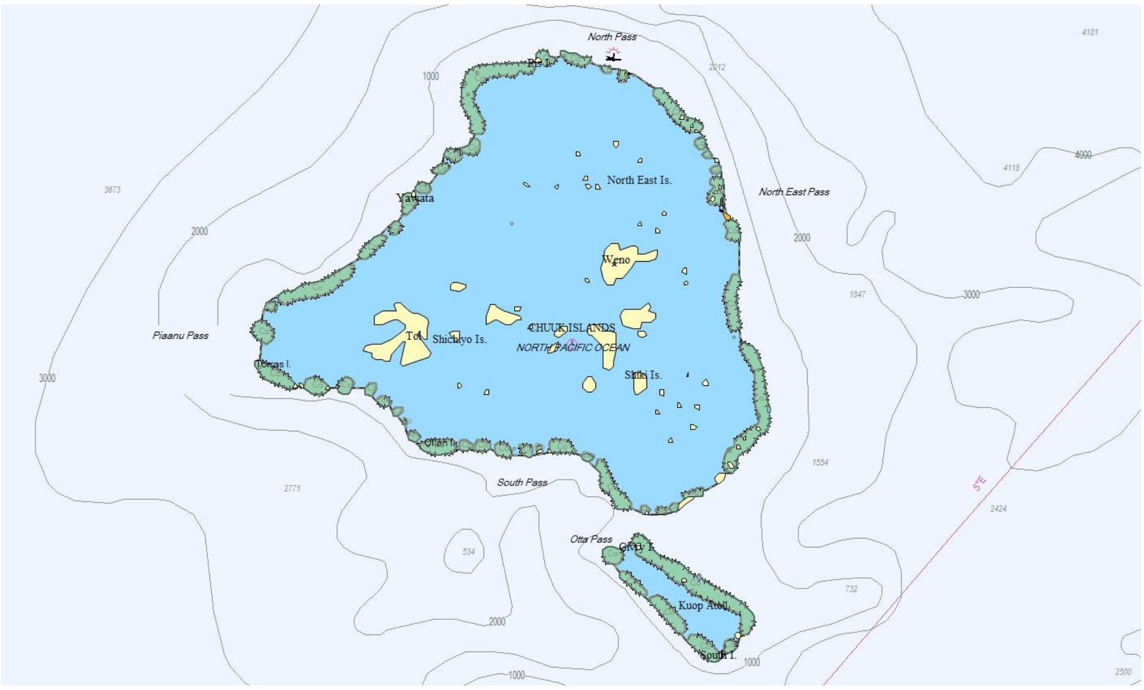
STRATEGIC ENVIRONMENTAL ASSESSMENT AND POTENTIAL FUTURE SHORELINE IMPACTS OF THE OIL SPILL FROM WWII SHIPWRECK *HOYO MARU* CHUUK LAGOON- FEDERATED STATES OF MICRONESIA



By
Anthony Talouli, Secretariat of the Pacific Regional Environment Programme (SPREP).
Trevor Gilbert, Asia Pacific Applied Science Associates (Asia Pacific ASA).
Rean Monfils Gilbert, Sea Australia

EXECUTIVE SUMMARY

For many years locals have indicated that a WWII vessel in Chuuk lagoon was leaking causing deleterious effects on the surrounding coastline and fisheries. SPREP by the FSM government to provide technical advice surrounding the issue of WWII shipwrecks and as such a Strategic Environmental Assessment (SEA) was conducted.

Anthony Talouli, the Marine Pollution Advisor from SPREP conducted on-site assessments in search of any shoreline oil. The shoreline survey did not come up with any oil even though there was a strong odour of oil coming from the position of the vessel and a visual sheen was also seen on the surface of the water.

Asia-Pacific ASA (APASA) was asked for assistance in order to model the possible direction and impacts of any further spills from the Hoyo Maru. The results clearly indicated that the shorelines of Fefan Island would be most dramatically affected by any oil coming from the Hoyo Maru due to the dominance of the winds and the proximity to the vessel. The modeling also showed that the oil would reach Fefan Island rapidly thus allowing for limited response options in a short amount of time.

A number of recommendations are provided for the government of FSM and technical assistance was provided on-site to assist with any further spills.

TABLE OF CONTENTS

1. INTRODUCTION

Marine pollution is widely recognised as one of the four major threats to the world's oceans, along with habitat destruction, over-exploitation of living marine resources and invasive marine species. Spills of oil and other chemicals into the marine environment, both from ships and land-based sources, is a significant source of pollution.

The Pacific Island Countries and Territories (PICTs) have agreed to work together, through regional arrangements, in order for marine pollution to be addressed effectively. No single country in the region can address this problem in isolation. The Secretariat of the Pacific Regional Environment Programme (SPREP) as part of its role to assist island members to address environmental issues in accordance with the SPREP Action Plan has developed a comprehensive programme to address marine pollution from ship-based sources. This is called the *Pacific Ocean Pollution Prevention Programme* (PACPOL) which has recently been revised in 2009 for the period 2010-2014.

At the request of the members of the 12th SPREP meeting in 2001, SPREP was required to investigate and formulate a regional strategy to address the pollution risk posed by the many World War II shipwrecks across the Pacific. PACPOL was tasked with formulating a Regional Strategy (Nawadra 2002) to address the issues related to World War II Wrecks. In 2003 the SPREP member countries decided that the secretariat would have no further action on the strategy, and that any further developments be undertaken bilaterally between the flag state and the coastal state with SPREP offering technical assistance only. Essentially any remedial actions, like the removal of oil or environmental damages from WWII shipwrecks would need to be carried out on a bi-lateral basis between the affected country and the shipwrecks flat state.

This report is a strategic environmental assessment of the risks posed by the chronically leaking Hoyo Maru in Chuuk Lagoon, Federated States of Micronesia.

1.1 Aim of Study

The aim of this strategic environmental assessment is to determine the extent of shoreline oiling and potential future oiling coming from the *Hoyo Maru*, a WWII shipwreck located in Chuuk Lagoon- FSM. This in turn will assist the government of FSM to make long-term decisions about the WWII wrecks located in Chuuk Lagoon.

1.2 Objectives

The objective of the strategic environmental assessment is to:

- Assess the extent of oiling to date and provide an impact assessment,
- Determine the resources at risk in the area of the spill and any ecological damage,
- Ascertain the potential impact of a worst case scenario i.e. a catastrophic failure of the wreck resulting in all the oil being spilled into the marine environment,
- Identify potential mitigation/remedial actions that can be taken to protect vulnerable resources,
- Act as a catalyst for the drawing up of bi-lateral or multi-lateral arrangements to address marine pollution issues related to WWII shipwrecks,
- Train and provide capacity building to Chuuk so that they can carry out their own future assessments and monitor the shipwrecks,
- To assess the Chuuk state National Plan (NATPLAN) and capacity to respond to a WWII shipwreck oil spill,
- Provide environmental, technical and spill response advice to the FSM government and agencies.

2. BACKGROUND

2.1 Geographic Area of the Study

The FSM is a Federation of four States in geographic sequence from west to east Yap, Chuuk, Pohnpei and Kosrae. Each State has considerable autonomy for internal administration but all foreign affairs are the responsibility of the National Government.

The FSM consists of more than 600 islands with a total land-mass of 270 square miles. FSM's Exclusive Economic Zone (EEZ) is over one million square miles and consists of rich and bio-diverse marine resources.

The FSM has a population of approximately 107,000 as recorded in the 2000 census.

Chuuk, in the Caroline Islands of FSM, encompasses fifteen large islands, 192 outer islands and 80 islets and has one of the largest lagoons in the world.

2.2 WWII Wrecks in the Pacific Islands

WWII was the single, largest loss of shipping in a relatively short amount of time the world has ever witnessed. As part of the Regional Strategy, SPREP produced a GIS map of all WWII shipwrecks in the Pacific Ocean. The Asia-Pacific region is host to over 3,800 WWII shipwrecks (Monfils 2005) including 330 tankers and oilers.

The international community is becoming increasingly aware of the problem of sunken wrecks and the potential pollution threat. It was only in March 2004 that the International Maritime Organization (IMO) OPRC (Oil Pollution Preparedness, Response and Cooperation) Technical Group acknowledged this problem and encouraged "regional centres and secretariats… to assess the situation regarding WWII wrecks that may cause oil pollution on their respective sea areas" (IMOC 2004).

2.3 Shipwrecks of Chuuk Lagoon

The FSM became one of the scenes for the "Pacific Theatre of WWII." Names such as Pearl Harbour, Midway, the Coral Sea, Guadalcanal, Truk Lagoon (now called Chuuk Lagoon), Betio and Iwo Jima were previously unheard of names that were immortalised as places where the main battles of this theatre were fought (Figure 1). The Pacific Island people were caught in the crossfire and many are the sad and heroic tales of what they had to endure.

Figure 1: Major sea battles of WWII in the Pacific

More than 65 years have passed since the end of World War II and the protagonists have long since returned to their homes and countries. The FSM people have rebuilt their lives and nation. However, every once in a while we are reminded of that War by the unwanted legacy it left behind. This legacy is the abandoned machinery of war – tanks, weapons, unexploded ordnance, abandoned fuel and other hazardous material sites and lurking in the deep, the wrecks and cargoes of sunken vessels.

The oil, chemicals and unexploded ordnances still on board many of these wrecks pose a grave and imminent danger to the people, marine and coastal environments, tourism and fisheries of the region. In addition many of these wrecks are also war graves and as such have a special status.

In the 40-mile wide Chuuk lagoon, over 60 Japanese vessels were sunk. A satellite image of Chuuk Lagoon and the nearby atoll Kuop is shown in Figure 2 along with an overview nautical chart of the area for reference.

In Figure 3 the known wreck locations for the inner lagoon region of Chuuk is provided. This spatial data is drawn from the Sea Australia Global Database of WWII Shipwrecks (Monfils 2005).

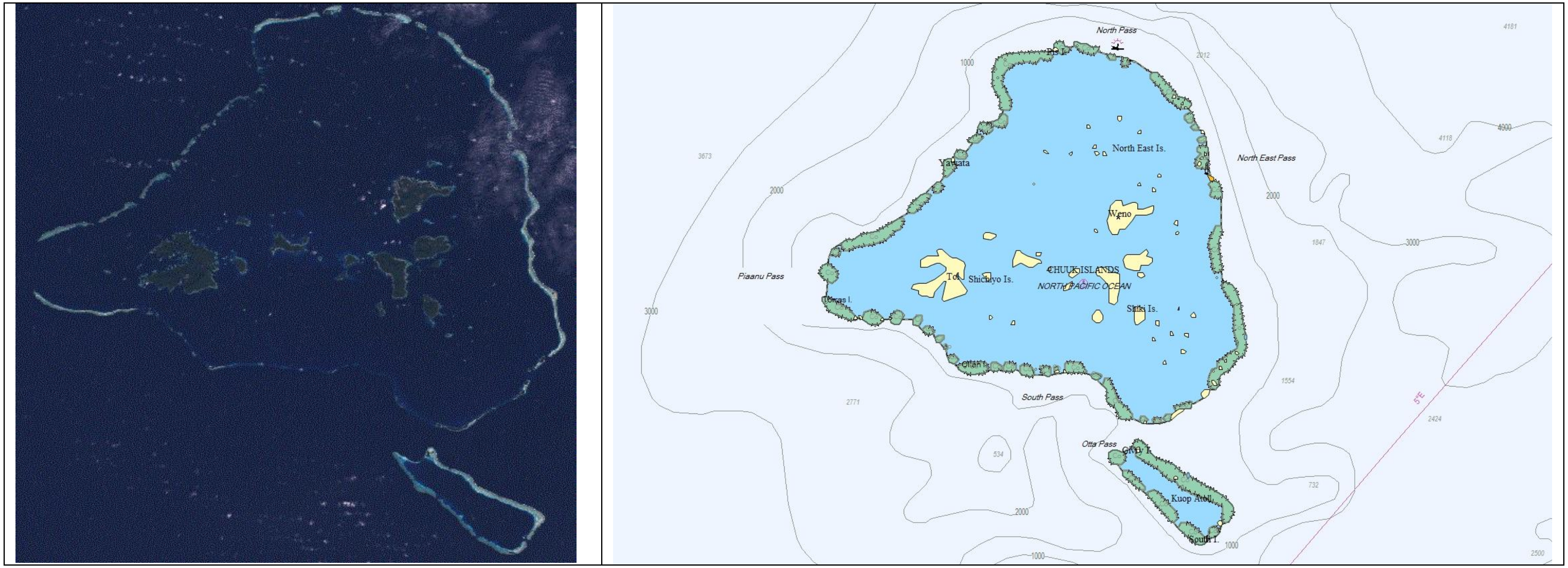


Figure 2: Satellite image of Chuuk Lagoon and Kuop Atoll with overview navigation chart

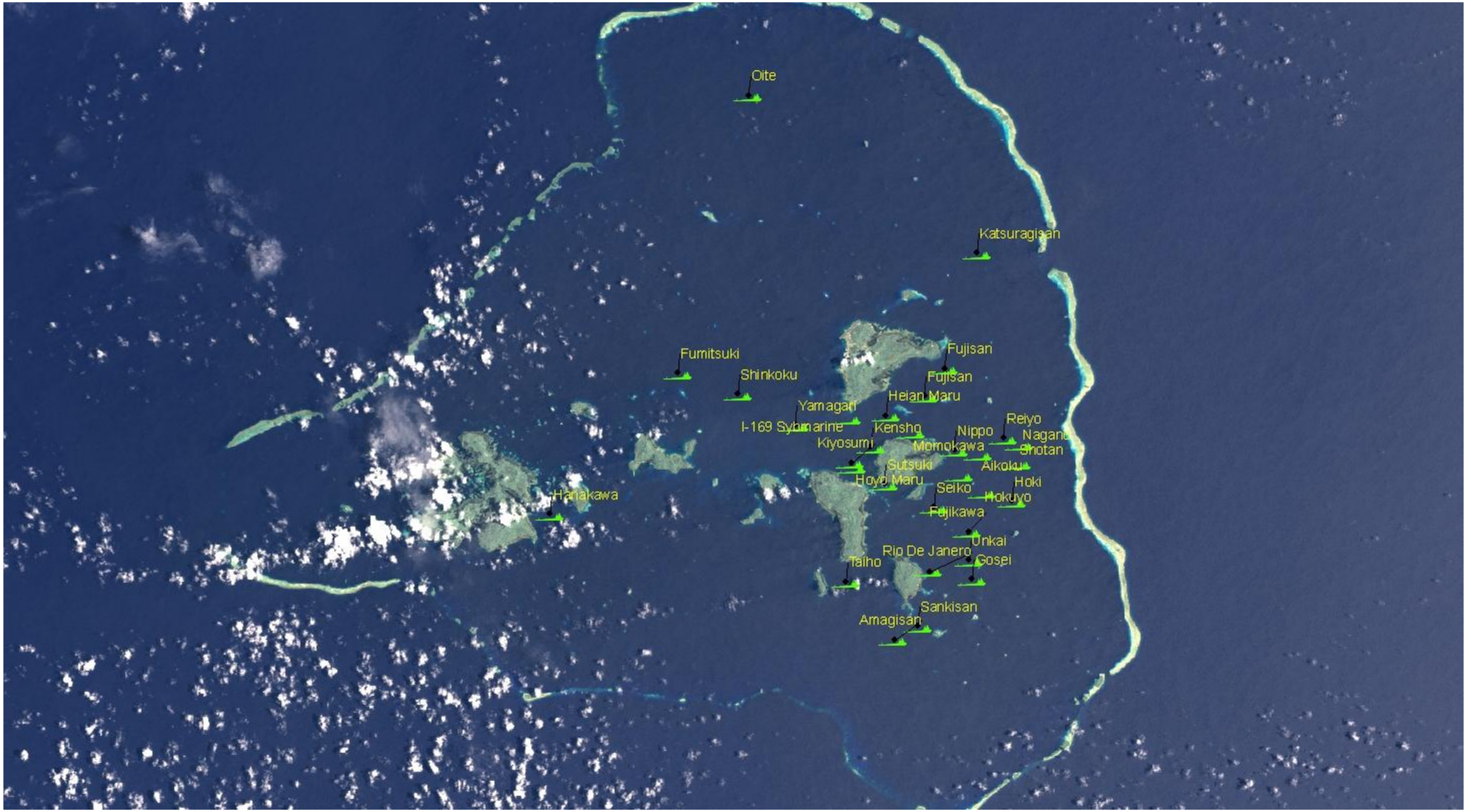


Figure 3: Location of WWII shipwrecks from the global shipwreck database of Sea Australia

Amongst the shipwrecks in Chuuk lagoon are 2 oilers, 1 tanker, 1 aircraft carrier, at least 19 cargo vessels over 1000 tonnes, 3 destroyers and at least 4 transport vessels over 8000 tonnes.

A number of WWII Wrecks have been leaking for some time in Chuuk Lagoon. According to the database compiled as part of the Regional Strategy and an Earth Watch study conducted in 2008 three WWII wrecks in Chuuk lagoon have been found to be leaking. The Earthwatch study also included a corrosion study that concluded that the wrecks have only 10-15 years before the metal is fully corroded and that there is potentially still a large quantity of oil contained within these wrecks which could result in a huge environmental problem.

The local authorities have advised that there are potentially 6 WWII shipwrecks leaking within Chuuk Lagoon. They are described in Table 1 and in Figure 4 which shows the positions plotted on a satellite image of the lagoon.

Table 1: Locations of the key WWII wrecks in Chuuk lagoon as provided by FSM government

Ship Name	**Tonnage**	**Latitude**	**Longitude**	**Type**
Rio de Janeiro	9626	N 07deg 18′ 16.0″	E151deg 53′ 37.8″	Transport
San Francisco	5831	N 07deg 21′ 58.5″	E 151deg 54′ 50.5″	Cargo
Nippo	3764	N 07deg 22′ 57.2″	E 151deg 54′ 39.7″	Cargo
Fujisan	9524	N 07deg 25′ 04.0″	E 151deg 53′ 29.8″	Oiler
Hoyo Maru	8691	N 07deg 22′ 16.2″	E 151deg 50′ 41.1″	Oiler
Kiyosumi	8613	N 07deg 22′ 29.7″	E 151deg 50′ 35.8″	Transport

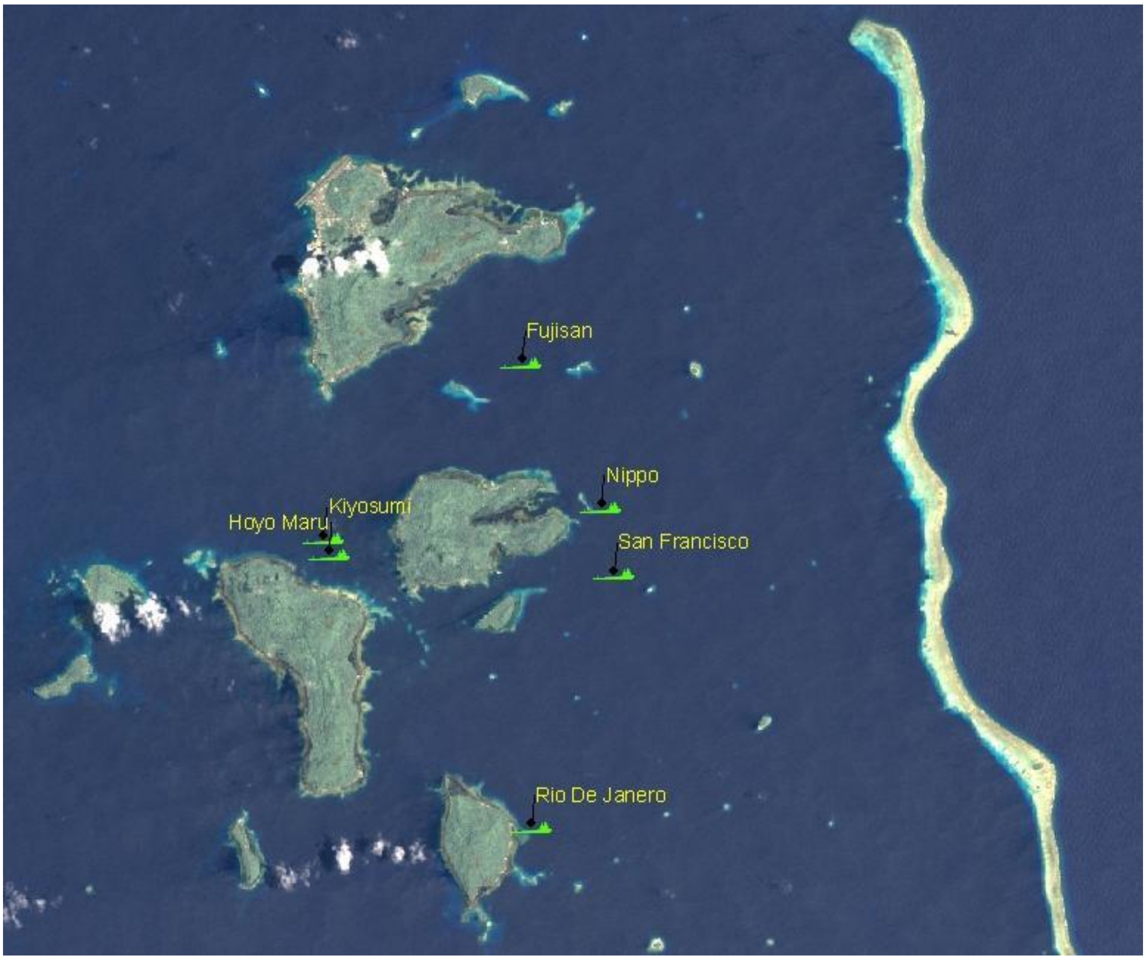


Figure 4: Locations of the key WWII wrecks as provided by FSM government

Chuuk Lagoon sits high upon a Pacific Ocean seamount and once outside the main lagoon and that of Kuop the depth of water is many thousands of metres (Figure 5).

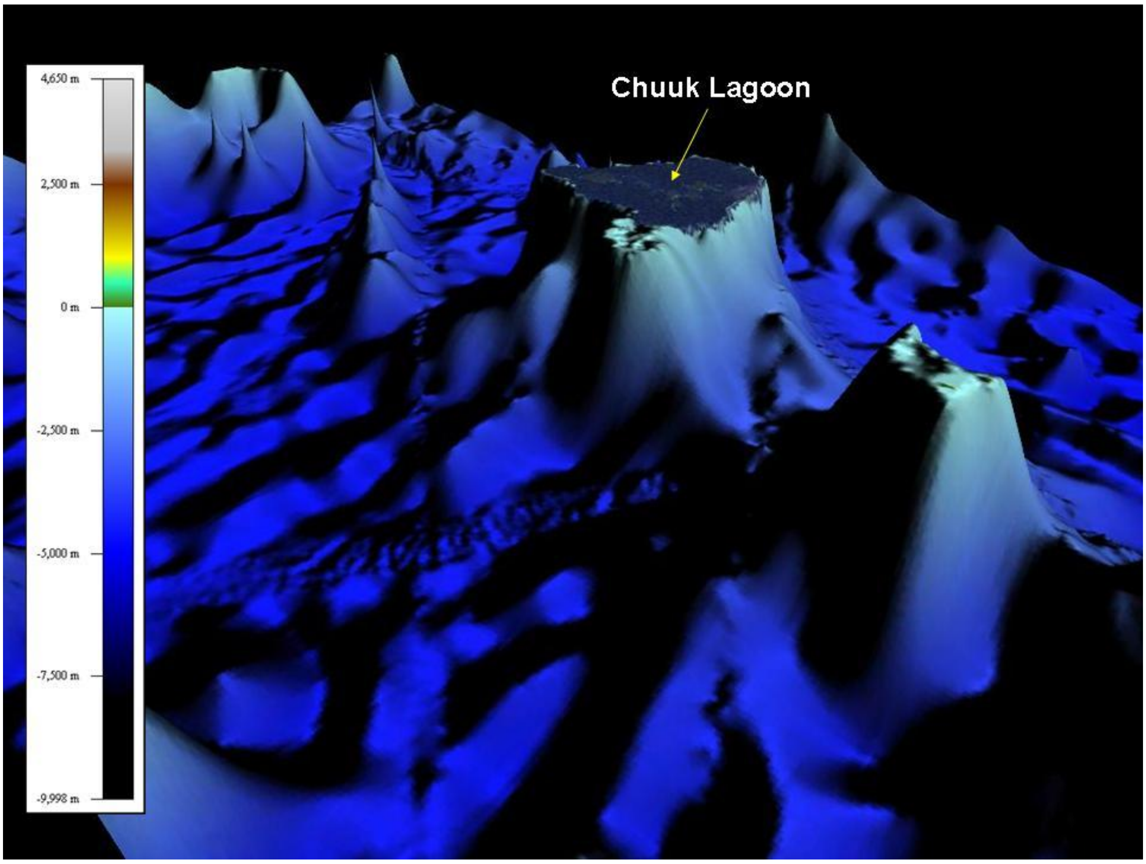


Figure 5: Satellite image of Chuuk lagoon overlaid upon 3 dimension bathymetry model of the region

2.4 Marine Pollution Legal Instruments

There are a number of agreements, conventions, instruments, policies and other initiatives that require countries to work co-operatively to address marine pollution and protect the marine environment.

At the international level these include; - *the United Nations Convention on Law of the Sea* (UNCLOS); *Agenda 21* arising out of the United Nations Conference on Environment and Development (UNCED) and the *Barbados Programme of Action on the Sustainable Development of Small Island Developing States*.

At the regional level they include the *Convention for the Protection of the Natural Resources and Environment of the South Pacific Region* (the Noumea Convention) and associated Protocols and the *Action Plan for Managing the Environment of the South Pacific Region 2001- 2004* (SPREP Action Plan).

At Noumea, New Caledonia on 25 November 1986, the Members of SPREP adopted the *Convention for the Protection of the Natural Resources and Environment of the South Pacific Region* (the Noumea Convention), with associated Protocols. The Protocols provides a formal framework for co-operation between Pacific

Island Countries and Territories to prevent and respond to pollution incidents such as marine spills. FSM is a party to the Noumea Convention and its Pollution Emergencies Protocol.

3. SHORELINE AND ENVIRONMENTAL ASSESSMENT

A shoreline assessment was conducted in and around Chuuk lagoon to establish any deleterious effects from the oil leaking out of the Hoyo Maru. For more information on shoreline contamination assessment techniques (a.k.a. SCAT surveys) please refer to Appendix A. Appendix A also contains in depth information about the biological impacts of oil spills, the type of oil expected in WWII vessels and some background information about oil spill fate and weathering.

3.1 Environmental Assessment

SPREP and EPA staff undertook detailed shoreline assessments of the coastline around Fefan Island that may have been impacted by oil releases from the Hoyo Maru. At the time of the survey there was light shimmer of oil on the water surface as well as a strong odour emanating from the Hoyo Maru.

The principal objective of the surveys was to confirm that no shoreline oiling was present. The secondary objective was to document shoreline types in the area in the event of a future release of oil.

The reef was observed to be alive with an abundance of fish and other marine life. What this means is that the slow release of oil is not having an impact on the reef as would natural disasters such as cyclones, typhoons and other sources of pollution. However, due to its close proximity to the Hoyo Maru, it also means that it is far more vulnerable to disturbance and any pollution event could potentially be very damaging on this reef.

The reef is very heavily used for subsistence fishing by the local population - there were 3 fishermen spear fishing during the time of the survey. Any negative effect on this reef would cause for a disruption of the fishery which in turn would affect the people of Chuuk lagoon as their food source is disrupted. With the fishery disrupted the locals of FSM would have to find alternative food sources. When the fishery was disrupted in Ulithi lagoon due to the oil leaking out of the USS Mississinewa the locals needed to find alternative food sources and many were plundering turtle egg nests thus having a far reaching ecological effect (Gilbert *et al.* 2003)

The shoreline was examined for any surface or buried oil and no physical evidence of any shoreline oiling was observed during the survey.

Information on shoreline types was documented and photographs were taken at all sites to illustrate the shoreline characteristics and possible response issues that would arise in the event of an oil spill (Figure 6).

All photographs taken by SPREP during the surveys were provided to the Chuuk EPA. Shoreline types observed included fine-grain sand beaches, medium – coarse grain sand beaches, rock coral exposed beaches, sand-flats, coral reefs, coral rubble, lagoon and mangroves.

 *Fine sand beach, mangrove*	 *Dense fallen leaves mud crab hole*
 *Fefan Island coastline*	 *Dense crab burrows*
 *Mangroves*	 *Rocky coral semi-submerged shoreline*

Mangroves mid-tide

High tide Fefan Island

Figure 6: Shoreline types documented and photographed during the assessment

Mangroves 50 metres inland

Mature mangroves

*Figure 7**:** Shoreline types documented and photographed during the assessment*

During the surveys SPREP staff discussed response options and issues and potential impact monitoring methodologies for the different sites with Chuuk EPA.

3.2 Technical Advice

Following the surveys, meetings were held at the EPA compound. Topics covered included:

- Shoreline cleanup issues, options and methodologies for each of the shoreline types surveyed.

- Impact monitoring methodologies and programmes required to demonstrate impacts from a spill, principally focussing on monitoring that may be required for evidential purposes for compensation claims.
- Shoreline cleanup assessment techniques (SCAT) concepts and methodologies.
- A summary of eco-toxicity data on the impacts of oil on corals.
- Shoreline pre-segmentation methodologies and benefits.

Information on each of the above was documented during the meeting and provided to Chuuk EPA. Further documentation will be forwarded by SPREP to Chuuk EPA on shoreline pre-segmentation.

3.3 Training Issues

During the discussions with Chuuk EPA the potential value of SPREP running a 1-day training course for a number of key personnel on Oil Spill Response was brought up. Subsequently an inventory was carried out of the oil spill equipment, and on the Thursday, an Oil Spill Exercise was held with local government agencies and industry partners. A full report was provided to Chuuk EPA.

3.4 Planning

A copy of the revised Chuuk National Marine Spill Contingency Plan (CHUUK NATPLAN) was provided to Chuuk EPA for comments.

4. SPILL PROBABILITY STOCHASTIC MODELLING

In order to assist the Chuuk EPA with their planning and oil spill risk assessment, Asia-Pacific ASA provided some stochastic spill modeling to simulate a hypothetical worst-case scenario spill coming from the Hoyo Maru. This stochastic modeling will give the probability of each shoreline being oiled in the event of a spill from the Hoyo Maru. This will determine where the Chuuk EPA should focus their oil spill response attention in the event of a spill.

Risk assessment is a combination of the probability of an event happening and the consequences of that event happening. The stochastic spill modelling outputs produced by OILMAP provides the probability of shoreline impacts, the probability of oil passing through a water region as well as the minimum time taken to reach that location. The environmental habitat and resource mapping provides the "resources at risk" for the consequence analysis.

4.1 Chuuk Lagoon Hydrodynamic Model

The tidal speeds and directions (as a function of time) for this study were generated using the ASA advanced three-dimensional ocean/coastal model (HYDROMAP). HYDROMAP's model formulations and output (current speed/direction and sea levels) predicted current and sea levels have been verified through field measurements around the world the over past twenty-three years (Isaji and Spaulding,1984; Isaji et al., 2001; Zigic et al., 2003). HYDROMAP current data has been used as input to forecast (in the future) and hind cast (in the past) previous spills in Australian waters and forms part of the Australian national oil spill emergency response system operated by AMSA (Australian Maritime Safety Authority). The model is also the hydrodynamic engine used by a number of maritime organisations globally including the US Coast Guard for maritime rescue planning and oil spill modelling systems.

HYDROMAP simulates the flow of ocean currents within a model region due to forcing by astronomical tides, wind stress and bottom friction for any location on the globe. The model employs a sophisticated nested-grid strategy, supporting up to six levels of spatial resolution. This allows for higher resolution of currents within areas of greater bathymetric and coastline complexity, or of particular interest to a study.

To simulate the ocean-circulation over any area of interest, the model must be provided with the following data:

(1) Measured bathymetry for the area, which defined the shape of the seafloor;

(2) The amplitude and phase of tidal constituents, which were used to calculate sea heights over time at the open boundaries of the model domain. Changes in sea heights were used, in turn, to calculate the propagation of tidal currents through the model region; and

(3) Wind data to define the wind shear at the sea surface.

The numerical solution methodology follows that of Davies (1977 a, b) with further developments for model efficiency by Owen (1980) and Gordon (1982). A more detailed presentation of the model can be found in Isaji and Spaulding (1984).

HYDROMAP was set up over a domain that extended 450 km (east – west) by 360 km (north - south). The domain was subdivided horizontally into a grid with four levels of resolution. The finer grids were allocated in a step-wise fashion to areas where higher resolution of circulation patterns were was required to resolve flows through reefs, channels, around shorelines or over more complex bathymetry (Figure 8).

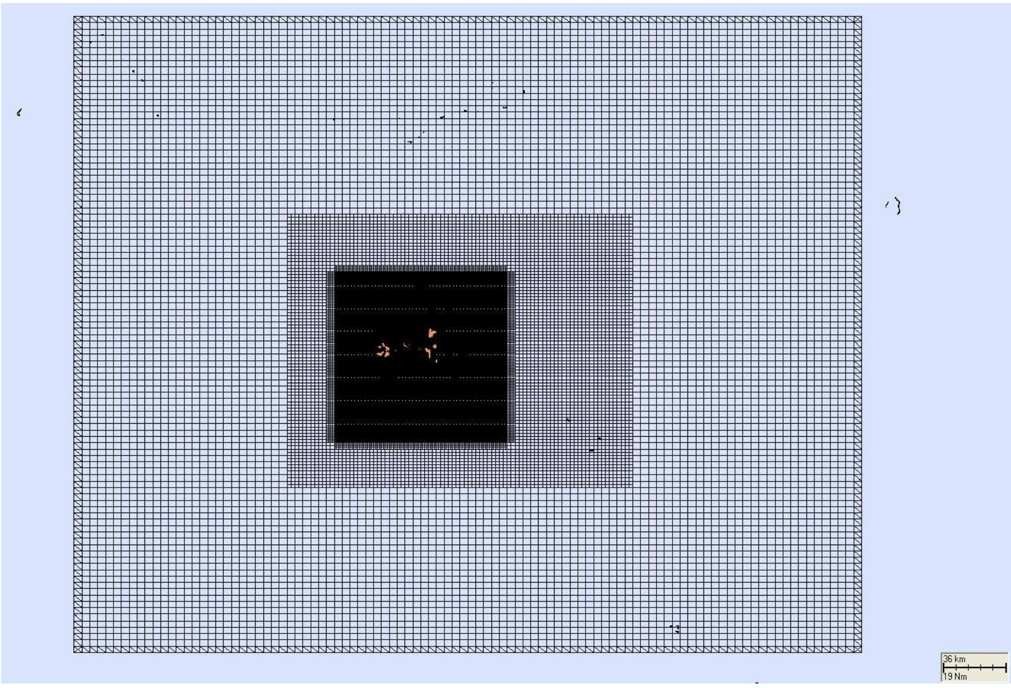


Figure 8: Chuuk Lagoon grid extent

Particular attention was given to accurately resolve the water through-flow between the islands matrix within the port resulting in over 67,000 individual cells modelled in this study (Figure 9).

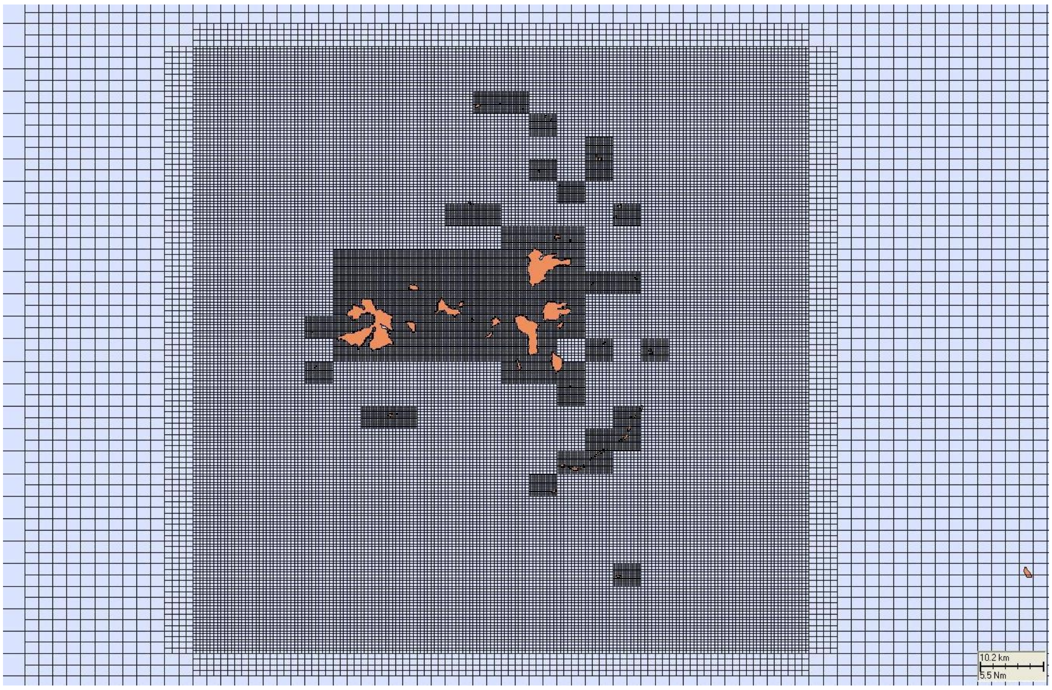


Figure 9: Chuuk Lagoon Grid 4 level of nesting

Bathymetric data used to define the three-dimensional shape of the study domain was extracted from field survey data provided by digitising nautical charts and the SRTM 30 second arc global data (refer to Figure 10 & Figure 11).

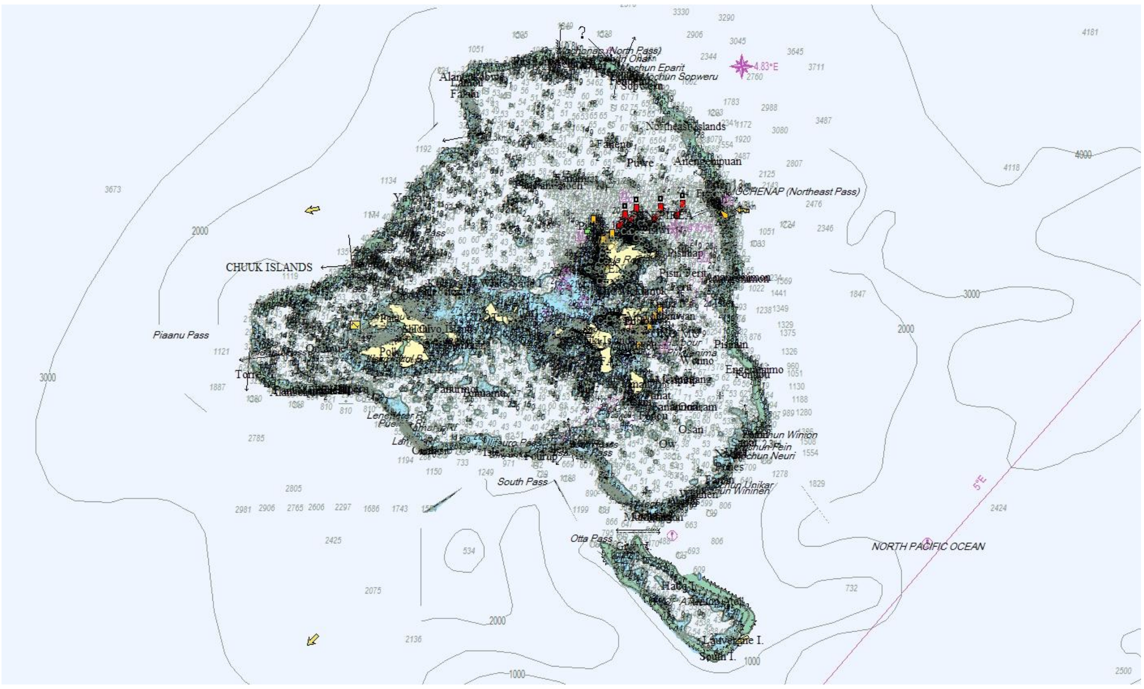


Figure 10: Nautical chart and depth of water – Chuuk Lagoon

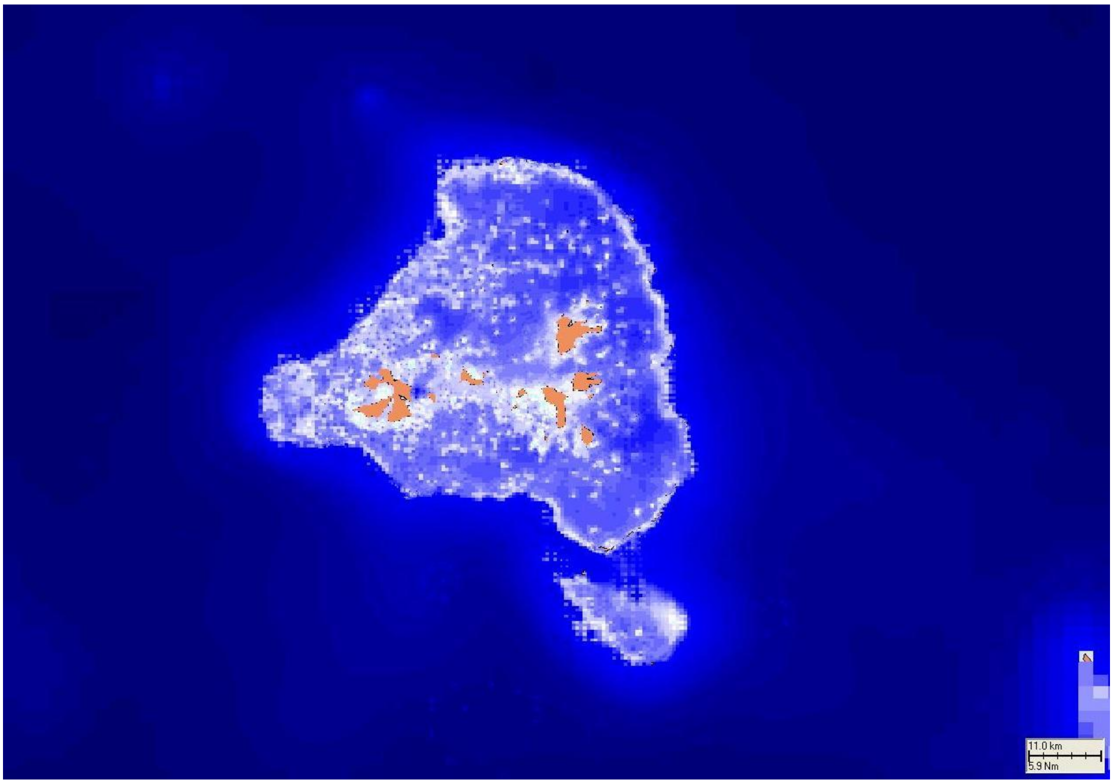


Figure 11: Combined SRTM and nautical chart depth data for hydrodynamic model setup

The detailed tidal data was in the form of amplitude and phase records along the open boundaries of the model grid, which was extracted from the Topex Poseidon global tidal database (TPX07.2), derived from long-term satellite measurements. Using the tidal data, surface heights were firstly calculated along the open boundaries, at each time step in the model, using the 8 largest and most significant tidal constituents for the area (M2, S2, K1, O1, N2, P1, K2, and Q1). The model then circulated the water mass over the entire grid and calculated the sea heights and resulting tidal currents at each cell. In Figure 12 a "snap-shot" of the total net current for each cell is shown. The net current is a composite of all tidal constituents M2, S2, K1, O1, N2, P1, K2, and Q1.

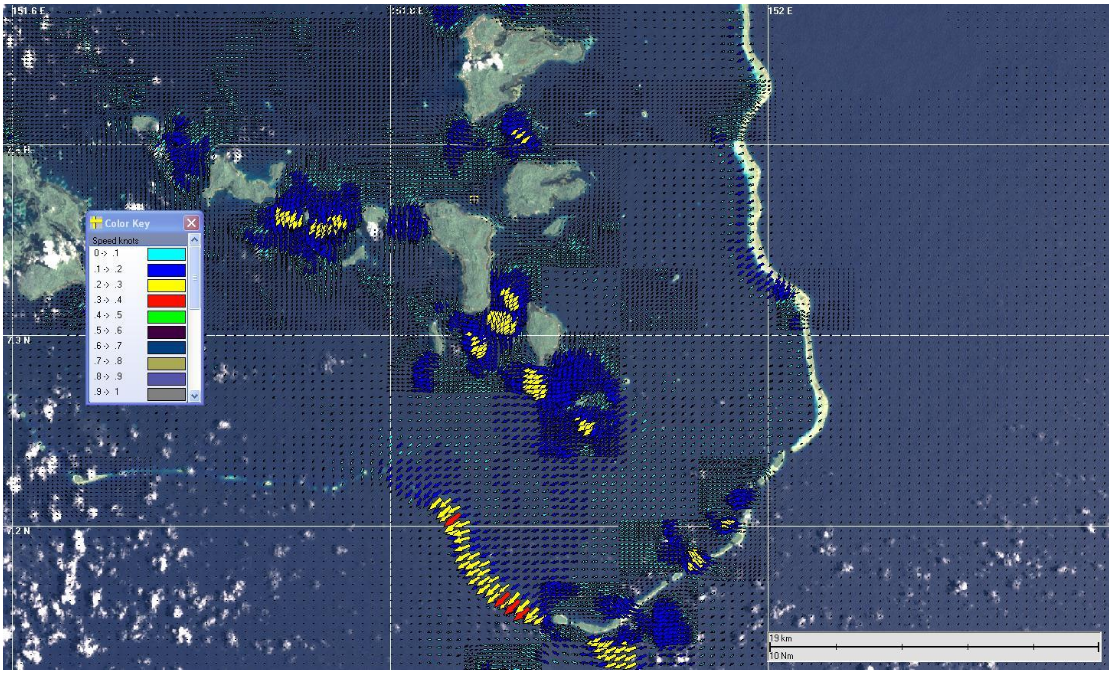


Figure 12: Example of resulting tidal currents generated by HYDROMAP

4.2 Chuuk Lagoon – Climatic Conditions

Chuuk Lagoon is a tropical maritime setting and diurnal variations in temperature are greater than between seasons. The Chuuk Islands are dominated by trade wind season from November to May and a wet variable season from June to October.

The typhoon season runs from June/July to November, but out of season typhoons are not uncommon. The lowest incidence occurs around January and February.

Constant high temperatures and high humidity with very high average rainfall characterize the wet tropical maritime. Typical daytime maximal temperatures are near 30^0 C with minimum around 24^0 C. Rainfall in the State of Chuuk averages about 365 cm a year and seawater temperature averages are between 29-30^{o}C.

NCEP Winds

To account for the wind influence, local wind data was sourced from the NOAA-CIRES Climate Diagnostics Centre within the National Centres for Environmental Predictions (NCEP). This dataset is a synthesis of climatic data from a variety of global sources including ships at sea, the World Meteorology Organisation and the Australian Bureau of Meteorology and using state-of-the-art reanalysis software and supercomputing produces gridded wind datasets over both land and open ocean. Essentially the NCEP wind data is the integration (assimilation) of extensive historic and observed atmospheric data into a state-of-the-art atmospheric computer model with global coverage and predictions at 6-hourly intervals across the globe. The NCEP dataset does not represent actual wind measuring stations but interpolated winds at each data point. NCEP wind data for 20 years (1989 through 2008 inclusive was available for these purposes), was extracted for several nodes throughout the lagoon region model domain, and a spatially varying wind file was generated. This was a vital and necessary input for the oil and chemical spill models. A 20 year wind dataset (7303 days) with wind speed and direction averages each 6 hours was essential to capture cyclonic and severe weather events for the region as well as natural climatic oscillations e.g. El Nino La Nina episodes. Over 29,200 records were included in this spatial wind dataset over the project domain.

Figure 13 shows the monthly and annual wind roses according to the NCEP wind node #7495, which was the closest NCEP node to the area of interest. Note that the atmospheric convention for defining wind direction, that is, the direction the wind blows **from**, is used to reference wind direction throughout this report. Each branch of the rose represents wind coming from that direction, with north to the top of the diagram. Eight directions are used. The branches are divided into segments of different thickness, which represent wind speed ranges from that direction. Speed intervals of five knots are used in these wind roses. The width of each segment within a branch is proportional to the frequency of winds blowing within the corresponding range of speeds from that direction (thick segments represent high frequencies, thin segments represent low frequencies).

The NCEP wind data (Figure 13) demonstrates that the winds are on average just over 9 knots in strength (Beaufort scale 3 – light winds) with a maximum of 39 knots (gale on Beaufort scale 8) based upon four records per day i.e. 6 hour average. Periods of calm weather (less than 1 knot – Beaufort scale 0) are rare with only on average 0.22% of the year being categorised as calm. The direction of the wind is on a yearly average is dominated with winds from the northeast. During July through to October winds are variable and no one wind pattern dominates during this period.

During April, the trade winds begin to diminish in strength, and by July they give way to the lighter and more variable winds of the doldrums. Between July and November the islands are frequently under the influence of the inter-tropical convergence zone. This is also the season when moist southerly winds and tropical disturbances are most frequent.

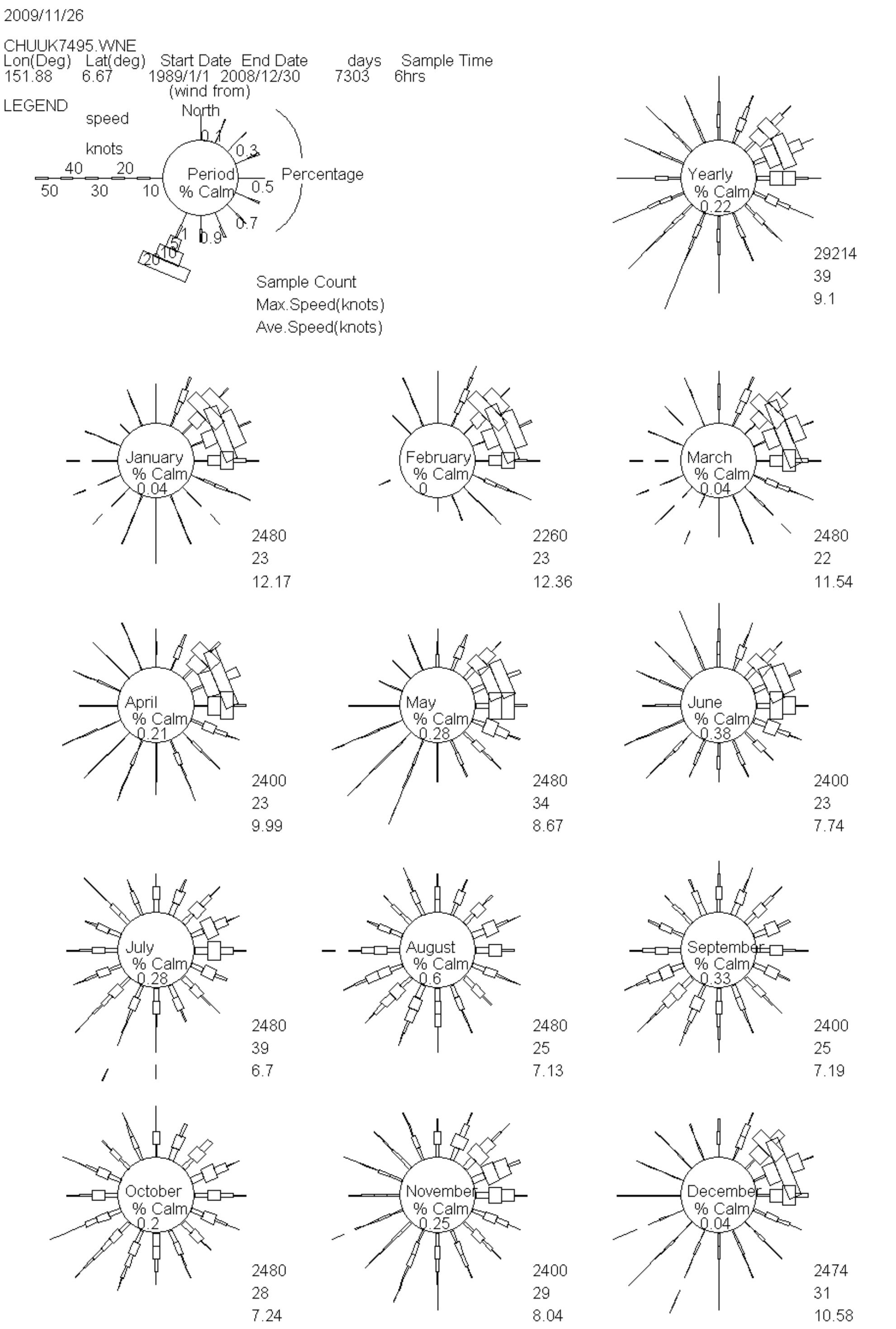


Figure 13: Wind rose for each month and annual for NCEP No. 7495

4.3 Oil Thickness Thresholds

The lowest visually detectable level of oil on water as stated by the internationally accepted Bonn Agreement Oil Appearance Code (BAOAC) is 0.04 µm. A description of the various oil appearances and oil thickness levels are provided in Table 2 and shown in Figure 14. In this study this lowest observable limit was used in all stochastic models.

Table 2: *Bonn Agreement Oil Appearance Code (BAOAC) 02 May, 2006*

Code	Description	Thickness (µm)	Concentration (g/m^2)
S	Sheen (silvery/grey)	0.04 – **0.30**	0.04 – 0.30
R	Rainbow	**0.30** – 5.0	0.30 – 5.0
M	Metallic	5.0 – 50	5.0 – 50
T	Transitional Dark Colour	50 – 200	50 – 200
D	Dark (or True) Colour	> 200	> 200

Figure 14: A photograph of sheen and rainbow oil. The thickness of this oil is less than 0.001 mm (1 µm) (Source: "Oil on water sheens" – Ron Goodman Innovative Ventures Ltd)

4.4 Hoyo Maru Oil Properties and Weathering

The main oil used in Japanese cargo ships of this size was referred to as "black fuel oil". It was equivalent the US Navy Special Fuel Oil (NSFO) and similar to the ASTM Fuel oil No. 5. This fuel oil No.5 consists of straight-run and cracked distillates and refinery residuals, and contains a complex array of aliphatic and aromatics hydrocarbons as well as asphaltene and polar organic hydrocarbons. Fuel oil numbers 4, 5, and 6 are commonly known as "residual oils" or "bunker fuels" since they are manufactured in whole or in part from distillation residues from refinery processing. NSFO is the equivalent of No. 5 (light) fuel oil which is produced by blending No. 6 fuel oil with lighter distillates. In Figure 15 (below) a sample of NSFO taken from the leaking *USS Mississinewa* is shown – Figure 16.

Figure 15: Oil sample NSFO USS Mississinewa


Figure 16: Oil leaking from the hull of the USS Mississinewa 2001

As war ships were potentially required to operate in cold as well as tropical waters and in all seasons the fuel oil was a blend that allowed it to remain fluid in arctic waters without heating. Compared to the heavy fuel oils used in large commercial vessels today this fuel did not require tank or fuel line heaters or preheating prior to engine injection, hence less machinery and cost of construction.

Fuel Oil Number 5 is typically about 75-80% Fuel Oil No. 6. NSFO and is cut with a lighter marine diesel up to 20% in some cases has a final viscosity of 170 centistokes at ambient temperature. The cutter light oil will entrain into the water column and weather quite quickly when spilt in tropical waters whereas the residual oil will be more persistent and likely to be transported long distances by wind and currents until it comes ashore or impact fringing reef systems.

How do we define persistent and non-persistent oils? The definition as used under legislation by the US Environment Protection Agency and US Coast Guard is that an oil must comply with the following criteria to be defined as non-persistent when spilt on water:

1. At least 50% of which by volume, distils at a temperature of 340°C (645°F); and
2. At least 95% of which by volume, distils at a temperature of 370°C (700°F).

The above definition of "non-persistent oil" has also been adopted by the International Oil Pollution Compensation Fund and many Protection & Indemnity (P&I) Clubs for international consistency. Oils and bunker fuels falling out of this category will be defined as "environmentally persistent when spilt".

The determination of an oils "persistence" is significant in determining the following:

- Spill movement, weathering extent & fate of the oil.
- Determining travel distances from spill site therefore - planning distances.
- Determination of on-water recovery techniques, logistics and placement of assets.
- Scale of shoreline cleanup capacity and worst case planning volumes.

The composition, physical properties and resulting toxicity of NSFOs used in WWII varied depending on the original crude oil source used in the countries refinery, the refining process, the amount and type of waste oils used in the blending, and the amount and type of cutter stock used. Therefore no full physical property datasheet is available for the fuel oil used in the *Hoyo Maru*.

Following a release of oil from the *Hoyo Maru*, the lighter, more volatile components will be lost by evaporation, dissolution and biodegradation. The water-soluble fraction, which principally contains aromatic hydrocarbons and polar compounds, will be responsible for the acute toxicity effects on organisms. The remaining heavy fraction will become attached to the substrate or sequestered in the sediments. The tar-like residue will persist for many years (see Figure 17)

Figure 17: Fresh and weathered oil residues on the shores of Ulithi lagoon from USS Mississinewa oil spill 2001

A sample of oil leaking from the *USS Mississinewa* was subjected to room temperature weathering and lost only 15% of its mass within one day (Gilbert 2001). This demonstrated the lack of light hydrocarbons and the persistent nature of the oil.

For stochastic spill modelling purposes a light crude oil was used as an analogue for NSFO and represents a mixture of light evaporative and heavier persistent hydrocarbons.

4.5 Stochastic Oil Spill Modelling

The importance of metocean data sources and spill modelling to determine the movement and fate of oil for spill response, during maritime emergencies and also for shoreline risk assessment has been widely published. (Daniel etc 2008, & Gilbert 1998)

Surface spill modelling was carried out using ASA's two-dimensional oil spill model, OILMAP. OILMAP is a computerised modelling system for predicting the physical and chemical fates and effects of hydrocarbon spills on the ocean. OILMAP incorporates a geographic information system (GIS) for defining the location and nature of natural resources, and a suite of models that predict the behaviour of hydrocarbon slicks on the sea surface.

The OILMAP model simulates the transport of the hydrocarbon slicks within a model domain using time- and space-varying data for the speed and direction of water currents, and time-varying data for the speed and direction of the wind. The distribution and mass balance of particular hydrocarbon types are predicted over time based on the physical characteristics of the specific oil type and the prevailing weather conditions. For this latter purpose, OILMAP includes algorithms that account for hydrocarbon spreading, evaporation, emulsification, entrainment, and shoreline interactions. If hydrocarbon strands

on shorelines (as defined in the OILMAP GIS), details are recorded on the quantity, time to contact and resources at the strand location.
Predictions of the OILMAP model have been validated worldwide (Spaulding *et. al.* 1992, 1994) and in Australia (King *et. al.* 1999) by field observations and by hind-casting past hydrocarbon spills.

The combined HYDROMAP/OILMAP model system can be used to predict the fate of a spill during a response situation of a spill drill, or for multiple spills that occur under a random selection of prevailing conditions (known as stochastic modelling). This latter approach provides a more informative estimate of the risk of hydrocarbon exposure for adjacent resources, because it provides multiple spills as samples which are collectively analysed to provide statistical weighting of the potential outcomes of spills for likely ambient conditions while less common conditions are also represented as well. This approach is also more realistic as accidental spills, by their nature, could occur at any time of the day and under any combination of the ambient conditions rather than specific controlled conditions.

OILMAP can be used to predict the fate of a single spill under defined conditions, or of multiple spills that occur under a random selection of prevailing conditions (known as stochastic modelling). The stochastic model performs a large number of simulations for a given spill site in this case 500 spill runs. The model randomly varying the spill time, so that the transport and weathering of each slick are subject to a different set of prevailing wind and current conditions recorded for that site. During each simulation, the model records the grid cells that were in contact with oil particles. Once the stochastic modelling is complete, the results are compiled from each of the sample trajectories to provide a statistical weighting. Results can be summarised as:
(1) the probability that a grid cell may be exposed to oil slicks; and
(2) the minimum time before exposure could occur.

The first estimate is calculated from the rate of exposure during all simulations, while the latter estimate is the worst-case for any of the sample trajectories (French *et al.*, 1999).

The stochastic modelling approach provides an objective measure of the possible outcomes of a spill, as well as the means of quantifying the likelihood of a given outcome. The most commonly occurring conditions would be selected most often while more unusual conditions can also be represented. Shoreline cells impacted by oil are recorded along with statistics on probability of oiling and mass of oil ashore.

It should be noted that the stochastic (or random) method provides a measure of the most likely outcomes of a spill, and not specific certain outcomes.

A summary model parameters used in this study are detailed in Table 3.

Table 3: Summary of fixed model settings used for spill modelling

Parameter	Model Value
Location spill	- 7.37117 Latitude 151.84475 Long.
Release Timing	Anytime over 12 month period
Oil Type	Light Crude oil
Number of randomly selected spill start times per site.	500 model runs
Water temperature (°C)	Average Yearly 29 °C
Wind Records	NCEP 20 years records 1988-2008
Oil Thickness Minimum	0.04 um (microns)
Length of each model run	72 hours
Volume oil Released	1 Barrel
Spill Duration in Hours	Instantaneous

4.6 Stochastic Model Results

In Figure 18 the combined water probability from 1 to100 % for 500 individual random releases of 1 barrel of light crude oil at the surface from the *Hoyo Maru* at any time over a 12 month period is provided.

It can be seen that the majority of the main islands of Chuuk Lagoon are at risk from an oil spill from the *Hoyo Maru* with the island of Fefan at most risk. Shoreline impacts are possible on the islands of Fefan, Dublon, Moen, Parah, Udot and Lidot.

Wind strength and direction appears to be the main driving force for movement of oil spills and potential shoreline impact zones within Chuuk Lagoon. The dominant northeasterly trade winds place the Island of Fefan mostly at risk from the Hoyo Maru.

For a water probability of 20-100% (Figure 19) only the Island of Fefan is at risk from a spill from the *Hoyo Maru* under yearly average conditions. The shoreline oil impact probability between 20-100% is shown in Figure 20.

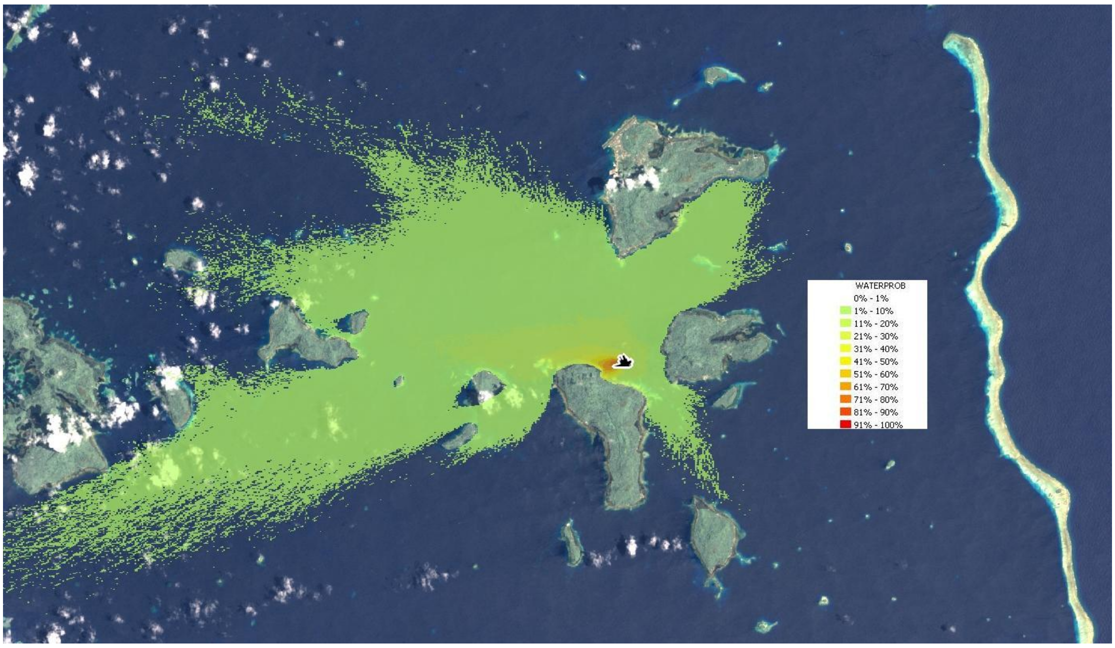


Figure 18: Percent water probability 1 to 100%

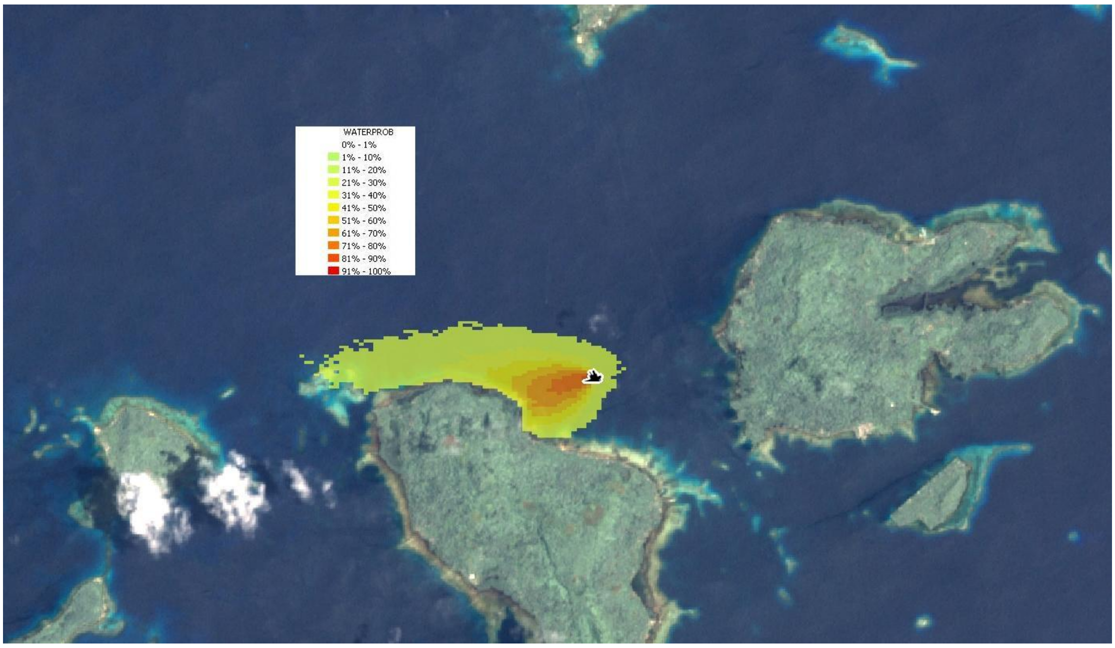


Figure 19: Percent water probability 20 to 100%

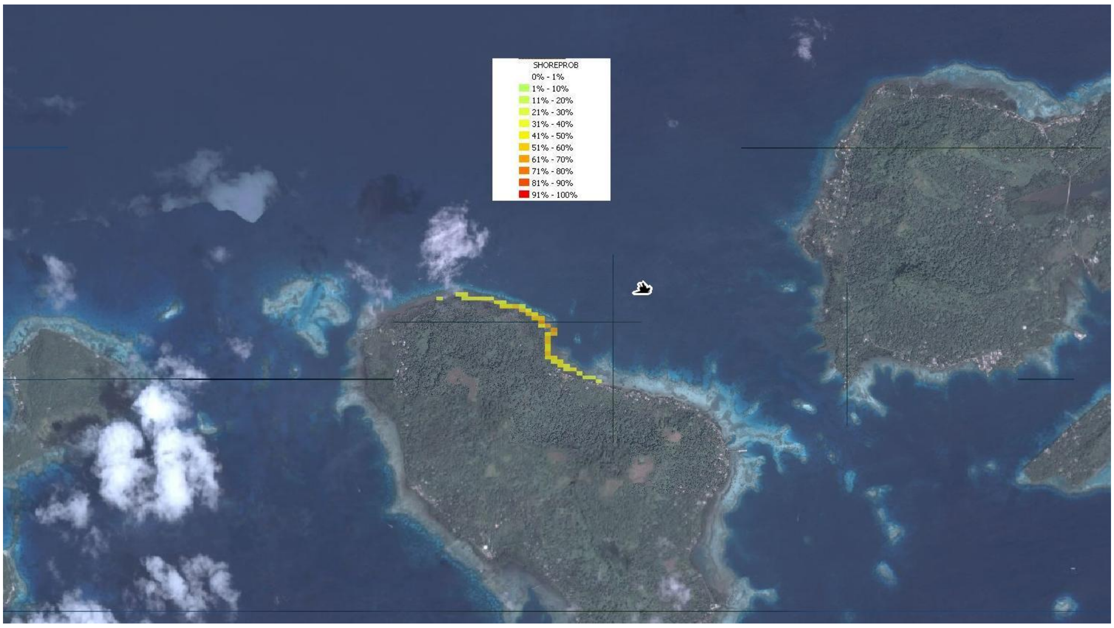


Figure 20: Percent shoreline impact probability 20 to 100% only

The water impact probability from 40-100% is provided in Figure 21 and shows that approximately 1000 metres of the coastline of Fefan is a high risk of impact from oil spills from the *Hoyo Maru*.

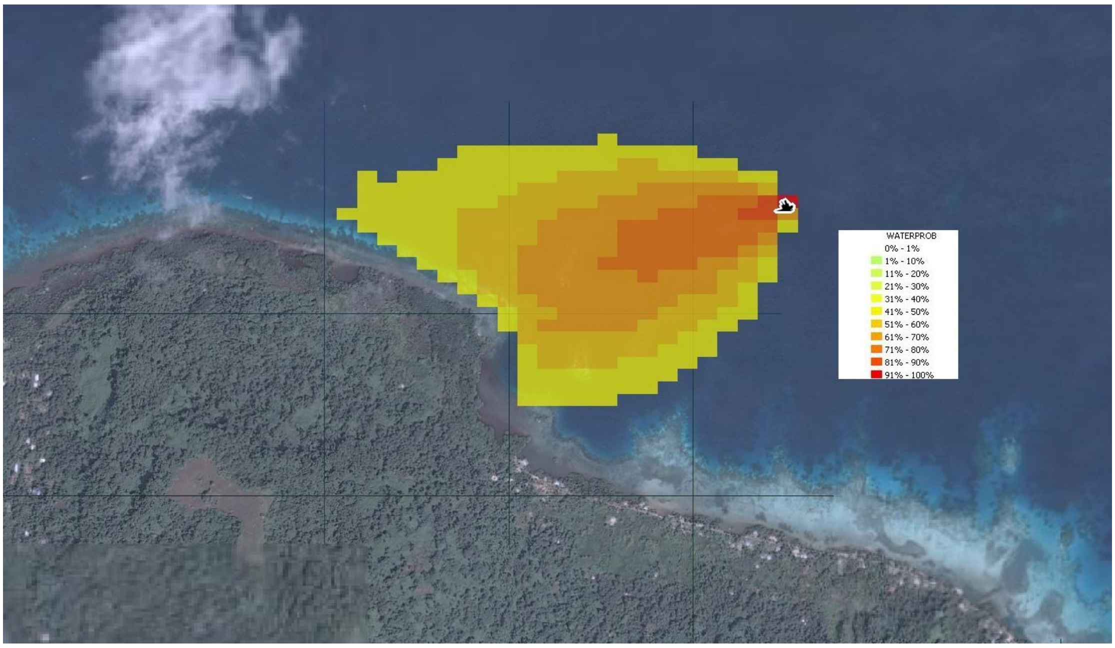


Figure 21: Percent water probability 40 to 100% only

In Figure 22 the shoreline oil impact probability is provided highlighting the fringing mangroves and fringing reefs of the northern shoreline of Fefan Island are at most risk from oil spill from the sunken Hoyo Maru.

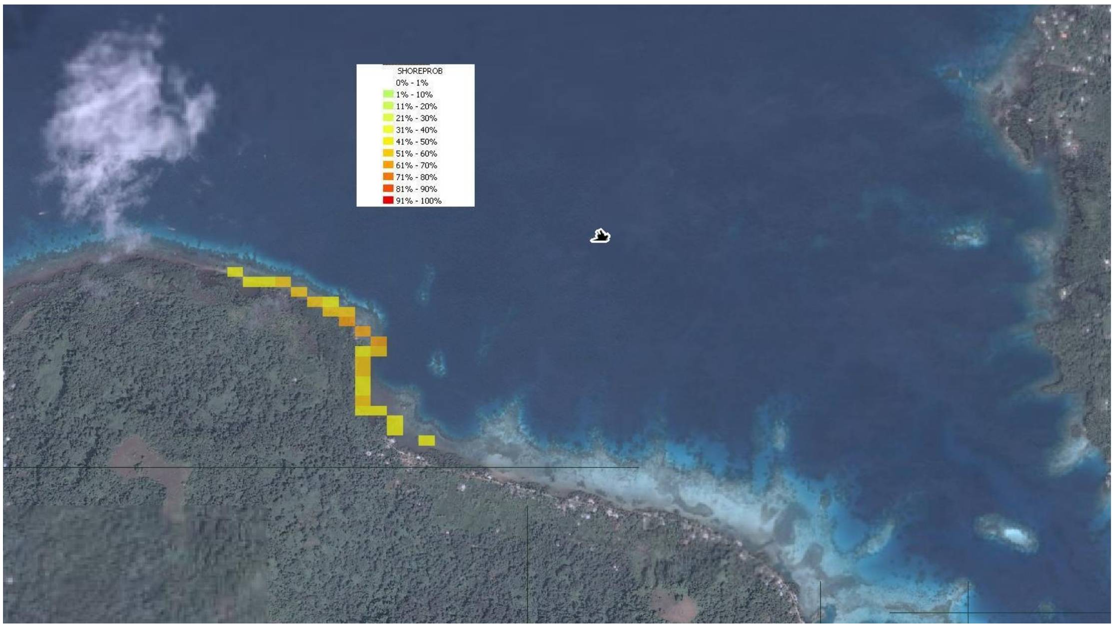


Figure 22: Percent shoreline impact probability 40 to 100% only

5. CONCLUSIONS OF THE STUDY

The shoreline assessment showed that at the time of the survey there was no visible oil on any of the shorelines examined. Examinations were conducted for both surface and sub-surface oil on each shoreline and no oil was found at the time. This does not mean that the Hoyo Maru is not leaking, it simply means that at the time of the survey no oil was found on shorelines examined. The strong oil odour in the area and the light shimmer on the surface of the water clearly indicate to a sub-surface release. What is unknown is the quantity of oil that is leaking out of the vessel nor do we know how much oil is left on board.

The stochastic model uses winds and current data to simulate an oil spill from the Hoyo Maru at any possible time.

The sunken WWII wreck of the *Hoyo Maru* is only 1.1 kilometre from northern shoreline of Fefan Island. With the tidal model provided by HYDROMAP and the 500 stochastic model runs using OILMAP, the following conclusions can be made regarding oil spill risks from this wreck.

Wind strength and direction are the main driving forces for movement of oil spills and potential shoreline impact zones within Chuuk Lagoon. The dominant northeasterly trade winds place the Island of Fefan mostly at risk from the *Hoyo Maru*. Over 1000m of Fefan Island is at risk to 40% of all the probable oil spills from the *Hoyo Maru*.

Shoreline impacts from oil spills from the *Hoyo Maru* are also possible on the islands of Dublon, Moen, Parah, Udot and Lidot but with a much reduced risk in the order of less than 10%. This indicates that an oil spill occurring at any random time would have less than 10% probability of impacting these shorelines.

Approximately 50% of the oil volume spilt will be evaporated due to the warm tropical waters and wind with the remainder 50% likely to come ashore somewhere within the lagoon. In high sea states conditions a proportion of this oil would be entrained as oil droplets exposing marine life. Therefore response personnel should plan that at least 50 % of the oil escaping from the vessel is likely to be persistent and also impact on the natural coastal and marine resources somewhere within the lagoon.

For spill response planning purposes of particular interest is the minimum time for oil to come ashore which takes into account the worse case scenario. Most of the oil scenario's showed the oil impacting shorelines within the lagoon 2-6 hours of the spill.

Oil is likely to impact the shoreline of Fefan Island within 1 hour of the spill from the sunken wreck.

The potential short timing between an oil spill and shoreline impacts highlights the need to ensure the most sensitive resources within the lagoon are identified and response actions are carried out immediately to divert or contain oil before an oil spill strands onshore. An immediate understanding of wind direction and speed prevailing on-site will assist responders appreciate and determine oil trajectory impact locations.

6. RECOMMENDATIONS

1. It is recommended that an in-depth assessment of the Hoyo Maru be carried out to determine extent of corrosion and amount of possible oil left on board.
2. No chronic oil release scenarios from the wreck of the *Hoyo Maru* were modeled as part of this study. We recommend this work be done as a priority.
3. We also recommend the FSM government action stochastic spill modeling of all known WWII shipwrecks in Chuuk Lagoon to identify the potential shorelines at risk from these vessels and rank them on order of environmental impact.

7. REFERENCES

Daniel P, Gilbert T.D, Hackett B, Hines, A and Tiercelin C. (2008) Operational Metocean Products and Services In Support of Marine Pollution Emergency Response Operations, Proceedings of the International Oil Spill Conference 2008. American Petroleum Institute, Washington, D.C. www.iosc.org

Davies, A. M. 1977a. The numerical solutions of the three-dimensional hydrodynamic equations using a B-spline representation of the vertical current profile: in Bottom Turbulence, Proceedings of the 8th liege colloquium on Ocean hydrodynamics. Nihoul, J.C.J. (Editor): Elsevier.

Davies, A.M. 1977b. Three-dimensional model with depth-varying eddy viscosity: 27-48 in Bottom Turbulence, Proceedings of the 8th liege colloquium on Ocean hydrodynamics. Nihoul, J.C.J. (Editor). Elsevier.

French, D., H. Schuttenberg, and T. Isaji, (1999). "Probabilities of oil exceeding thresholds of concern: examples from an evaluation for Florida Power and Light." In *Proceedings of the 22nd Arctic and Marine Oil Spill Program (AMOP) Technical Seminar*, June 1999, Environment Canada, pp. 243-270.

Gilbert, T.D. (1998) *Maritime Response Operations- Requirements for Met/Ocean Data and Services.* In proceedings of the Conference on Meteorological and Oceanographic Services for Marine Pollution Emergency Operations (MARPOLSER 98) July 13-17, 1998, Townsville, Pub World Meteorological Organisation Report #960 pp 67-89.

Gilbert, T.D (2001) *Report of the Strategic Environmental Assessment, USS Mississinewa Oil Spill, Ulithi Lagoon, Yap State, Micronesia*. Pub. September 18th 2001, South Pacific Regional Environment Programme – presented to the Governor of Yap State. (Pub. SPREP)

Gilbert, T.D. (2002), *WWII Shipwrecks – A Pollution Threat to the Fisheries, Marine and Coastal Environments of the Pacific*, Waves, Vol 9, No.1, p10. ISSN 1321-7593.

Gilbert T.D., S. Nawadra, A. Tafileichig, and L. Yinug, (2003). *Response to an Oil Spill from a Sunken WWII Oil Tanker In Yap State, Micronesia.* Proceedings of the International Oil Spill Conference 2003. American Petroleum Institute, Washington, D.C. pp. 1-8.

Gordon, R. 1982. *Wind driven circulation in Narragansett Bay*. Ph.D. Thesis. Department of Ocean Engineering. University of Rhode Island: Kingston, Rhode Island , 161 pp

IMO (2004) (MEPC51/QP3). Implementation of the OPRC Convention and the OPRC-HNS Protocol and relevant OPRC Conference Resolutions. Draft Report of the Meeting.

Isaji, T. Howlett, E. Dalton C. and Anderson E. (2001). "Stepwise-Continuous-Variable-Rectangular Grid." Proc. 24th Arctic and Marine Oil Spill Program Technical Seminar, pp 597-610.

Isaji, T. and Spaulding, M. 1984. A Model of the Tidally Induced Residual Circulation in the Gulf of Maine and Georges Bank. Journal of Physical Oceanography 14: 1119-1126.

King B., F.McAllister, G. Hubbert (1999). "Data requirements for calibration and validation of the spill model OILMAP". In, *Marine Meteorology and Related Oceanographic Activities*. WMO Report No. 44. MARPOLSER 98 Proceedings Volume 1 – Research Papers. WMO/TD – No. 959. Pages 35-52.

Michel J, Gilbert T.D. Etkin D, Urban, R Waldron J and Blocksidge, C (2005) *Potentially Polluting Wrecks in Marine Waters,* An Issues Paper for the International Oil Spill Conference May 2005, Pub. American Petroleum Institute, Washington, D.C. p1-84. http://www.iosc.org/docs/IOSC_Issue_2005.pdf

Monfils R.M. Gilbert, T.D, Nawadra, S (2006) *Sunken WWII Ship Wrecks of the Pacific and East Asian Region: The Need for Regional Collaboration to Address the Potential Marine Pollution Threat*. Presented at East Asian Congress of the Sea, Kuala Lumpur, Malaysia, December 2003. Pub. J. Ocean and Coastal Management, Vol. No 2006.

Monfils R. (2005) The Global Risk of Marine Pollution from WWII Shipwrecs: Examples from the Seven Seas. Proceedings of the International Oil Spill Conference, Miami, 2005.

Nawadra, S. (2002). Regional Strategy to Address Marine Pollution from World War II Shipwrecks, Thirteenth SPREP Meeting of Officials (Item 7.2.2.1) Majuro, Marshall Islands 21-25 July, 2002. (Pub. SPREP)

Owen, A. 1980. A three-dimensional model of the Bristol Channel. *Journal of Physical Oceanography* 10: 1290-1302

Spaulding, M.L., E. Howlett, E. Anderson and K. Jayko (1992). "OILMAP: A global approach to spill modelling". *15th Annual Arctic and marine Oil Spill Program, Technical Seminar*, Edmonton, Alberta, Canada, June 9-11, 1992.

Spaulding, M.L., V.S. Kolluru, E. Anderson and E. Howlett (1994). "Application of three-dimensional oil spill model (WOSM/OILMAP) to hindcast the Braer Spill". *Spill Science & Technology Bulletin*, Volume 1, No. 1, pp. 23.

Zigic, S., M. Zapata., T. Isaji., B. King and C. Lemckert (2003). "Modelling of Moreton Bay using an ocean/coastal circulation model." Coast and Ports Australasian Conference, 9 -12 September Auckland, New Zealand, paper 170.

Appendix A – SCAT SURVEYS

In the international spill response community a standardised survey technique called SCAT has been widely adopted. It was originally referred to as Shoreline Cleanup and Assessment Teams (SCAT), but is now gaining a more widespread use as a Shoreline Contamination Assessment and Treatment process.

The basic concepts of a SCAT survey are:

- a systematic assessment of all shorelines in the affected area;
- a division of the coast into geographic units or "segments";
- a set of standard terms and definitions and documentation;
- determination of the most environmentally acceptable cleanup options and techniques.

Fuel oil on beach – Jody F Millennium oil spill New Zealand (photo T.Gibert)

Biological and Other Impacts from Oil Spills from WWII Shipwrecks

In assessing the potential risk posed by an individual wreck, we must examine the potential impacts of the spill.

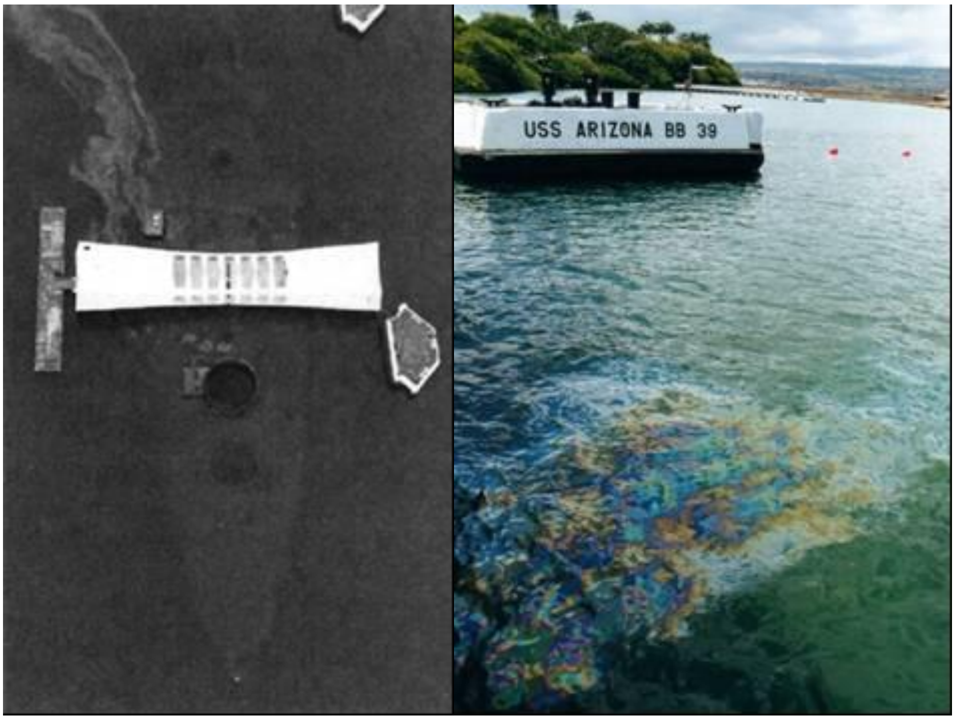
The general terms the range of oil impacts during and after an oil spill can range from:

- physical and chemical alteration of natural habitats, both short and long term e.g. resulting from oil absorption into/onto sediments.
- physical smothering effects on wildlife (fauna) and plants (flora).

- lethal and sub-lethal toxic effects on fish, fauna and flora.
- short and longer term changes in biological communities resulting from oil effects on key organisms (e.g. food chain interruptions).
- tainting of edible species, notably fish and shell fish.
- loss of use of amenity areas such as sandy beaches.
- loss of market for fisheries and tourism.
- fouling of boats, fishing gear, boat ramps, jetties etc.
- temporary interruption of any marine based industries.

Assimilation of Oil into the Environment

Most oils will eventually be assimilated by the marine environment. However, the rate at which this occurs will depend on the chemical and physical properties of the oil, the amount spilled, the prevailing climatic and sea conditions, whether the oil remains at sea or is washed on shore and the type of shore it is washed onto.



Fuel Oil leaking from the battleship USS Arizona Sunk Pearl Harbour, Hawaii (PHOTO REF)

Oil Types Expected in Sunken WWII Vessels

It is expected the majority of oil within the large sunken WW II vessels will be heavy fuel oil along with diesel, lubrication oils and some aviation fuels and gasoline.

Vessels such as submarines would be mostly diesel driven and have smaller quantities of fuel on board whereas large carriers, battle ships, destroyers are likely to have large quantities of heavier fuel oil.

In considering the fate of spilled oil at sea and the likely impacts, a distinction has to be made between persistent and non-persistent oils. In most of the larger vessels during the Pacific war, the fuel oil was a blend of non-persistent as well as persistent oils. It appears to be a blend of bunker oil (No#6 fuel oil) and marine diesel (No#2 fuel oil).

Oil Spill Fate and Weathering

Diesel oil from WWII wrecks would weather relatively quickly with the majority of any diesel spill in tropical waters being dispersed into the water column or evaporated within 12-24 hours. This does not mean there would not be ecological impacts on aquatic life, coral reefs or possible wildlife impacts but that it would be 'removed' from the water surface within a short time after release. Once dispersed or dissolved within the water, column diesel oil could still have significant impacts on inter-tidal life and fisheries.

When the heavier fuel oil mixtures are released into the marine environment, some of the oil will naturally disperse and dissipate as the slick spreads; some components will dissolve into the water; other amounts onto sediments, which can settle into inter-tidal zones if near shore. The heavier persistent components can form emulsions in rough seas or end up as tar balls and pats on shorelines or travel long distances at sea.

To assist the understanding of the weathering and fate of oil in the marine environment, it is necessary to have a good understanding of the oil type and environmental conditions.

The environmental factors that affect the fate and removal of oil are:

- area of slick exposed, which changes rapidly.
- wind speed and water surface roughness.
- air temperature and exposure to sunlight (solar radiation).
- formation of emulsions, which dramatically slows evaporation.

The high water and ambient temperatures of the lagoon as well as high winds accelerate the evaporation rate of the oil spilled. Average Pacific air and water temperatures are high between 25-32 C degree with often less than 10 C degree variance between night and day.

Under the spill conditions in most central and southern Pacific locations, the released fuel oil after weathering would behave in a manner similar to conventional #6 fuel oils. This heavy oil has a slightly lower density than full-strength seawater at tropical temperatures. Many heavy fuel oils are likely to float and remain liquid during the early stages of a spill. The light fractions will be lost by evaporation, and the floating oil will initially form contiguous slicks. Eventually the slicks will break up into widely scattered fields of pancakes and tar-balls, which can persist over large distances and concentrate in convergence zones. Because of the higher viscosities of these oils, the tar balls may be more persistent than expected for conventional crude oils.

Fuel Oil Residues on beach of Island in Ulithi Lagoon – Spill from sunken USS Mississinewa August 2001 (PHOTO REFERENCE?)