BEFORE THE ENVIRONMENTAL PROTECTION AUTHORITY
AT WELLINGTON

IN THE MATTER
of the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012

AND

IN THE MATTER
of a decision-making committee appointed to hear a marine consent application by Trans Tasman Resources Limited to undertake iron ore extraction and processing operations offshore in the South Taranaki Bight

CORPORATE EVIDENCE OF SHAWN THOMPSON ON BEHALF OF TRANS TASMAN RESOURCES LIMITED

16 DECEMBER 2016

Second Statement – Operational Description
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EXECUTIVE SUMMARY

1. This evidence provides an overview of operational aspects of the project should the marine consent be granted.

2. The project’s operation will be conducted under the provisions of Maritime Transport Act 1994 and the Health and Safety at Work Act 2015 and will comply with all applicable Maritime and Marine Protection Rules.

3. The project’s operation will be regulated by:

   (a) Maritime New Zealand (MNZ) as the national regulatory body ensuring compliance with:

      i. The Maritime Rules, which relate to the safety of ships and people. The rules prescribe requirements for ship design, construction, equipment, crewing, operation and tonnage measurement, and for the carriage of passengers and cargoes. Many of the standards are based on international ship safety conventions.

      ii. The Marine Protection Rules, which aim to prevent the disposal of waste and marine pollution from ships. Marine Protection Rules implement international conventions and standards. These rules regulate:

            1. Dumping of waste at sea; and

            2. Oil spill contingency plans.

   (b) The Environmental Protection Authority (EPA) ensuring compliance with the marine consent conditions and applicable legislation.

4. Through its project development process and partnerships with experienced reputable offshore operators, TTR has
developed a detailed framework for a robust and safe operation supporting the environmentally sustainable extraction of iron sands from the South Taranaki Bight.

INTRODUCTION

Qualifications and experience

1. My name is Shawn Thompson.

2. I am the Engineering and Project Director at Trans Tasman Resources Limited (TTR) for this project.

3. My qualifications and experience are set out in my First Statement of Evidence – Project Description.

4. I confirm that I am authorised to give this evidence on behalf of TTR.

SCOPE OF EVIDENCE

5. My evidence is aimed at providing a detailed description of the project operation presented in the Environmental Impact Assessment.

PRE-OPERATION

6. Before iron sand extraction operations could commence TTR would have to ensure that the following elements have been completed, established and are functioning.

7. All operating conditions have been finalised by the EPA in accordance with the granted marine consent. This would include:

   (a) Any conditions that would have been revised to take into account the results of the completed Baseline Environmental Monitoring program (BEMP).
(b) The establishment and independent verification of the Operational Sediment Transport model complying with proposed conditions 18 and 19.

8. The completion and approval, by MNZ and Work Safe’s High Hazards Unit (HHU), of an operational Safety Case. The Safety Case is required to comply with all requirements of Part 40G of the Maritime Rules and the Health and Safety at Work Act 2015. The Safety Case will typically consist of the following components:

(a) Operational Description – This would include a complete scope of operation, design philosophy, physical aspects, activities, types and numbers of people present, mitigation systems etc.

(b) Summary of a formal evaluation of major hazards, demonstrating the effectiveness of the systems and barriers in place to manage the hazards.

(c) A summary of TIR’s safety management system and verification.

9. All elements of the Environmental Management and Monitoring Plan (EMMP) will be established and operationally verified.

10. The establishment of an exclusion or safety zone around TIR’s immediate operational location. In addition to operating in an established International Maritime Organisation (IMO) defined precautionary area (Appendix 1), where ships must navigate with particular caution in order to reduce the risk of a maritime casualty and resulting marine pollution, TIR will request an exclusion or safety zone around its immediate operational location as allowed for under the Continental Shelf Act 1964 whereby Regulations may be made prohibiting entry into these zones to all except authorised vessels.
11. The establishment of the fully staffed geotechnical sampling and environmental monitoring facility in the Port of Whanganui, which will include a dedicated, commissioned and crewed vessel.

12. The establishment of a TIR training facility in Hawera. The training facility’s role will be to provide training to staff to operate and maintain the equipment on the project vessels and provide ongoing professional development to experienced personnel.

13. The establishment of a comprehensive approved and verified mine plan. This plan will include long, medium and short term components, providing progressively more detailed information with regards to factors including designating the optimal block dimensions, the grade of the mining block (i.e. proportion of the iron in the sediment), orientation of the integrated mining vessel, plant constraints etc. Aspects of these plans i.e. locations of operations, will be shared with all existing users to ensure that the immediate location of the TIR operation is always available.

14. The successful commissioning and integration of all the operational vessels:

(a) IMV; which will have the extraction module (crawlers) aft, the processing, operating and utility modules integrated mid-ships above deck and the de-ored sediment deposition system incorporated at the bow of the vessel.

(b) Floating, Storage and Offloading Vessel (FSO); a purpose built self-unloading, trans-shipment vessel with a cargo capacity of 60,000 million tonnes (mt).

(c) Anchor Handling Tug (AHT); a dedicated vessel that will provide essential support to the operation at sea including assisting with the relocation of anchors,
transfer hose connection, spill response and firefighting.

(d) Geotechnical and environmental monitoring vessel; this will be an adequately sized support vessel that will operate out of the Port of Whanganui.

(e) Helicopter Personnel Transfer facility.

OPERATIONAL RISK SETTING

15. TTR together with representatives from MNZ, Work Safe’s HHU, Taranaki Regional Council and Horizons Regional Council completed an initial Operational Risk Review.

16. The following major risks were identified during this initial review:

(a) Vessel collision, largely due to there being numerous vessels operating and interacting with each other during production, processing, offloading, maintenance, anchor movement, and supply transfer activities. The maximum amount of marine operations comprising of vessel interactions (SIMOPS) that could occur in a single month is 89. An additional risk was posed by other vessel traffic in the region.

(b) The AHT is vulnerable to impact from larger vessels.

(c) Release of Heavy Fuel Oil (HFO) during transfer and refuelling.

(d) Helicopter crash onto a vessel or into the sea.

(e) Loss of anchors and the IMV being swept off station.

17. Several key risk mitigation measures were identified and included in the proposal:
(a) The establishment of an Exclusion Zone/Safety Zone of up to 1km around the operation to cover the vessel and the anchor spread process for notifying mariners of the changes every 10 days. TTR has undertaken to request such a zone should the project obtain consent.

(b) The importance of the four point mooring system for the IMV.

(c) The importance of a comprehensive simultaneous operations procedure (SIMOPS) providing contingency and emergency response plans.

18. As part of the ABS Approval in Principle process (See Appendix 3 of my First Statement of Evidence - Project Description), TTR provided a Risk Assessment for the IMV operations that was prepared by its Naval Architect, Vuyk Engineering Rotterdam BV.

19. The key risks and mitigations specifically related to the operation of the IMV were listed as:

(a) **Failure of the mooring system**

The mooring system has been designed in compliance with the Thruster assisted Mooring (TAM) notation from Class (ABS). The mooring system will consist of four independent mooring winches, assisted by six thrusters. If the environmental loads on the winches exceed set values i.e., due to a change in sea state or direction, the thruster system has been designed to automatically assist the mooring system thus reducing the loads on the mooring wires and dynamically maintains the position of the vessel. The mooring winches will also be provided with a quick release system to clear the mooring wire in case of an extreme emergency. This may be due to a
mechanical failure or to the inability of the AHT to retrieve the anchor in adverse weather conditions.

(b) **Extreme weather conditions**

The IMV has been designed for operation up to a sea state of 4.0 m significant wave height. With the installed thruster power the vessel is capable of maintaining “bow on” conditions up to 8m significant wave height\(^1\). In the event that an extreme weather event is predicted, that in the captain’s opinion would endanger the vessel or the crew, the vessel is capable of leaving the mining area and relocating to a more sheltered area or out to open sea to ride out the storm.

(c) **Equipment failure risks**

The vessel has been designed for continuous operation. To ensure that no equipment failure would lead to failure of the mooring system, or other critical operational system, all systems have been designed with sufficient redundancy i.e. double execution, cross-over feeding, standby equipment and bypasses etc. (As required by ABS Guide For The Classification Notation Thruster-Assisted Mooring For Mobile Mooring Systems, 2014).

**OPERATIONAL DESCRIPTION**

**Start of iron sand extraction operation**

20. Before the iron sand extraction operation can begin the following elements will have to be in place and operational:

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\(^1\) Significant wave height (Hs) is defined as the average height of the highest one-third waves in a wave spectrum, with the theoretical maximum wave height (Hmax), approximately equal to two times the Hs.
(a) All environmental monitoring equipment;
(b) Mammal observation in place and active;
(c) Weather clear for the next seven days, forecasted ocean conditions noted and IMV dynamic stability adjusted; and
(d) The exclusion zone/safety zone around all project vessels in place and no unauthorised vessels present.

**Iron sand extraction**

21. The IMV will verify its position above the first planned extraction location in accordance with the approved mine plan schedule and initiate operations as follows:

(a) The crawler will be lowered through the water column and be placed in position on the seabed.

(b) The crawler systems will be tested and verified and on being given the all clear with regards to the absence of marine mammals and unauthorised vessels the captain will issue the instruction to start the crawler pump in accordance with the controlled start-up procedure detailed in condition 2.6.4 (Operational Vessel – “Soft Starts”).

(c) Once unimpeded water flow through the process system has been verified, and the re-deposition pipe is in position the crawler’s boom will be lowered onto the seabed to commence extraction.

(d) Once the captain has verified that the re-deposition pipe is in position and the initial de-ored sediment is being deposited the captain will give the instruction to the crawler operator to commence forward movement.
22. The IMV will proceed to continually track and shadow the crawler as it progresses along its predetermined extraction path.

SIMULTANEOUS OPERATIONS

23. Marine SIMOPS (Simultaneous Operations) are described as joint activities involving two or more independently operated marine vehicles (vessels and helicopter). All SIMOPS will be conducted within IMCA M 203, Guidelines on Simultaneous Operations (SIMOPS) (See Appendix 3).

24. Key simultaneous operations (SIMOPS) include:
   - The positioning and anchoring of the IMV using the AHT;
   - All product transfers between the IMV and FSO;
   - All product transfers between FSO and export vessels;
   - All helicopter operations;
   - All fuel and other liquids transfers between vessels; and
   - All transfers of equipment, provisions and stores between project vehicles.

25. The project’s Safety Case will include an assessment of safe upper environmental limits for all simultaneous operations using formal risk analysis, hazard and operability studies. This will be accomplished using vessel (IMV and FSO) designers’ hydrodynamic models and motion studies as well as verified meteorological (MetOcean) data.

26. The project Safety Case will also provide the procedural basis for applications to MNZ for fuel and product transfer operations at sea as required under the Marine Protection Rules Part 103.

Positioning and anchoring of the IMV

27. The positioning and anchoring of the IMV will make use of a pre-installed anchor system, whereby a set of anchors will be
placed and set by the AHT in accordance with the approved mine plan and schedule, in advance of the arrival of the IMV. This will reduce the time required for the planned SIMOP.

28. The pre-installed anchor set will have mooring lines that will be buoyed off to keep them free from the seabed in order to facilitate an easy pick-up by the AHT when connecting the IMV in its new position.

29. Once the IMV has completed the extraction and re-deposition on a planned block, the AHT will help disconnect the mooring lines from the anchor set being used.

30. Keeping a safe distance from the IMV in accordance with the developed SIMOP procedure, the AHT will retrieve each mooring line and disconnect it from its respective anchor.

31. After retrieving and safely stowing all its mooring lines, the IMV will then move to the new position as dictated by the approved mine plan and the AHT will assist the IMV in deploying the mooring lines and reconnecting them to the new fixed anchor set.

32. Once the IMV has tested and verified the tension on each of the mooring lines, the AHT will be released to retrieve the previous anchor set and place and fix them in the next planned location in preparation for the next IMV move.

Iron sand transfer (IMV to FSO)

33. All iron sand transfer operations will be done in strict accordance with the legislation governing safe carriage of solid bulk cargoes i.e. the International Maritime Solid Bulk Cargoes (IMSBC) Code, which is mandatory under the SOLAS (Safety Of Lives At Sea) Convention and the operation’s approved SIMOP procedures.
34. As the concentrate storage tanks aboard the IMV approach capacity, and taking into consideration the weather and forecast the captain will call the FSO into position to commence the iron sand transfer operation.

35. The 60,000 dead weight tonnage (DWT) FSO will approach the IMV, bow to bow, and using its dynamic positioning system match the movement of the IMV maintaining a fixed distance and orientation from the IMV.

36. The AHT will assist in connecting the bow mounted floating slurry line from the IMV to the FSO and then remain on station during the iron sand transfer.

37. Using the desalinated water produced aboard the IMV, the iron sand concentrate slurry will be pumped to the FSO via the hyperbaric disc filters aboard. The disc filters on-board the FSO will dewater the concentrate allowing the relatively dry concentrate to be stored aboard the FSO.

38. Once the FSO has reached capacity, it will disconnect from the IMV and sail to where the bulk carrier has anchored.

**Iron sand transfer (FSO to Bulk Carrier)**

39. Taking into consideration the weather and forecast, the FSO will approach the Bulk Carrier in accordance with the approved SIMOP procedures and tie up alongside the bulk carrier.

40. The FSO will be fitted with optimized mooring systems and an azimuth propulsion system, allowing for a higher degree of manoeuvrability, shorter cycle times and improved safety. The FSO will have the ability to operate without tug assistance.

41. The FSO will commence offloading, i.e. transferring the relatively dry concentrate to the bulk carrier.
42. On completion of the loading cycle, the FSO will disconnect and return to the IMV to recommence the loading of iron sand slurry.

**Helicopter operations**

43. The helicopter operations will provide for the safe and efficient personnel transfer, delivery of urgent freight and will be the primary means of emergency evacuation.

44. TTR envisage two to three routine helicopter flights per week.

45. Helicopters used will be twin engine jet helicopters, similar to those currently flying out of New Plymouth supporting the oil and gas industry.

46. The helicopter transfer services will be provided by a reputable offshore operator that will be integrated into the detailed design and commissioning phases of the project.

**Refuelling at sea**

47. All bunkering (refuelling) operations conducted within or near to the proposed project area will be characterised as ship-to-ship (STS) bunkering operations i.e. the transfer of bunkering supplies between sea-going ships positioned alongside each other, either while stationary or underway and as such will be conducted in strict accordance with the IMO’s MARPOL regulations especially chapter 8, ICS/OCIMF “Ship to Ship Transfer Guide (Petroleum) 4th Edition” and MNZs requirements as the flag state regulator, specifically notification requirements as per Marine Protection Rules Part 103.

48. The project’s vessels will always act as the terminal and the refuelling vessel, using its DPS system, will manoeuvre and moor alongside.
49. The AHT will remain on station throughout the refuelling operation to act as an emergency environmental response and fire-fighting vessel.

50. Each fuel transfer operation will be carefully planned and documented and, will include the following:

- Information on:
  - The quantity and type of each fuel to be transferred;
  - Flow rates;
  - Normal stopping and emergency shutdown procedures;
  - Emergency and spill containment procedures;
  - Local or government rules that may apply; and
  - Material Safety Data Sheets.

- Coordination of plans for cargo hose connection, monitoring, draining and disconnection.
- Declaration of Inspection is signed.
- Pre Transfer Checklists are Completed.
- Due regard to vessel stability at all times.

**Transfers of equipment and provisions**

51. All transfers to and from the project’s vessels will be containerised. This includes the transfer of materials such as provisions, chemicals and other miscellaneous consumables.

52. Waste materials will be transferred from the project’s vessels to supply vessels for onshore disposal. For example, oily wastes and general waste will be contained on each vessel, transferred to the supply vessel by crane and then to shore for treatment and disposal at an appropriately licensed facility.
OPERATIONAL EMERGENCY RESPONSE

Medical emergency

53. All project vessels will have a dedicated Offshore Medic responsible for providing immediate and emergency medical services and support in accordance with good medical practice, rules and regulations.

54. In the event of a serious injury the contracted helicopter services will be the primary means of emergency evacuation, providing weather and conditions permit.

55. Taranaki Base Hospital in New Plymouth is the main regional hospital and includes an emergency department, intensive care unit and heliport. Hawera Hospital also operates a 24 hour emergency department.

Oil spill

56. Of all its operational activities, TTR considers that refuelling operations are the most exposed area with regards to the risk of an oil spill.

57. TTR has mandated that all refuelling operations will be conducted in strict accordance with the limits and procedures that will be detailed in its approved Safety Case, IMO’s MARPOL regulations especially chapter 8, ICS/OCIMF “Ship to Ship Transfer Guide (Petroleum) 4th Edition” and MNZ’s requirements as the flag state regulator.

58. Marine Protection Rules Part 130A require every New Zealand and foreign vessel of 400 gross tonnage ("grt") or greater, and every oil tanker of 150 grt or greater operating in New Zealand water to carry an approved shipboard oil pollution emergency plan (SOPEP). The SOPEP sets out for these vessels how the vessel master will respond to a spill.
59. In the event that the spill is of such a magnitude, or occurs in conditions, that the master is unable to deal with the spill, the response would escalate to either a regional or a national spill response as required by New Zealand’s internationally-recognised, conventional three-tiered marine oil spill response system.

60. In addition to the procedural controls TTR has also incorporated the following elements into the design of the project components:

(a) The AHT will be equipped with the necessary equipment and trained crew to act as the first response to any spill event.

(b) All project vessels will have DP2 position keeping capability, enabling the vessels to maintain the set distances from each other during the refuelling operation and prevent any hose rupture during the refuelling operation.

61. In addition to the procedural controls TTR has also incorporated the following elements into the design of the project components

62. TTR has modelled a worst-case scenario for coastal impacts in the event of an un-mitigated and uncontrolled release of 100 mt (five times the content of the hose) of 380 cSt HFO over a two hour period. (Appendix 2)

63. Analysis of the trajectory database shows that 92.4 – 97.8% of spill events are predicted to result in a beaching outcome. The spring season has the highest probability of beaching (97.8%) while autumn has the lowest (92.4%). The minimum time between a spill and beaching varies throughout the seasons; from 12.5 hours in summer to 16.6 hours in spring and autumn.
64. For the worst-case spill modelling, oil concentrations of over 2 m³ per kilometre of shore have been predicted in parts of the South Taranaki Bight. A maximum concentration of 4.79 m³ km⁻¹ was found around Wanganui.

65. In terms of TIR’s operations, any potential spill that exceeds the response capability of the vessels and/or IMV will immediately trigger a national (Tier 3) response.

66. The Maritime Transport Act 1994 and Marine Protection Rules Part 102, require all of the project’s vessels to hold public liability insurance to cover any claims for any damages arising from a marine oil spill.

OTHER OPERATIONAL ISSUES

67. As part of the development of the operational Safety Case and SIMOPS procedures, taking into account vessel characteristics and design, and TIR’s obligations under the Maritime Transport Act 1994, Health and Safety at Work Act 2015 and all applicable Maritime and Marine Protection Rules, a commissioned detailed hydrodynamic modelling and analysis will inform the determination of the approved final safe operating limits for all SIMOPS.

Shawn Thompson

16 December 2016
Appendix 1: The West Coast, North Island Navigational Precautionary Area
Pollution Prevention

SHIPPING ROUTEING – AREAS TO BE AVOIDED

Three Kings Islands
(1) 34° 06'.00 S 172° 00'.00 E
(2) 34° 06'.00 S 172° 12'.50 E
(3) 34° 13'.50 S 172° 12'.50 E
(4) 34° 13'.50 S 172° 00'.00 E

The Three Kings Islands, situated off the northern tip of the North Island, were declared as a Wildlife Sanctuary in 1995. The area is protected to avoid the risk of pollution and damage to the environment from ships of 500 gross tons or more.

Poor Knights Islands
(1) 35° 51'.30S 174° 35'.50E
(2) 35° 34'.55S 174° 49'.20E
(3) 35° 29'.60S 174° 50'.80E
(4) 35° 24'.70S 174° 50'.20E
(5) 35° 10.20'S 174° 20'.10E

The extended area around the Poor Knights Islands, situated off the North-East coast of the North Island, were identified as an area to be avoided in 2003. This area incorporates a marine reserve close to the islands. It is protected to avoid the risk of pollution and damage to the environment from ships of 45 m overall length or more.
An extended area off the Taranaki coast has been declared a precautionary area with effect from 2007. The area covers a high level of offshore petroleum operations including two floating production, storage and offloading facilities serviced by offtake tankers. All ships should navigate with particular caution in order to reduce the risk of a maritime casualty and resulting marine pollution.
OIL SPILL TRAJECTORY MODELLING

TTR mining barge, New Zealand

Prepared for Trans-Tasman Resources
It is the responsibility of the reader to verify the currency of the version number of this report.

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EXECUTIVE SUMMARY

An 11-year database containing all the likely trajectories for an oil spill from the mining barge located in the centre of the permit area has been produced. Oil spills have been tracked continuously from 1999 to 2009 until they beach or leave the modelled region. This technique provides a robust statistical basis to quantify the most likely pathways for oil in the unlikely event of a spill from the mining barge, and from this knowledge an assessment of the coastal areas that are most likely to be affected can be reliably determined. Results from the trajectory database have been examined for the seasonal conditions, showing the relative probabilities for beaching and statistics for beaching times.

The hydrocarbon used for this study is a 380 Heavy Fuel Oil (HFO). Weathering of this oil is expected to result in around 20% of the released volume evaporating or being dispersed 120 hour from initial release (Table E.1). Wind speed has a significant effect on the amount of dispersion, evaporation and mechanical weathering experienced by the oil. Accordingly, while the stronger wind conditions may lead to shorter beaching times, it may be the more moderate winds that result in the highest volumes of oil reaching the shore.

Analysis of the trajectory database shows that some 92.4 – 97.8% of spill events are predicted to result in a beaching outcome. The spring season has the highest probability of beaching (97.8%) while autumn has the lowest (92.4% - Table E.2). The minimum time between a spill and beaching varies throughout the seasons; from 12.5 hours in summer to 16.6 hours in spring and autumn (Table E.2).

A series of coastal beaching probability maps have been produced, and maps of beaching probabilities are provided for each season. The region of coast most likely to be affected from a spill is located in the South Taranaki Bight in the vicinity of the Rangitikei River Mouth (e.g. Figs. E.1 - E.4).

The worst-case outcome of an accidental release of 100 mT of 380 Heavy Fuel Oil has been investigated. The release date in the 11-year trajectory database that produces the maximum beaching outcome has been identified, and the coastal impacts associated with that scenario are quantified. The area with the highest impact is in the South Taranaki Bight near Wanganui, where oil concentrations of 4.79 m³ per kilometre of coastline are predicted (Fig. E.5).
Table E.1  Volume percentage of oil remaining on surface after a 2-hour release of 100 mT of 380 Heavy Fuel Oil as a function of wind speed and exposure time, calculated using ADIOS2. The model considers evaporation and dispersion in the water column under the action of wind and waves. Calculations were run for water temperatures of 13°C and 17°C, providing an interval of percentage indicated in each table cell. A table cell containing a single value indicates no difference in results between 13°C and 17°C.

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<td>70-76</td>
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<td>70-75</td>
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</table>
Table E.2  Percentage of events that resulted in beaching within the 11-year database and minimum time (in hours) for released oil to beach per season from the approximate centre of the TTR permit area.

<table>
<thead>
<tr>
<th>Season</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total % beaching</td>
<td>97.8</td>
<td>94.9</td>
<td>92.4</td>
<td>95.0</td>
</tr>
<tr>
<td>Min beaching time (hours)</td>
<td>16.6</td>
<td>12.5</td>
<td>16.6</td>
<td>12.7</td>
</tr>
</tbody>
</table>

Figure E.1  Summer season beaching probability based on an 11-year trajectory database.
Figure E.2  Autumn season beaching probability based on an 11-year trajectory database.

Figure E.3  Winter season beaching probability based on an 11-year trajectory database.
Figure E.4  Spring season beaching probability based on an 11-year trajectory database.

Figure E.5  Predicted beached percentages from a 2 hour accidental release of 100 mT of Heavy Fuel Oil from the mining barge. This figure represents the worst coastal beaching outcome within the 11-year trajectory database.
1. INTRODUCTION

Trans-Tasman Resources (TTR) has commissioned MetOcean Solutions Ltd (MSL) to undertake an oil spill trajectory model study to assess the potential coastal beaching from a release at the TTR mining barge site. The chosen location, in the centre of the permit area, is located at 39.873614°S / 174.125229°E (5585664.423 E / 1696227.169 N NZTM) in an estimated depth of 37.7 m in the offshore Taranaki Basin (Fig. 1.1).

Oil spill trajectory modelling involves simulating the release of hydrocarbon products from a given offshore location and tracking the “fate” (where it goes) and “persistence” (how long it remains in the system) of the release under the influence of ocean conditions, until beaching occurs or the contaminants are advected beyond the model boundaries. By running spill simulations over multi-year periods using the actual historical conditions (recreated using numerical models of the atmospheric and oceanographic processes) it is possible to produce statistical probability maps of the trajectory patterns, beaching locations and predictions of the likely times for spilled oil to reach the shore. In this study, a proprietary release trajectory model (EROil) has been used to simulate the dispersal of spilled hydrocarbons from the mining barge location.

Evaporation, dissolution and other weathering processes gradually reduce the volume of hydrocarbons at the sea surface over time. These processes were not simulated in the EROil trajectory model (i.e. the released product was completely conserved from release until beaching) because they do not materially change the contaminant trajectory, beaching times or the relative coastal beaching. Non-weathering simulations therefore allow the physical transport pathways to be clearly identified. Weathering of the surface hydrocarbons is considered by the ADIOS2 model from the National Oceanic and Atmospheric Administration Hazardous Materials Response Division (NOAA/HAZMAT). ADIOS2 estimates the volume of hydrocarbon remaining over time as a function of wind and oceanic conditions, using the physical and chemical properties of the released hydrocarbons.

This report is structured as follows; Section 2 describes the various metocean data sources that have been used as input to the oil spill model. Section 3 provides technical details of the oil trajectory model. The simulations carried out and the post-processing and analysis are described in Section 4. The study results are provided in Section 5 and a summary of the work is provided in Section 6. The references cited are listed in the final Section 7.
Figure 1.1  Location of the TTR mining barge (39.873614°S / 174.125229°E or 5585664.423 E / 1696227.169 N NZTM). The dashed black box represents the boundaries of the models: 171°E to the West, 175.25°E to the East, 41.32°S to the South and 37°S to the North.
2. **METOCEAN DATA**

2.1. **Winds**

The spatially varying wind field used in this study is an extract of a 33-year regional atmospheric hindcast produced by MetOcean Solutions Ltd. The hindcast was obtained by running the Weather Research and Forecasting model (WRF) nested within the Climate Forecast System Reanalysis (CFSR) data set from NOAA. The result is a nationwide 12 km resolution hindcast of full 3-dimensional atmospheric variables for each hour since January 1979, with a 4 km nested region through central New Zealand. The variables include the surface wind field (i.e. 10-minute mean at 10 m elevation) along with air temperature, humidity, solar radiation and precipitation.

The wind speed from this hindcast has been validated at numerous sites around New Zealand; shown in Figure 2.1 are time series data from Auckland Airport in January 2007 and a quantile-quantile plot from a full year (2007) at Brother’s Island in the Cook Strait.

![Figure 2.1](image)

*Figure 2.1* Comparison of both CFSR data and a high-resolution WRF hindcast for Auckland Airport during a few days in January 2007 (left) and quantile-quantile plot of both CFSR (magenta) and the WRF hindcast (green) against the observations from Brother’s Island in the Cook Strait during 2007.

2.2. **Currents**

Surface non-tidal currents were defined from a fully nested high-resolution 28-year ROMS model hindcast that includes the barge location. The ROMS model is a three dimensional ocean model nested within the CFSR ocean hindcast. By using the CFSR boundary, a realistic time-varying deep-water boundary can be prescribed for ROMS. The hindcast is forced with the NZ atmospheric hindcast described in Section 2.1. The long duration of the hindcast provides a good statistical basis for estimating and characterising inter-annual variability. Tidal currents were obtained from the MSL NZ tidal solution and were added to the oceanic currents to provide combined residual and tidal current fields at an hourly interval.
2.3. **Sea surface temperatures**

Monthly average sea surface water temperatures at the approximate centre of the permit area were extracted from the satellite records (1999-2009, Table 2.1). Note that sea surface temperature does not influence the surface oil trajectory, but it does affect the weathering process.

**Table 2.1** Mean monthly sea surface temperatures (SST) at 39.873614°S / 174.125229°E from satellite data (1999-2009).

<table>
<thead>
<tr>
<th>Season</th>
<th>Month</th>
<th>Sea surface temperature (°C)</th>
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<tr>
<td></td>
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<td>Monthly average</td>
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<tr>
<td>Summer</td>
<td>December</td>
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<td>February</td>
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</tr>
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<td>13.65</td>
</tr>
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<td>14.20</td>
</tr>
<tr>
<td></td>
<td>November</td>
<td>15.09</td>
</tr>
</tbody>
</table>

Annual 15.75
3. **OIL SPILL MODEL DESCRIPTION**

3.1. **Overview**

EROil is a Lagrangian model for simulating the transport and fate of hydrocarbon liquids and gases, both on the surface as a slick, and in its subsurface phases such as following a deep water loss of well control. The model has been developed by MSL using well established methodologies and techniques described in the scientific literature. The main model simulates the trajectories of particles advected by currents, and when on the surface, blown by the wind. There is parameterisation for turbulent mixing. A plume module simulates the initial stages of a deep water loss of well control, during which the initial momentum of the hydrocarbon jet is important.

3.2. **Lagrangian particle model**

EROil simulates hydrocarbon dispersion with Lagrangian particles that move within a continuous Eulerian environment. The spreading and dispersion of the particles is based on a Fickian random walk. The motion of each particle is governed by the equation:

\[
\frac{d\vec{X}}{dt} = \vec{U} + \vec{D} + C_w \vec{W}_{10}
\]  

(3.1)

where \( \vec{X} \) is the particle position, \( \vec{U} \) is the current speed, \( \vec{D} \) is a random diffusion component, \( \vec{W}_{10} \) is the wind velocity vector at 10-metres above the surface and \( C_w \) is the windage factor. The windage factor can be given a range of values, from which a random value is chosen at each time step to allow for uncertainty in its value. The particle motion is integrated using a 4th order Runge-Kutta method for the current component and a 1st order forward time method for the wind and diffusion components.

The diffusion component is a random vector defined as:

\[
D_i = \frac{1}{\Delta t} \sqrt{6K_i \Delta t} U_i(-1,1)
\]

(3.2)

where \( K_i \) is the diffusion coefficient in each direction and \( U_i(-1,1) \) is a random number drawn from a uniform distribution between -1 and 1.

When a particle hits a shoreline it can either be held in place (sticky shoreline) or is allowed to move again after a re-float half-life timescale.

EROil has been verified by undertaking an extensive range of tests for surface slicks and ensuring that the trajectories obtained from EROil were similar to those obtained in GNOME, the NOAA oil response model (Beegle-Krause, 2001, 1999).
4. NUMERICAL SIMULATIONS

4.1. Release scenarios

In the present work, EROil was used to consider the fate of all possible spill trajectories that would have occurred within an historical 11-year period (1st of January 1999 to 31st of December 2009). Simulation of the trajectories over many years provides a robust statistical basis to identify the most probable pathways in the unlikely event of a spill, and also to identify the coastal regions most likely to be affected by beaching of a spill. Multi-year simulations do not imply that a spill of this duration is anticipated; rather it is a modelling technique used to provide information from many seasons and years with a range of realistic weather patterns.

The simulated discharge rate was 10,000 barrels per day of 380 Heavy Fuel Oil with a 30% gas/oil ratio. The models were run with a time-step of 15 minutes for the particle component, which is short enough to capture the movement of tidally induced currents. The results were output every 24 hours for visual checks, display and data processing. The diffusion coefficient was 10 in both horizontal axes. The windage factor \( C_W \) in Equation 3.1 was set to the range 0.01 to 0.04 (1% to 4%).

In the present work, if a particle reaches the shore during the simulation it is immobilized for all subsequent time-steps until the end of the model simulation (i.e. “sticky coast”). The time elapsed since release and the time elapsed since beaching are both recorded, thereby allowing the age of the particle when beaching occurred to be determined. The western, eastern, southern and northern model boundaries were respectively 171°E, 175.5°E, 41.32°S and 37°S (see Fig. 1.1).

4.2. Seasonal results

The final state of the model outputs (particles final position, time since release, beaching state and time since beaching, if applicable) were combined for all years to produce seasonal results. Quantitative information was then extracted from these results, including:

- The percentage of the total release that beached,
- The percentage of the total release that was still in the water at the end of the model simulation,
- The percentage of the total release that left the model domain, and
- The minimum beaching age in days (minimum difference between time elapsed since release and time elapsed since beaching), and the beaching location of the associated particle.

4.3. Beaching concentration and age analysis

4.3.1. Beaching concentration calculation

Maps of the relative concentration of spill products along the coastline can be produced from the distribution of beached particles in the seasonal results. In the present work, a kernel method with variable bandwidth was
used to reconstruct the concentration calculated at the location of receptors defined at 10 km intervals along the coastline while a 1 km bandwidth was used to calculate the median and minimum beaching times. The use of a variable bandwidth (kernel size) attempts to represent true variability of spatial concentration, while minimising statistical variability that inevitably occurs away from the source due to a necessarily finite number of particles. A small kernel is used in regions gathering a high number of particles, where it is statistically appropriate to infer relatively small scale changes in concentration. Conversely, a larger kernel is used in regions presenting a low number of particles, so as to prevent unrealistically high concentrations around the precise (but partially random) locations of a few isolated particles.

In practice, the concentration \( C \) at a receptor location \((x,y)\) on the coastline is computed as:

\[
C(x, y) = \sum_{i=1}^{n} \frac{m_i}{\lambda_x(x,y)\lambda_y(x,y)} K\left(\frac{x_i - x}{\lambda_x}\right) K\left(\frac{y_i - y}{\lambda_y}\right)
\]  

(4.1)

where \((x_i, y_i)\) is the location of each particle \(i\), \(n\) is the total number of particles, \(m_i\) is the loading for each particle, \(\lambda_x\) and \(\lambda_y\), are the kernel bandwidth in the \(x\) and \(y\) directions for location \((x,y)\) and \(K\) is the kernel function.

The loading \(m_i\) for each particle depends on the quantity being calculated and may represent, in the case of an oil spill (for example), the remaining amount of oil represented by a particle after weathering. Since weathering was not implemented in the present trajectory modelling, \(m_i\) was equal to 1 for all particles.

Following Vitali et al., (2006), an Epanechnikov kernel function was used:

\[
K(q) = \begin{cases} 
0.75(1 - q^2), & |q| \leq 1 \\
0, & |q| > 1 
\end{cases}
\]  

(4.2)

A receptors-based method (a modification of the RL3 in Vitali et al., 2006) was used to define the bandwidths \(\lambda_x\) and \(\lambda_y\). For each receptor location \((x,y)\), a neighbourhood was defined as the region enclosing the 1/20th closest particles. Then, for each direction \(x\) and \(y\), the bandwidths \(\lambda_x\) and \(\lambda_y\) were defined as the minimum value between the maximum projected distance of the particles within the neighbourhood and twice the standard deviation of the projected distances within the neighbourhood. Finally, in order to prevent unrealistically elongated kernels, the aspect ratio \(\lambda_x/\lambda_y\) was limited to be no greater than 5:1, with the smaller value increased.

### 4.3.2. Beaching age analysis

The beaching concentration calculation algorithm described above includes a step to record, for each receptor location \((x,y)\) along the coastline, the minimum and median beaching age (time difference between particle release and beaching) of all beached particles within the bandwidths \(\lambda_x\) and \(\lambda_y\), thereby allowing maps of minimum and median beaching ages to be produced.
4.4. Short-term probability distributions

The relative probabilities of wind direction and wind speed at the spill location provide “best-guess” information as to the short-term direction and extent of the surface expression of a release. However, this information does not take into account the short-term variation in wind direction and speed, nor the influence of the other environmental movers (currents and diffusion).

In order to provide a more precise assessment of the probabilities of short-term trajectory patterns, the 11-year trajectory database was used to estimate probability distributions at 24, 48 and 72 hours after release. First, the location of all particles aged between 21 and 27 hours (24±3 hours) were recorded for each season and combined over each of the years, thus producing the seasonal distributions of particles with age of 24 hours. Then, the concentration calculation algorithm described in Section 4.3.1 was applied to these seasonal distributions over a grid of oceanic receptors (instead of coastline-based) set at a 500 m resolution, thus producing seasonal relative concentrations at 24 hours after release. Besides the offshore location of receptors, the only difference to the coastal concentration algorithm is that the neighbourhood for each grid point (x,y) was defined as the region enclosing the 1/10th closest particles (instead of 1/20th for the coastal algorithm).

Finally, the concentration was blanked out, outside the 99th percentile convex-hull, thus producing the final seasonal maps displaying the probabilistic distribution of a 24-hours-old spill. The process was repeated for particles aged between 45 and 51 hours to produce seasonal 48-hours-old release probability distribution maps and for particles aged between 69 and 75 hours to produce seasonal 72-hour-old release probability distribution maps.

4.5. Weathering model

The ADIOS2 model is used to simulate and estimate the gradual weathering of the released products as a function of oil type, physical and chemical properties, wind speed and water temperature.

Since weathering is highly dependent on the type of oil, ADIOS2 contains a detailed library of oils compiled from a number of sources (including Environment Canada, the U.S. Department of Energy, the International Oil Companies’ European Organization for Environmental and Health Protections, and other industry groups). For each oil product, information about the location, density, viscosity, flash point, pour point, hydrocarbon group analysis, and distillation data is included in the library. MSL has added several Taranaki crudes to this database, including Maari crude, Tui crude, Amokura crude, Kupe crude and Pohokura crude. For the presented study, hydrocarbon weathering has been estimated using the chemical composition of 380 Heavy Fuel Oil.

The ADIOS2 model computes the remaining volume percentage of oil products at given time intervals after a release of user-input parameters, including release timing and amount, by considering the processes of oil evaporation, emulsification, dispersion and spreading, based on user-input environmental parameters, including water temperature, water sediment
load, water salinity, and wind speed (Jones, 1997; Lehr et al., 2000). ADIOS2 uses the wind speed information to estimate wave height—a required parameter for the calculation of the physical weathering of a hydrocarbon—by assuming a constant wind speed over the model duration.

In the present study, ADIOS2 was used to estimate the remaining oil volume percentage at time intervals ranging from 2 hours until 120 hours after the beginning of a 2 hour release of 100 mT of 380 Heavy Fuel Oil. Wind speeds ranging from 1 m.s\(^{-1}\) and 30 m.s\(^{-1}\) and water temperatures ranging between 13°C and 17°C have been considered in these estimates.

### 4.6. Uncontrolled release scenario

The worst-case outcome of an accidental spill from the mining barge has been investigated. To consider the worst case outcome for coastal impacts in that situation, the release date associated with the highest potential beaching was identified within the 11-year trajectory database. Assuming a total release of 100 mT of 380 Heavy Fuel Oil over this period, and using the method outlined in Section 4.3, the worst-case shoreline concentrations have been derived. Weathering is accounted for using ADIOS (Section 4.5) and assuming the released oil has an average resident time exceeding 120 hours before beaching and is subjected to an average wind speed of ~10 m.s\(^{-1}\).

The relative costal impact and worst case scenarios were also investigated for representative sections of coastline for the same spill conditions. For each shoreline segment, the worst case outcome was identified within the 11-year trajectory database. The released volume and weathering were accounted for as described above. The maximum and average beaching concentrations, along with the beaching percentage of released volume were obtained for each segment.
5. RESULTS

5.1. Wind and current climate

Joint probability distributions of wind speed and direction at the approximate centre of the permit area are given in Table 5.1, while Figures 5.1 - 5.5 present the annual, summer, autumn, winter and spring wind compass rose plots. This data suggests a bimodal wind distribution, with the primary mode represented by winds from the NW sector, with a second smaller directional mode from the SE.

The joint probability distribution of the depth-averaged current speed and direction at the approximate centre of the permit area are provided in Table 5.2, while Figures 5.6 - 5.10 present the annual, summer, autumn, winter and spring current velocity compass rose plots. This data shows a clear bimodal current distribution with the dominant flows directed towards the E-SE. The dominant currents are due to a combination of local and regional wind-stresses on the ocean surface, as well as the tidal flows.

Table 5.1 Annual joint probability distribution (parts-per-thousand) of the wind speed and direction at 10 m above sea level at the approximate centre of the permit area.

<table>
<thead>
<tr>
<th>Wind speed (m.s⁻¹)</th>
<th>337.5-22.5</th>
<th>22.5-67.5</th>
<th>67.5-112.5</th>
<th>112.5-157.5</th>
<th>157.5-202.5</th>
<th>202.5-247.5</th>
<th>247.5-292.5</th>
<th>292.5-337.5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0 &lt;= 2</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4.2</td>
<td>4.2</td>
<td>4.7</td>
<td>5.5</td>
<td>4.9</td>
<td>37.2</td>
</tr>
<tr>
<td>&gt; 2 &lt;= 4</td>
<td>14.9</td>
<td>13.8</td>
<td>12</td>
<td>11.7</td>
<td>12.5</td>
<td>11.9</td>
<td>18.8</td>
<td>16.3</td>
<td>111.9</td>
</tr>
<tr>
<td>&gt; 4 &lt;= 6</td>
<td>19.3</td>
<td>17.3</td>
<td>13.7</td>
<td>20.2</td>
<td>15</td>
<td>11.3</td>
<td>30.8</td>
<td>31</td>
<td>158.6</td>
</tr>
<tr>
<td>&gt; 6 &lt;= 8</td>
<td>18.8</td>
<td>15.3</td>
<td>11.6</td>
<td>27.1</td>
<td>13.8</td>
<td>9.3</td>
<td>42.8</td>
<td>49.6</td>
<td>188.3</td>
</tr>
<tr>
<td>&gt; 8 &lt;= 10</td>
<td>17.9</td>
<td>10.8</td>
<td>7.5</td>
<td>29.4</td>
<td>13.1</td>
<td>7.9</td>
<td>49</td>
<td>56.2</td>
<td>191.8</td>
</tr>
<tr>
<td>&gt; 10 &lt;= 12</td>
<td>14.7</td>
<td>6</td>
<td>4.5</td>
<td>27.4</td>
<td>11.8</td>
<td>4.7</td>
<td>41.2</td>
<td>41.2</td>
<td>151.5</td>
</tr>
<tr>
<td>&gt; 12 &lt;= 14</td>
<td>10.3</td>
<td>2.1</td>
<td>1.5</td>
<td>17.5</td>
<td>9.5</td>
<td>2.3</td>
<td>24.4</td>
<td>22.5</td>
<td>90.1</td>
</tr>
<tr>
<td>&gt; 14 &lt;= 16</td>
<td>4.9</td>
<td>0.7</td>
<td>0.4</td>
<td>7.3</td>
<td>7</td>
<td>1</td>
<td>10.8</td>
<td>11</td>
<td>43.1</td>
</tr>
<tr>
<td>&gt; 16 &lt;= 18</td>
<td>2.6</td>
<td>0.2</td>
<td>0.3</td>
<td>3.7</td>
<td>4</td>
<td>0.2</td>
<td>4</td>
<td>3.8</td>
<td>18.8</td>
</tr>
<tr>
<td>&gt; 18 &lt;= 20</td>
<td>0.8</td>
<td>0</td>
<td>0.1</td>
<td>1.2</td>
<td>1.9</td>
<td>0</td>
<td>0.9</td>
<td>1.2</td>
<td>6.1</td>
</tr>
<tr>
<td>&gt; 20 &lt;= 22</td>
<td>0.1</td>
<td>0</td>
<td>0.4</td>
<td>0.8</td>
<td>0</td>
<td>0.1</td>
<td>0.3</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>&gt; 22 &lt;= 24</td>
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<td>0</td>
<td>0.1</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>109.3</td>
<td>70.9</td>
<td>55.6</td>
<td>150.2</td>
<td>93.8</td>
<td>53.3</td>
<td>228.3</td>
<td>238.1</td>
<td>1000</td>
</tr>
</tbody>
</table>
Table 5.2 Joint probability distribution (parts-per-thousand) of the depth-averaged current speed and direction at the approximate centre of the permit area.

<table>
<thead>
<tr>
<th>Current speed (m.s⁻¹)</th>
<th>Current direction (going to) (degT)</th>
<th>337.5 - 22.5</th>
<th>22.5 - 67.5</th>
<th>67.5 - 112.5</th>
<th>112.5 - 157.5</th>
<th>157.5 - 202.5</th>
<th>202.5 - 247.5</th>
<th>247.5 - 292.5</th>
<th>292.5 - 337.5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.00 &lt;= 0.05</td>
<td></td>
<td>18.5</td>
<td>20.7</td>
<td>20.9</td>
<td>18.9</td>
<td>18.1</td>
<td>16.7</td>
<td>18.1</td>
<td>18.0</td>
<td>149.9</td>
</tr>
<tr>
<td>&gt; 0.05 &lt;= 0.1</td>
<td></td>
<td>29.7</td>
<td>51.6</td>
<td>55.5</td>
<td>35.5</td>
<td>20.8</td>
<td>20.2</td>
<td>40.8</td>
<td>32.8</td>
<td>286.9</td>
</tr>
<tr>
<td>&gt; 0.1 &lt;= 0.15</td>
<td></td>
<td>18.5</td>
<td>49.9</td>
<td>68.3</td>
<td>33.1</td>
<td>10.2</td>
<td>10.7</td>
<td>42.5</td>
<td>25.5</td>
<td>258.7</td>
</tr>
<tr>
<td>&gt; 0.15 &lt;= 0.2</td>
<td></td>
<td>6.4</td>
<td>23.1</td>
<td>53.7</td>
<td>26</td>
<td>4.5</td>
<td>4.4</td>
<td>30</td>
<td>18.8</td>
<td>166.9</td>
</tr>
<tr>
<td>&gt; 0.2 &lt;= 0.25</td>
<td></td>
<td>1.6</td>
<td>6.4</td>
<td>28.7</td>
<td>16.6</td>
<td>1.8</td>
<td>1.5</td>
<td>16.6</td>
<td>11</td>
<td>84.2</td>
</tr>
<tr>
<td>&gt; 0.25 &lt;= 0.3</td>
<td></td>
<td>0.4</td>
<td>1.9</td>
<td>11.8</td>
<td>8.9</td>
<td>0.7</td>
<td>0.5</td>
<td>6.5</td>
<td>4.6</td>
<td>35.3</td>
</tr>
<tr>
<td>&gt; 0.3 &lt;= 0.35</td>
<td></td>
<td>0</td>
<td>0.1</td>
<td>4.1</td>
<td>3.4</td>
<td>0.2</td>
<td>0</td>
<td>3</td>
<td>1.4</td>
<td>12.2</td>
</tr>
<tr>
<td>&gt; 0.35 &lt;= 0.4</td>
<td></td>
<td>0</td>
<td>0</td>
<td>1.7</td>
<td>1</td>
<td>0.1</td>
<td>0</td>
<td>1.1</td>
<td>0.2</td>
<td>4.1</td>
</tr>
<tr>
<td>&gt; 0.4 &lt;= 0.45</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>&gt; 0.45 &lt;= 0.5</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>&gt; 0.5 &lt;= 0.55</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 0.55 &lt;= 0.6</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>75.1</td>
<td>153.7</td>
<td>245.3</td>
<td>143.9</td>
<td>56.4</td>
<td>54</td>
<td>159.3</td>
<td>112.3</td>
<td>1000</td>
</tr>
</tbody>
</table>

Figure 5.1 Annual wind rose for the approximate centre of the permit area. Sectors indicate the direction from which wind is coming.
Figure 5.2  Summer wind rose for the approximate centre of the permit area. Sectors indicate the direction from which wind is coming.

Figure 5.3  Autumn wind rose for the approximate centre of the permit area. Sectors indicate the direction from which wind is coming.
Figure 5.4 Winter wind rose for the approximate centre of the permit area. Sectors indicate the direction from which wind is coming.

Figure 5.5 Spring wind rose for the approximate centre of the permit area. Sectors indicate the direction from which wind is coming.
Figure 5.6    Annual regime of surface current at the approximate centre of the permit area. Note currents are shown in the ‘going to’ directional convention.

Figure 5.7    Summer regime of surface current at the approximate centre of the permit area. Note currents are shown in the ‘going to’ directional convention.
Figure 5.8 Autumn regime of surface current at the approximate centre of the permit area. Note currents are shown in the ‘going to’ directional convention.

Figure 5.9 Winter regime of surface current at the approximate centre of the permit area. Note currents are shown in the ‘going to’ directional convention.
5.2. Short-term probability distributions

The seasonal results for probability distribution at 24, 48 and 72-hours after a spill are provided in Figures 5.11 – 5.22. The results are expressed as normalised probability densities, which represent the relative likelihood of oil visitation at the given time interval from release.
Figure 5.11  Summer season probability density distribution of non-weathered oil at 24 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).

Figure 5.12  Summer season probability density distribution of non-weathered oil at 48 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).
Figure 5.13  Summer season probability density distribution of non-weathered oil at 72 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).

Figure 5.14  Autumn season probability density distribution of non-weathered oil at 24 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).
Figure 5.15 Autumn season probability density distribution of non-weathered oil at 48 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).

Figure 5.16 Autumn season probability density distribution of non-weathered oil at 72 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).
Figure 5.17 Winter season probability density distribution of non-weathered oil at 24 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).

Figure 5.18 Winter season probability density distribution of non-weathered oil at 48 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).
Figure 5.19 Winter season probability density distribution of non-weathered oil at 72 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).

Figure 5.20 Spring season probability density distribution of non-weathered oil at 24 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).
Figure 5.21  Spring season probability density distribution of non-weathered oil at 48 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).

Figure 5.22  Spring season probability density distribution of non-weathered oil at 72 hours following release from the mining barge at the approximate centre of the permit area (based on an 11-year trajectory database).
5.3. Beaching probabilities

The seasonal results, showing the potential beaching outcomes identified by the 11-year trajectory database are provided in Figures 5.23–5.34. Also shown on the maps are the minimum beaching times. These probability results represent the relative likelihood of a beaching outcome should a release occur in any given season. The percentage of trajectory outcomes that result in beaching and the minimum times for beaching from the 11-year database are summarised in Table 5.3.

Table 5.3 Percentage of events that result in beaching (determined from the 11-year trajectory database) and the minimum time (in hours) for beaching per season.

<table>
<thead>
<tr>
<th></th>
<th>Season</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spring</td>
<td>Summer</td>
<td>Autumn</td>
<td>Winter</td>
</tr>
<tr>
<td>Total % beaching</td>
<td>97.8</td>
<td>94.9</td>
<td>92.4</td>
<td>95.0</td>
</tr>
<tr>
<td>Min beaching time (hours)</td>
<td>16.6</td>
<td>12.5</td>
<td>16.6</td>
<td>12.7</td>
</tr>
</tbody>
</table>
Figure 5.23  Summer season beaching probability based on an 11-year trajectory database.

Figure 5.24  Summer season minimum beaching times.
Oil spill trajectory modelling for the TTR mining barge

Figure 5.25  Summer season median beaching times.

Figure 5.26  Autumn season beaching probability based on an 11-year trajectory database.
Figure 5.27  Autumn season minimum beaching times.

Figure 5.28  Autumn season median beaching times.
Figure 5.29 Winter season beaching probability based on an 11-year trajectory database.

Figure 5.30 Winter season minimum beaching times.
Figure 5.31  Winter season median beaching times.

Figure 5.32  Spring season beaching probability based on an 11-year trajectory database.
Figure 5.33  Spring season minimum beaching times.

Figure 5.34  Spring season median beaching times.
5.4. Weathering budgets

A weathering table has been produced for 380 Heavy Fuel Oil (Table 5.4). This table expresses the volume percentage of spilled oil predicted to remain on the sea surface at time increments out to 120 hours after the release. The two key variables to weathering are water temperature and wind speed.
Table 5.4 Volume percentage of oil remaining on surface after a 2-hour release of 100 mT of 380 Heavy Fuel Oil as a function of wind speed and exposure time, calculated using ADIOS2. The model considers evaporation and dispersion in the water column under the action of wind and waves. Calculations were run for water temperatures of 13°C and 17°C, providing an interval of percentage indicated in each table cell. A table cell containing a single value indicates no difference in results between 13°C and 17°C.

<table>
<thead>
<tr>
<th>Wind speed (m.s⁻¹)</th>
<th>Hours into spill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>99-100</td>
</tr>
<tr>
<td>5</td>
<td>99-100</td>
</tr>
<tr>
<td>10</td>
<td>98-99</td>
</tr>
<tr>
<td>15</td>
<td>95-96</td>
</tr>
<tr>
<td>20</td>
<td>90-92</td>
</tr>
<tr>
<td>25</td>
<td>84-88</td>
</tr>
</tbody>
</table>
5.5. **Worst-case beaching predictions**

The potential worst-case beaching arising from an accidental release of 100 mT of 380 Heavy Fuel Oil for 2 hours from the TTR mining barge is presented in Figure 5.35. The worst-case release date has been identified as the 27\textsuperscript{th} of June 2008. During this period the highest beaching concentrations are predicted to occur in the South Taranaki Bight, with maximum concentrations of 4.79 m\textsuperscript{3} per kilometre of coastline in the vicinity of Wanganui.

The results of the same uncontrolled release on the beaching at shoreline sections defined in Figure 5.36 are presented in Table 5.5.
Table 5.5 Beaching outcomes from the worst case 2 hours accidental spill scenario identified from the 11-year trajectory database for 12 shoreline segments (Fig. 5.36).

<table>
<thead>
<tr>
<th>Shoreline Section</th>
<th>Release Duration (days)</th>
<th>Start Date</th>
<th>Maximum Concentration (m³/km)</th>
<th>Beaching %</th>
<th>Average Concentration (m³/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>15-Mar-03</td>
<td>3.76</td>
<td>100.00</td>
<td>0.17</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>22-Aug-01</td>
<td>4.30</td>
<td>41.87</td>
<td>0.06</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>10-Aug-09</td>
<td>7.03</td>
<td>99.22</td>
<td>0.08</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>-</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>11-Jun-04</td>
<td>10.20</td>
<td>19.04</td>
<td>0.06</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>13-Sep-03</td>
<td>3.43</td>
<td>100.00</td>
<td>0.40</td>
</tr>
<tr>
<td>G</td>
<td>1</td>
<td>18-Feb-04</td>
<td>7.18</td>
<td>100.00</td>
<td>0.44</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>22-May-09</td>
<td>17.70</td>
<td>100.00</td>
<td>0.40</td>
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<tr>
<td>I</td>
<td>1</td>
<td>27-May-09</td>
<td>8.94</td>
<td>100.00</td>
<td>0.29</td>
</tr>
<tr>
<td>J</td>
<td>1</td>
<td>12-Jan-03</td>
<td>5.24</td>
<td>82.87</td>
<td>0.27</td>
</tr>
<tr>
<td>K</td>
<td>1</td>
<td>8-Sep-06</td>
<td>5.34</td>
<td>88.48</td>
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<td>L</td>
<td>1</td>
<td>9-Nov-00</td>
<td>2.71</td>
<td>50.80</td>
<td>0.16</td>
</tr>
<tr>
<td>Complete coastline</td>
<td>1</td>
<td>27-Jun-08</td>
<td>4.79</td>
<td>100.00</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Figure 5.35 Predicted beached percentages from a 2 hours accidental release of 100 mT of Heavy Fuel Oil from the mining barge at the approximate centre of the permit area. This figure represents the worst coastal beaching outcome within the 11-year trajectory database.

Figure 5.36 Shoreline sections used for the detailed beaching assessment and identification of the worst case scenario in the event of an accidental spill.
6. SUMMARY OF RESULTS

An 11-year database containing all the likely trajectories for an oil spill from a mining barge located at the centre of the permit area has been constructed. Oil spills have been tracked continuously from 1999 to 2009 until they beach or leave the modelled region. This technique provides a robust statistical basis to quantify the most likely pathways for oil in the unlikely event of a spill from the mining barge, and from this knowledge an assessment of the coastal areas that are most likely to be affected can be reliably determined.

Results from the trajectory database have been examined for the seasonal conditions, showing the relative probabilities for beaching and statistics for beaching times. The season with the highest probability of beaching is spring, while the season that exhibits the lowest beaching outcome is autumn. Taking a conservative approach without including the effects of weathering on spilled oil, beaching is a likely outcome from a spill for 92.4 – 97.8% of events, depending on the season. The minimum time for beaching of spilled oil ranges between 12.5 hours during summer to 16.6 hours during spring and autumn.

A series of coastal beaching probability maps have been produced, and maps of beaching probabilities are provided for each season. The region of coast most likely to be affected from a spill is in the South Taranaki Bight in the vicinity of the Rangitikei River Mouth.

Short-term probability density distributions have been calculated to show the likely spread of spilled oil from the mining barge at the approximate centre of the permit area, at the T+24, 48 and 72-hour time horizons. A hydrocarbon weathering model has been used to estimate the time-varying release budget for 380 Heavy Fuel Oil. A volumetric percentage remaining on the sea surface is provided for a range of probable water temperatures and wind speed scenarios.

The worst-case outcome of an accidental release of 100 mT of 380 Heavy Fuel Oil has been investigated. The release date in the 11-year trajectory database that produces the maximum beaching outcome has been identified, and oil concentrations of over 2 m3 per kilometre of shore have been predicted in the South Taranaki Bight. A maximum concentration (4.79 m³.km⁻¹) was found around Wanganui. The maximum and average concentrations of weathered oil, per linear kilometre of coast have been reported for representative sections of the coastline.
REFERENCES


