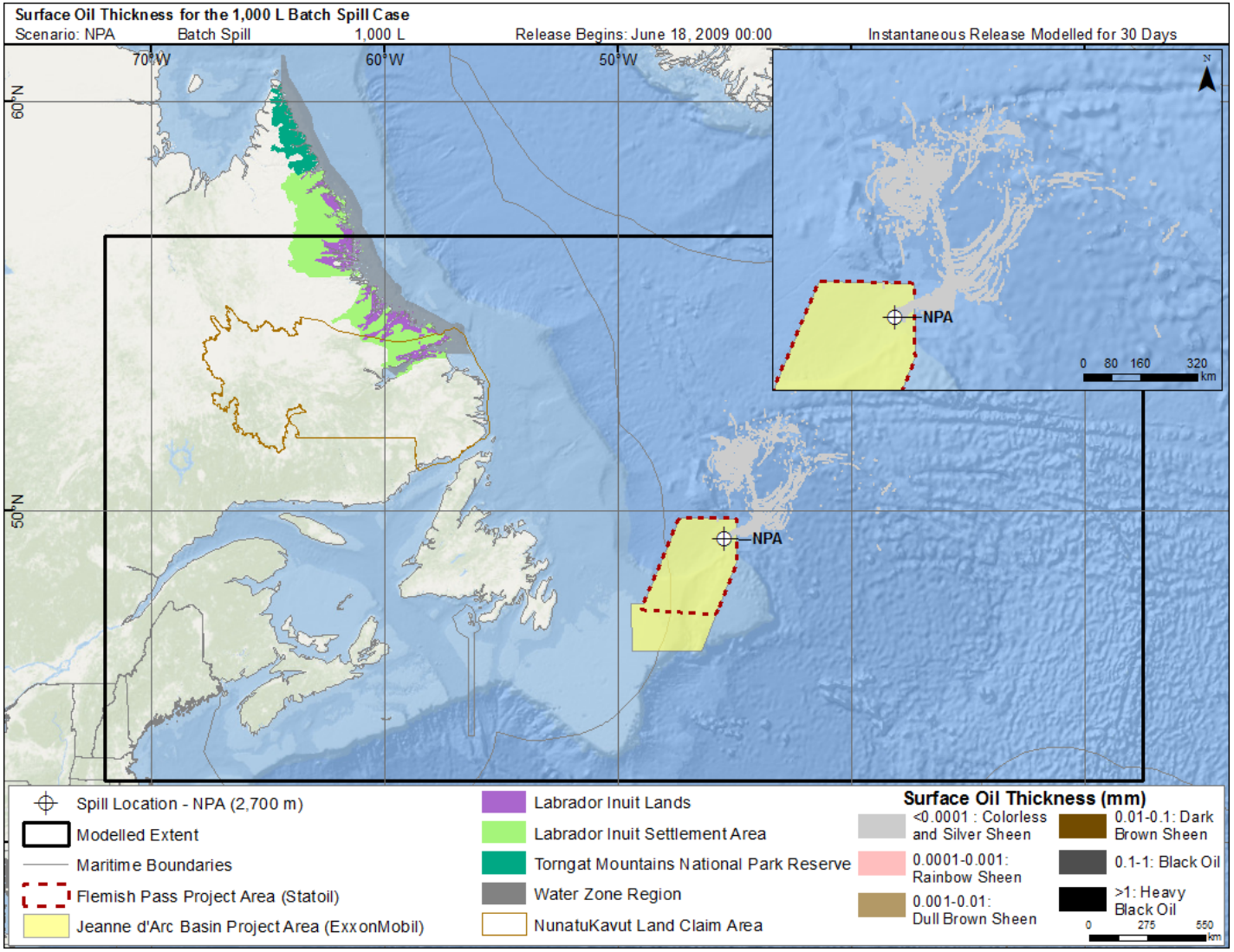


Figure 2-37. Surface oil thickness for the marine diesel batch spills of 1,000 L at the NPA site. The minimum thickness of surface oil > 0.04 µm is displayed (cumulative over all modelled time steps).

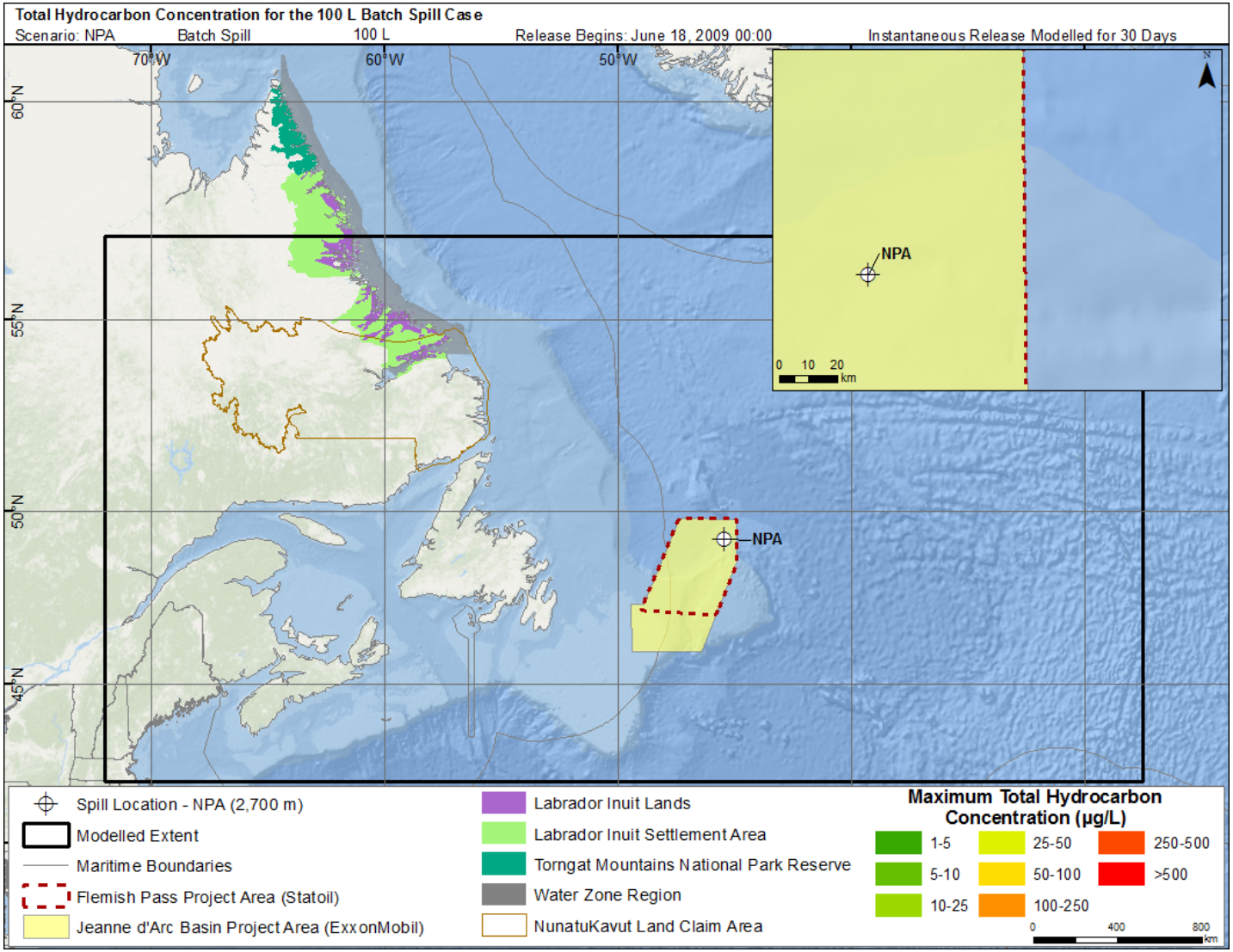


Figure 2-38. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the marine diesel batch spills of 100 L at the NPA site. The minimum threshold of THC > 1 µg/L is displayed (cumulative over all modelled time steps).

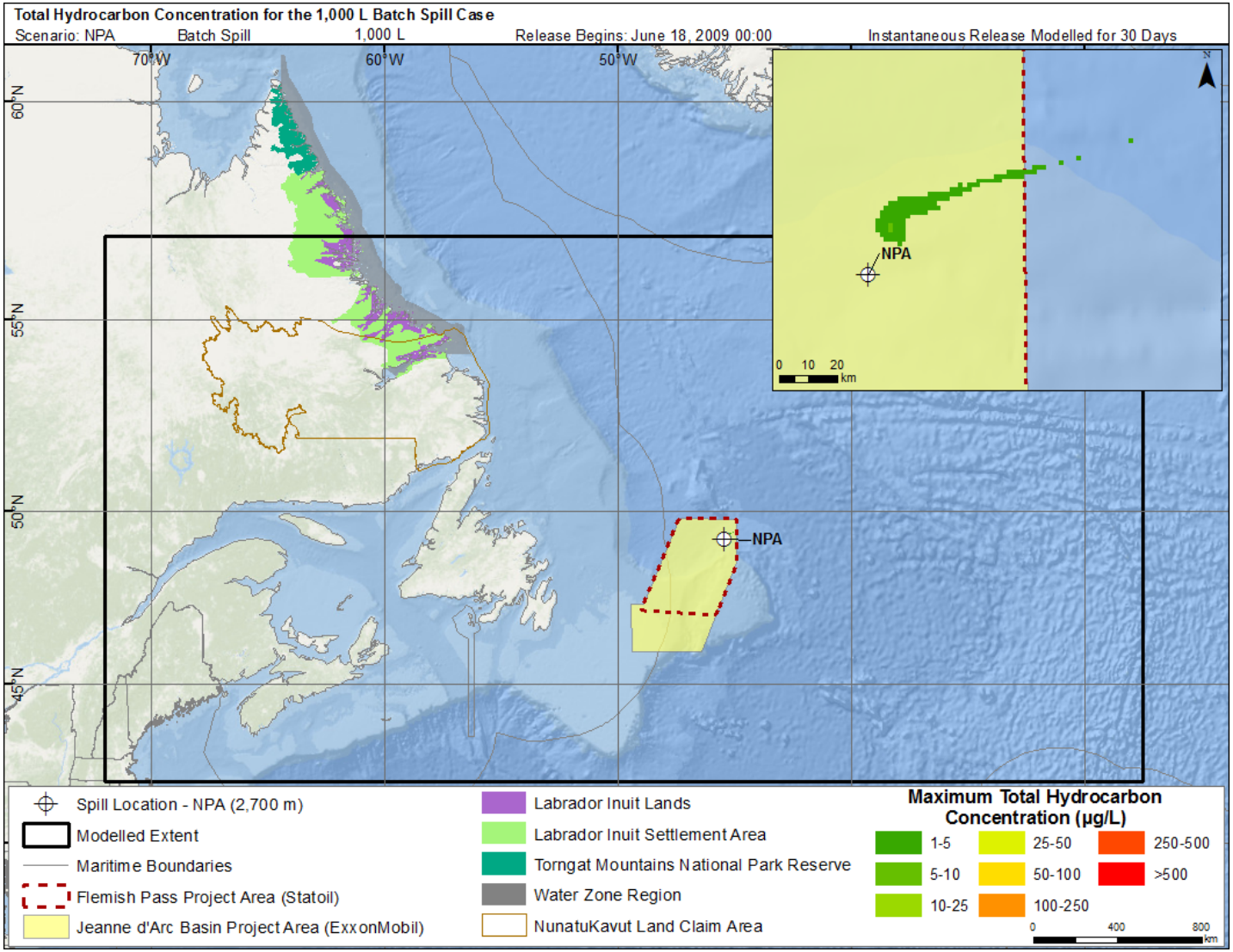


Figure 2-39. Maximum total hydrocarbon concentration (THC) at any depth in the water column for the marine diesel batch spills of 1,000 L at the NPA site. The minimum threshold of THC > 1 µg/L is displayed (cumulative over all modelled time steps).

APPENDIX F

Species Names

Appendix F List of Species Known of Likely to Occur off Eastern Newfoundland

Common Name	Scientific Name
Fish	
Atlantic cod	*Gadus morhua*
American plaice	*Hippoglossoides platessoides*
Atlantic halibut	*Hippoglossus hippoglossus*
Atlantic wolffish	*Anarhichas lupus*
Barndoor skate	*Dipturus laevis*
Black dogfish	*Centoscyllium fabricii*
Blue hake	*Antimora rostrata*
Cusk	*Brosme brosme*
Greenland halibut	*Reinharditus hippoglossoides*
Haddock	*Melanogrammus aeglefinus*
Longnose eel	*Synaphobranchus kaupi*
Longfin hake	*Physis chesteri*
Marlin-spike	*Nezumia bairdi*
Monkfish	*Lophius americanus*
Northern wolffish	*Anarhichas denticulatus*
Northern sandlance	*Ammodytes dubius*
Pollock	*Pollachius virens*
Redfish	*Sebastes mentella / Sebastes fasciatus / Sebastes norvegicus*
Roughhead grenadier	*Macrourus berglax*
Roundnose grenadier	*Coryphaenoides rupestris*
Common grenadier	*Nezumia bairdi*
Armed grenadier	*Coryphaenoides armatus*
Hookear sculpin	*Artediellus* sp.
Sculpin	*Triglops* sp.
Smooth skate	*Malacoraja senta*
Spotted wolffish	*Anarhichas minor*
Spiny dogfish	*Squalus acanthias*
Thorny skate	*Amblyraja radiata*
Eelpout	*Lycodes* sp.
Vahl's eelpout	*Lycodes vahlii*
White hake	*Urophycis tenuis*
Winter skate	*Leucoraja ocellata*
Witch flounder	*Glyptocephalus cynoglossus*
Yellowtail flounder	*Limanda ferruginea*

Common Name	Scientific Name
Barracudina	Paralepididae
Albacore tuna	*Thunnus alalunga*
Atlantic bluefin tuna	*Thunnus thynnus*
American eel	*Anguilla rostrata*
Atlantic herring	*Clupea harengus*
Atlantic mackerel	*Scomber scombrus*
Atlantic salmon	*Salmo salar*
Basking shark	*Cetorhinus maximus*
Bigeye tuna	*Thunnus obesus*
Blue shark	*Prionace glauca*
Capelin	*Mallotus villosus*
Dragonfish	*Stomias boa ferox*
Greenland shark	*Somniosus microcephalus*
Lanternfish	Myctophidae
Porbeagle shark	*Lamna nasus*
Shortfin mako shark	*Isurus oxyrinchus*
Swordfish	*Xiphias gladius*
White shark	*Carcharodon carcharias*
Skates	Rajidae (F)
Deep-sea catshark	*Apristurus* spp.
Viperfish	*Chauliodus sloani*
Large scale tapirfish	*Notacanthus chemnitzii*
Shortspine taprifish	*Polyacanthonotus rissoanus*
Blacksmelts	*Bathylagus* sp.
Ogrefish	Melamphaidae
Threebeard Rockling	*Gaidropsarus ensis*
Shortnose snipe eel	*Serrivomer beanii*
Chimera / Smalleyed rabbitfish	*Hydrolagus affinis*
Butterfish	Stomiatidae
Marine Mammals	
Sei whale	*Balaenoptera borealis*
Fin whale	*Balaenoptera physalus*
Humpback whale	*Megaptera novaengliae*
Blue whale	*Balaenoptera musculus*
North Atlantic right whale	*Eubalaena glacialis*
Sowerby's beaked whale	*Mesoplodon bidens*
Harbour porpoise	*Phocoena phocoena*

Common Name	Scientific Name
Killer whale	*Orcinus orca*
Northern bottlenose whale	*Phocoena phocoena*
Bowhead whale (Eastern Canada-West Greenland population)	*Balaena mysticetus*
Minke whale	*Balaenoptera acutorostrata*
Sperm whale	*Physeter macrocephalus*
False killer whale	*Pseudorca crassidens*
Long-finned pilot whale	*Globicephala melas*
Common bottlenose dolphin	*Tursiops truncatus*
Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Atlantic spotted dolphin	*Stenella frontalis*
Short-beaked common dolphin	*Delphinus delphis*
Striped dolphin	*Stenella coeruleoalba*
Risso's Dolphin	*Grampus griseus*
White-beaked Dolphin	*Lagenorhynchus albirostris*
Spinner Dolphin	*Stenella longirostris longirostris*
Beluga whale (St. Lawrence Estuary population)	*Delphinapterus leucas*
Seals	
Harp seal	*Pagophilus groenlandicus*
Hooded seal	*Cystophora cristata*
Grey seal	*Halichoerus grypus*
Harbour Seal (Atlantic subspecies)	*Phoca vitulina ssp. concolor*
Sea Turtles	
Leatherback sea turtle	*Dermochelys coriacea*
Loggerhead sea turtle	*Caretta caretta*
Green sea turtle	*Chelonia mydas*
Kemp's ridley sea turtle	*Lepidochelys kempii*
Seabirds	
Great Cormorant	*Phalacrocorax carbo*
Double-crested Cormorant	*Phalacrocorax auritus*
Northern Gannet	*Morus bassanus*
Red Phalarope	*Phalaropus fulicarius*
Red-necked Phalarope	*Phalaropus lobatus*
Herring Gull	*Larus argentatus*
Iceland Gull	*Larus glaucoides*
Glaucous Gull	*Larus hyperboreus*
Great Black-backed Gull	*Larus marinus*
Ring-billed Gull	*Larus delawarensis*
Black-headed Gull	*Chroicocephalus ridibundus*

Common Name	Scientific Name
Sabine‘s Gull	*Xema sabini*
Ivory Gull	*Pagophila eburnea*
Black-legged Kittiwake	*Rissa tridactyla*
Common Tern	*Sterna hirundo*
Arctic Tern	*Sterna paradisaea*
Caspian Tern	*Hydroprogne caspia*
Dovekie	*Alle alle*
Razorbill	*Alca torda*
Common Murre	*Uria aalge*
Thick-billed Murre	*Uria lomvia*
Atlantic Puffin	*Fratercula arctica*
Black Guillemot	*Cepphus grylle*
Pomarine Jaeger	*Stercorarius pomarinus*
Parasitic Jaeger	*Stercorarius parasiticus*
Long-tailed Jaeger	*Stercorarius longicaudus*
Great Skua	*Stercorarius skua*
South Polar Skua	*Stercorarius maccormicki*
Northern Fulmar	*Fulmarus glacialis*
Great Shearwater	*Ardenna gravis*
Sooty Shearwater	*Ardenna grisea*
Manx Shearwater	*Puffinus puffinus*
Cory’s Shearwater	*Calonectris borealis*
Leach’s Storm-petrel	*Oceanodroma leucorhoa*
Wilson’s Storm-petrel	*Oceanites oceanicus*
Waterfowl	
Canada Goose	*Branta canadensis*
Wood Duck	*Aix sponsa*
Gadwall	*Anas strepera*
Eurasian Wigeon	*Anas penelope*
American Wigeon	*Anas americana*
American Black Duck	*Anas rubripes*
Mallard	*Anas platyrhynchos*
Blue-winged Teal	*Anas discors*
Northern Shoveler	*Anas clypeata*
Northern Pintail	*Anas acuta*
Green-winged Teal	*Anas crecca*
Ring-necked Duck	*Aythya collaris*
Tufted Duck	*Aythya fuligula*
Greater Scaup	*Aythya marila*

Common Name	Scientific Name
Lesser Scaup	*Aythya affinis*
King Eider	*Somateria spectabilis*
Common Eider	*Somateria mollissima*
Harlequin Duck (Eastern population)	*Histrionicus histrionicus*
Surf Scoter (	*Melanitta perspicillata*
White-winged Scoter	*Melanitta fusca*
Black Scoter	*Melanitta Americana*
Long-tailed Duck	*Clangula hyemalis*
Bufflehead	*Bucephala albeola*
Common Goldeneye	*Bucephala clangula*
Barrow's Goldeneye (Eastern population)	*Bucephala islandica*
Hooded Merganser	*Lophodytes cucullatus*
Common Merganser	*Mergus merganser*
Red-breasted Merganser	*Mergus serrator*
Red-throated Loon	*Gavia stellate*
Common Loon	*Gavia immer*
Pied-billed Grebe	*Podilymbus podiceps*
Red-necked Grebe	*Podiceps grisegena*
Shorebirds	
Black-bellied Plover	*Pluvialis squatarola*
American Golden-Plover	*Pluvialis dominica*
Semipalmated Plover	*Charadrius semipalmatus*
Piping Plover (melodus ssp.)	*Charadrius melodus*
Killdeer	*Charadrius vociferus*
Spotted Sandpiper	*Actitis macularius*
Solitary Sandpiper	*Tringa solitaria*
Greater Yellowlegs	*Tringa melanoleuca*
Willet	*Tringa semipalmata*
Lesser Yellowlegs	*Tringa flavipes*
Whimbrel	*Numenius phaeopus*
Hudsonian Godwit	*Limosa haemastica*
Ruddy Turnstone	*Arenaria interpres*
Red Knot (rufa ssp.)	*Calidris canutus*
Sanderling	*Calidris alba*
Semipalmated Sandpiper	*Calidris pusilla*
Least Sandpiper	*Calidris minutilla*
White-rumped Sandpiper	*Calidris fuscicollis*
Baird's Sandpiper	*Calidris bairdii*
Pectoral Sandpiper	*Calidris melanotos*

Common Name	Scientific Name
Purple Sandpiper	*Calidris maritima*
Dunlin	*Calidris alpina*
Stilt Sandpiper	*Calidris himantopus*
Buff-breasted Sandpiper	*Calidris subruficollis*
Short-billed Dowitcher	*Limnodromus griseus*
Wilson's Snipe	*Gallinago delicate*
American Woodcock	*Scolopax minor*

APPENDIX G

Flemish Pass Exploration Drilling Program, Drill Cuttings Modelling
(Amec Foster Wheeler 2017)

Statoil Canada Ltd. - Flemish Pass
Exploration Drilling Project 2018-2028,
ExxonMobil Canada Limited - Eastern Newfoundland Offshore
Exploration Drilling Project 2018-2030

Drill Cuttings Modelling

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7 November 2017
Amec Foster Wheeler Project #: TF1654118

IMPORTANT NOTICE

This report was prepared exclusively for Statoil Canada Ltd. and ExxonMobil Canada Ltd. by Amec Foster Wheeler Environment & Infrastructure, a Division of Amec Foster Wheeler Americas Limited (Amec Foster Wheeler). The quality of information, conclusions and estimates contained herein is consistent with the level of effort involved in Amec Foster Wheeler's services and based on: i) information available at the time of preparation, ii) data supplied by outside sources and iii) the assumptions, conditions and qualifications set forth in this report. This report is intended to be used by Statoil Canada Ltd. and/or ExxonMobil Canada Ltd. only, subject to the terms and conditions of its contract with Amec Foster Wheeler. Any other use of, or reliance on, this report by any third party is at that party's sole risk.

EXECUTIVE SUMMARY

Amec Foster Wheeler Environment & Infrastructure, a Division of Amec Foster Wheeler Americas Limited (Amec Foster Wheeler), has completed a cuttings dispersion modelling study for Statoil Canada Ltd. (Statoil) and ExxonMobil Canada Ltd. (ExxonMobil). The objective of the study is to model drill cuttings release from exploration well drilling in a Project Area – comprised of Northern and Southern Sections - offshore Newfoundland in support of the associated Statoil and ExxonMobil Environmental Impact Assessment (EIS).

Once a well site location has been identified, drill site clearance has been completed and the drilling unit has been positioned the initial top hole drilling commences, which is a large diameter hole that is drilled without a riser in place. The initial sections are drilled using a water-based mud (WBM), where mud and cuttings are returned to the seabed in accordance with the Offshore Waste Treatment Guidelines (OWTG) (NEB et al 2010). When top section drilling has been completed to the depth where the rock formation strength is sufficient, the structural casing is run and cemented and the wellhead is installed at seabed. Synthetic-based muds (SBM) are used for deeper hole sections. Once the riser has been installed, drilling mud and cuttings are then returned to the drilling installation deck in a closed loop system, where the drilling fluids and cuttings are separated; the cuttings are treated prior to discharge overboard and the drilling fluids are recycled and used again.

Drill cuttings are the small pieces of rock, ranging in size from coarse sand to fine silts and clays, created when a drill bit penetrates rock. The material is forced up the annulus of the well hole as drilling proceeds. The composition of the drill cuttings is dependent on the stratigraphy of the area, the type of drill bit used, the type of drilling mud used and the nature of the cuttings treatment applied on the drilling platform prior to discharge to the ocean. The drill cuttings composition along with water depth and ocean current determine the deposition of the cuttings on the seabed.

A numerical computer model, developed by Amec Foster Wheeler, employs a transport computation to simulate the advection of dispersed drill cuttings materials in three dimensions through the water column, following release into the sea, until the particles come to rest on the sea bottom. Key inputs for the model include cuttings particle characterizations and ocean currents. The primary outputs are predictions of the deposition pattern of released drill cuttings on the seabed (e.g., weight, density, thickness of cuttings).

The modelling was completed for four drilling locations across the Project Area: three locations in the Project Area - Northern Section and one location in the Project Area - Southern Section. The four locations are considered representative of the range of water depths where exploratory wells may be drilled. With the potential to drill multiple wells and at any time during the year, four model simulation runs or ‘scenarios’ (for March, June, September, December) are considered to capture the associated seasonal variation in ocean currents at each location. Each scenario model run provides a prediction of the initial cuttings footprints from drilling of a representative (i.e., similar water depth and current regime) well at one of the four locations for a given time of year.

For each location, the results presented include a summary of the amount of cuttings material that initially settles on the seabed and associated thicknesses by distance from the well site together with plan-view map figures of the cuttings deposition thickness footprints.

Project Area – Northern Section

Drilling of one well was considered at each of the three locations: Northern Project Area (NPA), Eastern Project Area (EPA) and Southern Project Area (SPA). Cuttings from drilling the upper two well sections with WBM are released close to the seafloor. Therefore, there is little time for the cuttings to be transported large distances by the ambient currents. Conversely SBM cuttings, treated and released in accordance with the OWTG, will be released near the sea surface. For the three deep water locations in the Project Area – Northern Section with depths of 2,700 m, 1,100 m and 362 m very little of the SBM cuttings reach the seabed within the model domain; these cuttings will drift for several days and travel for distances on the order of 20 to 200 km.

The hypothetical NPA wellsite was located at 2,700 m water depth on the north slope of the Flemish Cap. Modelled WBM cuttings were discharged at 2 to 4 m above the seabed with all of the drill cuttings settling within 4 km of the wellsite. Across seasons, the cuttings drift and deposit predominately to the northeast. Average WBM cutting thickness across seasonal scenarios range from 4-35 mm within 10 m of the wellsite and 1-8 mm within 100 m of the wellsite. Beyond 100 m from the wellsite, average WBM cuttings thicknesses are less than or equal to 4 mm with a maximum range of 1-2 km in the September scenario though with a mean thickness of 0.4 mm. Maximum WBM cuttings thickness is highest (55-78 mm) across season scenarios less than 500 m from the wellsite. Treated SBM cuttings discharged near the surface at the NPA wellsite settle in low quantities within the 32 km modelled domain. Across seasonal scenarios, 98 percent of SBM cuttings settle outside the 32 km model area. Assuming a mean current speed of 10 cm/s, the material will take on the order of 31 days to settle and likely drift over 200 km. Within the model area, the SBM cuttings that do initially settle are in average thicknesses of less than 0.01 mm with maximum thicknesses of 0.02 mm located between 2 and 4 km away.

The hypothetical EPA wellsite was located on the north slope of the Flemish Cap at 1,100 m water depth. Modelled discharges of WBM and SBM cuttings predominantly drifted to the northeast in the model. Due to relatively low currents in the region, both SBM and WBM cuttings released from the wellsite will mainly settle within the 32 km model area with the exception of SBM cuttings in June where 97.5 percent settle beyond the model area. Average WBM cuttings thicknesses across seasonal scenarios ranged from 10-41 mm within 10 m of the wellsite and 6-12 mm within 100 m of the wellsite. Beyond 100 m from the wellsite, average WBM cuttings thickness is less than or equal to 6 mm with a maximum range of 200-500 m for across season scenarios. Maximum WBM cuttings thickness was highest (80-116 mm) across season scenarios at less than 100 m from the wellsite: the largest thickness of 116 mm was observed 60 m to the southeast of the wellsite. Treated SBM cuttings discharged near the surface at the EPA wellsite have relatively low quantities settle within the first 5 km. For three of the four seasonal scenarios, over 97 percent of SBM cuttings do settle between 5 and 32 km of the wellsite. Only the June scenario had over 97 percent of the SBM cuttings which settle outside the 32 km model

area. Within the model area, SBM cuttings settle in average quantities of 0.05 mm or less and with maximum thicknesses of up to 0.4 mm between 5 to 32 km.

The hypothetical SPA wellsite was located at 362 m water depth on the northeast slope of the Grand Bank and adjacent to the Flemish Pass. Across seasons the cuttings drift and deposit predominately to the south-southwest. The majority of the discharged WBM cuttings settle within 1 km of the wellsite and the majority (98.3 percent) of SBM cuttings drift outside the 32 km model domain. Average WBM cuttings thickness across seasonal scenarios ranged from 0.3-4.0 mm and drifted up to 2 km from the wellsite. The maximum thickness of WBM cuttings was mainly between 100 m to 1 km from the wellsite and ranged from 66-80 mm, with the largest thickness of 80 mm observed in the March scenario 320 m to the south-southwest. SBM cutting thicknesses within the model area were low with average thicknesses of less than 0.01 mm. Maximum SBM cuttings thickness in the model area reached 0.06 mm.

Project Area – Southern Section

One site was modelled for drill cuttings discharge within the Southern Project Area (SPA): a hypothetical Jeanne D'Arc Basin (JDB) modelled wellsite, located northwest of the Hibernia Platform on the Grand Bank Shelf at approximately 89 m water depth. As currents are distributed in most directions in most months, discharged WBM and SBM cuttings drift in all directions at this relatively shallow site. Discharged WBM cuttings settle within 2 km of the wellhead, mainly at distances 100 m to about 1.7 km away. The average thicknesses of accumulated WBM drill cuttings are 8 mm or less across all seasonal scenarios. Some areas of higher maximum cuttings thickness occur within 500 m of the wellsite reaching up to 102 mm (December at 210 m to the northwest). SBM cuttings initially settle within the 32 km model area with the majority (5-59 percent of SBM material settled) of accumulation from 2-31 km away from the wellsite. The overall average thickness of settled SBM material is 0.4 mm or less across all seasonal scenarios and distances from the wellsite. Maximum SBM cuttings thicknesses reach 0.7 mm at 7.7 km from the wellsite.

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APPENDIX A-1: OCEAN CURRENTS FOR MODELLING LOCATIONS

1.0 INTRODUCTION

Amec Foster Wheeler Environment & Infrastructure, a Division of Amec Foster Wheeler Americas Limited (Amec Foster Wheeler), has been contracted by Statoil Canada Ltd. (Statoil) and ExxonMobil Canada Ltd. (ExxonMobil) to complete cuttings dispersion modelling for representative drilling locations offshore Eastern Newfoundland.

1.1 Background

Statoil, in association with its partners BP Canada Energy Group ULC, BG International Limited, Chevron Canada Limited and ExxonMobil Canada Ltd., is proposing to undertake an exploration/appraisal/delineation (herein referred to as exploratory) drilling program and associated activities on various land holdings in the Canada-Newfoundland and Labrador offshore area in which it is the Operator or a partner.

Similarly, ExxonMobil Canada Ltd. and its co-venturers are planning to conduct a program of exploratory drilling and associated activities on land holdings in the Canada-Newfoundland and Labrador offshore area for which ExxonMobil is currently the Operator or is a co-venturer.

The proposed Projects include the drilling, testing, and eventual decommissioning of exploratory wells using one or more mobile offshore drilling units (MODUs), which may include semi-submersible drilling units and/or drill ships. The Project Area is shown in Figure 1-1. Over the course of the anticipated duration of the Projects, it is estimated that up to 30/35 wells respectively, could be drilled, with specific well site locations being selected as planning and design activities progress.

Once a well site location has been identified, drill site clearance has been completed and the drilling unit has been positioned the initial top hole drilling commences, which is a large diameter hole that is drilled without a riser in place. The initial sections are drilled using a water-based mud (WBM), where mud and cuttings are returned to the seabed in accordance with the *Offshore Waste Treatment Guidelines (OWTG)* (NEB et al 2010). When top section drilling has been completed to the depth where the rock formation strength is sufficient, the structural casing is run and cemented and the wellhead is installed at seabed. Synthetic-based muds (SBM) are used for deeper hole sections. Once the riser has been installed, drilling mud and cuttings are then returned to the drilling installation deck in a closed loop system, where the drilling fluids and cuttings are separated; the cuttings are treated prior to discharge overboard and the drilling fluids are recycled and used again.

Drill cuttings are the small pieces of rock, ranging in size from coarse sand to fine silts and clays, created when a drill bit penetrates rock. The material is forced up the annulus of the well hole as drilling proceeds. The composition of the drill cuttings is dependent on the stratigraphy of the area, the type of drill bit used, the type of drilling mud used and the nature of the cuttings treatment applied on the drilling platform prior to discharge to the ocean. The drill cuttings composition along with water depth and ocean current determine the deposition of the cuttings on the seabed.

A numerical computer model, developed by Amec Foster Wheeler, employs a transport computation to simulate the advection of dispersed drill cuttings materials in three dimensions through the water column, following release into the sea, until the particles come to rest on the sea bottom. Key inputs for the model include cuttings particle characterizations and ocean currents. The primary outputs are predictions of the deposition pattern of released drill cuttings on the seabed (e.g., weight, density, thickness of cuttings).

1.1 Objectives

The objective of this study is to model drill cuttings release from exploration well drilling in the Project Area with the results intended to support the associated Environmental Impact Assessment (EIS). Four drilling locations are considered at representative drill locations to account for variation in water depth across the Project Area: three locations in the Project Area - Northern Section and one location in the Project Area - Southern Section (Figure 1-1). With the potential to drill multiple wells and at any time during the year, four model simulation runs or ‘scenarios’ (for March, June, September, December) are considered to capture the associated variation in ocean currents at each location. Each scenario model run provides a prediction of the cuttings footprints from drilling of a representative (i.e., similar water depth and current regime) well at one of the four locations for a given time of year. This report presents details of the model methods, inputs and results.

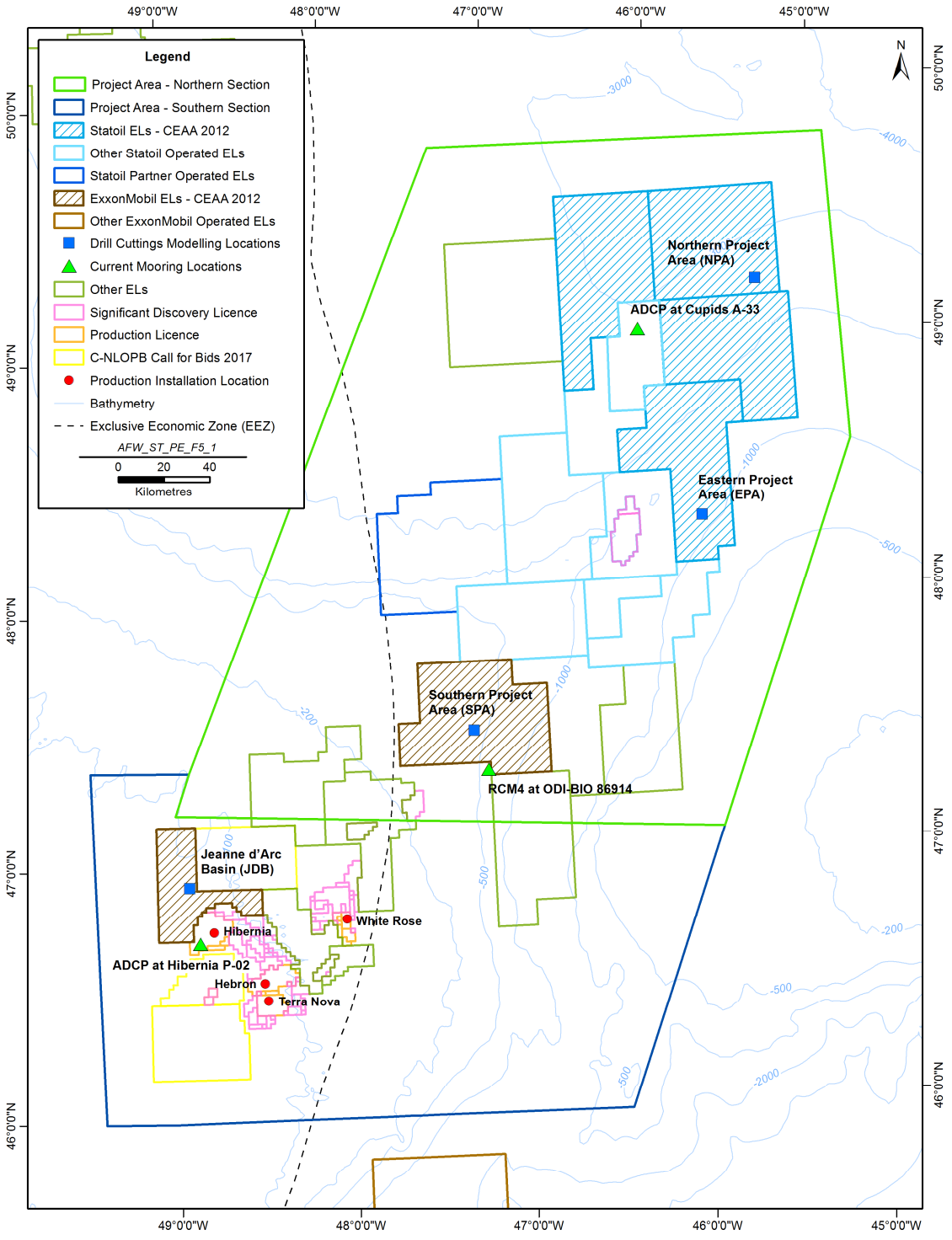


Figure 1-1 Project Area, Drill Cuttings Modelling and Current Mooring Locations

2.0 DRILLING PROGRAMS

This section provides a summary of key elements of the drilling programs considered in modelling of the release of drill cuttings to the sea.

Drilling muds are used to keep the well clean, lubricate the drill bit and control pressure within the well. Water-based muds (WBM) are used for drilling of upper well hole sections; synthetic-based muds (SBM) are used in deeper hole sections, especially during directional drilling operations where drilling conditions are more difficult and hole stability is critical to safety and success.

Drill cuttings are the small pieces of rock, ranging in size from coarse sand to fine silts and clays, created when a drill bit penetrates rock. The material is forced up the annulus of the well hole as drilling proceeds. The composition of the drill cuttings is dependent on the stratigraphy of the area, the type of drill bit used, the type of drilling mud used and the nature of the cuttings treatment applied on the platform or mobile offshore drilling unit (MODU) prior to discharge. These factors along with water depth and current, determine the deposition of the cuttings on the seabed.

The release of drill cuttings from exploration well drilling in the Project Area is modelled for four locations: three in the Project Area - Northern Section and one in the Project Area - Southern Section. These four drill site locations are shown in Figure 1-1 and Table 2-1. Estimated well hole section sizes and drill cuttings volumes (per well) for each of the well locations are presented in Table 2-2 and Table 2-3.

With the potential to drill multiple wells, these locations, and associated estimated cuttings volumes, are considered representative in terms of the water depths and local ocean currents to be encountered. For example, it is reasonable to assume a similar cuttings discharge footprint from another well nearby one of these locations.

Table 2-1 Drill Cuttings Modelling Locations

Location	Latitude (N)	Longitude (W)	Water Depth (m)
Northern Project Area (NPA)	49° 13’ 43.764”	45° 25’ 05.054”	2,700
Eastern Project Area (EPA)	48° 18’ 45.85”	45° 49’ 41.45”	1,100
Southern Project Area (SPA)	47° 30’ 44.539”	47° 14’ 09.916”	362
Jeanne d’Arc Basin (JDB)	46° 55’ 43.801”	48° 54’ 58.995”	89

Table 2-2 Well Hole Sections

	Depth (m)			
Well Hole Section (hole size)	**Northern Project Area**	**Eastern Project Area**	**Southern Project Area**	**Jeanne d'Arc Basin**
Conductor (1067 mm)	75	75	75	79
Surface (660 mm)	700	750	750	379
Intermediate (445 mm)	1,500	1,500	1,700	1,729
Production or Reservoir (311 mm)	2,200	2,300	2,300	2,838
Note: the depths are the bottom of the section below mud line (BML), e.g., for JDB, the production casing runs from 1,729 to 2,838 m below the seabed.				

Table 2-3 Drill Cuttings Volumes (m^3) and Release Locations

Well Hole Section	Release Location	Northern Project Area	Eastern Project Area	Southern Project Area	Jeanne d'Arc Basin
Conductor	Seabed [(a)]	80	80	80	92
Surface	Seabed [(b)]	260	140	125	133
Intermediate	Subsea [(c)]	140	125	80	173
Production	Subsea [(c)]	60	95	25	71
	Total WBM cuttings	340	220	205	225
	Total SBM Cuttings	200	220	105	244
	Total Cuttings	540	440	310	469

Notes: a) WBM cuttings from conductor section are released directly at the seabed: estimate 2 m above seabed allowing for some initial upward momentum as cuttings materials exit the well hole;

b) WBM cuttings from surface section are released ~1-2 m above seabed: similarly estimate 4 m above seabed allowing for some initial upward momentum;

c) SBM cuttings from intermediate and reservoir released from the MODU at an estimated 14 m below the sea surface. Cuttings volumes are per well, e.g., one Northern Project Area (NPA) well yields 540 m^3 of cuttings.

3.0 DRILL CUTTINGS DEPOSITION

The drill cuttings deposition model considers sequences of wells to be drilled and the associated cuttings discharges. The subsequent path of the discharged cuttings (with advection as a result of the ambient ocean current) to their ultimate fate on the seabed is predicted with a three-dimensional sedimentation software model.

3.1 Methods

3.1.1 Advection Dispersion Model Description

The analysis of the drill cuttings discharges was accomplished by using a numerical computer model developed by AMEC[1] to determine cuttings depositions at the time of drilling operations. The AMEC Advection Dispersion Model (ADM) software is written in Visual Fortran and developed based on previous corporate experience and modelling algorithms including those from the Hibernia (Hodgins 1993) and White Rose (Hodgins and Hodgins 2000) cuttings fate modelling studies. The ADM model has also been used as part of the Hebron Project environmental assessment (AMEC 2010) and the White Rose Extension Project environmental assessment (AMEC 2012, Amec Foster Wheeler 2016b)

In the model, a transport computation is employed to simulate the advection of the dispersed drill cuttings materials in three dimensions through the water column, following release into the sea, until the particles come to rest on the sea bottom. For the purposes of predicting their physical deposition on the seabed, the cuttings are considered as a composition of particle types or sizes, typically sand, silt and clay. These particle sizes are assumed to be generally representative of the materials likely to be encountered in the area and generated using WBM or SBM.

At any given time, a cuttings particle is assumed to be subject to independent displacing forces due to the ocean current and to a fall velocity that is constant for a given particle type. A term to model turbulent diffusion is added to the displacements. Over the time step of the available ocean current data, the displacements are calculated and added to yield a new particle position. Vector additions are computed over each successive time step until the simulation terminates with deposition on the sea bottom (which may be some time after well drilling has terminated).

A model grid is selected to encompass the drilling area and possible domain for the deposition of the cuttings. The model tracks the fate and deposition of the particles. In addition to each particle's path, the weight of material is tracked. This is the primary particle attribute. After completion of a model run, when all particles have settled, or have reached the model grid boundaries (in which case, they are taken to have drifted outside the domain and are tabulated as 'lost'), each particle is binned in one of the model grid cells and the total weight, W, is calculated. In addition, the following other parameters are calculated for each grid cell:

[1] AMEC Environment & Infrastructure legally changed its name to Amec Foster Wheeler Environment & Infrastructure in January 2015. Any reference to AMEC herein can be understood to mean Amec Foster Wheeler, and vice versa.

$$C = W \times 1000 / A \quad (1)$$

$$T = C / \gamma \quad (2)$$

$$OC = OC_{initial} \times W / \left(A \times h \times (1-n) \times \gamma_s\right) \quad (3)$$

where

W = cuttings weight (kg)
C = cuttings density (g/m^2)
T = cuttings thickness (mm)
OC = oil concentration on cuttings (mg/kg)
A = area of one grid cell (m^2)
γ = in situ bulk density (1,850 kg/m^3)
$OC_{initial}$ = initial oil concentration
h = sediment mixing depth (0.08 m)
n = seabed porosity (0.4)
γ_s = specific weight of cuttings (2,596 kg/m^3)

The approach for calculating T and OC follows that employed by Hodgins and Hodgins (2000). The oil concentration on cuttings (OC), is the weight of material times its initial concentration, divided by the volume of an assumed thin benthic layer in which the cuttings are assumed to settle and mix with the seabed sediments. Oil concentration is only applicable where SBM are discharged during MODU drilling. All cuttings are assumed to be adequately treated to reclaim oil as required by present regulations. Oil content on cuttings produced during drilling with SBM, $OC_{initial}$ was set to 7.4 g / 100 g, equal to 6.9 g / 100 g oil on wet solids, as per the OWTG (NEB et al. 2010).

3.2 Model Input

3.2.1 Scenarios, Well Sequences, Well Types

Drill cuttings modelling ‘scenarios’ are simply model simulation runs of drill cuttings release for the drilling of one or more wells of a given well design, at an assumed drilling location (e.g., NPA, EPA, SPA or JDB as per Table 2-1) and time of year with assumed release conditions, e.g., volumes of cuttings and particle compositions.

While full details of the drilling schedules have not been finalized, well durations have been estimated. While the EIS assumes a drilling duration of 35-65 days for any well in any location, for modelling purposes, a 65-day duration was chosen for the Northern Project Area and a 35-day duration for the other three locations. The estimated timing for drilling each well hole section is presented in Table 3 1.

The associated drill cuttings are assumed released to the sea within these time periods. For example, the four well hole section discharges for a Jeanne d'Arc Basin well are simulated to take place at days 1, 6, 15, and 26 (of 35) and last 2, 2, 8, and 10 days respectively, a very conservative approach.

Table 3-1 Cuttings Discharge Schedule

Phase	Northern Project Area			Eastern Project Area			Southern Project Area			Jeanne d'Arc Basin		
	Start Day	End Day	Duration (d)	Start Day	End Day	Duration (d)	Start Day	End Day	Duration (d)	Start Day	End Day	Duration (d)
Drill Conductor Hole	1	3	3	1	2	2	1	2	2	1	2	2
Drill Surface Hole	9	14	6	6	7	2	6	7	2	6	7	2
Drill Intermediate Hole	32	41	10	15	22	8	15	22	8	15	22	8
Drill Production Hole	50	65	16	26	35	10	26	35	10	26	35	10

Notes: a) The well duration is the total time from start to end of drilling. Start and duration day values are rounded to the nearest day; b) between drilling of the conductor and surface holes, the conductor casing is run; c) between drilling of the surface and intermediate holes, the surface casing, then BOP and riser are run; d) between drilling of the intermediate and production holes, the intermediate casing is run.

Since drilling of the wells could happen during any month of the year, four seasonal scenarios are considered, for each location, to simulate ocean current conditions most likely to be encountered. Accordingly, well start dates as follows are assumed:

- winter: 15 March
- spring: 15 June
- summer: 15 September
- fall: 15 December

A unique well type, used for cuttings release in the model, is defined for each of the four locations. The well type defines, for each of the four well hole sections of a given well, the volume of cuttings (WBM for conductor and surface sections; SBM for intermediate and production sections, as per Table 2-3), cuttings particle compositions (Section 3.2.2) and release locations.

3.2.2 Cuttings Particle Characterization

The best estimates of cuttings particle size distributions used for the four modelled well locations are based on cuttings sample analysis from historical wells in the Project Area.

Laser diffraction data by Weatherford Laboratories of cuttings samples, from the Statoil Canada Ltd. et al Bay de Verde F-67 well in 2014 are available. This location near Bay du Nord is at a water depth of about 1,200 m and about midway between the NPA and SPA well locations in the Project Area – Northern Section. The four samples consist of two samples at lag depth 2,700 m and two samples at lag depth 3,300 m. These could correspond to the reservoir section (Table 2-2). Given there was no intermediate section at the Bay de Verde well, to provide some further 'resolution', the upper two samples are assumed to characterize the intermediate section. The mean of the lower two samples is assumed for the reservoir section. The intermediate section characterization is also assumed for the upper conductor and surface sections to be drilled with WBM.

For the JDB location in the Project Area – Southern Section, sieve analysis by Core Laboratories of four cuttings samples from the HMDC Hibernia P-02 1A well – located about 3.5 km southeast of the JDB location - in 2014 are available. In a similar manner as that employed above for the Bay de Verde F-67 samples, the mean of the two samples at 2,050 m and 2,400 m are taken as the percent of material composition for the top three sections. The reservoir section characterization assumed is the mean of two samples at depths 2,650 m and 3,090 m.

These cuttings particle size compositions are presented in Table 3-2. These are estimates: the actual compositions of the drill cuttings will depend on rate of penetration, rotary table speed, hydraulics, bit selection, geology of the well, and, for SBM cuttings, how the cuttings are processed through solids control systems onboard the MODU, e.g., shale shakers, cuttings dryers, or centrifuges.

Table 3-2 Cuttings Particle Size Composition

		Measured Weight Percent Material					
Location	**Cuttings Type, Well Section**	**COARSE SAND**	**MEDIUM SAND**	**FINE SAND**	**V. FINE SAND**	**COARSE-MEDIUM SILT**	**FINE SILTS-CLAYS**
Northern, Eastern and Southern Project Area	WBM, conductor and surface	0.1	0.1	0.5	3.9	28.1	67.4
	SBM, intermediate	0.1	0.1	0.5	3.9	28.1	67.4
	SBM, production	1.5	0.9	2.5	5.9	19.0	70.2
Jeanne d'Arc Basin	WBM, conductor and surface	0.0	0.3	1.0	4.9	3.9	90.0

		Measured Weight Percent Material					
Location	**Cuttings Type, Well Section**	**COARSE SAND**	**MEDIUM SAND**	**FINE SAND**	**V. FINE SAND**	**COARSE-MEDIUM SILT**	**FINE SILTS-CLAYS**
	SBM, intermediate	0.0	0.3	1.0	4.9	3.9	90.0
	SBM, production	0.0	0.7	2.8	7.7	5.6	83.1
Notes: a); for the Northern, Eastern and Southern Project Areas, samples from Statoil Bay de Verde F-67 are employed. The WBM and SBM sections are the average of the two 2,700 m samples; the SBM production section is the average of the two 3,330 m samples; b) for Jeanne d'Arc Basin: for WBM and SBM intermediate sections, take the average of the 2,050 m and 2,400 m samples from Hibernia P-02 1A; for the SBM production section, take the average of the 2,650 m and 3,099 m samples from Hibernia P-02 1A.							

It is assumed that the cuttings will enter the sea in a relatively disaggregated form. The model considers the sand materials will remain disaggregated in their fall to the seabed. Any fines are assumed to aggregate into flocs of size of approximately 0.1 mm and settle with a constant speed.

In addition to the percent compositions shown in Table 3-2, the associated particle fall velocities are also essential for the deposition modelling. Table 3-3 lists, for each particle type, its diameter and associated fall velocity, estimated from particle diameter following Sleath (2014).

Particle fall velocities, w, were estimated from the particle diameter using the following relationships, from Sleath (1984):

$$w = 4.2\sqrt{D}, D > 0.0001m \quad (4)$$

$$w = 12x10^{4} D^{2}, D \leq 0.0001m \quad (5)$$

where w is the fall velocity in m/s and D is the diameter in m.

For the six particle types considered, this yields the values reported in Table 3-3.

Table 3-3 Cuttings Particle Size Characterizations

Particle Parameter	Cuttings Material					
	COARSE SAND	**MEDIUM SAND**	**FINE SAND**	**V. FINE SAND**	**COARSE-MEDIUM SILT**	**FINE SILTS-CLAYS**
Particle diameter (mm)	0.595	0.297	0.149	0.074	0.031	0.005
Particle fall velocity (m/s)	0.102	0.072	0.051	0.001	0.001	0.001

Based on equation (5), the settling velocities for the three smallest particles are 0.0007, 0.0001 and $3x10^{-6}$ m/s respectively; however, these are not likely scenarios given the components of WBMs and SBMs are likely to flocculate.

In the sensitivity analysis discussion for particle settling velocities in the 2012 AMEC report (Section 3.4) the work of Tedford et al. (2003) was referenced. The approximations there considered a fast settling (of flocs) of 0.005 m/s assumed for early stages of discharge, followed by a slowing to 0.0001 m/s (for floc breakup when the bottom stress exceeds a threshold), and finally a larger settling of 0.001 m/s (when the bottom stress falls back below that threshold). The 'base case' values of 0.001 m/s for the three smallest particle types as reported in Table 3-3, were deemed the most reasonable and selected for the model runs. These slightly smaller values also provide a somewhat more conservative estimate in terms of how far horizontally the cuttings may disperse.

3.2.3 Ocean Currents

Together with particle settling velocities, horizontal current is the other key factor in determining how far cuttings may potentially be dispersed, so it is important to employ a good characterization of the local current behaviour as a driving force for the model. Since the cuttings will settle through the water column, a characterization of the currents as a function of depth is required.

The temporal coverage of the current data record allows application of the drilling well sequences and provides some statistical reliability of conclusions drawn from analysis of the current data. The regularity of time spacing is essential due to the structure of the advection calculations in the model.

Ocean current measurements from near the NPA, SPA and JDB locations are used as inputs for the drill cuttings model. There are no measurements near enough to the EPA site to likely be applicable. Therefore, for EPA, input currents are derived using the WebDrogue CECOM (Canadian East Coast Ocean Model) and model, and tidal predictions (DFO 2015a, DFO 2015b). The locations of the current measurements are shown in Figure 1-1. An illustration of current speed and direction used as model input as well as the associated current roses for near-surface, mid-depth and near-bottom depths is presented, for all four locations, in Appendix A.

NPA

For the Northern Project Area scenario location (49° 13' 43.764" N, 045° 25' 5.054" W) a physical environmental monitoring current measurement program for Statoil (Amec Foster Wheeler 2016b) provides about two months of data. The Statoil Met-Ocean Monitoring Program in support of drilling at Cupids A-33 located in EL 1123B was at 49° 03' 31.320" N, 046° 08' 23.220" W. Currents were measured from 8th October 2015 22:40:00 to 11th December 2015 15:50:00 at 10 minute intervals using a combination of Acoustic Doppler Current Profilers (ADCP) and single point current meters. Time series representing near-surface and near-bottom currents were generated by averaging ADCP bins in the 0 m to 355 m and 2100 m to 2844 m ranges respectively. The time series recorded at 1431 m was

chosen to represent the mid-depth currents. The monthly statistics for the currents at Cupids A-33 for the three depth layers are presented in Table 3-4.

Table 3-4 Statistics of Measured Current Speed and Direction, Cupids A-33 (NPA), Oct to Dec 2015

Parameter	Near-surface			Mid-depth			Near-bottom		
	Oct	Nov	Dec	Oct	Nov	Dec	Oct	Nov	Dec
Mean current speed (cm/s)	21.7	16.0	14.6	16.5	13.5	11.3	15.8	13.5	10.2
Standard deviation of current speed (cm/s)	7.1	6.6	7.3	4.9	4.8	3.9	4.2	4.2	2.9
Most frequent direction relative to True North (to)	NE	NE	NE	NE	NE	NE	NE	NE	NE

The ocean currents at both the NPA and SPA (see below) sites are characterized by strong mean currents and high variability. The strong observed mean currents are associated with the western boundary currents of the general thermohaline circulation: the offshore branch of the Labrador Current around Flemish Pass, and shelf break/upper slope branch flowing through Flemish Pass. The observed variability is mainly associated with the low frequency processes along the slope as well as the ocean's response to various atmospheric disturbances (atmospheric pressure gradients, wind forcing during storms, local or remote effects of tropical cyclones tracking in the area). In contrast, the highly-predictable tidal current components play a relatively minor role, and explain at the most 20 percent of the current variability at both of these sites.

In order to build a representative time series spanning a full year of uninterrupted coverage, the time series from Cupids A-33 for NPA and from BIO-ODI Site 86914 for SPA were replicated to fill the periods with no data for near-surface, mid-depth and near-bottom depth levels. The monthly mean speeds at the three depth levels were adjusted and scaled accordingly using mean current values close to the three depth levels from the Nalcor Energy Exploration Strategy System (NESS) Cell 314 and Cell 348 (from pp. 105 and 90 of the C-CORE Report on MetOcean Climate Study, Offshore Newfoundland & Labrador Cell # 314 and 348, 2015a and 2015b, respectively). These steps ensure that the full year representative current data include relevant non-tidal signature from the measurements and reflect the annual cycle observed for the mean current speeds in the region. The monthly statistics for these derived currents for NPA and SPA, for the three depth layers, are presented in Table 3-5 and Table 3-8.

Table 3-5 Monthly Statistics for Derived Currents at NPA

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Near-Surface	Min (cm/s)	6	6	3	0	0	0	0	0	1	5	4	0
	Mean (cm/s)	21	16	16	10	9	10	9	12	13	22	16	14
	Max (cm/s)	45	35	44	29	34	34	32	32	42	45	41	39
Mid-Depth	Min (cm/s)	3	0	0	0	0	0	0	6	4	6	2	0
	Mean (cm/s)	13	7	5	7	7	10	10	17	16	16	14	11
	Max (cm/s)	24	22	15	23	17	26	21	33	27	29	30	24
Near-Bottom	Min (cm/s)	1	0	0	0	0	0	0	5	6	6	3	1
	Mean (cm/s)	11	5	3	5	6	6	8	15	16	16	14	10
	Max (cm/s)	19	17	13	17	15	19	18	28	26	27	24	23

EPA

In the absence of any nearby measurements, ocean current inputs for the drill cuttings model are seasonal average currents at near-surface, mid-depth and near-bottom depths through the water column (100 m, 500 m and 1,000 m resp.) derived using the WebDrogue CECOM (Canadian East Coast Ocean Model) model with tidal predictions for a full year taken from the WebTide model. A complete, year-long, hourly, time series of currents for the EPA well location was assembled.

Ocean currents in the area are very low. Monthly near-surface mean current speeds range from 4 cm/s in fall and winter to 8 cm/s in summer, with maximum values ranging from 6 cm/s in March and October to 10 cm/s in summer (Table 3-6). At mid-depth, monthly mean currents range from 2 cm/s in the fall to 5 cm/s in summer. Maximum current speeds at mid-depth reach 8 cm/s in July. Near-bottom mean current speeds are about 2 cm/s in all months, and maximum speeds are 4 to 5 cm/s for all months.

Table 3-6 Monthly Statistics for Modelled Currents at EPA

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Near-Surface	Min (cm/s)	1	1	1	4	4	4	5	5	6	1	1	1
	Mean (cm/s)	4	4	4	7	7	7	8	8	8	4	4	4
	Max (cm/s)	7	7	6	9	9	9	10	10	10	6	7	7
Mid-Depth	Min (cm/s)	1	1	1	1	1	2	2	2	2	0	0	0
	Mean (cm/s)	3	3	3	4	4	4	5	5	5	2	2	2
	Max (cm/s)	6	6	6	7	7	7	8	7	7	5	5	5
Near-Bottom	Min (cm/s)	0	0	0	0	0	0	1	0	1	0	0	0
	Mean (cm/s)	2	2	2	2	2	2	2	2	2	2	2	2
	Max (cm/s)	5	4	4	4	5	5	5	5	4	5	5	5

SPA

Current measurements in the region nearest to the Southern Project Area location (47° 30' 44.539" N, 047° 14' 9.916" W) include data from the Bedford Institute of Oceanography – Ocean Data Inventory (BIO-ODI; Gregory 2004; DFO 2017). The BIO-ODI Site 86914 is located at 47° 21' 15.120" N, 047° 9' 42.480" W at the southern boundary of EL 1135 and northwestern boundary of EL 1134 (Figure 1-1).

This site is close to the SPA location and the measured currents there are similar to the mean current predictions by WebDrogue Drift Prediction Model v0.7 (DFO 2015). Currents from BIO-ODI Site 86914 were measured from 25th July 1986 15:00:00 to 31st October 1986 17:00:00 at 20 minute intervals. The measurements were taken by Aanderaa RCM4 currents meters at depths of 67 m and 334 m. A time series at intermediate depth (~200 m) was generated by taking the average of the currents at 67 m and 334 m. The time series at 67 m, 200 m and 334 m are taken to be representative of the near-surface, mid-depth, and near-bottom currents. The monthly statistics for the currents at BIO-ODI Site 86914 for the three depth layers are presented in Table 3-7.

Table 3-7 Statistics of Measured Current Speed and Direction, BIO-ODI Site 86914, Jul to Oct 1986

Parameter	Near-surface				Mid-depth				Near-bottom			
	Jul	Aug	Sep	Oct	Jul	Aug	Sep	Oct	Jul	Aug	Sep	Oct
Mean current speed (cm/s)	19.9	21.5	32.3	40.5	17.9	16.8	24.2	33.0	16.0	12.1	16.2	25.3
Standard deviation of current speed (cm/s)	8.3	7.0	7.1	7.7	4.7	4.3	4.5	4.7	2.5	4.1	4.4	5.2
Most frequent direction relative to True North (to)	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW

A monthly statistical summary of the resultant year-long current time series is presented in Table 3-8. Monthly near-surface mean current speeds range from about 21 to 24 cm/s during March to August peaking at 40 cm/s between October and January. Maximum current speeds near-surface range from 40 cm/s in August to 62 cm/s in October. At mid-depth, monthly mean currents range from 16 to 20 cm/s between February and August to 33 cm/s in October and November. Maximum currents at mid-depth range from 27 cm/s in August to 47 cm/s in October. Near-bottom mean current speeds range from 11 cm/s in April to 27 cm/s in November; maximum speeds are 43 cm/s in October.

Table 3-8 Monthly Statistics for Derived Currents at SPA

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Near-Surface	Min (cm/s)	22	12	0	0	5	4	0	3	6	4	10	21
	Mean (cm/s)	40	27	24	21	24	22	22	22	32	40	40	38
	Max (cm/s)	55	52	44	44	43	42	42	40	53	62	60	54
Mid-Depth	Min (cm/s)	21	8	4	4	6	6	2	5	13	4	5	19
	Mean (cm/s)	31	20	19	16	18	17	18	17	24	33	33	30
	Max (cm/s)	41	35	32	30	28	30	30	27	37	47	43	40
Near-Bottom	Min (cm/s)	15	0	0	0	2	0	0	2	2	0	0	10
	Mean (cm/s)	24	14	14	11	12	12	13	12	16	25	27	23
	Max (cm/s)	32	23	30	24	22	25	30	22	29	43	37	35

JDB

For the JDB modelling location currents measured from the nearby MODU West Aquarius, bottom mounted upward-looking ADCP are used. This mooring (Amec Foster Wheeler 2016, Amec Foster Wheeler 2017) has been deployed to support drilling at Hibernia P-02 since May 2014 and is located about 8.5 km west-northwest of the West Aquarius and 7.5 km south-southwest of the Hibernia Platform (Figure 1-1) as part of fulfilling the Physical Environmental Monitoring Guidelines. Measurements from two recent deployments were combined (several small measurement gaps less than 24 h were filled with linear interpolation) to yield a year-long record of currents for model input. To characterize near-surface, mid-depth and near-bottom conditions, currents at three of the ADCP measurement bins were selected as follows:

- Deployment September 2015 to February 2016: currents at 28, 44 and 68 m
- Deployment February to October 2016: currents at 29, 45 and 69 m

Monthly near-surface mean current speeds range from 13 cm/s in June to 23 cm/s in winter, with maximum values ranging from 36 cm/s in May to 93 cm/s in September (Table 3-9). At mid-depth, monthly mean currents range from 11 cm/s in June to 20 cm/s in September. Maximum current speeds at mid-depth reach 83 cm/s in September. Near-bottom mean current speeds are 12 to 15 cm/s for most months, and maximum speeds range from 30 cm/s in June and July to 58 cm/s in September.

Table 3-9 Monthly Statistics for Measured Currents at JDB

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Near-Surface	Min (cm/s)	1	1	1	0	1	0	0	1	0	1	1	0
	Mean (cm/s)	21	23	16	14	14	13	14	19	17	19	17	15
	Max (cm/s)	77	71	57	47	36	39	44	58	93	64	59	49
Mid-Depth	Min (cm/s)	1	1	0	0	1	1	1	0	0	1	1	0
	Mean (cm/s)	16	17	15	13	12	11	12	14	20	17	16	15
	Max (cm/s)	44	52	51	42	26	36	37	48	83	61	41	48
Near-Bottom	Min (cm/s)	0	1	0	1	1	1	1	0	1	0	1	0
	Mean (cm/s)	15	15	14	13	12	12	12	13	16	15	13	12
	Max (cm/s)	38	42	46	41	31	30	30	47	51	58	36	29

Model Application of Currents

It is assumed that the currents are generally representative of conditions at the drilling locations and are uniform over the deposition grids modelled.

In the model algorithm, as each calendar day of drilling and possible discharge is followed, the corresponding day of current data is input from the representative year time series file and is used to advect the particles as per equations (6) and (7) in Section 3.2.5.

3.2.4 Model Geometry

The transport (and spatial extent) and fate of the cuttings are modelled as a function of time. A given well sequence as a number of days drilling is employed. For each day, and for each different size class of material (i.e., the four sand sizes, silt and clay in Table 3-3), a collection of particles are discharged. Particles are assigned a weight apportioned on the number of days drilling (Table 3-1) and the volume of cuttings associated with the particular well section. A time step is assigned appropriate for the geographic scale and model grid of the study area and the ambient current conditions. It is also necessary to choose time steps appropriate for each of the different particle types which exhibit a range of fall velocities. At each time step in the model, a new location for a given particle is calculated. Selection of too large a time step may yield inaccurate results. Too small a time step makes for overly intensive computations in the model. The time steps employed are listed in Table 3-10.

Table 3-10 Model Time Steps for Cuttings Particle

Particle Parameter	Cuttings Material					
	COARSE SAND	MEDIUM SAND	FINE SAND	V. FINE SAND	COARSE-MEDIUM SILT	FINE SILTS-CLAYS
Time Step, Δt (s)	60	120	120	3600	3600	3600
# Particles per Δt	3	6	6	180	180	180
# Steps per day	1,440	720	720	24	24	24

It is instructive to consider these time steps together with the particle settling velocities presented in Section 3.2.2. Their application in the model has a direct bearing on the deposition predictions. For the WBM cuttings discharge 2 to 4 m above the seafloor, the particles will quickly settle to the seabed. Coarse and medium sand particles will settle within one minute, while the very fine sand, silt and clay sized particles will take about one hour to settle. For SBM cuttings released near the sea surface (14 m depth assumed) the water depth is clearly a defining parameter in how quickly materials will settle. At the deepest location modelled, NPA, at 2,700 m, coarse sand particles (fall velocity of 0.102 m/s) will be modelled to settle to the seabed in just over seven hours, while the very fine sand, silt and clay sized particles (fall velocity of 0.001 m/s) will take over 30 days. At the shallowest of the four locations, JDB, at 89 m water depth, the coarse sand sized particles settled in 12 minutes with the fines taking about 21 hours. This illustrates the key roles of the location water depth and the large influence of the particle size composition and settling velocity assumptions.

A grid of the seabed is used in the model to track the spatial extent of depositions. The model grid is a Cartesian grid of size 2000x2000 centred at the drill cuttings scenario location (i.e., at the wellhead) and extending out a finite distance both in X (or East-West) and Y (or North-South) directions. Two grid cell sizes are used. A 32 m cell provides coverage out to 32 km, while a smaller 4 m cell size is used for greater resolution about the wellhead, particularly for the WBM cuttings released near the seabed.

The model assumes uniform depth, with values set equal to the water depth at each modelling location (Table 2-1): NPA at 2,700 m, EPA at 1,100 m, SPA at 362 m and JDB at 89 m.

3.2.5 Model Algorithm

The path of each particle released is tracked by calculating at each new time step, n+1, its position (x,y,z) based on its position at the previous time step, n, as given by equations (6) to (8):

$$x_{n+1} = x_n + u \times \Delta t + x' \times R_x \quad (6)$$

$$y_{n+1} = y_n + v \times \Delta t + y' \times R_y \quad (7)$$

$$z_{n+1} = z_n + w \times \Delta t + z' \times R_z \quad (8)$$

Where

- x = the particle position in the east-west horizontal distance (m)
- y = the particle position in the north-south horizontal distance (m)
- z = the particle position, or depth, in the vertical distance (m) (depth positive downwards)
- u = east-west component of the ocean current (m/s)
- v = north-south component of the ocean current (m/s)
- Δt = time step for the given particle type (s)
- w = fall velocity for the given particle type (m/s)
- Rx, Ry, Rz= random numbers in the range (-1,1)

and where the x'×Rx terms, and similarly for y and z, are included to simulate an element of turbulence in the current drift of the particles.

3.3 Model Output

Following each well run, an output file is generated containing an x,y grid of the model domain with the following variables calculated for each grid cell:

- x, y, origin of cell (km), relative to discharge (x,y,z) origin
- range (km) and bearing (°T) from origin
- for each of WBM cuttings, SBM cuttings, and total (WBM+SBM) cuttings:
  - total weight of cuttings (kg)
  - cuttings density (g/m^2)
  - cuttings thickness(mm)
- number of particles of each of six types (coarse, medium, fine and very fine sand, coarse and medium silt, fine silts and clays)

A run log file is also generated that echoes key model inputs and reports the total weight of cuttings (WBM and SBM) deposited on the seabed and the amount of any cuttings which drift outside the model grid.

4.0 RESULTS

The cuttings model tracks and outputs separately, the WBM, SBM and total (WBM plus SBM) deposition results. Model results are presented in Section 4.1 to 4.4 for the four locations Northern Project Area (NPA), Eastern Project Area (EPA), Southern Project Area (SPA) and Jeanne d'Arc Basin (JDB). For each location, each results section presents a summary of cuttings material that settles on the seabed and associated thicknesses by distance from the well site origin together with plan-view maps of the cuttings deposition footprints.

Cuttings from drilling the upper two well sections with WBM will all be released as per the Offshore Waste Treatment Guidelines (OWTG) (National Energy Board (NEB) et al. 2010) close to the seafloor. Therefore, there is little time for the cuttings to be transported large distances by the ambient currents. Conversely SBM cuttings, treated and released in accordance with the OWTG, will be released near the sea surface (14 m assumed, see Table 2-3). For the deeper water locations – all but JDB - very little of the SBM cuttings reach the seabed within the model domain; these cuttings will drift for several days and travel for distances on the order of 20 to 200 km.

In the results sections for each site, the amounts of WBM and SBM cuttings material modelled to settle for selected distances from the well site (origin) are presented in a table. All four seasonal scenarios are reported. In a second, similar, table a summary of mean and maximum cuttings thicknesses is presented. Mean thicknesses are calculated over those sea bottom cells with cuttings deposition, i.e., cells with no cuttings deposits are not considered. The maximum thicknesses are the one largetst thickness observed in each 'distance from well site' bin. For example, for NPA (Table 4-2), in the 200 to 500 m distance bin, for June, the mean WBM cuttings thickness is 3 mm, while the largest WBM thickness in any of the model grid cells within that range is 56 mm. As noted below the table, this amount is located 220 m to the northeast. At this distance none of the SBM cuttings have yet to settle – indicated by the '-' in the table cells. Statistics out to 5 km from the well site are reported using the 4 m x 4 m finer resolution grid model run; the 32 m x 32 m grid model runs which cover to 32 km are used to report statistics outside of 5 km. For all locations and seasons, all WBM cuttings settle within the 4 km finer model grid domain.

A set of four cuttings deposition map figures are also presented for each of the four seasonal scenarios at each site. This includes footprints of the modelled thicknesses for i) total cuttings, ii) WBM cuttings, iii) SBM cuttings and iv) total cuttings above predicted no effect thresholds (PNET) of 1.5 mm and 6.5 mm.

The PNET thresholds are shown to assist in the EIS's assessment of potential biological effects of drill cuttings deposition. Previous studies indicate that sedimentation and burial effects from drill muds and cuttings on benthic invertebrates have mainly been localized to the vicinity of a drill cuttings pile area (Neff et al 2000; Holdway 2002; Schaanning et al 2008; Trannum et al 2010; Gates and Jones 2012; Larsson et al 2013; Cordes et al 2016; Tait et al 2016). Average burial depths of 6.5 mm are considered to be the predicted no effect threshold (PNET) for non-toxic sedimentation based on benthic invertebrate species tolerances to burial, oxygen depletion and change in sediment grain size (Kjeilen-Eilertsen et al

2004; Smit et al 2006; 2008). However, as some species may be more susceptible to shallower burial depths, an average PNET burial depth of 1.5 mm is suggested to be a more conservative approach to assessing drilling discharges (Kjeilen-Eilertsen et al 2004; Smit et al 2006, 2008). This level coincides with assessments on more sensitive coral species where injury from sedimentation was observed with sedimentation of less than 6.3 mm (Larsson et al 2011, 2013).

Different distance scales are set to best illustrate the spatial extent and show detailed resolution in the footprint maps, e.g., depending on the modelled site, 10 km is used for total cuttings, 500 m for WBM and 3 km for SBM, 4 km for the PNET thresholds - all in an attempt to use consistent scales between seasons to facilitate comparison of results. The total cuttings with PNET limits footprints include radii drawn at 200 m, 500 m, 1 km, 2 km, 3 km, and 4 km.

4.1 Northern Project Area

This section presents results of cuttings modelling for the NPA location. Four seasonal scenarios are presented with drilling of wells commencing in March, June, September and December. At the NPA site all of the WBM cuttings released at the wellhead settle within 4 km. Conversely, the vast majority of the SBM cuttings released from the MODU at the sea surface – with a large water depth at NPA of 2,700 m - fail to settle within the model domain of 32 km (Table 4-1).

When the SBM materials do reach the seabed their footprints are far from the well site. Only about 1.5 percent or less (depending on scenario month: 98.3 percent remain unsettled in March, 99.2 percent remain unsettled in September) of the SBM cuttings released settle on the seabed before drifting outside the model domain. At a depth of about 2,700 m to settle, the very fine sand, silts and clay SBM cuttings particles released near the surface might be expected to take on the order of 31 days to settle and, at an assumed mean current speed of 10 cm/s, travel over 200 km.

Table 4-1 Cuttings Material Settled by Distance, NPA

NPA		Distance from Well Site										
		0-10m	10-100m	100-200m	200-500m	500m-1km	1-2km	2-4km	4-5km	5-31km	>31km	
Month	Cuttings Type	% Material Settled										% Material Unsettled
Mar	WBM	2	46	29	22	-	-	-	-	-	-	-
	SBM	-	-	-	<0.1	0.1	0.5	0.8	0.2	0.3	-	98.0
Jun	WBM	0.6	11	27	54	4	-	-	-	-	-	-
	SBM	-	-	-	-	<0.1	<0.1	0.4	0.4	1.0	-	98.0
Sep	WBM	0.3	0.6	13	18	68	0.4	-	-	-	-	-
	SBM	-	-	-	-	-	<0.1	0.4	0.4	1.1	-	98.0
Dec	WBM	0.8	20	3	30	46	-	-	-	-	-	-
	SBM	-	-	-	<0.1	<0.1	0.3	0.8	0.3	0.5	-	98.0

Note: due to rounding some row percentage totals may not exactly equal 100.

Mean and maximum cuttings thicknesses at NPA are reported in Table 4-2. The notes under Table 4-2 list the location of each month's maximum WBM thickness, e.g., in June the largest thickness is 56 mm, 220 m to the northeast of the well site (this maximum also shows up as an orange footprint cell in the June WBM thickness Figure 4-6). The farthest distance that any SBM cuttings settle, at any thickness, is March at 6.5 km, June at 9.9 km, September at 12.2 km, December at 9.6 km.

Table 4-2 Cuttings Thickness by Distance, NPA

NPA		Distance from Well Site									
		0-10m	10-100m	100-200m	200-500m	500m-1km	1-2km	2-4km	4-5km	5-31km	>31km
Cuttings Type		Cuttings Thickness (mm)									
	March										
WBM	Mean	35	8	4	3	-	-	-	-	-	-
	Maximum	63 [1]	63	50	18	-	-	-	-	-	-
SBM	Mean	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
	Maximum	-	-	-	0.01	0.01	0.02	0.02	<0.01	0.01	-
	June										
WBM	Mean	8	3	3	3	1	-	-	-	-	-
	Maximum	21	15	50	56 [2]	8	-	-	-	-	-
SBM	Mean	-	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	-
	Maximum	-	-	-	-	<0.01	<0.01	0.02	0.01	0.01	-
	September										
WBM	Mean	4	1	2	2	2	0.4	-	-	-	-
	Maximum	14	14	48	55 [3]	13	1	-	-	-	-
SBM	Mean	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	-
	Maximum	-	-	-	-	-	0.01	0.01	0.01	0.01	-
	December										
WBM	Mean	11	5	1	3	3	-	-	-	-	-
	Maximum	24	78 [4]	8	22	28	-	-	-	-	-
SBM	Mean	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
	Maximum	-	-	-	0.01	0.01	0.02	0.02	<0.01	<0.01	-

[1] maximum of 63 mm located at well site; [2] 56 mm at (0.22 km, 45°); [3] 55 mm at (0.26 km, 38°); [4] 78 at (0.04 km, 53°)

The cuttings deposition map figures are presented for each of the four seasonal scenarios – March, June, September and December - and for each, the modelled total cuttings, WBM cuttings, SBM cuttings and total cuttings for PNET limits thicknesses are shown. For the NPA site, these maps are shown in Figure 4-1 to Figure 4-16.

At NPA, the predominant direction for drift and deposition is to the northeast. Cuttings deposition footprints extend to about 6 km in March (Figure 4-1), just over 9 km in June and December and to about 12 km in September (Figure 4-9). The WBM cuttings footprints lie within about 500 m in March (Figure 4-2), 700 m in June, 1.2 km in September and 1 km in December (Figure 4-14).

As reported above, few of the SBM cuttings settle within the model domain. These are all the coarse, medium and fine sands with none of the very fine sand, silt or clay particles settling.

As reported in Table 4-2 WBM thicknesses are as large as 63 mm at the wellhead in March with the largest thickness of 78 mm seen at 40 m out from the wellhead in December. Average WBM cuttings thicknesses out to 500 m are generally between 2 or 3 mm and 11 mm in all months – the exception is a mean thickness of 35 mm within 10 m of the wellhead in March.

The closest any SBM cuttings are predicted to settle is 300 m in March (Figure 4-3) with thicknesses less than 0.1 mm (mean and maximum thicknesses are about 0.01 mm, Table 4-2). For all four months modelled, SBM cuttings thicknesses do not exceed 0.1 mm. It is safe to assume also that any bottom deposits from the SBM cuttings that drift outside the model domain of 32 km would likely be highly dispersed and negligible in thickness.

March

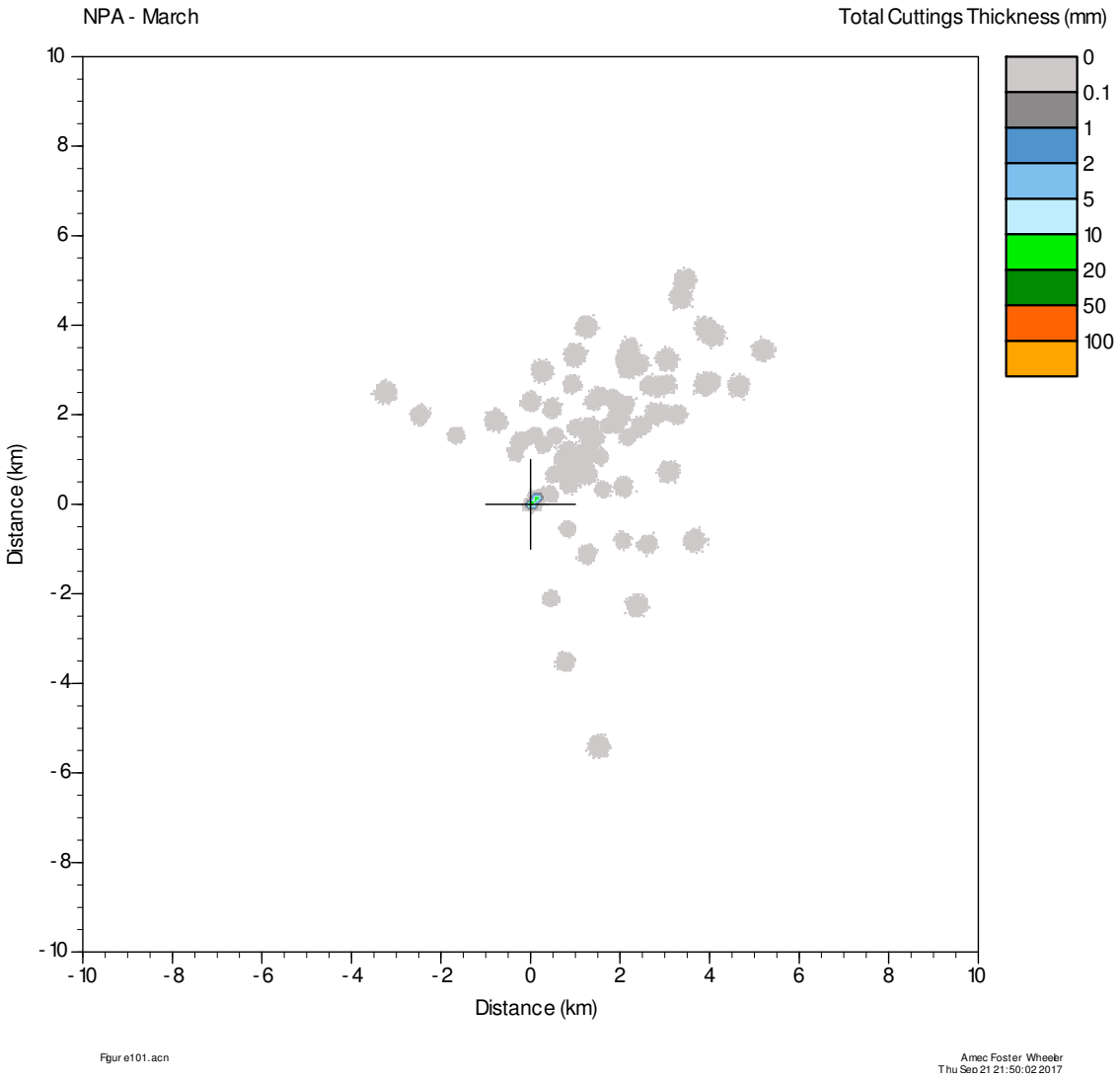


Figure 4-1 Total Drill Cuttings Deposition, NPA, March, 10-km View

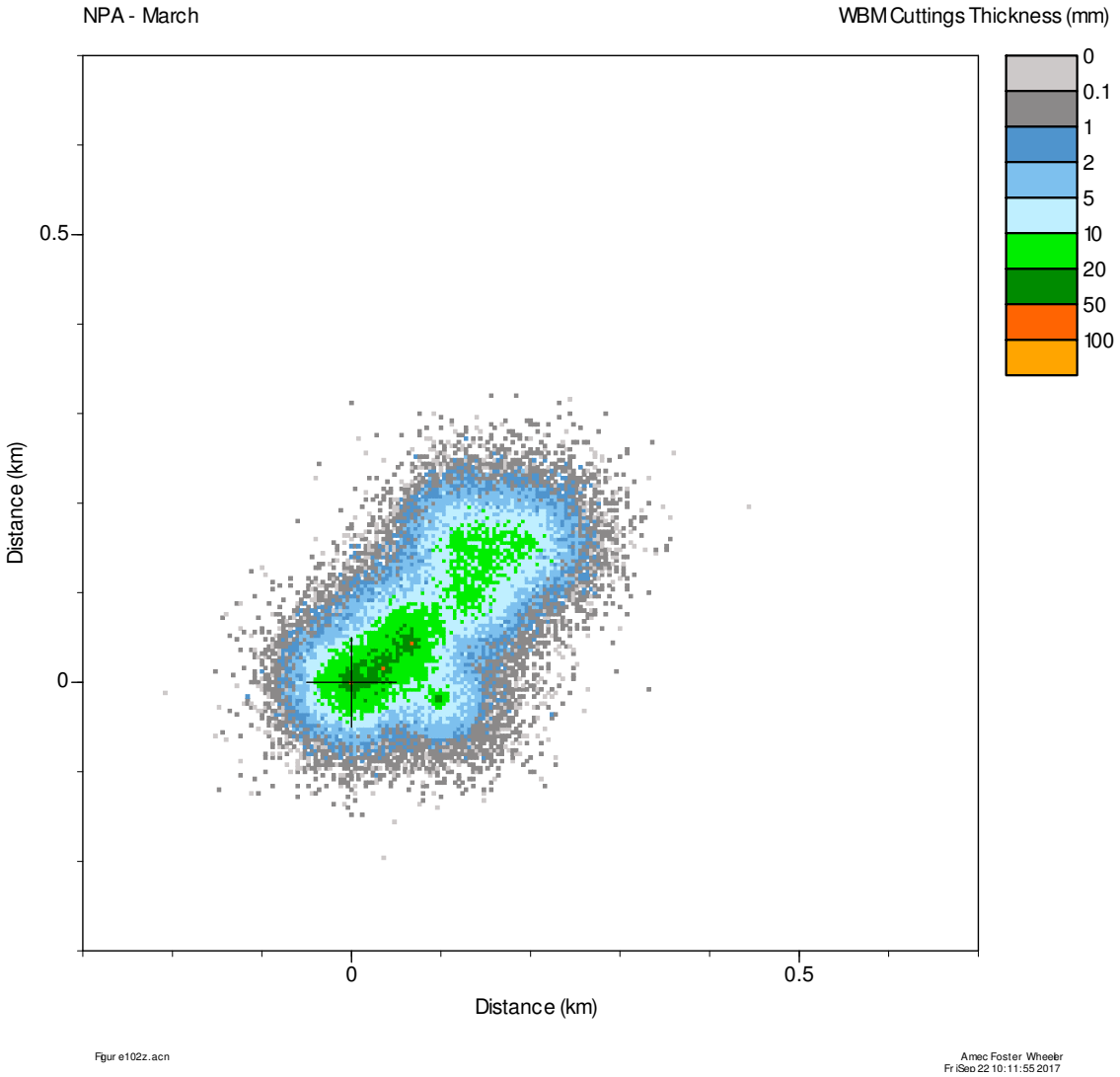


Figure 4-2 WBM Drill Cuttings Deposition, NPA, March, 500-m View

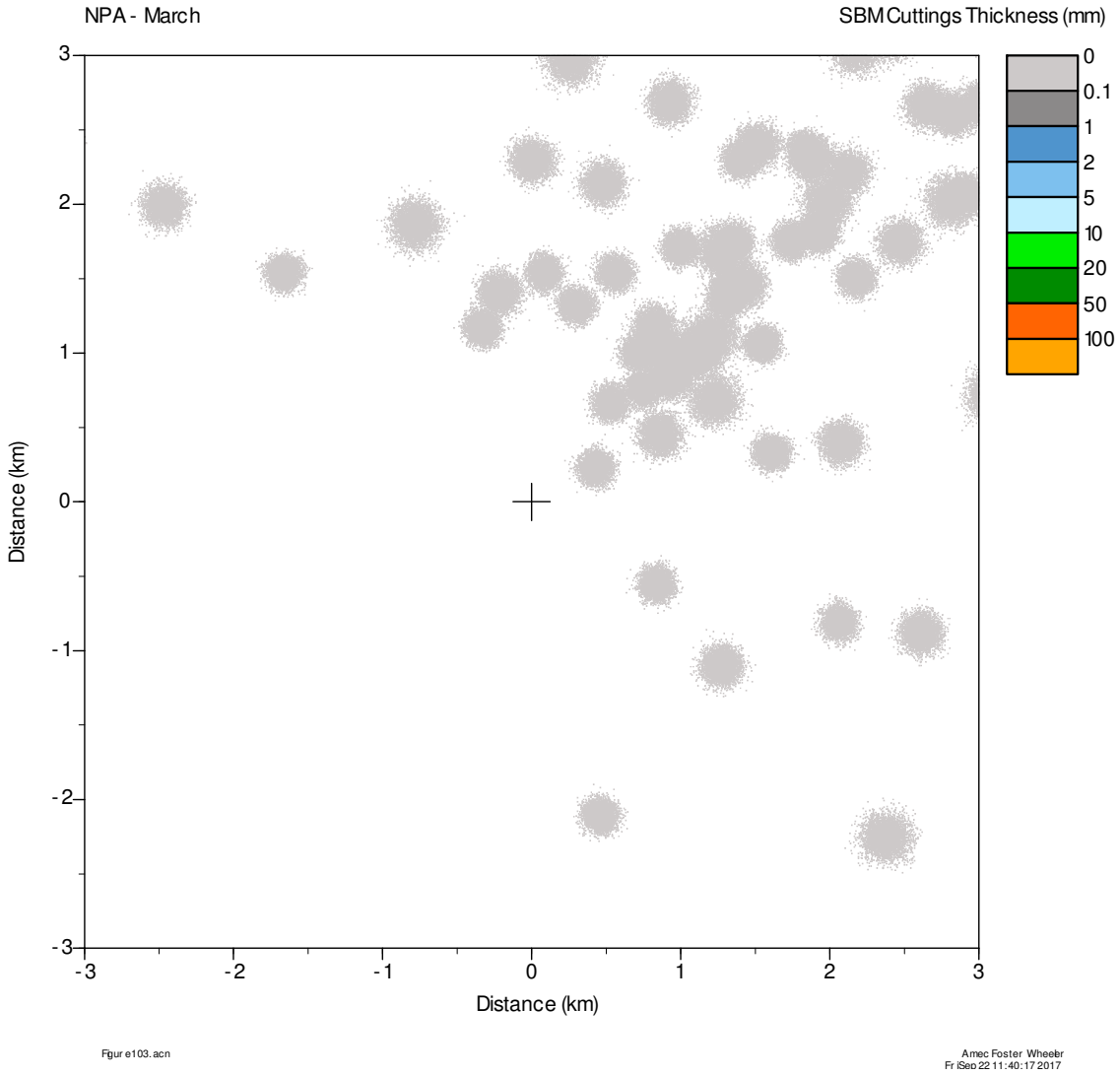


Figure 4-3 SBM Drill Cuttings Deposition, NPA, March, 3-km View

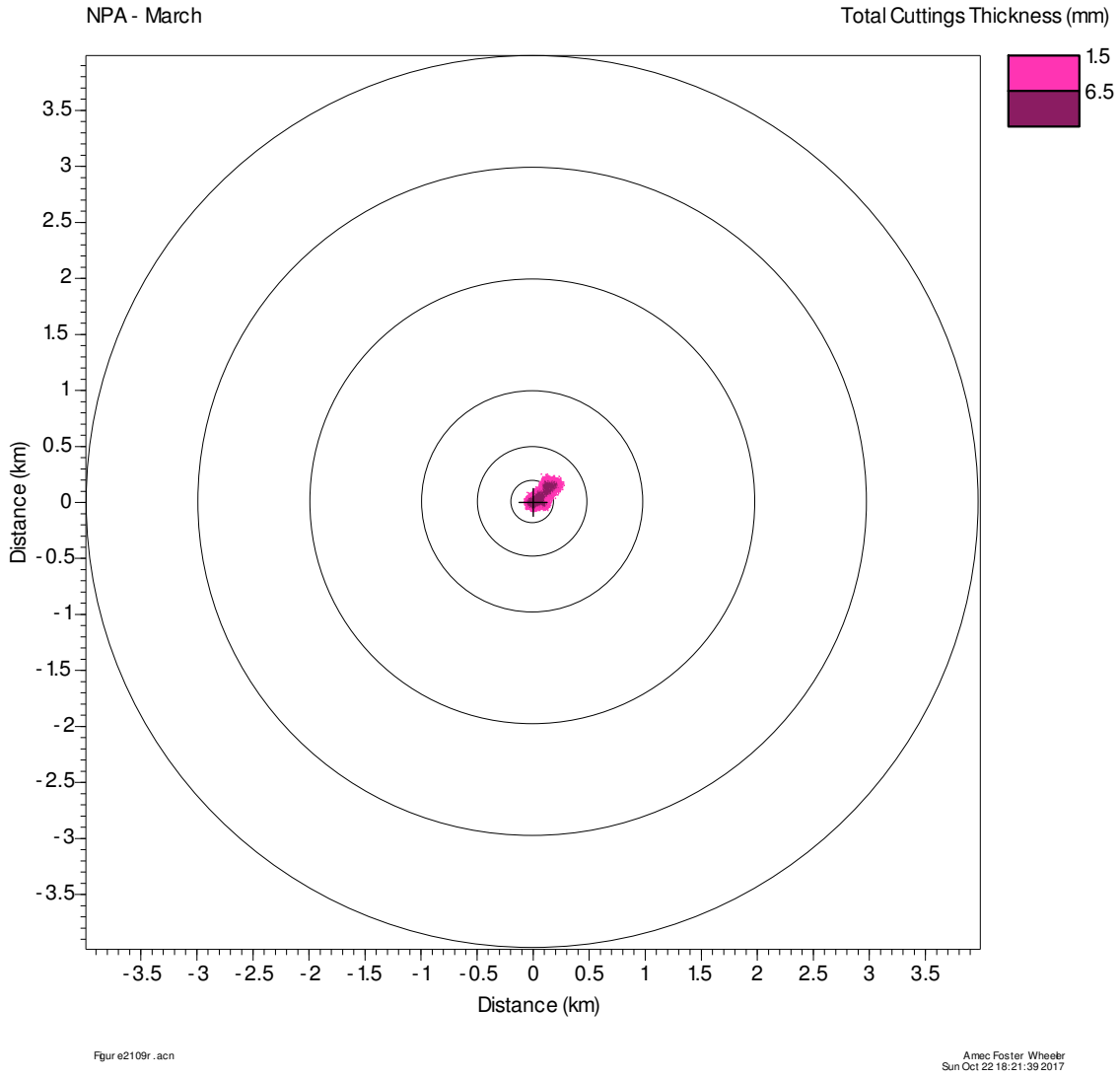


Figure 4-4 Total Drill Cuttings Deposition, PNET Limits, NPA, March, 4-km View

June

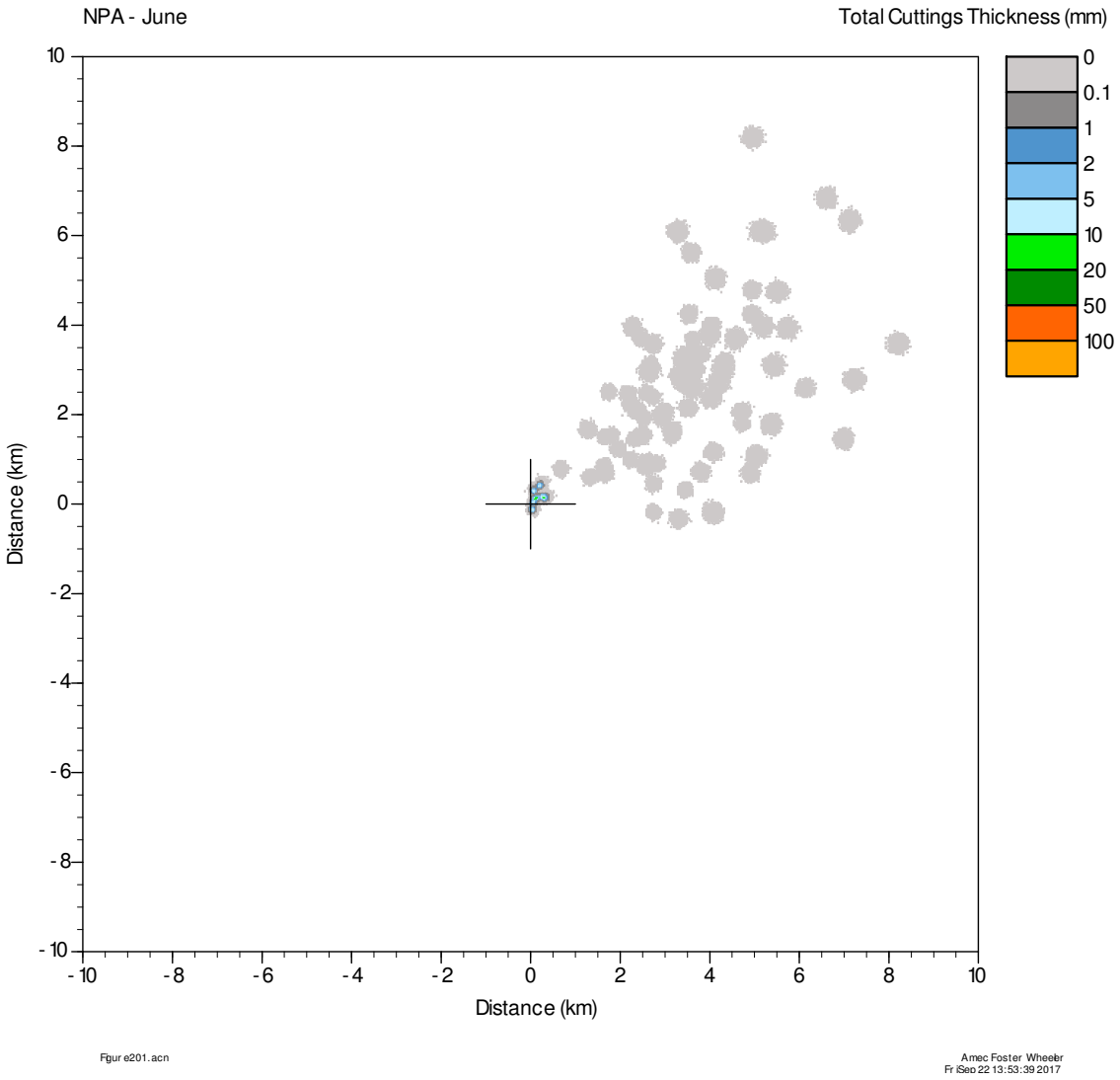


Figure 4-5 Total Drill Cuttings Deposition, NPA, June, 10-km View

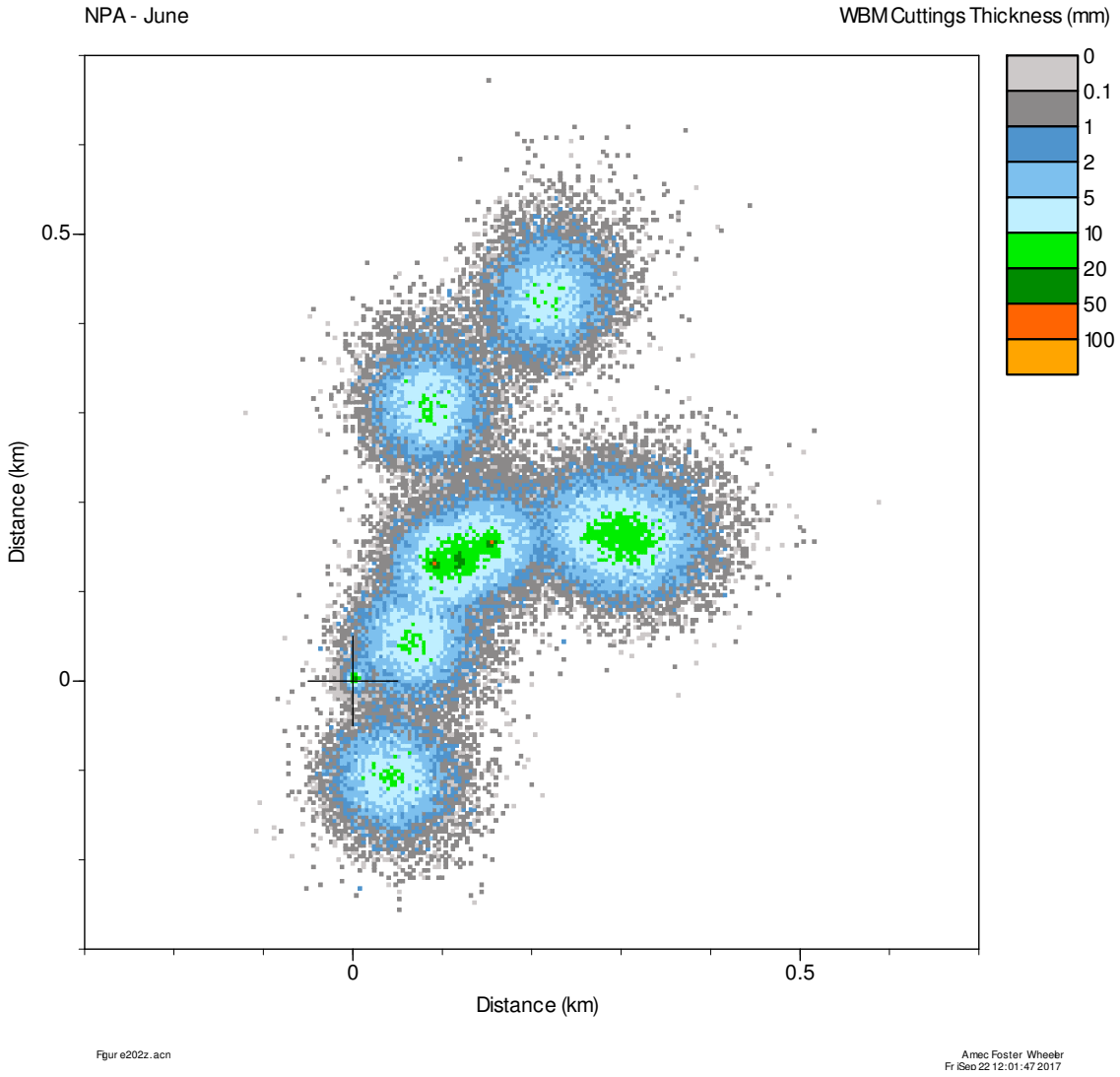


Figure 4-6 WBM Drill Cuttings Deposition, NPA, June, 500-m View

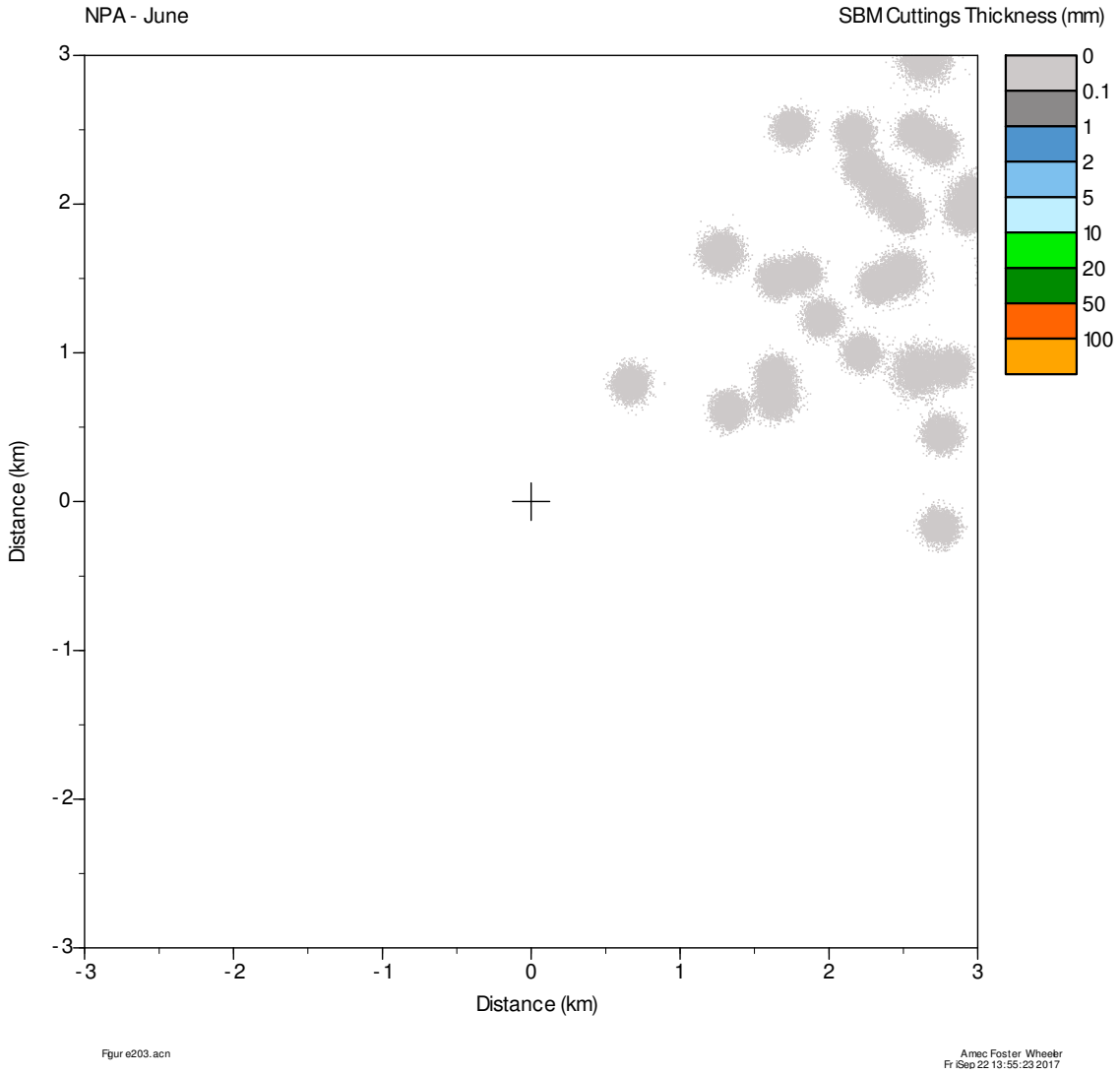


Figure 4-7 SBM Drill Cuttings Deposition, NPA, June, 3-km View

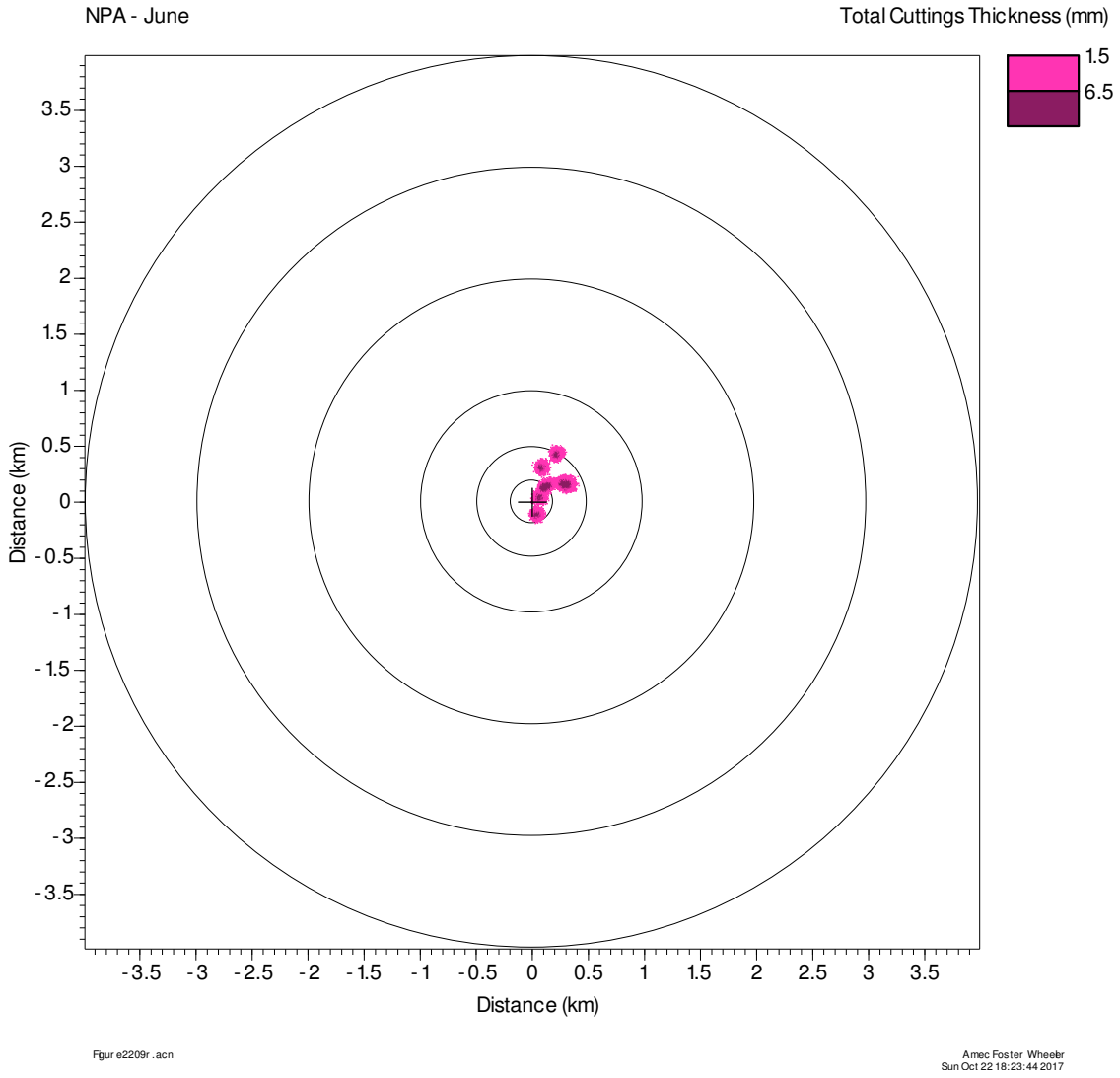


Figure 4-8 Total Drill Cuttings Deposition, PNET Limits, NPA, June, 4-km View

September

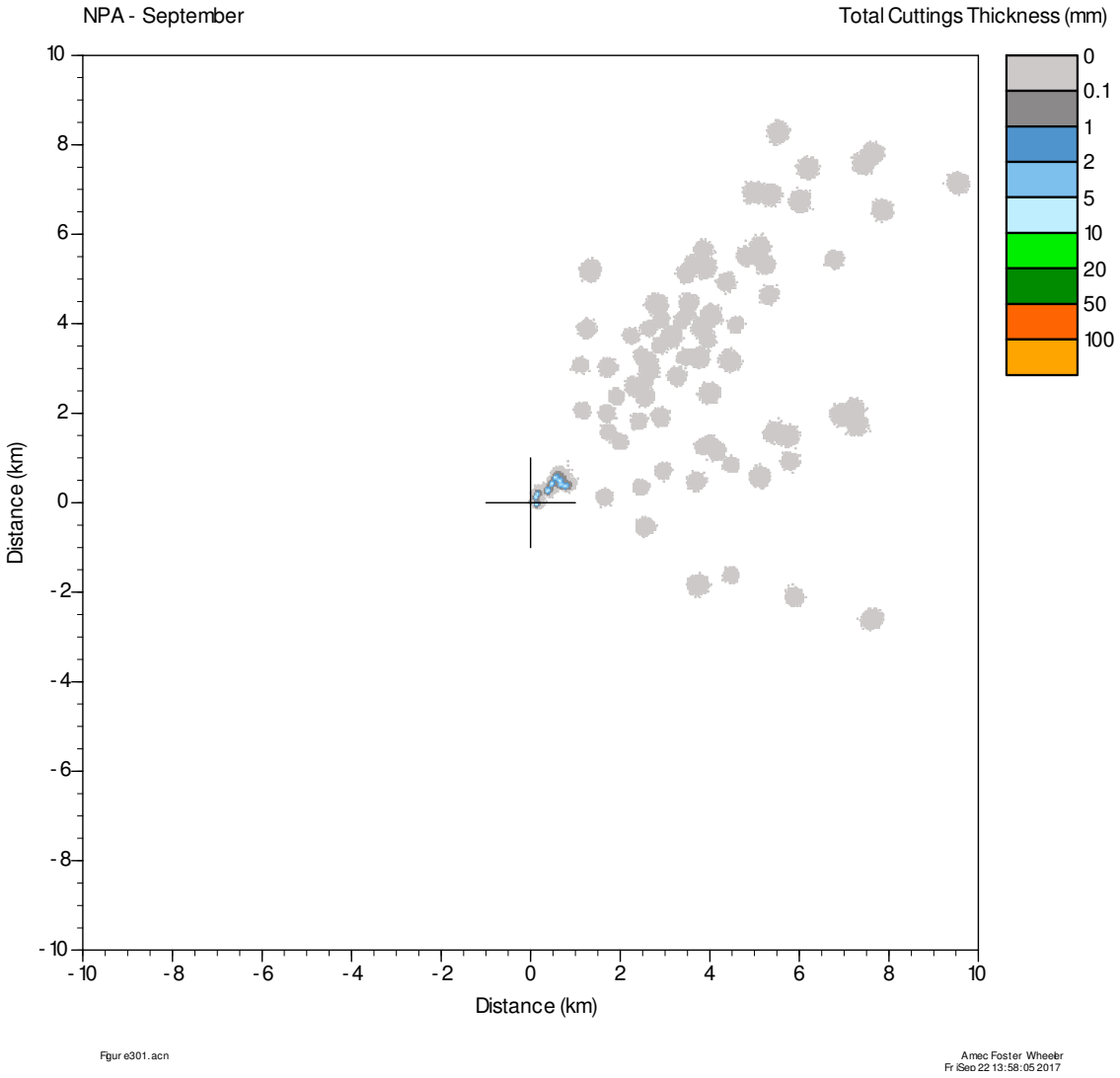


Figure 4-9 Total Drill Cuttings Deposition, NPA, September, 10-km View

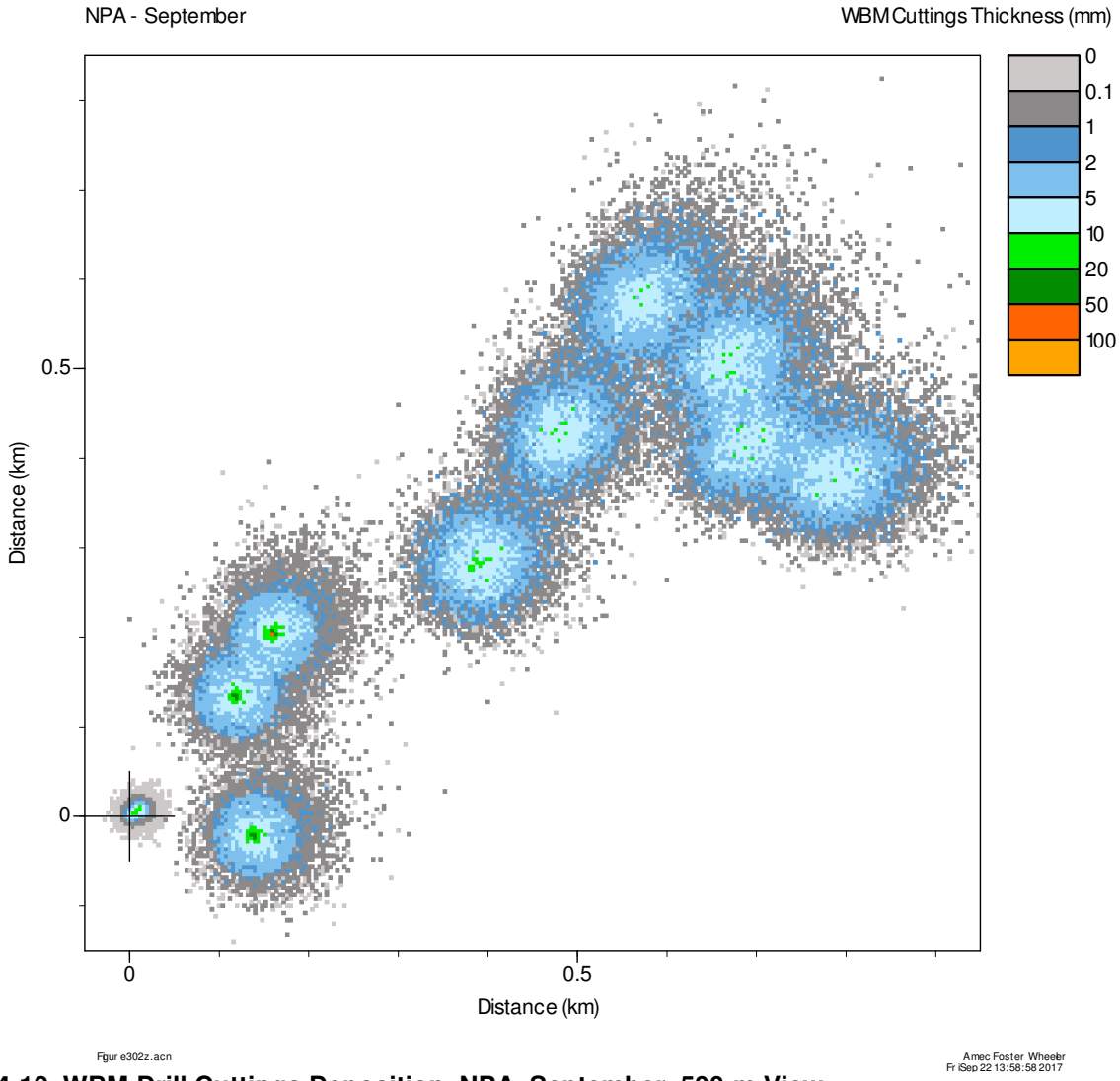


Figure 4-10 WBM Drill Cuttings Deposition, NPA, September, 500-m View

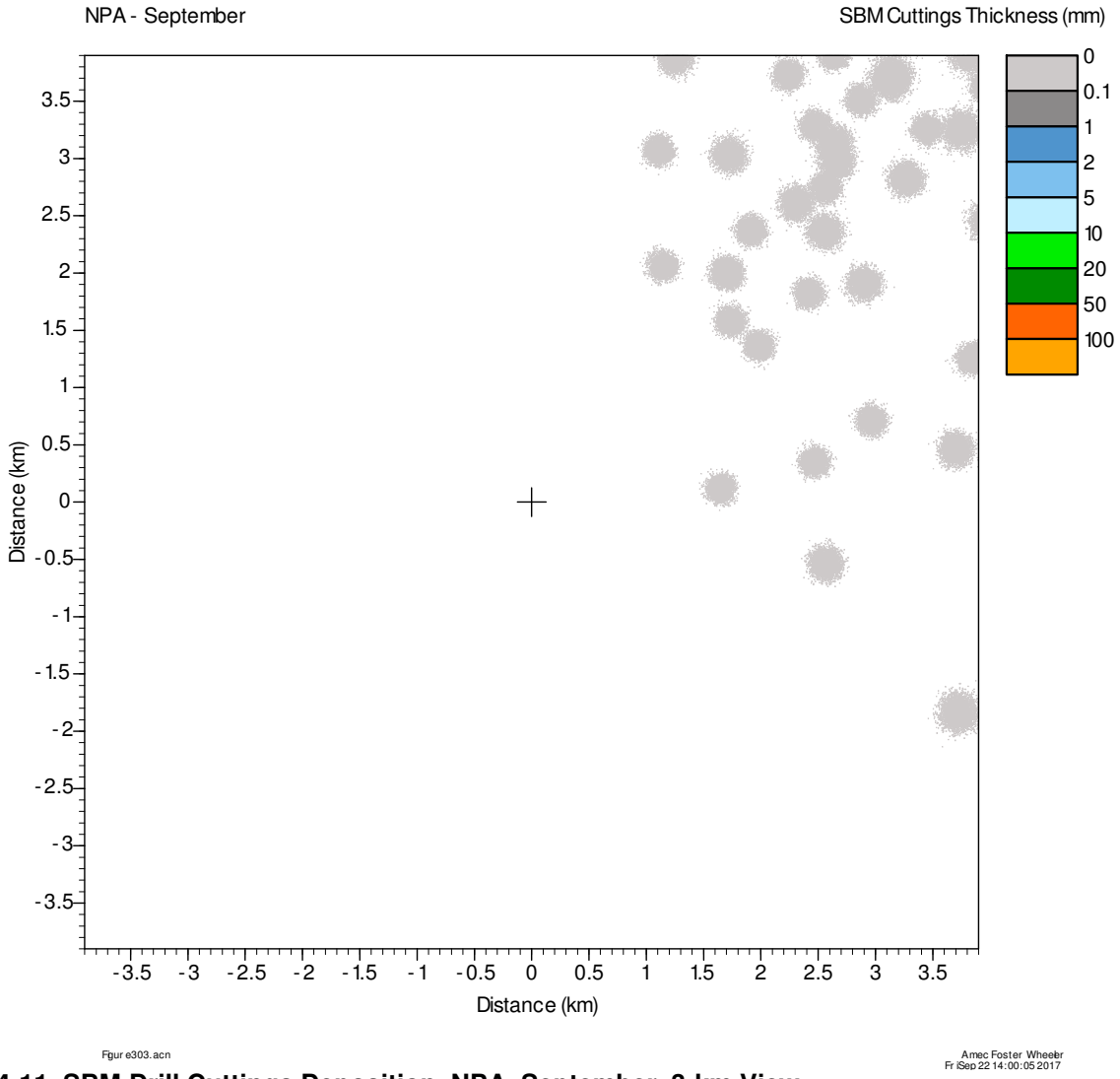


Figure 4-11 SBM Drill Cuttings Deposition, NPA, September, 3-km View

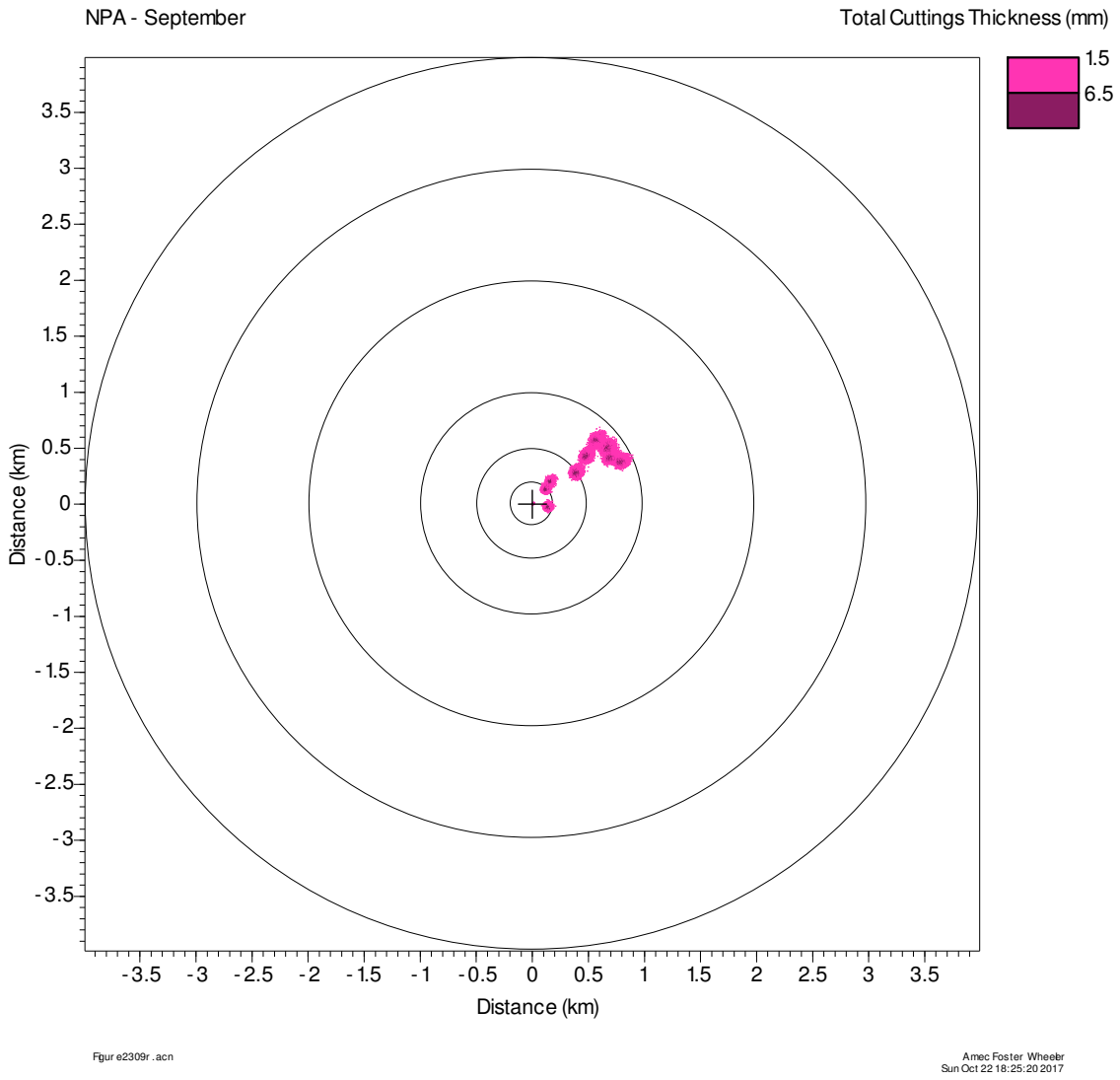


Figure 4-12 Total Drill Cuttings Deposition, PNET Limits, NPA, September, 4-km View

December

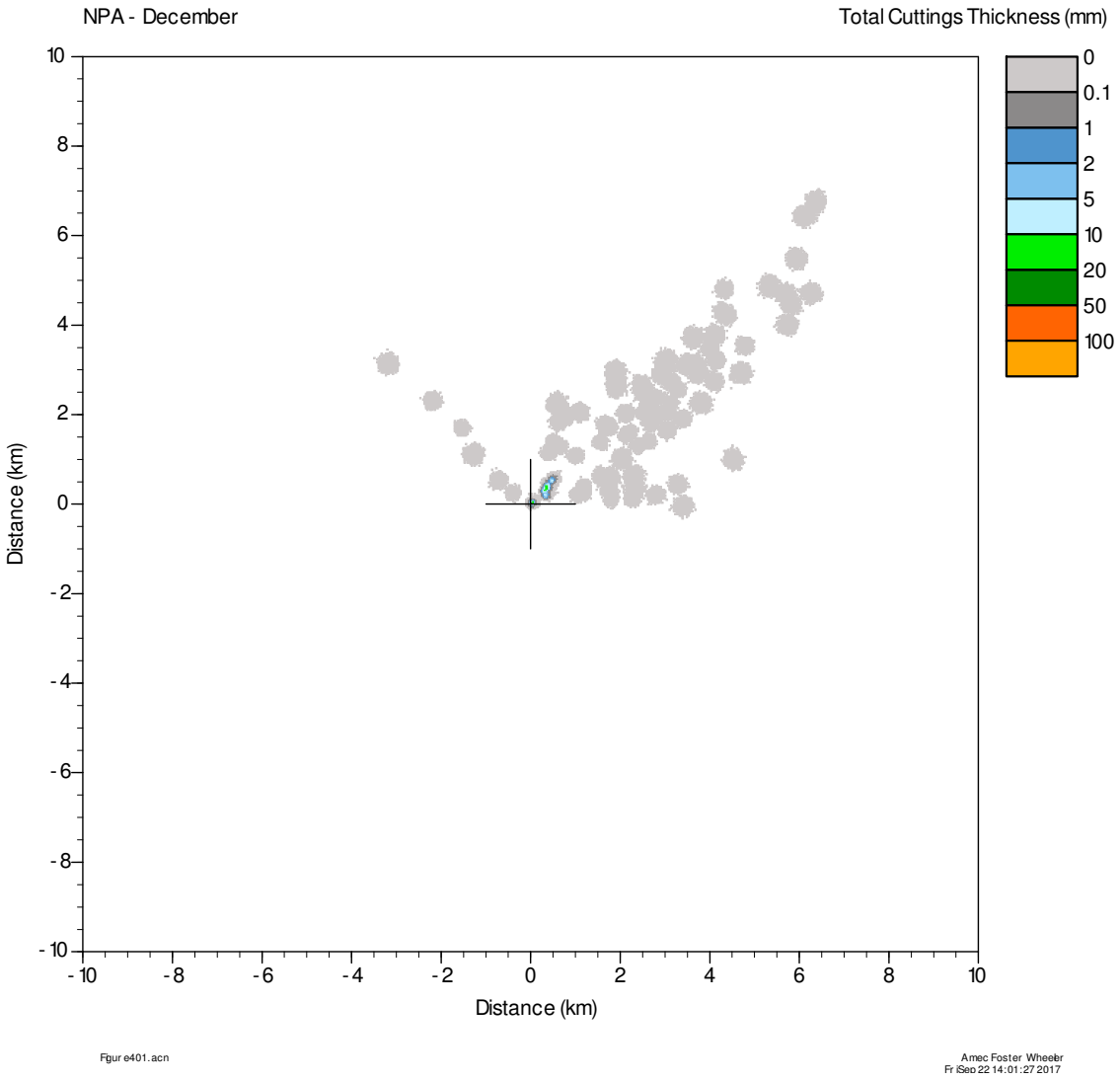


Figure 4-13 Total Drill Cuttings Deposition, NPA, December, 10-km View

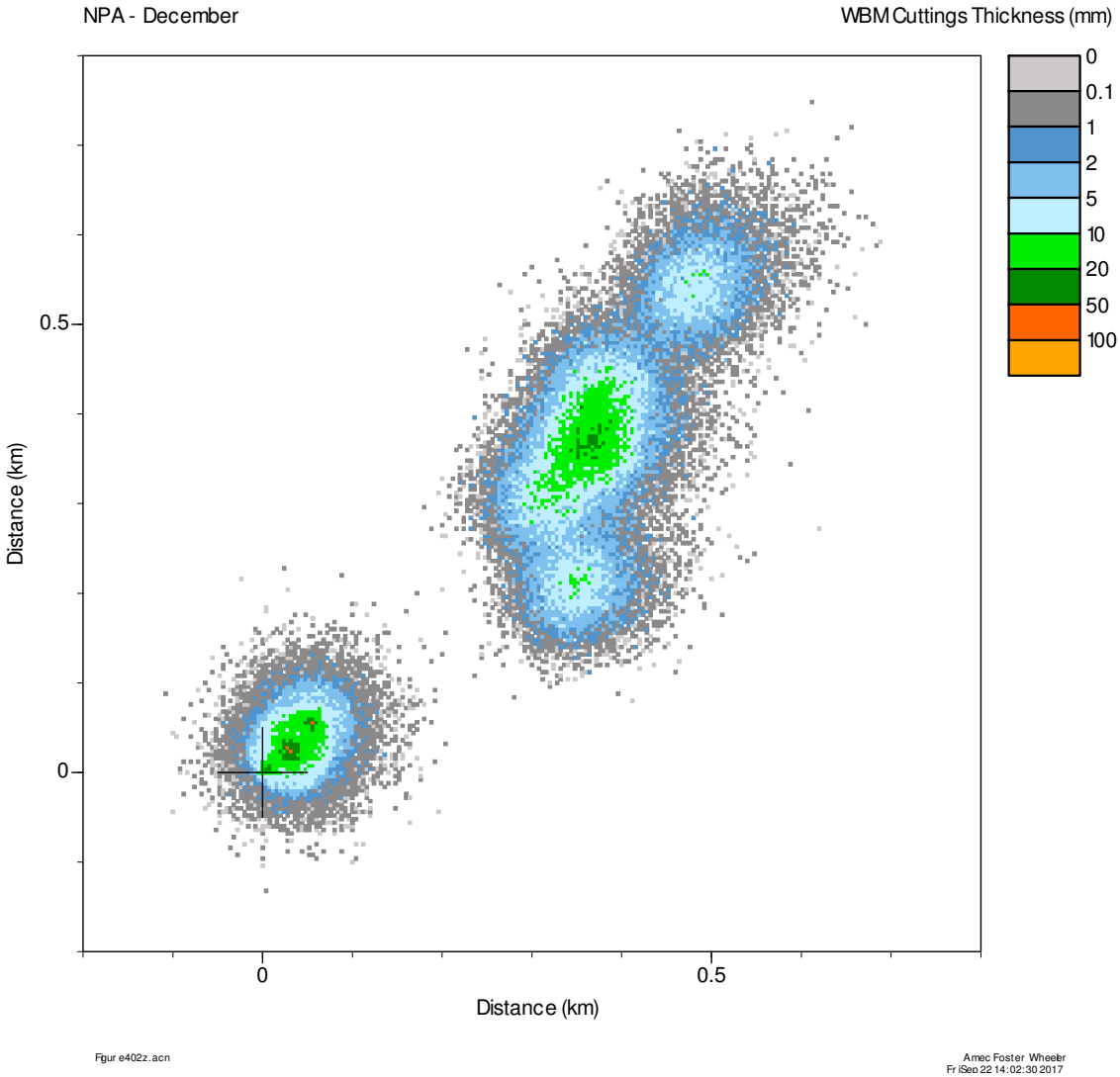


Figure 4-14 WBM Drill Cuttings Deposition, NPA, December, 500-m View

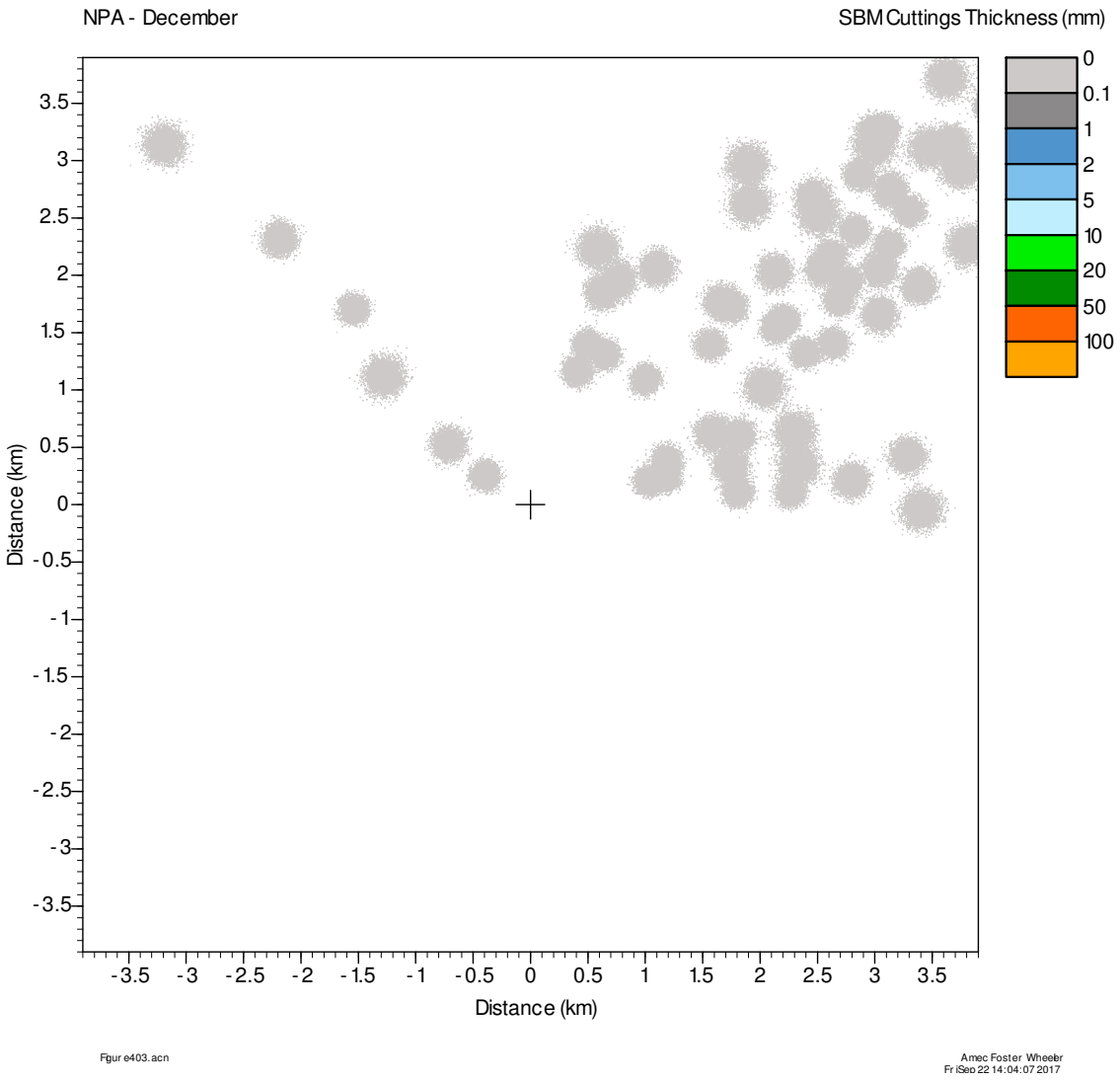


Figure 4-15 SBM Drill Cuttings Deposition, NPA, December, 3-km View

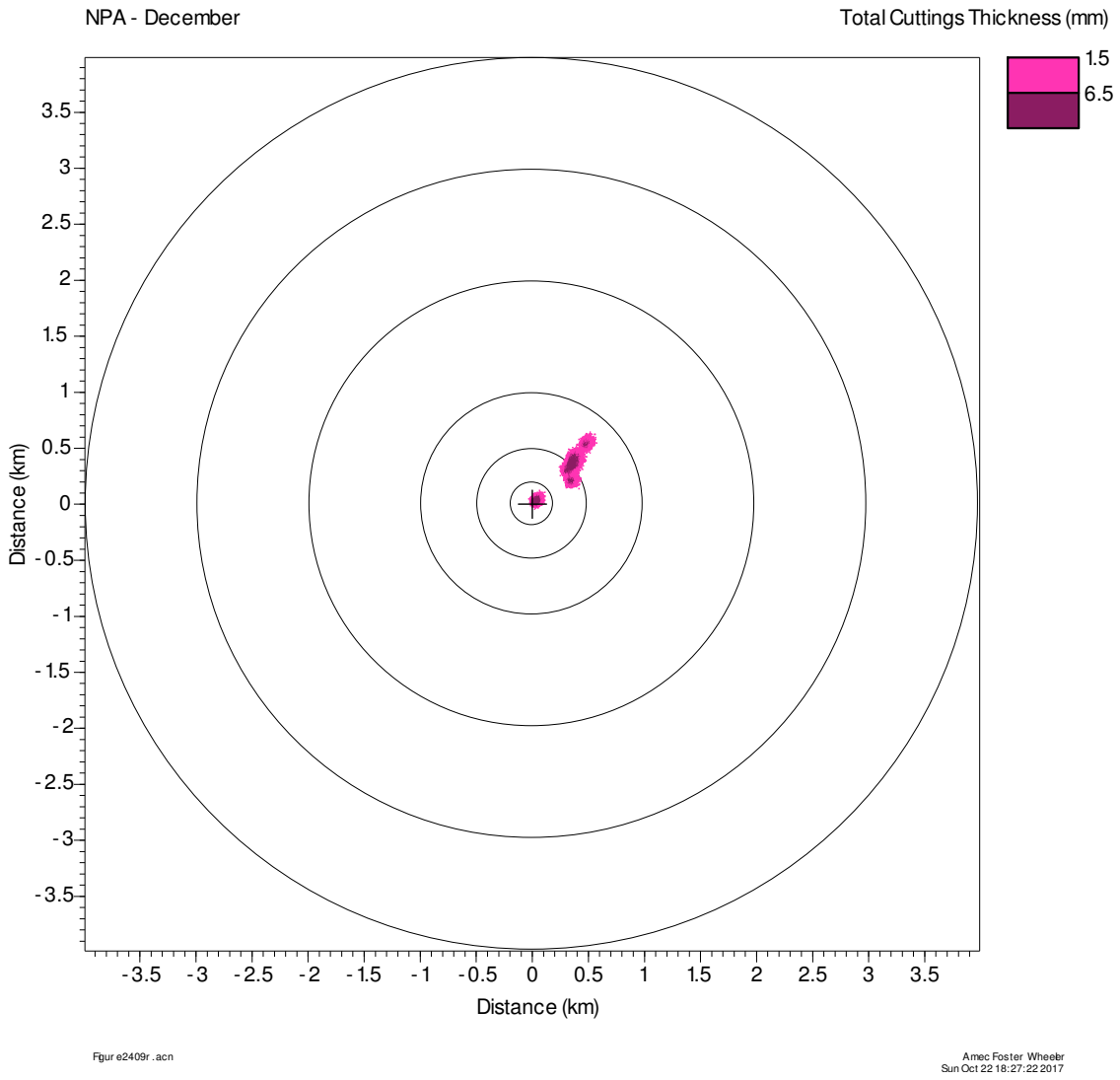


Figure 4-16 Total Drill Cuttings Deposition, PNET Limits, NPA, December, 4-km View

4.2 Eastern Project Area

This section presents results of cuttings modelling for the EPA location. Four seasonal scenarios are presented with drilling of wells commencing in March, June, September and December.

At the EPA site all of the WBM cuttings released at the wellhead settle within 500 m (Table 4-3). This is due to the very small currents. In March, 97 percent of WBM materials are predicted to settle within 100 m; in December the value is 89 percent. With slightly larger current speeds in summer, the deposits are slightly farther away with almost 100 percent settling within 200 m in June, and 96 percent within 200 m in September. At EPA the predominant direction for drift and deposition is to the northeast consistent with the prevailing currents.

Due to the low currents in the region (Table 3-6) the SBM cuttings released from the MODU at the sea surface settle on the seabed within the 32 km model domain – despite the large water depth of 1,100 m. The one exception is the June scenario since currents in June and July are 2-3 cm/s higher on average for near the surface and at mid-depth compared to other months. As a result only about 3 percent of the SBM cuttings settle within the 32 km model domain for the June scenario. In the June model run, cuttings deposition is restricted to about a 1 km^2 area at the wellhead and just to the northeast (Figure 4-21). In March the SBM cuttings material reach the seabed about 26 to 34 km to the northeast (total cuttings in Figure 4-17). All SBM cuttings thicknesses are predicted to be on the order of 1 mm or less: in most locations less than 0.1 mm.

Table 4-3 Cuttings Material Settled by Distance, EPA

EPA		Distance from Well Site										
		0-10m	10-100m	100-200m	200-500m	500m-1km	1-2km	2-4km	4-5km	5-31km	>31km	
Month	Cuttings Type	% Material Settled										% Material Unsettled
Mar	WBM	4	93	3	<0.1	-	-	-	-	-	-	-
	SBM	-	<0.1	<0.1	0.6	1.8	0.1	-	-	7.1	90.4	-
Jun	WBM	2	72	26	0.2	-	-	-	-	-	-	-
	SBM	-	-	-	<0.1	1.0	1.5	-	-	-	-	97.5
Sep	WBM	1	38	57	4	-	-	-	-	-	-	-
	SBM	<0.1	0.2	0.8	1.3	0.2	<0.1	-	-	97.5	-	-
Dec	WBM	2	87	12	0.1	-	-	-	-	-	-	-
	SBM	<0.1	<0.1	0.1	0.9	1.5	<0.1	-	-	97.5	-	-

Note: due to rounding some row percentage totals may not exactly equal 100.

At EPA, the farthest distance that any SBM cuttings settle, at any thickness, is March at 38.6 km, June at 1.3 km, September at 15.1 km, December at 27.8 km. The notes under Table 4-4 list the location of each month's maximum WBM thickness.

Table 4-4 Cuttings Thickness by Distance, EPA

EPA		Distance from Well Site									
		0-10m	10-100m	100-200m	200-500m	500m -1km	1-2km	2-4km	4-5km	5-31km	>31km
Cuttings Type		Cuttings Thickness (mm)									
	March										
WBM	Mean	41	10	1	1	-	-	-	-	-	-
	Maximum	58	88 [1]	4	1	-	-	-	-	-	-
SBM	Mean	-	<0.01	0.01	0.02	0.03	0.02	-	-	0.01	0.03
	Maximum	-	<0.01	0.04	0.1	0.1	0.1	-	-	0.05	0.3
	June										
WBM	Mean	20	8	3	1	-	-	-	-	-	-
	Maximum	35	97 [2]	28	1	-	-	-	-	-	-
SBM	Mean	-	-	-	<0.01	0.01	0.02	-	-	-	-
	Maximum	-	-	-	0.01	0.1	0.12	-	-	-	-
	September										
WBM	Mean	10	6	6	1	-	-	-	-	-	-
	Maximum	25	80 [3]	40	9	-	-	-	-	-	-
SBM	Mean	<0.01	0.03	0.05	0.02	<0.01	<0.01	-	-	0.03	-
	Maximum	0.01	0.13	0.19	0.15	0.06	0.02	-	-	0.4	-
	December										
WBM	Mean	17	12	2	1	-	-	-	-	-	-
	Maximum	37	116 [4]	17	2	-	-	-	-	-	-
SBM	Mean	<0.01	<0.01	<0.01	0.02	0.02	<0.01	-	-	0.06	-
	Maximum	<0.01	0.02	0.06	0.10	0.10	0.05	-	-	0.4	-

[1] maximum located at (0.02 km, 0°); [2] at (0.02 km, 292°); [3] at (0.05 km, 35°); [4] at (0.06 km, 151°)

The cuttings deposition map figures are presented for each of the four seasonal scenarios – March, June, September and December - and for each, the modelled total cuttings, WBM cuttings, SBM cuttings and total cuttings for PNET limits thicknesses are shown. For the EPA site, these maps are shown in Figure 4-17 to Figure 4-32.

As reported in Table 4-4, the maximum monthly WBM thicknesses reach 80 to 116 mm and are located within 20 to 60 m of the wellhead. The largest thickness is 116 mm at 60 m to the southeast in December. WBM cuttings mean thicknesses within 100 m of the wellhead are about 10 mm up to 41 mm (in March).

Outside of 100 m out to 500 m mean thicknesses are on typically the order of 1 to 2 mm with maximum thicknesses of 40 mm at 150 m to the east in September.

March

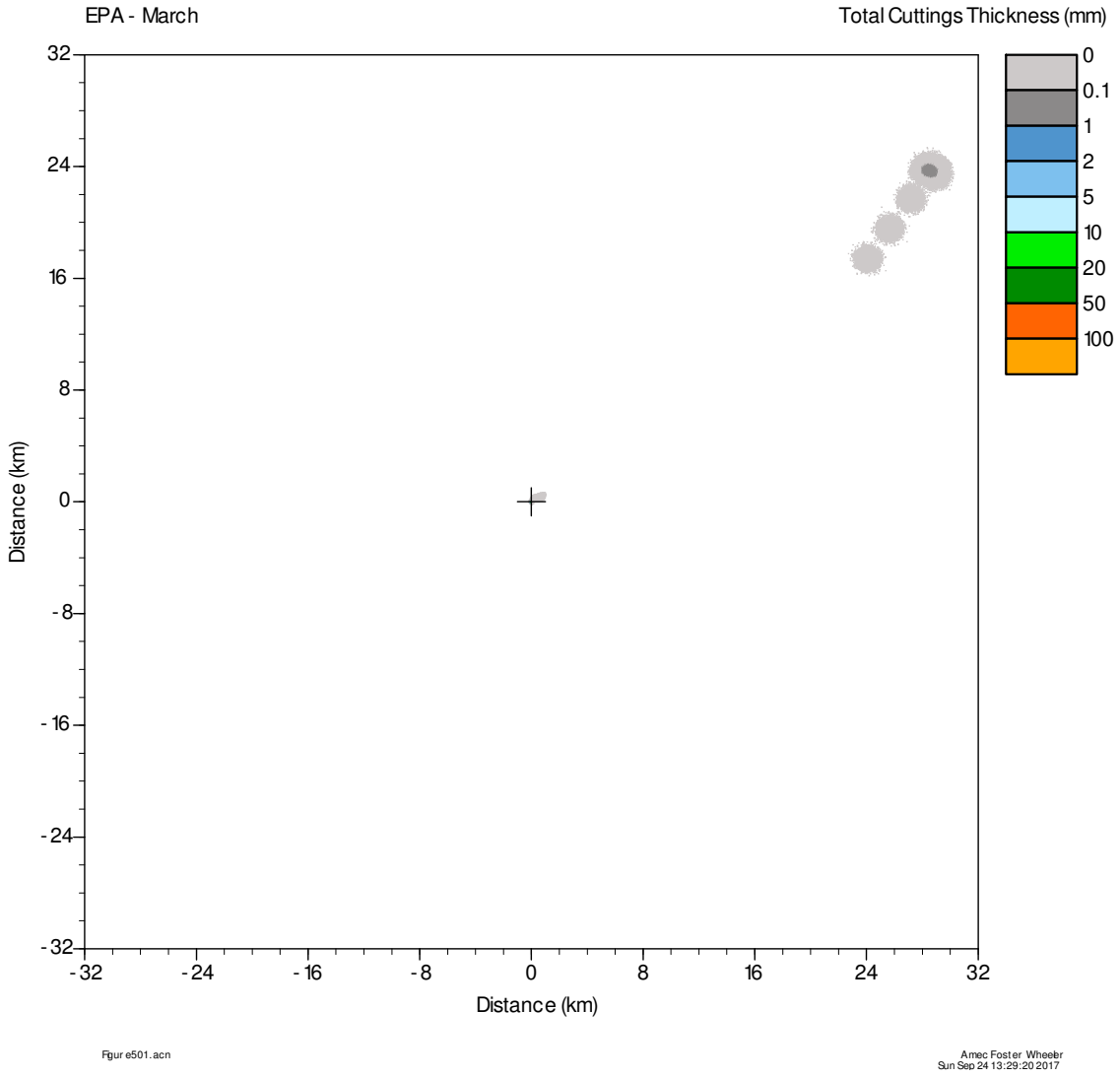


Figure 4-17 Total Drill Cuttings Deposition, EPA, March, 32-km View

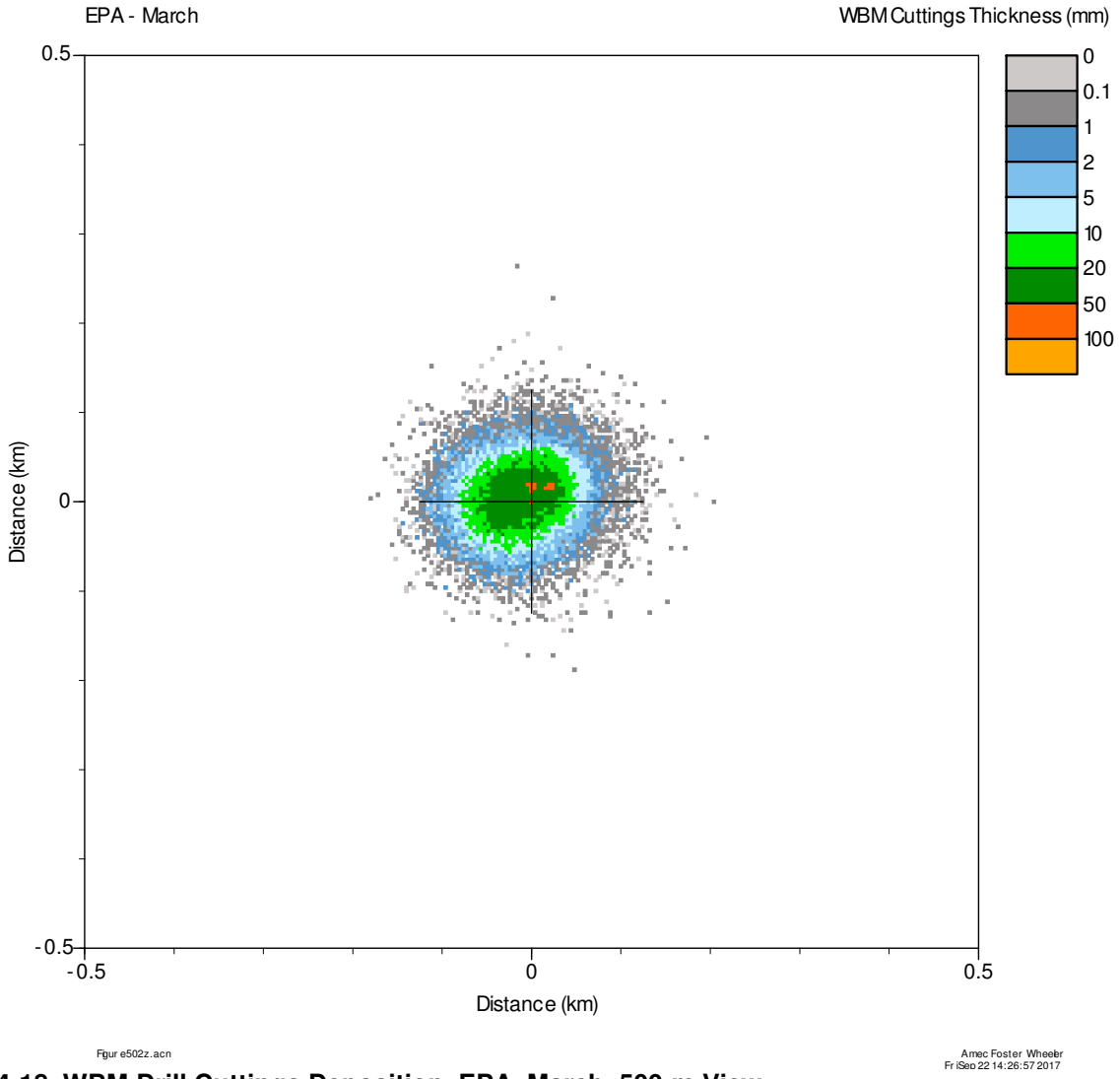


Figure 4-18 WBM Drill Cuttings Deposition, EPA, March, 500-m View

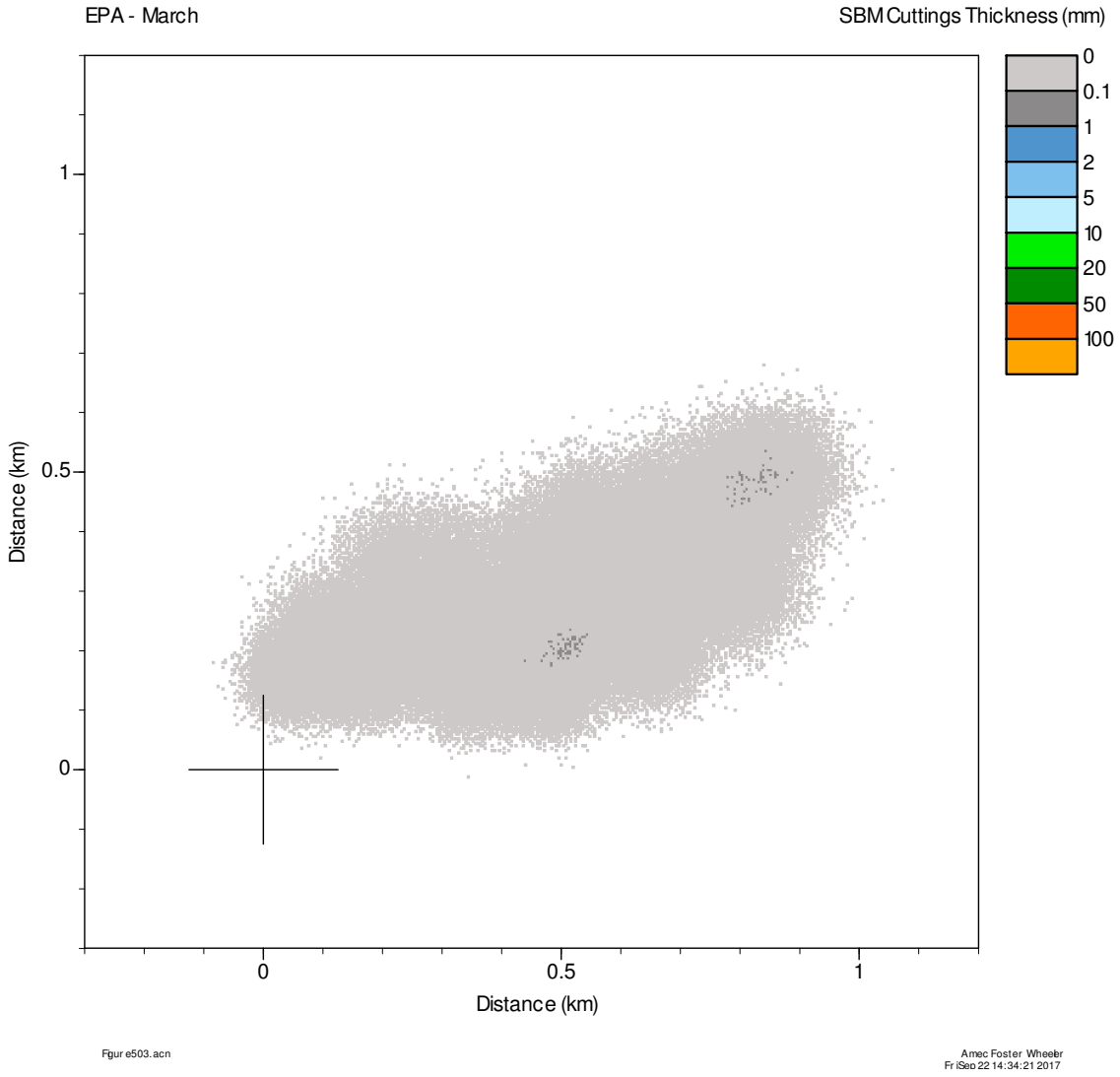


Figure 4-19 SBM Drill Cuttings Deposition, EPA, March, 750-m View

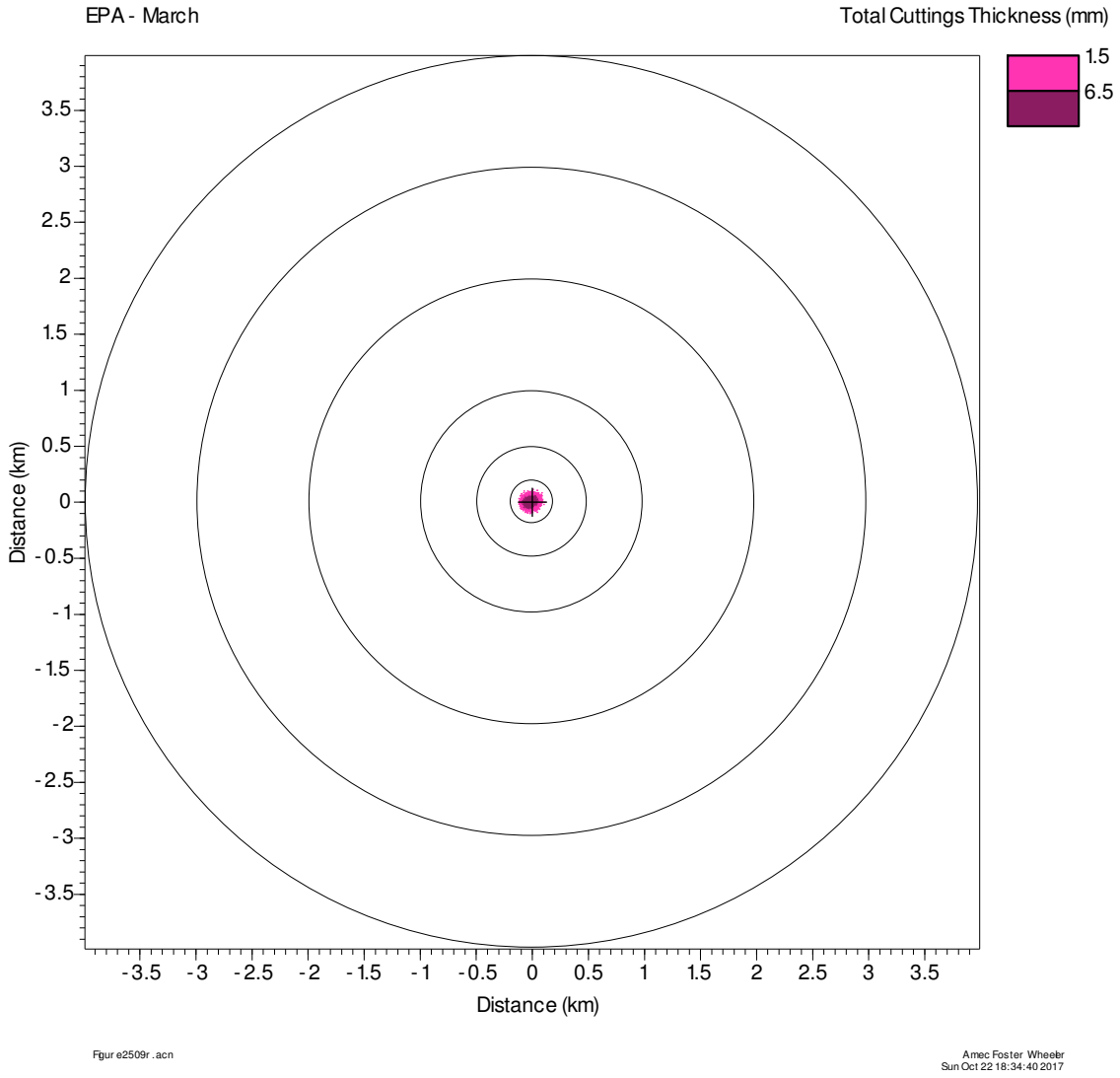


Figure 4-20 Total Drill Cuttings Deposition, PNET Limits, EPA, March, 4-km View

June

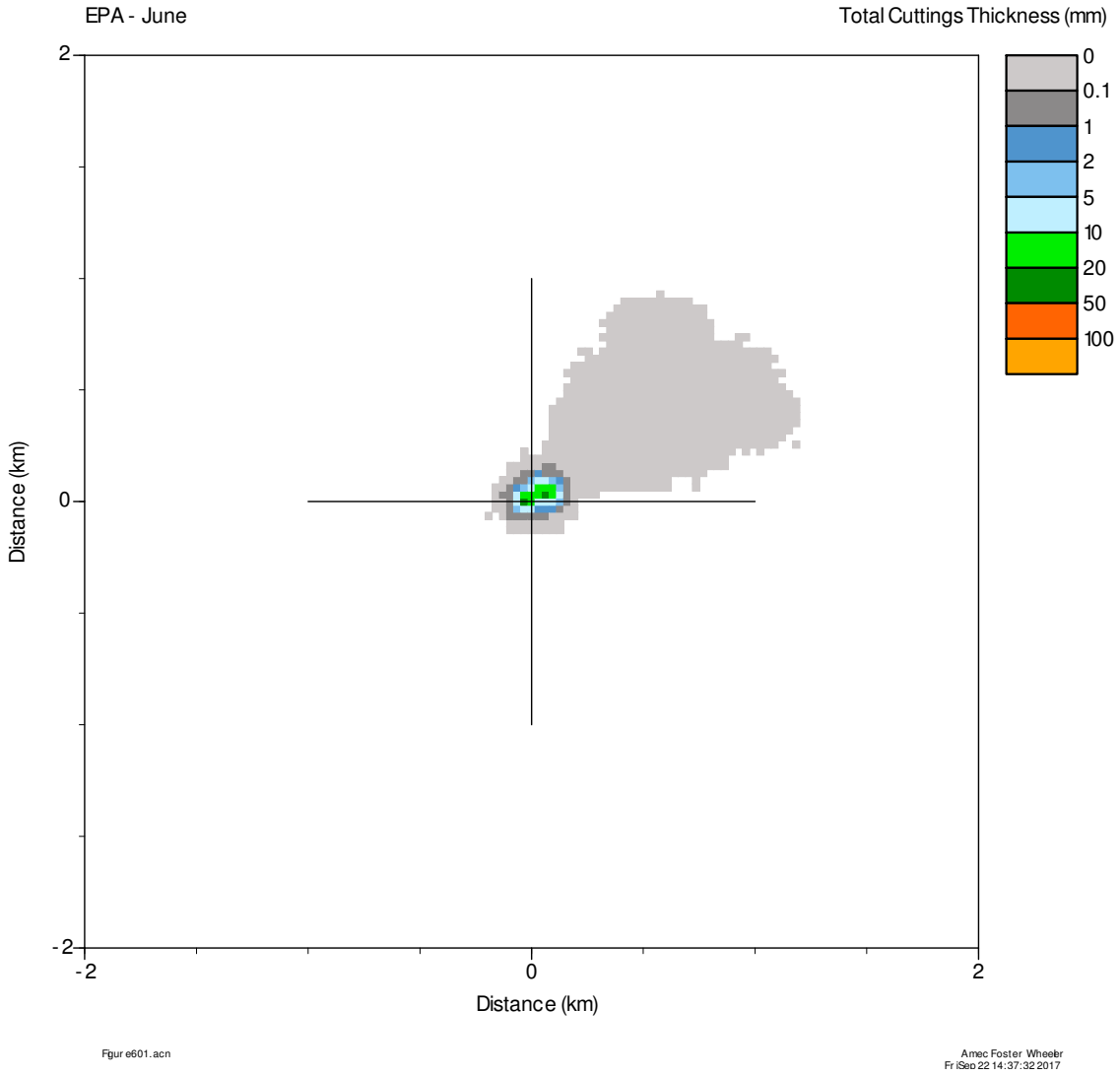


Figure 4-21 Total Drill Cuttings Deposition, EPA, June, 2-km View

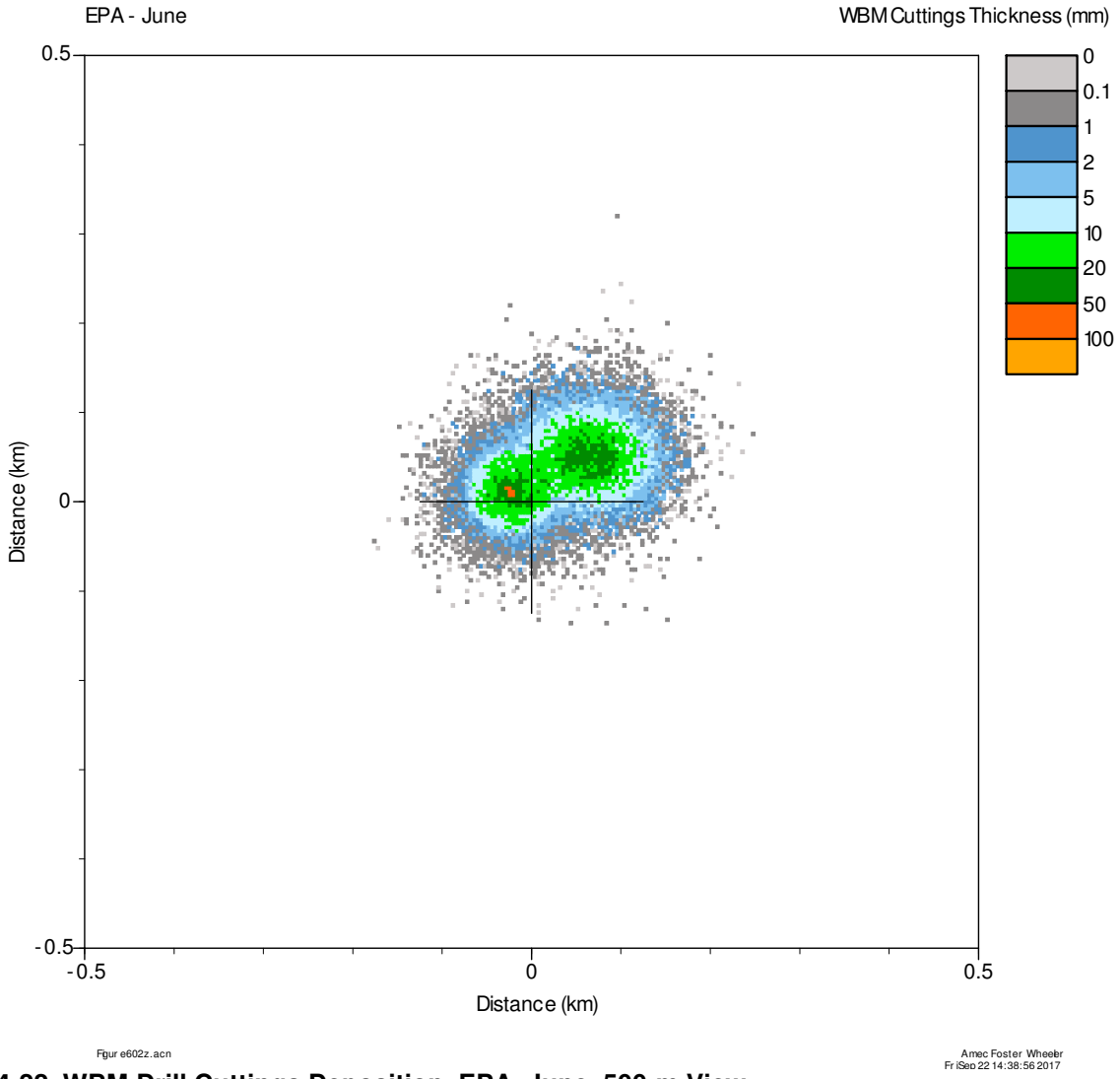


Figure 4-22 WBM Drill Cuttings Deposition, EPA, June, 500-m View

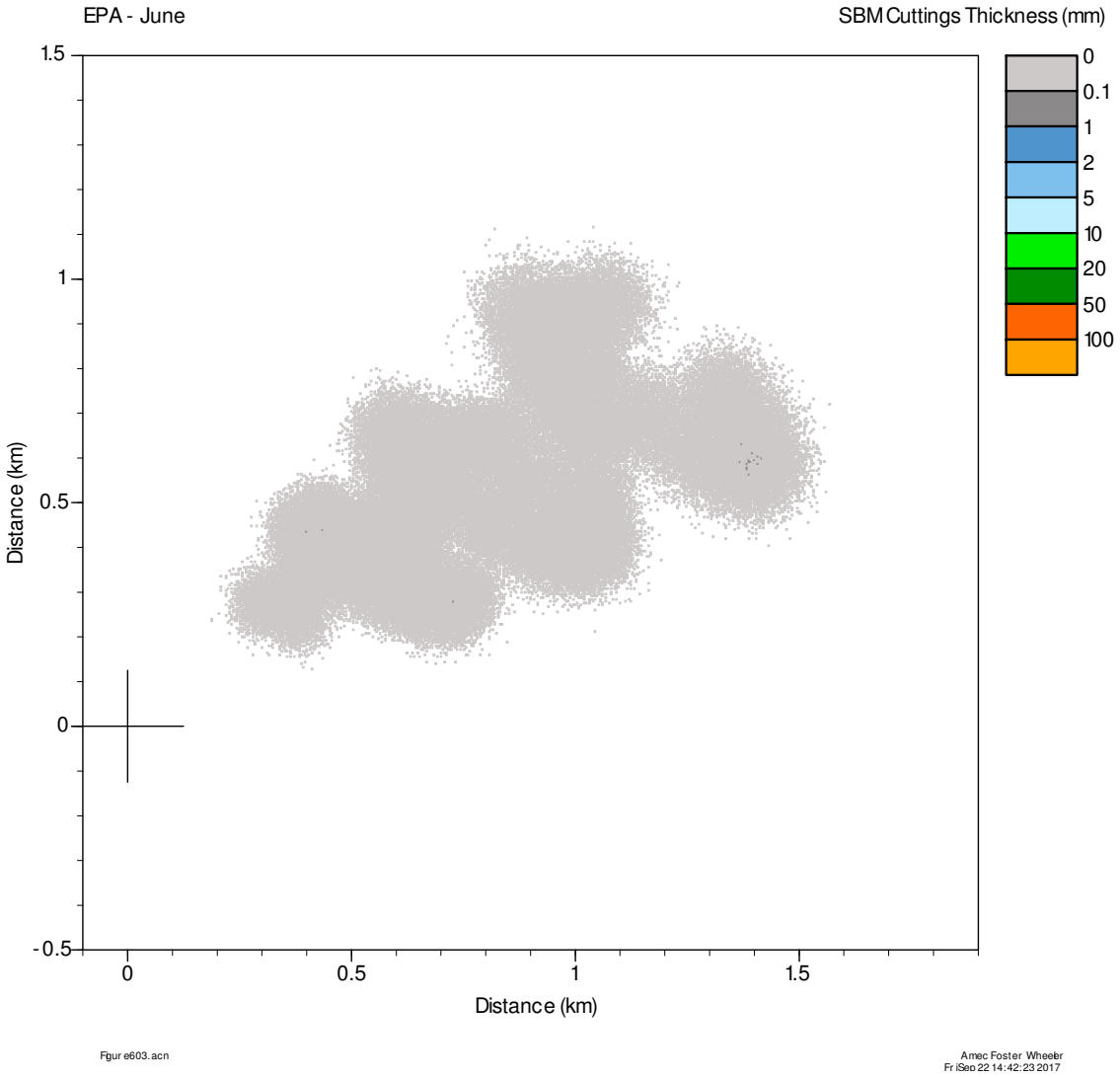


Figure 4-23 SBM Drill Cuttings Deposition, EPA, June, 750-m View

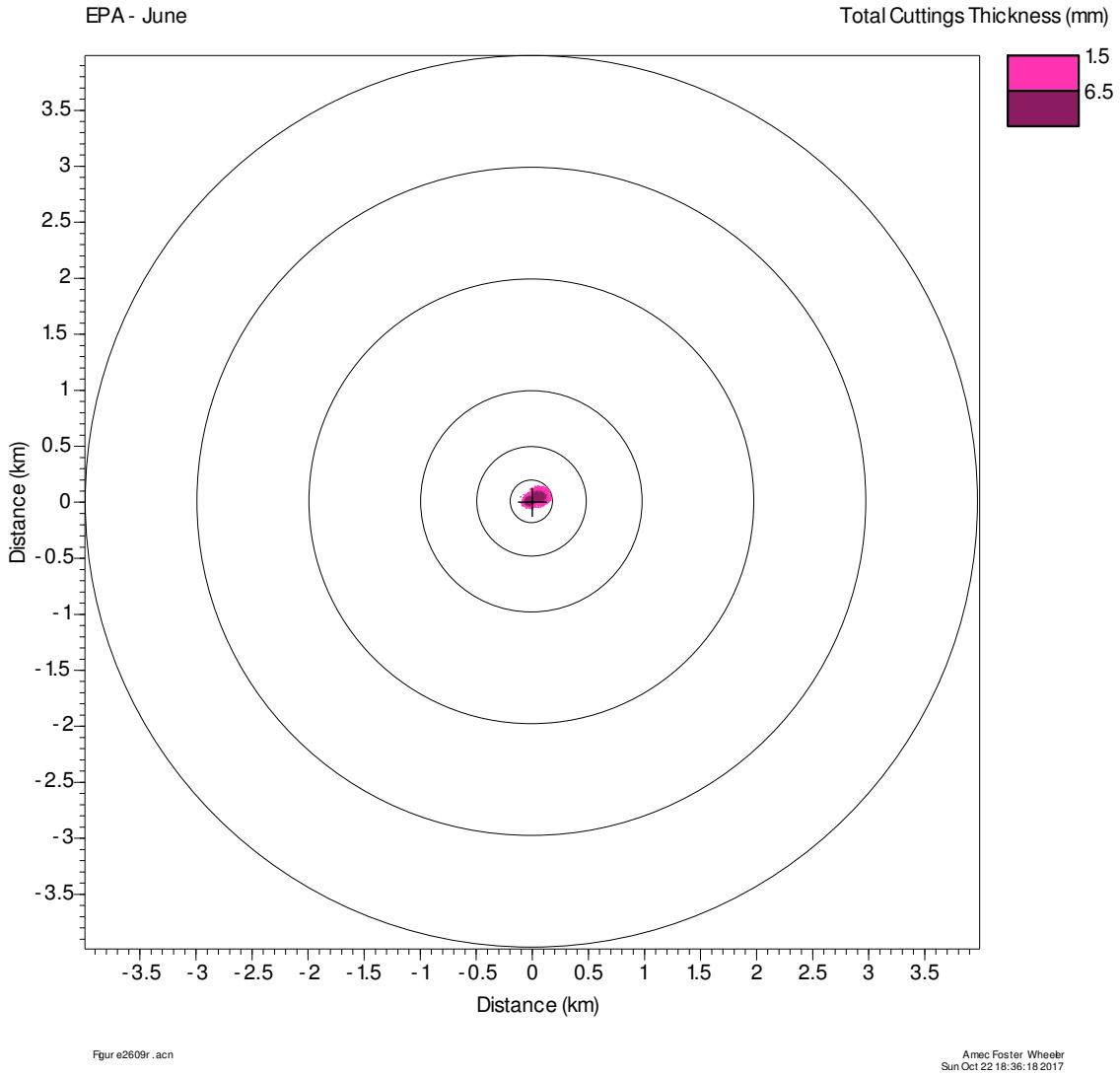


Figure 4-24 Total Drill Cuttings Deposition, PNET Limits, EPA, June, 4-km View

September

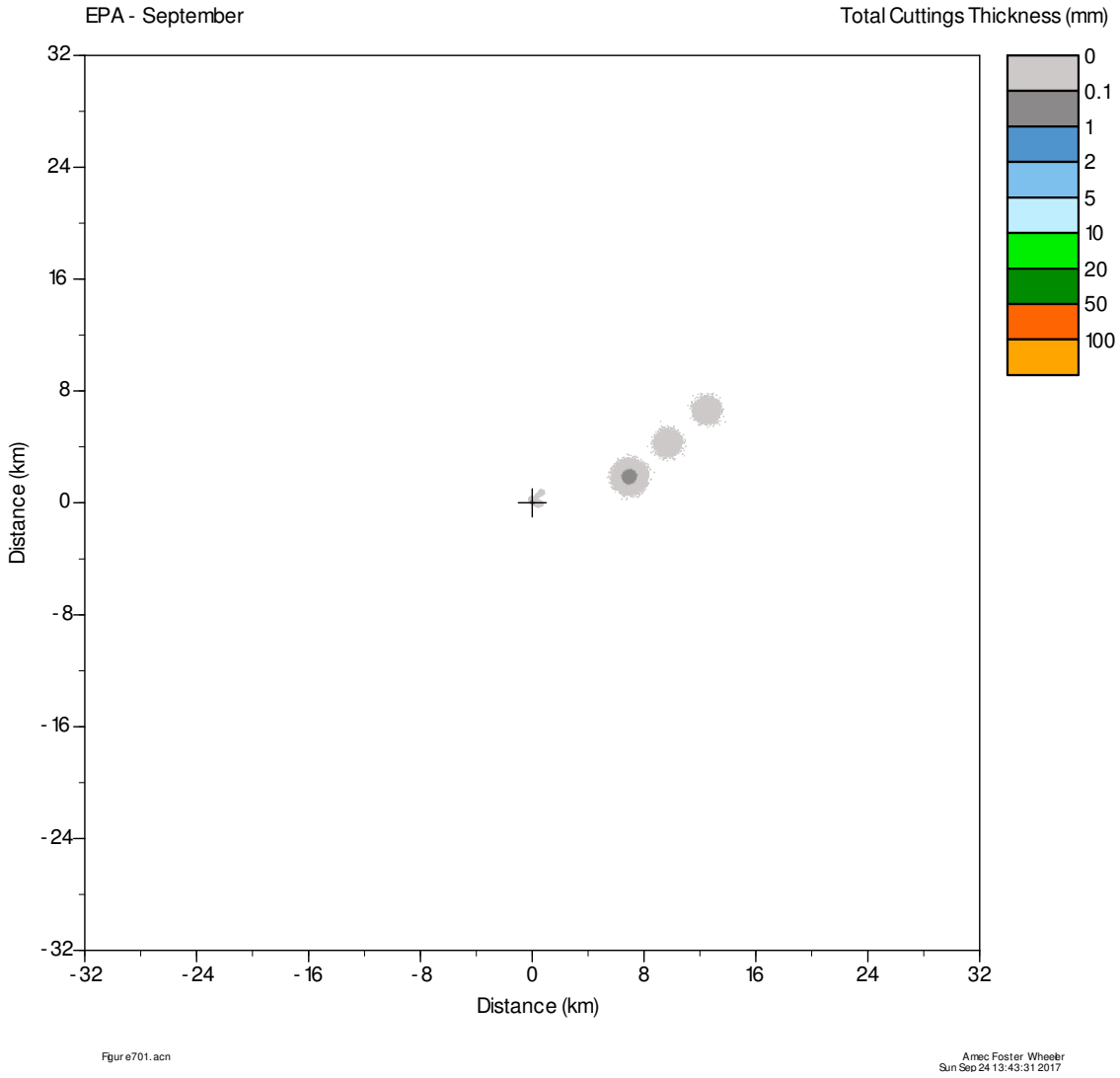


Figure 4-25 Total Drill Cuttings Deposition, EPA, September, 32-km View

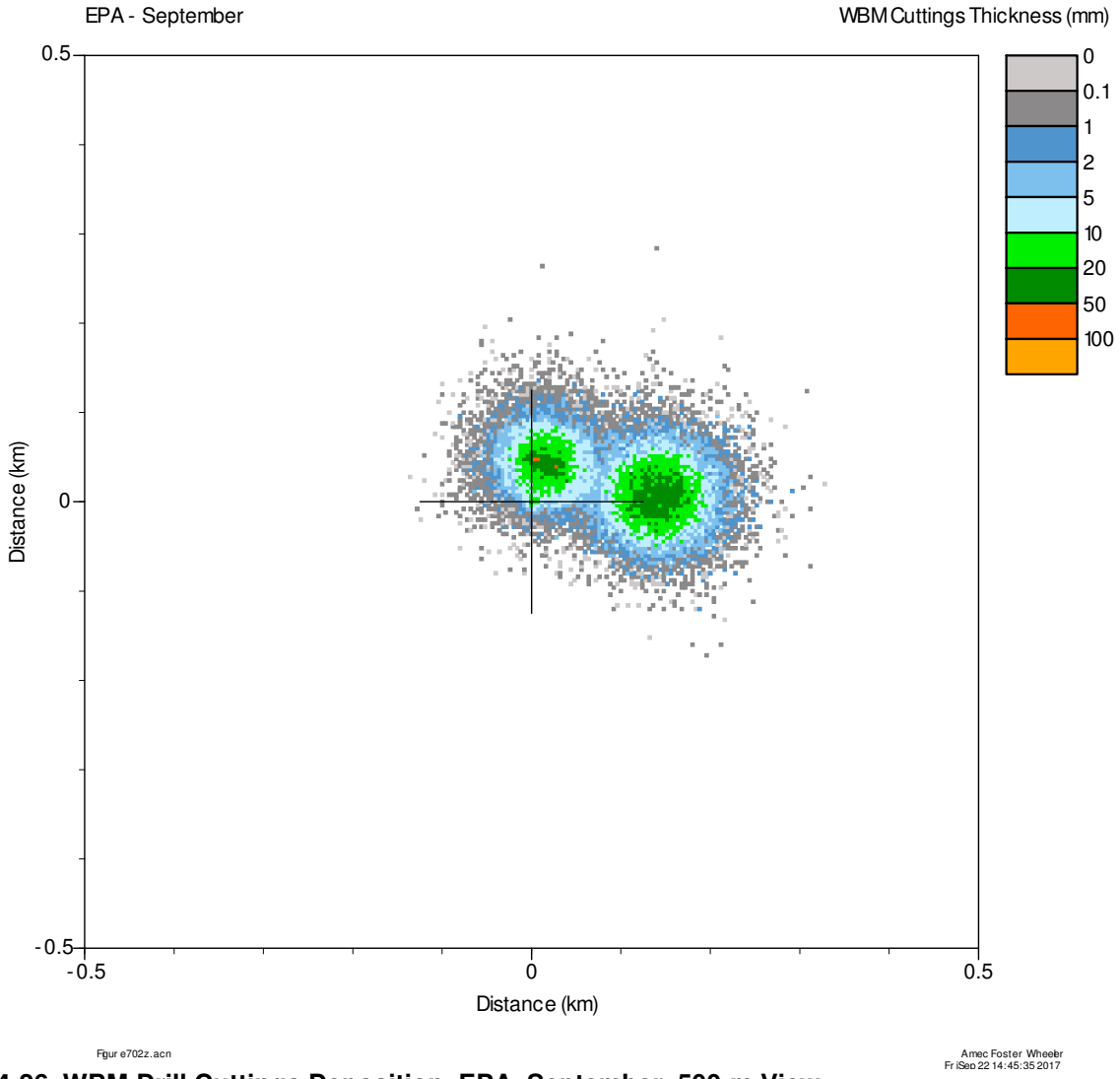


Figure 4-26 WBM Drill Cuttings Deposition, EPA, September, 500-m View

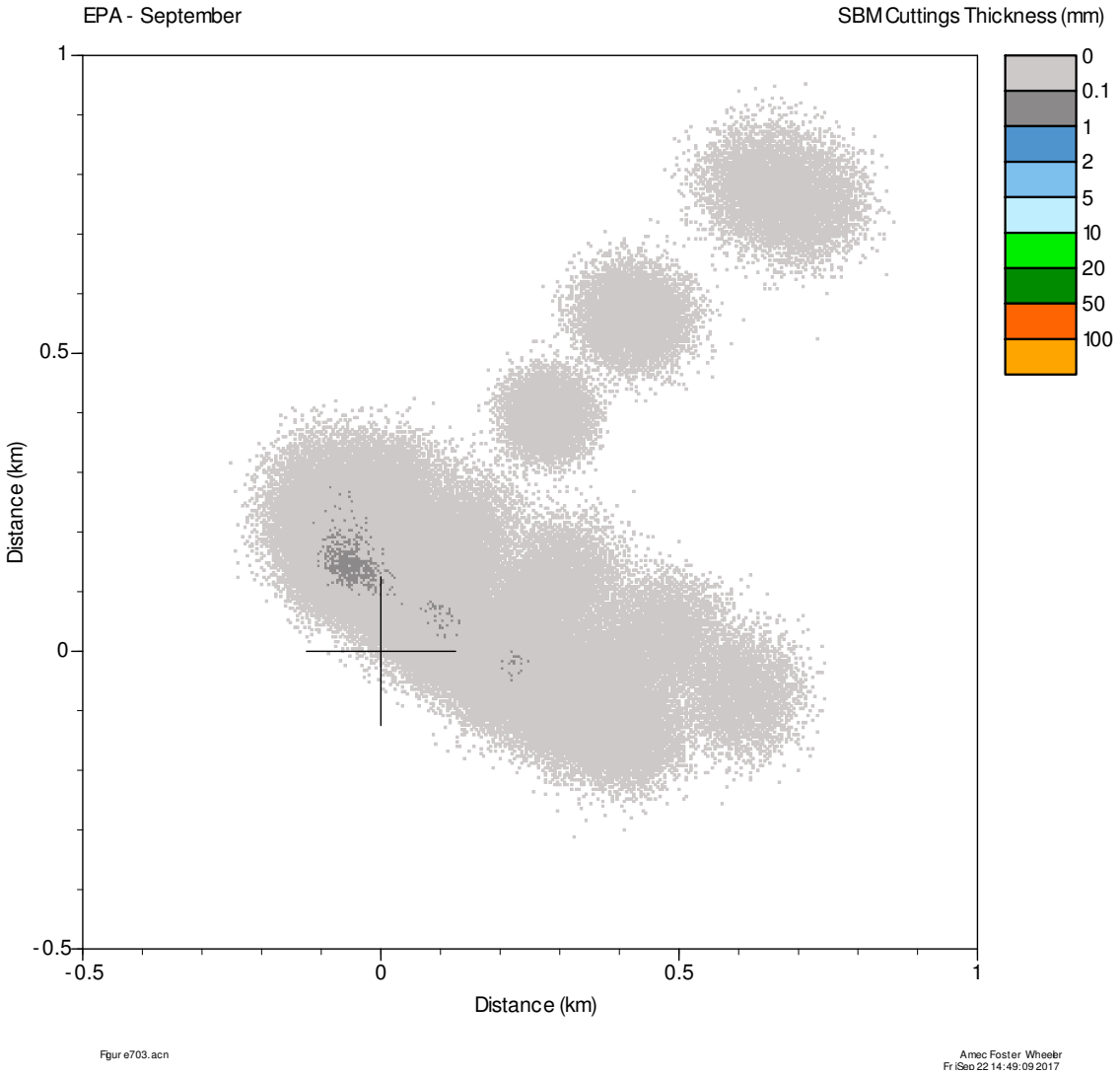


Figure 4-27 SBM Drill Cuttings Deposition, EPA, September, 750-m View

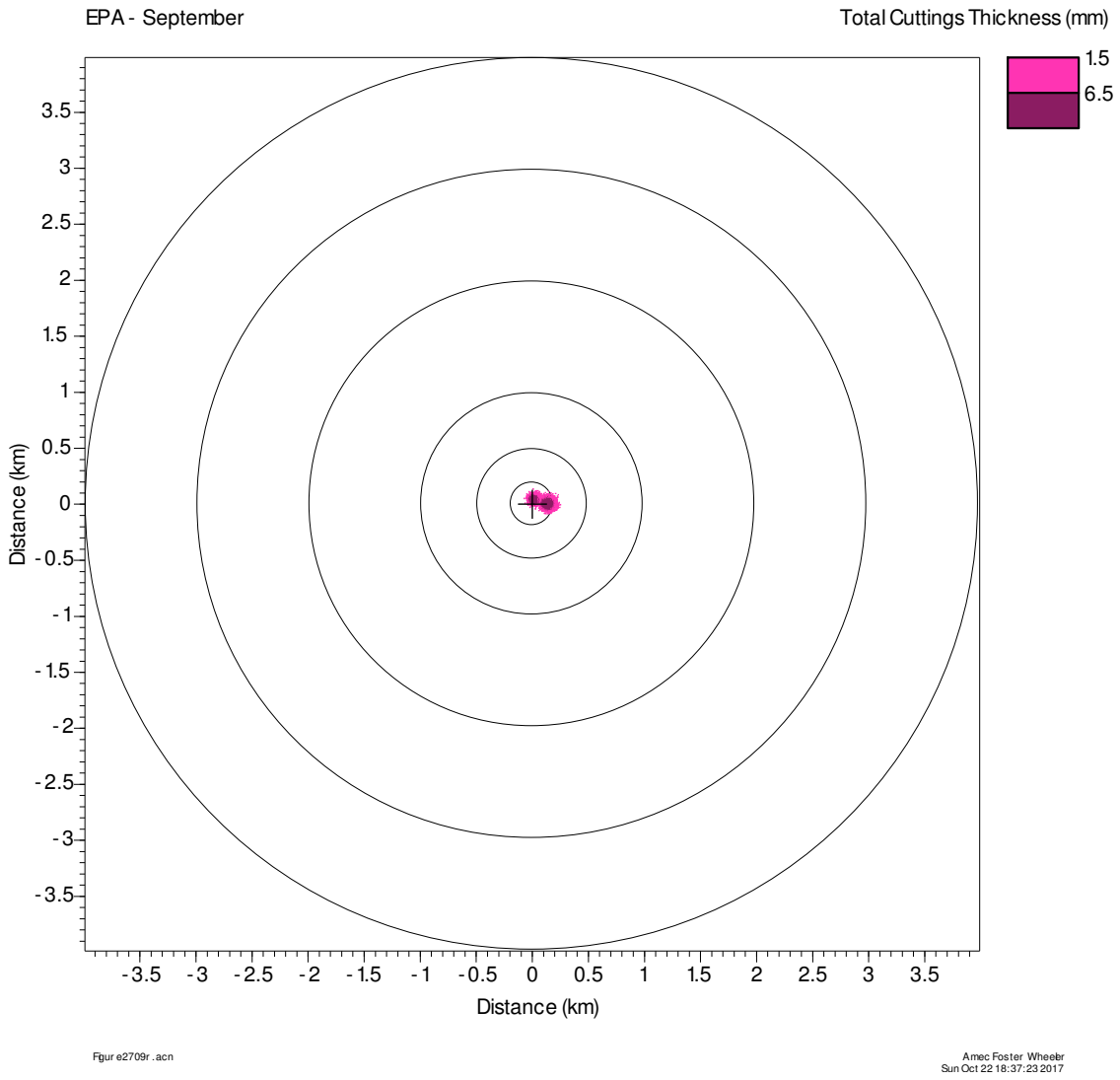


Figure 4-28 Total Drill Cuttings Deposition, PNET Limits, EPA, September, 4-km View

December

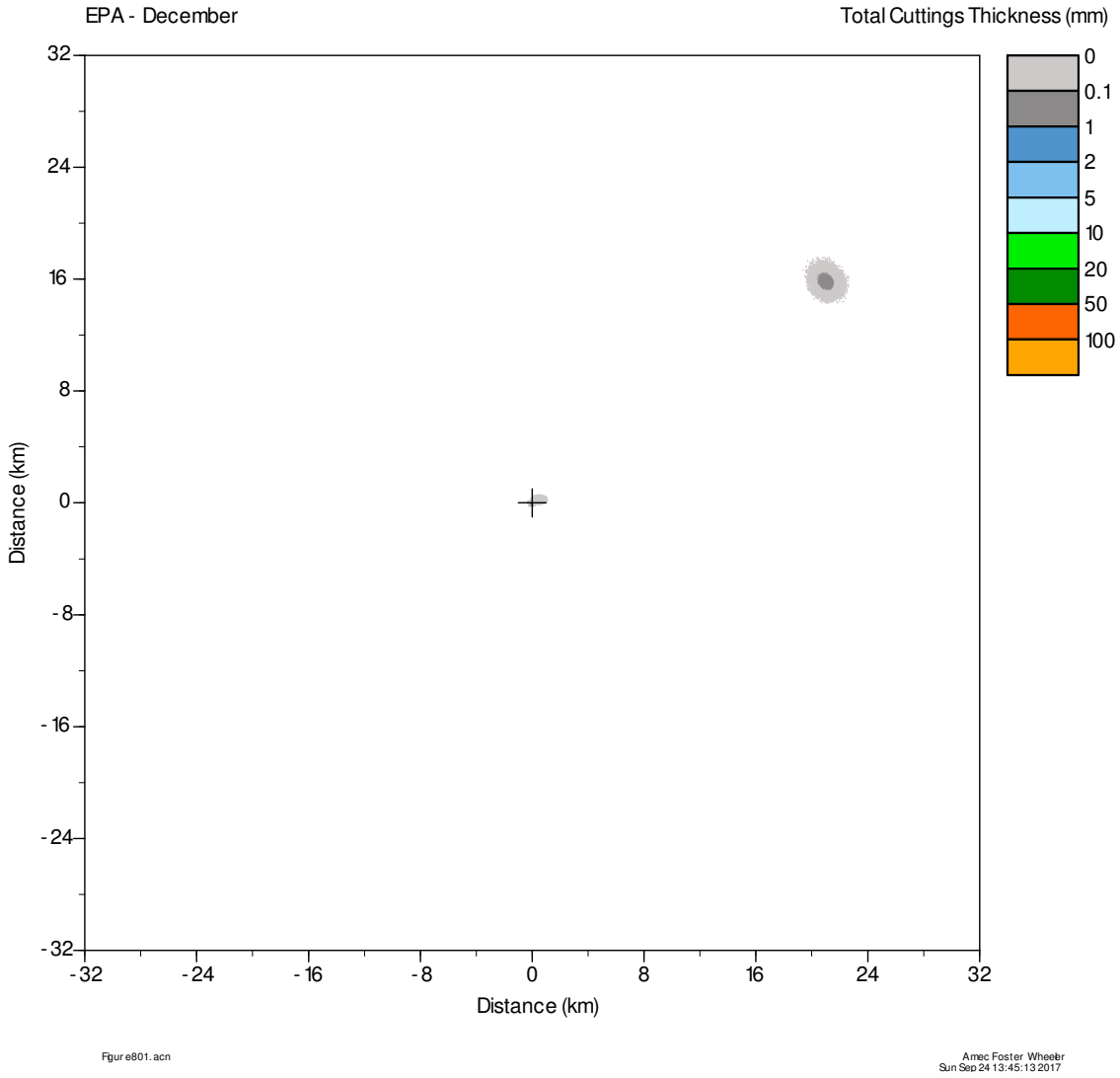


Figure 4-29 Total Drill Cuttings Deposition, EPA, December, 2-km View

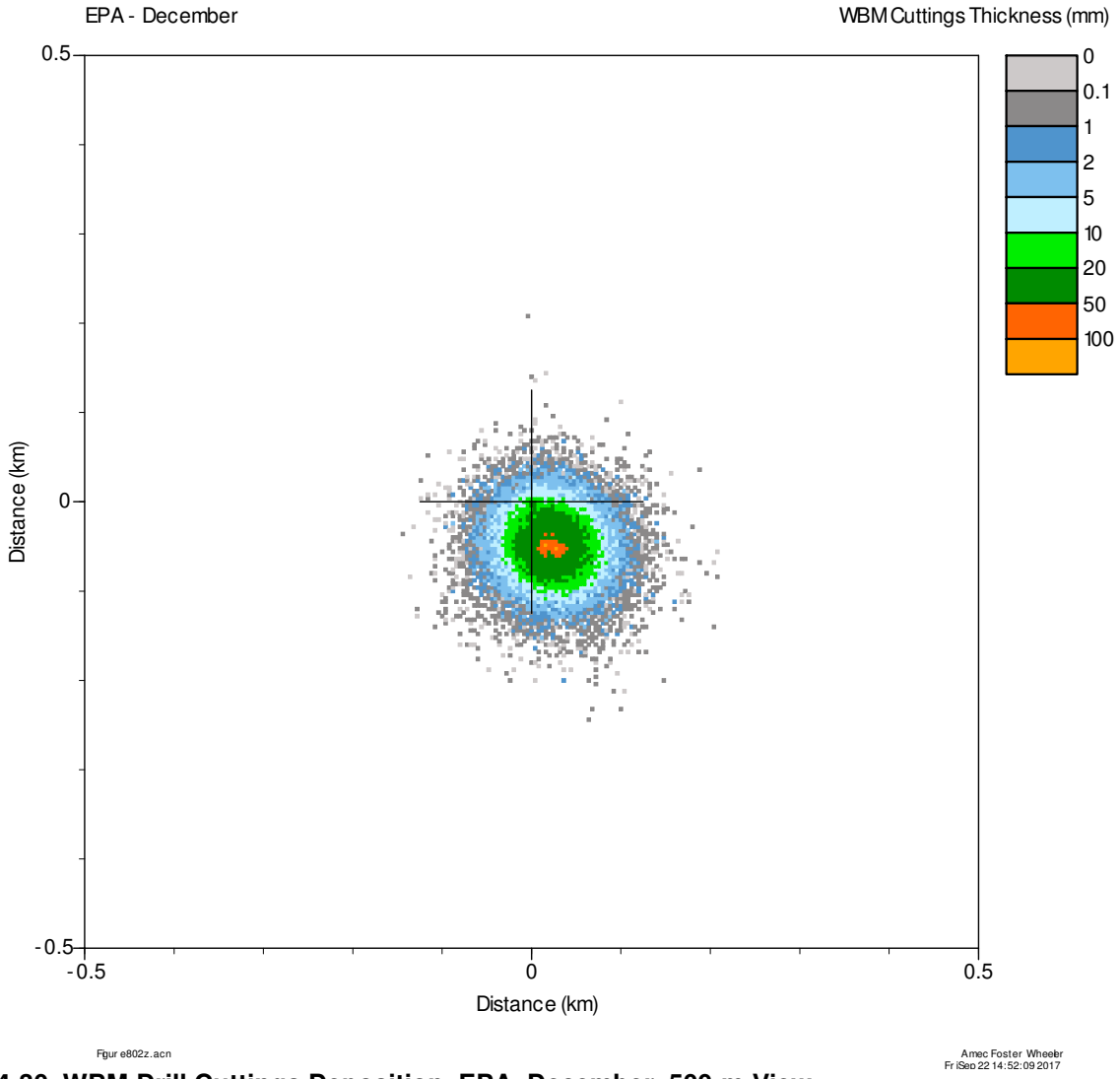


Figure 4-30 WBM Drill Cuttings Deposition, EPA, December, 500-m View

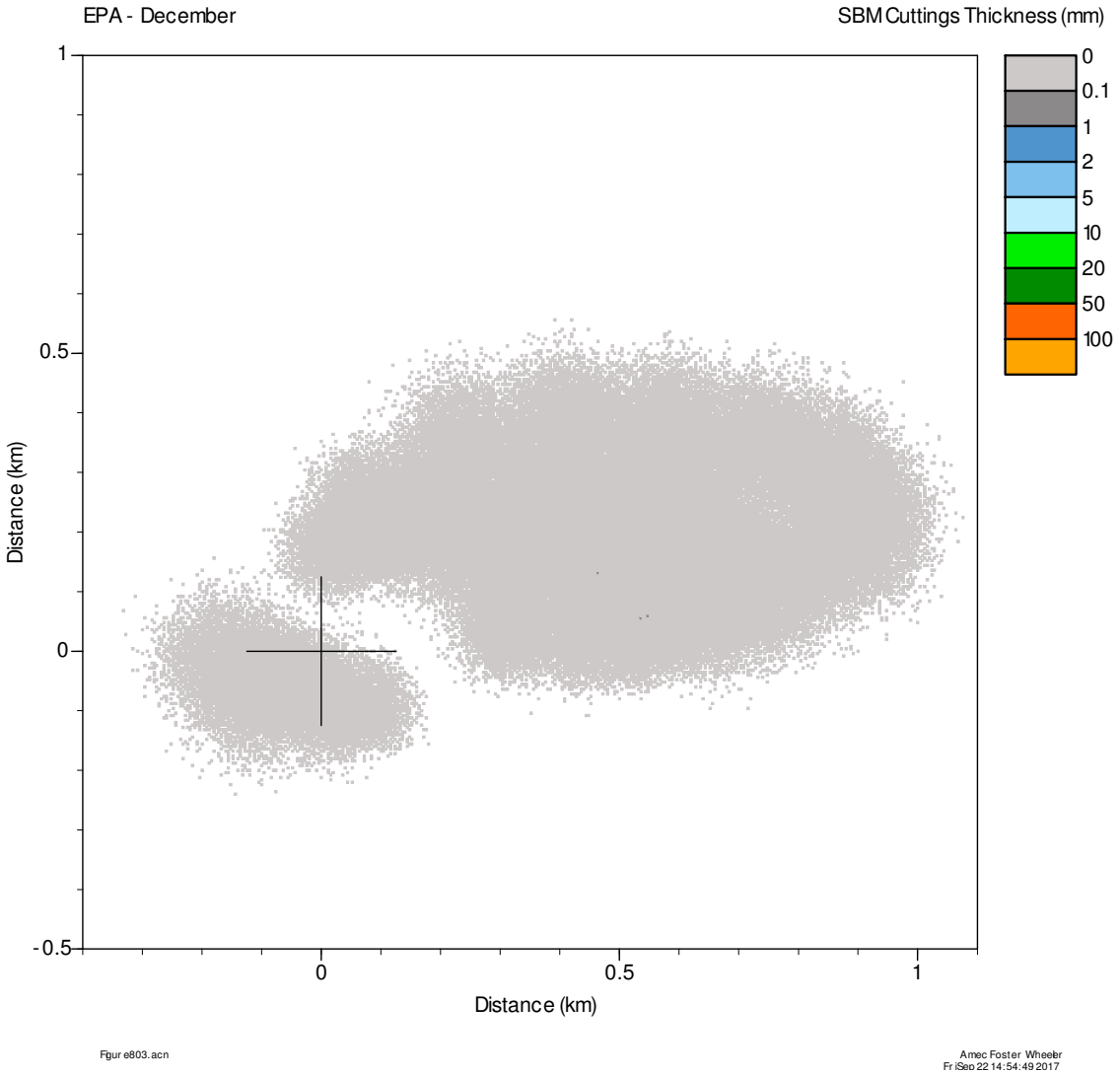


Figure 4-31 SBM Drill Cuttings Deposition, EPA, December, 3-km View

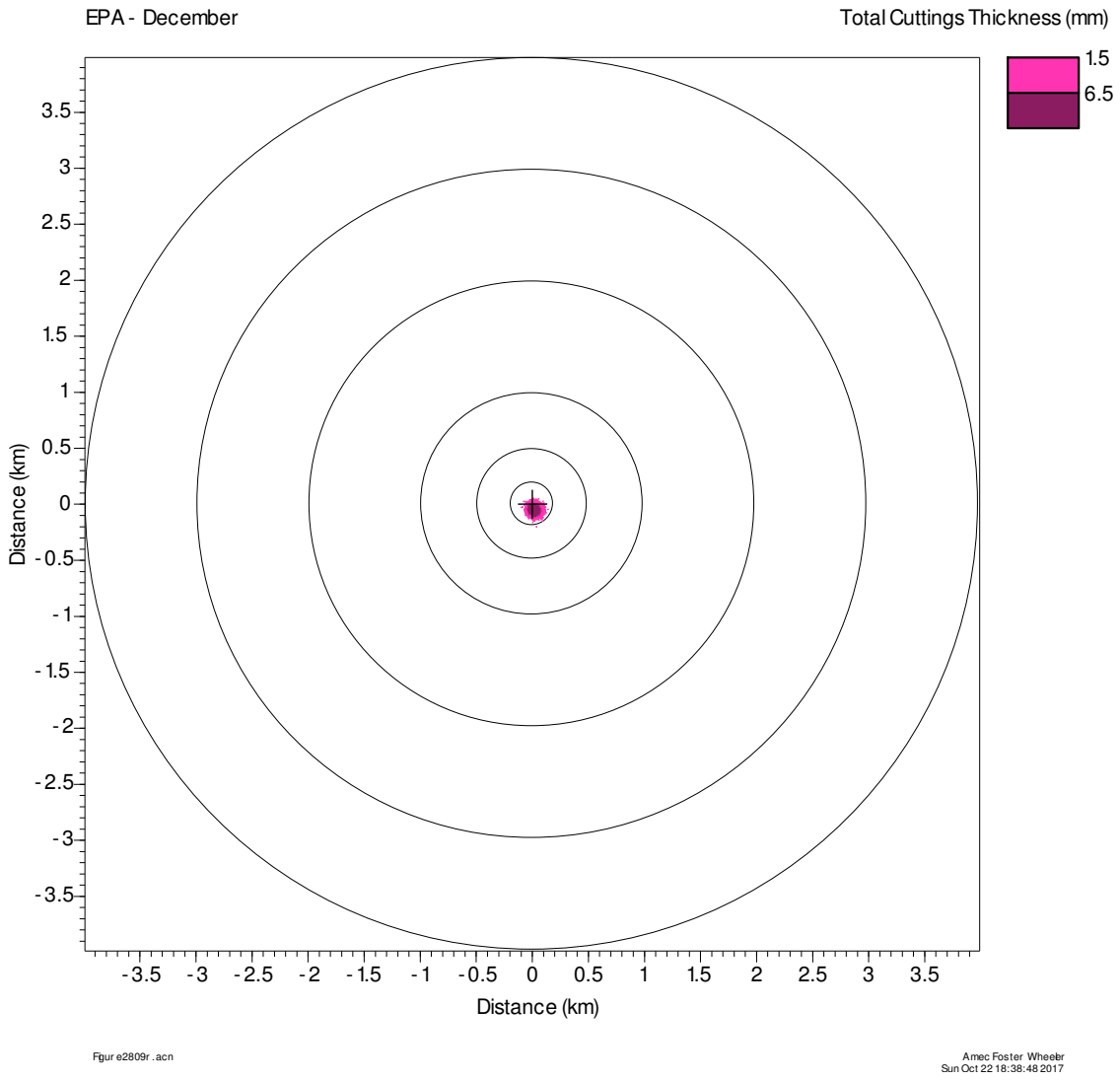


Figure 4-32 Total Drill Cuttings Deposition, PNET Limits, EPA, December, 4-km View

4.3 Southern Project Area

This section presents results of cuttings modelling for the SPA location. Four seasonal scenarios are presented with drilling of wells commencing in March, June, September and December.

At the SPA site all of the WBM cuttings released at the wellhead settle within 1 km (Table 4-5). In all months a small amount of material (less than one percent) settles within 100 m of the wellhead with the rest settling between 100 m to 1 km. The material travels the least in September with virtually all (greater than 99 percent) of the WBM cuttings settling within 500 m.

Conversely, the vast majority of the SBM cuttings released from the MODU at the sea surface – with a water depth at SPA of 362 m - fail to settle within the model domain of 32 km (Table 4-5). Only about 1.7 percent or less of SBM cuttings released settle on the seabed before drifting outside the model domain. At a depth of about 362 m to settle, the very fine sand, silts and clay SBM cuttings particles released near the surface might be expected to take on the order of 4 days to settle and, at an assumed mean current speed of 15-20 cm/s (e.g., Table 3-8), travel greater than 50 km.

Table 4-5 Cuttings Material Settled by Distance, SPA

SPA		Distance from Well Site										
		0-10m	10-100m	100-200m	200-500m	500m-1km	1-2km	2-4km	4-5km	5-31km	>31km	
Month	Cuttings Type	% Material Settled										% Material Unsettled
Mar	WBM	0.4	0.3	<0.1	44	56	-	-	-	-	-	-
	SBM	-	-	-	0.3	0.8	0.6	-	-	-	-	98.3
Jun	WBM	0.4	0.3	9	51	39	-	-	-	-	-	-
	SBM	-	-	-	<0.1	0.7	0.9	-	-	-	-	98.3
Sep	WBM	0.3	0.5	21	78	0.1	-	-	-	-	-	-
	SBM	-	-	-	-	0.1	0.9	0.6	-	-	-	98.3
Dec	WBM	0.2	0.5	34	8	58	-	-	-	-	-	-
	SBM	-	-	-	-	0.1	0.9	0.7	-	-	-	98.3

Note: due to rounding some row percentage totals may not exactly equal 100.

At SPA, the farthest distance that any SBM cuttings settle, at any thickness, is March at 1.7 km, June at 1.9 km, September at 3.0 km and December at 2.8 km.

Table 4-6 Cuttings Thickness by Distance, SPA

SPA		Distance from Well Site									
		0-10m	10-100m	100-200m	200-500m	500m -1km	1-2km	2-4km	4-5km	5-31km	>31km
Cuttings Type		Cuttings Thickness (mm)									
	March										
WBM	Mean	3	0.4	0.3	2.4	4	-	-	-	-	-
	Maximum	12	10	1	80 [1]	20	-	-	-	-	-
SBM	Mean	-	-	-	<0.01	<0.01	<0.01	-	-	-	-
	Maximum	-	-	-	0.05	0.06	0.04	-	-	-	-
	June										
WBM	Mean	4	0.3	3	3	2	-	-	-	-	-
	Maximum	13	8	54	66 [2]	15	-	-	-	-	-
SBM	Mean	-	-	-	<0.01	<0.01	<0.01	-	-	-	-
	Maximum	-	-	-	0.03	0.06	0.06	-	-	-	-
	September										
WBM	Mean	2	0.6	-	2	3	0.6	-	-	-	-
	Maximum	9	11	-	57	74 [3]	1	-	-	-	-
SBM	Mean	-	-	-	-	<0.01	<0.01	<0.01	-	-	-
	Maximum	-	-	-	-	0.03	0.03	0.03	-	-	-
	December										
WBM	Mean	2	0.6	-	3	1	2	-	-	-	-
	Maximum	7	7	-	77 [4]	10	18	-	-	-	-
SBM	Mean	-	-	-	-	<0.01	<0.01	<0.01	-	-	-
	Maximum	-	-	-	-	0.04	0.04	0.04	-	-	-

[1] maximum located at (0.32 km, 194°) [2] at (0.20 km, 188°); [3] at (0.52 km, 194°); [4] at (0.34 km, 204°)

The cuttings deposition map figures are presented for each of the four seasonal scenarios – March, June, September and December - and for each, the modelled total cuttings, WBM cuttings, SBM cuttings and total cuttings for PNET limits thicknesses are shown. For the SPA site, these maps are shown in Figure 4-33 to Figure 4-48.

At SPA the predominant direction for drift and deposition is to the south-southwest consistent with the prevailing currents of moderate speed (on the order of 20-30 cm/s).

The WBM cuttings footprints lie in patches along a line to the south-southwest. The material settles as far as about 700 m away in March, within 800 m in June, 1 km in September and as far as 1.5 km in December (Figure 4-46).

As reported in Table 4-6 WBM thicknesses are as high as 80 mm in March seen at 320 m to the south-southwest of the wellhead. The largest thicknesses are seen in the range of 200 to 500 m and include 57 mm in September, 66 mm in June and 77 mm in December. Average WBM cuttings thicknesses out to 1 km are generally between 1 mm (or less) and 4 mm in all months.

March

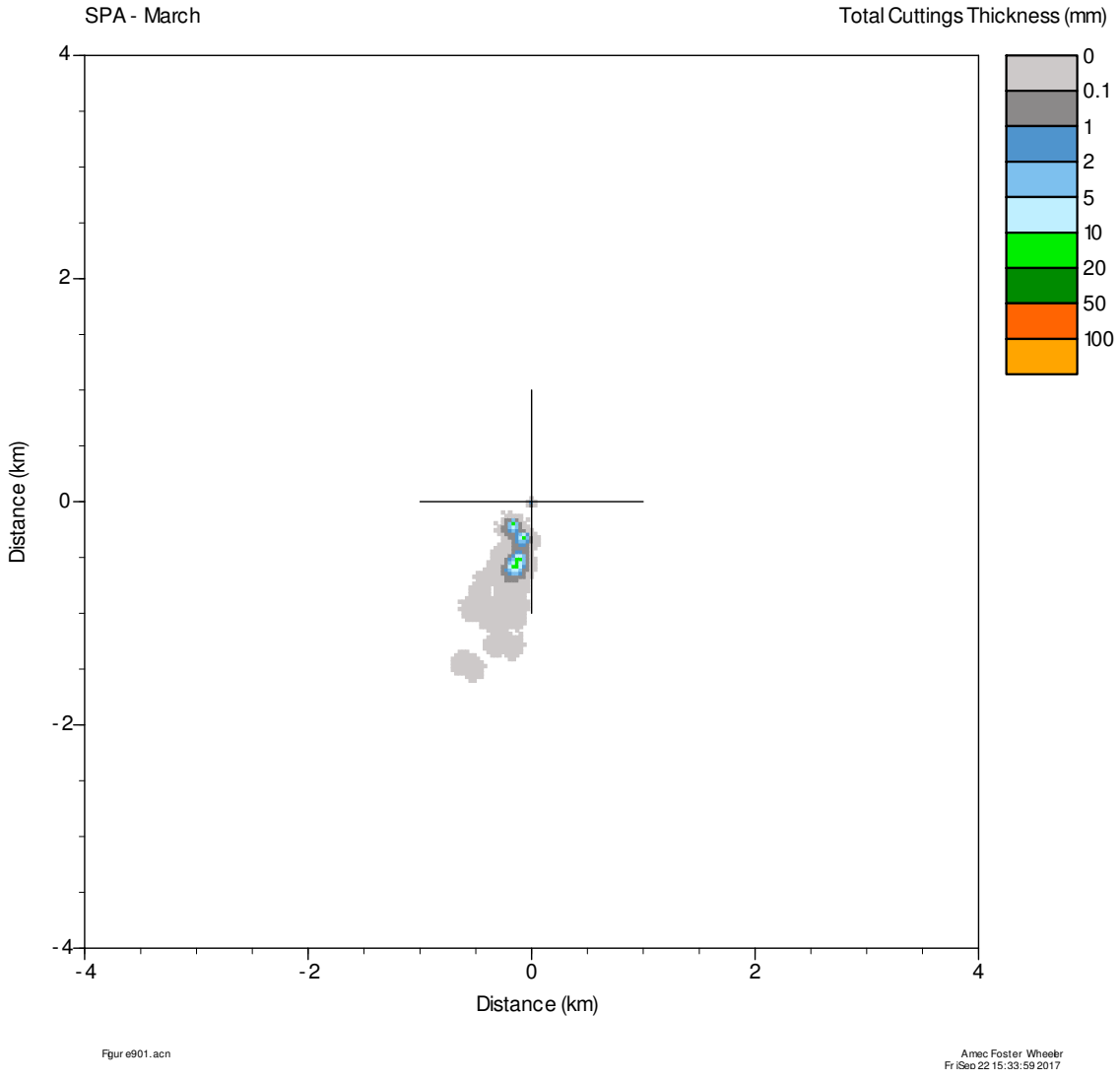


Figure 4-33 Total Drill Cuttings Deposition, SPA, March, 4-km View

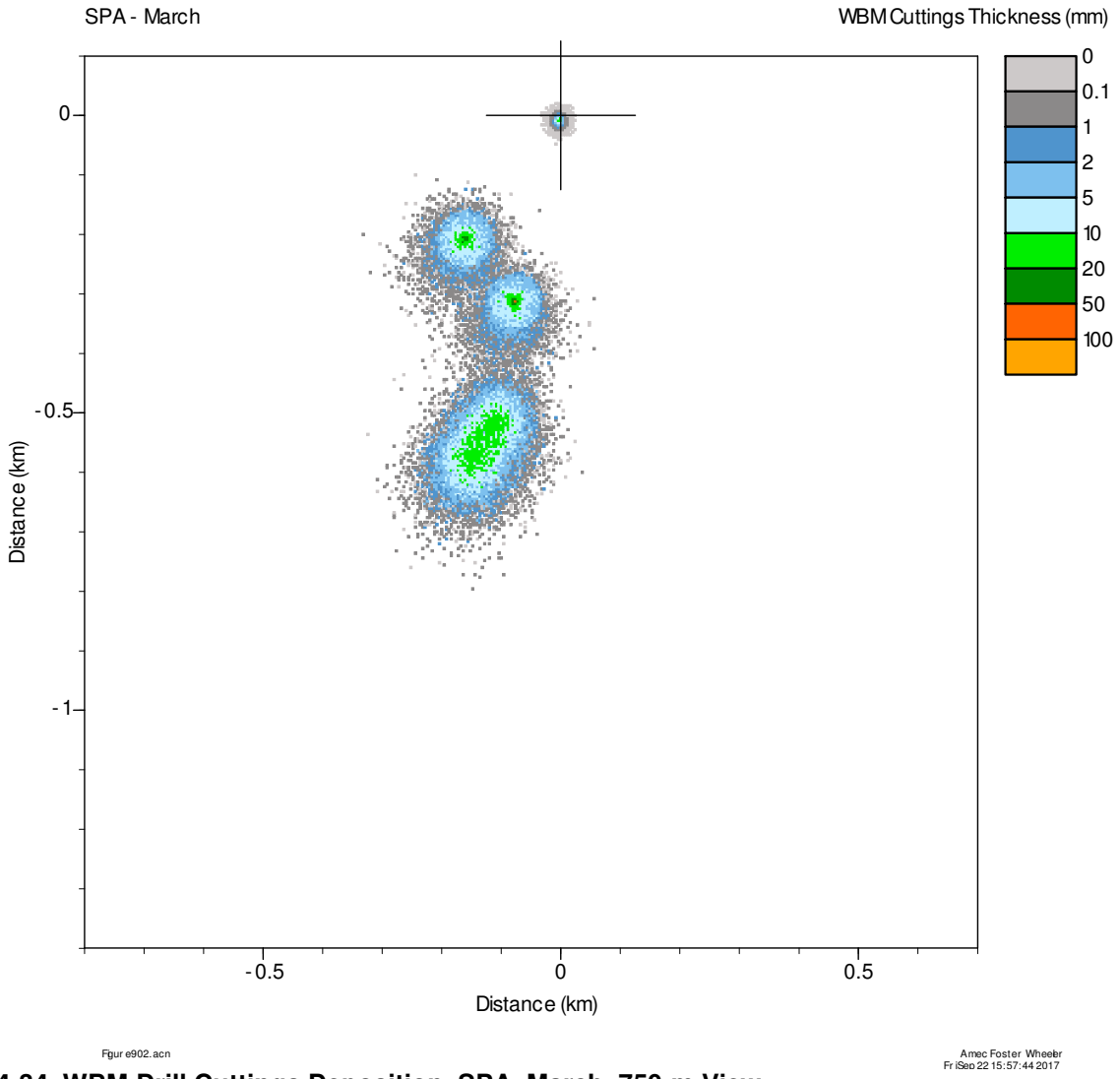


Figure 4-34 WBM Drill Cuttings Deposition, SPA, March, 750-m View

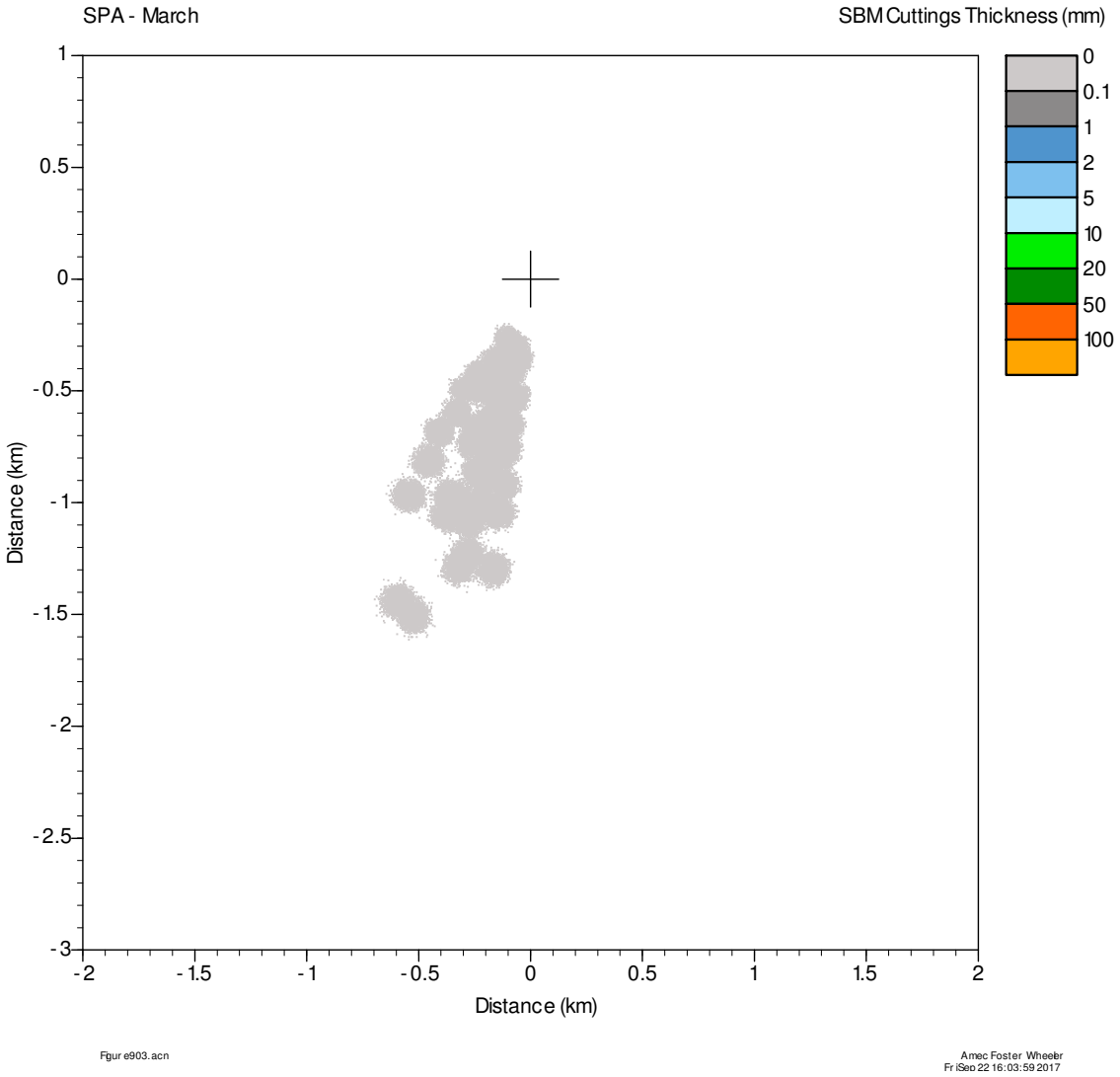


Figure 4-35 SBM Drill Cuttings Deposition, SPA, March, 2-km View

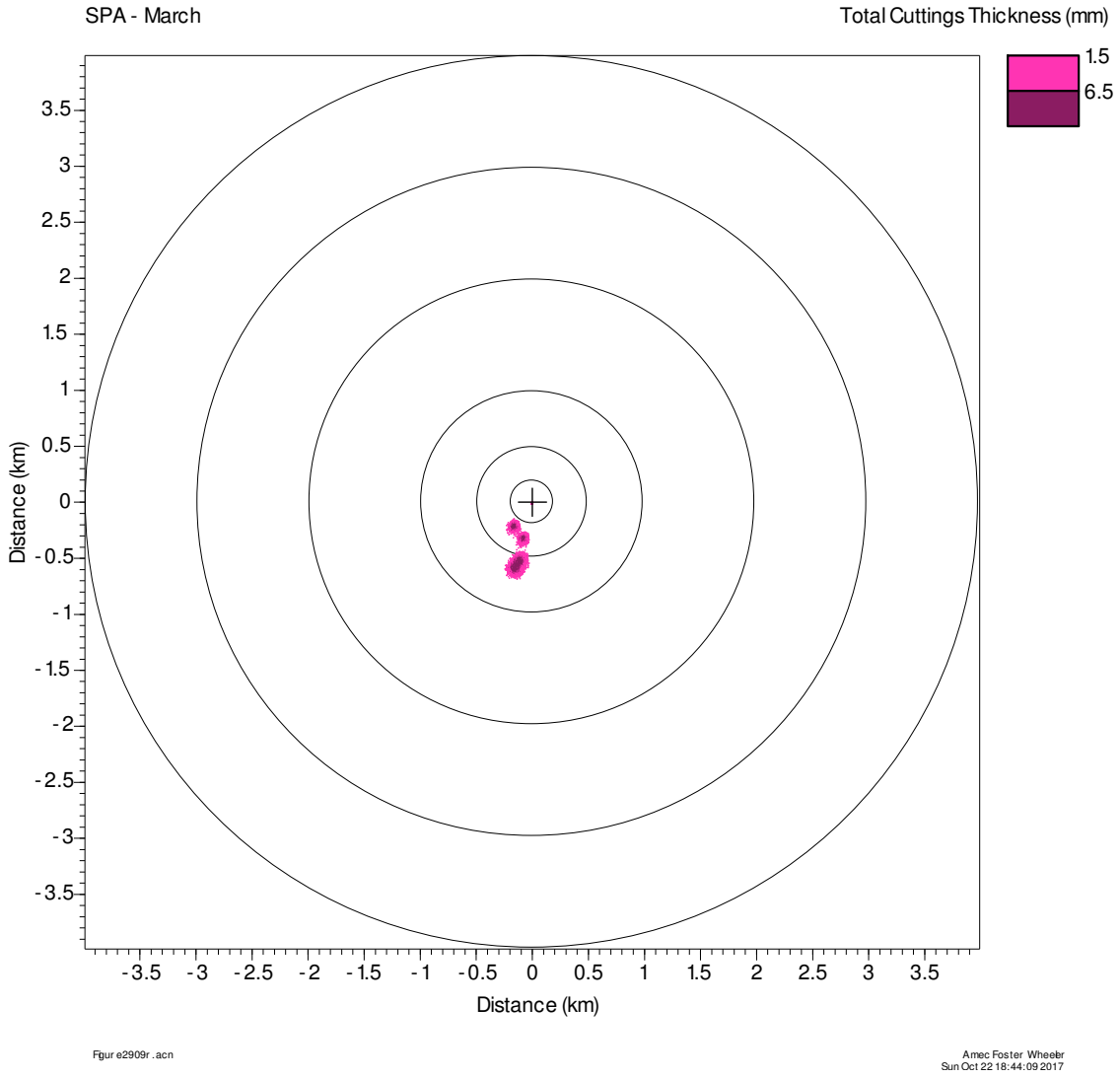


Figure 4-36 Total Drill Cuttings Deposition, PNET Limits, SPA, March, 4-km View

June

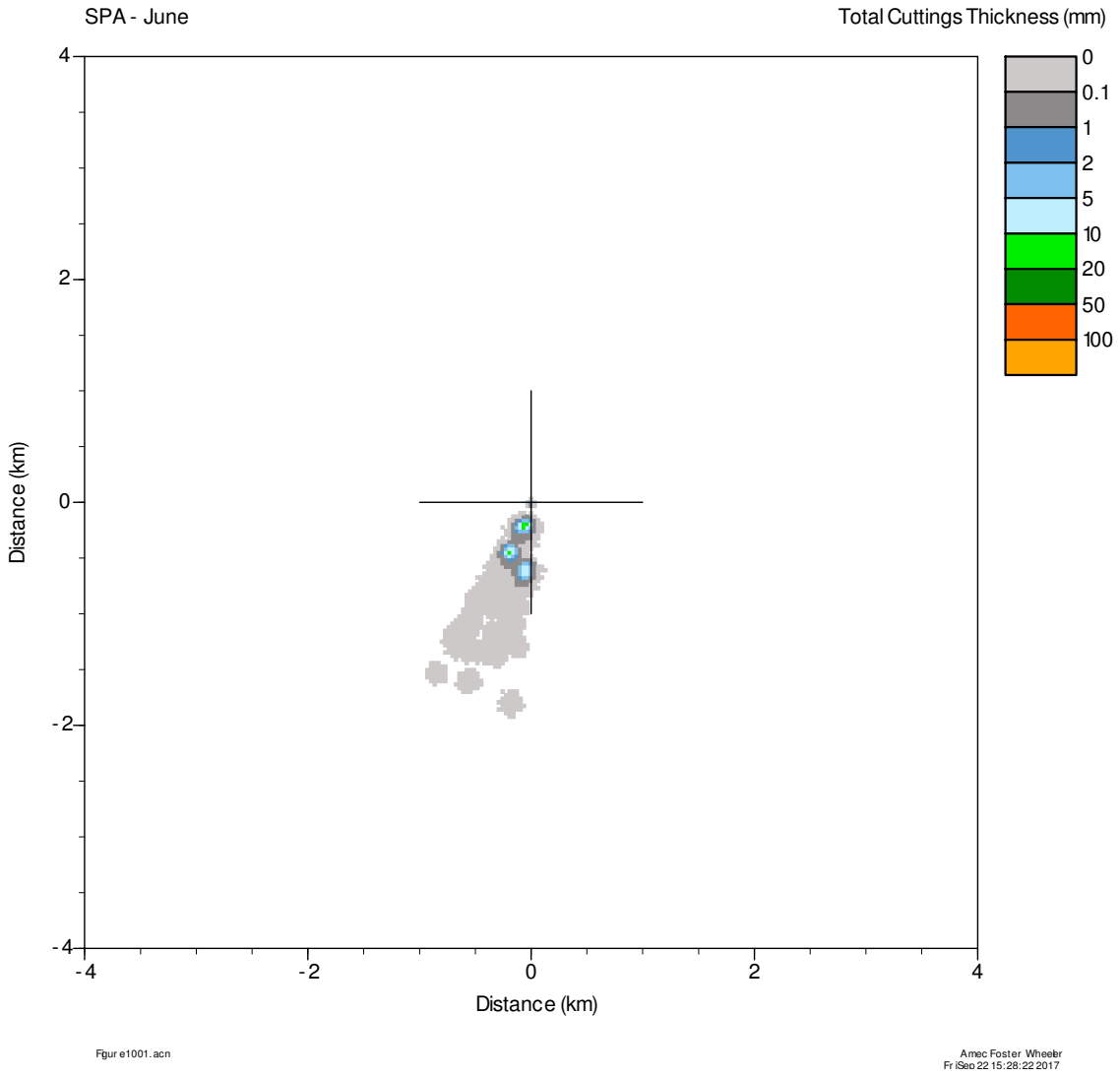


Figure 4-37 Total Drill Cuttings Deposition, SPA, June, 4-km View

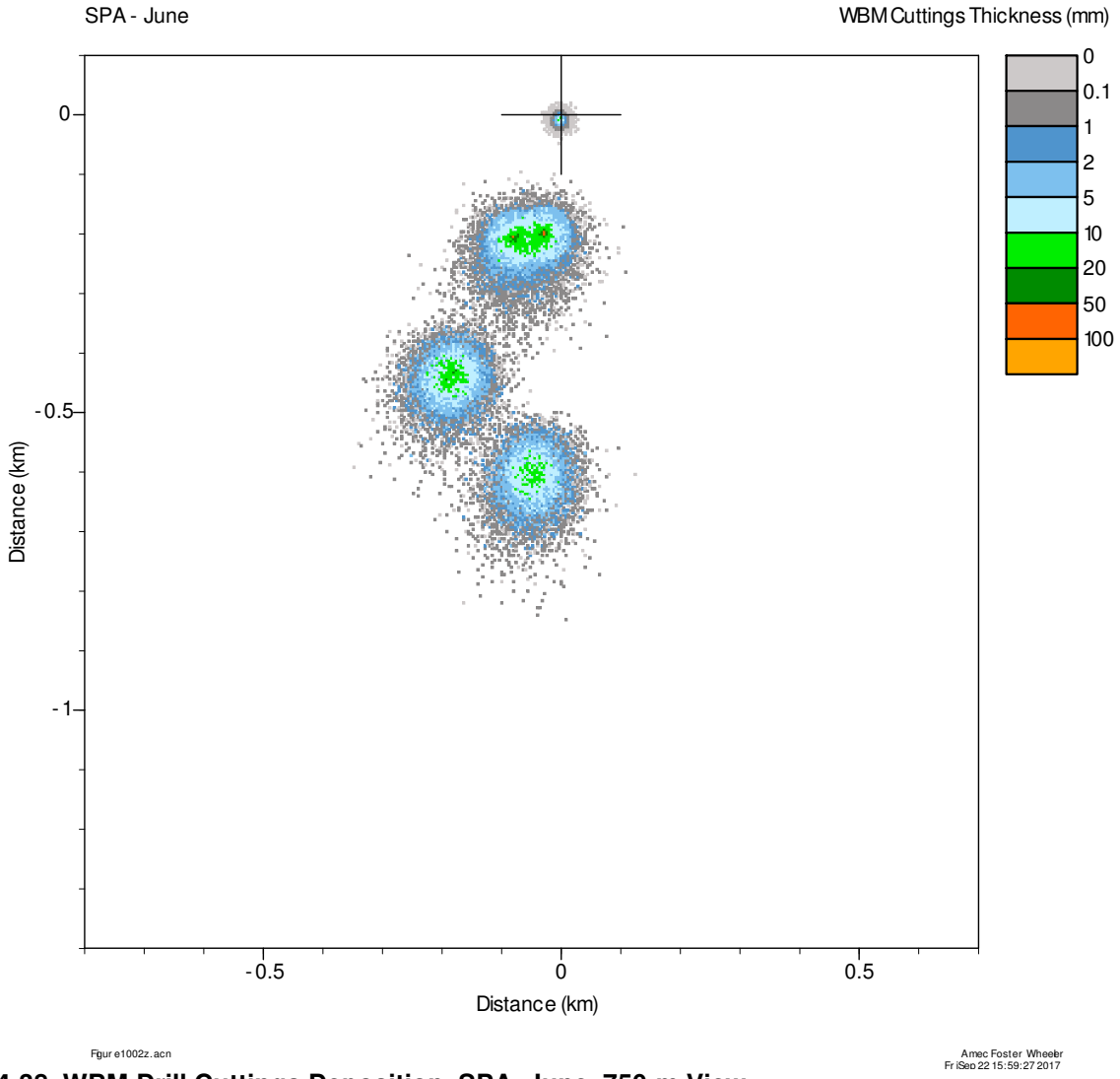


Figure 4-38 WBM Drill Cuttings Deposition, SPA, June, 750-m View

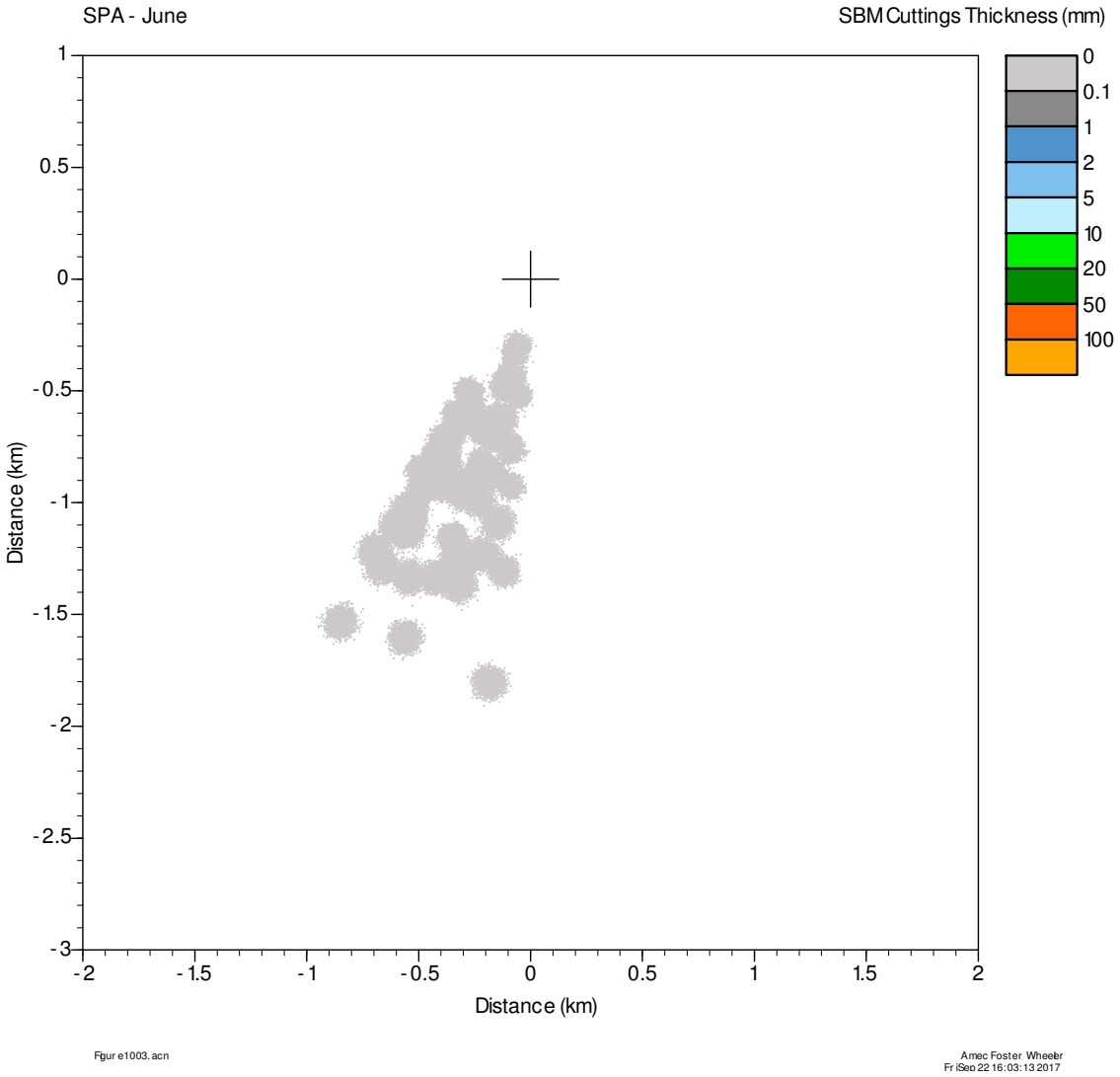


Figure 4-39 SBM Drill Cuttings Deposition, SPA, June, 2-km View

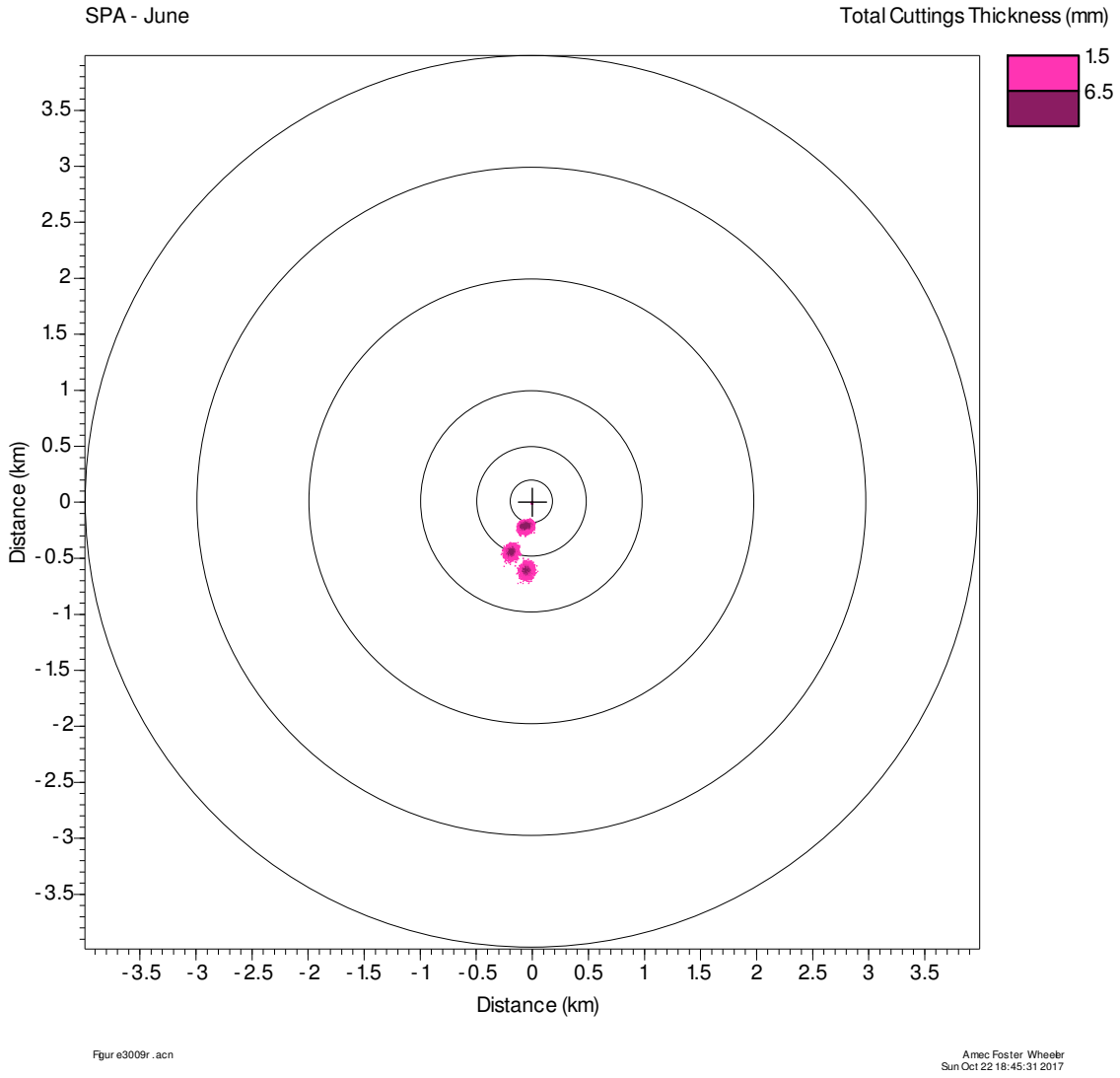


Figure 4-40 Total Drill Cuttings Deposition, PNET Limits, SPA, June, 4-km View

September

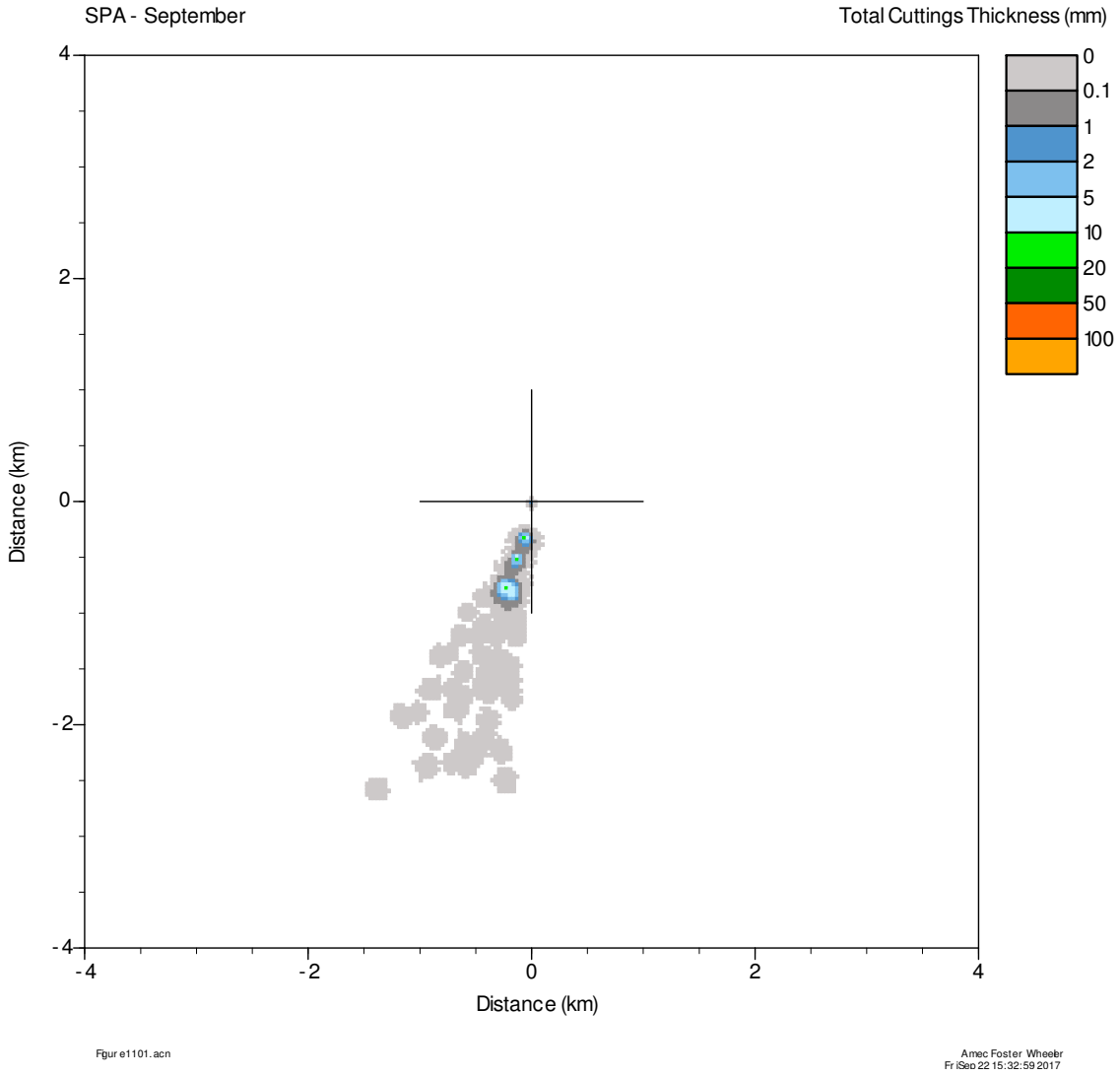


Figure 4-41 Total Drill Cuttings Deposition, SPA, September, 4-km View

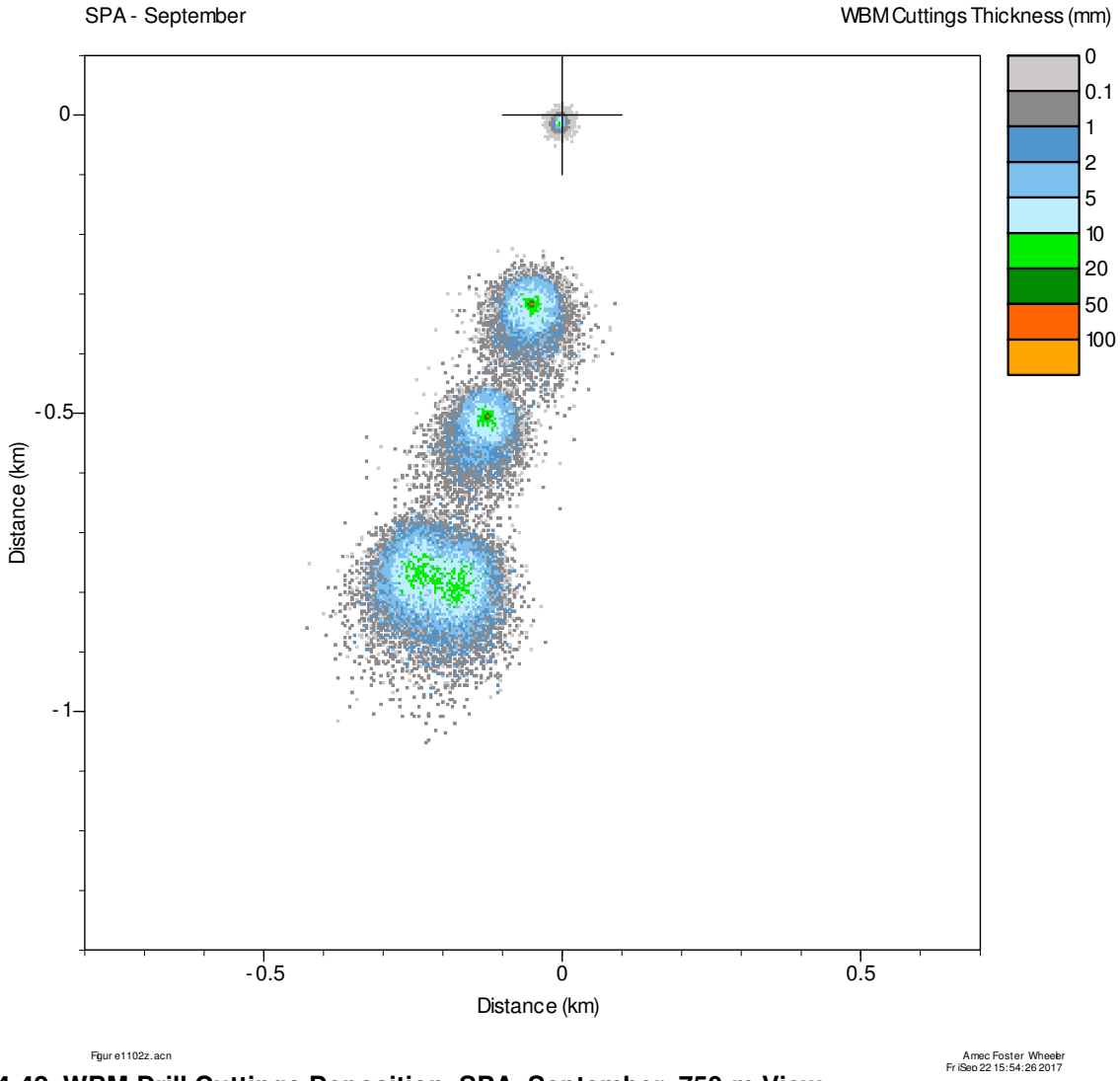


Figure 4-42 WBM Drill Cuttings Deposition, SPA, September, 750-m View

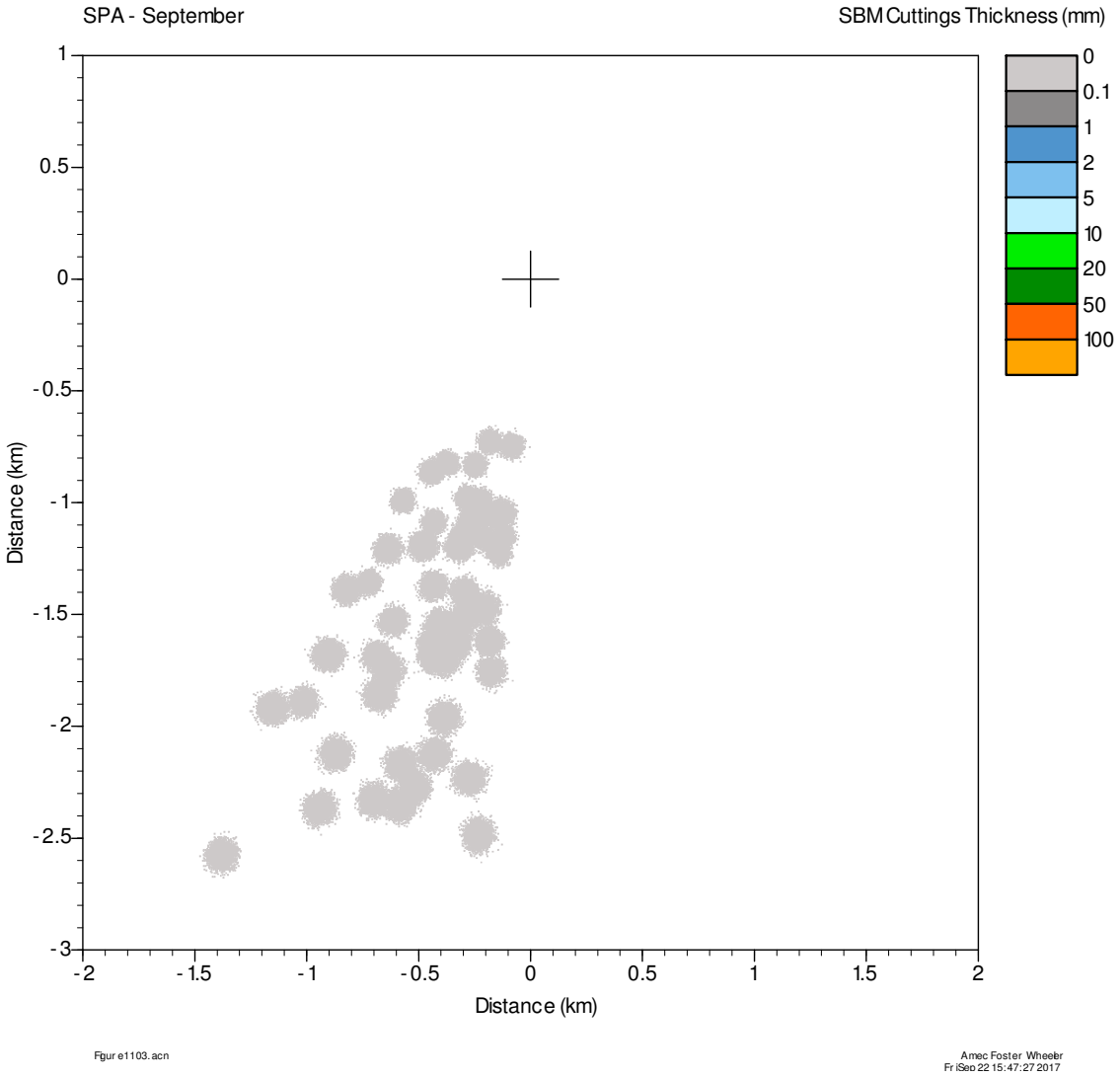


Figure 4-43 SBM Drill Cuttings Deposition, SPA, September, 2-km View

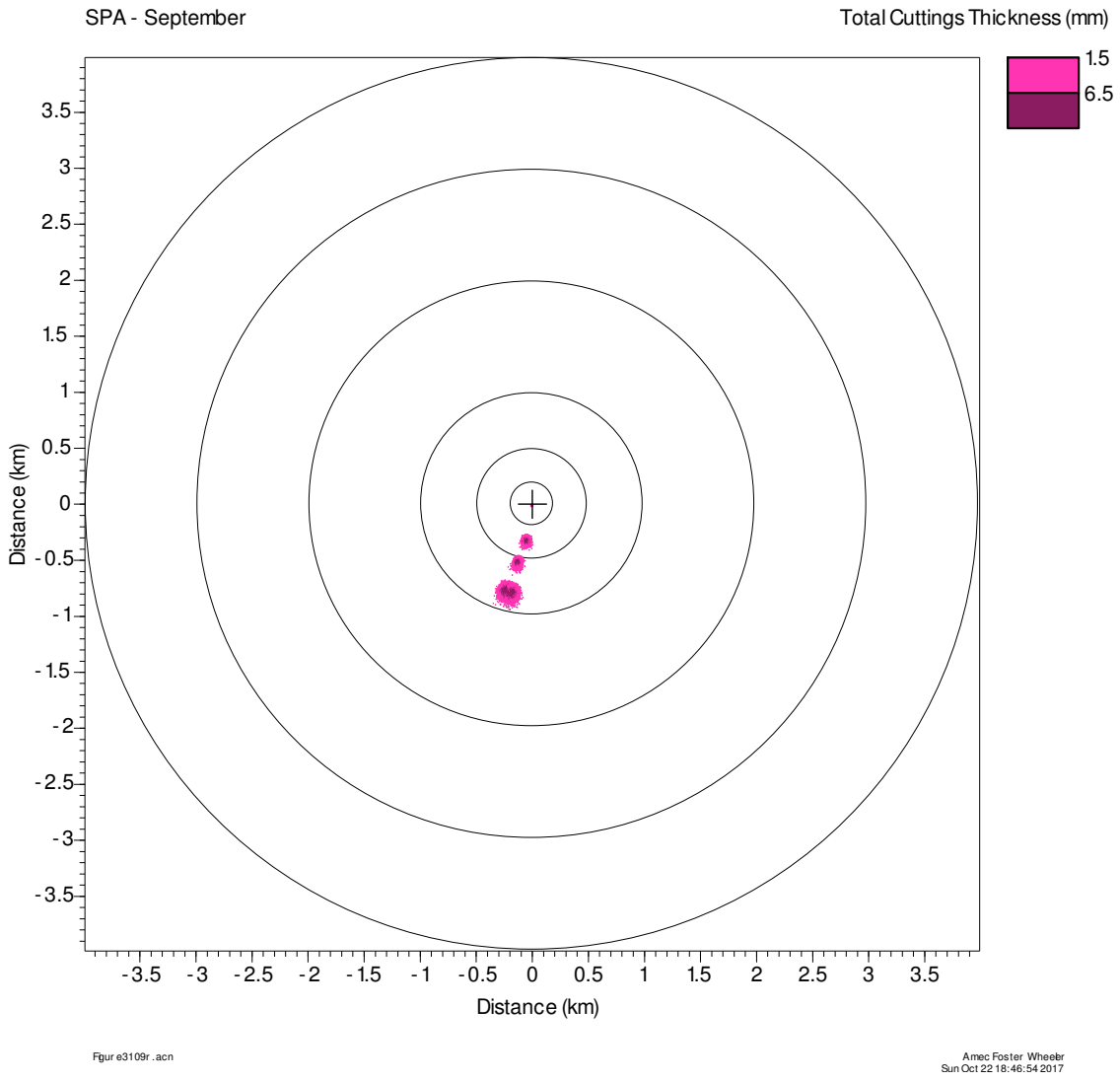


Figure 4-44 Total Drill Cuttings Deposition, PNET Limits, SPA, September, 4-km View

December

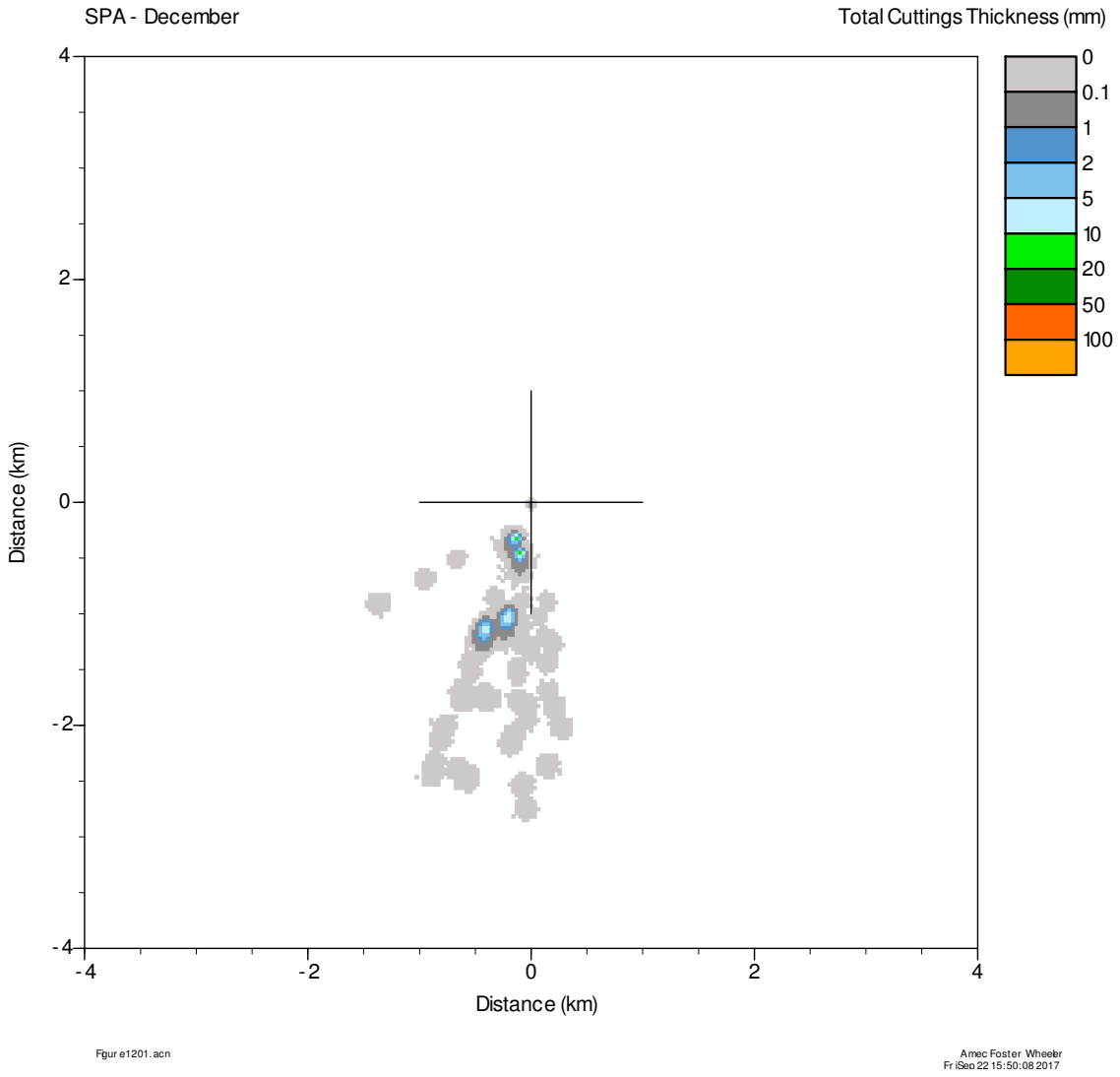


Figure 4-45 Total Drill Cuttings Deposition, SPA, December, 4-km View

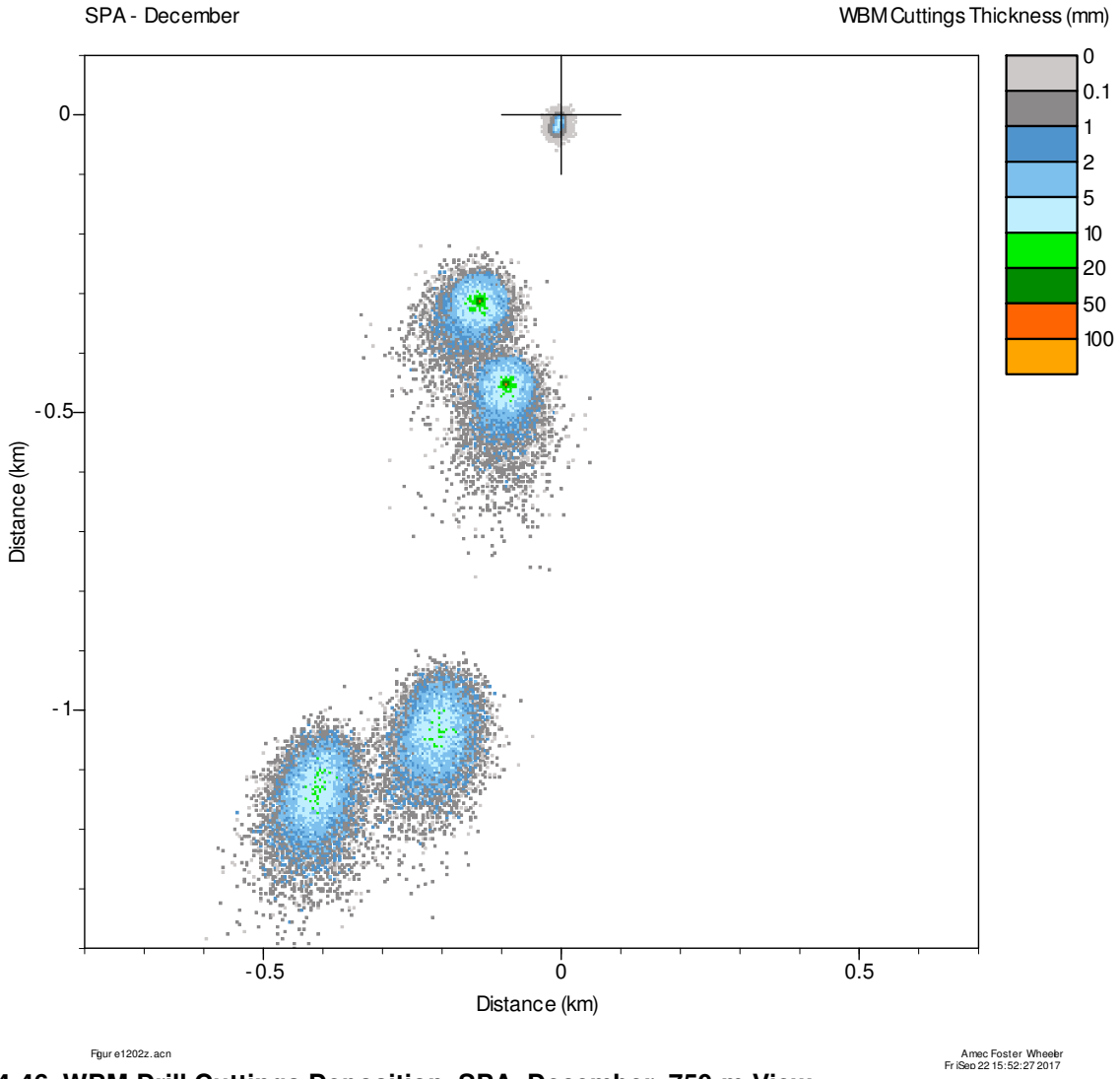


Figure 4-46 WBM Drill Cuttings Deposition, SPA, December, 750-m View

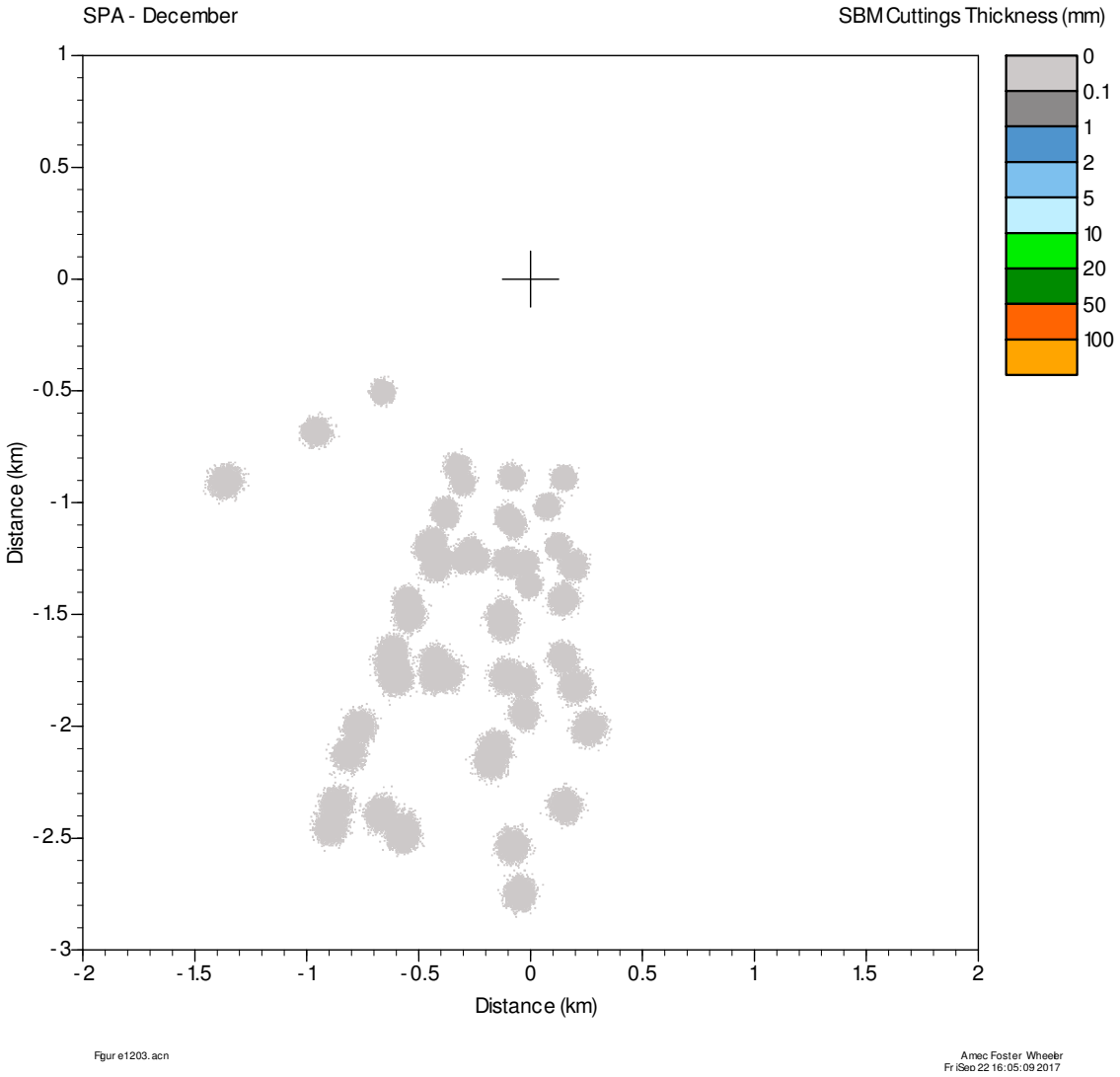


Figure 4-47 SBM Drill Cuttings Deposition, SPA, December, 2-km View

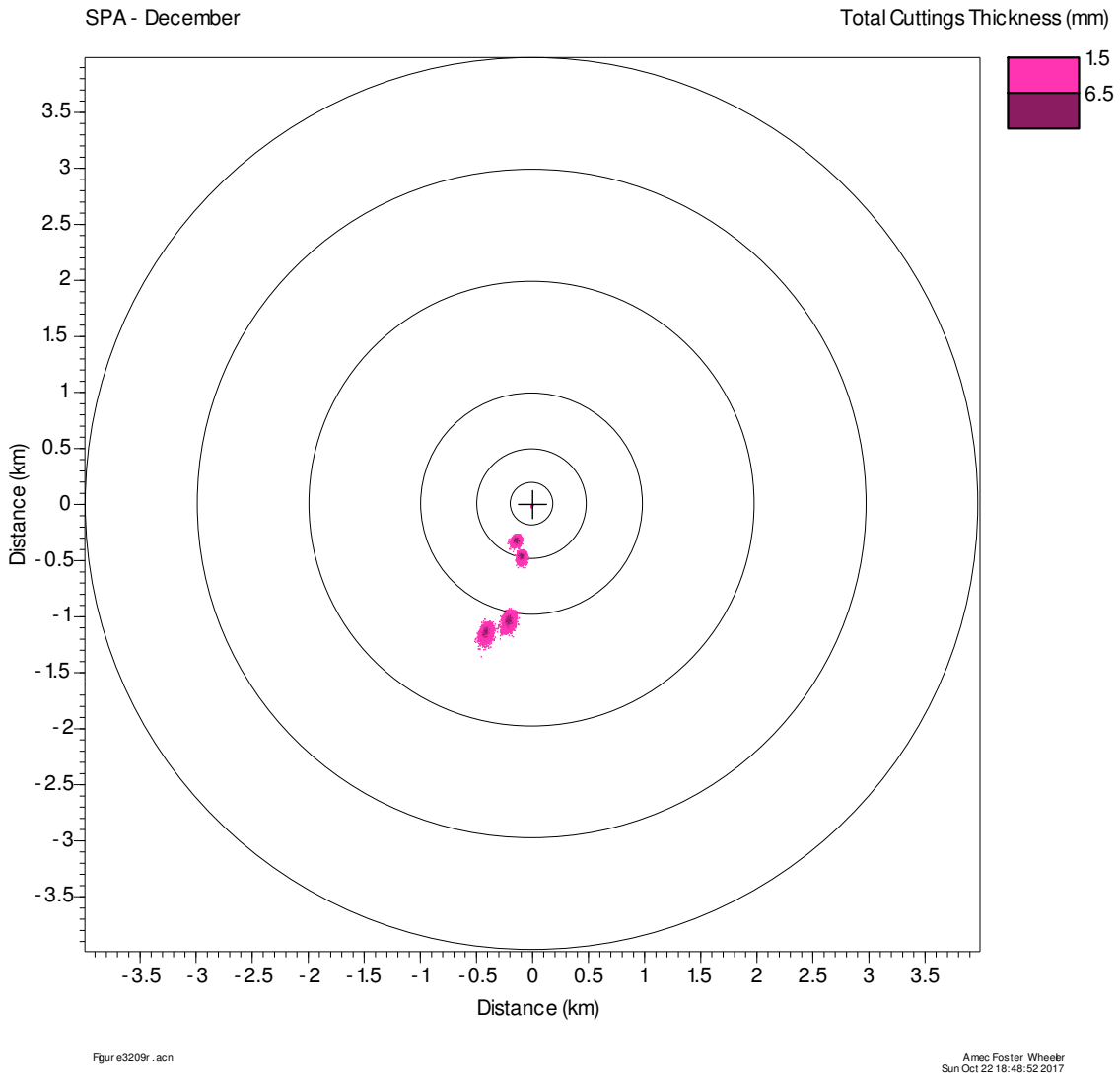


Figure 4-48 Total Drill Cuttings Deposition, PNET Limits, SPA, December, 4-km View

4.4 Drill Cuttings Results Summary, Project Area – Northern Section

Three sites were modelled for drill cuttings discharges: the Northern Project Area (NPA), Eastern Project Area (EPA) and Southern Project Area (SPA).

Drilling of one well was considered at each location. Cuttings from drilling the upper two well sections with WBM will all be released as per the Offshore Waste Treatment Guidelines (OWTG) (National Energy Board (NEB) et al. 2010) close to the seafloor. Therefore, there is little time for the cuttings to be transported large distances by the ambient currents. Conversely SBM cuttings, treated and released in accordance with the OWTG, will be released near the sea surface. For these three deep water locations in the Project Area – Northern Section, very little of the SBM cuttings reach the seabed in general within the model domain; these cuttings will drift for several days and travel for distances on the order of 20 to 200 km.

NPA

The hypothetical NPA wellsite was located at 2,700 m water depth on the north slope of the Flemish Cap. Modelled WBM cuttings were discharged at 2 to 4 m above the seabed with all of the drill cuttings settling within 4 km of the wellsite. Across seasons, the cuttings drift and deposit predominately to the northeast. Average WBM cutting thickness across seasonal scenarios range from 4-35 mm within 10 m of the wellsite and 1-8 mm within 100 m of the wellsite. Beyond 100 m from the wellsite, average WBM cuttings thicknesses are less than or equal to 4 mm with a maximum range of 1-2 km in the September scenario though with a mean thickness of 0.4 mm. Maximum WBM cuttings thickness is highest (55-78 mm) across season scenarios less than 500 m from the wellsite. Treated SBM cuttings discharged near the surface at the NPA wellsite settle in low quantities within the 32 km modelled domain. Across seasonal scenarios, 98 percent of SBM cuttings settle outside the 32 km model area. Assuming a mean current speed of 10 cm/s, the material will take on the order of 31 days to settle and likely drift over 200 km. Within the model area, SBM cuttings initially settle in average thicknesses of less than 0.01 mm with maximum thicknesses of 0.02 mm located between 2 and 4 km away.

EPA

The hypothetical EPA wellsite was located on the north slope of the Flemish Cap at 1,100 m water depth. Modelled discharges of WBM and SBM cuttings predominantly drifted to the northeast in the model. Due to relatively low currents in the region, both SBM and WBM cuttings released from the wellsite will mainly settle within the 32 km model area with the exception of SBM cuttings in June where 97.5 percent settle beyond the model area. Average WBM cuttings thicknesses across seasonal scenarios ranged from 10-41 mm within 10 m of the wellsite and 6-12 mm within 100 m of the wellsite. Beyond 100 m from the wellsite, average WBM cuttings thickness is less than or equal to 6 mm with a maximum range of 200-500 m for across season scenarios. Maximum WBM cuttings thickness was highest (80-116 mm) across season scenarios at less than 100 m from the wellsite: the largest thickness of 116 mm was observed 60 m to the southeast of the wellsite. Treated SBM cuttings discharged near the surface at the EPA wellsite have relatively low quantities settle within the first 5 km. For three of the

four seasonal scenarios, over 97 percent of SBM cuttings do settle between 5 and 32 km of the wellsite. Only the June scenario had over 97 percent of the SBM cuttings which settle outside the 32 km model area. Within the model area, SBM cuttings settle in average quantities of 0.05 mm or less and with maximum thicknesses of up to 0.4 mm between 5 to 32 km.

SPA

The hypothetical SPA wellsite was located at 362 m water depth on the northeast slope of the Grand Bank and adjacent to the Flemish Pass. Across seasons the cuttings drift and deposit predominately to the south-southwest. The majority of the discharged WBM cuttings settle within 1 km of the wellsite and the majority (98.3 percent) of SBM cuttings drift outside the 32 km model domain. Average WBM cuttings thickness across seasonal scenarios ranged from 0.3-4.0 mm and drifted up to 2 km from the wellsite. The maximum thickness of WBM cuttings was mainly between 100 m to 1 km from the wellsite and ranged from 66-80 mm, with the largest thickness of 80 mm observed in the March scenario 320 m to the south-southwest. SBM cutting thicknesses within the model area were low with average thicknesses of less than 0.01 mm. Maximum SBM cuttings thickness in the model area reached 0.06 mm.

In summary, for the Northern Section of the Project Area, the modelling indicates that more than 99 percent of discharged WBM cuttings will initially settle less than 1 km from each of the wellsites. At the NPA well site, WBM cuttings disperse up to 2 km from the well in the September scenario; however, the average (0.4 mm) and maximum (1.0 mm) thicknesses are low. At the EPA location, WBM cuttings thickness was highest within 100 m from the wellsite, with an average thickness reaching up to 41 mm and a maximum thickness reaching up to 116 mm. Average thicknesses at distances greater than 100 m were up to 6 mm with some areas of accumulation up to a maximum thickness up to 80 mm.

For the NPA and SPA locations, 98 percent of discharged SBM cuttings material drifts beyond the model boundary in all season scenarios. For the EPA scenarios, with low currents (generally 5 cm/s or less) initial settling of SBM cuttings takes place from 4-32 km away from the wellhead in all seasons except for June, during which time the current speeds are slightly larger with the result that again about 98 percent of the SBM cuttings drift just outside the model domain. Due to the large settling distances away from the well sites, overall average and maximum SBM cuttings thicknesses are relatively low (less than 0.5 mm). The discharge of SBM cuttings in generally deep waters in the Northern Section of the Project Area enhances dispersion and as such accumulation levels are considered minimal.

PNET Thickness Limits

The estimated areas for which total cuttings thicknesses are greater than 1.5 mm range from about 0.025 km^2 to 0.103 km^2 (about 320 m square) with the largest areas of about 0.1 km^2 at the NPA site in the June and September scenarios. For thicknesses greater than 6.5 mm, total areas range in size from about 0.0125 km^2 to 0.0325 km^2 (March at NPA, about 180 m square). Total areas with cuttings thicknesses above the PNET thresholds are shown in Figure 4-49.

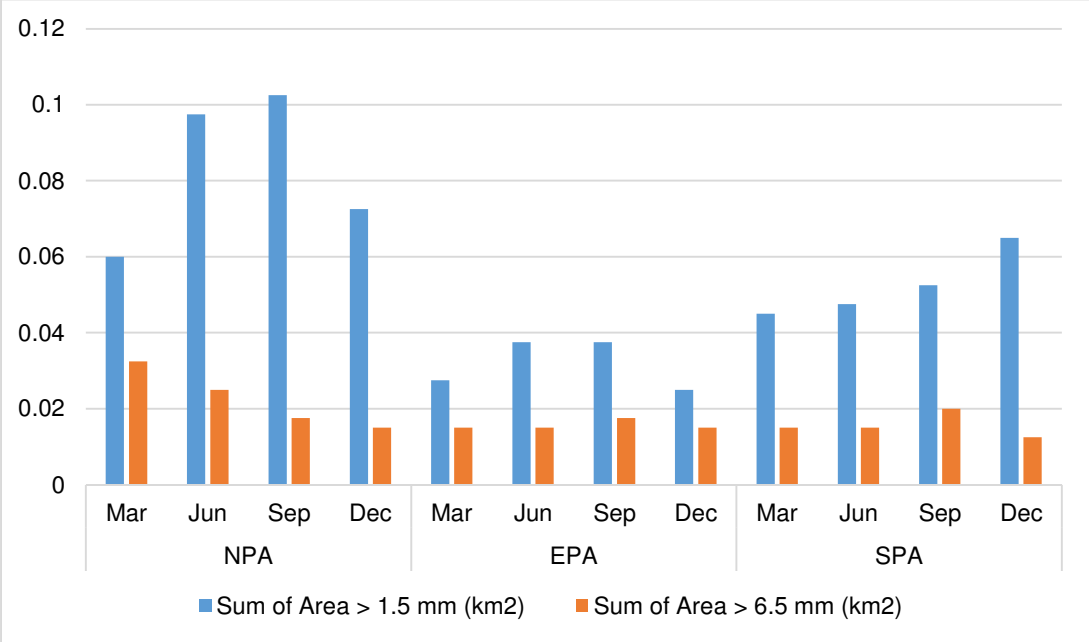


Figure 4-49 Total Cuttings Thickness Areas above PNET Thresholds, Project Area – Northern Section

At the NPA site, the areas above the 1.5 mm and 6.5 mm thresholds are confined to within about 300 to 900 m or less from the wellhead and to the northeast. At the EPA site, these thickness areas are confined to within about 200 m or less from the wellhead. Due to the small currents, the areas are confined to the wellhead or slightly to the east. For the SPA site, these thickness areas lie within about 700 m (March and June) to 1300 m (December) to the south-southwest from the wellhead. The predominant currents in this direction result in the patches being confined to a fairly narrow band of about 30°. Given that the SBM cuttings disperse much farther, these total cuttings amounts will be primarily composed of WBM cuttings. The footprint areas above the two PNET thresholds of interest are generally of a size 100-200 m square (smaller for the 6.5 mm threshold) with the areas sometimes lying adjacent to each other.

4.1 Jeanne d'Arc Basin

This section presents results of cuttings modelling for the JDB location. Four seasonal scenarios are presented with drilling of wells commencing in March, June, September and December.

At the JDB site all of the WBM cuttings released at the wellhead settle within 4 km. The majority of these settle between 100 m and 1.7 km away. In June and September, the settling is closer with virtually all WBM cuttings within 1 km.

About one third of the SBM cuttings settle within 4 km of the wellhead as well with the remaining two thirds settling within about 8 to 16 km (Table 4-7). Generally about 2 to 3 percent of SBM materials generally settle within 1 km, exceptions being in September and December with about 10 percent and

8 percent of SBM cuttings respectively settling within 1 km. At a depth of 89 m, the very fine sand, silts and clay SBM cuttings particles released near the surface might be expected to take on the order of 21 h to settle and, at an assumed mean current speed of 10 cm/s, travel about 8 km.

Table 4-7 Cuttings Material Settled by Distance, JDB

JDB		Distance from Well Site										
		0-10m	10-100m	100-200m	200-500m	500m-1km	1-2km	2-4km	4-5km	5-31km	>31km	
Month	Cuttings Type	% Material Settled										% Material Unsettled
Mar	WBM	0.4	1	0.1	37	32	29	-	-	-	-	-
	SBM	-	0.2	1	1	-	15	19	5	59	-	-
Jun	WBM	0.8	14	22	34	29	-	-	-	-	-	-
	SBM	<0.1	0.4	1	0.2	<0.1	6	50	15	28	-	-
Sep	WBM	0.3	0.6	13	18	68	0.4	-	-	-	-	-
	SBM	<0.1	0.4	2	8	0.2	5	28	14	42	-	-
Dec	WBM	0.8	15	20	35	0	29	-	-	-	-	-
	SBM	<0.1	0.4	1	1	6	5	17	26	44	-	-

Note: due to rounding some row percentage totals may not exactly equal 100.

At JDB, the farthest distance that any SBM cuttings settle, at any thickness, is March at 15.6 km, June at 9.5 km, September at 13.6 km, December at 13.9 km.

The notes under Table 4-8 list the location of each month's maximum WBM thickness, e.g., in June the largest thickness is 108 mm, 90 m to the east-southeast of the well site (this maximum also shows up as an orange footprint cell in the June WBM thickness (Figure 4-55).

Table 4-8 Cuttings Thickness by Distance, JDB

JDB		Distance from Well Site									
		0-10m	10-100m	100-200m	200-500m	500m -1km	1-2km	2-4km	4-5km	5-31km	>31km
Cuttings Type		Cuttings Thickness (mm)									
	March										
WBM	Mean	4	1	0.3	3	2	2	-	-	-	-
	Maximum	12	10	1	101[1]	20	16	-	-	-	-
SBM	Mean	-	0.1	0.1	0.1	-	0.3	0.4	0.02	0.05	-
	Maximum	-	0.3	0.6	0.5	-	2.8	2.4	0.5	0.7	-
	June										
WBM	Mean	8	4	4	3	3	-	-	-	-	-
	Maximum	21	108 [2]	25	61	19	-	-	-	-	-
SBM	Mean	<0.1	0.1	0.1	0.1	<0.1	0.1	0.2	0.04	0.04	-
	Maximum	0.1	0.5	0.6	0.3	0.1	0.7	2.9	1.2	0.5	-
	September										
WBM	Mean	4	1	2	2	2	0.4	-	-	-	-
	Maximum	14	14	48	55 [3]	13	1	-	-	-	-
SBM	Mean	<0.01	0.1	0.1	0.3	0.2	0.3	0.2	0.05	0.04	-
	Maximum	<0.01	0.8	1.6	2.8	0.4	2.0	2.5	2.8	0.6	-
	December										
WBM	Mean	7	4	3	3	1	3	-	-	-	-
	Maximum	17	22	23	102 [4]	1	22	-	-	-	-
SBM	Mean	<0.01	0.1	0.1	0.1	0.3	0.1	0.3	0.08	0.04	-
	Maximum	<0.01	0.3	0.4	0.4	2.5	1.6	2.4	2.4	0.5	-

[1] at (0.45 km, 265°); [2] at (0.09 km, 118°); [3] at (0.26 km, 38°); [4] at (0.21 km, 349°)

The cuttings deposition map figures are presented for each of the four seasonal scenarios – March, June, September and December - and for each, the modelled total cuttings, WBM cuttings, SBM cuttings and total cuttings for PNET limits thicknesses are shown. For the JDB site, these maps are shown in Figure 4-50 to Figure 4-65.

At JDB the currents are distributed in most directions in most months (Appendix 1 JDB current roses). Footprints are scattered about the well site in all months. Total cuttings deposits reach to about 16 km to the south-southeast and also 5-6 km to the northeast in March (Figure 4-50). In June, the farthest depositions are 8 km to the southeast and northwest and 6 km to the northeast (Figure 4-54). In

September deposits are again to the east, southeast, northwest at about 9 km and about 14 km to the south-southwest. In December deposits are as far as 14 km to the north-northeast, and also about 9 km to the south and northwest (Figure 4-62). Total cuttings thicknesses – these are SBM cuttings - are less than 2 mm away from the wellhead and generally 1 mm or less.

As reported in Table 4-8, the maximum monthly WBM thicknesses reach about 100 mm and are located within 500 m of the wellhead. Maximum thicknesses are 101 mm at 450 m to the west in March, 108 mm at 90 m to the east-southeast in June (Figure 4-55 with inset zoomed in), 55 mm seen 260 m to the northeast of the wellhead in September, and 102 mm at 210 m to the northwest in December. Within 500 m of the wellhead, average WBM thicknesses are on the order of 3 to 8 mm. Between 500 m and 2 km the maximum WBM thicknesses are about 20 mm (maximum of 22 mm in December).

SBM cuttings are predicted to settle within 500 m; however only at very small thicknesses of 0.1 mm or less on average and a maximum of about 0.6 mm. Outside of 500 m, out to less than 4 km away, SBM cuttings reach a maximum of about 2 to 3 mm.

March

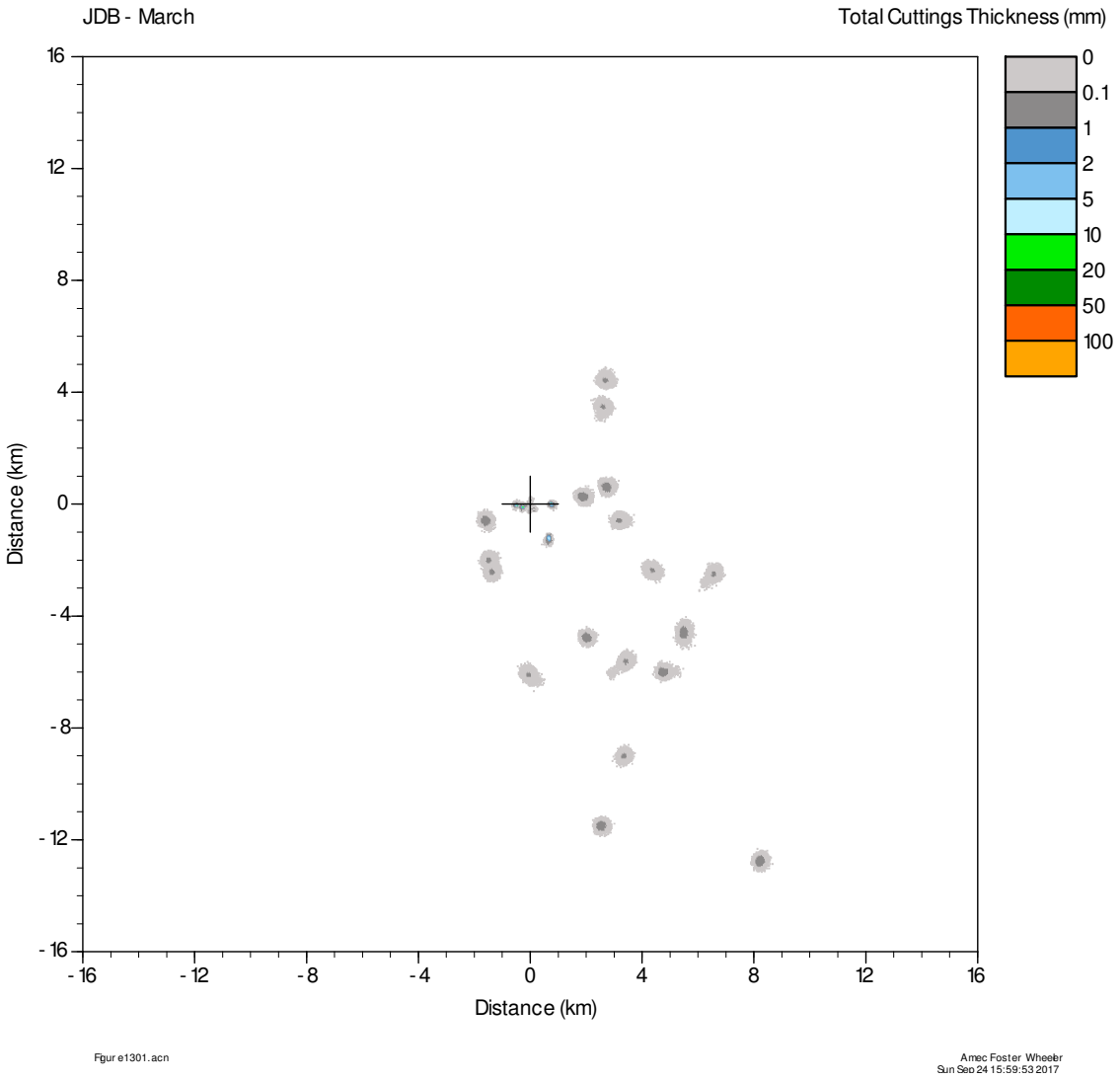


Figure 4-50 Total Drill Cuttings Deposition, JDB, March, 16-km View

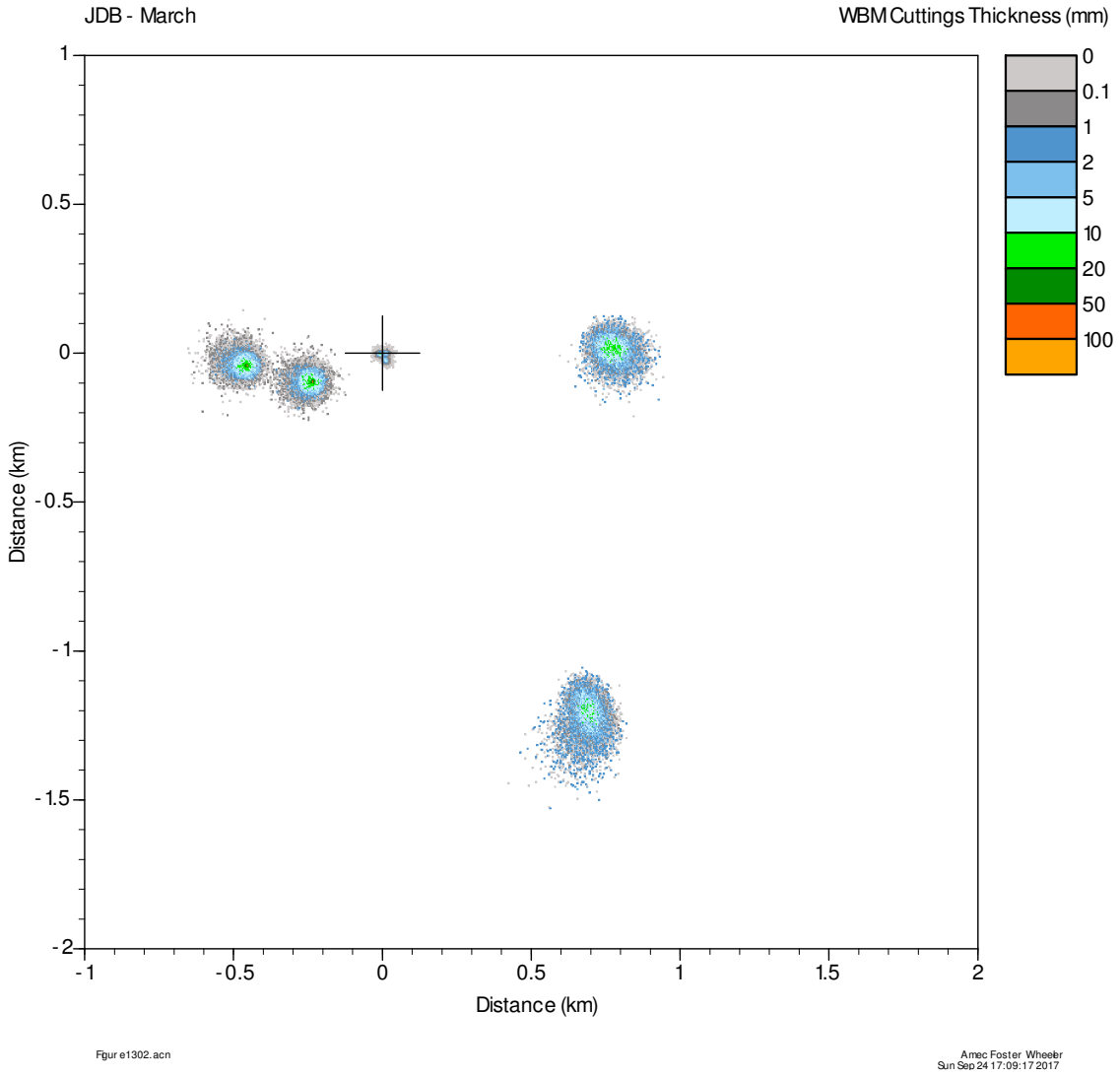


Figure 4-51 WBM Drill Cuttings Deposition, JDB, March, 1.5-km View

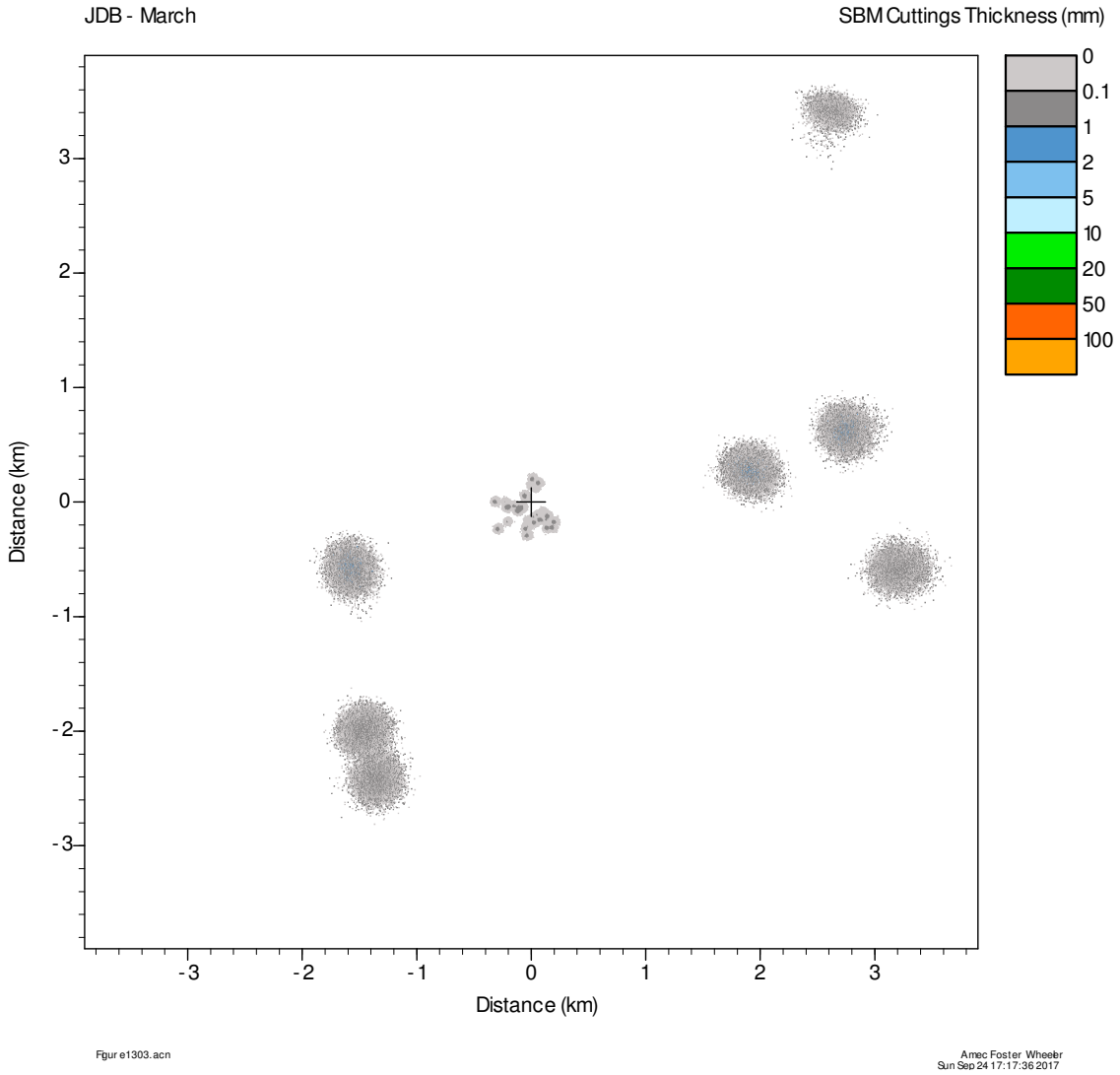


Figure 4-52 SBM Drill Cuttings Deposition, JDB, March, 4-km View

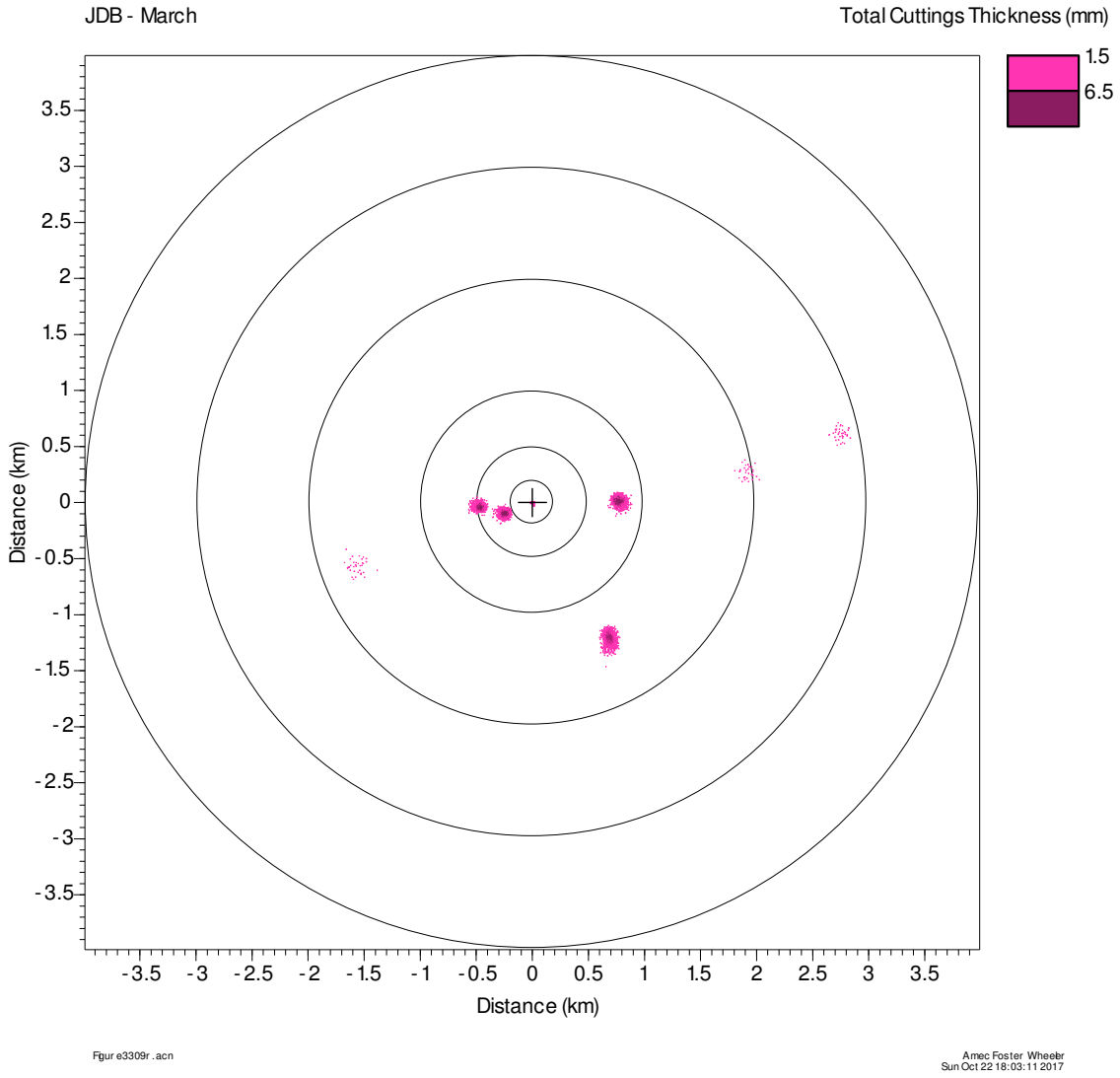


Figure 4-53 Total Drill Cuttings Deposition, PNET Limits, JDB, March, 4-km View

June

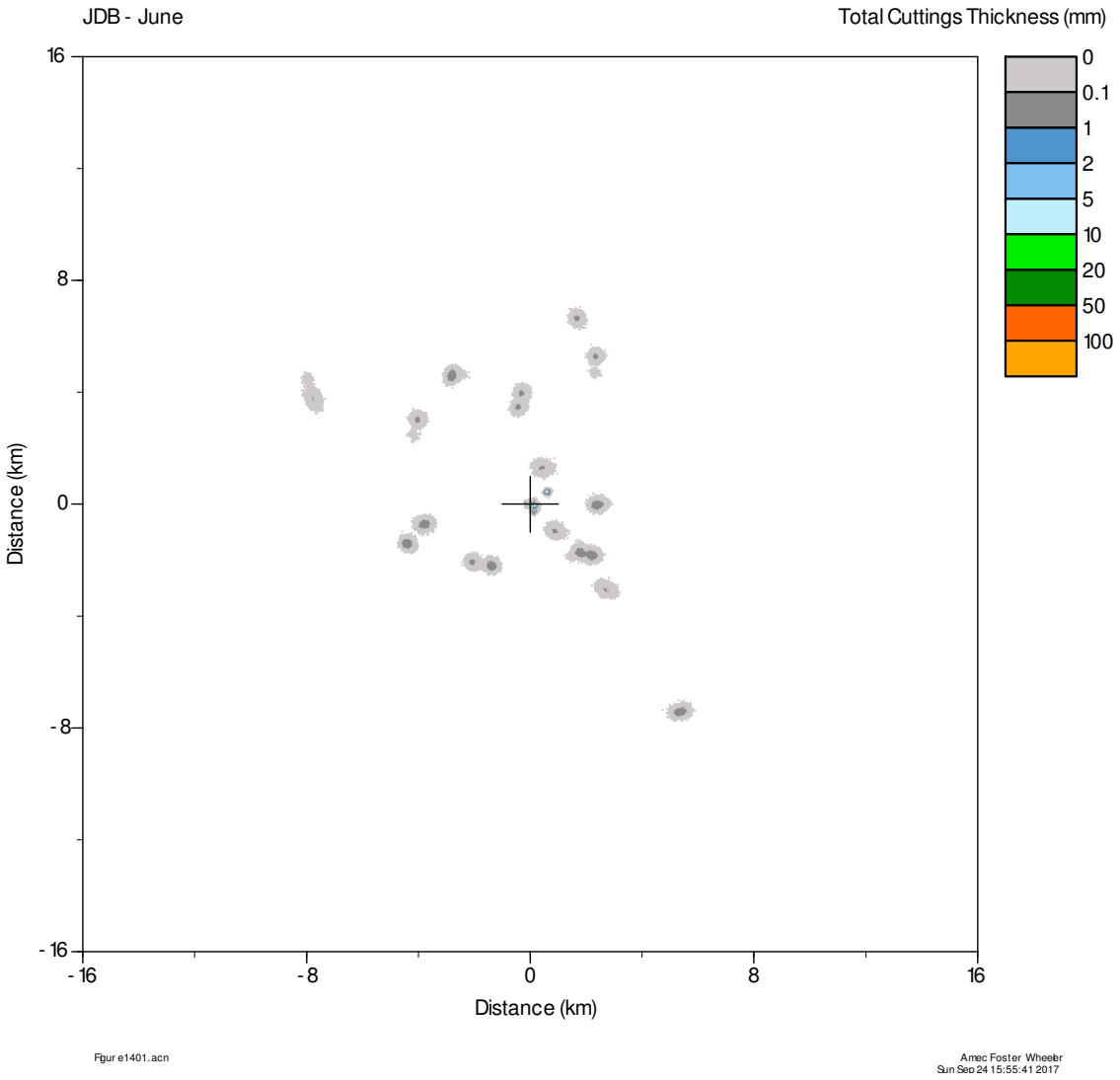


Figure 4-54 Total Drill Cuttings Deposition, JDB, June, 16-km View

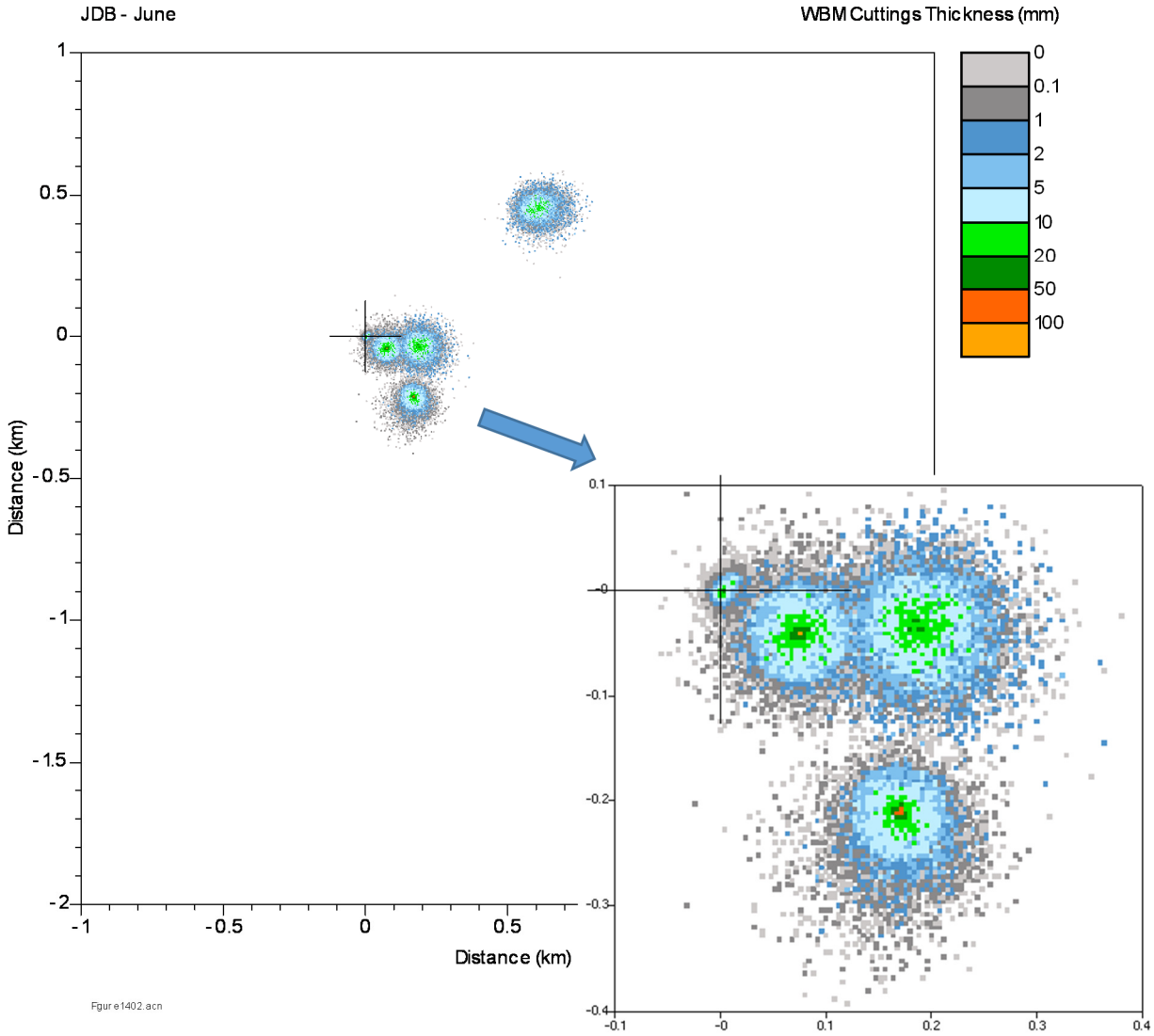


Figure 4-55 WBM Drill Cuttings Deposition, JDB, June, 1.5-km View

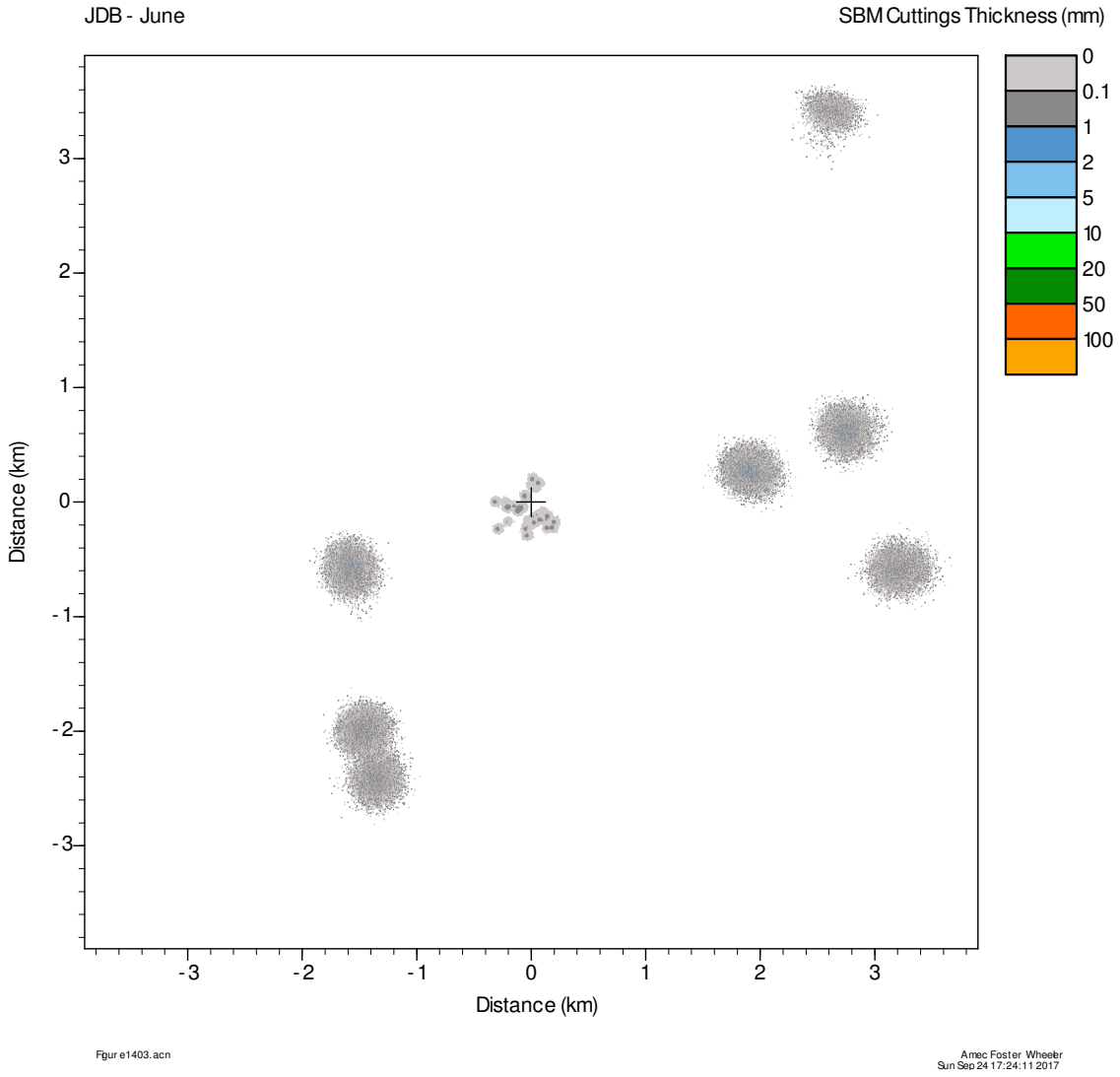


Figure 4-56 SBM Drill Cuttings Deposition, JDB, June, 4-km View

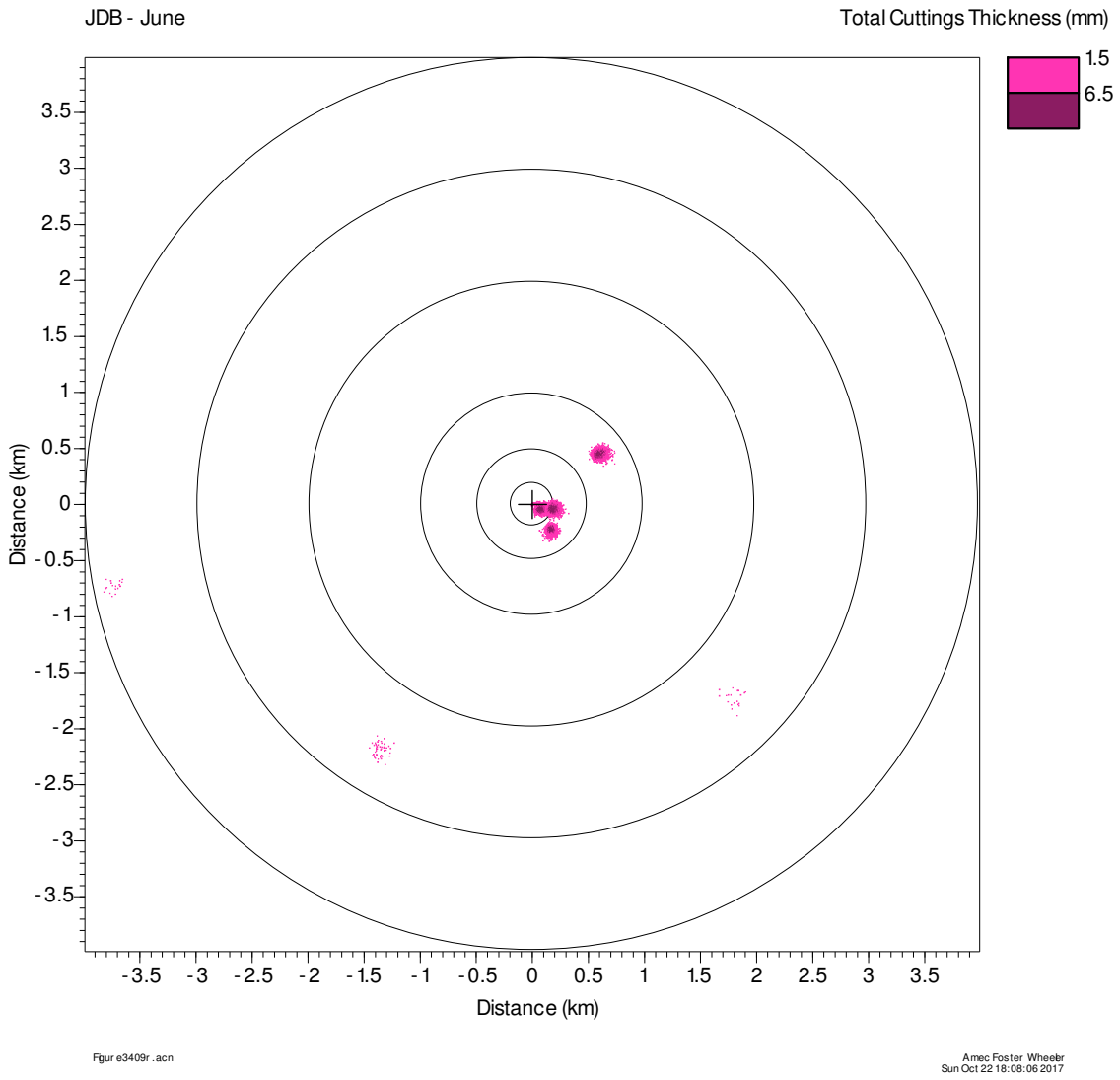


Figure 4-57 Total Drill Cuttings Deposition, PNET Limits, JDB, June, 4-km View

September

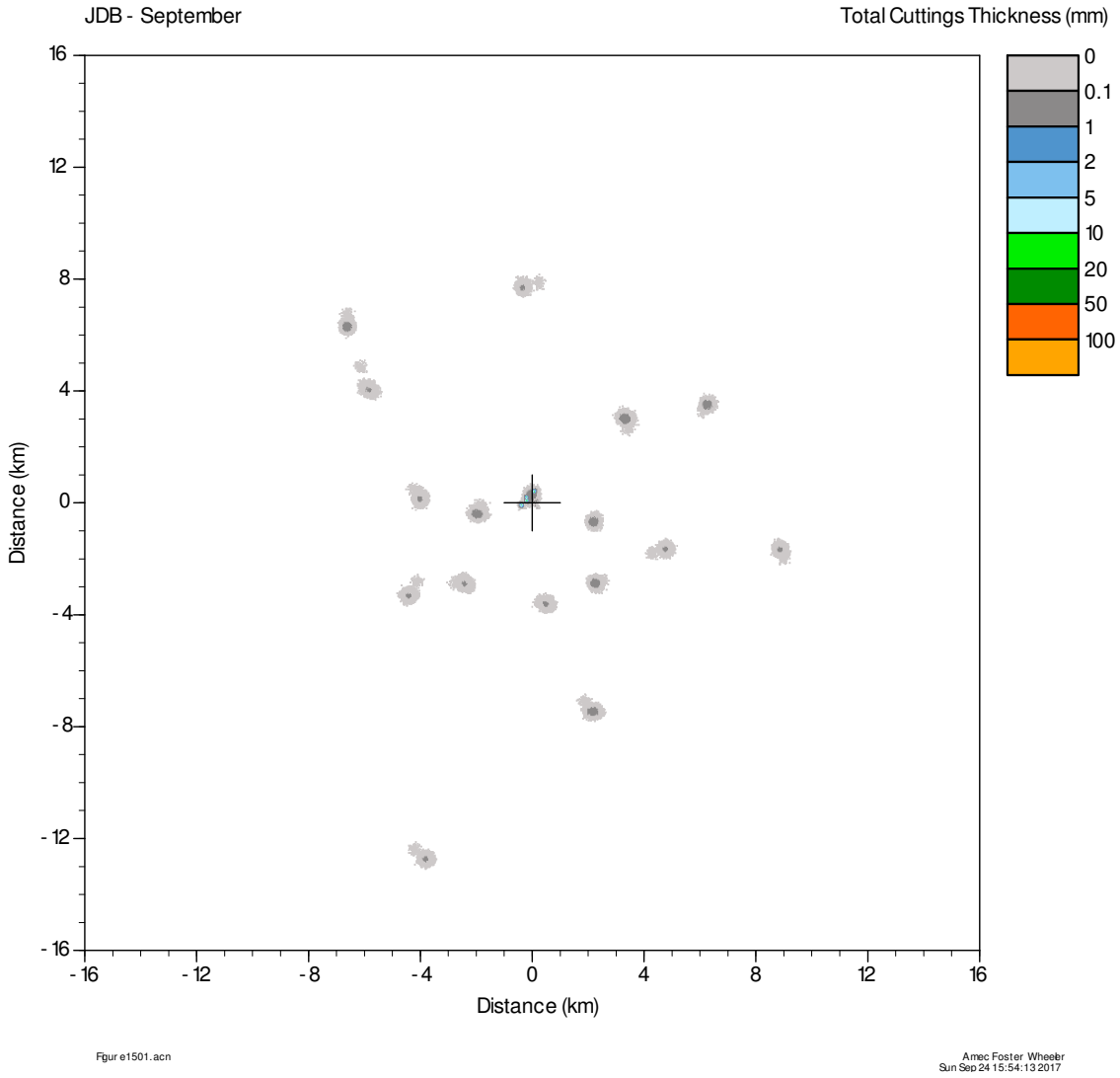


Figure 4-58 Total Drill Cuttings Deposition, JDB, September, 16-km View

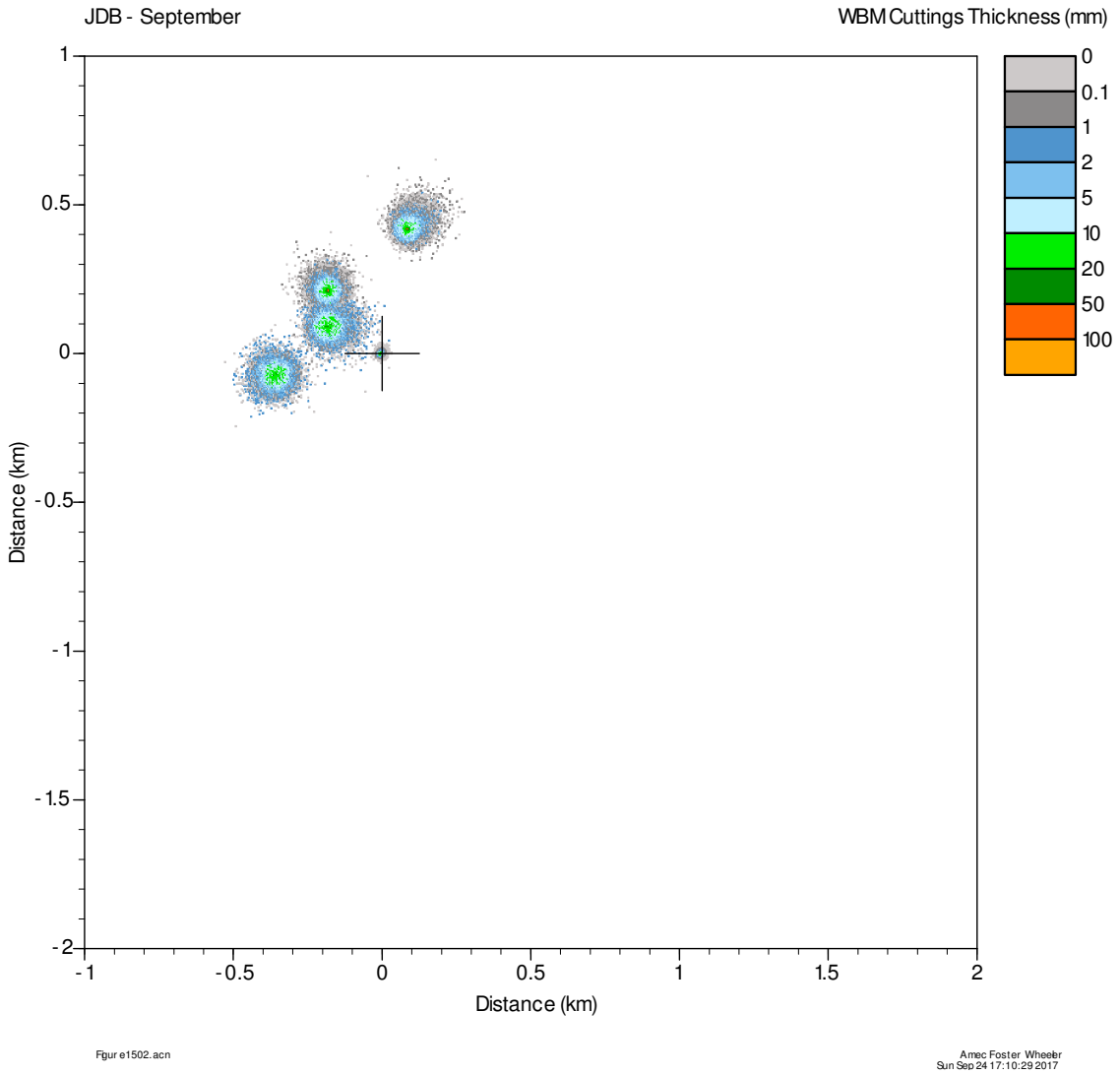


Figure 4-59 WBM Drill Cuttings Deposition, JDB, September, 1.5-km View

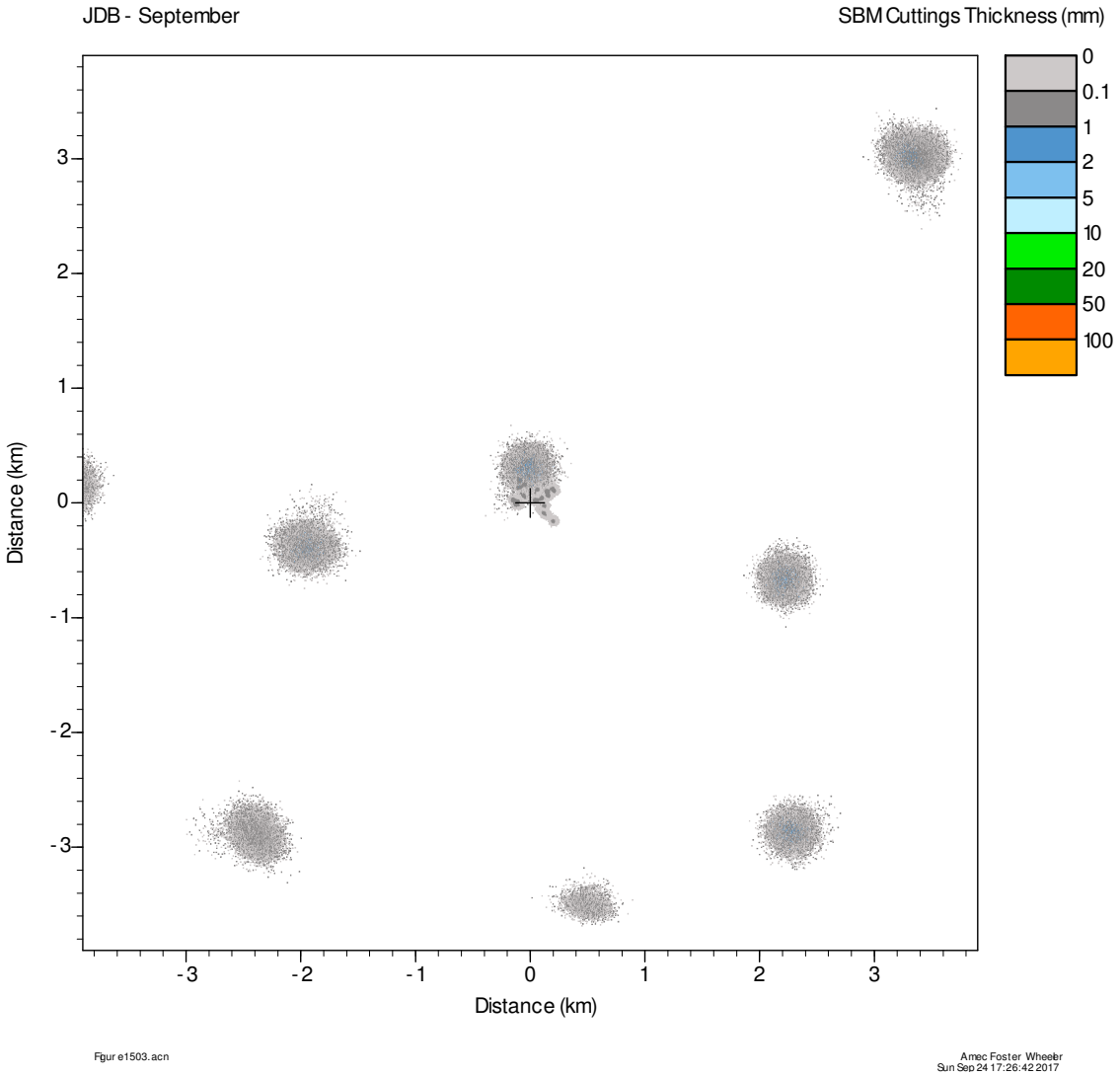


Figure 4-60 SBM Drill Cuttings Deposition, JDB, September, 4-km View

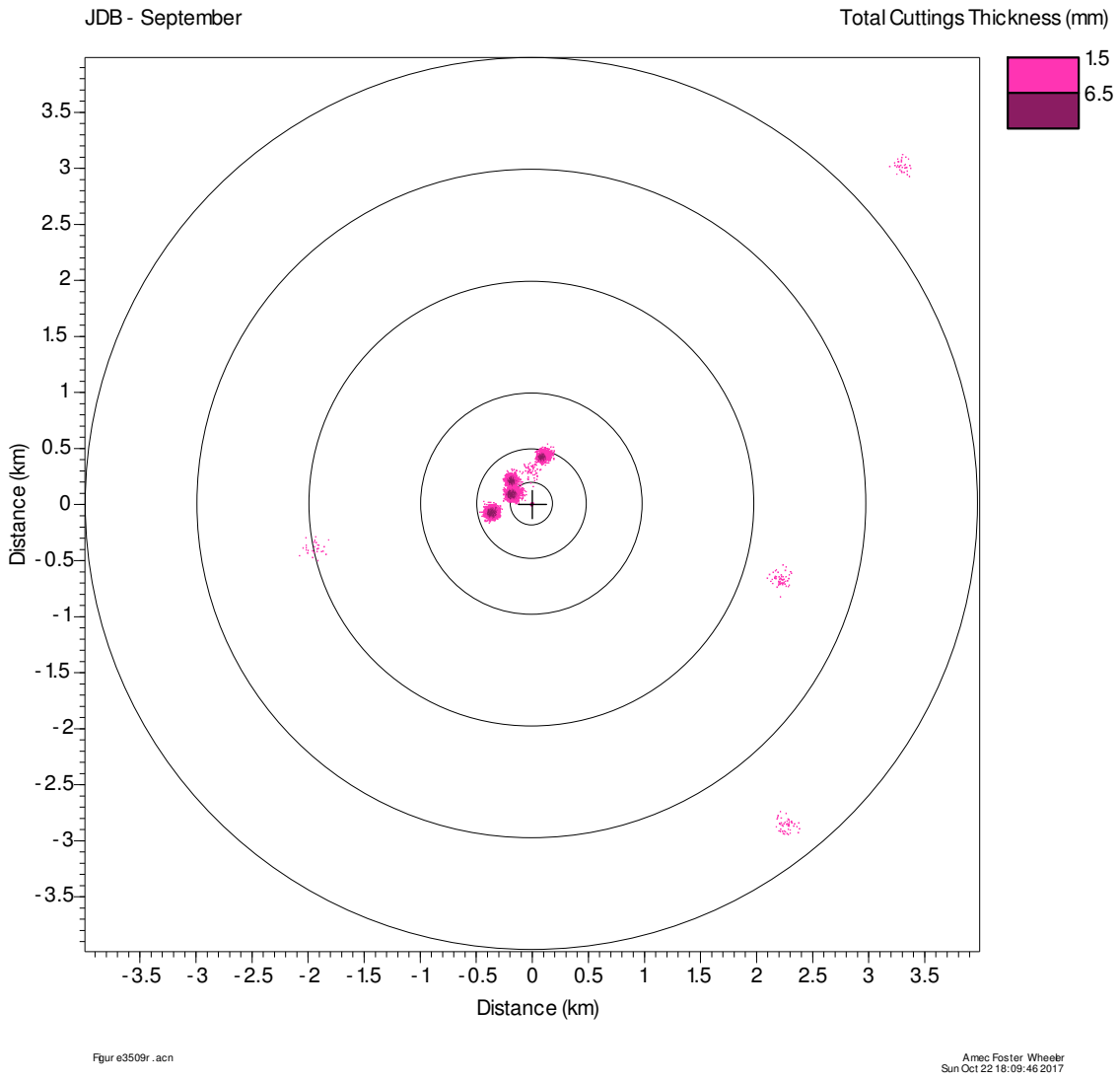


Figure 4-61 Total Drill Cuttings Deposition, PNET Limits, JDB, September, 4-km View

December

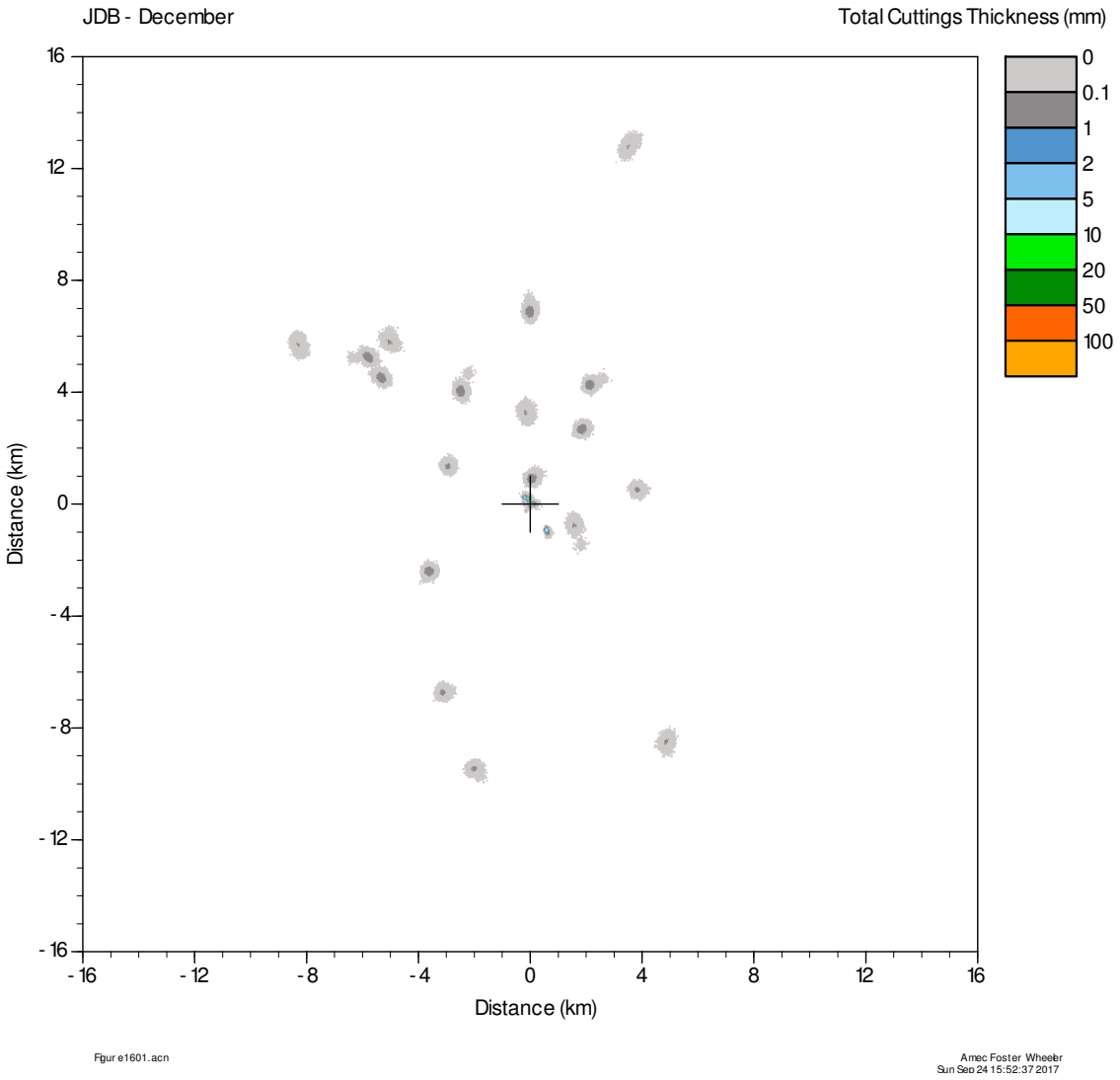


Figure 4-62 Total Drill Cuttings Deposition, JDB, December, 16-km View

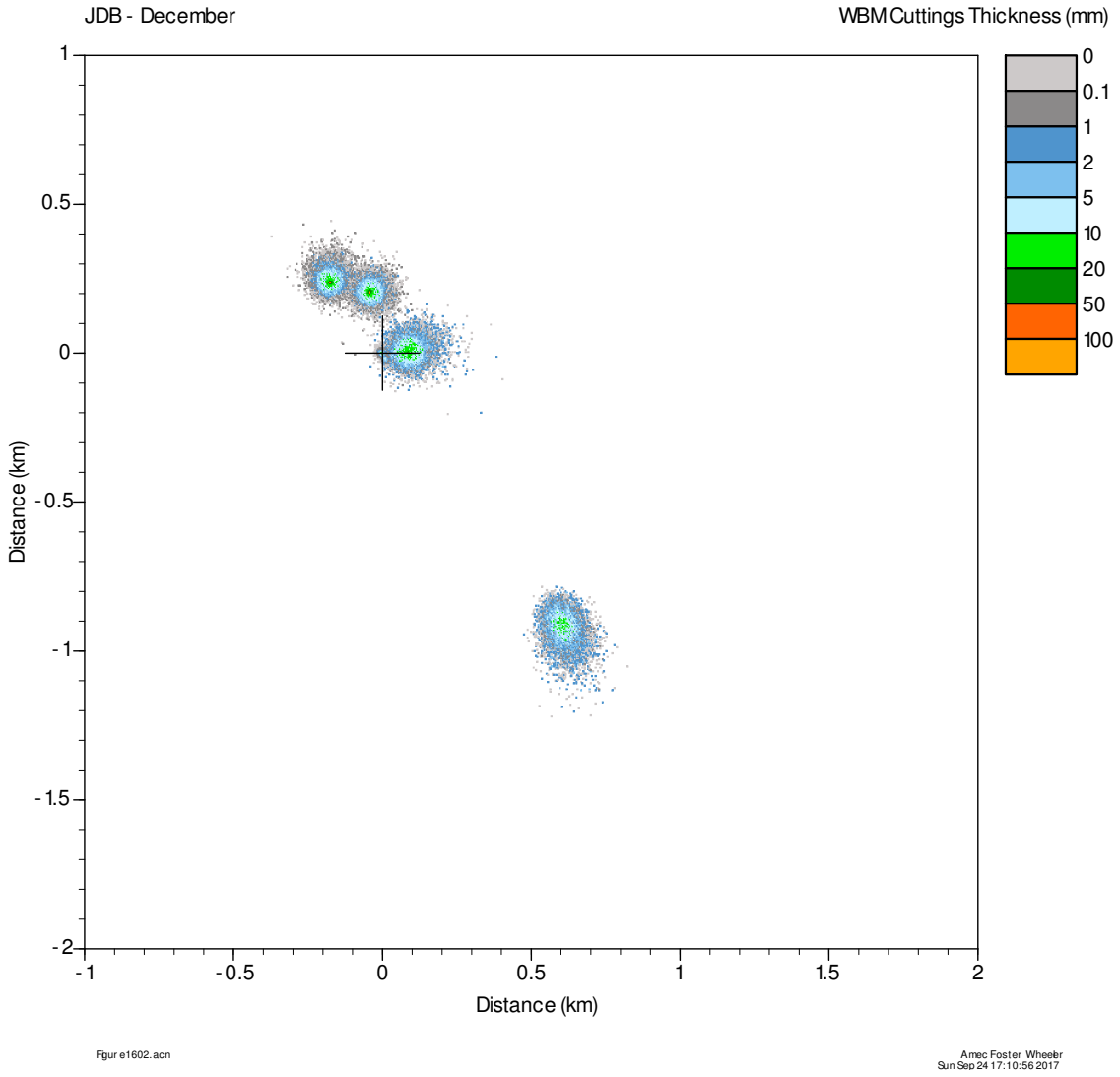


Figure 4-63 WBM Drill Cuttings Deposition, JDB, December, 1.5-km View

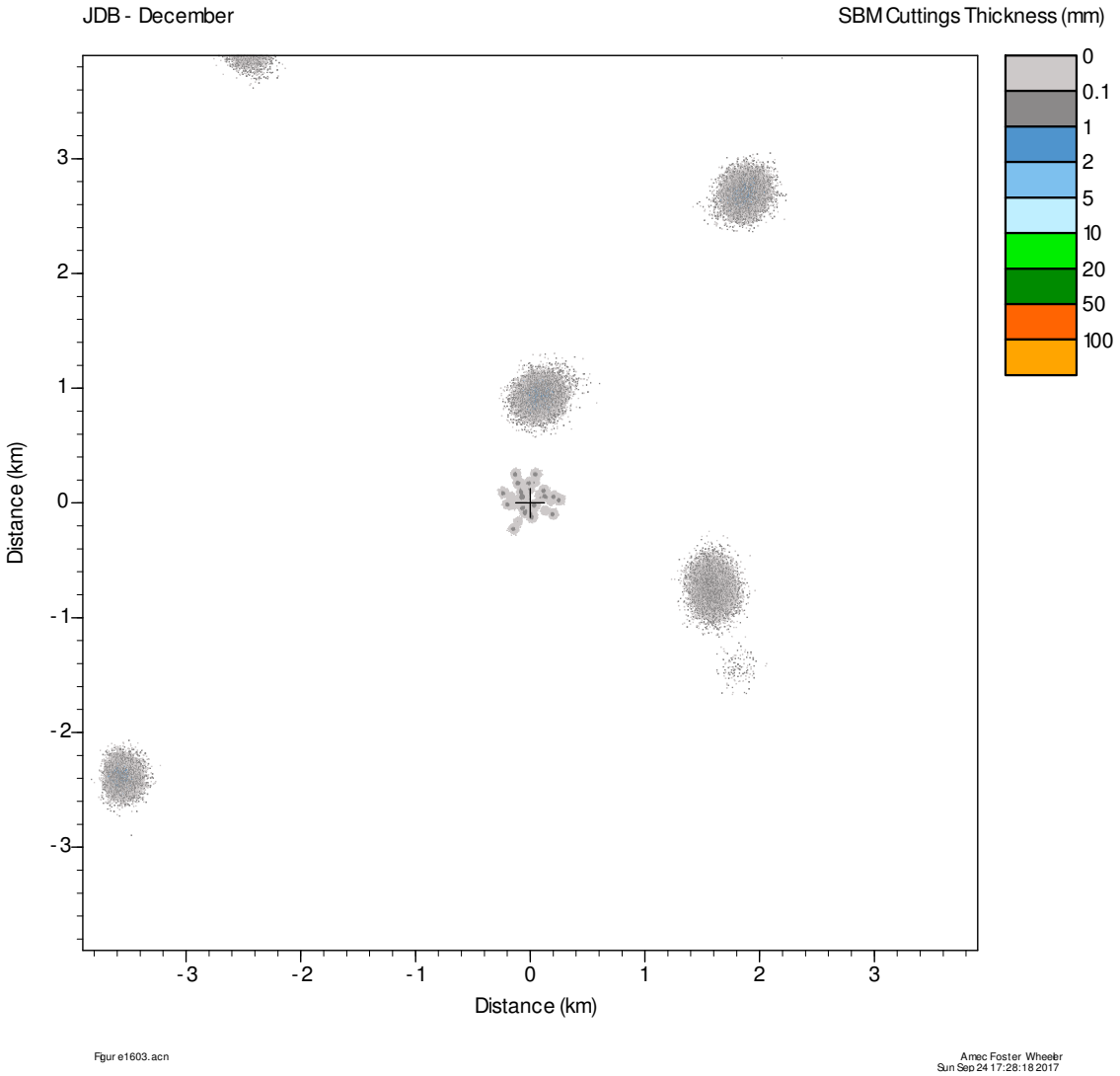


Figure 4-64 SBM Drill Cuttings Deposition, JDB, December, 4-km View

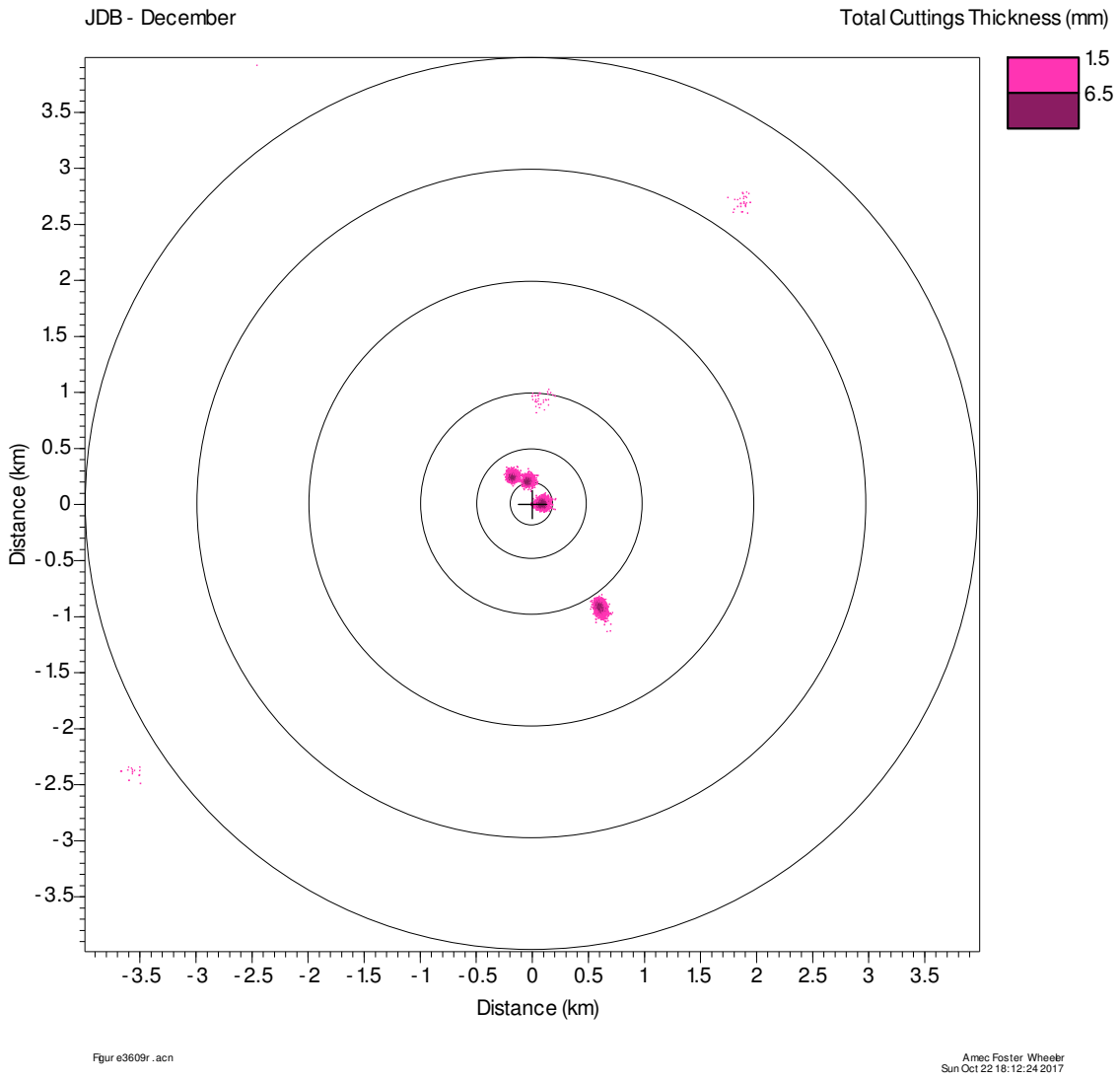


Figure 4-65 Total Drill Cuttings Deposition, PNET Limits, JDB, December, 4-km View

4.1 Drill Cuttings Results Summary, Project Area – Southern Section

One site was modelled for drill cuttings discharge within the Southern Project Area (SPA): a hypothetical Jeanne D'Arc Basin (JDB) modelled wellsite, located northwest of the Hibernia Platform on the Grand Banks at approximately 89 m water depth. As currents are distributed in most directions in most months, discharged WBM and SBM cuttings drift in all directions at this relatively shallow site. Discharged WBM cuttings settle within 2 km of the wellhead, mainly at distances 100 m to 2 km away. The average thicknesses of accumulated WBM drill cuttings are 8 mm or less across all seasonal scenarios. Some areas of higher maximum cuttings thickness occur within 500 m of the wellsite reaching up to 102 mm (December model run, 210 m to the northwest). SBM cuttings initially settle within the 32 km model area

with the majority (5-59 percent of SBM material settled) of accumulation from 2-31 km away from the wellsite. The overall average thickness of settled SBM material is 0.4 mm or less across all seasonal scenarios and distances from the wellsite. Maximum SBM cuttings thicknesses reach 0.7 mm at 7.7 km from the wellsite.

In summary, any areas of accumulation for WBM cuttings will occur within 2 km of the wellsite. While SBM cuttings are discharged at relatively shallower depths in comparison to the deeper Project Area – Northern Section locations, overall average thickness is minimal (0.4 mm or less); however, there are some areas of accumulation that reach up to 3 mm within the model boundary. Due to the dispersion of SBM cuttings material higher accumulations within the model area are spatially small.

PNET Thickness Limits

At the JDB site in the Project Area – Southern Section, the estimated total areas for which total cuttings thicknesses are greater than 1.5 mm range from about 0.045 km^2 (in December) to 0.0625 km^2 (in March, about 250 m x 250 m square). For thicknesses greater than 6.5 mm, total areas range in size from about 0.01 km^2 (March) to 0.025 km^2 (June, about 160 m x 160 m square). Total areas with cuttings thicknesses above the PNET thresholds are shown in Figure 4-66.

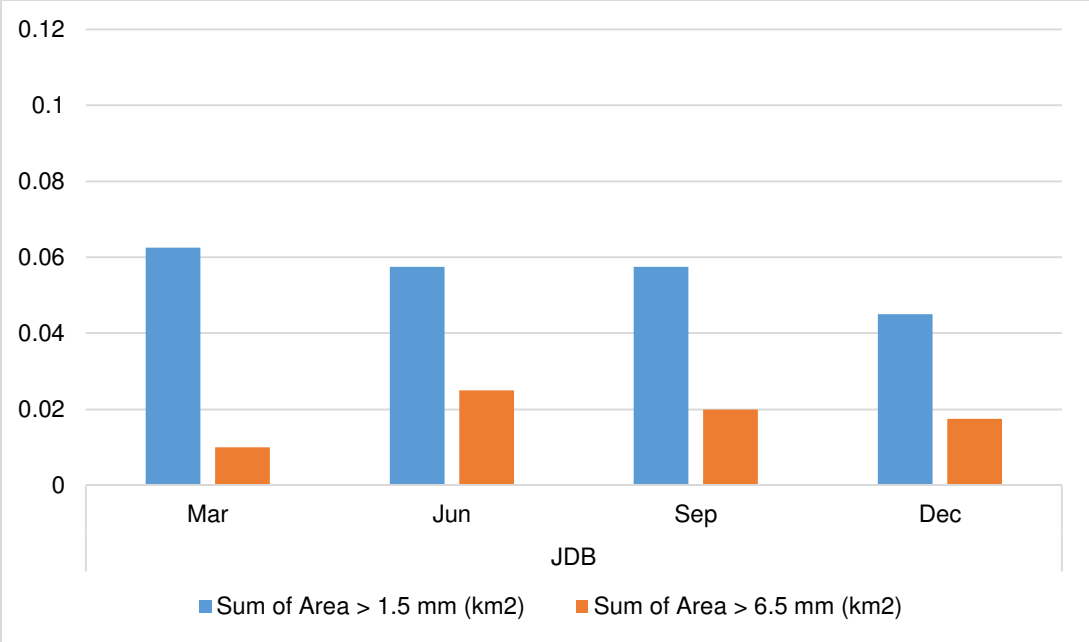


Figure 4-66 Total Cuttings Thickness Areas above PNET Thresholds, Project Area – Southern Section

At the JDB site, the areas above the 1.5 mm and 6.5 mm thresholds are located in patches generally within about 300 to 800 m from the wellhead. In March and December, there are localized patches to the southeast that exceed the 6.5 mm threshold: in March 15.7 mm at 1.4 km to the southeast; in December 21.6 mm at 1.1 km to the southeast. These total cuttings amounts will be primarily composed

of WBM cuttings. Footprints where thicknesses are above these two thresholds of interest are generally of a size 100-200 m x 100-200 m (smaller for the 6.5 mm threshold) with the areas sometimes lying adjacent to each other. These are evident in the PNET threshold figures for each month: March (Figure 4-53), June (Figure 4-57), September (Figure 4-61) and December (Figure 4-65).

For all months at JDB, there are several reported thicknesses (of SBM cuttings) above the PNET of 1.5 mm at distances beyond 1.5 km. The largest thickness is 2.9 mm in June at 2.6 km. The farthest distances by month are 2.9 km in March, 3.9 km in June and 4.6 km in September and December; however, these thickness values (1.6 mm or less) are all scattered and isolated to single model grid cells (size 4 m x 4 m or 16 m^2) and represent very small amounts of cuttings material. If aggregated over the larger model grid cells of size 32 m x 32 m (a more realistic model resolution at these distances from the wellsite) the thicknesses of any of these areas above the PNET 1.5 mm beyond 1.5 km all drop below 1.5 mm.

5.0 CLOSURE

This report presents the data and methods used to model drill cuttings release for exploration drilling at three Flemish Pass and one Jeanne d'Arc Basin well locations. Modelling scenarios during four seasons are considered for each location. Results presented include cuttings footprints and statistics on percent of material settled and mean and maximum cuttings thicknesses.

Yours sincerely,

Amec Foster Wheeler Environment & Infrastructure,
a Division of Amec Foster Wheeler Americas Limited

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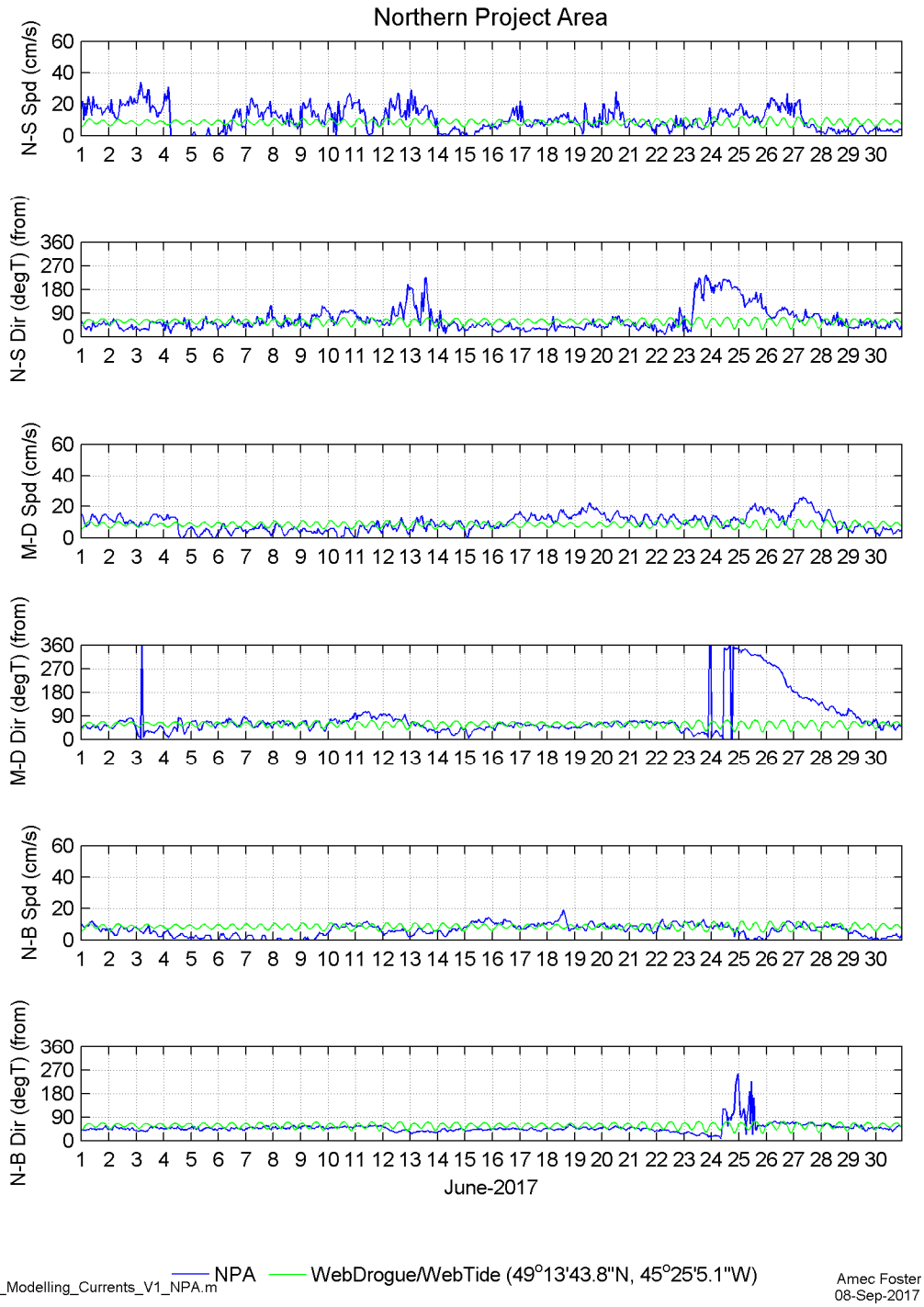
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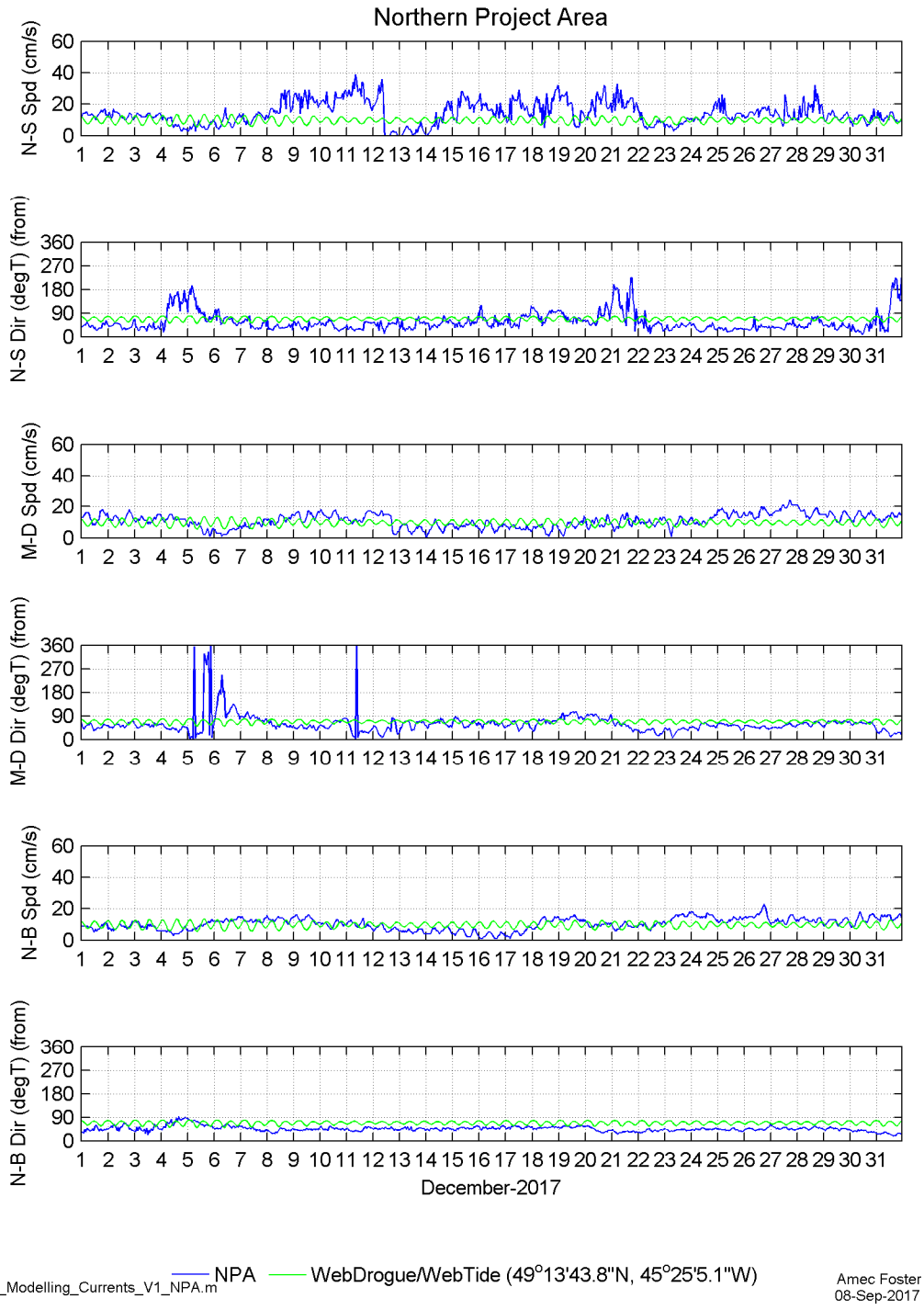
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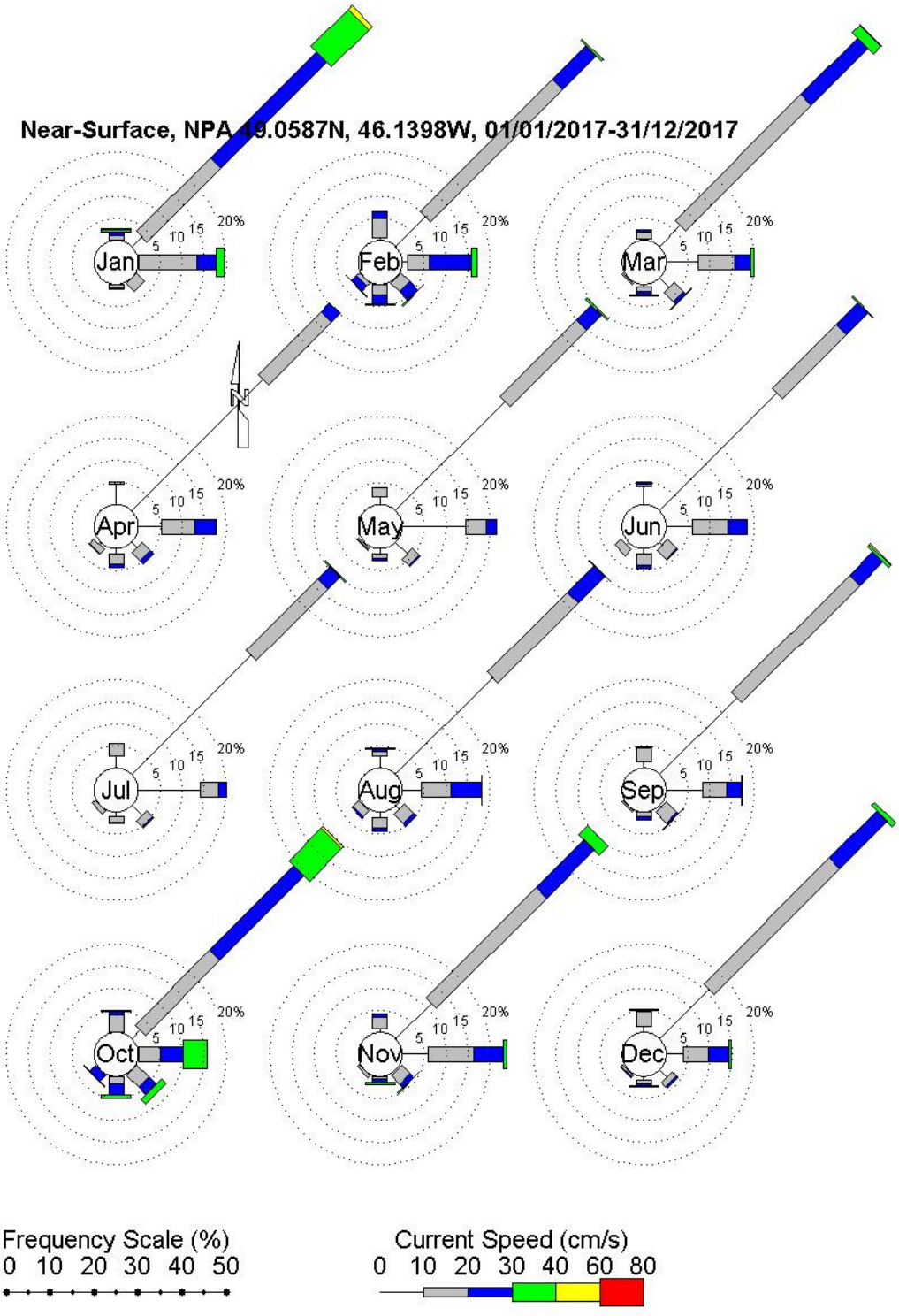
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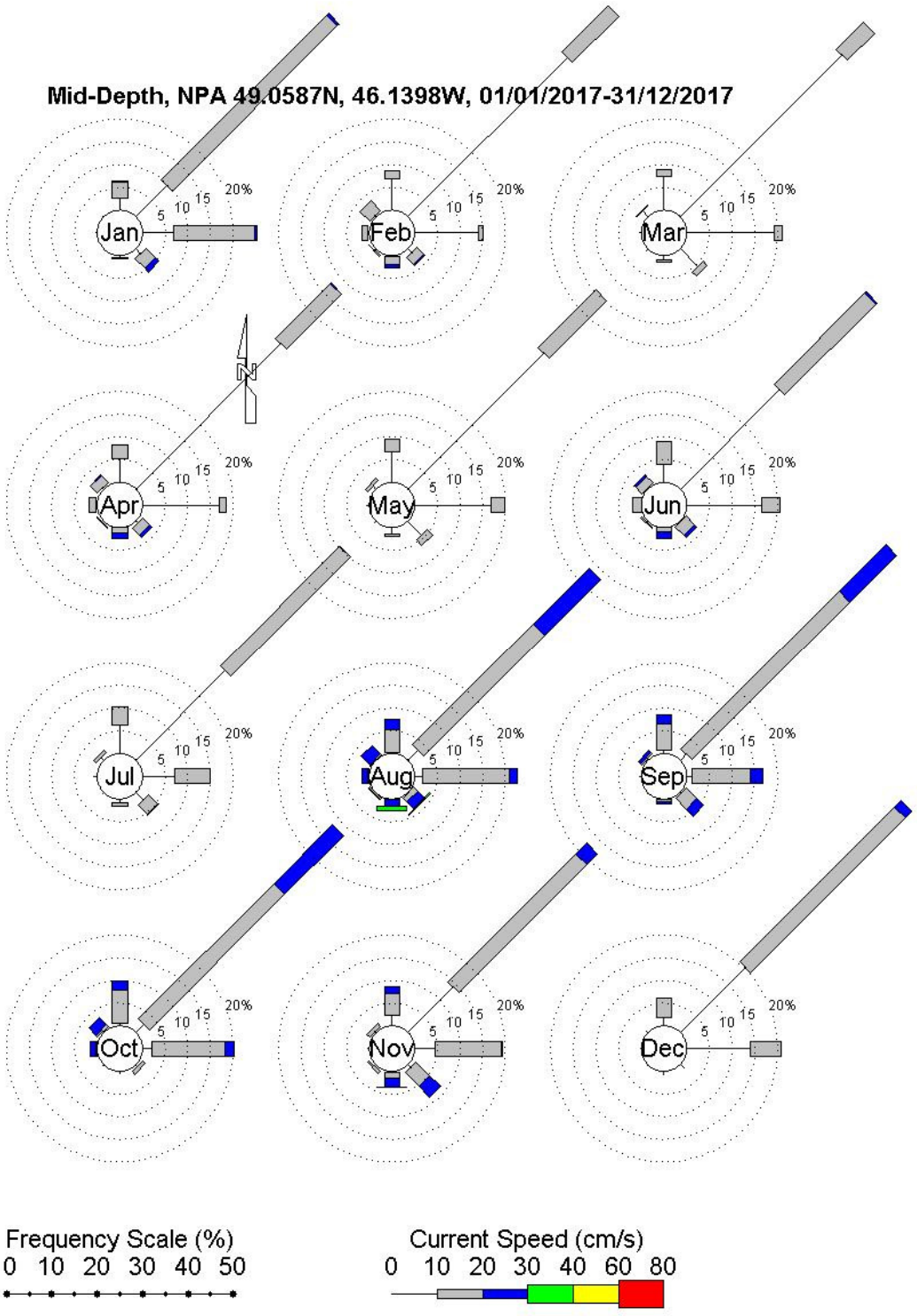
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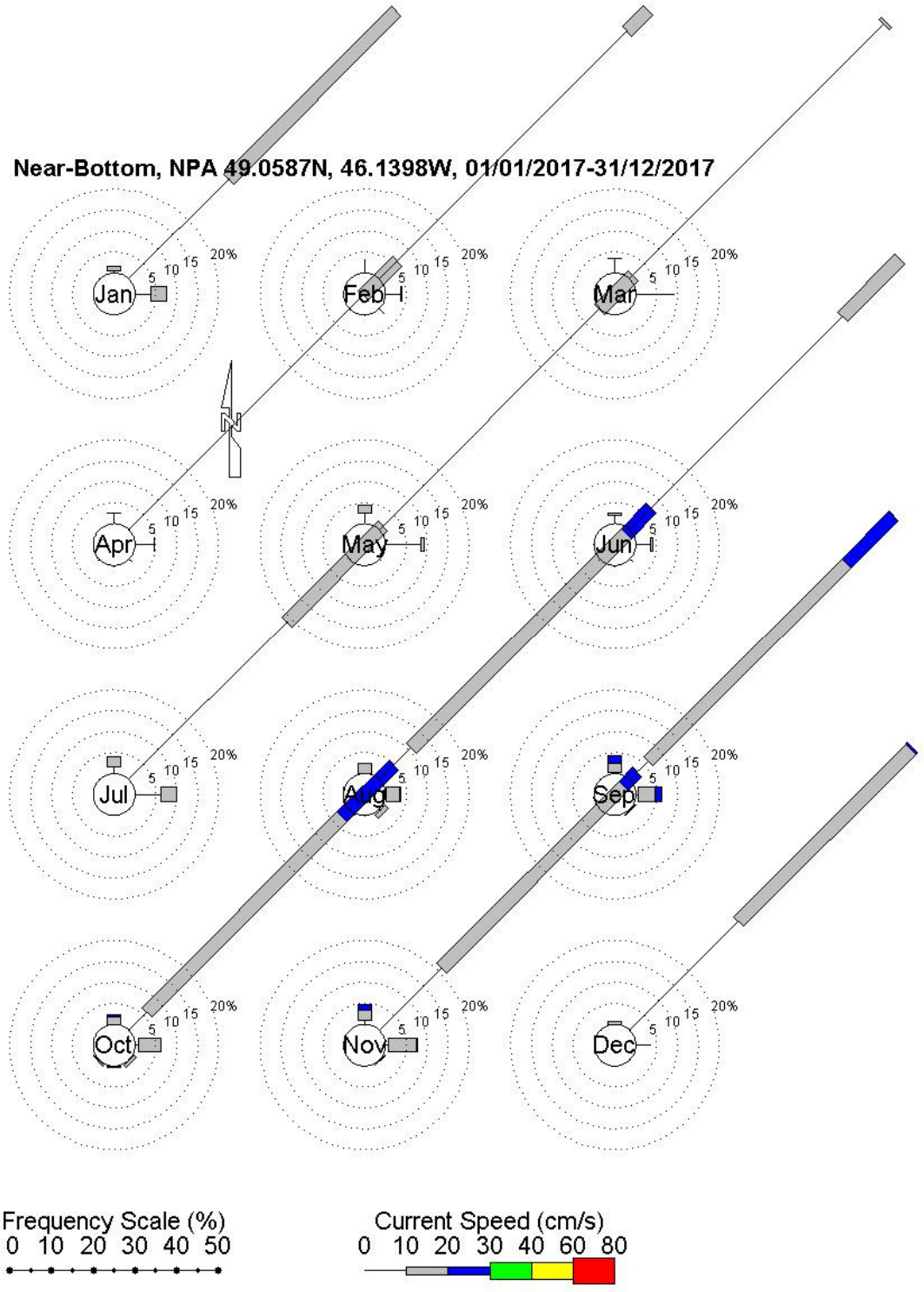
APPENDIX A-1: Ocean Currents for Modelling Locations

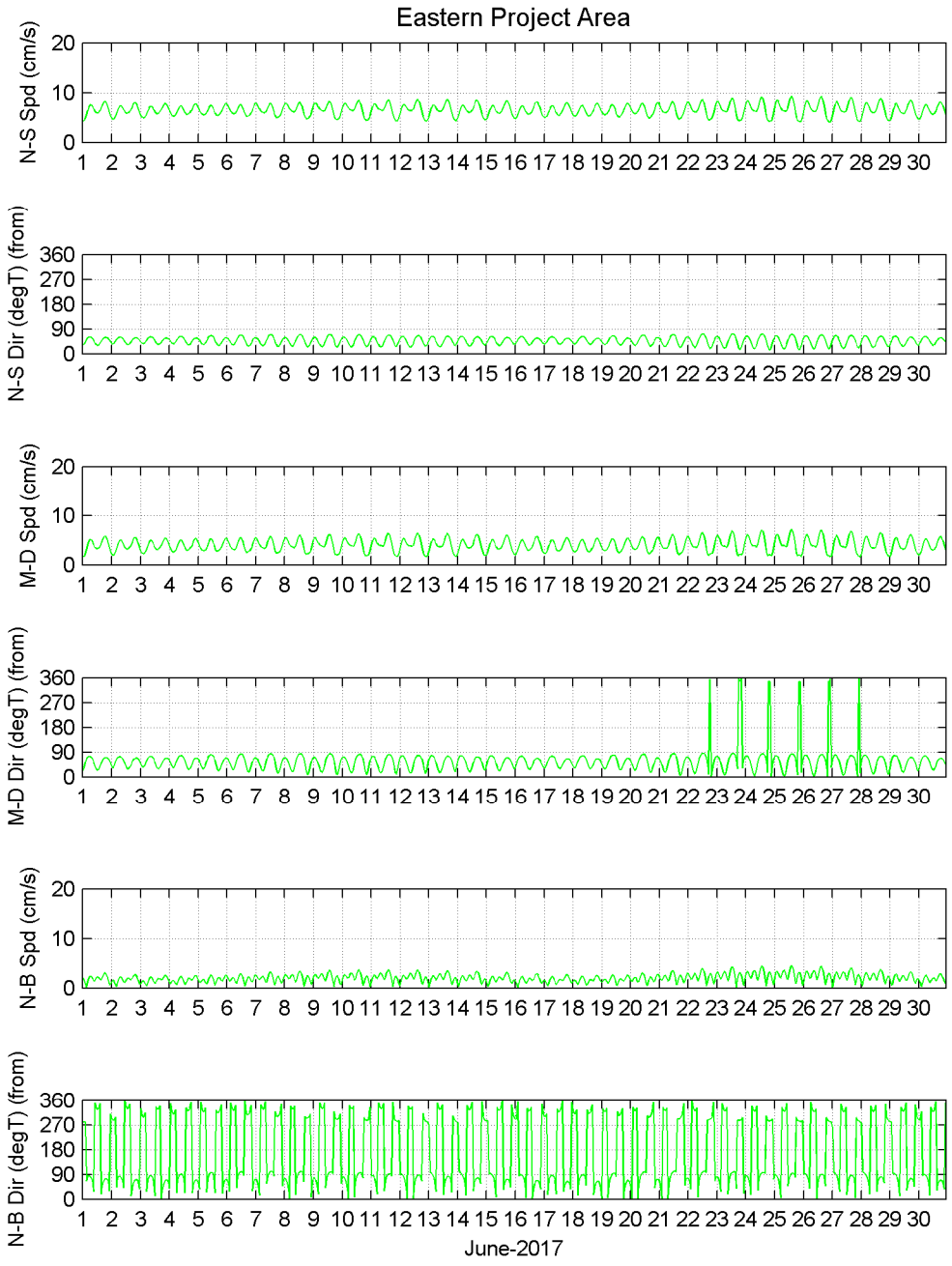

Northern Project Area
N-S Spd (cm/s)
N-S Dir (degT) (from)
M-D Spd (cm/s)
M-D Dir (degT) (from)
N-B Spd (cm/s)
N-B Dir (degT) (from)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
June-2017
NPA
WebDrogue/WebTide (49°13'43.8"N, 45°25'5.1"W)
ADM_Modelling_Currents_V1_NPA.m
Amec Foster Wheeler
08-Sep-2017 16:58:13

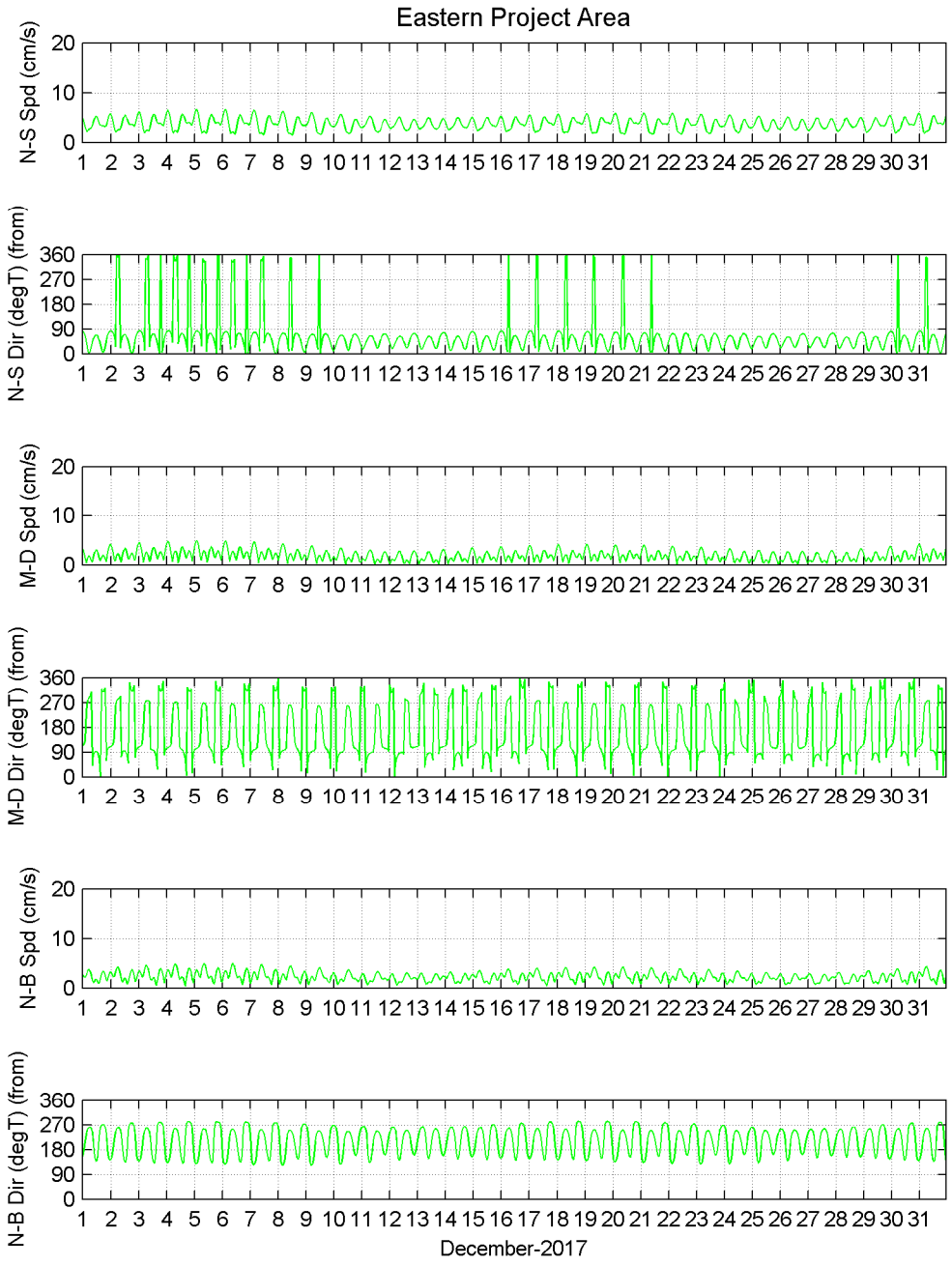

Northern Project Area
N-S Spd (cm/s)
N-S Dir (degT) (from)
M-D Spd (cm/s)
M-D Dir (degT) (from)
N-B Spd (cm/s)
N-B Dir (degT) (from)
December-2017
NPA
WebDrogue/WebTide (49°13'43.8"N, 45°25'5.1"W)
ADM_Modelling_Currents_V1_NPA.m
Amec Foster Wheeler
08-Sep-2017 16:58:22

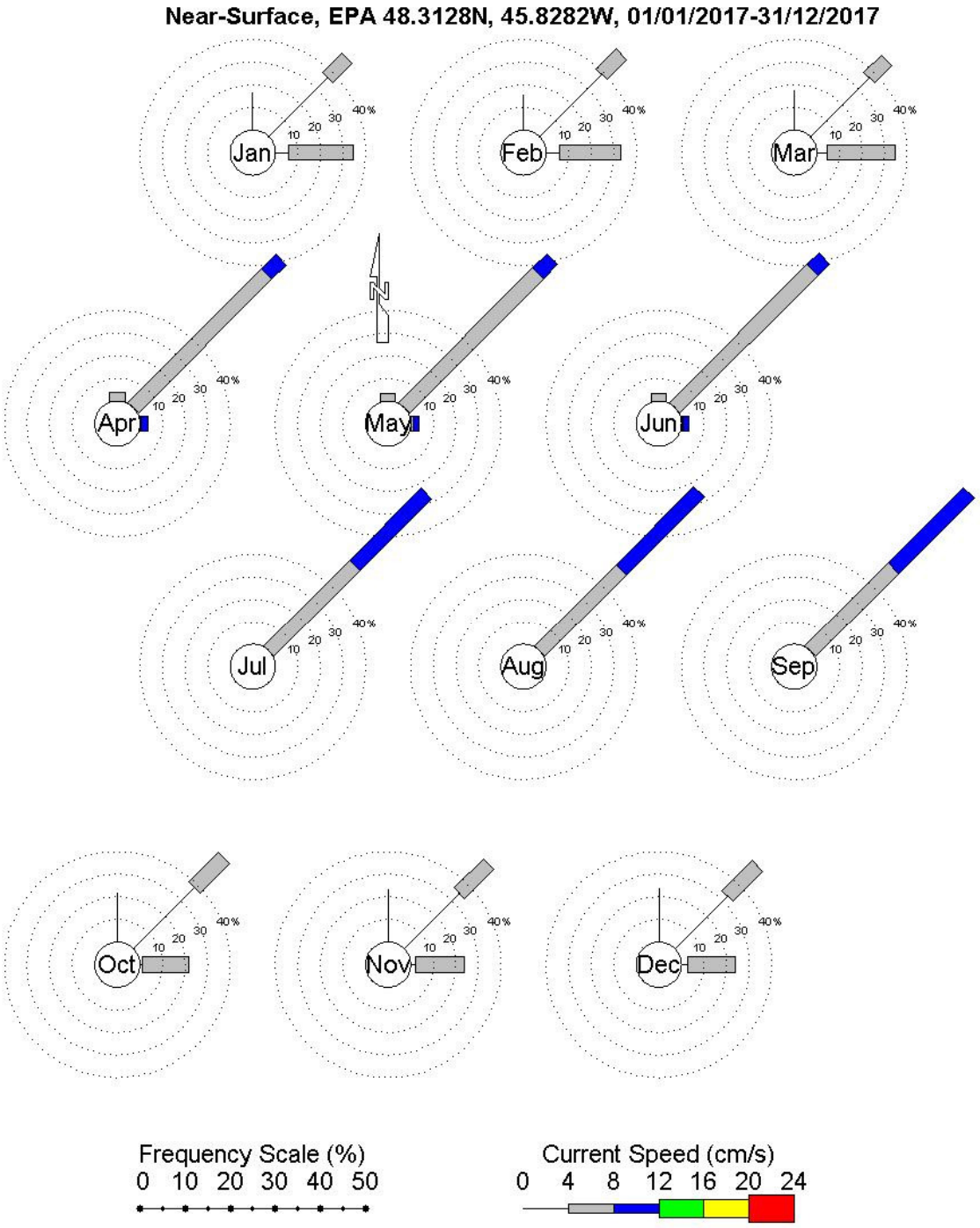

Near-Surface, NPA 49.0587N, 46.1398W, 01/01/2017-31/12/2017
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
N
5 10 15 20%
Frequency Scale (%)
0 10 20 30 40 50
Current Speed (cm/s)
0 10 20 30 40 60 80


Mid-Depth, NPA 49.0587N, 46.1398W, 01/01/2017-31/12/2017
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
N
5 10 15 20%
Frequency Scale (%)
0 10 20 30 40 50
Current Speed (cm/s)
0 10 20 30 40 60 80

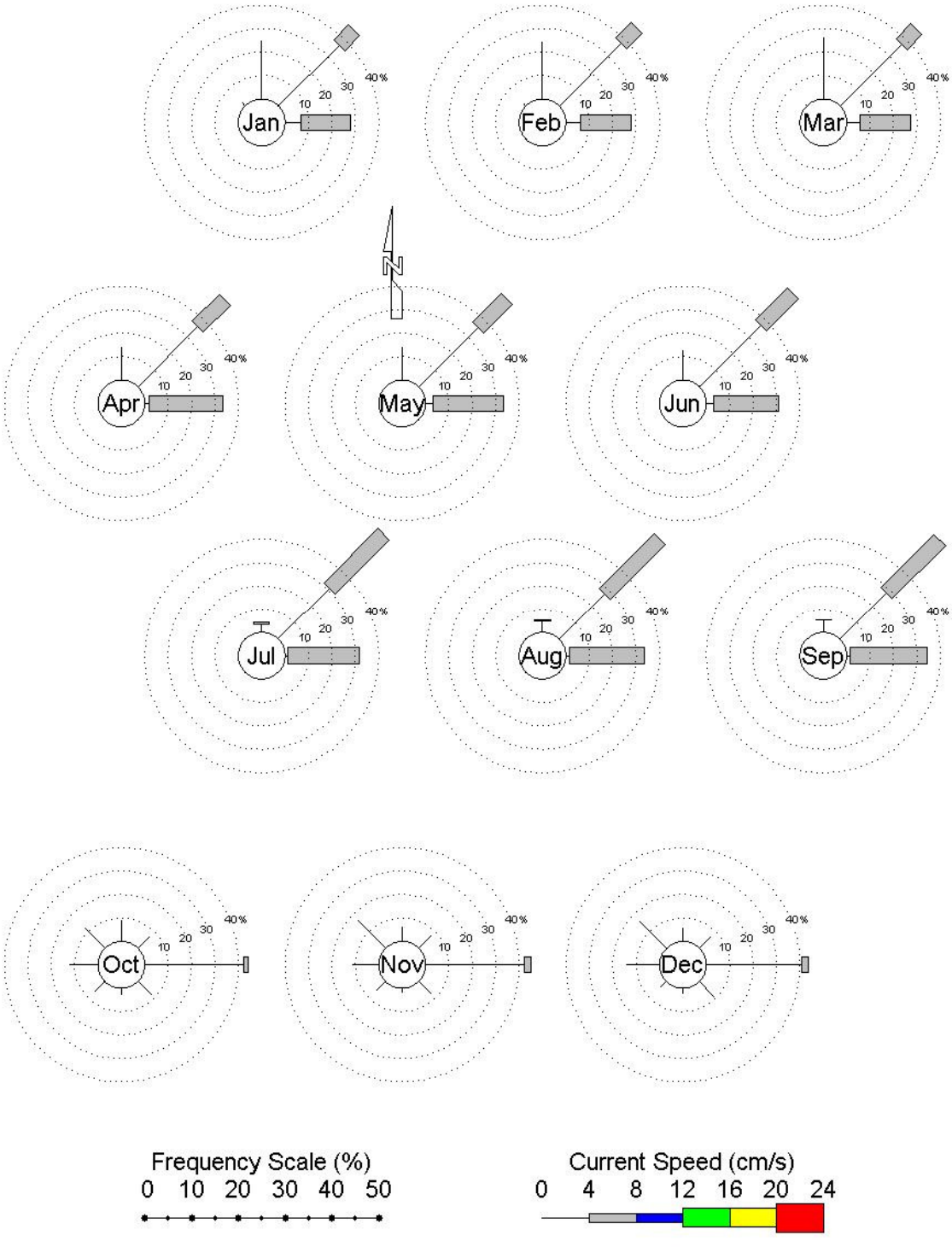

Near-Bottom, NPA 49.0587N, 46.1398W, 01/01/2017-31/12/2017
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
N
5 10 15 20%
Frequency Scale (%)
0 10 20 30 40 50
Current Speed (cm/s)
0 10 20 30 40 60 80


Eastern Project Area
N-S Spd (cm/s)
N-S Dir (degT) (from)
M-D Spd (cm/s)
M-D Dir (degT) (from)
N-B Spd (cm/s)
N-B Dir (degT) (from)
June-2017
WebDrogue/WebTide (48°18'45.9"N, 45°49'41.5"W)
ADM_Modelling_Currents_V1_EPA.m
Amec Foster Wheeler
08-Sep-2017 17:31:59

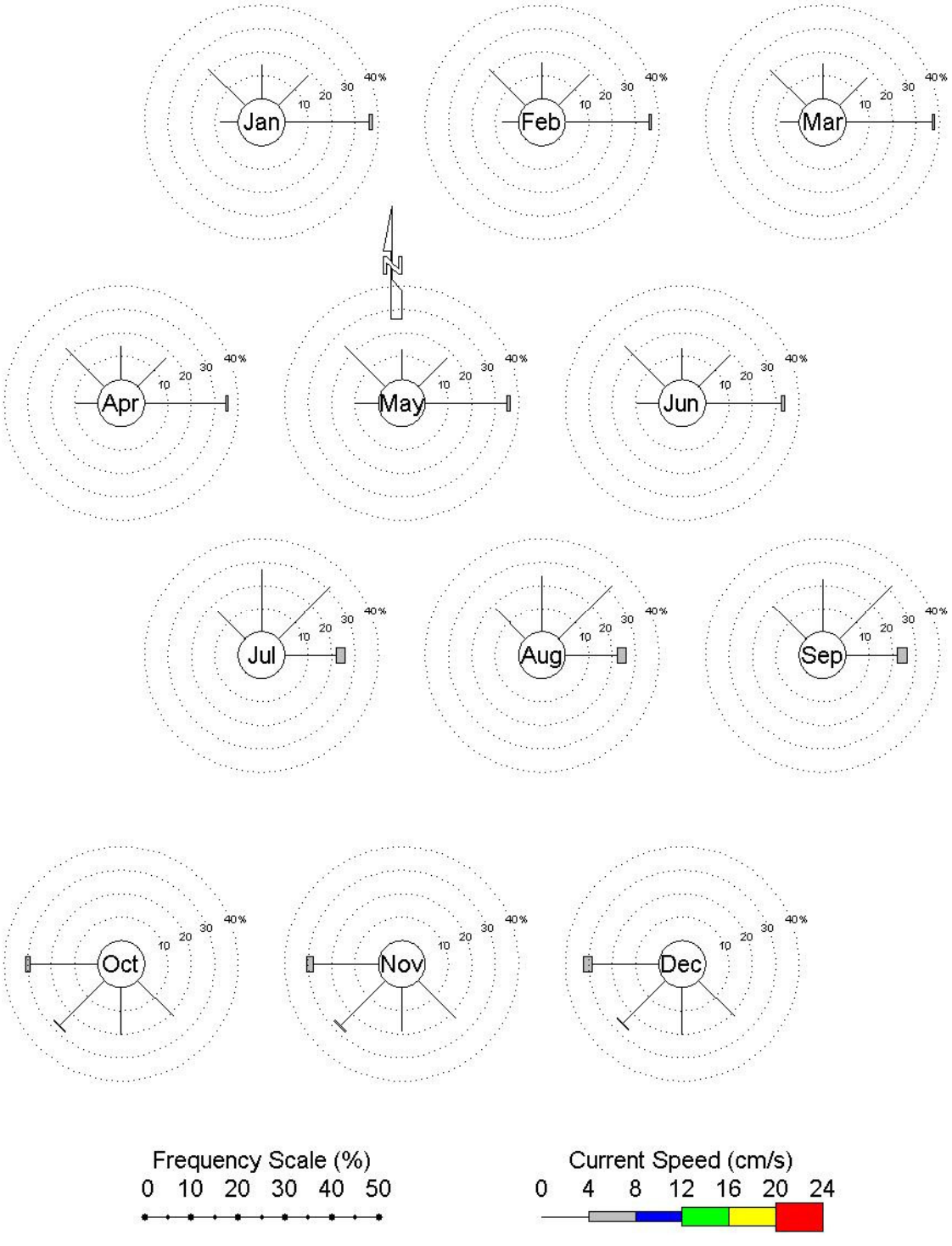

Eastern Project Area
N-S Spd (cm/s)
N-S Dir (degT) (from)
M-D Spd (cm/s)
M-D Dir (degT) (from)
N-B Spd (cm/s)
N-B Dir (degT) (from)
December-2017
ADM_Modelling_Currents_V1_EPA.m
WebDrogue/WebTide (48°18'45.9"N, 45°49'41.5"W)
Amec Foster Wheeler
08-Sep-2017 17:32:08

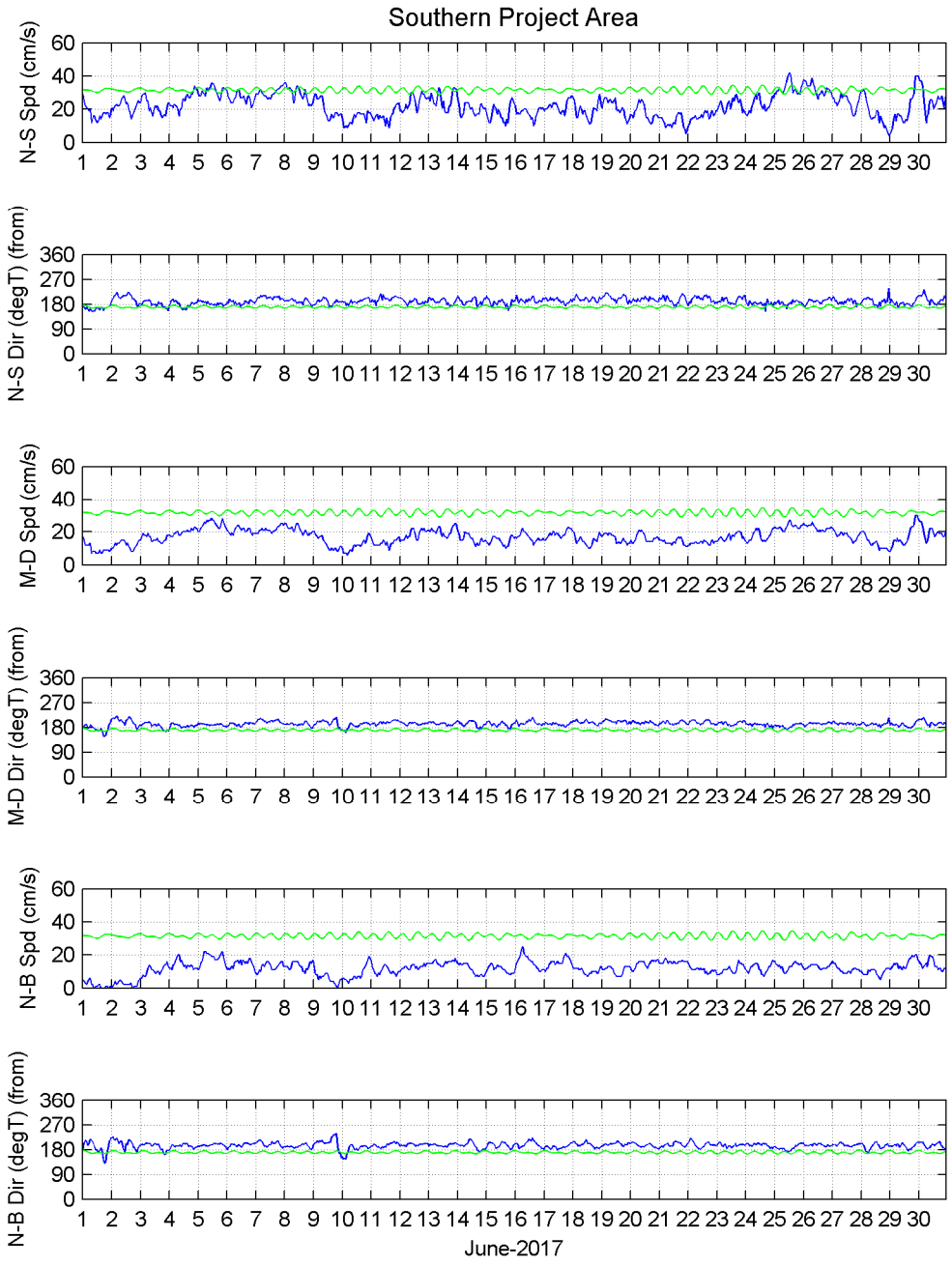

Near-Surface, EPA 48.3128N, 45.8282W, 01/01/2017-31/12/2017
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
10
20
30
40%
Frequency Scale (%)
0 10 20 30 40 50
Current Speed (cm/s)
0 4 8 12 16 20 24

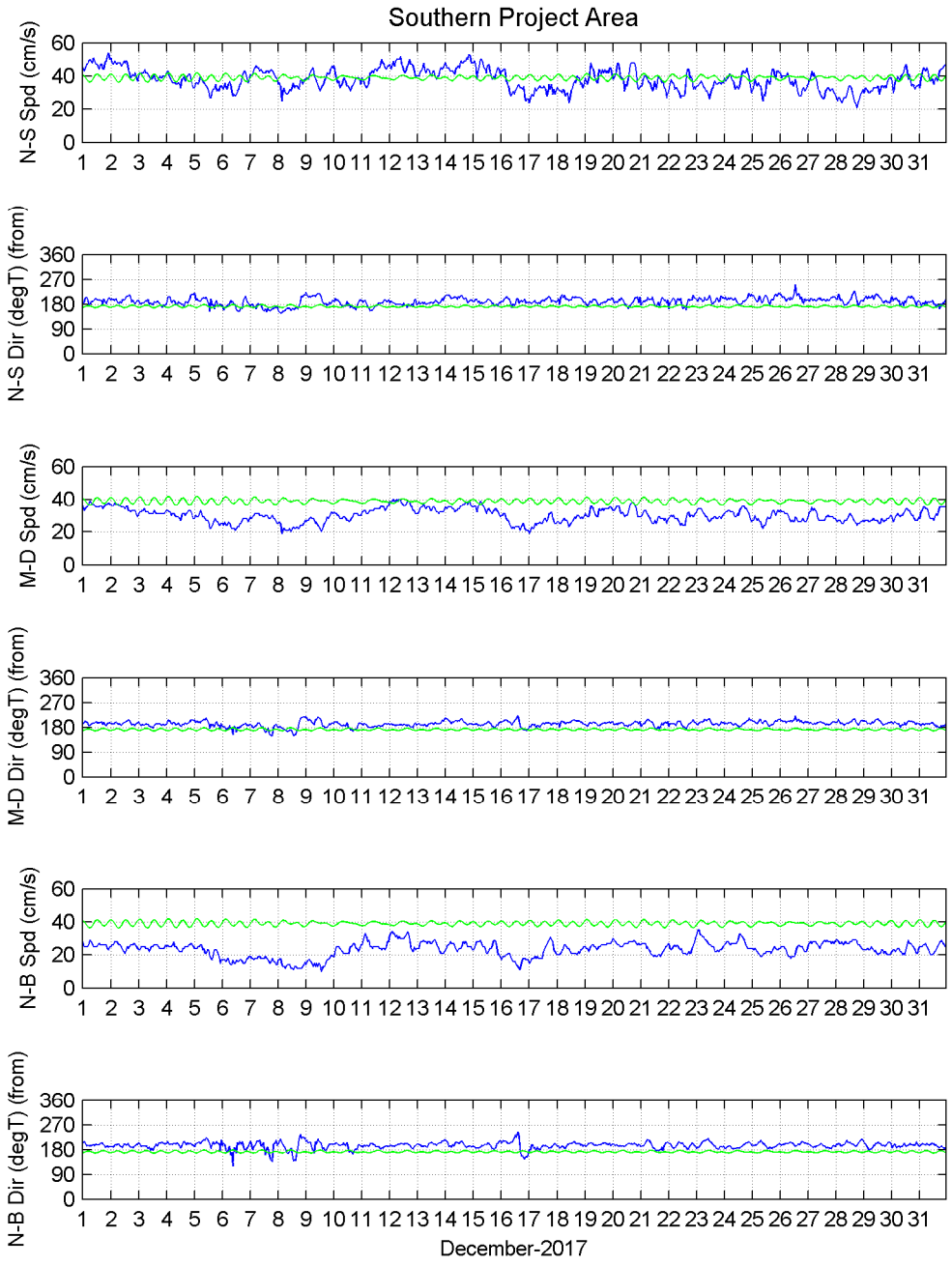
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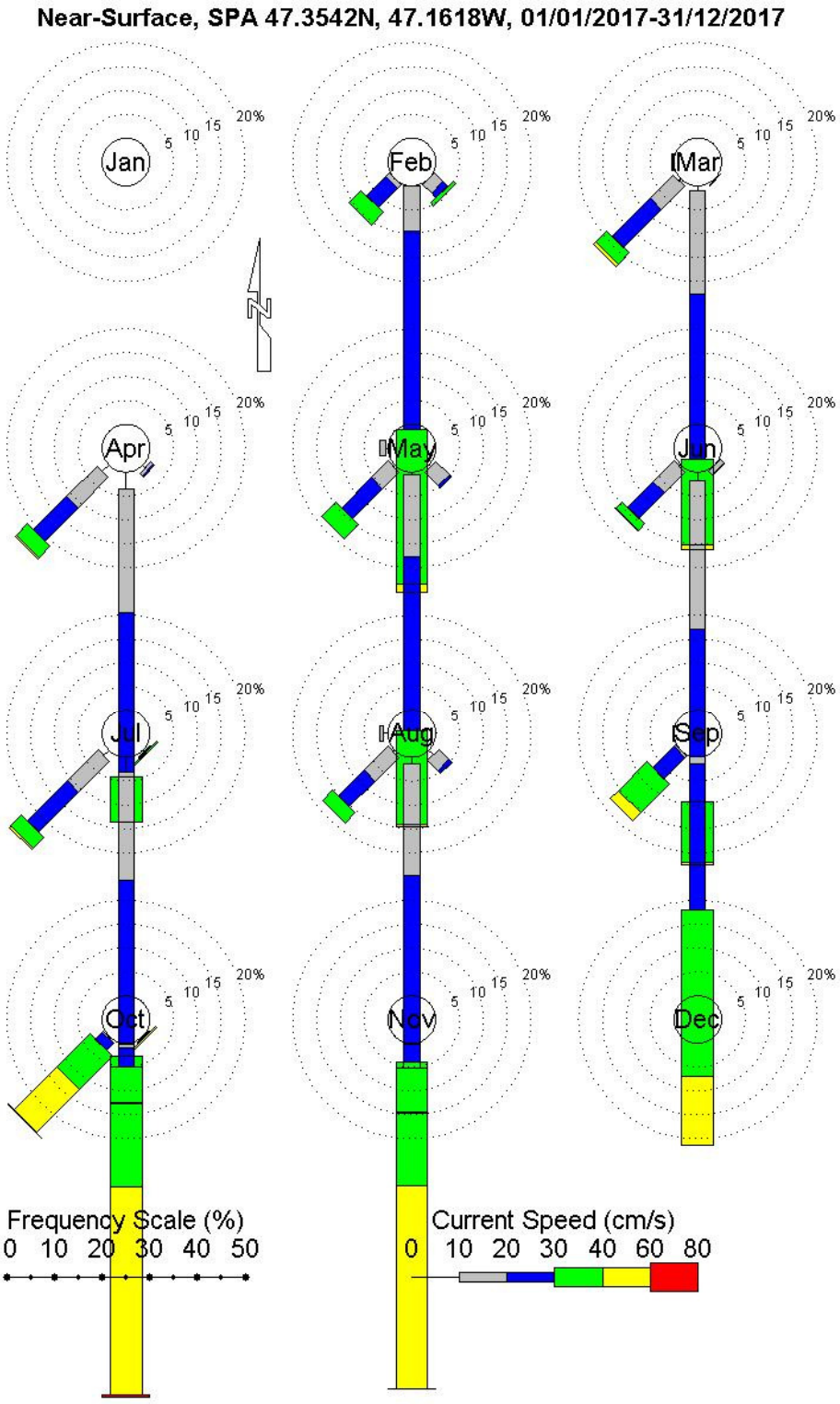


Near-Bottom, EPA 48.3128N, 45.8282W, 01/01/2017-31/12/2017

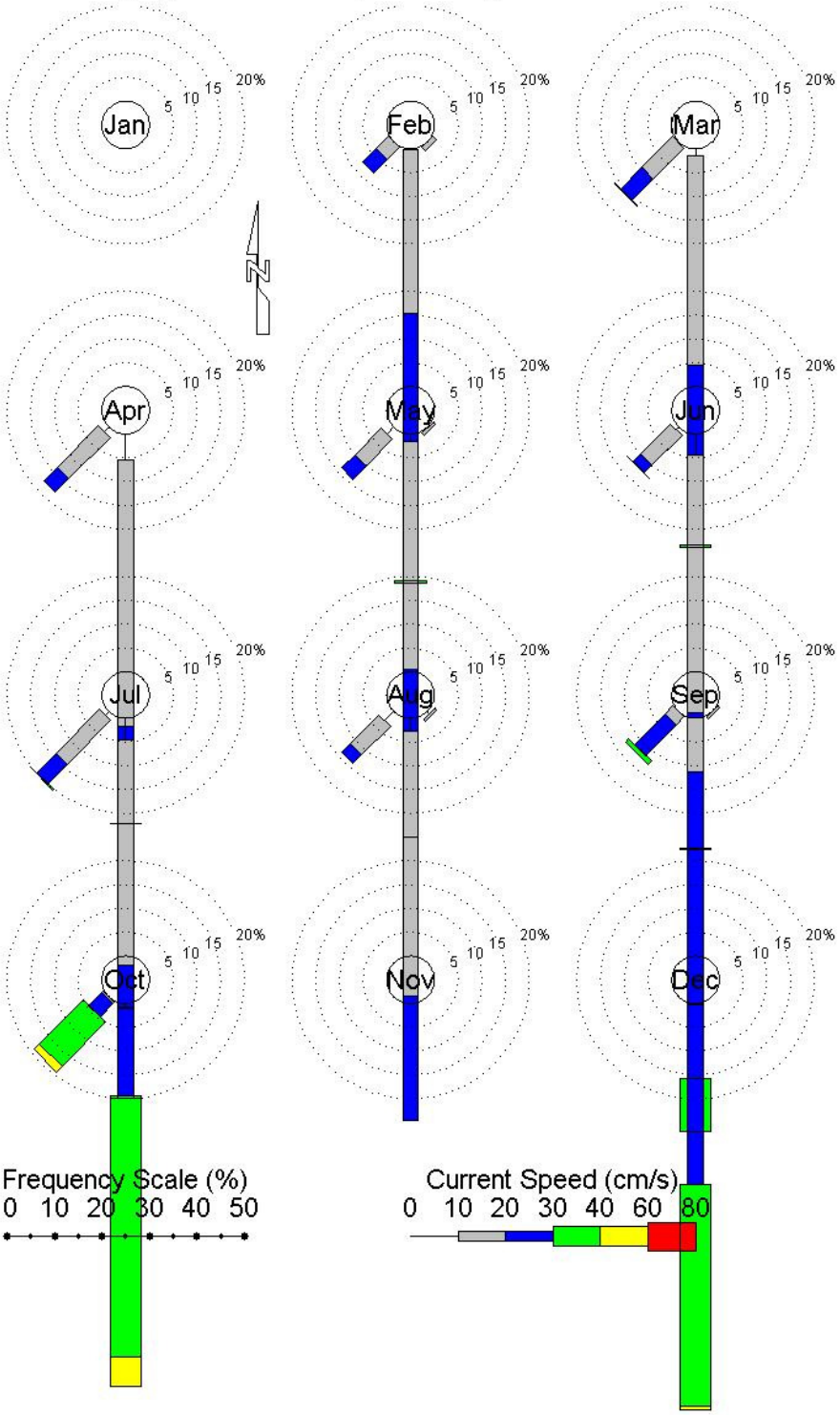



Southern Project Area
N-S Spd (cm/s)
N-S Dir (degT) (from)
M-D Spd (cm/s)
M-D Dir (degT) (from)
N-B Spd (cm/s)
N-B Dir (degT) (from)
June-2017
ADM_Modelling_Currents_V1_SPA.m
SPA
WebDrogue-CECOM/WebTide (47.51°N, 47.24°W)
Amec Foster Wheeler
07-Sep-2017 15:48:38

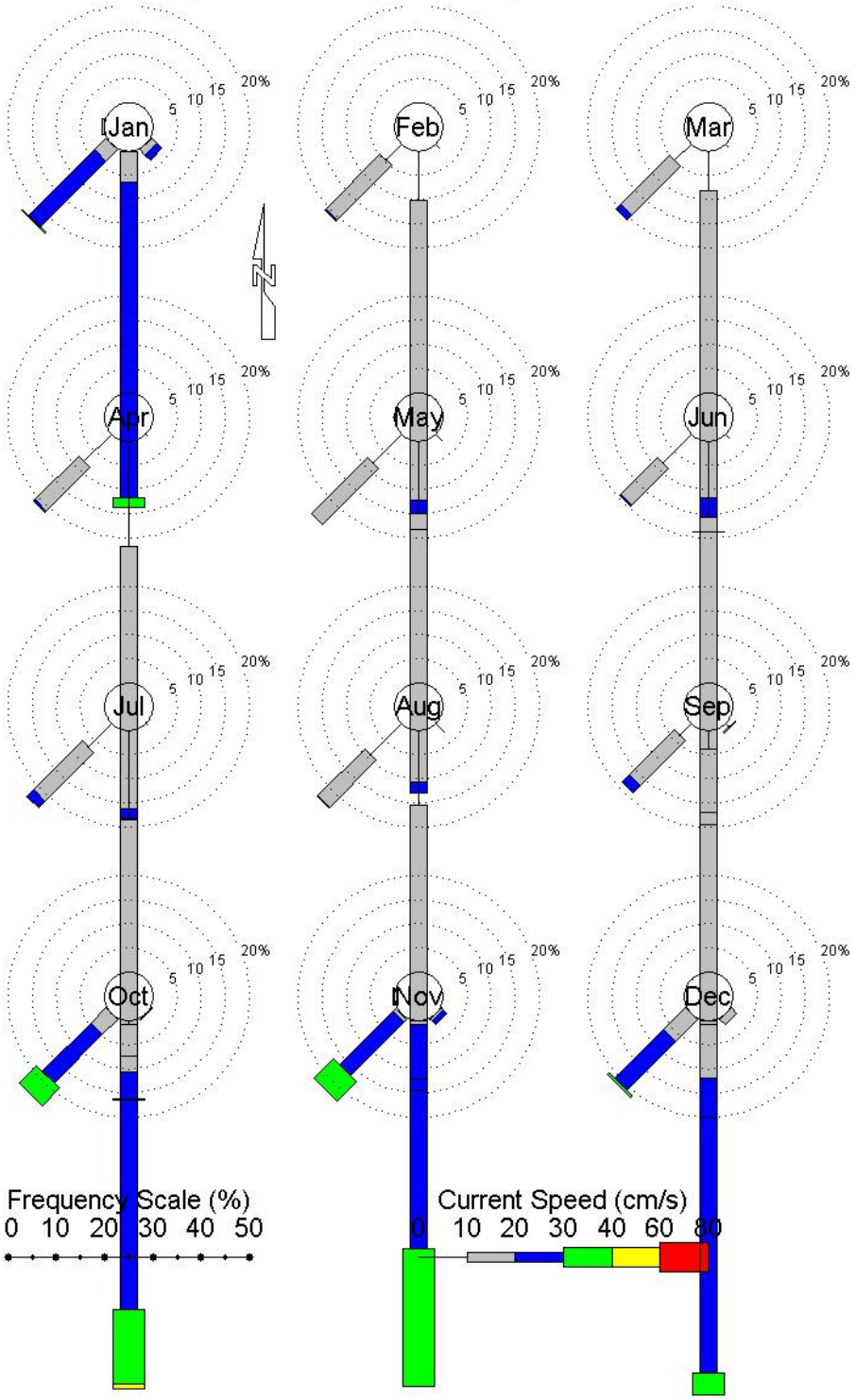

Southern Project Area
N-S Spd (cm/s)
N-S Dir (degT) (from)
M-D Spd (cm/s)
M-D Dir (degT) (from)
N-B Spd (cm/s)
N-B Dir (degT) (from)
December-2017
ADM_Modelling_Currents_V1_SPA.m
SPA
WebDrogue-CECOM/WebTide (47.51°N, 47.24°W)
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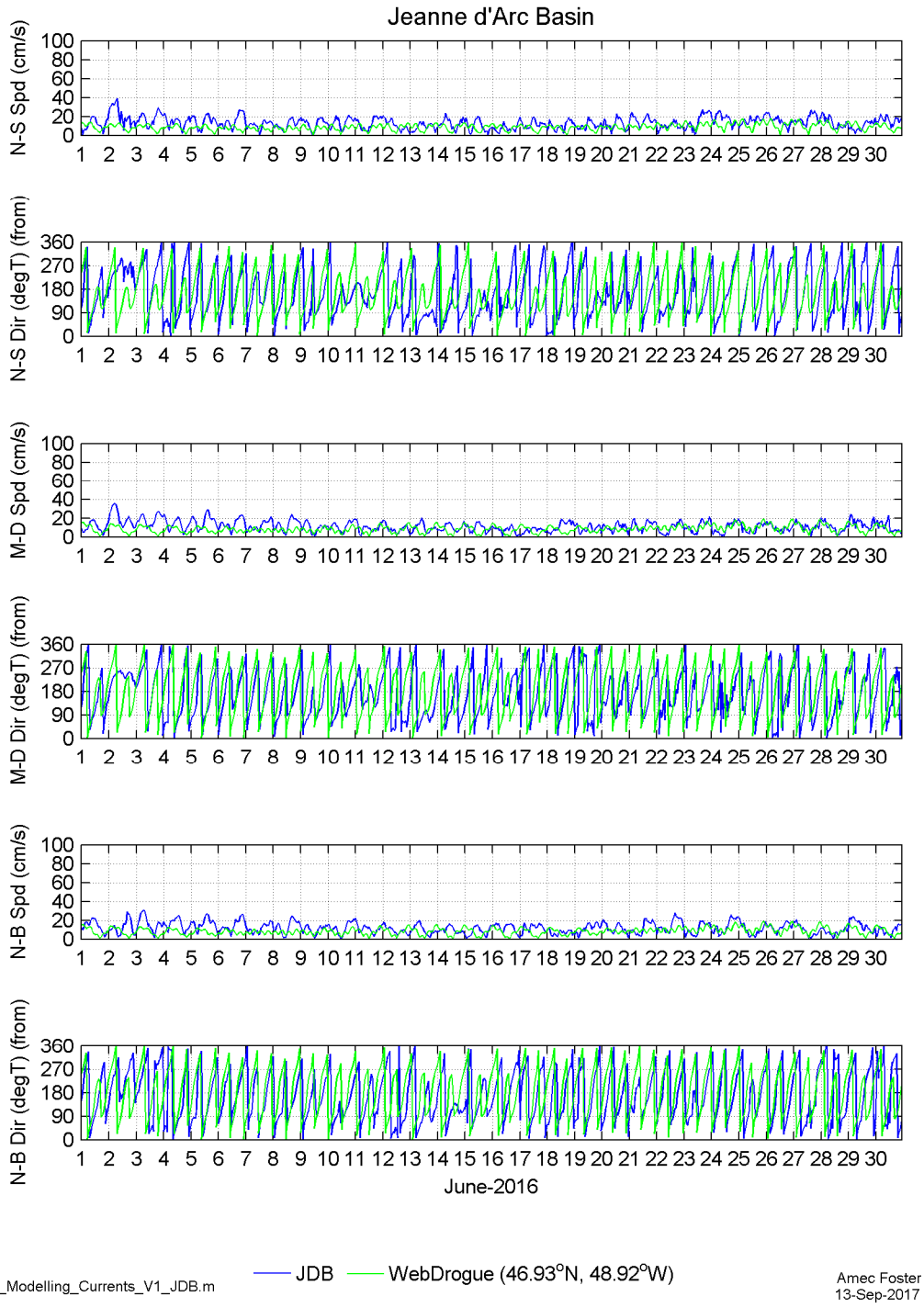

Near-Surface, SPA 47.3542N, 47.1618W, 01/01/2017-31/12/2017
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
5 10 15 20%
N
Frequency Scale (%)
0 10 20 30 40 50
Current Speed (cm/s)
0 10 20 30 40 60 80

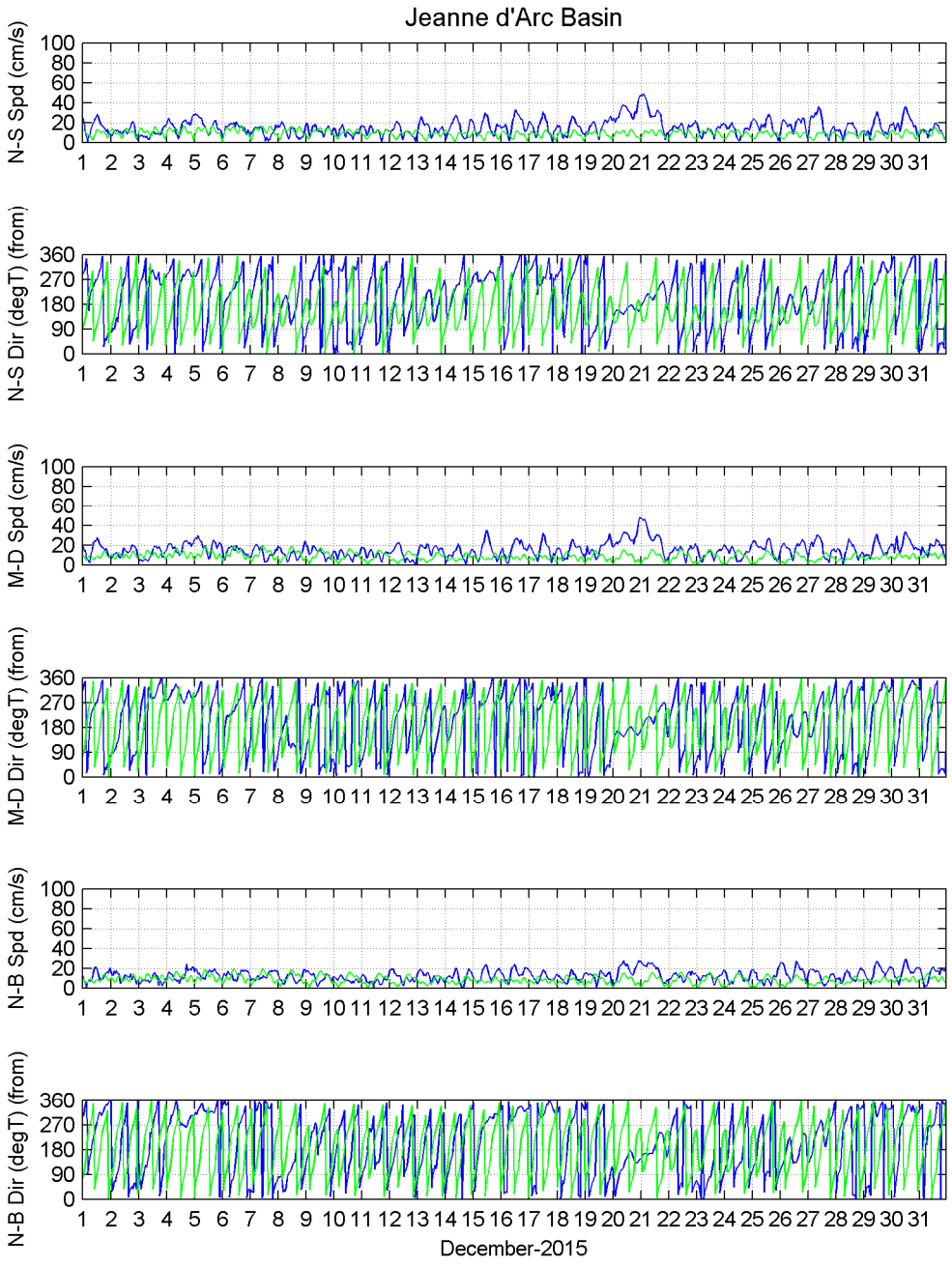
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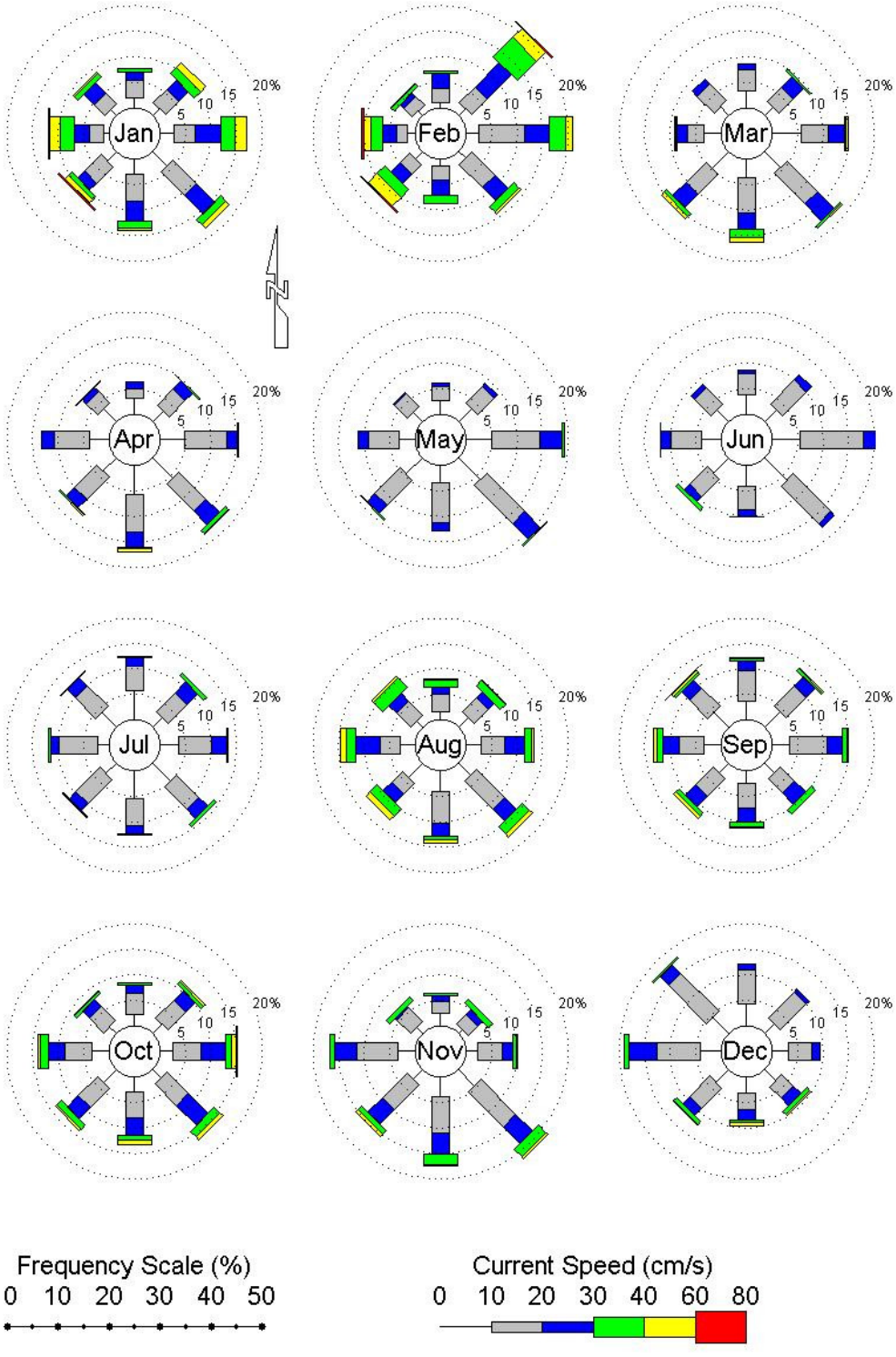
Near-Bottom, SPA 47.3542N, 47.1618W, 01/01/2017-31/12/2017



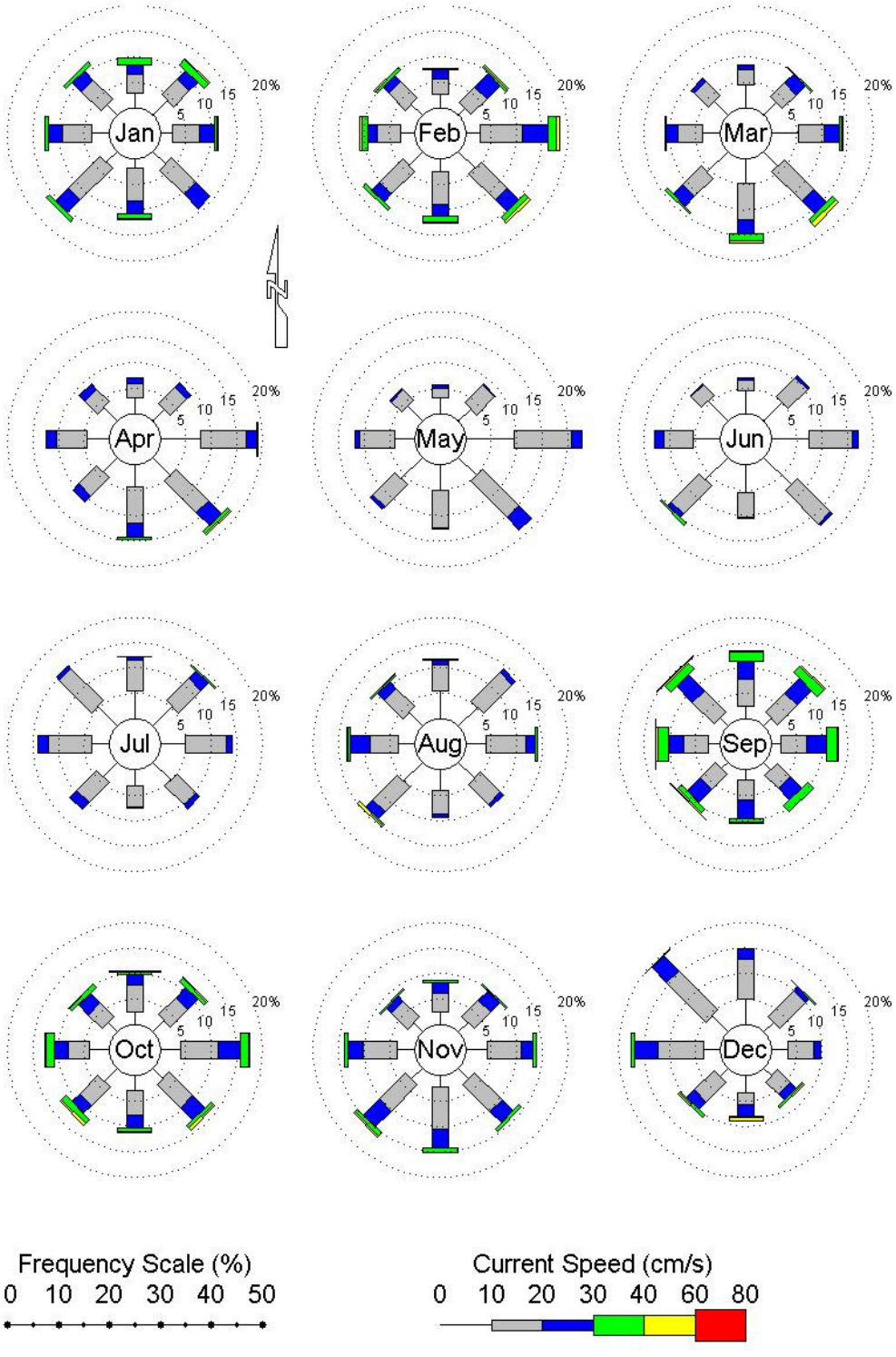

Jeanne d'Arc Basin
N-S Spd (cm/s)
N-S Dir (degT) (from)
M-D Spd (cm/s)
M-D Dir (degT) (from)
N-B Spd (cm/s)
N-B Dir (degT) (from)
June-2016
ADM_Modelling_Currents_V1_JDB.m
JDB
WebDrogue (46.93°N, 48.92°W)
Amec Foster Wheeler
13-Sep-2017 11:26:43


Jeanne d'Arc Basin
N-S Spd (cm/s)
N-S Dir (degT) (from)
M-D Spd (cm/s)
M-D Dir (degT) (from)
N-B Spd (cm/s)
N-B Dir (degT) (from)
December-2015
ADM_Modelling_Currents_V1_JDB.m
JDB
WebDrogue (46.93°N, 48.92°W)
Amec Foster Wheeler
13-Sep-2017 11:25:09

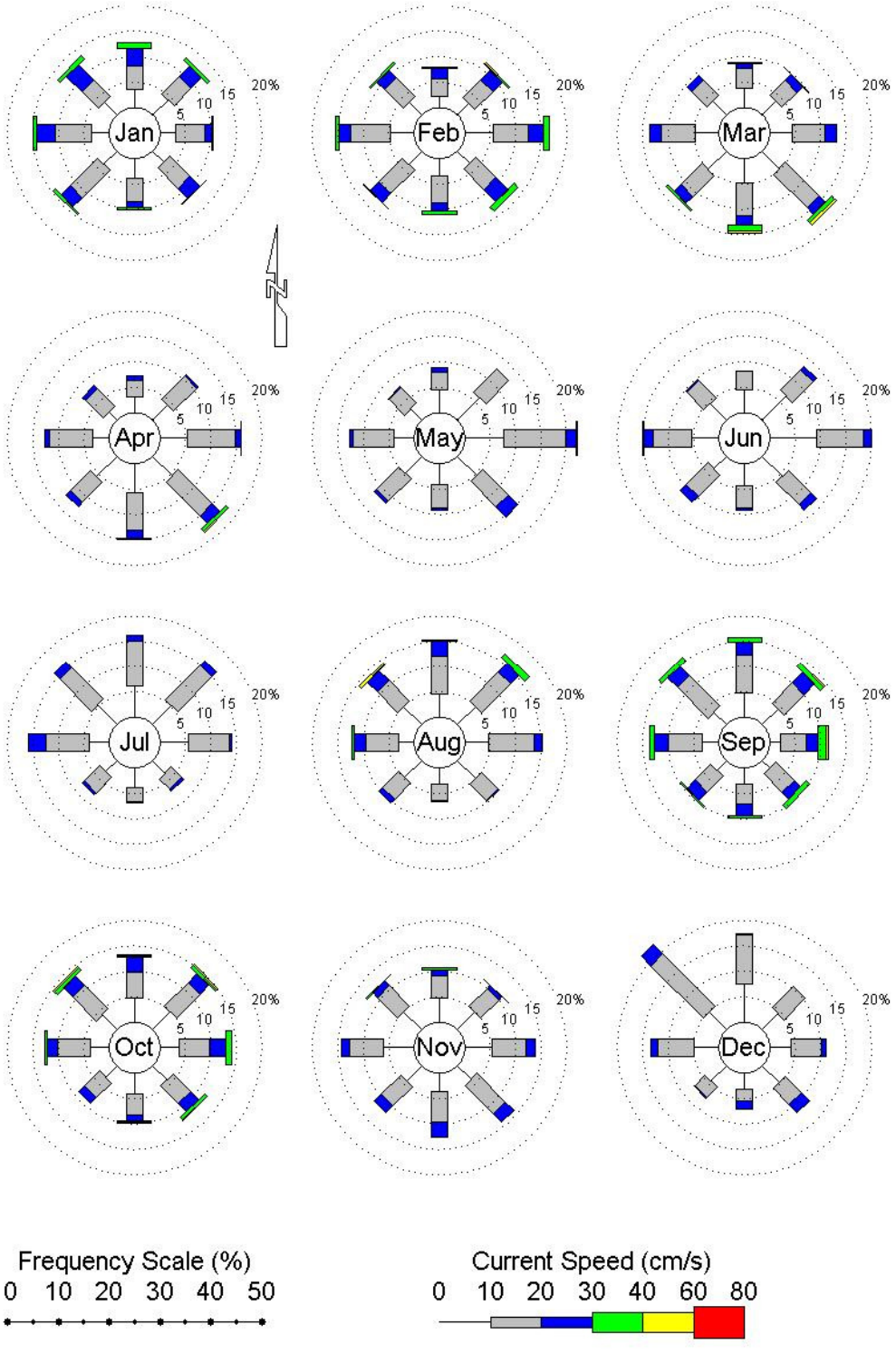
Near-Surface, JDB 46.7074N, 48.8605W, 01/09/2015-31/10/2016



Mid-Depth, JDB 46.7074N, 48.8605W, 01/09/2015-31/10/2016



Near-Bottom, JDB 46.7074N, 48.8605W, 01/09/2015-31/10/2016



APPENDIX H

Capping Stack Technology Details

Statoil Canada Ltd.

Well Intervention Strategies

1.0 WELL INTERVENTION RESPONSE STRATEGIES

This section describes the activities associated with stopping well flow in the event of an accidental discharge due to a subsea well blowout. It is generally recognized that a subsea well source control response strategy consists of three operational objectives, these are;

- BOP Intervention
- Well Capping
- Well Containment
- Relief Well(s) Drilling

Statoil is a member of the Subsea Well Response Project (SWRP) and has access to the emergency response equipment available under the Subsea Well Intervention Services agreement (SWIS) with Oil Spill Response Limited (OSRL). This equipment is stored in various strategic locations throughout the world, it is maintained regularly and ready for deployment. This equipment is in addition to the well control equipment that is available on the mobile offshore drilling unit which is the first line of defence in a well control event.

1.1 BOP Intervention

Statoil's first response in a well control scenario is to attempt to control well flow by utilizing the drilling installation's Blowout Preventer (BOP). The BOP is comprised of multiple rams capable of shearing the drill pipe and sealing the well. The BOP has additional backup activation systems which include an acoustic control system capable of being activated from elsewhere on the drilling installation, from a lifeboat or from a standby vessel, an ROV intervention package and several other fail-safe systems that allow the BOP to close and shut in the well in the event of loss of communications and/or disconnection from the lower marine riser package. BOP intervention is performed immediately upon indication that a well kick is occurring.

1.2 Capping, Containment and Relief Well Drilling

The viability of the Capping and Containment operations is contingent on many factors including the actual weather and sea state, the impact of the well flow since the incident occurred, possible reduced well integrity, vertical access to the well, jet-stream uplift forces, capping interfaces, and the remaining structural integrity related to fatigue and the well load capacity. Hence, review and revision of plans with consideration of possible alternative solutions for source control will be required after an actual incident.

In the case of a subsea well incident, the primary focus of response would be to shut in and/or kill the well, stopping the source of all hydrocarbon flow to the environment. There are three major elements to source control – well capping, well containment and relief well drilling:

- Well Capping places an additional High-pressure (HP) shut-in device on top of a failed BOP, Lower Marine Riser Package (LMRP) or wellhead to shut in well flow as an interim measure. If well flow isn't shut-in completely then restriction of flow helps reduce the environmental impact and the capping stack provides a mechanical interface to facilitate additional well containment if required

- Well Containment systems divert hydrocarbon flow from the Incident Well to a surface system for processing and disposal as an interim measure. Well containment systems may be needed on rare occasions when Well Capping does not fully shut in the Incident Well
- Relief Wells are drilled to intercept and kill the original well, shutting off the source of flow to the environment

A capping and containment response plan is prepared in addition to the normal relief well contingency plans, and is tailored to the drilling operation and it's location (i.e. Eastern Newfoundland Offshore Area) to ensure compliance with local regulations, availability of specialised vessels, air freight and other logistical and commercial arrangements.

The engineering, equipment and analysis required for this source control planning will depend on the defined incident scenario, well and location specific details, and the various surveying and debris clearance operations to be completed during the overall source control emergency response. It is important to understand the tasks and processes, which make up the overall capping and containment response plan, and to utilize the documentation related to the emergency equipment available from Oil Spill Response Limited.

For illustration purposes, a capping and containment concept overview schematic is illustrated in Figure 1-1 below.

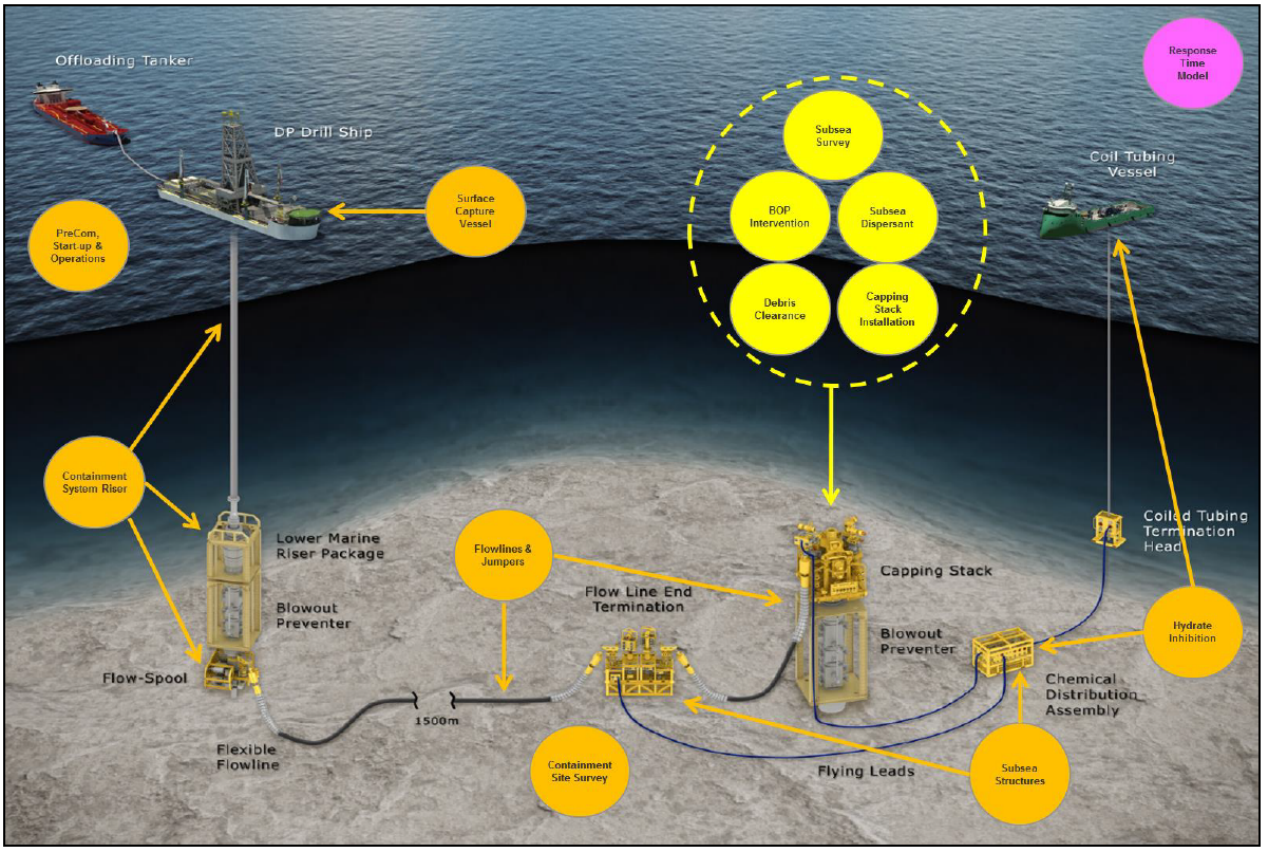


Figure 1-1 Capping and Containment Concept Overview

2.0 OSRL SUBSEA WELL INTERVENTION SERVICES

Oil Spill Response Limited's Subsea Well Intervention Service (SWIS) is a non-profit joint initiative providing the industry with the capability to better respond to subsea well control incidents. OSRL owns, maintains and stores in a response ready state the equipment required for well-intervention operations, as designed and procured by the Subsea Well Response Project (SWRP) with input from the end-users.

As part of the OSRL SWIS membership, access is provided to an OSRL Electronic Document Management System (EDMS) with technical documentation on the equipment available. These documents range from mobilization procedures, operation manuals, technical drawings, lifting certificates etc, and provide the information required for the OSRL SWIS members to plan and prepare for subsea capping operations. Statoil utilize the various OSRL documents in conjunction to local area knowledge to develop a robust and effective response.

The mobilization of the SWIS equipment starts from the OSRL storage location, this is done in coordination with Trendsetter and Oceaneering in order to configure, test and prepare the system according to Statoil's requirements. Once mobilized, the equipment is now the responsibility of Statoil as owner of the well and is transported to the port of mobilization, for operations in the Eastern Newfoundland Offshore Area the equipment will be mobilized from Stavanger, Norway and/or Angros doe Reis, Brazil. Both locations have a 15,000 psi capping stack system and complete Subsea Incident Response Toolkits (SIRT) on stand-by at all times and ready for deployment. OSRL also provide access to the Global Dispersant Stockpile with approximately 5000m^3 of dispersant chemicals to be used with the subsea dispersant equipment included in the SIRT.

2.1 Notification and Activation

2.1.1 Statoil Notification and Activation

In case of a subsea blowout which requires the mobilization of the SIRT, the Capping Stack System (CSS) and the Containment Toolkit (GCT), the activation of the Statoil Blowout Task Force and the OSRL Subsea Well Intervention Service is performed according to Statoil's governing documents and OSRL's Notification and Activation Procedure. Statoil's Notification and Activation chart is shown in Figure 2-1 below.

The activation of OSRL with the handling of well capping and well containment emergency response activities is complex and demands the engagement of multiple resources and skills. Statoil's Line 3 emergency response team (in Norway) has the authorization to call off support from OSRL and will facilitate the contact between OSRL and the well owner representatives. Extensive support is required from the Statoil Line 2 Incident Command System (ICS) emergency response team located in the local office in St. John's, NL and who are intimately familiar with the local area, specific well incident information and local regulations.

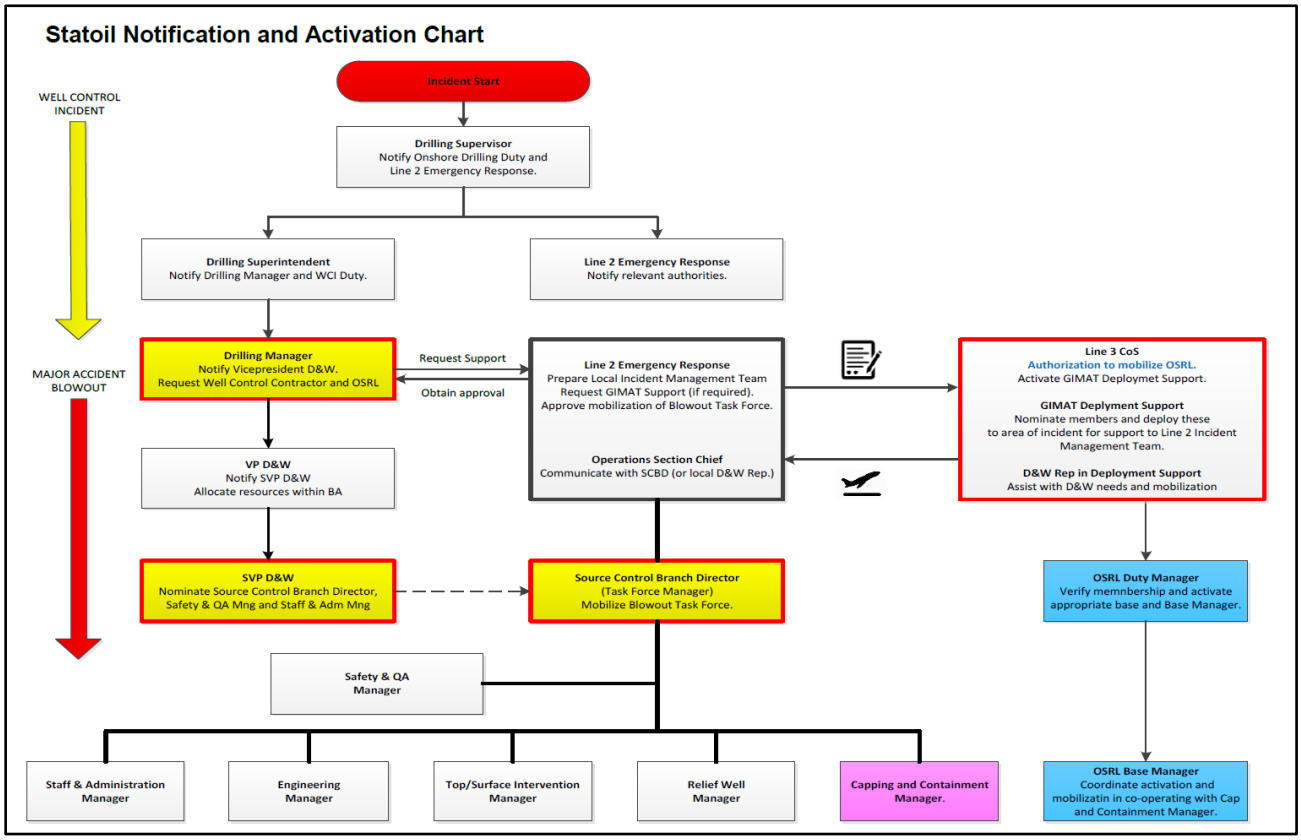


Figure 2-1 Statoil Notification and Activation Chart

Activation of OSRL is via a 24-hour emergency phone number in Southampton UK or Singapore where a discussion with the OSRL Duty Manager will be initiated. The OSRL Duty Manager has extensive response experience, and will discuss the emergency scenario and explain the current status of all response resources. The OSRL Duty Manager acts as the primary point of contact for the incident owner and the initial discussion with the incident owner will include;

- Scenario of spill
- Assets required
- Location assets to be mobilized from
- Transportation mode (air/sea/land)
- Special logistical/permits required for the country of disembarkation
- Additional technical support required (from Oceaneering/Trendsetter)
- Additional oil spill response equipment required

In addition to verbal activation several activation forms are required to be completed by the incident owner which includes technical details of the incident which will allow for successful mobilization of the SWIS package. Upon confirmation by the OSRL Duty Manager that the initial response requirements have been met, the OSRL Duty Manager then activates the Base Manager at the required storage location(s). The OSRL Base Manager is responsible for;

- Co-ordinating in country response team
- Liaising with manufacturers and technical support teams

- Overall responsibility for preparation, pre-testing, loading and handover of equipment to incident owner
- Managing the logistics chain
- Ensure that exportation procedures and customs clearance are completed

Statoil, as a member of the SWRP, has access to the full suite of response equipment and can mobilize a maximum of two capping stack systems and once subsea dispersant toolbox in the event of a response.

The Statoil Capping and Containment Manager is responsible for planning and execution of all operations related to the attempts to regain control of the blowing well by well capping and well containment. Furthermore, the Capping and Containment Manager is responsible for coordinating the well capping and well containment activities with other ongoing activities in the overall blowout situation (e.g. relief well drilling). The emergency response operational requirements will depend on the severity of the incident, location specific details and missions to be completed related to the overall source control activities. In order to handle these missions the response organization will need support with personnel and resources from Statoil Line 2 Incident Command System.

3.0 WELL CAPPING

3.1 Well Capping Overview

The capping stack is the contingency well isolation device used to 'cap' a blowout and stop the flow of hydrocarbons from the well. It is designed to interface primarily with the Blowout Preventer (BOP) stack by connecting to the top profile of the BOP after the removal of the Lower Marine Riser Package, using a compatible connector. Once mated, the stack's rams are deployed to isolate flow from the well.

The viability of well capping operations is contingent on many factors including the impact of the well flow since the incident occurred (i.e. casing washout and reduced well integrity), vertical access to well, jet-stream forces, BOP interfaces and design, and remaining structural integrity related to fatigue and the well load capacity.

In the event that shut-in of the well is not attainable due to wellbore integrity issues, the Capping Stack may serve as the mechanical interface for contingency flow-back (well containment) and/or restricting the well flow before and during the relief well dynamic kill operations.

Before the capping stack can be installed and used to shut in the well, a number of separate operations take place depending on the incident scenario. These are:

1. Subsea Survey: To determine the appropriate response and conduct necessary planning relative to the incident, information on the current state of the well is required
2. BOP Intervention: Based on initial subsea survey results, BOP intervention may be considered as a means to isolate the well flow or reduce the hydrocarbon outflow by attempting to operate the incident rig BOP pipe and shear rams to the CLOSED position
3. Debris Clearance: Based on initial subsea survey results, debris clearance may be required in order to provide access to the BOP Intervention panel, capping stack interface points or on the seafloor to facilitate the installation of ancillary response equipment
4. Subsea Dispersant Operations: The application of subsea dispersant at the source point may be desired to reduce environmental impact of flowing hydrocarbons and/or required to reduce Volatile Organic Compounds (VOC) and Lower Explosive Limits (LEL) at surface, so that

response vessels and personnel can work within the defined Safety Zone. Subsea dispersants will not be used prior to approval of the local Regulatory Authority

5. Capping Operations: The capping stack is the contingency well isolation device used to 'cap' a blowout. The capping stack is configured according to Statoil requirements and installed by positioning over the flowing well and latching it to the BOP, LMRP or Wellhead. If shut-in of the well is not attainable due to wellbore integrity or other issues, the capping stack may serve as the mechanical interface for contingency flow-back (containment) and/or assist in metering and/or restricting well flow during the relief well dynamic kill operations

When evaluating a specific well capping response it is necessary to have detailed information of the emergency equipment available and the specifications and limitations of the incident well. It is also important to identify Statoil provided equipment and resources in order to prepare a mobilization and deployment response. Furthermore, well intervention response strategies must be engineered to avoid additional and potentially irreversible wellbore damage which could result in prolonged environmental impacts. These evaluations are performed prior to initial spudding of the well such that major gaps related to logistics, equipment or methods for capping are identified and addressed.

The objectives for well capping operations are as outlined below:

- Eliminate environmental impacts by preventing hydrocarbons from exiting the wellbore or
- Minimize environmental impacts by reducing the amount of hydrocarbons exiting the wellbore through the use of Capping Stack chokes or
- Minimize or eliminate environmental impacts by providing interface for well containment operations
- Work with debris clearance team to ensure that the proper interface is accessible for capping stack installation
- Conduct engineering assessment of the well / BOP to determine proper capping stack configuration
- Mobilize appropriate response hardware to incident well AS SOON AS SAFELY POSSIBLE
- Conduct engineering and assessment of the well loads to determine capping feasibility
- Install capping stack onto the blowing well
- Conduct assessment of the well to determine proper shut-in procedures
- Perform shut-in of the well using the Capping Stack
- Support the relief well and/or well containment operations as required

3.2 OSRL Equipment and Support

The SWIS capping toolbox suite of equipment includes the Subsea Incident Response Toolkit (SIRT) and the Capping Stack Systems (CSS) with 10,000 psi or 15,000 psi pressure rating. In addition, OSRL provides access to the Global Dispersant Stockpile with 5000m3 of dispersant chemicals to be used with the subsea dispersant equipment included in the Subsea Incident Response Toolkit.

3.2.1 The Subsea Incident Response Toolkit (SIRT)

The OSRL Subsea Incident Response Toolkit (SIRT) is divided into four sub-categories with equipment available for subsea survey, BOP intervention, debris clearance and subsea dispersant injection. The subsea toolkit is stored in ready-for-shipment mode and consists of five 20 ft containers, two 10 ft containers, four subsea hose racks, four accumulator modules and once accumulator suspension beam. The entire toolkit is suitable for road and air transport.

Although OSRL is a provider of key critical emergency response equipment, Statoil provides significant resources and ancillary services in order to effectively deploy and use the OSRL provided kits.

3.2.2 The Capping Stack System (CSS)

The OSRL Capping Stack System (CSS) includes a total of four capping stack systems stored at various bases around the world. The 7 1/16", 10,000 psi CSS are stored in Singapore and Saldanha, South Africa. The 18 3/4", 15,000 psi, CSS are stored in Stavanger and Angra dos Reis, Brazil. All four Capping Stacks are designed into a standard configuration, with common pipework, valves, chokes and spools, which are rated to 15,000 psi and a water depth of 3000m. The common framework gives flexibility by utilizing interchangeable gate valves and rams.

The capping stack system comes with subsea accumulators, hydraulic flying lead (HFL) skids and required tools for installation with an 18 ¾" connector. The capping stack system also includes spacer spools, an inclination tool and the secondary containment cap which all may be required depending on the actual incident scenario.

The intended installation method for the CSS is based on vertical access to the incident well. The CSS is designed for installation with up to 10-degree inclination when utilizing the CSS inclination tool. In the situation where the wellhead and/or BOP has been subject to loading and inclination differs from the original, additional engineering and analysis is conducted to confirm that the well / BOP is able to support the additional weight of the CSS.

The preferred way of mobilization of the CSS is by sea, but the CSS can also be transported by air by breaking down and containerising the equipment. The CSS in it's broken down state would consist of fourteen 20ft containers and thirteen shipping skids. The capping stack is stored on a long term storage stand which also acts as the shipping stand and requires sea fastening to the vessel. Mobilization by air introduces additional risk since tear-down and rebuilding of the CSS may cause damage.

The 15,000 psi 18 ¾" CSS is showing in Figure 3-1 below.

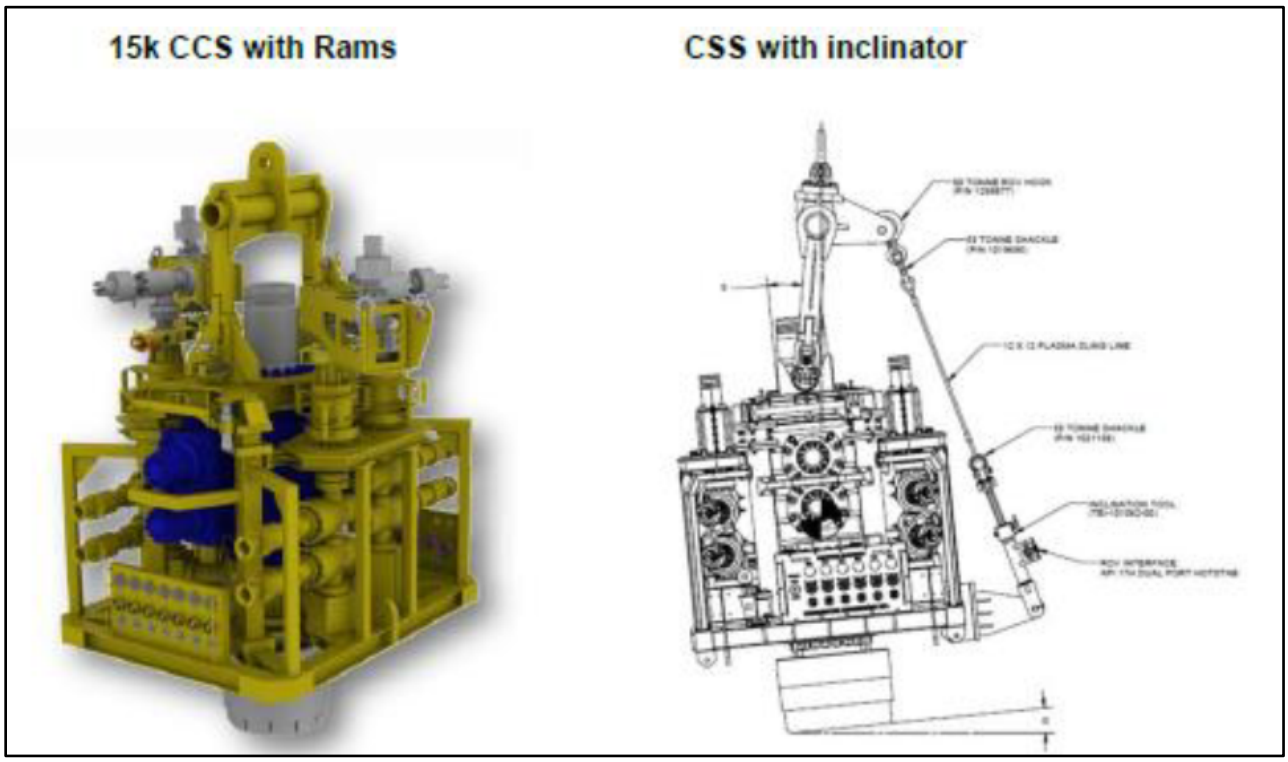


Figure 3-1

3.2.3 The Global Dispersant Stockpile (GDS)

OSRL provide members with access to a range of dispersant chemicals with the most worldwide approval via the OSRL Supplementary Agreement. The dispersant chemicals are held in 1m3 transport tanks at their location and OSRL arranges and coordinates air or sea freight to an airport or sea port as requested by Statoil.

The use of dispersants will not be contemplated unless approved by the local Regulatory Authority the C-NLOPB. The C-NLOPB consults with other federal departments such as the Department of Fisheries and Oceans and Environment and Climate Change Canada. A Spill Impact Mitigation Analysis (SIMA) otherwise known as a Net Environmental Benefit Analysis (NEBA) is a detailed environmental risk analyses regarding the application of dispersants to various spill scenarios. Statoil will prepare and submit a SIMA/NEBA for review by the C-NLOPB (and other federal departments) as part of the drilling program Operations Authorization (OA) application process.

Actual chemicals to be mobilized from the GDS will depend upon the NEBA performed based on oil samples from the incident well. The injection volumes required will be determined by the amount of hydrocarbon leaking subsea and type of dispersant selected. The details on quantities and location of the dispersant chemicals are presented in the OSRL Global Dispersant Stockpile Fact Sheet which can be found on the OSRL website at web address https://www.oilspillresponse.com/services/member-response-services/global-dispersant-stockpile/

3.3 Mobilization and Duration

The response plan includes a listing of key locations for the equipment required for capping operations with information on storage locations, response vessel(s) and planned Port of Mobilization

(POM). Also included are details on transit requirements from storage location to POM, POM activities and vessel requirements from POM to the incident well.

The preferred way of mobilization the CSS is by sea, but the CSS can also be transported by air by breaking down and containerising the equipment. Air transport is not advisable however since the tear down and rebuilding of the CSS introduces additional risk and the increased logistics associated with air travel and road transport increases the overall complexity of the logistical operation and the time savings realized are not significant and in some cases may actually increase overall mobilization time.

The main task for the well owner during mobilization of the CSS is related to the road / air transportation (if required) and loading to the Vessel of Opportunity, since the responsibility for the CSS is handed over from OSRL at the OSRL base quayside, or at airport cargo terminal for further transit. Hence, an overview of the plan for mobilisation of the personnel and equipment with information on capping stack configuration requirements and load-out plans is required. This is especially important if the capping stack is planned to be mobilized by air with the related deck loader handling and assembling requirement at departure and arrival location.

At the time of the incident the Well Owner prepares the final load-out plan, sources an adequate crane and ensures proper sea fastening together with the nominated vessel captain according to relevant CSS documentation.

In shallower water depths, typically less than 600 metres, an offset installation tool may be required. This tool enables CSS installation in situations where extreme jet forces from the incident well does not allow for vertical access to the wellbore by vessel. The toolkit and associated hardware is mobilized separately from its location in Italy.

For CSS transport by vessel, Table 3.1 below shows the minimum vessel requirements needed. This will allow Statoil to identify vessels of opportunity that are equipped to handle the CSS. Statoil maintains a vessel of opportunity database that identifies capable vessels that are currently under contract. Due to lack of local infrastructure including proper maintenance and storage facilities, transport and installation vessels and proper yard space it is not feasible to maintain a capping stack locally in St. John’s.

Table 3.1 Vessel Capability Requirements

Description	Minimum Requirements
Positioning	DP2
ROV	Min (2) Heavy Work Class w/capacity to reach ML at incident well centre and navigating work area at mud line, Carrying Capacity 100kg.
Crane	Capable of deploying 130t at mud line (based on Norway Capping Stack specifications)
Tank Capacity	n/a
Deck Space	400 m^2
Helideck	Preferred
Communications	Voice and Data (streaming video preferred)
Accommodations	25 Statoil and 3rd Party personnel
Other	Compliance with SIMOPS and HSE Requirements for operations with Safety Zone. Deck air, water and electricity

The equipment mobilization activities and durations for capping operations are summarized at a high level below. A typical capping operation can be executed within a 36-day (maximum) timeframe. This includes time for activation of OSRL, equipment preparation and mobilization, installation offshore and capping operations. Contingency time has been included for waiting on weather and other delays.

4.0 WELL CONTAINMENT

4.1 Well Containment Overview

The subsea well containment concept is intended to serve as the basis for developing a temporary subsea production system for capture of hydrocarbons in case the well capping operation is not adequate to stop the uncontrolled flow of hydrocarbons to sea. The well containment concept involves the use of the OSRL Containment Toolkit, which when combined with standard industry hardware can create a single or multiple leg containment system designed to flow hydrocarbons from a wellhead to the surface in a safe and controlled way and ready for storage or disposal.

The system is based on a common subsea system and the use of standard well test equipment installed on vessels of opportunity such as drill ships or semi-submersibles rigs to process captured hydrocarbons. The riser system will be the capture vessel marine riser/landing string system, incorporating subsea test trees (SSTT) with a floating Mobile Offshore Drilling Unit (MODU). Disposal of produced liquids would likely be by direct offloading to crude tankers.

Before the well containment system is ready for use a number of operations are required in order to install and commission this temporary subsea production system. These are:

1. Containment Survey: The Scope of the containment survey is to conduct the over-arching survey which will facilitate the containment operations that follow. This includes the identification of seabed features and debris caused by the incident which may affect the previously planned locations for the subsea system to be installed

2. Subsea Structures Survey: The scope of the subsea structures survey is to prepare and install the subsea structures as per overall field layout for the subsea system, prior to subsea lay of the flexible flowlines
3. Flowlines and Jumpers Survey: The scope of the subsea flowlines and jumper survey is to prepare and lay the subsea flowlines and jumpers required for the subsea system, and hook-up to the capping stack and flowspool on each containment leg
4. Containment System Riser Mission: The scope of the containment system riser (CSR) survey is to mobilize, deploy and install the CSR with foundation, flowspool, SSTT, landing string, surface flow tree and marine riser
5. Capture Vessel Surface System Deployment: The scope of the capture vessel surface operation is to deploy a surface hydrocarbon processing and offloading system, for the safe capture and disposal of well fluids
6. Hydrate Inhibition: The scope of hydrate inhibition is to prepare and deploy a chemical delivery system capable of providing the subsea system with hydrate inhibition chemical (glycol on demand
7. Pre-commissioning, Start-up and Operations: The scope is to provide guidance with regards to pre-commissioning of the containment system prior to start-up, ensure a controlled start-up of the system with the containment of the uncontrolled flow, and provide monitoring requirements during the containment operation for steady state and transient flow operations
8. De-commissioning and De-contamination: In addition to the operations above, a plan should be prepared for decommissioning and decontamination of equipment and resources used. This plan should also include the procedure for decontamination of vessels supporting the ongoing well capping and well containment operations

When evaluating a specific well capping response it is necessary to have detailed information of the emergency equipment available and the specifications and limitations of the incident well. It is also important to identify Statoil provided equipment and resources in order to prepare a mobilization and deployment response. Furthermore, well intervention response strategies must be engineered to avoid additional and potentially irreversible wellbore damage which could result in prolonged environmental impacts. These evaluations are performed prior to initial spudding of the well such that major gaps related to logistics, equipment or methods for capping are identified and addressed.

4.2 OSRL Equipment and Support

The SWIS Containment Toolkit (GCT) is designed to supplement standard industry well test hardware in order to create a containment system. The toolkit comprises long-lead equipment not readily available in the current industry and minimises response times by allowing a responding well operator to draw on existing resources. To ensure a quick response, the toolkit is stored in strategic locations around the world. The flexible flowlines and jumpers are stored in three regional sets in Brazil, Singapore and the UK. All other containment toolkit components can be moved by air and is predominantly stored at the original equipment manufacturers' facilities in Houston, Norway and the UK.

4.2.1 The Containment Toolkit

The Containment Toolkit includes several elements which combined with well owner equipment and resources can be deployed to enable the flow of hydrocarbons from the capping stack to an offloading tanker. The major components are shown in Figure 4-1 below.



Figure 4-1 Well containment toolkit

The containment system extends from the SWIS Capping Stack to an offloading tanker. Hydrocarbons are directed from the capping stack through a Flow Line End Termination (FLET) via a flexible jumper. From the FLET, flow continues through a flexible flowline and flowspool assembly into a standard well testing riser, terminating at a MODU. Hydrocarbons are processed using standard surface well testing equipment, and then stabilised and offloaded to a tanker positioned at a safe distance from the Incident Well.

The Well containment system is illustrated in Figure 4-2.

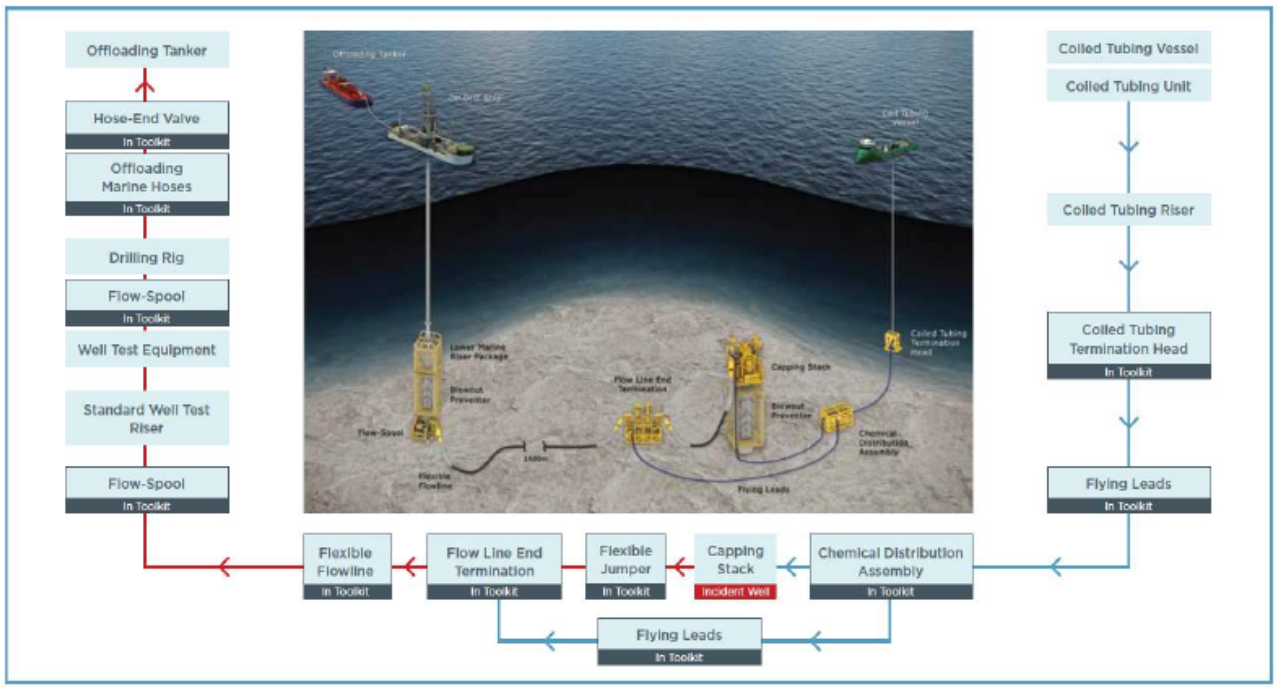


Figure 4-2 Well containment System

4.3 Mobilization and Duration

The containment toolkit elements have been designed to provide the most efficient way of deploying the equipment. Most of the equipment is packed in smaller units which allow for ease of transport by road, sea or air and require minimal assembly.

An agreement and procedures have been put in place between OSRL and the Original Equipment Manufacturers (OEMs) and storage location management to ensure a fluent mobilization of systems requiring OEM support. Upon notification from OSRL, the OEM's and other storage location managers will mobilize their own identified logistics enablers who will transport the cargo to the seaport or airport of embarkation as instructed to OSRL by Statoil.

Upon deployment of the capping stack systems, Statoil will also mobilize the containment toolkit at the same time to ensure that is it is readily available if needed.

5.0 RELIEF WELL DRILLING

5.1 Relief Well Drilling Overview

The installation of well capping or well containment equipment will temporary secure the subsea well and reduce the environmental impact from the incident. However, the killing of the well is still required for the permanent securing and abandonment of the well. This has traditionally been achieved by relief well drilling and is covered as part of the normal blowout contingency planning which is submitted to the C-NLOPB and approved under the existing Operations Authorization process.

The killing of the well by relief well drilling is executed similarly to the standard well plan. A relief well is typically drilled as a vertical hole down to a planned deviation ("kick-off") point, where it is turned toward the target well using directional drilling technology and tools. Once the target well is

intersected, dynamic kill well control commences by pumping drilling fluid down the relief well and into the incident well to kill the flow. Concrete may follow to seal and abandon the original well bore.

In developing the relief well drilling plan and well kill procedures, Statoil considers the potential operational impacts of other source control operations. The specific killing strategy is developed based on the actual incident well data taking account the well integrity modelling work and the capped and shut in or contained well system configuration.

The planned relief well locations are selected based on normal directional intersect and kill requirements, as well as any new constraints with regards to the planned capping and containment activities. The selected locations are integrated into the overall source control SIMOPS activities.

The relief well rigs are identified in advance of any drilling operations and meet the functional requirements needed for the specific well locations such as water depth restrictions, dynamic positioning capability etc. These rigs are commonly available within the operational area and are available through mutual aid agreements with other operators in the area. Drilling a relief well generally can executed within approximately 100 to 113 days. Well construction equipment including wellheads, running tools, crossovers, casing and tubulars is readily available locally and sourced in advance of any relief well drilling operations. Transit and mobilization times for the rig and any required equipment are evaluated and provided to the C-NLOPB in advance of their approval of drilling operations. Precise durations for capping and relief well execution will depend on a number of factors including local conditions (e.g. weather) and the condition of the well.

The killing of the well by relief well drilling is executed similarly to the standard well plan. A relief well is typically drilled as a vertical hole section down to a planned deviation (“kick-off”) point, where it is turned toward the target well using directional drilling technology and tools. Once the target well is intersected, dynamic kill well control commences by pumping drilling fluid down the relief well and into the incident well to kill the flow. Concrete is then pumped into the well to seal and abandon the original well bore.