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Final Report

Assessment of the Risk of Pollution from Marine Oil Spills in Australian Ports and Waters

Australian Maritime Safety Authority

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MANAGING RISK

Assessment of the Risk of Pollution from Marine Oil Spills in Australian Ports and Waters	DET NORSKE VERITAS LTD., UK Palace House, 3 Cathedral Street SE1 9DE London, United Kingdom Tel: +44 (0)20 7357 6080 Fax: +44 (0)20 7357 6048 http://www.dnv.com Org. No: 1503799
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Summary:

This study estimates the risk of pollution from marine oil spills in Australian ports and waters, in order to support a review by the Australian Maritime Safety Authority (AMSA) of the National Plan to Combat Pollution of the Sea by Oil and Other Noxious and Hazardous Substances (the National Plan) and National Maritime Emergency Response Arrangements (NMERA).

The report presents the oil spill risk results from the study, for current and future cases, in order to provide information for the review of the National Plan and NMERA. It also presents the data that has been collected for the study and explains the methodology that has been used to estimate the risks.

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EXECUTIVE SUMMARY

This study estimates the risk of pollution from marine oil spills in Australian ports and waters, in order to support a review by the Australian Maritime Safety Authority (AMSA) of the National Plan to Combat Pollution of the Sea by Oil and Other Noxious and Hazardous Substances (the National Plan) and National Maritime Emergency Response Arrangements (NMERA).

DNV's general approach to the present study involves the following key elements:

- The Australian coastal environment is divided into 120 sub-regions. Each is allocated an environmental sensitivity, based on the environmental receptors within it.
- Shipping densities and ship type and size distributions in each sub-region are estimated from Australian Ship Reporting (AUSREP) data.
- Oil spill frequencies for ships and offshore installations are obtained from recent world-wide accident data, and validated against Australian experience.
- Characteristic oil spill size distributions for ships and offshore installations are obtained from actual oil spill experience world-wide.
- The probabilities of oil spills at sea impacting on the coastline are estimated from simple transport and fate models, which depend on the oil type, the spill size and location, and the weather conditions.
- The overall spill risk is determined using a spreadsheet calculation, and displayed using the ArcMap Geographical Information System (GIS).

The chosen methodology in effect limits the level of detail of oil spill risk modelling to that appropriate for a large-scale national study.

The report presents the oil spill risk results from the study, for current and future cases, in order to provide information for the review of the National Plan and NMERA. It also presents the data that has been collected for the study and explains the methodology that has been used to estimate the risks.

The report includes recommendations on how to use the risk results in developing oil spill response arrangements, how the risk results may be updated in the future, and how the risk assessment approach may be enhanced in future studies.

1 INTRODUCTION

1.1 Background

The Australian Maritime Safety Authority (AMSA) is reviewing the National Plan to Combat Pollution of the Sea by Oil and Other Noxious and Hazardous Substances (the National Plan) and National Maritime Emergency Response Arrangements (NMERA). The National Plan was last comprehensively reviewed in 2000. NMERA was introduced in 2006 and is now due for review. This new review will examine the capacity of the National Plan to provide an adequate and effective response to pollution of the sea by oil and other noxious and hazardous substances, focusing on and making recommendations about those matters where improvements are warranted. The review will also examine the suitability and adequacy of NMERA as a risk reduction strategy.

The National Plan was informed by a risk assessment of oil and chemical spills performed by DNV in 1999. During the last 10 years there has been significant expansion of ports and a consequent growth in the movement of shipping around the Australian coast. In recent years there have been some major incidents resulting in oil pollution both from shipping and the offshore oil industry. In order to support the review of the National Plan, AMSA has therefore commissioned DNV to conduct a new risk assessment.

1.2 Objectives

The objective for the study is to estimate Australia's current marine oil spill risk profile based on a comprehensive updating of DNV's 1999 risk assessment, and report this in a way that can be used during the review of the National Plan and NMERA.

1.3 Scope Limitations

The scope of work is bounded as follows:

- The geographical area is Australia's Exclusive Economic Zone (EEZ) and Offshore Territories, including the Australian Antarctic Territory. The EEZ boundary is typically 200 nautical miles (nm) from shore. The Offshore Territories include Norfolk, Cocos, Christmas, Heard, McDonald and Macquarie Islands.

- The pollution sources include ships (tankers and other vessels), offshore installations (fixed and floating), exploration rigs and pipelines. Ships include fishing vessels, dredgers, navy ships, barges and other coastal vessels.

- The oil types include crude oil and condensate produced from offshore installations and exploration rigs, crude oil and liquid petroleum products shipped as cargo, and fuel or diesel oil used as bunkers. Other hazardous and noxious substances are excluded, but the study identifies suitable data sources that may be used in future risk assessments of them.

- The shipping traffic includes vessels approaching and leaving Australian ports, coastal traffic and international traffic passing through the Torres Strait and other parts of Australia's EEZ.

- Pollution sources in neighbouring territories (e.g. oil production facilities in Papua New Guinea and East Timor) are included where they have significant potential to produce oil pollution within Australia's EEZ.

- The limit of the study on the landward side includes any point from where oil may enter the marine environment. This includes tanker loading and unloading, ship bunkering, offshore pipeline landfalls. It also covers onshore activities that may cause marine spills, but does not require a risk assessment of onshore installations.

- The time period for the work is the present day, as far as this can be estimated from recent historical data. In practice, the study mainly uses data from 2010. It also addresses future risks up to 2020.

- Spills from intentional acts (e.g. illegal discharges or terrorism) are excluded from the scope. However, it has proved impossible to distinguish between deliberate and accidental discharges from shipboard equipment, so these are both included as "unauthorised discharges".

- Any pollution that results from legal and routine discharges is excluded from the scope.

- Natural oil seepages are not addressed in the study.

- Assessment of the acceptability of the estimated risks and selection of appropriate risk reduction options are not part of the study.

2 TECHNICAL APPROACH

2.1 General Approach

DNV's general approach to the present study involves the following key elements:

- The Australian coastal environment is divided into 120 sub-regions. Each is allocated an environmental sensitivity, based on the environmental receptors within it.

- Shipping densities and ship type and size distributions in each sub-region are estimated from Australian Ship Reporting (AUSREP) data.

- Oil spill frequencies for ships and offshore installations are obtained from recent world-wide accident data, and validated against Australian experience.

- Characteristic oil spill size distributions for ships and offshore installations are obtained from actual oil spill experience world-wide.

- The probabilities of oil spills at sea impacting on the coastline are estimated from simple transport and fate models, which depend on the oil type, the spill size and location, and the weather conditions.

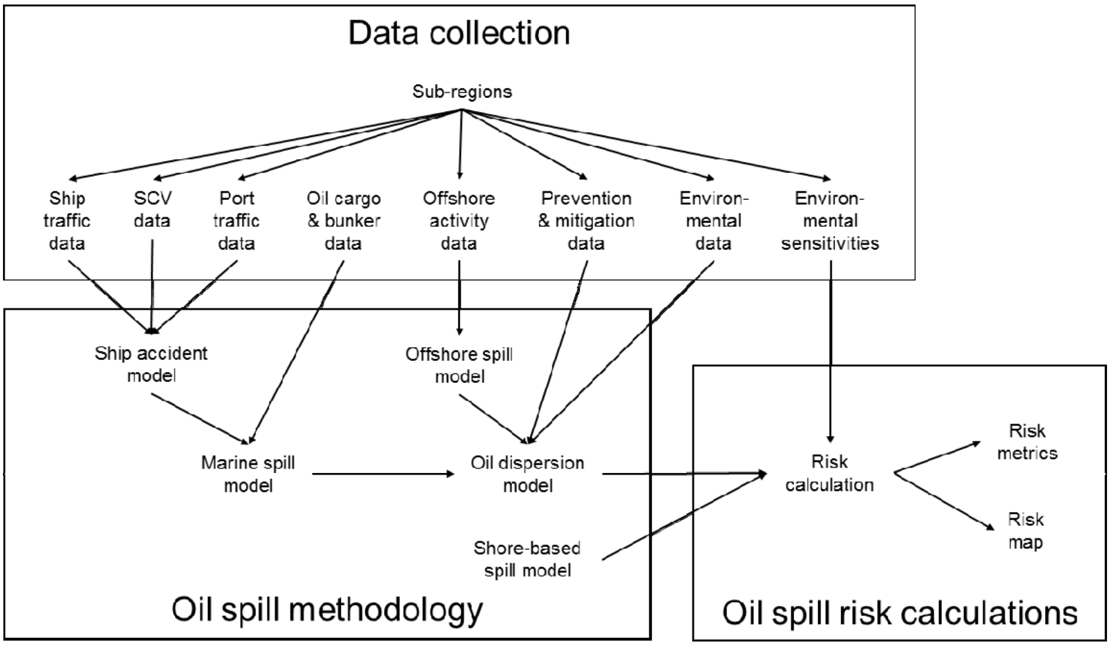
- The overall spill risk is determined using a spreadsheet calculation, and displayed using the ArcMap Geographical Information System (GIS).

The chosen methodology in effect limits the level of detail of oil spill risk modelling to that appropriate for a large-scale national study. It is consistent with the level of detail that was adopted in the previous study (DNV 1999), while the ship and offshore activities and the oil spill models have all been updated to reflect current conditions. The only significant difference in scope from the previous study is that chemical (i.e. non-oil) spills are not covered in the present study.

2.2 Study Tasks

Figure 2.1 shows the three main phases of the project, together with the tasks that were carried out in order to achieve the objectives of the project, and a simplified data flow scheme. The methodology in each task is outlined below.

Figure 2.1 Outline Data Flow



2.2.1 Phase 1 - Data Collection

In the first phase of the study, all necessary data was collected on the Australian marine environment and the shipping and offshore activities within it. Because of the wide-scale of the study, this is potentially an enormous task. Therefore the data collection was strictly limited to that which directly affects the risk results from the oil spill methodology, as developed in Phase 2.

The main datasets were as follows:

- Calculation sub-regions. The boundaries of the study region are defined in Section 2.3, and the split into sub-regions for risk calculations is explained in Section 2.4.

- Shipping traffic data. AUSREP was chosen as the main source of data on shipping traffic at sea, for reasons that are explained in Section 2.5. The method of analysis and the ship traffic results are presented in Appendix I.3.

- Port traffic data. AMSA provided data on arrivals of trading vessels at Australian ports in 2010, and this was used as the main source of port traffic. The method of analysis and the port traffic results are presented in Appendix I.2. Additional information was obtained on ship-to-ship transfers at sea, which have taken place intermittently in Australia, although not in 2010 (see Appendix I.2.9). Future port traffic growth through to 2020 is based on information provided by Ports Australia, with the assistance of the ports and State/NT National Plan stakeholders (see Appendix I.2.10).

- Small commercial vessel (SCV) data. The State/NT maritime authorities provided data on the population of small commercial vessels (including coastal passenger vessels, fishing vessels, tugs, barges and other harbour vessels) that are not included in the port arrivals data (see Appendix I.4).

- Oil cargo and bunker data. The distribution of oil types in tanker cargoes is estimated from refinery production data (see Appendix I.5.4). The maximum cargo size on oil tankers is defined by the ship deadweight. Bunker fuel capacities for other ship types are estimated in Appendix I.2.6.

- Offshore activity data. The Australian Petroleum Production & Exploration Association (APPEA) provided data on offshore drilling activity, as summarised in Appendix I.5.1. APPEA also provided a database of production facilities and their production rates in 2009 (see Appendix I.5.2). Other information on offshore activities that is used by the risk models, including predicted changes through to 2020, was provided by Geoscience Australia, the Australian Bureau of Agricultural Resource Economics (ABARE) and the Department of Resources, Energy and Tourism and is also presented in Appendix I.5.

- Environmental data. The Bureau of Meteorology provided wind rose data (see Appendix VI.4.4). Visibility data for each sub-region is unchanged from the previous study (DNV 1999).

- Oil spill prevention and mitigation measures. Other information that is used by the spill risk models, including the presence of traffic separation schemes, ship reporting schemes, compulsory pilotage, emergency towage vessels and fixed-wing dispersant capability data for each sub-region, has been provided by AMSA (Appendix I.6).

- Environmental sensitivities. DNV has developed an index to quantify the relative environmental sensitivity of each of the calculation sub-regions. It combines the physical sensitivity of the environment to spilled oil, its biological resources and human-use resources. The basis for this index is outlined in Section 2.6, and documented in full in Appendix II. The results are included in Section 3.

All the input values for each port, sub-region and offshore installation in the study are included in a parameter database in Phase 3. This allows AMSA to change these values and update the calculation in the future.

2.2.2 Phase 2 - Oil Spill Methodology

In the second phase of the study, the necessary models were developed to estimate the oil spill risk as a function of the shipping and offshore activities. These models are commonly used in risk assessment studies of specific locations. In order to use them in the present wide-scale of the study, some simplification is necessary. The study has developed models that can take account of the very different marine environments that exist in Australia in a consistent way, without excessive complexity.

The main models were as follows:

- Ship accident models. DNV estimated the frequencies of ship accidents (including collision, powered grounding, drift grounding, transfer spills, hull damage, fire/explosion and unauthorised discharge) for major ship types, based on world-wide ship accident data obtained from the Lloyd's Register Fairplay (LRF) casualty and fleet databases for the period 2000-10. They are expressed in different forms in order to combine with the different datasets:
    - Frequencies per hour at sea, suitable to combine with the ship traffic data.

  - o Frequencies per port visit and per km of movement in restricted water, suitable to combine with the port traffic data.

  - o Frequencies per vessel year, suitable to combine with the small commercial vessel data.

  These are modified to reflect local conditions in each port or sub-region, including traffic density, visibility, sea state, channel width and accident prevention measures. The potential for ships at sea to deviate from their normal course or drift after an accident into adjacent sub-regions, and in particular onto the coast, as well as the potential for rescue by emergency towing, is included in the grounding models. These models have been combined with the ship movements and checked against the recorded totals of oil spills in Australian waters. The models are presented in detail in Appendix IV.

- Marine spill model. DNV estimated oil spill probabilities and size distributions for oil tankers in each accident type, based on world-wide oil spill data obtained from LRF for the period 1992-2010. The data for bunker oil spills from oil tankers during 1992-97 (i.e. before the large-scale adoption of double hills) is used to estimate the probabilities of bunker oil spills from other ship types. These models are included in Appendix IV.

- Offshore spill model. DNV estimated oil spill probabilities and size distributions for offshore installations, for well drilling activities and for offshore pipelines from the best available risk models that are used in the offshore industry. These models are presented in detail in Appendix V.

- Shore-based spill model. DNV estimated oil spill probabilities and size distributions for onshore spills into the marine environment from the historical data on oil spills in Australia during 1982-2010, provided by AMSA. The analysis of the data and the selected shore-based model are presented in detail in Appendix III.

- Oil dispersion model. DNV adopted a simple methodology to indicate the amount of oil likely to move from the sub-region where the spill occurred to others further inshore or offshore. This takes account of likely spill locations, wind directions, sea states and oil spill response arrangements. The model is presented in detail in Appendix VI.

The models for port traffic, at-sea traffic, small commercial vessels, offshore production, offshore drilling, and shore-based spills are included in the spreadsheet calculation in Phase 3. These are intended to form the basis of future risk predictions in specific locations or applications.

2.2.3 Phase 3 - Oil Spill Risk Calculations

In the final phase of the study, the models from Phase 2 were applied to the data from Phase 1, in order to estimate the oil spill risk in Australian ports and waters. The main steps were:

- Parameter database. DNV collected the parameters in the models above (specifically, the parameters which future updates might wish to modify) in a spreadsheet attached to the risk calculation. As well as the modelling parameters, it includes all the input values for each port, region and offshore installation in the study.

- Risk metrics. Appropriate risk metrics are discussed in Section 2.7. The main selected risk metrics are:
    - The frequencies (i.e. numbers of events per year) of spills exceeding various quantities of oil.
    - Oil spill risks (i.e. number of tonnes of oil spilled per year).
    - An environmental risk index (ERI), which takes account of the main factors affecting the risk of oil spills in the marine environment, including spill size, oil type, oil dispersion and environmental sensitivity.
- Risk calculation. The above risk metrics were calculated in a spreadsheet, which follows the methodology and parameters defined above and applies it to the data collected for each sub-region and each port, and aggregates these to determine the overall national risks.
- Results. The study results are presented in Section 3, including the distribution of the risk metrics by sub-region. Some guidance on how to interpret and use these results is given in Sections 2.8 and 2.9.
- Validation. In Section 3.1.6, the distributions of oil spill frequency and size are checked against the historical marine oil spill data from Australian ports and waters, which is analysed in Appendix III. In Sections 3.1.7 and 3.1.8 the results are validated against other studies. Although these are not independent validations, because the same data underlies them, they do provide useful confirmation that the risk estimates are consistent with historical experience and other analyses of it.
- Future risks. The likely effects of key future changes and the predicted future risks for 2020 are given in Section 4.

The spreadsheet calculation of the risk results combines all the input data from Phase 1 with the risk models from Phase 2 to generate the results in Phase 3. Application to the future risks for 2020 illustrates how it can be used to change the inputs and update the calculation.

2.3 Definition of Study Region

The geographical extent of the study is defined by Australia’s Exclusive Economic Zone (EEZ) and Offshore Territories, including the Australian Antarctic Territory. The Offshore Territories include Norfolk, Cocos, Christmas, Heard, McDonald and Macquarie Islands. Lord Howe Island, which is part of New South Wales, is also included.

The EEZ boundary extends up to 200 nautical miles (nm) from the Territorial Sea Baseline (see below). The outer limit is less than 200nm in some areas, in accordance with agreements with neighbouring countries. Figure 2.2 shows the EEZ (Geoscience Australia 2002).

Figure 2.2 Australia's Maritime Zones

2.4 Definition of Calculation Sub-regions

The oil spill risks are presented as average values for 120 sub-regions of the EEZ. These consist of 40 coastal segments, divided into 3 zones:

- Near-shore 0-12nm offshore
- Intermediate 12-50nm offshore
- Deep-sea 50-200nm offshore

The boundaries of the study are defined with reference to the Territorial Sea Baseline. This baseline generally corresponds to the level of Lowest Astronomical Tide, but straight baselines are drawn further out to encompass river entrances, enclosed bays, and fringing islands. It divides Australia's Territorial Sea from its internal waters, which lie on the landward side of the baseline.

The inshore boundary of the study includes any internal waters that ships may enter and marine oil spills may affect, such as ports, bays and land between the level of Highest and Lowest Astronomical Tides. However, when plotting boundaries on a national scale, there is no significant difference between this and the Territorial Sea Baseline, so the latter is used for simplicity.

The 12nm boundary coincides with the outer limit of Australia's Territorial Sea, which extends up to 12nm from the Territorial Sea Baseline. Due to the proximity of Papua New Guinea, the Territorial Sea around certain Torres Strait islands is only 3nm wide.

The 50nm boundary is an arbitrary boundary intended to divide the rest of the EEZ into two zones that are as homogenous as possible.

The lateral boundaries of the sub-regions are chosen to divide each State's waters into a maximum of 10 segments, so that the segments are broadly consistent in size and as homogenous as possible in terms of oil spill risk. Table 2.1 shows the number of segments in each State. This gives a total of 40 segments.

Table 2.1 State Prefixes Used for Sub-Region Names

STATE	PREFIX	SEGMENTS
Queensland	QLD	6
New South Wales	NSW	4
Victoria	VIC	3
South Australia	SA	3
Western Australia	WA	10
Northern Territory	NT	3
Tasmania	TAS	3
Norfolk Island	NOR	1
Macquarie Island	MAC	1
Christmas Island	CH	1
Cocos (Keeling) Islands	COC	1
McDonald/Heard Islands	MDH	1
Australian Antarctic Territory	AAT	3

The sub-region names are then in the form SSS-XX-Z, where SS is the State or Territory prefix (see Table 2.1), XX is the segment number in each State counting clockwise from 1, and Z is the zone, i.e. sub-region distance offshore, which may be near-shore (N), intermediate (I) or deep-sea (D). For the island territories that have only one coastal segment, this naming is simplified to SSS-Z.

In calculating the risks, two additional sub-regions are considered, which are outside Australia's EEZ but might produce risks inside it. These are:

- Joint Petroleum Development Area (JPDA) between Australia and East Timor. This is adjacent to sub-region WA-10-D.

- The Torres Strait (TOR) within the Papua New Guinea EEZ. This is adjacent to sub-region QLD-2-N.

The regions in the study are shown in Figure 2.3. The relationship to the Great Barrier Reef Marine Park is shown in Figure 2.4. In this area, the near-shore and intermediate zones are mainly within the Marine Park.

Figure 2.3 Calculation Sub-Regions

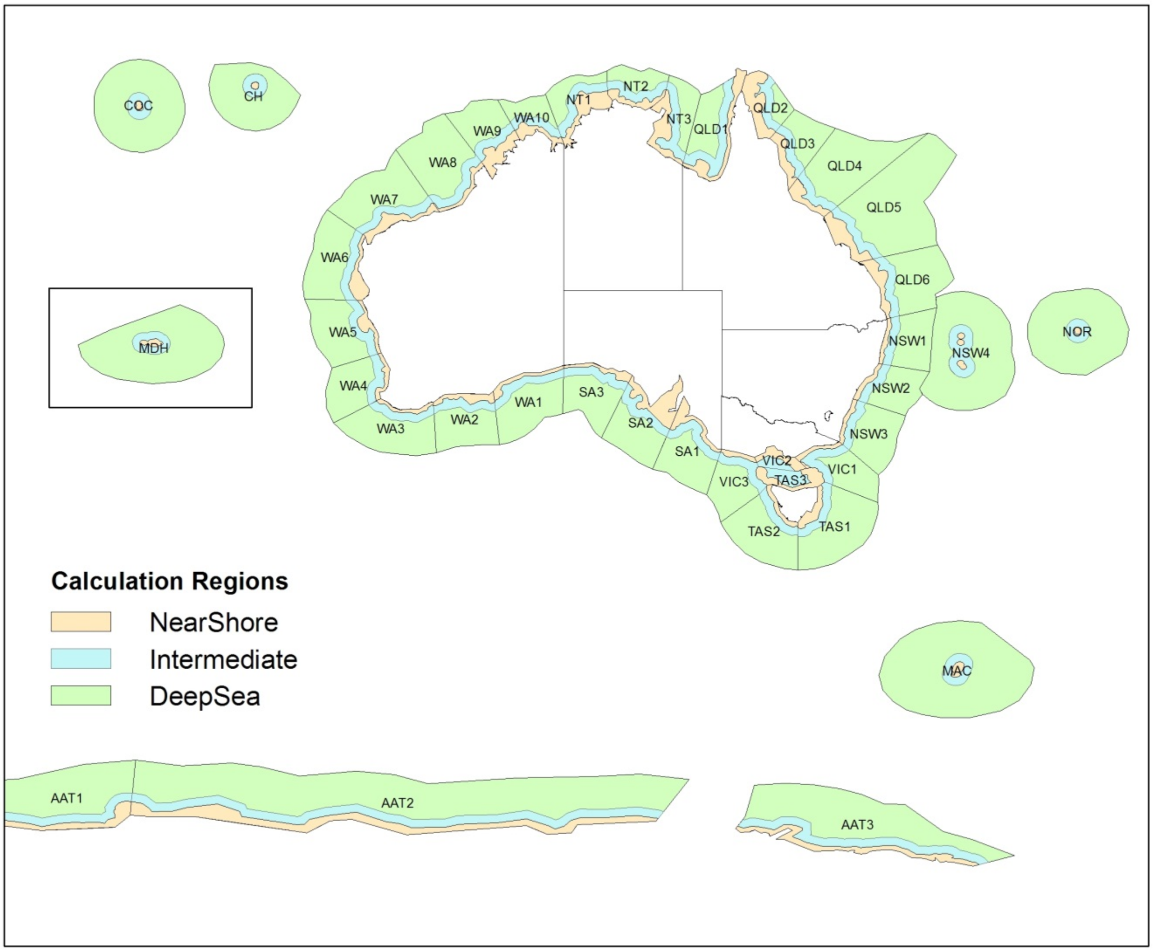
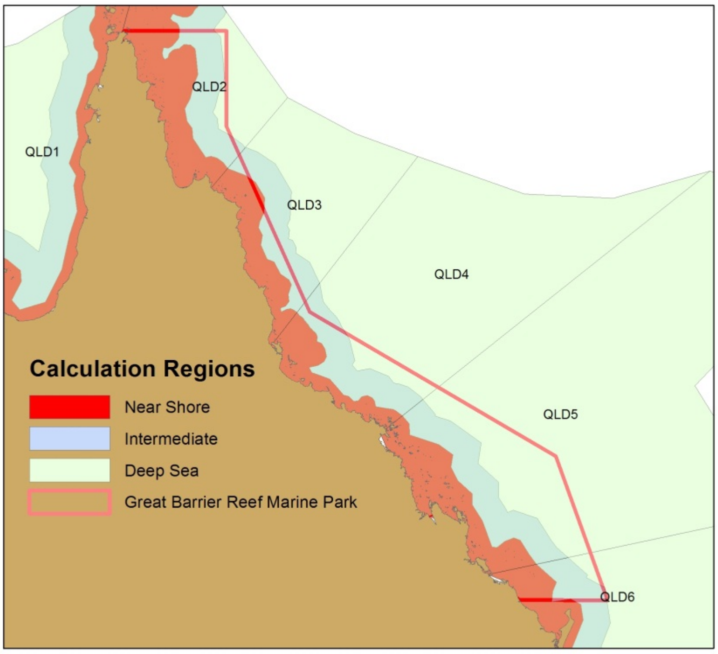


Figure 2.4 Relationship to Great Barrier Reef Marine Park



2.5 Ship Traffic Data Sources

2.5.1 AUSREP Data

The main source of ship traffic data for this project is the Australian Ship Reporting System (AUSREP). AUSREP provides positional data for maritime search and rescue, covering all ships transiting the reporting region (Figure 2.5). Reporting is mandatory for most types of ships and voyages, but is voluntary in some cases (e.g. foreign registered ships before arrival at their first Australian port or after departure from their final Australian port; and fishing vessels on domestic voyages), although voluntary reporting is strongly encouraged. Reports are required at the AUSREP boundary or up to 2 hours after departure from an Australian port, and subsequently at intervals no greater than 24 hours. Most ships are automatically polled via Inmarsat-C to determine their position every 24 hours, or send radio reports otherwise. Reporting is believed to be comprehensive because failure to receive a report within 2 hours of the expected time will alert action to confirm the ship's safety.

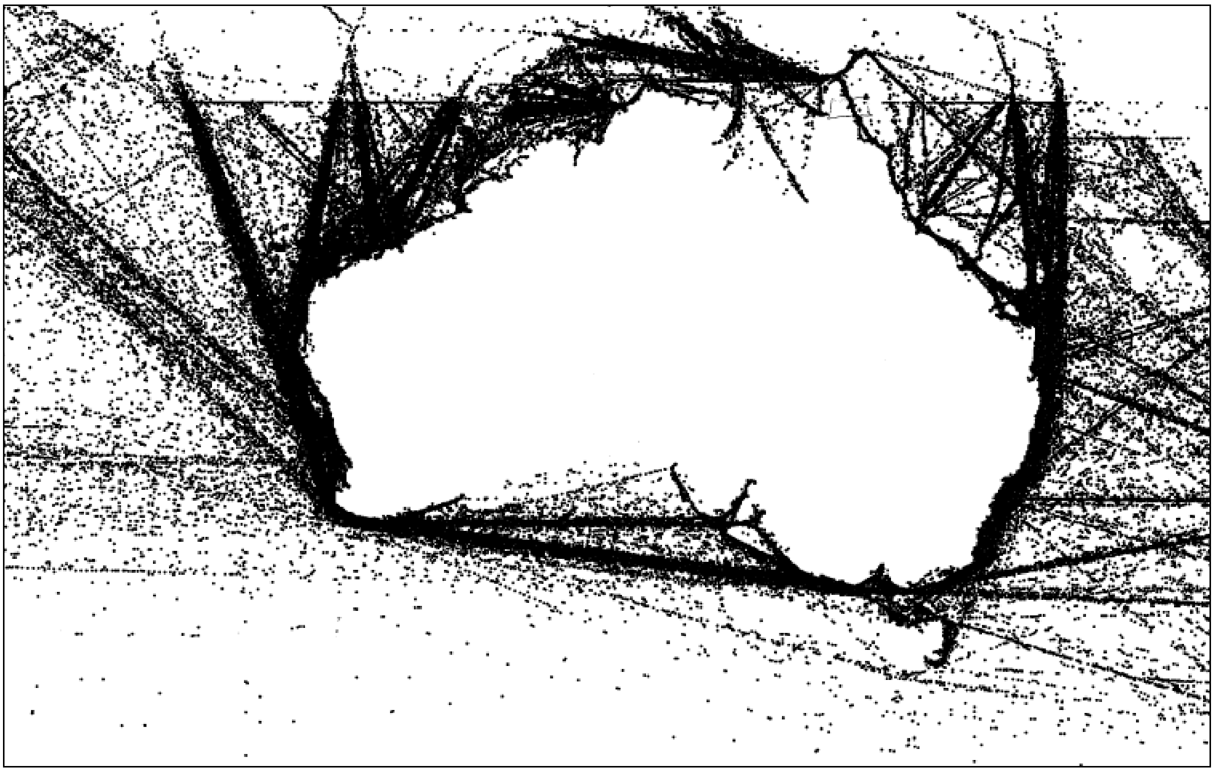
Figure 2.5 AUSREP Reporting Area

The main advantage of AUSREP for this study is that the reports are convenient and efficient to use. It provides the data on vessel numbers, sizes, types and locations that the model requires. Possible limitations are:

- The data does not show individual ship tracks between the reporting points. However, this is not essential for the present study.
- Some Australian Offshore Territories are outside the AUSREP reporting area. It is therefore necessary to make a separate estimate of the traffic in these areas.
- Many AUSREP reports are clustered at the boundaries of the reporting area. However, these clusters are smoothed when the reports are allocated to the calculation sub-regions, so they do not affect the study results.

Figure 2.6 shows a sample of the AUSREP data for 2009. This clearly shows the main shipping routes, and is also sufficient to show the relative density of shipping in other areas.

Figure 2.6 Sample AUSREP Data



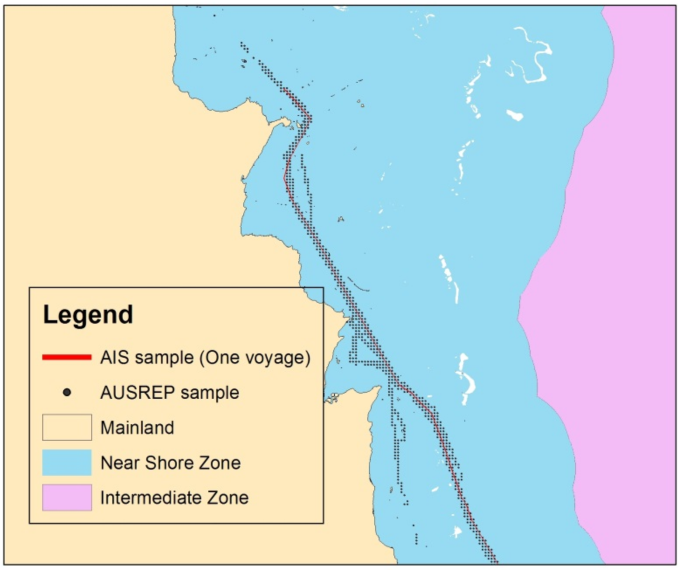
2.5.2 AIS Data

An alternative source of ship traffic data for this project is the Automatic Identification System (AIS). Ships larger than 300GT are required by IMO to carry an AIS transponder that sends out digital radio messages identifying the vessel and providing its position, course and speed. The aim of the system is to improve the possibilities of collision avoidance by forcing ships to share important information. A secondary benefit is that AIS messages can be systematically collected to obtain a detailed picture of the shipping in a region of interest. Networks of land based VHF receivers can gather such information, but their range of coverage is limited to about 40 nm. Satellite surveillance can provide long-range coverage, but data is only collected when a satellite passes over the region of interest, and provides periodic snapshots of the ship traffic.

The main advantage of AIS for this study is that the reports are very detailed, and show the individual ship tracks. The disadvantages are that the datasets are much larger, and may have gaps due to incomplete satellite coverage that are difficult to detect and remove.

Figure 2.7 compares some sample AUSREP data with a single AIS track in the same area. Other AIS tracks in the same area are almost exactly along the same line, and give the impression of a single track, although in reality it is a combination of many identical tracks. The scatter of the AUSREP data gives a more realistic picture of where ships might be at any time, which could only be reproduced in AIS by using a very large number of tracks. This plot also shows the Near-shore and Intermediate Zones, and demonstrates that, at the level of granularity used in this nationwide study, the AUSREP locations are sufficient to allocate traffic to the zones, and there is no need to analyse the more comprehensive AIS dataset.

Figure 2.7 Sample Comparison of AUSREP and AIS Data



2.6 Environmental Sensitivity Indicators

The objectives of this study require it to take account of the sensitivity of the different locations in Australian ports and waters where oil spills might occur. This sensitivity needs to be reflected quantitatively, so that it can be combined with the quantitative estimates of ship traffic densities and oil spill frequencies.

This is an extremely challenging requirement, because the Australian maritime environment covers a very large area with very great diversity and includes some uniquely sensitive features such as the Great Barrier Reef.

Although the Australian maritime environment has been studied extensively, there is no readily available indicator that could provide established sensitivity measures for different locations. Work on Marine Bioregional Planning by the Department of Sustainability, Environment, Water, Population and Communities provides a strong foundation for understanding the conservation values of the marine environment, and it would be desirable to develop this into a suitable sensitivity indicator, but this would require more extensive development work than was feasible in the present project.

Therefore, in order to complete the necessary indicator for this study, a simple environmental sensitivity index (ESI) has been developed, as explained in Appendix II. A single ESI is estimated for each of the 120 calculation sub-regions in Australian waters. The aim is to form an index that can be combined with the spill frequencies to measure environmental risk. ESI is intended to take account of the key features of the environment, while being independent of the oil type and spill quantity, which are considered separately.

The ESI takes account of the following main features of the environment:

- Physical sensitivity, including the environmental characteristics that affect the persistence of the oil and the expected ease of clean-up after a spill.

- Biological resources, including habitats, species (especially rare or endangered ones), and unique or rare natural environments.

- Human-use resources, including commercial fishing and aquaculture, tourism, other recreational activities and amenities, and other sites important to local communities.

In practice, ESI is formed by combining three separate indicators:

- Physical sensitivity index (PSI), formed from well-established classifications of shoreline types, which reflect the relative cost of clean-up after an oil spill.

- Biological resource index (BRI), which takes account of the fraction of the sub-region's area or coastal length that is within the following different locations:

    - World heritage sites (the Great Barrier Reef and others)
    - Marine protected areas
    - Ramsar sites
    - Coastal wetlands
    - Shorebird habitats
    - Australian Antarctic Territory (considered as a unique habitat)

  Each of the types of sites and habitats are given weightings to indicate the relative valuation of natural resource damage caused by a given oil spill.

- Human-use resource index (HRI), which takes account of available information on:

    - The intensity of commercial fishing
    - The intensity of passenger vessel activity along the coast
    - The proportion of the coast that is fringed by national parks

  Each of these indicators is given a weighting to indicate an overall valuation of the damage to social resources caused by a spill.

The three indicators are combined using information on the breakdown of costs in actual oil spills:

$$ESI = 0.3\ PSI + 0.5\ BRI + 0.2\ HRI$$

In reality environmental sensitivity is extremely diverse and complex, and so the reduction of the entire Australian EEZ to 120 indicators implies extreme simplification compared to the real world. It is therefore important that the necessary degree of simplification is understood, and that the resulting indicators are not used inappropriately outside their intended application.

2.7 Selection of Risk Metrics

The risk of marine oil spills is considered to be the combination of likelihood and consequences of oil spills in the marine environment. Several different risk metrics can be used, such as:

- The frequency of oil spills, i.e. the expected number of spills per year (F). This is really a measure of likelihood, but it can also be seen as a crude measure of risk, treating all spills as equally important.

- The frequency of oil spills exceeding given quantities. This is defined as:

  $$F > Q = \sum_{spills>Q} F \qquad \text{for F in spills per year}$$

  This has the convenience of the frequency metric above, but takes some account of the consequences, which in general are larger for larger spills. The complete distribution of the frequencies of spills of different quantities (FQ curve) is normally plotted as a complementary cumulative distribution function (CCDF), which is a curve that declines smoothly from high frequencies and low quantities to low frequencies and large quantities.

- The oil spill risk, i.e. expected number of tonnes of oil spilled per year. This is defined as:

  $$R = \sum_{spills} FQ \qquad \text{for F in spills per year; Q in tonnes}$$

  This is a convenient, simple measure of risk, but it has the limitation that it treats each tonne of spilled oil as equally important, regardless, of location, oil type or total spill quantity. In some cases it is very sensitive to the largest modelled spill (see Section 2.8).

- The frequency of oil spills reaching the shore. This is defined as:

  $$F_s = FP_s$$

  This is a better measure of risk, because it uses the probability of oil reaching the shore (P_S) as a measure of oil spill consequence. It is a useful stepping stone to better risk measures, but is inadequate on its own because it treats all spills that reach the shore as equally important, and neglects those that do not.

- The frequency of oil spills exceeding given quantities that reach the shore. This is defined as:

  $$F_s > Q_s = \sum_{spills>Q_s} F_s \qquad \text{for } F_s \text{ in spills per year}$$

  This is another stepping stone to a better measure, using the quantity of oil reaching the shore (Q_S) as a measure of oil spill consequence.

- The oil beaching risk, i.e. expected number of tonnes of oil reaching the shore per year. This is defined as:

  $$R_s = \sum_{spills} F_s Q_s \qquad \text{for } F_s \text{ in spills per year; } Q_s \text{ in tonnes}$$

  This is a convenient, simple measure of risk, but it has the limitation that it treats each tonne of oil that reaches the shore as equally important, regardless of location, oil type or total spill quantity, and neglects oil that does not reach the shore.

- The environmental sensitivity index (ESI) of the spill location. This is explained in Section 2.6 and Appendix II. The ESI is purely a measure of consequence, and takes no account of the oil type, spill quantity or spill likelihood. This is a new metric, which is a very simplified measure of environmental sensitivity, and so should be used with caution, as explained in Section 2.9.

- The environmental risk index (ERI). This is defined in Appendix VI as:

  $$ERI = \sum_{spills} FC\left[Q^{0.6} ESI + P_s {Q_s}^{0.6} ESI_s\right]$$

  This is the most comprehensive measure of risk that is used in this study. It takes account of the spill frequency (F), the environmental sensitivity of the sub-region where the spill occurs (ESI) and at the shoreline (ESI_s), the spill quantity (Q), the probability (P_s) and quantity (Q_s) of oil reaching the shore, and also the cost of a spill of the specific oil type (C). It is therefore able to take account of the most important parameters affecting oil spill risk. ERI is intended to be proportional to the total oil spill cost, measured in units of A$million. However, because it is not at present possible to estimate such costs accurately, it is appropriate to use the name ERI rather than oil spill cost. Since this is a new and uncertain metric, it should be used with caution, as explained in Section 2.9.

All these measures can be calculated for a given location (e.g. a port or calculation sub-region). Apart from ESI, they can all be summed for the whole study region (i.e. the Australian EEZ), or broken down to show the contributors from individual ship, accident or oil types.

All the measures (except ESI) refer to annual risks in the sub-region. They therefore tend to be larger for larger sub-regions with more shipping activity, even if the shipping densities and other factors are similar. Spill frequencies per unit activity are given in Appendices IV and V, but are not included in the main results.

In order to simplify the presentation of results, Section 3 concentrates on the following key metrics:

- The frequency of spills greater than 1, 100 and 10,000 tonnes (F>1, F>100, F>10k).

- The oil spill risk (R).

- The environmental risk index (ERI).

In plotting the risk metrics on maps, each metric is divided into 5 risk categories - “very high”, “high”, “moderate”, “low” or “very low”. This simplification avoids over-precision, acknowledging the inherent uncertainties in the estimates. The categorisation differs slightly in each case, so the definitions of each category are given next to the maps in Section 3.

Also, when plotting the risks on maps, the locations refer to the sub-region in which the accident occurs. In most cases, this is the same as the sub-region in which the oil spill impact occurs, but where a ship breaks down in an offshore zone and drifts to a near-shore zone where it grounds and spills, the risk is included in the offshore zone. Similarly, where a spill occurs in an offshore zone but drifts into a near-shore zone, the risk is included in the offshore zone. Despite these choices, the risk is in general largest for the near-shore zones.

2.8 Interpretation of Risk Metrics

Environmental risk is complex and difficult to quantify. It is not at present possible to define the environmental risk in a way that can be quantified accurately or agreed by diverse stakeholders. This is why several different risk metrics have been considered. Each risk metric has its own strengths and weaknesses. The frequencies of different sizes of spills (F>Q) may be considered the most robust metrics, since they are easiest to calculate and validate against historical experience. However, they are difficult to use for decision-making, because they vary with spill size, as shown on the FQ curve.

In principle, integrated metrics such as oil spill risk (R) and environmental risk index (ERI) are more useful for decision-making, because they combine all spill sizes. They are simple to tabulate and break down into their main contributors. However, they are more uncertain, because the necessary inputs are difficult to quantify, and because it is a matter of opinion which metric has the most appropriate weighting.

In the present study, there is a key uncertainty that affects the oil spill risk (R), and to a lesser extent the environmental risk index (ERI). In general, where large spills are relatively common, such that the FQ curve has a slope less steep than -1 on a log-log plot, the total oil spill risk (R) tends to be dominated by the largest spills. If the FQ curve has a slope less steep than -0.6, the ERI also tends to be dominated by the largest spills. Although these are the least likely events to occur, they dominate the integration, and hence the uncertainty in the overall metric. In the results below, this sensitivity to large spills is most important in the risks from offshore activities, where there is a significant possibility of blowouts causing very large spills. The total risk (measured in terms of tonnes of oil spilled per year) is dominated by blowouts, even though these are less likely than smaller spills.

This feature of oil spill risk makes it difficult to compare the risk estimates to actual experience. In such circumstances (i.e. where FQ curve has a slope less than -1), in most years the actual oil spill quantity will be much less than the predicted average. Very occasionally there will be a large spill whose quantity is far greater than the total previously recorded. This pattern has been shown in Australia by the Montara blowout in 2009, and also by the Macondo blowout in the Gulf of Mexico in 2010. Such a pattern is very difficult to use to validate the risk predictions. Even if the annual spill quantities are close to the predicted risk, this is mainly due to chance. The average risk would only be revealed once there had been many such large events, and in practice this would not be expected, except on a world-wide scale over many decades.

Despite these uncertainties, the integrated risk metric ERI appears to be the most appropriate measure to assess the oil spill risk in most cases. However, other metrics may give different conclusions about where and why the risk is largest. The following section therefore considers how ERI can be used in practice, while taking account of these uncertainties.

2.9 Use of Risk Metrics

For the purpose of emergency planning, it is desirable to understand which regions of the Australian coast experience the highest oil spill risks, and what typical causes of such spills might be. In this context, the meaning of “risk” encompasses all the risk metrics considered above. However, in order to draw consistent conclusions, ERI is believed to give the best available prediction of risks to the environment from oil spills, as it takes account of all the other risk metrics, and gives results that are expressed in financial terms.

ERI can be interpreted as a measure of the importance of the oil spill risks, from the emergency planning point of view, as far as this can be quantified at present. Large ERI values imply higher risks of economically and environmentally damaging oil spills, and hence greater opportunities to reduce them through emergency planning.

Given the uncertainties that are discussed above, it is necessary to take account of the fact that different risk metrics might lead to different conclusions. A possible method of doing this is as follows:

1. Obtain the ERI for the area under consideration. These results are presented in Section 3.5.5 below. They are the main results for identifying the areas that require the greatest protection against oil spills. If appropriate, they may be used to quantify the benefits of interventions to prevent or mitigate oil spills.

2. Obtain the breakdown of ERI into spill source and accident types. These results are presented in Section 3 as national totals, and in the spreadsheet for each sub-region. They are the main results for designing an appropriate oil spill response capability.

3. Obtain the frequencies of different spill sizes (F>Q) for the area under consideration. These results are presented in Section 3.1.2 below. They are the main results for anticipating the sizes of spill that may occur.

4. If there is a relatively high probability of large spills (which may be indicated by an FQ curve with a slope less steep than -0.6, or a high proportion of spills from offshore sources), there is a possibility that the ERI may be unreliable (see Section 2.8). In this case, obtain the breakdown of the frequency of each spill size into spill source and accident types. These results are presented in Section 3 as national totals, and in the spreadsheet for each sub-region. These should also be used to design an appropriate oil spill response capability, and it is possible that this will imply greater protection than obtained from ERI.

5. As a sensitivity test, obtain the breakdown of oil spill risk (R) into spill source and accident types. These results are presented in Section 3 as national totals, and in the spreadsheet for each sub-region. If they would lead to a significantly different oil spill response capability, then the results may be sensitive to the choice of risk metric. Unless the differences can be resolved by more detailed study, it would normally be appropriate to choose the greatest of the possible oil spill response capabilities.

6. As a final sensitivity test, compare the ESI with adjacent sub-regions. If they would lead to a significantly different oil spill response capability, then the results may be sensitive to the ESI. Unless the environmental sensitivity can be validated by expert

judgement, it would normally be appropriate to choose the greatest of the possible oil spill response capabilities.

For the purpose of validation of the risk estimates against recorded spill data, the most useful metric is the frequency of spills over 1 tonne. In large datasets the FQ curve may also be useful.

The main results, including ERI and the other selected metrics, are given in the following sections. The spreadsheet results allow further breakdown of the totals to show which spill sources and accident types contribute to the risk.

3 RESULTS FOR 2010

3.1 Overall Risk Results

3.1.1 Case Definition

The following results combine the contributions from ships at sea and in port, small commercial vessels, offshore production and drilling and shore-based spills. These contributions are presented individually in subsequent sections. The results refer to current risks, as far as can be estimated. In practice, this refers to activity levels in 2010, although a contribution has been included from ship-to-ship transfer at sea, which in fact did not occur in 2010.

3.1.2 Spill Frequencies

Figures 3.1 to 3.3 show the overall frequencies of spills exceeding 1, 100 and 10,000 tonnes for each calculation sub-region. The results for the near-shore zones include spills in ports within each sub-region.

Figure 3.1 Frequencies of Spills Greater Than 1 Tonne

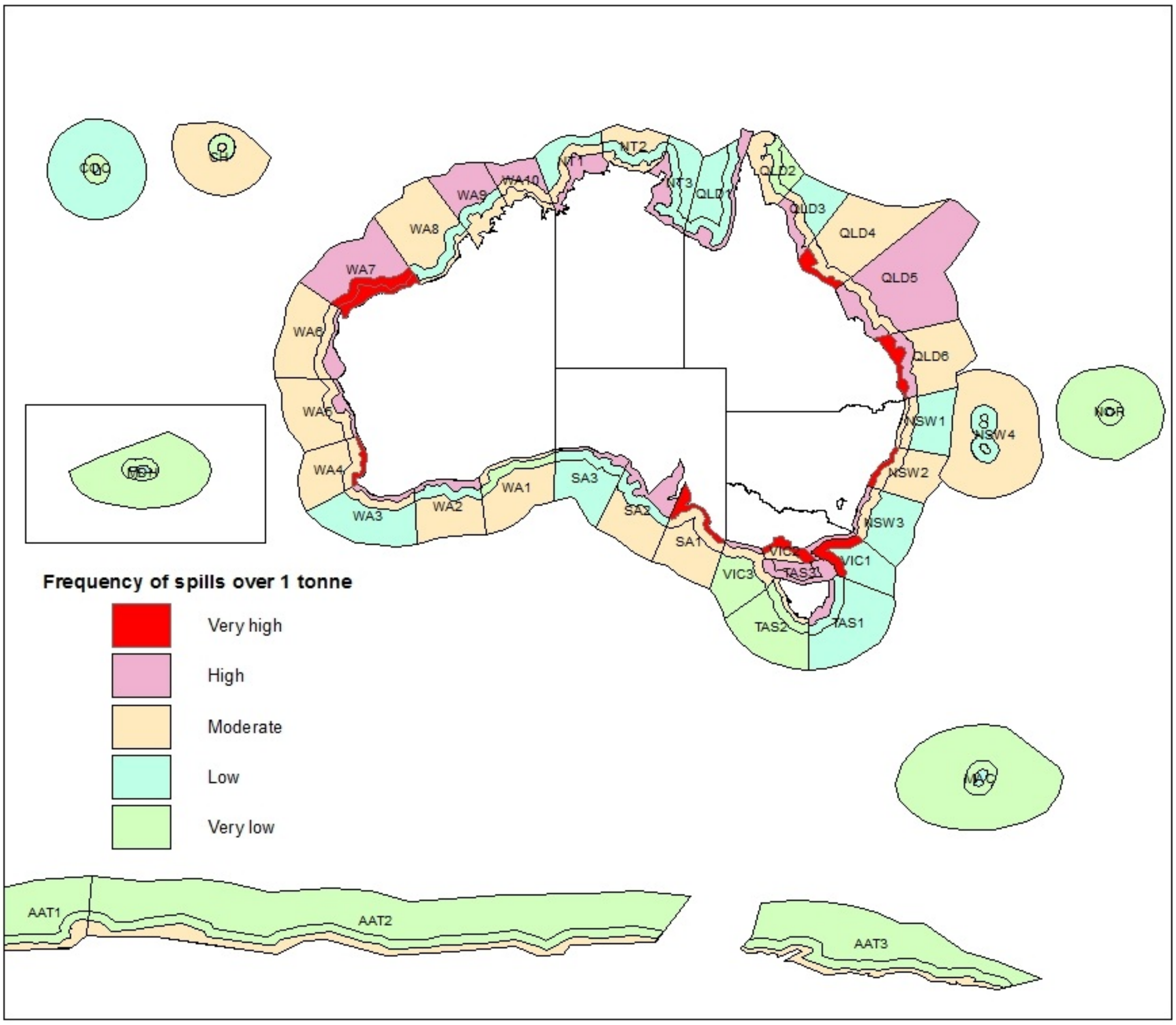


Table 3.1 gives the colour coding that has been used to divide the frequencies into 5 risk categories. This involves logarithmic steps, so that the frequency of spills in any category is typically 10x higher or lower than in the next highest or lowest categories. The frequencies refer to the total annual numbers of events in each sub-region. The categories are all relative to Australian average, since in absolute terms the frequencies in all sub-regions could be considered low or very low. The average intervals between spills are therefore included in the table.

Table 3.1 Definitions of Categories

CATEGORY	FREQUENCY (per year)	INTERVAL (years)
Very high	>0.1	<10
High	0.01 to 0.1	10 to 100
Moderate	0.001 to 0.01	100 to 1000
Low	0.0001 to 0.001	1000 to 10,000
Very low	<0.0001	>10,000

In general, the maps show the highest spill frequencies for near-shore zones containing major ports and large numbers of small commercial vessels. Intermediate and deep-sea zones have generally lower spill frequencies, but the highest of these are zones with high levels of trading ships or offshore activities.

Figure 3.2 Frequencies of Spills Greater Than 100 Tonnes

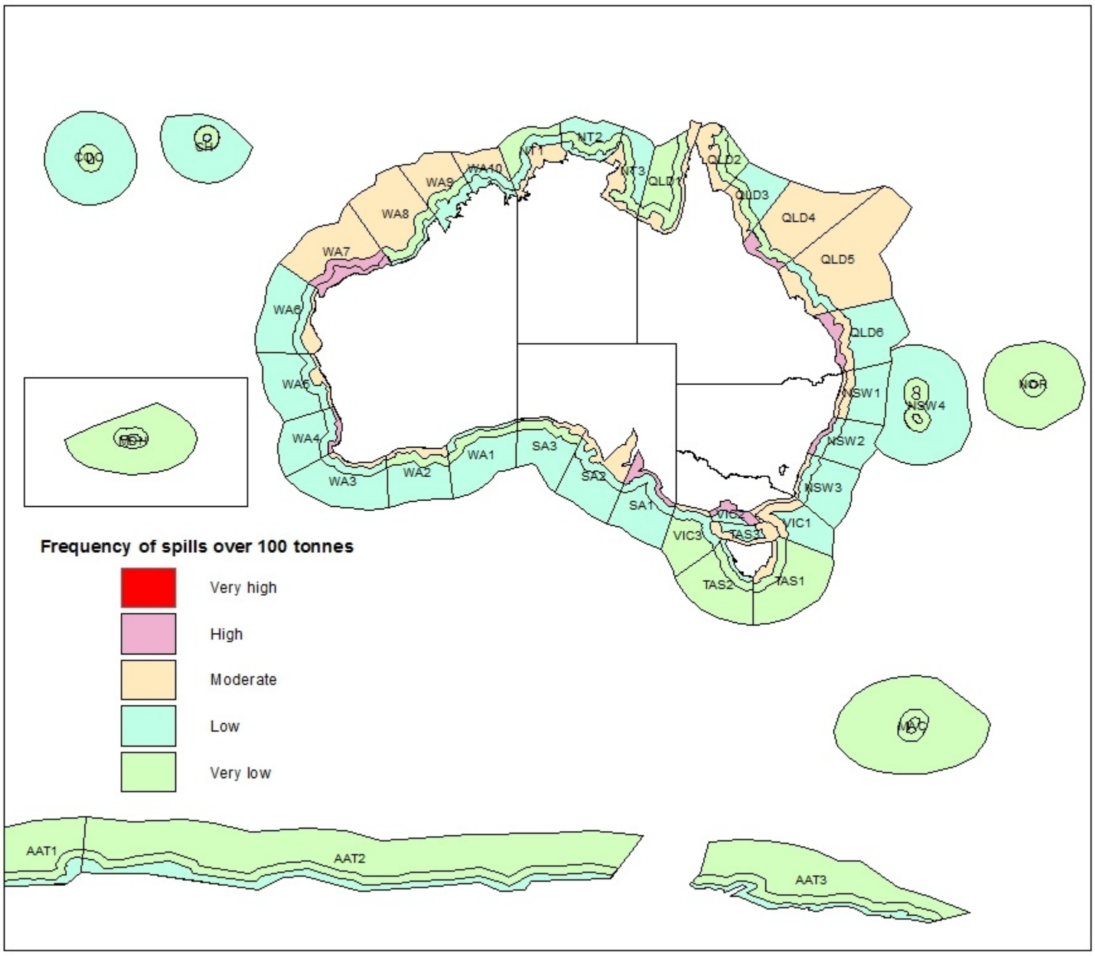
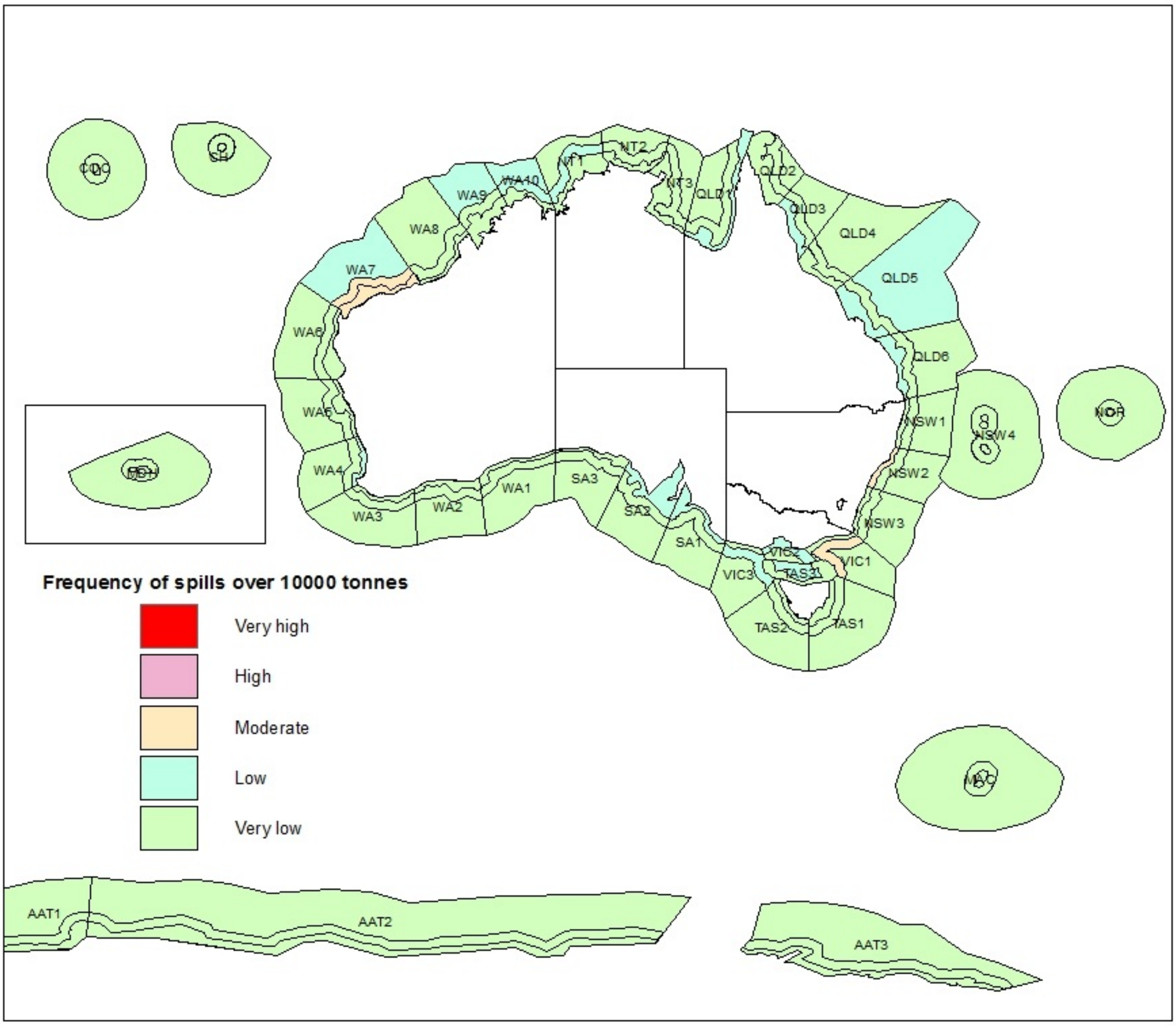


Figure 3.3 Frequencies of Spills Greater Than 10,000 Tonnes



In some cases, the frequencies for intermediate zones are lower than for the adjacent near-shore and deep-sea zones. This is because the intermediate zones are much smaller than the deep-sea zones, and some have little shipping traffic. In contrast to the near-shore zones, they also contain no ports.

Figure 3.4 gives the overall national FQ curve, i.e. the annual frequencies of spills exceeding different quantities, adding all sub-regions together. This also includes a breakdown into three main components:

- Ships, including ships at sea, in port and small commercial vessels.
- Offshore, including offshore production and drilling.
- Shore-based.

Figure 3.4 Overall National Spill Frequency-Quantity (FQ) Curve

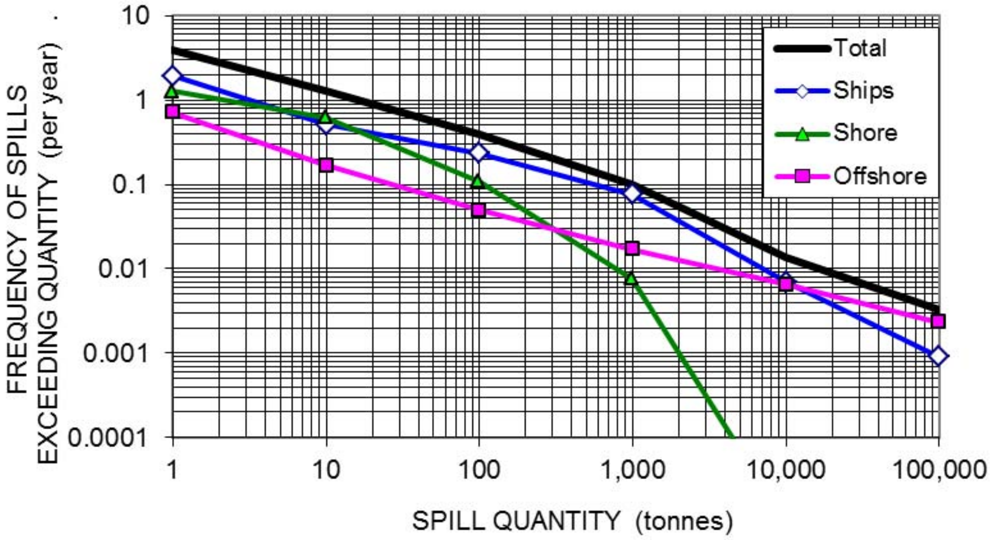


Table 3.2 gives the frequencies of this distribution. The total national frequency of spills of 1 tonne or more of oil into the marine environment is estimated as 3.9 per year.

It also includes a breakdown into the following components:

- Trading ships at sea (based on AUSREP data).
- Trading ships in port (based on AMSA port data).
- Small commercial vessels.
- Offshore production (including pipelines).
- Offshore drilling.
- Shore-based.

Table 3.2 Overall National Exceedence Frequencies for Oil Spills

SOURCE	>1 TONNE (per year)	>10 TONNES (per year)	>100 TONNES (per year)	>1,000 TONNES (per year)	>10,000 TONNES (per year)
Trading ships at sea	0.235	0.154	0.079	0.032	0.005
Trading ships in port	0.591	0.357	0.153	0.044	0.002
Small commercial vessels	1.105	0.000	0.000	0.000	0.000
Offshore production	0.685	0.152	0.041	0.013	0.004
Offshore drilling	0.033	0.016	0.008	0.004	0.002
Shore-based	1.272	0.618	0.109	0.008	0.000
Total	3.920	1.297	0.390	0.101	0.013

The frequencies of spills over 1 tonne are dominated by shore-based spills (32%) and small commercial vessels (28%). The frequencies of spills over 10,000 tonnes are dominated by trading ships at sea (33%) and offshore production (32%). In the mid-range the contributions follow the pattern shown in Figure 3.4.

3.1.3 Spill Risks

Table 3.3 gives the overall national spill risks, i.e. the expected annual quantities of oil spilled into the marine environment, adding all sub-regions together.

Table 3.3 Overall National Oil Spill Risk

SOURCE	SPILL RISK (tonnes per year)	%
Trading ships at sea	212	22.3%
Trading ships in port	174	18.3%
Small commercial vessels	2	0.2%
Offshore production	310	32.7%
Offshore drilling	209	22.0%
Shore-based	42	4.5%
Total	948	100.0%

The spill risk is dominated by offshore production (33%), offshore drilling (22%) and trading ships at sea (22%). However, it should be noted that the spill risks for offshore activities may be unreliable. This is because their FQ curve (Figure 3.4) has a slope of approximately -0.6, so that the spill risks in Table 3.3 are dominated by the quantities in the largest modelled blowouts, which are difficult to predict from historical data (see Section 2.8).

3.1.4 Environmental Sensitivity

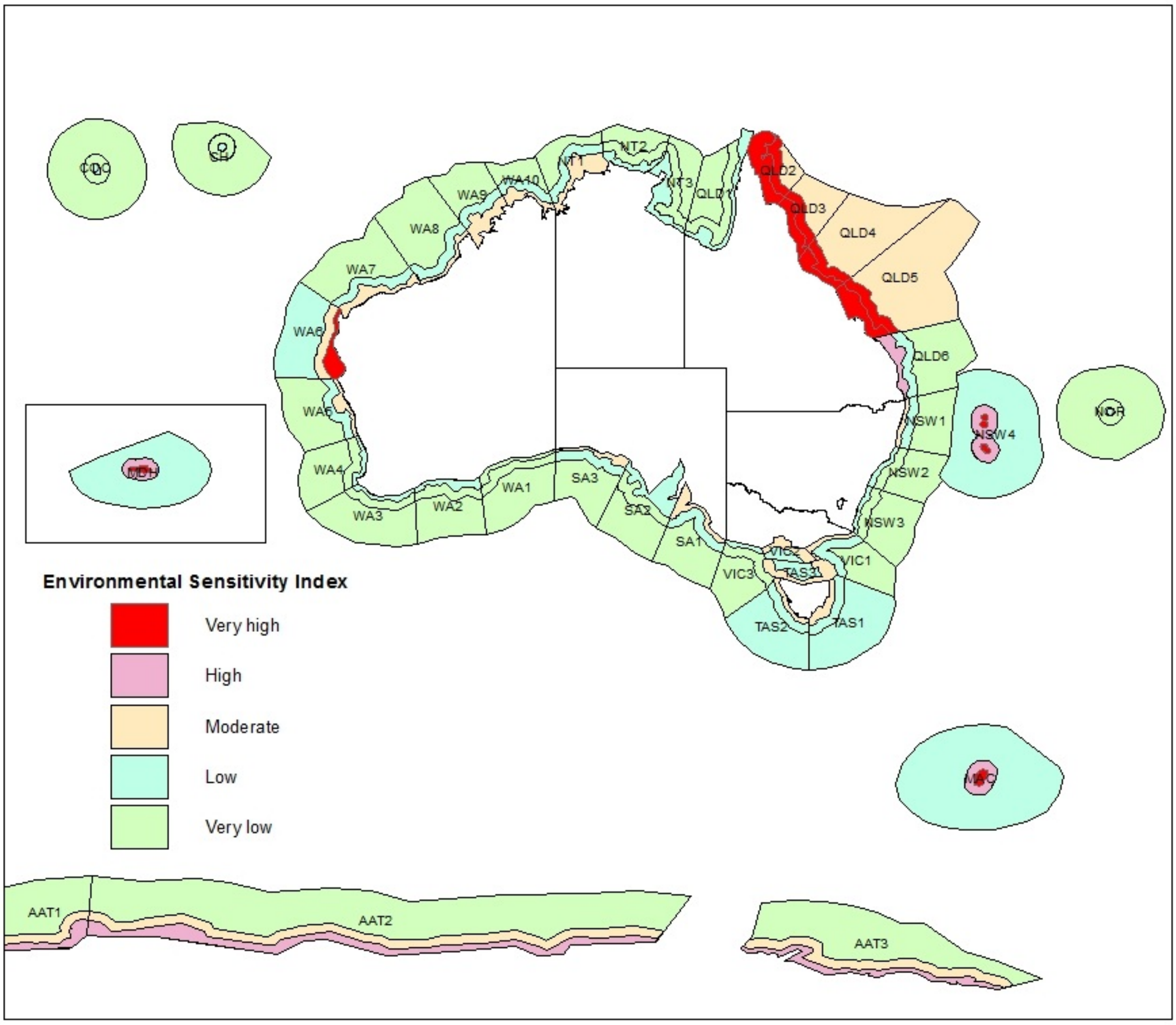
Figure 3.5 shows the environmental sensitivity index (ESI) that has been estimated for each calculation sub-region using the method from Appendix II. Table 3.4 gives the colour coding that has been used to divide ESI into 5 categories.

Table 3.4 Definitions of Categories

CATEGORY	ESI
Very high	>10
High	5 to 10
Moderate	2.5 to 5
Low	1 to 2.5
Very low	<1

The highest ESIs are for world heritage sites of the Great Barrier Reef, Shark Bay and Ningaloo Coast (sub-region WA-6), Lord Howe Island, Macquarie Island and McDonald/Heard islands. The next highest ESIs are for the Australian Antarctic Territory and the intermediate zones adjacent to the world heritage sites. Moderate ESIs are for many other near-shore zones, and the deep-sea zones adjacent to the Great Barrier Reef. Other deep-sea zones are categorised as low or very low. These categories refer to the environmental sensitivity relative to other parts of the Australian EEZ, according to the method explained in Appendix II, and are not intended to evaluate their importance in absolute terms.

Figure 3.5 Environmental Sensitivity Indices



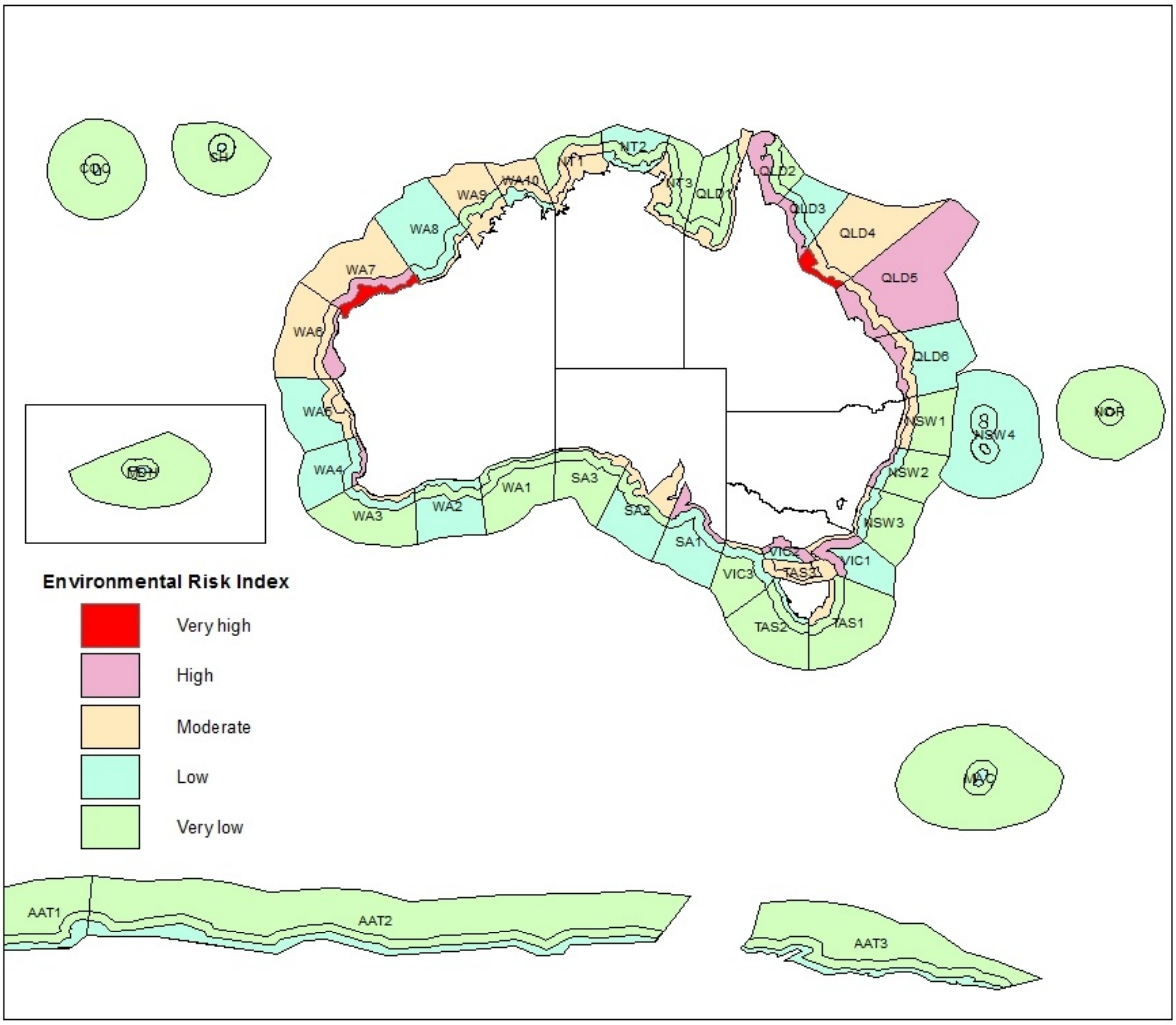
3.1.5 Environmental Risk

Figure 3.6 shows the environmental risk index (ERI) that has been estimated for each calculation sub-region using the method from Appendix VI.6.6. Table 3.5 gives the colour coding that has been used to divide ERI into 5 categories. This involves logarithmic steps, so that the ERI in any category is typically 10x higher or lower than in the next highest or lowest categories.

Table 3.5 Definitions of Categories

CATEGORY	ERI (million A$ per year)
Very high	>1
High	0.1 to 1
Moderate	0.01 to 0.1
Low	0.001 to 0.01
Very low	<0.001

Figure 3.6 Environmental Risk Indices



The highest ERIs are for sub-regions that combine high shipping activity with high environmental sensitivity, notably the Great Barrier Reef (centred on sub-region QLD-4-N), and areas with high levels of trading ship and SCV activity and moderate environmental sensitivity (notably sub-regions WA-7-N, but also QLD-6-N, NSW-2-N, VIC-2-N, SA-1-N and WA-4-N), or moderate shipping traffic and high environmental sensitivity (WA-6-N). There are also high ERIs for zones that combine high shipping traffic and moderate environmental sensitivity (QLD-5-D), or offshore activities (WA-7-I and VIC-1-I). Some of the patterns result from the arbitrary boundaries of the risk categories, in cases where the ERI of several regions is close to the boundary values in Table 3.5. Some intermediate zones have low or moderate risks because of their relatively low shipping traffic, despite their environmental sensitivity (e.g. QLD-5-I).

Table 3.6 gives the overall national ERI, i.e. the expected annual cost of oil spilled into the marine environment, adding all sub-regions together. It is dominated by trading ships in ports (50%), which was also a finding of the previous study (DNV 1999).

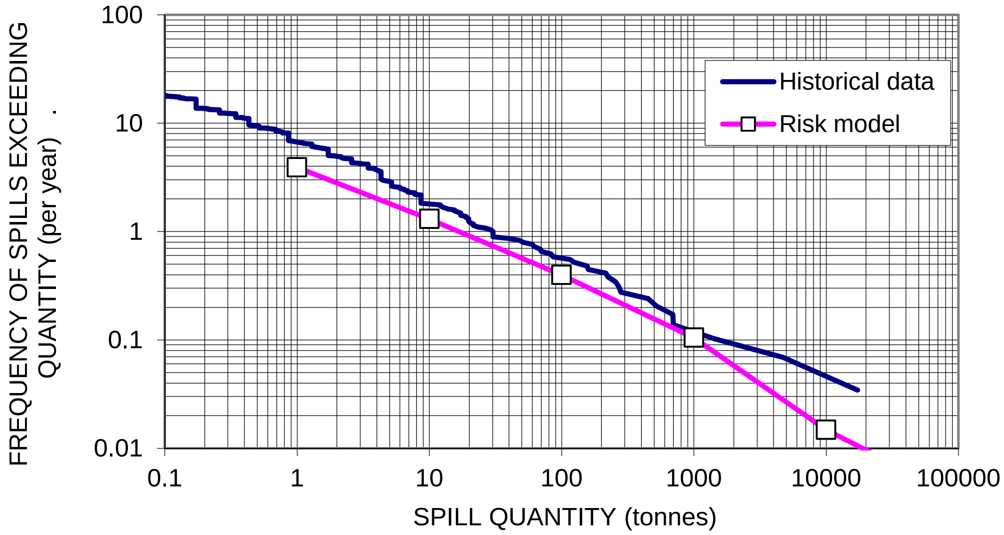
Table 3.6 Overall National Environmental Risk Index

SOURCE	ERI (million A$ per year)	%
Trading ships at sea	2.6	29.1%
Trading ships in port	4.5	49.7%
Small commercial vessels	0.1	1.2%
Offshore production	0.6	6.2%
Offshore drilling	0.2	2.3%
Shore-based	1.1	11.5%
Total	9.1	100.0%

3.1.6 Validation against National Data

Figure 3.7 compares the predicted national FQ curve from Figure 3.4 with the historical data from 1982-2010 (see Appendix III). The predicted results are slightly lower than the historical results, by less than a factor of 2 for spills of 1000 tonnes or less and approximately a factor of 3 for spills of 10,000 tonnes or more. They are all within the estimated uncertainty range on either the predictions (see Section 3.1.9) or the historical data (see Appendix III.7).

Figure 3.7 Comparison of Frequency-Quantity (FQ) Curve with Historical Data



The reduction compared to historical data may be explained by the adoption of double hull tankers and the general reduction in accident frequencies. On the other hand, the historical data may be under-reported, and some activities, such as offshore drilling, have increased during the period. The difference for spills of 100 tonnes or less is sensitive to the modelling of small commercial vessels, while the difference for spills of 10,000 tonnes or more is sensitive to the modelling of blowouts. Both are very uncertain, and so these uncertainties dominate the differences between historical and predicted risks.

The predicted oil spill risk of 948 tonnes per year is close to the average of 1010 tonnes per year in the historical data (Appendix III). This agreement is fortuitous, as the two results depend strongly on the largest events in the model and data (see Section 2.8).

It is recognised that this is not an independent validation, because the same data contributed to the development of the risk models. The shore-based spill frequencies were derived directly from the data, while the ship and offshore spill frequencies were individually validated against it. Nevertheless, it provides useful confirmation that the risk estimates are consistent with historical experience. They can therefore be used with greater confidence to provide results that are not available from the historical data.

3.1.7 Validation against Queensland Port Study

A recent semi-qualitative risk assessment of ship-sourced oil spills in Queensland ports (GHD 2010) combined the methodology of the earlier national risk assessment (DNV 1999) with port-specific judgements, and estimated a frequency of oil spills over 0.5 tonnes in the 20 Queensland ports of 4.1 per year. This was acknowledged to over-estimate the value of 0.3 per year that was obtained from actual experience reported to Maritime Safety Queensland during 2007-10.

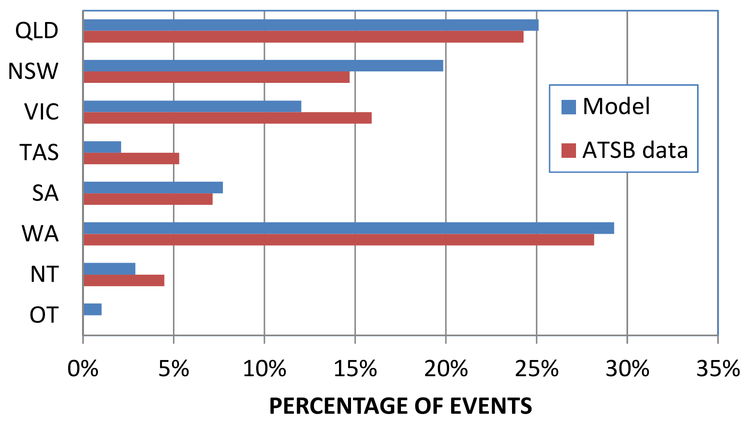
The present study gives a total frequency of spills over 1 tonne in the 15 modelled ports in Queensland of 0.15 per year. Using the FQ curve from above to extrapolate the frequency to spills over 0.5 tonnes, this would be 1.46 x 0.15 = 0.22 per year. This is much lower than the previous estimate, and relatively close to the historical data.

Again, this is not an independent validation, because the previous study used similar models, which have been updated in part to reflect recent improvements in performance. Nevertheless, it does show that the updates have reduced the accident frequencies as expected and improved agreement with historical data.

3.1.8 Validation against ATSB Data

ATSB (2011) provided a breakdown of 546 marine occurrences by area around the Australian coast during 2005-2010. These occurrences included all types of accident and incident on all types of trading ships except intrastate voyages. Only 7 of the occurrences involved oil pollution. Nevertheless, the locations of the full set of occurrences may be taken as an indicator of the possible distribution of oil spills, if further events occurred. Figure 3.8 compares the distribution by state in the ATSB data with the present model predictions of the frequency of oil spills over 1 tonne from trading ships. Given the different types of events in the two datasets, there is considered to be good agreement between the distributions.

Figure 3.8 Comparison of Distribution of Oil Spills with ATSB Marine Occurrence Data



3.1.9 Uncertainties

There are many sources of uncertainty in the risk estimates above. The main ones are considered to be as follows:

- The probabilities of oil spills for non-tanker vessels are difficult to estimate due to a lack of comprehensive data. The values in the study are based on single-hull tankers (Appendix IV), but may be unreliable.

- The spill size distributions are based on oil tanker data that is difficult to represent in simple models. The distributions that have been chosen (Appendix IV) are in some cases poor approximations of the data, and better models would be desirable.

- Small commercial vessel populations have been defined in detail, but they are represented in the model by a single vessel size (Appendix I.4). More detailed modelling of this population would be desirable.

- The available data on offshore drilling is not broken down into the same regions as are used in the study. The distribution of drilling activity is therefore modelled in a simple way (Appendix I.5), and an improved distribution would be desirable.

- The frequencies of oil spills from offshore process, storage and diesel use are based on old data (Appendix V), for which no suitable updates are available.

- There are some concerns about the quality of the Australian oil spill data (Appendix III), which has been used to provide the shore-based spill frequency estimates, as well as validate the work as a whole.

- The models of oil transport and fate (Appendix VI) are highly simplified, and so the estimates of shoreline risk from offshore spills should be treated with caution.

- The models of environmental impacts of different types of oils are based on world-wide clean-up cost data, and do not take account of the toxic effects of less persistent oil on sensitive environments (e.g. coral reefs), which may be important when comparing diesel and heavy fuel oils (see Appendix VI.6.5).

- The environmental sensitivity index is a very simplified measure of environmental sensitivity (Section 2.6).

- The environmental risk index is new and uncertain metric (Section 2.7).

It is not appropriate to quantify the uncertainties with precision. However, DNV's judgements, based on the uncertainties that have been discussed in Appendices II, III, IV, V and VI, are that the uncertainty range for the spill frequencies is approximately a factor of 3 higher or lower, while the uncertainty range for the spill risk and ERI is approximately a factor of 10 higher or lower. This means that any of the sub-regions on the map may be one category worse or better than shown. The uncertainties for the national totals are somewhat lower, as indicated by the good agreement in the validation above. The relative risks between different sub-regions would be expected to be more reliable than the absolute risks, but they may also be strongly influenced by individual spill models, which in some cases can be very uncertain. Therefore, in the absence of specific uncertainty estimates, the above ranges are considered applicable to differences in risk as well as absolute risks.

Recommended ways of improving the data quality and reducing the levels of uncertainty are given in Section 5.2.2. Recommended ways of taking account of the uncertainty in the risk metrics are given in Section 2.9.

The following illustrates the problem of uncertainty in the risk metrics. By the preferred risk metric (ERI), offshore drilling comprises 2.9% of the national risk (Table 3.6). Based on oil spill risk (measured in tonnes per year), it comprises 20.6% (Table 3.3). Based on the frequency of spilling 1 tonne or more, it comprises 0.8% (from Table 3.2). The latter figures could be considered confidence limits on the preferred figure. However, the method explained in Section 2.9 leads to the conclusion that the integrated metrics are unreliable because of the relatively high probability of large spills, and that the spill size distribution should be used instead. By this measure, offshore drilling comprises 0.8% of the national risk for spills over 1 tonne, varying up to 13% for spills over 10,000 tonnes (from Table 3.2). Although complex, this is the best available description of its contribution to the risk.

3.2 Breakdown for Ships

3.2.1 Breakdown by Ship Type

Table 3.7 shows the risk from oil spills from ships, broken down into the different ship types, using three risk metrics from above:

- The frequency of spills exceeding 1 tonne (per year)
- The spill risk (tonnes per year)
- The environmental risk index (million A$ per year)

Table 3.7 Risk Metrics for Ship Types

SHIP TYPE	SPILL FREQUENCY (per year)	%	SPILL RISK (tonnes per year)	%	ERI (million A$ per year)	%
Oil tanker	0.229	11.9%	276	71.2%	1.5	21.1%
Chemical tanker	0.021	1.1%	2	0.5%	0.1	1.8%
Bulk carrier	0.296	15.3%	59	15.3%	3.3	44.7%
General cargo ship	0.074	3.8%	9	2.4%	0.6	7.6%
Container ship	0.118	6.1%	28	7.3%	1.2	16.8%
Other ships	0.088	4.6%	10	2.7%	0.5	6.5%
Small commercial	1.105	57.2%	2	0.5%	0.1	1.5%
Total	1.931	100.0%	387	100.0%	7.3	100.0%

The spill frequencies are clearly dominated by small commercial vessels (57% of total spills). Among trading ships, bulk carriers and oil tankers make the largest contribution.

The spill risks are dominated by oil tankers (71% of total spill quantity). This is because oil tankers have the greatest potential to cause large spills, which dominate the result.

The ERI combines the above effects, and has significant contributions from bulk carriers (45%), oil tankers (21%) and container ships (17%). The contribution of small commercial vessels is small because the modelled vessel size has a small fuel capacity. These results may be sensitive to the uncertainties about relative environmental impacts of bunker and diesel oil.

3.2.2 Breakdown by Accident Type

Table 3.8 shows the same three metrics broken down into the following accident types:

CN Collision - leak due to striking or being struck by another ship, whether under way, anchored or moored.

CT Contact - leak due to striking or being struck by an external object, but not another ship or the sea bottom. While at sea, it includes striking offshore rigs/platforms.

FX Fire/explosion - leak due to fire and/or explosion where this is the first event reported. This includes fires due to engine damage, but not fires due to other categories, such as collision etc.

HD Hull damage - leak due to damage to hull, structural failure, loss of stability or flooding. It includes the LRF category "foundered".

TS Transfer - leak due to failure or error during loading/unloading cargo or fuel oil. This includes loading in port and during ship-to-ship transfer at sea.

UD Unauthorised discharge - pollution due to deliberate or accidental discharge of oil or oily water through hull valves, pipes or scuppers, except due to loading/unloading.

GD Drift grounding - leak due to grounding while not under control, typically due to loss of propulsion and/or anchors in adverse weather.

GP Powered grounding - leak due to grounding while under power, typically due to navigational error. This includes cases where power is lost close to the point of grounding, before the ship begins to drift.

Table 3.8 Risk Metrics for Accident Types

ACCIDENT TYPE	SPILL FREQUENCY (per year)	%	SPILL RISK (tonnes per year)	%	ERI (million A$ per year)	%
Collision	0.224	11.6%	68	15.8%	1.5	20.8%
Contact	0.054	2.8%	9	2.0%	0.2	2.9%
Fire/explosion	0.137	7.1%	29	6.8%	0.4	4.9%
Hull damage	0.236	12.2%	116	27.0%	1.8	24.2%
Transfer spill	0.384	19.9%	42	9.6%	1.0	14.1%
Unauthorised discharge	0.111	5.7%	4	1.0%	0.1	0.9%
Powered grounding	0.369	19.1%	121	28.1%	1.7	24.0%
Drift grounding	0.416	21.6%	42	9.7%	0.6	8.2%
Total	1.931	100.0%	432	100.0%	7.3	100.0%

The spill frequencies are dominated by transfer (20%), drift grounding (22%) and powered grounding (20%). This result is broken down further by ship type in Table 3.9 below. This shows that the transfer spills are mainly from oil tankers (i.e. cargo spills), and to a lesser extent from bulk carriers (i.e. bunker spills), whereas the grounding spills are mainly from small commercial vessels (i.e. fuel oil spills). This is mainly a consequence of combining the spill size distribution models (Appendix IV) with the assumed SCV size (Appendix I.4).

The spill risks are dominated by powered grounding (28%), hull damage (27%) and collision (16%). This is because, in contrast to the transfer spills that dominate the spill frequencies, these types of accidents have a much greater potential to cause large spills.

The ERI combines the above effects, and has significant contributions from powered grounding (24%), hull damage (24%), collision (21%) and transfer spill (14%).

Table 3.9 Spill Frequencies (per year) for Ship Types and Accident Types

TOTAL	CN	CT	FX	HD	TS	UD	GP	GD	TOTAL
Oil tanker	0.01	0.001	0.00	0.01	0.18	0.01	0.01	0.00	0.23
Chemical tanker	0.00	0.001	0.00	0.00	0.01	0.00	0.00	0.00	0.02
Bulk carrier	0.06	0.006	0.01	0.03	0.09	0.05	0.04	0.01	0.30
General cargo ship	0.01	0.002	0.00	0.01	0.02	0.01	0.01	0.01	0.07
Container ship	0.03	0.004	0.00	0.01	0.04	0.02	0.01	0.00	0.12
Other ships (inc SCVs)	0.11	0.040	0.12	0.18	0.05	0.01	0.30	0.39	1.19
Total	0.22	0.054	0.14	0.24	0.38	0.11	0.37	0.42	1.93

3.2.3 Breakdown by Accident Location

Table 3.10 shows the risks from trading ships, broken down into the following accident locations:

- In port - within the harbour or at the berth, excluding time in transit
- Restricted waters - in transit between the port and the open sea
- At sea. For consistency with AUSREP reporting, this includes any point more than 2 hours after leaving port.

This breakdown is not available for small commercial vessels, due to lack of data on time in port, restricted water and at sea.

Table 3.10 Risk Metrics for Accident Locations

LOCATION	SPILL FREQUENCY (per year)	%	SPILL RISK (tonnes per year)	%	ERI (million A$ per year)	%
In port	0.551	66.7%	144	33.4%	3.6	49.8%
Restricted waters	0.040	4.8%	38	8.9%	1.0	13.3%
At sea	0.235	28.5%	248	57.6%	2.6	36.9%
Total	0.826	100.0%	430	100.0%	7.2	100.0%

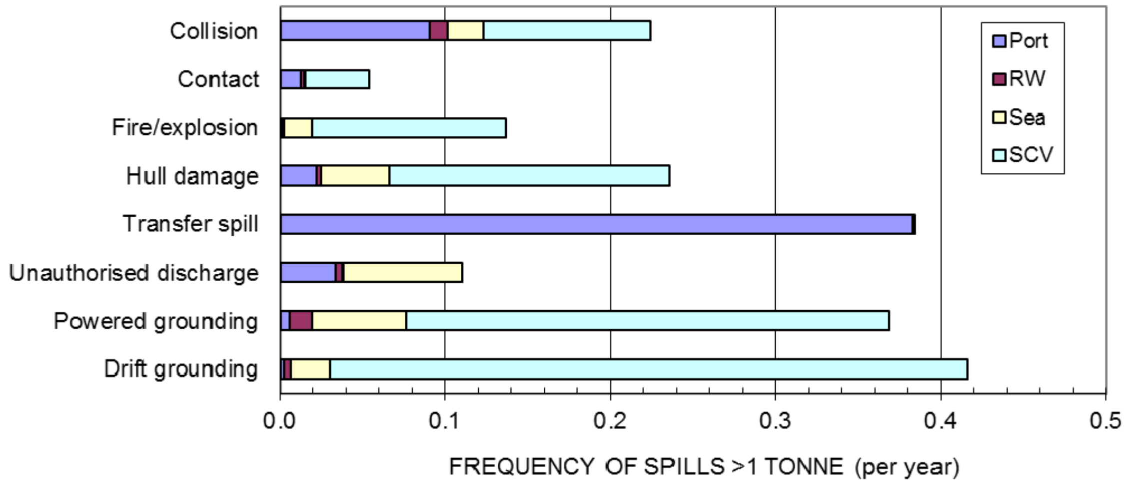
The spill frequencies are dominated by accidents in port (67% of total spills). Conversely, accidents in restricted water are relatively unimportant (5% of spills).

In the spill risks, accidents at sea make the largest contribution (58%). This is because powered groundings and hull damage dominate spill risks, because of their greater potential to cause large spills, and these occur mainly at sea. It is in contrast to the spill frequencies above, which are dominated by transfer spills, which mainly occur in port.

The ERI combines the above effects, and has significant contributions from accidents in port, restricted water and at sea. The precise values may be unreliable because they were obtained using a simplifying approximation in the spreadsheet.

Figure 3.9 shows a further breakdown of the spill frequencies by accident type, ship type and location.

Figure 3.9 Frequencies of Spills Exceeding 1 Tonne for Ships



Ship types and operating locations are split into the following categories:

- Port - trading ships in port (excluding time in transit)
- RW - trading ships in transit in restricted water
- Sea - trading ships at sea
- SCV - small commercial vessels (including time in port, restricted water and at sea).

The results for trading vessels are dominated by transfer spills in port, but there are no corresponding risks from SCVs because transfer spills the representative vessel size are predicted to be less than 1 tonne. The frequencies of transfer spills during ship-to-ship transfer are too small to be visible on this plot.

3.3 Summary of Results

For the purpose of emergency planning, it is desirable to understand which regions of the Australian coast experience the highest oil spill risks. This is complex for the reasons noted in Section 2.9. In the following, emphasis has been given to the ERI, which is considered the best available risk metric, and to the frequency of spills greater than 1 tonne, which reflects events most likely to occur.

The following regions have relatively high risks:

- Queensland coast centred on QLD4 but also including QLD3, QLD5 and QLD6. This arises mainly from trading ships in ports such as Hay Point (QLD4), Gladstone (QLD5) and Brisbane (QLD6). The main accident types are spills from bunkering of bulk carriers and cargo transfer on oil tankers. There are also significant contributions to smaller spills from small commercial vessels and shore-based activities. The high risk takes account of the high environmental sensitivity of the Great Barrier Reef, which extends from QLD2 to QLD5.

- Western Australia coast centred on WA7. This arises mainly from trading ships in ports such as Dampier and Port Hedland. The main accident types are collisions and transfer spills from bunkering of bulk carriers. There are also significant contributions to smaller spills from small commercial vessels and to larger spills from offshore production. The adjacent region of WA6 has higher environmental sensitivity, as it includes Shark Bay and Ningaloo Coast, but relatively little port traffic.

- Victoria coast centred on VIC2. This arises mainly from trading ships in Melbourne. The main accident types are collisions and transfer spills from bunkering of container ships. There are also significant contributions to smaller spills from small commercial vessels and shore-based activities. The adjacent region of VIC1 has relatively little port traffic, but significant offshore activity and passing traffic, which produces higher risks in the intermediate zone than the near-shore zone.

- New South Wales coast centred on NSW2. This arises mainly from trading ships in ports such as Newcastle and Port Botany.

- South Australia coast centred on SA1. This arises mainly from trading ships in Port Adelaide.

- West Australia coast centred on WA4. This arises mainly from trading ships in Fremantle.

In each of these cases, there are also significant contributions to larger spills from powered grounding in the near-shore zones, and from collision and hull damage of trading ships in the adjacent intermediate and deep-sea zones.

It is noted that the relatively low risks predicted for the Offshore Territories, including the Australian Antarctic Territory arise mainly from their low marine traffic levels, which outweighs their high environmental sensitivity in the risk metrics used here.

4 RESULTS FOR 2020

4.1 Case Definition

Risks have been estimated for the year 2020, in order to demonstrate the model's capability to respond to future changes.

The following significant changes have been modelled, compared to the 2010 case in Section 3:

- General port traffic growth is taken as 2% per year, i.e. 22% increase by 2020. Many ports have specific growth plans, and these have been modelled explicitly (see Appendix I.2.10). This includes new ports that are planned at locations such as Oakajee, Ankatell and Ashburton. This gives a growth of 79% in the total national port traffic by 2020. Although much higher than previously assumed, this is adopted for the present study.

- Traffic at sea is assumed to grow by the same amount as traffic in ports within the nearest near-shore zone, or 2% per year for near-shore zones with no ports. This gives a growth of 81% in the total national traffic at sea by 2020.

- Small commercial vessels are assumed to remain at their present levels.

- Ship-to-ship transfer at sea is assumed to grow from 4 per year at present to 12 per year in 2020 (Appendix I.2.9).

- A new MARPOL regulation addressing ship-to-ship (STS) transfers is assumed to be applied (IMO 2009). This will require an STS operations plan on any tanker conducting STS operations, prescribing how they are to be conducted.

- Radar-based Vessel Traffic Services and other navigational safety improvements are likely to be adopted in several ports, but the only specific ports where this is known to be planned are Port Botany, Port Hedland and Dampier. In the absence of more precise information, marine safety measures are assumed to be unchanged at other ports.

- Use of double hulls on oil tankers is already assumed to be universal in Australian waters.

- A new MARPOL provision (Annex I Regulation 12A) will require double hull protection of fuel tanks in ships with fuel oil capacity greater than 600m^3 built after 2010.

- Offshore drilling is assumed to remain at the current level of activity (Appendix I.5.1).

- Offshore oil production is predicted to reduce by 89% by 2020, while condensate production is predicted to increase by 73%, giving an overall decline by 35% (Appendix I.5.2).

- Shore-based oil consumption is assumed to grow at 1.3% per year (ABARE 2010), resulting in a 14% increase by 2020.

- Possible phasing out of heavy fuel oil as bunker fuel over the next 10 years. The motivation, practicality and desirability of such a change are beyond the scope of the present study. In order to illustrate the model capability, it is assumed that heavy fuel oil is replaced by equivalent quantities of marine diesel oil. Because this is very speculative, it is modelled separately from the other changes above. As a sensitivity test, the option of fitting scrubber units is considered, since this would not significantly change the current fuel consumption.

4.2 Modelling of Changes

The changes above are modelled in the following ways:

- Changes in port traffic are modelled by changing the inputs of the model, which automatically affects the corresponding results. This appears precise, although in reality the risks may not be precisely proportional to the traffic. The model of the effect of traffic density (Appendix IV.2.7) makes collision risks proportional to the square of the traffic, although where new terminals are constructed away from existing traffic the increase would be less than this.

- Changes in traffic at sea, and ship-to-ship transfer at sea are modelled by changing the inputs of the model, which automatically affects the corresponding results.

- In the absence of any risk analysis of the effects of the new STS regulation, the effects are very uncertain. Based on advice from NSW Maritime, it is assumed that the STS regulation helps maintain current oil spill probabilities, so no change is modelled.

- The effect of radar-based VTS is estimated using modification factors from previous studies (Appendix IV.2.10). In the absence of more recent analyses, these effects are very uncertain.

- The effect of double hulls on oil tankers was estimated to be a reduction in the probability of spills from collision, contact and grounding by 75% compared to single-hull (Appendix IV.2.11). However, this change was complete in 2010, and so no further effect is modelled.

- The effect of double hull protection of fuel tanks on large commercial ships is modelled as follows. Double hull protection is assumed to reduce the spill frequency from collision, contact and grounding by 75% (as for tankers above). The regulation covers most non-tanker ships in the size categories >10,000dwt, amounting to 82% of port visits (Appendix I.2.3). It is assumed that between 2010 and 2020 approximately 30% of these vessels are replaced and given this protection. Hence the spill frequency is reduced by an average of 0.3 x 0.82 x 75% = 18%.

- No change in offshore drilling is modelled. In reality future drilling may be in different locations, so future environmental risks are more uncertain than at present.

- Changes in offshore oil and condensate production are modelled by changing the numbers of platforms, wells, and the quantities of diesel use, oil storage, oil production and oil offloading in proportion to the changes in production. This automatically affects the corresponding results. Offshore oil pipelines and risers are assumed to continue as at present, since the reduced oil production will be mainly through lower flow-rates rather than removed facilities.

- The growth in shore-based oil consumption is modelled by assuming the frequencies of shore-based spills are proportional to the consumption, and hence increasing the historical frequencies by 14%.
- Replacement of heavy fuel oil by diesel oil as a bunker fuel is modelled by changing the oil type in the model of oil spills from non-tanker ships, which automatically affects the corresponding results. The option of fitting scrubber units would leave the risk results unchanged.

4.3 Effects of Changes

The following effects are estimated from the changes above:

- Port traffic growth by 79% produces approximately the same change in the annual risks of trading ships in ports and restricted water.
- Traffic growth at sea by 81% produces an 87% change in the annual risks of trading ships at sea. Collision risks increase in proportion to the square of the traffic, but these are a small contribution to the total. In the case of small commercial vessels, the change in collision risks is the only significant contribution, producing a 7% increase overall.
- Ship-to-ship transfer growth by 3-fold at sea produces the same change in the annual risks of transfer at sea.
- Radar-based VTS is estimated to reduce the probability of spills in the affected ports from collision and powered grounding by 84%.
- Adoption of double hulls on oil tankers is complete in 2010, and so no further effect is modelled.
- Adoption of double hull protection of fuel tanks is estimated to reduce the spill frequency from collision, contact and grounding on non-tanker trading ships by 18%.
- Offshore oil production reduction by 35% produces the same change in the annual risks of process and crude loading leaks, but the risks from oil pipelines and risers are unchanged, so the overall effect on offshore production risks is less than this.
- The growth in shore-based oil consumption by 14% is estimated to produce the same effect on the frequencies of shore-based spills.
- Replacement of heavy fuel oil by diesel oil as a bunker fuel would not affect the spill frequencies, but is estimated to reduce the environmental risk index by 58%, as the environmental impact of diesel oil is much less. This comes mainly from the 7-fold difference in the cost of diesel and heavy fuel oil spills in the world-wide spill data (Appendix VI.6.5). While other data indicates a larger difference, consideration of effects in sensitive environments suggests there may be little difference between the oil types (Appendix VI.6.5). Therefore this effect is not included in the results below.

In the sensitivity test, fitting scrubber units would result in no change in ERI for oil spills.

4.4 Combined Results

Table 4.1 gives the overall national spill frequencies, i.e. the expected annual frequencies of events spilling more than 1 tonne of oil into the marine environment, in the future case.

Table 4.1 Oil Spill Frequency in 2020

SOURCE	SPILL FREQUENCY (per year)	% OF 2020	% INCREASE FROM 2010
Trading ships at sea	0.42	9.0%	79%
Trading ships in port	1.10	23.7%	87%
Small commercial vessels	1.18	25.3%	7%
Offshore production	0.47	10.2%	-31%
Offshore drilling	0.03	0.7%	0%
Shore-based	1.45	31.1%	14%
Total	4.66	100.0%	19%

The overall increase is predicted to be 19%, but this is sensitive to the assumptions that small commercial vessels do not increase, and that collision risks in port increase with the square of the traffic.

Table 4.2 gives the overall national spill risks, i.e. the expected annual quantities of oil spilled into the marine environment, in the future case.

Table 4.2 Oil Spill Risk in 2020

SOURCE	SPILL RISK (tonnes per year)	% OF 2020	% INCREASE FROM 2010
Trading ships at sea	387	32.2%	83%
Trading ships in port	337	28.1%	94%
Small commercial vessels	2	0.2%	7%
Offshore production	217	18.1%	-30%
Offshore drilling	209	17.4%	0%
Shore-based	48	4.0%	14%
Total	1200	100.0%	27%

The overall increase is predicted to be 27%, because of the greater influence of oil spills in trading ship collisions on this metric. The result is again very sensitive to this assumption.

Table 4.3 gives the ERI in the future case. The overall effect is predicted to be a 96% increase, i.e. almost a doubling. The estimated benefit from phasing out heavy fuel oil would outweigh this, leading to a reduction in ERI, but this is not included in the results above. The sensitivity case, of using heavy fuel oil with scrubber units would result in the ERI shown in the table. It is concluded that the impact on environmental risk of changes in bulker oil usage is very sensitive to the way it is implemented and the relative environmental impacts, as discussed in Appendix VI.6.5. This should therefore be evaluated in a study focussed on this issue.

Table 4.3 Environmental Risk Index in 2020

SOURCE	ERI (million A$ per year)	% OF 2020	% INCREASE FROM 2010
Trading ships at sea	5.0	28.3%	91%
Trading ships in port	10.9	60.9%	141%
Small commercial vessels	0.1	0.6%	7%
Offshore production	0.4	2.3%	-28%
Offshore drilling	0.2	1.2%	0%
Shore-based	1.2	6.7%	14%
Total	17.9	100.0%	96%

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has estimated Australia's current marine oil spill risk profile based on a comprehensive updating of DNV's 1999 risk assessment, and developed risk metrics that will provide appropriate information for the review of the National Plan and NMERA. These results are presented in the main report. The appendices to the report also present the data that has been collected for the study and explain the methodology that has been used to estimate the risks.

The calculation has been implemented in a spreadsheet, which will allow the risks to be updated with improved parameters. To illustrate how this updating can be applied, the report includes risk predictions for the year 2020.

The overall spill risk profile is complex, and the different risk metrics show different patterns. For example, the frequencies of oil spills of 1 tonne or more are strongly influenced by small commercial vessels. The total expected annual quantities of oil spilled are much more affected by offshore production activities. The overall environmental risk index is dominated by spills from trading ships in port. Therefore, the risks have been presented as maps showing how the different risk metrics vary in different sub-regions.

5.2 Recommendations

5.2.1 Recommendations for Risk Reduction

This study has not made any systematic search for risk control options, and therefore it is not appropriate to make detailed recommendations for risk reduction. The study is intended to provide input to a review of the National Plan and NMERA, and this will be the appropriate stage for development of a risk reduction strategy.

Nevertheless, it is possible to use the main risk contributors to identify the main sources of risk, which may help identify appropriate methods of risk reduction. Based on the ERI, which is considered the most suitable metric for this purpose, the largest risk contributors are:

- Trading ships in port and at sea (see Table 3.6). The importance of this source is predicted to increase in the future (see Table 4.3). Oil spills from shore-based sources may be more frequent but are predicted to be mainly small. Oil spills from offshore drilling and production may be larger but are predicted to be relatively rare.

- Bulk carriers, oil tankers and container ships (see Table 3.7). Oil spills from small commercial vessels may be more frequent but are predicted to be mainly small.

- Powered grounding, collision, hull damage and transfer spill (see Table 3.8). Transfer spills are mainly from oil tankers (i.e. cargo spills), and to a lesser extent from bulk carriers (i.e. bunker spills).

Suitable methods of risk reduction may include greater attention to the inspection, approval and safety management of these sources.

It is also possible to use the main risk contributors to identify the main locations of risk, which may help identify appropriate locations for oil spill response equipment. These are:

- Queensland coast centred on QLD4 but also including QLD3, QLD5 and QLD6
- Western Australia coast centred on WA7.
- Victoria coast centred on VIC2.
- New South Wales coast centred on NSW2.
- South Australia coast centred on SA1.
- West Australia coast centred on WA4.

The main oil spill sources in these areas are identified in Section 3.3. The method of choosing an appropriate oil spill response capability is outlined in Section 2.9.

5.2.2 Recommendations for Enhancement of Future Risk Assessments

In future work, it would be possible to improve the quality of risk assessments by focussing on the main sources of uncertainty in the risk estimates. The provision of more robust data would assist in the process. Some of these are outlined as follows:

- Improve the models of small commercial vessels, which dominate the frequency of small spills. This would include the causes and sizes of spills, which at present are approximated using data from trading vessels.
- Improve the estimates of oil spill probabilities from non-tanker vessels. This would require comprehensive data on oil spills from groups of trading ships and small commercial vessels.
- Develop better models of spill size distributions, taking account of ship size and cargo/bunker capacity.
- Collect more detailed data on the locations of current and future offshore drilling.
- Collect recent data on the frequencies of oil spills from offshore process, storage and diesel use.
- Improve the quality of the Australian oil spill data, in order to provide better shore-based spill frequency estimates, and validation of the work as a whole.
- Consider whether more realistic models of oil transport and fate could be integrated into the study.
- Continue development of the environmental sensitivity index, to achieve a better representation of the complexity of this issue.
- Consider further the suitability of the different risk metrics, including the environmental risk index, as an indicator of the most important aspects of environmental risk.

5.2.3 Recommendations for Future Updating

The models for port traffic, at-sea traffic, small commercial vessels, offshore production, offshore drilling, and shore-based spills have been implemented in a spreadsheet to calculate the risk results. These are intended to form the basis of a future model for risk prediction in specific locations or applications. It is recommended that this capability is developed in the following steps:

- Consult the potential users of the program to identify the capabilities that they require, and their ability to generate the necessary inputs.

- Develop a computer program to implement the calculations, instead of the spreadsheet calculation tables. This would allow the user to create a database of inputs and would then calculate the risk results and allow the user to select their specific required results.

- Test the program with stakeholders, to ensure that it has the required capability, and that it places appropriate restrictions on users in order to prevent it being used in inappropriate ways.

It is also recommended that, once such a program was developed, the ways in which users apply it should be monitored, so as to identify when a centrally-managed update of the methodology is necessary. In the absence of such monitoring, it is considered that a 10-year update cycle is appropriate, being roughly equal to the time since the previous study.

6 ACRONYMS

AIS	Automatic Identification System
AMSA	Australian Maritime Safety Authority
AUSREP	Australian Ship Reporting System
DNV	Det Norske Veritas
DWT	deadweight tonnage
EEZ	Exclusive Economic Zone
ERI	environmental risk index
ESI	environmental sensitivity index
FQ	frequency-quantity curve
GT	gross tonnage
IMO	International Maritime Organization
nm	nautical miles
NMERA	National Maritime Emergency Response Arrangements
SCV	small commercial vessel
VHF	very high frequency

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