TRAJECTORY ANALYSIS OF DEEP SEA OIL SPILL SCENARIOS IN NEW ZEALAND WATERS

Report prepared for Greenpeace New Zealand

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LIST OF ABBREVIATIONS

ADIOS2	Automated Data Inquiry for Oil Spills
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority
GNS	New Zealand's Institute of Geological and Nuclear Science
GNOME	General NOAA Oil Modeling Environment
GPNZ	Greenpeace New Zealand
HYCOM	Global Hybrid Coordinate Ocean Model
MNZ	Maritime New Zealand
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Agency
NOGAPS	US Navy's Operational Global Atmospheric Prediction System
TAP	Trajectory Analysis Planner
TVSS	True Vertical Subsea Depth

EXECUTIVE SUMMARY

In April 2010, the Deepwater Horizon disaster in the Gulf of Mexico highlighted the wide-scale impacts that can be caused by a catastrophic deep sea well failure. Greenpeace New Zealand has raised concerns about exploratory drilling operations for deep sea oil that are planned for the summer of 2013/2014 offshore off the west coast of the North Island in the Taranaki Basin and the east coast of the South Island in the Canterbury Basin.

We provide an evaluation of the likely dispersal trajectory of a deep water oil spill at the two proposed exploration sites. Our analysis uses industry standard numerical modelling techniques to conduct an oil-spill trajectory analysis and determine the extent of oil propagation, dispersion and beaching in the event of a deep water blowout.

The numerical models are driven by a global database of meteorological and oceanographic conditions (waves, winds and tide) to reproduce the dispersion of thousands of oil spills under a variety of environmental conditions. We aim to describe a realistic deep sea blowout scenario based on past events and the best information available to us regarding the targeted prospects. We describe the impact analysis for Taranaki and Canterbury after 76 days of continuous oil input at a flow rate of 10,000 bbl/day during the summer season. We provide additional flow rate scenarios for comparison purposes (5,000 and 40,000 bbl/day).

We considered several levels of concern by defining socio-economic and ecological thresholds for both land and sea. The socio-economic threshold relates to closure of fisheries at sea (> 0.01 g/m^2) or shoreline clean ups on amenity beaches (>1 g/m^2) whereas ecological threshold integrates degrees of oiling known to mortally impact sea birds and other wildlife (>10 g/m^2).

In the Taranaki Basin, 90% of trajectories raised the level of concern above the socio-economic threshold somewhere on land, while 80% of the modelled spills impacted the entire coastline between Kaipara Harbour mouth and Raglan. The west coast stretch between Opononi and Cape Egmont is within the 50% trajectories impact area. The combined area covered by 95% of the modelled trajectories exceeding the socio-economic threshold of 1g/m^2 is 15,500 km^2 after 1 week, 132,400km^2 after 1 month and 226,800 km^2 after 76 days. In the event of a spill, this area represents the socio-economic threat zone where fisheries could potentially be closed due to visible oil on the sea surface. The model results show a significant impact on the shoreline for nearly the entire west coast of the North Island with oil thickness reaching levels as high as nearly 250 g/m^2 in some areas, well above ecological threshold.

In Canterbury, the extent of the probabilistic spread is much larger than for Taranaki as most spills drift freely across the ocean surface for months without encountering land. The model shows a wide impact plume that extends eastwards as far as the Chatham Islands. The socio-economic threat zone grows from an area of 14,300 km^2 after one week, to 162,100 km^2 after a month and 532,400 km^2 after 76 days. The socio-economic impact threshold at sea was reached during the simulation period at 91% of trajectories for the coastal waters of Kaikoura and between 21 and 44% for Oamaru, the Banks peninsula and Taiaroa Head.

I BACKGROUND

Greenpeace New Zealand (GPNZ) has raised concerns about exploratory drilling operations for deep sea oil that are planned for the summer of 2013/2014. The operations will be carried out by Anadarko New Zealand Company on the Romney and Caravel prospects which are located offshore off the west coast of the North Island in the Taranaki Basin and the east coast of the South Island in the Canterbury Basin (Figure 1).

In April 2010, the Deepwater Horizon disaster in the Gulf of Mexico highlighted the wide-scale negative impacts that can be caused by a catastrophic deep sea well failure. In October 2011, the spectre of an oil spill disaster was raised in New Zealand when the freighter Rena ran aground on Astrolabe Reef in the Bay of Plenty. While much smaller in scale than the Deepwater Horizon disaster, it nevertheless resulted in 350 tons of heavy fuel oil being spilled in to the ocean. The weather conditions at the time exacerbated the effects by pushing the spilled oil towards the coast resulting in locally significant impacts including oiled beaches and effects on wildlife (MNZ, 2013).

GPNZ is exceedingly concerned about New Zealand's lack of preparedness for dealing with a deep sea oil spill and in particular, it's geographic isolation in regards to the contracting and deployment of the relief rigs and support vessels necessary to contain such a spill. According to Maritime New Zealand (MNZ), New Zealand "maintains a response capability of sufficient size to counter an oil spill of 3,500 tons". In the event of a larger spill such as what would occur after a deep sea well failure, MNZ has secured arrangements with overseas contractors to provide spill response and clean up services. However, since this equipment must be brought in from overseas (e.g. Australia or Singapore) the immediate mitigation of such a disaster would be extremely difficult (REML, 2013). This would lead to the situation where large quantities of oil would continuously enter the marine environment until the response equipment arrives and successfully stops the flow.

The New Zealand Environmental Protection Authority (EPA) publicly released an Environmental Impact Assessment (EIA) for the Taranaki Basin exploration in September, 2013, however the numerical modelling section relating to impact in the event of loss of well control is missing at the time of writing. The report (Environmental Resources Management (b), 2013) presents the results of the spill modelling during the summer months, however no explanation is given on how the probabilistic quantities were obtained and no oil thickness estimated from scenarios is provided.

GPNZ has commissioned Dumpark Limited for its expertise in oceanographic data modelling and particle dispersal simulation to provide an independent evaluation of the likely dispersal trajectory of a deep water oil spill at the two proposed exploration sites. Our analysis uses industry standard numerical modelling techniques to conduct an oil-spill trajectory analysis and determine the extent of oil propagation, dispersion and beaching in the event of a deep water blowout at either the Romney or Caravel prospects. The numerical models are driven by a global database of meteorological and oceanographic conditions (waves, winds and tide) to reproduce the dispersion of thousands of oil spills under a variety of environmental conditions and spill scenarios. The resulting database of spill trajectories is then used to perform impact assessments, oiling analysis and response time analysis.

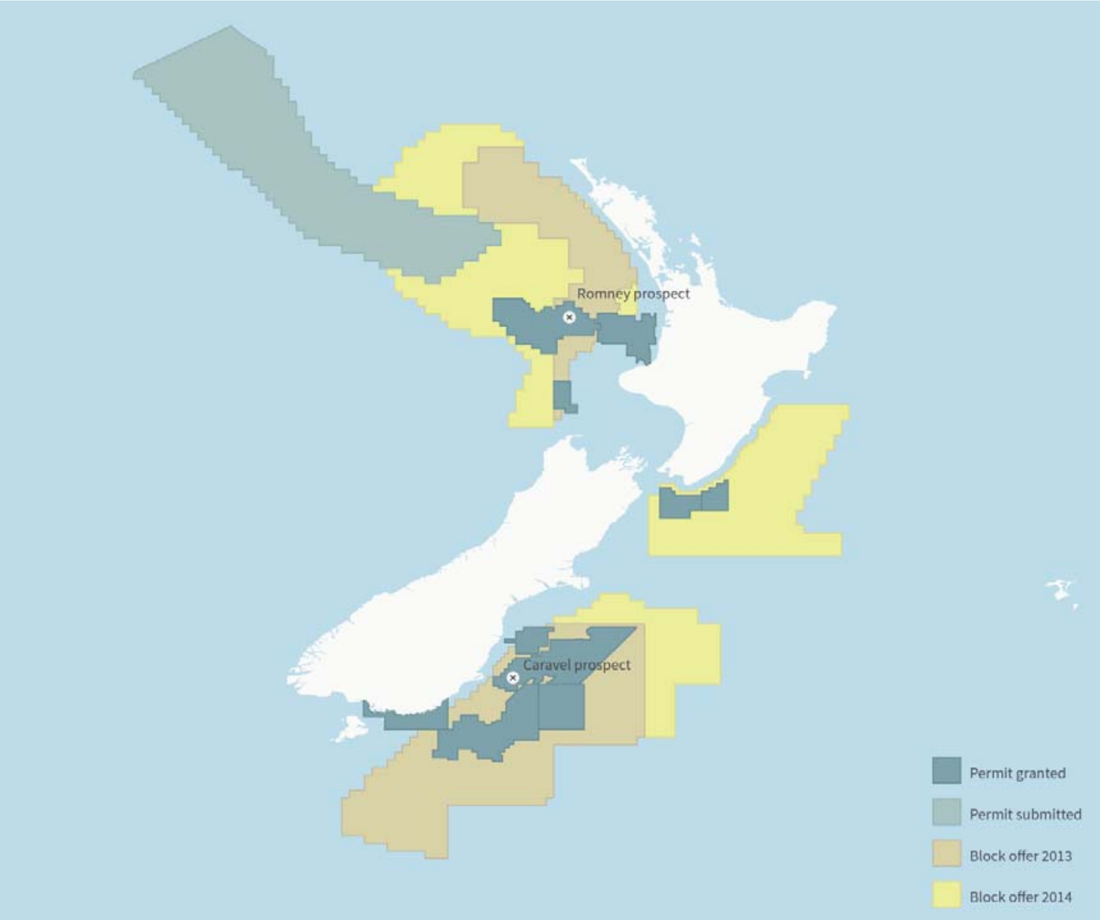

Figure 1: Granted or submitted petroleum permits at depth greater than 200m and open block offer for 2013 and 2014 in New Zealand. Romney and Caravel prospects respectively in the Taranaki Basin (PEP 38451) and Canterbury Basin (PEP 38264) permit areas.

II FATE OF MARINE OIL SPILLS

The fate of spilled oil in water bodies is governed by physical, chemical, and biological processes (Wang, Shen, & Zheng, 2005). This includes the chemical properties of the crude oil itself as well as the environmental conditions (Sebastiao & Guedes Soares, 1995) which are site and time dependent. When liquid oil is spilled on the sea surface, it spreads to form an oil slick (Wang, Shen, & Zheng, 2005). However, such slicks are not evenly distributed, but rather spread irregularly on the water as bands or tarballs with clean water in between. (NOAA, 2013)

The physical and chemical changes that spilled oil undergoes are collectively known as ‘weathering’. (ITOPFL, 2002). These processes include:

- **Advection** which is the transport of oil horizontally or vertically and depends primarily on the hydrodynamics, meteorological and environmental conditions. (Wang, Shen, & Zheng, 2005).

- **Evaporation** of the oil from its liquid to gas state and is the primary initial process involved in the removal of oil from sea. (Sebastiao & Guedes Soares, 1995).

- **Dispersion**, the process of forming small droplets of oil which become incorporated in to the water column and are then driven by current, wave and wind action (Wang, Shen, & Zheng, 2005). Besides evaporation, the rate of natural dispersion largely determines the life of an oil slick on the sea surface (Sebastiao & Guedes Soares, 1995).

- **Emulsification** which involves the dispersion of water droplets into the oil medium (Sebastiao & Guedes Soares, 1995). Emulsification and evaporation lead to decreased oil-water density difference, and increased pour point (Reed, et al., 1999). Emulsification is a key process in determining spill lifetime as well as the window of opportunity for spill response (Nordvik, Bitting, Hankins, Hannon, & Urban, 1995). However, reliable computations of emulsion formation, stability, and associated viscosity at present require laboratory or field observations. (Reed, et al., 1999).

- **Spreading** of low pour point oil released on water is probably the most dominant process in the first stage of the spill (Sebastiao & Guedes Soares, 1995). Spreading is important in determining the fate of spilled oil through evaporation, emulsification, and natural dispersion. Release conditions are also relevant in determining initial spreading. Underwater releases, for example, result in very different initial surface distributions of oil than surface releases (Reed, et al., 1999).

- Other processes are **dissolution**, **sedimentation** by sinking, photo-**oxidation** (Ferreira, Cabrai, & Junior, 2003) and also **biodegradation** (Sebastiao & Guedes Soares, 1995)

Although the individual processes causing these changes may act simultaneously, their relative importance varies with time (ITOPFL, 2002) as illustrated in Figure 2. It is well known that advection, dispersion and evaporation are the dominant processes in oil weathering, mostly governed by environmental forces (Reed, et al., 1999) and are the ones considered by mathematical models for quantitative estimation of oil spills at sea (Ferreira, Cabrai, & Junior, 2003).

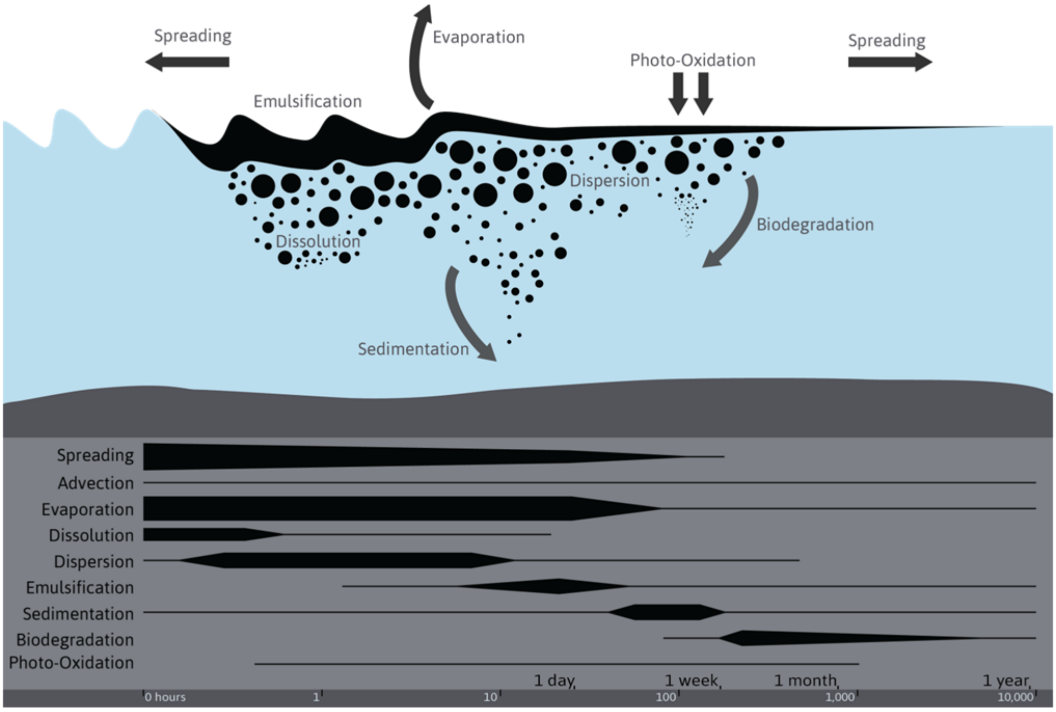

Figure 2: Physical and chemical processes causing change in oil characteristics of a typical medium crude oil under moderate sea conditions, adapted from (ITOPFL, 2002). The schematic at the bottom shows the relative importance of weathering processes of an oil slick over time. The width of the line shows the relative magnitude of the process in relation to other contemporary processes. Adapted from (Hazardous Materials Response and Assessment Division).

III TRAJECTORY MODELLING

III-1 Methodology

Numerical modelling of oil spill dispersion generally uses a Lagrangian approach (Reed, et al., 1999). In fluid mechanics, there are two general ways to look at a problem: Lagrangian or Eulerian. 'Lagrangian' refers to a method proposed by Joseph-Louis Lagrange while 'Eulerian' refers to the style advocated by Swiss mathematician Leonhard Euler.

The Eularian method focusses on a snapshot of the fluid, showing speed and direction everywhere at a given time, whereas the Lagrangian approach tracks the motion of individual fluid particles. In this framework, an oil slick is driven by an Eulerian representation of oceanic currents and winds and treated in a Lagrangian manner as a large number of independent particles whose paths and mass are followed and recorded as functions of time.

By analysing the progress of a large number of trajectory simulations, the potential severity of environmental impacts resulting from an oil spill can be assessed (Ferreira, Cabrai, & Junior, 2003). The systematic archiving of global ocean circulation model output over the last decade, as well as general advancements in computing technologies allows for the creation of a probabilistic trajectory set in a relatively short amount of time.

While traditional dispersal modelling studies would simulate a specific event (e.g. real time or characteristic events) and give a deterministic analysis, we used a probabilistic approach to simulate a large number of events randomly scattered through 10 years of environmental data and then compute the relative frequency of a given target being reached by the spill.

The oil spill modelling tools used in this study are public domain software available from the National Oceanic and Atmospheric Agency (NOAA) of the United States of America. This includes the General NOAA Oil Modelling Environment (GNOME), the Trajectory Analysis Planner (TAP) and the Automated Data Inquiry for Oil Spills (ADIOS2).

The environmental data used for this study is also public domain and includes wind data from the National Centres for Environmental Prediction (NCEP) and the National Centre for Atmospheric

Research (NCAR) global reanalysis (Kalnay, 1996) as well as oceanic current data computed and archived by the Global Hybrid Coordinate Ocean Model (HYCOM) consortium (Chassignet, et al., 2007).

The numerical modelling methodology is illustrated in Figure 3, which depicts the various components used to drive the GNOME model as well as the information flow relative to oil spill scenarios, environmental forcing, model processes and outputs.

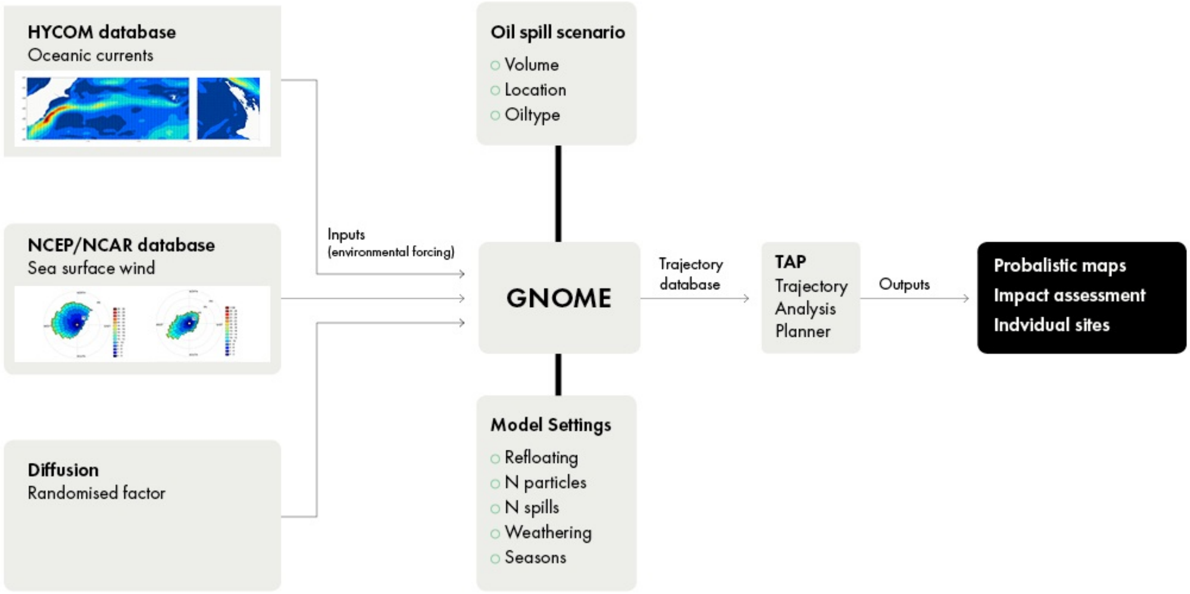

Figure 3: Trajectory modelling methodology.

III-2 GNOME

GNOME was designed for the rapid modelling of pollutant trajectories in the marine environment (Beegle-Krause J. , 2001). The basic data components are maps, movers (wind, currents, & diffusion), and inputs (i.e. oil spills). The model has been extensively tested and verified (NOAA, 2012). GNOME resolves a forward Euler-scheme to predict the overall movement of spill particles as they are forced by oceanic currents, wind and diffusion according to the equation (Beegle-Krause, 1999):

$$\frac{\partial X}{\partial t} = U_h + k_w U_w + D$$

Where $\frac{\partial X}{\partial t}$ is the particle displacement, U_h, the hydrodynamic forcing velocity, k_w, the windage[1] coefficient, U_w the wind forcing velocity and D, the turbulent diffusion component.

Model runs can be automated to produce a large number of trajectories under variable environmental conditions. NOAA's TAP software computes probabilistic quantities from a large number of pre-computed trajectories (NOAA, 2000). TAP was designed to assist with the following planning tasks (Samuels, Amstutz, Bahadur, & Ziemniak, 2013):

- Assessing potential threats from possible spill sites to a given sensitive location,
- determining which shoreline areas are most likely to be threatened by a spill,
- calculating the probability that a certain amount of oil will reach a given site within a given time-period and
- estimating the levels of impact on a given resource from a spill.

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[1] Windage is the movement of oil by the wind and ranges typically between 1 to 4% of the wind speed (Lehr & Simecek-Beatty, 2000).

III-3 Oil Spill Scenarios

An oil spill is characterised through the critical parameters of:

- location
- duration
- flow rate
- oil type

We determined specific values for these parameters during an extreme oil-spill scenario based on the best available information regarding the proposed exploration projects.

In this study we are considering an oil spill caused by the blowout of an oil drilling rig that leads to the uncontrolled release of crude oil at the sea bed into the water column. This is analogous to the type of spill that occurred in 2010 during the Deepwater Horizon event in the Gulf of Mexico.

Drilling Locations

Greenpeace New Zealand provided estimated location information for both the Romney and Caravel prospects. These location estimates were based on a presentation made by the Anadarko Petroleum Corporation to the Citigroup Global Energy and Utilities Conference on May 15th, 2013. The precise coordinates of the drilling locations were only released after the analyses in this report were already complete (Environmental Resources Management (a), 2013). However, to test whether the exact release location would drastically influence our probabilistic analyses, for each permit area we produced several probabilistic maps in which the release location was shifted from our estimated release location by 0.1 degree in both longitudinal and latitudinal direction, resulting in nine different scenarios that covered the official drilling site coordinates (Figure 4). The variation in release location did not result in major changes to the final probabilistic maps. The estimated locations and corresponding water depths used for this report are indicated in Figure 4 .

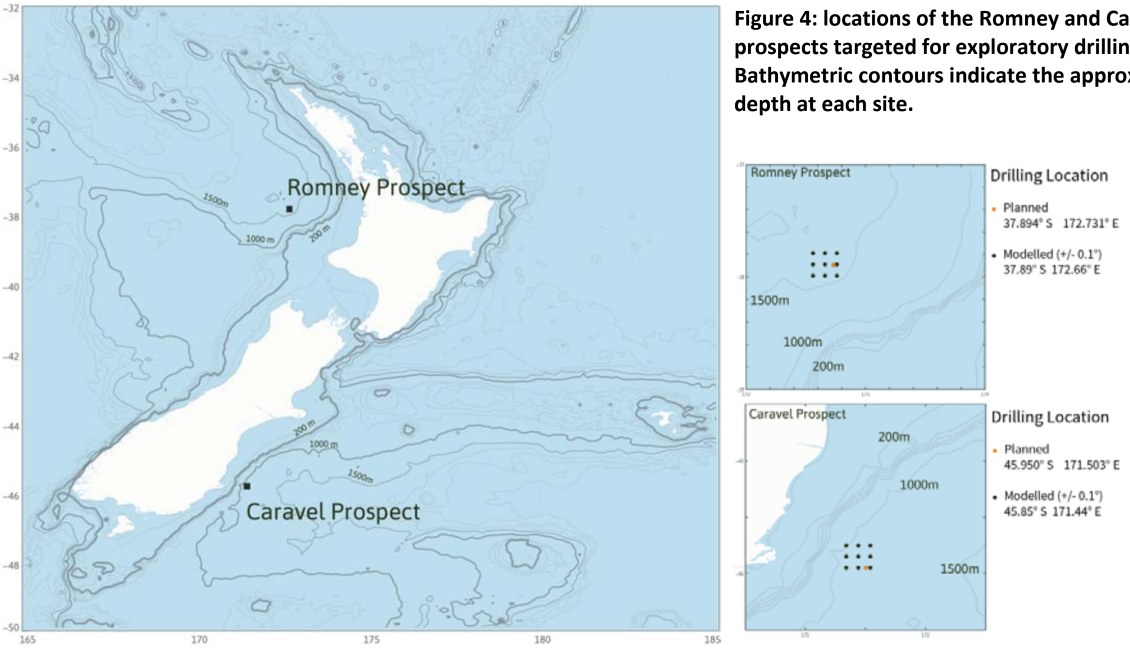


Figure 4: locations of the Romney and Caravel prospects targeted for exploratory drilling. Bathymetric contours indicate the approximate depth at each site.

Blowout Duration

Calculating the duration of a worst case scenario oil spill requires an estimate of the time required for relief equipment to be deployed to the spill site and contain the spill. In the New Zealand context, the time required to complete each of the following steps must be considered (BP, 2011):

- A relief rig suspends its own operations.
- The rig moves to the spill location.
- Drilling a relief well to the required depth.
- Perform ranging runs (this involves pulling the drill string and attaching a special ranging tool to determine the exact location relative to the damaged well).
- Drilling into the spilling well and performing kill operations.

If it were necessary to drill a relief well, a drilling rig could be contracted from operations in Singapore, Australia's North West Shelf or Papua New Guinea (REML, 2013). A typical time-frame for a drilling rig to cease its drilling activities and mobilise to New Zealand is approximately 60 to 75 days depending on vessel availability (REML, 2013). The time to drill a relief well is probably on the order of 60 days (REML, 2013) which gives a total blowout duration of 120 to 135 days. As a matter of comparison, it took 152 days to successfully drill a relief well and perform kill operations on the Macondo well (NCBP, 2011) in the Deepwater Horizon event, and 74 days to stop the flow from the

Montara well in the Timor Sea northwest of Australia (MCI, 2010), despite the Montara well being situated in relatively shallow waters (77m). An EIA for the North Uist prospect, located approximately 125 km North West of the Shetland Islands (UK) in a water depth of 1,291 m, estimated a conservative blowout duration of 140 days (BP, 2011).

For this report, we calculated the blowout duration using estimates of the parameters described above:

- The suspension of operations of an overseas relief rig: **5 days**
- The rig relocation: **18 days**, giving a total of 23 days for mobilisation which is shorter than the 60 to 70 days period defined by shallow water drilling impact assessments for New Zealand (REML, 2013).
- Relief well drilling, well interception and kill: **53 days**, based on the time required to drill and kill relief well at Montara – drilled to a similar subsurface depth (2600m) to the Caravel prospect but in only 77m of water.

Together, the above estimates give a minimum total blowout duration of **76 days** for our model.

Blowout Flow Rate

While specific information related to the possible flow rate of the Romney and Caravel prospects could not be provided by New Zealand's Institute of Geological and Nuclear Science (GNS) or EPA, it has been noted by BP (2011) that most operating regions worldwide contain wells with flow rates less than 100,000 barrels of oil per day.

Some examples of flow rates from typical drilling sites include the Cardhu reservoir (North Uist) in the North Sea with a pumping rate of 45,000 barrels per day. The North Uist well is in 1,291 m of water, with maximum reservoir pressures predicted to be 7,582 psi for oil. The Macondo well (Deepwater Horizon) was located in 1544 m of water and reached depths of over 3,960 m below the seafloor (NCBP, 2011). The flow rate reached 62,200 barrels per day on April 22, 2010 and dropped to 52,700 barrels per day by July 14, 2010 (the day the capping stack was installed; McNutt et al. 2011) and in total, the well discharged 4.9 million barrels of oil. The Montara well in Australia was located in 77 m of seawater and the reservoir rocks were at an overburden depth of 2600 m (MCI, 2010). Unsubstantiated estimates made by the operator PTTEPPA, stated that the flow rate of the blowout was 400 barrels per day. However, Geoscience Australia provided estimates of 2,000 barrels a day, while the West Australia Green Party estimated the rate at 3,000 barrels per day.

The factors that can influence the flow rate from a well blowout are the conduit through which the reservoir fluids can flow to get to surface, the pressure of the reservoir, the type of fluid and the amount of open hole drilled into the reservoir (BP, 2011). The explored reservoirs in New Zealand are generally of lower pressure than those found in other production fields. Therefore, although instantaneous flow may be several tens of thousands of barrels, over the duration of a blowout event, based on natural flow rates of existing wells in Taranaki, a more realistic scenario for New Zealand is 5,000 to 10,000 bbl/ day (MED, 2009). For the purposes of modelling flow rates, the reservoir characteristics in Taranaki have been assumed to be similar to Taranga-1, Arawa-1 and Kanuka-1. In Canterbury, oil and gas reservoirs are predicted to be at 3000 m to 4500 m for a pressure of 4700 psia at 3000 m TVSS (True Vertical Subsea Depth) and 6570 psia at 3500 m TVSS (Adams, 2009).

Therefore, using past blowout events and publicly available EIA reports as a guide, we settled on using flow rates of 5,000, 10,000 and 40,000 bbl/day at each site. These flow rates over the assumed 76 day spill period are compared to major historical oil spill events in Figure 5.

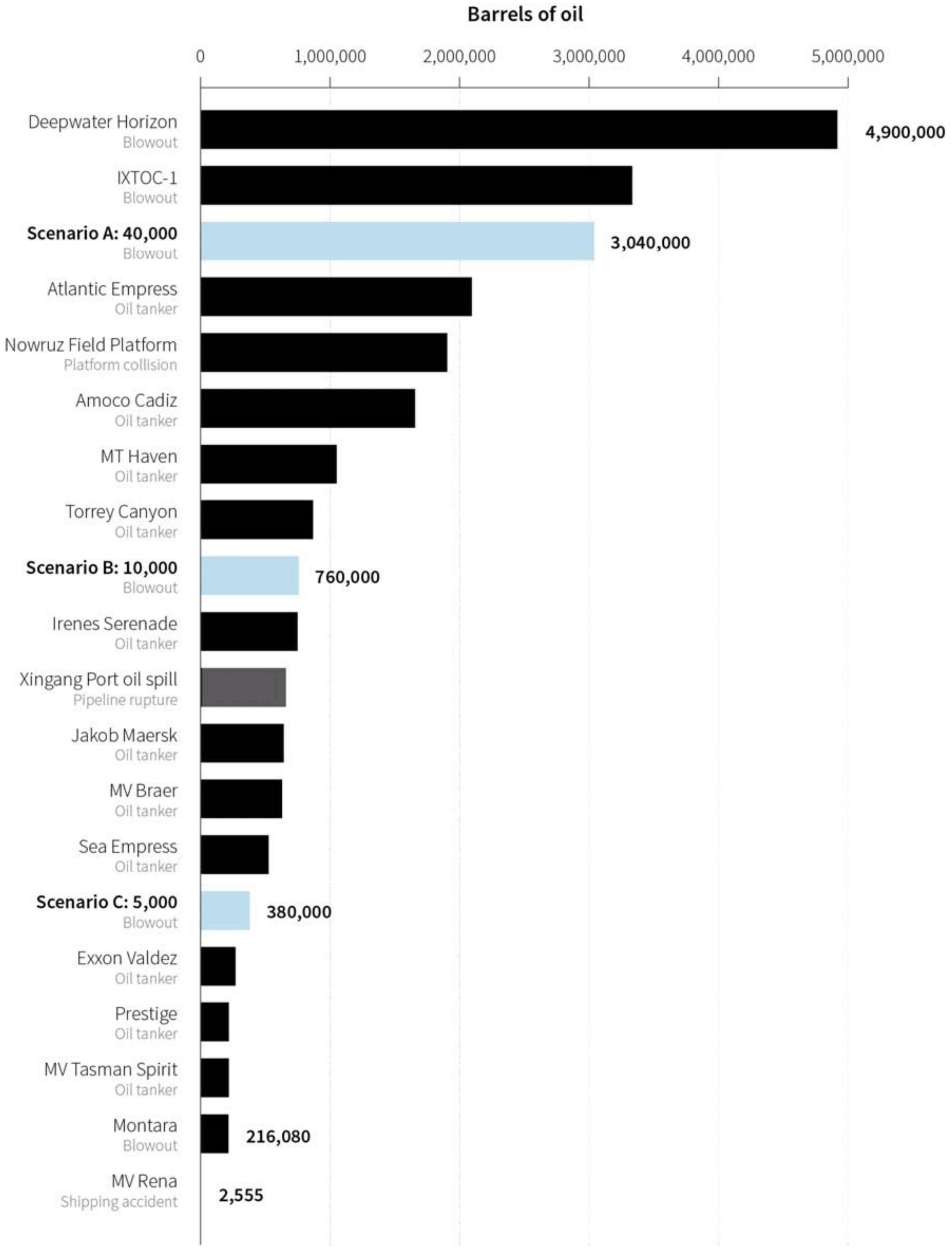


Figure 5: Comparison of the modelled volume scenarios (5,000, 10,000 and 40,000 bbl/day during 76 days) and major historical oil spill events worldwide. Volumes are expressed in barrels. (M. K. McNutt, 2011, J. S. Patton, 1981, Etkin, 1999, Steiner, 2011, MCI, 2010, ITOPF, 2013, MNZ, 2013)

Oil Type

Crude oils of different origin vary widely in their physical and chemical properties. The main physical properties which affect the behaviour and the persistence of oil spilled at sea are the specific gravity, distillation characteristics, viscosity and pour point (ITOPFL, 2002).

Lenting and Pratt (1998) characterised specific oil handled in New Zealand by ranking the characteristics of spilled oil in water (Table 1). This classification system is used by NOAA and The International Tanker Owners Pollution Federation.

A distinction is frequently made between non-persistent oils, which because of their volatile nature and low viscosity tend to disappear rapidly from the sea surface, and persistent oils, which dissipate more slowly and usually require a clean-up response. As a general rule, the lower the specific gravity of the oil the less persistent it will be.

Table 1: Oil classification and associated specific gravity, taken from (Lenting & Pratt, 1998).

Group	Specific gravity	Description and examples
I	< 0.8	Light distillates Maui and Kapuni condensate Gasoline blendstocks Motor spirit (RMS/PMS), Avgas Jet A1, kerosene
II	0.80 - 0.85	Middle distillates and light crudes Gas oils Light crudes
III	0.85 - 0.95	Medium – heavy crudes, fuel oils LFO Medium – heavy crudes
IV	0.95 - 1.00 or high pour point crudes	Heavy crudes and residues HFO Residues Fletcher blend, Maui F sands below pour point Lube oils and lube blendstocks
V	> 1.0	Very heavy fuel and bunker oils HBFO Bitumen

The concept of a 'half-life' is helpful in defining removal rates of less persistent oils. A half-life is the time required for a quantity of oil to fall to half its original value, consequently non-weathering oils are represented by an infinite half-life parameter. GNOME uses a relatively simple 3-phase evaporation algorithm where the pollutant is treated as a three-component substance with independent half-lives (Boehm, Feist, Mackay, & Paterson, 1982).

While a conservative approach would be to use non-weathering oil for an impact assessment, to achieve a more realistic understanding we used the weathering characteristics of a classical medium crude which takes into account the weathering of lighter components. Table 2 presents the parameters used to characterise the oil in the model. A more detailed analysis of half-life removals and comparison of modelled medium crude against other known oil type in New Zealand are presented later in this study.

Table 2: Three component substance and associated half-lives for the medium crude oil type used during this study.

	Light component	Medium component	Heavy component
Proportion	22 %	26 %	52%
Half-Life in hours	14.4	48.6	$1.0\text{x}10^9$

III-4 Model Forcing and Inputs

Oceanic Forcing

Sea surface currents are extracted from the Global Hybrid Coordinate Ocean Model (Global HYCOM) (Chassignet, et al., 2007). The HYCOM model is forced by the US Navy's Operational Global Atmospheric Prediction System (NOGAPS) and includes wind stress, wind speed, heat flux, and precipitation. The model provides systematic archiving of daily three-dimensional ocean circulation on a global scale with output data archived back to 2003. The global model resolution is 1/12° around the modelled area (a grid size of approximately 7 x 9 km). The dispersal model GNOME then uses the u (east-west) and v (north-south) velocity combined with components of wind and diffusion to induce individual particle displacement using a forward Euler scheme (NOAA, 2012).

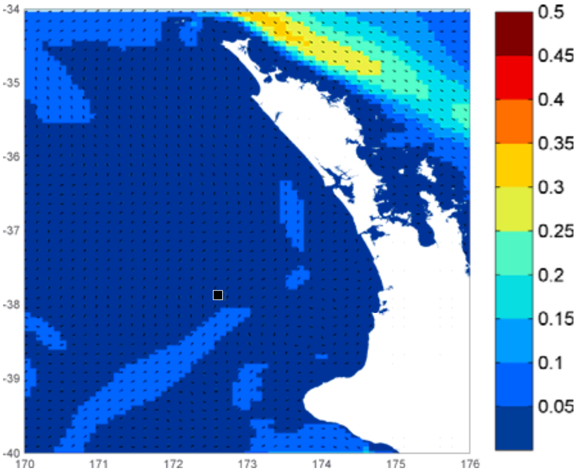
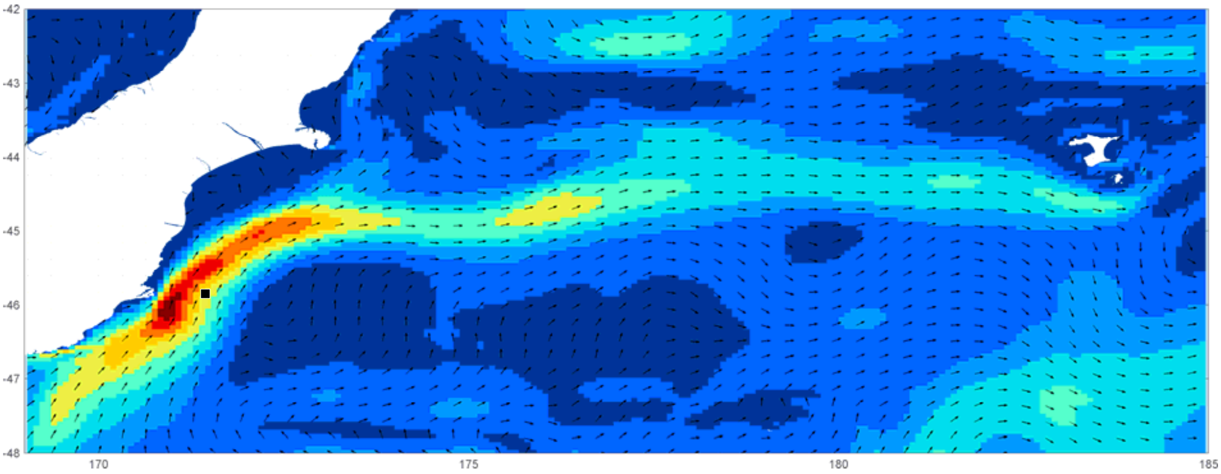


Figure 6: Average modelled hind-cast surface current velocities in m/s from HYCOM daily reanalysis for the period of November 3rd, 2003 to June 22nd 2013 in Taranaki (left) and Canterbury Basin (right). Black dots indicate the modelled spill locations.



We extracted daily sea surface currents for the Taranaki and the Canterbury basin models from November 3rd, 2003 to June 22nd, 2013 (3519 days) with average and maximum current velocities shown in Figure 6 and Figure 7. In Taranaki, the sea surface currents are relatively weak, with an average of 0.05 to 0.1 m/s around the study area. Maximum current speeds (Figure 7) can reach up to 2 m/s on the continental shelf south of the Taranaki peninsula and 1 m/s from Cape Egmont to Manukau Harbour. In Canterbury, the currents are much stronger around the targeted drilling site, with velocities as high as 2 m/s on average just offshore of Dunedin. The Southland Current flows from the southern tip of the South Island along the east coast and diverges south of the Banks Peninsula with a larger branch splitting towards the east along the Chatham rise while a smaller branch of the current hugs the coast flowing north towards Kaikoura. The eastward flow along the Chatham rise is on average 0.8 to 1 m/s.

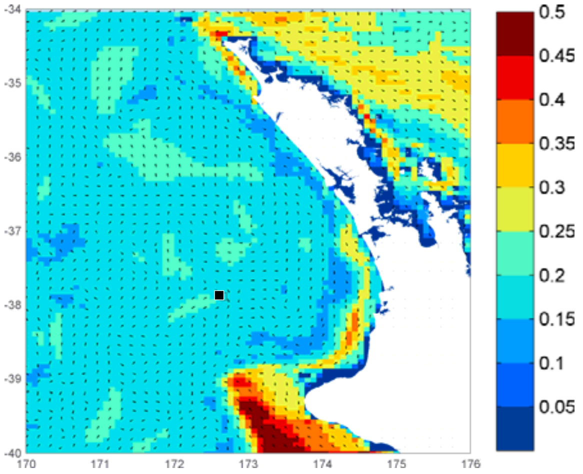
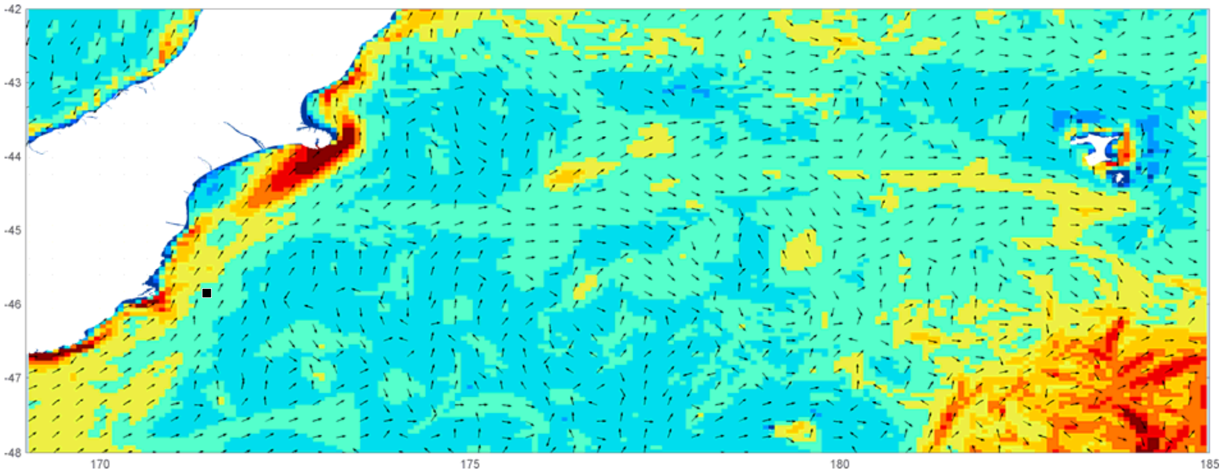


Figure 7: Maximum modelled hind-cast sea surface current velocities in m/s from HYCOM daily reanalysis for the period of November 3rd, 2003 to June 22nd 2013 in Taranaki (left) and Canterbury Basin (right). Black dots indicate the modelled spill locations.



Diffusion

Random spreading is simulated using a simple ‘random walk’ approach with a square unit probability (Csanady, 1973). We used a random diffusion factor of 100,000 cm^2/sec (horizontal eddy diffusivity as recommended for the default GNOME setting).

Atmospheric Forcing

We used sea surface wind data from the NCEP/NCAR global reanalysis (Kalnay, 1996) provided by NOAA from January 1st, 2003 to August 1st, 2013 at a 6 hourly time step and a spatial resolution of 2.5 degrees.

In a manner similar to the ocean currents, u (east-west) and v (north-south) wind velocity components induces the motion of particles to simulate the windage. This is typically about 3% of the wind speed based on analytical derivation and empirical observations of oil spreading out in the direction of the wind (Stolzenbach, Madsen, Adams, Pollack, & Cooper, 1977). It is noted that the windage is reduced as the oil weathers and spends more time below the surface (NOAA, 2012). Based on observation and experience (Lehr & Simecek-Beatty, 2000), a windage of 1 to 4% was selected for this modelling exercise with a wind persistence of 15 minutes.

Figure 8 depicts seasonal wind roses for 3 sites; one for Taranaki, 37.5°S, 172.5°E and two for Canterbury, 45°S, 172.5°E and 45°S, 175°E for the total length of data records. The data suggests that the Taranaki region is dominated by south-westerly winds that are stronger in winter and spring. Summer and autumn winds are more evenly distributed between south-westerly (onshore) and north-easterly (offshore).

The winds in the Canterbury basin, situated at a more southerly latitude, are stronger with frequent 40 to 50 knots gales. The direction is predominantly from the west-southwest and north-northwest. South-westerly winds are more frequent in winter and north-westerly winds are generally more common from spring to autumn with a peak in summer.

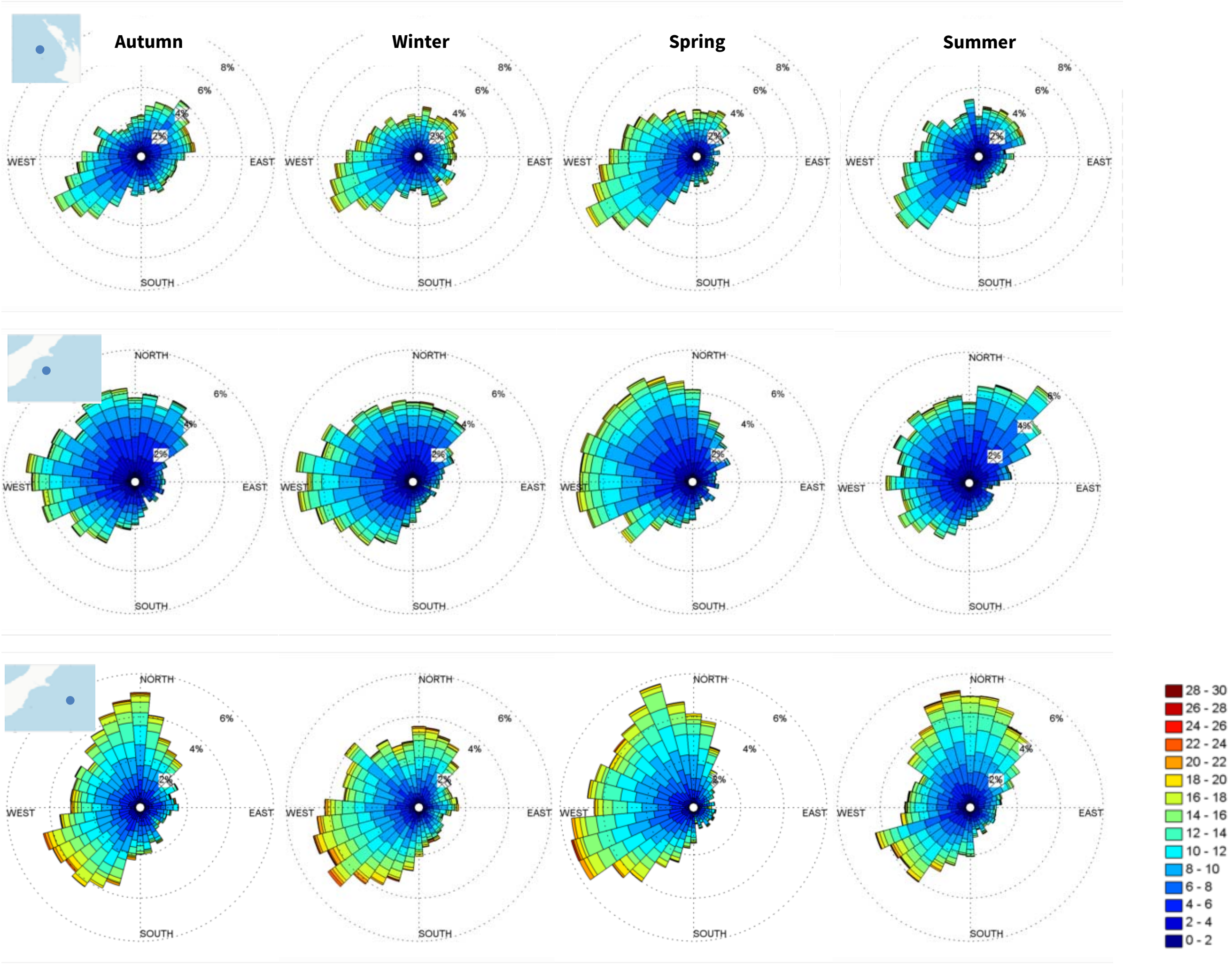


Figure 8: Seasonal wind direction roses and occurrence of wind speed amplitude expressed in m.s^{-1} from the global 6 hourly reanalysis NCEP-NCAR at 37.5ºS, 172.5ºE (top, Taranaki model), 45ºS, 172.5ºE and 45ºS, 175ºE (middle and bottom, Canterbury model).

III-5 Model Settings

Resolution

The computational grids used to assess the trajectory analysis are detailed in Table 3. The grid resolution was chosen to be in the same range of the environmental input resolution with sea surface current provided at 1/12 (0.083) degree cell size.

Table 3: Numerical grid resolution and extent used for the trajectory analysis at Taranaki and Canterbury.

	dx (degree)	dy (degree)	Nx	Ny	Latitude start	Latitude end	Longitude start	Longitude end
Taranaki	0.05	0.05	120	120	40ºS	34ºS	170ºE	176ºE
Canterbury	0.1	0.1	160	60	48ºS	42ºS	169ºE	185ºE

The results in this study are presented for 1,000 spill scenarios (one spill every 3.5 days for 10 years average) equally divided over a winter season (500) and summer season (500).

Each spill contains a total of 10,000 particles (lagrangian elements) that are continuously released during a period of 76 days. At 10,000 bbl/day, a particle therefore represents 76 bbl. of oil released into the model approximately every ten minutes.

We let the model run for an additional 104 days beyond the original 76 days of spill duration (180 days total) to simulate the fate of the remaining oil after the blowout is stopped.

Test simulations were carried out with a higher number of trajectories (Appendix VII). The results are generally similar. However, a higher number of trajectories will naturally produce smoother impact probability contours.

Weathering

Since the exact nature of the oil produced from each of the drill sites remains unknown, a detailed calibration of the weathering process would require laboratory analysis to determine the composition of the crude oil.

The properties of the oil used for the trajectory simulations are given in Table 4 and are based on the chemical composition of two known oil types found around New Zealand, Maari-2 and Amokura-1 crude.

Schimel (2012) used the ADIOS2 oil weathering model to predict the weathering of Maari-2 and Amokura-1 type crudes under various wind exposures and sea temperatures. ADIOS2 provides output on oil weathering parameters such as evaporation, dispersion into the water column, and changes in oil density and viscosity (Samuels, Amstutz, Bahadur, & Ziemniak, 2013). However, ADIOS2 will only make predictions for a maximum of five days. For periods longer than this, other processes, such as biodegradation and photo-oxidation, may be important and are not modelled (NOAA, 2006). Mathematical models generally consider only the dominant processes advection, scattering and evaporation for quantitative estimation of oil spills (Ferreira, Cabrai, & Junior, 2003).

Table 5 and Figure 9 compare the weathering rates between the three component half-life method for two combination of crudes computed by GNOME/TAP and as calculated by ADIOS2 (Schimel, 2012) for specific oil types and various wind speeds. While ADIOS2 predicts a faster loss of material in the first hours of the spill, after five days of weathering the medium crude using the three component half-life method has lost as much material as predicted by ADIOS2 for Maari-2 type crude under a constant wind of 20 m/s and about the same amount as Amokura-1 crude under calm wind conditions. We investigated the use of ‘custom’ crude by reducing the half-life of one of the first constituents, in order to better match the ADIOS2 predictions of the 2 reference oil types. However, after one week of weathering, both medium and ‘custom’ crudes plateau above 52% as only the persistent fraction of oil remains. When looking at longer term impact, there is no significant difference between the two crude oil types. Based on this analysis, the medium crude type was used for this modelling exercise.

Table 4: Percentage of constituent for default medium-crude and 'custom' crude and their corresponding half-lives. By comparison, a more conservative approach would use a non-weathering material which corresponds to a single component with an infinite half-life.

Pollutant Type	Component Proportion	Half-Life (hours)
Medium Crude	22%	14.4
	26%	48.6
	52%	$1.0x10^9$
'Custom' Crude	22%	14.4
	26%	*2.0*
	52%	1.0×10^9
Non-Weathering	100%	1.0×10^9

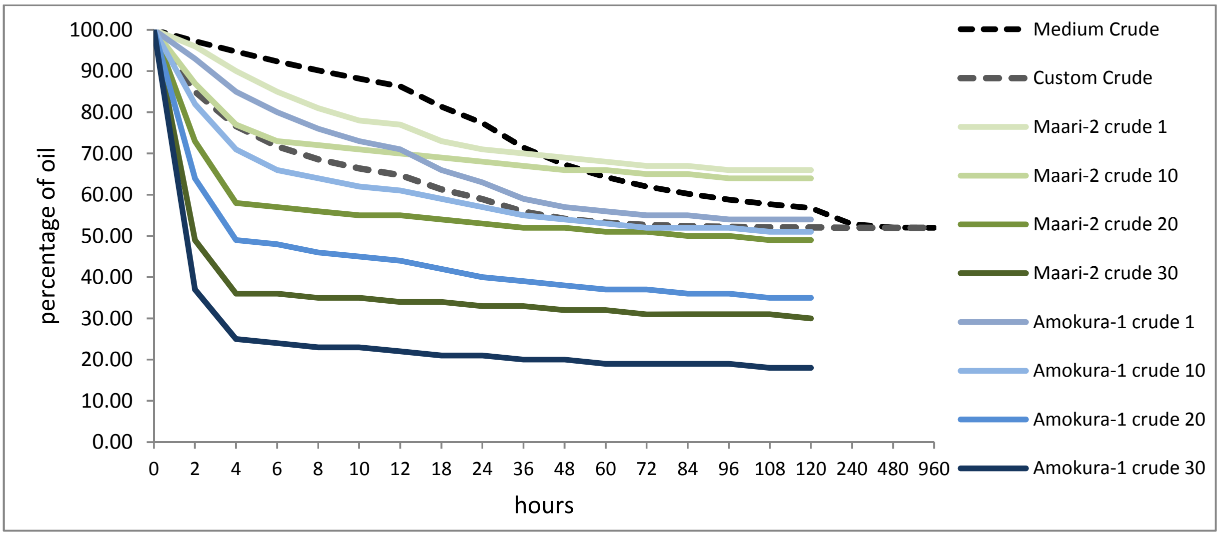


Figure 9: Medium crude weathering as calculated by the three components half-life method using Maari-2 and Amokura-1 crudes under different wind condition as predicted by ADIOS2 (Schimel, 2012). The "custom" crude is another version of the medium-crude with reduced half-life for a light constituent. The vertical axis shows the amount of oil remaining after the time indicated along the horizontal axis.

Table 5: Quantities of oil remaining after different time period for medium-crude and custom-crude weathering using half-life method in TAP and for Maari-2 and Amokura-1 crudes calculated by ADIOS2 under different wind speed and for a temperature of 13°C (Schimel, 2012). The "custom" crude is another version of the medium-crude with reduced half-life for a light constituent.

	Half-Life Method using TAP		ADIOS2							
Hours	Medium Crude	Custom Crude	Maari-2 crude				Amokura-1 crude			
			1	10	20	30	1	10	20	30
0	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
2	97%	85%	96%	87%	73%	49%	93%	82%	64%	37%
4	95%	77%	90%	77%	58%	36%	85%	71%	49%	25%
6	92%	72%	85%	73%	57%	36%	80%	66%	48%	24%
8	90%	69%	81%	72%	56%	35%	76%	64%	46%	23%
10	88%	66%	78%	71%	55%	35%	73%	62%	45%	23%
12	86%	65%	77%	70%	55%	34%	71%	615	44%	22%
18	81%	61%	73%	69%	54%	34%	66%	59%	42%	21%
24 (1 d)	77%	59%	71%	68%	53%	33%	63%	57%	40%	21%
36	71%	56%	70%	67%	52%	33%	59%	55%	39%	20%
48 (2 d)	67%	54%	69%	66%	52%	32%	57%	54%	38%	20%
60	64%	53%	68%	66%	51%	32%	56%	53%	37%	19%
72 (3 d)	62%	53%	67%	65%	51%	31%	55%	52%	37%	19%
84	60%	52%	67%	65%	50%	31%	55%	52%	36%	19%
96 (4 d)	59%	52%	66%	64%	50%	31%	54%	52%	36%	19%
108	58%	52%	66%	64%	49%	31%	54%	51%	35%	18%
120 (5 day)	57%	52%	66%	64%	49%	30%	54%	51%	35%	18%
240	53%	52%								
480	52%	52%								
960	52%	52%								

Beaching

Beaching is the process of oil washing up on shore and either adhering or being remobilised by wind and/or wave activity. The re-floatation half-life is a parameter which empirically describes the adhesiveness of the oil to the shoreline. It is a function of substrate porosity, the presence or absence of vegetation, the inherent stickiness of the oil, and other physical properties and environmental processes (Danchuk, 2009). Re-floatation half-life values such as those provided by (Torgrimson, 1980) are generally given in terms of the number of hours over which half of the oil on a given shoreline is expected to be removed if (1) there is an offshore wind or diffusive transport and (2) sea level is at the same level or higher than the time when the oil was beached. Since it is based on observations of removal rates from previous spills, the half-life method does not represent the detailed physics of the remobilization process, but is commonly used due to the complexity of trying to model shoreline-oil interactions at large scales. Oil re-floatation half-lives are different for each shoreline type depending on substrate, vegetation and oil type (Torgrimson, 1980). Values typically used for mud, sand and vegetation are 1, 24 and 8760 hours respectively. This parameter, along with the other environmental data, allows re-floating of oil after it has impacted a given shoreline. (NOAA, 2012). We set the re-floating half-life parameter to 24 hours as recommended for the sandy coastlines that are predominant in both study areas.

IV TRAJECTORY ANALYSIS

We followed three different approaches while assessing the trajectory analysis. For a given blowout flow rate (5,000; 10,000; 40,000 bbl/day) and a given season (Summer-Winter), the trajectory analysis can be treated by varying three parameters: **Time** since the spill started, percentage of spills (**PROB** - probability) and level of concern for oil thickness on water (**LOC** - threshold for calculating the percentage of spills).

To focus on one of the metrics or dimensions, one must fix another dimension while varying the third one. For example:

- An **Impact analysis** is a series of maps of percentage of spills (PROB) for a given LOC (1 g/m^2) and various time step (ranging from 1 week to 6 months)

- A **Response Time analysis** shows travel time contours for different LOC (0.01; 1; 10 g/m^2) at a fixed PROB (containing 95% of trajectories).

- A **Density analysis** depicts minimum volume per area (**LOC**), calculated by fixing **time** (76 days when the leak stops and no more material is inputted in the system) and varying **PROB** (probable: 50%; likely: 80%; very likely: 95%).

Table 6: Three trajectory analyses and their dependency to the three main dimensions: probability, time and density of oil (threshold).

	Impact Analysis	**Response Time Analysis**	**Density Analysis**
PROB percentage of spills	array	constant	variable
TIME since spill started	variable	array	constant
LOC level of concern	constant	variable	array

In this study, we generally focus on four different levels of concern (LOC). We used the socio-economic and ecological thresholds for both water and shoreline as defined by NOAA (2013):

- **Socio-economic impact at sea: 0.01 g/m²**. This level of density would correspond to a barely visible sheen of oil on the water surface. This level would likely result in the closure of fisheries since fishing is prohibited in areas with any visible oil to prevent contamination of fishing gear and catch.

- **Socio-economic impact on land: 1 g/m²**. This level would trigger the need for shoreline clean ups on amenity beaches and coastal recreational zones.

- **Ecological impact at sea: 10 g/m²**. That amount of oil has been observed to mortally impact sea birds and other wildlife.

- **Ecological impact on land: 100 g/m².** French (1996) shows that shoreline life is significantly affected by this degree of oiling.

Table 7: Oil thickness thresholds used in calculating area of water impacted. Adapted from (NOAA, 2013).

Oil Description	Sheen Appearance	Approximate Sheen Thickness		No. of 1 inch Tarballs	Threshold
Oil Sheen	Barely Visible	0.00001 mm	0.01 g/m^2	~5-6 tarballs per acre	Socio economic impact at sea
Heavy Oil Sheen	Dark Colours	0.01 mm	10 g/m^2	~5,000-6,000 tarballs per acre	Ecological impact at sea
Oil Sheen/Tarballs	Dull Colours	0.001 mm	1 g/m^2	~0.12-0.14 tarballs/m^2	Socio economic impact on land
Oil Slick/Tarballs	Brown to Black	0.1 mm	100 g/m^2	~12-14 tarballs/m^2	Ecological impact on land

IV-1 Impact Analysis

An impact analysis is the most natural way of assessing a trajectory analysis. Given a set of trajectories, an impact analysis calculates the proportion of spills that reach an oil thickness level exceeding a fixed level of concern. One should be careful in understanding these maps, they do not represent the extent of an oil spill at a particular time but the probability of a given area (or model cell in our case) to reach a certain level of oil thickness. As a simple example, if in the early stage of a spill, one trajectory moves northward and another southward, the resulting impact analysis for the two trajectories will show a vertical extent, north to south at an impact probability of 50%. This does not mean that an oil spill has 50% chance to have this extent but would rather mean that for areas inside the extent, there is 50% chance to be reached by oil (as alternatively going north or south).

For comparison purposes we present the results of an impact analysis for a fixed density level of 1 g/m^2 at different release scenario and time. The full impact analysis at different time frames after the spill started ranging from one week to six months, for both Taranaki and Canterbury models are presented in Appendix I and Appendix II. Figure 10 depicts the impact analysis for Taranaki and Canterbury after 76 days of continuous oil input at a flow rate of 10,000 bbl/day during the summer season. In Taranaki, for the total blowout duration, 90% of trajectories raised the level of concern above the socio-economic threshold somewhere on land, while 80% of the modelled spills impacted the entire coastline between Kaipara Harbour mouth and Raglan. The west coast stretch between Opononi and Cape Egmont is within the 50% trajectories impact area.

Once the blowout has been killed and oil input is stopped, oil would still be present on the sea surface and could still potentially beach on the shoreline. The longer term analysis (Appendix I) shows that the area between Kaipara Harbour and Raglan has 95% chance after 6 months to have an oil thickness level that would require a clean-up. When looking at the winter season, the 95% confidence zone extends south to Cape Egmont. The coastline is generally more impacted during the winter season than during the summer season as westerly winds are stronger and more consistent during that time. The impact plume logically spreads faster in winter with oil thickness potentially (10%) above socio-economic threshold after less than 2 weeks. The overall probabilistic spread first reaches the coast north of Manukau Harbour in summer and to the south of Manukau Harbour in winter.

In Canterbury, most trajectories follow the eastward flowing subtropical convergence currents and drifting away from the east coast of the South Island. The extent of the probabilistic spread is much larger than for Taranaki as most spills drift freely across the ocean surface for months without encountering land. However, some of the trajectories (20% after 76 days when the spill stops and 80% after 6 months) reach the Chatham Islands raising the oil thickness above the 1 g/cm^2 threshold. There is no significant difference between the summer and winter season, although the summer season generally shows more spread in the southern latitudes with a potential (10% after 3 months, 20% after 6 months) oiling thickness above 1 g/m^2 as far south as the Bounty Islands (latitude 47.75ºS). The east coast of the south island could be potentially (10%) impacted with an oil thickness above socio-economic threshold on land from Dunedin to north of Kaikoura. The divergence of currents offshore from Banks peninsula results in higher level of oil density on the northern coast of the Canterbury region with a singular peak of probability at 70% of trajectories north of Kaikoura after 6 months of simulation.

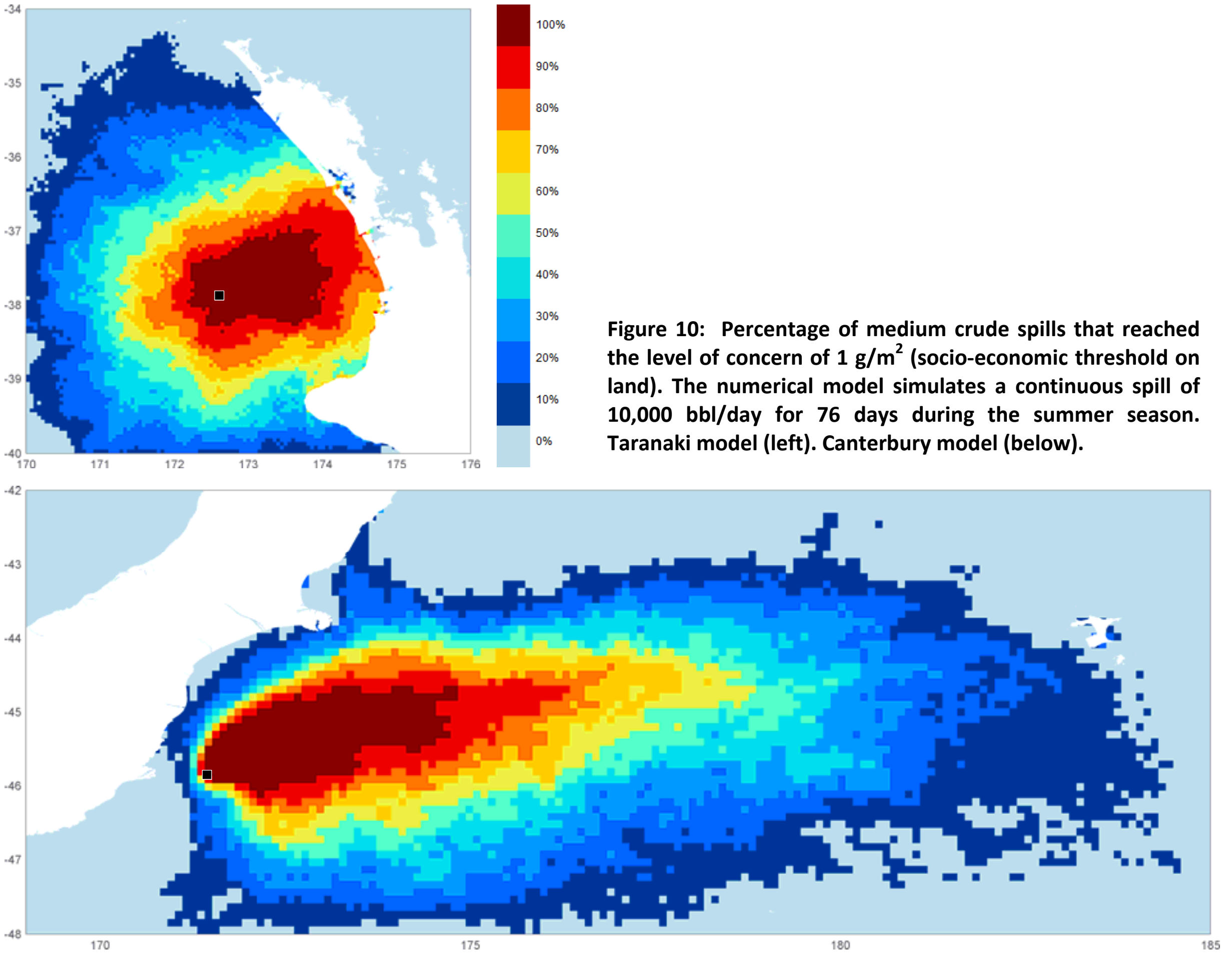


Figure 10: Percentage of medium crude spills that reached the level of concern of 1 g/m^2 (socio-economic threshold on land). The numerical model simulates a continuous spill of 10,000 bbl/day for 76 days during the summer season. Taranaki model (left). Canterbury model (below).

IV-2 Response Time Analysis

A response time analysis looks at how fast the combined area of oil spills above a certain level of concern spreads, allowing for careful emergency response planning. Here we present the result for an oil thickness above the socio-economic threshold of 1 g/m^2, considering that this level is high enough to trigger a fishing ban and beach clean-up efforts. Figure 11 shows the combined travel time of 95% of trajectories that increased the oil thickness above the socio-economic threshold at sea after one week, two weeks, 1 month and 6 months and under summer weather conditions.

In the Taranaki Basin the combined surface area covered by 95% of the modelled trajectories exceeding the socio-economic threshold of 1g/m^2 has the size of 15,500 km^2 after 1 week, 132,400km^2 after 1 month and 226,800 km^2 after 76 days. In the event of a spill, this area represents the socio-economic threat zone where fisheries could potentially be closed due to visible oil on the sea surface. On land, the coastal waters between Kaipara Harbour and Port Waikato could be affected during the first two weeks by a quantity of oil above the socio-economic threshold (1g/m^2). The threat zone reaches Opononi in the North and cape Egmont in the South after one month. Appendix III gives the full response time analysis for the Taranaki model using different release scenarios (5,000, 10,000, and 40,000 bbl/day) and oil thickness threshold (0.01, 1 and 10 g/m^2) for both summer and winter seasons. As observed in the impact analysis, the extent of oil affected areas is generally larger during winter than during summer with a more western oriented probabilistic spread. For a 10,000 bbl/day release scenario, the growth of the socio-economic threat zone for both land (1g/m^2) and sea (0.01 g/m^2) are relatively in the same order of magnitude. After one month of oil building up, the ecological threat zone at sea (10 g/m^2, primarily formulated for seabird mortality) reaches the coastal waters between Kaipara and Raglan in summer and between Kaipara and Cape Egmont in winter. Most of the North Island west coast could possibly be reached by this level in less than 6 months.

In the Canterbury basin, as previously observed, the impact plume covers a much bigger area than for the Taranaki model. The socio-economic threat zone grows from an approximate area of 14,300 km^2 after one week, to 46,400 km^2 after two weeks, 162,100 km^2 after a month and 532,400 km^2 after 76 days. The socio-economic impact threshold on land (1 g/m^2) can be reached for the coastal areas of Oamaru and the Banks peninsula after one month of simulation, while on the eastern extent, the impacted zone spread towards the international dateline.

The full response time analysis for the Canterbury model, provided in Appendix IV, clearly shows that the area above a given threshold grows faster in winter with more south westerly winds pushing the spill further north (up to Kaikoura after one month in winter).

When looking at different levels of concern, at 10,000 bbl/day, the ecological threat zone at sea (10 g/m^2) is met at an offshore area east of Dunedin that grows from 88 km^2 after one week to 1,850 km^2 after one month and to 6,250 km^2 after 76 days when the spill ends. After 6 months, several coastal waters can be impacted with an oil thickness above ecological impact threshold: the Banks peninsula, Christchurch, Kaikoura and the Chatham Islands for both seasons and the stretch between Taiaroa heads to Oamaru in winter.

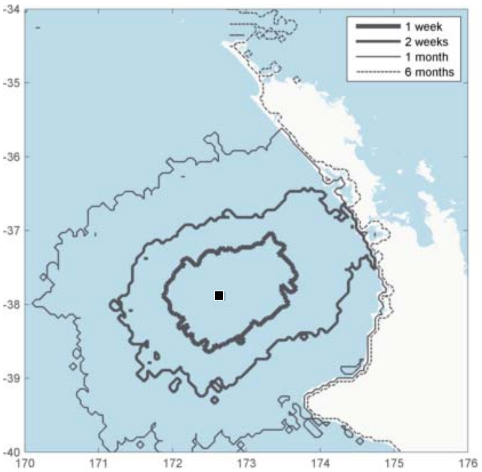
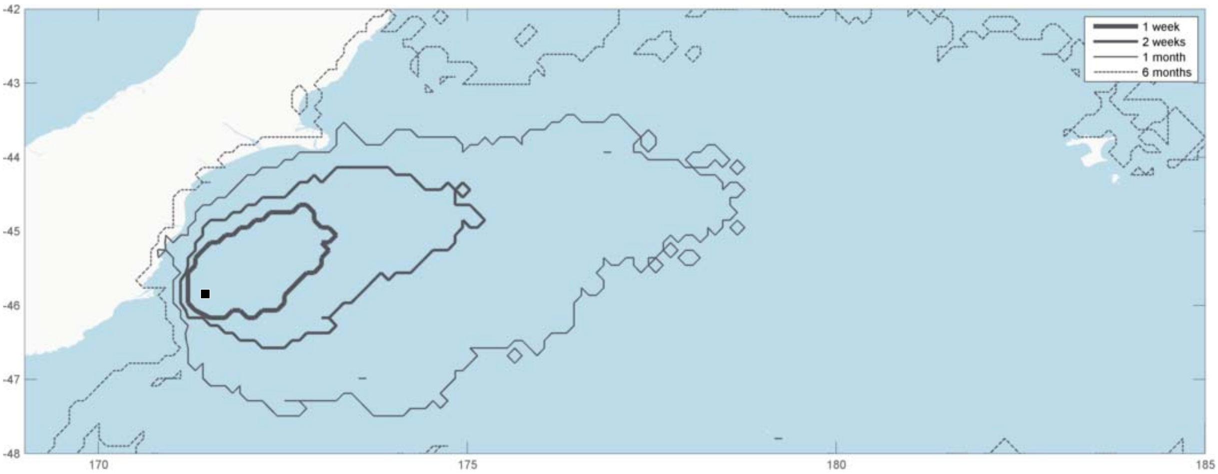


Figure 11: Travel time (1 week, 2 weeks, 1 month, 6 months) of the 1 g/m^2 (visible oil sheen, socio-economic threshold at sea, potential closure of fisheries) for a combined 95 % of trajectories during the summer season. Taranaki model (left). Canterbury model (below).



IV-3 Density Analysis

This analysis provides a map of minimum expected oil thickness for a given percentage of spills. Here we present the results for the 80% confidence interval after 76 days of continuous spill at 10,000 bbl/day during the summer season.

This visualisation is useful when assessing the minimum likely oil thickness in a specific area. The likely maximum for the Taranaki model is around the Manukau Harbour mouth, although singularities such as points or headlands tend to show a similar level of oil accumulation e.g. Kawhia, Raglan, Port Waikato. Oil thickness above the socio-economic threshold is likely to be observed from north of Kaipara to the New Plymouth area.

The Canterbury model shows a much wider plume with a likely area of oil density above socio-economic threshold stretching from the proposed drill site towards east beyond the international dateline. However no statement on oil thickness at the coastline can be made at that level of confidence (80%, likely).

This analysis best shows the relative impact differences between the blowout flow rate scenarios and how levels of oil thickness build up when increasing the total spill volume. Figure 12 and Figure 13 compares the minimum oil thickness for 80% of oil trajectories for the three blowout flow rate scenarios used during this study for both Taranaki and Canterbury basin models. Appendix V and Appendix VI show the full density analysis for both sites at different seasons and different blowout flow rate.

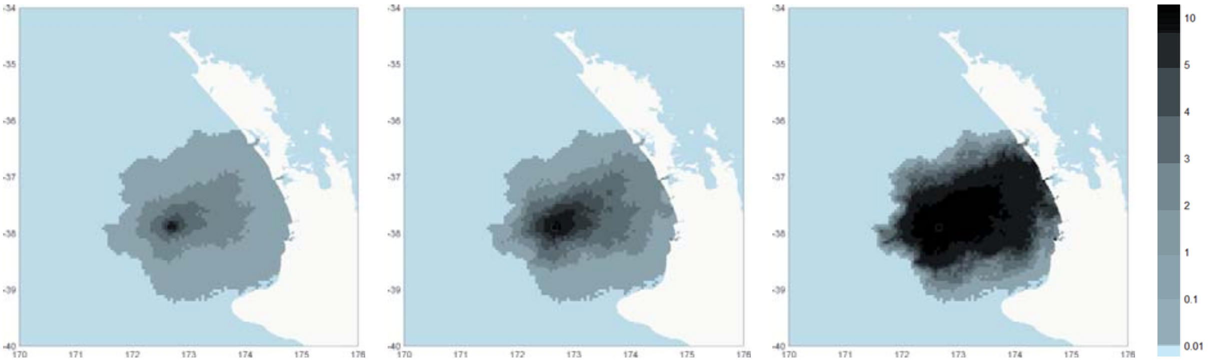


Figure 12: Minimum density level in g/m^2 for 80% (likely) of trajectories after 76 days of continuous spill at 5,000 (left), 10,000 (middle) and 40,000 (right) bbl/day in Taranaki during summer season.

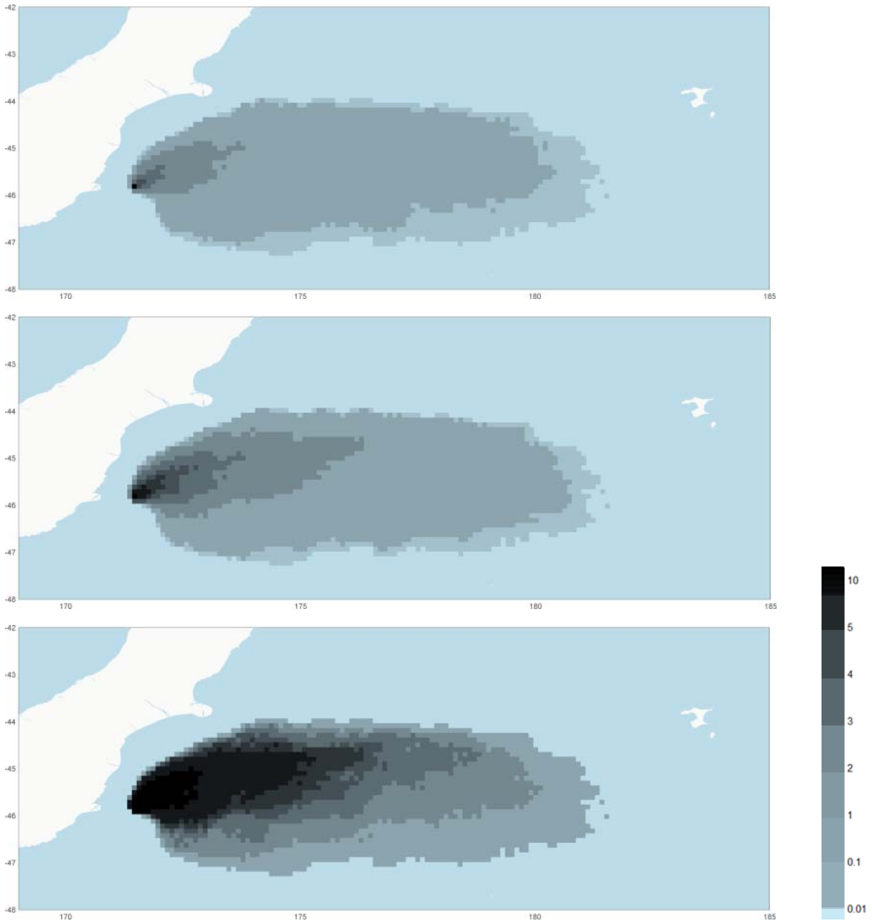


Figure 13: Minimum density level in g/m^2 for 80% (likely) of trajectories after 76 days of continuous spill at 5,000 (top), 10,000 (middle) and 40,000 (bottom) bbl/day in Canterbury during summer season.

IV-4 Oiling Analysis

In this section we provide an oiling analysis for different sites of interest in both Taranaki and Canterbury models. An oiling analysis determines volume and time of arrival of oil particles and gives information about the probability of oil thickness beaching at a specific coastal area. While further analysis should take into account coastal dynamics with higher resolution models, information was extracted at the nearest model cell for each site (5 to 11 km resolution depending on the latitude). For each site and at each output time step (one week to 6 months), we analysed every individual spill and recorded the worst case scenario, the probable (50%), the likely (80%) and very likely (95%) scenarios. We also computed the exact percentage of spills for a given level of concern as well as the estimated time of arrival for different percentage of spills.

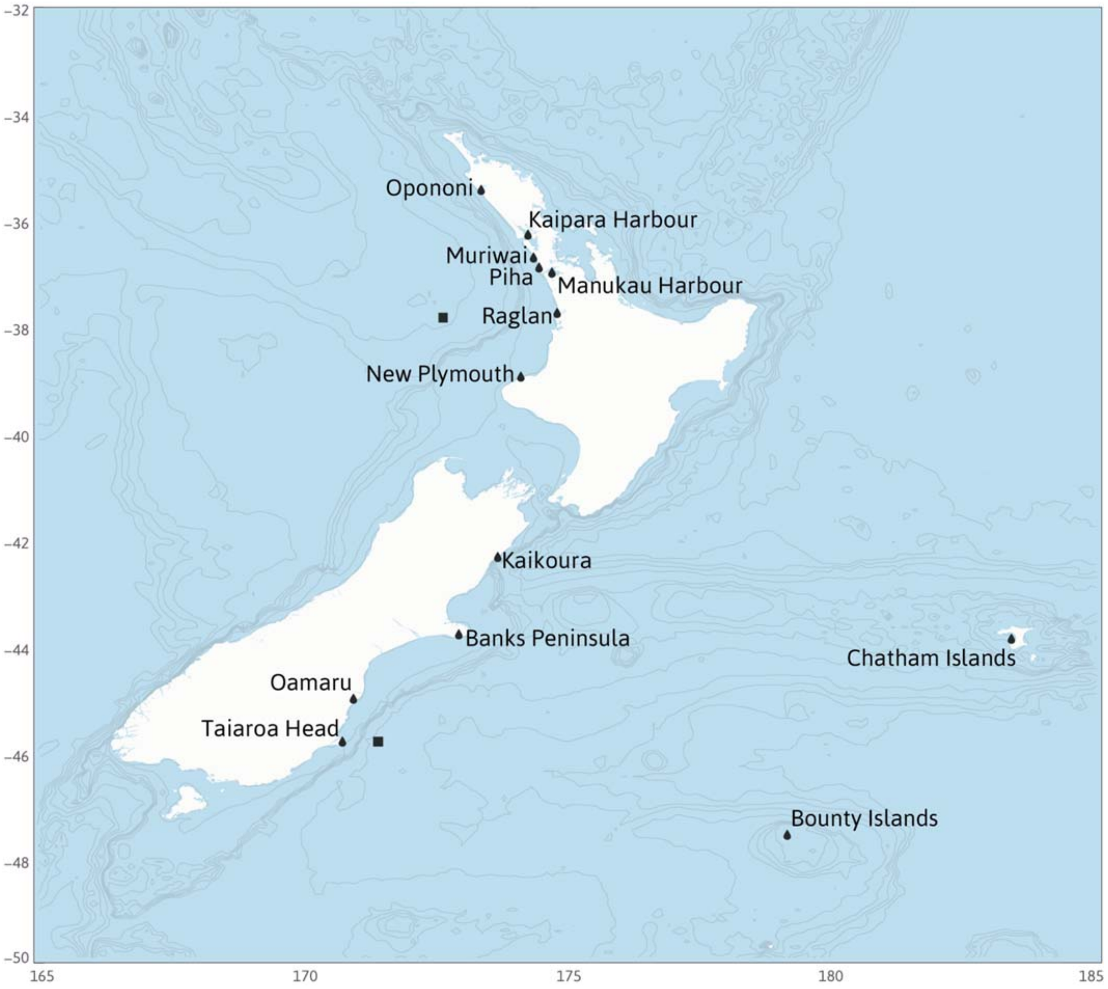


Figure 14: Map of coastal output locations for the oiling analysis.

In Taranaki, the worst case scenarios show oil reaching the coastline in less than a week for Muriwai, Piha or Manukau Harbour. The biggest impact is recorded for a spill that raises the oil thickness in Manu Bay, Raglan at nearly 250 g/m^2, well above the ecological impact on land. Modelled trajectories during the winter season generally present a higher impact on the coast. However, 95% of trajectories show an oil thickness above socio-economic threshold on land in Muriwai, Piha Manukau Harbour, Raglan and New Plymouth regardless of the season.

In Canterbury, the oiling analysis demonstrates a lower overall impact on the east coast of the South Island with an oil thickness above socio economic threshold for 2 to 4% of the trajectories in Kaikoura, 4 to 6% on the Banks Peninsula, 3 to 5% in Oamaru and 0 to 4% for Taiaroa Head. However when looking at socio-economic impact at sea, the area of Kaikoura is predicted with the highest impact probability (79 to 91% of trajectories against 20 to 44 % for the other selected sites on the South Island). Isolated land masses such as the Chatham Islands have a much higher impact probability with 30% of trajectories above socio-economic threshold on land and 95% of the trajectories hitting the islands within 148 days in summer. Except for Taiaroa Head, the modelled impact at the selected sites is generally higher in summer.

The full oiling analysis is presented by sites in Appendix VIII.

CONCLUSION

We conducted an oil-spill trajectory analysis based on modelled probabilistic quantities derived from 1000 spill scenarios under various weather conditions at two sites offshore from New Zealand.

Although the parameters defining the oil spill remain subject to some variability, we aimed to describe a realistic deep sea well failure scenario based on past events and the best information available to us about the targeted prospects.

The model results show a significant impact on the shoreline for nearly the entire west coast of the North Island, with oil thickness reaching levels as high as nearly 250 g/m^2 in some areas. More than 95% of the spills ended up beaching somewhere on the coastline for the Taranaki model.

The Canterbury model shows a wide impact plume that extends eastwards as far as the Chatham Islands with a moderate impact probability for the South Island's east coast.

In case of a blowout event at one of these two sites, the modelling system implemented for this study can be re-used to assess a real time simulation of the fate of oil at sea and assist in emergency response operations.

This study could be refined with further investigations such as studying the fate of neutrally buoyant oil components (heavy crude) that could remain somewhere along the water column and never surface and/or nesting the regional model structure with finer local grids around headlands and estuaries to provide a better resolution when assessing an oiling analysis on specific sites.

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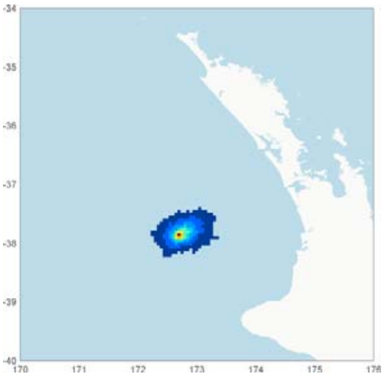
Dr. Jose C. Borrero of eCoast Ltd. provided commentary and review of the report document.

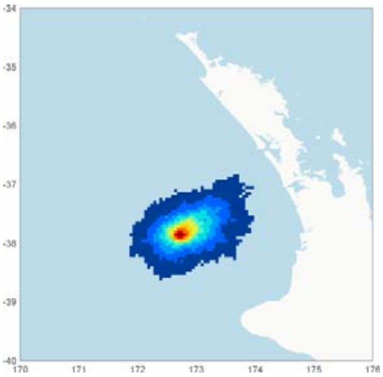
APPENDICES

Appendix I Impact analysis – Taranaki

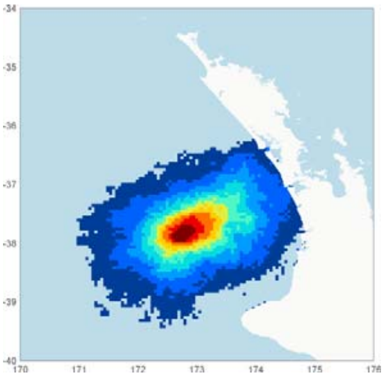
Percentage of spills above 1g.m^{-2} during a 5,000 bbl/day release (76 days long)



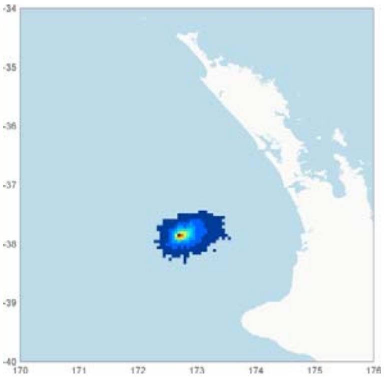
+ 1 week (summer)



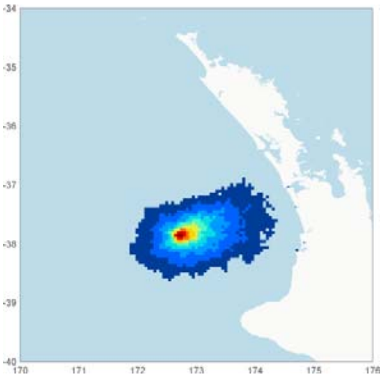
+ 2 weeks (summer)



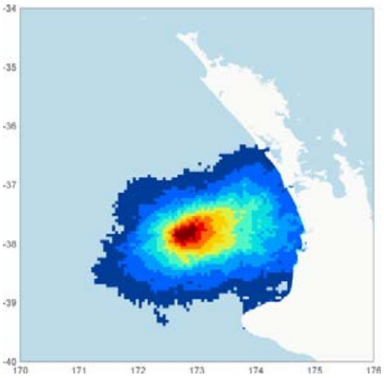
+ 1 month (summer)



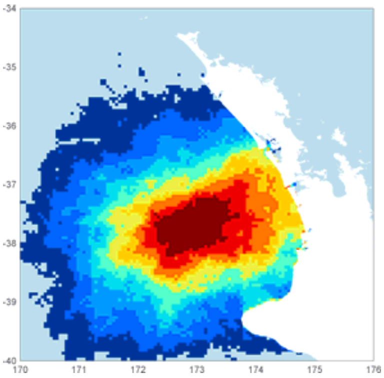
+ 1 week (winter)



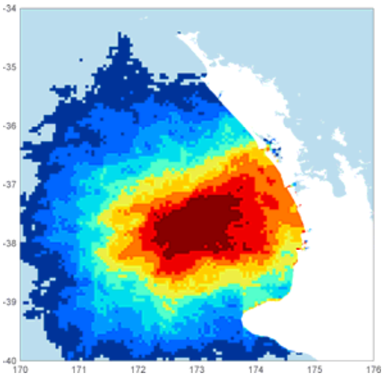
+ 2 weeks (winter)



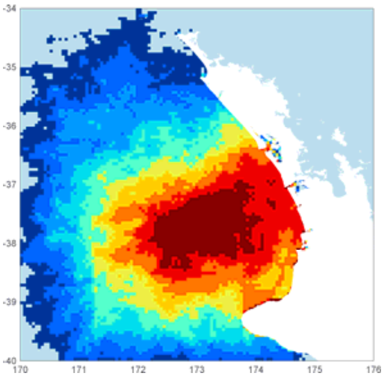
+ 1 month (winter)



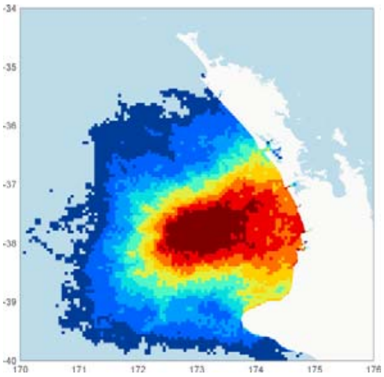
+ 76 days, spill stops (summer)



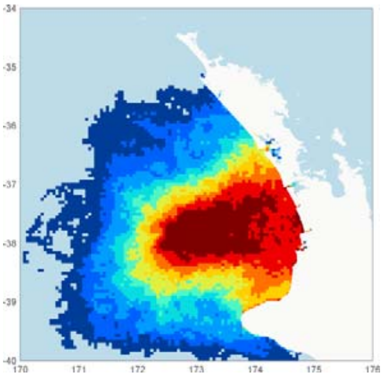
+ 3 months (summer)



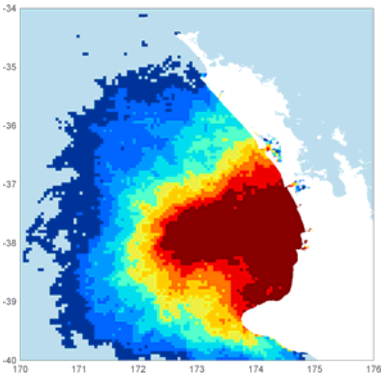
+ 6 months (summer)



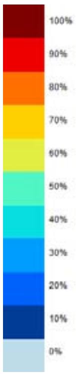
+ 76 days, spill stops (winter)



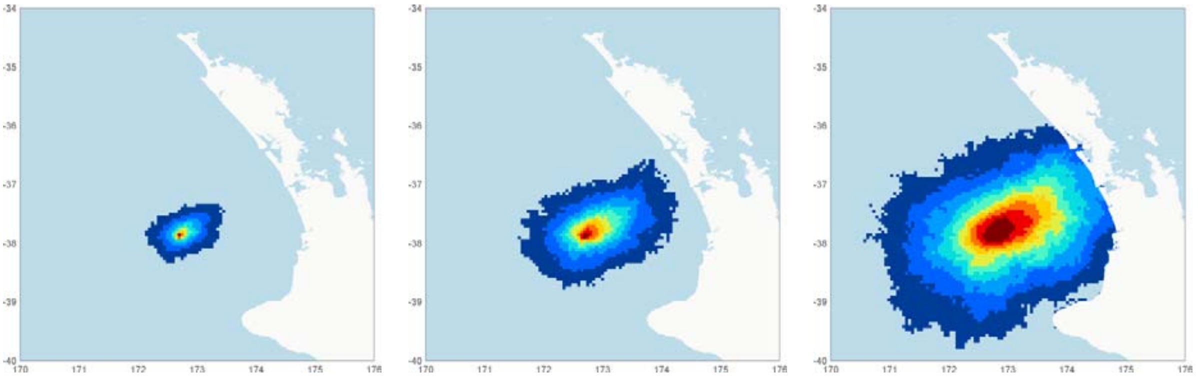
+ 3 months (winter)



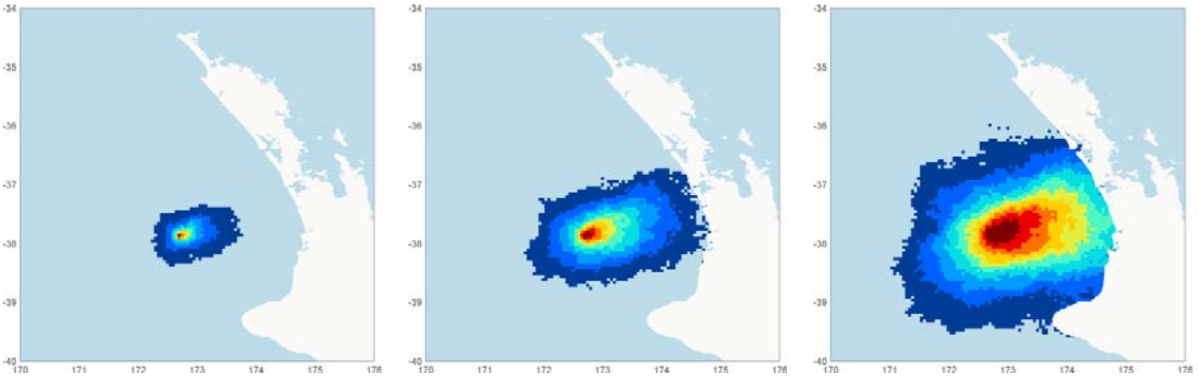
+ 6 months (winter)



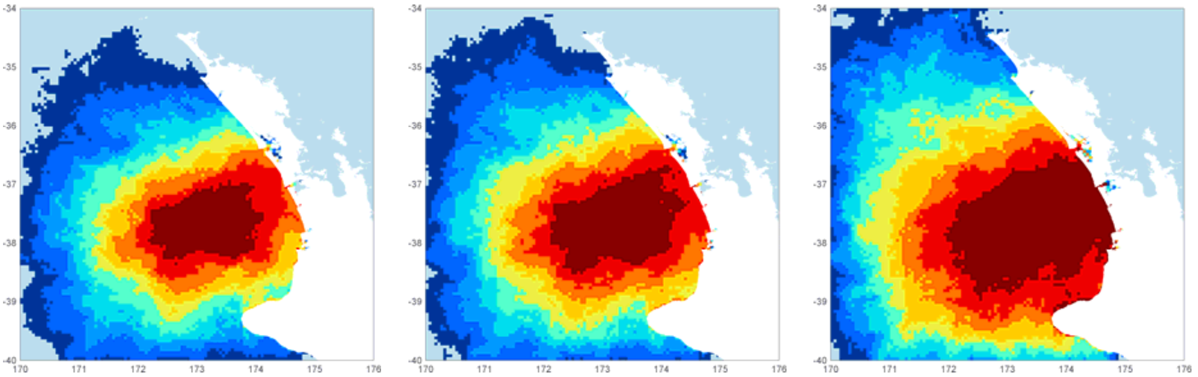
Percentage of spills above 1g.m^{-2} during a 10,000 bbl/day release (76 days long)



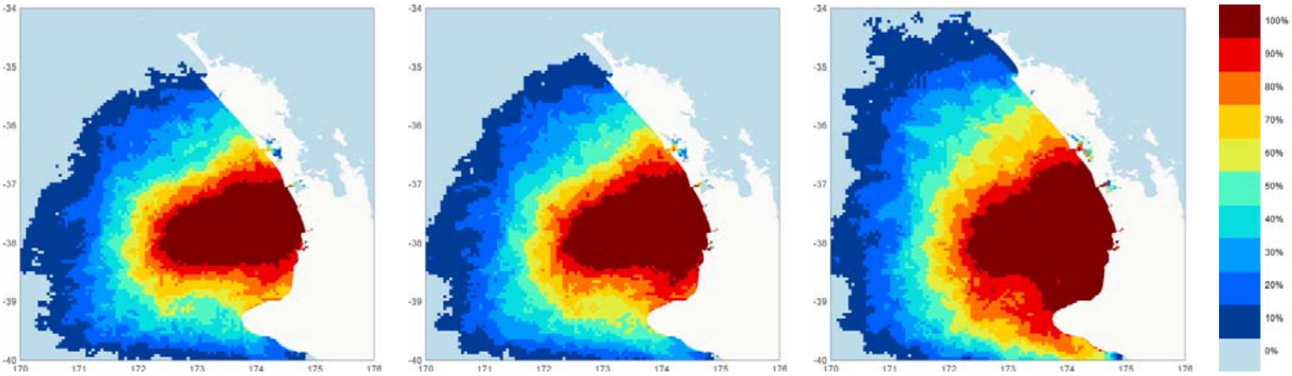
+ 1 week (summer) + 2 weeks (summer) + 1 month (summer)



+ 1 week (winter) + 2 weeks (winter) + 1 month (winter)

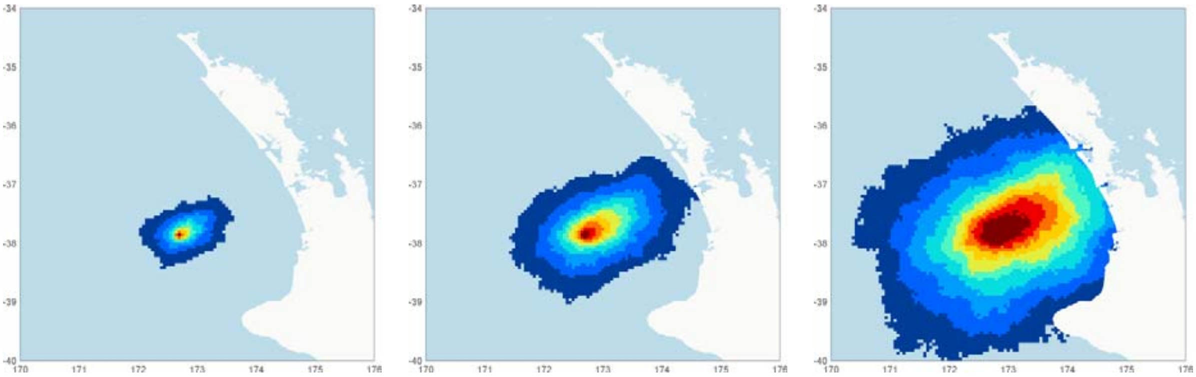


+ 76 days, spill stops (summer) + 3 months (summer) + 6 months (summer)

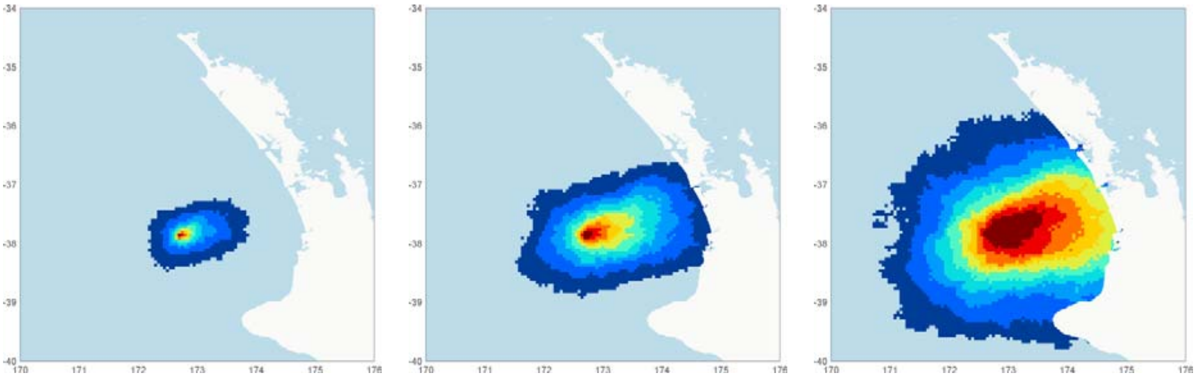


+ 76 days, spill stops (winter) + 3 months (winter) + 6 months (winter)

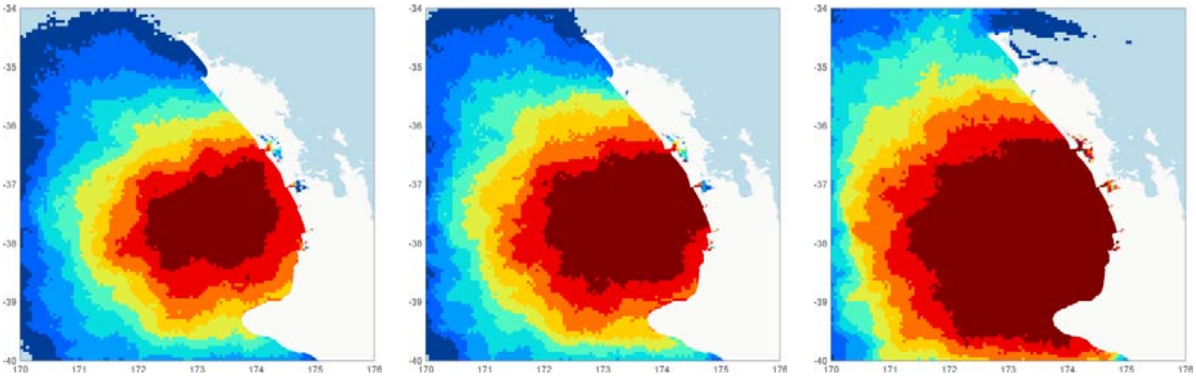
Percentage of spills above 1g.m^{-2} during a 40,000 bbl/day release (76 days long)



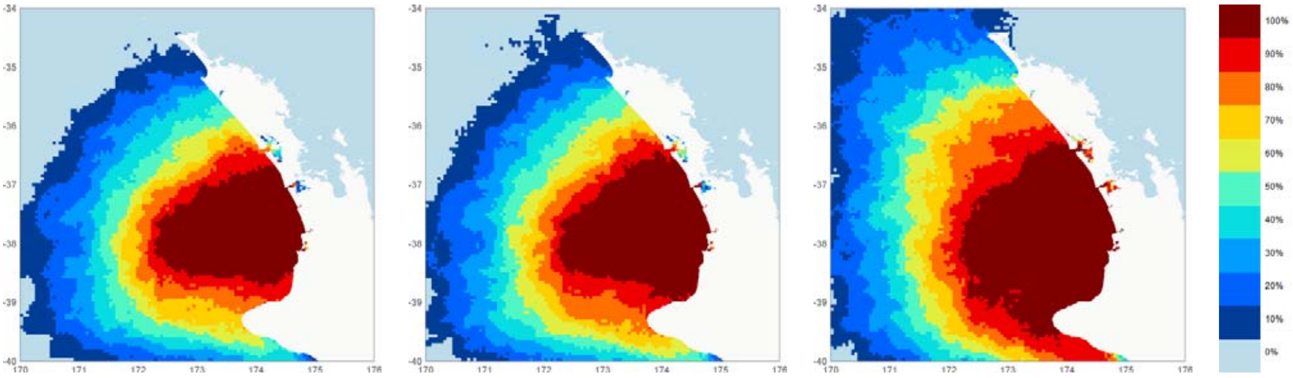
+ 1 week (summer) + 2 weeks (summer) + 1 month (summer)



+ 1 week (winter) + 2 weeks (winter) + 1 month (winter)



+ 76 days, spill stops (summer) + 3 months (summer) + 6 months (summer)



+ 76 days, spill stops (winter) + 3 months (winter) + 6 months (winter)

Appendix II Impact analysis – Canterbury

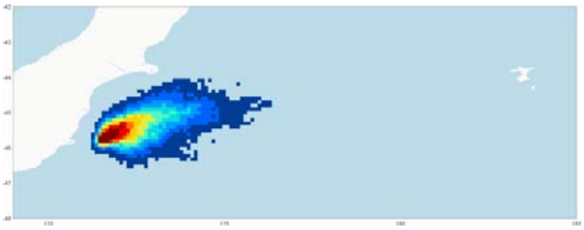
Percentage of spills above 1g.m^{-2} during a 5,000 bbl/day release (76 days long)

+ 1 week (summer)

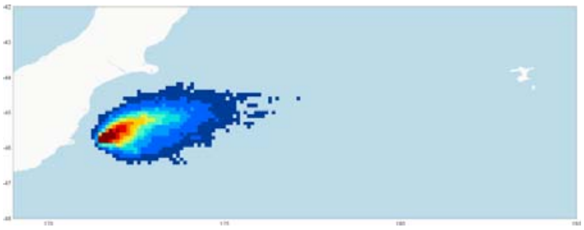
1 week (winter)

+ 2 weeks (summer)

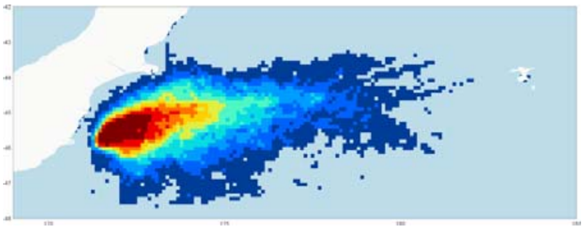
+ 2 weeks (winter)



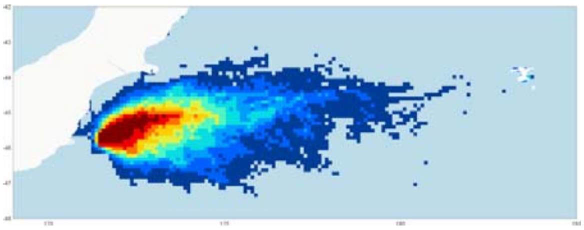
+ 1 month (summer)



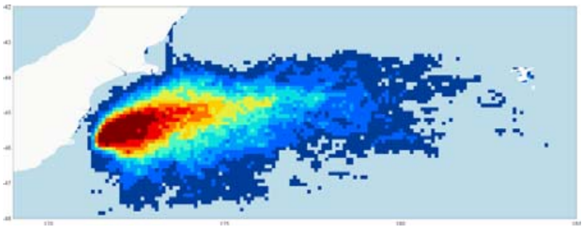
+ 1 month (winter)



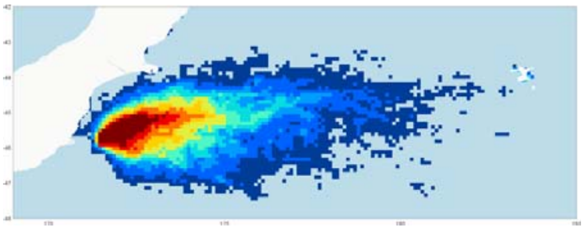
+ 76 days, spill stops (summer)



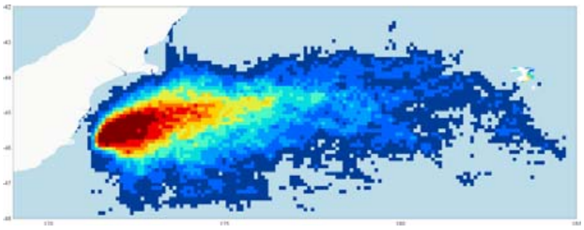
+ 76 days, spill stops (winter)



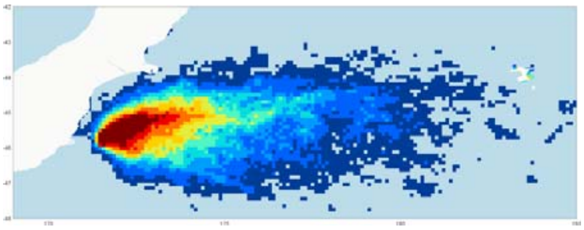
+ 3 months (summer)



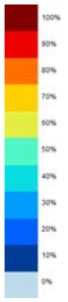
+ 3 months (winter)



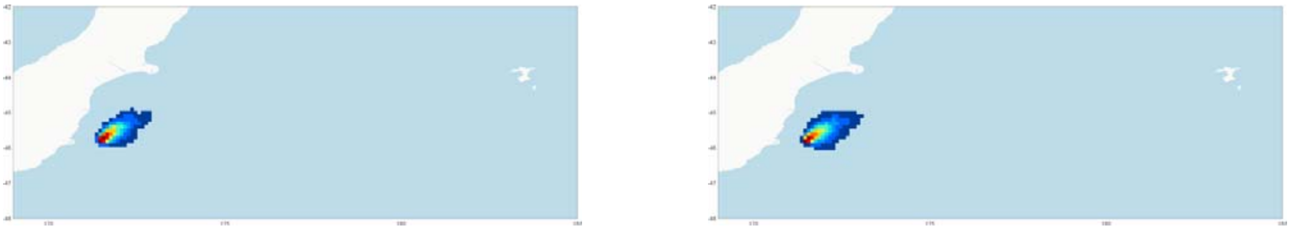
+ 6 months (summer)



+ 6 months (winter)

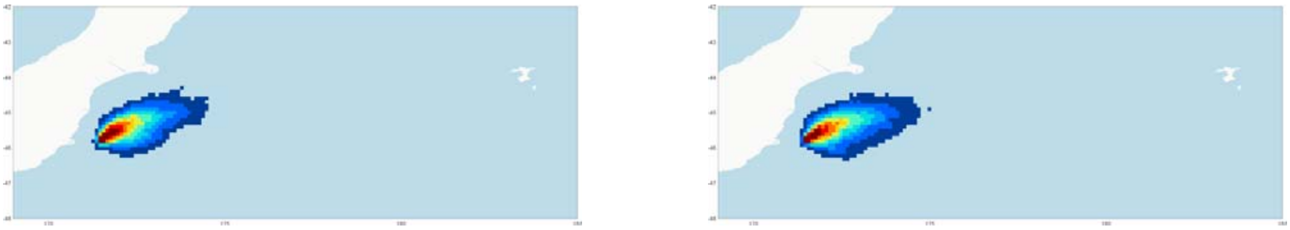


Percentage of spills above 1g.m^{-2} during a 10,000 bbl/day release (76 days long)



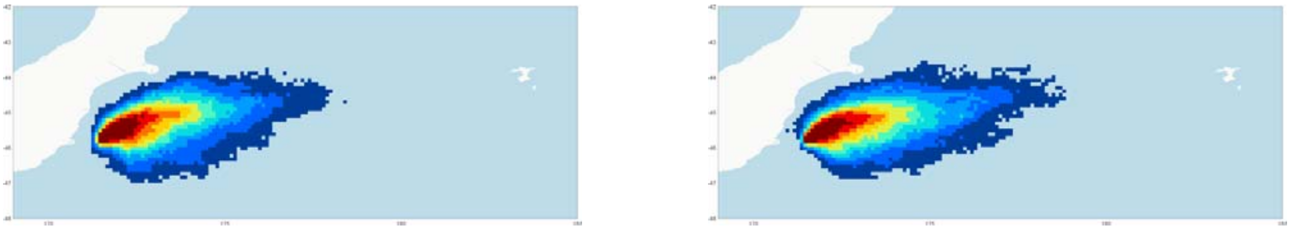
+ 1 week (summer)

1 week (winter)



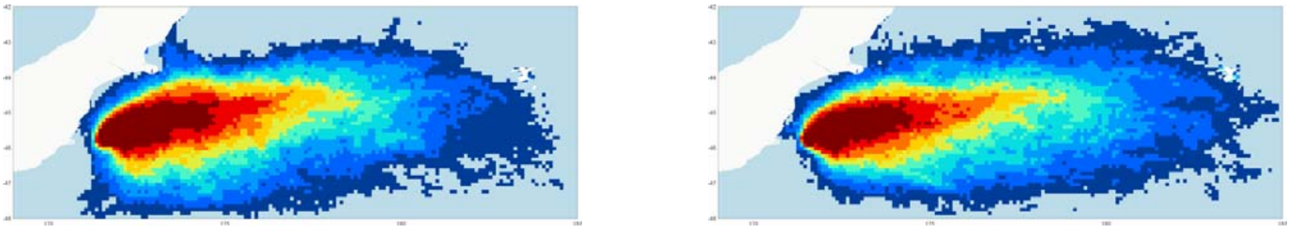
+ 2 weeks (summer)

+ 2 weeks (winter)



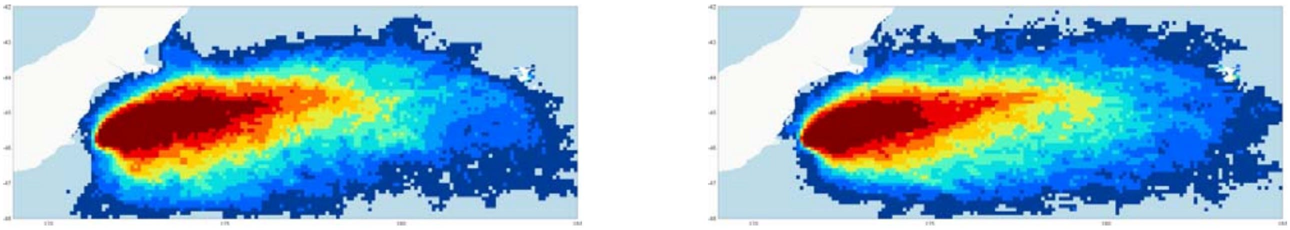
+ 1 month (summer)

+ 1 month (winter)



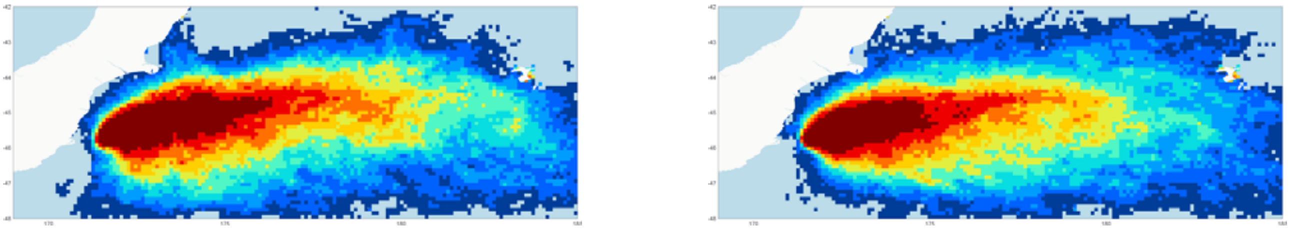
+ 76 days, spill stops (summer)

+ 76 days, spill stops (winter)



+ 3 months (summer)

+ 3 months (winter)



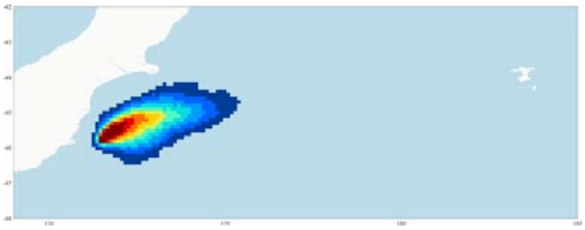
+ 6 months (summer)

+ 6 months (winter)

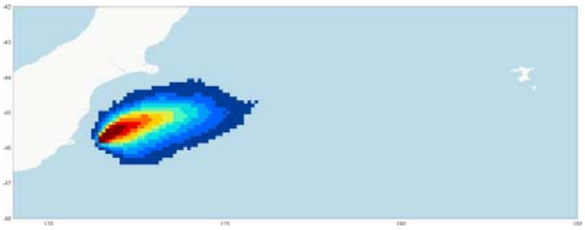
Percentage of spills above 1g.m^{-2} during a 40,000 bbl/day release (76 days long)

+ 1 week (summer)

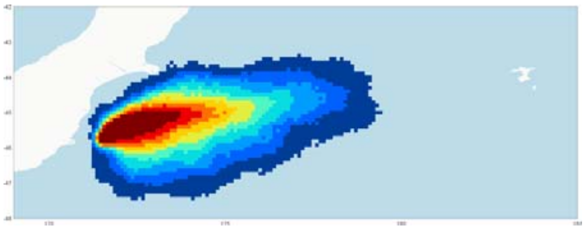
1 week (winter)



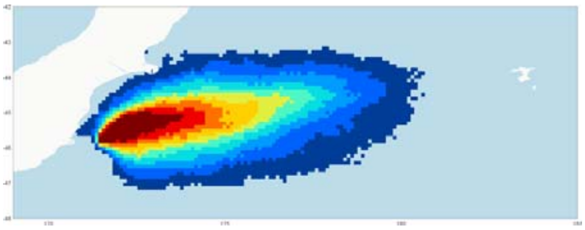
+ 2 weeks (summer)



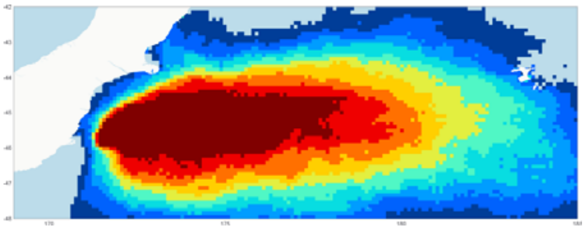
+ 2 weeks (winter)



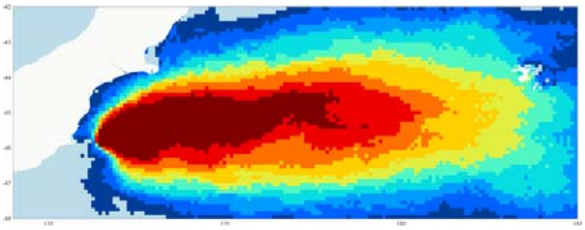
+ 1 month (summer)



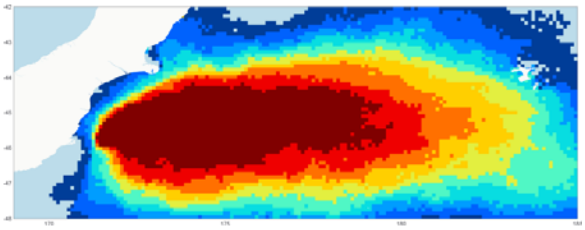
+ 1 month (winter)



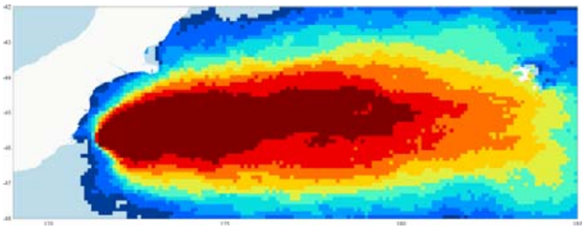
+ 76 days, spill stops (summer)



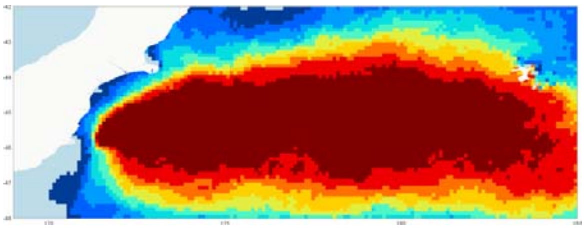
+ 76 days, spill stops (winter)



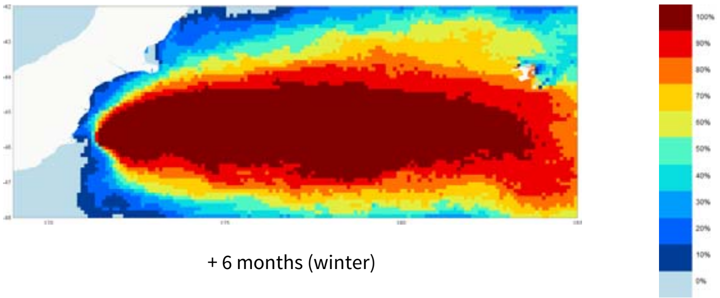
+ 3 months (summer)



+ 3 months (winter)



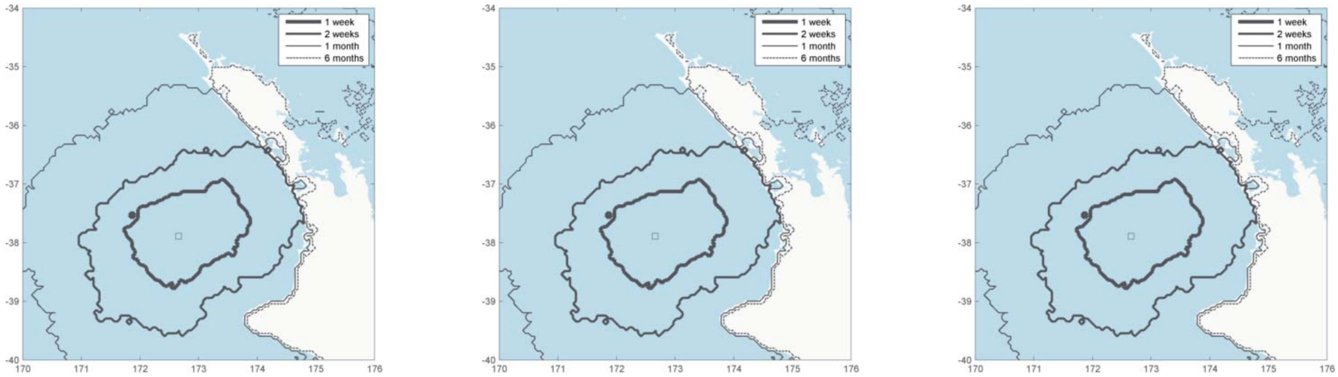
+ 6 months (summer)



+ 6 months (winter)

Appendix III Response time analysis – Taranaki

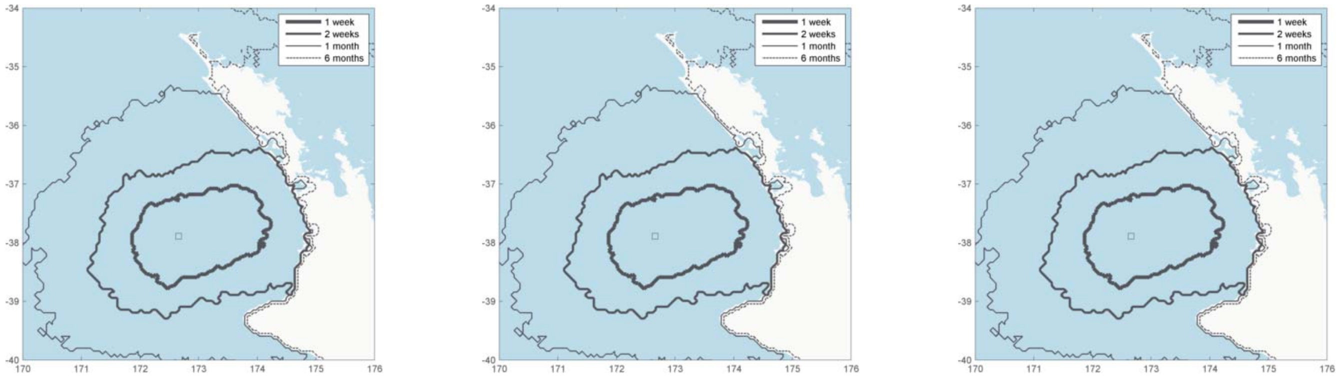
Travel time of the 0.01 $g.m^{-2}$ (fisheries closure) density level for 95% of trajectories



5,000 bbl/day, summer

10,000 bbl/day, summer

40,000 bbl/day, summer

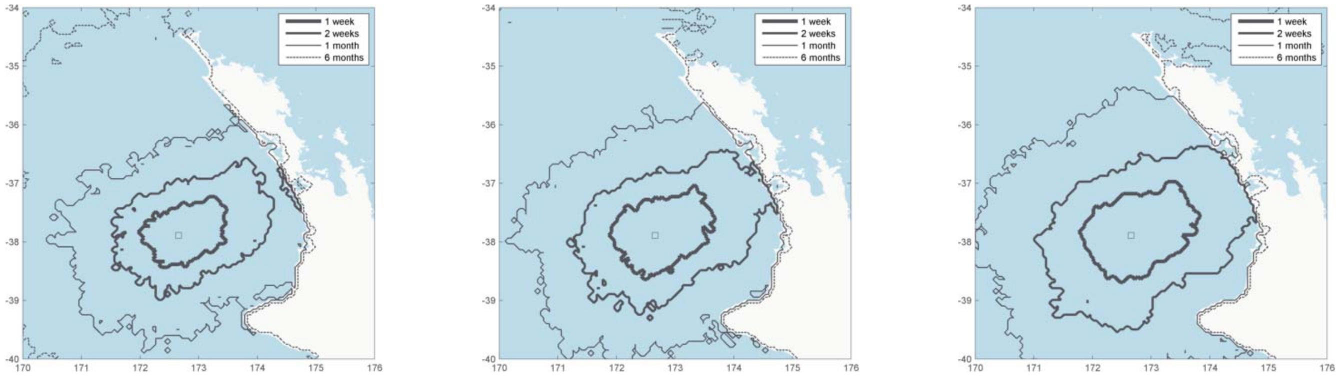


5,000 bbl/day, winter

10,000 bbl/day, winter

40,000 bbl/day, winter

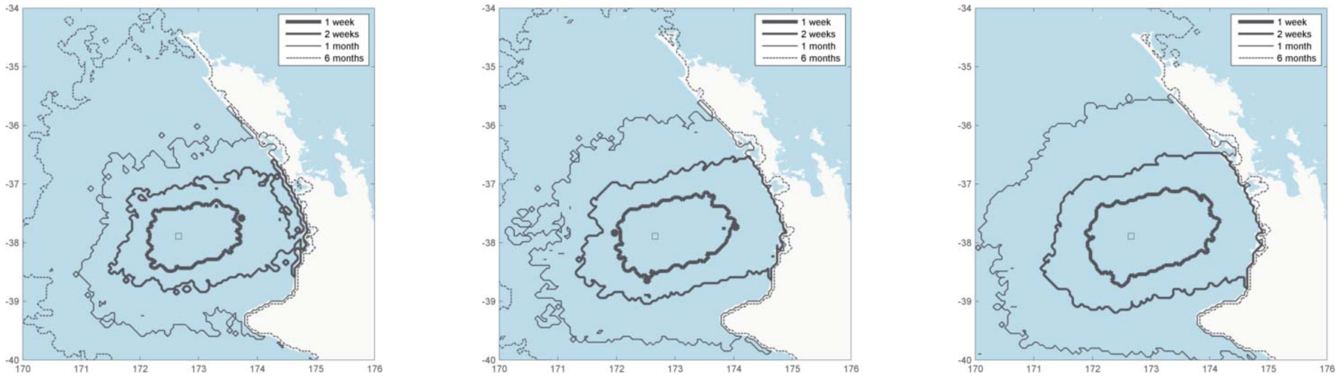
Travel time of the 1 $g.m^{-2}$ (socio-economic threshold) density level for 95% of trajectories



5,000 bbl/day, summer

10,000 bbl/day, summer

40,000 bbl/day, summer

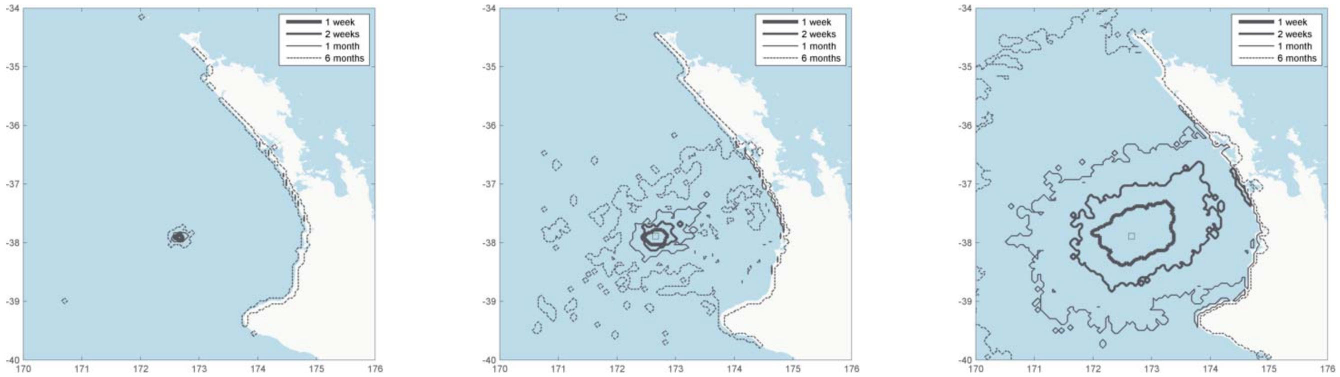


5,000 bbl/day, winter

10,000 bbl/day, winter

40,000 bbl/day, winter

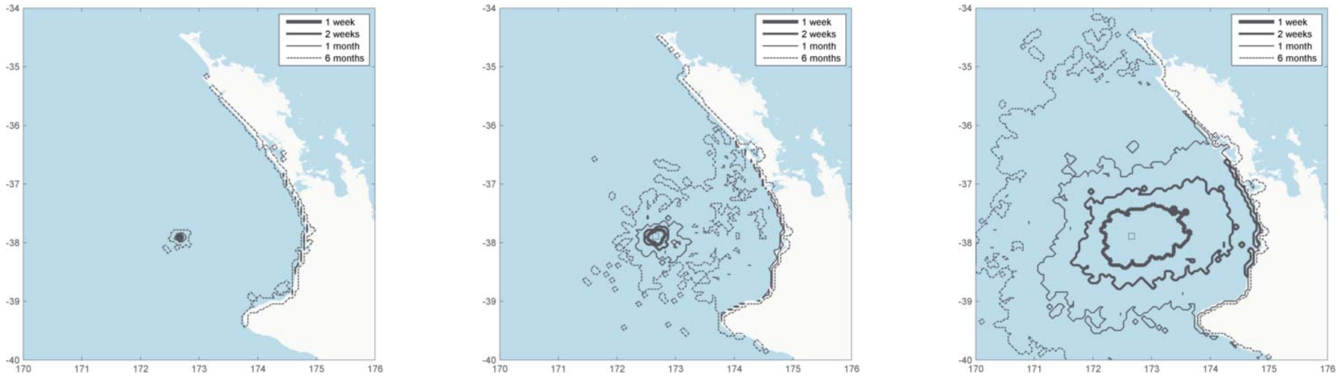
Travel time of the 10 g.m^{-2} (ecological impact threshold) density level for 95% of trajectories



5,000 bbl/day, summer

10,000 bbl/day, summer

40,000 bbl/day, summer



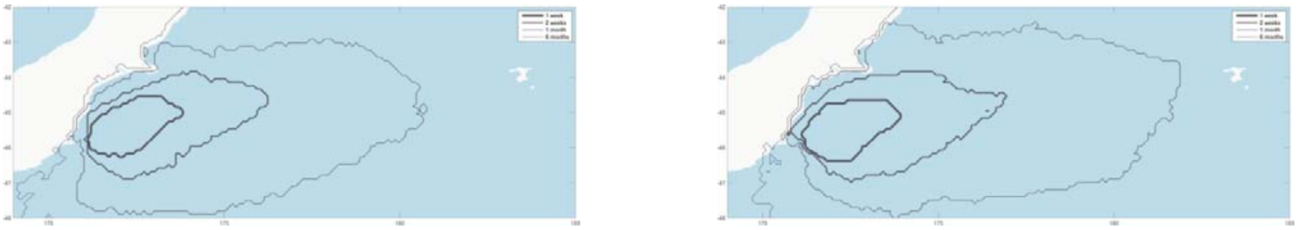
5,000 bbl/day, winter

10,000 bbl/day, winter

40,000 bbl/day, winter

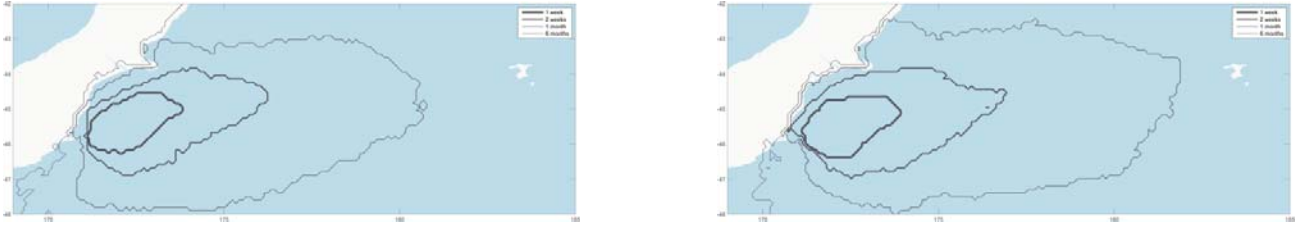
Appendix IV Response time analysis – Canterbury

Travel time of the 0.01 g.m^{-2} (fisheries closure) density level for 95% of trajectories



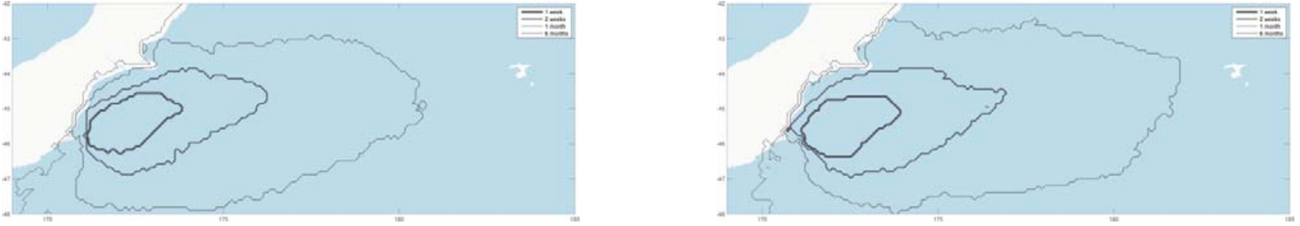
5,000 bbl/day, summer

5,000 bbl/day, winter



10,000 bbl/day, summer

10,000 bbl/day, winter



40,000 bbl/day, summer

40,000 bbl/day, winter

Travel time of the 1 g.m^{-2} (socio-economic threshold) density level for 95% of trajectories

5,000 bbl/day, summer

5,000 bbl/day, winter

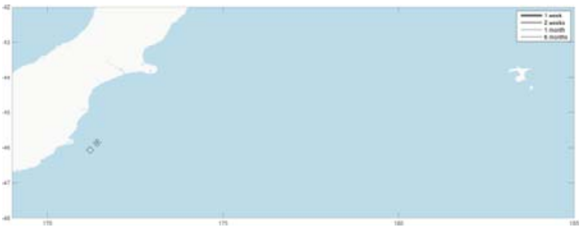
10,000 bbl/day, summer

10,000 bbl/day, winter

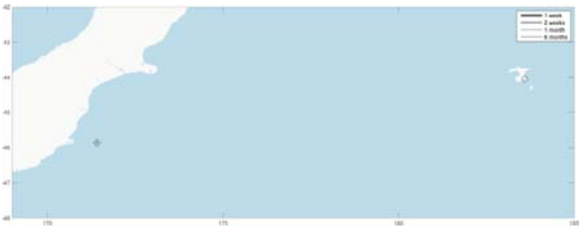
40,000 bbl/day, summer

40,000 bbl/day, winter

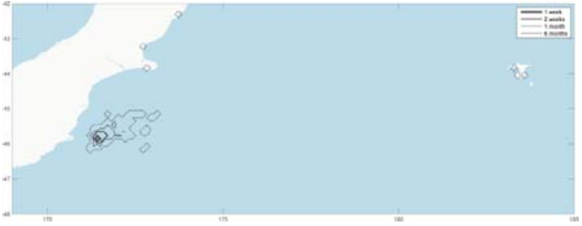
Travel time of the 10 g.m^{-2} (ecological impact threshold,) density level for 95% of trajectories



5,000 bbl/day, summer



5,000 bbl/day, winter



10,000 bbl/day, summer

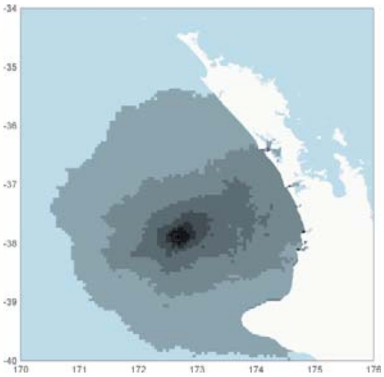
10,000 bbl/day, winter

40,000 bbl/day

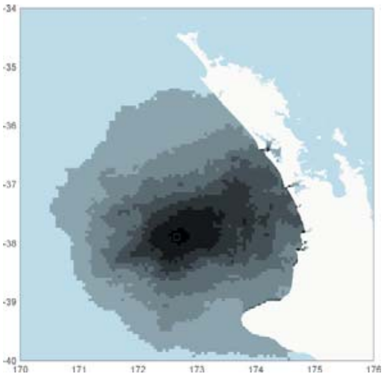
40,000 bbl/day, winter

Appendix V Density analysis – Taranaki

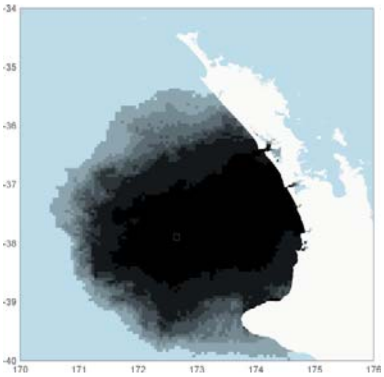
Minimum density level for 50% (probable) of trajectories after 76 days of continuous spill



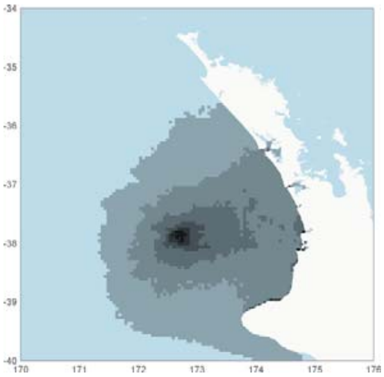
5,000 bbl/day, summer



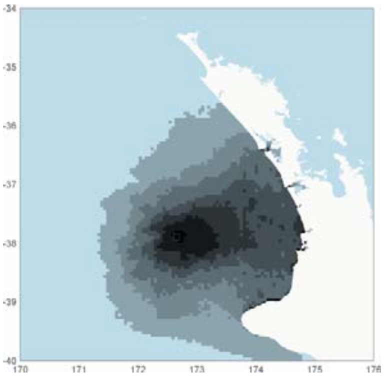
10,000 bbl/day, summer



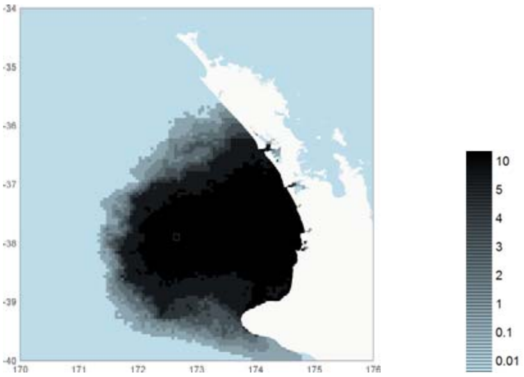
40,000 bbl/day, summer



5,000 bbl/day, winter

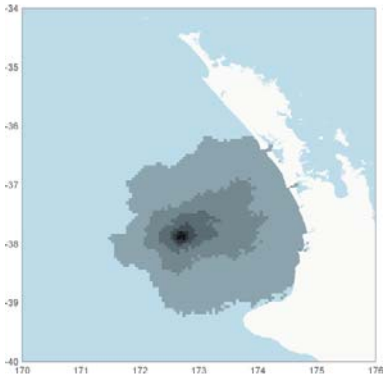


10,000 bbl/day, winter

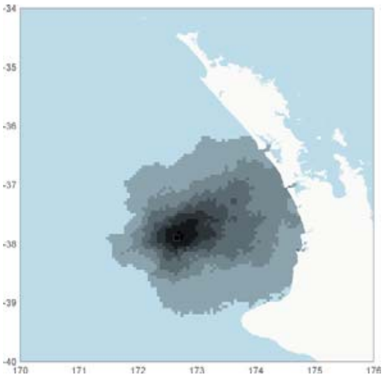


40,000 bbl/day, winter

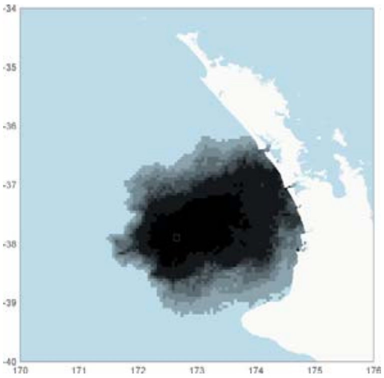
Minimum density level for 80% (likely) of trajectories after 76 days of continuous spill



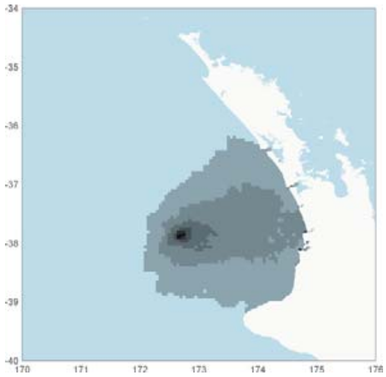
5,000 bbl/day, summer



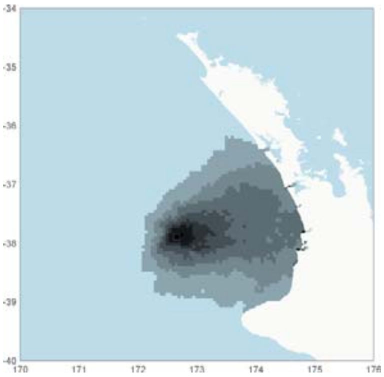
10,000 bbl/day, summer



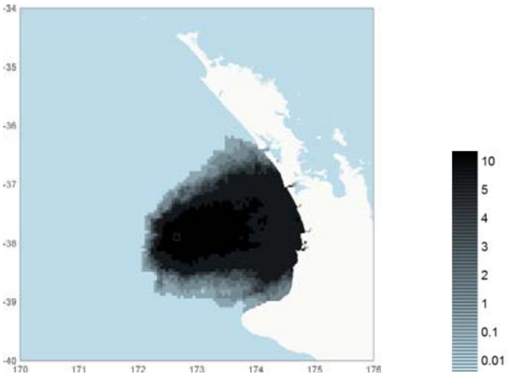
40,000 bbl/day, summer



5,000 bbl/day, winter

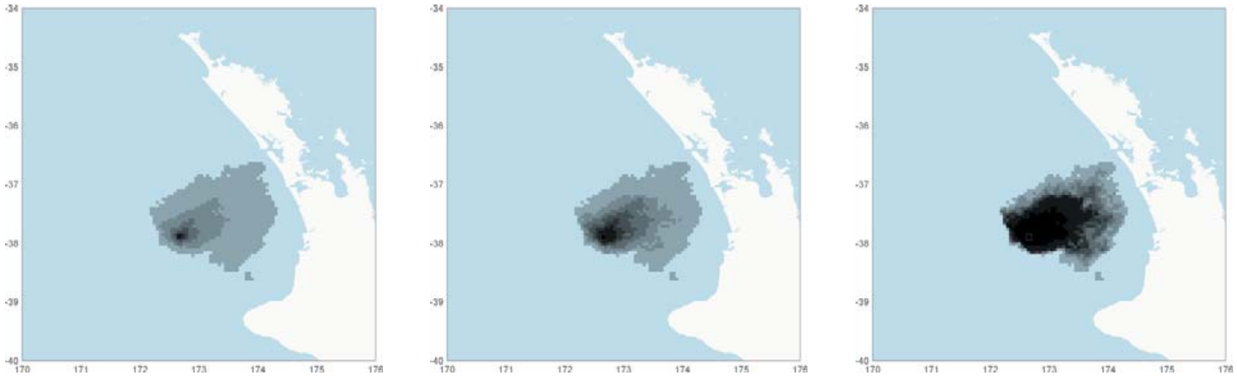


10,000 bbl/day, winter

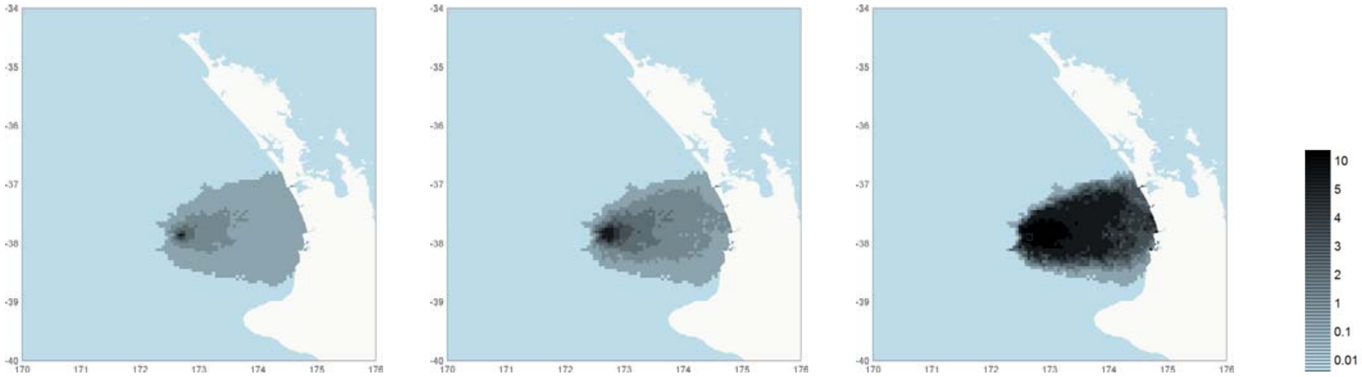


40,000 bbl/day, winter

Minimum density level for 95% (very likely) of trajectories after 76 days of continuous spill



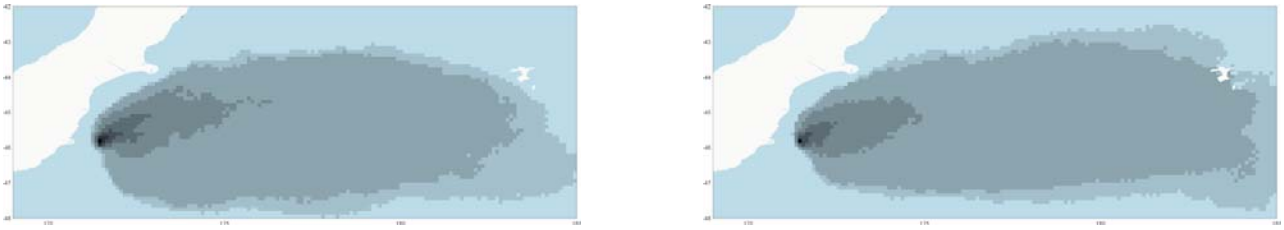
5,000 bbl/day, summer, PROB: 95%   10,000 bbl/day, summer, PROB: 95%   40,000 bbl/day, summer, PROB: 95%



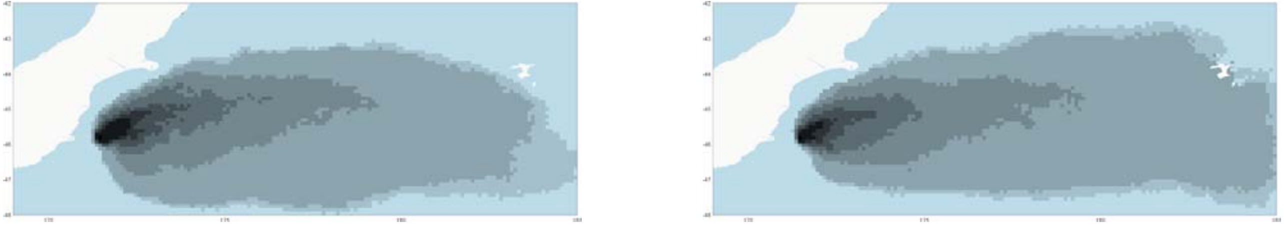
5,000 bbl/day, winter, PROB: 95%   10,000 bbl/day, winter, PROB: 95%   40,000 bbl/day, winter, PROB: 95%

Appendix VI Density analysis – Canterbury

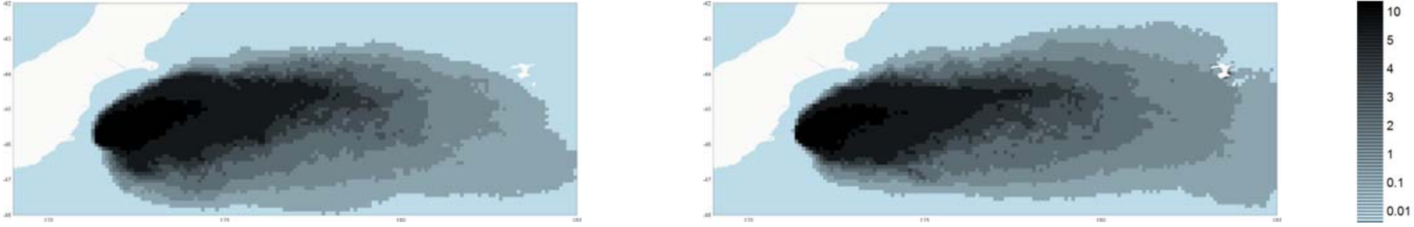
Minimum density level for 50% (probable) of trajectories after 76 days of continuous spill



5,000 bbl/day, summer   5,000 bbl/day, winter

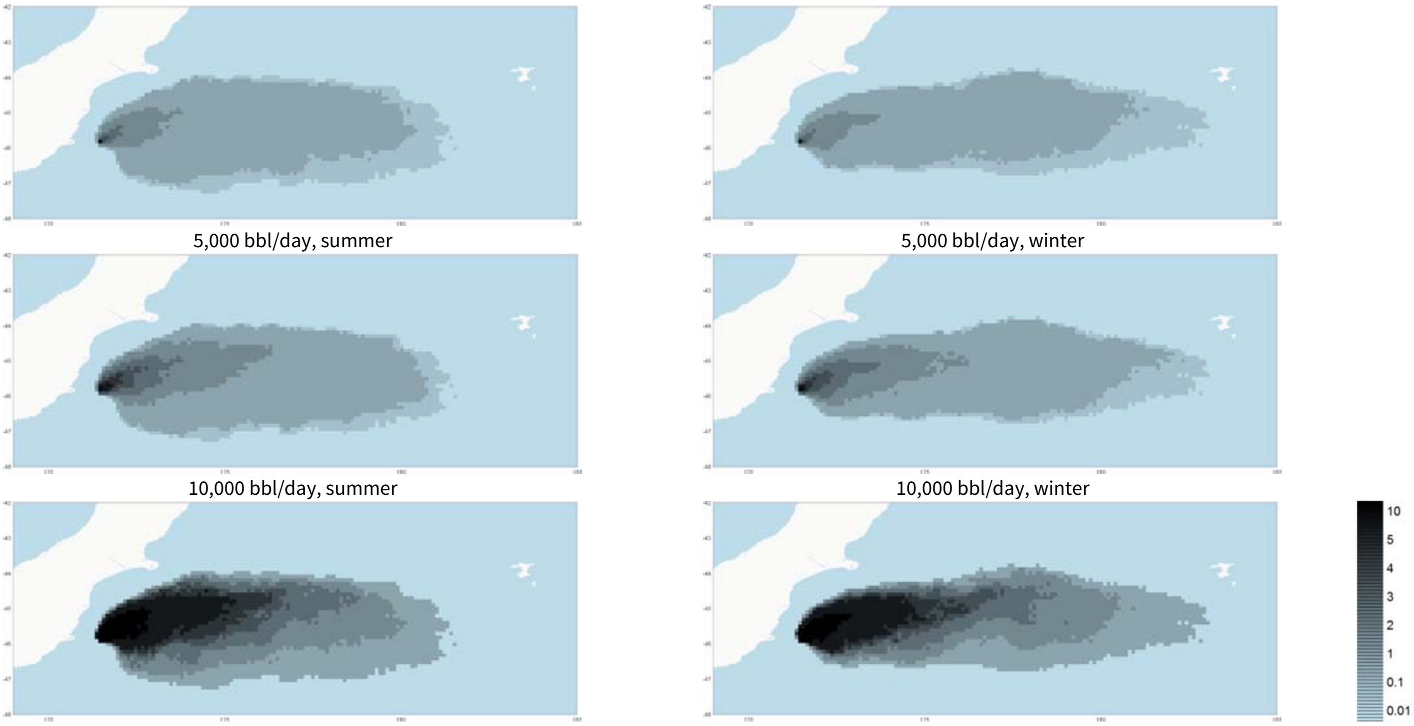


10,000 bbl/day, summer   10,000 bbl/day, winter

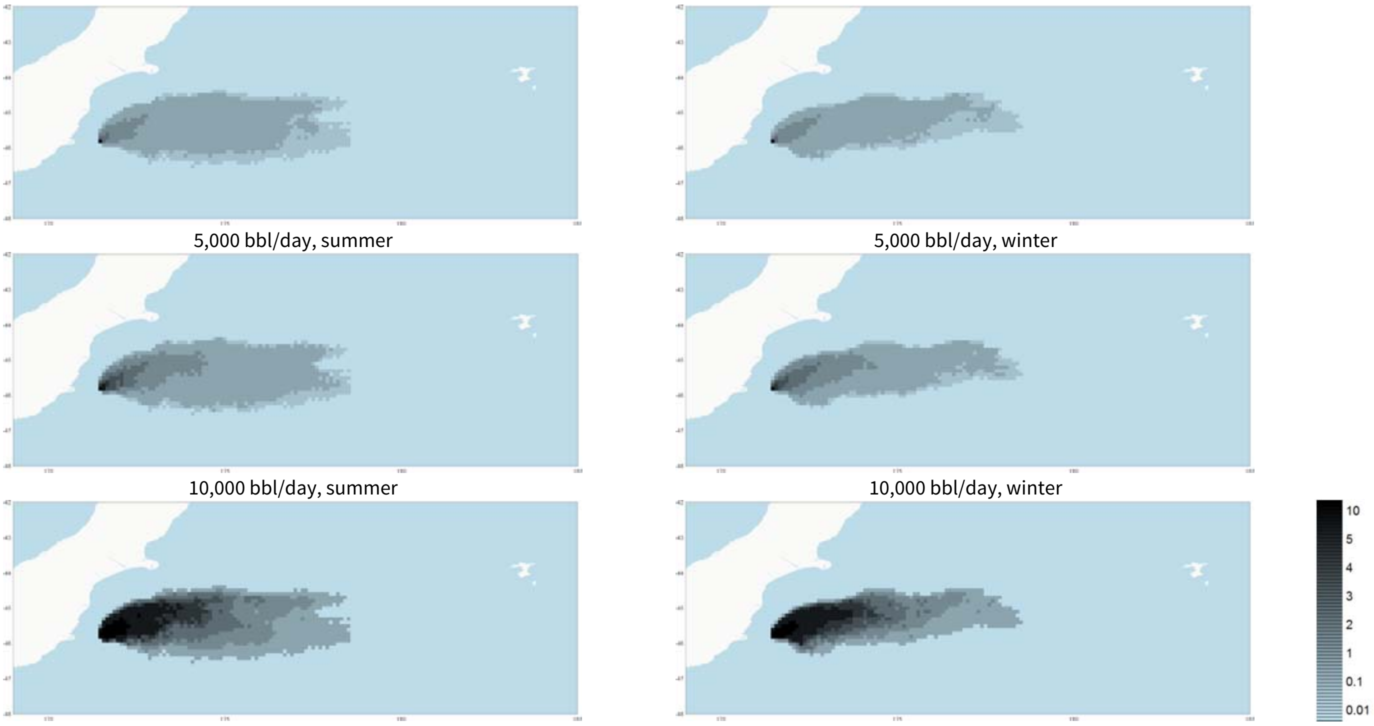


40,000 bbl/day, summer   40,000 bbl/day, winter

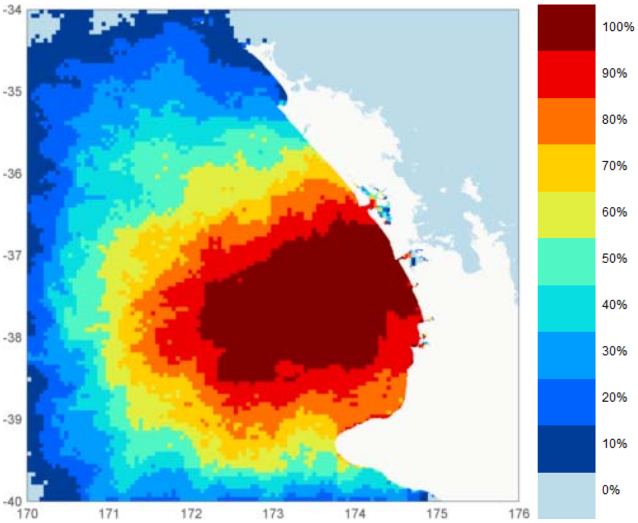
Minimum density level for 80% (likely) of trajectories after 76 days of continuous spill


5,000 bbl/day, summer
5,000 bbl/day, winter
10,000 bbl/day, summer
10,000 bbl/day, winter
40,000 bbl/day, summer
40,000 bbl/day, winter

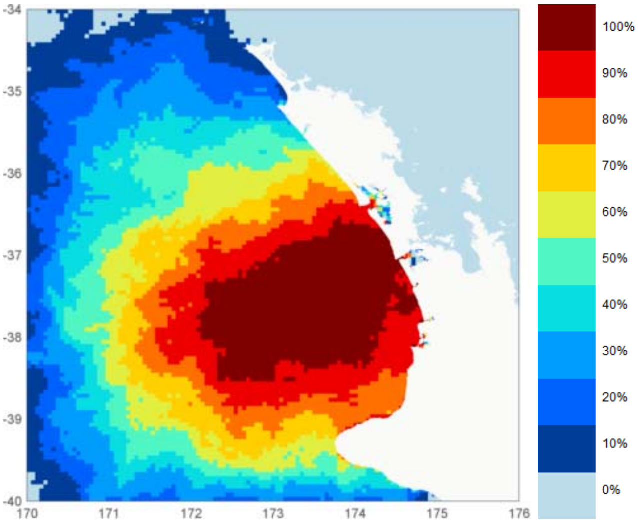
Minimum density level for 95% (very likely) of trajectories after 76 days of continuous spill


5,000 bbl/day, summer
5,000 bbl/day, winter
10,000 bbl/day, summer
10,000 bbl/day, winter
40,000 bbl/day, summer
40,000 bbl/day, winter

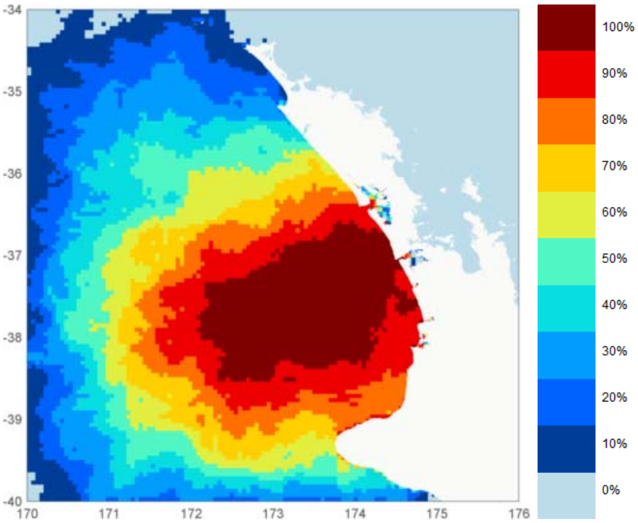
Appendix VII Comparison of different trajectory analysis resolution



500 trajectories, summer season, 120 days



1000 trajectories, summer season, 120 days



2000 trajectories, summer season, 120 days

Appendix VIII Full Oiling Analysis

Opononi

Opononi is located in the historic Hokianga Harbour, which is an area of great cultural importance for the Maori people and is considered the location of the first settlement after Kupe arrived from Hawaiiki in Te Tai Tokerau traditions. Oponini is a laid-back coastal settlement that attracts tourists, mostly for fishing and the sight of the giant sand dunes across the Hokianga entrance.

estimated oil density in gm^{-2} for different probability at Opononi

Time from blowout	Worst spill scenario		50% of spills		80% of spills		95% of spills	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1 month	4.5	3.8	0.0	0.0	0.0	0.0	0.0	0.0
2 months	11.1	10.9	0.0	0.0	0.0	0.0	0.0	0.0
76 days: spill ends	16.1	16.6	0.0	0.0	0.0	0.0	0.0	0.0
3 months	16.1	23.5	0.2	0.2	0.0	0.0	0.0	0.0
4 months	26.1	23.5	0.9	1.4	0.0	0.0	0.0	0.0
5 months	28.7	23.5	1.4	2.4	0.0	0.0	0.0	0.0
6 months	28.7	23.5	1.7	2.6	0.2	0.0	0.0	0.0

percentage of spills for different levels of concern at Opononi

presence of oil		0.01 gm^{-2}		1 gm^{-2}		10 gm^{-2}	
summer	winter	summer	winter	summer	winter	summer	winter
85%	86%	82%	84%	24%	34%	0%	0%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories at Opononi at various levels of concern

	first spill		mean total spills		50% of trajectories		80% of trajectories		95% of trajectories	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	17 d	17 d	67 d	72 d	68 d	73 d	126 d	136 d	-	-
0.01 gm^{-2}	17 d	18 d	71 d	75 d	75 d	78 d	152 d	145 d	-	-
1 gm^{-2}	43 d	45 d	103 d	93 d	-	-	-	-	-	-
10 gm^{-2}	-	-	-	-	-	-	-	-	-	-

Kaipara Harbour

The Kaipara Harbour is the largest estuarine harbour on the West Coast of New Zealand. It is an important nursery for many fish species, including west coast snapper, of which 98% of the entire stock comes from Kaipara. Its beaches, mud flats and mangroves are also critical habitat for thousands of migratory birds. The Kaipara is the wintering ground and a breeding area for one of the rarest birds in New Zealand, the fairy tern. estimated oil density in gm^{-2} for different probability at Kaipara Harbour mouth

Time from blowout	**Worst spill scenario**		**50% of spills**		**80% of spills**		**95% of spills**	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	8.1	4.5	0.0	0.0	0.0	0.0	0.0	0.0
1 month	30.8	27.7	0.0	0.0	0.0	0.0	0.0	0.0
2 months	48.1	28.0	2.1	1.4	0.0	0.0	0.0	0.0
76 days: spill ends	48.1	30.1	4.7	5.0	0.5	0.2	0.0	0.0
3 months	58.3	31.8	7.1	8.3	1.2	0.9	0.0	0.0
4 months	58.3	47.7	9.5	9.0	3.3	2.6	0.0	0.2
5 months	58.3	47.7	10.2	10.0	4.0	3.1	0.7	0.5
6 months	58.3	47.7	10.4	10.0	4.3	3.1	0.7	0.7

percentage of spills for different levels of concern at Kaipara Harbour mouth

presence of oil		**0.01 gm^{-2}**		**1 gm^{-2}**		**10 gm^{-2}**	
summer	winter	summer	winter	summer	winter	summer	winter
97%	99%	96%	99%	69%	60%	0%	0%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories at Kaipara Harbour mouth at various levels of concern

	first spill		**mean total spills**		**50% of trajectories**		**80% of trajectories**		**95% of trajectories**	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	9 d	10 d	41 d	46 d	37 d	40 d	59 d	67 d	97 d	98 d
0.01 gm^{-2}	9 d	11 d	44 d	49 d	41 d	43 d	65 d	72 d	102 d	101 d
1 gm^{-2}	17 d	19 d	78 d	68 d	95 d	88 d	-	-	-	-
10 gm^{-2}	-	-	-	-	-	-	-	-	-	-

Muriwai

Muriwai is a popular surf beach near Auckland. It is also home to one of only three colonies of gannets on the New Zealand mainland.

estimated oil density in gm^{-2} for different probability in Muriwai

Time from blowout	Worst spill scenario		50% of spills		80% of spills		95% of spills	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	20.9	26.2	0.0	0.0	0.0	0.0	0.0	0.0
1 month	52.9	33.7	0.0	0.5	0.0	0.0	0.0	0.0
2 months	89.9	89.9	11.4	13.7	0.7	2.8	0.0	0.0
76 days: spill ends	100.8	104.3	17.3	19.9	4.0	7.6	0.0	0.0
3 months	100.8	116.6	22.5	24.7	9.5	11.9	0.0	2.4
4 months	100.8	121.9	27.7	29.9	13.3	15.4	0.0	5.7
5 months	100.8	127.5	28.7	31.8	13.7	17.3	2.1	6.2
6 months	100.8	127.5	29.4	33.9	14.7	18.3	2.1	6.4

percentage of spills for different levels of concern in Muriwai

presence of oil		0.01 gm^{-2}		1 gm^{-2}		10 gm^{-2}	
summer	winter	summer	winter	summer	winter	summer	winter
96%	100%	96%	100%	90%	91%	2%	8%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories in Muriwai at various levels of concern

	first spill		mean total spills		50% of trajectories		80% of trajectories		95% of trajectories	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	7 d	6 d	37 d	32 d	33 d	28 d	55 d	46 d	123 d	74 d
0.01 gm^{-2}	7 d	7 d	38 d	34 d	34 d	29 d	58 d	49 d	129 d	75 d
1 gm^{-2}	12 d	11 d	65 d	59 d	65 d	58 d	99 d	90 d	-	-
10 gm^{-2}	60 d	60 d	89 d	97 d	-	-	-	-	-	-

Piha

Piha is certainly Auckland's region most popular surf beaches and an important tourist draw-card close to the country's largest city.

estimated oil density in gm^{-2} for different probability in Piha

Time from blowout	Worst spill scenario		50% of spills		80% of spills		95% of spills	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	11.9	21.4	0.0	0.0	0.0	0.0	0.0	0.0
1 month	38.2	28.0	0.0	1.4	0.0	0.0	0.0	0.0
2 months	76.3	71.8	8.3	14.0	0.7	4.3	0.0	0.0
76 days: spill ends	88.4	93.2	16.1	20.6	3.8	9.7	0.0	3.8
3 months	95.1	108.8	20.6	24.9	7.3	12.8	0.0	6.6
4 months	95.1	119.7	24.2	30.3	13.0	15.9	0.0	7.3
5 months	95.1	119.7	26.3	31.8	14.2	17.3	2.1	7.3
6 months	95.1	119.7	27.0	33.4	15.4	18.0	2.4	7.3

percentage of spills for different levels of concern in Piha

presence of oil		0.01 gm^{-2}		1 gm^{-2}		10 gm^{-2}	
summer	winter	summer	winter	summer	winter	summer	winter
96%	100%	96%	100%	90%	94%	1%	9%

predicted time of arrivals of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories in Piha at various levels of concern

	first spill		mean total spills		50% of trajectories		80% of trajectories		95% of trajectories	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	7 d	5 d	37 d	30 d	33 d	26 d	56 d	42 d	124 d	67 d
0.01 gm^{-2}	7 d	5 d	38 d	31 d	34 d	27 d	57 d	44 d	128 d	67 d
1 gm^{-2}	16 d	13 d	65 d	53 d	68 d	52 d	100 d	79 d	-	-
10 gm^{-2}	57 d	63 d	83 d	95 d	-	-	-	-	-	-

Manukau Harbour

The Manukau Harbour defines the western margin of Auckland city. The harbour is a popular recreational fishing area for Aucklanders and is home to several sailing clubs. It is also a highly valuable habitat for many native and migratory wading birds, such as stilts, godwits and herons. In fact, the harbour supports 20% of the total population of New Zealand's wading bird species. estimated oil density in gm^{-2} for different probability at Manukau Harbour mouth

Time from blowout	Worst spill scenario		50% of spills		80% of spills		95% of spills	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.2	3.7	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	21.4	9.8	0.0	0.0	0.0	0.0	0.0	0.0
1 month	62.4	26.6	0.0	1.2	0.0	0.0	0.0	0.0
2 months	72.5	54.5	7.3	9.7	0.5	3.6	0.0	0.0
76 days: spill ends	72.5	64.2	12.1	13.3	3.8	7.1	0.0	3.3
3 months	72.5	73.0	14.5	17.3	7.1	9.7	0.0	5.0
4 months	72.5	73.0	16.8	21.1	9.2	12.6	0.0	5.7
5 months	72.5	73.0	18.3	22.5	10.7	12.8	1.4	6.2
6 months	72.5	73.0	18.5	23.0	11.1	13.0	1.7	6.6

percentage of spills for different levels of concern at Manukau Harbour mouth

presence of oil		0.01 gm^{-2}		1 gm^{-2}		10 gm^{-2}	
summer	winter	summer	winter	summer	winter	summer	winter
96%	100%	96%	100%	90%	95%	1%	5%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories at Manukau Harbour mouth at various levels of concern

	first spill		mean total spills		50% of trajectories		80% of trajectories		95% of trajectories	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	6 d	6 d	37 d	29 d	33 d	25 d	55 d	40 d	124 d	62 d
0.01 gm^{-2}	7 d	6 d	38 d	30 d	34 d	26 d	57 d	42 d	124 d	64 d
1 gm^{-2}	10 d	21 d	63 d	56 d	65 d	54 d	94 d	79 d	-	-
10 gm^{-2}	62 d	55 d	67 d	78 d	-	-	-	-	-	-

Manu Bay, Raglan

Raglan is an internationally renowned surf town. Its three point breaks, Manu bay, Whale Bay and Indicators are all recognised as surf-breaks of national significance in the New Zealand Coastal Policy Statement 2010.

estimated oil density in gm^{-2} for different probability in Raglan

Time from blowout	Worst spill scenario		50% of spills		80% of spills		95% of spills	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	6.7	9.5	0.0	0.0	0.0	0.0	0.0	0.0
1 month	11.1	37.7	0.0	0.7	0.0	0.0	0.0	0.0
2 months	44.8	86.3	2.6	14.0	0.0	2.4	0.0	0.2
76 days: spill ends	57.1	132.3	6.4	22.8	0.5	5.7	0.0	1.4
3 months	60.7	180.2	11.9	30.6	2.1	10.9	0.0	3.6
4 months	89.6	240.2	17.5	40.1	5.9	17.1	0.0	6.2
5 months	89.6	247.7	22.5	49.1	6.6	19.2	1.2	12.3
6 months	109.3	247.7	24.4	52.4	9.7	21.6	1.7	14.7

percentage of spills for different levels of concern in Raglan

presence of oil		$0.01\ gm^{-2}$		$1\ gm^{-2}$		$10\ gm^{-2}$	
summer	winter	summer	winter	summer	winter	summer	winter
98%	100%	97%	100%	84%	97%	7%	21%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories in Raglan at various levels of concern

	first spill		mean total spills		50% of trajectories		80% of trajectories		95% of trajectories	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	10 d	6 d	44 d	28 d	39 d	25 d	64 d	40 d	103 d	54 d
$0.01\ gm^{-2}$	10 d	6 d	47 d	30 d	43 d	26 d	67 d	44 d	125 d	57 d
$1\ gm^{-2}$	22 d	16 d	81 d	62 d	83 d	57 d	150 d	86 d	-	137 d
$10\ gm^{-2}$	86 d	65 d	136 d	117 d	-	-	-	-	-	-

New Plymouth

The city has invested heavily in developing a coastal walkway, which has won several awards. It is the current infrastructure centre for the oil and gas industry in New Zealand.

estimated oil density in gm^{-2} for different probability in New Plymouth

Time from blowout	Worst spill scenario		50% of spills		80% of spills		95% of spills	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	15.2	8.6	0.0	0.0	0.0	0.0	0.0	0.0
1 month	25.6	30.6	0.0	0.0	0.0	0.0	0.0	0.0
2 months	33.7	54.8	0.7	3.1	0.0	0.0	0.0	0.0
76 days: spill ends	56.4	70.6	2.4	6.6	0.0	0.2	0.0	0.0
3 months	78.0	89.1	5.0	10.0	0.5	1.4	0.0	0.0
4 months	102.4	98.4	9.7	23.0	1.4	5.2	0.2	0.5
5 months	102.4	98.4	12.3	34.1	2.8	11.1	0.9	1.7
6 months	102.4	103.1	13.7	39.4	5.0	14.5	1.7	3.3

percentage of spills for different levels of concern in New Plymouth

presence of oil		0.01 gm^{-2}		1 gm^{-2}		10 gm^{-2}	
summer	winter	summer	winter	summer	winter	summer	winter
100%	100%	100%	100%	73%	87%	4%	14%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories in New Plymouth at various levels of concern

	first spill		mean total spills		50% of trajectories		80% of trajectories		95% of trajectories	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	9 d	7 d	53 d	47 d	47 d	39 d	74 d	70 d	105 d	103 d
0.01 gm^{-2}	10 d	7 d	56 d	50 d	50 d	42 d	78 d	73 d	108 d	107 d
1 gm^{-2}	17 d	22 d	95 d	83 d	106 d	81 d	-	143 d	-	-
10 gm^{-2}	90 d	80 d	116 d	132 d	-	-	-	-	-	-

Kaikoura

Off the coast of Kaikoura, a complex system of deep marine canyons supports a great diversity of marine life. The rich waters surrounding Kaikoura attract many species of marine mammal and most notably sperm whales. The town of Kaikoura is reliant on the presence of these large marine mammals for its whale watch industry. Kaikoura also has two surf-breaks recognised of national significance in NZCPS10.

estimated oil density in gm^{-2} for different probability in Kaikoura

Time from blowout	Worst spill scenario		50% of spills		80% of spills		95% of spills	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1 month	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0
2 months	10.5	11.4	0.0	0.0	0.0	0.0	0.0	0.0
76 days: spill ends	14.1	14.1	0.3	0.1	0.0	0.0	0.0	0.0
3 months	14.7	14.6	0.7	0.5	0.0	0.0	0.0	0.0
4 months	14.8	15.0	1.6	2.0	0.4	0.0	0.0	0.0
5 months	14.9	15.0	2.0	2.3	0.5	0.1	0.0	0.0
6 months	15.8	15.1	2.1	2.4	0.5	0.1	0.0	0.0

percentage of spills for different levels of concern in Kaikoura

presence of oil		0.01 gm^{-2}		1 gm^{-2}		10 gm^{-2}	
summer	winter	summer	winter	summer	winter	summer	winter
96%	87%	91%	79%	4%	2%	0%	0%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories in Kaikoura at various levels of concern

	first spill		mean total spills		50% of trajectories		80% of trajectories		95% of trajectories	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	19 d	15 d	65 d	68 d	63 d	71 d	85 d	110 d	140 d	-
0.01 gm^{-2}	21 d	16 d	73 d	73 d	72 d	78 d	101 d	-	-	-
1 gm^{-2}	80 d	73 d	111 d	93 d	-	-	-	-	-	-
10 gm^{-2}	-	-	-	-	-	-	-	-	-	-

Banks Peninsula

With its many bays and harbours, Banks Peninsula provides ideal habitat for the endangered Hector's dolphin, as well as many other marine animals. To protect these small, coastal water dwelling dolphins from becoming bycatch in set nets, New Zealand's first Marine Mammal Sanctuary was established here in 1988. It is also an important area for aquaculture in New Zealand. estimated oil density in gm^{-2} for different probability at the Banks Peninsula

Time from blowout	**Worst spill scenario**		**50% of spills**		**80% of spills**		**95% of spills**	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	1.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	2.2	2.6	0.0	0.0	0.0	0.0	0.0	0.0
1 month	4.2	4.2	0.0	0.0	0.0	0.0	0.0	0.0
2 months	5.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0
76 days: spill ends	5.9	5.2	0.0	0.0	0.0	0.0	0.0	0.0
3 months	5.9	5.2	0.0	0.0	0.0	0.0	0.0	0.0
4 months	5.9	5.2	0.0	0.0	0.0	0.0	0.0	0.0
5 months	5.9	5.2	0.0	0.0	0.0	0.0	0.0	0.0
6 months	5.9	5.2	0.0	0.0	0.0	0.0	0.0	0.0

percentage of spills for different levels of concern at the Banks Peninsula

presence of oil		**0.01 gm^{-2}**		**1 gm^{-2}**		**10 gm^{-2}**	
summer	winter	summer	winter	summer	winter	summer	winter
52%	49%	44%	43%	4%	6%	0%	0%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories at the Banks Peninsula at various levels of concern

	first spill		**mean total spills**		**50% of trajectories**		**80% of trajectories**		**95% of trajectories**	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	7 d	6 d	52 d	44 d	102 d	-	-	-	-	-
0.01 gm^{-2}	7 d	6 d	51 d	44 d	-	-	-	-	-	-
1 gm^{-2}	48 d	55 d	74 d	72 d	-	-	-	-	-	-
10 gm^{-2}	-	-	-	-	-	-	-	-	-	-

Oamaru

The local eco-tourism in Oamaru is related to colonies of yellow-eyed and little blue penguins. Oamaru is an historical town that has evidence of very early Maori settlement and was visited by Captain Cook on his voyage of discovery.

estimated oil density in gm^{-2} for different probability in Oamaru

Time from blowout	Worst spill scenario		50% of spills		80% of spills		95% of spills	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	7.3	9.4	0.0	0.0	0.0	0.0	0.0	0.0
1 month	7.7	14.7	0.0	0.0	0.0	0.0	0.0	0.0
2 months	14.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0
76 days: spill ends	14.1	16.0	0.0	0.0	0.0	0.0	0.0	0.0
3 months	14.1	16.2	0.0	0.0	0.0	0.0	0.0	0.0
4 months	14.1	16.2	0.0	0.0	0.0	0.0	0.0	0.0
5 months	14.1	16.2	0.0	0.0	0.0	0.0	0.0	0.0
6 months	14.1	16.2	0.0	0.0	0.0	0.0	0.0	0.0

percentage of spills for different levels of concern in Oamaru

presence of oil		0.01 gm^{-2}		1 gm^{-2}		10 gm^{-2}	
summer	winter	summer	winter	summer	winter	summer	winter
31%	23%	30%	20%	5%	3%	0%	0%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories in Oamaru at various levels of concern

	first spill		mean total spills		50% of trajectories		80% of trajectories		95% of trajectories	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	3 d	6 d	48 d	46 d	-	-	-	-	-	-
0.01 gm^{-2}	4 d	7 d	49 d	46 d	-	-	-	-	-	-
1 gm^{-2}	33 d	30 d	57 d	55 d	-	-	-	-	-	-
10 gm^{-2}	-	-	-	-	-	-	-	-	-	-

Taiaroa Head

Taiaroa Head is renowned as the site of one of only two mainland albatross breeding colonies in the world. It is also home to yellow-eyed penguins and New Zealand sea lions. Tourism relying on the regular return of these animals from the sea to land is believed to generate at least $100 million dollars annually for Dunedin's local economy. estimated oil density in gm^{-2} for different probability at Taiaroa Head

Time from blowout	**Worst spill scenario**		**50% of spills**		**80% of spills**		**95% of spills**	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.1	14.9	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	0.5	18.3	0.0	0.0	0.0	0.0	0.0	0.0
1 month	0.9	21.2	0.0	0.0	0.0	0.0	0.0	0.0
2 months	2.0	23.4	0.0	0.0	0.0	0.0	0.0	0.0
76 days: spill ends	17.1	23.7	0.0	0.0	0.0	0.0	0.0	0.0
3 months	17.1	23.8	0.0	0.0	0.0	0.0	0.0	0.0
4 months	17.1	23.8	0.0	0.0	0.0	0.0	0.0	0.0
5 months	17.1	23.8	0.0	0.0	0.0	0.0	0.0	0.0
6 months	17.1	23.8	0.0	0.0	0.0	0.0	0.0	0.0

percentage of spills for different levels of concern at Taiaroa Head

presence of oil		**0.01 gm^{-2}**		**1 gm^{-2}**		**10 gm^{-2}**	
summer	winter	summer	winter	summer	winter	summer	winter
27%	27%	21%	25%	0%	4%	0%	0%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories at Taiaroa Head at various levels of concern

	first spill		**mean total spills**		**50% of trajectories**		**80% of trajectories**		**95% of trajectories**	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	7 d	4 d	53 d	42 d	-	-	-	-	-	-
0.01 gm^{-2}	7 d	4 d	52 d	46 d	-	-	-	-	-	-
1 gm^{-2}	71 d	26 d	76 d	53 d	-	-	-	-	-	-
10 gm^{-2}	-	-	-	-	-	-	-	-	-	-

Chatham Islands

The Chatham's are home to a great diversity of seabirds, including the critically endangered Magenta petrel. These islands also provide habitat for many marine mammals, including New Zealand sea lions and fur seals, leopard seals, and southern elephant seals. The abundant and diverse bird life and marine life is essential for supporting the livelihoods of the 600 or so permanent residents of the Chatham Islands through fishing, conservation and tourism. estimated oil density in gm^{-2} for different probability in Chatham Islands

Time from blowout	Worst spill scenario		50% of spills		80% of spills		95% of spills	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1 month	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 months	5.5	12.9	0.0	0.0	0.0	0.0	0.0	0.0
76 days: spill ends	10.8	17.2	0.0	0.9	0.0	0.0	0.0	0.0
3 months	18.7	21.4	0.4	2.0	0.0	0.0	0.0	0.0
4 months	19.7	27.1	2.0	3.9	0.1	0.1	0.0	0.0
5 months	19.7	27.1	3.9	5.0	0.8	0.2	0.0	0.0
6 months	19.7	27.1	4.4	5.1	0.9	0.4	0.1	0.0

percentage of spills for different levels of concern in Chatham Islands

presence of oil		0.01 gm^{-2}		1 gm^{-2}		10 gm^{-2}	
summer	winter	summer	winter	summer	winter	summer	winter
97%	90%	95%	84%	30%	31%	0%	0%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories in Chatham Islands at various levels of concern

	first spill		mean total spills		50% of trajectories		80% of trajectories		95% of trajectories	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	35 d	26 d	82 d	65 d	79 d	61 d	109 d	100 d	148 d	-
0.01 gm^{-2}	38 d	32 d	86 d	67 d	84 d	65 d	119 d	114 d	-	-
1 gm^{-2}	64 d	64 d	109 d	101 d	-	-	-	-	-	-
10 gm^{-2}	-	-	-	-	-	-	-	-	-	-

Bounty Islands

The Bounty Island group is a tiny outcrop of granite in a huge expanse of ocean. Despite its size and isolation, it is teeming with life and is a major hotspot for oceanic birds, including erect-crested penguins and Salvin's albatrosses. It is also home to the world's rarest species of cormorant, the Bounty shag, of which only 500 or so individuals remain.estimated oil density in gm^{-2} for different probability in Bounty Islands

Time from blowout	**Worst spill scenario**		**50% of spills**		**80% of spills**		**95% of spills**	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
one week	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
two weeks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1 month	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 months	7.8	3.5	0.0	0.0	0.0	0.0	0.0	0.0
76 days: spill ends	8.8	4.0	0.1	0.0	0.0	0.0	0.0	0.0
3 months	8.8	4.4	0.1	0.1	0.0	0.0	0.0	0.0
4 months	8.8	4.4	0.3	0.5	0.1	0.0	0.0	0.0
5 months	8.8	4.4	0.3	0.5	0.1	0.0	0.0	0.0
6 months	8.8	4.4	0.3	0.5	0.1	0.0	0.0	0.0

percentage of spills for different levels of concern in Bounty Islands

presence of oil		**0.01 gm^{-2}**		**1 gm^{-2}**		**10 gm^{-2}**	
summer	winter	summer	winter	summer	winter	summer	winter
92%	81%	84%	73%	0%	0%	0%	0%

predicted times of arrival of the fastest spill, the average of all the spills that hit the coast and of different percentage of trajectories in Bounty Islands at various levels of concern

	first spill		**mean total spills**		**50% of trajectories**		**80% of trajectories**		**95% of trajectories**	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
presence of oil	30 d	30 d	74 d	75 d	70 d	81 d	109 d	136 d	-	-
0.01 gm^{-2}	33 d	32 d	81 d	79 d	81 d	90 d	133 d	-	-	-
1 gm^{-2}	76 d	-	85 d	-	-	-	-	-	-	-
10 gm^{-2}	-	-	-	-	-	-	-	-	-	-