NAVIGATUS CONSULTING

Main Report

Financial Assurance Review – Integrated Damages Assessment Model

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Prepared by Navigatus Consulting Ltd on behalf of:

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Ministry of Transport

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1. Executive Summary

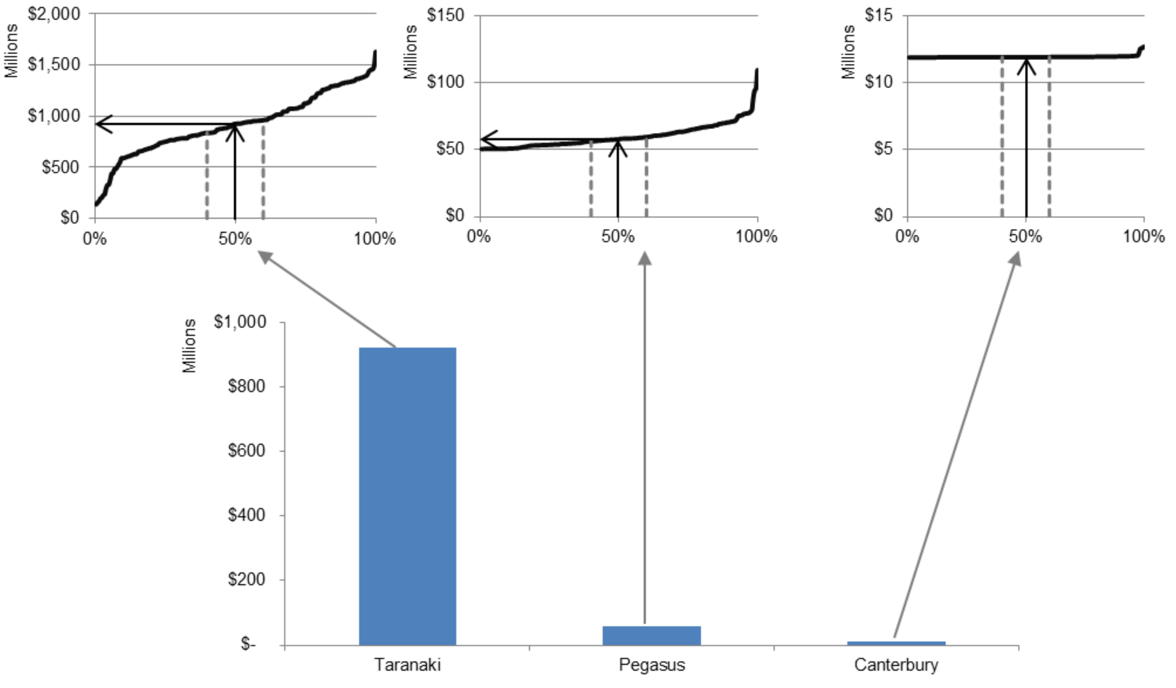
The Ministry of Business, Innovation and Employment (MBIE) and the Ministry of Transport (MoT) contracted Navigatus Consulting to quantify the financial liabilities that could arise from oil exploration, development and production. The estimates are intended to help inform decision-making by MBIE and MoT in quantifying financial assurance amounts in their review of the financial security regime for offshore installations.

The *Oil Spill Cost Study – OPOL Financial Limits* report (OPOL, 2012) was used as the basis for this study, but adjustments were made for New Zealand conditions and some other advancements were made to the method. Spill modelling was undertaken for three hypothetical well locations – one in each of the Deepwater Taranaki Basin, the Canterbury Basin, and the Pegasus Basin. These basins were chosen based on MBIE's understanding of contingent forward drilling programmes. The modelling was based on the effects of pollution damage from a 120-day period of spilling.

The direct cost of pollution damages on tourism, fisheries and clean-up costs were estimated by using a hybrid approach of case studies and applied science to inform the assessment of the form and scale of likely impacts.

Navigatus developed a model to combine the outputs of oil spill modelling with the estimated damages. The main output from the model was a probability density function of damages for each of the basins (based on 200 modelled spills for each basin), as shown in Figure 1.1 below.

Figure 1.1 Modelled median and probability distribution of total damages for Taranaki, Pegasus and Canterbury



The estimated median damages levels are $926, $58 and $12 million respectively for Deepwater Taranaki, Pegasus and Canterbury for the scope of damages evaluated in this assessment.

Results showed damages were strongly related to location in relation to prevailing winds (locations where prevailing winds blow onshore will likely have significantly greater effects than east coast locations). Damages were also strongly related to spill volume and oil type - persistent oils have a much larger effect on the damages and shoreline clean-up than non-persistent oils.

The results of this study lend support to consideration of varying financial assurance amounts based on factors such as well location, nature of activity (production or exploration), and whether the reservoir requires pressure support.

While there are limitations to the modelling, which are discussed in this report and in the supplementary technical reports, the results of modelling are considered suitable to inform the MBIE and MoT Financial Assurance Review.

2. Introduction

2.1. Project Background and Aim

The Ministry of Business, Innovation and Employment (MBIE) and the Ministry of Transport (MoT) contracted Navigatus Consulting to quantify the financial liabilities that could arise from oil exploration, development and production.

If an incident occurs at an offshore installation, the operators are liable for costs relating to the incident, including pollution damages and clean-up costs. Operators are required under Marine Protection Rule Part 102 to provide evidence of financial assurance (e.g. insurance or other financial security) to at least the minimum specified amount – currently about NZ$30 million.[1]

MBIE and MoT consider the current minimum specified assurance amount to be insufficient to cover the impacts of an offshore installation spill. The recent Rena spill, while not an offshore installation, had clean-up costs alone of NZ$47 million (Ministry of Transport 2014).

The purpose of this study is to estimate the likely damages that would arise from an offshore installation spill. The results are intended to be relevant for petroleum activities that could reasonably take place over the next five years (2015-2020).

This estimate is intended to help inform decision-making by MBIE and MoT in quantifying a financial assurance amount in their review of the financial security regime for offshore installations.

2.2. Project Scope

For this study, spill modelling was undertaken for three hypothetical well locations – one in each of the Deepwater Taranaki Basin, the Canterbury Basin, and the Pegasus Basin. The modelling was based on the effects of pollution damage over a 120-day period.

The well locations in the model were intended to be representative, not actual.

Comment has also been provided on the likely nature and scale of consequences arising from spills from operations in existing producing fields in the South Taranaki Basin.

The project required the direct costs of the oil spill to be estimated, including direct costs on tourism and fisheries, as well as the clean-up costs.

The direct financial costs were defined as:

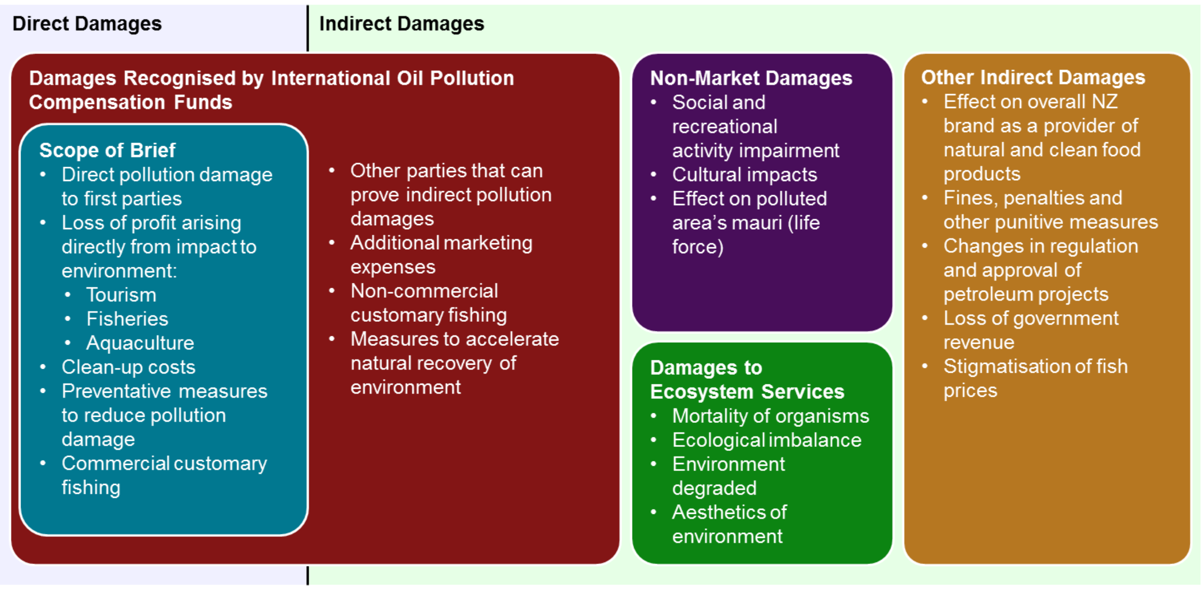
- Damage to other parties
- Costs incurred by public agencies in preventing and cleaning up a spill
- Costs of reasonable measures of reinstatement of the environment
- Losses of profit from impairment of the environment

[1] The current specified amount is 14 million International Monetary Fund Units of Account (as at 5 August 2015, 1 International Monetary Fund Unit of Account is equal to NZ$2.13).

The project scope does not include the cost of well control by the operator. Costs of dispersant application are presented separately.

Figure 2.1 below shows costs inside and outside the scope of the project brief, as interpreted by the project steering group. This includes parties that directly collect, catch or grow marine species commercially, and excludes activities such as downstream fish processing.

Figure 2.1 Damages inside and outside scope of project brief



2.3. Reports Produced

This report summarises the model method, technical findings, and results from the modelling and a discussion of these results. A summary of industry feedback on the draft version of this report is provided in Addendum 1.

In addition to this report, there are five technical reports covering work undertaken to inform the modelling in further detail:

- New Zealand Oil Spill Flow Rate Forecasts for Selected Offshore Basins (Prof. Rosalind Archer, University of Auckland)
- Oil Spill Modelling Study (RPS-APASA)
- Method for Estimating Damages to Tourism (Navigatus Consulting 2015c)
- Method for Estimating Damages to Fisheries (Navigatus Consulting 2015b)
- Method for Estimating Clean-up Costs (Navigatus Consulting 2015a)

A disclosure statement for authors and peer reviewers involved in the production of these reports is available in Appendix A.

3. Method

The project used a hypothetical well location in each of the following basins:

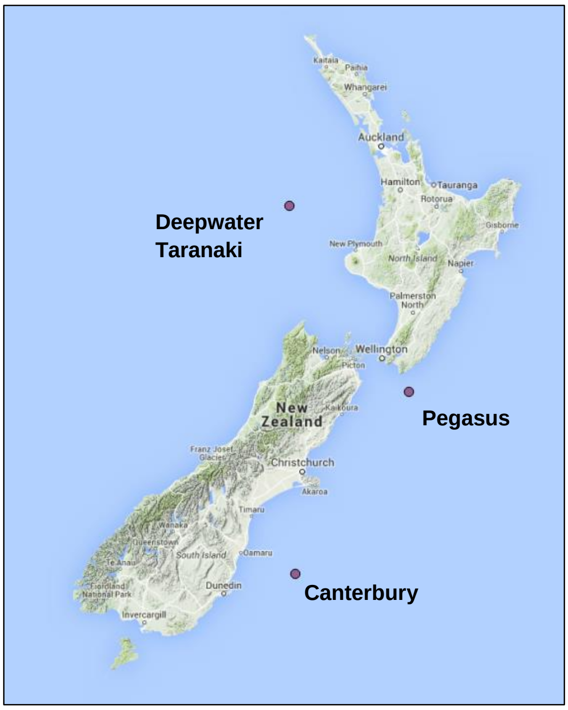
- Deepwater Taranaki
- Canterbury
- Pegasus

These basins were chosen to be representative of areas where petroleum activity may occur in the next five years.

MBIE provided the proposed representative well locations for each basin – they are located in the approximate centroid of the permitted area for which there is upcoming contingent drilling in each basin.

Pollution damages for each well location were estimated by developing an Integrated Damages Assessment model.

Figure 3.1 Hypothetical well locations

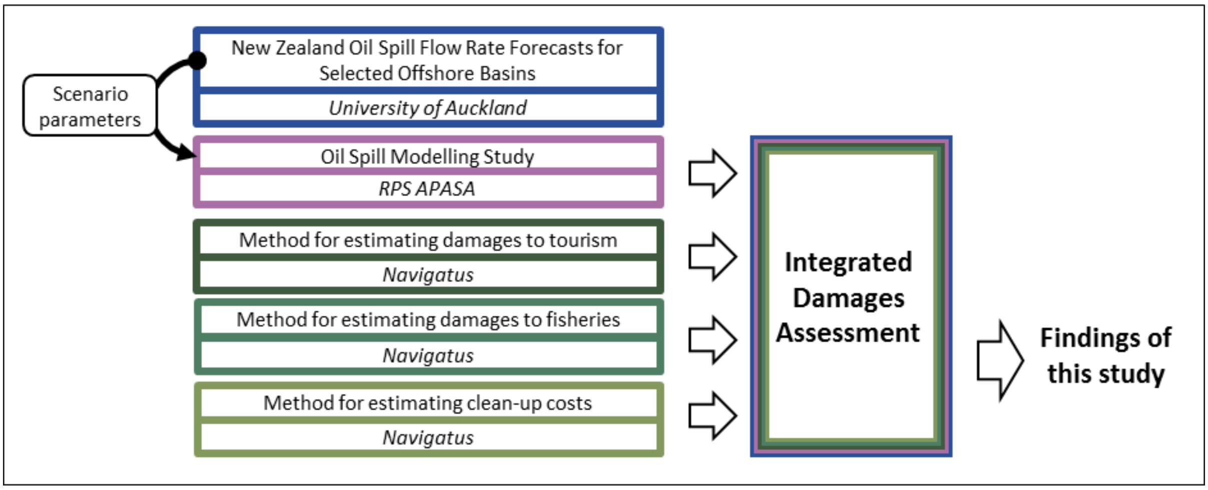


The Integrated Damages Assessment combined outputs from oil spill modelling and estimated direct costs from a spill (fisheries, tourism, and clean-up costs).

The method assumes a spill period of 120 days, which allows sufficient time to drill a relief well.

Figure 3.2 below shows how the technical reports feed into the Integrated Damages Assessment.

Figure 3.2 Overall method for Financial Assurance Review



The brief (see Appendix B) required that the method for this Financial Assurance Review use the *Oil Spill Cost Study – OPOL Financial Limits* (OPOL, 2012) as a basis, with modifications made to suit New Zealand conditions and to allow for some advancements in method to be made. A comparison to the OPOL study is provided in Section 3.4.

3.1. Damage Estimates

The cost of pollution damages on tourism, fisheries and clean-up costs were estimated by using a hybrid approach of case studies and applied science to inform the assessment of the form and scale of likely impacts. The methods are formally documented in the technical reports and have been peer reviewed. The damage estimates only take into account direct costs, as per the scope of the brief (refer back to Figure 2.1).

3.1.1. Fisheries

For damages to fisheries, case studies of what damages actually resulted from historical major spills in temperate waters form an important component to this assessment.

The method uses best available marine farm data, commercial catch data and seafood port prices to estimate pollution damages to fisheries.

The estimates take into account the value of different species and the length of time harvesting or catching fish species is prohibited due to oil spills. The full method is available in the technical report *Method for Estimating Damages to Fisheries*.

3.1.2. Tourism

For damages to tourism, the method advice commissioned by Navigatus from the New Zealand Institute of Economic Research was used and combined with Navigatus research on the observed effects of recent major oil spills on tourism.

The method used three parameters - initial impact, duration, and speed of recovery.

The method is stylised due to the small number of relevant case studies and the difficulty distinguishing spill effects from other effects. Case studies were drawn on as the best available source of information. The full method is available in the technical report *Method for Estimating Damages to Tourism*.

3.1.3. Clean-Up Costs

The scope of this model is limited to physical oil spill containment, recovery and clean-up costs. In this respect, “recovery” refers to recovering the oil from the water.

Case studies were used to estimate the costs of clean-up, which were calculated based on implementing the National Oil Spill Contingency Plan, and guided by industry best practice.

The full method is available in the technical report *Method for Estimating Clean-up Costs*.

3.2. Oil Spill Forecasting and Modelling

More detail on oil spill forecasting and modelling is given in Section 4 Technical Findings and in the technical reports. In summary, a 120-day oil spill was modelled for each of the three basins using the three-dimensional oil spill model (SIMAP). There were 200 oil spill trajectories modelled for each of the well locations. Outputs of each trajectory included extent of shoreline oiled and amount of oil washed ashore.

3.3. Integrated Damages Assessment Model

The Integrated Damages Assessment model implements the methods for estimating damages (as detailed in the technical reports) using the oil spill modelling results for each of the 200 trajectories to determine the total cost of response. Appendix C provides more information on the Integrated Damages Assessment model.

3.4. Comparison to OPOL Oil Spill Cost Study Method

The project brief suggested that the *Oil Spill Cost Study – OPOL Financial Limits* report (OPOL, 2012) should be used as the basis for this Financial Assurance Review. Accordingly, this study applied the OPOL method to New Zealand conditions with some advancements.

The main advancement was to include the oil spill modelling directly within the Integrated Damages Assessment, rather than using a single ‘worst case’ scenario as in the OPOL method. This allows pollution damages from all modelled scenarios to be evaluated and avoids the need to pick a scenario based on a metric such as the quickest time of arrival on shore.

This advancement in method means the Integrated Damages Assessment provides a probability density function of damages, which will help inform decision-making on the required level of financial assurance.

A key difference in method was setting a timeframe based on re-establishment of well control by relief well drilling (as specified in the brief), rather than a cap being successfully deployed. This difference was due to the intention of the modelling to determine the level of financial assurance required, rather than expected damages.

4. Technical Findings

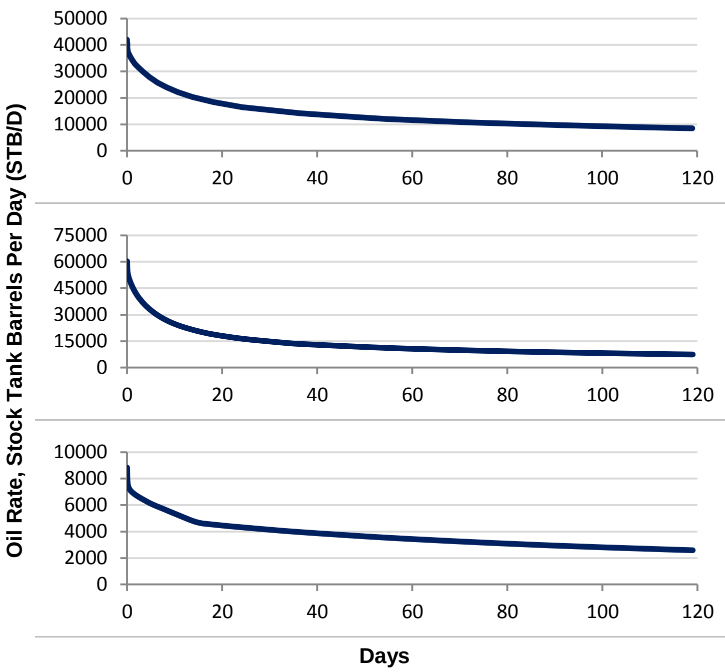
This section summarises technical findings from the oil spill forecasting and modelling.

4.1. Oil Spill Forecasting

Prof. Rosalind Archer, University of Auckland, was commissioned to assess reservoir characteristics and to forecast a maximum credible oil release scenario for each of the three basins. The full details of this assessment are given in the technical report *New Zealand Oil Spill Flow Rate Forecasts for Selected Offshore Basins*.

Figure 4.1 shows the forecast oil flow rate profile for each of the basins over 120 days, as well as the assumed oil type, reservoir pressure and oil depth for each basin.

Figure 4.1 Oil spill forecast profiles for Deepwater Taranaki, Pegasus, and Canterbury basins



Deepwater Taranaki
Oil type
31 API oil (0.87 specific gravity)
Pressure
5950 psi
Representative oil depth (below sea level)
4,000m

Pegasus
Oil type
47.6 API oil (0.79 specific gravity)
Pressure
8490 psi
Representative oil depth (below sea level)
3,500m

Canterbury
Oil type
51 API oil (0.775 specific gravity)
Pressure
3900 psi
Representative oil depth (below sea level)
2,500m

The maximum credible oil spill release over 120 days was modelled for each basin. Deepwater Taranaki and Pegasus had similar forecasted total spill volumes – approximately 1.5 million barrels. In contrast, the forecast total spill for Canterbury was less than a third of this volume.

New Zealand crude oils tend to have a distinct combination of liquid fractions, which have low persistence, and heavier waxes and long chain hydrocarbons which are more persistent in the environment. Generalised assessment of oil fate and persistence using international five step classifications[2] are not sufficiently accurate for the purposes of this study. Accordingly, specific modelling based on the predicted oil properties was commissioned.

[2] For example, see ITOPF (2014a).

4.2. Oil Spill Modelling

RPS APASA was commissioned to undertake oil spill modelling for each of the three basins. Full detail of the modelling is provided in the technical report *Oil Spill Modelling Study*.

The modelling was informed by the oil spill forecasting undertaken by Prof. Rosalind Archer (see Section 4.1).[3] Modelling undertaken used the closest oil type analogues available to those identified in the oil spill forecasting. Note that spill modelling requires making assumptions and these assumptions may differ to spill modelling undertaken by others. The differences in assumptions will lead to differences in overall results (for example, spill volume).

Modelling was undertaken by:

- Developing a ten year current dataset that included the combined influence of three-dimensional ocean and tidal currents; and
- Using currents, spatial winds and oil properties as inputs in the three-dimensional oil spill model (SIMAP) to simulate drift, spread, weathering and fate of the spilled oil.

The model calculated transport, spreading, entrainment and evaporation of spilled hydrocarbons over time. The model ran 200 spill trajectories for each of the three basins so that each trajectory was subject to different wind and current conditions (and consequently different movement and weathering of oil/condensate). Results were reported to a minimum of 0.5 g/m^2 – which is below levels that would cause ecological harm but which may still trigger temporary closure of fishing areas due to its visibility.

Table 4.1 Summary of results for Deepwater Taranaki, Pegasus and Canterbury basins[4]

Deepwater Taranaki	***Spill volume***	1.56 million barrels
	Oil type	Maari crude proxy
	Trajectories reaching shoreline	200 (100%)
	Minimum days to reach shore	13 days
Pegasus	***Spill volume***	1.49 million barrels
	Oil type	Pohokura condensate proxy
	Trajectories reaching shoreline	195 (97.5%)
	Minimum days to reach shore	8 days
Canterbury	***Spill volume***	0.43 million barrels
	Oil type	Pohokura condensate proxy
	Trajectories reaching shoreline	1 (0.5%)
	Minimum days to reach shore	51 days[5]

[3] The modelling used earlier total spill volume estimates than those presented in the final report *New Zealand Oil Spill Flow Rate Forecasts for Selected Offshore Basins*. The difference in total spill volume was 2.2% for Pegasus and approximately 0.5% for Deepwater Taranaki and Canterbury. Analysis found these differences would have no material effect on the results.

[4] Based on 200 spill trajectories. Minimum number of days to reach shore uses a threshold of 20 barrels of weathered oil accumulated ashore and is recorded as the first time this threshold is reached.

[5] In two other model runs oil arrived sooner (after 2.8 days), however the quantity of oil ashore was below the 20 barrel reporting threshold.

4.3. Notable Features of Oil Spill Forecasting and Modelling

- Declining flow rate
  - The oil spill forecasting predicts a declining flow rate due to pressure decline in the reservoir, and this declining flow rate is used in the modelling. In most models, this is either simplified to a point discharge or to a constant flow rate. This declining flow rate enables the model to align more closely to the reality of significant oil spills
- Geological Parameters
  - Comparative to other countries, little information is available on offshore drilling in New Zealand. Information available included existing well reports in the public domain (for example, in the Deepwater Taranaki and Canterbury basin) but no wells have been drilled in the Pegasus Basin. This meant that the forecasts are in many ways generic estimates that should be treated with appropriate caution.
- Forecasting Assumptions
  - While it is not an objective of this study to identify a worst case, the Society of Petroleum Engineers recommend that analysis of loss of well control events should seek to estimate a 'worst case discharge'. Essentially this is a case where the shear rams in the blow out preventer have completely failed and the drill string has been removed to leave a completely free flowing bore. Use of the worst case discharge is a conservative element of the analysis, which will tend to bias the cost estimates towards the upper end of the likely range.
- Modelled 200 runs with weathering rather than one run
  - The modelling included weathering in each of the 200 trajectories. Other models more commonly use a weathering model for a single worst-case run. Including weathering in each of the trajectories gives more robust results.
- Holding capacity of shoreline
  - The model uses a simplified array of shoreline types that each have a specific 'holding capacity' for oil (e.g. how much of the oil will wash ashore). This is different from many oil spill models that have 'sticky' shores, whereby all oil reaching the shoreline will wash ashore. Using a holding capacity is a significant advancement as it better represents the scenario where oil that cannot land ashore is transported to new locations by wind and tide.
- Models oil on surface and in water column
  - Interchange between entrained and surface oil is modelled according to sea conditions. The model then transports entrained and floating oil separately, taking account of the effects of current and wind where appropriate.

5. Major Spill Pollution Damages

In order to determine the damage estimates for each trajectory and basin, the results of the fate and transport modelling were combined with the methods outlined in the Tourism, Fisheries and Clean-up Cost technical reports in the Integrated Damages Assessment model, as per Appendix C. This results in damage estimates for each of the 200 modelled trajectories for each basin. These results are summarised in this section.

Each model run represents historical weather and ocean conditions taken from different points in time. As such, some runs will represent extreme weather, and others represent weather patterns that occur more regularly. The following figures reflect the proportion of runs where total damages were less than or equal to a given value for each basin.

Each run has a different make-up of damages due to differing trajectories of oil and consequent impacts. The estimated probability distribution of total damages for each location is shown in Figure 5.1. Table 5.1 shows the average contribution of each of the modules to the 20% of runs in the central quintile of assessed damages (i.e. where 40% of runs had damages less than and more than the trajectory). The average estimated damages for all quintiles is available in Appendix D.

Figure 5.1 Estimated probability distribution of total damages

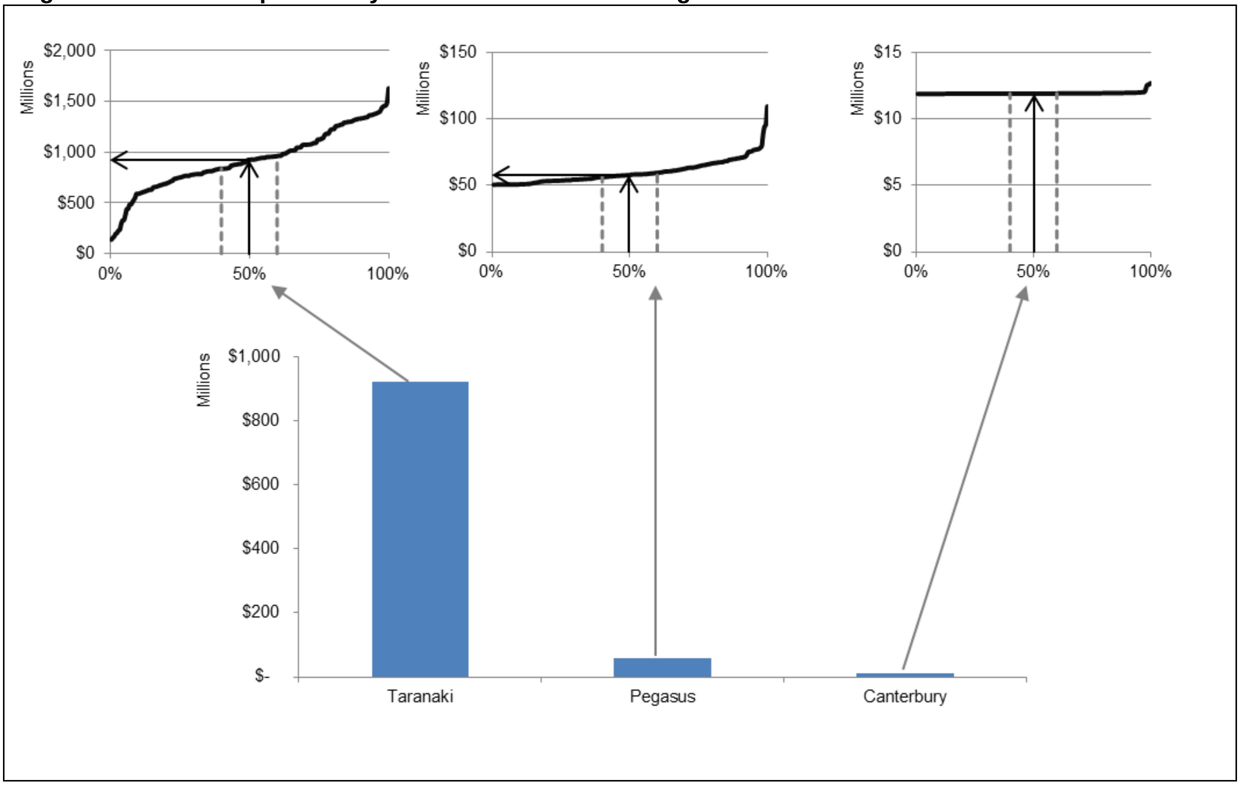


Table 5.1 Breakdown of the total assessed damages for middle quintile

	Deepwater Taranaki	Pegasus	Canterbury
Tourism	13.3%	0.0%	0.0%
Fisheries	0.4%	2.8%	0.3%
Clean-up	86.3%	97.2%	99.7%

These estimated damages exclude well control undertaken by the operator and costs of dispersant application by either the operator or by Maritime New Zealand.

Deepwater Taranaki has the highest assessed damages. This reflects the more persistent nature of the modelled oil for this well, the estimated spill volume, and the estimated volume of oil reaching the shore. Due to the persistence of the oil, the oil remains on the sea surface for longer, leading to larger fisheries closures, which is reflected in larger damages. In addition, oil tends to reach more distant coastal cells thereby requiring additional clean-up and management teams and impacting tourism in further communities.

The Canterbury well has the lowest assessed damages. This reflects the fact that only one cell was oiled during one run.

The assessed damages for the Pegasus well are slightly higher than the Canterbury well. Both the Pegasus and Canterbury well have the same, less persistent, modelled oil type. This difference in the results for the two wells also reflects the generally favourable offshore weather and ocean conditions at the modelled well locations. The Canterbury well has more prevailing offshore winds, which kept the oil away from the shore in all but one modelled trajectory.

The following tables explore each component of the fisheries and clean-up costs for the trajectories that resulted in the middle quintile of total assessed damages.

Table 5.2 Breakdown of the damages for the fisheries module for the middle quintile

	Taranaki	Pegasus	Canterbury
Mussels	14%	0%	0%
Oysters	29%	0%	0%
Salmon	7%	83%	0%
Finfish	49%	16%	100%
Paua	0%	0%	0%
Lobster	1%	1%	0%

Estimated fisheries damages for Deepwater Taranaki are predominantly made up of closures to commercial fin-fisheries. This is in contrast to the Pegasus fisheries module, where damages to the salmon industry are relatively larger.

The damages to salmon farming for the Pegasus scenario are predominantly comprised of defensive measures, including harvesting early at the first sign of oil or moving farms to a safer location. The threshold for instigating such measures is relatively low in the model, reflecting the caution that will likely be placed around ensuring the ongoing supply of produce.

A significant proportion of New Zealand oyster marine farms are located in the Kaipara Harbour. This location has a high probability of impact if a spill occurs from Deepwater Taranaki, but never from the Pegasus or Canterbury fields. This is reflected in the proportion of fisheries costs attributed to oysters for each well. Mussel farms were also more likely to be contacted by oil from the Taranaki well than the Pegasus well. Though the Pegasus well is closer to the Marlborough Sounds, oil does not often arrive on shore in sufficient quantities to affect many mussel farms. This may be reflective of the persistence of the modelled oils.

Paua and lobster fishing activities have shorter closure periods, which is reflected in the lower damage estimates for these components of the fisheries module.

As oil only appeared on shore in one cell for one run for the Canterbury well location, there were no damages to any of the nearshore fisheries in the middle quintile. All fisheries damages arose from wild commercial fin-fisheries in the vicinity of the wellhead.

Table 5.3 Breakdown of the damages for the clean-up costs module for the middle quintile

	Taranaki	Pegasus	Canterbury
Command and Control	12%	42%	38%
On-water Containment	2%	20%	47%
Reconnaissance	1%	8%	15%
Boom	4%	4%	0%
Shoreline Clean-up	67%	5%	0%
Waste Disposal	4%	1%	0%
Maui and Hectors	1%	0%	0%
Wildlife	9%	20%	0%

Command and control costs for Pegasus comprise a larger portion of clean-up costs than Taranaki. This is due to the baseline network of command centres activating on the first day of the spill and running until one week post spill (Level A, 1 Level B and 2 Level C). Whereas the shorelines may be cleaned up relatively quickly and at a lower cost, command centres are not demobilised until at least one week after the spill. In essence, the command and control network is activated and ready to respond, but the modelling suggests that oil does not often reach shore, and when it does so it is in relatively small quantities. This results in a relatively small overall clean-up cost.

6. Discussion

The purpose of this discussion section is to discuss the study results, while drawing attention to notable features and limitations of the work.

Each of the main modules of the modelling will be discussed in turn, followed by commentary on extending the results to other cases, an assessment of sensitivity and an overall comment on the strengths and limitations of the method.

6.1. Scope of Brief

In essence, the brief boils down to the following questions:

- What level of direct damages and clean-up costs might be caused by a loss of well control event?
- Should the same level of financial assurance be required for all offshore installations, regardless of location, nature of activity and expected oil type?

As stipulated in the brief, this project has generally followed the conceptual framework of the OPOL method. The general method has been applied to New Zealand conditions, while the transparency and rigour of the analysis has been lifted in some respects.

The adjustments to method required development of a suite of linked conceptual models to assess the effects on tourism and fisheries and to estimate clean-up costs over a wide range of conditions.

At the outset of this project, there were six prospective offshore basins with conditional drilling programmes identified (Figure 6.1). From these basins, three scenarios were selected, which were representative of the wider range. This approach was similar to the OPOL study.[6] While modelling a greater number of basins, cases and oil types would provide more information, this is not standard practice and would have a much higher cost.

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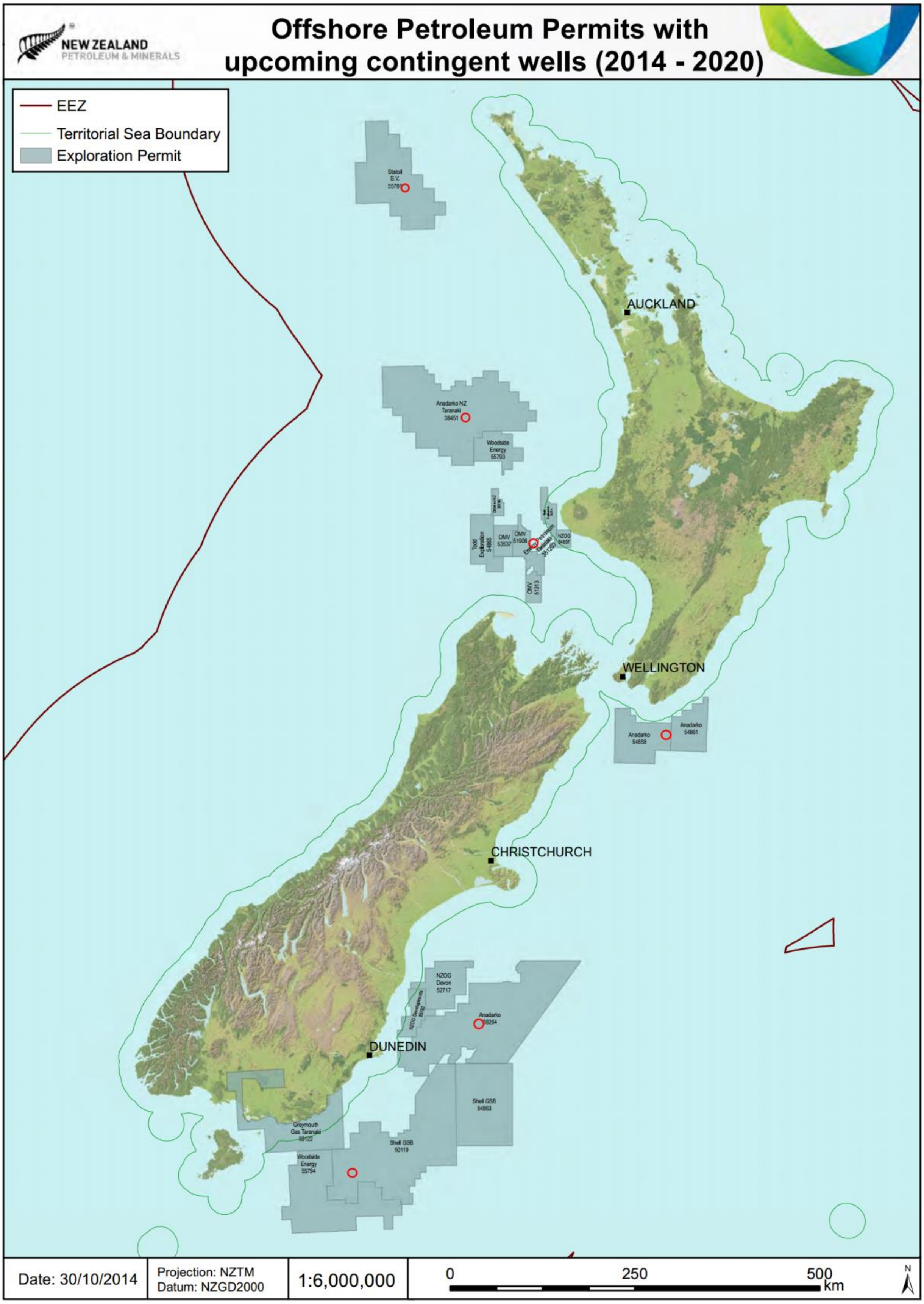
[6] The OPOL study modelled four representative locations for the United Kingdom. Two proportions of oil reaching shore were modelled for each location (low and high). This study considered three prospective spill locations (Deepwater, Pegasus, and Canterbury) in detail, as well as an additional six locations in the South Taranaki Basin (see Section 7).

Figure 6.1 Six prospective offshore basins with conditional drilling programmes



6.2. Duration of Loss of Well Control

The study brief called for the basis of well control to be the drilling of a relief well, on the assumption that the offshore installation was incapacitated. The analysis by Navigatus of the logistics of drilling such a well concluded that a 120-day duration could be expected (see Appendix E).

The analysis drew on case histories of relief drilling for the Montara and Deepwater Horizon incidents to estimate times to mobilise and drill a relief well (51 days and 93 days respectively). The 120-day timeframe is slightly beyond the outer edge of the envelope of industry estimates (for example, 80 – 115 days (Anadarko 2013)). A significant element is the time to contract and mobilise a drill rig. This study allowed for mobilisation from the vicinity of Singapore, whereas some operator assessments have assumed that a relief well rig would be mobilised from Western Australia.

A key assumption of the assessment is that a relief well drilling rig would be contracted within seven days of loss of well control. Mobilising such a rig is a major commitment and the decision would be taken within the context of a planned sequence of other interventions designed to bring the well under control at the earliest possible time. These range from remote actuation of blow-out preventer (BOP) shear rams, through to subsea remotely operated vehicle (ROV) actuation of the BOP via ROV-operated control panel, and installation of a capping device.

It was a capping device that eventually brought the Deepwater Horizon well under control, following several failed attempts and rapid evolution of the capping design. Such capping devices are now routinely available for mobilisation as required. The Navigatus analysis suggests that such a device could be mobilised and installed in around 38 days. This is similar to industry estimates (Anadarko 2013).

Drilling a relief well is a proven technology and the study brief specified this method as the containment option. If a capping stack was successfully deployed in a shorter timeframe, the volume of oil discharged and resulting damages would also decrease substantially. On the other hand, if a relief well proves to be required, any delays in contracting and mobilising the rig, possibly while other interventions are attempted, will translate directly into a longer time that the well continues to spill.

6.3. Reservoir Assessment

The reservoir modeller did not have access to the detailed assessments of the petroleum companies and, in some cases, the companies themselves have not yet acquired or analysed the relevant seismic data. Accordingly, the reservoir assessment is not specific to a particular geologic formation, but is based on a notional reservoir located in the centre of the permitted exploration area. The reservoir parameters were selected based on the best available public domain information. However, the New Zealand offshore environment is under-explored and information is scarce. For instance one of the selected basins, Pegasus, has never been drilled.

The reservoir flow assessments are a critical model input, but cannot be known with accuracy in advance of drilling. The estimated flows must therefore be treated with caution.

The reservoir assessment is a worst case in one respect: it adopts a method of estimating the worst case discharge recommended by the Society of Petroleum Engineers (2010). In essence this assumes that the shear rams have not impinged on the flow and that the drill string is withdrawn, leaving a free flowing bore.

It is not a purpose of this assessment to adopt the worst-case scenario at each step of modelling; such an event is exceedingly unlikely. However, given the range of unknowns in the assessment of such reservoir flows it was considered by Navigatus that the worst case discharge, as recommended by the Society of Petroleum Engineers (Society of Petroleum Engineers 2010) and required by the US Department of Interior Bureau of Ocean Energy Management, was a suitable modelling input to the latter parts of the model, given the uncertainties of the reservoir information.

A feature of the reservoir model is that it assessed the reduction in flow over time, as pressure in the reservoir reduces over the course of the spill. This is recommended by the Society of Petroleum Engineers and is more realistic. Operators sometimes assume no reduction in flow as a worst case. The reservoir modelling for this study suggests that operators who use a constant flow, set at the initial flow rate, may be adopting a particularly conservative approach for New Zealand reservoir conditions.

6.4. Tourism

The tourism model draws heavily on case studies to estimate likely tourism impacts. This approach has three limitations. Firstly, there are very few instances of spills of similar scale in comparable situations. Secondly, definitive studies on tourism effects are rare in the literature. Thirdly, confounding effects are often present in tourism market data – such as method changes, currency movements, pandemics, financial crises, and natural disasters.

Literature searches in English, Spanish, French and Italian revealed few definitive studies. A personal visit to the county records office where the Sea Empress spill occurred in 1996 also provided little new information. The Deepwater Horizon spill is an obvious case history, but the region was recovering at that time from both Hurricane Katrina and the 2008 financial crisis. The year of the spill marks an obvious break point in the relative market share of the affected states, but they had then recovered at or near previous levels, so no firm conclusions can be drawn. Examination of the MV Rena spill on tourism in Tauranga was similarly inconclusive; in part because of the limitations in tourism survey data.

The best documented case history is the 2002 Prestige tanker spill. The Prestige tanker, carrying heavy fuel oil, broke up and eventually sank about 200 km offshore in the North Atlantic Ocean. The northern coast of Spain was heavily affected, with the region of Galicia being hardest hit. The tourism method draws on this case history to estimate the likely depth and duration of effect.

One caution is that Galicia has similarities to New Zealand, but is also an area of rich cultural heritage. Accordingly, present day tourism activities in Galicia are less orientated to coastal outdoor activities than is typical in New Zealand. While New Zealand is not marketed overseas as a beach holiday destination, the differences in tourism market profile between present day Galicia and present day New Zealand may infer that tourism impacts derived from the Prestige case history are possibly a lower bound estimate.

Tourism effects were assessed at a territorial local authority level, depending on the modelled amount of oil that washed ashore. Potential effects on the overall New Zealand tourism brand were not included, as these were not within the scope of the brief (which called for direct effects).

6.5. Fisheries

Impacts on fisheries were considered in two broad groups, aquaculture and commercial fisheries.

Effects on three aquaculture crops were assessed: mussels, oysters and salmon. The detailed assessment accounted for likely defensive measures and residual losses. Costs of defensive measures, crop losses due to oiling, and clean-up costs were included in the model. The assessment was undertaken on a coastal cell basis, where the New Zealand coastline is broken into approximately 300 coastal cells.

Aquaculture impacts were assessed on a coastal cell basis. The analysis included all consented water space except for large undeveloped offshore farms. The aquaculture technology to successfully farm in those rough conditions has not yet been developed to commercial viability and may not be within the year 2020 study planning horizon.

Losses were dependent on both the quantity of weathered oil arriving in the coastal cell and the number of days of oiling.

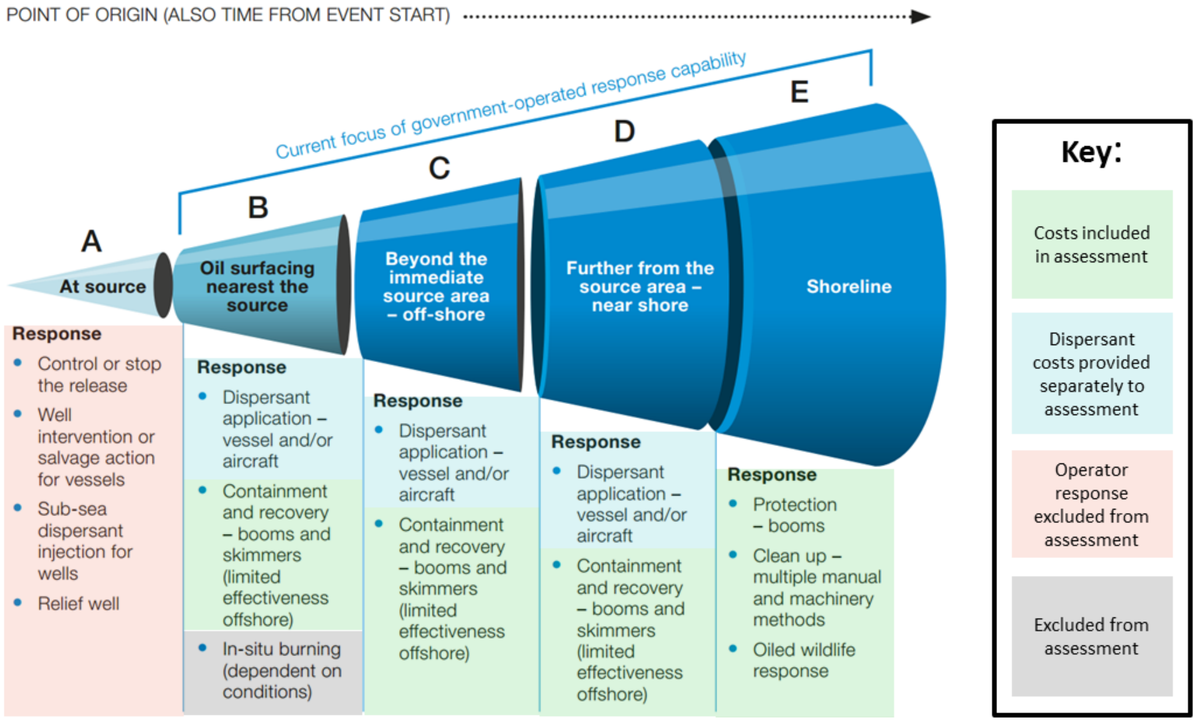
Commercial fishing impacts were assessed for the top 15 species by landed value. Fin fisheries impacts were modelled for each trajectory, taking into account the geographic distribution and port price of each species. Pāua and lobster damages were assessed separately.

The main effect on commercial fishing arose from partial closure of fin-fishing grounds during and after the spill. The assessment excluded the effects of stigmatisation on fish prices as this was beyond the defined scope. Evaluation of downstream effects through the processing and distribution supply chain was also outside the defined scope.

6.6. Clean-Up Costs

Clean-up costs were based on implementing the National Oil Spill Contingency Plan, and guided by industry best practice. The clean-up model applied the cone of response approach adopted by Maritime New Zealand (Figure 6.2).

Figure 6.2 Cone of response model from New Zealand Marine Oil Response Strategy 2015-2019 (Maritime New Zealand 2014). Key added by Navigatus to show relationship to damages in assessment.



Under the cone of response approach, the operator is responsible for wellhead activities, including subsea dispersant injection (SSDI), if applicable for the oil type.

The main method of shoreline clean-up in the model is manual pickup, with machinery handling thereafter. This is consistent with the method used for the Rena spill and produces low volumes of waste per unit of weathered oil washed ashore.

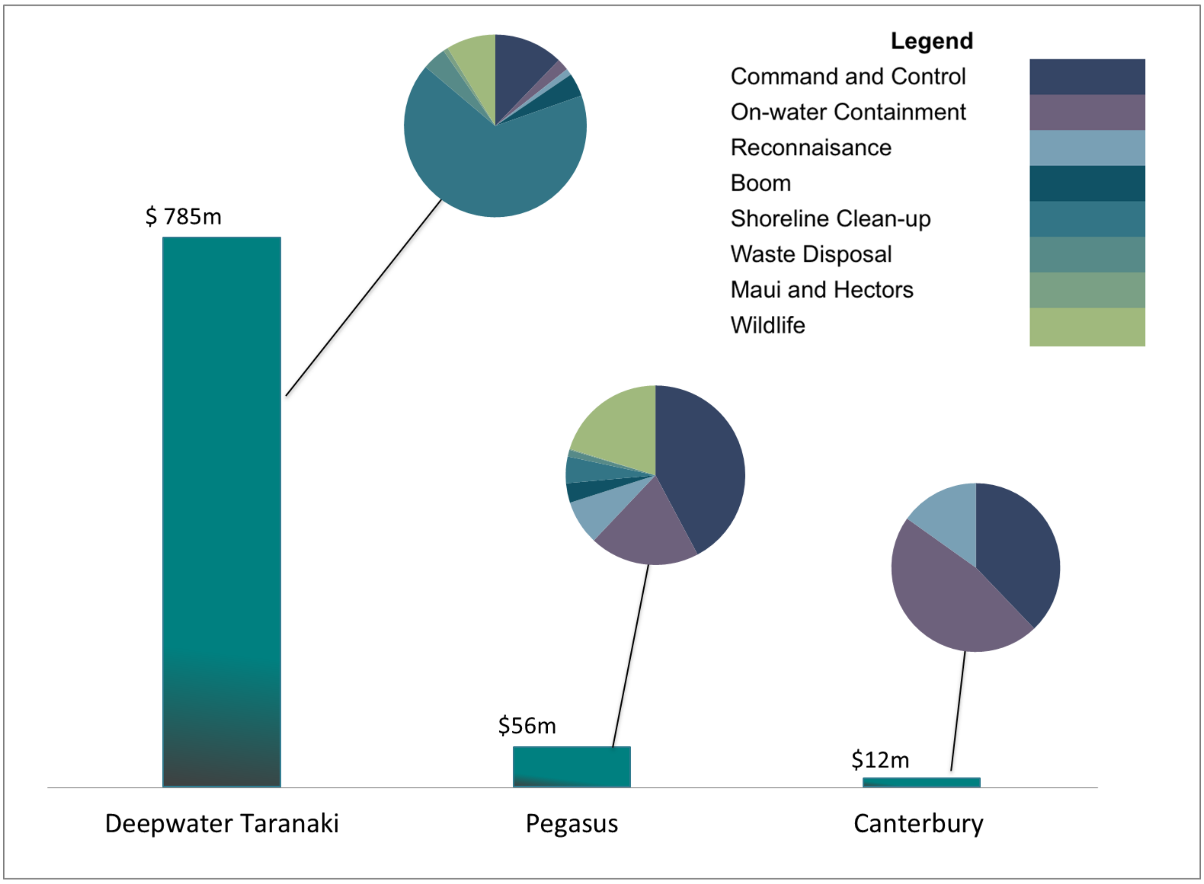
An issue for any spill clean-up is sourcing labour. This issue would be magnified for clean-up on the scale of the Deepwater Taranaki spill modelled in this study and could constrain some aspects of the response. The model allows for the difficulty in sourcing larger pools of labour by allowing for an uplift in cost to account for heavier duties labour used in shoreline pick-up to be sourced from inland areas, out of the region concerned.

6.7. Clean-Up Costs Composition

A comparison of clean-up costs for the three modelled scenarios is presented in Figure 6.3 below. It is apparent that:

- The range of estimates is high; and
- The breakdown of costs varies significantly between scenarios.

Figure 6.3 Breakdown of clean-up costs for middle quintile



For the three scenarios modelled in this study, attention was paid to ensuring that the type and scale of command and control related resources was appropriate to each spill. Case studies, such as the Montara spill in Australia, were drawn on to inform those considerations. As a result, the command and control varies between modelled spills, depending on factors such as the likely volumes and locations of oil ashore.

The command and control network was modelled on a flexible basis, consisting of a baseline network for each spill, supplemented by “contingent” command centres that were activated if oiling reached additional areas. This flexible approach, intended to reflect how a real oil spill response is likely to unfold, results in different compositions of cost for each modelled spill run and for each spill scenario. A notable feature of the model is that command and control costs vary significantly in relation to shore clean-up costs. As the volume of oil ashore increases, the command and control decreases as a proportion of overall costs (i.e. the response becomes more efficient).

The Deepwater Taranaki spill response appears efficient, as command and control is a low proportion of overall costs. This is influenced by the larger volumes of oil ashore, which require repetitive bulk cleaning from a generally static command network.

In all of the scenarios, the clean-up costs do not include the operator costs of response and well control such as drilling a relief well. In the Montara spill, the spill response alone was reported to have cost NZD$5.8 million[7] at the time that well control was re-established, but overall costs later reported by the operator amounted to NZD$354 million.[8]

6.8. Dispersants

A range of oil spill control agents are available to responders. Marine Protection Rules Part 132 covers the use of dispersants and demulsifiers (Maritime New Zealand 2010).[9] Chapter 7 of the National Oil Spill Contingency Plan covers the uses of dispersants (Maritime New Zealand 2013b). Dispersants are not suitable for all oil types and situations. An MNZ publication, *Guidelines for the Use of Oil Dispersants in New Zealand*, sets out criteria for deciding whether to use dispersants and defines areas where dispersants should not be used.

Costs of surface application of dispersants by the responder are reported separately to the other clean-up costs as dispersant application may or may not be implemented, depending on the oil characteristics. The fate and transport model incorporates weathering of the oil but does not account for the effects of dispersant application. The shoreline clean-up costs are therefore those that would apply without dispersant application.

A feature of dispersant application that became apparent during the course of the study was the difficulty of applying aerial dispersants at the distance offshore that a deep-water rig may be located. Maritime New Zealand has developed, tested and trialled capability to apply dispersants out to 50 nautical miles offshore (90km), using agricultural aviation aircraft and helicopters. Such aircraft can typically operate at full payload out to around 90 nautical miles (180 km), which is short of the 250 km or more range that would be required for many deep-water drilling locations.

Flying part loads may increase range somewhat and alternatives, such as the spray-equipped Bandeirante aircraft currently available from Oil Spill Response Limited (OSRL) in Singapore, may be able to undertake the duty, operating at part load capacity due to both runway length and operating range. An OSRL spray-equipped Hercules could readily handle the duty, but is currently stationed in West Africa.

All costs associated with subsea dispersant injection by the operator are excluded from the above estimates. Dispersant application costs should not be simply added to the clean-up costs identified in this study as it could reasonably be expected that application of dispersants would reduce shoreline clean-up costs. The estimated cost of dispersant application is $83m for Deepwater Taranaki, $46m for Pegasus and $16m for Canterbury. This includes the purchase, airfreight and application of dispersants to 20% of the spilled oil

[7] $5.3 million AUD (WA Today 2009)
[8] $319 million AUD (Ryan & O'Brian 2010)
[9] Maritime New Zealand has been consulting with industry regarding expanding Part 132 to cover other types of oil spill control agents.

in Deepwater Taranaki. For Pegasus and Canterbury, the expected proportions of spilled oil treated are 10% and 5% due to the natural dispersibility of the lighter oils and likely direction of travel.

6.9. Other Pollution Damages Not Included in Assessment

The study focuses on three cost elements: tourism, fisheries and clean-up costs. Pollution damages can also arise in other sectors due to a sustained oil spill. For instance, ports may be closed due to the explosion risk of vapours collecting under wharfs, or ships may elect not to call to a port due to the risk of fouling the hull, which may preclude the ship from stopping at other ports, or necessitate a clean.

An analysis prepared by Navigatus for Maritime New Zealand in 2010 found that the effects of a short-term oil spill on ports was relatively small in relation to other spill effects (Navigatus Consulting, 2010). In summary, the effects of other pollution damages are expected to be relatively minor.

6.10. Sensitivity

The sensitivity analysis presented in Appendix F shows that the model is sensitive to:

- How quickly and fully the command and control network expands as the oil spreads; and
- The duration of tourism effects.

For spills affecting Auckland, damages were also sensitive to the degree of impact on Auckland tourism. Overall damages were not sensitive to any of the modelled parameters relating to fisheries impacts. The sensitivity to these factors suggests that any related uncertainties should be considered when assessing financial assurance requirements.

While the following factors are not tested in the sensitivity analysis, they are known to be key determinants of oil spill impacts (White & Molloy 2003; Kontovas et al. 2010; Kontovas et al. 2011):

- Oil type;
- Spill volume (oil flow rates and duration of spill);
- Location of spill; and
- Scope of damages included in assessment.

Inspection and comparison of the results from the three different scenarios modelled as part of this study confirms these are also important factors for New Zealand offshore oil spills.

6.11. General Relationship of Total Damages to Spill Volume

A question for policy implementation is whether it is possible to develop a rule of thumb that allows the effects of spills of different sizes to be compared. An example of such a question might be “what would the estimated damages be if well control was established in 90 days, instead of the 120 days adopted in this report?” Literature searches have not identified any method that has been developed specifically for offshore installations. However, extensive studies have been undertaken of clean-up costs from shipping spills, such as (Kontovas et al. 2010; Montewka et al. 2013; Ventikos & Sotiropoulos 2014; Kontovas et al. 2011).

Limitations of these studies include:

- They mainly relate to spills from vessels, not fixed offshore installations;
- Most of the spills occur at or near the coast, rather than far offshore;
- Most of the spills are very small (median typically less than one tonne);
- None of the spills is as large as the spills evaluated in this report;
- The analyses do not take account of New Zealand’s isolation which lengthens response times and increases costs;
- The costs are highly variable, typically ranging over two orders of magnitude for a given spill volume;
- Compensation amounts are often capped which limits the amount of damages reported as paid; and
- The analyses are sensitive to the inclusion or deletion of individual events.

Careful analysis has been undertaken by a number of authors, seeking to control for those variables where possible. This list of major limitations suggests, however, that the results should be treated as broadly indicative only. These authors generally agree that the overall trend is that costs of clean-up are proportional to an exponent of spilled volume in the form of:

$\text{Cost} \propto (\text{Volume})^{\text{Exponent}}$

Recent estimates of the exponent for total costs, including compensation, range from 0.65 (Psarros et al. 2011) through to 0.85 (Ventikos & Sotiropoulos 2014).

As an example, adopting a mid-range value of 0.75, estimates of overall damages for a range of spill volumes can be estimated from the modelled scenarios, as illustrated in Table 6.1.

Table 6.1 Effect of reduced spill volume on total costs

Location	Oil Type	Estimated Spilled Volume (m barrels)		90 Day Spill as Proportion of 120 Day	
		120 Day Spill	90 Day Spill	Spill Volume	Estimated Cost
Taranaki	API 34.6	1.56	1.29	83%	87%
Pegasus	API 47.6	1.49	1.28	86%	89%
Canterbury	API 47.6	0.43	0.35	81%	86%

6.12. Relationship of Total Damages to Volume of Oil Ashore

Figure 6.4 shows total damages for the Financial Assurance Review scope versus oil ashore for the Deepwater Taranaki and Pegasus scenarios.[10] Two hundred model trajectories for each of the two scenarios are plotted.

Also shown are estimated damages and oil ashore for the single modelled Canterbury trajectory where oil reached shore. In addition, four historical spills are plotted. All of the estimated costs exclude operator activities such as well control, salvage and subsea dispersant injection.

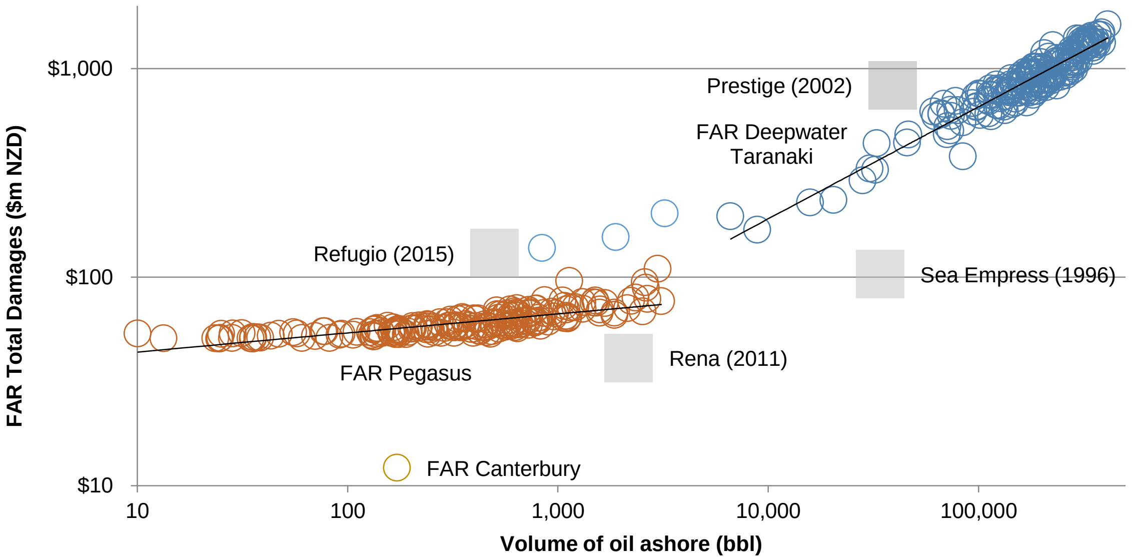


Figure 6.4 Financial Assurance Review total damages versus oil ashore[11]

A wide range of volumes of oil ashore is apparent for each modelled scenario[12]. Within each of the three scenarios each trajectory has an identical flow rate, discharge location and duration. The range of volume of oil ashore is entirely due to the combination of wind, tide and weathering conditions. This illustrates the role of chance in oil spill outcomes.

A second feature of this plot is the range of vertical dispersion of total costs for simulated spills with similar volumes of oil ashore. Again, this illustrates the influence of chance; clean-up costs depend on factors such as the type of shore that the oil lands on. Damages to tourism and fisheries are also variable and contribute to the vertical dispersion. The range of vertical dispersion in these model outputs is typically plus or minus 10%.

The models have a range of built-in fixed costs of elements such as baseline command and control networks,[13] reconnaissance, and on-water recovery. For trajectories with low

[10] 'Oil ashore' is the total amount of weathered oil that washes ashore each day and excludes further onshore weathering. See Appendix C.1 for more detail.

[11] Financial Assurance Review total damages includes tourism and fisheries damage estimates for Financial Assurance Review scope.

[12] Volumes of oil ashore less than 10 bbl not shown as models have not been developed to simulate smaller spills.

[13] The baseline network is command and response centres activated immediately that the spill occurs. This is supplemented by contingent networks that activate if oil arrives in their geographical area above defined thresholds. Refer *Method for Estimating Clean-up Costs* report for further detail.

volumes of oil ashore the response is activated and costs are incurred in preparation, monitoring and management, but little oil eventually reaches shore. These are the points plotted towards the left hand side of the graph.

The historical spill cost data is more widely dispersed than the simulations. This illustrates how spill costs depend on context – not only the metocean conditions, oil type and environmental context, but also the regulatory context and public expectations. For instance, records at the time noted seals were heavily oiled by the 1996 Sea Empress spill and commented that they could not be approached. In contrast, marine mammal response is an important component of the 2015 Refugio response, with 62 live marine mammals being captured and treated at significant cost (University of California Davis School of Veterinary Medicine 2015).

The Rena spill response plots below the Deepwater Taranaki and Pegasus scenarios for similar quantities of oil ashore. This is partly due to fixed elements of modelled offshore response. The fixed elements in each of the three scenarios are different to each other, reflecting the different risk profiles of the three scenarios. Should a spill occur, some risk profile information will be known at the outset, from modelling studies supplied by the operators during the regulatory consent process.

As an example, the modelled Canterbury oil spill response scenario is estimated to cost significantly less than the other two scenarios as it has fewer fixed response elements, reflecting the lower probability of oil making landfall. The estimated Canterbury response cost is also less than the Rena response, despite much more oil spilled in this scenario, for the same reason.

A limitation of these analyses is that high quality data is not available for historical spills, especially for consequential damages. The historical spill costs are based on extensive literature searches by Navigatus, including site visits in some instances and review of archival records. The plotted historical data points only include those costs considered by Navigatus to be known with reasonable confidence. The historical costs do not have identical scopes to the modelled scenarios and accordingly comparisons should be treated with care.[14]

While the Financial Assurance Review cost models are designed to simulate the likely response in each scenario, a range of factors can increase or decrease costs beyond the ranges shown. For instance, different decisions by spill commanders would lead to different costs. Different oil types and flow rates would also lead to different cost estimates.

6.13. Comparison to APPEA Method

Estimates of costs associated with monitoring response and clean up from a method published by the Australian Petroleum Production and Exploration Association (APPEA) are presented in Appendix G and shown in Figure 6.5 below, together with estimates of clean-up costs in this study.

[14] For the Refugio spill the estimated costs of $96 million USD was given by the operator partway through the clean-up. The final cost may be significantly higher. An estimated 500 barrels of spilled oil reached the sea and was subsequently washed ashore.

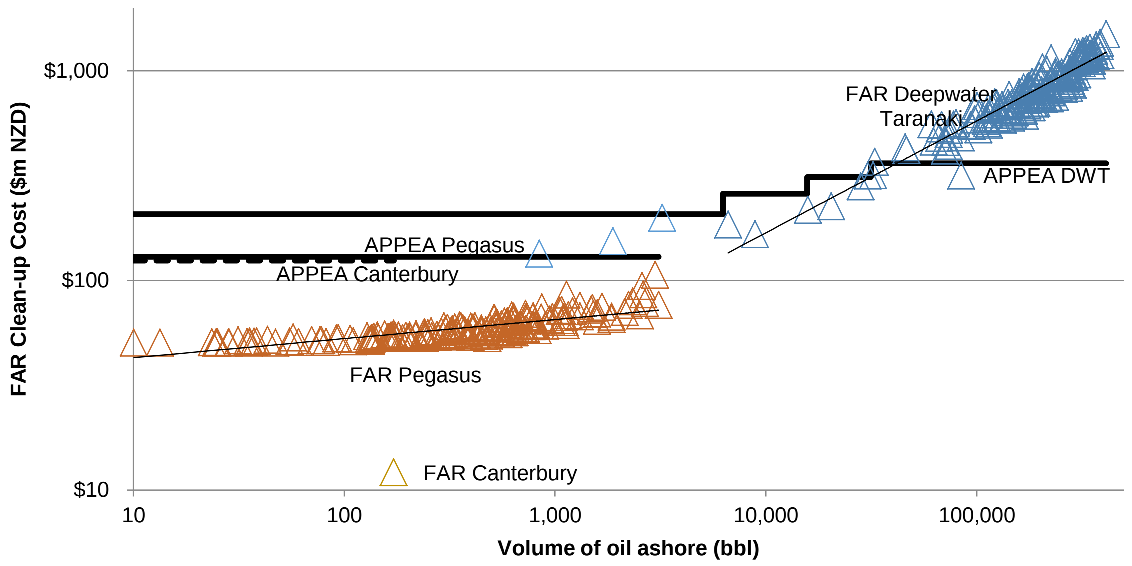


Figure 6.5 Clean-up Costs versus Volume of Oil Ashore[15]

The APPEA method was derived from *Guidelines to assist licensees in demonstrating Financial Responsibility to DECC for the consent of Exploration & Appraisal Wells in the UKCS,* published by Oil & Gas UK in 2013.

A strength of the APPEA method is that it is simple to apply. The cost estimates derived from the APPEA method were:

- Significantly higher than those derived from the site-specific Financial Assurance Review modelling for the two modelled spills of less persistent oils to the east of New Zealand; and
- Significantly lower than the Financial Assurance Review site-specific estimate for Deepwater Taranaki.

It is noted that the APPEA method has been produced for Australian conditions and is not intended to be applied to New Zealand.

[15] Excludes damages to tourism and fisheries and operator activities such as well control and subsea dispersant injection. For Canterbury the volume of oil ashore is 162 barrels, being the volume of oil ashore for the only modelled trajectory which made landfall. ‘Oil ashore’ is the total amount of weathered oil that washes ashore each day and excludes further onshore weathering. See Appendix C.1 for more detail.

7. Existing Production Facilities

Existing production facilities are different cases from exploration well drilling. This section provides further comment on potential damages due to spills from offshore production facilities. These facilities are all located in relatively shallow water in the South Taranaki Basin.

This further comment is not part of the core modelling undertaken for this project and has not followed the same robust method (for example, no oil spill forecasting or fate and transport modelling has been undertaken in this study for these specific scenarios). This further comment is an exploration that draws on the results from the core modelling as well as published studies on existing production facilities. Consequently, the results from this analysis should be considered broadly indicative of potential damages that could arise, and do not have the same reliability as the results in Section 5 this report.

7.1. Background

The New Zealand offshore production facilities can be separated into two broad classes (Table 7.1). Refer to Appendix H for New Zealand offshore crude oil characteristics.

Table 7.1 Existing offshore production facilities[16]

Field	Type	Format
Maari – Manaia	Lower pressure oil.	New developments may have higher initial reservoir pressure.
Tui – Amokura – Pateke		
Maui A & B	Higher pressure gas.	Light condensate oil also produced.
Kupe		
Pohokura		

Oil Fields Requiring Pressure Support

Some New Zealand offshore oil fields require pressure support to flow. In the event of a loss of well control, the amount of oil that might spill from the reservoir is expected to be small and possibly nil.

Somewhat more risk may arise during any production or development drilling in these fields. Once a field is in production, additional drilling may be undertaken by the operator to tap into additional pockets of reserves.

Floating Production Storage and Offloading (FPSO) vessels are engaged in production from several New Zealand offshore fields. Such vessels may present a different risk profile, but are outside the scope of this study.

Gas Production

Existing New Zealand offshore gas production facilities tend to have more sustained high pressure and produce a light condensate with significant proportions of more persistent

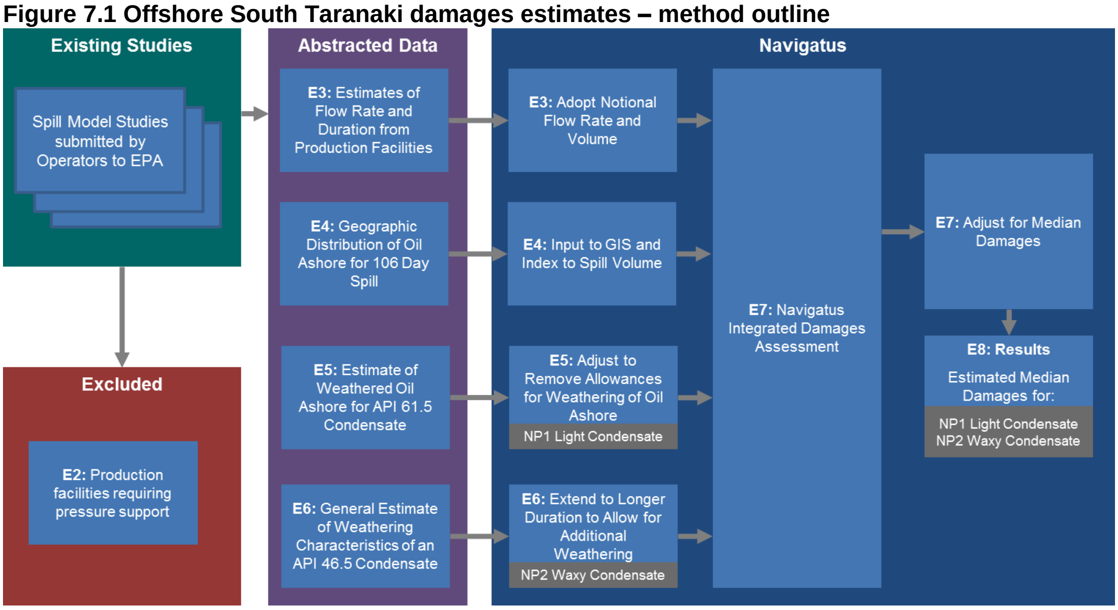
[16] Type classification by Navigatus for purposes of this report. The Maari-Manaia field uses pressure support by water injection into one of four oil producing formation structures (Zelt 2014). The Tui-Amokura-Pateke uses gas lift to raise oil to the surface (Resource and Environment Management Limited 2013). Depending on the formation and well concerned, spill volumes may reduce upon withdrawal of pressure support, possibly to zero.

waxes. Accordingly, the consequences of a condensate spill from a gas production facility would likely be less than the crude oil release scenarios assessed in this study for the Deepwater Taranaki.

7.2. Method

The method used by Navigatus to consider potential damages for a notional spill from an offshore facility in the South Taranaki Basin is outlined in Figure 7.1 below.

Figure 7.1 Offshore South Taranaki damages estimates – method outline



Fate and transport modelling of spills in the South Taranaki Basin was not undertaken for this project. This section draws on existing published model studies to develop estimates of clean-up costs.

The following method and estimates are not applicable to production facilities that employ pressure support to extract hydrocarbons, as spill flow rate and duration are likely to be significantly different for such facilities.

7.2.1. Spill Size

The data was sourced from modelling reports prepared on behalf of operators, which are publically available on the Environmental Protection Authority website. The reports mostly relate to exploration and appraisal wells, with estimated flow rates ranging from 10,000 to 56,000 barrels per day, depending on the field and well concerned.

One of the studies available from the EPA website modelled a discharge of 301,300 barrels over 106 days of API 61.5 oil for a production well blowout in the offshore South Taranaki Basin, this being an average of 2,840 barrels per day (RPS APASA 2014).

7.2.2. Geographic Distribution of Oil Ashore Distribution

In most instances in the modelling reports, results were reported as cumulative probabilities of shoreline contact, without allowance for weathering. Weathering effects are generally estimated separately and are not integrated into the models. Comparison of the reports shows similar geographic distribution of oil ashore for hypothetical spills from existing production facilities and from exploratory wells in this locality.[17] In general, the highest volumes of oil ashore are found on the adjacent Taranaki coast. In most cases, spilled oil generally moves south-west under the influence of tide and wind, with significant quantities landing on the Manawatu coast. Contamination sometimes occurs to the north Taranaki coast, and to the top of the South Island, in lesser quantities and/or less frequently.

The outputs reported in the studies are generally not suitable for use in the current form of the damages model, as developed for this project. However, one of the reports provided the distribution of oil ashore, reported in cubic metres per kilometre, for a hypothetical single 106-day "worst case" discharge. The case concerned was an exploration well and was for a continuous 10,000 barrels per day flow rate (MetOcean Solutions Ltd 2013). Navigatus was able to transcribe the reported oil ashore from the published maps using GIS.

A continuity check confirmed that the reported result was without weathering. In the lowest band of reported oil loading, at the outer edges of the oiled area, Navigatus assumed that oiling of shorelines was sporadic with around 25% of the shore being oiled. Oil spill case studies show that, in less affected areas oiling tends to be clumped in patches, with large gaps between. The modelling by RPS-APASA for this study also showed a similar pattern of oiling in the less heavily oiled areas. Accordingly, any one Level C response area (roughly analogous to a territorial local authority)[18] in the most lightly oiled band was assigned a 75% probability of being oiled. This resulted in reasonable agreement with the amount of oil released in the hypothetical spill. As no weathering had been allowed for in the above model, the amounts of oil ashore can be indexed to assess other spill flow rates under the same conditions.

7.2.3. Estimate of Weathered Quantity of Condensate Ashore

A study modelling the discharge of 301,300 barrels of API 61.5 oil over 106 days for a production well blowout concluded that the maximum amount of condensate reaching shore was 11,000 barrels in winter conditions[19] (RPS APASA 2014).

It is apparent that the study allowed for on-going weathering of condensate after it reached shore, thus reducing the accumulated quantity. Continuation of weathering when oil is ashore is an advanced modelling feature, which would be useful in some circumstances. However, good oil spill response practice is to bulk clean most shores as soon as possible.[20]

The clean-up model developed for this Financial Assurance Review report is predicated on bulk cleaning as a priority. Analysis by Navigatus of Deepwater Taranaki model outputs found that the sum of daily oil ashore was generally around 2.2 times larger than the maximum oil ashore reported from the model after allowing for weathering onshore.[21] Adjusting the reported maximum oil ashore by this factor provides a rough estimate of 24,000 barrels as the sum of daily condensate ashore. This is the estimated amount that

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[17] 'Oil ashore' is the total amount of weathered oil that washes ashore each day and excludes further onshore weathering. See Appendix C.1 for more detail.
[18] Refer *Financial Assurance Review Technical Report Method for Estimating Clean-up Costs* (Navigatus Consulting, 2015) for definition of clean-up cost method.
[19] 1,738 cubic metres for the worst case of two modelled discharge locations. Less under summer conditions.
[20] Bulk clean is defined as ITOPF Stages 1 and 2 (ITOPF 2014b).
[21] Same value for median and average. Range: 1.3 to 3.2 times.

could be collected if bulk shoreline cleaning was undertaken within a day or so of arriving ashore.

This estimate is just 8% of the total oil spilled. That low proportion may reflect several factors. The oil concerned is a light gas condensate, so high rates of loss due to weathering should be expected, especially to distant shores with longer travel times. Another potential factor is, given the typical transit times, especially to areas south of the spill, some oil would still have been on the sea surface when the model run terminated at 120 days. A portion of that oil could reasonably be expected to have reached shore after the model run terminated. Allowing an uplift for this last factor, the sum of total daily oil ashore for a longer model run might be around 9% under similar conditions.

7.2.4. Adopted Scenarios

A continuous spill of 3,000 barrels of condensate per day of API 61.5 condensate is adopted as an example of a notional gas condensate production blowout, with 9% landing ashore. This notional case is labelled as Case NP1.

Taking into account the persistent waxy content in some New Zealand condensates, a second damages case is developed where 34% of discharged oil reaches shore. This case is intended to represent a notional API 46.5 condensate with a higher fraction of persistent hydrocarbons (Case NP2).[22]

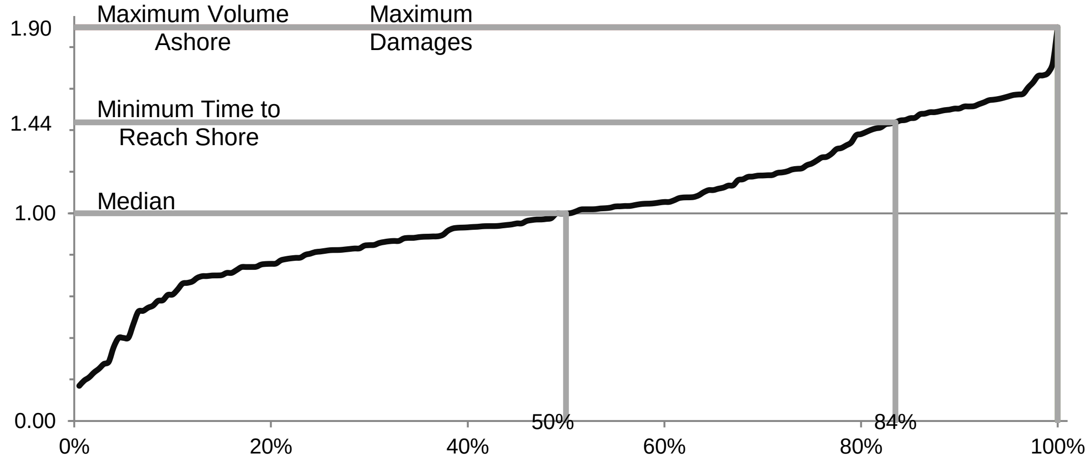
7.2.5. Integrated Damages Model

The Navigatus integrated damages assessment model was then employed to estimate both tourism and clean-up costs for this notional example. Fisheries damages were not included as modelling studies for the Financial Assurance Review found that fisheries damages did not comprise a significant portion of the overall total damages for the defined scope of damages and a number of the parameters rely on detailed modelling information that was not available.

The existing studies generally report cases from metocean conditions that result in maximum oil ashore, sometimes referring to those as “worst case”. Other modelling reports use minimum time to reach shore as a proxy to identify the “worst case”. From a damages perspective, the worst case is the case where maximum damages arise. The graph below shows the relationship between the median case, adopted in this report as a benchmark, and various alternative worst case estimates of total damages for the modelled Deepwater Taranaki scenario.

[22] Persistent fraction derived from reported results from ADIOIS 2 modelling of an API 46 oil.

Figure 7.2 Deepwater Taranaki indexed Damages (Clean-up costs only)[23]



It can be seen that minimum time to reach shore is a relatively poor proxy for the worst case, being around the 84th percentile of damages in this instance. The maximum cumulative volume of oil arriving ashore is a better predictor.[24] In the Deepwater Taranaki case this was also the same model run in which maximum damages occurred. This is a reasonable expectation for the scope of pollution damages assessed in this Financial Assurance Review integrated damages assessment model, where most damages arise from clean-up costs.

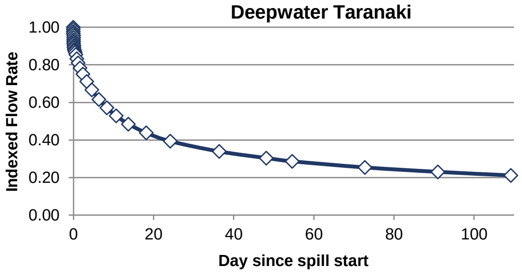
If damages for production facilities follow a similar statistical distribution to the modelled Deepwater Taranaki scenario, then a first order estimate of median damages could be obtained by dividing the worst case estimate by a factor of 1.9.

7.2.6. Reducing Spill Flow Rate

We indexed spill flow rates against initial discharge for all three scenarios modelled (Deepwater Taranaki, Pegasus and Canterbury) to derive generalised spill profiles against time for each. The three profiles were similar, showing a steeper initial decline then flattening out. The Deepwater Taranaki profile was selected as an intermediate example of the three derived profiles. Flows decreased by 79% over 106 days, with a 106 day spill volume of 36 times the initial flow rate.

The base case for scenario NP1 is a spill of 318,000 barrels. This spill volume is equivalent to a spill with the above profile and an initial flow rate of 8,830 barrels per day.

Figure 7.3 Indexed Flow rate for Deepwater Taranaki



[23] Damages index is the estimated damages for a run divided by the median damages.
[24] Excluding on-shore weathering.

7.3. Results

The notional scenarios and median damage estimates resulting from the above process are tabulated below.

Table 7.2 Estimated damages from notional spill in South Taranaki Basin[25]

Oil Properties		Spill				Estimated Damages	
Case	API Gravity	Initial Release (bbl/day)	Volume (barrels)	Proportion of Oil Ashore	Oil Ashore (barrels)	Clean-up ($m)	Tourism ($m)
NP1	61.5	5,000	180,044	9%	16,204	$120	$0.1
		8,830	318,000		28,620	$130	$0.1
		20,000	720,114		64,810	$170	$0.9
NP2	46.5	5,000	180,044	34%	61,215	$170	$0.9
		8,830	318,000		108,120	$220	$2.4
		20,000	720,114		244,839	$360	$6.5

7.4. Discussion

The above analysis synthesises the outputs from several model studies to generate an approximate estimate of the quantity and distribution of spilled oil. The above results should be considered broadly indicative, rather than definitive assessments, as Fate and transport modelling was not undertaken as it was for other modelled scenarios in this study.

A limitation of this analysis is that industry estimates of spill flow rates have not been prepared for subsequent application to estimating clean-up costs. A more sophisticated analysis of spill quantity may have been employed, if this purpose had been intended at that time. For instance, flow estimates for damages estimation purposes might provide for reducing spill flow rates over the spill duration as the reservoir pressure is depleted, and as the water cut increases. This is the approach taken in the reservoir models used for the scenarios modelled in this project.

A second limitation is that the same spill volume has been applied to two different oil densities. It could be expected that, all other things being equal, the spill flow rate and spilled volume for a thicker oil would both be less than for a lighter oil.

Taking these factors into account, it is possible that the estimated damages for these two notional cases are conservatively high.

7.5. Conclusion

The above estimates are only valid for the specific set of assumptions for each of the notional cases described above. The estimates are sensitive to the assumptions made and to the size of the various adjustments. As such, the estimates should be regarded as broadly indicative of potential damages that could arise for the specific set of assumptions given for each notional case, rather than definitive assessments that can be applied to any existing

[25] These clean-up costs are derived from models developed to emulate clean-up activities for spills in the range concerned. Extension to flows outside this range may not be reliable and is not recommended. Refer discussion for limitations.

production facility. The wide range of weathering estimates reflects in part the sensitivity to the specific weathering properties of gas condensates.

The scale of adjustments required to derive damage estimates from existing model studies, and wide range of resulting estimates, indicates that specific weathering tests and damage modelling for each facility for the flow rates and specific condensates concerned would be required to generate reliable estimates of potential damages.

8. Conclusions

This project has generally followed the conceptual framework of the OPOL method to New Zealand conditions, and at the same time has lifted the level of transparency and rigour of the analysis. This approach has required development of a suite of related methods to assess the effects on tourism and fisheries and to estimate clean-up costs over a wide range of conditions.

The conclusions drawn from this analysis are:

- Effects are strongly related to location in relation to prevailing winds - western locations where prevailing winds blow onshore will likely have significantly greater effects than east coast locations;
- Effects are strongly related to oil type: persistent oils have a much larger effect on the damages and shoreline clean-up than non-persistent oils; and
- Effects are related to volume of oil, which is a function of flow rates and the time to regain well control.

The damages quantum is sensitive to the above factors, and to the scope of pollution damages that are included in the assessment.

The method has been designed to provide a high level of transparency about the range of damages that can occur. The estimated median damages levels, including pollution damages to tourism and fisheries, are $926, $58 million and $12 million respectively for Deepwater Taranaki, Pegasus and Canterbury for the scope of damages evaluated in this assessment.

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Appendices

Appendix A. Disclosure Statement

The following disclosure statements cover all aspects of this report, including the technical reports:

Authors

- Oil Spill forecasting – forecasting was undertaken by Rosalind Archer, University of Auckland. Rosalind currently serves on the board of directors of New Zealand Oil & Gas Limited. The oil spill forecasting was undertaken in her capacity as a staff member at the University of Auckland and was based on public domain data.
- Oil spill modelling was undertaken by RPS APASA. RPS provides consultancy services to both the private and public sectors on the exploration and production of oil and gas.
- Navigatus provides risk management advice to commercial and government clients across a range of domains. Navigatus is currently advising Maritime New Zealand on navigational risk and marine oil spill risks and consequences for the whole coastline of New Zealand. Navigatus is also currently engaged by the Ministry for Primary Industries to provide advice on navigational risks associated with proposed salmon farms in the Marlborough Sounds and is advising the Deepwater Group in relation to deep water fishing vessels sheltering at the sub-Antarctic islands.
- Navigatus director and co-author of this report, Kevin Oldham, has a beneficial interest in marine farms, growing mussels commercially in the Marlborough Sounds.

Peer review

- Peer review comment on the fisheries method was provided by Ministry for Primary Industries staff, who may provide policy advice to government on a range of related matters.
- Navigatus commissioned peer review of salmon farming aspects of the fishing method from Mark Gillard in a professional consulting capacity through specialist consultancy Aquaculture Direct. Mark has been an employee of New Zealand King Salmon Limited and continues to work for New Zealand King Salmon on a part time basis. He was chair of the Salmon Farmers Association from 1994-2013 and is currently on the board of Aquaculture New Zealand.
- Navigatus engaged Tom Hollings of Hollings Resource Management in his capacity as a consultant to peer review oyster and mussel farming aspects of the fisheries method. Tom works as the representative for northern marine farming interests and is employed as Secretary of the New Zealand Oyster Industry Association and as Executive Officer of the Coromandel Marine Farmer’s Association.
- The New Zealand Institute of Economic Research (NZIER) was commissioned to provide advice and comment on tourism method. NZIER is an independent economic consultancy in both private and public sectors.

Appendix B. Project Brief

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Appendix A

MBIE/MOT Financial Assurance Review
Outputs sought from modelling of oil spill scenarios

Background

New Zealand's regulatory framework for offshore exploration and production focuses on preventing spills by ensuring operators have plans and resources in place to minimise the likelihood, and reduce the effect, of any adverse event. Should an incident occur, owners of offshore installations are liable for the full cost of pollution damage. This includes:

- damage to other parties
- costs incurred by public agencies in preventing and cleaning up a spill.
- the costs of reasonable measures of reinstatement of the environment
- losses of profit from impairment of the environment.[1]

To support this requirement operators are required under Marine Protection Rule Part 102 (Part 102) to provide evidence of financial assurance, such as insurance or alterative financial security, which covers the operator's potential liability to at least the minimum amount specified. Part 102 currently sets the minimum requirement at approximately NZ$26 million, and is irrespective of the operation's type, possible risk or the potential impact of a spill. As part of a broader review, Cabinet has instructed officials to consider the required level of financial assurance being scaled to reflect differences in pollution damage costs that may be associated with different types or locations of installations.

Purpose

To establish the likely cost of pollution damage from a series of loss of well control events, resulting in significant release of hydrocarbons into the marine environment from an offshore installation.

This will allow us to:

a) establish whether there is significant variation between the expected cost of pollution damage of a spill from different types of activities to justify the introduction of a differentiated financial assurance requirement
b) set the minimum financial assurance requirements at a level that is reflective of the expected cost of pollution damage of a spill

Deliverables

MBIE and MOT are seeking a report that estimates the cost of pollution damage associated with an oil spill from an offshore installation. The report is expected to model a number of scenarios to estimate the expected costs of:

1) pollution damage to other parties
2) any reasonable preventive measures taken to prevent or reduce pollution damage
3) reasonable measures of reinstatement of the environment
4) losses of profit from impairment to the environment, such as the impact on:
    - Fishing interests
    - Tourism
    - Other existing commercial interests whose profits/revenue may be affected as a result of impairment of the environment

Similar modelling was undertaken in the United Kingdom in 2012.[2]

The pollution damage cost scenarios for this study are expected to reflect:

- One scenario at each location incorporating the three different types of hydrocarbon which may be present in a spill (heavy crude, condensate, gas)

[1] Frequently known as pure economic loss.

[2] The United Kingdom Offshore Oil and Gas Industry Association Limited and the Offshore Pollution Liability Association Ltd (2012). *Oil Spill Cost Study - OPOL Financial Limits.* http://www.oilandgasuk.co.uk/templates/asset-relay.cfm?frmAssetFileID=2182

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- Expected flow rate based on different geographic locations which are consistent with MBIE's forward schedule of activity (Taranaki; Northland-Reinga; Pegasus; Canterbury-Great South)
- A loss of well control of each hydrocarbon type in each location lasting for XX days commensurate with well control through use of a relief well
- Government oil spill response measures will be costed, but their mitigating effects during the period of active spilling will be ignored to give an assessment of the maximum expected impact

Appendix C. Integrated Damages Assessment Model

The Integrated Damages Assessment (IDA) model was developed using Microsoft Excel 2010 with macros developed by Navigatus in Visual Basic. The IDA implements the methods for estimating damages (as detailed in the technical reports) using the oil spill modelling results for each of the 200 trajectories to determine the total cost of response.

Appendix C.1. Pre-processing of Oil Spill Modelling Results

Each component of the tourism, fisheries and clean-up cost methods has a threshold for when effects are expected to occur. Before integration into the IDA, the oil spill modelling results were pre-processed to provide the input needed to assess the damages.

The first step in the pre-processing of the oil spill modelling results involved finding the amount of oil which washed ashore each day. One of the fate and transport modelling outputs from RPS-APASA was a sum of the cumulative oil ashore in each cell on day-by-day basis for every model run. The amount arriving could be deduced by the difference in cumulative oil ashore on consecutive days. A complication was that the RPS-APASA model continued the weathering process on shore, which had a minor effect on the deduced volume of oil arriving ashore.[26] An analysis of the RPS-APASA results found that typically the volume of oil ashore reduced by around 3.2% per day in the onshore weathering model.

The pollution damages methods identified thresholds for various effects and responses. With the amount of oil washing ashore for each day and each run calculated, the first and last day where oil washed ashore above each threshold was assessed, as well as the number of days where oil greater than the threshold washed ashore. The amount of oil ashore was also summed from these daily amounts (this represents the amount of oil which washes ashore, but does not account for weathering of the oil once ashore).

For the clean-up costs, the total amount of oil washed ashore, the amount of oil on each shoreline type and the length of each type of shoreline oiled for each coastal cell was needed as input to the model. These determine the method for shoreline cleaning and therefore the amount of effort required. The length of shoreline of each type oiled was provided as an output table from the oil spill modelling. The amount of oil ashore in each shoreline type for each cell was estimated by apportioning the total oil ashore by the portion of the length of oiled shoreline for each shoreline type in the coastal cell.

The pre-processed results were combined into a single table on a run by cell basis, and transferred to the Integrated Damages Assessment.

Appendix C.2. Integrated Damages Assessment

Having imported the pre-processed results, each of the methods as outlined in the tourism, fisheries and clean-up cost technical reports was used, calculating the applicable

[26] The continuation of weathering ashore is not consistent with the beach clean up processes in the financial assurance review, which is based on an initial bulk clean-up of all accessible oil to prevent remobilisation, in accordance with industry best practice guidelines (e.g. ITOPF, 2014). Refer *Method for Estimating Clean-up Costs* (Navigatus Consulting, 2015a) for further information on method for estimating clean up costs. For these reasons the peak volumes of weathered oil ashore reported in RPS-APASA 2015 are not considered to be an appropriate metric for the purposes of this study and have not been used in estimating shoreline clean-up costs.

components for each trajectory by the geographic unit of the damage as outlined in Table C1.

The scale of geographic units used to assess each type of damages was determined by the geographic units of the available data that the damages were being assessed from. For example wild commercial fin fisheries data is presented on a fisheries management area (FMA) basis.

Table C1 Geographic unit of damages

Assessed Damages	Geographic Unit of Damage
Tourism	Territorial Local Authority
Pāua	Coastal Cell
Lobster	Coastal Cell
Wild Commercial Fin Fisheries	FMA
Oysters	Coastal Cell
Mussels	Coastal Cell
Salmon	Salmon Farm
Shoreline Clean-up	Coastal Cell
Booming	Coastal Cell
Level C Command	Level C Command
Wildlife Ashore Team	Level C Command
Wildlife Stabilisation	Level C Command
Animal Waste	Level C Command and Level B Command
Level B Command	Level B Command
Wildlife Treatment	Level B Command
Level A Command	National
Marine Reconnaissance	National
Offshore Dispersant	National
On-water containment and Recovery	National
Maui and Hectors	National
Offsite Wildlife Advisory	National

Following the calculation of each of the assessed damages, the total cost of damages was summed for each run to find the total estimated damages per trajectory.

Appendix D. Table of Estimated Damages

This appendix lists estimated damages by quintile. Each quintile represents 40 runs, out of 200, ranked by estimated damages. The first quintile is the first 40 ranked runs and is representative of model runs where the fate of the released oil resulted in the least overall damages. The values reported are the average of that quintile. The fifth quintile average is representative of runs where the overall damages were highest.

The amount of oil reaching the shoreline is the sum of the daily quantities of oil that arrives on shore. Weathering of oil while at sea is included. Ongoing weathering on shore is not included, on the basis that bulk clean[27] of oil ashore will be completed within a few days of arrival, in accordance with industry guidelines. Final clean-up and polishing will take longer, particularly in difficult areas and some areas would be best achieved by natural processes.[28]

Table D1 Summary of estimated damages – average for quintile

	Quintiles Sorted by Total Damages	Amount of oil reaching shoreline (bbl)	Estimated clean-up costs ($ million)	Estimated tourism damages ($ million)	Estimated fisheries damages ($ million)	Extent of initial shoreline response (km)[29]
Deepwater Taranaki	First Quintile	70,000	450	50	5	720
	Second Quintile	150,000	670	100	6	930
	Third Quintile	200,000	790	120	4	960
	Fourth Quintile	250,000	940	130	6	1,100
	Fifth Quintile	330,000	1,210	130	6	960
Pegasus	First Quintile	50	50	-	0.2	10
	Second Quintile	190	50	-	1.1	30
	Third Quintile	370	60	-	1.6	50
	Fourth Quintile	660	60	-	1.8	80
	Fifth Quintile	1,390	70	-	2.3	130
Canterbury	First Quintile	-	12	-	0.02	0
	Second Quintile	-	12	-	0.03	0
	Third Quintile	-	12	-	0.04	0
	Fourth Quintile	-	12	-	0.05	0
	Fifth Quintile	2	12	-	0.16	0.3

Estimates of the length of shoreline affected in each quintile are also presented in the final column. A feature of the Deepwater Taranaki shoreline extent is that the average affected coastline length for the fourth quintile is greater than the fifth quintile. This is a reflection of variability in the relationship between length of coastline affected and overall damages, due to factors such as the influence of type of coastline affected on clean-up costs.

27 Bulk clean is defined as ITOPF Stages 1 and 2 (ITOPF 2014b).

28 The approach to clean-up modelled in this study is set out in the technical report *Financial Assurance Review Technical Report Method for Estimating Clean-up Costs* (Navigatus Consulting, 2015).

29 Extent of initial shoreline response represents the length of coastline that Navigatus expects to be prioritised for assessment and bulk clean-up due to the quantities of oil arriving on shore. For Deepwater Taranaki, the extent of initial shoreline response excludes an allowance for areas of sporadic light contamination, which would receive attention in subsequent clean-up phases. Overall estimated total affected shoreline extents from spill modelling results are 20% higher than reported in the above table for Deepwater Taranaki. For Pegasus and Canterbury affected shorelines Navigatus expects that all areas of contaminated shore will receive attention within a few days of oil arrival, so reported response shoreline length quintiles are unadjusted from spill model outputs.

Appendix E. Estimated Spill Duration

The spill duration for the oil spill forecasting and modelling was informed by a number of case histories, notably the timeframe for drilling relief wells for the Montara and Macondo spills (see Table E1 and Table E2 below). The spill duration was also informed by Anadarko's anticipated mobilisation timeline for a loss of well control in Canterbury and Deepwater Taranaki Basins (see Figure E1).

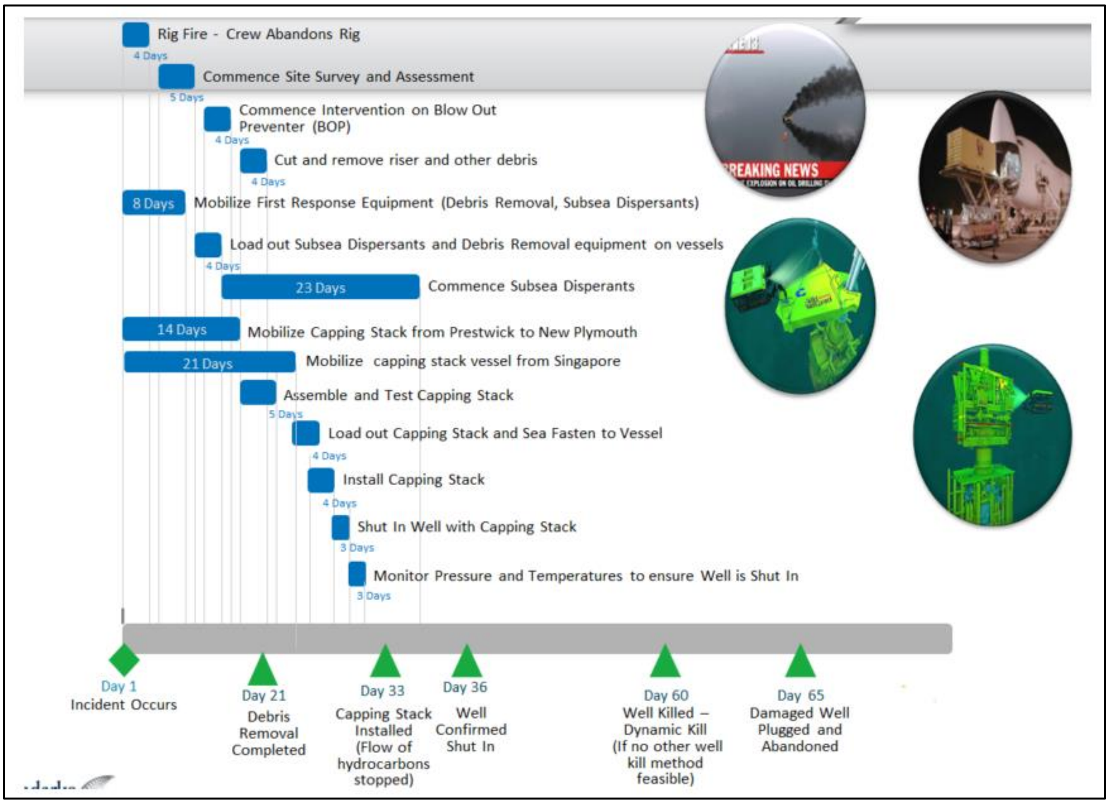
Table E1 Montara Timeline (West Atlas)

Activity	Date	Task Duration (Days)	Overall Duration (Days)
Blowout	21-Aug-09	N/A	N/A
Rig Arrives on site	11-Sep-09	21	N/A
Well killed	1-Nov-09	51	72
Intercept at approximately 2,500m depth below mudline.			

Table E2 Macondo Timeline (Deepwater Horizon)

Activity	Date	Task Duration (Days)	Overall Duration (Days)
Blowout	20-Apr-10	N/A	N/A
Rig Arrives on site	2-May-10	12	N/A
Well killed	3-Aug-10	93	105
Intercept at approximately 4,000m depth below mudline. The spill was controlled by capping shortly before the relief well intercept and well kill.			

Figure E1 Mobilisation timing from Well Control Contingency Plan Summary for Canterbury and Taranaki Basins Drilling Program (Anadarko 2013)



The table below shows the estimated spill duration used for the modelling, and was developed based on the case studies and Anadarko's anticipated mobilisation timeframe. The total spill timeframe adopted in the model (from the analysis below) is 120 days.

Table E3 Well Control Timeframe for Deepwater Wells

	Activity	Estimated (days)	Operator (Note 1) (days)	Comments
1	**ROV**			
1.1	Source ROV	3		Assumes suitable ROV not present in NZ
1.2	Source local ROV support ship	5		In parallel with task 1.1
1.3	Transfer to NZ by air and load ROV to ship	3		
1.4	Transit from port to site	1		
1.5	Survey, assess and actuate BOP	3		
	Total to ROV Actuation of BOP	**10**		
2	**Subsea Dispersants**			
2.1	Source subsea dispersant equipment and dispersant	7		Air freight.
2.2	Source local vessel	7		In parallel with item 2.1
2.3	Load equipment and transit to location	3		
	Total to Commence Subsea Dispersant Release	**10**		
3	**Clear Debris**			
3.1	Source and load cutting equipment on petroleum operations support ship	5		Assumed ex Singapore.
3.2	Fast transit to NZ	17		6000 NM @ 15 knots
3.3	Cut away debris.	10		Allows for weather contingency.
	Total to Debris Removed	**32**		
4	**Cap**			
4.1	Mobilise cap to Singapore	5		Multiple cap sources depending on operator.
4.2	Assemble and test cap	5		
4.4	Source cap stack transfer and operational vessel	7		Non-critical path
4.3	Load onto vessel and sea fasten	1		
4.5	Fast transit to NZ	17		6000 NM @ 15 knots
4.6	Install cap, check and shut in well	5		
	Total to Well Capped	**38**	33	Refer diagram for Anadarko estimate of duration, based on cap assembly in NPL.
5	**Drill Relief Well**	**Estimate**	**Operator**	
5.1	Source and contract rig	7		
5.2	Tow to NZ from Singapore locality	42	35-45	Refer note 2 below.
5.3	Drill relief well, intercept and kill well	72	45-70	Depends on range of factors. Navigatus adopted average of Montara (51 days) and Macondo (93 days).
	Total to Well Kill via Relief Well	**121**	80-115	**Round to 120 days**
Notes				
1	Operator estimate from Anadarko, 2013 - *Well Control Contingency Plan Summary Canterbury and Taranaki Basins Drilling Program Offshore New Zealand*, Anadarko New Zealand, October 2013.			
2	Navigatus estimate assumes semi-submersible rig ex Singapore locality. 6000 NM tow at 6 knots. Operator estimate includes sourcing. Montara relief rig mobilised in 21 days including repositioning, Macondo 11 days.			

Appendix F. Sensitivity Analysis

The sensitivity analysis was undertaken in two steps:

- In step one, Navigatus project personnel considered each variable in the model and shortlisted those where there was both uncertainty regarding the value and the potential for it to lead to a significant change to the damages estimates.
- In step two, each of these shortlisted variables was adjusted one by one to the sensitivity case, as outlined in Table F1. For each case, the change to the overall damages estimate for the middle quintile of runs was recorded. This helped identify the modelling parameters that make the greatest change to the overall damages estimates.

The Deepwater Taranaki scenario was chosen for sensitivity testing as damages estimates involved all elements of the model. This was also the only location where significant tourism effects were predicted by the model. Sensitivity was undertaken on the middle quintile of runs, rather than picking a single run as “representative” as any single run is unlikely to encompass all the variables in a representative manner. Sensitivity cases results were compared against the base case scenarios using that same model.

The damages to fisheries comprise only a small proportion of overall damages. As such, any changes to the fisheries parameters are unlikely to make a significant difference to the overall damages.

The tourism model is sensitive to the overall estimated damages for Auckland. In the base case, pollution damages from oil reaching Auckland shorelines was reduced by half as it has coastlines on both sides of the North Island. Damages to Auckland tourism comprises a high proportion of the estimated tourism damages for a spill from the Deepwater Taranaki basin. The Auckland west coast would be contacted by oil from a Deepwater Taranaki spill for most trajectories and has a long stretch of coastline on the west coast. Removing the Auckland City reduction, results in a 12% increase to the overall estimated damages for the middle quintile.

The other tourism parameter which results in significant changes to the overall estimated damages is the duration of tourism effects. Increasing this parameter by 1 year for all tourism categories (aside from business tourism) results in a 5% increase in the overall cost of damages from the Deepwater Taranaki Location.

For clean-up costs, the three most sensitive parameters are all related to command and control. The duration of shoreline clean-up affects the length of time that command centres are open. Similarly, the thresholds for expansion determine the number of the contingent command level C centres that are activated, which in turn influences the number of level B centres activated. This parameter is related to span of control and affects both the establishment and disestablishment of command centres. Likewise, the command structure reflects the number of lower level command centres that are active before a higher level command is opened. Command and control represents the second largest portion of the total clean-up costs for Deepwater Taranaki. Accordingly, the parameters defining how quickly and fully the network of command and control expands has a significant influence on overall costs.

The sensitivity analysis also examined the sensitivity of overall costs to labour costs, and specifically the costs of the labour used to initially pick up oil-contaminated materials under the mass manual approach adopted in the model. Under the mass manual approach such labour could become scarce and more expensive. The analysis found that a 10% increase in costs of this labour resulted in a 1.3% increase in overall damages for the Deepwater Taranaki case. This tallies with pick-up labour being around 30% of the shoreline cleaning component of response costs, and the response being around half the total damages for the base case. It is concluded that the overall damages are only moderately sensitive to pick-up labour costs.

Table F1 Sensitivity of model parameters

	Model Parameter	Implemented Value	Sensitivity Case	Cost of overall damages relative to base case
Clean-up	Maui Threshold	1,000bbl/day = 50% 10,000bbl/day = 100%	100bbl/day = 50% 1,000bbl/day = 100%	100.4%
	Wildlife $/day - Collect	Base Case	10% higher $	100.2%
	Wildlife $/day - Stabilise	Base Case	10% higher $	100.2%
	Wildlife $/day - Treat	Base Case	10% higher $	100.4%
	Labour Rate / Productivity	Base Case	Increase labourer rate by 10%	102%
	Probability of shoreline clean-up / duration	Base Case	Move each shoreline type up one band (beach 75%).	84%
	Shoreline Clean-up - Polishing $	Base Case	10% higher $	104%
	Shoreline Clean-up - Fixed rates per km	Base Case	10% higher $	101%
	Command Structure	1 Level C or shoreline can self-manage	2 Level C or shorelines can self-manage	96%
	Command and Control - Base network size	Command Level C and B for shorelines where at least 50% of trajectories impacted	Command Level C and B for shorelines where at least 75% of trajectories impacted (1 less level C)	99.8%
	Command and control - thresholds for expansion	Day when 100bbl ashore	100bbl in single day	99%
Tourism	Market Share Depth	16% international 11% domestic	10% increase to depth of effects	101%
	Threshold for effect	25,000bbl 5,000bbl	12,500bbl 2,500bbl	102%
	Auckland effect	50%	100%	112%
	Years of Effects	Low : 0 Domestic, 1 Int, 2 Asian High : 2 Domestic, 2 Int, 3 Asian	+1 year to all durations	106%

	Model Parameter	Implemented Value	Sensitivity Case	Cost of overall damages relative to base case
Fisheries	Losses Proportionate to area of closure and proportion of year	Base Case	10% increase in losses	No significant change
	Paua & Lobster - Threshold	100bbl	10bbl	No significant change
	Paua & Lobster - Effect	10%	10% increase to effect	No significant change
	Salmon - Threshold for moving	>0bbl	>10bbl in single day	No significant change
	Salmon - Threshold for early harvest	>0bbl	>10bbl in single day	No significant change
	Salmon - Closure period duration	Base Case	+1 month	No significant change
	Aquaculture Proportion Oiled	Proportion of Shoreline	10% increase in shoreline	No significant change

Appendix G. Case History and APPEA Damage Estimates

Appendix G.1. Case Histories

Table G1 Estimated total damages for selected case histories

	Volume Spilt (bbl)[30]	Volume Ashore (bbl)[31]	Clean-up ($m)[32]	Tourism ($m)[33]	Fisheries ($m)[34]	Total Damages ($m)
Rena (2011)	2,940	2,175	$41	$-	$-	$41
Refugio (2015)	500	500	$131	$-	$-	$131
Sea Empress (1996)	540,000	34,099	$67	$7	$30	$104
Prestige(2002)	379,000	39,000	$833	$8	$6	$847

Appendix G.2. APPEA Estimate of Clean Up Costs

The APPEA method assigns a score based on the hydrocarbon impact, total spill volume and shoreline impact. These scores are summed to provide a total score which gives an indicative cost ($m AUS) this is then converted to NZD. The score based on the hydrocarbon impact and total spill volume remain constant for all trajectories, however the shoreline impact score varies. The following table sets out the assigned scores for the modelled range of scores for shoreline impacts for each of the Deepwater Taranaki, Pegasus and Canterbury cases.

Table G2 APPEA score and indicative cost of operational response[35]

	Score due to hydrocarbon impact[36]	Score due to total spill volume[37]	Score due to shoreline impact[38]	Total Score	Indicative cost of operational response $million NZD
APPEA DWT	2	0	1-4	3-6	207-363
APPEA Pegasus	1	0	0-1	1-2	78-130
APPEA Canterbury	1	0	0-1	1-2	78-130

[30] As reported in Addendum 7 of Clean-up Costs method (Navigatus Consulting 2015a).
[31] Sea Empress midpoint of Edwards & White (1999) converted to bbl, Prestige as estimated in tourism method (Navigatus Consulting 2015c), Rena and Refugio as estimated in Clean-up Costs method (Navigatus Consulting 2015a).
[32] As reported in Addendum 7 of Clean-up Costs method (Navigatus Consulting 2015a).
[33] Compensated damages as reported in the case history (Navigatus Consulting 2015b) with inflation and exchange rate as of 18/03/2015.
[34] As above.
[35] GHD (2014).
[36] Pegasus and Canterbury condensate, Taranaki light/medium crude (API 34.6 $\rho \approx 850$ kg/m^3).
[37] RPS APASA (2015).
[38] Median shoreline impact from 200 trajectories.

Appendix H. New Zealand Offshore Crude Oil Characteristics

Table H1 New Zealand offshore crude oil characteristics (copied directly from Maritime New Zealand 2013a)[39]

Crude	SOURCE	Age (Hours)	Specific Gravity	Density API	Pour Point (°C)	Wax %	Viscosity Temp (°C)	Viscosity CST	Flash Point API Method
Kupe Condensate	Kupe Gas Field	0	0.7821@15°C	49.4	+18.0		18	2	
		1 – 24	0.7890@15°C	47.8	-		-	-	
		24 - 48	0.8404@15°C	36.8	-		-	-	
		Residue	0.8657@15°C	22.2	+48		18	31	
Maari (Moki Crude)	Maari Field	0	0.8441 – 0.8489		21 - 27	21.1	30	2.459 – 2.93 @ 50 °C	< 20 – 25 °C
Manaia-1 Crude	Maari Field	0	0.8062		+24	n/a		2.328 @ 50 °C	< 25 °C
Maari / Manaia Blend	Maari Field	0	0.8389		+27	n/a		2.888 @ 50 °C	< 25 °C
Maui Condensate	Maui A and B Field	0	0.7413 @ 15.5C	59.4 @ 15.5C	< - 51°		38	0.6502	
Pohokura Condensate	Pohokura Field	0	0.79	46.71	21		30	1.492	-33.9
Tui	Tui Field	0	0.798 @ 15°C	42.9	24		50	2.46	
		14	0.849 @ 15°C		33		50	7.46	
		24	0.857 @ 15°C		36		50	10.2	
		48	0.863 @ 15°C		39		50	15.8	
		96	0.868 @ 15°C		42		50	22.6	

[39] Flash Point column is measured in degrees Celsius.

Addendum 1: Summary of Industry Feedback

A workshop was held to discuss the assumptions underpinning the modelling, with representatives from relevant industries and government agencies. Attendees were from:

- the Petroleum Exploration and Production Association (PEPANZ)
- the Tourism Industry Association (TIA)
- Seafood New Zealand
- Maritime New Zealand
- Ministry for the Environment
- Environmental Protection Agency
- Ministry of Transport
- Ministry of Business, Innovation and Employment.

Written comment was provided by TIA and PEPANZ. The tables below set out Navigatus' responses to the written comments.

Feedback from Tourism Industry Association

No.	Summary of Comment	Response/Actions
1	Limitation of using case studies, difficult to estimate effects and results in guessing game.	Analysis draws carefully from well-researched case studies to provide a best estimate of likely tourism damages for the defined scope.
2a	Scope excludes indirect costs - too limited.	Analysis is for damages that could be directly attributed to a spill, as set out in report.
2b	Potential effects on NZ tourism brand sizeable, yet not within scope.	Agree that the effects on Brand NZ were excluded from scope. Further research, beyond the scope of this study, would be required to explore the scale and direction of overall tourism impacts.
3	Non-inclusion of cruise industry.	The cruise industry comprises only a small portion of the tourism industry and cannot be added due to the RTE already containing some of the tourism industry and the cruise industry data being collected on a different basis. Explanatory text added to Appendix 4.2 of the tourism report.
4	Deepwater Horizon is not a good example to use to estimate effects as BP's funding of tourism promotion had a strong impact.	Agree. The tourism model does not use the Deepwater Horizon to determine model parameters for this reason, amongst others. The Deepwater Horizon case study is only used to explore the relative impact on cities.
5	Limitations of MBIE and StatsNZ tourism data.	The MBIE and StatsNZ data is the best available source of information. Further comment on limitations of RTE method added to tourism report (Section 4.3 and Appendix 4.2).
6	Comparison of Christchurch Earthquake in Section 5. Cannot draw conclusions on visitor numbers and expenditure as you can't compare the effects of an earthquake and resulting risk avoidance by tourists with an oil spill.	The Canterbury Earthquake was only used to explore differences in the effects of disasters on segments of tourists visiting New Zealand. The base recovery time is from oil spill case studies only.

7	Limitation of tourism statistics. New Zealanders spending money at a place at least 40km away from home is seen as domestic visitor. Spill clean-up workers may be captured in this.	While tourism industry services may have been used by clean-up workers rather than tourists, this is not in itself a negative effect on regional tourism businesses.

Feedback from Petroleum Exploration and Producers Association of New Zealand (PEPANZ)

No.	Summary of Comment	Response
1	Various comments on policy issues	Not in Navigatus scope.
Comments on Main Report		
1	Sample size is insufficient, study is hypothetical, wells may be drilled in different locations, reservoir properties are unknown.	Agree that study is hypothetical as are all prospective analyses. Agree that reservoir properties cannot be known in advance and that sample size is small. Further South Taranaki production well cases have been added to Section 7.
2	Study claims that it is not a worst case scenario, but basing the evaluation on drilling a relief well is already a worst case as it assumes that the BOP and Capping stack have both failed.	Navigatus used a 120-day spill scenario, but did not adopt a worst-case scenario at each step of the integrated damages assessment. Navigatus has clarified and added further wording in Section 3.4.
3	Study should be based on 35 day scenario for capping stacks as per the OPOL study.	The purpose of the review is to determine the level of financial assurance required, not expected damages. Re-establishment of well control by relief well drilling was set in the brief. See Section 3.4 for further wording added.
4	Differences in the oil properties estimated in reservoir report and as used in RPS-APASA fate and transport model?	Oils used in RPS-APASA fate and transport model were the closest oils for which properties were known or could reasonably be synthesised. Agree that the flow rates and oil properties will no longer match exactly, but given the other modelling assumptions, such as undrilled reservoirs, this is not considered to be material to the analysis.
5	Use of Maari as an oil proxy should be justified.	The oil properties are similar to those adopted by the operator. Modelling undertaken used the closest oil type analogues available to those identified in the oil spill forecasting.
6	Need to justify why Pegasus and Canterbury oils are slightly different in reservoir report but the same in fate and transport modelling.	The fate and transport modelling used Pohokura as a proxy for both Pegasus and Canterbury, as was indicated as appropriate in the reservoir report.
7	Insufficient attention to existing production facilities.	New Section 7 added to report, reworking and incorporating former Section 6.11 and Appendix G, with additional cases.
8	Drafting: References to Deepwater Taranaki should not be abbreviated to Taranaki. Table E2 is a repeat of E1.	Corrected.
Comments on Oil Spill Modelling Study by RPS-APASA		
1	Query re suitability of 200 events.	The replication of 200 events x 120 days + 10 days post-discharge days is approximately 26,000 days of simulation. This is a large sample and is considered fit for purpose.
2	As drilling tends to take place in summer period it is unrealistic to equally feature winter scenarios.	A 120-day long spill commencing in mid to late summer will continue on into autumn or winter conditions.
3	It would be useful to outline how the stochastic events were selected (e.g. Box-Jenkins, first order autoregressive, Monte Carlo etc.).	A Monte Carlo simulation approach was used.

4	It would be useful for the report to comment on the applicability of a stochastic approach to capture variability due to El Niño-Southern Oscillation (ENSO) or PDO (Pacific Decadal Oscillation).	While it would be useful to assess and then comment on the ability to capture the variable climate patterns, it is beyond the current scope of work.
5	Query the approach to the near-field plume implications because the effect that the density structure has on an ascendant oil. The study would greatly benefit from sensitivity testing of the surfacing of oil, based on the expected range in water column properties.	Due to the large oil droplets sizes (~1,000 - 10,000) and consequential fast rise velocities, significant influence from water density structure is not envisaged. Changes in the water density can cause plume trapping if the plume droplet sizes are very small (i.e. low buoyancy and hence low rise velocity), weak currents, and there are rapid changes in the density of the water (i.e. the pycnocline – the layer where the density gradient is greatest). That is not the case for this study. Suggested sensitivity testing is unlikely to provide insights of material consequence to the Financial Assurance Review.
6	Concern re use of the relatively coarse temperature and salinity profile data to weather and advect the various weathered stages of the hydrocarbon. Suggestion that the study would benefit from sensitivity testing based on the expected range and spatial distribution of water column properties.	As stated above, the rise velocities of the oil droplets would dominate its ascent. While the dataset may be considered coarse, it is comprised from decadal climatological data from highly reliable and quality controlled government sources. Whilst there might be a +/- 1 degree difference in the temperature data, it will not affect the weathering of the oils assessed.
7	Query re resolution of bathymetry datasets, particularly in shallow waters and effects predicted current velocities (speeds and directions) within these areas and subsequent beaching times and locations; though the model validates well within open water areas.	As part of the study, the high resolution tidal flow dataset was added to HyCOM in coastal areas where this physics is dominant. Therefore, the current data was interpolated onto a grid with a resolution down to 500 m along the coastline.
8	The CFSR atmospheric data is expected to be biased in the nearshore and coastal regions.	On all occasions that the CFSR data was compared to wind measurements at sites within Australian waters, inclusive of sides adjacent to elevated land, there is an excellent agreement overall and the modelled winds have been able to capture the shift in speed and direction over time and space.
9	Query re shoreline types used, such as most of the west coast of the North Island (including 90-Mile Beach) being classified as mixed sand/gravel, whereas Goodhue, et al., (2012) define this coastline as predominantly sandy.	The shoreline data was sourced from the Department of Conservation (Department of Conservation and Ministry of Fisheries, 2011). The difference between classification as mixed sand/gravel and sandy is not material.
10	Contention that the study applies a shoreline contact and sea surface exposure threshold of 0.5 g m^2 and ceases the tracking or estimation of shoreline contact at lower concentrations, which would result in a proportion of the discharged hydrocarbons not being tracked.	The model continues to track oil of any concentration and continues to track oil at concentrations orders of magnitude lower than 0.5 g m^2. All simulations track oil of any concentration throughout the simulation to allow for accumulation of the oil concentrations on shorelines (due to the compression of the area over which the oil is spread as oil strands on a shoreline) or build-up of the oil that arrives at lower concentrations over the full period of the incident being simulated. The model-produced data was then post-processed to identify those locations that were exposed at concentrations > 0.5 gm^2 at any point in time.
11	The shoreline contact threshold is very low at 0.5 g/m^2.	A threshold of 0.5 gm^2 was applied on the basis that this level might be indicative of visible tainting or socio-economic effects (such as cautionary closure of fisheries).
12	There should be discussion of how the fate of dissolved and entrained oil have been combined.	The modelling does not include dissolved hydrocarbons. Entrained and floating oil concentrations are considered to be of most relevance for the Financial Assurance Review.

Comments on Reservoir Report – New Zealand Oil Spill Flow Rate Forecasts for Selected Offshore Basins		
1	**Model geometry** - homogenous reservoir is a simplification and leads to higher assumed flow rates than the likely reality of a more heterogeneous and complex structure. A Monte Carlo analysis might be appropriate to address uncertainty. Rock properties chosen, deliberately represent a good quality (i.e. high flowing) reservoir, which is a "conservative" assumption.	Agreed. These points are acknowledged in the report.
2	Casing sizes from description appear unrealistic. More realistic well layout suggested.	Well construction adopted in model is similar to that suggested. Description reworded and well diagram added to clarify well construction adopted in model.
3	Clarify if drill string is in or out.	Out. There is assumed to be no obstruction to flow inside the well. This does increase the maximum possible flow rate. That condition could only occur if the drill string had been pulled (permanently, or to change a drill bit etc.). Clarified in well construction diagram.
4	Does "tubing" roughness referring to casing internal bore?	Yes. Reworded to clarify, replacing "tubing" with "casing" where appropriate.
5	The hypothetical 31 API oil for the Deepwater Taranaki is heavier than any oil discovered offshore in New Zealand to this point.	Reservoir report notes that the 31 API is the same as adopted by the operator for the Deepwater Taranaki Romney well. The fate and transport modelling used the slightly lighter Maari oil from offshore Taranaki as a proxy.
6	The report refers inaccurately to Anadarko having drilled in the Pegasus basin.	Intended to refer to Canterbury. Removed.