NEW ZEALAND
FOREIGN AFFAIRS & TRADE
Aid Programme

Land Information New Zealand
Toitū te whenua
Hydrographic Authority

SOUTH-WEST PACIFIC REGIONAL HYDROGRAPHY PROGRAMME

LINZ HYDROGRAPHY RISK ASSESSMENT METHODOLOGY UPDATE

Report Number: 15NZ322
Issue: 03

Supported by the
New Zealand Aid Programme

MARICO MARINE NEW ZEALAND LTD

SOUTH-WEST PACIFIC REGIONAL HYDROGRAPHY PROGRAMME

LINZ HYDROGRAPHY RISK ASSESSMENT METHODOLOGY UPDATE

Prepared for:	**Land Information New Zealand** **Level 7, Radio New Zealand House** **155 The Terrace** **PO Box 5501** **Wellington 6145**
Author(s):	**John Riding / Andrew Rawson**

The views expressed in this publication do not necessarily reflect those of the New Zealand Government.

Marico Marine NZ Ltd
Level 11
156 Willis Street
Wellington 6011
New Zealand

5th August 2015

CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

The South West Pacific area is, in general, in need of hydrographic development and charting improvements, to update the nautical charts that vessels require to navigate safely and efficiently. This need is considered a priority, with MFAT and LINZ working together with international agencies to deliver the strategy. However, in an ocean region of very large geographic spread the need to prioritise where improvements are needed is a key factor. This hydrographic risk methodology delivers a systematic process, which is data driven and evidence based, to assess hydrographic risk across regions and thus prioritise the rollout of charting improvements.

The design of a risk-based assessment to understand risk sourced from charting standards is unusual insomuch that it needs to deliver a comparative prioritisation of differing areas for hydrographic survey or charting improvements. It is not necessarily a question of charting adequacy; inadequate charting can be tolerated in areas where vessels of any size do not trade. Thus, hydrographic risk can be low where vessel traffic is light, yet a technical review would consider a charting upgrade is necessary. Conversely hydrographic risk can be significant where vessel traffic is dense, with the presence of vessel types posing significant adverse casualty outcomes, yet charting standards meet the needs of contemporary shipping. A hydrographic risk assessment has a safety perspective which has to take account of varieties of coastal areas, each with differing bathymetry and trading/growth characteristics. Safety risk is only one factor that the methodology needs to take into account. For example, the economic activity in an area dictates the ship types and sizes that serve the area (and that is also true of domestic coastal vessels), but information about the potential for economic development is also needed, as realisation of that potential may require an increase in vessel traffic volume, and possibly vessel type and size. Thus, there are three key components (**risk, ship types/ sizes, economic potential**) that, when combined, provide evidence to promote one area over another for the prioritisation of charting upgrade.

A location with a **pristine environmental status** provides a fourth factor in prioritisation; an incident in any area sensitive to environmental damage provides for an increased consequence impact in the event of vessel loss. Environmental damage (which may be loss of utility such as beaches, loss of habitat or endangered plant species) in an area of economic activity linked to environmental utility provide further impact. Grounding consequence in both environment and economics is related to the release of bunkers or cargo. Environmental status can therefore be attached to risk, which is linked to vessel size and type. Thus the need to consider charting upgrade may be complex, given the number of relevant factors. A charting upgrade may also not in itself mean further extensive hydrographic survey; it may mean a review of the national/regional charting schema or increased use of high density bathymetry for harbour approach channels. It may even suggest a review of vessel routeing guidance or Aids to Navigation (AtoN).

To be of value, the prioritisation process has not only to be risk based, but transparent against set criteria. It will also need to be clearly documented, systematic and recorded in a uniform manner. To achieve this, the methodology and required input data must be designed before the project starts, and then uniformly applied across the candidate coastal and ocean areas.

The process is a crucial base for survey planning, as it is unlikely that comprehensive statistical data will be available in all areas. It is also unknown if groundings have occurred that could be directly linked to out of date charts, therefore it is anticipated that the risk work will be mainly proactive.

There are a variety of risk assessment methodologies in use but there are no “off the shelf” methodologies suitable for the specific needs of LINZ, the New Zealand Hydrographic Authority. The Formal Safety Assessment (FSA) used by IMO is designed for the rule making process. It was developed by the UK Maritime and Coastguard Agency in 1995 and then adopted and updated by the IMO Member Governments. This methodology is marine related, proactive, logical, structured and comprehensive. Of the risk assessment methodologies in current usage, the FSA concept is the one which can be most readily adapted to the needs of a national or regional hydrographic programme needing prioritisation. Indeed the International Association of Lighthouse Authorities (IALA) has used the concept as a basis for its own risk based solution. There are other good risk solutions, such as the NOAA risk prioritisation system. However, the FSA solution is now part of the UN Maritime Regulatory System and IHO forms part of that system, so the logic of an IHO methodology linked to the FSA concept is logical.

Since traditional hydrographic assessments are largely a function of expert opinion from a direct hydrographic specialist, they can be exposed to challenge from differing viewpoints, or commercial or political objectives. The assessment reports themselves are necessarily technical and each end up making a competing technical case, which is not always consistent and leaves decision-makers with an incomplete picture, which only serves to compound decision-making complexity.

This can be addressed by use of an approach founded on data and location information, in this case economic data and ship type and volume data, together with a robust and comprehensive methodology that is consistently applied. In this way, comparative results between the candidate areas will be robust and provide a worthwhile prioritisation tool.

The use of Geographic Information System technology (GIS), to display risk pictorially over any charted area provides an easily interpreted output for this type of risk assessment. A GIS package can combine risk criteria with marine traffic levels in areas of coastal or offshore significance. It can further link the quality of charting in such areas (as just one example risk criteria) and output an overlay of risk mapping (a heat map) onto the charted area.

The risk based result can significantly benefit hydrographic decision-making and assist to identify the areas that are priority candidates for charting improvements.

1 INTRODUCTION

1.1 STUDY CONTEXT

The maritime trade in the South West Pacific region, in common with the rest of the world, has changed dramatically in recent decades. Larger, faster cargo vessels are calling at fewer hub ports, feeder services have increased and there has been a dramatic increase in cruise ship calls, with visits by large vessels to remote islands becoming increasingly common place.

The New Zealand charting area includes the Kermadec Islands, Tonga, Cook Islands, Samoa, Niue and Tokelau Islands. Most of these charts are published on the WGS 84 datum and display soundings in metres. However, some areas of coverage are on an undetermined datum with soundings in fathoms which have been converted to metric, without further new survey work (this can be the result of applying a datum shift and conversion of sounding units using existing data). Whilst the main ports may have been surveyed within the last 20 years, the charts of some of the outer islands rely on surveys conducted up to a century ago.

There is an IHO S-57 quality of data meta object called M_QUAL, which provides the mariner with advice about the quality of the underlying data. However, it is problematic to properly assess data quality when oceanic charts throughout the Pacific rely, for the main part, on on-passage soundings, sporadic surveys or other information gleaned from a variety of sources. Thus, the charting of many of the island groups, and particularly the more remote islands, is now out of date and the completeness and accuracy of depth and datum information does not meet modern standards.

The size of vessels and the accuracy of navigation now possible using satellite derived positioning are significantly different from the original intended purposes for which many existing charts were derived. The mariner is advised accordingly, both during training and by remarks on the charts and source data advice. This effectively mitigates liability risk by providing clarity of chart limitations, but it does not solve the underlying charting problem.

There remains a reasonable concern that inadequate and inaccurate nautical charting could adversely affect safety of life at sea and the protection of the marine environment. It may also inhibit maritime trade, thereby adversely affecting the economy of some of the island groups. There are also concerns that various coastal state administrations, party to the SOLAS conventions, retain an underlying problem of liability associated with not providing fit for purpose charts. The provision of adequate and reliable Aids to Navigation for any coastal area is also an important consideration, especially if traffic is increasing.

Therefore, the risks associated with the use of out of date chart data have increased significantly in recent years and there is a need to systematically re-survey many of the Pacific island groups. There is a practical need, though, to prioritise. This report considers a methodology that is risk based, but combines the economic drivers with the risk considerations.

The complexity of interacting data pertinent to hydrographic risk assessment makes the use of Geographical Information System software essential to relate the developed risks geographically (by colour) with the candidate areas being considered. This provides integrated information using technology that is both accessible and intuitive, thereby visualising complex data for presentation to key decision makers.

1.2 2015 REVISIONS AND LESSONS LEARNED

This methodology, originally published in 2013 following an application of the prototype methodology to the Vanuatu Proof of Concept Pilot Study, has been revised after the application to the Kingdom of Tonga and the Cook Islands. It has also taken account of the design of the risk criteria for a New Zealand wide risk assessment. This methodology has been both refined and expanded, taking account of lessons learned as follows.

- A study of Tongan waters showed the need to develop a new module to allow traffic predictions to be made, in remote area of low traffic density where significant expansion of the cruise industry was being evaluated.
- In parallel, an improved Cost Benefit methodology was developed to consider the risk reduction that existing chart improvements in any area delivered. This module was developed to provide better information about the cost effectiveness of charting improvements in areas where recent charting upgrades may have been undertaken. It addressed a problem of the existing methodology, where because of high traffic volume, a significant risk result can be present in an area where charting standard is already high. This addition allowed the risk reduction of such a situation to be shown.
- The development of risk criteria for a developed economy, where traffic density is greater and traffic variance around the country coastline is more significant.

2 RISK THEORY AND BACKGROUND

Risk is a fact of life; it can be controlled and it can in some way be isolated, but not necessarily eliminated. Modern society accepts a degree of risk (we all drive cars) but demands that risk be kept to low levels, particularly where the risk is outside the individuals' control (we all like safe airlines and expect them to be competently operated). There is also a societal aversion to risk, where rare incidents involving large loss are less acceptable than relatively frequent events involving small loss (this is true of either spills or loss of life); as ship sizes grow, societal aversion is becoming more relevant.

The study of formal risk assessment began in the nuclear industry in the early 1970s, with a probabilistic risk assessment of a core melt down accident. Other high risk industries followed the nuclear industry lead. Since then a variety of risk assessment tools have been developed by industries and organisations and the use of risk assessment is now widespread through many industries and organisations, not only to reduce risk and liability, but to test concepts and systems during their development. Used correctly it is a powerful management tool to inform decision making.

2.1 DEFINITIONS

Definitions in risk management disciplines are not absolute and are, to some extent, still evolving and dependent on the nature of the study. For the purposes of this discussion document the following definitions are pertinent.

Risk is a product of the likelihood and consequences of an event.

Frequency is the measure of the actuality or probability of an event occurring. It can be expressed descriptively (e.g. frequent, possible, rare) or in terms of the number of events occurring in a unit of time (e.g. more than one a year, once in every 10 years, once in every 100 years). Frequency can be absolute, i.e. derived entirely from statistics, or subjective, i.e. an informed estimation of the likelihood of an event occurring, or a combination of the two.

Consequence can be positive (particularly in a planned event) or negative (particularly in the case of an accident). Consequences can be expressed in terms of "most likely" and "worst credible" and a combination of the two gives a balanced overview of the risk. Note that "worst credible" is quite different from "worst possible". For example, in the case of a passenger ship grounding on a reef at high speed the "worst credible" result might involve the death of 10% of the complement. The "worst possible" result would be the death of 100% of the complement. The latter is so unlikely to occur that it would not be helpful to consider it.

Events are usually described as unwanted or unplanned occurrences with consequential harm (i.e. accidents). However, events can be planned and have positive consequences. In this case the risk assessment asks the question "what will happen if we carry out these actions?"

Hydrographic risk is dependent on Traffic (with inherent potential loss of life, potential pollution (volume, Type and Size)) x Likelihood Criteria (Ocean conditions; Navigational Complexity, Aids to Navigation, Navigational Hazards) x Consequence Criteria (Environmental importance, Cultural importance, Economic importance).

Inherent Risk is the probability of loss arising out of circumstances or existing in an environment, in the absence of any action to control or modify the circumstances.

Risk analysis involves the systematic use of available information and expert judgment to identify hazards and estimate their risks to people, property, environment and stakeholders.

Risk evaluation involves establishing the tolerability level of a risk and an analysis of risk control options.

Risk assessment involves risk analysis and evaluation.

Risk management involves decision making on the implementation of controls stemming from risk assessment and monitoring the efficacy of the controls.

3 METHODOLOGY - BASED ON THE IMO FSA PROCESS

3.1 INTRODUCTION

The decision to base the Hydrographic Risk methodology on the concept of the IMO Formal Safety Assessment (FSA) process was made after a full review of the options. Annex A presents this review, which provides context. The review was used to derive the approach needed to be taken to develop something that was appropriate for Hydrographic use.

This section describes at an overview how the five step FSA concept can be modified to serve the requirements of a regional maritime safety programme focussing on hydrography improvements. It also shows the link to the IHO Capacity Building (CB) process for coastal states, i.e. Awareness, Assessment, Analysis and Action (the 4 As of Capacity Building).

3.2 THE HYDROGRAPHIC ANALYSIS CONCEPT

There are essentially two drivers for the need to undertake a hydrographic survey. The first is the level of economic activity, both real (today) and expected (tomorrow) and the second is the risk of an adverse outcome affecting shipping and island stakeholders. The risk of relevance that is associated with shipping is that of grounding, resulting in loss of life and serious environmental damage. Risk analysis is Step 2 of the FSA process, economic (or cost and benefit) analysis is a Step 3 activity. The type of economic analysis needed for hydrographic prioritisation is different to that of the FSA process. The economic analysis of the FSA process is to assess the impact cost of proposed new regulations across a fleet of ships, whereas the hydrographic need is to assess the actual and potential economic activity relevant to the need to survey. The concept of the proposed Hydrographic methodology is shown below in Figure 1.

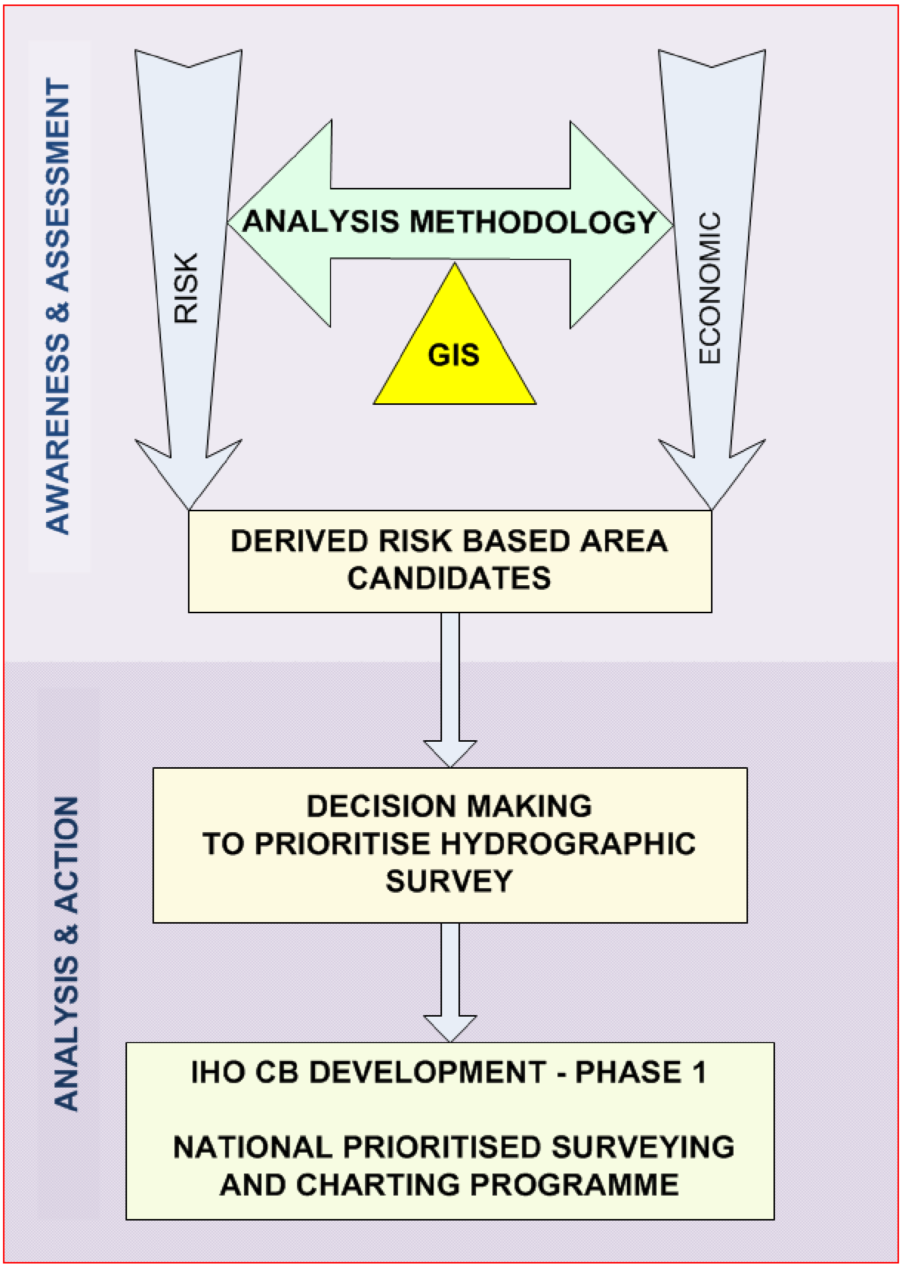


Figure 1: The Hydrographic Decision Making Process.

Figure 1 identifies that the present IHO, analysis & action technical visits need only start after the case to proceed is made on both risk grounds and economic grounds. The IHO current technical reports give a high level overview of the area of concern with a more detailed review of the SOLAS obligations to provide hydrographic services. The reports identify individual areas and charts where hydrographic work is required and provide an overview that can be taken to detailed specification. The IHO CB visits are of high quality, undertaken by competent hydrographic expertise, and therefore have significant cost attached to them. The subsequent reports overall are a key input into hydrographic survey decision making, but they end up making competing cases themselves, which only adds to the complexity of the decision-making. If the IHO technical visits are considered as two separate parts, they provide advice to a jurisdiction about the obligation to provide hydrographic services (awareness & assessment) and separately they provide the overview scope for hydrographic survey and charting (analysis & action), then this latter part of the CB process can be very usefully integrated into the proposed methodology.

The new methodology concept suggests that the analysis & action part of these IHO technical visits should instead be an output. As an output the analysis & action study would be conducted and developed into detailed specifications, once the location had been prioritised for survey by decision-makers accepting the results of the hydrographic risk analysis methodology.

Thus the proposed methodology should result in efficiency savings in that these high quality and detailed IHO technical analysis & action visits and reports are needed after a high level decision is taken to proceed, based on a combined basis of economics and risk.

3.3 THE HYDROGRAPHIC CASE ANALYSIS METHODOLOGY

The proposed methodology is presented over the page (Figure 2), and at Annex B. The methodology recognises the importance of economic data as well as stakeholder analysis and consultation in the process. It also recognises the complexity of this type of risk assessment.

Colouring is used to reference recognisable components of the FSA system. Within the methodology the analysis of the types of incident outcomes in an area need to be developed. This is related to the ship types using the area under investigation and derives an upper and lower bound on accident outcomes. An appropriate design of event trees to achieve this is given in Annex C (this will be a Step 1 activity in the hydrographic methodology).

The overall severity of impacts from a marine accident on a coastal zone is dependent on a large number of factors. Areas of economic success or environmental importance can be severely affected, but dependent on their distance from the casualty. Longer term impacts on trade, especially tourism, are also lessened the greater the distance from the event. Severity of consequence are thus geographically relevant and the best way to assess such impacts is to employ a Geographical Information System to evaluate the risk.

It is proposed that the use of GIS software is the most practical and effective way of calculating and displaying risk. The use of GIS and related risk matrices is discussed in detail in Sections 4 and 5.

The risk matrices need frequency information, which can be derived from analysis of factual AIS ship transponder records received by terrestrial stations or satellites (T&S-AIS data) and information, particularly on non-SOLAS vessels, obtained from site visits. It also needs consequence information, which is developed from event trees. Event trees are used to lay out, using marine expertise, the type of accident scenarios arising from any grounding or loss of hull integrity in the areas being considered. The grounding outcomes will be related to vessel types trading in the area of interest, as well as vessel size. This information can also be derived from TAIS and SAIS data and site visits.

A summary of the proposed methodology is described in a series of steps in this section. This description is intentionally stated at an overview level and these steps will run concurrently with one another. Each step will inform the analysis undertaken elsewhere and a continual cycle of review will be undertaken.

A GIS is used to collect, analyse and display the vessel traffic and risk factors. A number of outputs are produced in the form of vessel traffic plots and coloured maps to give immediate visual appreciation of the areas of highest risk. The GIS methodology is described in detail in Section 4 and 5.

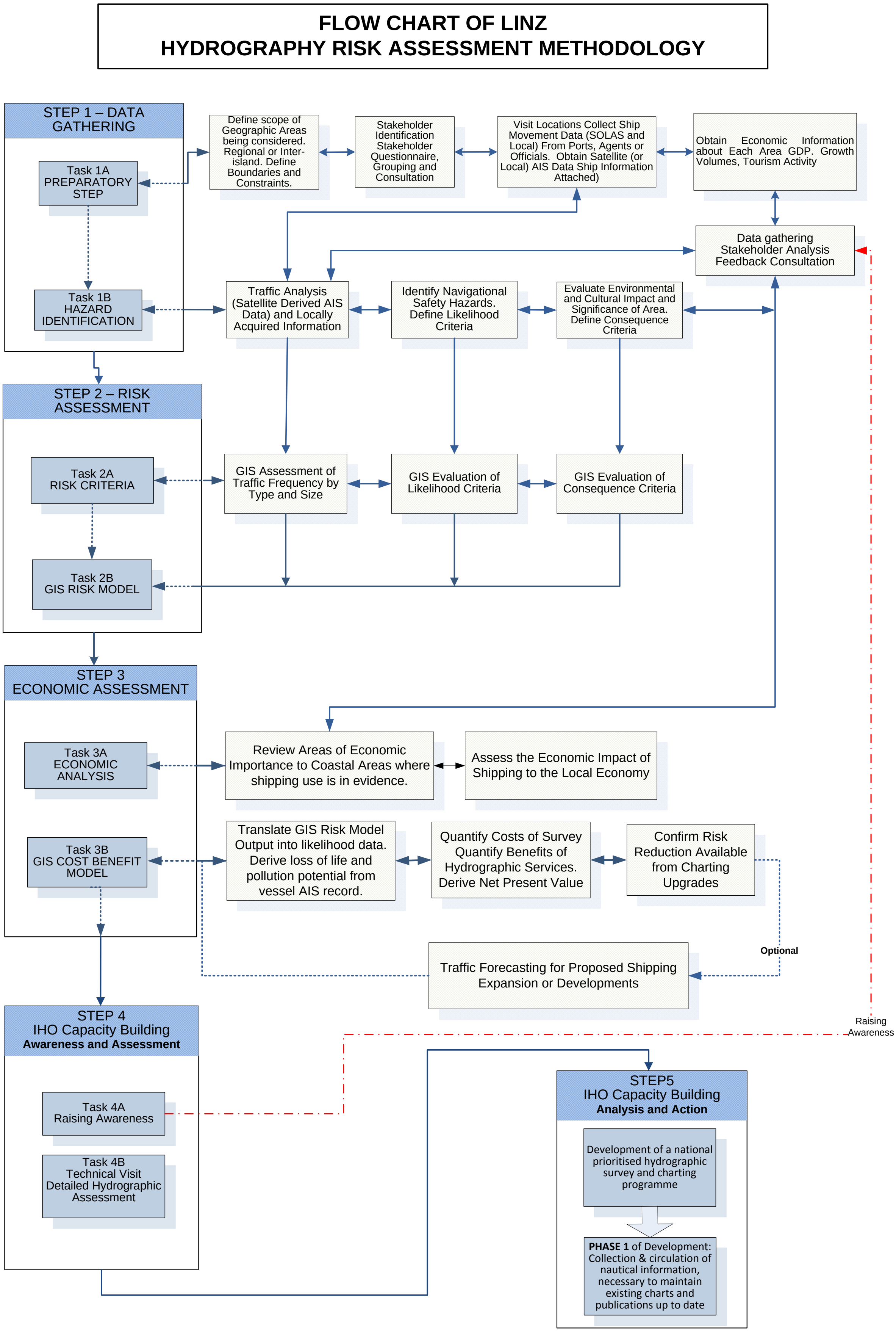


Figure 2: Overview of Hydrographic Methodology

3.4 STEP 1 – DATA GATHERING

3.4.1 Task 1A - Preparatory Step

1) Clearly define the problem to be assessed along with relevant boundary conditions and constraints. Define the areas for study by island groups and, if required for an in-country assessment, individual islands within groups.
2) Decide the composition and skill base of the group to carry out the hydrographic FSA process. The principal skill bases required will be:
   a. Marine
   b. Hydrography
   c. Risk assessment
   d. GIS
   e. Economic
3) Define the information required to inform the risk assessment, given the preliminary knowledge of the sea areas and economies being considered.
4) Design a questionnaire to be used as a prompt or agenda for stakeholder meetings (as opposed to it being delivered to be filled in by identified stakeholders). (See example in Section 7)
5) Identify local and remote stakeholders who are affected by, or influence all aspects of marine trade and its growth. This can involve organisations directly and indirectly associated with, involved with or affected by marine trade such as:
   - Government departments
   - Public officials
   - Port authorities
   - Ship owners and agents
   - Local businesses
   - Environmental interests
   - Tourism interests
6) Visit the areas of interest (or the area being evaluated). Collect SOLAS and local vessel movement data from port officials, customs, agents, etc. Organise and host local stakeholder meetings to gather information indicated in the questionnaire.
7) Obtain T&S-AIS information on movements of vessels fitted with AIS transmission equipment.

8) Economic information should be gathered in parallel with the preparatory steps above. As such, it is expected that economic analysis will be a separate but complementary part of the process. The economic information is used to inform the risk assessment about current levels and types of trade and GDP, potential for growth, as well as potential effects on trade and tourism. The assessment should include a prognosis of growth and development to be reasonably expected, with information about the sensitivity of trade and tourism to the consequences of a marine disaster.

3.4.2 Task 1B - Hazard Identification

1) Analyse statistical and environmental information collected in the preparatory step.
2) Use a GIS system to analyse traffic routes, ship types, sizes, densities and characteristics from T&S-AIS (SOLAS vessels). Add in locally gathered information for coastal or non-SOLAS vessels (which may not necessarily be fitted with AIS transponders).
3) Identify the probabilities (frequencies) and consequences using vessel transit analysis outcome and incident information available and expert judgement. Use a risk matrix to combine the components into risk within the matrix.
4) Identify navigational safety hazards and define likelihood criteria stemming from the hazard category of "grounding due to out-of-date (not fit for purpose) charts". Develop event trees into the relevant scenarios for the areas. The generic grounding Event Tree Analysis at Annex C is designed to be used in this process. The generic event tree can be modified and developed to reflect the type of scenarios (and thus consequences) that are likely to occur, given the vessel types using the area, the nature of the bathymetry and the significance of the environment in local and international terms. Creative and analytical techniques should be used.
5) Evaluate environmental utility and significance of areas. Information is required on the possible cultural, social and economic impacts of a significant oil spill. Define consequence criteria.
6) Design and agree risk matrices to be used in scoring (See Section 4) from the frequency and consequence criteria defined above. There is a need for more static criteria in areas of low traffic density and more dynamic criteria in areas of higher traffic density. Static criteria fix the range of risk scoring output, whereas dynamic criteria allow the risk range output to reflect areas where high traffic volume may need to be differentiated from low traffic volume. Examples of the two different matrix approaches are shown at Annex D.

3.5 STEP 2 – RISK ASSESSMENT

3.5.1 Task 2A – Risk Criteria

1) Conduct an evaluation of most likely causes and consequences of the significant hazards identified in Step 1.
2) Refine the risk matrices (see further information in Section 4.3 and Section 5 and an example risk matrix at Annex D) frequencies and consequences using frequency information derived from traffic analysis and any incident information available.
3) Use the event tree branches (see Annex C) to relate consequence of outcome scenarios geographically, which may modify the risk matrix relationships. Develop consequences and matrix criteria with respect to risk impact on people, property, environment and stakeholders (overall).
    a. Since statistical information is likely to be sparse, the frequency can be derived from traffic analysis of ship transit frequency, as well as analysis of traffic density, type and size. The consequence level is also derived from vessel type and size, economic and environmental information and stakeholder feedback from the questionnaire.
4) Use GIS to assess and evaluate:
    a. Traffic frequency by type and size.
    b. Likelihood criteria based on traffic frequency type and size, and proximity to navigational hazards.
    c. Consequence criteria based on the environmental, cultural, social and economic consequences of a grounding and oil spill.

Note:- In applying this methodology to a region/area, there is a need to take account of the existing levels of traffic overall. For example, in the SW Pacific, ship traffic is lower than other locations, and a significant change of traffic levels, will mean a need for recalibration to take account of this. It is still possible to link risk assessments together as there is a known relationship between the matrix calibrations for different regions/areas.

3.5.2 Task 2B - GIS Risk Model

1) Develop a GIS risk model built from the GIS traffic analysis produced in Task 2A.
2) Add in datasets for environmentally sensitive sites or marine breeding grounds, corals, locations of areas of changing topography (seismic), etc.

3) Score the proximity and importance of each risk factor; Link the developed risk matrix criteria to complete the GIS risk model; and
4) Evaluate and test the risk model using multiple iterations.

3.6 STEP 3 – ECONOMIC ASSESSMENT

3.6.1 Task 3A - Economic Analysis

1) Analyse economic information for each island or group of islands to inform the decision making process. Of particular importance are:
   a. Present overseas trade and prognosis.
   b. Present cruise vessel trade and prognosis.
   c. Present domestic trade and prognosis.
   d. Present tourism (non-cruise) and prognosis.
   e. Present GDP and prognosis of principal elements of the GDP.
   f. Present coastal areas of development, such as tourism, where a vessel accident may have a significant economic impact.

3.6.2 Task 3B – GIS Cost Benefit Model

1) Develop cost benefit model using the outputs of the GIS Risk Model;
2) Calculate annual frequency of vessel grounding incidents in study area;
3) Calculate costs of incidents for loss of life and pollution following an incident and compare;
4) Compare difference in annual costs to those following a hydrographic survey programme;
5) Calculate economic development potential of regions as a result of increase vessel traffic following a survey; and
6) Calculate New Present Value of improvement of hydrographic resources.
7) If there is currently no traffic in the area, but development is expected, a traffic prediction can be added to the GIS model, using representative vessels.

3.7 STEP 4 – UNDERTAKE DETAILED HYDROGRAPHIC TECHNICAL VISIT

3.7.1 Awareness & Assessment

This step is partly one of decision making and is the traditional technical assessment ideally undertaken by a qualified hydrographer. The raising Awareness of Step 4 commences at the same time as the data gathering visit commences, as the high level contact with a regional administration provides a natural opportunity for Awareness of the Hydrographic obligations of a State to be promulgated and advice/support provided. The success of data gathering for the GIS risk assessment is also enhanced as Awareness is realised. Local consultation and fact finding is improved whilst providing context to those undertaken the site visit.

1) Assess the accuracy and adequacy of existing paper and ENC chart schema.
2) Initiate a 3rd party data discovery and assessment.

3.8 STEP 5 – HYDROGRAPHIC SURVEY PRIORITY DECISION MAKING

3.8.1 Analysis & Action

1) Specify paper and ENC chart schema.
2) Specify hydrographic surveys.
3) Cost surveys and chart production.
4) Cost/benefit analysis using economic analysis information from Step 3.
5) Decide priorities informed by the risk assessment, hydrographic assessment, cost benefit assessment and the economic analysis.
6) Hydrographic survey and chart production implementation plan, dependant on funding stream.

4 DEVELOPMENT OF A HYDROGRAPHIC RISK MODEL

4.1 INTRODUCTION

This section provides a systematic and evidence based methodology for identifying localised regions of heightened maritime risk and measuring the return on investment from a hydrographic survey program. The results of this analysis inform decision makers; who must cost effectively direct hydrographic resources for the protection of lives and the environment, and the development of the marine economy of the area/region of interest.

The section provides an introductory overview of spatial risk analysis models. This is followed by a summary of the review of literature relating to work undertaken in other studies that have utilised a similar approach. Finally, a risk and cost benefit analysis model is proposed to achieve the goals laid out for this project.

4.2 MARINE RISK ANALYSIS

Marine risk analysis is the science of calculating the likelihood and consequences of marine hazards, through both quantitative and qualitative means. These can be achieved through a variety of means including statistical analysis, incident investigation, fault trees, Bayesian probabilities, oil spill modelling, event trees and many more approaches (see Annex A).

4.2.1 Quantitative Assessment of Likelihood

Probabilistic models of ship incidents seek to quantify the number of incidents by calculating the number of candidates and the probability that a candidate will have an incident. This approach to modelling, born in academy (see MacDuff, 1974 and Fujii, 1974), recognises that the probability of an incident requires both the presence of vessels and a cause. Possible causes include loss of control, excessive wind or poor visibility.

The number of candidates refers to the density of shipping in an area and reflects the number, makeup and size of the traffic profile. This can be inferred from movement records, local knowledge or can be more accurately assessed by vessel traffic analysis using Automatic Identification System (AIS) data or radar tracks.

The causation factor has been under considerable debate for the last forty years. The concept recognises that there are certain aggravating and mitigating risk factors that contribute to the likelihood of an incident occurring. A considerable amount of research has been undertaken to identify these factors and quantify their relative contributions to historic accident records (see among others Kite-Powell et al. 1999, Montewka et al., 2011 and Mullai et al., 2011, as well as innumerable region specific assessments).

From this research five broad groups of factors contributing to the likelihood of an incident in a given waterway can be identified:

- **Vessel Characteristics** (dimensions, windage area, type, flag state, age, on board aids to navigation etc.);
- **Human Factors** (experience, stress, fatigue, distractions, language, crew size, operational procedures);
- **Route Characteristics** (fairway length/width/depth, traffic density, complexity of turns, composition of sea floor, presence of Vessel Traffic Service, submerged dangers such as reefs);
- **MetOcean Characteristics** (wind speed and direction, current speed and direction, significant wave height and direction, tidal conditions, visibility, time of day, presence of ice); and
- **Availability of Mitigation** (tugs, pilots, high quality and accurate charts, working aids to navigation and buoyage).

4.2.2 Quantitative Assessment of Consequence

The consequence of incidents has likewise garnered considerable analytical attention. Consequence can range from a slight delay in service, for example in the case of a soft grounding, to a major human and / or environmental catastrophe following the grounding of a large cruise liner, for example the Costa Concordia, or oil tanker on a pristine coral reef.

Broadly four consequence categories can be described, namely:

- People: minor injuries to multiple fatalities;
- Property: minor damage to catastrophic damage (loss of vessel);
- Environment: minor pollution to a tier 3 oil spill with lasting ecological damage;
- Business: damage to reputation and loss of future business.

These consequence categories can be drawn out more specifically to:

- Damage to vessel and contents:
    - Loss of life (crew or passenger);

   - Loss of cargo contents; or
   - Loss of vessel.
- Damage to the environment (physical damage of impact or pollution):
   - Biological impact (loss of flora, fauna or habitat);
   - Cultural impact (damage to culturally important sites);
   - Economic impact (closure of businesses such as tourist or fishing).
- Indirect damage:
   - Damage to tourist trade through international reputation;
   - Loss of sea trade to local economy.

4.3 SPATIAL RISK MODELS AND GIS

4.3.1 Introduction

Risk is typically determined by geography. Put simply, risk can be much greater in one location compared to another both in terms of likelihood and consequence. For topics in which the results are geographically varied, a spatial risk model is required. A spatial model can be described as an analysis methodology in which both the input data and output results vary in their significance across the study area.

Spatial data can be defined as any data (e.g. observations, measurements) with a direct or indirect reference to a specific location. Therefore, spatial datasets comprise geographic features (e.g. coastal areas, reefs) with associated attribute information (e.g. mangroves, breeding grounds, exceptional beaches). The operating systems used to manage, analyse and display spatial data are known as Geographic Information Systems (GIS).

The predominant output of spatial analysis is a map or other graphic form, which has the potential to facilitate more effective communication by complimenting written descriptions, and enhancing the understanding of the distribution, patterns, and linkages between factors within an area. Coloured heat maps are immediately expressive and recognisable for non-experts and facilitate the promulgation of the results to stakeholders.

Linking risk quantification to spatial data provided evidence-based information to better inform decision-making.

4.3.2 Weighted Overlay Analysis

Spatial modelling which is routinely used in GIS analysis can take one of three forms:

- Binary modelling approach; identification of areas that fulfil or do not fulfil certain criteria. Expressed as a Yes/No only;
- Ranked modelling approach; a number of criteria combined to provide a range of values based on simple addition; and
- Weighted modelling approach; a number of criteria are combined with each factor scored on its contribution to the total model, normally expressed as a percentage.

The technique of weighted overlay analysis is widely employed for multi-criteria problems such as optimal site selection and suitability modelling.

There are two premises to this analysis. Firstly an issue may be impacted by multiple factors, but these factors are independent and measured on different scales. Secondly, the importance of the factors differs.

The application of weighted overlay analysis to this project follows a series of steps (see Figure 3 for a graphical illustration of this technique):

1) A study area is divided into a number of equally sized grid cells[1];
2) A nominal scale is defined for each factor from most favourable to least favourable, for example temperatures which were recorded using degrees Celsius are converted to a scale of 1 being the least favourable to 5 being the most favourable. The same scale is utilised for each of the factors under analysis, with the scales well defined as part of the methodology;
3) The defined scale is used to score each factor across all grid cells;
4) A weighting is given to each factor, a proportion of the total model (100%). A 20% weighting for example indicates that the factor makes up 20% of the model.
5) The weighted score for each grid cell is calculated, a grid cell with a score of 4 out of 5 for a factor which is 50% important has a weighted score of 2.
6) The total score for each cell is calculated by combining the weighted scores for each factor. A suitability/preference map is therefore created which can be displayed as a heat map, clearly identifying and contrasting high and low scoring areas.

[1] Where port approach and berthing charts are of different schema it is possible to change the GIS grid size to provide more refined analysis into a port area.

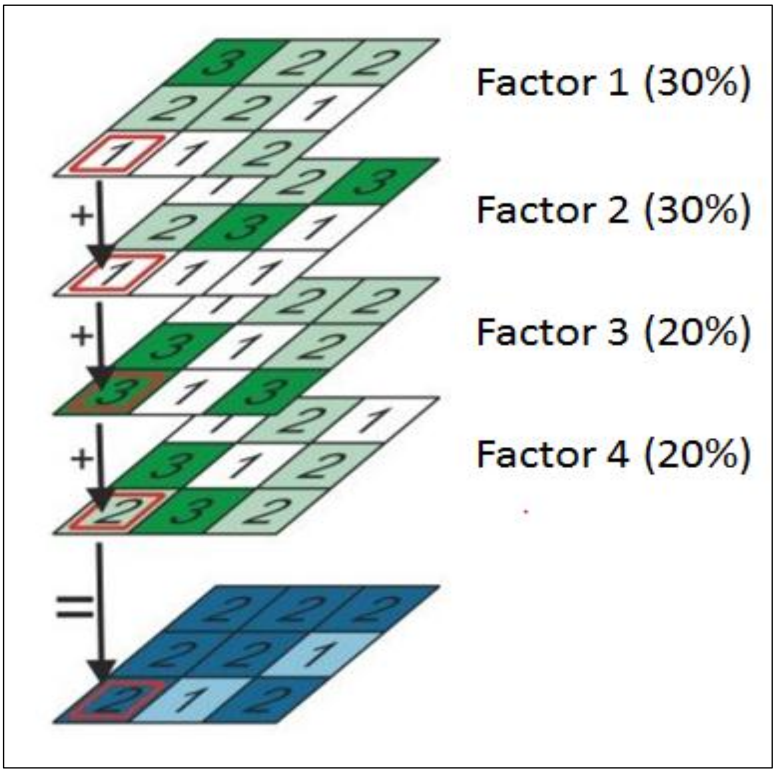


Figure 3: Weighted overlay analysis methodology.

4.3.3 Limitations of Non-Spatial Models

Perhaps the most basic method for expressing risk is through a risk matrix. A hazard is scored on a predefined scale of likelihood and consequence and the scores multiplied together to produce a combined risk score (Figure 4). Therefore hazards that have both a high consequence and high likelihood achieve risk scores greater than those with either low likelihood and low consequence, or only score highly on one axis but not the other. A risk assessment conducted through this approach can be quantitative or qualitative; numbers may be assigned to define each category, for example the use of cost brackets for consequence or a yearly return period for frequency.

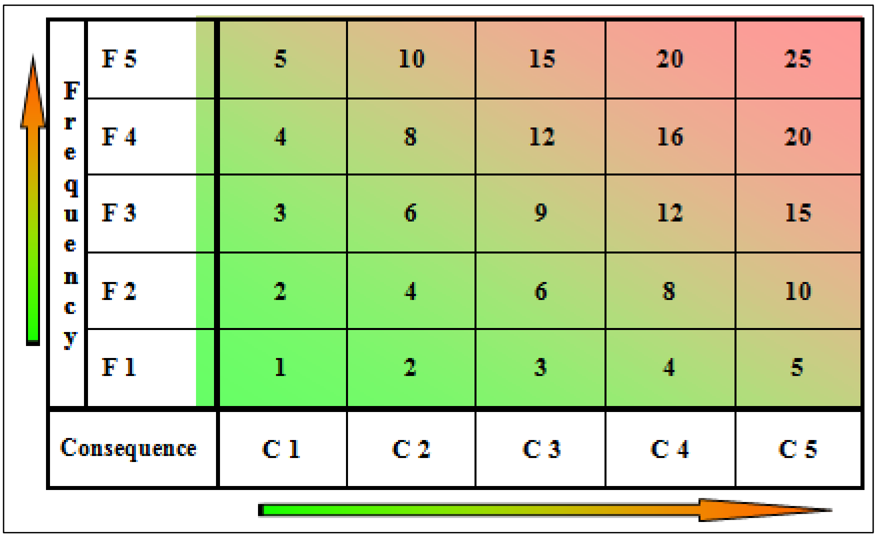


Figure 4: Traditional 5x5 risk matrix.

A traditional risk matrix however is limited in a number of respects and is poorly suited to assessing the hydrographic risk of a region or sea area. The use of a GIS and a spatial risk model is the favoured approach; the reasons for this decision are described in Table 1.

Table 1: Comparison of traditional models and capabilities of GIS.

Factor	Traditional Approach	GIS
Multitude of inputs	Limited to only a single likelihood and consequence category.	Capable of handling multiple inputs.
Spatial nature of problem	Risk is a spatial problem but traditional approaches are non-spatial, limited to only a single area of analysis.	A GIS is purpose built for spatial analysis, hundreds of thousands of grid cells can be analysed easily.
Granularity of results	Analysis areas must be large as scoring is time consuming and laborious.	Analysis areas can be small providing more detailed results.
Presentation of results	Traditional approach produces a tabled risk score.	GIS produce heat maps that are powerful and intuitive visual tools that can inform non-experts. Furthermore cartographic outputs provide a sense of scale and an appreciation of the risk profile across an a large area from a single glance.
Repeatability	Process is laborious which prevents repetition.	A model, once setup, can be repeated multiple times with ease allowing for sensitivity testing.

Factor	Traditional Approach	GIS
Limitation of subjectivity	Relies on human input to combine multiple factors together, reaching a judgement of a single likelihood and consequence score. The limitations of human judgement are well documented and bias, misunderstanding and personal experience impact upon the results.	Data driven by using spatial datasets as the principal input. The potential for bias is therefore reduced.

4.3.4 Literature Review of Marine Spatial Risk Models

A number of studies have attempted to highlight the localised risk of environmental damage from pollution incidents. Two broad categories can be drawn concerning their raison d'être, namely whether they are strategic or tactical tools.

A strategic tool is used for identifying areas at high risk before an incident occurs in order to inform resourcing and decision making, such as the "Marine Environment High Risk Areas (MEHRA's)" study in the United Kingdom. The second category is used for tactical response to an incident and highlights areas [2] of significance in terms of environmental or economic capital that are at risk of pollution. Tactical tools are often interactive and coupled with detailed pollution flow modelling to enable targeted response to an incident and so minimise the impact. Examples of the latter include "Environmental Sensitivity Index (ESI) Maps" by NOAA in the United States and Dynamic Sensitivity Mapping undertaken within the framework of a European Union sea efficiency project studying the Baltic Region.

4.3.4.1 Marine Environment High Risk Areas (MEHRAs)

Marine Environment High Risk Areas (MEHRA's) were initiated in the UK by the Donaldson Report (1994) following the BRAER oil spill in 1993. The study sought to identify: "Comparatively limited areas of high sensitivity which are also at risk from shipping. There must be a realistic risk of pollution from merchant shipping for MEHRA designation."

[2] EU Interreg project "EfficienSea".

A number of considerations were identified in the designation of MEHRA's, including shipping routes, past oil spill events, met-ocean conditions and the existence of any environmentally sensitive areas. The risk scores were calculated by the equation:

*MEHRA's Score=Environmental Sensitivity*Pollution Risk*

The MEHRA's project was begun in the late 1990s, before the introduction of AIS, and so there was difficulty in sourcing accurate vessel traffic information. Vessel track data was collected by radar in the 2000's to supplement the original report and so validate the MEHRA's study.

The results of this study were then analysed to produce 32 recommended MEHRA's sites (Figure 5).

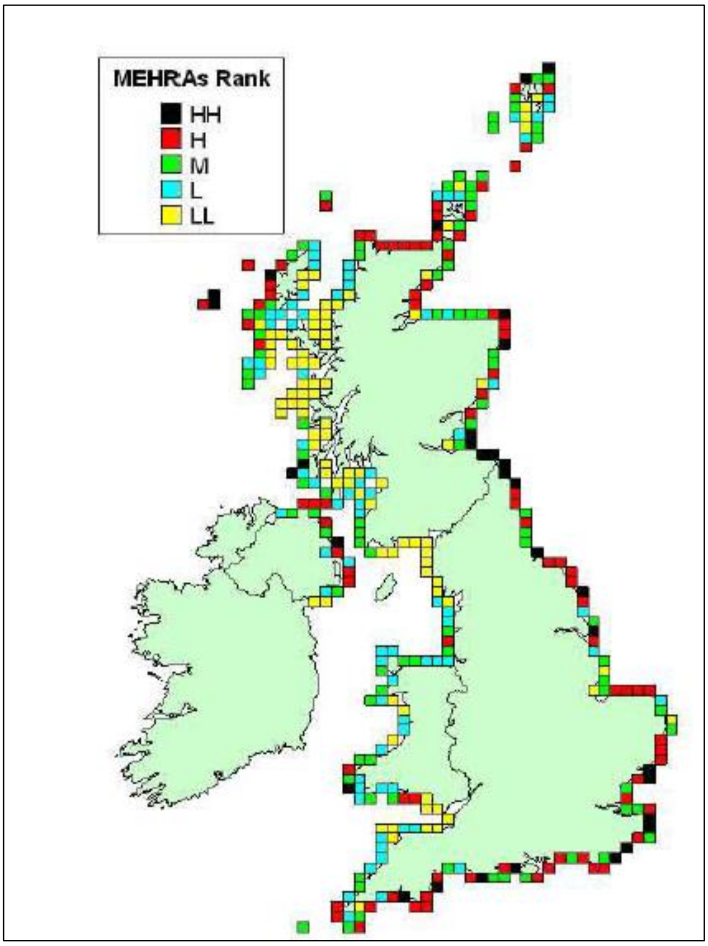


Figure 5: Results of MEHRAs study (HH is highest, LL is lowest).

4.3.4.2 Environmental Sensitivity Index (ESI) Maps

The National Oceanic and Atmospheric Administration (NOAA) have relied on ESI maps since the 1970s following the IXTOC I well blowout in the Gulf of Mexico. The maps are for use as decision support tools to aid in the identification of high sensitivity areas following an oil spill. ESI maps are comprised of three types of information:

- Shoreline Classification – ranked according to a sensitivity scale for the natural persistence of oil and the ease of clean-up;
- Biological Resources – oil sensitive animals, habitats and plants; and
- Human-Use Resources – specific areas that have added sensitivity due to their use (beaches, parks, and archaeological sites).

These elements are combined, and colour coded to produce a local environmental map for the United States highlighting key oil spill concerns. They were of value in the aftermath of the "*Deep Water Horizon*" oil well blowout and spill in the US Gulf.

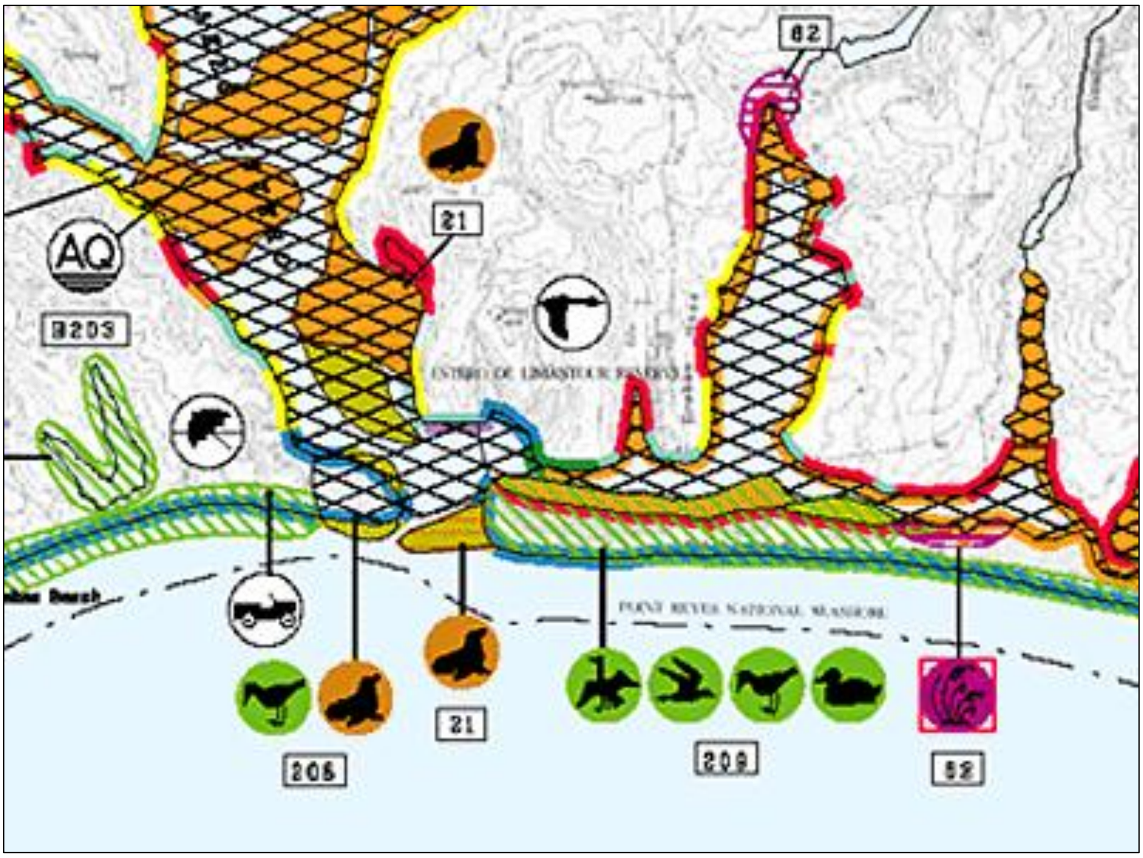


Figure 6: Extract of Point Reyes National Seashore ESI.[3]

[3] NOAA. Available at: http://celebrating200years.noaa.gov/transformations/eco_forecast/image5.html.

4.3.4.3 Global Map of Human Impact on Marine Ecosystems

The National Centre for Ecological Analysis and Synthesis, United States (2008) undertook a study published in the Journal *Science* to develop an ecosystem specific, multi-scale spatial model to quantify the human impact on marine ecosystems.

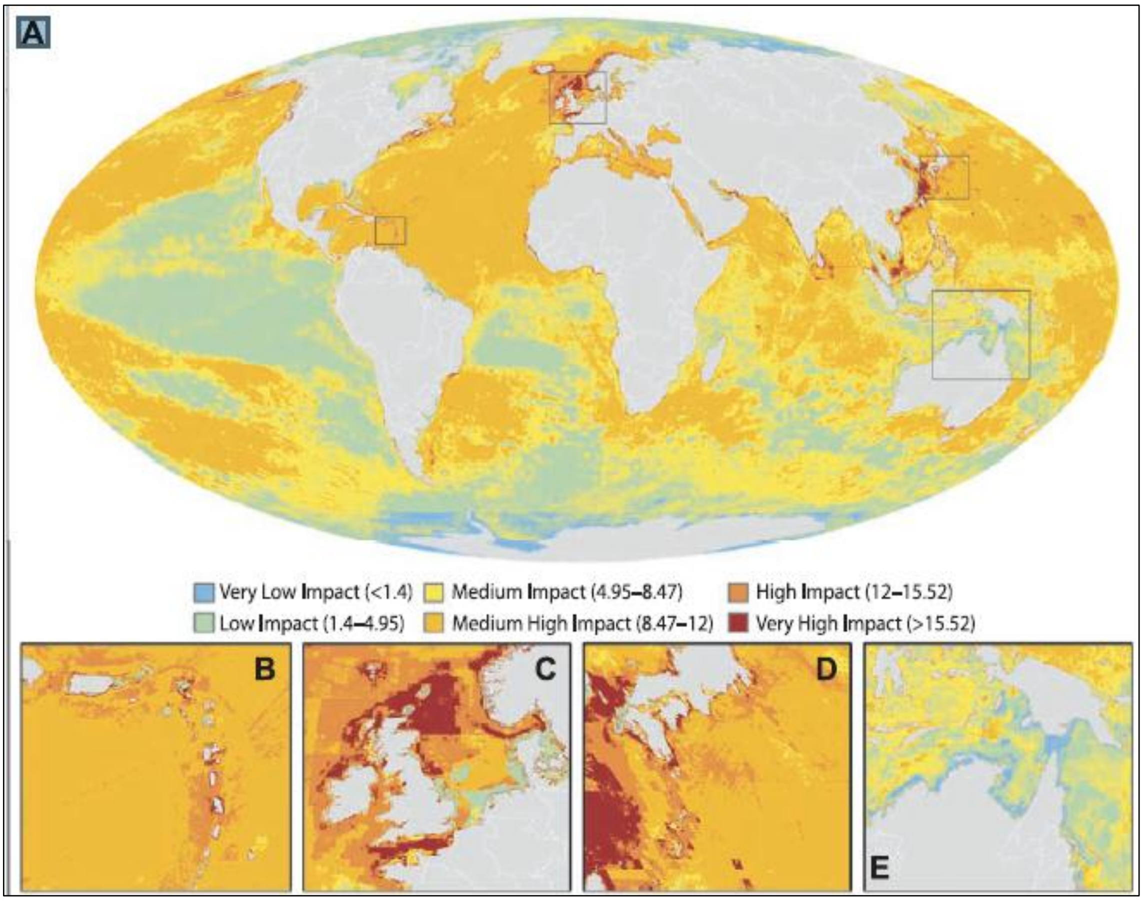


Figure 7: Study impact map.

4.4 METHODOLOGY FOR ASSESSING HYDROGRAPHIC RISK

4.4.1 Introduction

The methodology proposed for this analysis is one of weighted overlay analysis using a GIS. Given that risk is the combination of likelihood and consequence, hydrographic risk can be assessed by identifying factors that cause vessels to have an incident and factors which increase the consequence of that incident.

The use of weighted overlay analysis for the purposes of risk assessment has been referred to as Risk Terrain Modelling (RTM). RTM is the process by which a number of factors related to the "likelihood" and "frequency" of a hazard occurring are combined to produce a single composite framework for use in strategic decision making. RTM was developed by crime analysts who saw crime as a spatial problem and so could map crime risk and hotspots by plotting casual environmental factors, enabling targeted policing. The approach is named as such for the following reasons:

- **Risk** – Measures the frequency and likelihood of a hazard occurring;
- **Terrain** – Production of a two-dimensional cartographic grid to standardise the display of the risk factors; and
- **Modelling** – Study is not based on historic pollution incidents but is the abstraction of the real world, analysing contributory factors to predict future incidents.

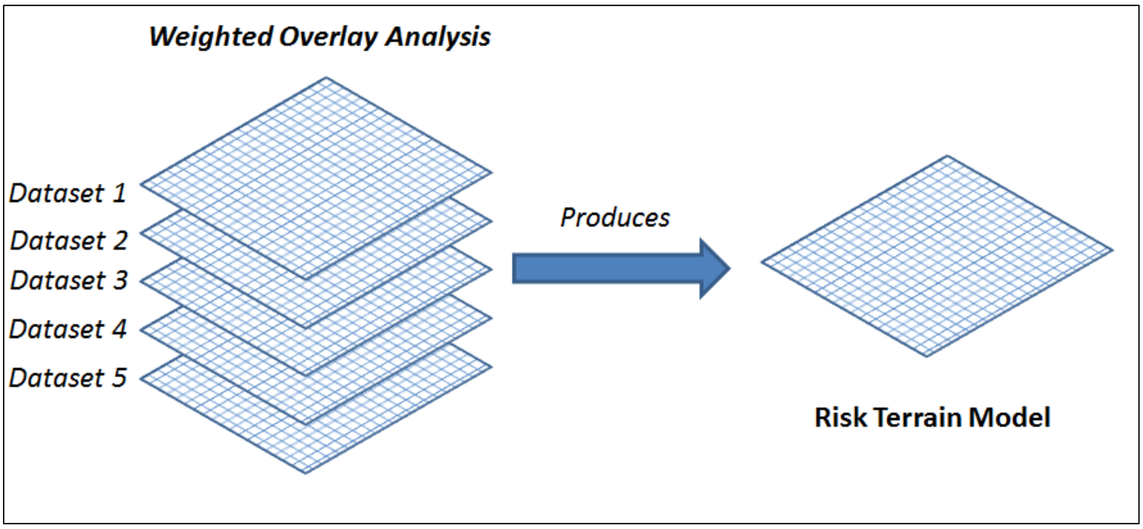


Figure 8: Production of risk model.

The methodology for this analysis follows several steps:

1) Identify aggravating and mitigating risk factors;
2) Geocode risk factors into a GIS;
3) Score risk factors in each location using a specified scale;
4) Weight significance of factors; and
5) Combine factors into composite map.

4.4.2 Risk Factors

Considerable academic and industrial research has been undertaken to better understand the factors which both cause vessels to have an incident, and those that exacerbate the consequences (see Section 4.2.1 and 4.2.2). A summary of those factors pertinent to this project are outlined below. It should be noted that some factors, whilst deemed important are difficult to quantify or collect data for. The selection of factors is therefore pragmatic, tailored to the availability and cost accessibility of datasets. Where pre-existing data is unavailable, field survey and consultation with stakeholders is used to elicit the required information.

4.4.2.1 Vessel Traffic

Vessel traffic is a significant input factor into any assessment on marine risk. Clearly if no vessels navigate through a waterway, the likelihood of a vessel having an incident is nil. Each vessel has an inherent potential for loss of life or pollution that could occur once an accident has taken place. This potential is, to an approximation, a function of the size and type of a vessel, which indicates both the number of passengers or fuel it could normally carry (for example, a large tanker would carry more product that a smaller one and a passenger vessel would carry more persons than a cargo ship). A model of traffic risk was built by multiplying the gross tonnage of each vessel type, by a respective vessel type risk factor.

Fault trees were constructed for each vessel type for grounding hazards and the “most likely” and “worst credible” consequences were established. A risk factor for both people and pollution was created as an average of the “most likely” and “worst credible” occurrences of a grounding accident. This approach reflects the range of possible outcomes such a hazard could have, which in most cases would have a small impact while rarely the result could be catastrophic. This is necessarily an approximation as it is not possible to know from AIS data alone the number of persons or cargo a vessel is carrying at any particular point in time.

4.4.2.2 Likelihood Factors

A review of the academic and industry literature along with the results of the first in-country field survey of Vanuatu identified a range of factors which contribute to the likelihood of a vessel being involved in an incident. These factors are identified as follows:

- Meteorological and ocean conditions:
    - Exposure to prevailing weather conditions.
    - Spring mean current speed.
    - Visibility.
- Navigational complexity (type of navigation required).
- Aids to navigation:
    - Chart ZOC rating.
    - Proximity to non-working or out of position aids to navigation.

- Bathymetry:
  - Depth of water (proximity to 15 metre depth contour.
  - Type of seabed.
  - Proximity to navigational hazards:
  - Proximity to known reefs.
  - Proximity to known under sea volcanic activity.
  - Proximity to known seamounts.
  - Proximity to charted tidal hazards (overfalls, rips and races).
  - Proximity to WW2 military sites.

4.4.2.3 Consequence Factors

Consequence criteria define the effects of an accident, the principal factors being:

- Environmental impact:
  - Proximity to a large coastal reef.
  - Proximity to a key offshore reef.
  - Proximity to a large wetlands resource.
  - Proximity to a small wetlands resource.
  - Proximity to important breeding grounds.
  - Proximity to world biological protected site.
  - Proximity to a regional biological protected site.
  - Proximity to local protected or important site.
- Damage to culturally sensitive areas:
  - Proximity to world cultural protected or important site.
  - Proximity to a regional cultural protected or important site.
  - Proximity to a local cultural protected or important site.
- Damage to economically sensitive areas:
  - Proximity to sites of high economic contribution.
  - Proximity to sites of moderate economic contribution.
  - Proximity to key infrastructure (ports).
  - Proximity to important tourist sites.
  - Cruise ship places of call.

4.4.3 Scoring

All factors in each grid cell are scored on a scale of 0 (absent) to 5 (maximum category value). Whilst each factor is scored slightly differently, there are three broad themes in the scoring:

- Severity scoring – A factor with numerical values (e.g. traffic density as a function of cargo or passenger carriage) is classified into five bounded categories. Data input into the GIS is analysed and the categories automatically generated;
- Descriptive scoring – A factor is qualitatively described by expert input (e.g. navigational complexity). Descriptive scoring is undertaken manually; and
- Proximity scoring –A factor is scored based on the distance between a cell and the factor under analysis (e.g. the closer to an area of coral reefs, the greater the risk scores). Proximity scoring is undertaken using the input risk factors and a GIS buffering tool to determine distances.

4.4.4 Weighting of Factors

There are multiple levels of weighting utilised in the risk model, at the highest level:

- Causation factors account for 50% of the model in combination;
    - Traffic accounts for 25% of the model result;
    - Likelihood factors account for 25% of the model result;
- Consequence factors account for 50% of the model result.

Each individual factor is then weighted as part of their category.

4.4.5 Model Results

As previously discussed, the theoretical approach to risk in this study is that of likelihood combined with consequence. Where there is low likelihood, or low consequence, then there must be low risk. A simple multiplication of likelihood and consequence is capable of achieving this, through the following steps:

1) The weighted scores for each grid cell are calculated for each risk factor;
2) The traffic, likelihood and consequence factors are each individually summed to produce total traffic, total likelihood and total consequence risk scores;
3) To produce a single likelihood score, the total traffic score and total risk score are multiplied together; and
4) The combined likelihood score and the consequence score are multiplied to produce an overall risk score.

A number of useful outputs for decision makers can therefore be produced as a result of this analysis:

- A comparison of hydrographic risk between different countries, by using a standardised scale of analysis;
- A ranking of sites within a country, by using an individual in country scale, or a risk matrix developed with criteria of relevance to the economy and continuous scales to reflect traffic density variance (Annex D) ;
- The "inherent risk", combination of likelihood risk factors and consequence risk factors (excluding traffic);
- Information on the density and distribution of shipping, both international and domestic; and
- Plots on the distribution of each risk factor across a South Pacific EEZ.

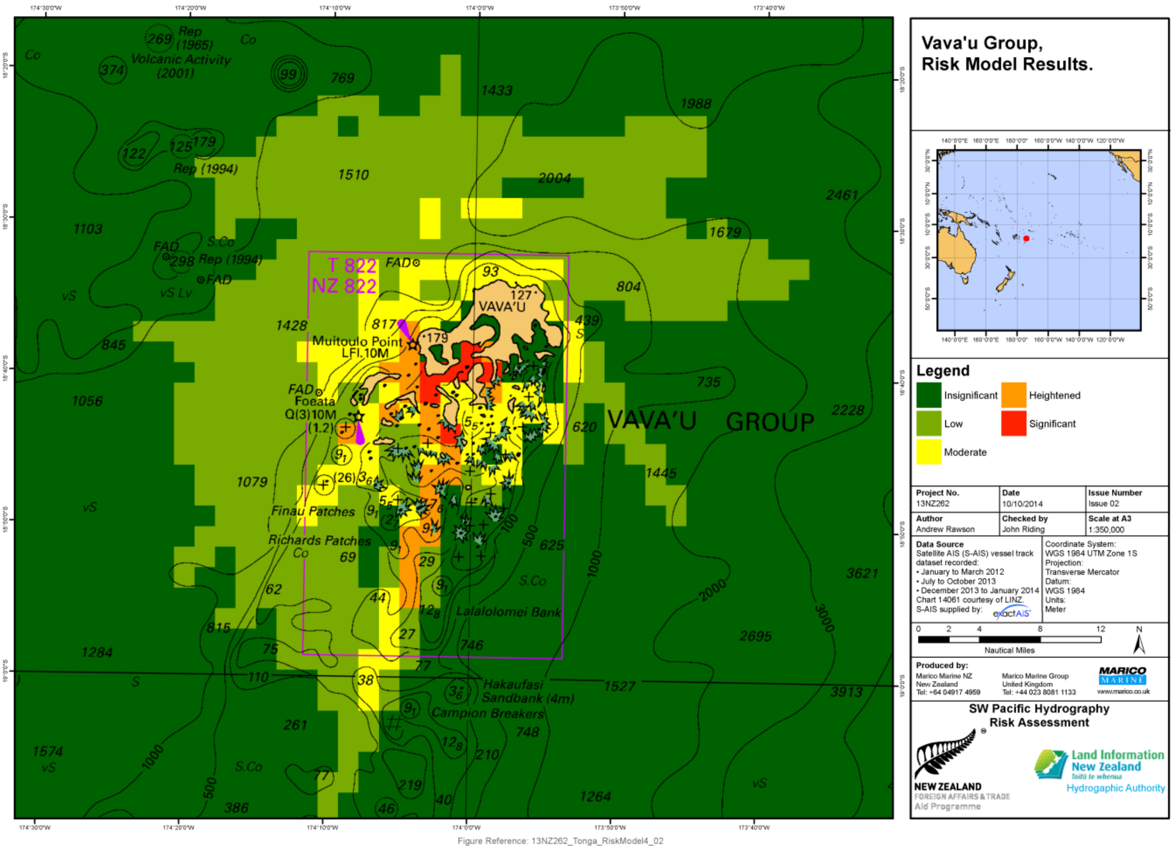


Figure 9: Example risk model results.

5 DEVELOPMENT OF HYDROGRAPHIC COST BENEFIT MODEL

5.1 INTRODUCTION

Risk analysis provides only a partial answer for decision makers. The assessed risks may be categorised in one of three areas:

- **Acceptable/Tolerable** – hazards which do not exceed the risk appetite of an organisation;
- **Unacceptable/Intolerable** – hazards which exceed the risk appetite of an organisation requiring either immediate mitigation or cessation of activities; and
- **"As Low as Reasonably Practicable" or ALARP** – a hazard is neither insignificant nor intolerably high, but for which investment in additional risk control measures is not cost effective i.e. the costs of mitigation significantly outweigh the benefits.

For example, in the context of the South West Pacific Hydrography Risk Assessment, it is necessary for both an understanding of where hydrographic risk is higher, but also whether a new hydrographic survey program can provide a significant return on investment through the improvement of marine safety and development of local economic potential.

5.2 COST BENEFIT MODELS

Cost benefit analysis (CBA) is a varied and complex field; however it can be broadly summarised as a method of determining the monetary return on an investment over a given time period. The CBA models typically used share a number of features:

- Costs and benefits are expressed as monetary of equivalent values;
- Costs and benefits may include social costs, environmental costs and other externalities which are not usually expressed in monetary values; and
- Cost benefit models are time based i.e. the initial investment is compared to a discounted gain over a number of years. Money is of more value now than in the future, often expressed through the concept "Net Present Value".

5.3 METHODOLOGY FOR ASSESSING HYDROGRAPHIC COST BENEFIT

5.3.1 Introduction

The initial cost benefit analysis conducted for the South West Pacific Hydrography Risk Assessment in the Tonga Group and Cook Islands involved the development of a new independent methodology. Subsequent review identified a number of possible avenues through which the risk assessment methodology and cost benefit analysis could be fused into a single continuous process, a description of which is outlined in this document.

The costs and benefits of a hydrographic surveying program are summarised thus:

- Costs:
  - Cost of surveying, equipment, chartering, expertise, distribution, promulgation etc.
- Benefits:
  - Reduction in likelihood of vessel grounding
    - Prevention of fatalities/injuries,
    - Oil spilt with environmental damage and clean-up costs;
    - Economic impact of reduced trade.
  - Development of marine industry.

Estimate costs and values can be placed on each of these factors and a Net Present Value (NPV) calculation performed to geographically identify the cost benefit of hydrographic surveying in a local area.

Such a model is necessarily an approximation for a number of reasons:

- Firstly, the future is inherently uncertain and therefore circumstances may change which negate the analysis conducted. The risk model has exclusively considered the current risk profile of an area, whereas the cost benefit model is attempting to predict.
- Secondly, the financial values assigned to benefits, in particular the equivalent financial value of a human life or environmental damage is open to differing interpretations.
- Finally, a feedback exists within this model which is too complex to be properly quantified. As new investment is applied, more marine trade is encouraged which increases the number of vessels, which in turn increases the risk of a grounding. Improved charts may reduce the risk per movement, however the total exposure of vessels would increase which may increase the risk profile over the current baseline.

5.3.2 Assessing Incident Likelihood

To compare the cost of surveying, to the benefits as a function of reduced fatalities and pollution from grounding, it is necessary to estimate the likelihood of grounding per year. Such a calculation is fraught with difficulties and whilst the resulting answer can be inaccurate, it is still a useful metric for comparing risk across an area. The hydrographic risk model specifically avoided estimating the annual likelihood of an incident each year for this reason; however the use of cost benefit analysis necessities a likelihood input.

Considerable analysis of vessel traffic has already been undertaken as part of the risk model and much of this analysis can be reapplied to calculate a grounding probability. The annual probability of a vessel grounding in an area can be estimated from the following formula:

$$Annual\ Probability = Traffic\ risk * Generic\ Rate * Local\ Calibration$$

Where:

- Traffic risk is the total loss of life and pollution potential of all vessels transiting through an area per year;
- Generic rate is a causation probability of the likelihood of a single vessel running aground per year within an area; and
- Local calibration is a factor which modifies the generic rate taking into account local specific conditions – derived from the risk model likelihood score.

5.3.3 Quantifying Costs

A single cost is used in this analysis, namely the cost of surveying a single grid cell, taking into account all of the associated costs and technology. Given the variety of methods that may be employed, and any economies of scale which may be achieved, a range of values are employed to provide sensitivity testing:

- US$35/km^2 – low estimate with satellite survey;
- US$500/km^2 – moderate estimate with single beam;
- US$1600/km^2 – high estimate with multibeam; and
- US$2400/km^2 – maximum estimate with Lidar.

These costs need to be developed by sharing knowledge[4]. Lidar cost especially seems to vary with some references reflecting lower cost than single beam, especially in waters under 20 metres depth. The point of the cost data is to show the possibility of using CBA techniques to select the best technology for a particular location.

The cost of surveying each grid cell is assumed to be the same within the GIS model.

[4] The costs shown were taken from an IH0 presentation by SHOM, with further research based on internet records in the USA and Europe.

5.3.4 Quantifying Benefits

As discussed, assigning financial values to immaterial benefits can only be achieved as an approximation. The hydrographic risk model has already discussed the consequences of an incident in two key areas; potential loss of life and potential pollution, each of which will be considered in turn. The effectiveness of new charts and ECDIS at reducing the likelihood of a vessel grounding reduces the risk of both these consequences. The level of effectiveness is dependent upon the existing level of charting, a survey program in an area of poor charts derives more benefit than an area of already high quality charts. To account for this phenomenon, the benefits are linked to the chart ZOC rating of each grid cell, a summary of which is shown in Table 2. The risk reduction percentage is the amount by which the likelihood of an incident would be reduced from current levels.

ZOC Rating	Risk Reduction (%)
A	2.5%
B	5%
C	10%
D	20%
U	30%
Fathoms Charts	45%

Table 2: Effectiveness of Improved Charting.

The likelihood difference between an incident with and without improved charting can therefore be estimated. Thus, two probabilities per year of an incident are produced using the methodology laid out in Section 6**.** These probabilities need to be combined with a cost of loss of life and cost of pollution (expressed in tonnes spilt), the difference of which will be the benefit of hydrographic surveying.

5.3.4.1 Loss of Life

The potential loss of life in a grid cell per year used as an input for the cost benefit model must be converted into a monetary value. Whilst there are limitations of this approach it can provide valuable results when discussing the cost benefit of measures that would reduce the likelihood of a fatality. One of the most well used concepts is that of ICAF, the Implied Cost of Averting a Fatality, or the cost of reducing a statistical fatality. Values proposed range from £1.5 to £6 million by the Health and Safety Executive in the United Kingdom (US$ 2.3 to US$ 9.2 million) across a variety of activities. An ICAF value for this project of US$ 3.3 million is proposed; thereby the investment of US$ 3.3 dollars per person would reduce the risk of a statistical fatality by 1 in a million. The investment of $33,000 would reduce the risk of a fatality by 1%, or $330 would reduce the risk of 100 fatalities by 1%.

5.3.4.2 Pollution

The pollution potential of shipping within a grid cell has also been calculated as part of the risk methodology. The costs of a tonne of oil spilt must also be calculated. These costs are wide ranging, including:

- Death and disease to Flora and Fauna;
- Clean up costs;
- Damage to the tourist industry both during clean up and legacy effects;
- Loss of local fishing industry or subsistence activity; and
- Cultural and socio-political impacts.

Similar to assigning costs to human life, the inherent economic value of the protection of the environment is also a controversial topic. Guidance has been sought from studies into major shipping pollution incidents that have occurred elsewhere in the world to better understand the value assigned to environmental damage through punitive damages or compensation claims. An analysis of clean-up costs shows that figures given range from $10,000 per tonne spilt to $40,000 per tonne spilt. It should be noted that much of the research conducted into oil spills has been in the developed world where considerable expense is used to maximise clean up; far greater than the resource availability of much of say the South Pacific. This is partly offset by the intrinsic quality of the environment and the considerable damage to a globally valuable resource. The costs therefore are assumed to be comparable.

However the cost of clean-up is a non-linear function, the cost to clean up one tonne is comparatively greater per tonne than the cost to clean up a much greater volume, due to fixed mobilisation costs. Therefore several studies have proposed more complex regression models (Yamada 2009, Psarros et al 2009). For this study we propose the following method of assessing the costs of environmental pollution, using an evidence-based analysis of spills in the IOPCF database (simplified following Kontovas et al. 2010).

$$K * W^{0.7} * C$$

Where:

- K is a constant ($50,000 cost of clean-up per tonne spilt); and
- W is the weight of oil spilt (tonnes);
- 0.7 is the multiplier that creates the non-linear function; and
- C is the consequence factor, as derived from the risk model.

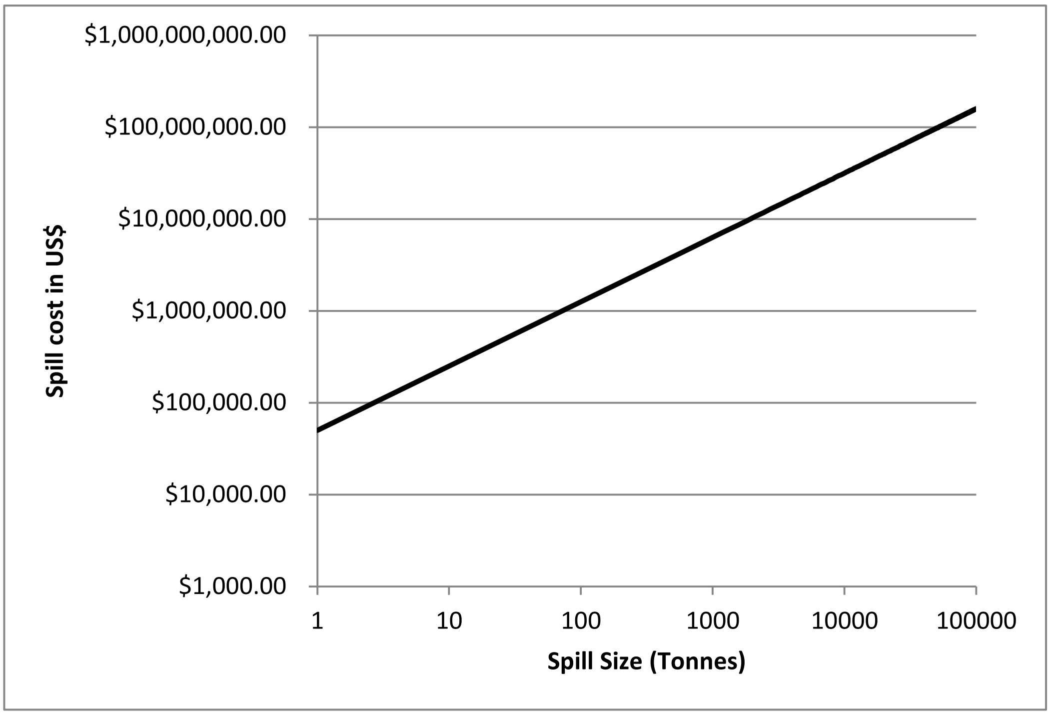


Figure 10: Oil spill costs.

The average of the most likely and worst credible pollution potentials per grid cell are converted into monetary values through this method. The modelled pollution costs are the combination of the likelihood of grounding per year multiplied by the economic cost of an oil spill per incident.

5.3.4.3 Economic Development

The final benefit identified is an economic growth benefit, a hydrographic survey program not only improves safety but it also encourages more vessel visits, investment and tourism, all of which contribute to the local economy. Analysis indicates that a cruise vessel passenger spends on average US$150 and the crew US$50 into the local economy per visit (Worley and Akehurst, 2013). With cruise vessels operating in the South Pacific carrying more than 2,000 passengers, even one additional visit has significant benefits to the local economy. Smaller “boutique” vessels also operate with fewer, but generally wealthier, passengers. Furthermore the improvement of quays, facilities and an expanding local expertise encourages commercial trade through improved import and export.

Unlike the previous two benefits, which may happen in any one particular location, for an economic benefit to be realised a whole route must be surveyed. Therefore the economic development benefit per grid cell would be divided by the number of grid cells of survey required.

The following inputs would have to be specified for each project:

- Areas of high (2x), medium (1x) and low (0.5x) maritime economic development potential;
- The average economic benefit of a survey program for a national economy; and
- The total area required to be surveyed before the economic development potential is realised.

The economic contribution of each grid cell would be calculated by multiplying the average economic benefit of a survey program by the local potential modifier and dividing by the number of grid cells required to realise that potential.

5.3.4.4 Combination

Each grid cell therefore has:

- The cost of surveying;
- The loss of life reduction benefit/year in US$;
- The pollution reduction benefit/year in US$; and
- The economic development benefit/year in U$.

The loss of life cost/year and pollution cost/year are calculated twice, once without hydrographic surveying, and secondly with hydrographic surveying using the aforementioned probability reduction factors. The difference in these two values is the benefit in terms of a reduction in loss of life and pollution. Once added to the economic development benefit/year this provides an annual benefit/year in US$.

A Net Present Value (NPV) function is then conducted using the following inputs. The assessment is made for a ten year forecast where the benefits are only realised once surveying has been completed (i.e. year two).

- The survey cost (US$);

- A 2% interest rate; and
- The sum of benefits.

The cost-benefit for hydrographic surveying is therefore presented using a colour coded map (see Figure 11).

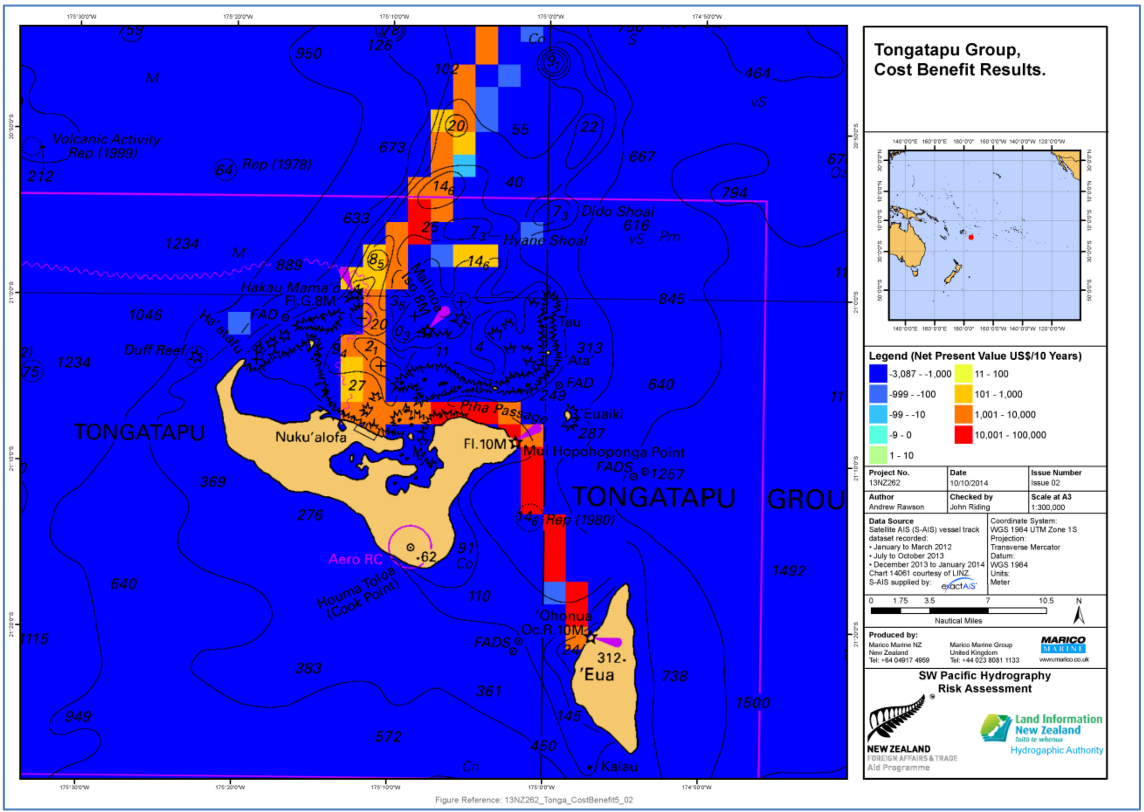


Figure 11: Cost benefit output example.

5.4 COST BENEFIT AND RISK INTERACTION WITHIN A GIS MODEL

A functional network diagram of the GIS model with Cost Benefit Assessment is shown in **Figure 12**. This shows the relationships for calculation, and is also presented at Annex D**.**

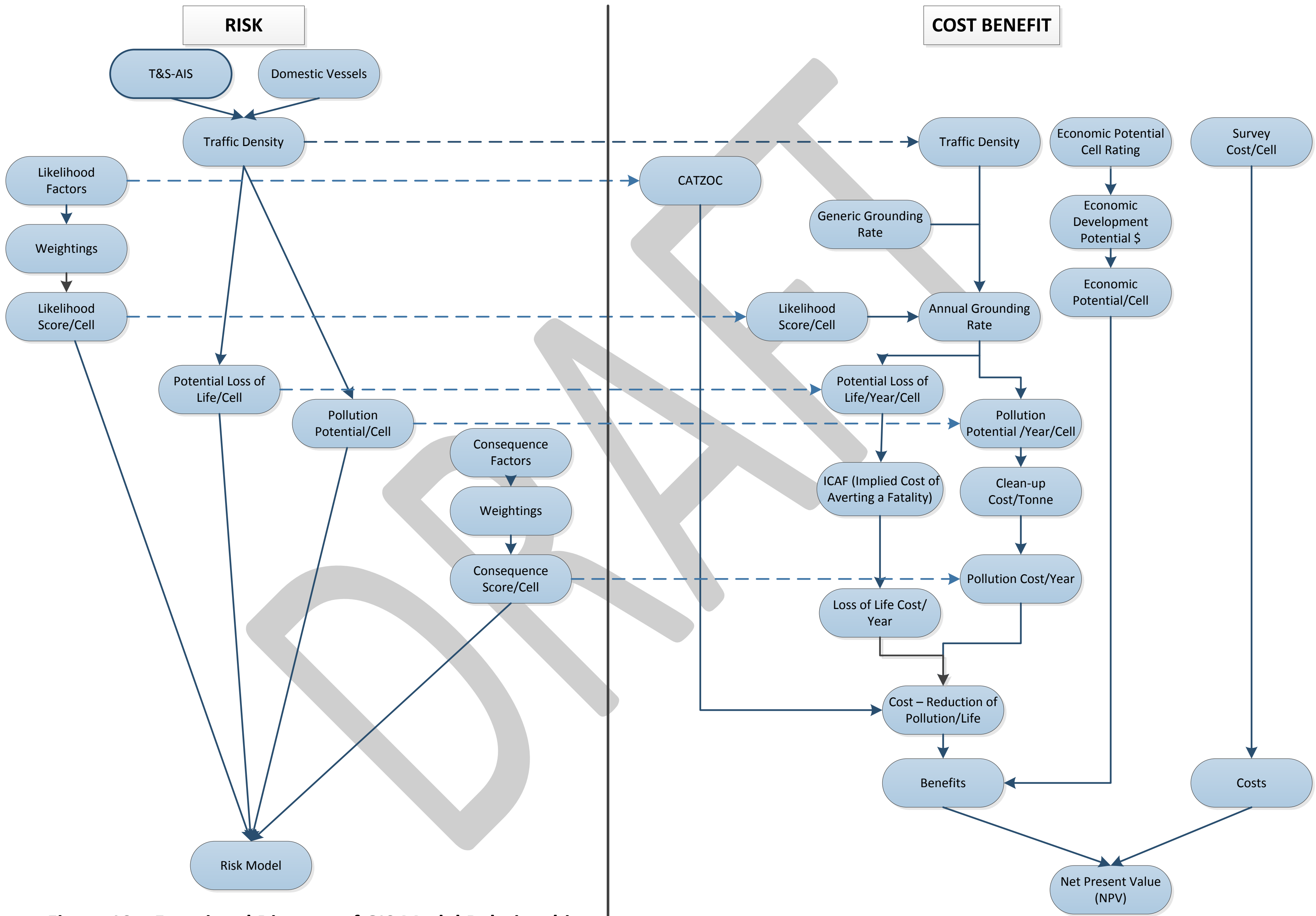


Figure 12 – Functional Diagram of GIS Model Relationships

6 TRAFFIC FORECASTING AND FUTURE SCENARIO MODELLING

6.1 INTRODUCTION

The analysis presented thus far has provided a methodology on how to assess the baseline (present day) hydrographic risk of a coastal state. There are a number of occasions when a baseline analysis is inadequate to properly answer the study scope. For example, changes in the traffic profile in the immediate future, which is not accounted for in the data analysis will significantly alter the risk and cost benefit results.

An additional aspect to the traffic modelling is to demonstrate the need for hydrographic surveying in certain areas. Where charts are wholly inadequate vessels may not choose to transit, and are therefore absent from the baseline risk assessment. These locations may have considerable economic development potential and if charts were improved vessels would transit to these locations. Without accounting for these desired routes the analysis methodology would not highlight these areas of significant risk. By including an additional vessel transit route it is possible to demonstrate what the risk results would be with increased traffic.

6.2 FORECASTING METHODS

The process for conducting the hydrographic risk assessment with forecast data is as follows:

1) In Country data gathering - consultation with stakeholders to establish routes, types and frequency of likely vessel transits;
2) Traffic modelling – model the routes and frequency of the additional vessels in a GIS and overlay with existing traffic profile; and
3) Forecast analysis – repeat the analysis of the risk assessment and cost benefit with the modelled vessel traffic to produce new risk maps.

7 SITE VISIT QUESTIONNAIRE

7.1 INTRODUCTION

This section provides an assessment of the types of questions needed to be answered when data gathering in the field.

7.2 INFORMATION REQUIREMENTS

7.2.1 Reliability of Charts

1) M_QUAL (Especially Zone of Confidence (ZOC) rating);
2) Date of last survey;
3) Technology used in survey;
4) Coverage of survey;
5) Scale of survey;
6) Datum of survey. If WGS84, is it based on new survey or datum shift of old survey?
7) Sounding unit. If metres, is it based on new survey or metrication of old data?

7.2.2 Use of Chart

1) Ocean passage;
2) Coastal (island and inter island);
3) Port approaches;
4) Port plan.

7.2.3 Shipping Volume

1) Terrestrial (T-AIS) and/or Satellite (S-AIS) data;
2) Local data (port, marine department, customs, agents, anecdotal).

7.2.4 Type of Vessels

1) Cruise vessels;
2) Passenger vessels (local service);
3) Foreign-going cargo vessels;
4) Local cargo/supply vessels;
5) Tankers;

6) Foreign fishing vessels;
7) Local fishing vessels;
8) Cruising yachts;
9) Others.

7.2.5 Characteristics of Vessels

1) Number and frequency of visits for above vessels and vessel details including, as appropriate:
    - Vessel Type;
    - Length;
    - Draught;
    - Size: Gross tonnage.

7.2.6 Accident and Incident Statistics

1) Information surrounding any accident/incident statistics available.
2) Anecdotal evidence of any accidents/incidents and near misses.
3) Concerns of local communities in relation to incidents.

7.2.7 Type of Harbour (s)

1) Wharf;
2) Sheltered anchorage within reef;
3) Roadstead anchorage to seaward of reef;
4) No anchorage: hove to in the offing.

7.2.8 Harbour Characteristics and Infrastructure

1) Width, length and depth of channels;
2) Depths in inner anchorage or roadstead;
3) Availability of day/night aids to navigation;
4) Reliability of aids to navigation;
5) Are dangers clearly marked or visible (eye and radar);?;
6) Availability of local MSI;
7) Is navigation conducted using colour of water, e.g. in vicinity of submerged reefs, coral outcrops?
8) Availability of local pilotage service or advice

9) Are radio communications with the port available?
10) Are tugs available, otherwise location of nearest tugs?
11) Environmental significance of surrounding areas?
12) Is aquaculture farming in the area, including FADs?
13) Is there a Harbour Master? If so, qualifications and experience.
14) Method of landing passengers.
15) Method of landing cargo, including petroleum products.
16) Location of nearest oil spill response equipment.
17) Is there any local SAR capability?

7.2.9 Possible Local Impacts of a Casualty

1) Is the area a World Heritage site or protected area?
2) Physical damage to reefs
3) Pollution causing:
    - Damage to ecologically important breeding grounds.
    - Damage to local commercial and subsistence fishing.
    - Damage to local reef ecosystems making the area less attractive to tourists.
    - Damage to local environment, such as beaches, making the area less attractive to tourists.
    - Loss of income to local community due to reduction in vessel visits and /or tourism.

7.2.10 Effects on Economy (National and Local)

1) Income from tourism or economic activity relying on the sea interface (if possible as a percentage of GDP).
2) Income from cruise vessel visits as a percentage of tourism.
3) Stake holder feedback on possible increase in GDP with introduction of modern charts (tourism, exports)
4) Economic impact of temporary loss of:
    - Cruise vessel trade;
    - Local cargo/passenger services;
    - Commercial fishing;
    - Subsistence fishing;
    - Loss of environmental utility.

REFERENCES

Fujii, Y. et al. (1974). Some Factors Affecting the Frequency of Accidents in Marine Traffic. Journal of Navigation, 27(2), pp.239-247.

International Maritime Organisation. (2002). SOLAS Chapter V.

International Maritime Organisation. (2007). Formal Safety Assessment. MSC 83/INF.2

Kite-Powerll, H.L. et al. (1999). Investigation of Potential Risk Factors for Groundings of Commercial Vessels in U.S. Ports. International Journal of Offshore and Polar Engineering, 9(1), pp.16-21.

Kontovas, C.A. Psaraftis, H.N. Ventikos, N.P. (2010). An empirical analysis of IOPCF oil spill cost data. Marine Pollution Bulletin, 60, 1455-1466.

Macduff, T. (1974). The Probability of vessel Collisions. Ocean Industry, 9(9), pp. 144-148.

Montewka, J. (2011). Marine Traffic Risk Modelling - an innovative approach and case study. Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability, 225(3), pp.307-322.

Mullai, A. and Paulsson, U. (2011). A Grounded Theory Model for Analysis of Marine Accidents. Accident Analysis and Prevention, 43, pp.1590-1603.

Psarros, G., Skjong, R., Endersenm O., Vanem, E. (2009). A perspective on the development of Environmental Risk Acceptance Criteria related to oil spills, Annex to International Maritime Organisation Document MEPC 59/INF.21.

Worley, T. and Akehurst, G. (2013). Economic Impact of the New Zealand Cruise Sector. Cruise New Zealand CNZ008.13.

Yamada, Y. (2009). The cost of oil spills from tankers in relation to weight of spilled oil. Marine Technology 46(4), 219-228.

International Hydrographic Organisation (IHO), Capacity Building Strategy, October 2014 – EIHC5

ANNEX A METHODOLOGY DEVELOPMENT BACKGROUND

1 RISK ANALYSIS METHODS IN COMMON USAGE

The following is an overview assessment of the various risk assessment tools in common use. The review was used to derive the approach needed to be taken to develop something that was appropriate for Hydrographic use.

1.1 PRIMARY RISK ANALYSIS METHODS

1.1.1 Coarse Risk Analysis

A coarse risk analysis is a common method of presenting a risk picture with relatively modest effort (sometimes referred to as a risk overview). The hazards, causes, consequences and probability are rapidly assessed, often by expert judgement, and the results presented in graph format with supporting arguments of probability and consequence. A separate graph is required for different categories of consequence, e.g. risk to people, property, environment and stakeholders.

1.1.2 The Safety Case

The safety case is a detailed and systematic risk assessment that is developed to demonstrate compliance with a level of safety proscribed by a regulator. It is used extensively in the offshore oil and gas, as well as the chemical industries. Its origins are in the UK nuclear industry, with the science being developed following the 1956 Windscale pile fires, which resulted in uncontrolled atmospheric release of nuclides. It is expensive and detailed and uses a traditional approach to risk assessment that is bottom up. Essentially, the safety case is submitted as part of an application for an operating licence.

1.1.3 Formal Safety Assessment (FSA)

FSA is a tool for proactively assessing risk before an accident occurs. It was originally developed by the British Maritime and Coastguard Agency as a method of deriving regularity requirements that were based on risk. The concept of a top down approach was tabled to the IMO following the Lord Carver enquiry into UK Cross Channel Safety as a response to the HERALD OF FREE ENTERPRISE Ro-Ro disaster. Following a second Ro-Ro ferry disaster, ESTONIA, the UK MCA developed the methodology, trialled it and delivered it to IMO. It was later adopted in a modified format by IMO as a tool to evaluate risks and controls, and the cost benefits of those controls, in the rule making process. FSA is a proactive tool which allows comparison of different options. It has five steps and, as a concept, has been used in a number of other marine areas. FSA provided a breakthrough in areas where top-down decision-making is needed, often based on limited information. In its simplest format, the steps are lined as shown in Figure 13, below.

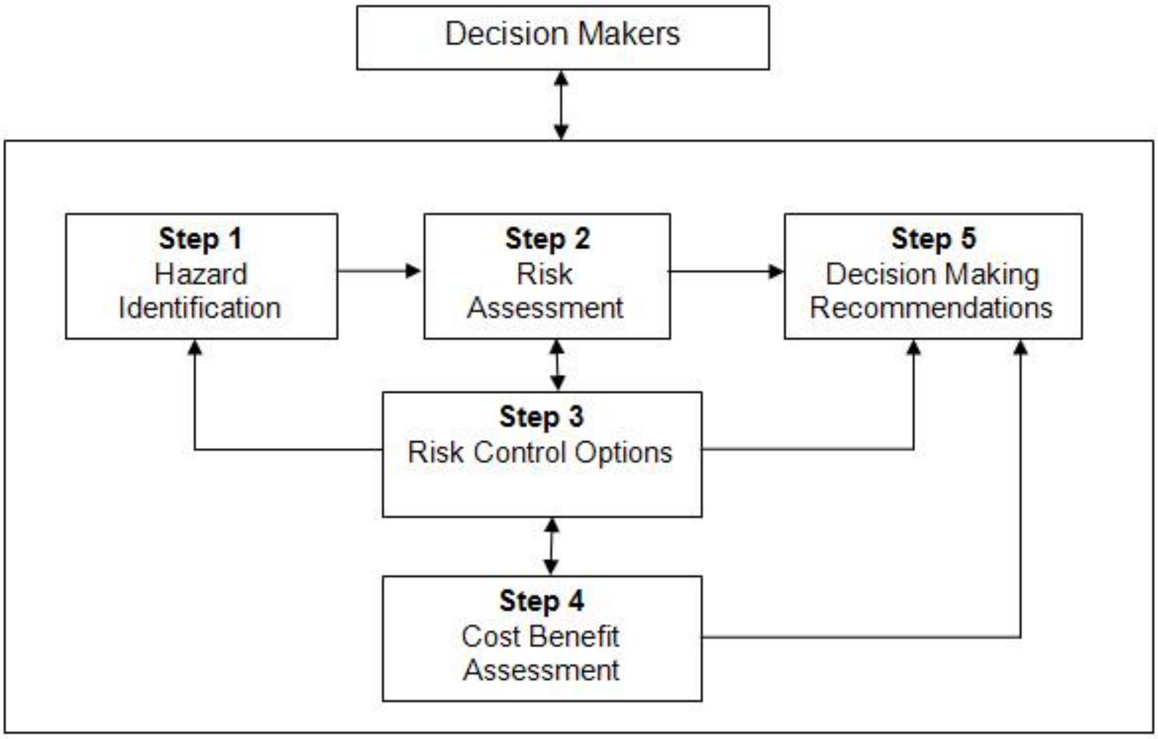


Figure 13: The IMO FSA Five Step Process.

1.1.4 Failure Modes and Effects Analysis (FMEA)

FMEA is an inductive reasoning approach best suited to reviews of mechanical and electrical hardware systems. It is primarily used to predict the effects of failure in a mechanical or electrical system, or part of a system, and is often used during the design process to identify critical weaknesses. This can be used to develop trouble shooting systems, and safe guards such as planned maintenance and inspection plans.

A quantitative version of FMEA is known as failure modes, effects and criticality analysis (FMECA).

1.1.5 Hazard and Operability Studies (HAZOP)

HAZOP is a qualitative risk analysis method primarily used during the design of a processing facility to identify design weaknesses and hazard impacts if they are realised. The process studies deviation from design intent and considers possible causes and consequences if safeguards fail. It is used in some sectors of the oil and gas industry to review procedures and sequential operations to ensure an appropriate depth of safeguards are in place. These are both hardware and procedural.

1.1.6 Structure What-If Technique (SWIFT)

SWIFT is a risk analysis method in which the lead question "what if" is systematically used to identify deviations from normal conditions. SWIFT is often used as a precursor to a HAZOP study, as the SWIFT concept maintains an overview. Possible problems, and combinations of conditions which can be problematic, are identified and possible risk reduction measures derived, which are often coarse in nature. SWIFT is a brainstorming technique, relying on personnel familiar with the system under examination. It is thus a technique to deliver preliminary answers in a short timescale.

1.1.7 Pareto Analysis

Pareto analysis is a prioritization technique based solely on historical data. The technique uses the Pareto 80/20 principle which states that 80% of the problems are produced by 20% of the causes. It is often used to identify the most important risk contributors for more detailed analysis. It can be used in conjunction with the SWIFT methodology.

1.1.8 Change Analysis

Change analysis systematically studies possible risk impacts and risk management strategy in situations in which change is occurring. It is generally applicable to any situation in which change from normal configuration, operation, activity or procedure is likely to affect risks and can be used as a predictive tool to study possible effects of planned changes.

1.2 RISK ANALYSIS TECHNIQUES – SUPPORTING METHODOLOGIES

1.2.1 Tree Analysis

1.2.1.1 Fault Tree Analysis

This predictive analysis method is widely applied in many industries and often uses specialised computer programs. The fault tree is a logical diagram that illustrates the relation between system failure, or failure of a system barrier, and failures of the components of the system, including human error. The analysis is deductive and is carried out by repeatedly asking the questions "How can this happen?" or "What are the causes of this event?" This method is used widely in the space and nuclear power industries.

1.2.1.2 Event Tree Analysis

This method is used to establish the possible consequences of an initiating event. There are several methods of showing event tree analysis diagrams, the two primary ones being event sequence diagrams and barrier block diagrams. Both are widely used in industry.

1.2.1.3 Risk Contribution Tree

This tool is used to diagrammatically display the risk distribution amongst different hazard categories and sub categories. It is, essentially, a combination of a fault tree and an event tree analysis and is used in the IMO FSA process within step two. The fault tree element is used to diagrammatically describe how a combination of basic events results in an accident and the event tree describes the possible outcomes of that accident.

1.2.2 Bayesian Network

A Bayesian network is a type of Event Tree Analysis. It consists of events (nodes) and arrows, with the latter indicating causal connections. There are two separate levels in the diagram showing conditions and the effect those conditions may have. If the network is used for quantitative analysis the results are displayed in a yes/no table with percentage probabilities calculated using the Bayes' formula.

1.2.3 Root Cause Analysis

Root cause analysis systematically dissects how an accident occurred to understand the underlying root causes of key contributors to the accident. It is generally applied to accident investigation with the aim of making recommendations for correcting the root causes. Root causes are often related to organisational issues.

1.2.4 Influence Diagrams

This method is particularly useful where empirical data is not available. The influence diagram models the network of influences on an event, linking failures with their direct causes. The method is mostly judgmental and is set in an organisational context. It can be of assistance when analysis of stakeholders is being considered.

1.2.5 Monte Carlo Simulation

This system uses a computer model of the system to be investigated to generate realisations of the systems performance. A great deal of information has to be input to produce accurate results and the reliability of the results is dependent on the quality of the computer modelling as well as the input data. It is a quantitative risk technique that attempts to model every possible outcome. It is suitable for systems that can readily be modelled on a computer and scenarios run. Complex production systems can make the best use of this type of simulation.

1.2.6 Job Safety Analysis

As its name suggests this tool is particularly useful for identifying work related hazards and establishing control procedures to reduce risk. Such an analysis is often used to help design standard work procedures. It can also be used prior to conducting non-standard work which may require special controls.

2 RISK ANALYSIS METHODS USED IN THE MARITIME INDUSTRY

There are two key risk analysis tools used for major risk analysis studies for safety of shipping movements which are worthy of consideration:

2.1 IMO GUIDELINES FOR FORMAL SAFETY ASSESSMENT (FSA)

The FSA process is the most easily recognised methodology within the maritime industry. Following its adoption, the IMO membership developed detailed guidelines (MSC/Circ.1023 with amendments contained in MSC/Circ.1180 and MSC-MEPC.2/Circ.5.). The guidelines are focused on the rule making process and the cost/benefit of proposed regulatory requirements derived in response to identified risk levels.

The guidelines describe FSA as "….. a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost benefit assessment".

The five steps of the IMO FSA process are explained earlier but repeated below:

1) Hazard identification
2) Risk analysis
3) Risk control options
4) Cost benefit assessment
5) Recommendations for decision-making

IMO's adoption of the FSA process represents a fundamental change from a reactive regulatory approach to one which is proactive and based on risk evaluation.

2.1.1 Comments

The FSA step process and IMO guidelines on its use are comprehensive. The use of statistical information is discussed but the emphasis is on proactive risk assessment. As the FSA concept has been adopted by Governmental and non-Governmental organisations that operate on an international basis, the concept is readily adaptable to address hydrographic needs.

2.2 IALA RISK MANAGEMENT TOOL

This tool was developed for identifying and quantifying risk associated with Aids to Navigation. It incorporates American models for Port and Waterways Safety Assessment (PAWSA), which is qualitative, and IALA Waterway Risk Assessment Program (IWRAP), which provides a form of quantitative assessment built around traffic evidence from known locations. IWRAP is a computer programme that employs statistical data relating to vessels (often with AIS inputs), navigational methods and channel conditions to produce results relating specifically to collisions and groundings. It was calibrated by assessment of busy waterways, such as The Strait of Dover and Singapore Strait.

IALA use the same five step concept as originally developed by the IMO member Governments. The five steps of the IALA interpretation of the process are as follows:

1) Identify hazards
2) Assess risks
3) Specify risk control options
4) Make a decision
5) Take action

2.2.1 Comments

The IALA guidelines on risk management are broad, comprehensive and detailed. The core methodology is not necessarily specific to Aids to Navigation (AToNs), and the guidelines have been derived from the FSA concept. The PAWSA process contains proactive elements and describes a basic descriptive risk matrix.

On the face of it, the IWRAP system and hydrographic needs assessment are closely aligned. However, IWRAP is designed to apply risk to provide a similar but subtly different answer to that needed to prioritise a hydrographic survey programme. There is a need for hydrographic survey irrespective of the volume of traffic; a lower volume of traffic (or vessel types with minimal pollutants on board) only suggests the quality of existing data may remain fit for purpose. Thus, a lower risk from a hydrographic perspective lowers the survey priority. A lower risk from an IWRAP AToN perspective may suggest there is no need to deploy physical aids to navigation at all.

IWRAP employs historical incident data, i.e. accidents which have happened as opposed to accidents which may happen, as well as ship traffic volume and outputs a prediction of Collisions and Groundings. This is useful for the design of traffic management systems or deployment of new aids to navigation. The need for hydrographic survey is related to the possibility of Grounding only, but historic incident data of Groundings with a direct causal link to deficient hydrographic survey are at best scarce. Further, the need for improvements to hydrographic survey is strongly linked to economic activity, and importantly the potential for significant economic expansion affecting the volume of marine traffic associated with one ship type.

Statistical data, where available should be employed in risk analysis, but over-reliance on it can give misleading results, particularly when considering worst case scenarios which may have a frequency of one in a hundred or one in a thousand years (essentially conditions of low probability). The risk process runs into difficulties where statistical data is sketchy or non-existent. When that occurs, those without domain knowledge of the subject matter (in this case ship operating and shipping market experience) can interpret the lack of data inappropriately.

2.3 CONCLUSIONS ON THE RISK ASSESSMENT METHODS

The risk assessment tools briefly described in Section 3 have generally been designed by particular industries to fulfil specific needs of, or within, that industry. The tools are not necessarily mutually exclusive and designing a new assessment process to satisfy a particular need may draw upon elements of a variety of tools, particularly fault tree and event tree analysis.

No model currently available fully answers the needs of LINZ and a new methodology is proposed, but again based on the FSA concept. The risk assessment required by LINZ must be proactive as it can be expected that there is little appropriate accident data which can be used in analysis.

Evidence of groundings directly related to the use of out of date charts is unlikely to be found. This may, in part, be due to some vessel owners (e.g. Cruise Operators) avoiding an area because of inadequate and inaccurate charting (when compared to modern standards), and to extra caution being displayed by mariners knowingly using unreliable charts.

It can be argued that the increasingly widespread use of Electronic Chart Display & Information Systems (ECDIS) may increase the risk associated with unreliable charts. The ECDIS display does not give the mariner an inherent “feel” for the quality of the displayed information. Accidents are now occurring through over-reliance on ECDIS and the risk of those accidents occurring increases with reduced quality of information displayed.

Risk is a combination of frequency and consequence and, given an expected lack of robust statistical accident data, it is probable that frequency will have to relate directly to traffic density, obtained from traffic analysis. The FSA concept was developed around an industry that was lacking in the type of high quality data that is needed for traditional risk assessment. As it was designed for assessment of new regulatory requirements, about which there is often scant information, FSA uses a wider range of possible information sources, other than risk alone, to deliver the information which is of value to the decision making process. Hydrographic decision-making for candidate sea-area prioritisation shares this common theme that FSA provides for the regulatory level.

Of the risk assessment tools in common use, the FSA concept, being transparent, auditable and primarily proactive, is the most likely to meet the need of LINZ. The IMO model provides a good base from which to derive a risk-based hydrographic tool, which is aligned to the FSA methodology, and thus IMO and international risk-thinking in the maritime area.

The FSA tool is now well developed and accepted. It is also used, to some degree, by IALA in its IWRAP technical risk assessment of Aids to Navigation (IALA have, in effect, developed a modified version of the FSA process for their risk based needs). It is logical for a hydrographic decision-making methodology to similarly adopt a modification of the FSA process, which allows a compatibility to be provided at IHO and IMO levels.

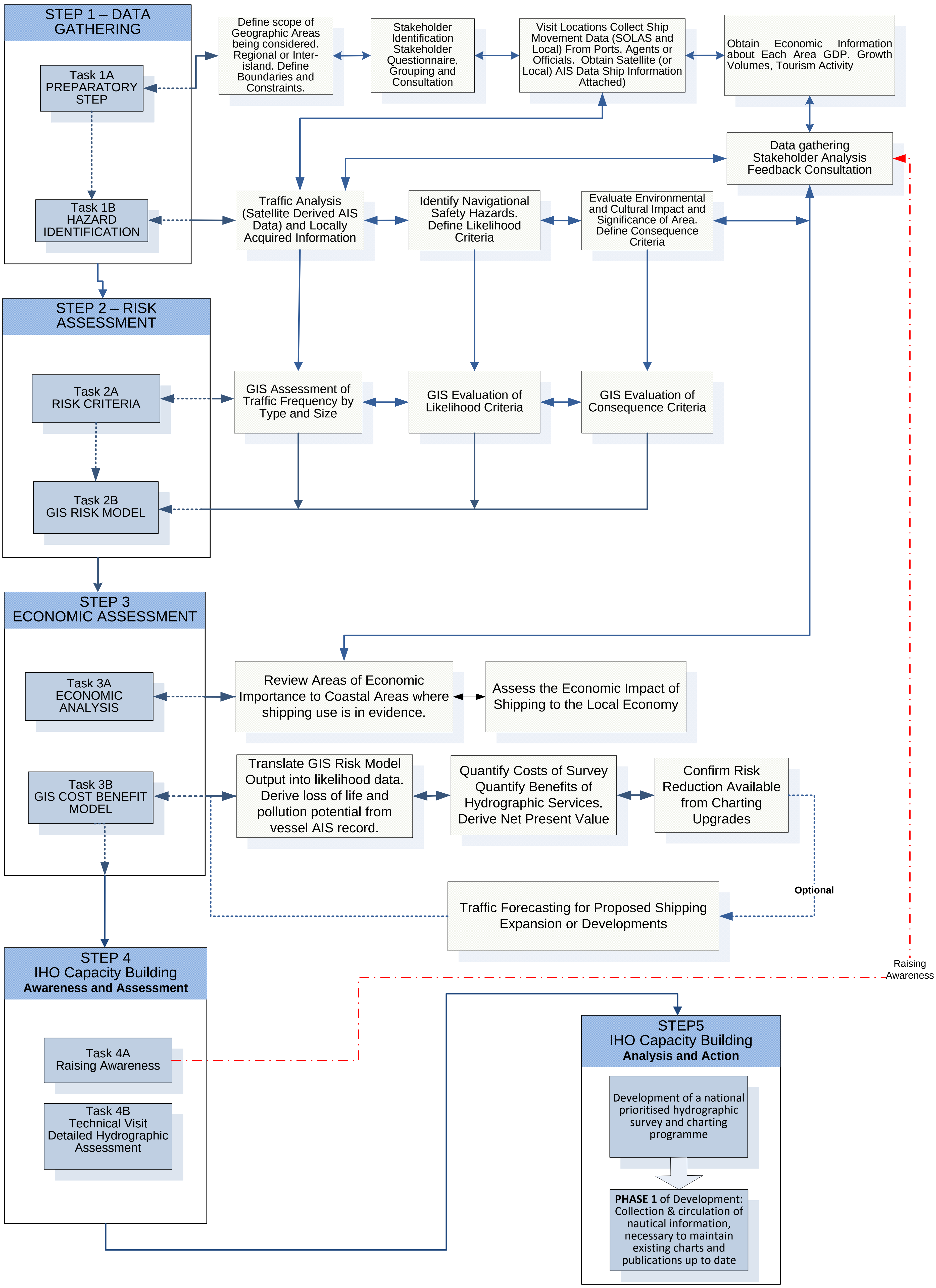
In summary, some evidence of the economic potential of an area being in the process of realisation, as well as some evidence of heightened risk is needed to prioritise the hydrographic case. This is key. For this reason, a variation on the FSA methodology needs to be considered. It appears that the same reasoning was used to base the development of the IWRAP methodology on the FSA concept.

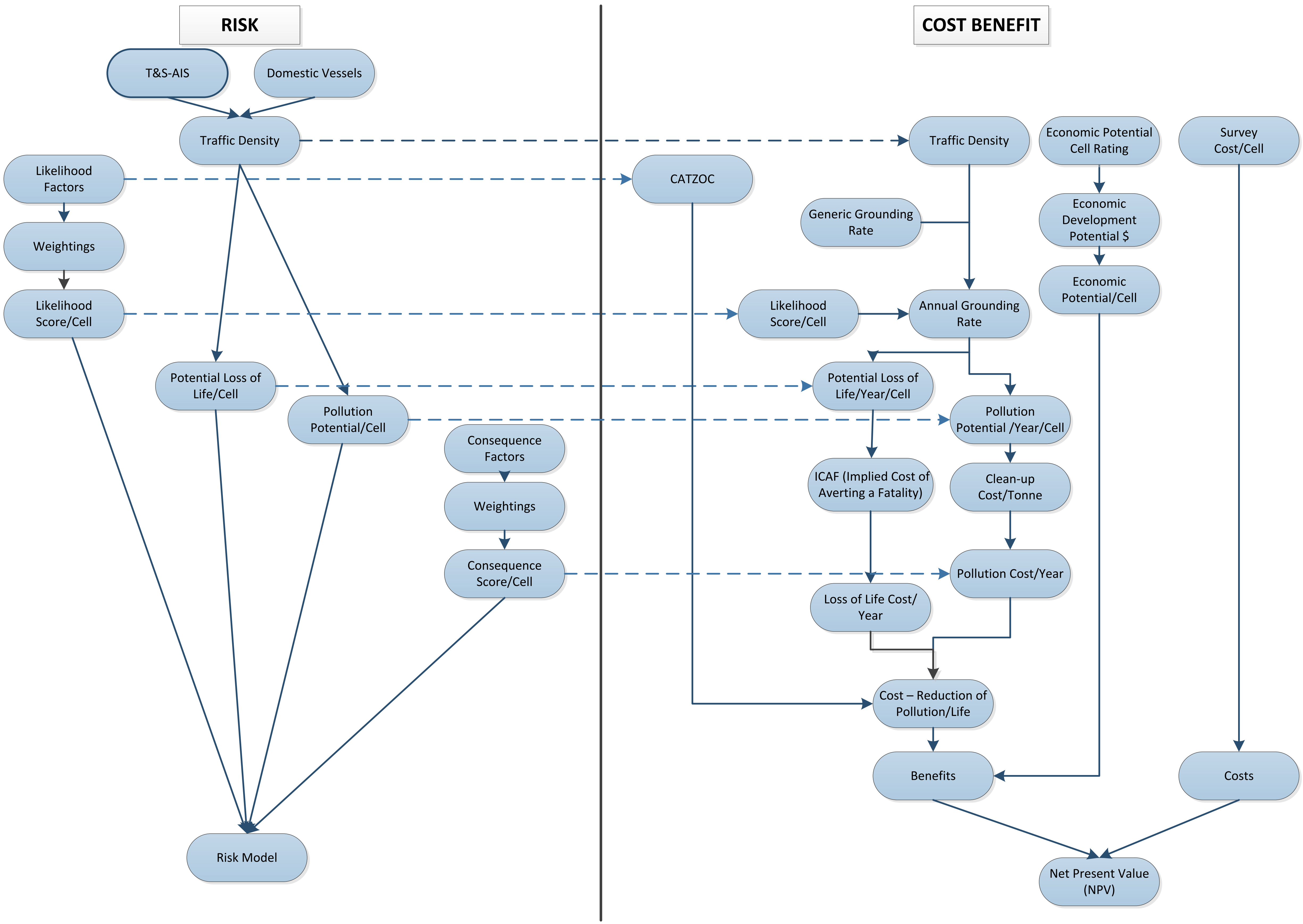
ANNEX B METHODOLOGY FLOW CHARTS

Overview Methodology

Methodology within the GIS

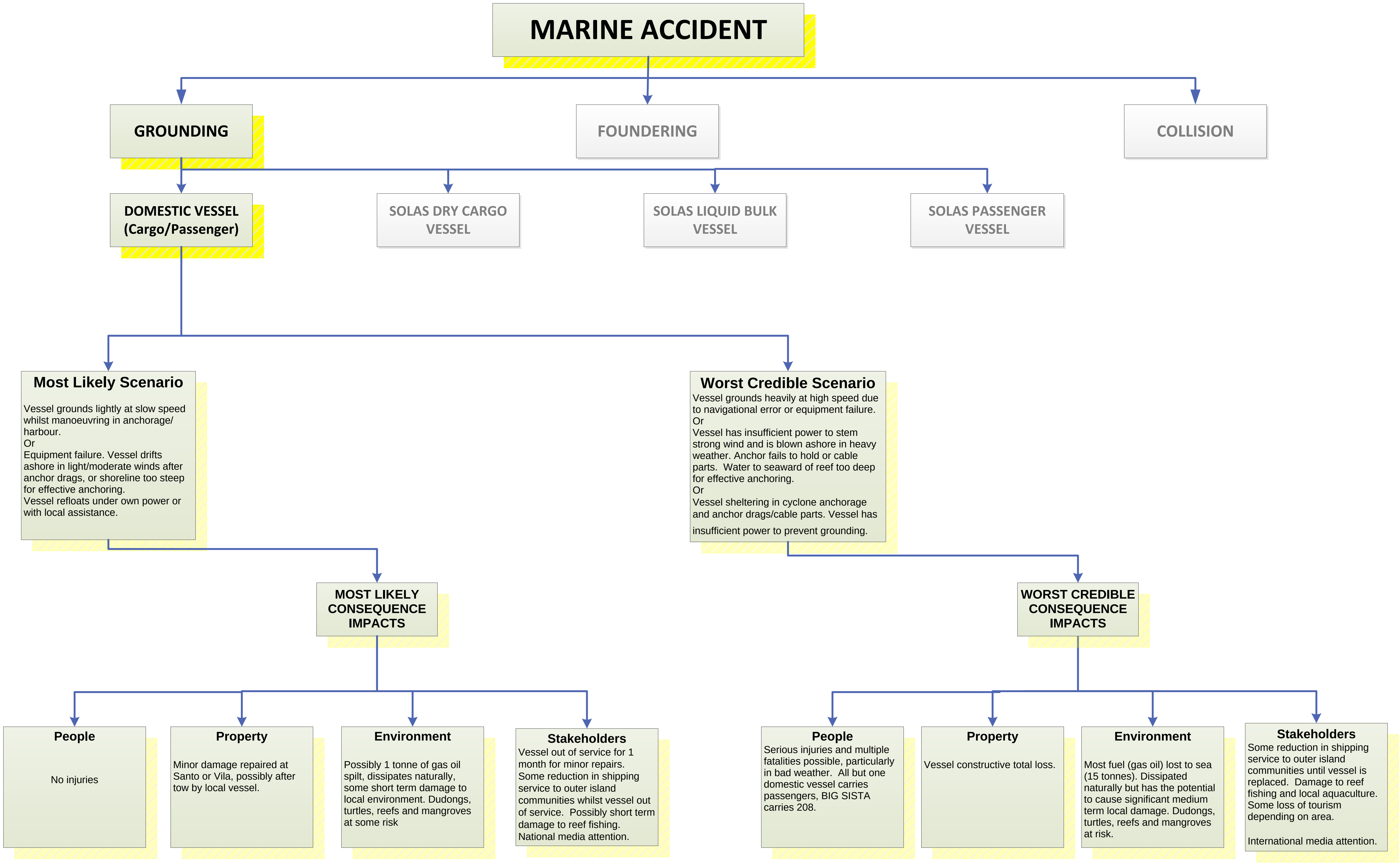
FLOW CHART OF HYDROGRAPHY RISK ASSESSMENT METHODOLOGY

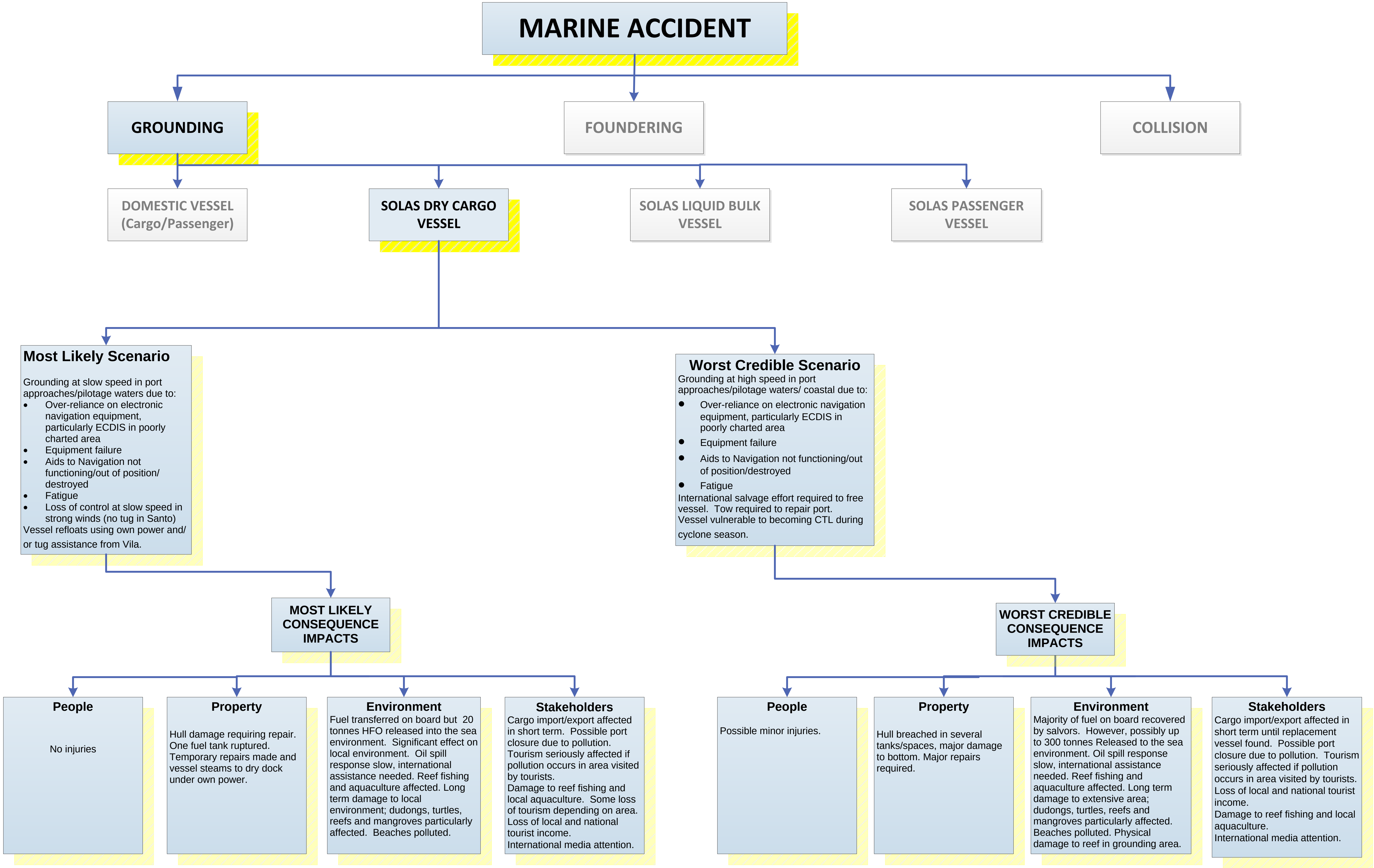


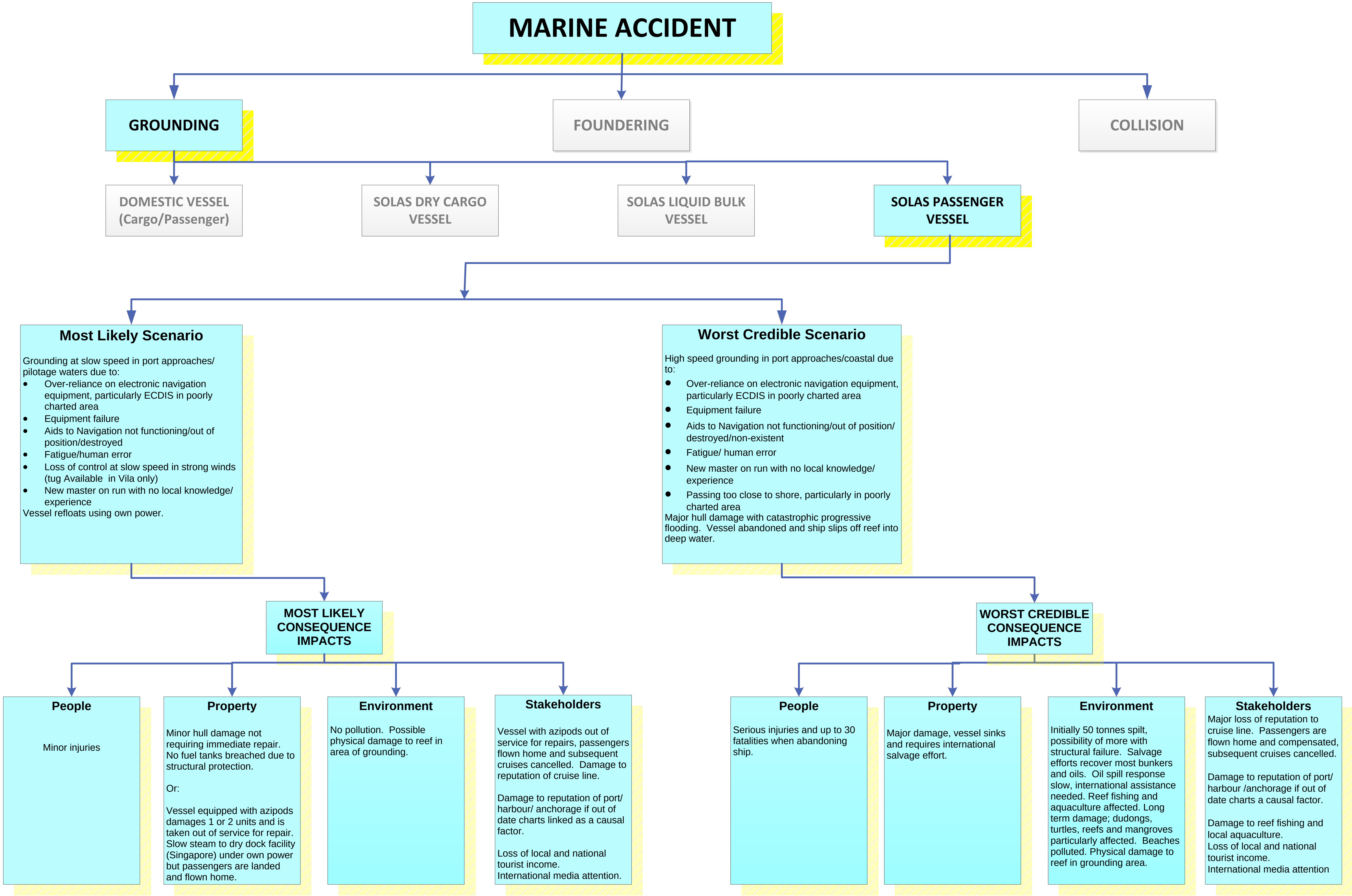

RISK
T&S-AIS
Domestic Vessels
Traffic Density
Likelihood Factors
Weightings
Likelihood Score/Cell
Potential Loss of Life/Cell
Pollution Potential/Cell
Consequence Factors
Weightings
Consequence Score/Cell
Risk Model
COST BENEFIT
Traffic Density
Economic Potential Cell Rating
Survey Cost/Cell
CATZOC
Generic Grounding Rate
Economic Development Potential $
Economic Potential/Cell
Likelihood Score/Cell
Annual Grounding Rate
Potential Loss of Life/Year/Cell
Pollution Potential /Year/Cell
ICAF (Implied Cost of Averting a Fatality)
Clean-up Cost/Tonne
Pollution Cost/Year
Loss of Life Cost/ Year
Cost – Reduction of Pollution/Life
Benefits
Costs
Net Present Value (NPV)

This page has been left intentionally blank

ANNEX C EXAMPLE EVENT TREES (GENERIC)


MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Vessel grounds lightly at slow speed whilst manoeuvring in anchorage/ harbour.
Or
Equipment failure. Vessel drifts ashore in light/moderate winds after anchor drags, or shoreline too steep for effective anchoring.
Vessel refloats under own power or with local assistance.
Worst Credible Scenario
Vessel grounds heavily at high speed due to navigational error or equipment failure.
Or
Vessel has insufficient power to stem strong wind and is blown ashore in heavy weather. Anchor fails to hold or cable parts. Water to seaward of reef too deep for effective anchoring.
Or
Vessel sheltering in cyclone anchorage and anchor drags/cable parts. Vessel has insufficient power to prevent grounding.
MOST LIKELY CONSEQUENCE IMPACTS
WORST CREDIBLE CONSEQUENCE IMPACTS
People
No injuries
Property
Minor damage repaired at Santo or Vila, possibly after tow by local vessel.
Environment
Possibly 1 tonne of gas oil spilt, dissipates naturally, some short term damage to local environment. Dudongs, turtles, reefs and mangroves at some risk
Stakeholders
Vessel out of service for 1 month for minor repairs. Some reduction in shipping service to outer island communities whilst vessel out of service. Possibly short term damage to reef fishing. National media attention.
People
Serious injuries and multiple fatalities possible, particularly in bad weather. All but one domestic vessel carries passengers, BIG SISTA carries 208.
Property
Vessel constructive total loss.
Environment
Most fuel (gas oil) lost to sea (15 tonnes). Dissipated naturally but has the potential to cause significant medium term local damage. Dudongs, turtles, reefs and mangroves at risk.
Stakeholders
Some reduction in shipping service to outer island communities until vessel is replaced. Damage to reef fishing and local aquaculture. Some loss of tourism depending on area.
International media attention.


MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Grounding at slow speed in port approaches/pilotage waters due to:
• Over-reliance on electronic navigation equipment, particularly ECDIS in poorly charted area
• Equipment failure
• Aids to Navigation not functioning/out of position/ destroyed
• Fatigue
• Loss of control at slow speed in strong winds (no tug in Santo)
Vessel refloats using own power and/ or tug assistance from Vila.
Worst Credible Scenario
Grounding at high speed in port approaches/pilotage waters/ coastal due to:
• Over-reliance on electronic navigation equipment, particularly ECDIS in poorly charted area
• Equipment failure
• Aids to Navigation not functioning/out of position/destroyed
• Fatigue
International salvage effort required to free vessel. Tow required to repair port.
Vessel vulnerable to becoming CTL during cyclone season.
MOST LIKELY CONSEQUENCE IMPACTS
People
No injuries
Property
Hull damage requiring repair. One fuel tank ruptured. Temporary repairs made and vessel steams to dry dock under own power.
Environment
Fuel transferred on board but 20 tonnes HFO released into the sea environment. Significant effect on local environment. Oil spill response slow, international assistance needed. Reef fishing and aquaculture affected. Long term damage to local environment; dudongs, turtles, reefs and mangroves particularly affected. Beaches polluted.
Stakeholders
Cargo import/export affected in short term. Possible port closure due to pollution. Tourism seriously affected if pollution occurs in area visited by tourists.
Damage to reef fishing and local aquaculture. Some loss of tourism depending on area. Loss of local and national tourist income.
International media attention.
WORST CREDIBLE CONSEQUENCE IMPACTS
People
Possible minor injuries.
Property
Hull breached in several tanks/spaces, major damage to bottom. Major repairs required.
Environment
Majority of fuel on board recovered by salvors. However, possibly up to 300 tonnes Released to the sea environment. Oil spill response slow, international assistance needed. Reef fishing and aquaculture affected. Long term damage to extensive area; dudongs, turtles, reefs and mangroves particularly affected. Beaches polluted. Physical damage to reef in grounding area.
Stakeholders
Cargo import/export affected in short term until replacement vessel found. Possible port closure due to pollution. Tourism seriously affected if pollution occurs in area visited by tourists. Loss of local and national tourist income.
Damage to reef fishing and local aquaculture.
International media attention.


MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Grounding at slow speed in port approaches/ pilotage waters due to:
• Over-reliance on electronic navigation equipment, particularly ECDIS in poorly charted area
• Equipment failure
• Aids to Navigation not functioning/out of position/destroyed
• Fatigue/human error
• Loss of control at slow speed in strong winds (tug Available in Vila only)
• New master on run with no local knowledge/ experience
Vessel refloats using own power.
Worst Credible Scenario
High speed grounding in port approaches/coastal due to:
• Over-reliance on electronic navigation equipment, particularly ECDIS in poorly charted area
• Equipment failure
• Aids to Navigation not functioning/out of position/ destroyed/non-existent
• Fatigue/ human error
• New master on run with no local knowledge/ experience
• Passing too close to shore, particularly in poorly charted area
Major hull damage with catastrophic progressive flooding. Vessel abandoned and ship slips off reef into deep water.
MOST LIKELY CONSEQUENCE IMPACTS
WORST CREDIBLE CONSEQUENCE IMPACTS
People
Minor injuries
Property
Minor hull damage not requiring immediate repair. No fuel tanks breached due to structural protection.
Or:
Vessel equipped with azipods damages 1 or 2 units and is taken out of service for repair. Slow steam to dry dock facility (Singapore) under own power but passengers are landed and flown home.
Environment
No pollution. Possible physical damage to reef in area of grounding.
Stakeholders
Vessel with azipods out of service for repairs, passengers flown home and subsequent cruises cancelled. Damage to reputation of cruise line.
Damage to reputation of port/ harbour/ anchorage if out of date charts linked as a causal factor.
Loss of local and national tourist income.
International media attention.
People
Serious injuries and up to 30 fatalities when abandoning ship.
Property
Major damage, vessel sinks and requires international salvage effort.
Environment
Initially 50 tonnes spilt, possibility of more with structural failure. Salvage efforts recover most bunkers and oils. Oil spill response slow, international assistance needed. Reef fishing and aquaculture affected. Long term damage; dudongs, turtles, reefs and mangroves particularly affected. Beaches polluted. Physical damage to reef in grounding area.
Stakeholders
Major loss of reputation to cruise line. Passengers are flown home and compensated, subsequent cruises cancelled.
Damage to reputation of port/ harbour /anchorage if out of date charts a causal factor.
Damage to reef fishing and local aquaculture.
Loss of local and national tourist income.
International media attention

ANNEX D EXAMPLE HYDROGRAPHIC RISK MATRICES

Risk Matrix Example, for use in Low Traffic Areas – SW Pacific. (Fixed Scales)

		Risk Scores						Weightings		
		0	1	2	3	4	5	Factor	Category	TotalModel
		Increasing Risk ----------------->								
Traffic	**Vessel Traffic**									
	Potential Loss of Life		Insignificant	Low	Moderate	High	Catastrophic			0.5000
	Pollution Potential		Insignificant	Low	Moderate	High	Castastrophic			0.5000
Likelihood Risk Criteria	**MetOcean Conditions**									
	Prevailing Conditions Exposure		Sheltered at most times	Mainly Sheltered	Moderate Exposure	Mainly Exposed	Exposed on most days	3	0.3	0.1500
	Spring Mean Current Speed	Open Sea (insignificant)	1-2 knots	2-3 knots	3-4 knots	>5 knots	>5 knots	2		0.1000
	Visibility	Unknown	Poor Visibility Very Unlikely	Poor Visibility Unlikely	Occasional Poor Visibility	Often Poor Visibility	Poor Visibility Common	1		0.0500
	Navigational Complexity									
	Type of Navigation Required		Open Sea >10nm	Offshore Navigation (5-10nm)	Coastal Navigation (1-5nm)	Port Approaches	Constrained Navigation (Within 1nm)	3	0.15	0.1500
	Aids to Navigation									
	ChartZoc		A	B	C	D	U	3	0.3	0.1800
	Proximity to Non Working AToNs	No Lights	100% effective range	80% effective range	70% effective range	60% effective range	Within 50% effective range	2		0.1200
	Bathymetry									
	Depth of Water 15m Contour	>10nm	5-10nm	2.5-5nm	1.5 to 2.5nm	1 to 1.5nm	Within 1nm	3	0.1	0.0600
	Bottom Type		Soft				Hard/Rocky	2		0.0400
	Navigational Hazards									
	Proximity to Known Reefs	>10nm	5-10nm	2.5-5nm	1.5 to 2.5nm	1 to 1.5nm	Within 1nm	2	0.15	0.0333
	Proximity to Volcano	>10nm	5-10nm	2.5-5nm	1.5 to 2.5nm	1 to 1.5nm	Within 1nm	2		0.0333
	Proximity to Known SeaMounts	>10nm	5-10nm	2.5-5nm	1.5 to 2.5nm	1 to 1.5nm	Within 1nm	1		0.0167
	Proximity to WW2 Military Sites	>2.5nm	2-2.5nm	1.5-2nm	1-1.5nm	500m-1nm	Within 500m	1		0.0167
	Proximity to Charted Tidal Hazard (Overfalls/Race)	>2.5nm	2-2.5nm	1.5-2nm	1-1.5nm	500m-1nm	Within 500m	3		0.0500
Consequence Risk Criteria	**Environmental Impact**									
	Proximity to Large Reef (High Quality / or Isolated Shoreline	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	3	0.5	0.0789
	Proximity to Key Offshore Reef	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	2		0.0526
	Proximity to Large Wetlands Resource (Mangroves) (Large Volume or Small Volume)	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	3		0.0789
	Proximity Small Wetlands Resource (Mangroves) (Large Volume or Small Volume)	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	2		0.0526
	Proximity to Important Breeding Grounds	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	3		0.0789
	Proximity to World Biological Protected Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	3		0.0789
	Proximity to Regional Biological Protected Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	2		0.0526
	Proximity to Local Biological Protected/Important Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	1		0.0263
	Culturally Sensitive Areas									
	Proximity to World Cultural Protected/Important Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	3	0.15	0.0750
	Proximity to Regional Cultural Protected/Important Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	2		0.0500
	Proximity to Local Cultural Protected/Important Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	1		0.0250
	Economically Sensitive Areas									
	Proximity to Sites of High Economic Contribution	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	3	0.35	0.1000
	Proximity to Sites of Moderate Economic Contribution	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	1		0.0333
	Proximity to Key Infrastructure (Ports)	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	3		0.1000
	Proximity to Tourist Diving Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	1.5		0.0500
	Cruise Ship Stops	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm	2		0.0667

Risk Matrix Example, for use in High Traffic Areas with Developed Ports –NZ. (Continuous Scales)

			0	1	2	3	4	5	Rating	Category Weighting	Model Weighting	Overall Weighting
Traffic				*CONTINUOUS SCALES*								
		Potential Loss of Life		Insignificant	Low	Moderate	High	Catastrophic		42.0%		25%
		Potential Oil Outflow		Insignificant	Low	Moderate	High	Catastrophic		38.0%		
		Vessel Damage + Salvage Costs		Insignificant	Low	Moderate	High	Catastrophic		5.0%		
		Economic Costs		Insignificant	Low	Moderate	High	Catastrophic		15.0%		
		LIKELIHOOD SCALES										
Causation Risk Criteria	Charting	Chart Quality		A	B	C	D	U	3	30.0%	15.00%	25%
		Survey Age		<5 years	5-10 years	10-20 years	20-30 years	>30 years	1		5.00%	
		Chart Adequacy		Excellent	Good	Moderate	Poor	Unacceptable	2		10.00%	
	Route Characteristics	Navigational Complexity		Open Sea >10nm	Offshore Navigation (5-10nm)	Coastal Navigation (1-5nm)	Port Approaches	Constrained Navigation (<1nm)	3	17.5%	8.75%	
		Depth of Water 15m Contour	>10nm	5-10nm	2.5-5nm	1.5-2.5nm	1-1.5nm	Within 1nm	2		5.83%	
		Traffic Density		Insignificant	Low	Moderate	High	Catastrophic	1		2.92%	
	MetOcean	Prevailing Wave/Wind		Sheltered at Most Times	Mainly Sheltered	Moderate Exposure	Mainly Exposed	Exposed on Most Days	3	17.5%	5.83%	
		Tides/Current	Open Sea	1-2kts	2-3kts	3-4kts	4-5kts	>5kts	3		5.83%	
		Longwave/Surge		Very Unlikely	Unlikely	Occasional	Often Poor	Frequent	2		3.89%	
		Poor Visibility		Very Unlikely	Unlikely	Occasional	Often Poor	Frequent	1		1.94%	
	Navigational Hazards	Sea Mounts	>10nm	5-10nm	2.5-5nm	1.5-2.5nm	1-1.5nm	Within 1nm	1	17.5%	2.19%	
		Isolated Dangers - Rocks/Wrecks/etc.	>2.5nm	2.5-2nm	1.5-2	1-1.5nm	500m-1nm	<500m	2		4.38%	
		Charted Tidal Hazards	>2.5nm	2.5-2nm	1.5-2	1-1.5nm	500m-1nm	<500m	2		4.38%	
		Breaking Reefs	>10nm	5-10nm	2.5-5nm	1.5-2.5nm	1-1.5nm	Within 1nm	3		6.56%	
	Mitigation	Harbour Risk Mitigation Resources		Available				Absent	2	10.0%	4.00%	
		Pilotage		Pilotage				No Pilotage	3		6.00%	
	Bathymetry	Dynamic Seabed - Estuarial		Insignificant	Low	Moderate	High	Significant	3	7.5%	4.50%	
		Seismic/Volcanic Factors	>10nm	5-10nm	2.5-5nm	1.5-2.5nm	1-1.5nm	Within 1nm	2		3.00%	
		CONSEQUENCE SCALES										
Consequence Risk Criteria	Loss of Life	Response Complexity		100%	125%	150%	175%	200%	N/A	N/A		50%
	Property	Salvage Complexity		100%	125%	150%	175%	200%	N/A	N/A		
	Environmental Impact	Formal Reserves - World Heritage	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	3	N/A	17.65%	
		Marine Reserves	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	2.5		14.71%	
		Coastal Reserves	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	2		11.76%	
		Wetland Resources	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	1.5		8.82%	
		Aquaculture/Fishing Grounds/Shellfish Harvest Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	2		11.76%	
		Tourism	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	2		11.76%	
		Cultural (Iwi)/Treaty History Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	2		11.76%	
		Recreational/Social Amenity	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	2		11.76%	
	Economic Impact	Port Access Channels	>2.5nm	2.5-2nm	1.5-2nm	1 to 1.5nm	500m to 1nm	<500m	3	N/A	25.00%	
		Critical Infrastructure (Berths) - Economic Contribution	Absent	Very Low	Low	Moderate	High	Critical	1		8.33%	
		Proximity to Sites of High Economic Contribution	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	2		16.67%	
		Proximity to Sites of Moderate Economic Contribution	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	1		8.33%	
		Cruise Ship Stops	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	<1nm	2		16.67%	
		Pipelines/Cables	>10nm	5-10nm	2.5-5nm	1.5-2.5nm	1-1.5nm	Within 1nm	3		25.00%	

This page has been left intentionally blank

ANNEX E IHO CAPACITY BUILDING STRATEGY

Phases of Development

PHASES OF DEVELOPMENT OF HYDROGRAPHIC SURVEYING AND NAUTICAL CHARTING CAPABILITY

Phases of Development	National Activity
PHASE 1 Collection and circulation of nautical information, necessary to maintain existing charts and publications	▪ Form National Authority (NA) and/or National Hydrographic Coordinating Committee (NHCC). ▪ Create/improve current infrastructure to collect and circulate information. ▪ Strengthen links with charting authority to enable updating of charts and publications. ▪ Minimal training needed. ▪ Strengthen links with NAVAREA Coordinator to enable the promulgation of safety information
PHASE 2 Creation of a surveying capability to conduct: Coastal projects Offshore projects	▪ Establish capacity to enable surveys of ports and their approaches. ▪ Maintain adequate aids to navigation. ▪ Build capacity to enable surveys in support of coastal and offshore areas. ▪ Build capacity to set up hydrographic databases to support NA/NHCC. ▪ Provide basic geospatial data via MSDI. ▪ Requires funding for training, advising and equipment or contract survey.
PHASE 3 Produce paper charts, ENC and publications independently.	▪ The need shall be thoroughly assessed. Requires investment for production, distribution and updating ▪ Alternatively, bi-lateral agreements for charting can provide easier solutions in production and distribution (of ENC through RENCs) and rewards. ▪ Further development of MSDI.