LAND INFORMATION NEW ZEALAND

RISK METHODOLOGY:

SOUTH WEST PACIFIC REGIONAL HYDROGRAPHY PROGRAMME

TONGA, KIRIBATI, COOK ISLANDS, SAMOA, FIJI, VANUATU, SOLOMON ISLANDS, TOKELAU, NIUE, TUVALU

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South West Pacific Regional Hydrography Programme

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EXECUTIVE SUMMARY

The South West Pacific area is, in general, in need of hydrographic surveys to modern standards, to update the charts that vessels require to navigate safely. This need is considered a priority, with MFAT and LINZ working together with international agencies to deliver a strategy. However, the hydrographic programme delivery is, by necessity, in the longer term and a systematic process founded on risk is needed to prioritise the survey rollout.

The design of a risk-based assessment for prioritisation of hydrographic work is unusual insomuch that it needs to assist in comparative selection of areas for hydrographic survey, between varieties of coastal areas, each with differing bathymetry and trading/growth characteristics. *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, but information about the potential for *economic growth* 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 and sizes*; *economic growth*) that, when combined, provide the evidence required to promote one area over another for hydro-survey prioritisation.

A location with outstanding *environmental status* provides a fourth factor in prioritisation; an incident in any area sensitive to environmental damage provides increased consequence impact. An environmental damage in an area with 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.

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 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 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.

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, 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 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

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 of undetermined datum and survey data in fathoms have been converted to metric, without further new survey work being done. 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.

The charts of other island groups[1] also often rely on old surveys and some are based on old datum and soundings recorded in fathoms. Where charts, including New Zealand charts, are based on the WGS 84 datum and display soundings in metres, this can often be the result of applying a datum shift and conversion of sounding units using existing data from old surveys. 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[2]. However, oceanic charts throughout the Pacific rely, for the main part, on sporadic surveys and 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 sounding information and positional information is below 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.

Despite this, there remains a reasonable concern that inadequate and inaccurate nautical charting could adversely affect safety of life at sea and

[1] Other competent charting authorities with responsibilities in the South West Pacific include France, United States of America, Australia and the United Kingdom.
[2] There is an M_QUAL attribute, called CATZOC (Zone of Confidence), which is an assessment of underlying data quality available. It is not universally applied.

the protection of the marine environment. It may also inhibit maritime trade, thereby adversely affecting the economy of some of the island groups. There also remains concern with the various island administrations party to the SOLAS conventions over the underlying problem of liability associated with not providing fit for purpose charts.

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 decision makers.

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 frequency 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.

Consequences 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?"

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 RISK ANALYSIS METHODS IN COMMON USAGE

The following is a brief assessment of the various risk assessment tools in common usage.

3.1 PRIMARY RISK ANALYSIS METHODS

3.1.1 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.

3.1.2 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.

3.1.3 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 1**, below.

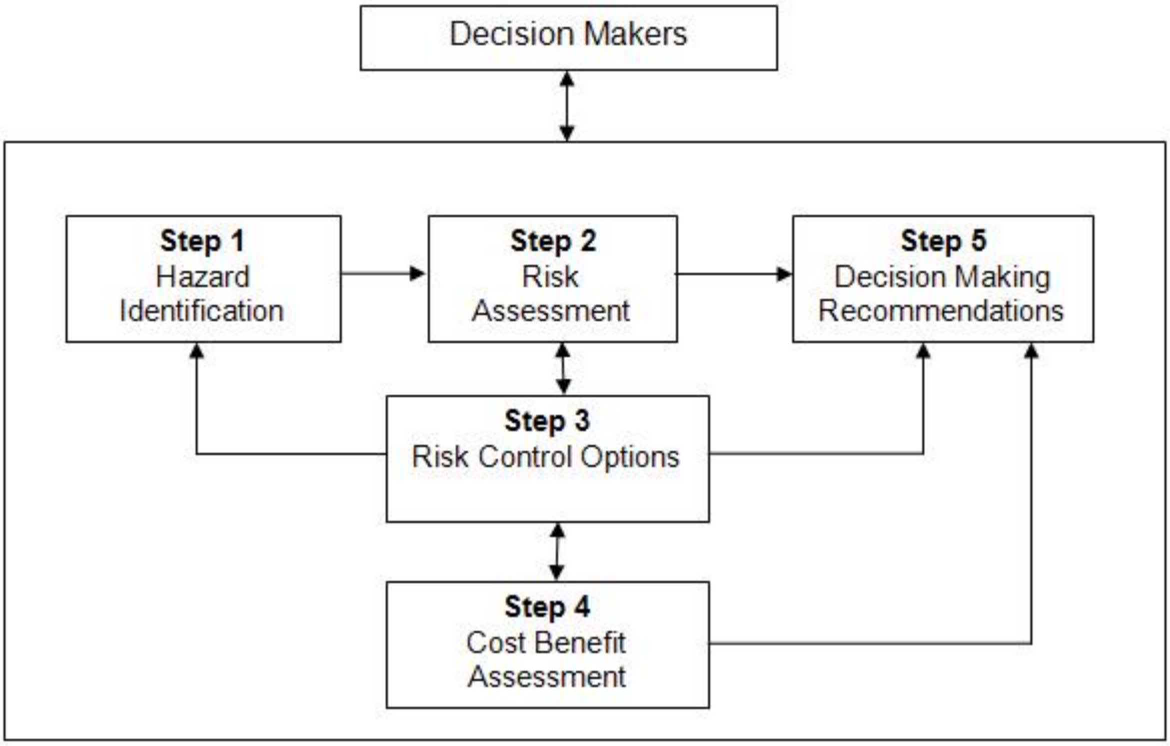


Figure 1: The IMO FSA Five Step Process

3.1.4 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).

3.1.5 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.

3.1.6 Structured 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.

3.1.7 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.

3.1.8 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.

3.2 RISK ANALYSIS TECHNIQUES - SUPPORTING METHODOLOGIES

3.2.1 Tree Analysis

3.2.1.1 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.

3.2.1.2 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.

3.2.1.3 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.

3.2.2 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.

3.2.3 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.

3.2.4 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.

3.2.5 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.

3.2.6 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.

4 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:

4.1 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.

4.1.1 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.

4.2 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 attempts to provide a quantitative assessment. 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

4.2.1 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[3]. 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) will interpret the lack of data inappropriately.

[3] There are some examples, e.g. ROCKNESS, involving a grounding and loss of life, where a hydrographic office has been involved in the subsequent enquiry. However a risk assessment based on such rare data cannot draw conclusions about one area over another.

5 CONCLUSIONS ON 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 (in modern terms) charting, and to extra caution being displayed by mariners knowingly using unreliable charts.

It can be argued the increasingly widespread use of electronic chart and information display 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.

6 PROPOSED METHODOLOGY BASED ON THE IMO FSA PROCESS

6.1 INTRODUCTION

This section describes a high-level overview of how the five step FSA concept can be appropriately modified for applicability to the South West Pacific Hydrographic Project requirements.

6.2 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 4 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, **Figure 2.**

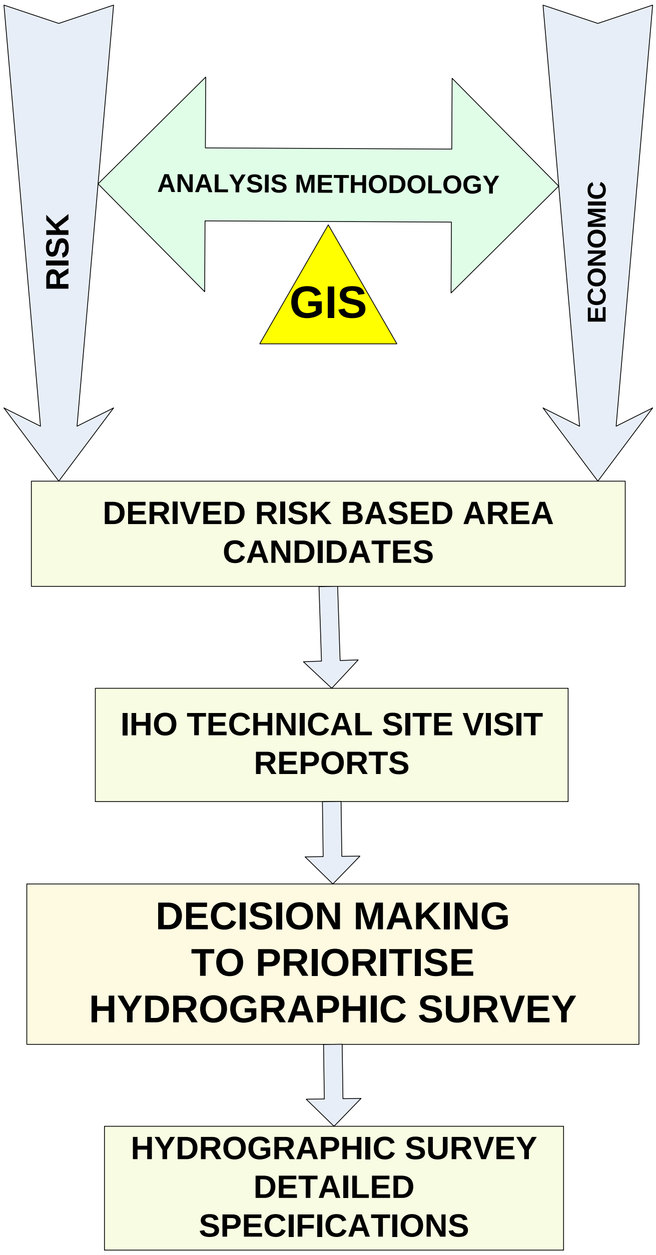


Figure 2: The Hydrographic Decision Making Process

Figure 2 identifies that the present IHO technical reports need only start after the case to proceed is made on both risk grounds and economic grounds. The 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 assessments are of high quality, undertaken by competent hydrographic expertise, and therefore have significant cost attached to them. The 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 reports are considered as two separate parts, they provide advice to a jurisdiction about the obligation to provide hydrographic services and separately they provide the overview scope for hydrographic survey and charting, then the latter part of the reports can be very usefully integrated into the proposed methodology.

The new methodology concept suggests that the scoping part of these IHO technical reports should instead be an output[4]. As an output the scoping 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 analysis methodology.

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

6.3 THE HYDROGRAPHIC CASE ANALYSIS METHODOLOGY

The proposed methodology is presented over the page (**Figure 3)**, and in **Annex A**. The methodology recognises the importance of economic data as well as stakeholder analysis and consultation in the process. It also recognises the complexity of .....what?

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 B** (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

[4] The IHO advice to States about the obligation for, and the delivery of hydrographic services would remain as the key thrust of these reports.

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 7 and 8.**

The risk matrices need frequency information, which can be derived from analysis of factual AIS ship transponder records received by satellites (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 using the waters, as well as vessel size. This information can also be derived from satellite recorded AIS data and site visits.

FLOW CHART OF REVISED LINZ FORMAL HYDROGRAPHIC METHODOLOGY

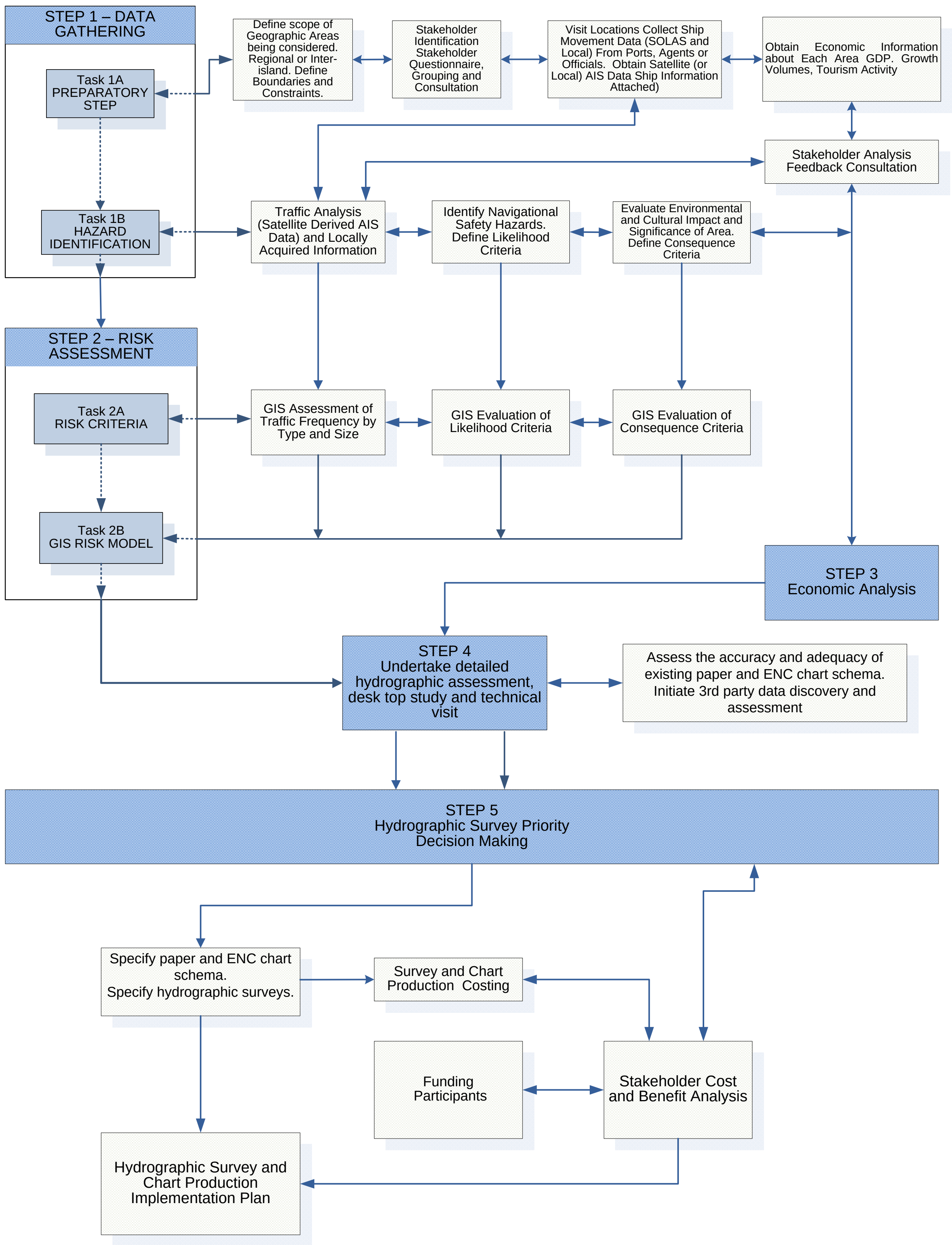


Figure 3: Overview of Proposed Methodology

6.4 METHODOLOGY STEPS

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.

Geographical Information System (GIS) is used to both display the traffic analysis results and, using information layers, to visually display the results of the risk assessment by the use of colour. The GIS methodology is described in detail in **Section 8**.

6.5 STEP 1 – DATA GATHERING

6.5.1 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 9**)
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 South West Pacific 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 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.

6.5.2 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 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 B** 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 7**) from the frequency and consequence criteria defined above.

6.6 STEP 2 - RISK ASSESSMENT

6.6.1 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 7**) frequencies and consequences using frequency information derived from traffic analysis and any incident information available. Use the event tree branches (see **Annex B**) to relate consequence scenarios geographically. Develop consequences 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.
3. 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.

6.6.2 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. Link the developed risk matrix criteria to complete the GIS risk model.
4. Evaluate and test the risk model using multiple iterations. (See **Section 8**).

6.7 STEP 3 – 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.

6.8 STEP 4 – UNDERTAKE DETAILED HYDROGRAPHIC TECHNICAL VISIT

This step is partly one of decision making and is the traditional technical assessment undertaken by a qualified hydrographer. Step 4 is informed by the GIS risk assessment results.

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

6.9 STEP 5 – HYDROGRAPHIC SURVEY PRIORITY DECISION MAKING

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 dependant on funding available and 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.

7 DEVELOPMENT OF A RISK MATRIX

7.1 INTRODUCTION

This section provides an explanation of the risk matrix and how it can be used as an effective tool for risk assessment, especially where information is sparse. Given the large number of criteria that need to be assessed in terms of risk impact, a risk matrix that sets criteria to be measured in a GIS overlay is a recommended approach.

Risk is a combination of frequency and consequence. Since the risk is “grounding due to an out of date chart” it is to be expected that statistical incident data to inform frequency will either be non-existent or too sparse to be robust.

Therefore it will be necessary to derive frequency from the AIS transponder and coastal traffic analysis referenced in **Section 6**, as the likelihood of an accident occurring is, in part, proportional to traffic density. Where there is no traffic there is no risk and the greater the traffic density the greater the likelihood of an accident occurring.

Similarly, there is no risk if there are no consequences to an accident.

Where robust incident data is not available the assessment becomes consequence driven and the assessment outcome will reflect traffic density and the level of consequences of an unwanted event occurring (grounding and associated pollution).

Consequence can be derived using an event tree analysis as shown at **Annex B**. The analysis describes possible consequences affecting life, property, environment and stakeholders. The event tree outcomes are readily developed into consequences following site visits and stakeholder meetings.

A generic approach to a risk matrix is shown below.

7.2 RISK MATRIX DEVELOPMENT

A risk matrix should be developed during Step 1 and refined in Step 2. This ensures that the matrix is relevant to the scope of the assessment and the quality and depth of information available. The size of the matrix needed is related to the needs of the assessment and the larger the matrix, the more refined the risk assessment would be.

Figure 1 provides an example of a commonly used size; a five by five matrix. Frequency ratings are shown on the Y axis with F1 being low frequency and

F5 high frequency. Consequence is shown on the X axis with C1 being low consequence and C5 high consequence.

Frequency and consequence each increase on a logarithmetic[10] scale. Frequency and consequence scales are descriptive, as well as quantitative. Judgments can be made on the descriptive scale where lack of data precludes the use of the quantitative scale.

Risk, being the combination of frequency and consequence, is shown in the body of the table. It varies relatively between 0, insignificant and 10, catastrophic. Risk should be assessed for impact on life, property (infrastructure), environment and stakeholders.

Frequency						
	F 5	5	6	7	8	10
	F 4	4	5	6	7	9
	F 3	3	3	4	6	8
	F 2	1	2	2	3	6
	F 1	0	0	0	1	2
Consequence		C 1	C 2	C 3	C 4	C 5

Figure 4: Risk Matrix

Where:-

Risk	
0 & 1	Insignificant
2 & 3	Low
4, 5, 6	Moderate
7, 8, 9	High
10	Catastrophic

Table 1

7.3 FREQUENCY AND CONSEQUENCE CRITERIA FOR GIS ANALYSIS

A derived risk matrix suitable for linking into GIS analysis is illustrated in **Figure 5**.

Frequency, or likelihood criteria is based on traffic density and factors which increase the risk of an accident occurring.

Traffic density, derived from S-AIS and locally acquired information is weighted for individual vessels potential for loss of life and pollution, which in turn is related to the vessel type and size.

Factors which increase the likelihood of an event occurring are:

- 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.

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 critically 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 tourist diving sites.
  - Cruise ship places of call.

	Risk Criteria	0	1	2	3	4	5
		Risk Scores					
		Increasing Risk -------------->					
Traffic	**Vessel Traffic**						
	Potential Loss of Life (Vessel Type + GT Weighed)		Insignificant	Low	Moderate	High	Catastrophic
	Pollution Potential (Vessel Type + GT Weighted)		Insignificant	Low	Moderate	High	Catastrophic
Likelihood Risk Criteria	MetOcean Conditions						
	Prevailing Conditions Exposure		Sheltered at most times	Mainly Sheltered	Moderate Exposure	Mainly Exposed	Exposed on most days
	Spring Mean Current Speed	Open Sea (Current insignificant)	1-2 knots	2-3 knots	3-4 knots	>5 knots	>5 knots
	Visibility	Unknown	Poor Visibility Very Unlikely	Poor Visibility Unlikely	Occasional Poor Visibility	Often Poor Visibility	Poor Visibility Common
	Navigational Complexity						
	Type of Navigation Required		Open Sea >10nm	Offshore Navigation (5-10nm)	Coastal Navigation (1-5nm)	Port Approaches	Constrained Navigation (Within 1nm)
	Aids to Navigation						
	ChartZoc		A	B	C	D	U (=D-)
	Proximity to Non Working AToNs (Nav Lights)	No Lights	100% effective range	80% effective range	70% effective range	60% effective range	Within 50% effective range
	Bathymetry						
	Depth of Water 15m Contour	>10nm	5-10nm	2.5-5nm	1.5 to 2.5nm	1 to 1.5nm	Within 1nm
	Bottom Type		Soft				Hard/Rocky
	Navigational Hazards						
	Proximity to Known Reefs	>10nm	5-10nm	2.5-5nm	1.5 to 2.5nm	1 to 1.5nm	Within 1nm
	Proximity to Sub-Sea Volcanic Activity	>10nm	5-10nm	2.5-5nm	1.5 to 2.5nm	1 to 1.5nm	Within 1nm
	Proximity to Known SeaMounts	>10nm	5-10nm	2.5-5nm	1.5 to 2.5nm	1 to 1.5nm	Within 1nm
	Proximity to WW2 Military Sites	>2.5nm	2-2.5nm	1.5-2nm	1-1.5nm	500m-1nm	Within 500m
	Proximity to Charted Tidal Hazard (Overfalls/Race)	>2.5nm	2-2.5nm	1.5-2nm	1-1.5nm	500m-1nm	Within 500m
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
	Proximity to Key Offshore Reef (Cooks Reef or Rowa Island)	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity to Large Wetlands Resource (Mangroves) (Large Volume or Small Volume)	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity Small Wetlands Resource (Mangroves) (Large Volume or Small Volume)	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity to Important Breeding Grounds	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity to World Biological Protected Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity to Regional Biological Protected Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity to Local Biological Protected/Important Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Culturally Sensitive Areas						
	Proximity to World Cultural Protected/Important Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity to Regional Cultural Protected/Important Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity to Local Cultural Protected/Important Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Economically Sensitive Areas						
	Proximity to Sites of High Economic Contribution	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity to Sites of Moderate Economic Contribution	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity to Key Infrastructure (Ports)	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Proximity to Tourist Diving Sites	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm
	Cruise Ship Stops	>20nm	10-20nm	5-10nm	2.5-5nm	1-2.5nm	Within 1nm

Figure 5: Derived Risk Matrix Showing Example Criteria

7.4 RISK QUANTIFICATION – GIS AND MATRIX BASED

Risk scores become more complicated, but more useful, when "most-likely" and "worst-credible" scenarios for each of the consequence categories are developed. This approach provides more risk data scores per hazard, which allows an average to be used. In effect, the assessment scores the risk associated with two different outcomes from the same initiating event, one most-likely and one worst-credible. The concept is there are always most-likely events (with minor impacts) occurring at a relatively high frequency and much worse events, occurring at a lower frequency.

This is a particularly useful concept for shipping risk, where only a small change in factors causing a casualty can mean the difference between a modest insurance claim and a catastrophe. The use of the "most-likely" and "worst-credible" approach also provides a transparent risk assessment in the eyes of practical stakeholders, and these abound around maritime activities. The "most-likely" event references outcomes that those with professional experience can relate to.

The concept of the "worst-credible" event is a consequence of outcome that is a realistic worst accident outcome. This is differentiated from the worst case, which is often used by risk assessors with generic backgrounds, with disbelief from those with professional attachment to the subject being assessed.

7.4.1 Risk Quantification by GIS

If the frequency component of risk is derived by ship data attached to vessel tracks, risk can be quantified statistically in relation to the net Gross Tons on a route, or to the passenger volume on a route, or even the volume of bunkers transiting a route per annum, based on a vessel's fuel capacity. Each of those criteria are a choice of the risk matrix criteria design.

Either GIS software or a spread sheet (e.g. MS Excel) can be used for this function. However a GIS can provide a much more comprehensive analysis as it can geographically relate vessel traffic volume in any location to the consequence impact criteria, which is itself geographically relevant.

Hydrographic risk will thus not accrue in areas where there is no traffic, but is incrementally influenced in accordance with the risk criteria where there is both traffic and either a sensitive site, or an area where economic activity can be similarly damaged. The risk is displayed in a GIS by a contour map with a change of colour as the risk increment rises.

8 OUTLINE OF GIS METHODOLOGY

8.1 INTRODUCTION

This section explains a standardised, quantitative methodology for linking the need for updated charting to the consequences of a major maritime incident. The assessment of maritime risk requires the synthesis of both likelihood and consequence spatial datasets and so the main platform for analysis will be a geographical information system (GIS).

The approach will be used to identify regions where better return on investment can be achieved in the prioritisation of a hydrographic survey programme.

8.1.1 Spatial Data Analysis in a GIS

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 to manage such spatial datasets are known as Geographic Information Systems (GIS). GIS can be defined as an array of technological tools for the management, analysis and display of spatial data which, when linked to simple risk quantification, can provide evidence-based information to support better decision-making.

The presentation of spatial baseline data in map or graphic form, using GIS, has the potential to facilitate more effective communication by complimenting written descriptions, and enhancing the understanding of the distribution, patterns, and linkages between environmentally sensitive areas and marine traffic profile within an area.

8.1.2 Examples of Environmental Modelling in a GIS

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 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 the EU Interreg project EfficienSea[5] in the Baltic Region.

8.1.2.1 Marine Environment High Risk Areas (MEHRAs)

Marine Environment High Risk Areas (MEHRA's)[6] were initiated in the UK by the Donaldson Report (1994)[7] 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."

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. Marico Marine was commissioned to collect vessel track data 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 7**)[8].

[5] EfficienSea (2012). Dynamic Sensitivity Mapping. Available at: http://efficiensea.org/files/mainoutputs/wp5/dynamic_sensitivity_mapping.pdf.
[6] Safetec (1997). MEHRA's Report.
[7] HMSO (1994). Report of Lord Donaldson's inquiry into the Prevention of Pollution from merchant Shipping,
[8] MCA (2007). MGN 278(M+F) Marine Environmental High Risk Areas, MCA.

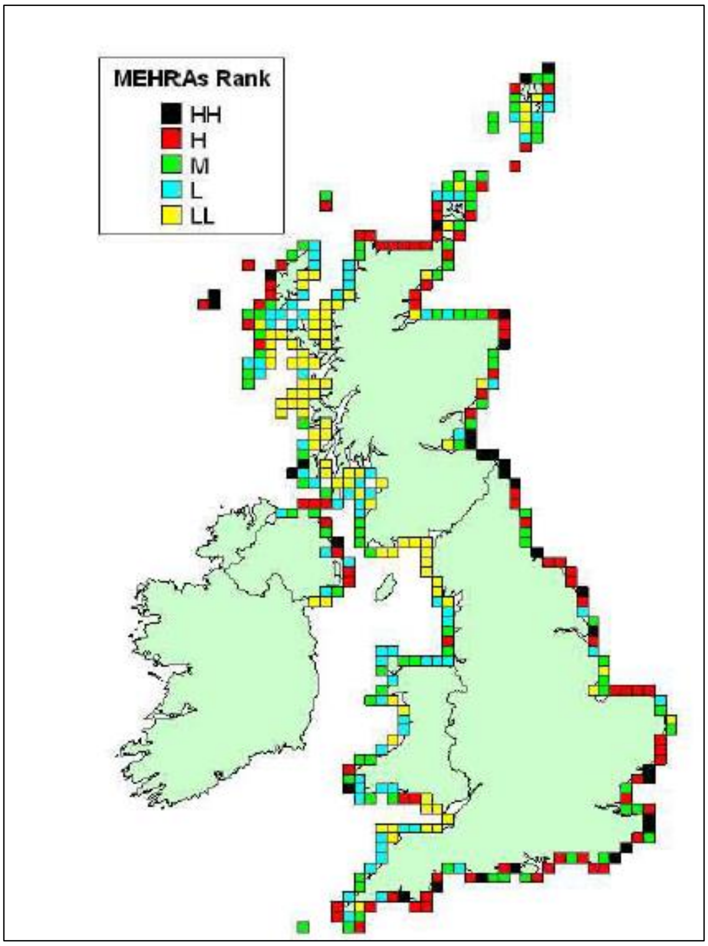


Figure 6: Results of MEHRA's Study (HH is highest risk, LL is lowest).

8.1.2.2 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[9]. 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.

[9] NOAA (1997). Environmental Sensitivity Index Guidelines, Vs.2.Available at: http://www.bb.undp.org/uploads/file/pdfs/crisis/ARU%20workshop%202011/NOAA%20ESI%20Guidelines.pdf

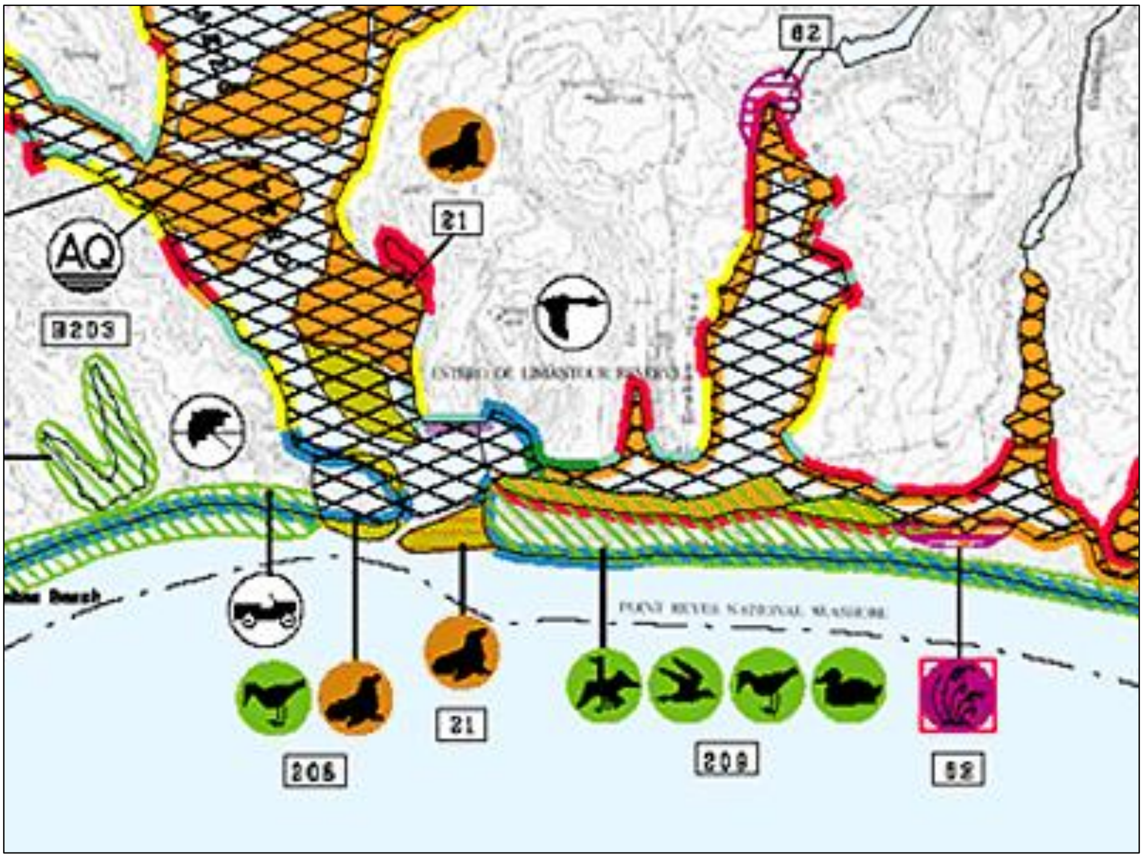


Figure 7: Extract of Point Reyes National Seashore ESI, United States[10].

8.1.2.3 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.

[10] NOAA. Available at: http://celebrating200years.noaa.gov/transformations/eco_forecast/image5.html {Accessed 21st August 2012}

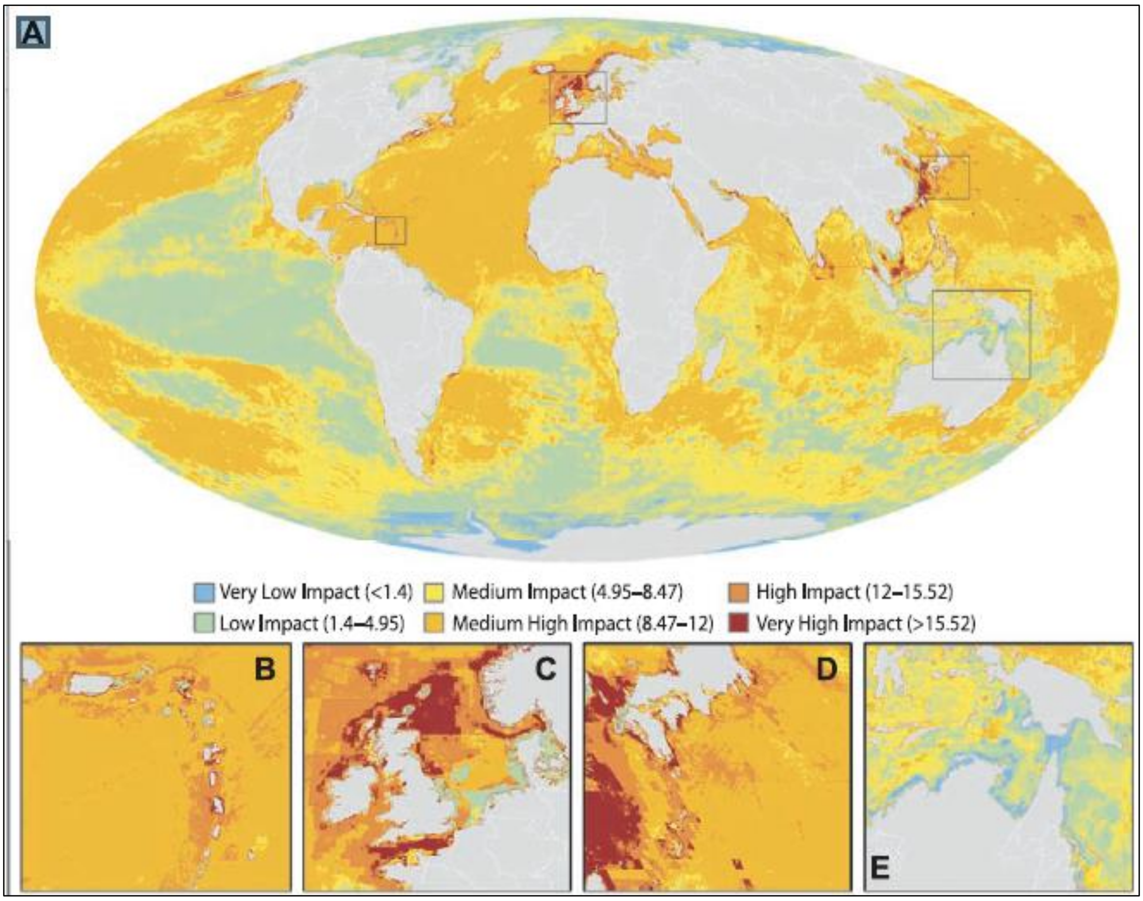


Figure 8: Study Impact Map

There is thus a body of evidential background to use this approach in support of a hydrographic risk methodology using the capability of GIS to collate and display both information and calculated risk.

8.2 METHODOLOGY

The approach utilised in this study is of Risk Terrain Modelling by Weighted Overlay Analysis.

8.2.1 Weighted Overlay

Risk Terrain Modelling (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[11]. 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.

Weighted Overlay Analysis refers to the scientific methodology by which Risk Terrain Modelling is achieved. The analysis technique is used for applying a common set of values to a number of diverse inputs to create an integrated analysis. Each input is weighted to signify the intensity of a risk factor and its relative contribution to the model as a whole. The method has been used extensively in problems involving site selection.

[11] Caplan, J.M. and Kennedy, L.W.(2010). Risk Terrain Modelling Manual: Theoretical FramEwork and Technical Steps of Spatial Risk Assessment. Rutgers Center on Public Security.

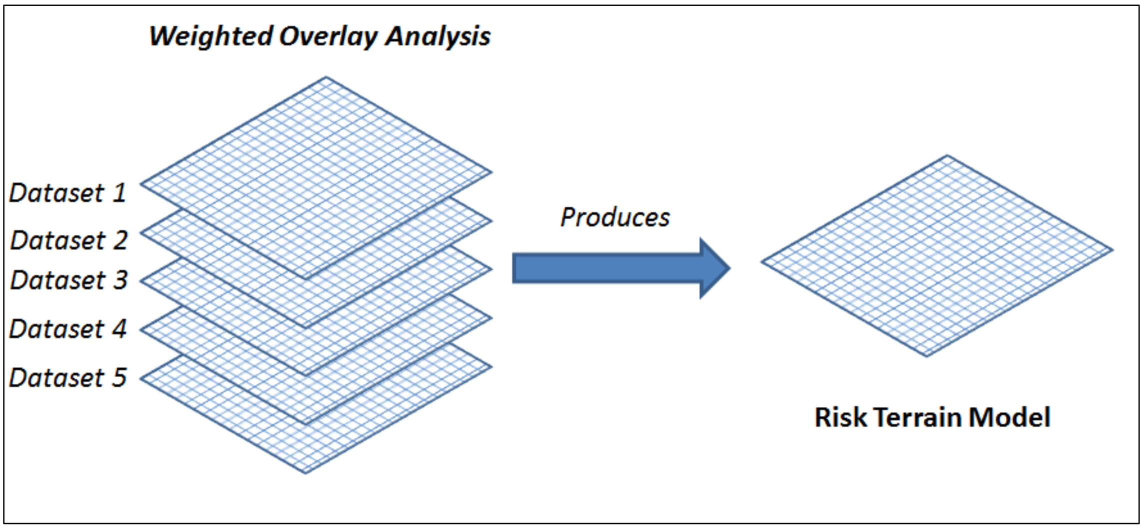


Figure 9: Relationship between Weighted Overlay and a Risk Terrain Model.

The method is outlined below:

- Identify aggravating and mitigating risk factors that are related to the outcome event;
- Geocode risk factors into an ESRI compatible format;
- Weight significance of factors;
- Run risk model to form a composite map; and
- Ground Truth map using other completed risk assessments.

8.2.2 Scoring and Weighting

The risk assessment methodology employed in this study utilises the 5 point consequence scale (described in **Section 7.5**) of:

- Consequence 1, Insignificant;
- Consequence 2, Low;
- Consequence 3, Moderate;
- Consequence 4, High; and
- Consequence 5, Catastrophic.

Furthermore a consequence of zero can be used to describe an area which would be unaffected by a hazard's occurrence, for example areas located geographically at a considerable distance from a vessel track.

The five-point scale is employed in two distinct forms in this study:

Firstly, study inputs are weighted relative to their contribution to the final risk model. A risk factor with a maximum weighting of 5 contributes five times more to the final risk model than a factor with the minimum weighting of one.

Secondly, a five-point scale is used to describe the proximity of, say, a 20km by 20km grid[12] cell to a risk factor. Two assumptions are made in this technique; firstly, an incident is assumed to have a greater consequence the closer it occurs to an area of importance. Secondly, the distance is circular and is independent of prevailing weather conditions or currents.

A series of buffer rings are created around the location of each model input and weighted to describe the proximity:

- Area within 2 nautical miles (nm): weighting of 5;
- Area between 2 and 5nm: weighting of 4;
- Area between 5 and 10nm: weighting of 3;
- Area between 10 and 20nm: weighting of 2;
- Area between 20 and 50nm: weighting of 1; and
- Area greater than 50nm: weighting of 0 (discounted).

The precision of satellite AIS data is such that use of this approach may result in a more coarse scale.

8.2.3 Multiple Iterations

The model can be repeated multiple times to include variations in predicted traffic numbers or the introduction of multiple new infrastructure developments, which can be compared and contrasted.

8.3 STUDY INPUTS

To fully encapsulate both the cause and effect of an incident, datasets are drawn from a number of sources, but initially supported and validated by the findings from data gathering deployment.

A pragmatic approach must be taken to ensure that data is fully available across the whole study area before inclusion in the study. Similarly the data must be sufficiently reliable and accurate to allow a robust analysis to take place.

[12] The size of the cells may need to be modified, dependant on the area being assessed.

Examples of datasets that could be used in an analysis are listed below:

Likelihood:

- S-AIS derived vessel density data;
- Chart ZOC ratings;
- Current and predicted cruise ship stops;
- Developed infrastructure; and
- Known economic expansion plans.

Consequence:

- Environmental:
  - World Heritage Sites (Environmental);
  - Coral Reefs;
  - Sea Grass;
  - Areas of environmental tourism; and
  - Protected environmental sites.
- Ecological:
  - Specie breeding grounds (turtles, protected fish species, etc.);
  - Key habitat locations; and
  - Diving sites.
- Cultural:
  - World Heritage Sites (Cultural);
  - Local cultural areas of importance; and
  - Areas of cultural tourism.

8.4 DELIVERABLES

Production of a report and high quality maps showing areas of sensitivity and ultimately a single 2D risk grid (see **Figure 11**, below). A KMZ file can also be created to allow the model to be viewed in Google Earth.

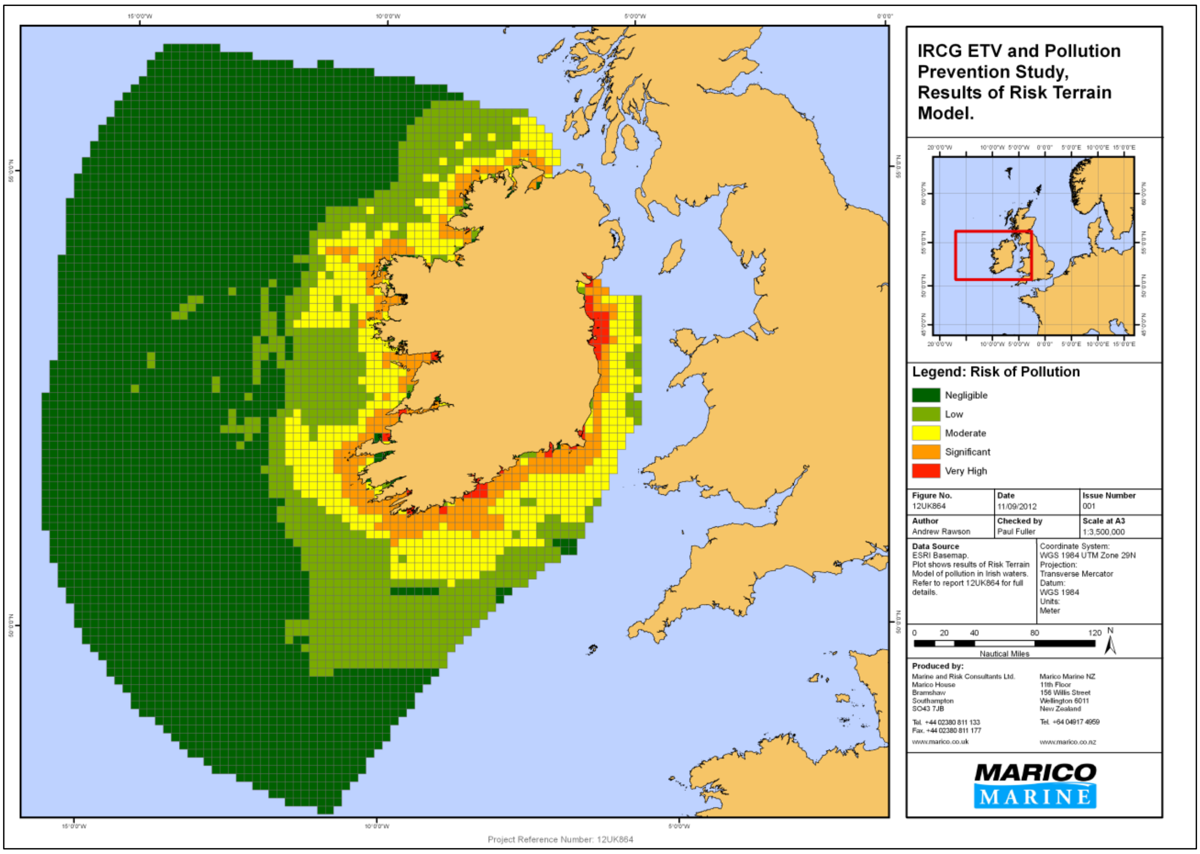


Figure 10: Results of Sensitivity Mapping in Ireland.

8.4.1 Further Optional Deliverables

8.4.1.1 ESRI Data files

All analysis plots and files can be provided in ESRI compatible, geo-referenced shape files with appropriate metadata attached. This option enables LINZ to incorporate the study results directly into their in-house infrastructure.

8.4.1.2 Creation of an Interactive ArcGIS Online Website

ArcGIS Online is a cloud based collaborative content management system for maps, data and other geographic information. It allows for ESRI datasets to be hosted online in the form of interactive maps that can be viewed and manipulated by a user. This would increase the promulgation of the study results to the relevant parties. An ArcGIS Online account would be created and the results of this study, as well as the datasets can be examined by different users.

For example collaboration between NOAA and the Bureau of Ocean Energy Management in the United States created a Multipurpose Marine Cadastre (**Figure 11**). The resulting web viewer (http://csc.noaa.gov/mmcviewer/)

brings multiple datasets together to improve the information available to regional and national planning bodies to make more informed marine related decisions.

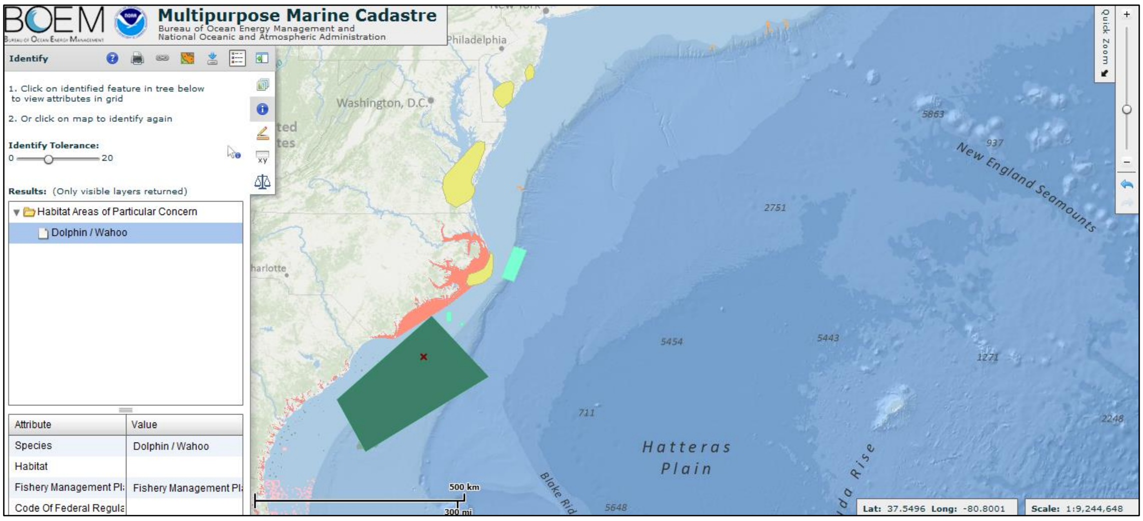


Figure 11: NOAA's Multipurpose Marine Cadastre showing Habitat Areas of Particular Concern

9 INFORMATION OF RELEVANCE TO DEVELOP QUESTIONNAIRE

9.1 INTRODUCTION

This section provides an assessment of the types of questions needed to be answered when data gathering in the field. Data gathered is related to both

9.2 INFORMATION REQUIREMENTS

9.2.1 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?

9.2.2 Use of Chart

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

9.2.3 Shipping Volume

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

9.2.4 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.

9.2.5 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.

9.2.6 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.

9.2.7 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.

9.2.8 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?

9.2.9 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.

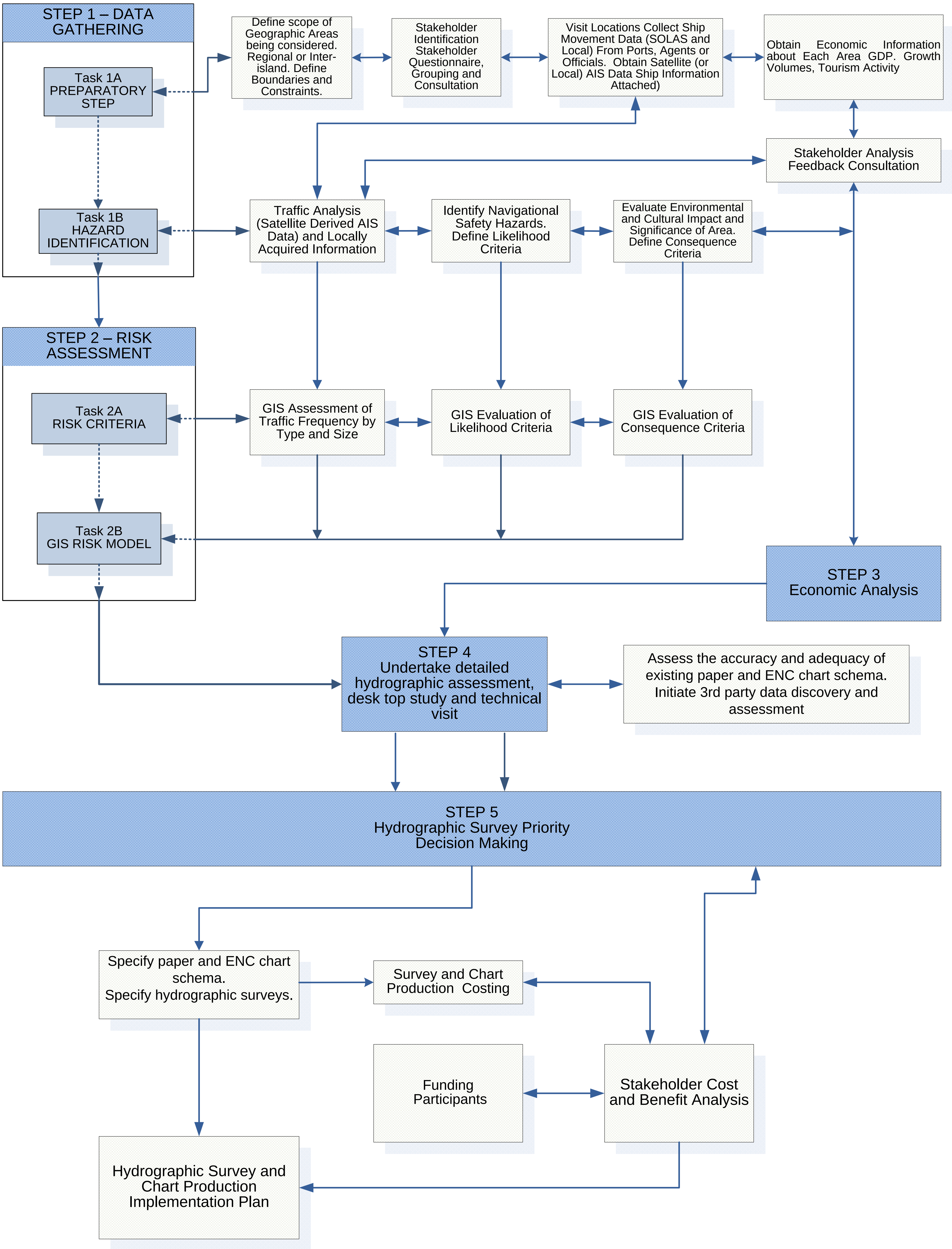
9.2.10 Effects on Economy (National and Local)

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.

Annex A

Methodology Flow Chart

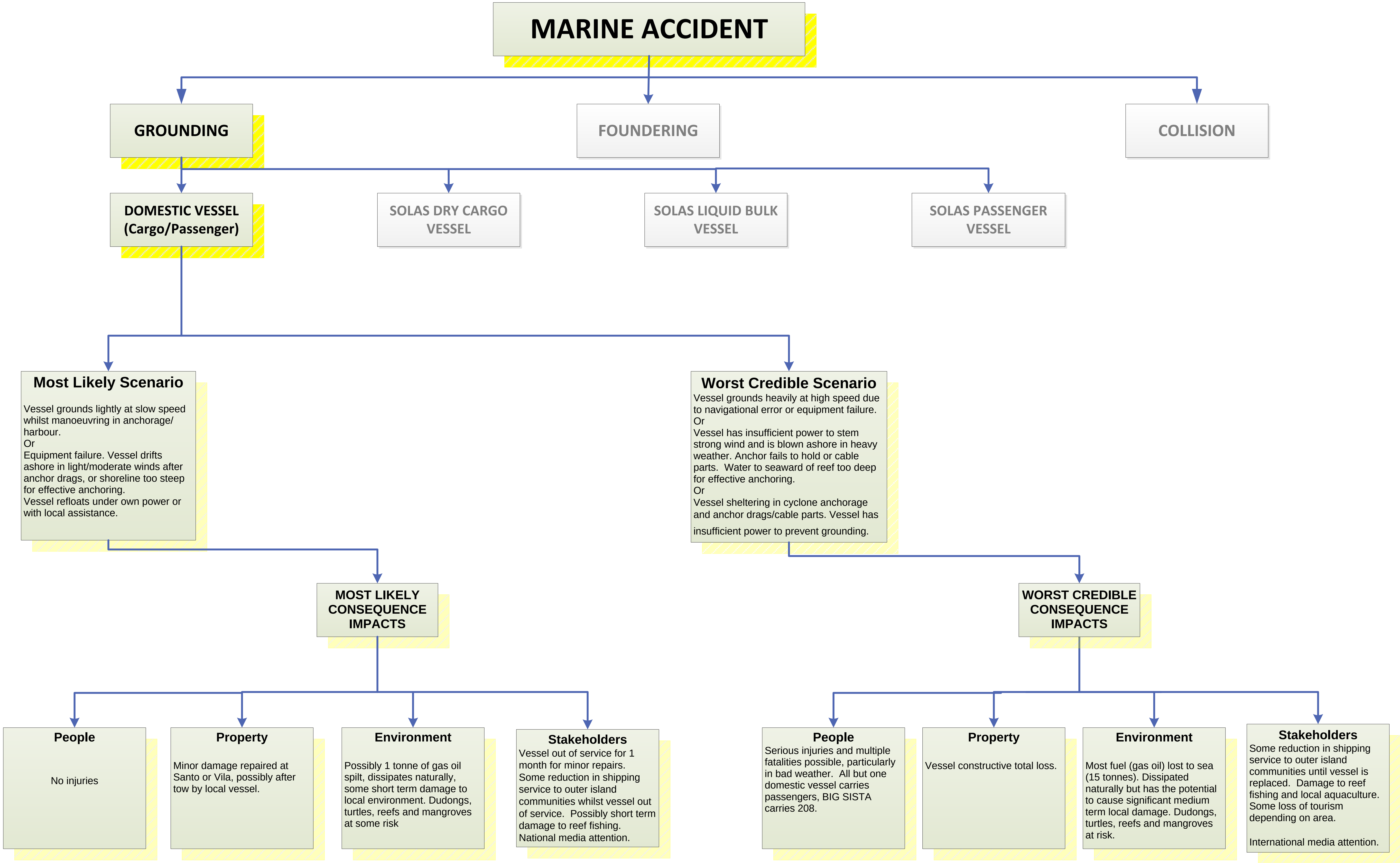
FLOW CHART OF REVISED LINZ FORMAL HYDROGRAPHIC METHODOLOGY

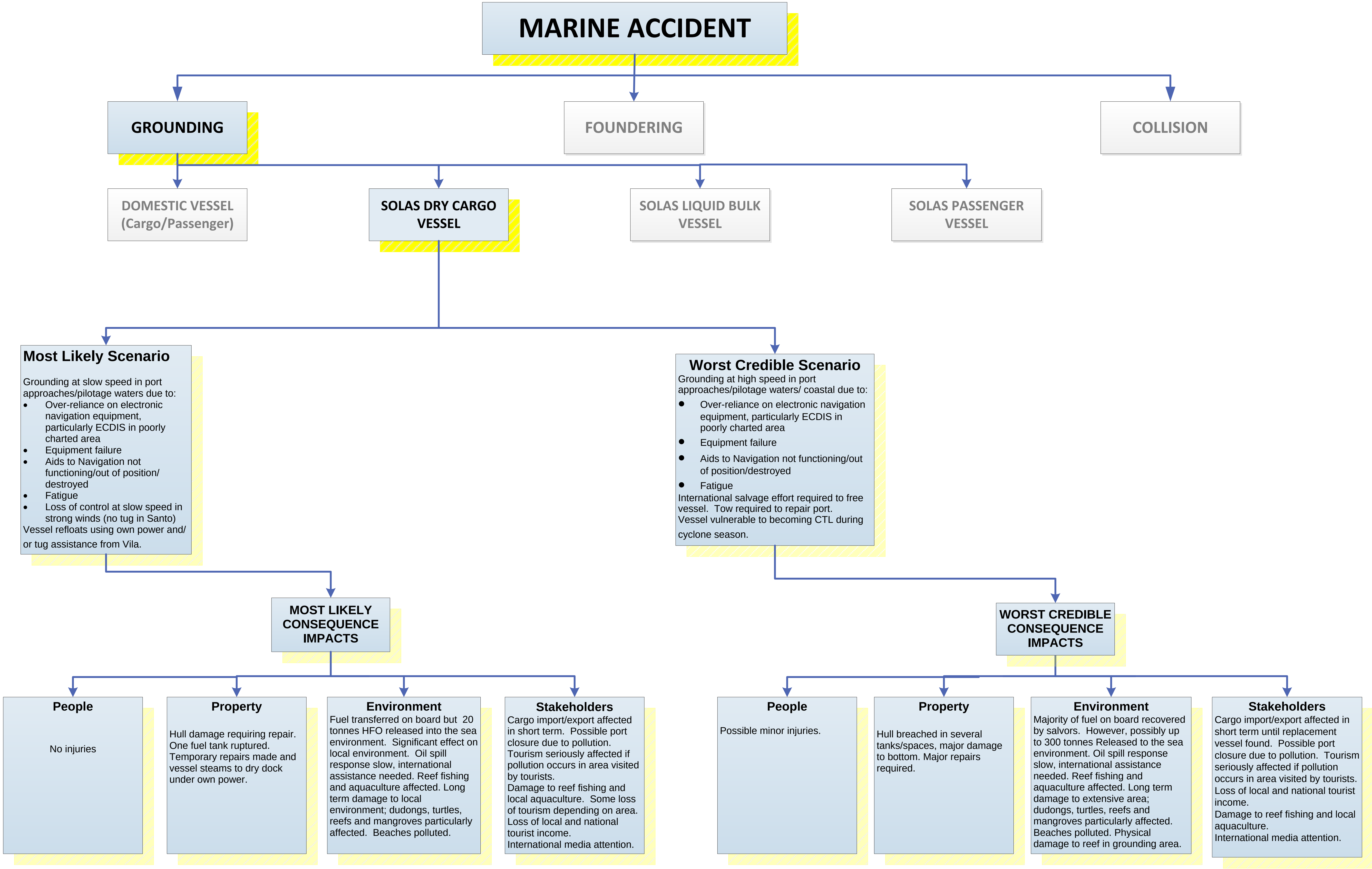


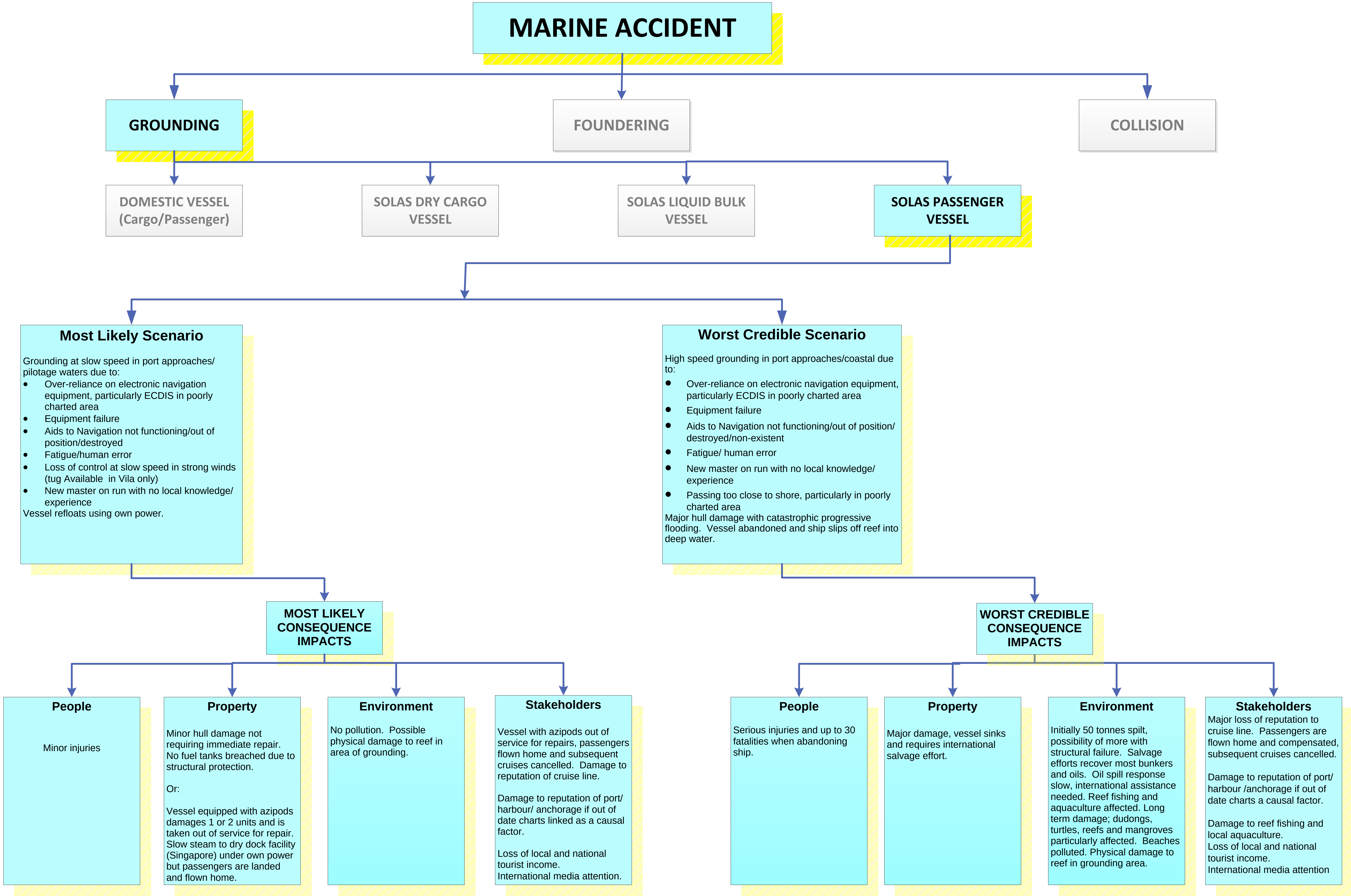
Annex B

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
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.
WORST CREDIBLE CONSEQUENCE IMPACTS
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