LAND INFORMATION

NEW ZEALAND

PACIFIC REGIONAL HYDROGRAPHY PROGRAMME - HYDROGRAPHIC RISK ASSESSMENT - VANUATU

ANNEXES

(BOUND SEPARATELY)

Report Number : 12NZ246-1
January, 2013

MARICO MARINE NZ LIMITED

Annex A

WW2 Information - Espiritu Santo and Éfaté

The islands of Vanuatu were not occupied by the Japanese during WWII, although invasion was considered imminent following their occupation of the Solomon Islands. During the course of the war there were no land battles in Vanuatu, but the American base at Espiritu Santo was shelled by Japanese submarines on several occasions. There were also six minor bombing raids recorded on the Espiritu Santo bases and shipping in the Segond Channel. The raids caused little damage but three unexploded bombs were reported on shore.

An American invasion fleet arrived in Mele Bay in May 1942, expecting the islands to be under Japanese control and prepared to fight its way ashore. However, this was not the case and the Americans established army, navy and air force bases on Éfaté and Espiritu Santo in preparation for the assault on the Philippines and the occupied islands of Micronesia.

The principal bases were:

a) Éfaté

- Major aviation and supply base;
- Bauerfield airstrip, Port Vila (bombers, fighters and transport aircraft);
- Navy hospital on the Bellevue plantation; and
- Havannah Harbour (main naval base and anchorage with two small fighter airfields nearby).

b) Espiritu Santo

- Major aviation and supply base;
- Three bomber airfields;
- Two fighter airstrips;
- PT boat base with maintenance and repair shops;
- Flying boat base;
- Navy yard and bases extending from the western end of Segond Cannal to Turtle Bay;
- Dry dock (the largest in the world at that time and capable of lifting battle ships) moored in Palekula Bay. During assembly off Aese Island

one of the four sections sank in 300 feet of water and was replaced with another section towed out from the USA;

- Two other floating docks and a floating crane moored in the Segond Channel; and
- Five military hospitals.

c) Aore

- A rest and recreation camp
- Mine depot

1.1.1 Espiritu Santo

Over 40,000 men were permanently stationed in Espiritu Santo and it is estimated that over 500,000 passed through during the course of the war. At any time between 1943 and 1944 there could be up to 97 ships in the Segond Channel and many more anchored in Palikulo Bay, which was favoured by larger vessels.

At the end of the war there was an understandably rapid repatriation of American troops. Some military equipment was flown off and some used jeeps, trucks and boats were sold locally. However, much equipment was destroyed, ostensibly to protect American manufacturers from a glut of second hand equipment. Such equipment was dumped into the sea using cranes and anything with wheels was driven into the sea. Million Dollar Point was one such dumping area with debris extending down to the 70 metre contour.

Coral rock was bulldozed over dumped material to create a ramp to enable further dumping.

After the Americans left, much equipment, particularly bulldozers, tyres and non-ferrous metals, was recovered from Million Dollar Point. Although six inch calibre gun barrels can be seen in many images of the dumped equipment there is no indication that munitions were ever dumped at Million Dollar point. This was confirmed by diving company with experience of the area[1], who suggested that dumped barrels were worn items removed from destroyers and battleships that had been refitted in the floating drydock that was stationed in Palekula Bay.

[1] Allan Power Dive Tours

1.1.2 Significant Military Wrecks

There are two military wrecks in Espiritu Santo of particular interest: the troop carrier *President Coolidge* and the destroyer *USS Tucker*. Neither vessel was informed of the existence of the protective minefields; both sank after contacting mines.

During 1943 attempts were made to salvage vehicles, weapons and munitions carried on deck and in the holds of *President Coolidge*. Little equipment was recovered. Later salvage attempts in 1958 removed live 105mm and 75mm shells, together, with small arms ammunition.

USS Tucker sank in 18m of water on a sandy bottom, making salvage relatively simple. Much equipment was removed from the wreck during the war, although a 1954 salvage recovered non-ferrous metal, including several tonnes of 3 inch shell casings. The casings were reportedly packed with cordite but did not have projectiles fitted.

1.1.3 Mine-Fields – Espiritu Santo and Éfaté

Figure -1 Researched Location of Mine laying – Luganville[2]

The location of Espiritu Santo minefields was researched for a book about the sinking of the *Coolidge*. **Figure 1** is the reproduced summary result of this research and the five areas of laying are identified.

The fleet in Port Havannah, Éfaté, was similarly protected, reportedly between the islands of Moso, Lélépa and Érétoka.

Local advice in Vanuatu suggests that all of these minefields were swept and removed, in total. Given that they were floating mines, tethered to the sea bed, confirmation of total removal is likely to be retained in American archives. It is thus recommended that intergovernmental liaison is conducted to clarify further.

[2] Image copyright retained by and reproduced with permission of, Mr Peter Stone, Author "The Lady and the PRESIDENT". ISBN 0-9586657-2-9

1.1.4 Munitions

Munition dumping was wide spread throughout the Pacific theatre of war following cessation of hostilities.

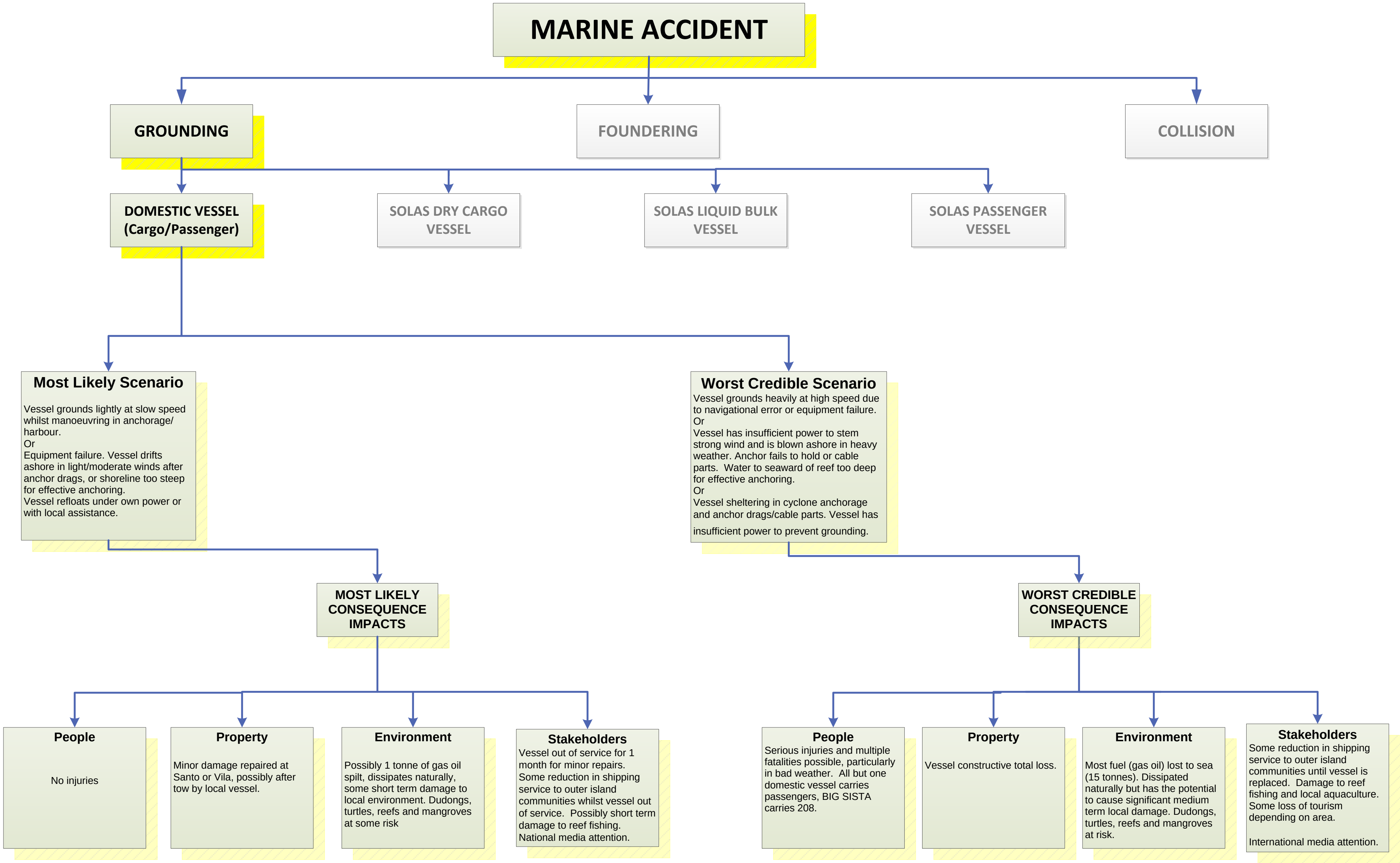
Local divers in Luganville report that there is no ammunition to be found in the vicinity of Million Dollar Point and the wrecks of *President Coolidge* and *USS Tucker*.

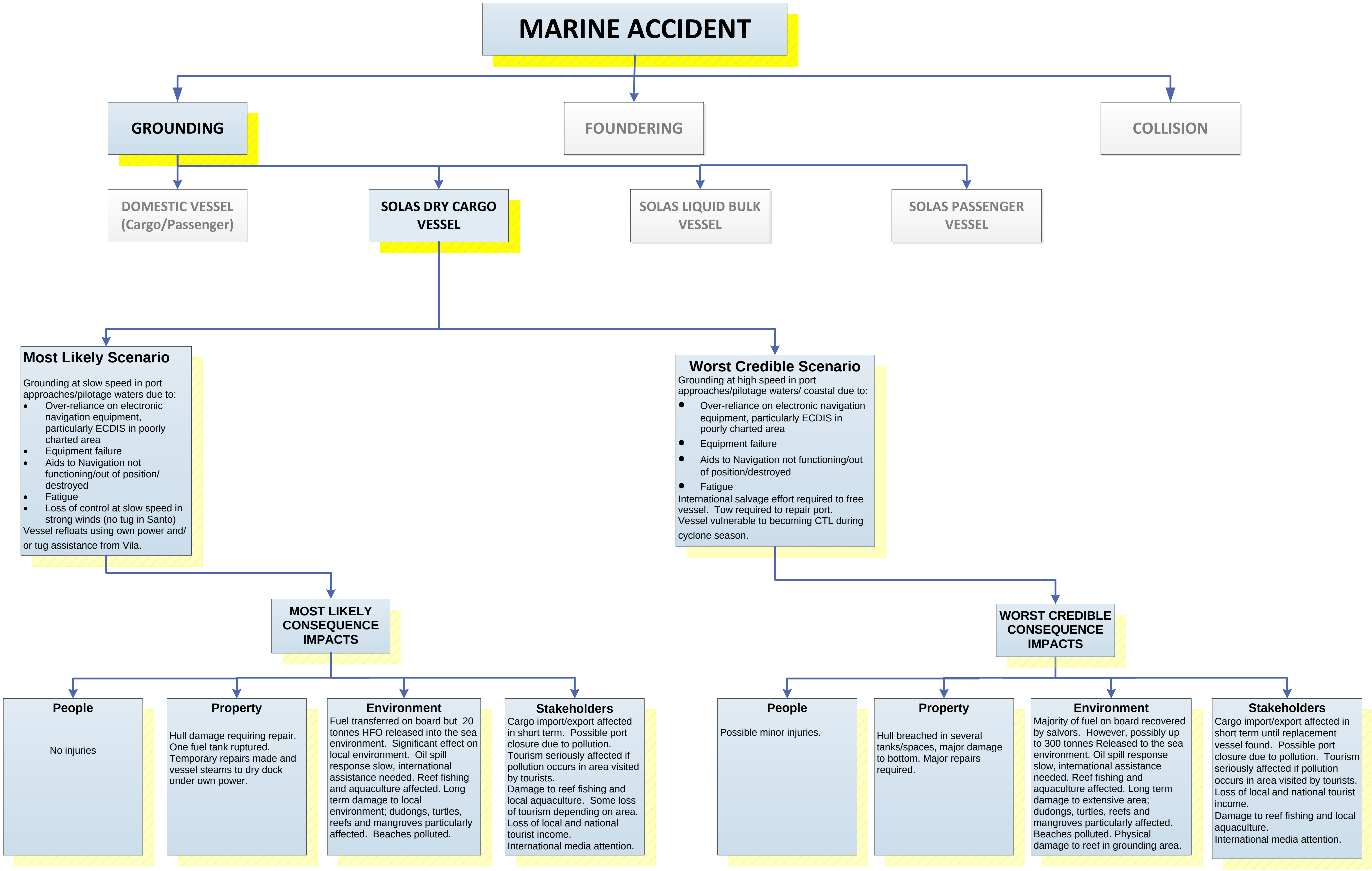
Similarly Secondo Channel has been dived for many years (there is a sunken tug attraction there), with no reports of munitions being recovered from there. However at Luganville, it is know that small arms munitions can still be found off Chapuis Point off Aoré Island.

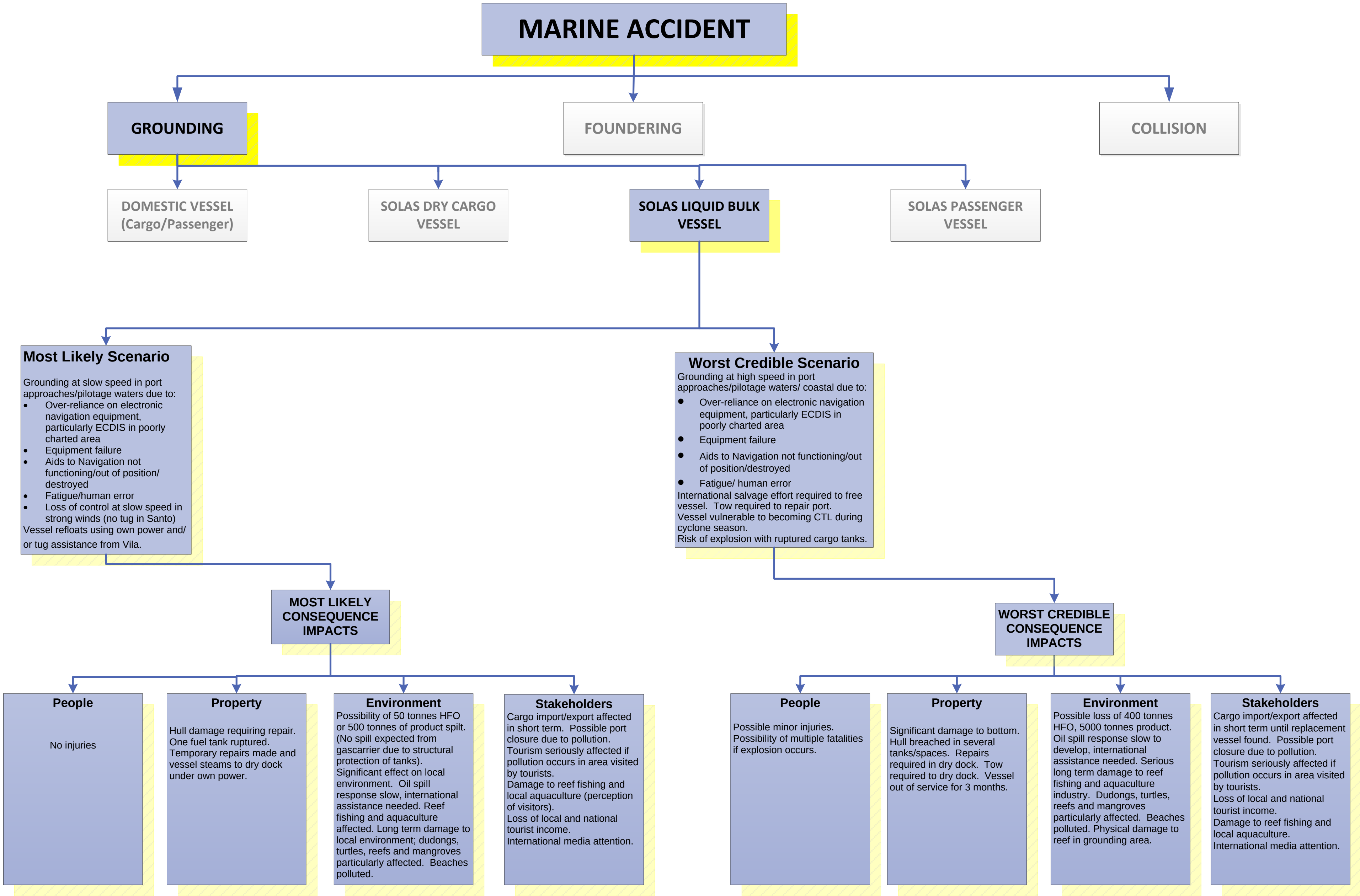
Local divers also report finding small arms ammunition and shells up to about two inch calibre in other areas, which have not been specified. Munitions are still being recovered by divers and kept as souvenirs. The projectiles are heavily wasted from corrosion and munitions recovered are not considered dangerous by Luganville locals. Further research is needed to identify where these are recovered from, which may assist and future hydrography programme of work.

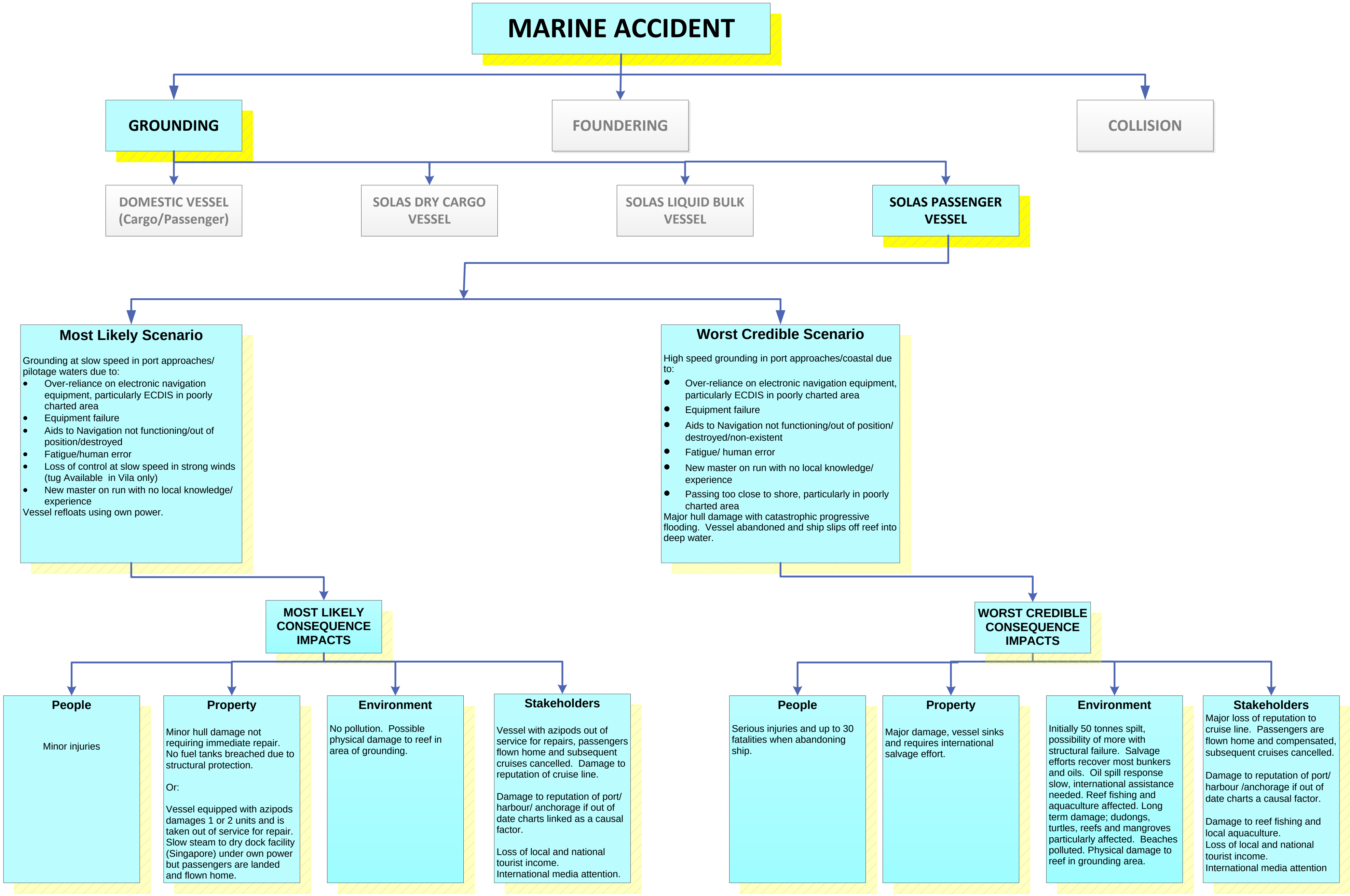
In the island of Éfaté, Port Vila Chart BA1494 records an ordinance dumping ground to the south of Malapoa Point, adjacent to the harbour entrance.

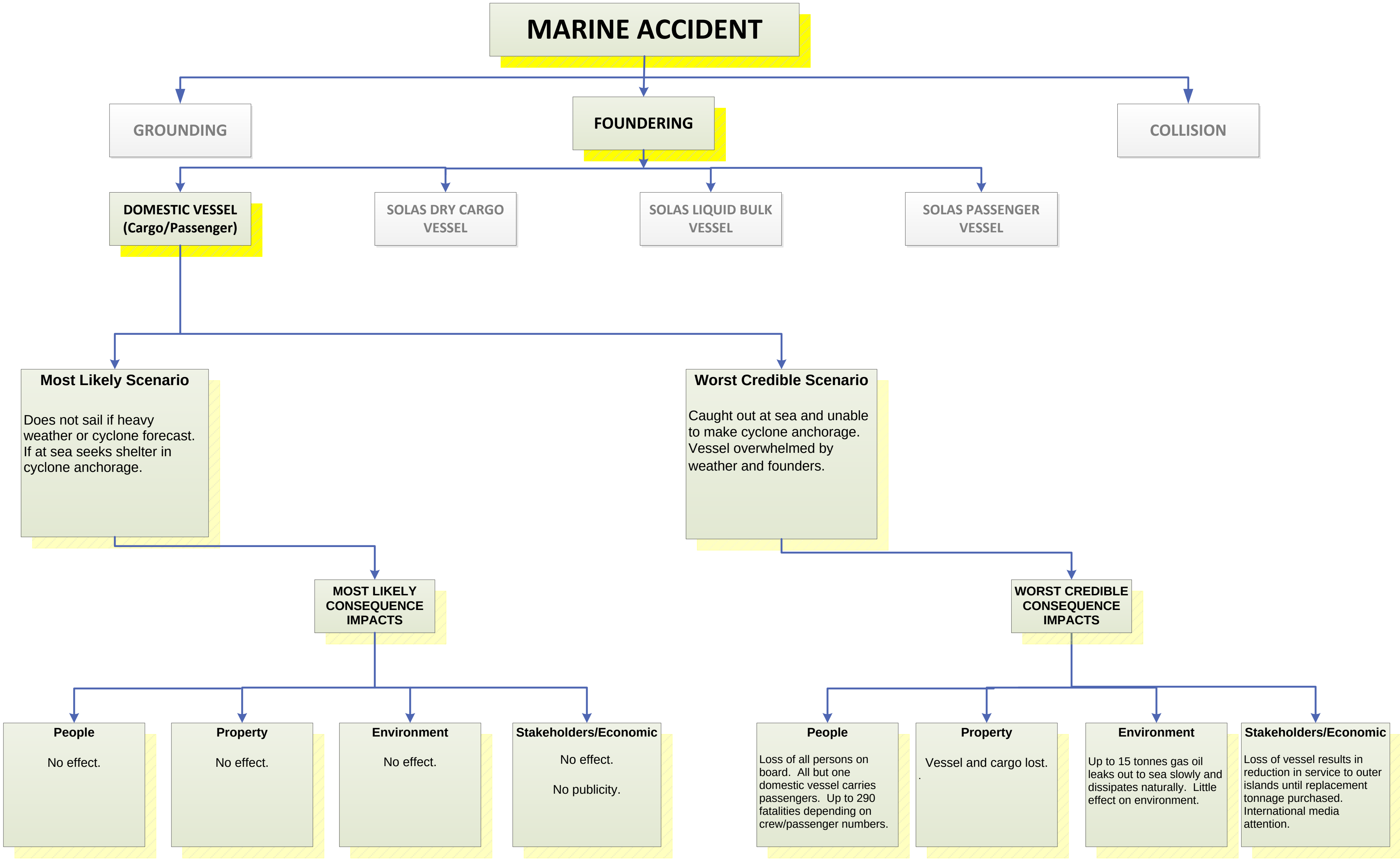
Annex B
Event Trees

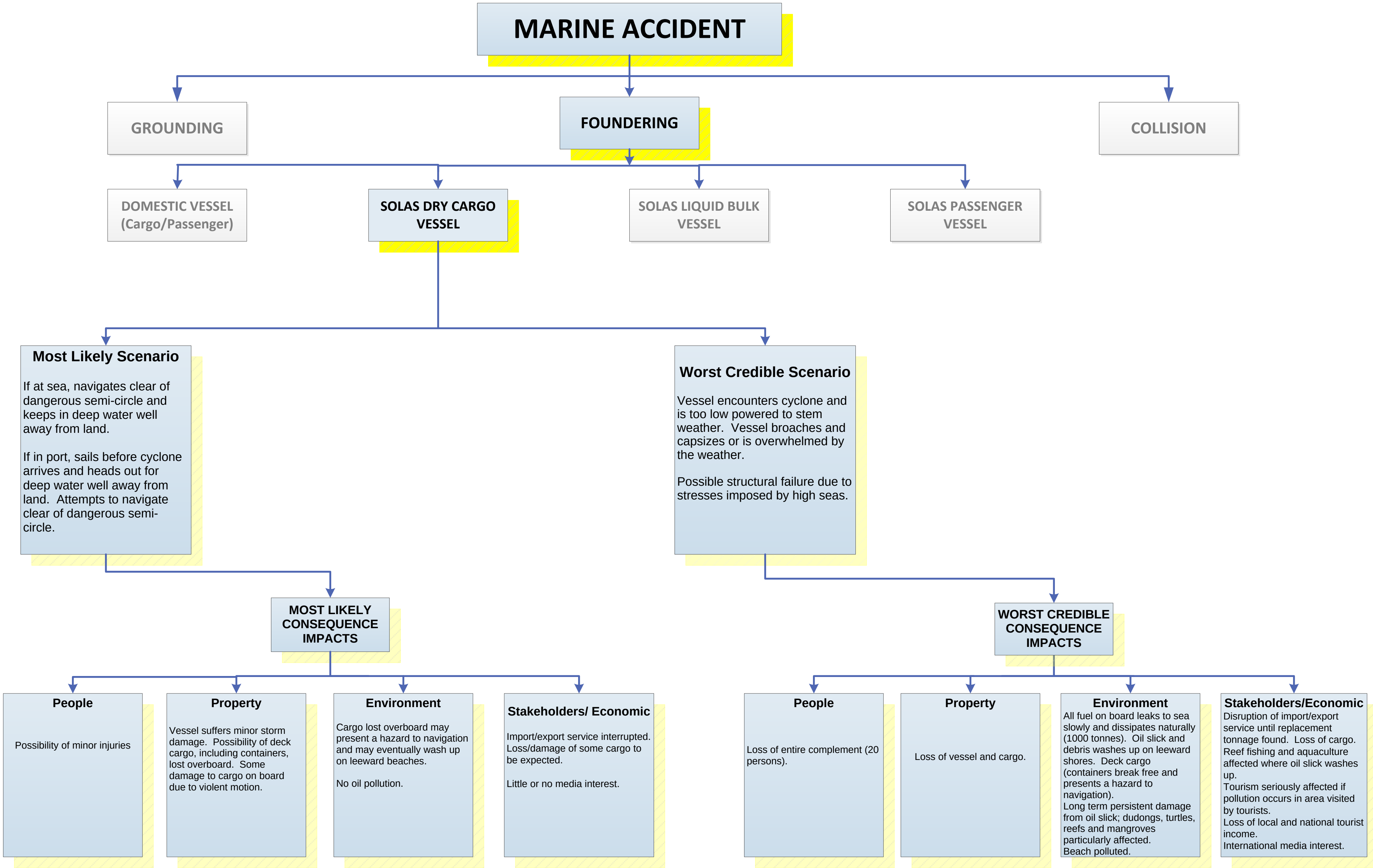

MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Vessel grounds lightly at slow speed whilst manoeuvring in anchorage/ harbour.
Or
Equipment failure. Vessel drifts ashore in light/moderate 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.

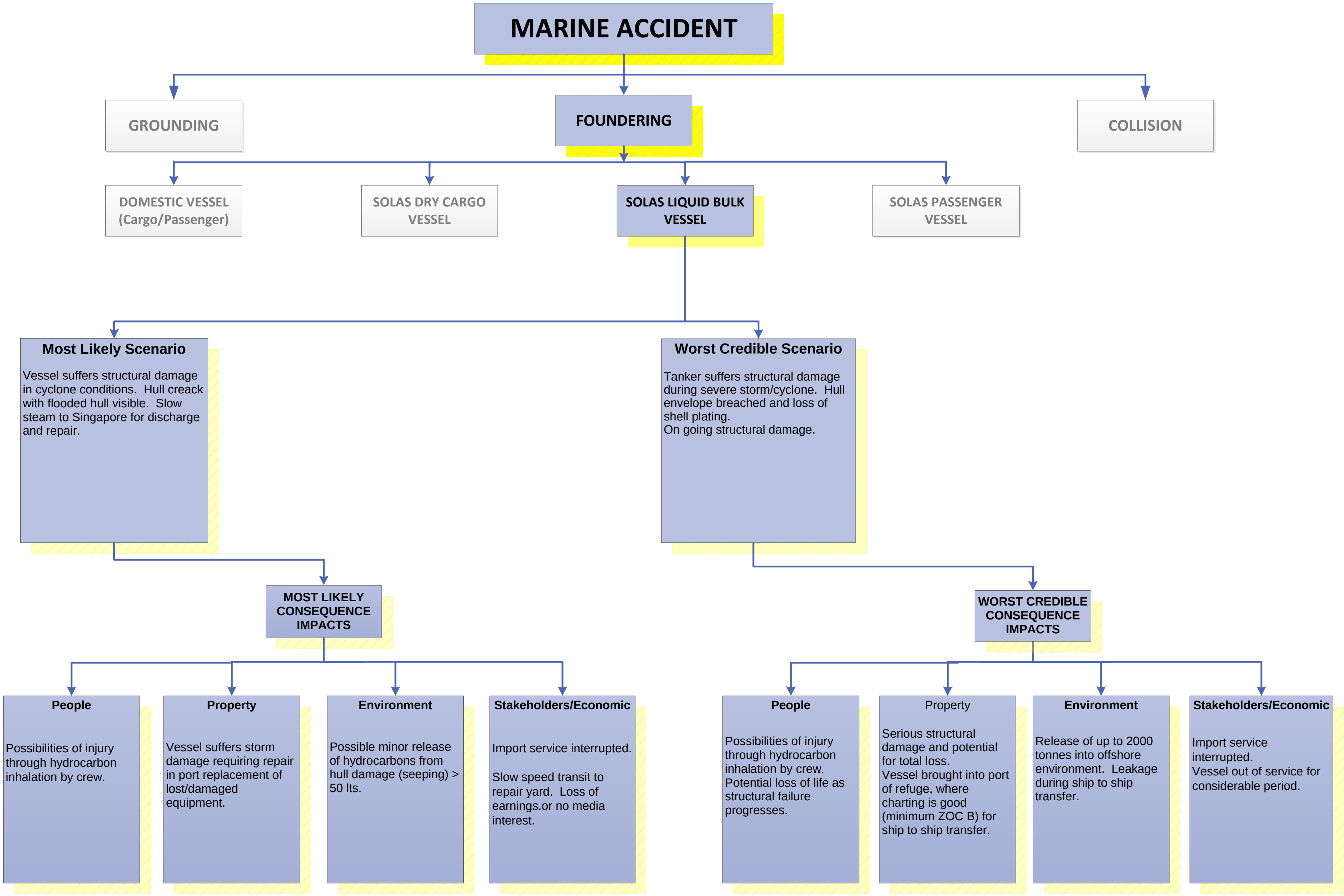

MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Grounding at slow speed in port approaches/pilotage waters due to:
• Over-reliance on electronic navigation equipment, particularly 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
WORST CREDIBLE 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.
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.

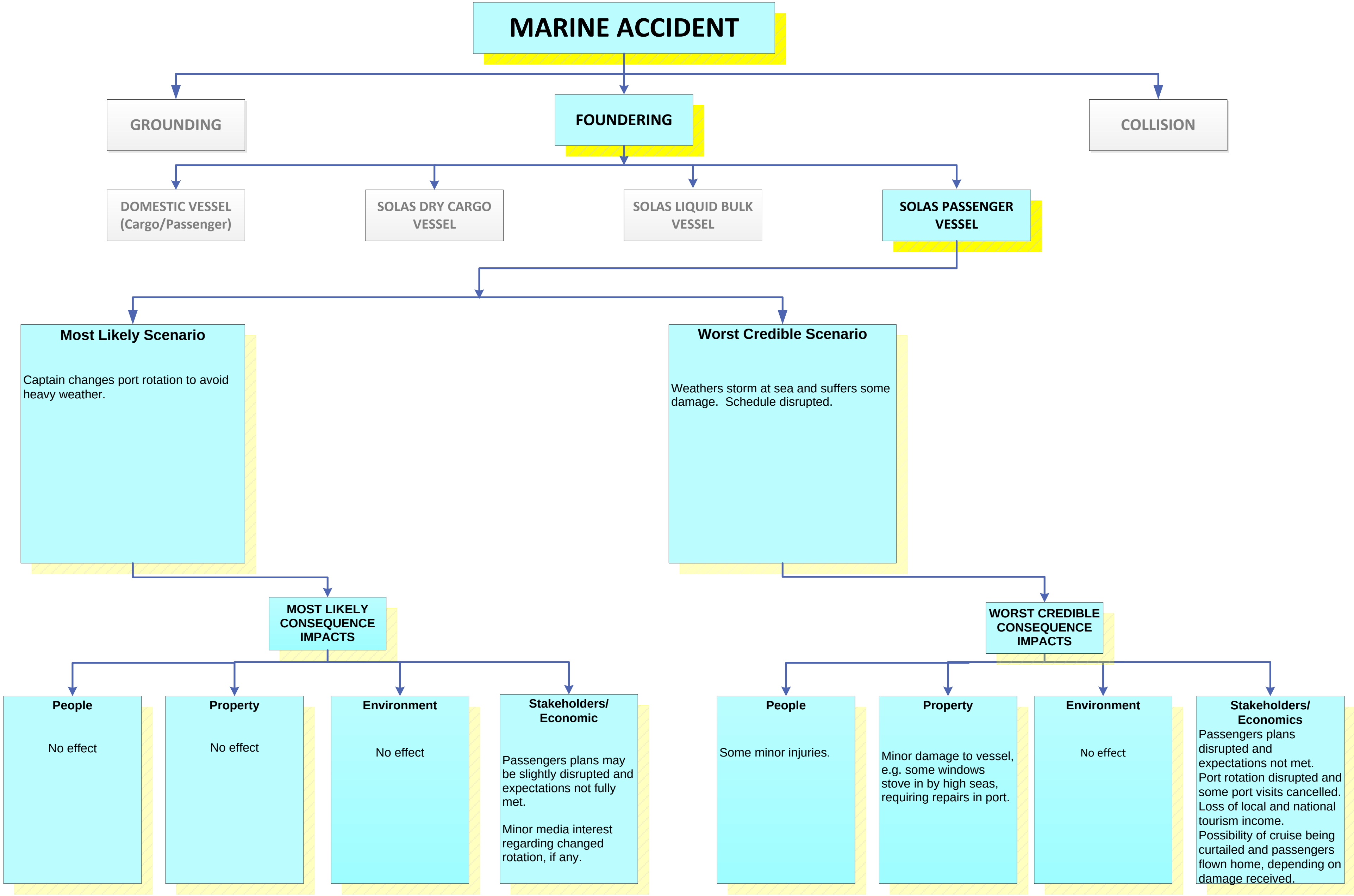

MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Grounding at slow speed in port approaches/pilotage waters due to:
• Over-reliance on electronic navigation equipment, particularly 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 (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/ human error
International salvage effort required to free vessel. Tow required to repair port.
Vessel vulnerable to becoming CTL during cyclone season.
Risk of explosion with ruptured cargo tanks.
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
Possibility of 50 tonnes HFO or 500 tonnes of product spilt. (No spill expected from gascarrier due to structural protection of tanks). 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 (perception of visitors). Loss of local and national tourist income. International media attention.
WORST CREDIBLE CONSEQUENCE IMPACTS
People
Possible minor injuries. Possibility of multiple fatalities if explosion occurs.
Property
Significant damage to bottom. Hull breached in several tanks/spaces. Repairs required in dry dock. Tow required to dry dock. Vessel out of service for 3 months.
Environment
Possible loss of 400 tonnes HFO, 5000 tonnes product. Oil spill response slow to develop, international assistance needed. Serious long term damage to reef fishing and aquaculture industry. 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.

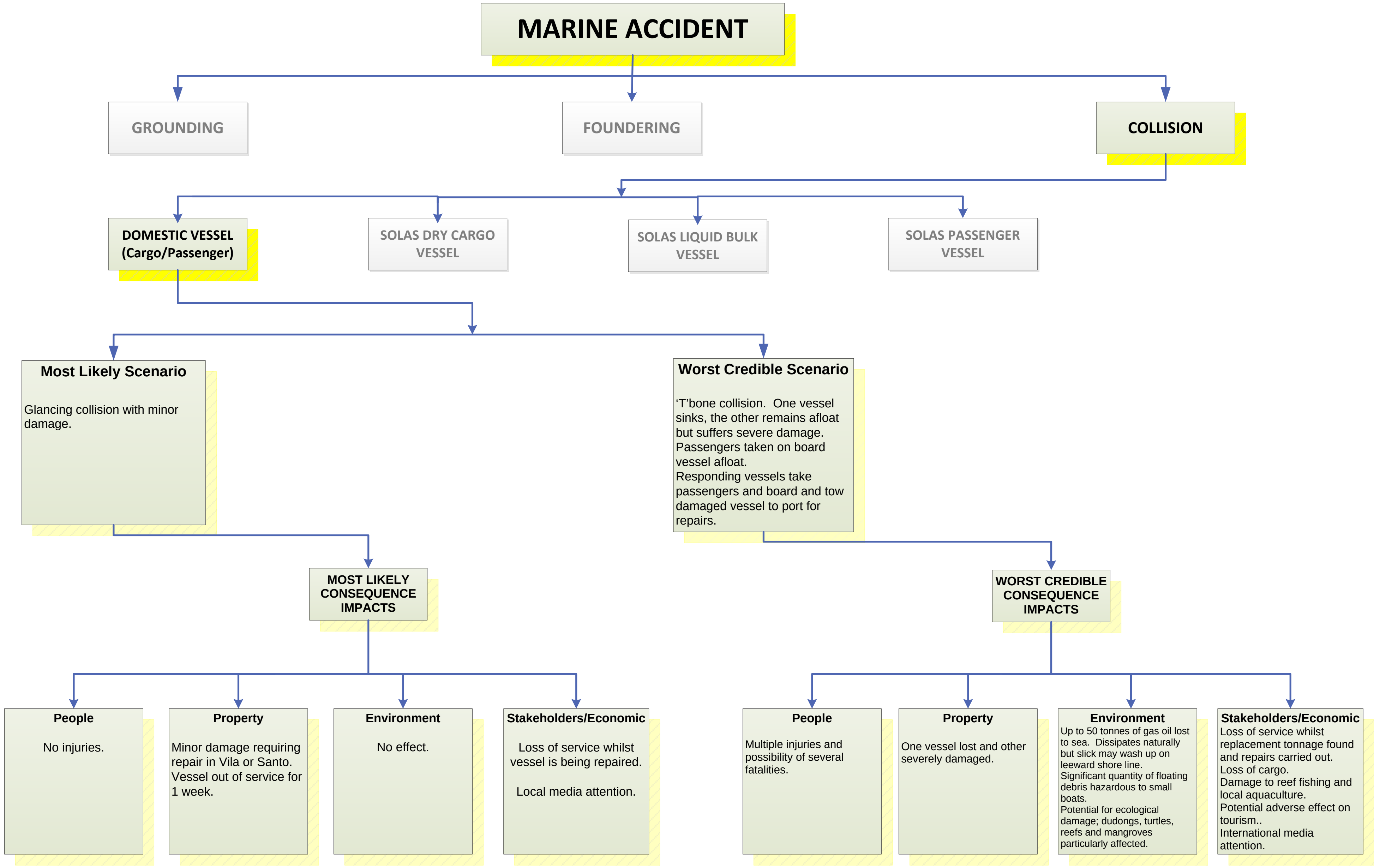

MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Grounding at slow speed in port approaches/ pilotage waters due to:
• Over-reliance on electronic navigation equipment, particularly 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

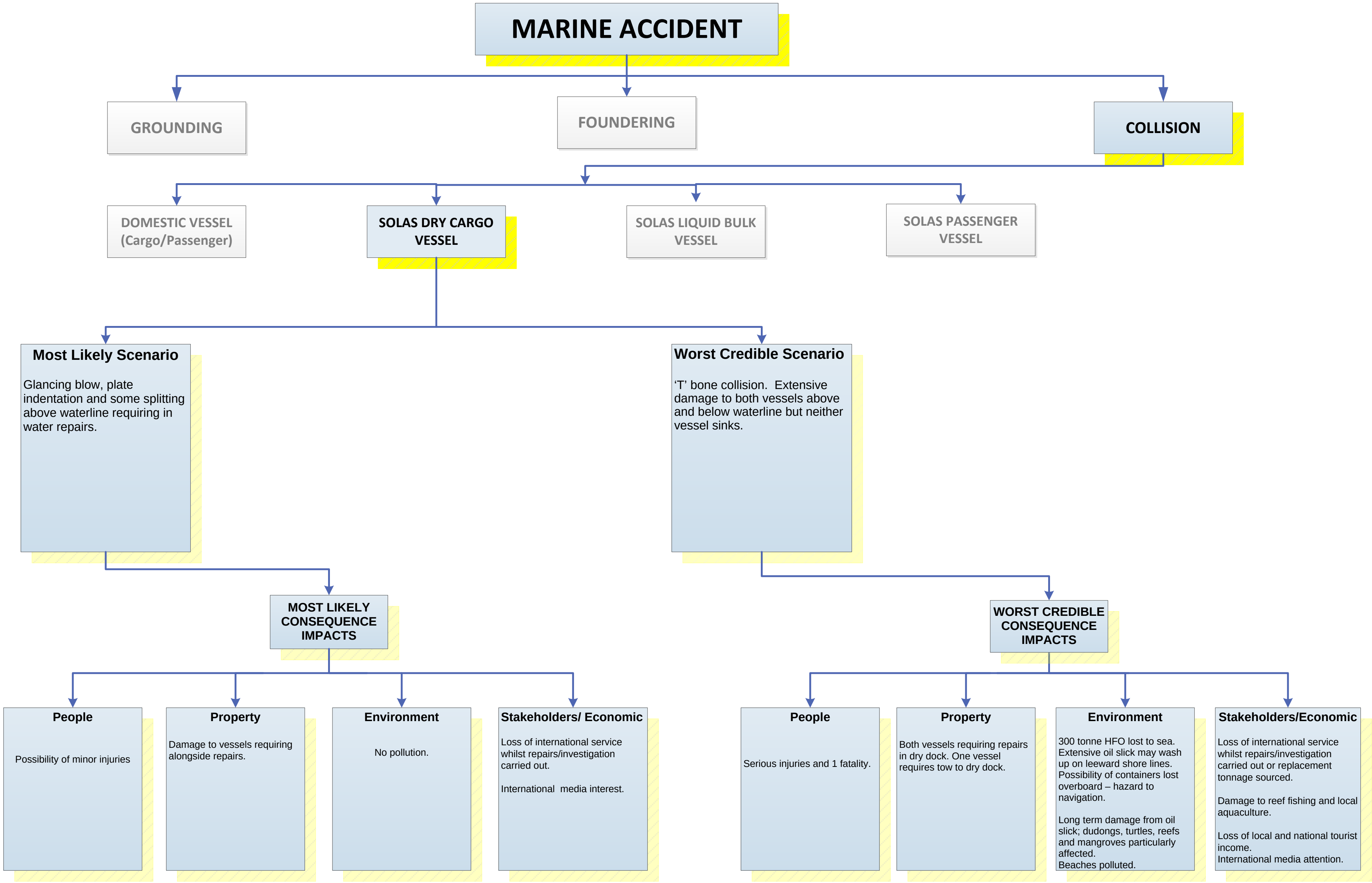

MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Does not sail if heavy weather or cyclone forecast. If at sea seeks shelter in cyclone anchorage.
Worst Credible Scenario
Caught out at sea and unable to make cyclone anchorage. Vessel overwhelmed by weather and founders.
MOST LIKELY CONSEQUENCE IMPACTS
WORST CREDIBLE CONSEQUENCE IMPACTS
People
No effect.
Property
No effect.
Environment
No effect.
Stakeholders/Economic
No effect.
No publicity.
People
Loss of all persons on board. All but one domestic vessel carries passengers. Up to 290 fatalities depending on crew/passenger numbers.
Property
Vessel and cargo lost.
Environment
Up to 15 tonnes gas oil leaks out to sea slowly and dissipates naturally. Little effect on environment.
Stakeholders/Economic
Loss of vessel results in reduction in service to outer islands until replacement tonnage purchased. International media attention.

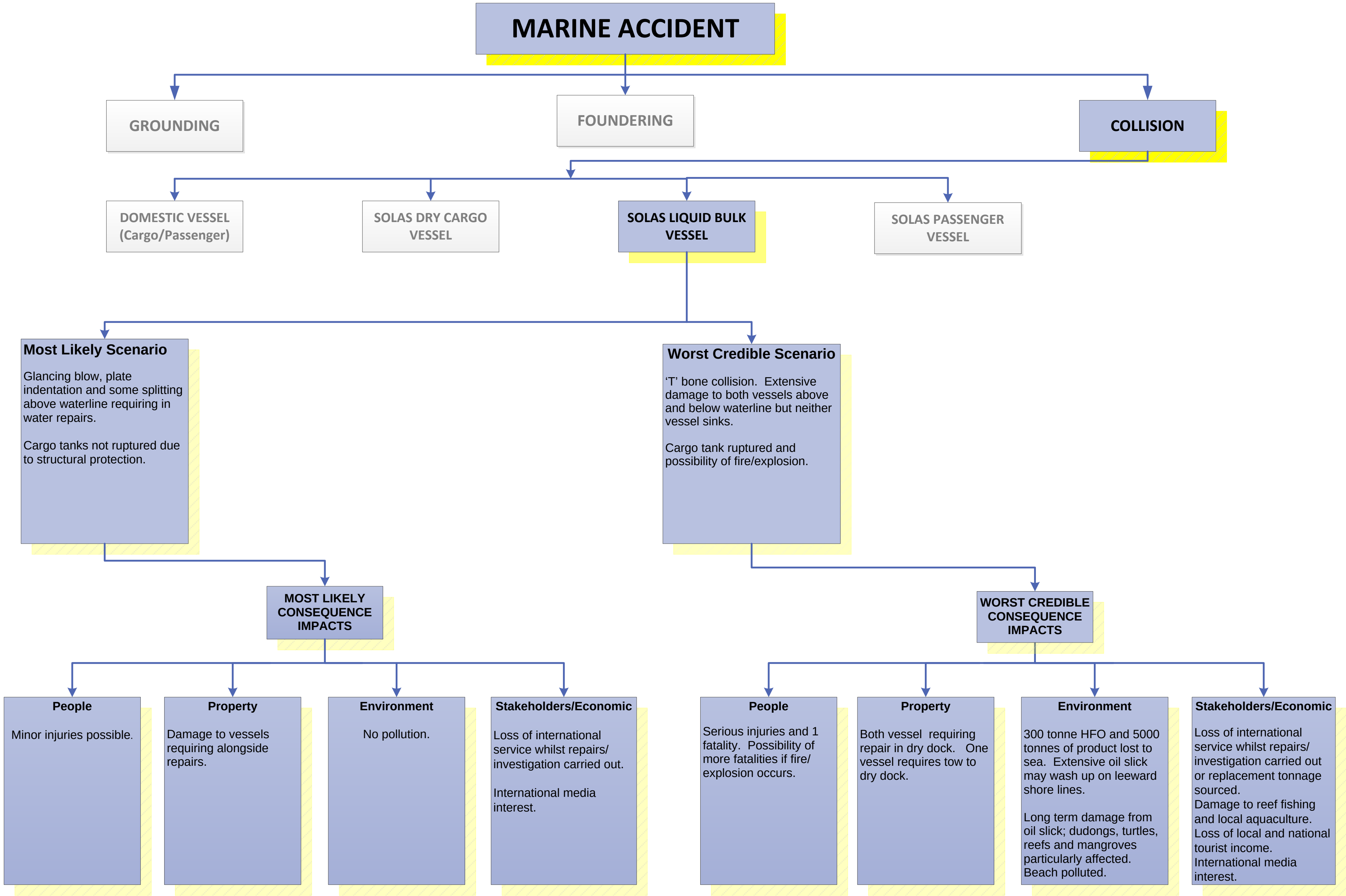

MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
If at sea, navigates clear of dangerous semi-circle and keeps in deep water well away from land.
If in port, sails before cyclone arrives and heads out for deep water well away from land. Attempts to navigate clear of dangerous semi-circle.
Worst Credible Scenario
Vessel encounters cyclone and is too low powered to stem weather. Vessel broaches and capsizes or is overwhelmed by the weather.
Possible structural failure due to stresses imposed by high seas.
MOST LIKELY CONSEQUENCE IMPACTS
WORST CREDIBLE CONSEQUENCE IMPACTS
People
Possibility of minor injuries
Property
Vessel suffers minor storm damage. Possibility of deck cargo, including containers, lost overboard. Some damage to cargo on board due to violent motion.
Environment
Cargo lost overboard may present a hazard to navigation and may eventually wash up on leeward beaches.
No oil pollution.
Stakeholders/ Economic
Import/export service interrupted. Loss/damage of some cargo to be expected.
Little or no media interest.
People
Loss of entire complement (20 persons).
Property
Loss of vessel and cargo.
Environment
All fuel on board leaks to sea slowly and dissipates naturally (1000 tonnes). Oil slick and debris washes up on leeward shores. Deck cargo (containers break free and presents a hazard to navigation).
Long term persistent damage from oil slick; dudongs, turtles, reefs and mangroves particularly affected.
Beach polluted.
Stakeholders/Economic
Disruption of import/export service until replacement tonnage found. Loss of cargo. Reef fishing and aquaculture affected where oil slick washes up.
Tourism seriously affected if pollution occurs in area visited by tourists.
Loss of local and national tourist income.
International media interest.

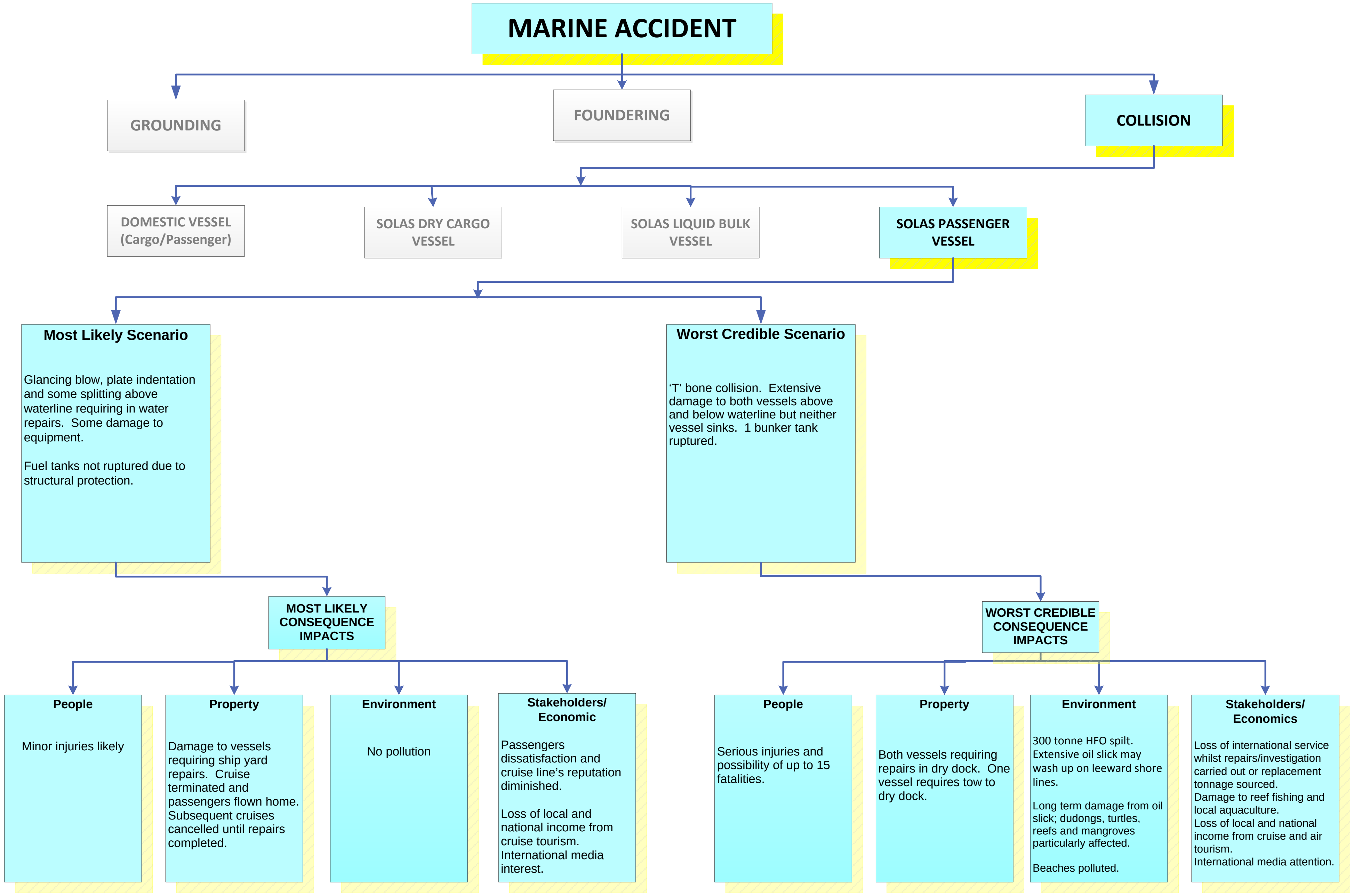

MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Vessel suffers structural damage in cyclone conditions. Hull creack with flooded hull visible. Slow steam to Singapore for discharge and repair.
Worst Credible Scenario
Tanker suffers structural damage during severe storm/cyclone. Hull envelope breached and loss of shell plating.
On going structural damage.
MOST LIKELY CONSEQUENCE IMPACTS
WORST CREDIBLE CONSEQUENCE IMPACTS
People
Possibilities of injury through hydrocarbon inhalation by crew.
Property
Vessel suffers storm damage requiring repair in port replacement of lost/damaged equipment.
Environment
Possible minor release of hydrocarbons from hull damage (seeping) > 50 lts.
Stakeholders/Economic
Import service interrupted.
Slow speed transit to repair yard. Loss of earnings.or no media interest.
People
Possibilities of injury through hydrocarbon inhalation by crew.
Potential loss of life as structural failure progresses.
Property
Serious structural damage and potential for total loss.
Vessel brought into port of refuge, where charting is good (minimum ZOC B) for ship to ship transfer.
Environment
Release of up to 2000 tonnes into offshore environment. Leakage during ship to ship transfer.
Stakeholders/Economic
Import service interrupted.
Vessel out of service for considerable period.


MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Captain changes port rotation to avoid heavy weather.
Worst Credible Scenario
Weathers storm at sea and suffers some damage. Schedule disrupted.
MOST LIKELY CONSEQUENCE IMPACTS
People
No effect
Property
No effect
Environment
No effect
Stakeholders/ Economic
Passengers plans may be slightly disrupted and expectations not fully met.
Minor media interest regarding changed rotation, if any.
WORST CREDIBLE CONSEQUENCE IMPACTS
People
Some minor injuries.
Property
Minor damage to vessel, e.g. some windows stove in by high seas, requiring repairs in port.
Environment
No effect
Stakeholders/ Economics
Passengers plans disrupted and expectations not met.
Port rotation disrupted and some port visits cancelled.
Loss of local and national tourism income.
Possibility of cruise being curtailed and passengers flown home, depending on damage received.


MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Glancing collision with minor damage.
Worst Credible Scenario
'T'bone collision. One vessel sinks, the other remains afloat but suffers severe damage. Passengers taken on board vessel afloat.
Responding vessels take passengers and board and tow damaged vessel to port for repairs.
MOST LIKELY CONSEQUENCE IMPACTS
WORST CREDIBLE CONSEQUENCE IMPACTS
People
No injuries.
Property
Minor damage requiring repair in Vila or Santo. Vessel out of service for 1 week.
Environment
No effect.
Stakeholders/Economic
Loss of service whilst vessel is being repaired.
Local media attention.
People
Multiple injuries and possibility of several fatalities.
Property
One vessel lost and other severely damaged.
Environment
Up to 50 tonnes of gas oil lost to sea. Dissipates naturally but slick may wash up on leeward shore line.
Significant quantity of floating debris hazardous to small boats.
Potential for ecological damage; dudongs, turtles, reefs and mangroves particularly affected.
Stakeholders/Economic
Loss of service whilst replacement tonnage found and repairs carried out.
Loss of cargo.
Damage to reef fishing and local aquaculture.
Potential adverse effect on tourism..
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
Glancing blow, plate indentation and some splitting above waterline requiring in water repairs.
Worst Credible Scenario
'T' bone collision. Extensive damage to both vessels above and below waterline but neither vessel sinks.
MOST LIKELY CONSEQUENCE IMPACTS
WORST CREDIBLE CONSEQUENCE IMPACTS
People
Possibility of minor injuries
Property
Damage to vessels requiring alongside repairs.
Environment
No pollution.
Stakeholders/ Economic
Loss of international service whilst repairs/investigation carried out.
International media interest.
People
Serious injuries and 1 fatality.
Property
Both vessels requiring repairs in dry dock. One vessel requires tow to dry dock.
Environment
300 tonne HFO lost to sea. Extensive oil slick may wash up on leeward shore lines. Possibility of containers lost overboard – hazard to navigation.
Long term damage from oil slick; dudongs, turtles, reefs and mangroves particularly affected.
Beaches polluted.
Stakeholders/Economic
Loss of international service whilst repairs/investigation carried out or replacement tonnage sourced.
Damage to reef fishing and local aquaculture.
Loss of local and national tourist income.
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
Glancing blow, plate indentation and some splitting above waterline requiring in water repairs.
Cargo tanks not ruptured due to structural protection.
Worst Credible Scenario
'T' bone collision. Extensive damage to both vessels above and below waterline but neither vessel sinks.
Cargo tank ruptured and possibility of fire/explosion.
MOST LIKELY CONSEQUENCE IMPACTS
WORST CREDIBLE CONSEQUENCE IMPACTS
People
Minor injuries possible.
Property
Damage to vessels requiring alongside repairs.
Environment
No pollution.
Stakeholders/Economic
Loss of international service whilst repairs/ investigation carried out.
International media interest.
People
Serious injuries and 1 fatality. Possibility of more fatalities if fire/ explosion occurs.
Property
Both vessel requiring repair in dry dock. One vessel requires tow to dry dock.
Environment
300 tonne HFO and 5000 tonnes of product lost to sea. Extensive oil slick may wash up on leeward shore lines.
Long term damage from oil slick; dudongs, turtles, reefs and mangroves particularly affected. Beach polluted.
Stakeholders/Economic
Loss of international service whilst repairs/ investigation carried out or replacement tonnage sourced.
Damage to reef fishing and local aquaculture.
Loss of local and national tourist income.
International media interest.


MARINE ACCIDENT
GROUNDING
FOUNDERING
COLLISION
DOMESTIC VESSEL (Cargo/Passenger)
SOLAS DRY CARGO VESSEL
SOLAS LIQUID BULK VESSEL
SOLAS PASSENGER VESSEL
Most Likely Scenario
Glancing blow, plate indentation and some splitting above waterline requiring in water repairs. Some damage to equipment.
Fuel tanks not ruptured due to structural protection.
Worst Credible Scenario
'T' bone collision. Extensive damage to both vessels above and below waterline but neither vessel sinks. 1 bunker tank ruptured.
MOST LIKELY CONSEQUENCE IMPACTS
WORST CREDIBLE CONSEQUENCE IMPACTS
People
Minor injuries likely
Property
Damage to vessels requiring ship yard repairs. Cruise terminated and passengers flown home. Subsequent cruises cancelled until repairs completed.
Environment
No pollution
Stakeholders/ Economic
Passengers dissatisfaction and cruise line's reputation diminished.
Loss of local and national income from cruise tourism. International media interest.
People
Serious injuries and possibility of up to 15 fatalities.
Property
Both vessels requiring repairs in dry dock. One vessel requires tow to dry dock.
Environment
300 tonne HFO spilt. Extensive oil slick may wash up on leeward shore lines.
Long term damage from oil slick; dudongs, turtles, reefs and mangroves particularly affected.
Beaches polluted.
Stakeholders/ Economics
Loss of international service whilst repairs/investigation carried out or replacement tonnage sourced.
Damage to reef fishing and local aquaculture.
Loss of local and national income from cruise and air tourism.
International media attention.

ANNEX C

VANUATU TRAFFIC METHODOLOGY

ANNEX C CONTENTS

FIGURES

1 INTRODUCTION

This technical annex provides detailed information on the process by which data was prepared for the vessel traffic analysis. The principal input for this study was Automatic Identification System (AIS) positions of vessels moving through the study area. This was satellite derived, giving it the acronym S-AIS. Although the positions are broadcast at regular intervals, the data could only be received when a satellite was overhead. This led to significant gaps in the data that presented a coarse and unrealistic representation of traffic movements.

For the benefit of this study therefore it was necessary to augment the S-AIS with other data sources to improve the quality of the analysis. This document will outline the steps taken to achieve the vessel traffic analysis contained in this report. Any limitations or assumptions will be outlined and when measures are taken to mitigate these then they will be described fully.

The steps undertaken in summary were:

- Decode raw NMEA data;
- Geocode into a GIS;
- Join points to form tracks;
- Use port movement data and cruise ship stop information to re-route vessels; and
- Extrapolate and re-route other vessels.

2 DATA SOURCES

2.1 THE AUTOMATIC IDENTIFICATION SYSTEM

The Automatic Identification System (AIS) was developed at the turn of the century as an aid to collision avoidance between vessels. A transponder is carried by vessels that broadcast key information about themselves (such as size and type) and their actions (speed, course) at regular intervals on a VHF bandwidth. Vessels carrying an AIS receiver are able to see these vessels and act accordingly. AIS operates in two forms, Class A and Class B, the former has priority and includes all vessels required to carry AIS by the International Maritime Organisation (IMO) mandate. Class B is used mainly by fishing vessels and recreational craft.

Those vessels required to carry AIS as dictated by SOLAS Chapter V[1] are:

All ships of 300 gross tonnage and upwards engaged on international voyages and cargo ships of 500 gross tonnage not engaged on international voyages and passenger ships irrespective of size shall be fitted with AIS [at the latest by 31 December 2004].

AIS Class A uses a time-division multiple access (TDMA) scheme on a VHF frequency where vessels transmit packets of dynamic and static information on different time-slots. There are 2250 26ms "slots" each minute, known as a "frame" and two dedicated AIS frequencies (AIS 1: 161.975 MHz and AIS 2: 162.025 MHz[2]). Static data of vessel information is broadcast every 6 minutes and dynamic information is broadcast at intervals dependent on the speed and type of the vessel. The normal reporting interval for Class A AIS[3] is:

- 3 minutes for a vessel at anchor (speed of less than 3 knots);
- 10 seconds for a vessel on transit (speed less than 14 knots);
- 4 seconds for a vessel on transit and changing course;

---

[1] SOLAS Chapter V, Regulation 19, section 2.4 (2002).

[2] IALA (2011). IALA Guideline No. 182: On an overview of AIS.

[3] IMO (1998). Resolution MSC.74(69) Adoption of New and Amended Performance Standards.

- 6 seconds for a vessel on transit (speed between 14 and 23 knots); and
- 2 seconds for a vessel on transit (speed greater than 23 knots) or changing course (speed greater than 14 knots).

For Class B the reporting interval differs further:

- 3 minutes for a vessel at anchor (speed of less than 2 knots); and
- 30 seconds for a vessel on transit (speed greater than 2 knots).

2.2 LONG-RANGE IDENTIFICATION AND TRACKING

The Long Range Identification and Tracking (LRIT) system is a designated IMO system designed to collect and disseminate vessel position information received from IMO member states ships that are subject to the Convention for the Safety of Life at Sea (SOLAS).

The obligations of ships to transmit LRIT information and the rights and obligations of SOLAS Contracting Governments and of search and rescue services to receive LRIT information are established in regulation V/19-1 of 1974 SOLAS Convention[4].

The system is global, secure and the shipboard equipment will accept remote commands from the flag states authorised, represented to increase the response rate to as a high as once a minute. The system was initially set up for the purposes of maritime security, but was soon extended for use in areas such as Search and Rescue (SAR), maritime safety and protection of the maritime environment.

The LRIT regulations apply to the following ship types engaged in international voyages who must report their positions to their flag administration at least four times a day:

- All passenger ships including high-speed craft;
- Cargo ships, of 300 gross tonnage and above; and
- Mobile offshore drilling units.

The system is independent of the communication method and can be transmitted via satellite or land based stations.

[4] International Mobile Satellite Organization (2012). Long Range Identification and Tracking of Ships (LRIT) [online]. Accessed on 15/11/2012. Available at http://www.imso.org/LRIT.asp.

For the purposes of this study LRIT data was not sought for the following reasons:

- LRIT data is not commercially available; and requests to the relevant flag states would be cumbersome;
- LRIT is limited in the number of ships that participate in comparison to AIS;
- It would be unlikely that LRIT data would be available from a single source over the entire South Pacific study area;
- S-AIS would be received in bursts that would indicate the vessels trajectory over several minutes when a satellite is overhead, which is advantageous for analysis over a single LRIT data point; and
- The constellation of S-AIS coverage is increasing every year and therefore if any further updates to this study are undertaken an improved but similar dataset could be implemented.

2.3 SATELLITE AIS DATA

The normal effective recording range of AIS is approximately equal to the range of VHF wave propagation and calculated by the formula:[5]

$$Range\ (nm) = 2.5(\sqrt{H} + \sqrt{h})$$

Where:

- H is the height of the receiving antenna (m); and
- h is the height of the transmitting antenna (m).

This range limits most shore stations to an effective range of between 20 and 50 nautical miles. The Vanuatu study area is considerably outside this range from any dedicated AIS recording stations and data was required from another source, namely a satellite based system.

Marico contacted exactEarth[6], a market leader in the field of global AIS vessel tracking, to provide a dataset for this study. exactEarth provide vessel monitoring solutions to commercial organisations and government

[5] IALA (2002). *IALA Guidelines on the Automatic Identification System (AIS), Volume 1, Part II – Technical Issues Edition 1.1*, Section 16.1.

[6] http://www.exactearth.com/

bodies by use of a dedicated constellation of satellites and a network of ground stations.

exactEarth's satellites orbit the earth in 90 minutes in a north-south direction, continually passing over different areas as the planet rotates. During each pass the satellite records as much AIS as possible, with an orbit of 650km the effective field of view is approximately 5,000km in diameter.

A satellite derived AIS dataset has a number of advantages over other formats:

- The system provides total and ubiquitous coverage of the study area during each sweep;
- AIS is carried by the majority of world shipping and is increasingly carried by smaller vessels such as fishing and recreational craft; and
- The system provides AIS in bursts during each sweep that increase the number of data points and improve the interpretation of the vessels behaviour in the analysis.

3 DATA PROCESSING METHODOLOGY

Raw NMEA AIS data was received from exactEarth's satellite recording system for the entirety of the study area. This data required processing and augmentation to enable useful analysis to be undertaken upon it. **Figure 1** below outlines the methodology by which the data processing was undertaken.

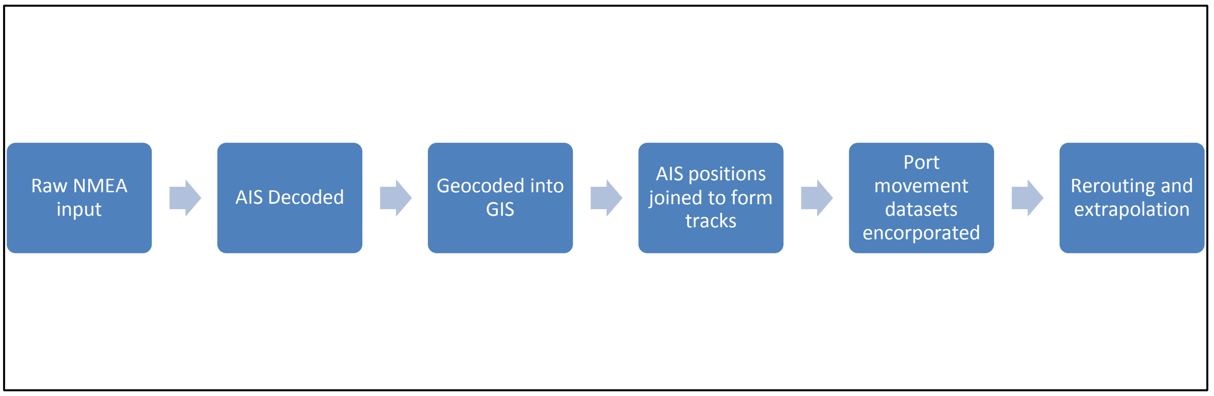


Figure 1: Vessel Traffic Analysis Process.

3.1 RECEIVED DATASET

The S-AIS was received as raw NMEA[7] encoded AIS data with a base station time stamp. This data was decoded by Marico to produce a series of discrete points representing each AIS position recorded. The entire dataset was in excess of 1.3 million recorded positions. **Figure 2** shows the full extent of the South Pacific S-AIS dataset.

[7] The NMEA format is the only uniform interface standard for digital data exchange between marine products and is the default data encoding method by which AIS operates.

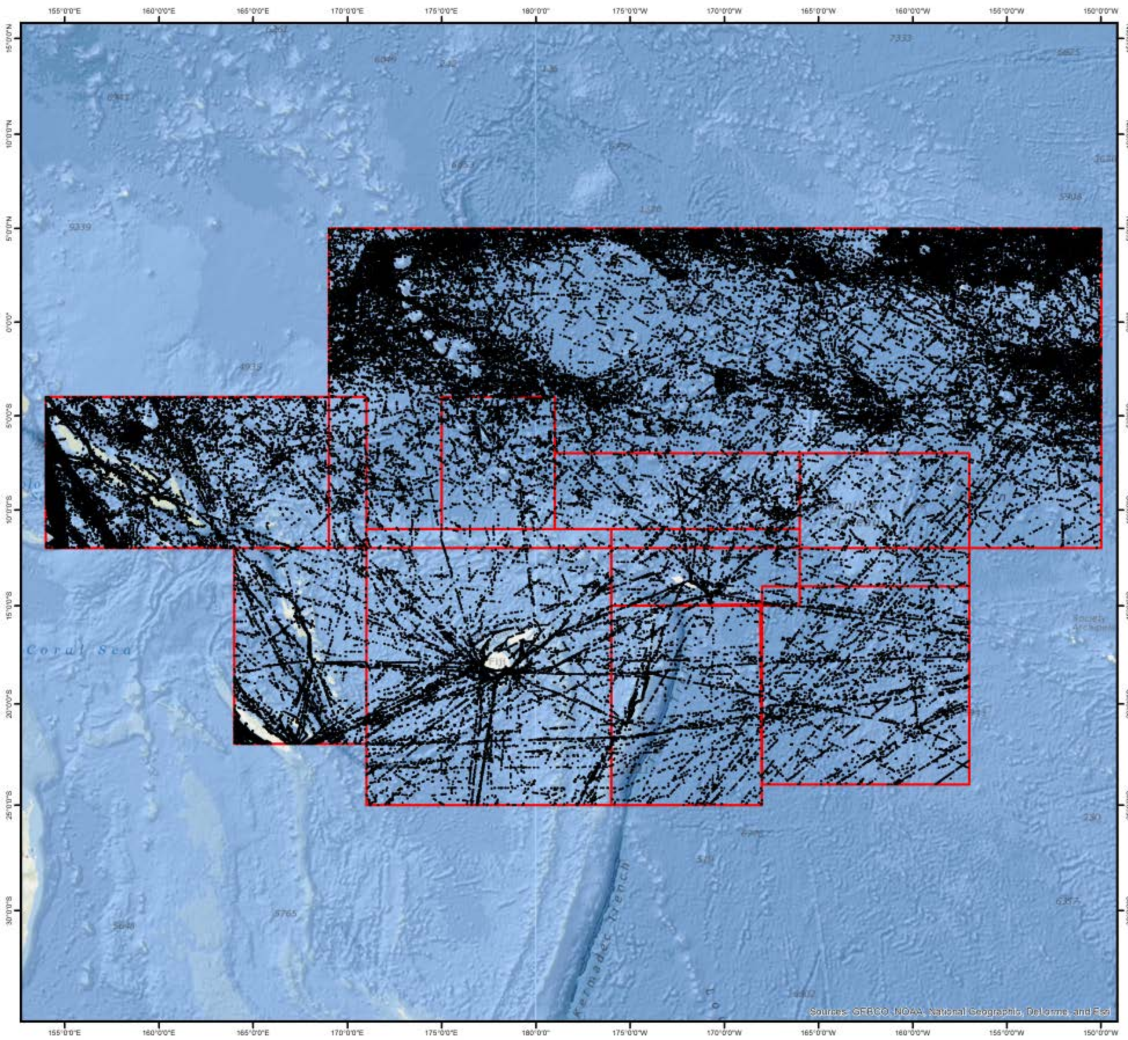


Figure 2: All recorded AIS positions, January to March 2012.

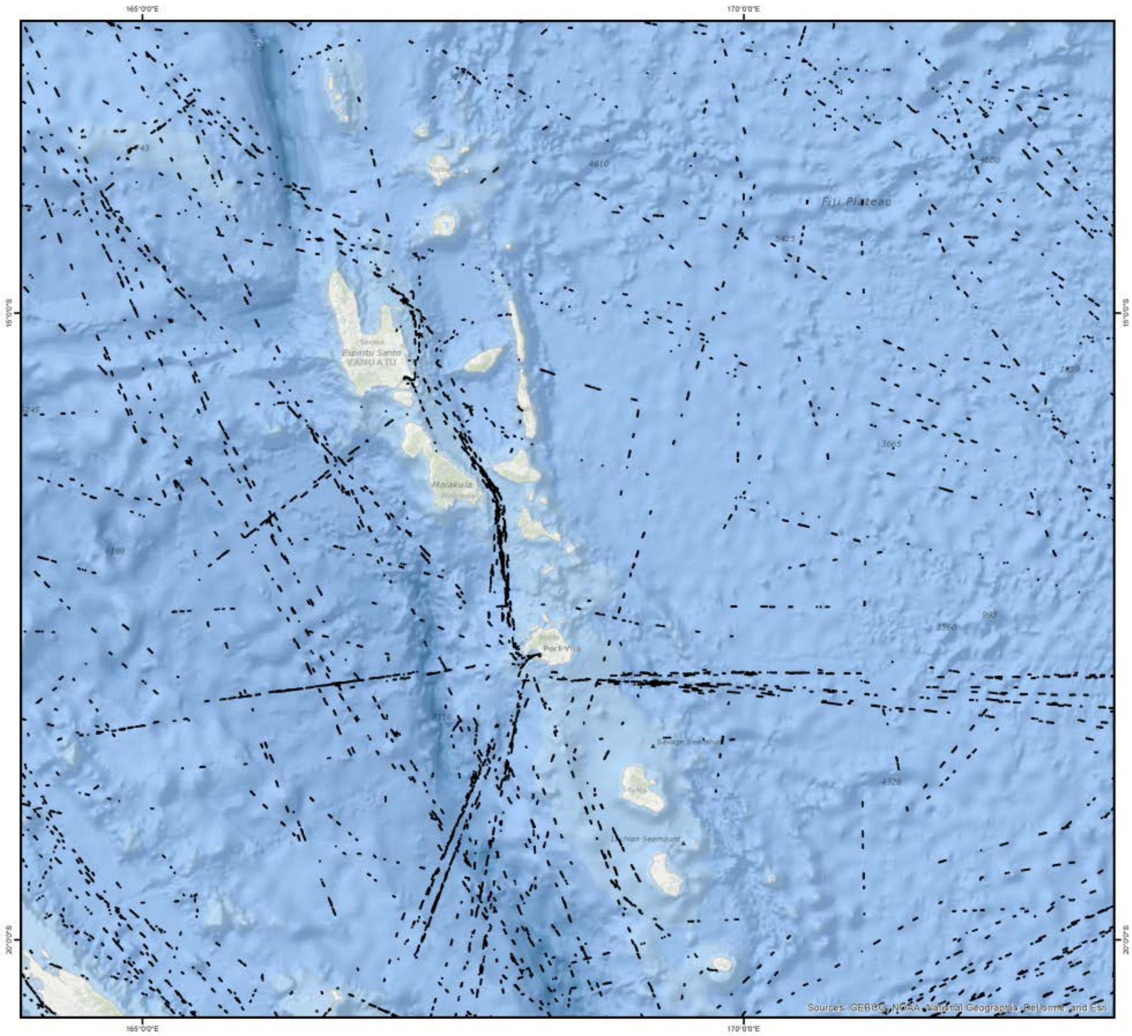


Figure 3: S-AIS positions in the vicinity of Vanuatu, January to March 2012.

For the purposes of this analysis, supplementary data was used to include traffic movements between May and 15th July 2012. This extent was chosen after a site visit in which a seasonal variation in traffic was identified as a result of the land diving events on Pentecost. This dataset was limited to the central islands of Vanuatu. The supplementary data and its geographical bounding box are contained in **Figure 4** below.

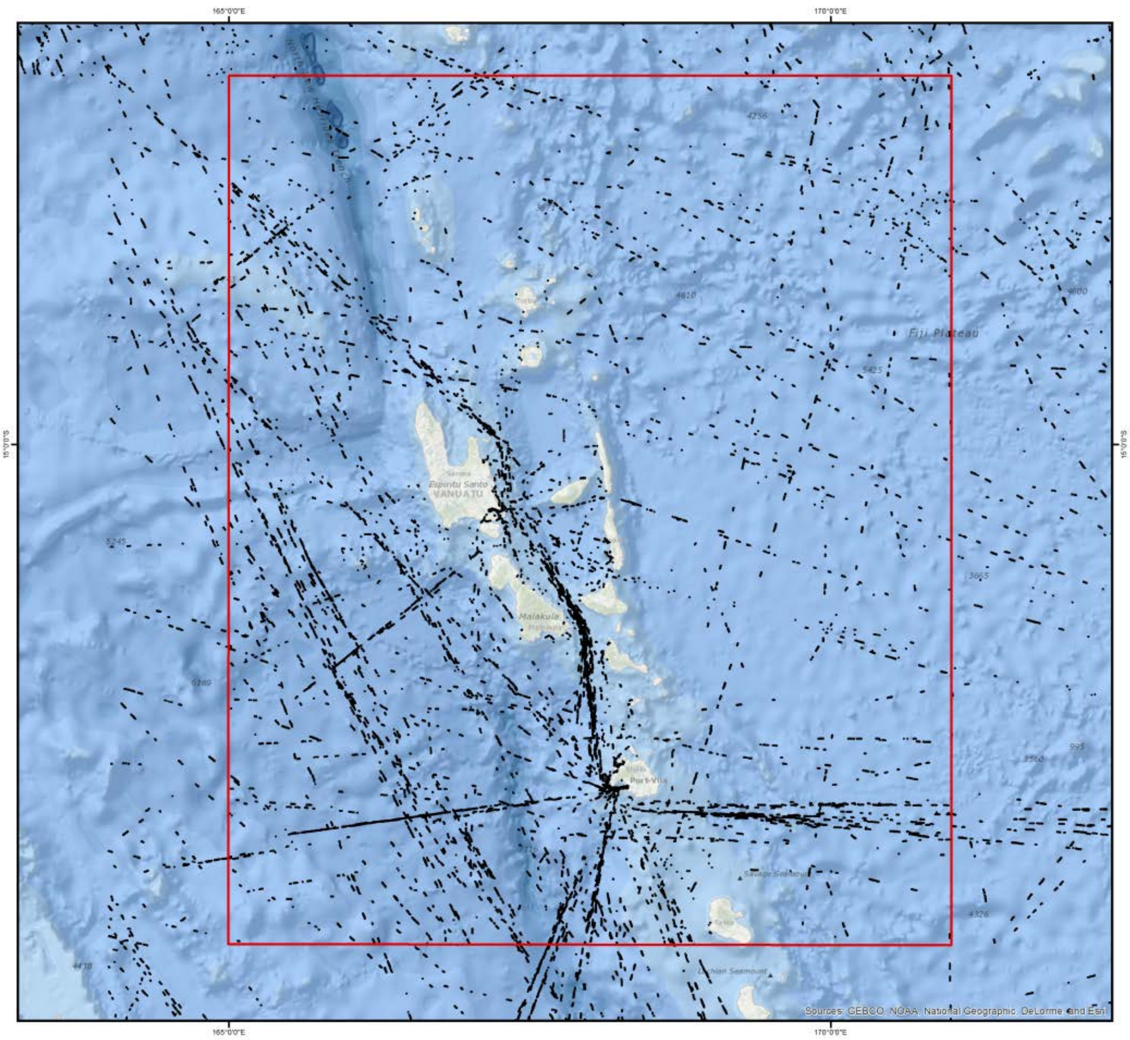


Figure 4: S-AIS positions January to July 2012.

3.1.1 S-AIS Interval Analysis

It is necessary to understand the nature of the received data to conduct a robust analysis; in particular, attention must be directed towards the time interval between transmissions.

Figure 5 and **Figure 6** chart the number of transmissions for each day during the two data extents. The charts show that, although there is some fluctuations in the received daily numbers, there is very little downtime.

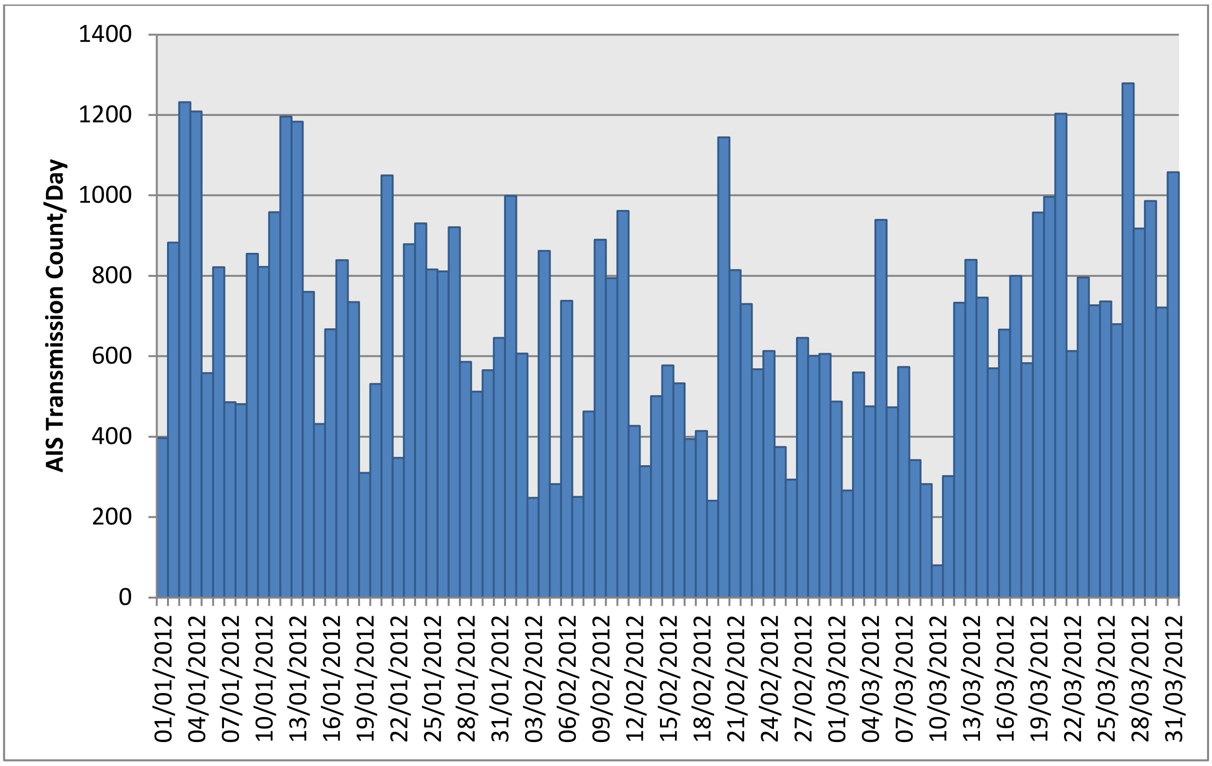


Figure 5: AIS Transmissions/Day (January to March 2012).

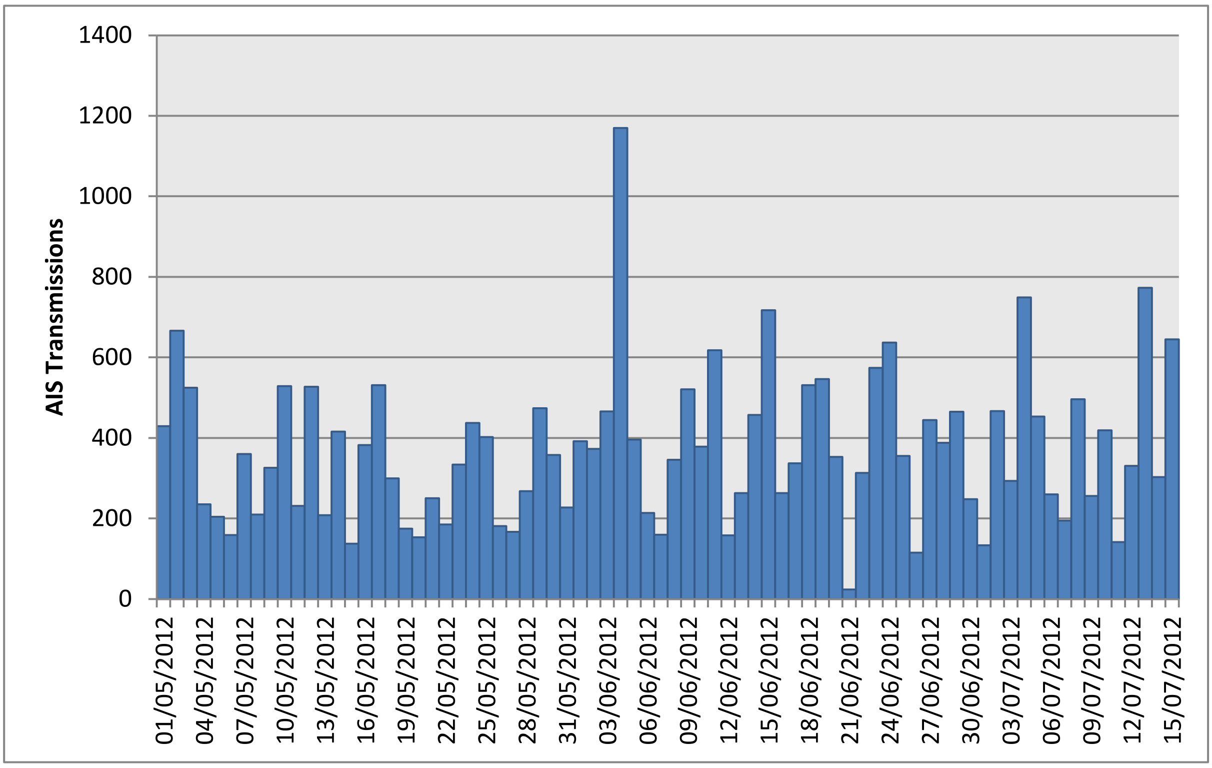


Figure 6: AIS Transmissions/Day (May to Mid-July 2012).

Figure 7 and **Figure 8** show the number of received transmissions for each hour of the day (Universal Time). It is clear from both data extents that Vanuatu has S-AIS Coverage for two periods, at 12:00 UT and at 00:00 UT. The coverage is sustained for approximately four hours during which time the satellite passes around the earth and so coverage is lost for an hour.

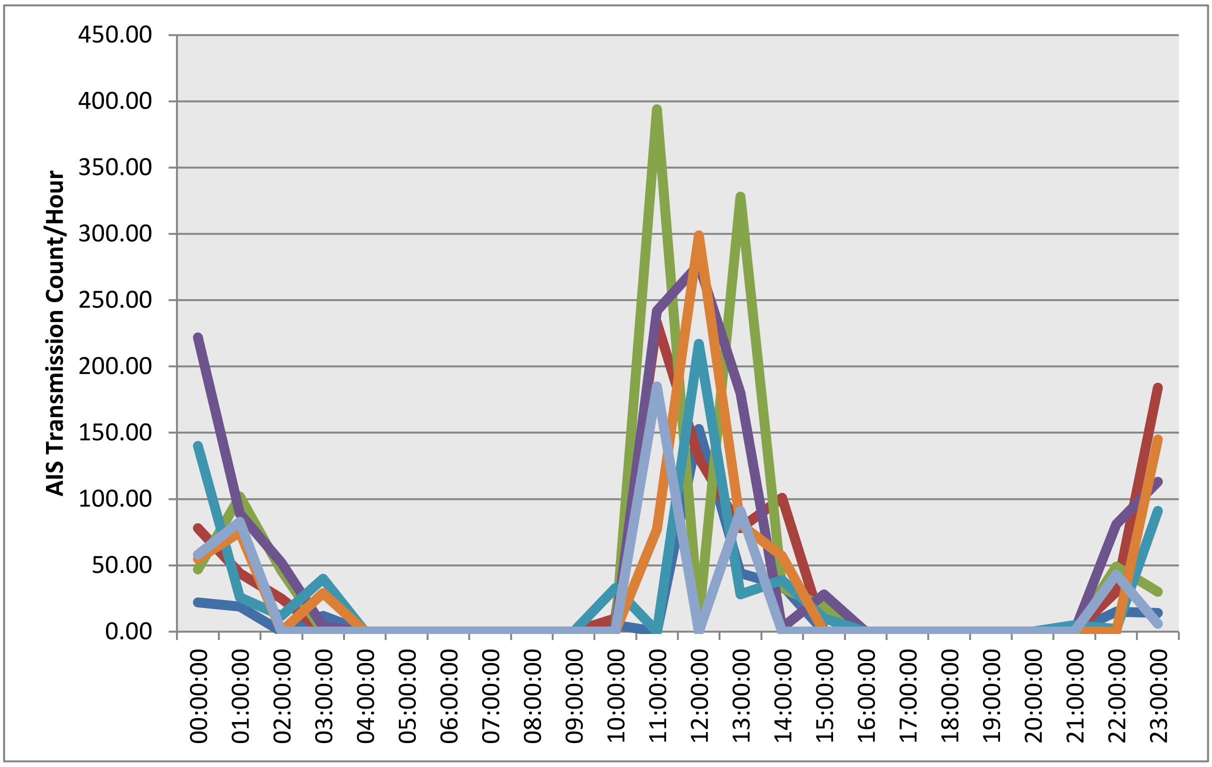


Figure 7: AIS Transmission/Hour (1st to 7th January 2012).

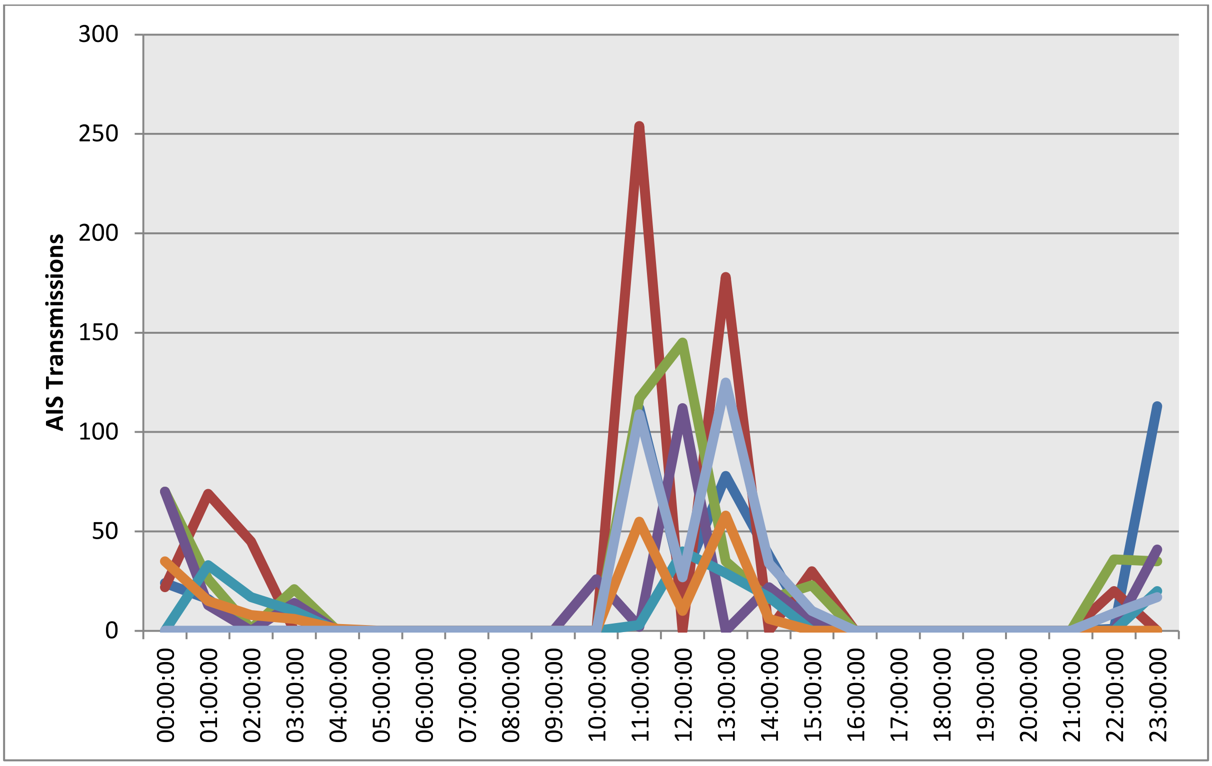


Figure 8: AIS Transmission/Hour (1st to 7th May 2012).

This pattern of AIS transmission leads to the manifestation of the data in a particular way. **Figure 9** shows the interval between AIS transmissions on a logarithmic scale. The pattern shows two distinct groups, a burst of low interval transmissions (**Figure 10**) when a satellite is overhead and a much greater interval between satellite passes.

Of further note is the greater consistency in the greater spread of intervals in the May to July dataset as compared to the January to March. exactEarth's coverage is continually being improved and, between the two datasets, greater satellite coverage and data extraction has increased the amount of data extracted.

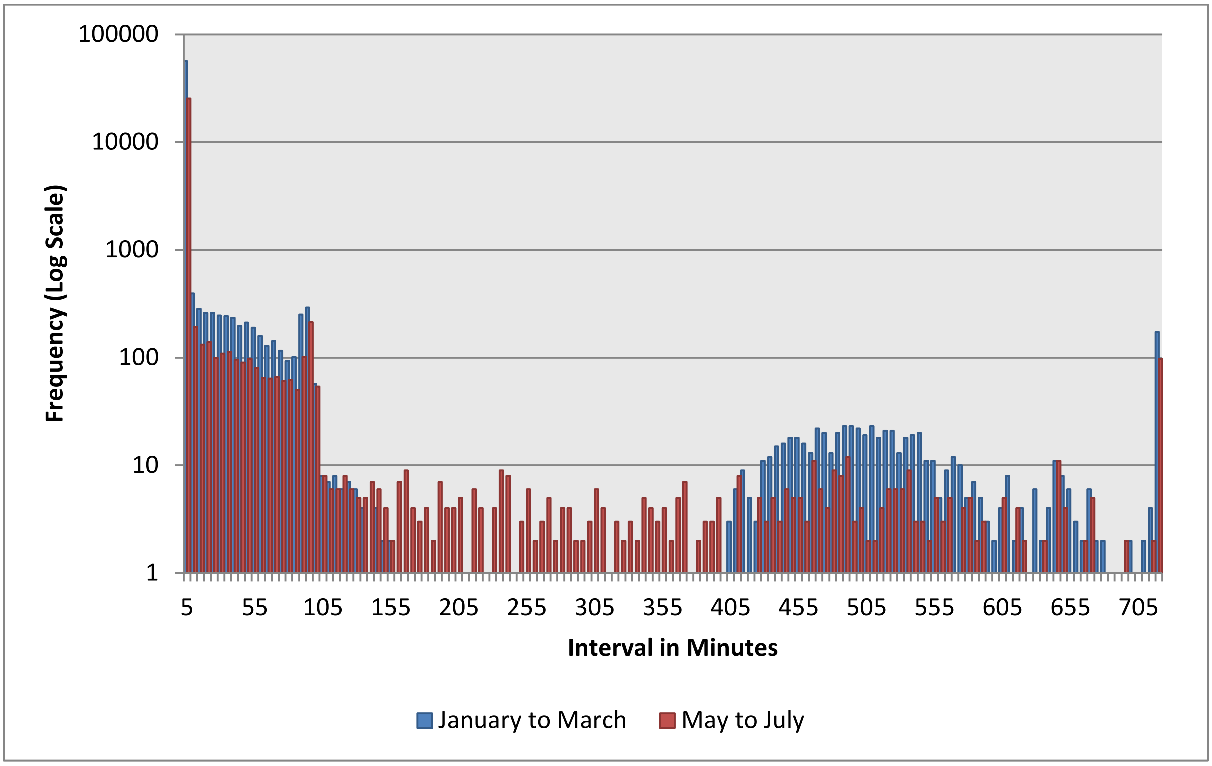


Figure 9: Interval between received AIS transmissions.

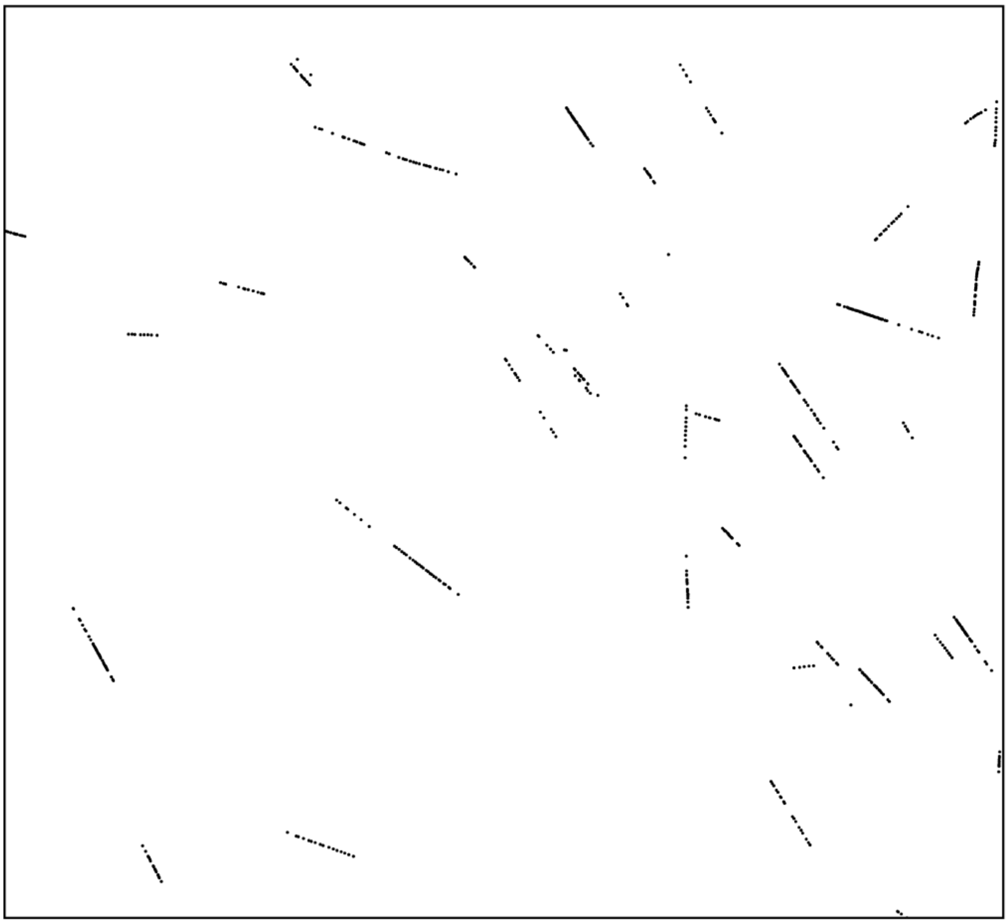


Figure 10: Characteristic S-AIS "Bursts".

3.2 TRACK CREATION

In order to produce a meaningful analysis it was necessary to convert these isolated AIS points into vessel track lines. A dedicated terrestrial based AIS system allows points to be connected as lines and the resulting network representing vessel movements. However, the time interval between received transmissions was great, such that a tailored approach must be taken (see **Section 3.1.1**).

Figure 11 below shows vessel track lines created, such that each line connects an individual vessel and that no line is created if the time interval between AIS points is greater than 48 hours.

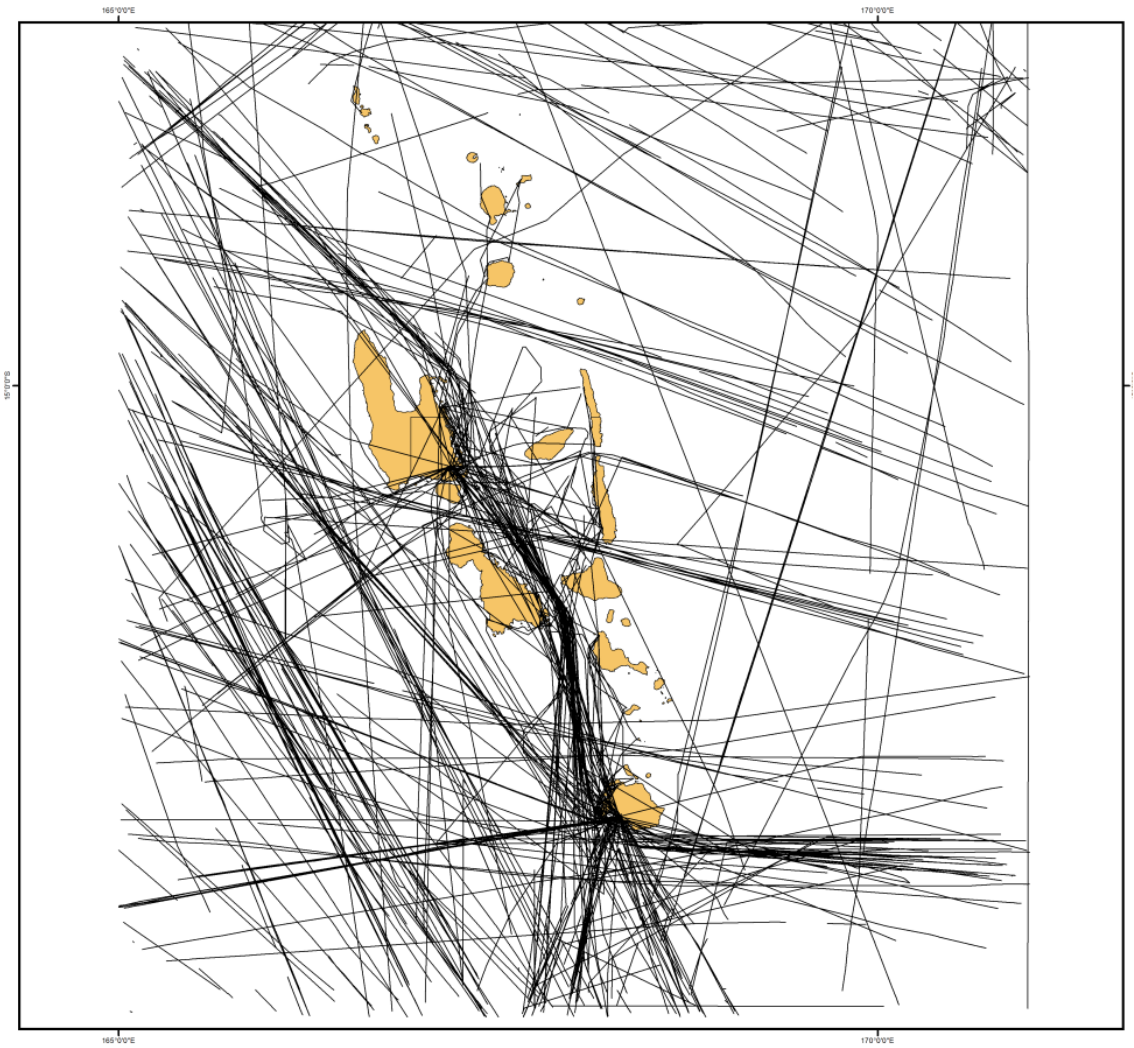


Figure 11: Unrefined Vessel Tracks

This plot shows the coarse nature of tracks and the coarse nature of the analysis that would be based on the unrefined tracks. In particular areas of fine navigation, such as around ports or constrained channels, the vessel tracks would be unreliable. **Figure 12** shows the spurious tracks that would result from this approach, with a number of vessels transiting across land. These tracks cannot be simply discounted as this would skew the analysis into suggesting that fewer vessels transited in areas of fine navigation and so data processing was required.

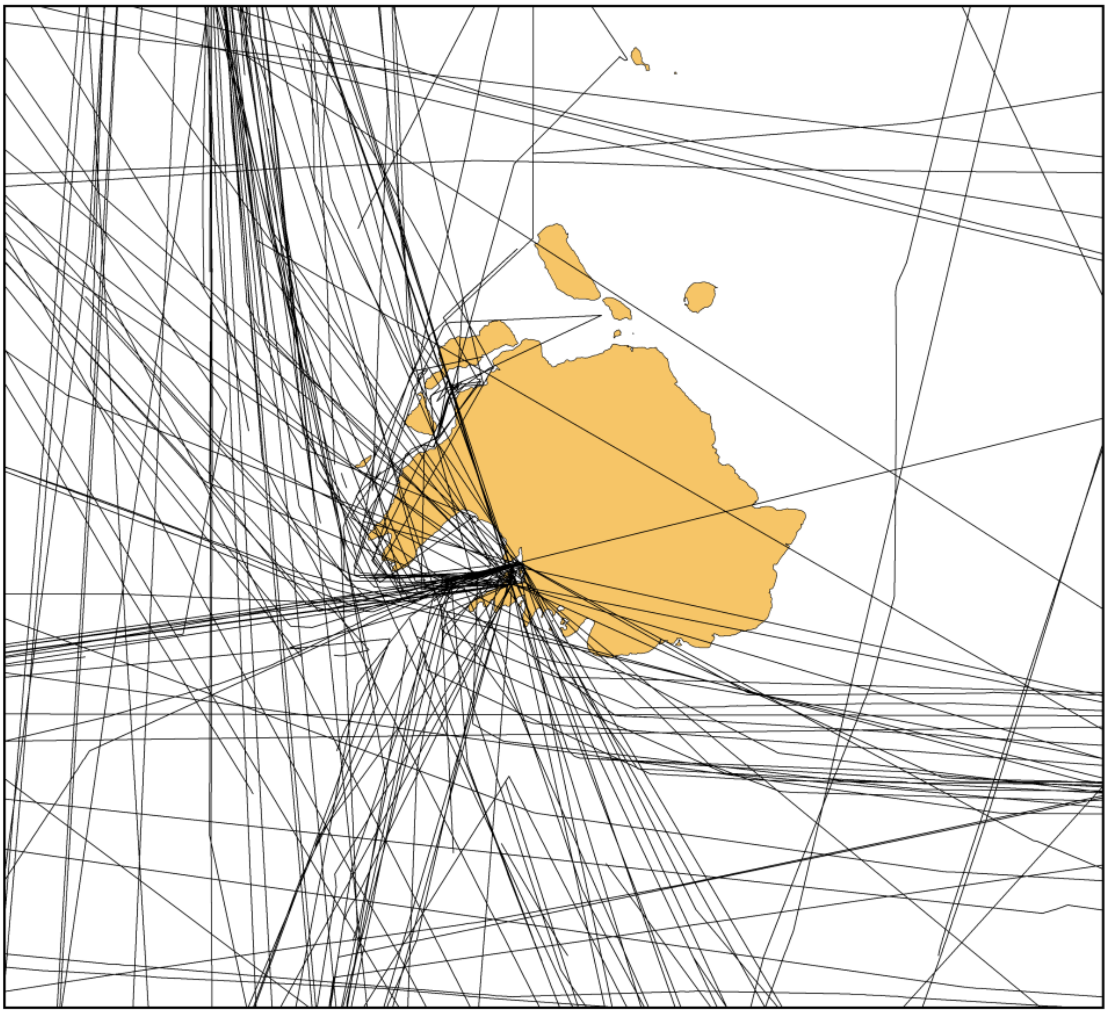


Figure 12: Unrefined Vessel Tracks around Port Vila.

3.3 AUGMENTATION METHOD

A number of techniques were used to improve the vessel traffic for use in the analysis of this study. Draft tracks were created by:

- Ordering AIS transmissions by the vessel MMSI number and the transmission time;

- Connecting points of identical vessel type in a time order to form track lines[8]; and
- Removing lines between points greater than 48 hours apart.

A series of vessel tracks was produced that required further augmentation (see **Figure 11** and **Figure 12**).

3.3.1 Port Movement and Cruise Ship Destination Data

During a site visit, Marico obtained the complete records from Vanuatu's principal ports of Port Vila and Luganville (Santo). This data represents a definitive list of all arrivals and departures from these ports for the last three years. Furthermore, cruise ship calls at popular destinations such as "Champagne Beach" and "Mystery Island" were also used. The dataset could be used to ensure that all vessels recorded during the dataset extent were correctly accounted for in the traffic analysis, even if the AIS alone was not precise enough. The list of data sets used to augment the AIS data in Vanuatu are outlined below:

- Port Movements Luganville;
- Port Movements Port Vila;
- Mystery Island Cruise Visits;
- Champagne Beach Cruise Visits;
- Port Talbot Cruise Visits; and
- Wala Island Cruise Visits.

The time intervals between transmissions were such that it would not be possible to precisely plot the fine routes that vessels had taken once inside the port approaches. However, by utilising the port movement datasets we can discern the name and date of arrival or departure of all large vessels. To enter the port these vessels must transit through a navigational channel and we can therefore simulate the route that these vessels took.

This method was necessary for two reasons; firstly vessels needed to be routed to their likely channel to improve the subsequent analysis, rather

[8] Due to multiple satellites and multiple base stations having different reception times, it was possible for some points to jump from the sequential order. For example if two satellites receive the same position at slightly different times it is possible for data to show a "jump back" along the course periodically. To mitigate this only one AIS position was used for each minute.

than transiting over land. Secondly, if for some reason a satellite orbit failed to detect a vessel's AIS when alongside in port, the tracks would pass by the port suggesting the vessel had not stopped. By using the port movements' dataset, all transits can be accounted for even if the S-AIS does not suggest the vessel visited that port. When a discrepancy between port movements and S-AIS is identified then the assumption is made that the port movement data is more accurate.

Two routes were created out of each of the ports aligned to the main channels. The port arrival and departures dataset was assigned to the respective routes and vessel tracks created for each movement in and out of the port. A randomised point generator was used to offset the tracks by up to 100m from the defined routes to improve visual interpretation.

These routes made all AIS information inside the port approaches to be redundant and so were relocated to the end of the approach channel. Each port therefore had a defined route with simulated AIS data for their arrivals and departures with all actual vessel tracks connecting to the ocean side limits of these routes.

A before and after comparison of the vessel routeing through Port Vila is presented in **Figure 13** below. Both the instances of cross-land transits have been altered and all port movements are now properly accounted for. The analysis undertaken upon the augmented data would be of a considerably greater quality.

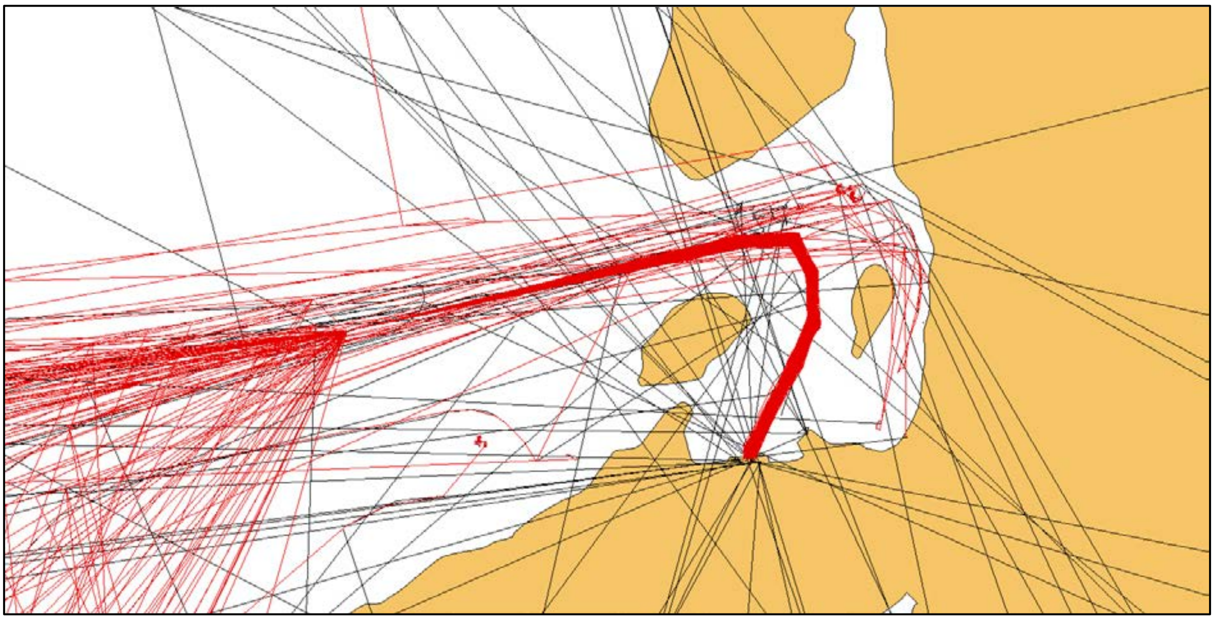


Figure 13: Unrefined Vessel Tracks (Black) with Refined Tracks (Red)

Smaller vessels that were not recorded in the port movement's dataset (such as yachts) were routed manually through the channel.

3.3.2 Track Extrapolation

At the extremities of the study area, vessel track lines would not reach the boundary box of the study area. The cause of this was that the track lines would end when the last transmission had been received and so it was possible that eight hours before a vessel reached the edge of the study area here, track would stop (**Figure 14**).

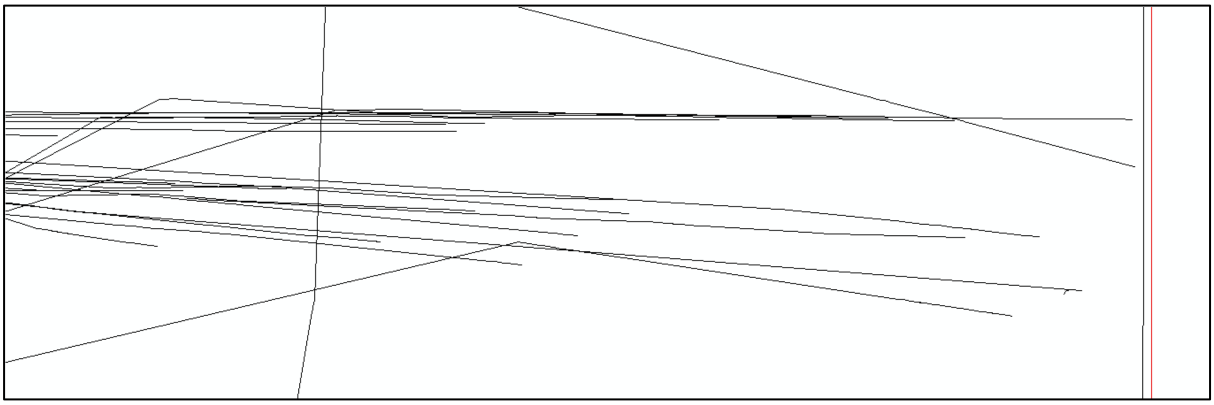


Figure 14: Vessel Tracks Ending Short of Study Area Boundary.

To account for this, track lines were extrapolated to the edge of the study area. An algorithm was created to cycle through the S-AIS data, identify tracks that ended within 150km of the boundary box, and provided their course had remained within 25 degrees for the last hour; the track line was extrapolated 150km on that course. Finally, the extrapolated tracks were clipped to the study area.

This augmentation is purely for visual purposes to identify vessels with a constant bearing that stop short of the study area extent. An assumption is made that those vessels near the limits of the study area that fulfil a course condition will continue to have a steady bearing.

3.3.3 Manual Routing

The final method of augmentation was to identify and manually route those vessels that had spurious tracks. In particular given the coarse nature of the data a large number of vessel tracks suggested an overland route. All tracks that intersected with the shape of the land were selected and each one was manually routed along their likely course line. Although possible to automatically re-route around a headland using an exclusion buffer, it was deemed better to manually re-route to ensure that the likely distance off the headland for which vessels transit could be interpreted as this would have a major impact on the subsequent risk assessment.

Information that was used to create new vessel tracks included:

- Vessel's historic activity using the assumption that many of the vessels repeat regular course lines;
- Characteristics of the vessel, in particular type and draught to provide appropriate routeing around any significant obstacles; and
- Other vessels behaviour, in particular the distance vessels of a similar size keep offshore and their transit route through the islands.

For example, **Figure 15** below suggests wrongly that the two cruise ships track across land.

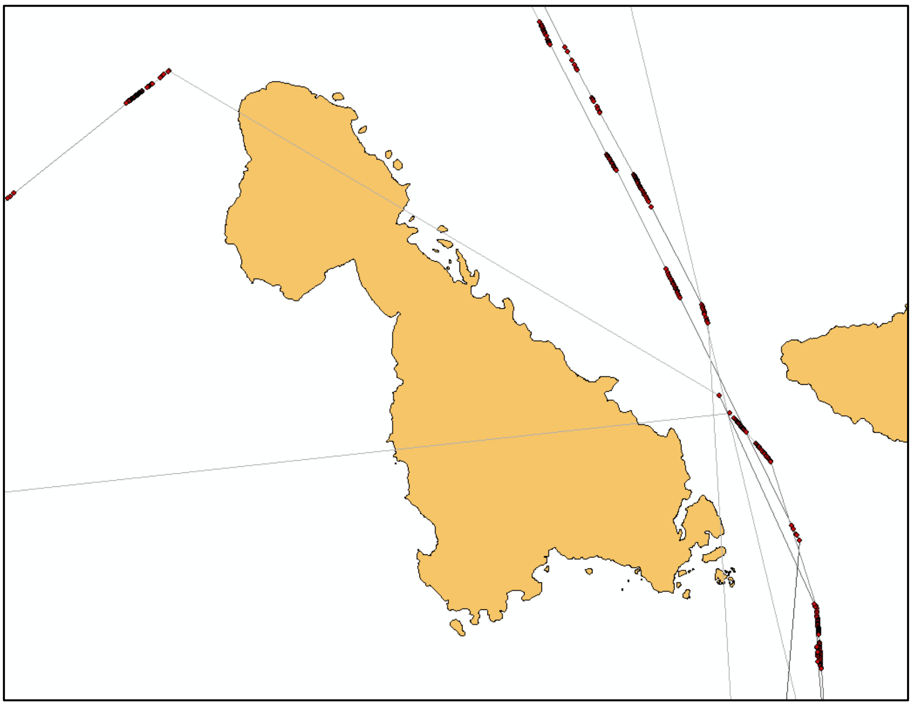


Figure 15: Vessel Track Missing Corner.

A secondary error was identified in **Section 3.3.1** where a discrepancy occurred between port movement data and AIS tracks. If a vessel is recorded in the port movement records but AIS is missed then the tracks would wrongly suggest the vessel transits passed the port without stopping.

This error was identified by selecting all tracks that transited within 100km of a port but which did not enter the port. Of these vessels the time interval was queried and when the interval was greater than 8 hours (the average satellite pass interval) then the resulting matches were cross-referenced with the port movement data. If a vessel was identified in this selection and did visit the port then new vertices in the track were created to divert the vessel track into the port and back out towards its next recorded position.

In **Figure 16** the satellite derived positions for *Pacific Jewel* are shown for three months. The track line shown is for a date when the ship is recorded as having entered Port Vila however missed AIS transmissions has drawn the vessel track past the port. The track was re-routed in line with historical positions.

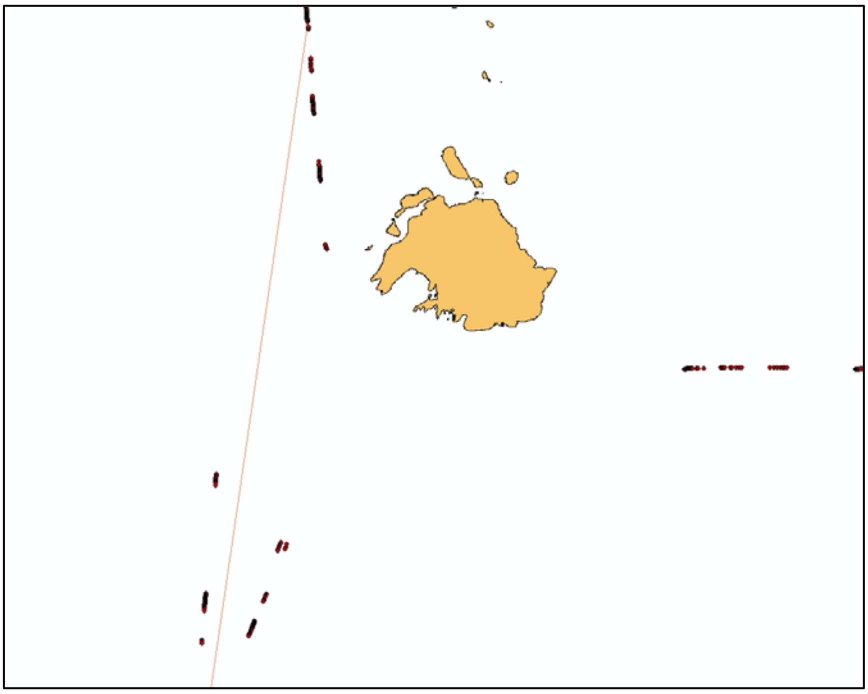


Figure 16: Cruise Ship's Track Suggesting a Passing of Port Vila.

4 FINAL RESULTS

A before and after comparison plot of the raw and augmented datasets is presented in **Figure 17** and **Figure 18** below. The plots show a considerable change in the quality of the data after augmentation that allows a far more robust analysis to take place.

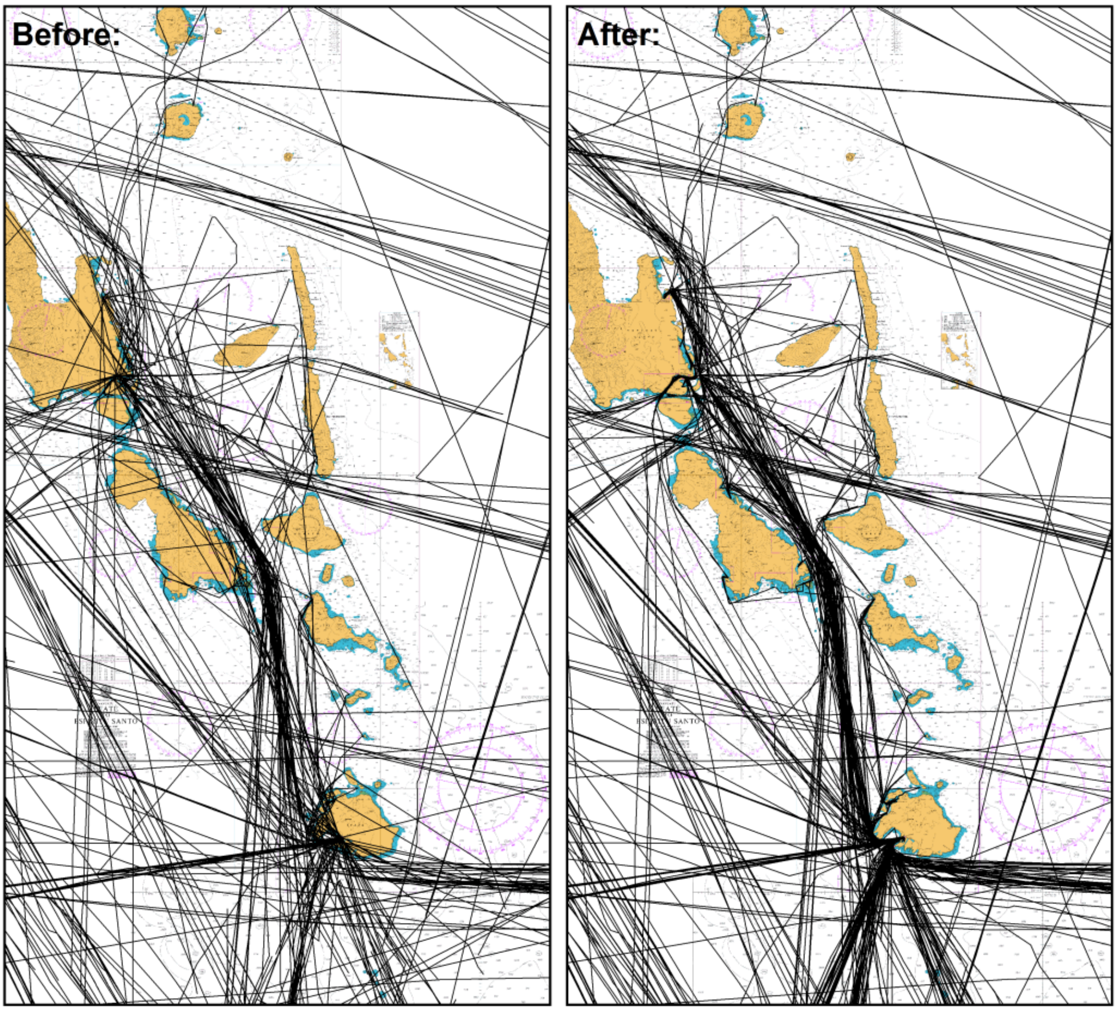


Figure 17: Comparison of Raw and Augmented Vessel Tracks.

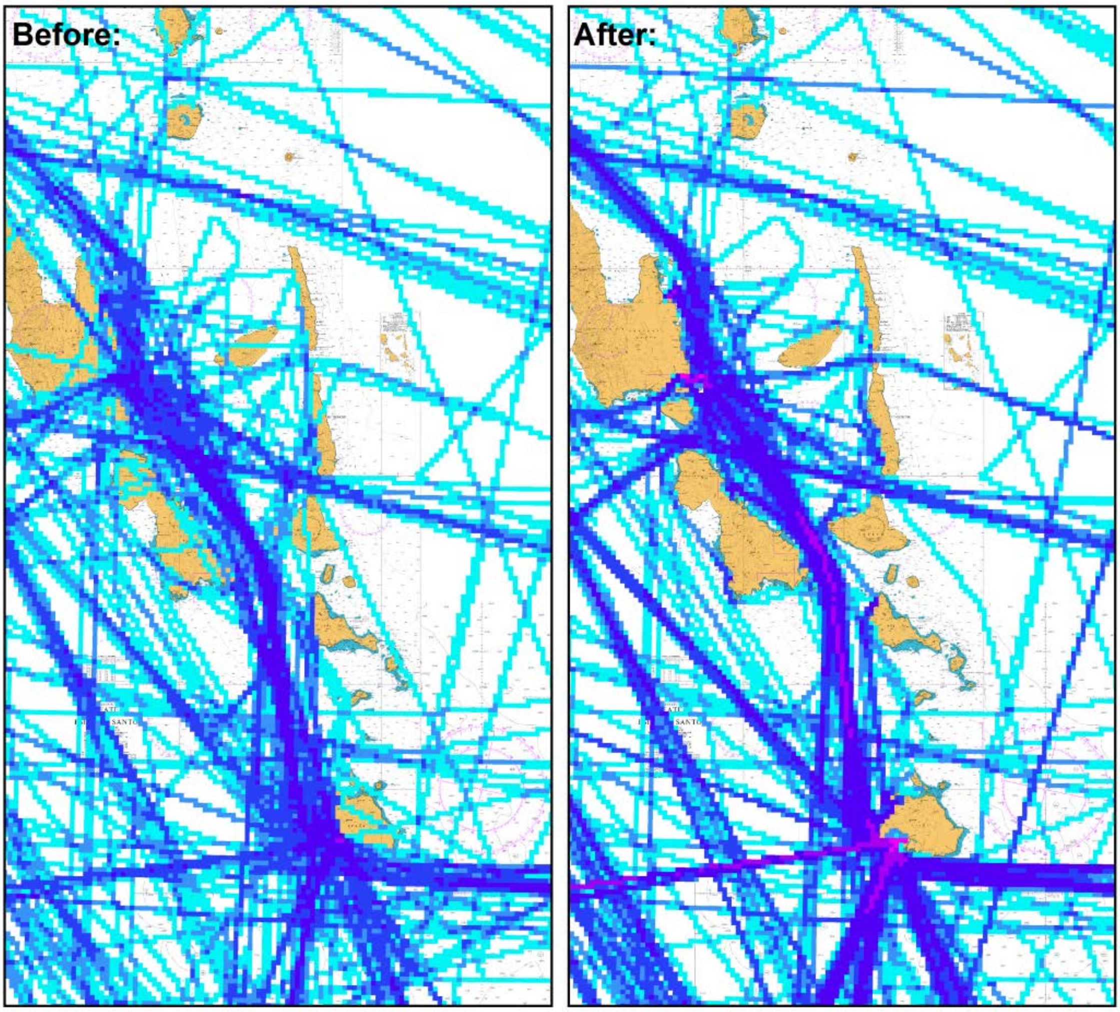


Figure 18: Comparison of Raw and Augmented Track Density.

ANNEX D

TECHNICAL ANNEX – RISK METHODOLOGY

A COMPARITIVE RISK ASSESSMENT OF SHIPPING

IN THE REPUBLIC OF VANUATU

CONTENTS

FIGURES

TABLES

1 INTRODUCTION

This technical annex describes the approach and results of an assessment of shipping risk in the vicinity of the Republic of Vanuatu. The islands of Vanuatu have experienced a large increase in commercial vessel traffic operating through their waters. Much of this growth is related to the number of large cruise ships stopping in Vanuatu's ports of Port Vila and Luganville, as well as visiting popular tourist destinations throughout the archipelago. This trend of growth is projected to continue.

A disparity now exists between the size of the vessels and the quality of the nautical charts used for navigation. Many of the charts used by vessels upwards of 60,000 gross tons date to the 1800s and mid-twentieth century and are in need of updating to modern standards. This study will identify areas of high shipping risk to aid decision making with regard to updating nautical charts.

The methodological approach undertaken is that of cartographic modelling through weighted overlay analysis in which a number of spatial datasets are combined to answer questions about spatial phenomenon. A Geographic Information System (GIS) was used to handle the multitude of datasets, undertake the analysis and present the results. This approach is advantageous as it is data driven, grounded with expert judgement and requires the identification and analysis of the relevant risk factors.

Vessel traffic analysis was undertaken on satellite derived AIS data for five months of 2012 to build a model of shipping movements through the archipelago. A number of aggravating and mitigating risk factors related to maritime risk were then identified and scored on a five point scale across the study area. Each risk factor was then weighted in terms of their relative importance to the final model and combined with the traffic analysis to produce a final cumulative plot of maritime risk in Vanuatu.

1.1 AIMS AND OBJECTIVES

The aims of this annex are to describe:

- A robust, risk based methodology for the prioritisation of hydrographic surveys;
- To investigate the comparative risk of a shipping incident in the Republic of Vanuatu; and
- To produce a plot showing the spatial distribution of shipping risk.

1.2 OUTLINE OF DOCUMENT

This document sets out the approach, methodology and results of the risk assessment of shipping in the vicinity of the islands of Vanuatu undertaken by Marico Marine.

- **Section 2** describes the theoretical approach taken in this document;
- **Section 3** details the methodological steps taken in this study;
- **Section 4** lists the independent variables used in this study and their sources;
- **Section 5** describes the variable weightings; and
- **Section 6** outlines the model results.

2 THEORETICAL APPROACH

2.1 THEORETICAL APPROACH TO RISK

Risk is inherent in all human activities. Maritime risk is often understood as a product of the frequency or probability of an undesired event occurring (P) and the expected consequences (C) (Kristiansen, 2004[1]), or as:

$$Risk = P \cdot C$$

The risk of a hazard can only exist if there is both a likelihood of occurrence and a detrimental effect of the occurrence. If a hazard has no possibility of occurring then there is no risk; likewise there can be no risk if there is no consequence. The consequence of a collision in a confined waterway may be extremely great however if no vessels transit a waterway then there is no risk. A risk model must treat these two variables as two sides of the coin.

[1] Kristiansen, S. (2004). *Maritime Transportation: Safety Management and Risk Analysis.* Butterworth-Heinemann.

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 1: Basic Risk Model.

2.1.1 Likelihood

Within the global shipping fleet of more than 180,000 vessels a considerable number of incidents occur every year. On average between 2000 and 2005, eighteen vessels collided, grounded, sank, caught fire or exploded every day. Every day two ships are lost from the global fleet and $4 million are paid out in claims (MCA, 2010).[2] There has therefore been a considerable amount of research undertaken to assess the factors that contribute to the causes of these incidents in an effort to mitigate them.

Probabilistic models of ship incidents attempt 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,

[2] Maritime Coastguard Agency, (2010). The Human Element: A Guide to Human Behaviour in the Shipping Industry. TSO.

introduced to maritime risk by MacDuff (1974)[3] and Fujii (1974)[4], 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.

$$Number\ of\ Incidents = Number\ of\ Candidates \cdot Causation\ Factor$$

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)[5], Montewka et al. (2011)[6] and Mullai et al. (2011)[7] as well as innumerable region specific assessments.

A summary of this literature can identify five broad groups of risk factors that contribute to the likelihood of an incident in a given waterway:

- **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);

[3] Macduff, T., (1974). The Probability of Vessel Collisions. *Ocean Industry*, 9(9), pp. 144-148.

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

[5] Kite-Powell, 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.

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

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

- **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).

2.1.2 Consequence

The consequences of a hazard can range from a slight delay in services in the case of a soft grounding to a major international disaster. Furthermore the consequences of an incident can differ by their affect. The consequence of a vessel grounding on a reef will be different if the vessel is a passenger vessel compared to an oil tanker.

It can be described that there are broadly four consequence categories, 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.

2.1.3 Cumulative Risk Model

Upon identification of likelihood and consequence risk factors, a risk model can be created. This model would combine the likelihood and consequence to produce a cumulative risk score.

2.2 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 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?”

Most Likely is the expected outcome of an incident under normal conditions (as opposed to the Worst Credible).

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.

Worst Credible is the worst outcome of an event that can be expected. The outcome must be credible, falling in line with the consequences of other maritime disasters and so is grounded in reality.

3 METHODOLOGY

The conceptual model for this study is described in **Figure 2**. **Section 2** has described how risk is the product of likelihood and consequence. In modelling risk posed to current traffic volumes we must include a third variable, namely the traffic profile of passing traffic. Risk requires the co-existence of three variables. Traffic must transit through an area, there must be a likelihood of that traffic to have an incident and there must be a consequence of that incident. By plotting the traffic profile, the factors that increase the likelihood of an incident and the factors that increase the consequence of an incident we can build a risk model.

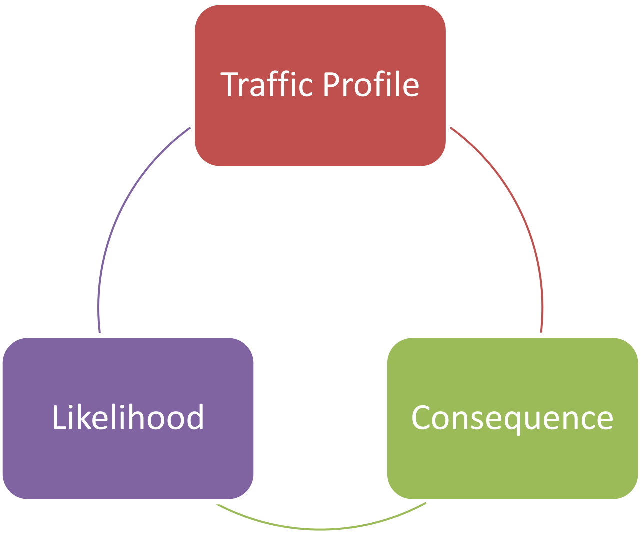


Figure 2: Conceptual Model of Methodology.

The model proposed is summarised in **Figure 3** below. The likelihood of an incident occurring in an area is calculated by quantifying the traffic volume, size and type transiting through the area as well as the existence of any aggravating risk factors whose presence or proximity could cause an incident. The consequence of that incident occurring is calculated by scoring the presence or proximity of aggravating consequence factors that would increase the damage. The final risk score is the product of the likelihood and consequence scores.

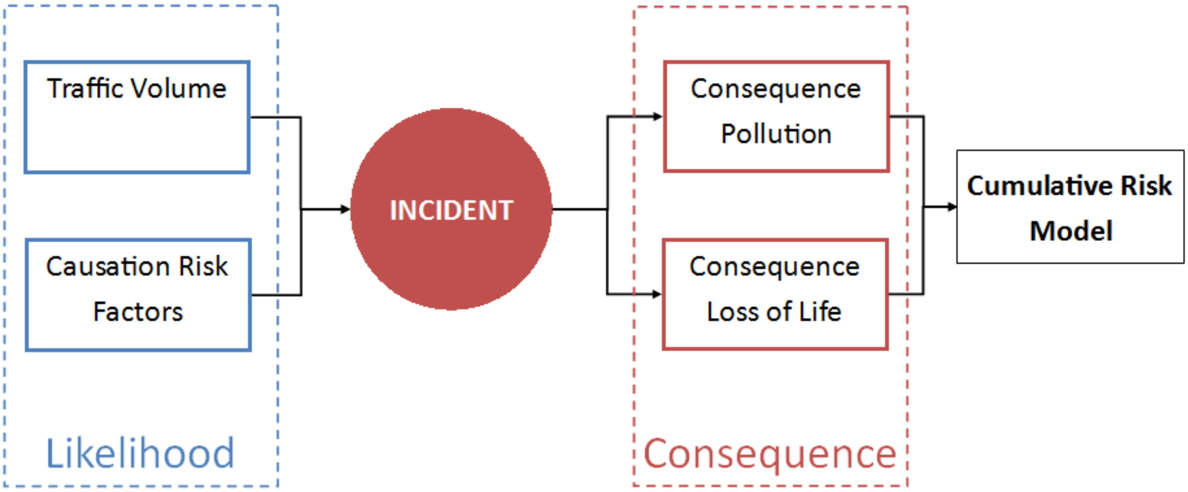


Figure 3: Proposed Risk Model

3.1 INTRODUCTION TO METHODOLOGICAL PROCESS

Spatial Modelling 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 risk model will be created by undertaking a spatial risk assessment by Weighted Overlay Analysis. A number of input variables are assembled for a study area and overlaid, a spatial calculation is then used to combine all inputs that overlay the same location and so output a final figure. Each input is weighted to signify the importance 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. **Figure 4** conceptualises the approach that weighted overlay analysis undertakes.

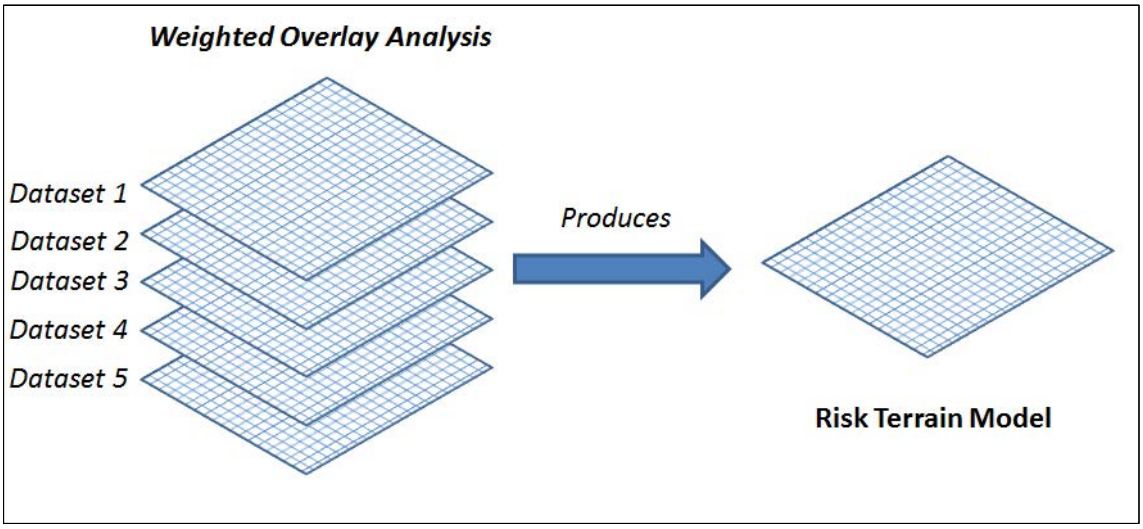


Figure 4: Relationship between Weighted Overlay and a Risk Terrain Model.

The method is outlined below:

- Identify aggravating and mitigating risk factors that are related to the outcome event (**Section 3.2** and **Section 4**);
- Geocode risk factors into a spatial data format (**Section 4**);
- Score risk factors in each location of the study area using a specified scale (**Section 4**);
- Weight significance of each individual factor (**Section 5**);
- Run risk model to form a composite map (**Section 6**); and
- Ground truth model (**Section 6**).

3.2 OVERVIEW OF MODEL VARIABLES

The risk score is dependent on a number of independent variables regarding the likelihood and consequence of an incident. The risk factors used in this study are grouped in **Figure 5** below and discussed in detail in **Section 4**.

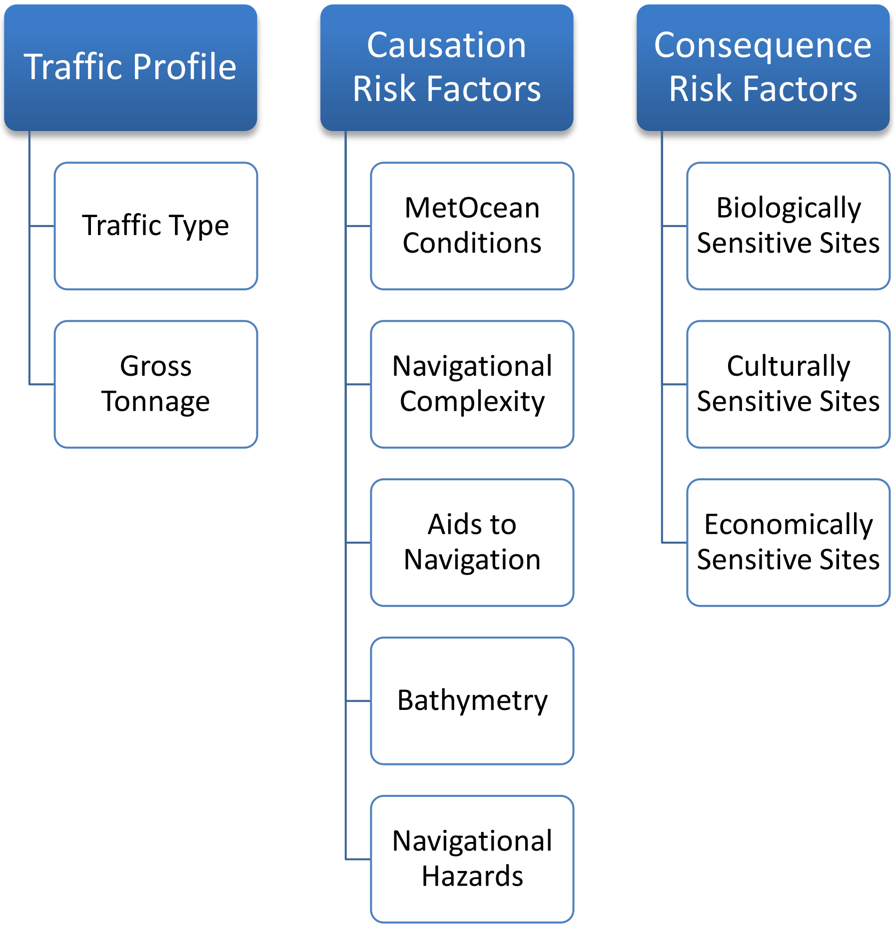


Figure 5: Model Variables.

The scoring criteria and sources for these variables are described fully in **Section 4**.

4 MODEL VARIABLES AND SOURCES

A number of variables and sources were used in the construction of this model. As with most developing countries the amount of available data is small and its quality is often poor. The higher the quality of input data the greater the accuracy of the resulting model will be. To complete this analysis a number of assumptions have been taken and some of the variables are necessarily simplistic. **Section 8** provides an assessment of the relative confidence in the accuracy and completeness of each dataset.

4.1 TRAFFIC PROFILE

4.1.1 Vessel Traffic Data

In order to quantify the risk of a maritime incident occurring in an area it is necessary to have a detailed understanding of the vessel traffic profile. In particular analysis is required of the number, type and size of vessels that can be found in the area.

The principal input for traffic analysis is data from the Automatic Identification System (AIS). The Automatic Identification System (AIS) was developed at the turn of the century as an aid to collision avoidance between vessels. A transponder is carried by vessels that broadcast key information about themselves (such as size and type) and their actions (speed, course) at regular intervals on a VHF bandwidth. Vessels carrying an AIS receiver are able to “see” these vessels and act accordingly.

The macro scale nature of this project has required that AIS data cannot be obtained from a terrestrial source and so satellite derived AIS data was required. exactEarth have provided three months of AIS data for the whole of the South Pacific for use in this study.

Two data extents are used; the first extent is from the 1st January 2012 to 31st March 2012 and comprises of 1.3 million received reports from across the Pacific. The geographic boundaries of this dataset used in the study of Vanuatu are:

- Northern Boundary: 12 degrees south;

- Eastern Boundary: 171 degrees east;
- Southern Boundary: 22 degrees south; and
- Western Boundary: 164 degrees east.

A supplementary dataset was used of the winter traffic profile through the central islands related to vessels observing the local custom of land diving on Pentecost from 1st May 2012 to 15th July 2012. The geographic boundaries of this dataset are smaller and are:

- Northern Boundary: 12 degrees south;
- Eastern Boundary: 171 degrees east;
- Southern Boundary: 19 degrees south; and
- Western Boundary: 165 degrees east.

4.1.2 AIS Traffic Data Processing

The data is recorded by satellite sweeps and as such there can be a considerable interval between received reports, up to eight hours. At such a data interval it is impossible to accurately reflect the fine navigation required by vessels transiting through the archipelago. Therefore it was necessary to undertake a large amount of post-processing to augment the AIS data.

Appendix 1: "Traffic Analysis Methodology"[8] details the process by which the input raw NMEA[9] AIS data was processed to produce useable vessel tracks. The process is outlined below:

- Raw NMEA AIS was decoded and plotted as geographic points;
- The points were connected to form vessel tracks;
- Port movements datasets were used to artificially create simulated AIS tracks of vessels in port approaches;
- Vessels identified in port movement records that were not recorded by AIS in that port were manually routed in using known navigation patterns and behaviour of similar vessels;
- Tracks near the boundary of the study area were extrapolated provided their course bearing was constant;

[8] Marico Marine (2012). 12NZ243 Appendix 1: Traffic Analysis Methodology.

[9] NMEA is the default marine data encoding format.

- A query was undertaken to select all remaining vessel tracks that intersected the coastline and were manually routed onto their likely route using the behaviour of similar vessels; and
- Finally vessel attributes, such as length and type, were attached to each vessel track from a centralised database.

Routes of coastal traders/passenger vessels that make stops at the islands were geocoded into the dataset to ensure that high risk but non-SOLAS ships were accounted for.

Having processed the AIS data, vessel traffic transit density plots are created. A vessel transit can have multiple definitions and interpretations. Shipping density is not accurately reflected by simple count of the number of AIS transmissions per unit area as this would incorrectly suggested a moored vessel transmitting one hundred times is one hundred vessels. A transit is defined here as "*a sequence of position reports from a particular ship, without significant time gaps, which show some level of purposeful motion*".[10] A transit starts when a vessel leaves a dock and ends when she returns or leaves the study area. If a transiting vessel stops and starts again then we interpret this as two transits.

[10] Calder, B. and Schwehr, K. (2009). Traffic Analysis for the Calibration of Risk Assessment Methods, US Hydro 2009, May 11-14 2009. Norfolk, VA. Available at: http://vislab-ccom.unh.edu/~schwehr/papers/2009ushydro-calder_schwehr_AIS_Traffic_Analysis.pdf

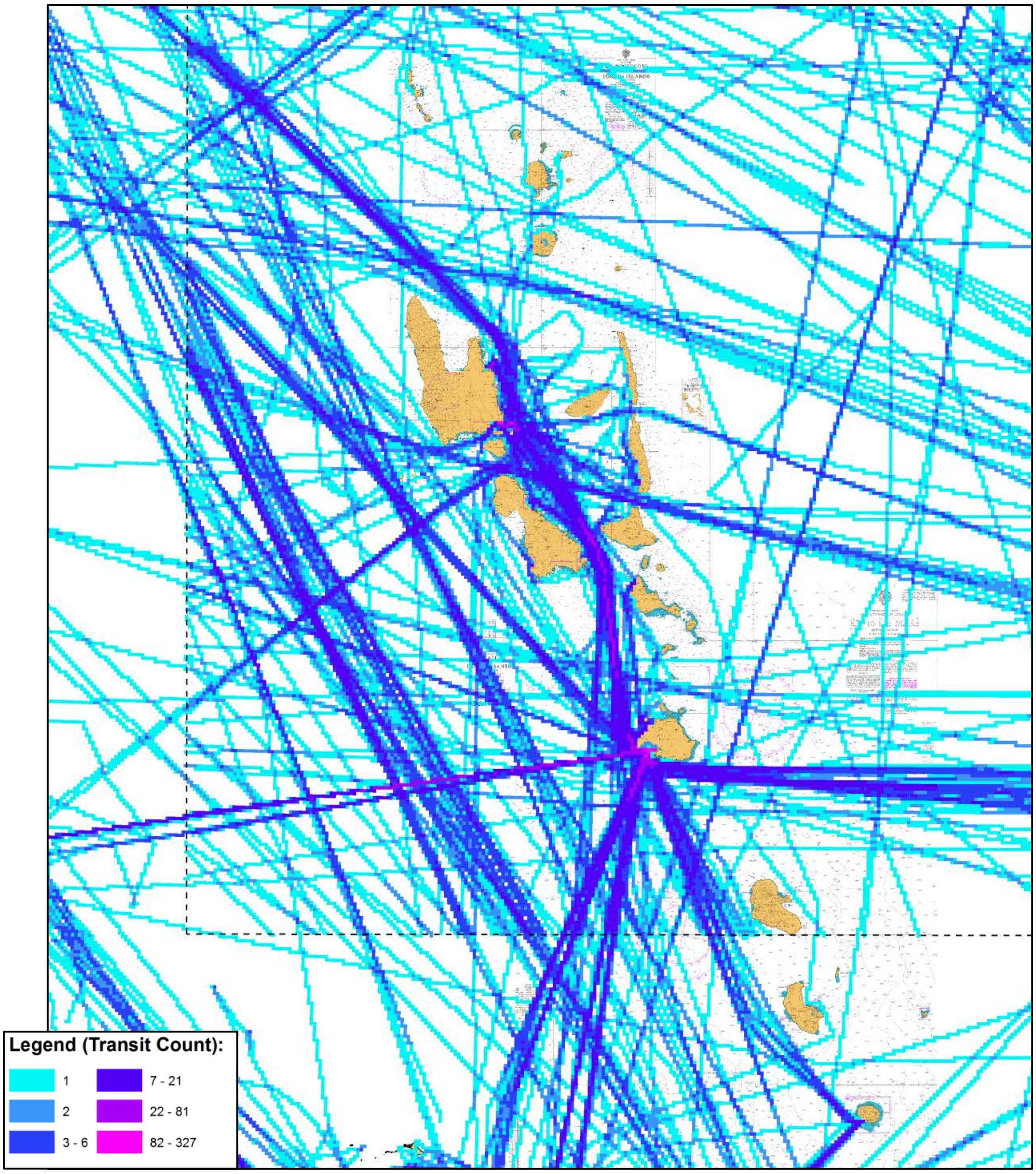


Figure 6: Vessel Transit Density Plot.

4.1.3 Domestic Coastal Vessels

AIS data analysis only captures part of the shipping risk in Vanuatu, with a large number of movements of smaller coastal craft. To incorporate this element into the model the results of consultation during a site visit were used to identify the routes, the size of vessels operating and the time tables of these vessels. This allowed the production of a flow model of gross tonnage along these routes (**Figure 7**).

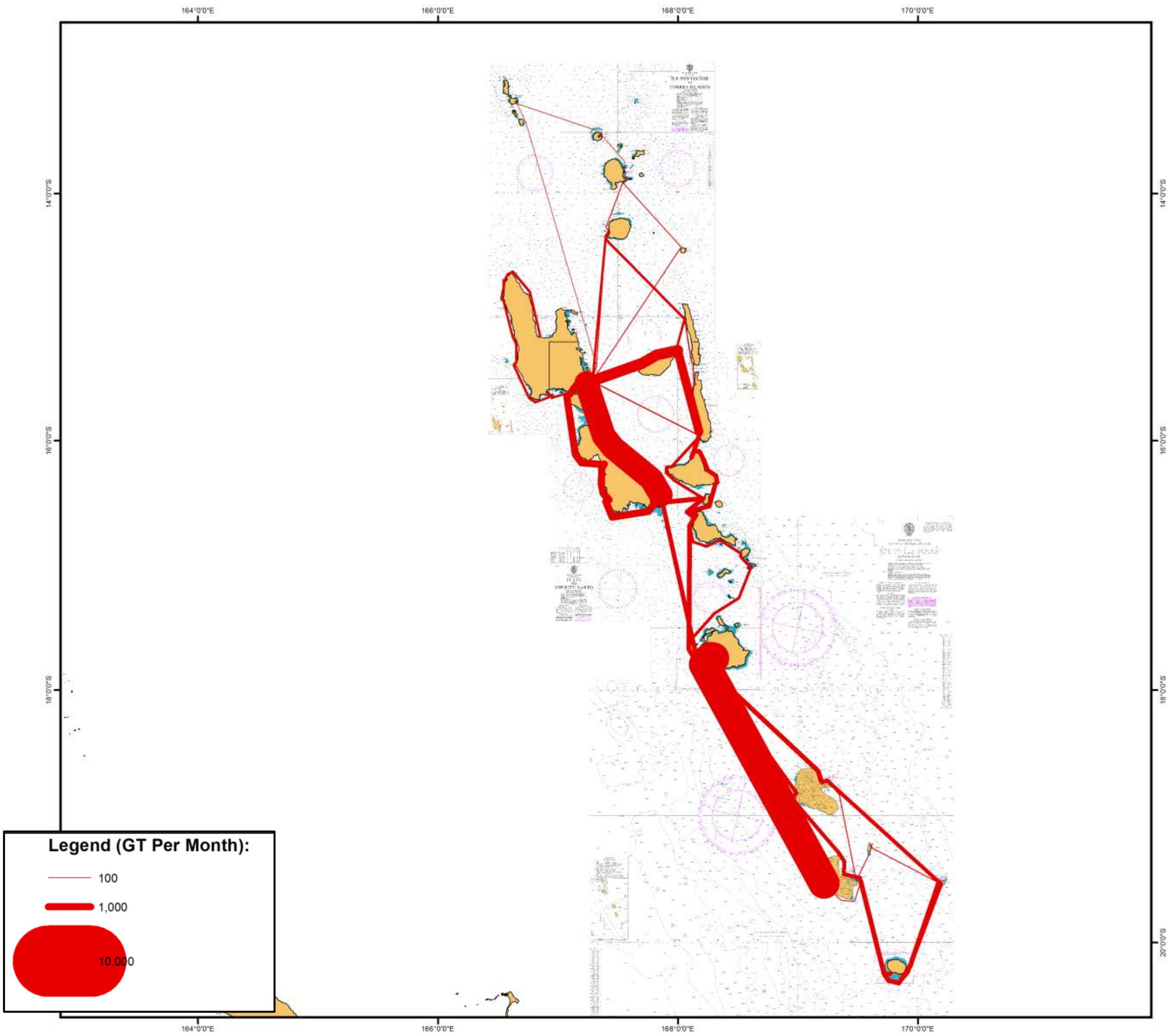


Figure 7: Modelled Routes of Coastal Traders.

4.1.4 Traffic Risk

Each vessel transit has an inherent potential for loss of life or pollution. This potential is the product of the size and type of a vessel. A multiplier of gross tonnage was created of each vessel type, identified in **Table 1**, as to the risk inherent in that ship type for pollution or loss of life. For example a large tanker has a higher pollution risk than a smaller one. A large cruise ship may have a smaller pollution risk than a small tanker, however the risk to life is the converse.

The multiplier was created by taking a model ship with a median tonnage that transits through Vanuatu and calculating the most likely and worst credible consequences of an incident from event trees[11]. The multiplier factor required to transform a consequence to a gross tonnage was calculated and is listed in **Table 1** below.

This approach is a necessary simplification of reality in a number of ways. Firstly the approach is limited in assuming a simplistic linear relationship between gross tonnage and consequence potential. Furthermore it is not possible to know the individual crew numbers and cargo volumes of each individual vessel transiting through the study area and so a model ship type will be used. This particularly limits the scoring of the coastal traders for whom the number of passengers must be estimated and can fluctuate dramatically between voyages; there is therefore the potential to overestimate the potential loss of life for this vessel type.

Ship Type	Loss of Life Risk Multiplier		Pollution Risk Multiplier	
	ML	WC	ML	WC
Tankers	$5*10^{-6}$	$7*10^{-5}$	$5*10^{-3}$	0.2
Passenger Ships	$1*10^{-5}$	$1.7*10^{-3}$	$1.6*10^{-5}$	$8.5*10^{-4}$
Cargo Ship	$8*10^{-6}$	$1.7*10^{-4}$	$1.5*10^{-3}$	$7.5*10^{-3}$
Fishing Ships	0.01	0.07	$1*10^{-5}$	0.04
Recreational/ Superyacht	0.01	0.07	$1*10^{-5}$	0.04
Coastal Traders	$8.5*10^{-3}$	0.75	0.06	0.45

Table 1: Ship Type Risk Factors

[11] Detailed information about these event trees and their method of calculation is presented in the relevant section.

The potential risk of a vessel transit in terms of pollution or loss of life is the average of the most likely and worst credible cases and is calculated by the formula below:

$$Potential = \frac{(GT * ML\ Multipler) + (GT * WC\ Multiplier)}{2}$$

For example the calculation for the pollution potential of a 30,000 GT tanker is:

- Most Likely = 30,000(GT)*0.005(Multiplier) = 150 tonnes spilt.
- Worst Credible = 30,000(GT)*0.2(Multiplier) = 6,000 tonnes spilt.
- Average = (ML+WC)/2 = 3,075 tonnes spilt.

Using a Jenks Natural Breaks interval method the distribution of average potential loss of life and average potential pollution were transformed to a 1 to 5 scale. **Figure 8** and **Figure 9** show the modelled potentials for loss of life and pollution respectively.[12]

[12] Traffic near New Caledonia has not been processed and due to their proximity to Vanuatu's risk factors will be automatically discounted from the risk assessment.

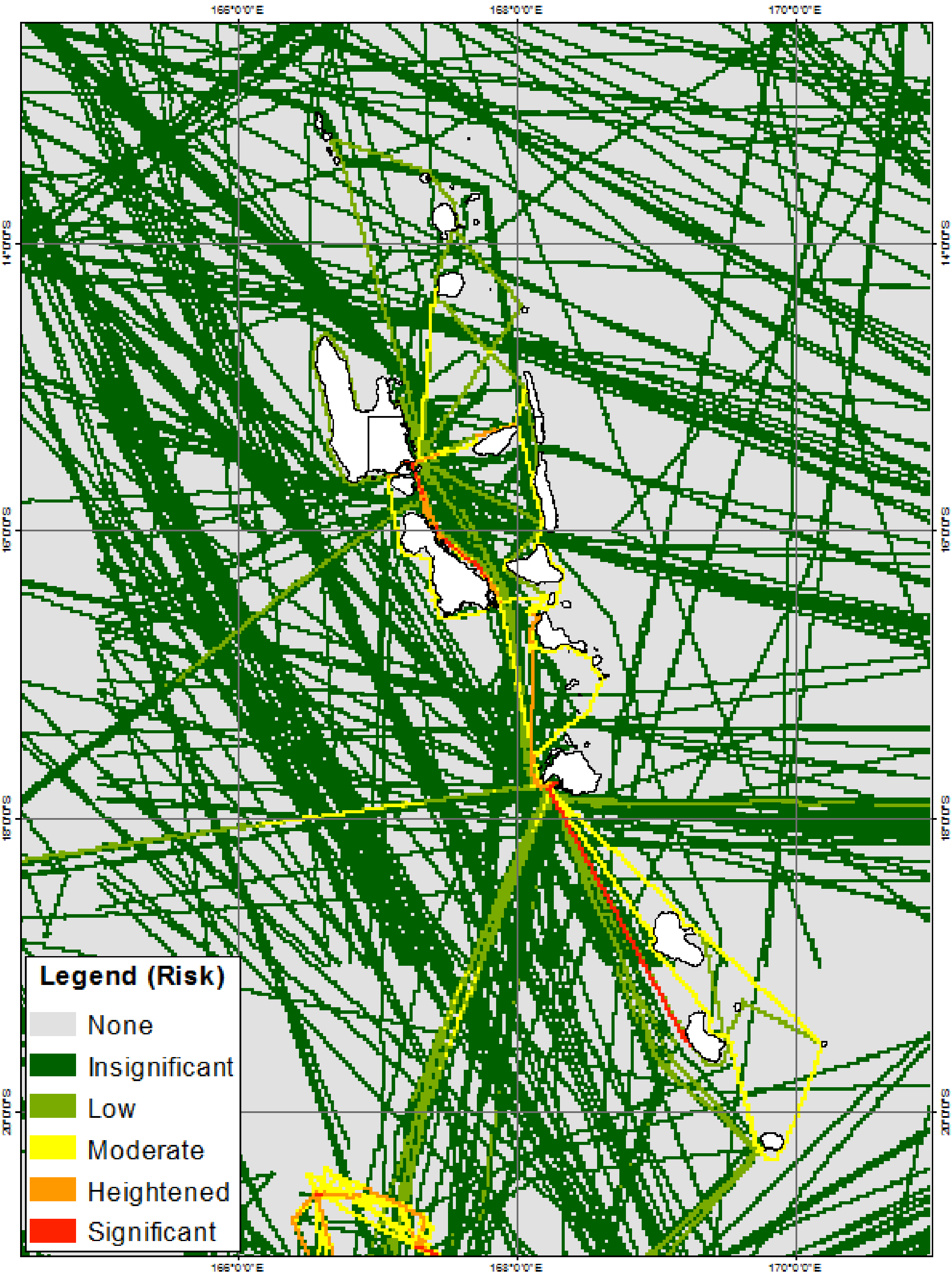


Figure 8: Modelled Potential Loss of Life.

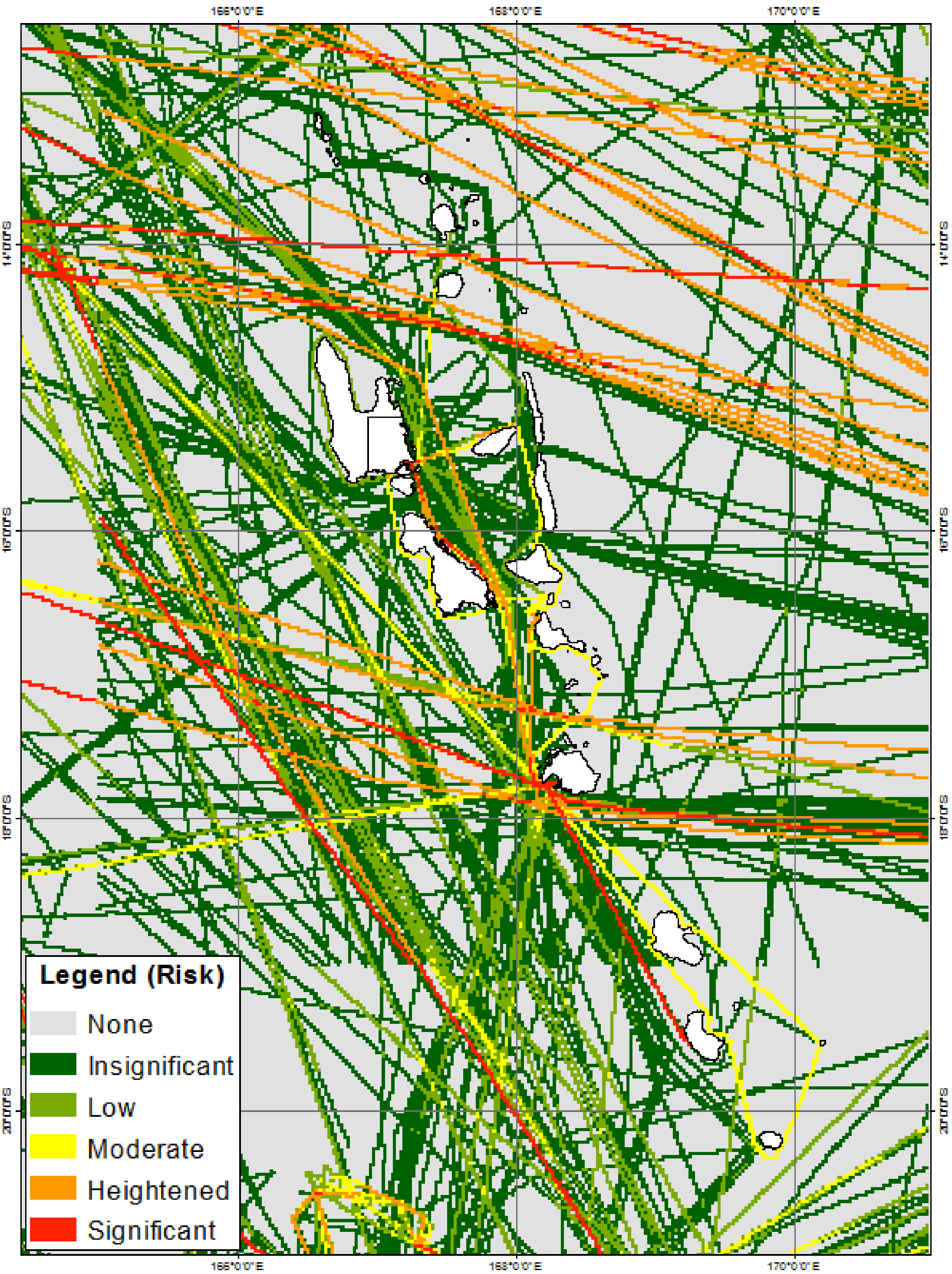


Figure 9: Modelled Potential for Pollution.

4.2 CAUSATION RISK FACTORS

4.2.1 Met Ocean Conditions

A number of studies have repeatedly shown that conditions of wind, visibility and swell is cited as one of the major contributory factors to maritime incidents.[13] With all other factors being equal, greater wind/swell strengths decrease the manoeuvrability and control of a vessel and likewise poor visibility hampers the navigation by a bridge team. A United States Coastguard (1991) study attributed 21.4% of more than two thousand recorded major casualties in US ports as having an environmental cause.[14]

For the purposes of this study we identify four meteorological and one hydrographic risk factor. Namely:

- Prevailing Conditions
    - Exposure to prevailing wind from N/NE sector;
    - Exposure to prevailing wind from E/SE sector;
    - Exposure to prevailing wind from S/SW sector; and
    - Exposure to prevailing wind from W/NW sector;
- Tidal Conditions;
    - Spring tidal current speed.

4.2.1.1 Meteorological Conditions

There are two principal adverse conditions that contribute to the likelihood of an incident. The first is the visibility of an area, with more frequent and less predictable occurrences of poor visibility hampering the safe navigation of vessels through an area.

An area can be scored on a 1 to 5 scale regarding the propensity for poor visibility. A more complete dataset would allow the use of the number of

[13] Kite and Powell (1999) examine accidents in US ports and conclude that poor visibility and high winds can increase the risk of vessel grounding by at least one order of magnitude.

[14] US Coastguard (1991) *Port Needs VTS: Vessel Traffic Services Benefits Volume 1*. National Technical Information Service, Springfield.

days/year in an area with poor visibility. Without such a dataset then a qualitative judgement is necessary regarding the comparative likelihood of different area.

- Score of 1: poor visibility very unlikely;
- Score of 2: poor visibility unlikely;
- Score of 3: occasional poor visibility;
- Score of 4: often poor visibility; and
- Score of 5: poor visibility common.

In Vanuatu no publically available dataset exists that could be used to compare the number of days with poor visibility between different regions of the study area.

The second meteorological risk factor that impacts upon safe navigation is that of prevailing wind, wave and swell conditions. The quality of the dataset directly affects the quality of the modelled conditions, therefore for the same reason a broader scale of 1 to 5 is used.

- Score of 1: sheltered at all times;
- Score of 2: mostly sheltered;
- Score of 3: occasional exposure;
- Score of 4: exposed to most conditions; and
- Score of 5: directly exposed to prevailing conditions.

A number of sources were drawn on to score this risk factor. In particular three sources drove the analysis;

- Firstly climate data from the Vanuatu meteorological office;[15]
- A summary of climatological statistics in the Pacific Islands published in the Journal of Climate (1990);[16]
- A technical report on the 'Wave Climate of Vanuatu' (Barstow and Haug, 1994);[17] and

[15] http://www.meteo.gov.vu/

[16] Harrison, D.E. and Luther, D.S. (1990). Surface Winds from Tropical Pacific Islands-Climatological Statistics, *Journal of Climate*, 3, pp.251-271.

[17] Barstow, S.F. and Haug, O. (1994). Wave Climate of Vanuatu, SOPAC Technical Report 202.

- A report on the 'Coastal Fisheries Atlas of Vanuatu' (Espérance et al. 2001).[18]

The climate of Vanuatu is dominated by the prevailing east/south-easterly trade winds. The island chain experiences a number of tropical cyclone events, with 58 recorded between 1940 and 1985. In the absence of digitised data available the sources listed above were consulted to produce an exposure model from the four compass points. The area of shoreline directly affected by a northerly, easterly, southerly and westerly direction was weighted with the approximate percentage of a year from which that wind originates. The comparison is unable to allow for the effects of land bends on wind or swell so was ground-truthed with the judgement of project staff and the literature review. The model is presented below in **Figure 10**

[18] Espérance, C. et al. (2001). Coastal Fisheries of Vanuatu [online]. Available at: http://www.cartographie.ird.fr/atlas_vanuatu/index.html. Accessed: 15th November 2012.

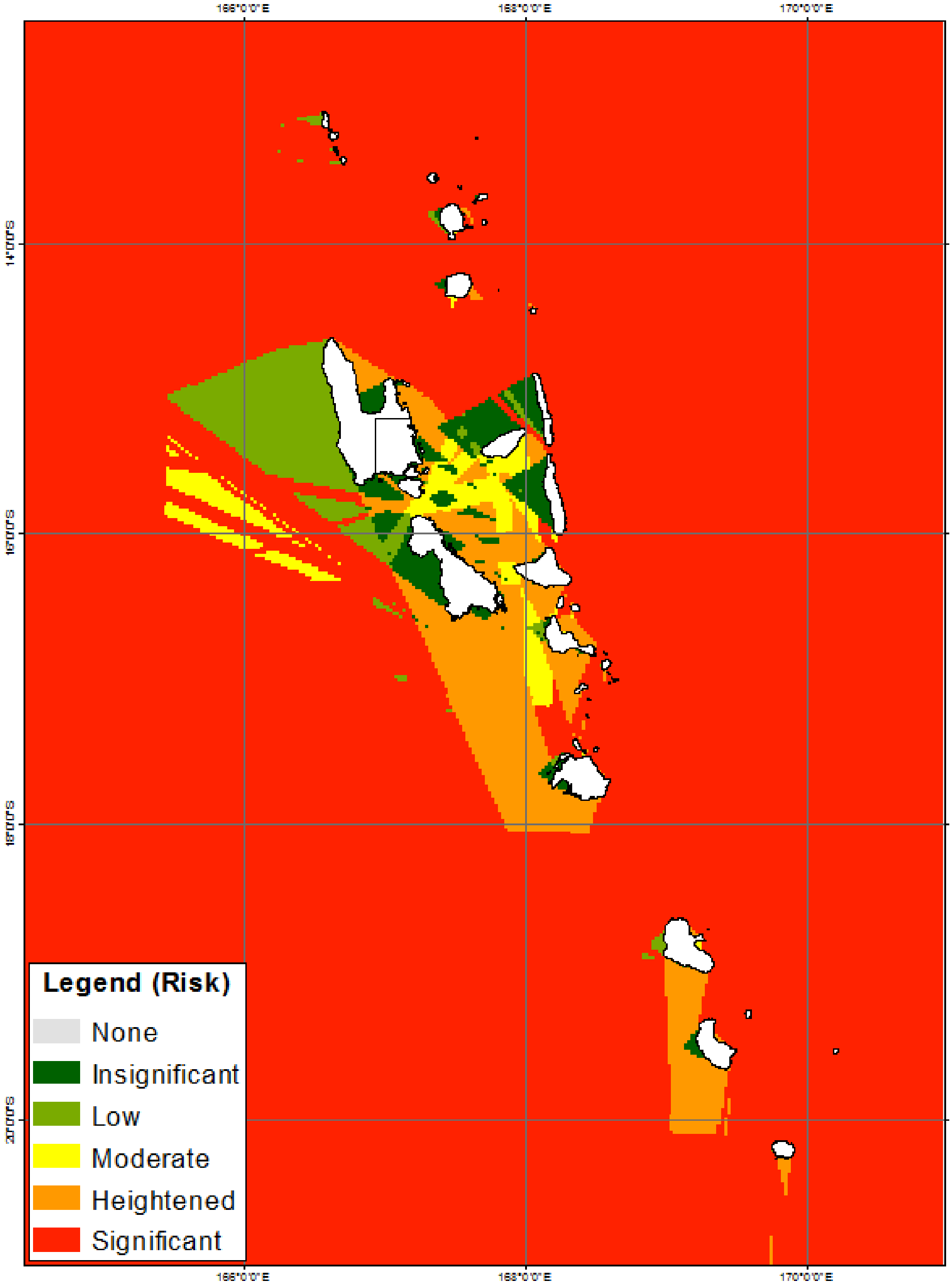


Figure 10: Modelled Exposure to Prevailing Conditions.

4.2.1.2 Tidal Conditions

Strong tidal conditions have an adverse effect upon the safe navigation of vessels through an area. A strong following or cross tidal stream requires significant expertise in pilotage. The risk scores are listed below.

- Score of 0: open sea, no significant tidal stream;
- Score of 1: little tidal current, mean speed of no greater than 2 knots;
- Score of 2: some tidal current, mean speed between 2 and 3 knots;
- Score of 3: moderate tidal conditions, between 3 and 4 knots;
- Score of 4: strong tidal conditions, between 4 and 5 knots; and
- Score of 5: tidal race of greater than 5 knots at spring tide.

In the absence of a high quality hydrodynamic model the tidal conditions are plotted using the spring mean tidal stream as marked on admiralty charts (**Figure 11**).

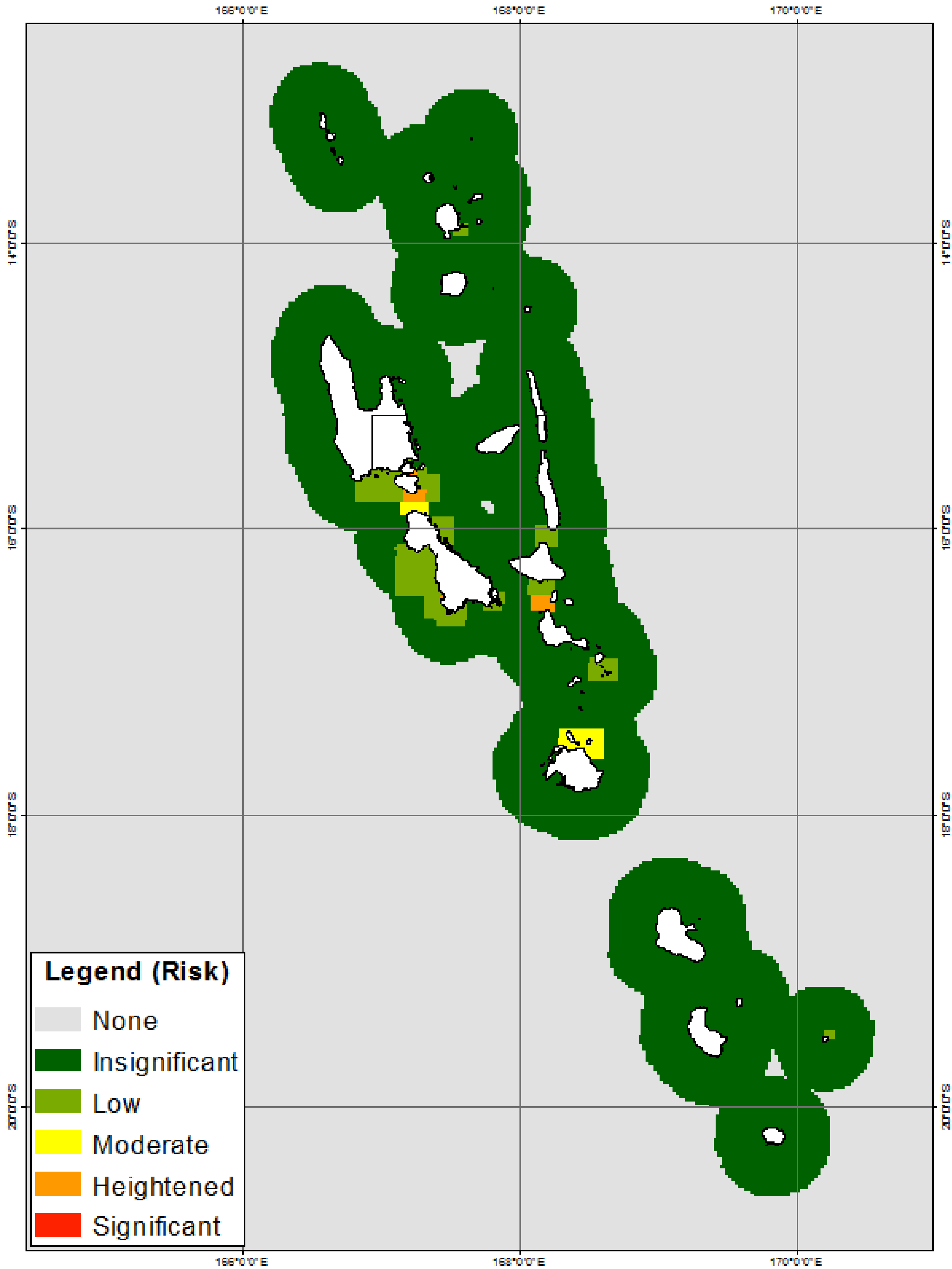


Figure 11: Modelled Spring Tidal Current Velocity.

4.2.2 Navigational Complexity

The risk for a transiting vessel is greater the more complicated the course is in a given area. In open waters with considerable sea room either side of the route the risk is significantly reduced to a constrained navigation channel in a port.

The scale of navigational complexity is described below:

- Score of 0: Not applicable;
- Score of 1: open sea conditions greater than 10 nautical miles from land;
- Score of 2: offshore navigation between 5 and 10 nautical miles from land;
- Score of 3: coastal navigation between 1 and 5 nautical miles from land;
- Score of 4: constrained navigation between 0 and 1 nautical mile from land; and
- Score of 5: navigation in port approaches, constrained channel with crossing traffic.

In Vanuatu the distance from shore is plotted below. Only the approaches to Port Vila and Luganville are marked with a risk score of 5.

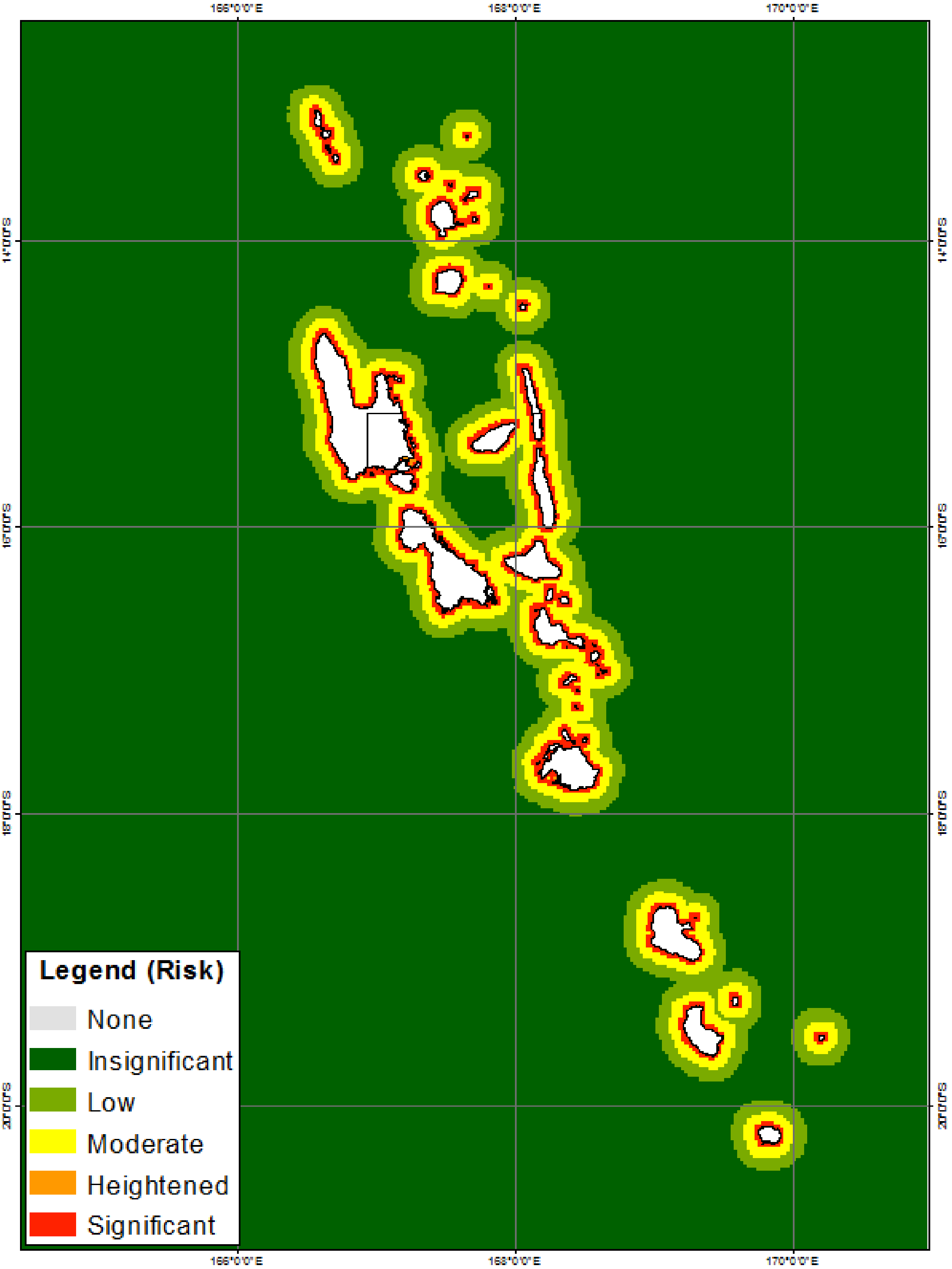


Figure 12: Modelled Navigational Complexity.

4.2.3 Fixed Aids to Navigation

A number of aids to navigation exist that if are either incorrect, inaccurate or not working can significantly contribute to the risk of a maritime incident. This methodology identifies two particular hazards in particular; namely an out of date nautical chart and an incorrectly marked conservancy such as buoyage or lighting.

4.2.3.1 Chart Quality Assessment

The quality of a nautical chart is indicated by its ZOC assessment rating. On an electronic chart the quality is indicated by the meta-object M_QUAL. The M_QUAL object has a CATZOC attribute, or category of zone of confidence in data. This is an assessment of the positional accuracy of plotted features and the depth accuracy of soundings. All M_QUAL objects are graded from A1, the highest confidence in accuracy to D, a low confidence, or U, unassessed.

Note that for the purposes of this risk assessment, areas with a CATZOC of U were graded as ZOC D.

Using the scale in **Table 2**, below the following risk scores are proposed

- Score of 0: Not applicable;
- Score of 1: CATZOC A;
- Score of 2: CATZOC B;
- Score of 3: CATZOC C;
- Score of 4: CATZOC D; and
- Score of 5: No S-57 Chart exists (Unclassified).

The charts in Vanuatu have a wide range of source dates and qualities; the S-57 CATZOC scores for Vanuatu are plotted below. Where a CATZOC has not been determined then a risk score of 5 is applied to differentiate where no S-57 charts for the area exist.

<table>
<tr><th>ZOC</th><th>Position Accuracy</th><th colspan="2">Depth Accuracy</th><th>Typical Survey Characteristics</th></tr>
<tr><td rowspan="3">A1</td><td rowspan="3">± 5 m</td><td colspan="2">a = 0.5; b = 1</td><td rowspan="3">Controlled, systematic high accuracy Survey on WGS 84 datum; using DGPS or a minimum three lines of position (LOP) with multibeam, channel or mechanical sweep system.</td></tr>
<tr><td>Depth (m)</td><td>Accuracy(m)</td></tr>
<tr><td>10
30
100
1000</td><td>± 0.6
± 0.8
± 1.5
± 10.5</td></tr>
<tr><td rowspan="3">A2</td><td rowspan="3">± 20 m</td><td colspan="2">a = 1.0; b = 2</td><td rowspan="3">Controlled, systematic survey to standard accuracy; using modern survey echosounder with sonar or mechanical sweep.</td></tr>
<tr><td>Depth (m)</td><td>Accuracy(m)</td></tr>
<tr><td>10
30
100
1000</td><td>± 1.2
± 1.6
± 3.0
± 21.0</td></tr>
<tr><td rowspan="3">B</td><td rowspan="3">± 50 m</td><td colspan="2">a = 1.0; b = 2</td><td rowspan="3">Controlled, systematic survey to standard accuracy.</td></tr>
<tr><td>Depth (m)</td><td>Accuracy(m)</td></tr>
<tr><td>10
30
100
1000</td><td>± 1.2
± 1.6
± 3.0
± 21.0</td></tr>
<tr><td rowspan="3">C</td><td rowspan="3">± 500 m</td><td colspan="2">a = 2.0
b = 5</td><td rowspan="3">Low accuracy survey or data collected on an opportunity basis such as soundings on passage.</td></tr>
<tr><td>Depth (m)</td><td>Accuracy(m)</td></tr>
<tr><td>10
30
100
1000</td><td>± 2.5
± 3.5
± 7.0
± 52.0</td></tr>
<tr><td>D</td><td>worse than ZOC C</td><td colspan="2">worse than ZOC C</td><td>Poor quality data or data that cannot be quality assessed due to lack of information.</td></tr>
<tr><td>U</td><td></td><td colspan="2"></td><td>Unassessed</td></tr>
</table>

Table 2: S-57 Catzoc Designations.[19]

[19] www.s-57.com

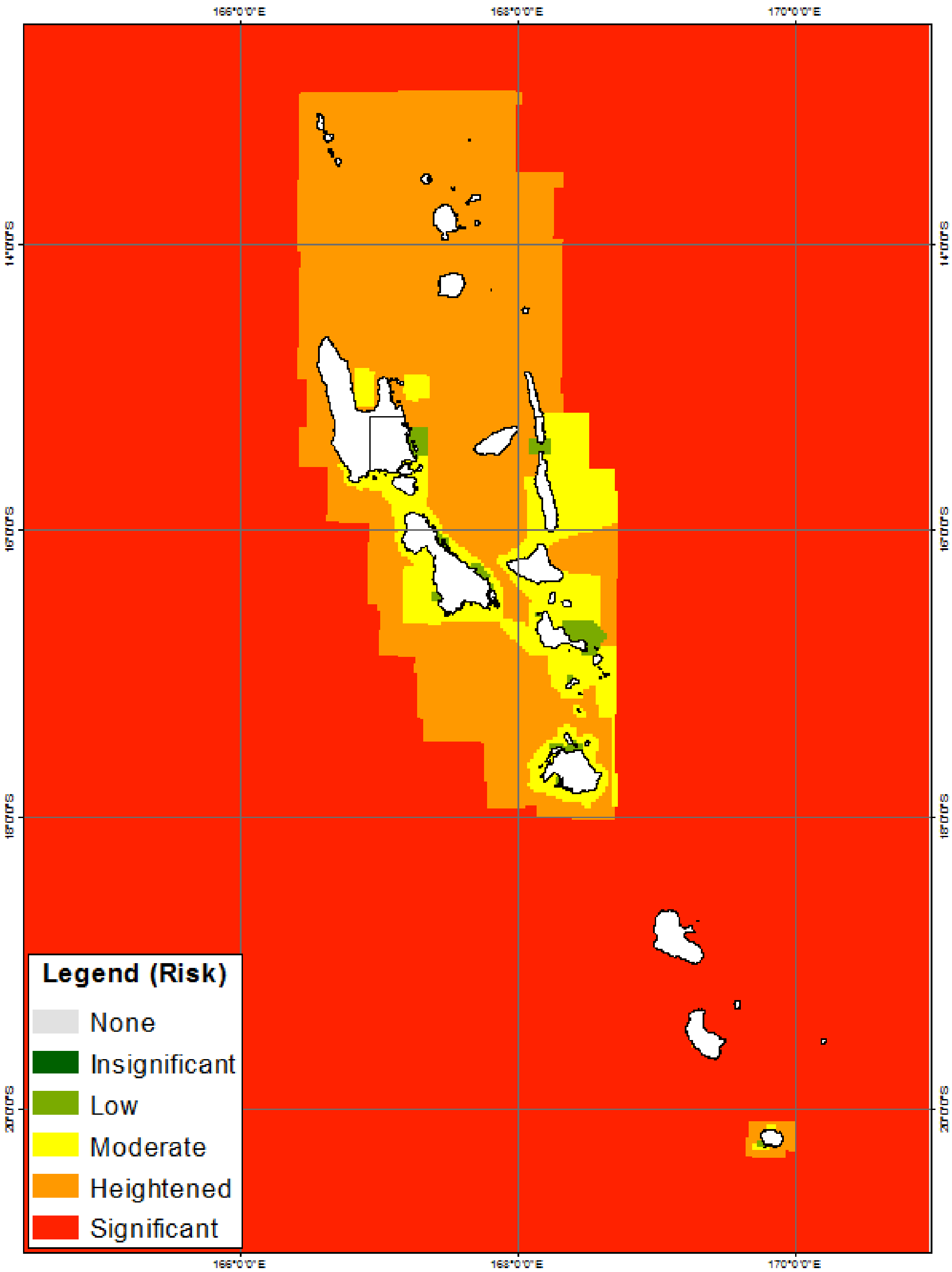


Figure 13: Modelled CATZOC Scores.

4.2.3.2 Conservancy

Lights and buoyage are essential aids for navigating vessels. If a charted object is not correctly positioned, missing; or not correctly lit then it can prove to be a hazard for vessels relying on them for navigation, particular in poor visibility. Furthermore even in an age of satellite tracking and position fixing equipment malfunctions can occur that require the use of these more traditional aids to prevent an error from occurring.

The risk of a navigation error occurring is greater the vessel is to a malfunctioning object and therefore a distance based approach is taken.

- Score of 0: Outside charted range of light;
- Score of 1: 80%-100% of charted light range;
- Score of 2: 70-80% of charted light range;
- Score of 3: 60-70% of charted light range;
- Score of 4: 50-60% of charted light range; and
- Score of 5: Within 50% of charted light range.

Vanuatu has a number of buoys and lights that are either not working or out of position. Whilst efforts are made to restore the aids to navigation or to correctly chart them then they pose a risk to navigating vessels, particular in restricted visibility. The ranges of all known lights that do not work are plotted below.

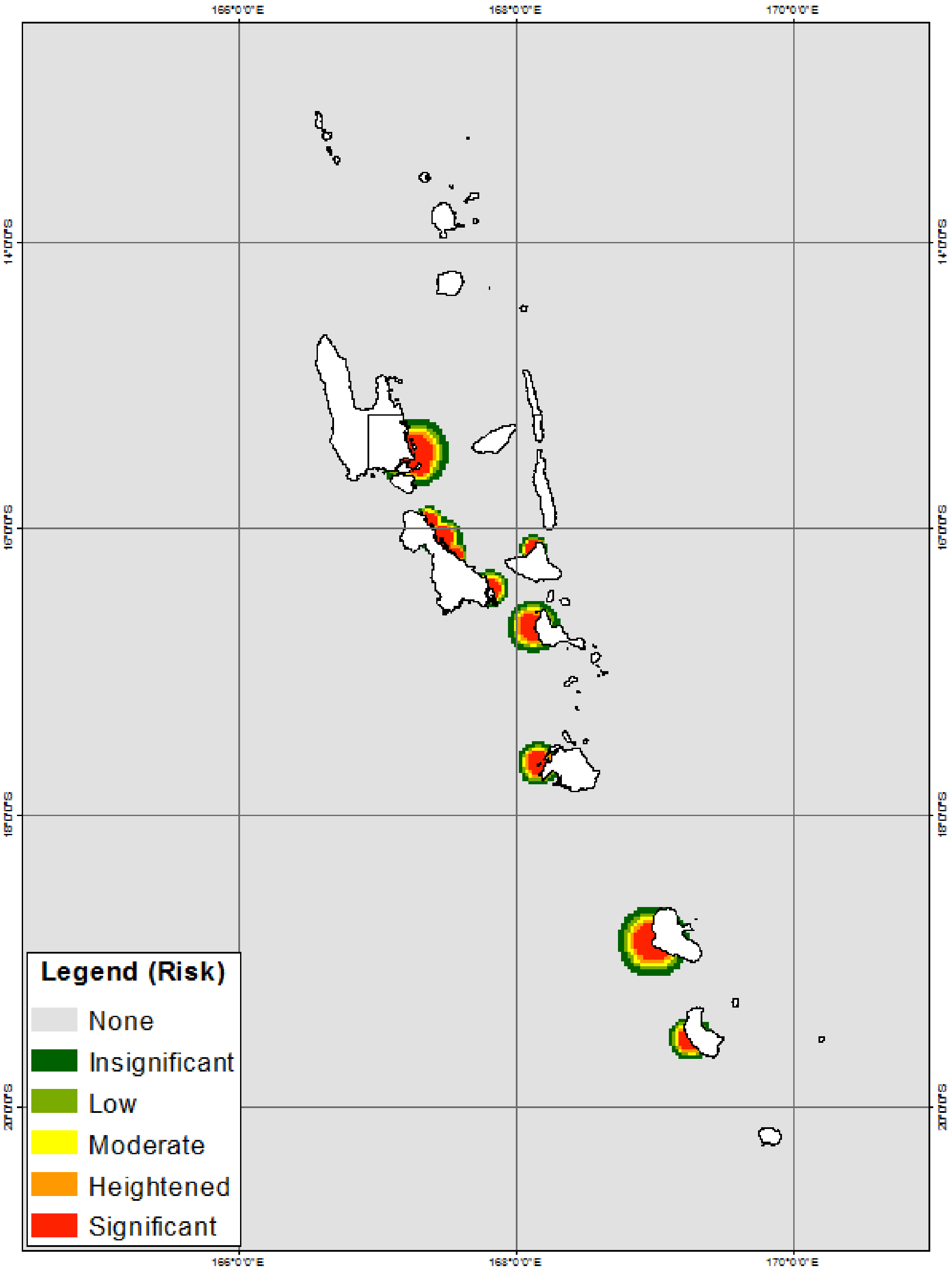


Figure 14: Modelled Disabled Light Range.

4.2.4 Bathymetry

Depth, specifically the lack thereof, is a considerable hazard to navigating vessels. The hazard is most readily linked to the risk of a vessel running aground however there is also a secondary effect in reducing the manoeuvrability of vessels to avoid either an object or another vessel. Proximity of a major shipping route to an area of shallow water reduces the time available for a disabled vessel to repair itself, drop an anchor or seek assistance before she is aground.

4.2.4.1 Proximity to 15m Contour

This study proposes that the 15 metre contour line is the limit at which deep draught vessels would consider navigating. A proximity approach is taken then to assess the distance to a 15m contour for all of the study area.

- Score of 0: greater than 10nm;
- Score of 1: between 5 and 10nm;
- Score of 2: between 2.5 and 5nm;
- Score of 3:between 1.5 and 2.5nm;
- Score of 4: between 1 and 1.5nm;
- Score of 5: within 1nm.

The plot below shows the depth of water risk in Vanuatu.

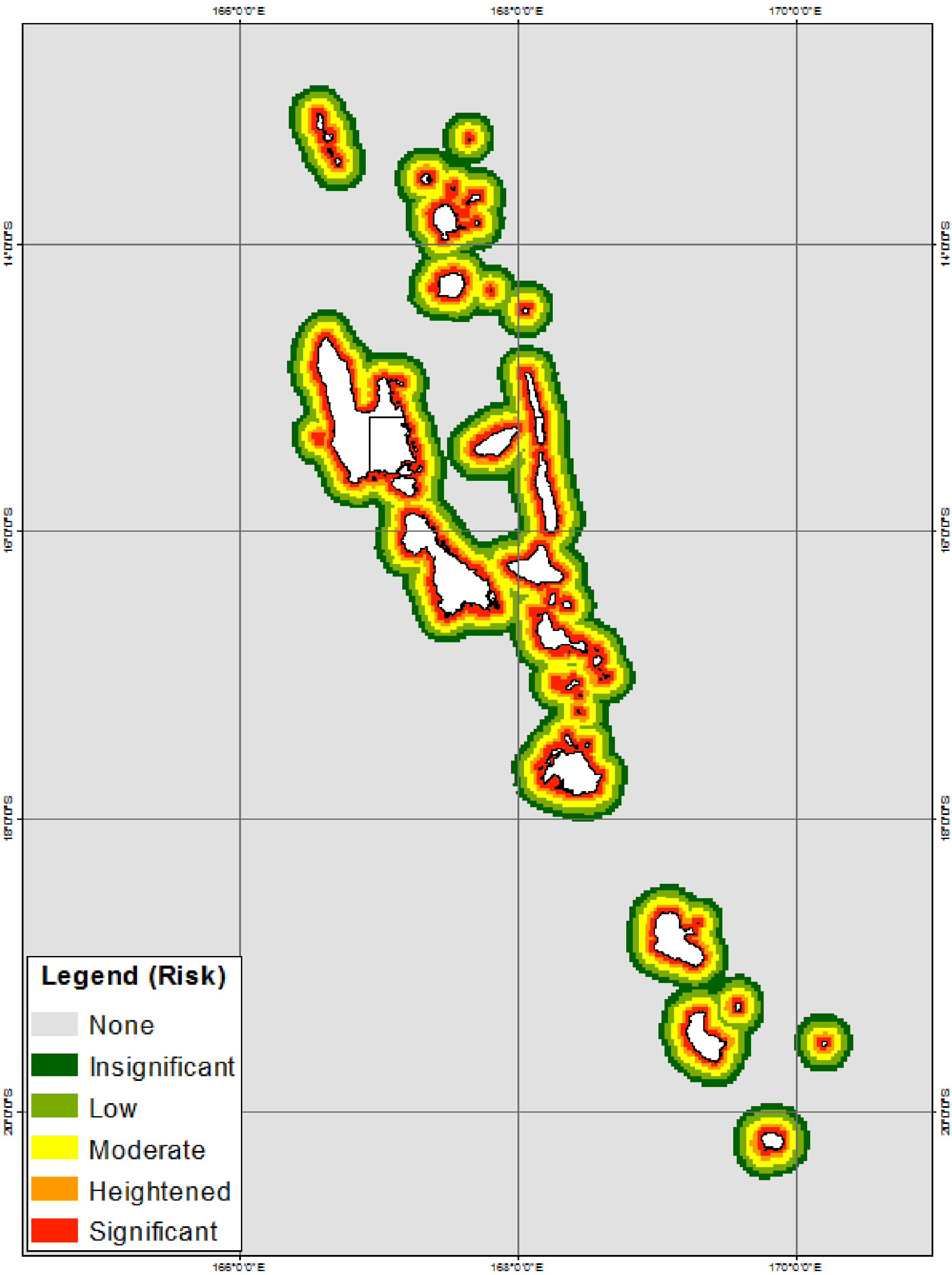


Figure 15: Modelled Distance to 15m Contour.

4.2.4.2 Bottom Type

The type of seabed can be a significant driver of the likelihood of a grounding incident having a consequence. If an area is known to have a hard bottom then any erratic or uncharted hazard is likely to share the rock type. A grounding on a harder surface type is considerably more likely to result in an incident occurring. Furthermore whether or not the seabed is a constant surface or sloped impact upon the likelihood for;

- Score of 1: soft and flat;
- Score of 2: soft and sloping
- Score of 3: not used;
- Score of 4: hard and flat; and
- Score of 5: hard and sloping.

In Vanuatu no high quality dataset is available of the bottom type therefore global datasets were sought. In particular course data from the NCEAS[20] was used in conjunction with a literature study to estimate the sub-surface rock type through the study area.

Located in the ring of fire, Vanuatu's origin is as an igneous formation of hard rock. Much of the bottom that lies away from the island chains are softer in nature.

[20] http://www.nceas.ucsb.edu/globalmarine/ecosystems

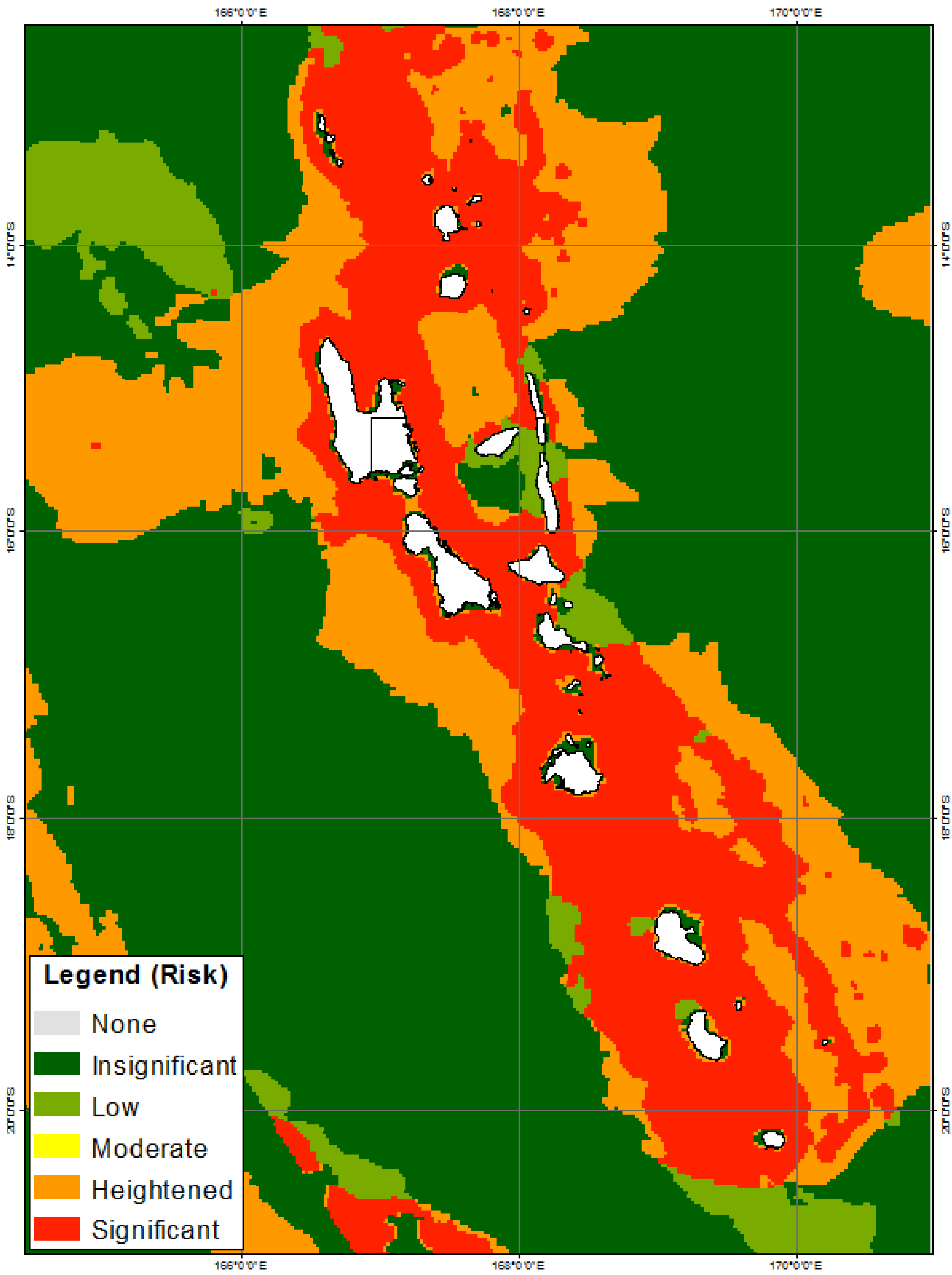


Figure 16: Modelled Bottom Type Risk.

4.2.5 Navigational Hazards

A number of hazards exist that are obstructions to navigating vessels. The risk for a transiting vessel is greater the closer the regular route is to such hazards. Hazards include:

- Underwater reefs that are awash at low tide;
- Known World War 2 military sites including dumping grounds and mined areas;
- Known underwater wrecks;
- Charted tidal hazard including shoaling and overfalls.

The risk for transiting vessel is greater the closer the transits to these risk factors and so are modelled in terms of distance.

4.2.5.1 Underwater Reefs

The proximity of shipping to reef structures that are awash at low tide is a significant hazard to passing shipping. Vessels that are navigating by eye may not notice their presence and run hard aground. Furthermore if a disabled vessel were to ground on a reef the wave action against the hard surface can inflict considerable damage to the vessel and make the safe evacuation of passengers impossible.

- Score of 0: greater than 10nm from a site;
- Score of 1: between 5 and 10nm from a site;
- Score of 2: between 2.5 and 5nm from a site;
- Score of 3: between 1.5 and 2.5nm from a site;
- Score of 4: between 1m and 1.5nm from a site; and
- Score of 5: within 1nm of a site.

Much of Vanuatu's coastline consists of reef structures that pose a hazard to shipping. Furthermore Vanuatu has offshore, isolated reefs that pose a significant risk to passing traffic. **Figure 17** shows a large reef that extends several hundred metres from a small island in Vanuatu. **Figure 18** presents the modelled results of the proximity to all reefs in Vanuatu.

Figure 17 : Breaking Reef (Rowa Island, Torba Province) (Source: Site Visit)

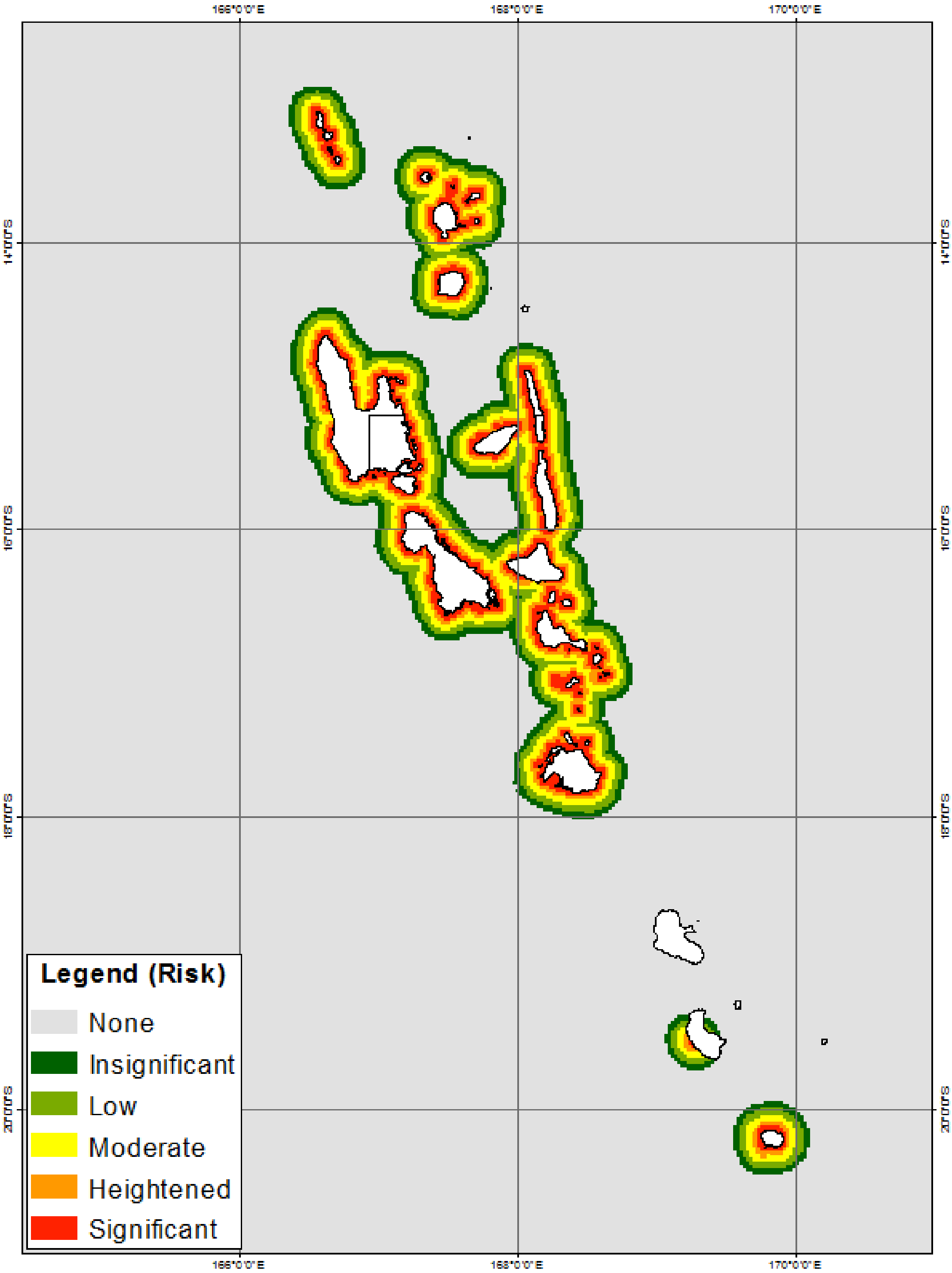


Figure 18: Modelled Breaking Reefs.

4.2.5.2 WW2 Military Sites

The Pacific front of the Second World War left an indelible mark upon many of the island groups of the south west Pacific. Some islands were marked by the scars of direct conflict, including the Solomon Islands and New Guinea through battles such as Guadalcanal. Many of those relatively untouched by direct fighting became supply stops, naval bases and airfields.

This factor is scored with a proximity approach to indicate the distance of at risk shipping from these sites. Vessels are advised not to anchor, nor submarines to bottom, in these areas.

- Score of 0: greater than 2.5nm from a site;
- Score of 1: between 2 and 2.5nm from a site;
- Score of 2: between 1.5 and 2nm from a site;
- Score of 3: between 1 and 1.5nm from a site;
- Score of 4: between 500m and 1nm from a site; and
- Score of 5: within 500m of a site.

The Vanuatu archipelago was an allied air and sea base during the Pacific conflict. In particular a number of mined areas are marked in the NP61 Pacific Islands Pilot Book:[21]

- Georges Philippar Passage;
- Million Dollar Point;
- Scorff Passage;
- Undine Passage; and
- Undine Bay, Éfaté.

A plot of the proximity of different cells to these areas is presented below in **Figure 19**.

[21] Admiralty (2006). Admiralty Sailing Directions: Pacific Islands Pilot Volume II (NP 61). Eleventh Edition.

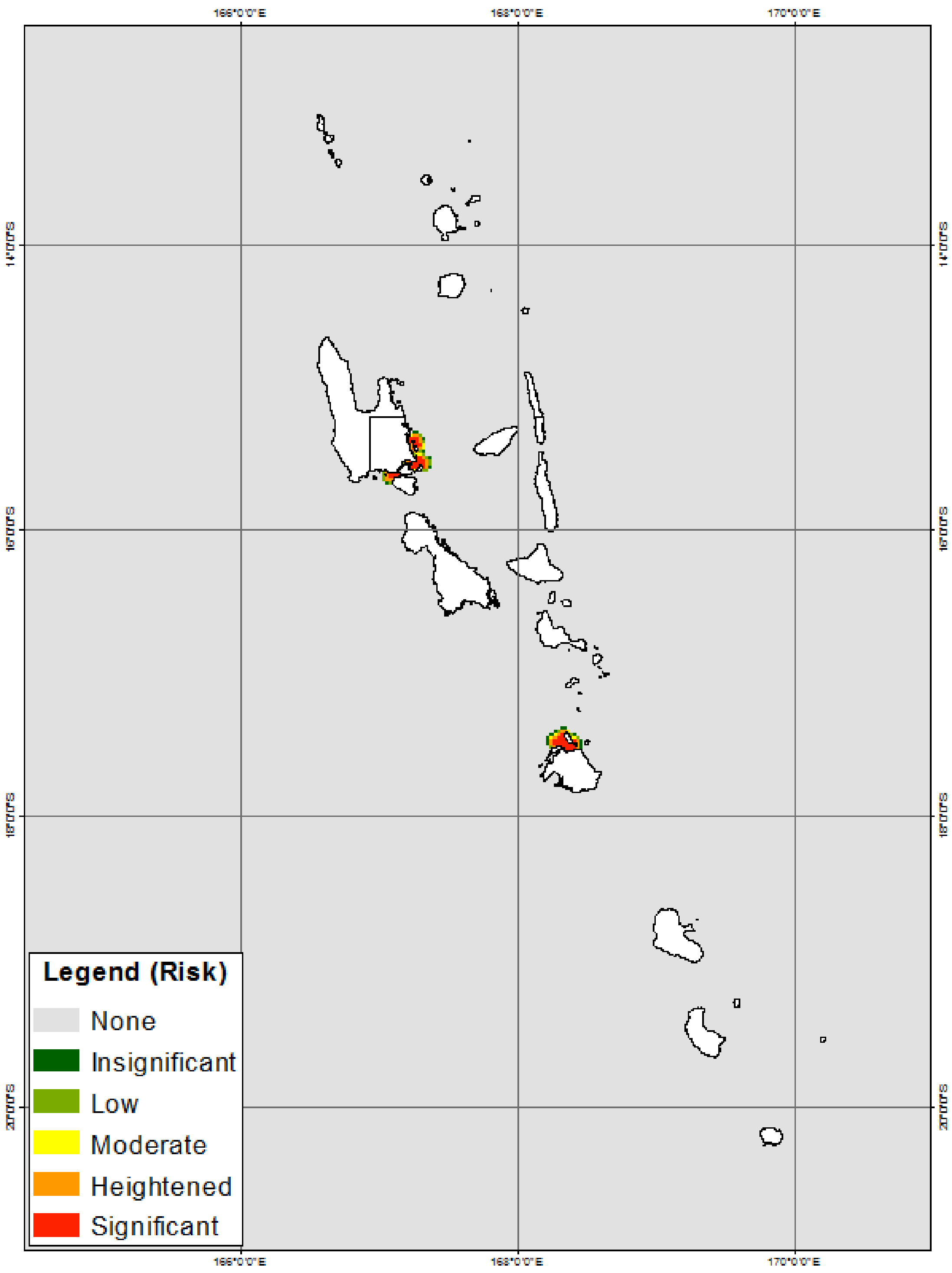


Figure 19: Modelled WW2 Military Sites.

4.2.5.3 Seamounts

Seamounts are underwater mountains of greater than 1000m from the seabed that do not reach the surface, formed in the majority of cases by historic volcanic activity. As the features do not reach the surface and are generally surrounded by deep water they are poorly charted and powered groundings have occurred with vessels believing they are in deep water. In 1973 the MV Muirfield sustained extensive damage striking an unmarked seamount in an area of charted depth greater than 5,000 metres[22]. In 2005 a US submarine struck a seamount south of Guam at 25 knots killing one crew member[23].

- Score of 0: greater than 10nm from a site;
- Score of 1: between 5 and 10nm from a site;
- Score of 2: between 2.5 and 5nm from a site;
- Score of 3: between 1.5 and 2.5nm from a site;
- Score of 4: between 1m and 1.5nm from a site; and
- Score of 5: within 1nm of a site.

In Vanuatu there is a high degree of uncertainty surrounding the location of seamounts and therefore a number of data sources were drawn upon; namely ESRI's Ocean Basemap, NCEAS[24] Seamounts Online[25].

[22] http://www.marine.csiro.au/nationalfacility/franklin/plans/2001/fr07_99.html

[23] http://www.ssbn611.org/uss_san_francisco.htm

[24] http://www.nceas.ucsb.edu/globalmarine/ecosystems

[25] http://seamounts.sdsc.edu/#tabs=tab3

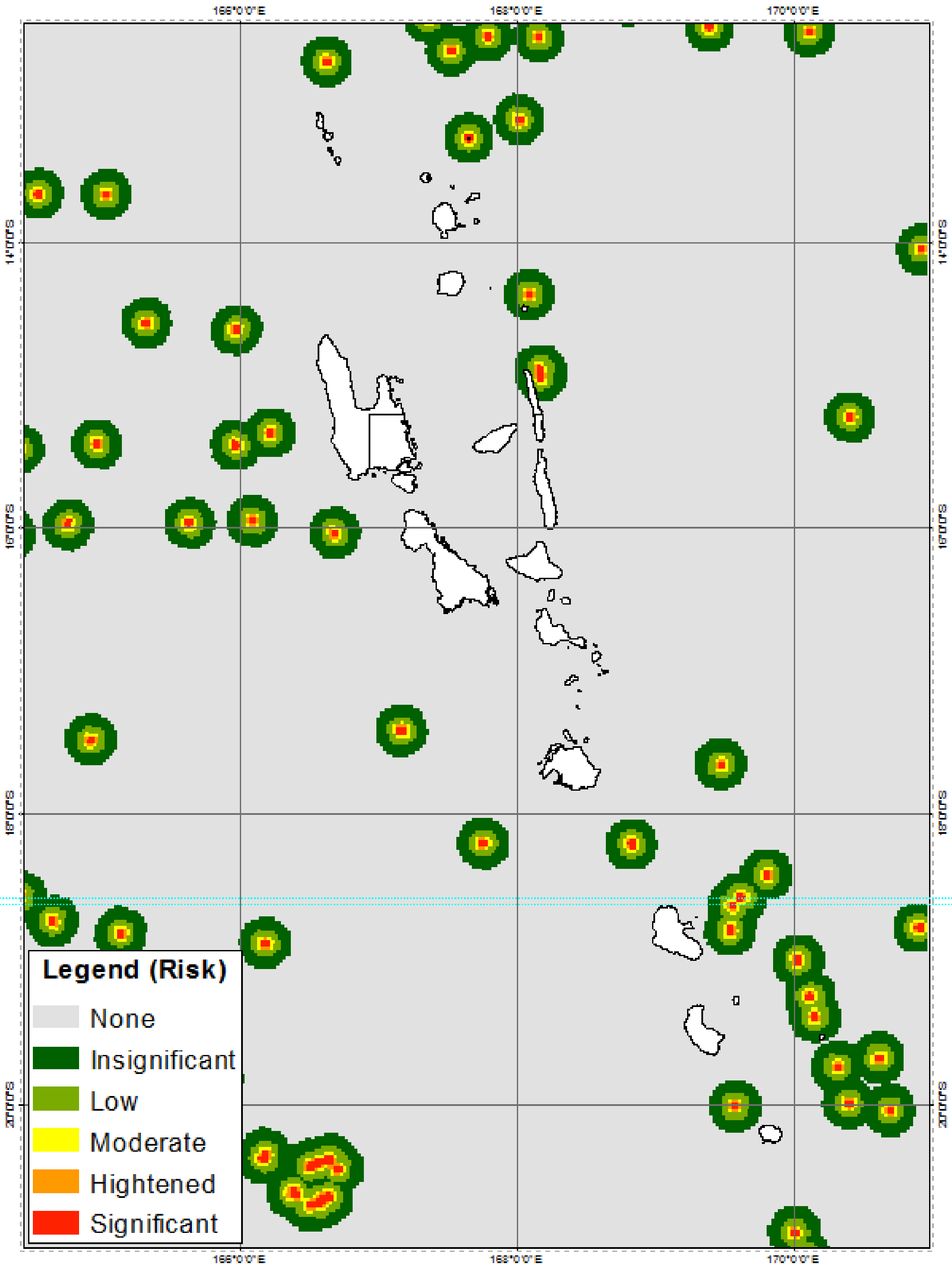


Figure 20: Modelled Seamounts Risk.

4.2.5.4 Sub-surface Volcanic Activity

Much of the Pacific Ring of Fire is host to active seismic and volcanic activity that can modify the landscape over time. Such a change can render navigational charts, especially concerning navigable depth as void and in need of updating. In the period between eruption and chart review there exists an uncertainty in depth that can pose a risk to shipping who do not take adequate precautions.

- Score of 0: greater than 2.5nm from a site;
- Score of 1: between 2 and 2.5nm from a site;
- Score of 2: between 1.5 and 2nm from a site;
- Score of 3: between 1 and 1.5nm from a site;
- Score of 4: between 500m and 1nm from a site; and
- Score of 5: within 500m of the site.

Vanuatu is host to a number of active and dormant volcanoes. Eruptions have occurred repeatedly in the last hundred years with a major eruption in 1913 on the west side of Ambrym.[26] Other sites continue to have period small eruptions that emit ash. Of particular risk to shipping is submarine volcanic activity that can deposit hardened lava that can pose a grounding risk to navigating vessels.

The charts in Vanuatu describe three areas whose depths "*may differ considerably from those charted*"[27], namely at:

- 16˚41'S 168˚23'E;
- 16˚50'S 168˚32'E; and
- 16˚12'S 167˚11'E.

These locations are plotted below in **Figure 21**.

[26] Admiralty (2006). Admiralty Sailing Directions: Pacific Islands Pilot Volume II (NP 61). Eleventh Edition.

[27] Admiralty Chart 1576 Epi to Ile Mare.

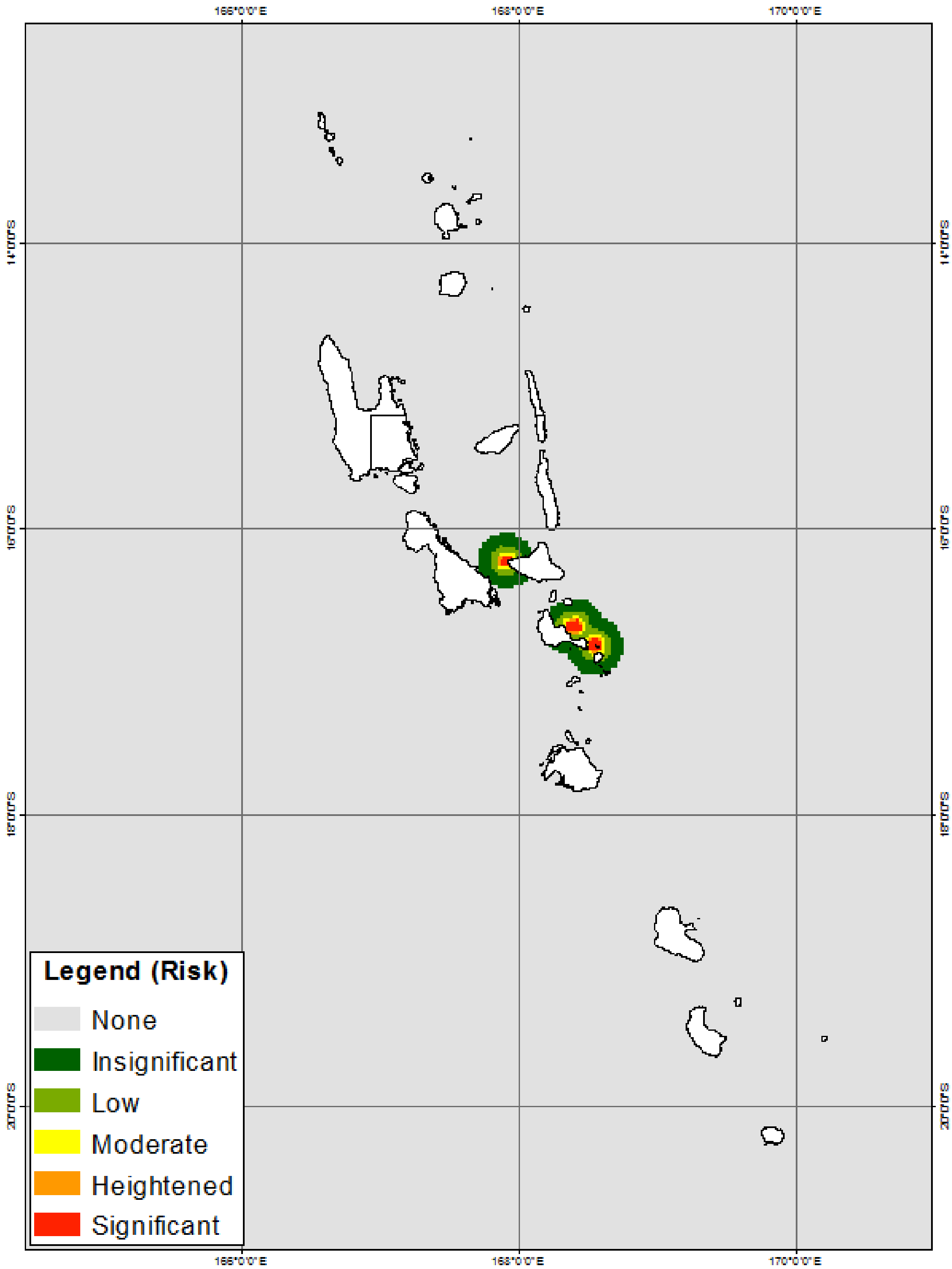


Figure 21: Modelled Sub-Surface Volcanic Activity.

4.2.5.5 Charted Tidal Hazard

Tidal races and over falls can be considerable localised tidal hazards that are distinct from a strong tidal current. The hazards can be unpredictable and difficult to navigate through, particularly for smaller craft.

- Score of 0: greater than 2.5nm from a site;
- Score of 1: between 2 and 2.5nm from a site;
- Score of 2: between 1.5 and 2nm from a site;
- Score of 3: between 1 and 1.5nm from a site;
- Score of 4: between 500m and 1nm from a site; and
- Score of 5: within 500m of a site.

The tidal hazards in Vanuatu and their relative proximity are presented below in **Figure 22**.

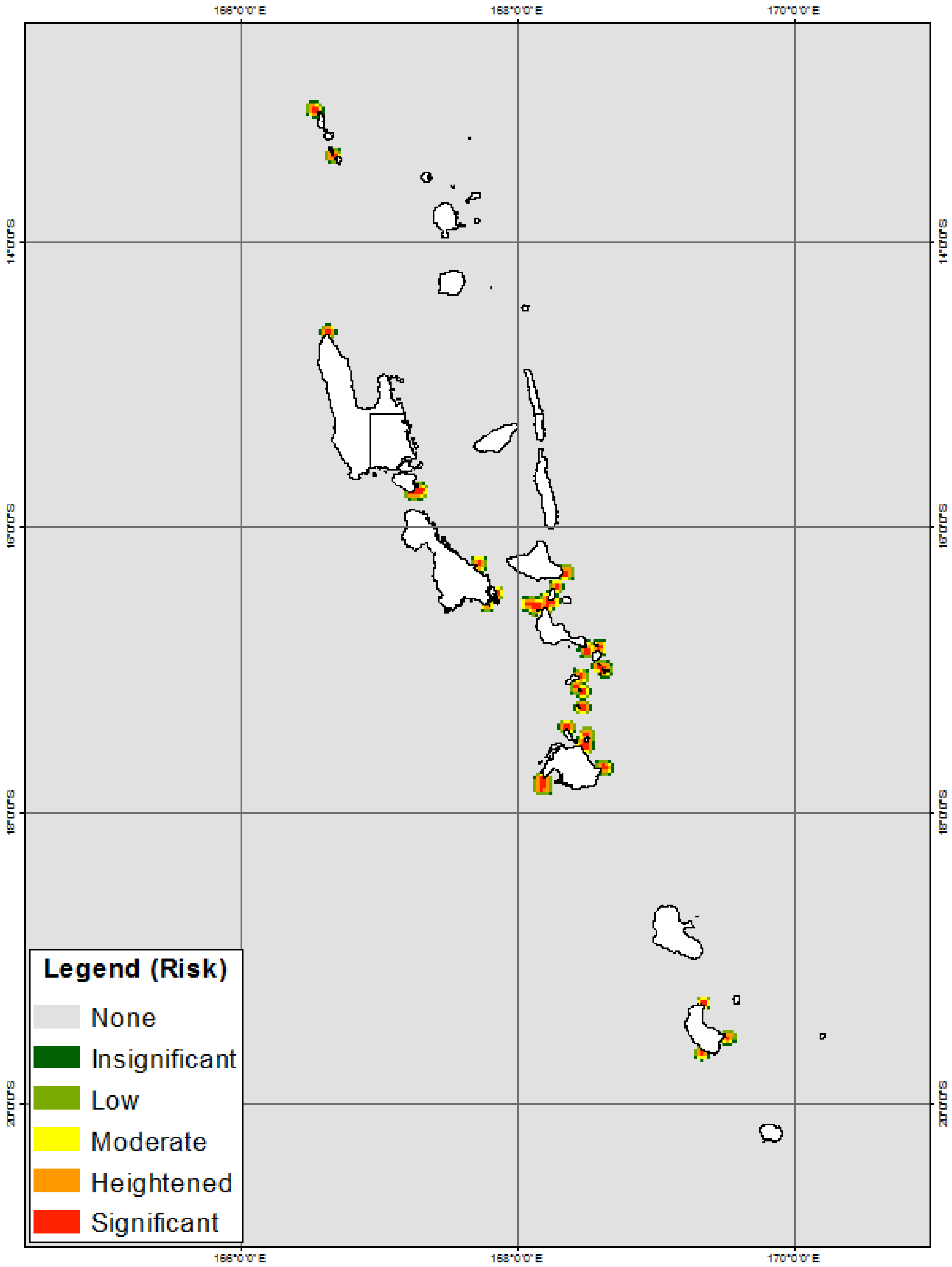


Figure 22: Modelled Charted Tidal Hazards.

4.3 CONSEQUENCE RISK FACTORS

Over the last thirty years there have been a number of high profile maritime disasters that have caused irreversible damage to sites of high environmental, cultural and economic value.

- In 1996 the grounding of the **Exxon Valdez** in the pristine Alaska Sound impacted upon more than 1,300 miles of coastline;
- In 1999 the oil tanker **Erika** broke apart in a storm and spilt over 10,000 tonnes of heavy fuel oil along 400km of French coastline; and
- The **Sea Empress** disaster of 1996 in the United Kingdom caused by a navigational error resulting in a hard grounding. 72,000 tonnes was released across a marine nature reserve.

4.3.1 Environmental Impact

The effect on the marine environment following a major maritime disaster can be devastating. In particular a considerable risk exists in the potential for a fuel tank or a cargo hold to breached, releasing pollutants. Shoreline habitats can be destroyed by either the primary physical impact of grounding or through the secondary release of a pollutant. In the South Pacific the sites at risk include:

- Coral Reefs, a world protected and endangered species;
- Wetlands Resources, such as mangroves;
- Important breeding grounds, including endangered species; and
- Sites protected under international conservation agreements.

4.3.1.1 Coral Reefs

Coral reefs are home to 25% of the world's marine life and are listed by the World Wildlife Fund as a priority species, of huge environmental significance.[28] Coral reefs can be damaged in two ways by a shipping incident. Firstly direct physical damage can occur from a grounding upon the reef and secondly the indirect release of a pollutant can kill the coral and the ecosystem that depends upon it.

The risk posed to a coral reef by a shipping incident is presumed to be proportional to the proximity of the incident to the reef. The assumption is of an a-directional release of pollutant and does not take into account prevailing conditions.

[28] World Wildlife Fund: http://wwf.panda.org/about_our_earth/blue_planet/coasts/coral_reefs/

- Score of 0: Greater than 20nm from coral;
- Score of 1: Between 10 and 20nm from coral;
- Score of 2: Between 5 to 10nm from coral;
- Score of 3: Between 2.5 and 5nm from coral;
- Score of 4: Between 1 and 2.5nm from coral; and
- Score of 5: Within 1nm of coral

Vanuatu's shoreline is host to a significant amount of coral, approximately 448km^2 in total.[29] Studies have shown that these regions are under threat with some marked decline recorded and remaining sites are judged to be of great importance (**Figure 23**). The reefs in Vanuatu have been geocoded from two sources; firstly coral reefs are marked on S-57 charts and their locations were extracted. Secondly a world coral reef dataset maintained by the IUCN Red List of Threatened Species was consulted.[30]

---

[29] Amos, M.J. (2007). Vanuatu fishery resource profiles, IWP-Pacific Technical Report (International Waters Project no.49). Available at: http://www.sprep.org/att/publication/000557_IWP_PTR49.pdf

Naviti, W. and Aston, J. (2000). Status of coral reef and reef fish resource of Vanuatu, Regional Symposium on Coral Reefs in the Pacific: Status and Monitoring; Resources and Management. 22-24 May 2000, Noumea, New Caledonia.

[30] IUCN Red List (2012). Available at: http://www.iucnredlist.org/technical-documents/spatial-data#corals.

Figure 23: Vanuatu's Coral Reefs (Source: Site Visit).

All coral reefs identified in the study area were manually queried to rate the damage that a pollution incident could potentially inflict upon the site. Three criteria were used to make the decision, namely the size of the reef and the amount and quality of coral it hosted as well as the isolation of the reef. Some sites were rated as high importance, such as Cook's Reef and the reef surrounding Rowa Islands whilst the rest were scored a moderate importance. **Figure 24** and **Figure 25** display the proximity to these reef sites.

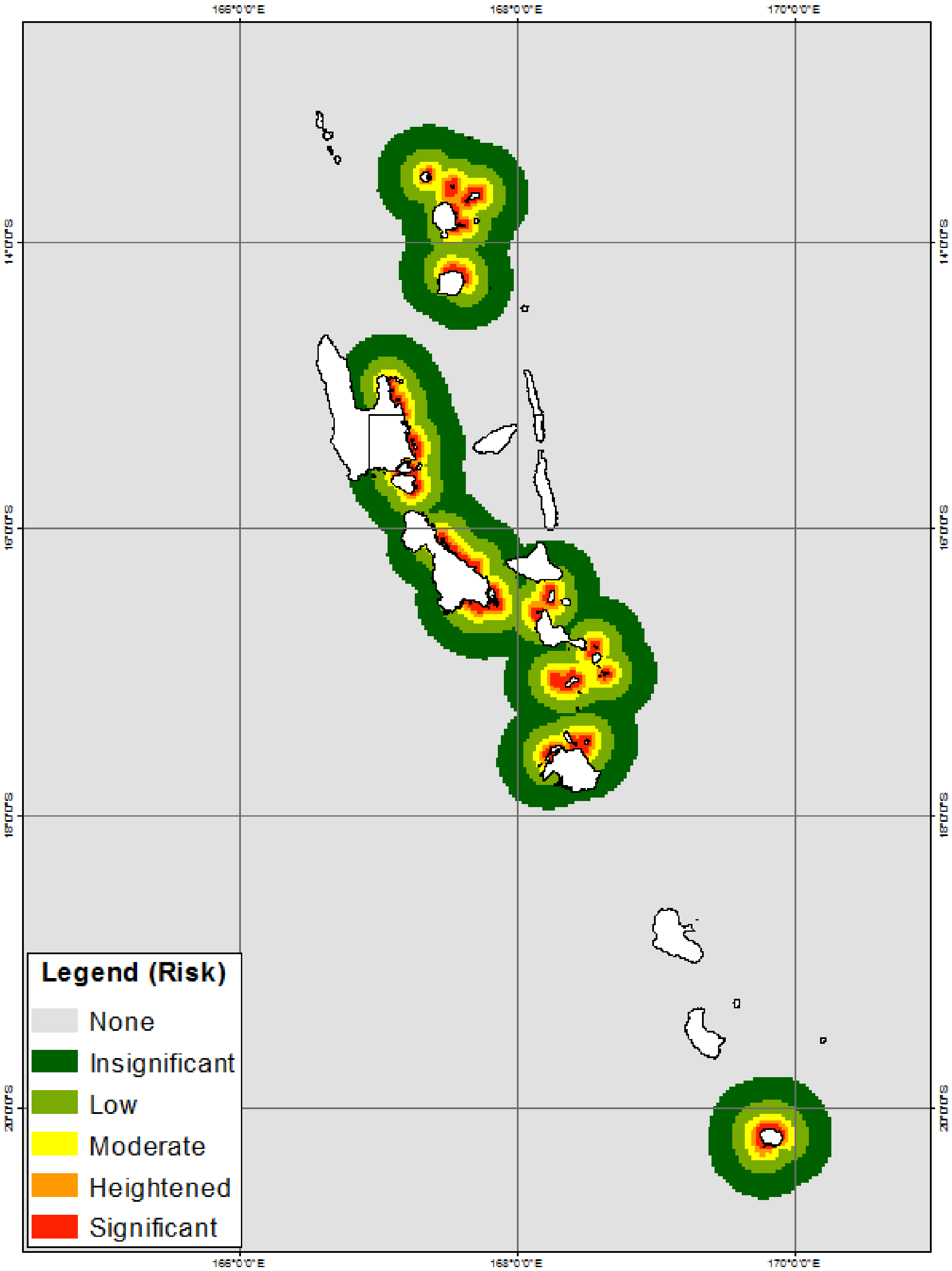


Figure 24: Modelled Proximity to High Value Coral Reefs.

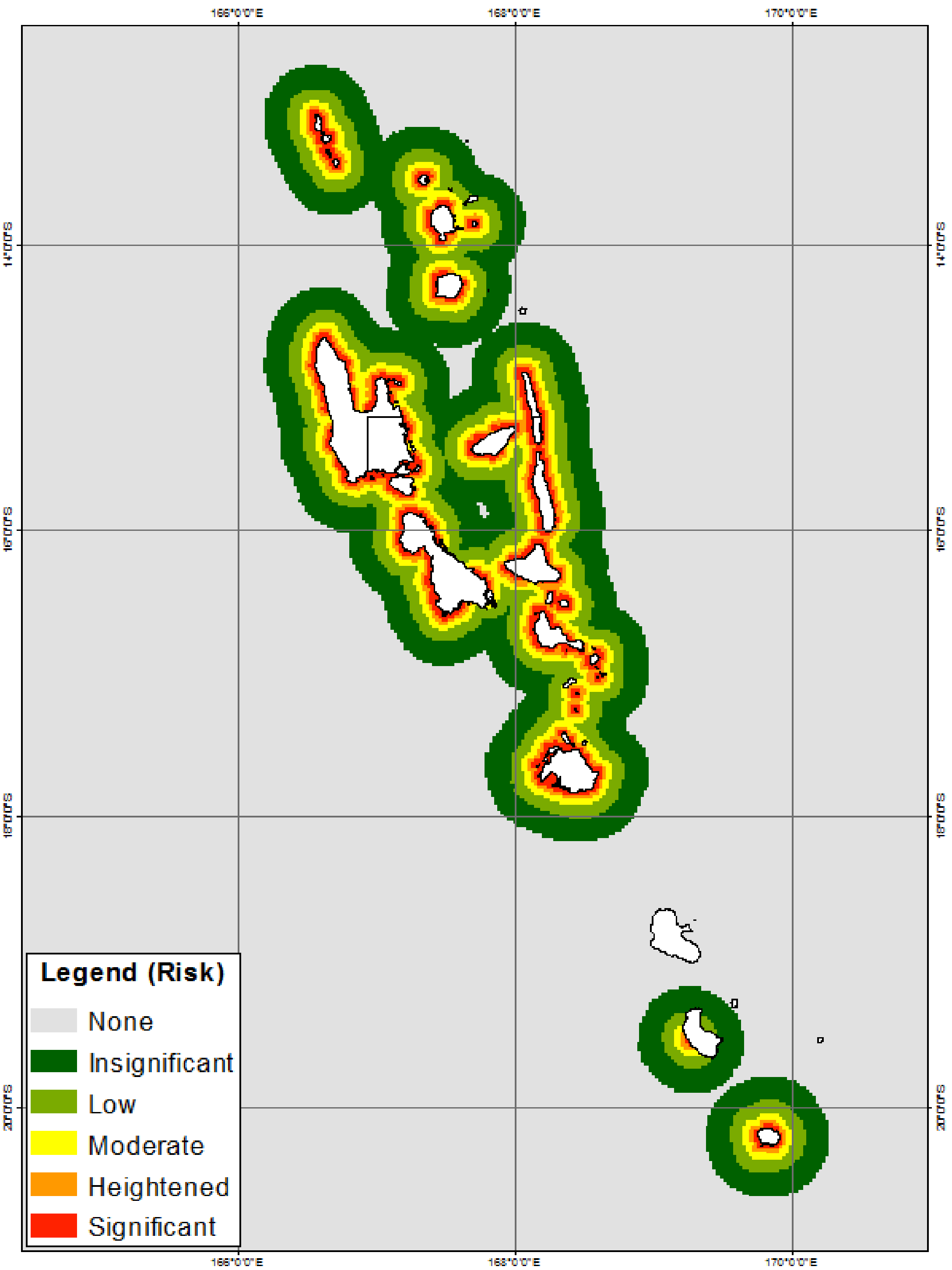


Figure 25: Modelled Proximity to Moderate Value Coral Reefs.

4.3.1.2 Wetlands Resources

Mangroves and other intertidal wetlands resources provide habitat, fertiliser and community resources. 50% of the global mangrove area has been lost since 1900 and 35% has been lost in the past two decades. The Pacific Islands account for 3% of the global inventory of mangroves.[31]

The risk posed to wetland resource by a shipping incident is presumed to be proportional to the proximity of the incident to the site. The assumption is of an a-directional release of pollutant and does not take into account prevailing conditions.

- Score of 0: Greater than 20nm from mangroves;
- Score of 1: Between 10 and 20nm from mangroves;
- Score of 2: Between 5 to 10nm from mangroves;
- Score of 3: Between 2.5 and 5nm from mangroves;
- Score of 4: Between 1 and 2.5nm from mangroves; and
- Score of 5: Within 1nm of mangroves.

Mangroves in Vanuatu account for approximately 2,500 ha of coastline.[32] The spatial location is more concentrated with presence on only nine of the islands in the archipelago.

Without a pre-existing database of mangrove locations a dataset was constructed of the mangrove locations using locations derived from a French fisheries report map published by Institut Français de Recherche Scientifique Pour Le Developpement En Cooperation (ORSTOM) in 1985.[33]

[31] Gilman, E. et al. (2006). Pacific Island Mangroves in a Changing Climate and Rising Sea. UNEP Regional Seas Reports and Studies No.179, United Nations Environmental Programme, Regional Seas Programme, Nairobi, Kenya.

[32] Naviti, W. and Aston, J. (2000). Status of coral reef and reef fish resource of Vanuatu, Regional Symposium on Coral Reefs in the Pacific: Status and Monitoring; Resources and Management. 22-24 May 2000, Noumea, New Caledonia.

[33] David, G. (1985). Peche de Subsistance et Milie Naturel: Les Mangroves de Vanuatu et Leur Interet Halieutique. Notes et Documents D'Oceanographie, 13, Sept 1985.

Figure 26: Vanuatu's Mangroves (Source: Vanuatu Visit).

All wetland resource sites identified in the study area were manually queried to rate the damage that a pollution incident could potentially inflict upon the site. The size and quality of the site were used as rating criteria. Some sites were rated as high importance, such as around Malakula whilst the rest were scored a moderate importance.

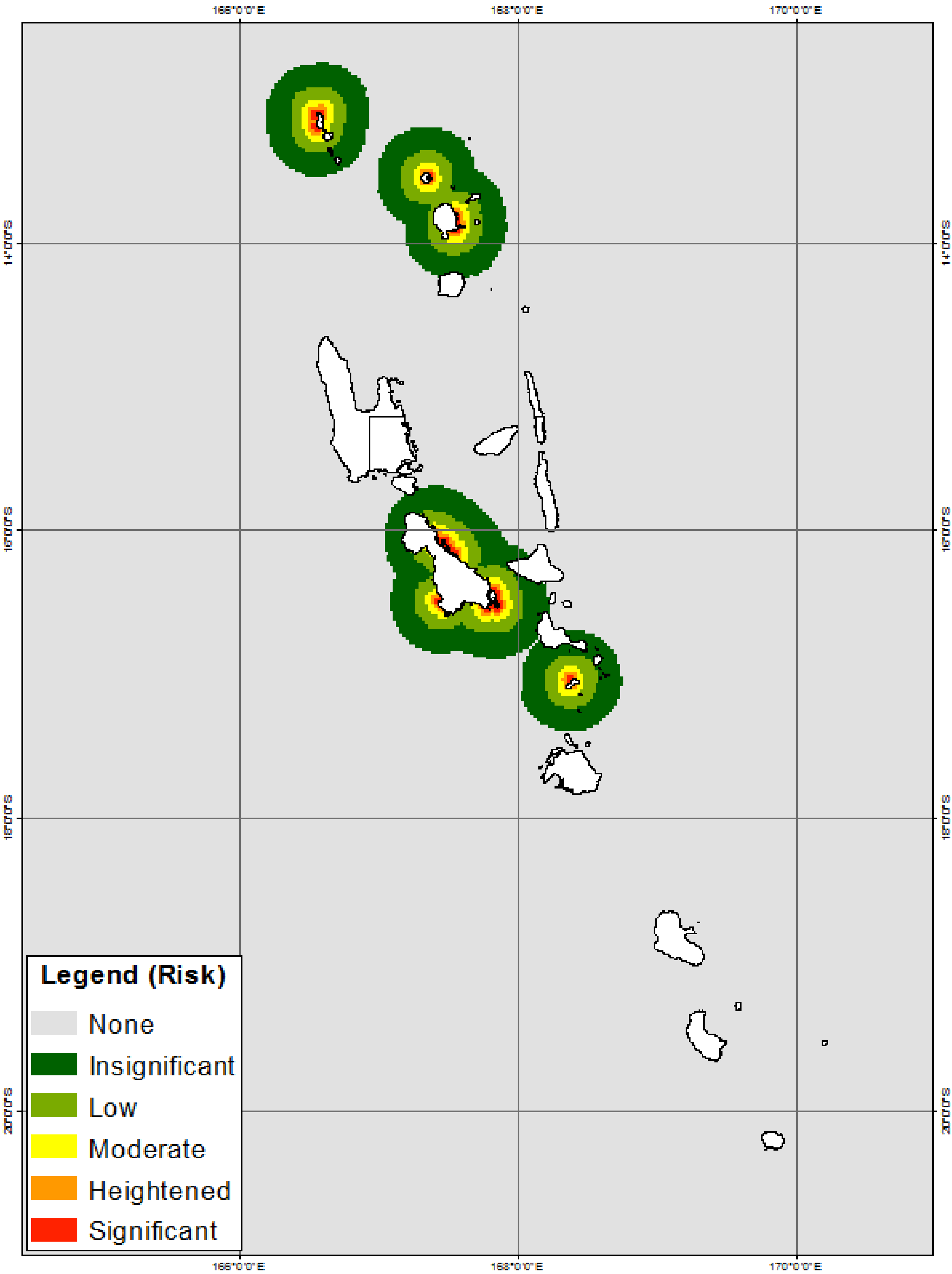


Figure 27: Modelled Proximity to High Value Wetlands Resource.

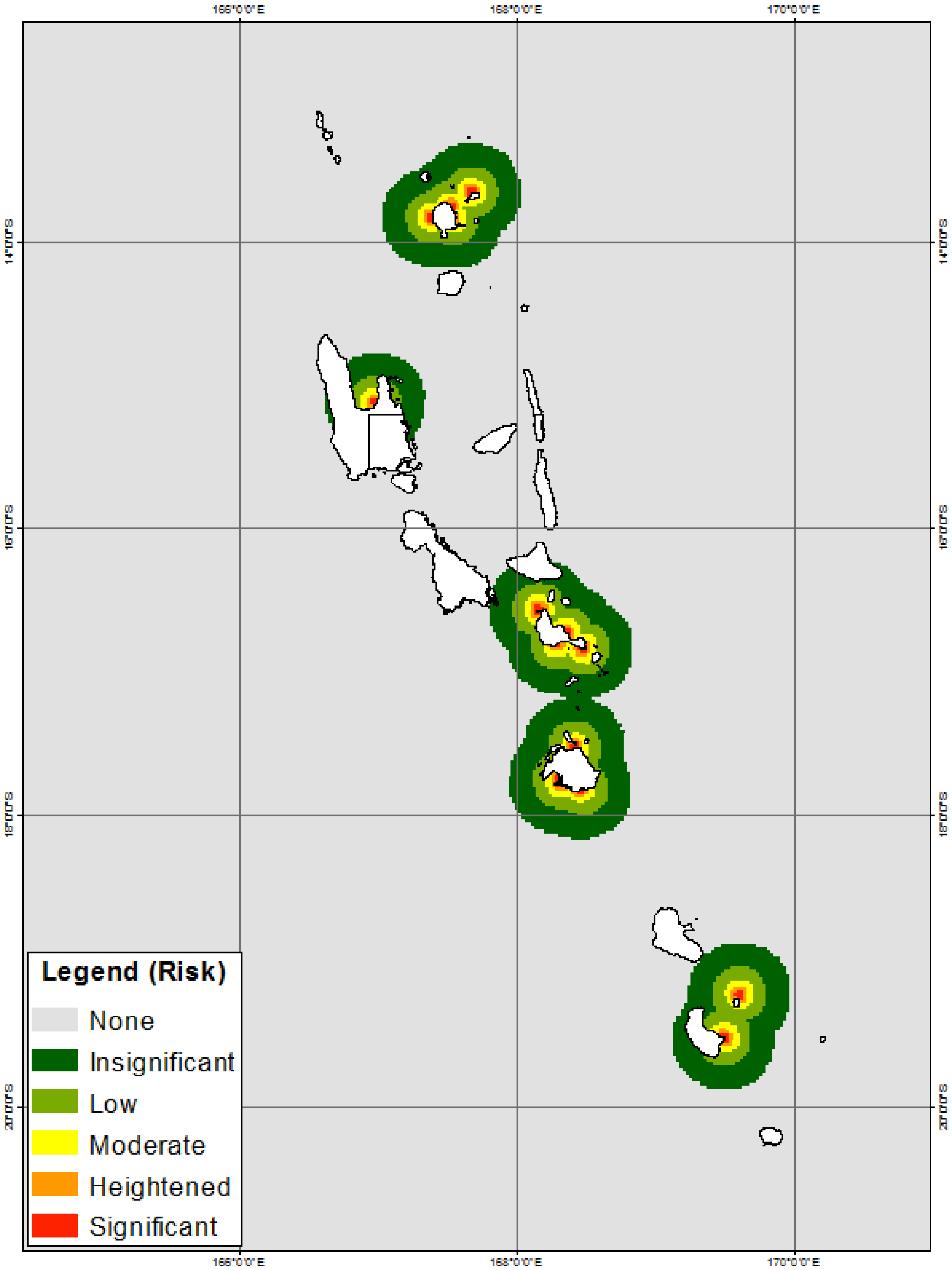


Figure 28: Modelled Proximity to Moderate Value Mangroves Resource.

4.3.1.3 Breeding Grounds

Often the direct impacts on wildlife are the images most promulgated following a major oil spill. However beyond the direct deaths of birds, animals and fish to exposure, the loss of future generations can have the most impact on the wildlife count.

The risk posed to a breeding ground by a shipping incident is assumed to be proportional to the proximity of the incident to the site. The assumption is of an a-directional release of pollutant and does not take into account prevailing conditions.

- Score of 0: Greater than 20nm from a major breeding ground;
- Score of 1: Between 10 and 20nm from a major breeding ground;
- Score of 2: Between 5 to 10nm from a major breeding ground;
- Score of 3: Between 2.5 and 5nm from a major breeding ground;
- Score of 4: Between 1 and 2.5nm from a major breeding ground; and
- Score of 5: Within 1nm of a major breeding ground.

In Vanuatu one of the most protected species are turtles for which the country has a number of important breeding grounds. These breeding grounds were identified by consultation with locals and a literature review.[34] These sites are presented in **Figure 29**.

[34] In particular the State of the Worlds Turtles dataset was interrogated: http://seaturtlestatus.org/

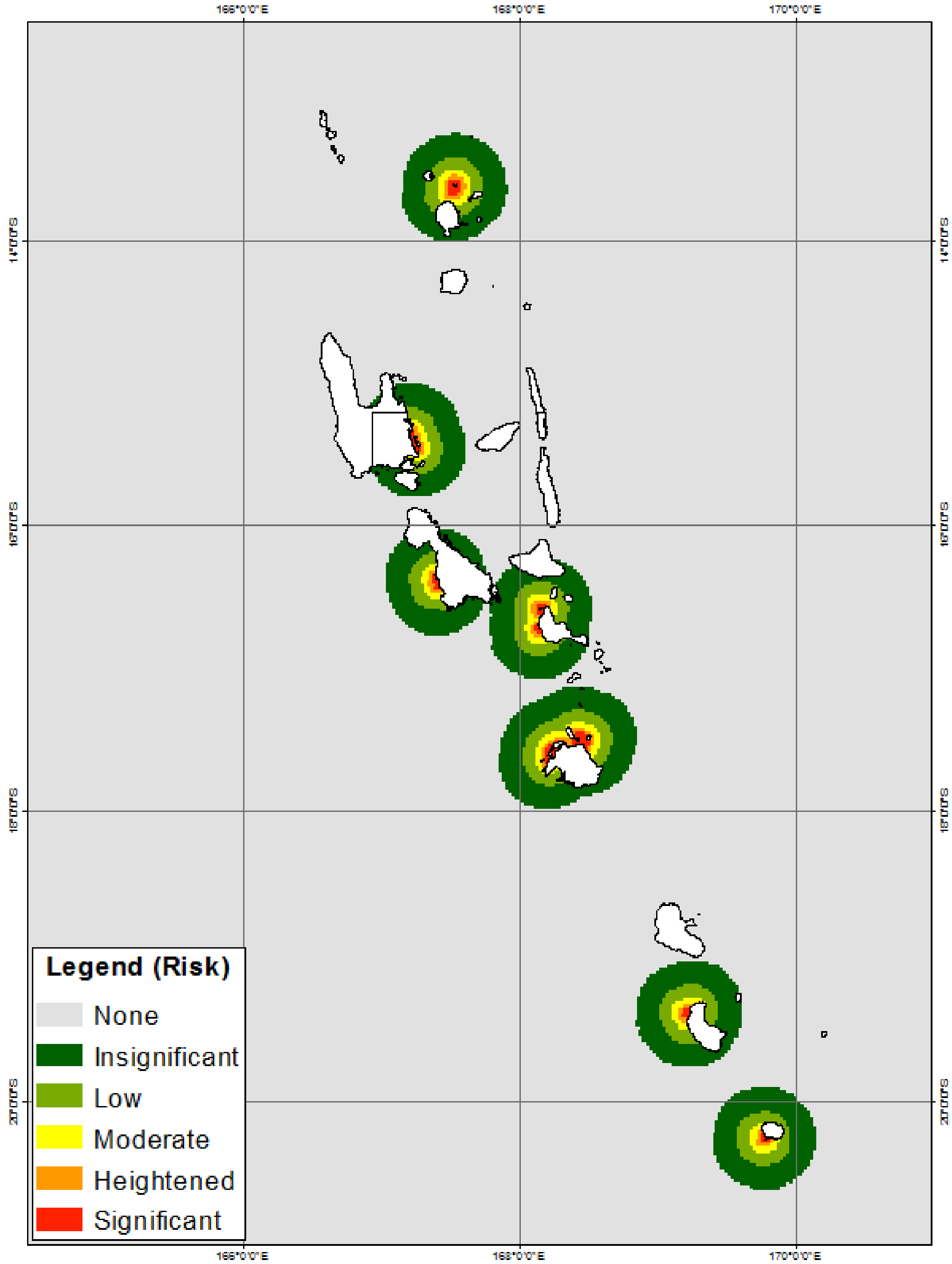


Figure 29: Modelled Proximity to Key Breeding Grounds.

4.3.1.4 Protected Sites

A number of world, regional and local programs and laws protect certain environmental areas. These range from UN World Heritage Sites to local informal agreements. In addition to the preceding impacts the destruction of a site of environmental protection would be

The risk posed to a protected site by a shipping incident is assumed to be proportional to the proximity of the incident to the site. The assumption is of an a-directional release of pollutant and does not take into account prevailing conditions.

- Score of 0: Greater than 20nm from a site;
- Score of 1: Between 10 and 20nm from a site;
- Score of 2: Between 5 to 10nm from a site;
- Score of 3: Between 2.5 and 5nm from a site;
- Score of 4: Between 1 and 2.5nm from a site; and
- Score of 5: Within 1nm of a site.

In Vanuatu there are few sites protected by legislation; however a number are protected by local tabus created by the indigenous communities. These sites were geocoded based on local consultation during a site visit and sourced from available literature.[35] As no official datasets exist and some sites are referred to with their local names then this dataset is approximate.

No sites with a global designation exist in Vanuatu's EEZ and there is a single national marine protected area; namely the foreshore area of the east Espiritu Santo.

[35] Naviti, W. and Aston, J. (2000). Status of coral reef and reef fish resources of Vanuatu. Regional Symposium on Coral Reefs in the Pacific: Status and Monitoring; Resources and Management, 22-24 May 2000, Noumea, New Caledonia.
http://www.protectedplanet.net/
http://www.mpatlas.org/region/nation/VUT/

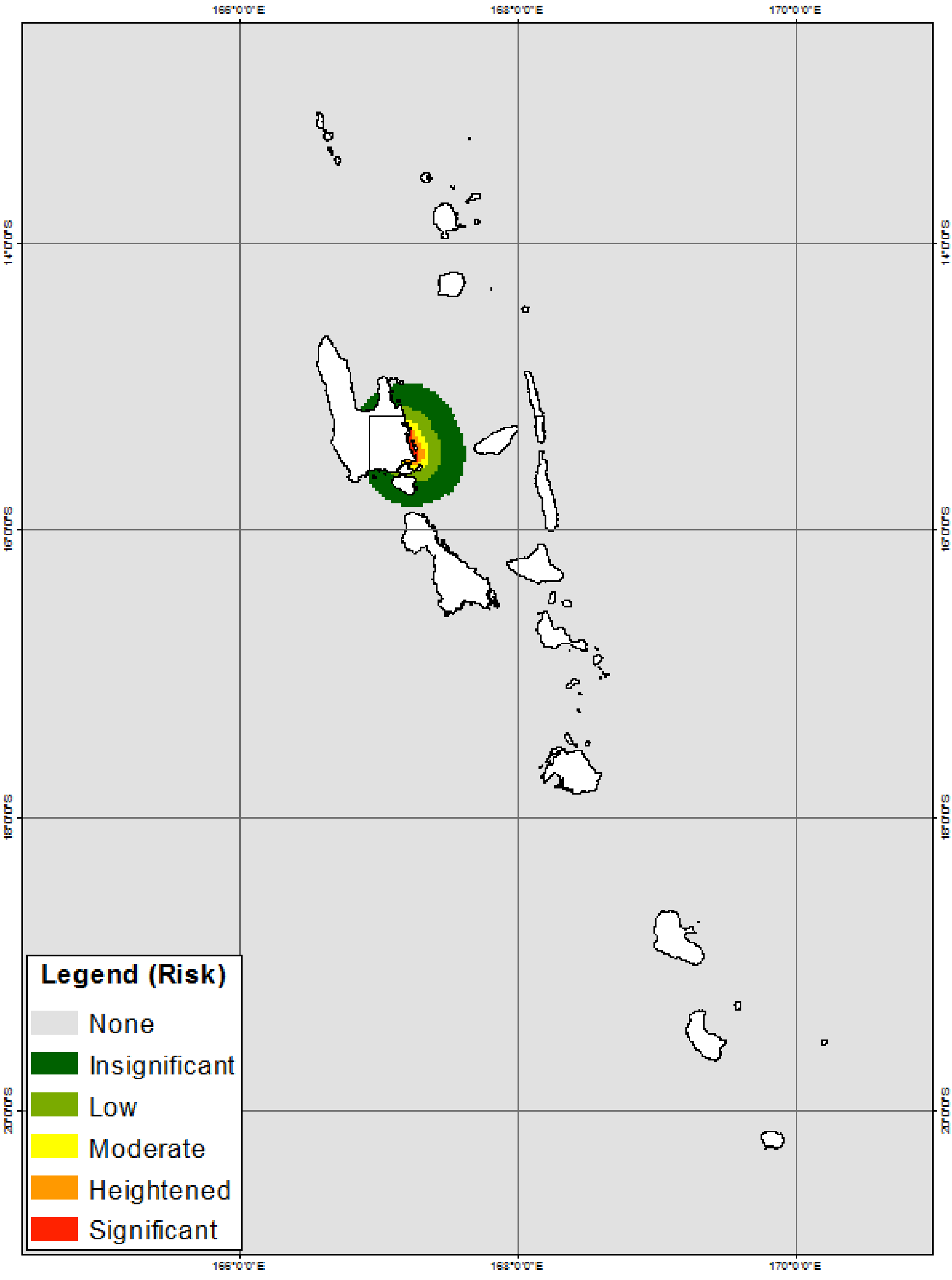


Figure 30: Modelled Proximity to Sites of National Environmental Value.

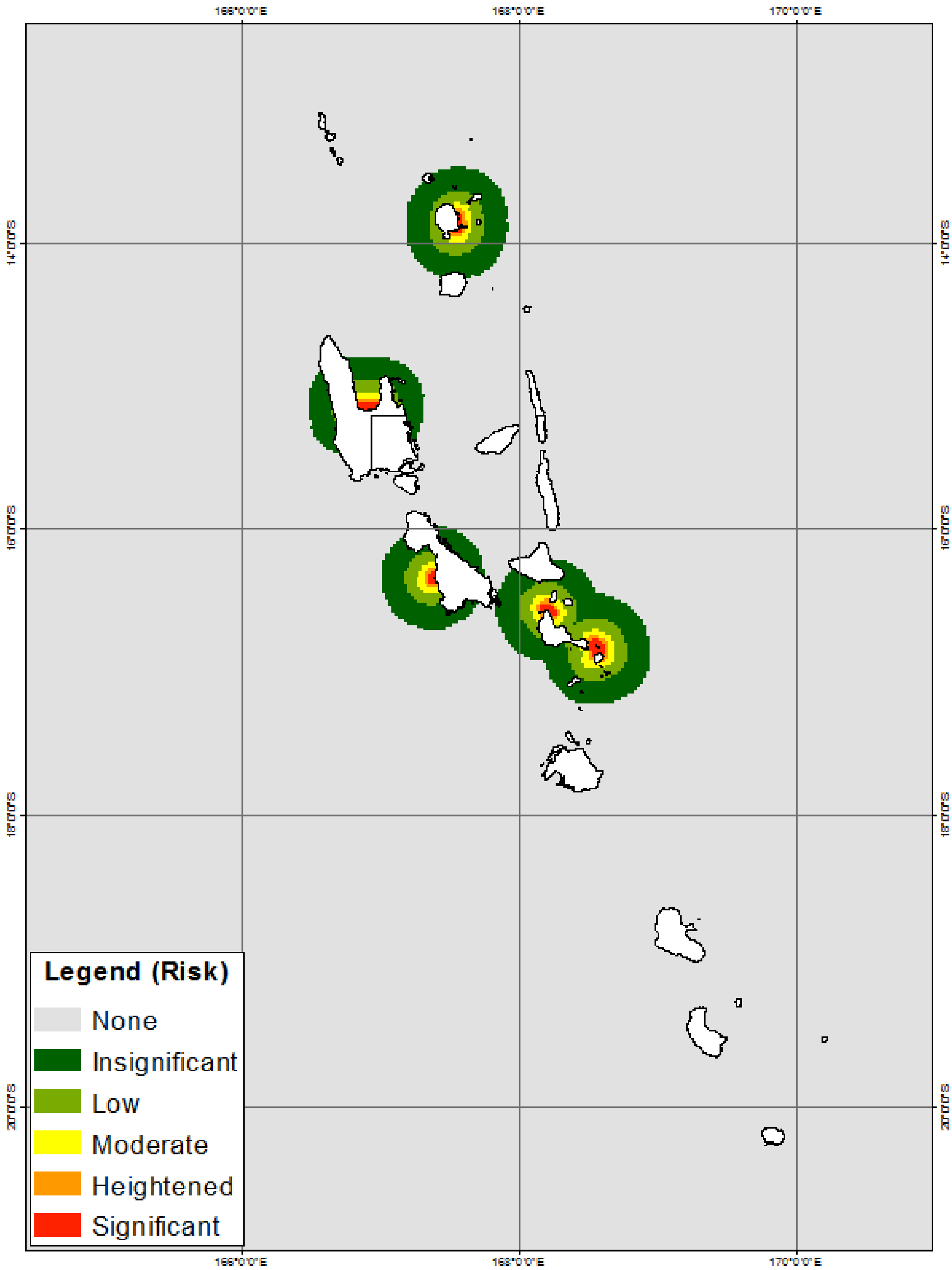


Figure 31: Modelled Proximity to Sites of Local Environmental Value.

4.3.2 Culturally Sensitive Areas

The consequences of a shipping incident cause damage beyond the environment. A number of areas of high cultural significance can be identified that would be themselves damaged and cause distress among local communities. As with environmentally significant sites the relative importance of these sites can range from sites of global significance such as World Heritage Sites to local tabus.

Three designations were created relating to the relative significance of a cultural site. Cultural sites can be globally, regionally or locally significant depending on the importance of a protection designation, such as a World Heritage Site, or the size of the group for whom the site is importance.

The risk posed to a protected site by a shipping incident is assumed to be proportional to the proximity of the incident to the site. The assumption is of an a-directional release of pollutant and does not take into account prevailing conditions.

- Score of 0: Greater than 20nm from a site;
- Score of 1: Between 10 and 20nm from a site;
- Score of 2: Between 5 to 10nm from a site;
- Score of 3: Between 2.5 and 5nm from a site;
- Score of 4: Between 1 and 2.5nm from a site; and
- Score of 5: Within 1nm of a site.

In Vanuatu one World Heritage Site exists northwest of Efate. Chief Roi Mata's Domain was listed as a World Heritage Site in 2008 and covers 886 hectares.[36] The site covers the traditional location of the chief's residence, the site of his death and his mass burial site. As a World Heritage Site the surrounding area is deemed as a site of universal global value and an outstanding example of a Pacific chiefly system.

In Vanuatu there are few sites protected by legislation but are protected by local tabus created by the indigenous communities. These sites were

[36] http://whc.unesco.org/en/list/1280

geocoded based on local consultation during a site visit and sourced from available literature.[37] As no official datasets exist and some sites are referred to with their local names then this dataset is approximate.

[37] Naviti, W. and Aston, J. (2000). Status of coral reef and reef fish resources of Vanuatu. Regional Symposium on Coral Reefs in the Pacific: Status and Monitoring; Resources and Management, 22-24 May 2000, Noumea, New Caledonia.

http://www.protectedplanet.net/

http://www.mpatlas.org/region/nation/VUT/

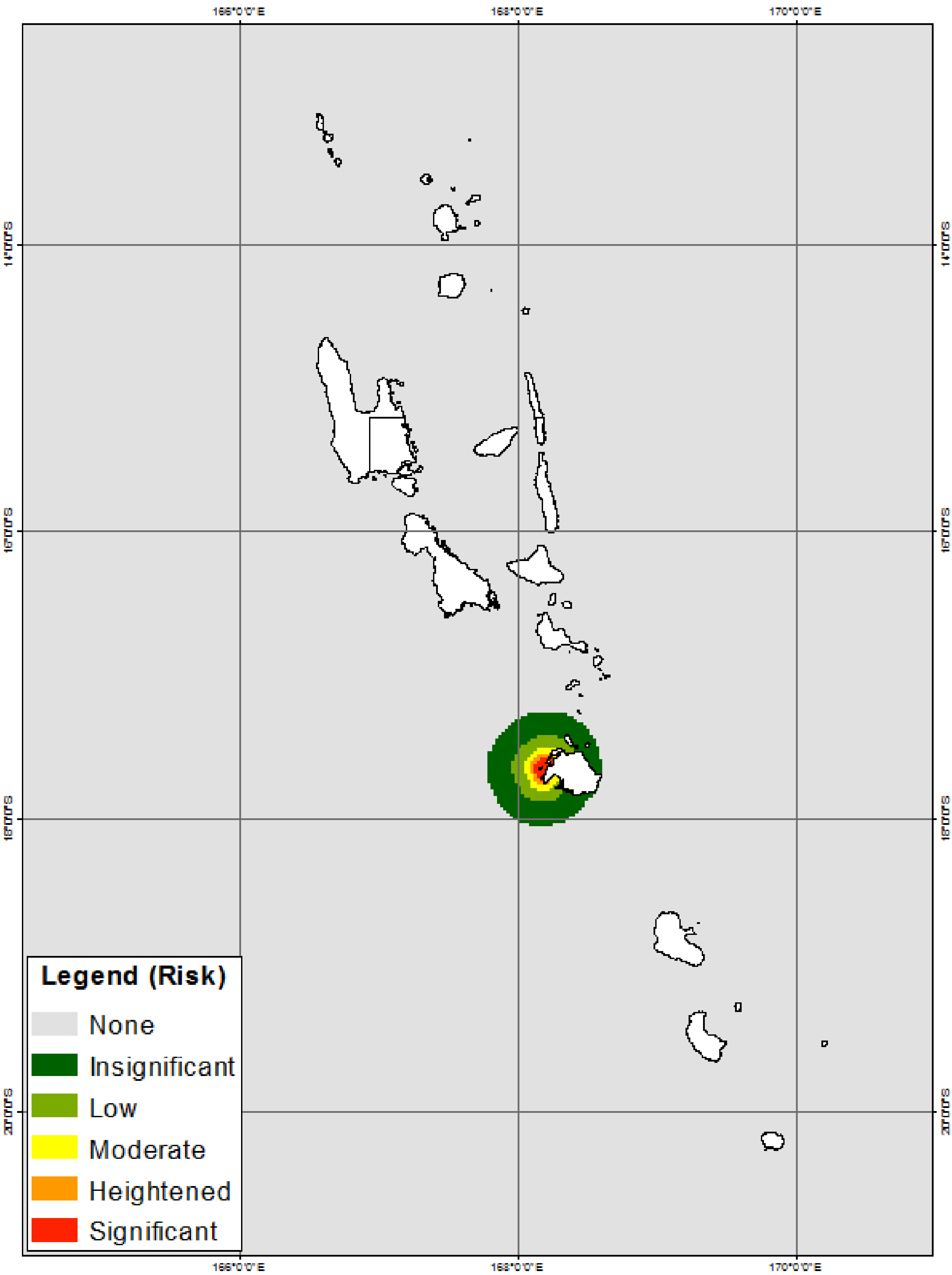


Figure 32: Modelled Proximity to Sites of Global Cultural Value.

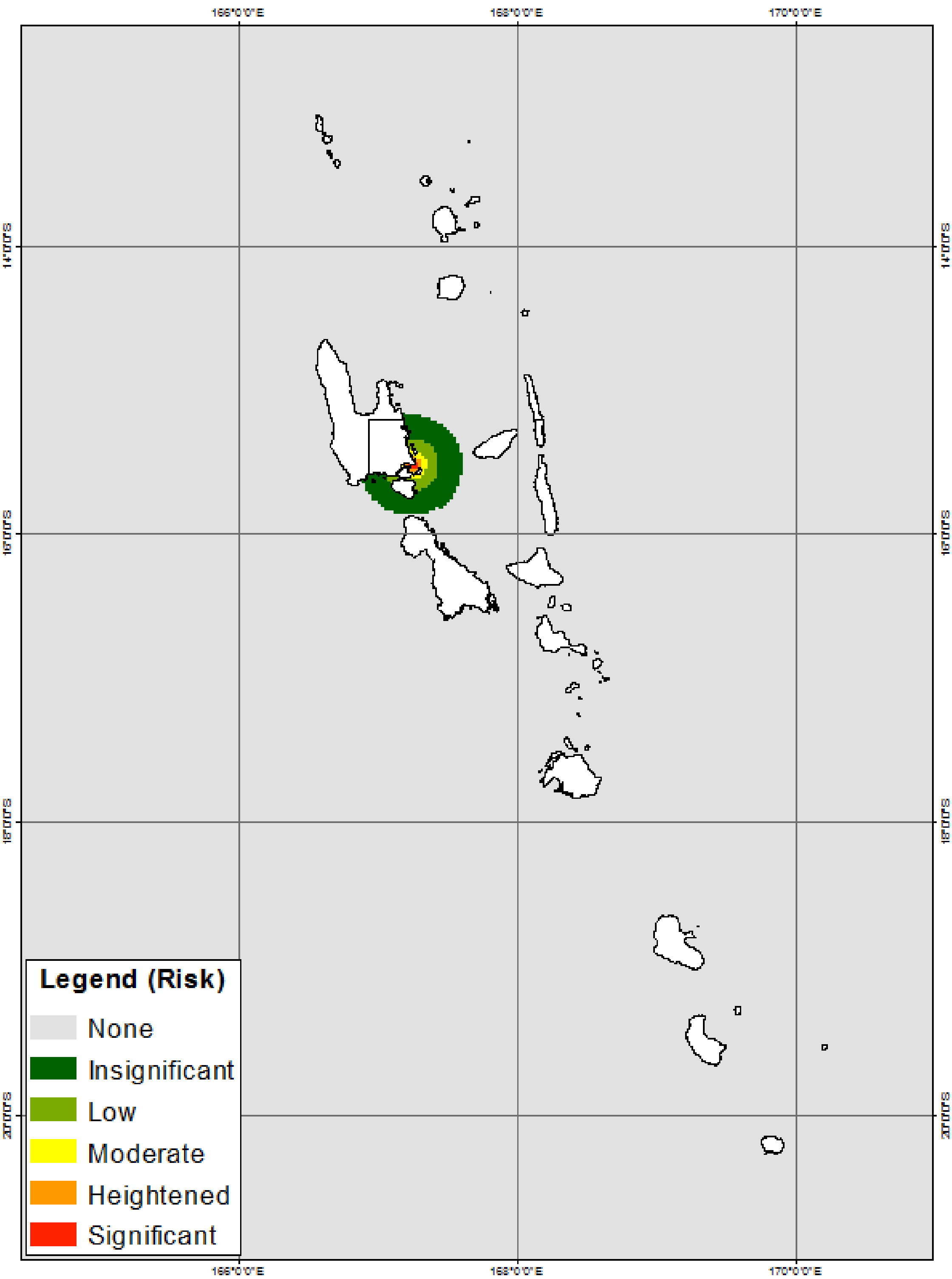


Figure 33: Modelled Proximity to Sites of National Cultural Value.

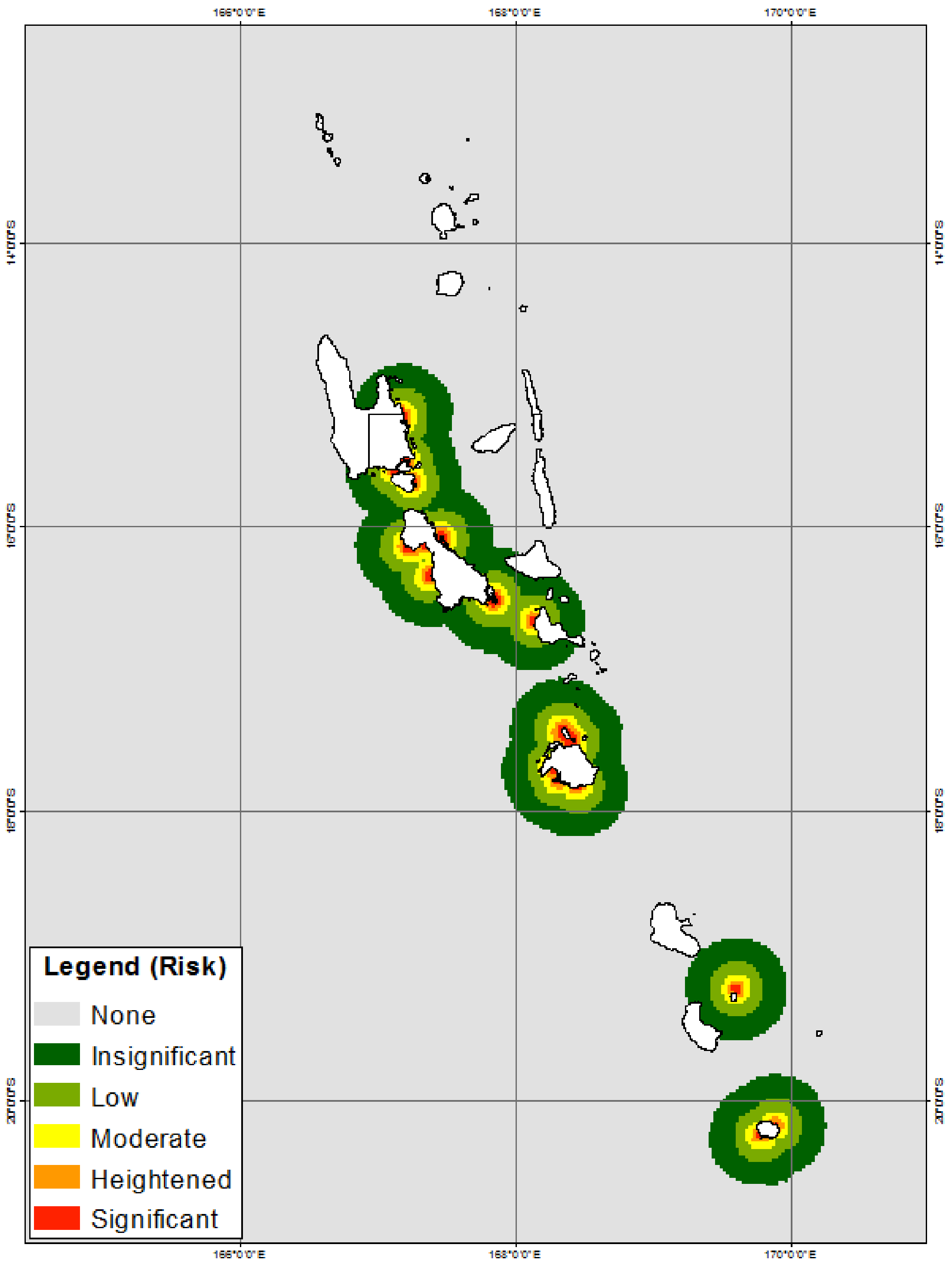


Figure 34: Modelled Proximity to Sites of Local Cultural Value.

4.3.3 Economically Sensitive Areas

The economic consequence of a shipping incident refers to the impact upon the local economy and not to the ship operator. The economic consequence is in most cases a denial of access problem with the loss of a resource, tourist potential or in the extreme a closure of a business.

Economic damage can include:

- Proximity to key infrastructure such as ports that would be closed following an incident in their approaches; thereby denying trade to local businesses;
- Proximity to key tourist sites, including cruise ship destinations and diving excursion sites; and
- Areas of high and moderate economic contribution.

4.3.3.1 Key Infrastructure

Following a major incident in a port approach then there is a high likelihood of a blockage factor that would prevent other trade from entering the port. A closure of a port can result in a large impact on the sectors of the local economy that is dependent upon sea-borne trade and cruise ship stops.

The risk posed to key infrastructure by a shipping incident is assumed to be proportional to the proximity of the incident to the site. The assumption is of an a-directional release of pollutant and does not take into account prevailing conditions.

- Score of 0: Greater than 20nm from a site;
- Score of 1: Between 10 and 20nm from a site;
- Score of 2: Between 5 to 10nm from a site;
- Score of 3: Between 2.5 and 5nm from a site;
- Score of 4: Between 1 and 2.5nm from a site; and
- Score of 5: Within 1nm of a site.

Figure 35: Port Vila (Source: Vanuatu Site Visit).

In Vanuatu the two major ports are Port Vila, Éfaté and Luganville, Espiritu Santo. These two ports account for the majority of Vanuatu's cargo and passenger movements and also host the hub of domestic services that operate around the archipelago.

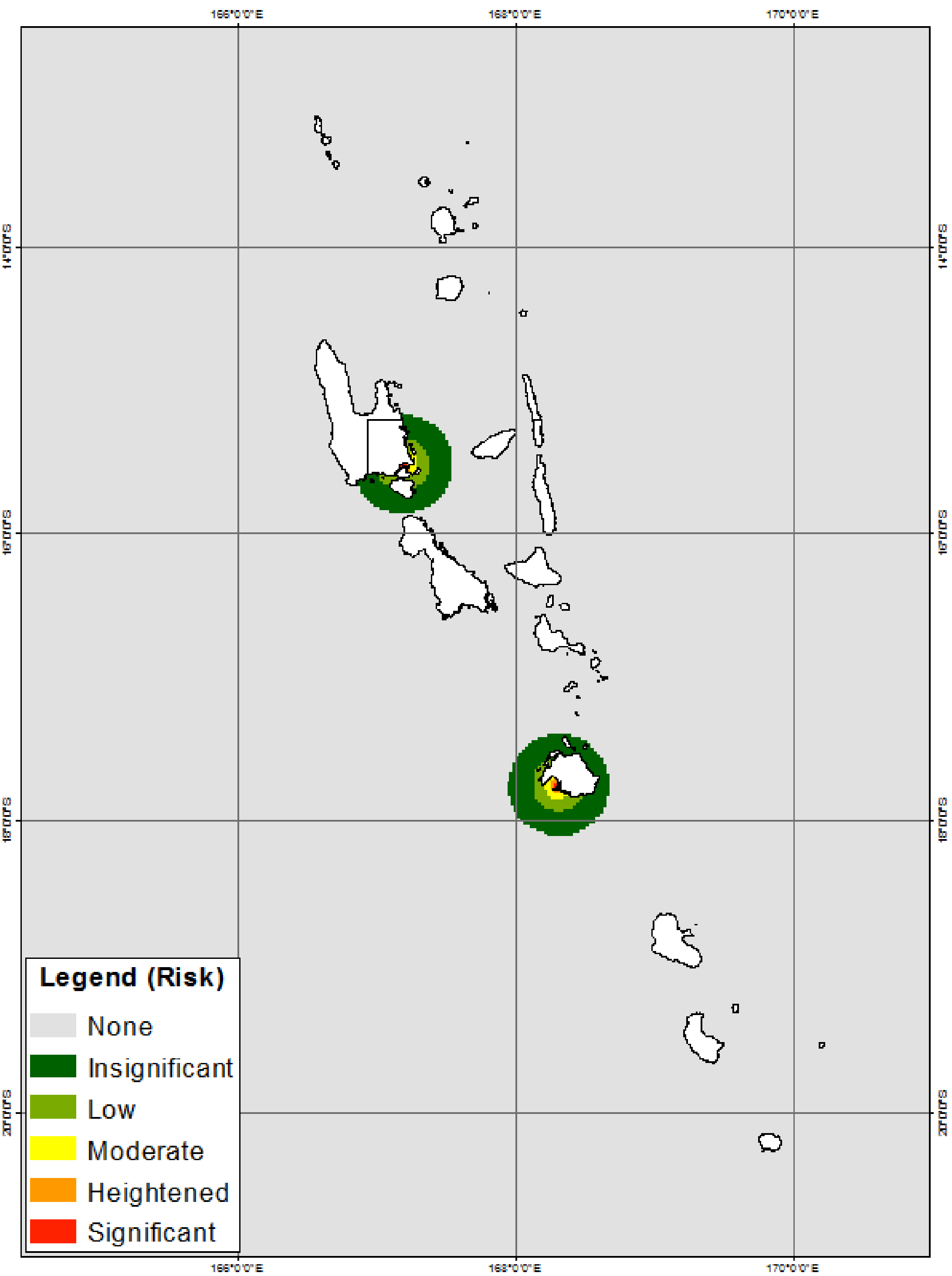


Figure 36: Modelled Proximity to Sites of Key Infrastructure.

4.3.3.2 Tourist Sites and Cruise Ship Stops

In much of the South Pacific, tourism dominates the local economies and any interruption to tourist numbers will impact upon the economy. In particular the scheduling of cruise ships dictates that considerable wealth is generated in a short time span during the regular stops of a cruise ship, carrying upwards of 3,000 people. An incident that interrupted or ended a visit to a site would have substantial economic implications.

The risk posed to tourist sites by a shipping incident is assumed to be proportional to the proximity of the incident to the site. The assumption is of an a-directional release of pollutant and does not take into account prevailing conditions.

- Score of 0: Greater than 20nm from a site;
- Score of 1: Between 10 and 20nm from a site;
- Score of 2: Between 5 to 10nm from a site;
- Score of 3: Between 2.5 and 5nm from a site;
- Score of 4: Between 1 and 2.5nm from a site; and
- Score of 5: Within 1nm of a site.

Tourism and travel in Vanuatu accounts for more than 40% of GDP.[38] More than half of all visitor arrivals in Vanuatu come by sea in cruise ships.[39] Any disruption to the coastal environment that draws tourists and generates cruise ship stops would be a significant impact on GDP. A number of sites can be identified that are significant draws for visitors and cruise ships:

- Port Vila;
- Luganville (Santo);
- Mystery Island;
- Champagne Beach;
- West Pentecôte and
- Wala Island (East Malakula).

Furthermore Vanuatu is host to some of the best diving locations in the world and are a popular draw to visitors. A dataset was created from locations identified during a site visit as well as the recommended sites from the Vanuatu Tourism Office.[40]

---

[38] International Finance Corporation (2010). State of Play Assessment for Vanuatu.

[39] Vanuatu's National Cruise Tourism Action Plan (2011).

[40] http://vanuatu.travel/

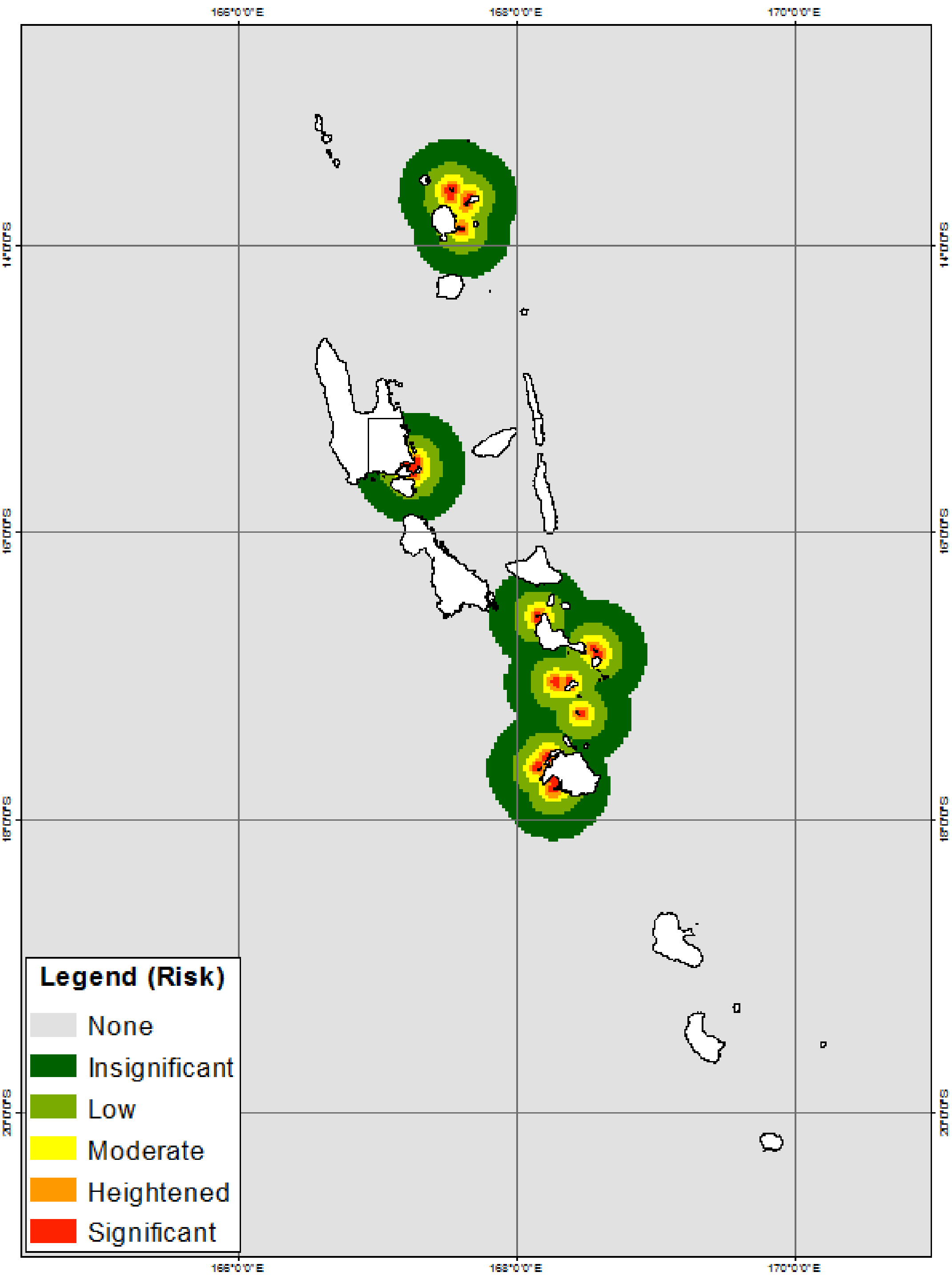


Figure 37: Modelled Proximity to Sites of Key Diving Activity.

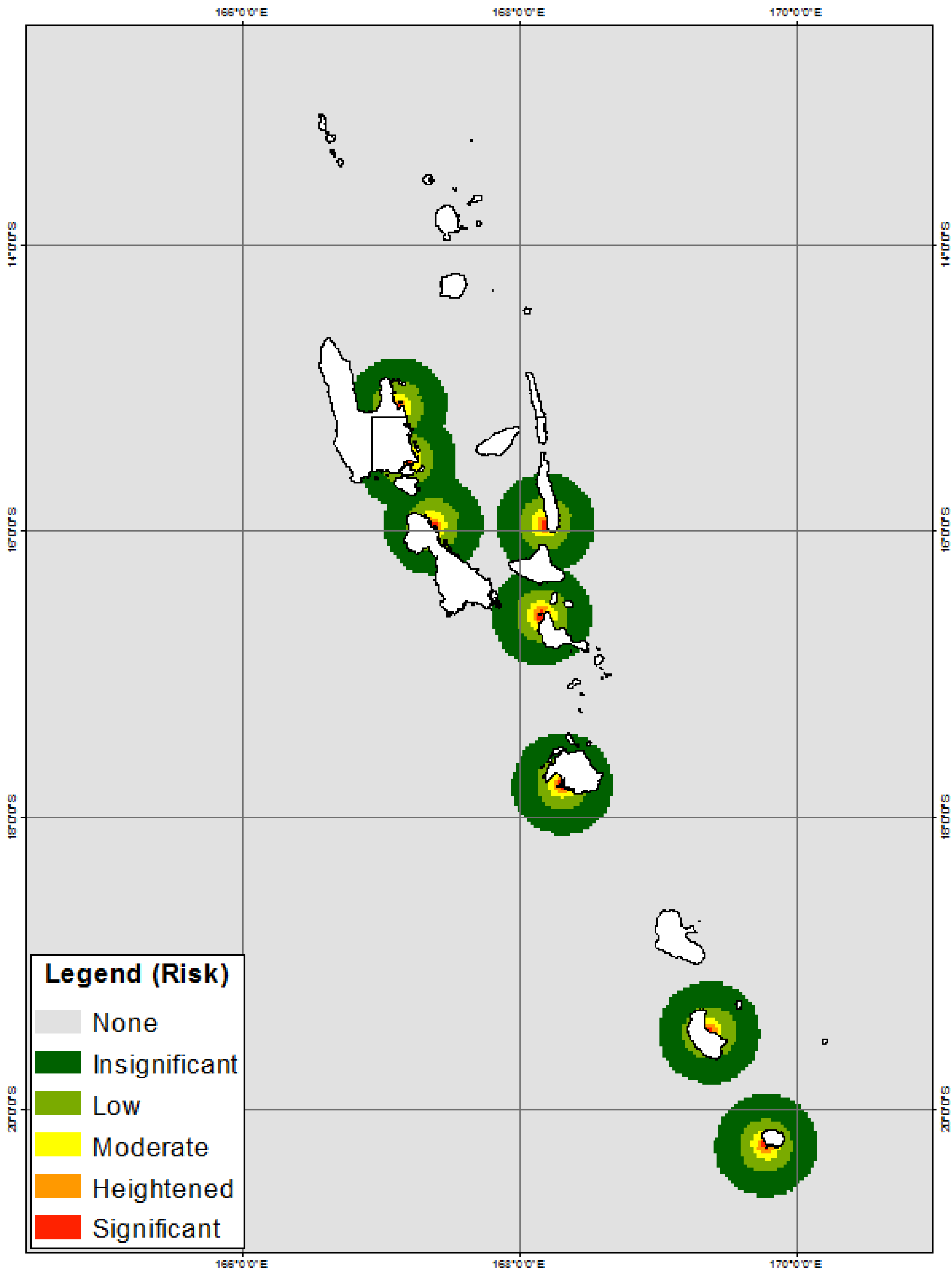


Figure 38: Modelled Proximity to Sites of Key Cruise Ship Stops.

4.3.3.3 Sites of High/Moderate Economic Contribution

A number of areas can be identified that contribute a significant amount to the national economy. These areas are far broader than the criteria identified so far and reflect the localised economic damage to the financial situation of a more general area. Sites were categorised into areas of 'High Economic Contribution' and areas of 'Moderate Economic Contribution'. The risk is then proximity based to these areas. These designations indicate the relative importance of these sites to the national economy including industry, tourism and trade.

- Score of 0: Greater than 20nm from a site;
- Score of 1: Between 10 and 20nm from a site;
- Score of 2: Between 5 to 10nm from a site;
- Score of 3: Between 2.5 and 5nm from a site;
- Score of 4: Between 1 and 2.5nm from a site; and
- Score of 5: Within 1nm of a site.

Areas of high economic contribution in Vanuatu include the east coast of Espiritu Santo including the port of Luganville, Homo Bay on the west coast of Pentecôte, the east coast of Tanna and the majority of the island of Éfaté. Areas of moderate economic contribution include Sola on Vanua Lava, Port Stanley and Wala Island on Malakula, the surrounding area to the Tongoa Wall, the west coast of Tanna and Mystery Island to the south.

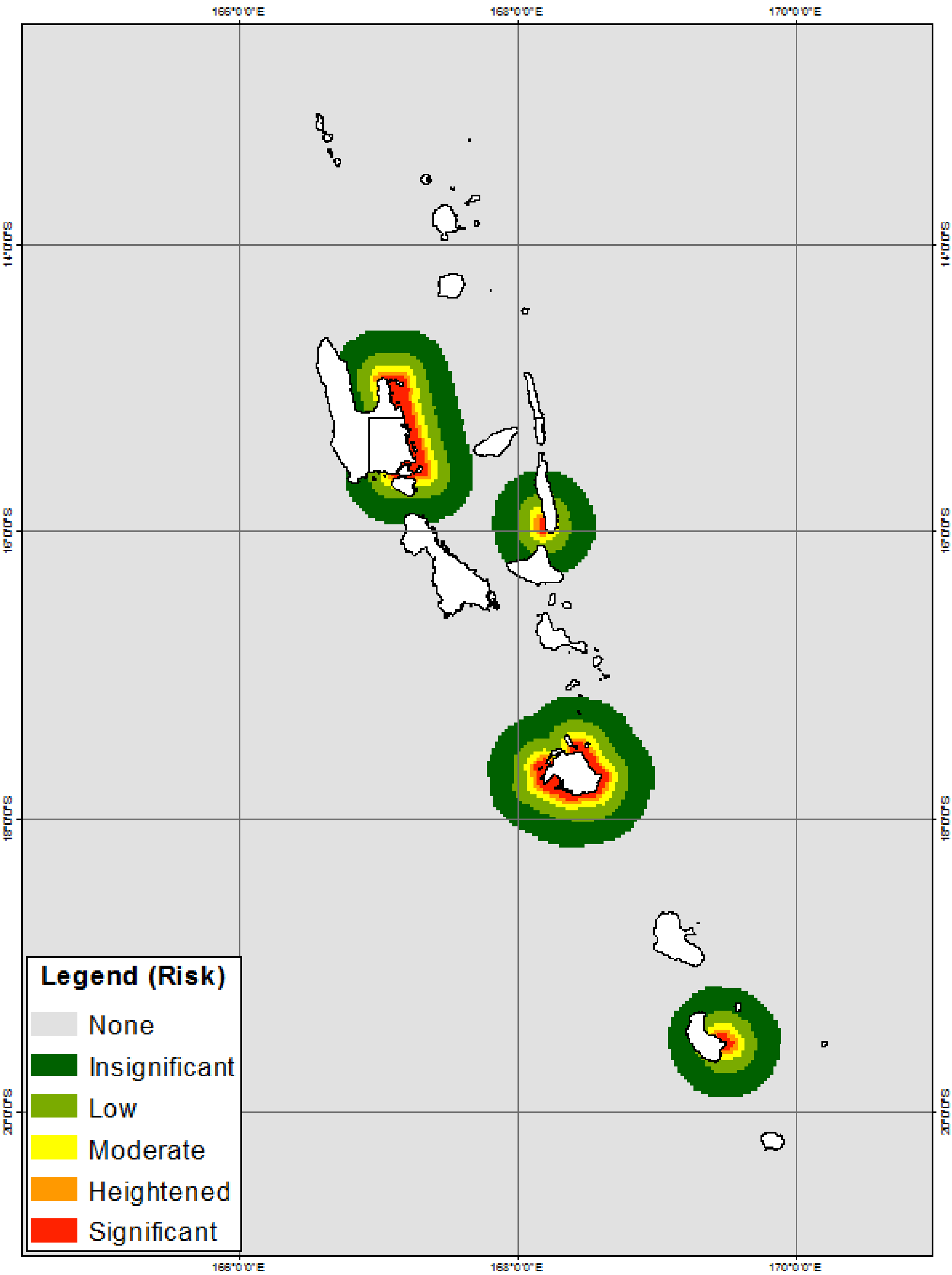


Figure 39: Modelled Proximity to Sites of High Economic Value.

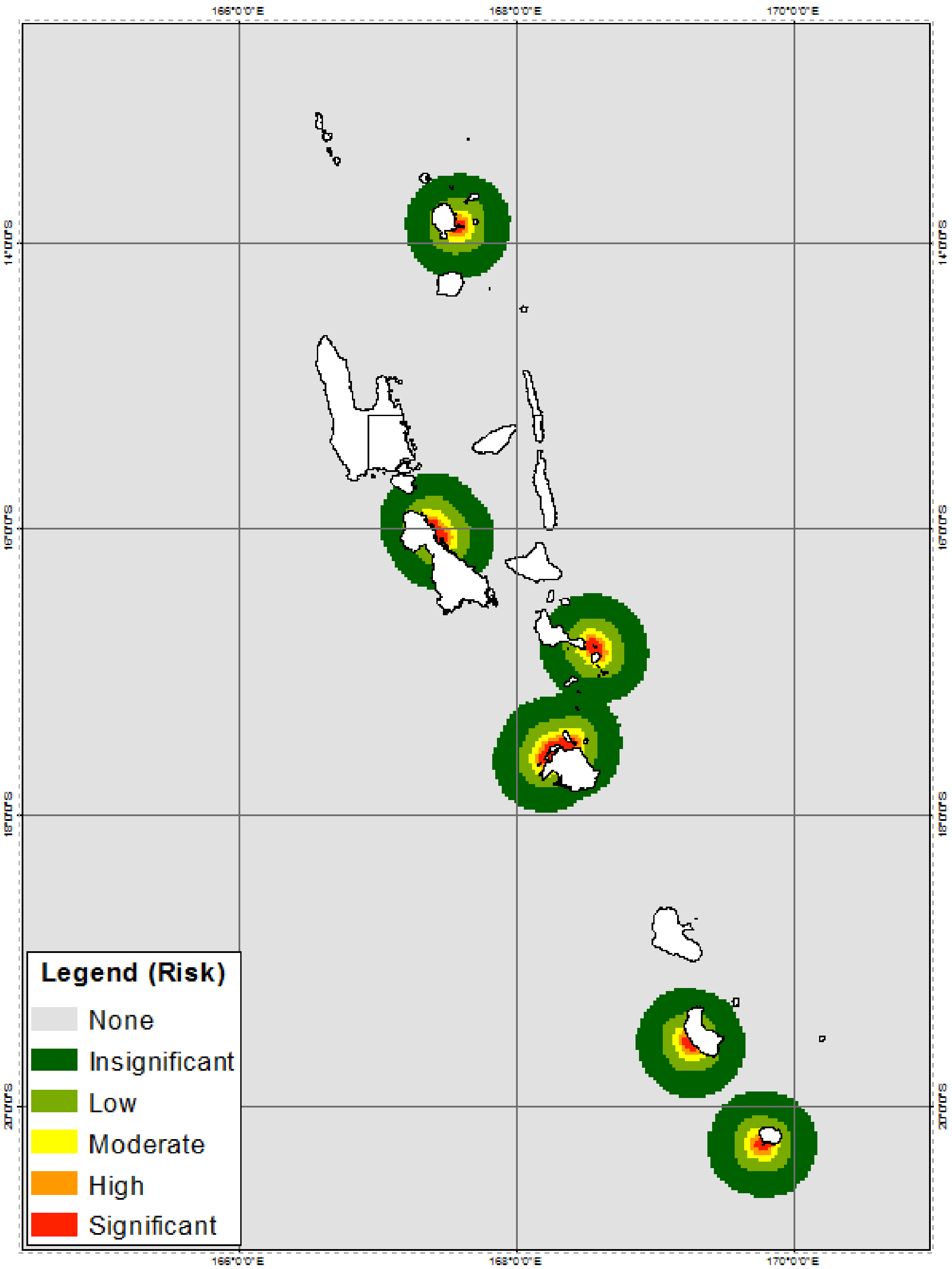


Figure 40: Modelled Proximity to Sites of Moderate Economic Value.

5 MODEL WEIGHTINGS

Upon scoring of the independent variables of likelihood and consequence it was necessary to weight the relative importance of each variable. The scorings of each variable were weighting to calculate the total contribution of a risk factor to the model. The weighting was undertaken by project staff and relied upon:

- Consultation with relevant stakeholders during a site visit;
- A literature review of past similar studies and academic research; and
- Expertise and judgement of project staff.

Each risk factor was weighted twice; firstly a high/medium/low scoring was applied to each risk factor to differentiate the importance of that individual factor. Secondly a category weighting was applied which modified the factor weightings to emphasise more general categories.

The weighting factor scorings is calculated by the following formula:

$$Factor\ Scoring = \left(\frac{Factor\ Weighting}{Sum\ Factor\ Weightings}\right) * Category\ Weighting$$

In the case of the MetOcean category below, the total factor weightings are equal to 6 (high plus medium plus low) and the category weighting is 30%. Therefore the weighting to prevailing conditions exposure is a high importance weighting (+++/3) divided by the total weighting of 6, resulting in 0.5, multiplied by 30%. This scores this risk factor a likelihood weighting of 15% that is applied to the 1 to 5 cell risk scores in the model.

The table of risk factor weightings is displayed below in **Table 3**.

	Risk Factor	Factor Weighting	Category Weighting
Traffic	Potential Loss of Life (Vessel Type + GT Weighed)	+++	50%
	Pollution Potential (Vessel Type + GT Weighted)	+++	50%
Likelihood	**MetOcean**		
	Prevailing Conditions Exposure	+++	30%
	Spring Mean Current Speed	++	
	Visibility	+	
	Navigational Complexity		
	Type of Navigation Required	+++	15%
	Aids to Navigation		
	ChartZoc	+++	30%
	Proximity to Non Working AToNs (Nav Lights)	++	
	Bathymetry		
	Depth of Water 15m Contour	+++	10%
	Bottom Type	++	
	Navigational Hazards		
	Proximity to Known Reefs	++	15%
	Proximity to Volcano	++	

	Risk Factor	Factor Weighting	Category Weighting
	Proximity to Known SeaMounts	+	
	Proximity to WW2 Military Sites	+	
	Proximity to Charted Tidal Hazard (Overfalls/Race)	+++	
Consequence	**Environmental**		
	Proximity to Large Reef (High Quality / or Isolated Shoreline	+++	50%
	Proximity to Key Offshore Reef (Cooks Reef or Rowe Island)	++	
	Proximity to Large Wetlands Resource (Mangroves) (Large Volume or Small Volume)	+++	
	Proximity Small Wetlands Resource (Mangroves) (Large Volume or Small Volume)	++	
	Proximity to Important Breeding Grounds	+++	
	Proximity to World Biological Protected Sites	+++	
	Proximity to Regional Biological Protected Sites	++	
	Proximity to Local Biological Protected/Important Sites	+	
	Cultural		
	Proximity to World Cultural Protected/Important Sites	+++	15%
	Proximity to Regional Cultural Protected/Important Sites	++	
	Proximity to Local Cultural Protected/Important Sites	+	
	Economic		

	Risk Factor	Factor Weighting	Category Weighting
	Proximity to Sites of High Economic Contribution	+++	35%
	Proximity to Sites of Moderate Economic Contribution	+	
	Proximity to Key Infrastructure (Ports)	+++	
	Proximity to Tourist Diving Sites	+/++	
	Cruise Ship Stops	++	

Table 3: Risk Factor Weightings

5.1 MODEL SYNTHESIS

As described in **Section 2**, the theoretical approach taken to risk in this project is that risk is the product of likelihood and consequence and that likelihood requires a number of candidates (traffic volume) and causation probability. There are a number of approaches that can be taken in slotting these variables together and upon experimentation with different iterations the model synthesis used in this study is:

- Traffic (potential pollution and loss of life) = **25%**;
- Likelihood (causation factors) = **25%**;
- Consequence = **50%**.

The logic of this approach provides a consequence driven risk assessment. There must be a traffic profile in the area, a cause of an incident and an effect of an incident. All three are required to generate a risk profile.

$$Risk\ Model = Traffic\ (25\%) * Likelihood(25\%) * Consequence\ (50\%)$$

6 RESULTS

6.1 TOTAL MODEL

The results of this study area are described in the plot below (**Figure 41**).

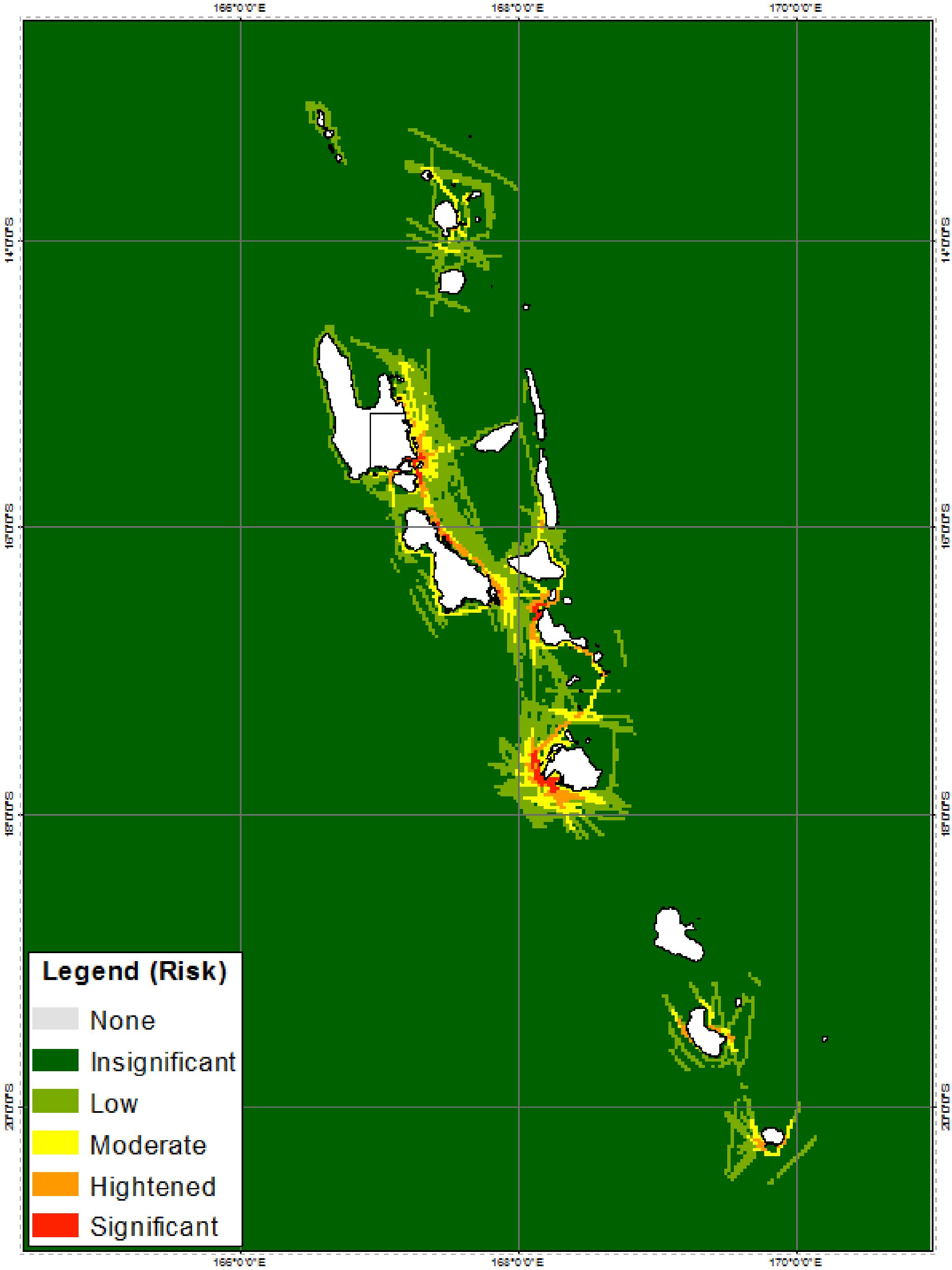


Figure 41: Risk Model Results

Whilst the majority of the waters of the Republic of Vanuatu are of low risk to shipping, the model shows a number of areas of high risk. In particular four high risk areas can be identified, namely:

- Approaches to Luganville (Santo);
- Port Vila and the west coast of Éfaté;
- The sea area between south-east Malakula, Epi and Ambrym; and
- The east coast of Malakula.

6.1.1 Luganville (Santo)

The approaches to the port of Luganville have the highest risk profile of any section of the model. This high value is largely an account of:

- High potential loss of life and pollution potential throughput;
- Constrained and shallow channel with several non-functioning lights;
- Several WW2 former mined areas and dumped artefact locations;
- Proximity to a number of sites of environmental importance including coral, breeding grounds and a national marine reserve;
- Proximity to sites of high cultural value; and
- Port is of high economic value as an active port.

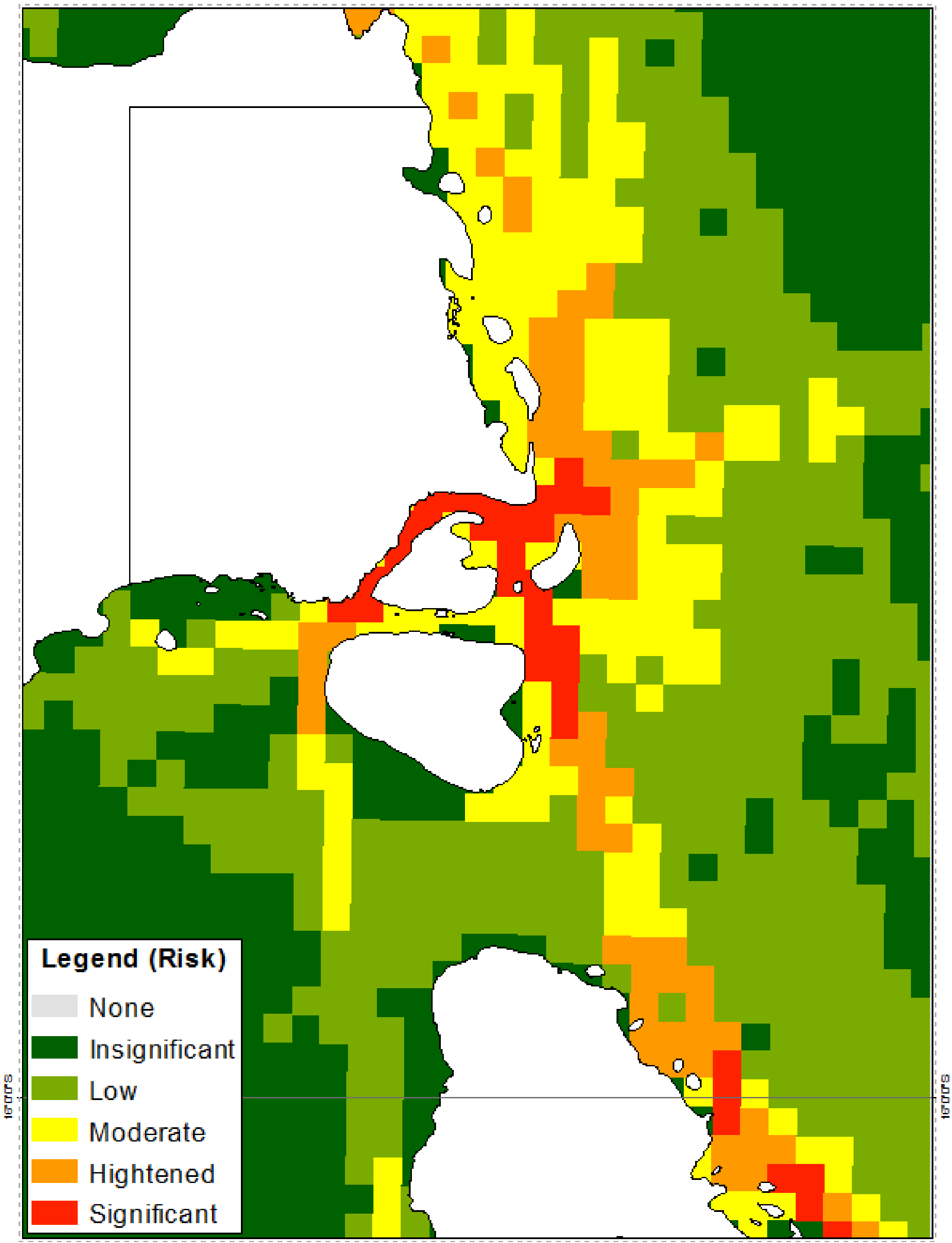


Figure 42: Risk Model for approaches to Luganville.

6.1.2 Port Vila and Efate

The harbour and approaches to Port Vila are of high value because:

- High potential loss of life and pollution potential throughput;
- Proximity of this shipping to shallow depths and breaking reefs;

- Proximity to some corals and wetland habitats; and
- Site of very high economic value as a port and tourist destination.

In addition there is an increased risk to the west coast of Éfaté due to:

- High potential loss of life and pollution potential of vessels transiting past the island;
- Moderate exposure to prevailing conditions in an area of shallow water, breaking reefs and a hard rocky bottom; and
- Traffic passes near to a cultural World Heritage Site with corals and breeding grounds (Port Havannah).

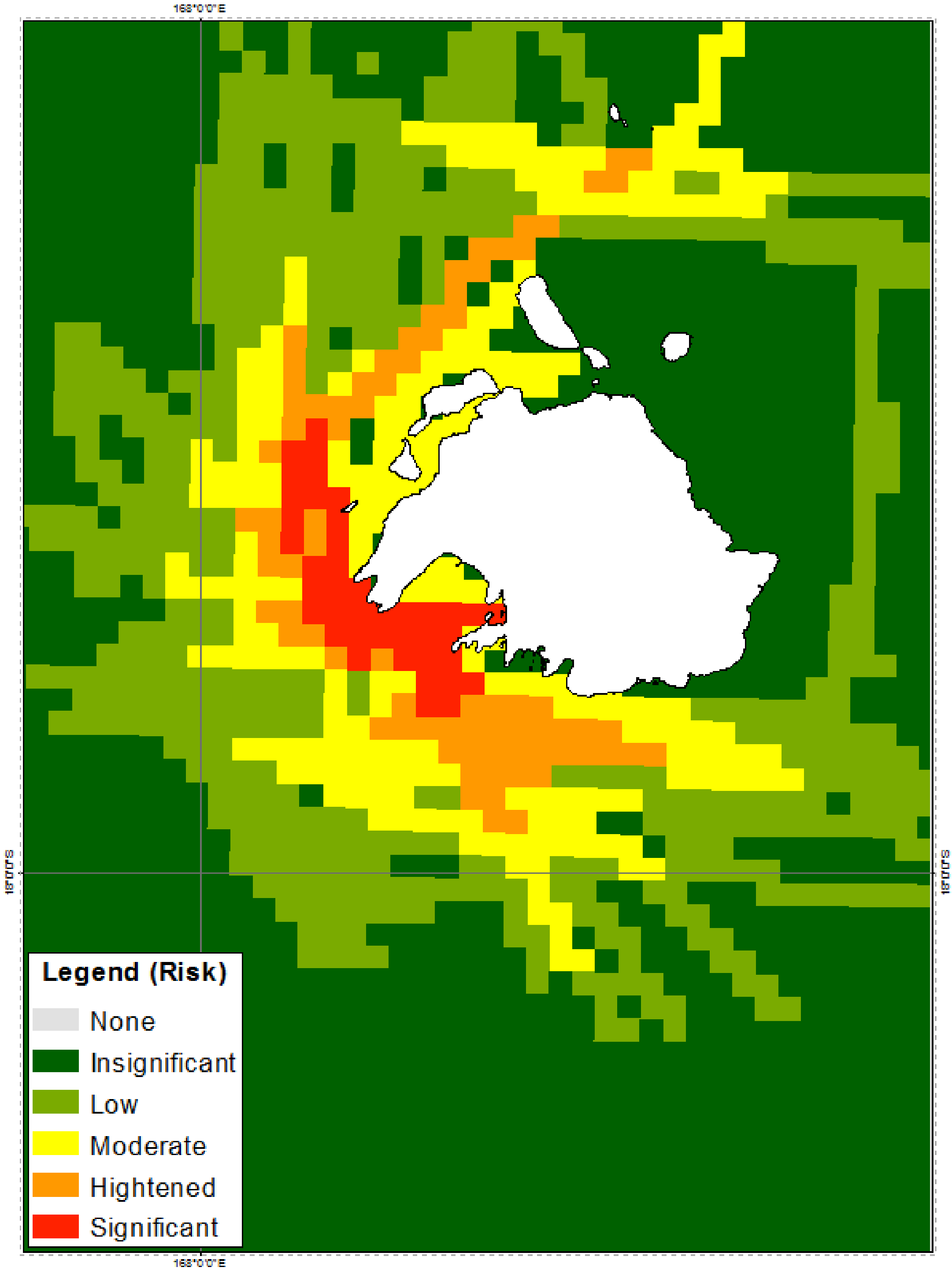


Figure 43: Modelled Risk for Efate.

6.1.3 Passage Through Central Islands

The passage through the central islands of Vanuatu is another area of significant risk.

South-east Malakula:

- High volume of traffic including large SOLAS vessels and small coastal traders passing around the tip of Malakula, with non-functioning aids to navigation;
- Vessels navigating close to the shore with a number of breaking reefs and tidal hazards, including a significant tidal stream further inshore; and
- Area has high wetlands value, high coral value and significance for local communities.

Lamen Bay:

- Moderate/High volume of local traders, cruise ships and recreational vessels;
- Vessels navigating close to the shore in shallow water with breaking reefs and non-functioning aids to navigation;
- Area is an important turtle breeding ground with considerable wetlands resources and corals in proximity;
- Site is popular with tourists for diving and cruise ships stops.

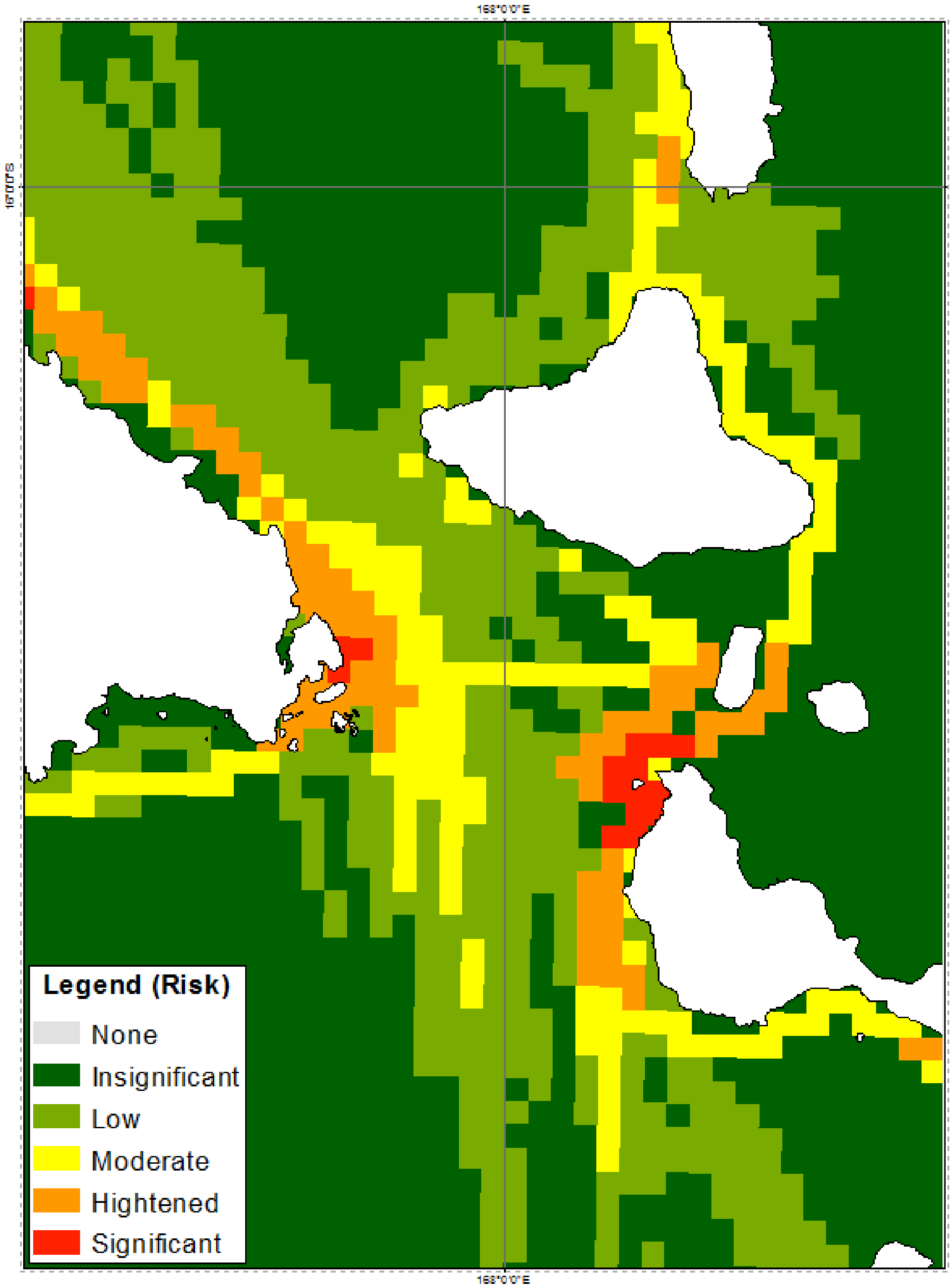


Figure 44: Modelled Results for the Central Islands.

6.1.4 East coast of Malakula

- A considerable amount of coastal traffic passes close to a moderately exposed lee-shore with non-functioning aids to navigation and breaking reefs;
- Traffic passes close to a large amount of coral and wetland resources with informal local tabus;

- The coast is popular with tourists and a number of large cruise ships stop by Wala Island;

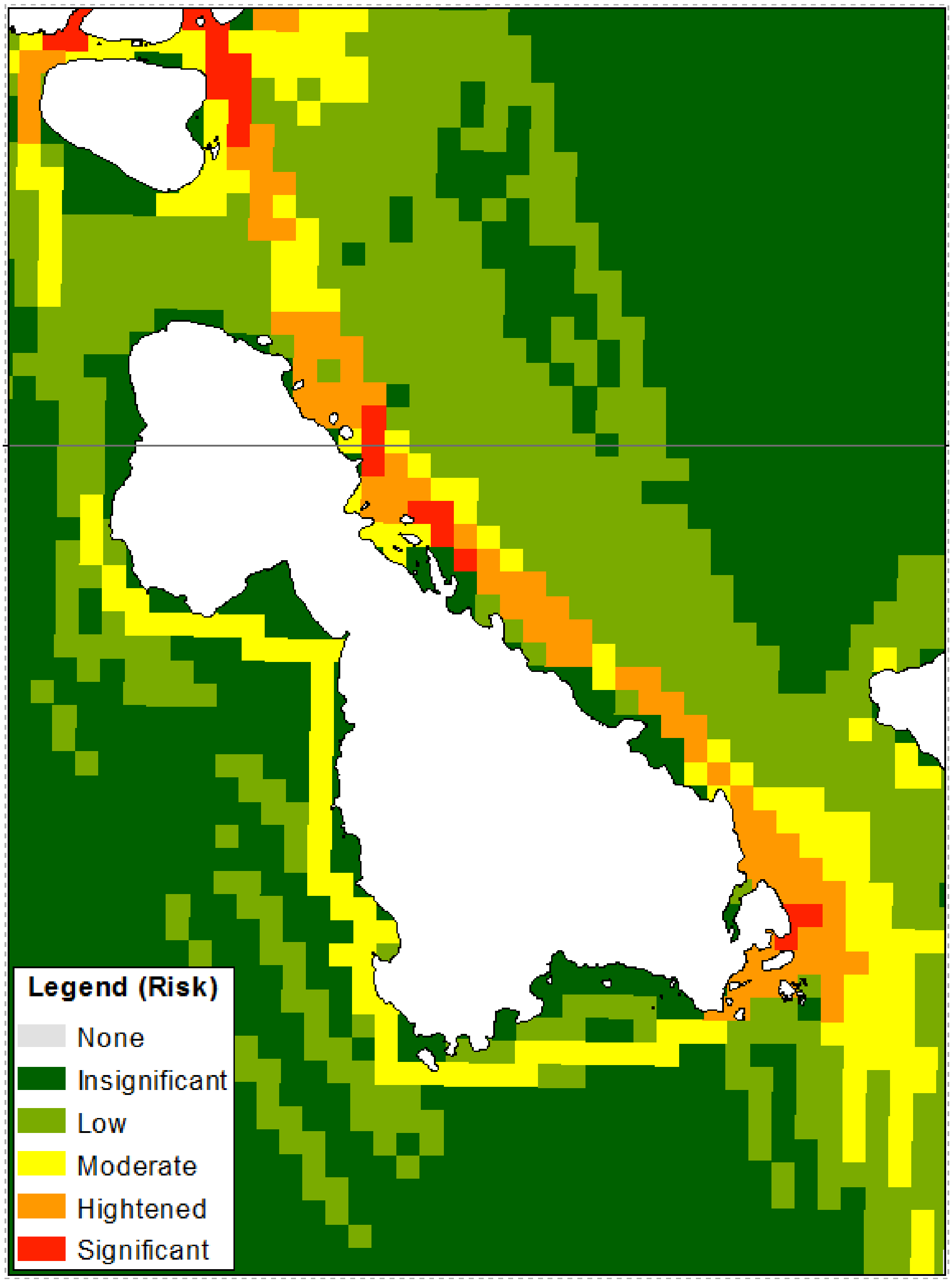


Figure 45: Modelled Risk for the East Coast of Malakula.

6.2 ITERATIONS

The model was recalculated with multiple iterations to investigate specific factors.

- Risk to AIS carrying vessels only;
- Risk to Non-SOLAS coastal traders only;
- Environmental risk;
  - Only the environmental category of consequence is used; cultural and economic risk discounted.
- Cultural Risk;
  - Only the cultural category of consequence is used; environmental and economic risk discounted.
- Economic Risk
  - Only the economic category of consequence is used; cultural and environmental risk discounted.

6.2.1 SOLAS and Non-SOLAS Vessel Risk

Figure 46 and **Figure 47** compare the risk profile for vessels carrying AIS and vessels not carrying AIS. These iterations allow a spatial comparison between the results of the model with and without taking into account coastal traders. The plots highlight the high contribution coastal traders make to the risk profile near to the shore, in particular around Malakula. However the areas identified as high risk remain consistent between the cumulative model and this iteration.

Port Vila and Luganville both remain areas of high risk as the main trading hubs in the archipelago. Similarly high risk exists in both iterations for vessels passing around the south-east tip of Malakula.

There are however a number of notable differences between the models. A considerable contribution to the total risk of vessels in Lamen Bay, Epi is made by coastal traders with a less pronounced risk profile for non-SOLAS vessels. The risk profile in the northern islands such as Santa Maria and Vanua Lava is specifically related to SOLAS vessels, including a number of large tankers transiting through.

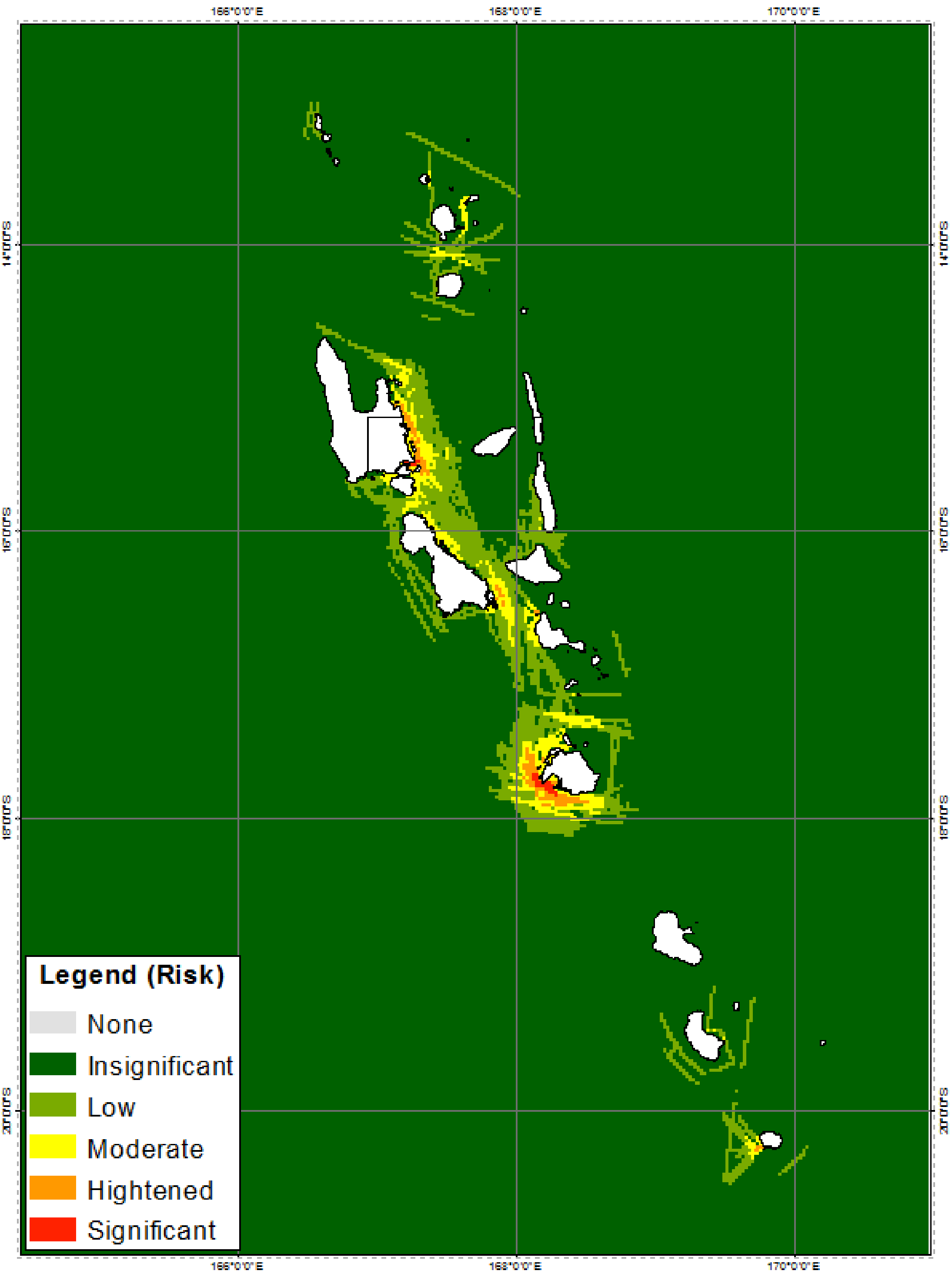


Figure 46: Model Iteration with SOLAS Vessels only.

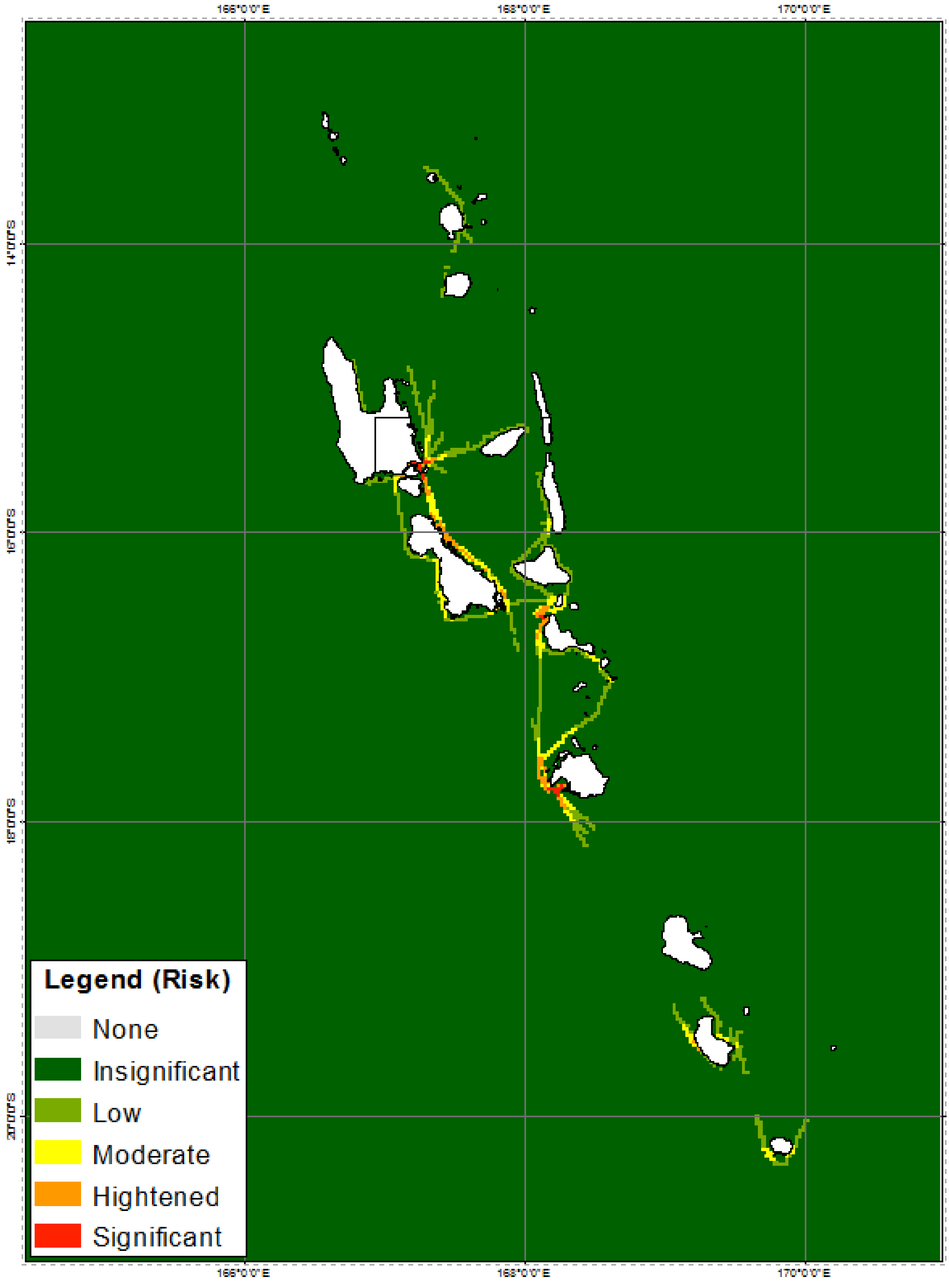


Figure 47: Model Iteration with Non-SOLAS Vessels only.

6.2.2 Consequence Category Iterations

6.2.2.1 Environmental Risk

There is little difference between the cumulative model and the environmental risk model, with the spatial pattern remaining consistent. The environmental consequence represents 50% of the consequence weighting in the total model is accounted by this one factor and so it is logical that they are largely similar. Areas of note in which difference occurs include the Torres Islands which provide a larger contribution of environmental factors than other areas. Furthermore the east coast of Malakula and the west coast of Epi show a considerable increase in risk in comparison to the standard model. Finally the approaches to Port Vila and the west coast of Éfaté have a diminished importance.

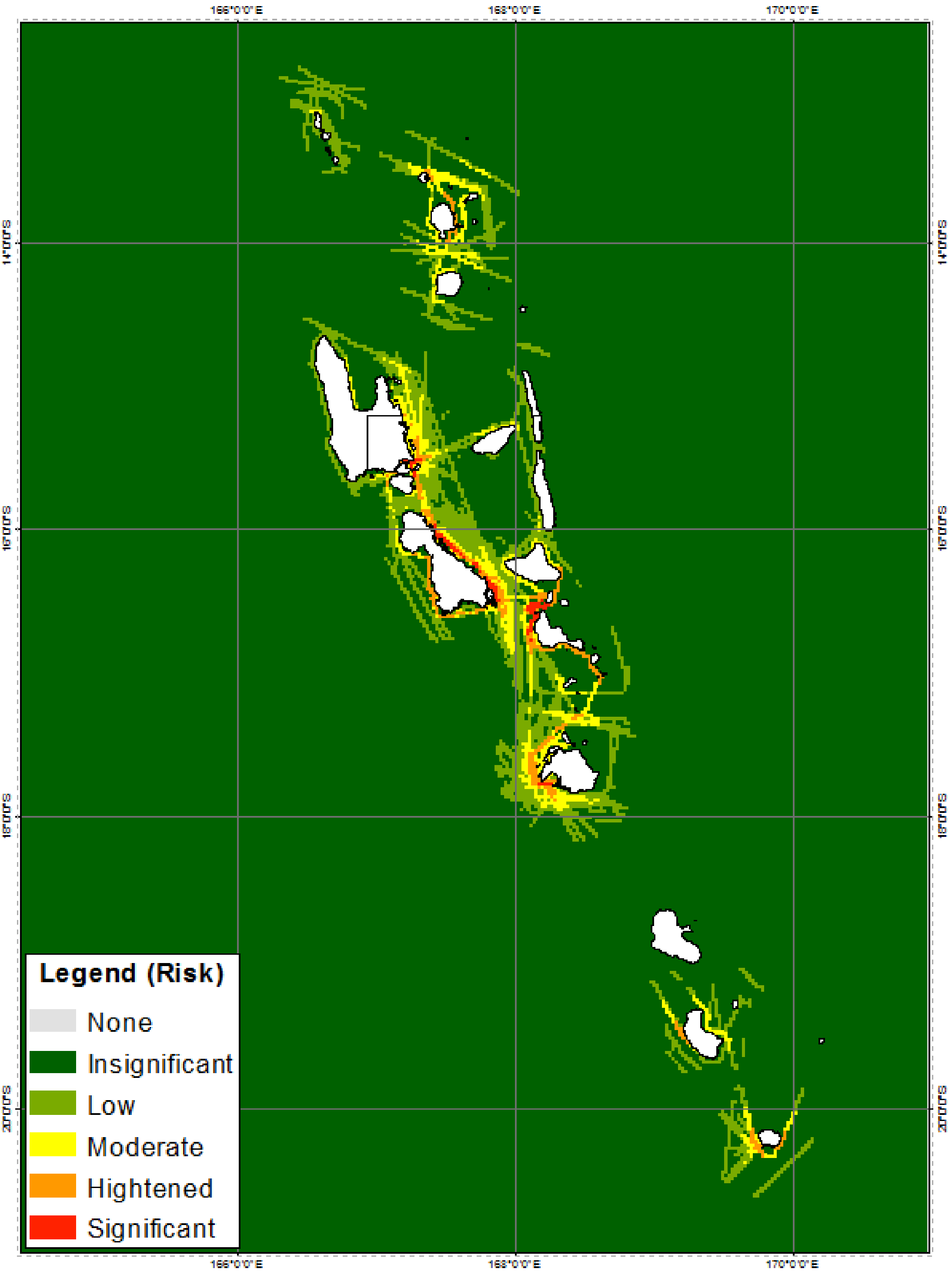


Figure 48: Model Iteration with Environmental Consequence only.

6.2.2.2 Cultural Risk

Cultural risk is far more centralised to specific areas, largely the result of where local communities have lived for hundreds of years. Of particular note is the World Heritage Site on Éfaté that has greatly increased the risk of vessels transiting passed; and the approaches of Luganville which remain high risk. Very little risk is now associated with the Northern Islands and Ambrym. Furthermore Malakula has a noticeably lower contribution to the overall risk profile in the model.

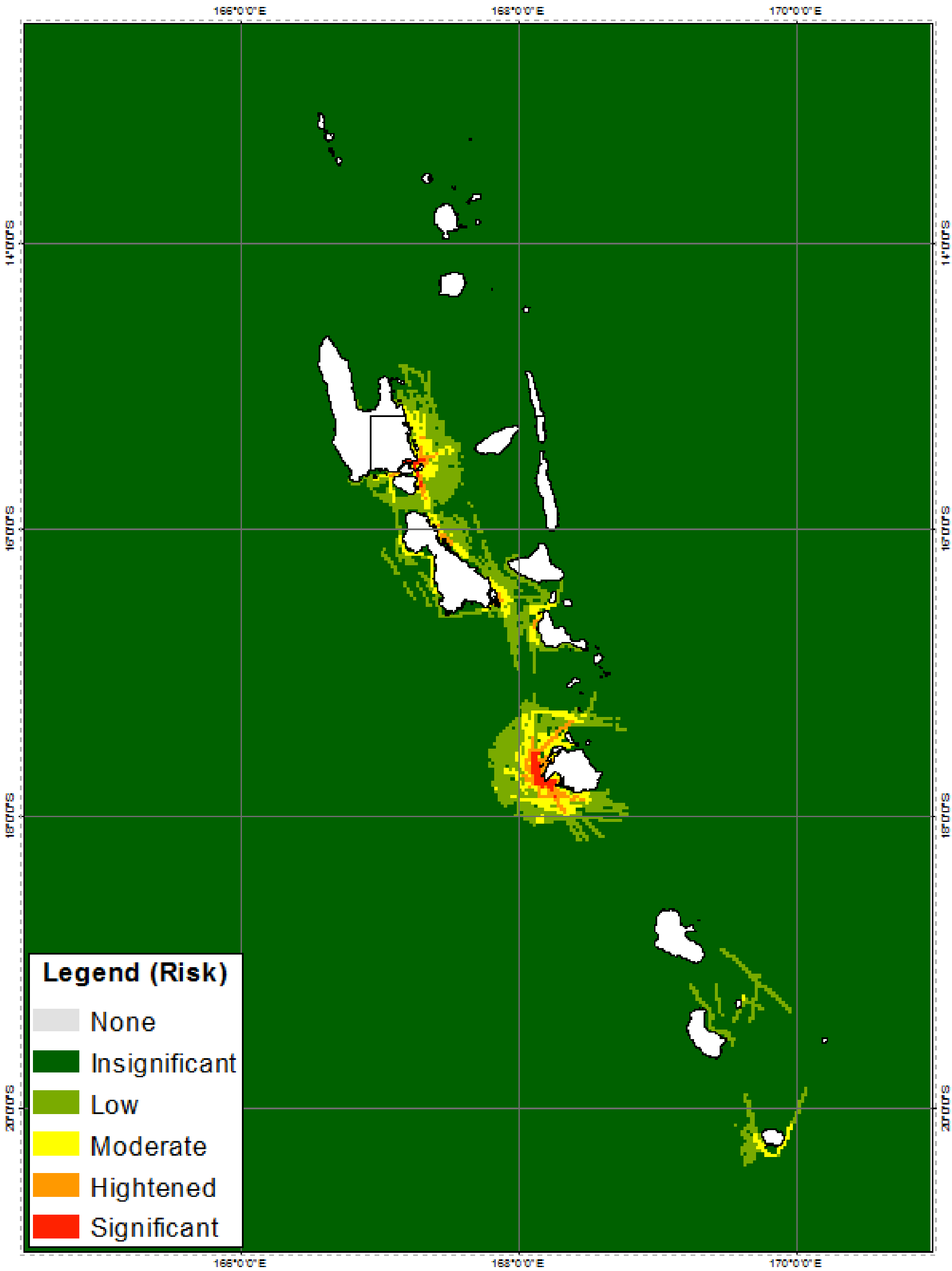


Figure 49: Model Iteration with Cultural Consequence Only.

6.2.2.3 Economic Risk

The economic risk is largely related to the areas of cruise ship activity. Areas highlighted include Wala Islands, Homo Bay, Champagne Beach and Mystery Island. The major ports of Luganville and Port Vila remain high as both trade hubs and cruise ship destinations.

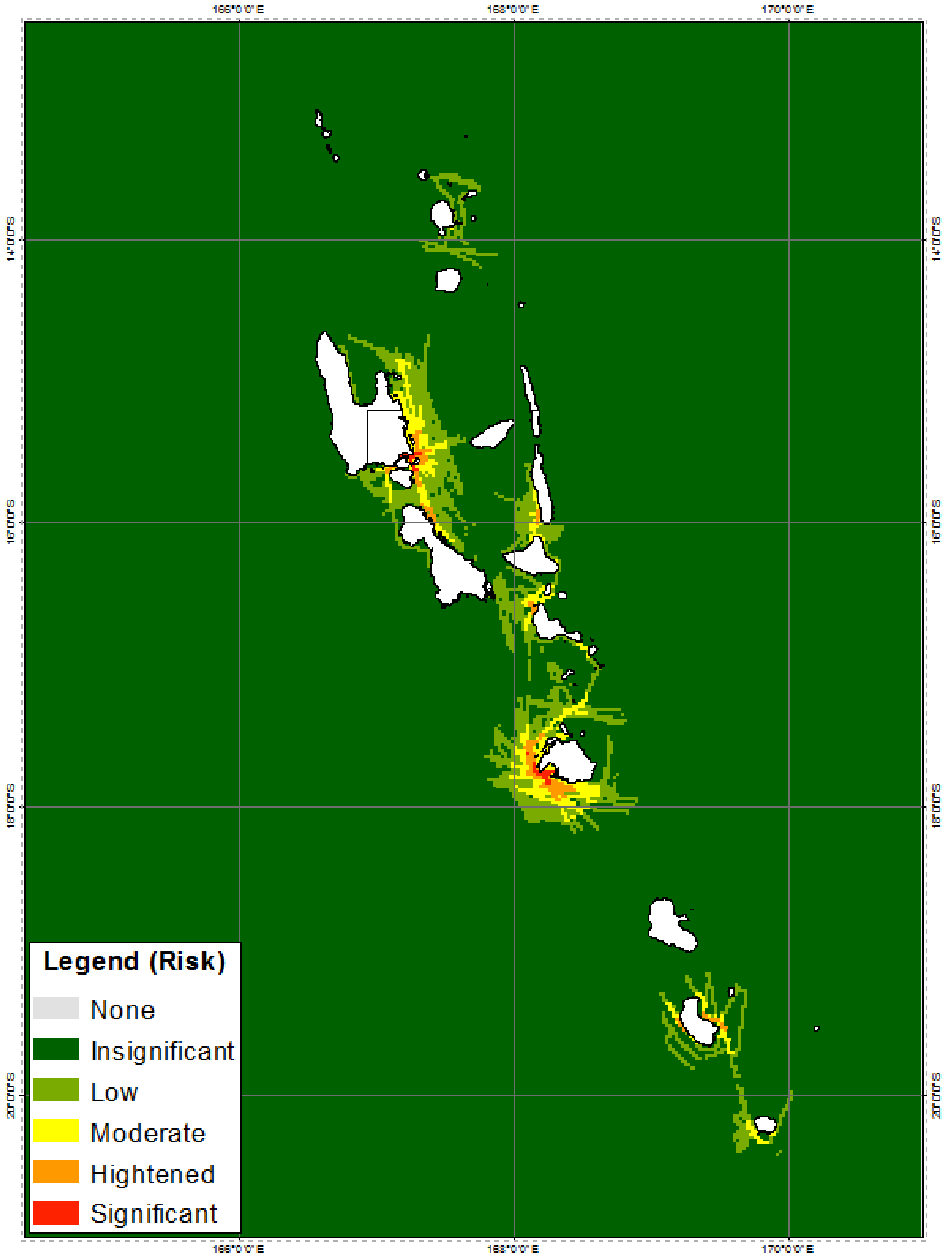


Figure 50: Model Iteration with Economic Consequence Only.

7 CONCLUSIONS

This report has provided a robust and data-driven modelling methodology for the identification of shipping routes at high risk. The model combines AIS datasets, non-AIS local trading routes, known navigational hazards, areas of cultural/environmental/economic value and produces a synthesised, cumulative risk model.

Such an approach is limited by the quality of the input datasets and therefore a number of sources have been drawn upon and some augmentation has been used. In particular the satellite derived AIS data required considerable modification before it could be inputted into the modelling process.

8 DATASET CONFIDENCE

Dataset	Confidence	Reason
Vessel traffic patterns	Moderate/ High	Use of satellite derived AIS and port records provide very good understanding of vessel movements.
Prevailing Conditions	Moderate	Absence of a universal and accurate digital dataset of Vanuatu's meteorological conditions required approximation using other sources. Modelled conditions are basic without wave propagation or refraction.
Tidal Conditions	Low	No dataset available, conditions approximated using nautical charts and sailing directions.
Navigational Complexity	N/A	Qualitative Assessment based on distance from shore.
Chart Quality Assessment	High	CATZOC ratings derived from S-57 charts. Where a CASTOC rating of U (Unassessed) was recorded, CATZOC was assumed to be D.
Fixed Aids to Navigation	High	All lights in Vanuatu digitised from charts and consultation during site visit marked each light operational or non-operational.
Depth	Moderate	Depth datasets drawn from admiralty charts and S-57. Dataset as accurate as the CATZOC score for that chart is.
Bottom Type	Low	Use of a global dataset does not accurately reflect localised changes in geology.
Significant Charted Reefs	Moderate/ High	Most significant reefs awash at low tide are accurately charted during historical surveys.
Seamounts	Moderate	Seamount locations drawn from a variety of different sources
WW2 Military Sites	Moderate	Known WW2 sites are referenced in sailing directions, however most are approximated, with some sites not known.
Sites of Volcanic Activity	Low	Digitised from nautical charts and so reliant on their accuracy, charts indicate uncertainty and so dataset is uncertain.
Tidal Streams	Moderate	Significant tidal streams as charted were used.

Dataset	Confidence	Reason
Coral Reefs	High	Multiple sources used to accurately map coral reef locations; scoring undertaken with local consultation. Global datasets available.
Wetlands Resource	Moderate	Literature review required to find most locations, some derived from site visit. Locations are therefore approximate.
Breeding Grounds	Low	Only breeding grounds for selected species are marked. Sites chosen are only those marked during local consultation.
Environmental Protected Sites	Moderate	Global protected sites well-marked, local, informal sites digitised using consultation.
Culturally Protected Sites	Moderate	Global protected sites well marked; local informal sites digitised using consultation.
Key Infrastructure	High	Only two ports operate in Vanuatu.
Tourist sites	Moderate	Consultation with local stakeholders used to map the most important tourist sites.
Sites of economic contribution	Low/ Moderate	Broad areas used without regional datasets.
Cruise ship destinations	High	Consultation with cruise ship operators, traffic analysis and local stakeholders provide all cruise ship destinations.

9 REFERENCES

Academic Literature and Conference Proceedings:

Calder,B. and Schwehr, K., (2009). Traffic Analysis for the Calibration of Risk Assessment Methods, *US Hydro 2009*, May 11-14 2009. Norfolk, VA.

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

Harrison, D.E. and Luther, D.S., (1990). Surface Winds from Tropical Pacific Islands-Climatological Statistics. *Journal of Climate*, 3, pp.251-271.

Kite-Powell, 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.

Kristiansen, S., (2004). *Maritime Transportation: Safety Management and Risk Analysis*. Butterworth-Heinemann.

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.

Technical Reports:

Amos, M.J., (2007). *Vanuatu fishery resource profiles.* IWP-Pacific Technical Report (International Waters Project no.49).

Barstow, S.F. and Haug, O., (1994). *Wave Climate of Vanuatu.* SOPAC Technical Report 202.

David, G. (1985). *Peche de Subsistance et Milie Naturel: Les Mangroves de Vanuatu et Leur Interet Halieutique.* Notes et Documents D'Oceanographie, 13, Sept 1985.

Espérance, C. et al., (2001). Coastal Fisheries of Vanuatu [online]. Available at: http://www.cartographie.ird.fr/atlas_vanuatu/index.html. Accessed: 15th November 2012.

Gilman, E. et al., (2006). *Pacific Island Mangroves in a Changing Climate and Rising Sea.* UNEP Regional Seas Reports and Studies No.279, United Nations Environmental Programme, Regional Seas Programme, Nairobi, Kenya.

International Finance Corporation (2010). *State of Play Assessment for Vanuatu.*

Maritime Coastguard Agency, (2010). *The Human Element: A Guide to Human Behaviour in the Shipping Industry.* TSO.

Naviti, W. and Aston, J., (2000). *Status of coral reef and reef fish resource of Vanuatu.* Regional Symposuim on Coral Reefs in the Pacific: Status and Monitoring; Resources and Management, 22-24 May 2000, Noumea, New Caledonia.

US Coastguard, (1991). *Port Needs VTS: Vessel Traffic Services Benefits Volume 1.* National Technical Information Service, Springfield.

Vanuatu Government (2011). *Vanuatu's National Cruise Tourism Action Plan.*

Vanuatu Government, (2012). *Trade Policy Framework.*

Datasets and Other Sources:

ESRI Basemaps: National Geographic World Map.

Vanuatu Met Service: www.meteo.gov.uk

IUCN Red List (2012). Coral Reef Dataset [online]. Available at: http://www.iucnredlist.org/technical-documents/spatial-data#corals

http://whc.unesco.org/en/list/1280

http://www.s-57.com

http://www.protectedplanet.net

http://www.mpatlas.org/region/nation/VUT

http://wwf.panda.org/about_our_earth/blue_planet/coasts/coral_reefs/

http://vanuatu.travel

http://www.marine.csiro.au/nationalfacility/franklin/plans/2001/fr07_99.html