POTENTIALLY POLLUTING WRECKS IN MARINE WATERS

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Cover Photograph: Oil seepage from USS *Mississinewa*, Ulithi Lagoon, Yap, Federated States of Micronesia. Photograph courtesy of the U.S. Navy Supervisor of Salvage.

Table of Contents

EXECUTIVE SUMMARY

There has been increased awareness and concern about the oil-pollution risks posed by sunken wrecks, both recent and relic. Recent cases such as M/T *Prestige* and M/T *Erika*, where the vessel or portions of the vessel sank with large volumes of heavy, persistent oils onboard, have triggered public demand for removal of the oil, regardless of the pollution threat. Mystery spills have been linked to older wrecks that have started leaking, such as USS *Mississinewa* and SS *Jacob Luckenbach*. Funding is usually a limitation, even when there is a responsible party, because of the high costs of oil and/or wreck removal. However, the concern is that these wrecks will eventually release their oil, either slowly or catastrophically resulting in significant damage to the environment. There are many complex issues associated with the pro-active response to these potentially polluting wrecks: Which pose the greatest risks? Who should pay for assessment and removal costs? What are feasible and cost-effective technologies for assessment and oil removal? The goals of this paper are to provide an objective analysis of the current state of potentially polluting wrecks, due to the discharge of petroleum, or the substantial threat of such a discharge, and to offer considerations for addressing the issues.

A step-wise process was followed. The first step was to compile existing data into the first-ever worldwide database of potentially polluting wrecks. The database includes non-tank vessels of at least 400 gross tonnage (GT) holding petroleum-based oil as fuel/bunkers (and for operations) and tank vessels of at least 150 GT holding petroleum-based oil as cargo and fuel/bunkers (and for operations). The intent was to consider those wrecks that posed a significant oil-pollution risk. The resulting database includes 8,569 potentially polluting wrecks, with 1,583 tank vessels and 6,986 non-tank vessels. Estimates of the likely volume of oil remaining onboard these wrecks were made, particularly when the volume of oil onboard was not known. A high estimate was calculated assuming that a tank vessel had at least 80 percent of its cargo capacity on board, and bunkers were assumed to be 70 percent full. A low estimate was calculated based on the assumption that half of the vessels would have been 80 percent full and half would have been 20 percent full at the time of sinking and that an estimated 80 percent of the oil would have either spilled at the time of the sinking or seeped out in the years following. The results were a low estimate of 2.5 million tonnes (757 million gallons) and a high estimate of 20.4 million tonnes (6 billion gallons).

The next step was a review of the different regulatory and financial regimes both in the United States and internationally. The United States has fairly structured pollution response and wreck removal regimes under the Wreck Act and the Clean Water Act, as amended by the Oil Pollution Act of 1990 (OPA 90). The Wreck Act provides a mechanism to remove wrecked vessels from navigable channels. OPA 90 provides a source of funds should an owner of a wrecked vessel either not be found or be unwilling to remove or otherwise mitigate the discharge or threat of discharge from a wreck, including removal of the wreck when it is determined to be absolutely necessary to abate the discharge, or substantial threat of such a discharge, to the environment. The major issue with the United States revolves around whether a wreck must be removed in order to abate the discharge, or threat of discharge, of its oil polluting contents under OPA 90. Internationally, States have various pollution-related wreck removal authorities, but they are generally weak because of the lack of funding mechanisms. The international community has struggled with a policy regarding wreck removal and began officially considering a comprehensive Draft Wreck Removal Convention (DWRC) in 1998. One of the most controversial points of this convention is the funding mechanism. The DWRC's inclusion of a financial security regime is intended to ensure that the owners of sunken vessels are primarily liable and responsible for marking and removing the polluting wrecks. The current draft of the DWRC contemplates using a system of insurance and other financial security to ensure that mitigating action is taken, which may arguably take care of a great percentage of the international removal efforts. However, an international fund should be established to provide funding in case the owner cannot be found or such funds are insufficient. This has been a major issue in the development of the DWRC. Adoption of the DWRC, even in its present form, could greatly improve the current gap internationally with regard to mitigating polluting or potentially polluting wrecks. The establishment of universally acceptable international rules on the rights and obligations of States and shipowners in responding to wrecks with dangerous cargoes and posing a threat to navigation and/or the environment may be a welcome improvement to the current situation.

The next step was to evaluate the technological feasibility for assessing the potential for an oil discharge from a vessel and oil offloading methods. Salvors and the response community have shown that they can be innovative and cost-conscious. There are few technological limitations to recovering oil from deep depths, cold waters, and other challenging conditions. As demonstrated by the recent and successful removal of most of the 14,000 tonnes of heavy oil remaining onboard the *Prestige* wreck in waters over 3,500 meters deep, remotely operated vehicles (ROVs) can be modified to perform a wide range of assessment and removal actions. Some of the remaining oil removal challenges are viscous oils that require heating to make them pumpable, double-hull oil cargo tanks that may increase the difficulty and risk of oil recovery operations, locating and estimating the volume of oil in cargo and other spaces, and close-out procedures. Further research is needed on wreck corrosion rates and field survey methods to support development of a wreck stability model. One of the key questions to be answered during a wreck assessment is "When might the wreck start to leak?" Better methods are needed to collect and interpret the data to assist in making this assessment.

The last step was development of guidance for assessing the risks and consequences of oil releases from potentially polluting wrecks. It is clear that most of the oil remaining on these wrecks will eventually be released. More than 75 percent of the wrecks date back to World War II and thus have been underwater for 55-65 years, so there is added concern that corrosion will lead to increased oil discharges. It is also clear the consequence of such discharges, when they occur, will vary greatly. There are limited funds available to proactively remove the oil, thus it is important that oil removal efforts be prioritized according to the likelihood and consequence of oil releases. Therefore, there is a need for a systematic risk assessment of potentially polluting wrecks. Such a framework would include ranking categories related to site, environmental, and economic criteria. Furthermore, the available databases of known wrecks lack key data for use in fully characterizing risk to the environment. Standardization of information and methods of risk assessment for individual wrecks or groups of wrecks could provide enough state and regional impetus for enactment of a viable international legal regime concerning action on such wrecks.

POTENTIALLY POLLUTING WRECKS IN MARINE WATERS

I. INTRODUCTION

Background

Catastrophic losses of vessels in recent years, such as M/T *Prestige*, M/T *Erika*, M/V *Tricolor*, and M/T *Ievoli Sun*, have produced increasing pressure on vessel owners and governments to engage in extraordinary efforts to remove all pollutants from submerged wrecks. Removal is particularly an issue where a recent wreck is causing impacts to the surrounding habitat, either from the fuel, cargo, or the vessel itself. Similarly, a number of vessels that sank decades ago (e.g., SS *Jacob Luckenbach*, M/V *Castillo De Salas*, and USS *Mississinewa*, among others), have begun releasing oil, fouling sensitive environmental habitats, stimulating criticism of the insufficient oil removal efforts undertaken (if any), and generating demands for removal of all pollutants from those wrecks and removal of the wreck itself if all the pollutants cannot be completely removed. However, what about vessels that have sunk, but have not started leaking, both recent and relic? These "potentially polluting wrecks" are in a gray zone, particularly relic wrecks that seldom have a Responsible Party who is willing or obligated to pay for the oil removal.

These events and the potential increase in the number older sunken vessels that are likely to start to leak as they deteriorate demand that governments and industry together begin planning now for how best to respond to potential future events. The "reactive" approach often followed in the past (e.g., respond only when oil starts to leak) has become scarcely acceptable. There is a growing public demand for "proactive" oil removal from wrecks, including war casualties or other sunken vessels, to remove any significant threat of future pollution (Basta and Kennedy, 2004). The justification is based on not "*if* there will be an oil release" but rather "*when* will the oil start leaking." Some in the environmental community refer to these wrecks as "oil time bombs" (Girin, 2004). These concerns lead, naturally, to the need for a viable risk assessment process that takes into consideration the potential for leaks, as well as possibilities of damage, mitigation, and cost recovery.

If the oil is easily removed or the vessel is a hazard to navigation, and if there is a Responsible Party or other funding source, then the choice is easy and mitigation efforts are often conducted and it becomes another case history from which to learn. The problems occur when the salvage operations are very difficult, expensive, and without a ready source of funds. We send astronauts into space using sophisticated technologies at very high costs. Why can't we use the best available technologies to address deep-sea wrecks that are potential pollution threats? Obviously, tradeoffs have to be made based on the risks.

Goals and Organization of the Paper

The goals of this paper are to provide an objective analysis of current state of potentially polluting wrecks, due to release of petroleum products, and to make recommendations for future actions. The paper is organized by: 1) data analysis, 2) legal and financial issues associated with wreck response, 3) technological feasibility of response, and risk assessment, as described below.

Chapter II outlines the scope of the problem of potentially polluting wrecks. A worldwide review of information concerning the number of wrecks and the amount of oil potentially onboard is provided, and the combined wreck database is analyzed for the geographic distribution and volumes of oil associated with the wrecks. This analysis provides the first worldwide assessment of the risks of potentially polluting wrecks.

Chapter III discusses the policy and financial issues, highlighting existing limitations with respect to wreck removal. Chapter IV describes the technologies available for pollutant and wreck removal. This Chapter and the case studies in each chapter clearly demonstrate that there are few technological limitations to oil or wreck removal; the true limitations are funding.

Chapter V provides a framework for assessing the risks of potentially polluting wrecks and determining appropriate courses of action in addressing both the potential for pollution from the total population of wrecks as well as in response to a specific wreck that begins to release pollutants. Through objective risk assessment, wrecks with the greatest potential environmental harm can be prioritized for proactive removal actions.

Chapter VI defines the problem and outlines considerations for addressing the potentially polluting wrecks issue, including: defining and describing technological challenges to pollutant removal; and discussing relevant factors and limitations involved in assessing environmental risks; and offers various ideas for consideration in addressing the funding issue.

Definitions

The following definitions apply to the scope of the analysis:

"Wreck" means following upon a maritime casualty (a collision of ships, stranding or other incident of navigation or other occurrence on board a ship or external to it resulting in material damage or imminent threat of material damage to a ship or its cargo):

a) a sunken or stranded ship; or
b) any part of a sunken or stranded ship, including any object that is or has been on board such a ship; or
c) any object that is lost at sea from a ship and that is stranded, sunken or at sea; or
d) a ship that is about, or may reasonably be expected, to sink or strand, where an act of activity undertaken to assist the ship or any property in danger is not already under way (Draft IMO Resolution on Wreck Removal, 2002).

"Ship" means a vessel of any type whatsoever operating in the marine environment and includes hydrofoil boats, air-cushion vehicles, submersibles, floating craft, and fixed or floating platforms.

"Tank vessel" means a ship constructed or adapted primarily to carry oil in bulk in its cargo spaces.

"Non-tank vessel" means a ship other than a tank vessel that carries oil of any kind as fuel for main propulsion and machinery (e.g., passenger, dry bulk, container, fishing, and other commercial and military vessels).

"Potentially Polluting" means that a wreck that contains oil. Wrecks where the pollution threat has been removed through salvage and/or lightering, or having spilled completely in the accident were excluded.

"Oil" means petroleum in any form including crude oils, fuel oil, sludge, oil refuse, refined products and intermediate products. For purposes of this paper, the term oil does not include petrochemicals. No other contaminants are considered in this analysis.

"Marine Waters" include open ocean, coastal, and estuarine settings. Rivers and freshwater lakes are excluded from consideration.

II. DATA SOURCES AND LIMITATIONS

Data Sources

An international database of potentially polluting wrecks, referred to as the Environmental Research Consulting (ERC) International Marine Shipwreck Database, was developed from various national and international data sources. The database incorporates information from the following sources:

- National Oceanic and Atmospheric Administration (NOAA) Resources and Under Sea Threats (RUST) database (Overfield, 2004)
- South Pacific Regional Environment Programme (SPREP) World War II Ship Wreck database
- NOAA Automated Wreck and Obstruction Information System (AWOIS)
- Lloyd's Casualty Archive data (1963 - 1997), Lloyd's Maritime Casualties (Hooke, 1997)
- ERC's Oil Spill and Marine Casualty Databases
- Worldwide Shipwreck Database (Hugh Brown)
- Northern Maritime Wreck Database
- Minerals Management Service Shipwreck Database (Alaska)
- California Shipwrecks Database
- German World War II Maritime Shipwreck List (Schiffwracksliste)
- World War II wrecks from the U.S. Navy and military veteran websites

The criteria used for inclusion of incidents in the database were:

- **Location**: marine waters, including navigable-in-fact estuarine waters;
- **Vessel types**: *non-tank vessels* of at least 400 gross tonnage (GT) holding petroleum-based oil or oil products as fuel/bunkers (and for operations); and *tank vessels* of at least 150 GT holding petroleum-based oil or oil products as cargo and fuel/bunkers (and for operations);[1] and
- **Incident types**: groundings, collisions, structural failures, or military attacks resulting in the sinking (submergence) of the vessels. Any incidents in which the vessel was reported to have been raised, salvaged, lightered, or scrapped were excluded from the data set.

There were considerable overlap in the data (i.e., the same incidents were included in more than one data source), and every effort was made to remove duplicate records and combine information to create the most comprehensive data set possible. For incidents in which there were conflicting information or incomplete data, best efforts were made, relying on previous research and experience, to determine the most logical and reasonable data for those incidents.

The accuracy of location data (latitude and longitude) varied with the data sources and specific incidents. In some cases, there were conflicting or incomplete reports on the location of a particular wreck (or parts of that wreck). For the NOAA RUST data, the location information had been adjusted to reduce the accuracy of the location (e.g., to no more accurate than within 100 nautical miles), to minimize the risk that the data could be used to pillage artifacts or destroy historically or environmentally significant wrecks, or to preserve the dignity of war graves. The SPREP data were provided by Marsden square. The Marsden square[2] was calculated for each vessel, based on the best available information on the location, even if the latitude and longitude data were inaccurate. A Marsden square map is shown in Figure 1, with regional sectors developed specifically for this paper so that estimates of potential risks can be made for different regions (described in Table 1).

The data fields included for each incident in the database are shown in Table 2. There are 1,583 tanker wrecks (including tank barges) and 6,986 non-tank vessel wrecks, for a total of 8,569 incidents in the database. The database spans the years 1890 through 2004. The majority of incidents stem from the years of World War II (1939 - 1945), with 69 percent of tanker incidents and 75 percent of non-tanker incidents (a total of 75 percent of all incidents).

The limitations of the database, as prepared for this paper, are similar to those of any database that is developed after the fact from a large variety of sources that are recording information for differing purposes. There are likely biases in the data because certain types of incidents (e.g., World War II wrecks) were more widely publicized and recorded for historical interest or were more closely tracked for the purpose of historical preservation or for the development of navigational obstruction maps (e.g., wrecks in US waters). The type of information in the databases and data sets used in the development of this paper were not necessarily recorded to determine future pollution threats from these wrecks. There are, therefore, incomplete records on the amount of oil on board or the condition of the vessel that would be essential to accurately determine pollution risk. This lack of accurate information necessitated the use of estimations, extrapolations, and often, "educated guesses" for many shipwreck incidents. The database may also entirely miss less carefully tracked incidents.

There is the possibility of duplicate records if the incidents are referred to by different vessel names.[3] Some of the data, notably that provided by SPREP, contained no vessel names or exact locations[4], but did include information on incident dates, vessel types, sizes (deadweight tonnage), and Marsden square location. Meticulous sorting of the data, matching by location, date, vessel type and size, and vessel name, was conducted to assure that each

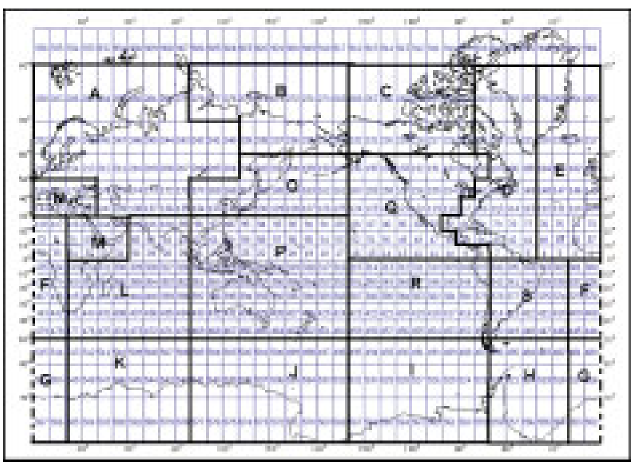

FIGURE 1. MARSDEN SQUARE NUMBERING SYSTEM (SOURCE: US NATIONAL CLIMATE DATA CENTER), WITH REGIONAL SECTORS (A THROUGH S) ANALYZED FOR POTENTIALLY POLLUTING WRECKS, DESCRIBED IN TABLE 1.

vessel was only represented once and that no vessels were incorrectly removed from the data set. While every effort was made to develop a "clean" database, there may still be errors, duplications, and omissions. In addition, this database, as does this study, focuses only on non-tank vessels of at least 400 GRT and tankers of at least 150 GRT. There is considerable evidence that there is a much larger set of wrecks of smaller vessels that, while holding less oil, could present significant environmental hazards on a localized level. Available data on many of these smaller vessels were excluded from the database due to the parameters of vessel size that were set.

At present, this is the most complete data set available. It appears unlikely that the database has failed to capture the vast majority of the largest vessels, particularly tankers, which hold the greatest amount of oil.

Table 1. Regional Sectors Analyzed for Potentially Polluting Wrecks.

Sector	General Region	Latitude/Longitude	Marine Marsden Squares[1]
A	Scandanavian-West Russian Arctic Ocean	N of 50°N E of 0° to 100°E	279 – 288, 245 – 252, 214 – 216
B	East Russian Arctic Ocean	N of 60°N E of 100°E to 160°W	269 – 278, 233 – 236
C	Canadian Arctic Ocean	N of 60°N E of 160°W to 80°W	261 – 268, 225 – 232
D	Northwest Atlantic Ocean	North of 0°, W of 80°W to 40°W, and east US/Caribbean	258 – 260; 221 – 224, 185 – 187, 149 – 152, 113 – 117, 077 – 082, 041 – 045, 005 – 007
E	Northeast Atlantic Ocean	North of 0° E of 40°W to 0°	253 – 255, 217 – 220, 181 – 184, 145 – 148, 109 – 112, 073 – 076, 037 – 040, 001 – 004
F	Southeast Atlantic Ocean	S of 0°, N of 50°S E of 20°W S of 30°N, N of 50°S E of 0°	107 – 108, 071 – 072, 003 – 036, 300 – 301, 334 – 337, 370 – 373, 406 – 409, 442 – 445, 478 – 479
G	Antarctic-Southeast Atlantic Ocean	S of 50°S E of 20°W to 20°E	480 – 481, 514 – 517, 550 – 553, 586 – 587
H	Antarctic-Southwest Atlantic Ocean	S of 50°S E of 70°W to 20°W	482 – 486, 518 – 522, 554 – 558
I	Antarctic-Southeast Pacific Ocean	S of 50°S W of 20°W to 160°W	487 – 495, 523 – 531, 559 – 567
J	Antarctic-Southwest Pacific Ocean	S of 50°S W of 160°W to 100°E	496 – 505, 532 – 541, 568 – 572
K	Antarctic-Indian Ocean	S of 50°S W of 100°E to 20°E	506 – 513, 542 – 549, 584 – 585
L	Indian Ocean	S of 30°N to 50°S E of E of 20°E to 100°E (excluding Sector M)	099 – 102, 063 – 066, 027 – 030, 326 – 333, 362 – 368, 398 – 404, 434 – 441, 470 – 477
M	Middle-Eastern Gulfs	S of 30°N to 0° E of 20°E to 70°E	103 – 105, 67 – 70, 031 – 034
N	Mediterranean Sea	S of 50°N to 30°N E of 0° to 40°E	177 – 180, 141 – 144
O	Northwest Pacific Ocean	N of 30°N to 60°N W of 160°W to 100°E	197 – 203, 161 – 169, 125 – 133
P	South Asian-Pacific Ocean	S of 30°N to 50°S W of 160°W to 100°E	089 – 098, 053 – 062, 017 – 026, 316 – 325, 352 – 361, 388 – 393, 395 – 397, 424 – 433, 460 – 469
Q	North Pacific Ocean	N of 0°, S of 60°N E US/Central America to 160°W	193 – 196, 157 – 160, 120 – 124, 083 – 088, 048 – 052, 008 – 016
R	Southeast Pacific Ocean	S of 0° W of 70°W to 160°W	307 – 315, 343 – 351, 379 – 387, 415 – 423, 451 – 459
S	Southwest Atlantic Ocean	S of 0° W of 20°W to 70°W	302 – 305, 338 – 340, 372 – 377, 410 – 414, 446 – 450

[1]Refers to Marsden squares in Figure 1. Excludes land-locked Marsden squares with no marine waters.

TABLE 2. Data Fields in the ERC International Marine Shipwreck Database.

Data Field	Description
Date	Reported date of sinking or best estimate
Year	Year of reported sinking
Vessel Name	Name of vessel
Vessel Type	Type of vessel – passenger ship, Liberty ship, Victory ship, tanker, cargo vessel, fishing vessel, military (navy) vessel, *etc*.
Vessel Category	*Tank* (vessel carrying oil as cargo) or *Non-tank* (vessel carrying oil as fuel/bunkers and for operations only)
GRT	Gross registered tonnage of vessel (same as GT or gross tonnage), which is the measure of a ship's capacity in units of 100 cubic feet of enclosed space. (*e.g.*, a 1,000 GT vessel has a capacity of 100,000 cubic feet).
DWT	Deadweight tonnage (mainly relevant for tank vessels), which is a measure of the vessel's carrying capacity to the nearest thousand metric tons (tonnes). Each tonne of DWT holds the equivalent of 1.05 tonnes, 7.3 barrels, or 308 gallons of oil.
Vessel Length	Reported length of the vessel (for estimation of vessel size when no GRT or DWT available)
Vessel Flag	Flag that the vessel was flying at the time of the incident
Location	Description of location of sunken vessel (e.g., name of nearest city, region)
Nation	Nearest nation to wreck site; does not necessarily imply national Exclusive Economic Zone status of location, *i.e.*, the wreck may technically be in international waters
Sea (Waterbody)	Name of the relevant sea, ocean part, or larger waterbody
Latitude	Best information on latitude
Longitude	Best information on longitude
Marsden Square	Marsden square location as shown in Figure 1.
Cargo	Petroleum-oil cargo, if known or reported, aboard tanker (for tank vessels only)
Cargo Amount	Amount of cargo
Cargo Unit	Unit of cargo reported (for standardization of cargo amounts)
Cause of Sinking	Reported cause of sinking (e.g., structural failure in storm, war casualty)
Depth of Sinking	Reported depth of wreck

Analytical Methods

The analytical objectives were to estimate: 1) the approximate number and type of shipwrecks present internationally and by region, and 2) the approximate amount and type of petroleum-based cargo and fuel aboard the sunken vessels, for the determination of risk from these sources.

Data on the actual amount of oil on board were often not available for the shipwreck incidents. In many cases, there was no information about the exact amount of oil on board, particularly in reference to fuel or bunkers. Fuel or bunker content would depend on the distance the vessel had traveled since last refueling or bunkering. In addition, oil may have leaked or spilled during the vessel sinking or due to the damage to the vessel that caused it to sink or in the aftermath.

Because data on the amount of oil were not readily available for most of the incidents, the amount of oil on board at the time of sinking was estimated. Unless a tanker was reported to be in ballast (i.e., not containing any oil cargo), it was assumed that it had at least 80 percent of its cargo capacity on board. Bunkers were assumed to be 70 percent full.[5] Oil cargo was determined based on the reported deadweight tonnage (DWT) or net tonnage (NT) of the vessel (Etkin, 1999), such that:

DWT x 1.05 = tonnes of oil, or NT x 1.047 = tonnes of oil

In cases where tank vessel deadweight or net tonnage were not known or recorded, it was estimated from gross tonnage (based on a known correlation of gross tonnage and deadweight tonnage developed from other databases) or the known type and/or age of the tankers.

All oil amounts were standardized to metric tons (tonnes) with the relationship between volume and tonnage measures converted by a formula[7] taking into account oil specific gravity (sp.gr.):

US gallons • sp.gr. • $4.1\text{x}10^{-3}$ =
tones, or Barrels • sp.gr. • $9.78\text{x}10^{-5}$ = tonnes

Cubic meters · sp.gr · $1.55\text{x}10^{-5}$ = tonnes

This methodology resulted in what would be considered a *high* estimate for oil content of wrecks. For the majority of vessels, there is little information on whether the vessel was full (or even 80 percent full), partially full (having unloaded cargo at a previous port or having burned bunker fuel *en route*), or in ballast (in the case of tankers). In addition, some or all of the oil that might have been on board may have spilled during the initial incidents that led to the sinking or slowly seeped out after sinking. For this reason, a *low* estimate was calculated based on the assumption that half of the vessels would have been 80 percent full and half would have been near empty (20 percent full) at the time of sinking and that an estimated 80 percent of the oil would have either spilled at the time of the sinking or seeped out in the years following. The 80 percent loss figure for the "low estimate" is based on an analysis of vessel sinkings and oil spills in the database, which indicate that for catastrophic vessel casualties (drift groundings, vessels breaking up and sinkings) for which oil remaining on board has been salvaged, there is, on average, about 80 percent loss. Complete loss is rare (see Etkin, 2002). An analysis of recent casualties bears this out. *Erika* lost 64 percent of its cargo, *Prestige* lost 83 percent, *Yu Il No. 2* lost 78 percent, and *Osung No. 3* lost 99 percent. The average of these losses is 83 percent.

This approach leaves roughly 16 percent of a full-load of oil in half the vessels and 4 percent of a full-load in the other half (Figure 2), or an average of 10 percent of the potential oil load still on board across all the vessels.

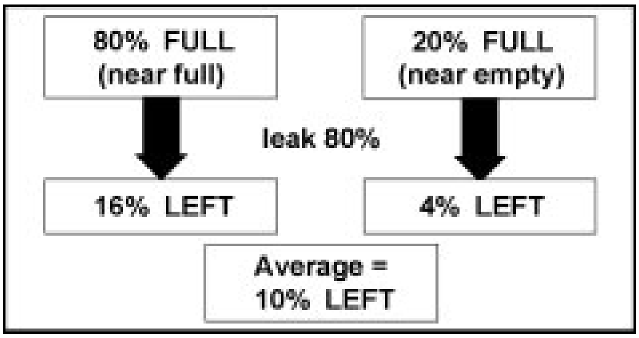

FIGURE 2. LOW OIL-ON-BOARD ESTIMATE METHODOLOGY. IT WAS ASSUMED THAT HALF THE VESSELS WERE 80 PERCENT FULL AND HALF WERE 20% FULL, AND ALL WOULD HAVE LOST 80 PERCENT OF THE OIL ON BOARD TO SEEPAGE. THE AVERAGE WOULD THEN BE 10 PERCENT OF THE TOTAL POTENTIAL AMOUNT OF OIL STILL LEFT.

SUMMARY STATISTICS

International Statistics

Based on the assumptions and methods described above, the number of shipwrecked vessels, the types of vessels, the size distribution of these vessels, the amount and types of oil likely to be held in these submerged wrecks, the age distribution of the submerged vessels, and geographic distribution of these vessels were approximated. The characteristics of the submerged wrecks were determined worldwide and for each of the regions shown in Figure 1. The estimated number of total submerged potentially oil-containing vessels meeting the criteria established (150 GT or greater for tank vessels and 400 GT or greater for non-tank vessels) is 8,569. The estimates of wrecked vessels and amount of oil contained in those vessels are shown in Table 3. The wrecks are distributed geographically as shown in Figure 3 and Table 4.

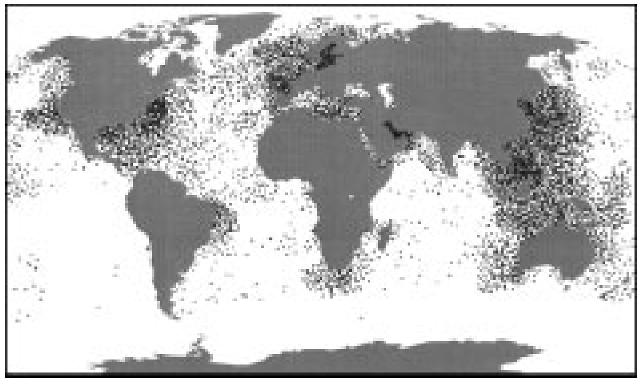

FIGURE 3. APPROXIMATE DISTRIBUTION OF POTENTIALLY POLLUTING SHIPWRECKS. (DOTS DO NOT INDICATE EXACT LOCATIONS, BUT ARE BASED ON APPROXIMATE LOCATIONS WITHIN MARSDEN SQUARES.)

The frequency distributions of the oil amounts estimated to be on board based on the high and low estimates shown in Figure 4 for sunken tankers and Figure 5 for sunken non-tank vessels.

Table 5 shows the percentile oil volumes from the probability distribution function of the A) high estimates and B) low estimates of oil contained in sunken tank vessels. The percentiles represent that oil amount for which that percentage of vessels contains at least that amount of oil. The remaining percentage contains more oil. For example, the 95th percentile shows the amount of oil for

Table 3. Estimates of Worldwide Oil-Containing Wrecks.

Vessel Type	Number Vessels	Estimated Potential Total Amount Oil	
		HIGH ESTIMATE	LOW ESTIMATE
Tank Vessels ≥ 150 GT	1,583	4.3 billion gallons 14.6 million tonnes	535 million gallons 1.8 million tonnes
Non-Tank Vessels ≥ 400 GT	6,986	1.7 billion gallons 5.8 million tonnes	212 million gallons 720,000 tonnes
TOTAL VESSELS	**8,569**	**6 billion gallons** **20.4 million tonnes**	**747 million gallons** **2.5 million tonnes**

Table 4. Estimated Number of Wrecks and Amount of Oil by Regional Sector.

Sector	General Region	Numbers of Vessels[1]			Amount of Oil max/min[1]	
		Non-Tank	Tank	Total	tonnes	gallons
A	Scandinavian-West Russian Arctic	324	74	398	876,000 110,000	258 million 32 million
B	East Russian Arctic	12	1	13	8,600 1,000	2.5 million 315,000
C	Canadian Arctic	11	2	13	14,000 1,800	4.3 million 533,000
D	Northwest Atlantic	1,039	354	1,393	4 million 512,000	1.2 billion 151 million
E	Northeast Atlantic	467	319	786	3.5 million 439,000	1 billion 129 million
F	Southeast Atlantic	47	27	74	785,000 98,000	231 million 29 million
G	Antarctic-Southeast Atlantic	0	0	0	0	0
H	Antarctic-Southwest Atlantic	1	0	1	193,000 24,000	56.8 million 7.1 million
I	Antarctic-Southeast Pacific	0	1	1	850 100	250,000 31,000
J	Antarctic-Southwest Pacific	0	0	0	0	0
K	Antarctic-Indian	1	0	1	47,000 5,900	13.8 million 1.7 million
L	Indian	210	86	296	1.3 million 160,000	376 million 47 million
M	Middle-Eastern Gulfs	82	111	193	1.5 million 193,000	454 million 57 million
N	Mediterranean Sea	262	99	361	1 million 132,000	310 million 39 million
O	Northwest Pacific	1,064	88	1,152	1 million 137,000	323 million 40 million
P	South Asian-Pacific	2,404	333	2,737	4.1 million 510,000	1.2 billion 150 million
Q	North Pacific	283	46	329	674,000 84,000	198 million 25 million
R	Southeast Pacific	8	4	12	86,000 11,000	25 million 3 million
S	Southwest Atlantic	142	18	160	346,000 43,000	102 million 13 million

[1]Totals differ from Table 3 due to the inclusion of vessels that do not have Marsden Square locations in Table 3.

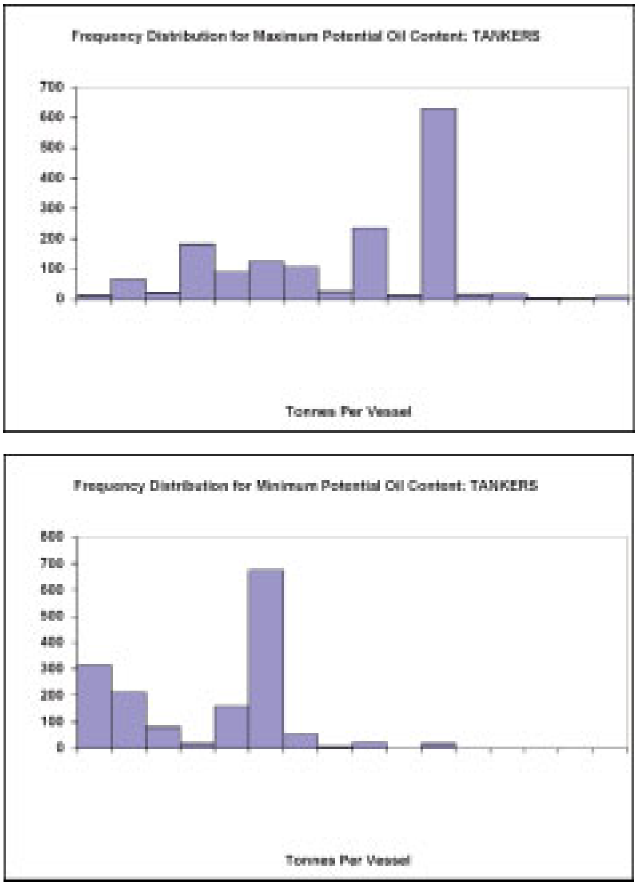

FIGURE 4. FREQUENCY DISTRIBUTION OF THE ESTIMATED AMOUNT OF OIL REMAINING ONBOARD SUNKEN TANKERS, BASED ON THE A) HIGH CALCULATIONS AND B) LOW CALCULATIONS.

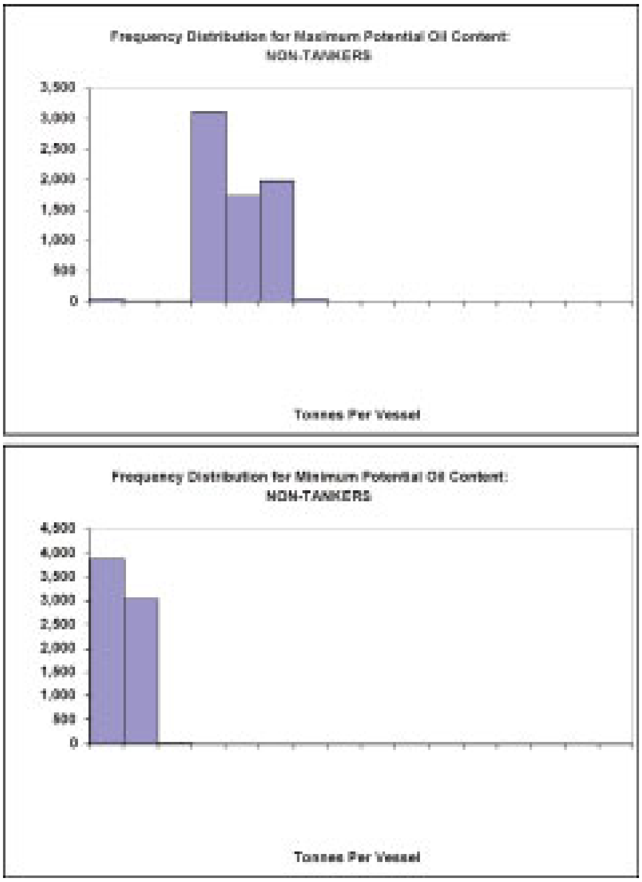

FIGURE 5. FREQUENCY DISTRIBUTION OF THE ESTIMATED AMOUNT OF OIL REMAINING ONBOARD SUNKEN NON-TANKERS, BASED ON THE A) HIGH CALCULATIONS AND B) LOW CALCULATIONS.

Table 5. Probability Distribution Function of Potential Oil Volumes Contained in Sunken Vessels.

Vessel Type	Estimate	Estimated Potential Oil Content of Sunken Vessels (Percentile Amount[1])				
		10th	50th	75th	95th	Worst Case
Tanker	High	600 t 176,400 gal	7,000 t 2.1 million gal	10,000 t 2.9 million gal	20,000 t 5.9 million gal	267,000 t 78 million gal
	Low	70 t 21,000 gal	800 t 235,000 gal	1,200 t 353,000 gal	2,000 t 588,000 gal	33,000 t 9.7 million gal
Non-Tanker	High	500 t 147,000 gal	650 t 191,000 gal	930 t 273,000 gal	1,200 t 353,000 gal	17,000 t 5 million gal
	Low	70 t 21,000 gal	90 t 26,000 gal	120 t 35,000 gal	170 t 50,000 gal	2,100 t 617,000 gal
All Vessels (Combined)	High	560 t 164,000 gal	790 t 232,000 gal	1,000 t 294,000 gal	10,000 t 2.9 million gal	267,000 t 78 million gal
	Low	70 t 21,000 gal	95 t 28,000 gal	130 t 38,000 gal	1,300 t 382,000 gal	33,000 t 9.7 million gal

[1]*nth* percentile volume is the potential amount of oil where *n*% of vessels contain *less* oil and 100 – *n*% of vessels contain *more* oil. *e.g.*, the 95th percentile is the amount for which 95% of vessels contain that amount or less, and only 5% of vessels contain more oil.

which 95 percent contain that amount or less. Only 5 percent of vessels contain more oil.

The frequency distribution of estimated vessel ages is shown in Figure 6. Clearly, wrecks associated with World War II comprise the largest group of potentially polluting wrecks. These wrecks are of particular concern because of age.

Table 6 lists summary data for selected case histories that are included in the database. This table, plus the detailed case studies highlighted in the different sections, provides a snapshot of the range of potentially polluting wrecks and the policy, technical, environmental, and financial issues associated with oil and wreck removal.

Regional Analyses

As shown in Table 4, the South Asian-Pacific region has the highest number of sunken potentially polluting tank vessels with 34 percent of the known tank vessels, 21 percent of the known non-tank vessels, and 20 percent of the worldwide estimate of oil remaining (maximum estimate of 4,100,000 tonnes and minimum estimate of 510,000 tonnes). The second highest region in terms of the number of tank vessel wrecks is the Northwest Pacific, with over 15 percent of the tank vessels but only about 5 percent of the estimated oil volume remaining. This concentration of wrecks reflects the importance of the "Pacific Theatre" during World War II. There is significant concern that these World War II vessels are reaching the age where further corrosion will lead to increased rates of oil leakage. The case of the World War II oil tanker, *Mississinewa*, is an example of the potential environmental and socio-economic impacts of these World War II wrecks (see case study).

The Northwest Atlantic has the highest number of non-tank vessel wrecks (22 percent), the third highest number of known tank vessels (15 percent), and about the same estimated volume of oil remaining as the South Asian-Pacific (maximum estimate of 4,000,000 tonnes and minimum estimate of 512,000 tonnes, or about 20 percent of worldwide estimates). The Northeast Atlantic is ranked third in the estimated number of non-tank vessels, with over 20 percent of the worldwide estimate, and third in the estimated volume of oil remaining with 17 percent of the worldwide estimates. Thus, the North Atlantic Ocean has 25 percent of the potentially polluting wrecks in the world, and these wrecks are estimated to contain nearly 38 percent of the worldwide oil estimates. The large numbers of sunken vessels in the combined North Atlantic reflect the intensity of the maritime attacks between the Germans and the Allied Forces during World War II (Campbell et al., 1977). See the case study in this Chapter on HMS *Royal Oak*.

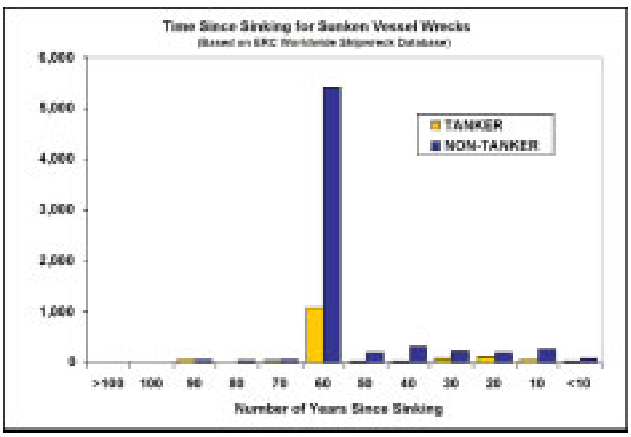

FIGURE 6. DISTRIBUTION OF THE NUMBER OF SUNKEN VESSELS BY AGE SINCE SINKING. THE LARGE PEAK AT BETWEEN 60 AND 70 YEARS OLD IS A RESULT OF THE WRECKS ASSOCIATED WITH WORLD WAR II.

The Middle-Eastern Gulfs region had the third highest estimated oil volume with 7.4 percent of the worldwide estimate but only 1.2 percent of the sunken tank vessels, reflecting the higher frequency of large oil tankers in this oil-producing region. Leaking sunken tankers could be making a significant contribution to the chronic oil associated with active oil transportation. The consequences of a catastrophic release in the shallow, slowly flushed Arabian Gulf have been well documented (Michel et al., 2005).

There are some particularly sensitive regions that have a significant potential for oil pollution from sunken wrecks. The Mediterranean Sea, for example, has 5 percent of the estimated oil volume and 4 percent of the sunken vessels, numbers that are disproportionate to its size. The five sectors ringing the Antarctic (G, H, I, J, and K) contain only three known potentially polluting wrecks, reflecting the limited ship traffic in this region.

Vessel Name: HMS *Royal Oak*

Location: In the Scapa Flow, by the Scottish Island of Orkney, United Kingdom. The Scapa Flow is a large embayment, 24 km by 13 km wide and was the main British fleet base during WWI and WWII. *Royal Oak* is marked with a permanent buoy to identify the wreck as a navigational hazard.

History of the Wreck: *Royal Oak* built in 1914 was a 25,000 tonne Royal Navy battleship anchored in what was considered to be the impenetrable home fleet base of Scapa Flow. Originally a coal-fired vessel, *Royal Oak* was converted in the 1930s to oil fired boilers. She was considered the pride of the British navy and unsinkable. However, on the night of 14 October 1939, only 6 weeks after the commencement of hostilities of World War II, the unthinkable happened when U-47 sneaked into the Scapa Flow and fired 3 torpedoes into her hull before disappearing into the darkness. *Royal Oak* sank in 15 minutes with over 833 officers and crew. Only 375 men survived. She was to be the first battleship lost by the British in World War II.

Oil Pollution Risk: *H.M.S. Royal Oak* rests in 27 m of water, and oil has constantly leaked since it's sinking in 1939. Over 3,000 tonnes of oil were on board when she sank but at least half of this is said to have leaked out during the initial sinking leaving an estimated 1,500 tonnes still remaining on board. The rusting and corroding rivets allowed oil release at a steady but slow rate in the early 1990s, however in 1996 oil was found to be soiling the beaches of Orkney. The release was said to be at a rate of 1.5 tonnes per week, threatening the local environment. There was much concern for the adjoining fish farms as salmon and oyster fisheries were very important to the regional economy. There was also considerable concern for seals, sperm whales, otters, and seabirds such as the Great Northern Divers and Long-tailed Ducks. The pride of the British Navy was definitely deteriorating, as was evident from the increasing amounts of oil leaking from her tanks. Oil flow rates increased from 100 liters per day to 300-500 liters per day. The Advisory Committee on Protection of the Sea (ACOPS) concluded in 2001 that the *"largest oil spillage of 75 tonnes* [in 2000] *resulted from a continuing seepage of fuel from the 1939 wreck of HMS Royal Oak in Scapa Flow"* (ACOPS 2001).

Legal, Policy and Financial Issues: Due to the large number of casualties during the sinking, HMS *Royal Oak* remains Britain's larges official war grave and, for this reason, the Ministry of Defence and the local Orkney people were reluctant to disturb the war grave (Ministry of Defence, 2004). The chronic oil pollution of local coastlines from the sunken vessel forced the Orkney authority to address the issue and resulted in the threat of legal action against the Ministry of Defence). Under direction of

Table 6. Summary data for selected potentially polluting wrecks.

Vessel Name	Vessel Type	Year	Tonnes Oil	Location	History	Sensitive Site Proximity	Issues	Pollution Potential
Blücher	WWII Warship (German heavy cruiser) 18,208 GT	1940	3,050t capacity bunker fuel 1,360 t in 1990 30t in 2002	Strait of Drøbak, (fjord near Oslo), Norway	Sunk in WWII at 58–88 m. Leaking small amounts since, up to 0.07t/day by 1990. 1970 survey showed 5% rusted. By 1990, hull severely rusted, estimated to break apart 2005. Norwegian officials pumped oil in 1994; 30t remain, still leaking from large cracks. Lies inverted on boulder slope.	Impact fjord	Salvors did not know where oil located (180 storage tanks). Used ultrasound sensors/non-destructive testing to locate oil. Total cost of operation: $7.1million	Partially Removed
Montebello	WWII tanker	1941	10,880t crude	Pacific Ocean off Cambria, California, USA 35°25'N 121°12'W	Sunk in WWII at depth of 274 m. Two of eight tanks destroyed. Discovered by submarine research team in 1996. Partial bow-down position means much oil probably leaked out. Heavy crude at that depth would leak out slowly.	Rests in waters just outside Monterey Bay NMS (whales, sharks, sea otters, sea lions)	Difficult to detect oil on board; natural seeps in area; unclear if owner would pay for salvage; no pollution laws in 1941; OPA 90 exempts "acts of war"	Possible
Ievoli Sun	Chemical tanker 7,308 DWT	2000	160 t IFO180 40t diesel	North Atlantic Ocean, 14 km N of Casquets, France	Vessel suffered structural failure and leaking, followed by bad weather; tried to tow vessel, but sank in 70 m in international waters between U.K and France. Salvage operations removed oil and styrene with ROV and released methyl ethyl ketone and isopropylic alcohol in 51 days.	Threat to Côte d'Armor coast	Cargo of 4,000t styrene, 1,027t methyl ethyl ketone, 996t isopropylic alcohol; immediate salvage to reduce pollution potential	Removed
Irving Whale	Oil barge	1970	3,100 t Bunker C	Gulf of St. Lawrence, off Iles-de-la-Madeleine, Québec	Barge sank in 67 m water; barge raised in 1996 with floating cranes onto submersible vessel and transported to drydock; oil and PCB-solution removed	Threat of PCBs	PCBs (7.5t); Small spill during recovery operations. Planning for possible spillage (remote sensing, trajectory modeling for oil and PCB) Cost: $29 million	Removed
Puerto Rican	Tanker	1984	1,214 t Bunker fuel	Pacific Ocean, off San Francisco Bay, California, USA 37°30'N 123°02'W	Explosion and fire caused vessel to break in two; stern sank.	Sank inside Monterey Bay NMS, adjacent to Gulf of the Farallones NMS	Presence of caustic soda reacted with zinc coating, producing hydrogen, ignited.	Potential
Ehime Maru	Fishing vessel 750GT	2001	250t diesel 4t lube 0.2t gasoline (155t remain)	Pacific Ocean, 17 km south of Diamond Head, Oahu, Hawaii, USA 21°05N 157°50W.	Fishing vessel sank in 600 m water after being hit by surfacing submarine. Wreck raised by US at request of Japan government. Two-phase salvage operation – move vessel to shallower location to remove human remains and remove oil, then sink in deeper location.	Proximity to Penguin Bank and within Hawaiian Islands Humpback Whale NMS	Complex, precedent-setting operation for vessel of this size from such depth' ; sensitive operations with removal of 9 bodies; extensive vessel damage; cost $60 million.	Removed; Minimal remaining risk
Coimbra	Tanker 6,778GT	1942	4,00 t lube oil	Off Long Island, New York, USA 40°25'N 72°21'W	Torpedoed and sank in 54 m water.	Impacting south shore of Long Island	Continuing source of leakage	Continuing
Spabunker Cuatro	Self-propelled bunker vessel	2003	1,500t oil	Algeciras Bay, Spain	Sank in 48 m water during bad weather; six-man diving team, underwater oil extraction equipment used to remove entire oil cargo; sheer leg crane lifted vessel			
Erika	Tanker 37,283 DWT	1999	Initial load of 31,000t No. 6 fuel oil; 15,000t onboard after sinking	Atlantic Ocean, off Brest, France (48°N 04°30W)	Tanker broke in two and sank in extreme weather – bow at 114 meters, stern at 125 m.	400 km shoreline oiled; over 60,000 birds killed, oyster beds oiled with 18,000t spilled; same amount oil remaining on board thus further threat	At sea temperature (10°C), No. 6 fuel still mobile enough to leak; water depth of 120 m, storm/swell potential, viscous nature of oil, wreck condition, and short schedule were challenges for salvors. No previous experience with pumping viscous oil at that depth (40,000 cSt). Used technical options selection matrix. Pumped 11,245t in 2.5 months.	

Table 6. Cont.

Asean Liberty	Cargo vessel 8,656 DWT	2001		Chokey Shoal, Rangoon River, 13 km S Yangon, Myanmar	Vessel broke in two and sank. Due to river conditions, attempt to pull fully laden wreck to river bank where it could be dismantled in dry; effort unsuccessful; revised plan to reduce wreck to 2.5-m over top at mean low water developed and completed.		Tidal, muddy river, with 8 knot current.	Removed
Castillo de Salas	Bulk carrier	1986	1,200 t HFO 105 t gasoil	GijonBay, Cerro de Santa Catalina, Spain	Sank after wreck on rocks in storm. Bow refloated and sunk in high depths; stern removed in pieces; bunker fuel in double bottom; authorities wanted bottom as artificial reef; repumping in 2001-2002 (400t removed)	Coastal oiling in 2000	Risk analysis showed no quantifiable hazard after 2001-2 pumping, but consistent social problem required removal of bottom	Removed
Yuil No. 1 (Shim, 2002)	Tanker 2,992 DWT	1995	2,870t No. 6 fuel cargo	Sea of Japan, Namhyeongjedo, off Pusan 34°55′N 128°59′E	Grounding and sinking in 70 m; Oil removal operations conducted together using remote operated vehicle and remote off- loading system. 634 t removed from *Yuil No. 1*; 20 t from *Osung No. 3* (rest spilled in initial accidents)	Heavy shoreline oiling of nearby islands; heavy impact on fish farms	Currents >3 kts, < 3-m visibility and 70-m depth were challenges. Small oil release during Yuil No. 1 removal. Two operations total of 135 days (40% of days lost due to adverse weather.) Total cost for both vessels: $13 million	Removed
Osung No. 3	Tanker 1,796 DWT	1997	1,614t No. 6 fuel cargo	Yellow Sea, Deunggado, Tongyong City, Kyungname Province, Korea				
Petrel Albatros Dias (Findlay, 2003)	Whaling vessels 350t displacement tonnage	1964		Grytviken Harbor, South Georgia and Sandwich Island	Abandoned at old whaling station, submerged, partially sunk with corroded hulls; surveys in 1999 estimated 23 t oil each vessel; 2001 estimate was 3 t each vessel. Decision to remove oil with mini-vac system and leave wrecks. Pumping partially successful, but oil remained on two vessels due to cold temperatures; will try to repeat oil removal during warmer temperatures and after refloating vessels for better access.	Threatening fragile environment in process of being rejuvenated; popular eco-tourist location	Remote location required detailed surveys before transport of personnel/equipment; anticipated all scenarios as more equipment not available; higher temperature oil easier to pump. Delayed to avoid tourist season, vulnerable breeding species	
Cleveco (Davin and Witte, 1997)	Tank barge	1942	4,000t No. 6 fuel	Lake Erie, near Cleveland, Ohio, USA	Barge sank in 10 m water; oil leaked 1942-1948, but no concern as lake polluted; in 1959 barge struck, releasing more oil; 1961 unsuccessful salvage, resinking at 20 m, release significant oil; 1994, oil leak 140 ml per hour, sheen but not environmental threat; hull in good shape; much oil still on board; pumping operation in 1995 removed 1,160 t oil, more than anticipated.		Significant oil in 10 cargo compartments; location > 14 km from closest land, 27 km to closest haven for floating equipment in event of heavy weather created challenges. Cost: $3.6 million (paid for by OSLTF)	

Parliament, an environmental assessment of the wreck was carried out and, based upon the significant environmental threat posed, a decision to offload the remaining oil was taken. The Defence Minister, Dr. Lewis Moonie, whose responsibilities include war graves and Ministry of Defence environmental issues, stated, *"it is abhorrent that human remains in war graves are disturbed unless there is overriding imperatives of marine or environmental safety"*.

Salvage Operations Summary: Many salvage attempts were considered and executed including metal plates secured to the battleships hull, and over 500 sandbags lain over the areas releasing the oil. These attempts were initially successful but only served as a temporary measure. An attempt to catch the oil as it flowed out from the hull was made by placing a stainless steel canopy or container or "umbrella" over the hull at a cost of US $300,000. The umbrella was unsuccessful because the tides and currents interfered with the collection of oil. The Orkney authorities has also placed oil absorbent booms around an adapted fish cage which was anchored over the wreck to attempt to collect the intermittent and chronic oil leakage from the vessel.

After the failure of many short-term remedial activities, it was concluded that the many fuel tanks on the vessel would have to be tapped in order to avoid further environmental damage in the region. In 2001, 'hot tapping' of the vessel tanks was carried out under funding and direction from the Ministry of Defence. The operation cost many millions of dollars and involved drilling into the oil tanks and fitting one-way valves that allowed the oil to be pumped to the surface into storage barges. The latest public report in January 2004, however, indicates that the vessel remains at risk from leaking with over 1,500 tonnes of oil still contained in the upturned vessel. (Navy News, 2004)

Costs: Total costs are not publicly available from the British authorities but include many salvage attempts by the Navy and salvors. Remedial activities included:

- US $300,000 containment umbrella
- Regular offloading costs for the containment system (not known)
- Multi-million dollar 'hot-tapping' salvage of oil in 2000
- Many thousands of US dollars by Orkney council for oil sorbent boom capture system and maintenance

Lessons Learned: *Royal Oak* has proved to be a chronic source of oil pollution for the Orkney region and a constant threat to the regional environment for over 60 years. In 2000, the *Royal Oak* sunken wreck was responsible for 96 percent of the total quantity of oil discharged into UK waters. Containment and hull patching operations carried out by a number of agencies, private contractors and the Navy proved to be short-term solutions. It was not until oil releases increased to intolerable levels and legal action was threatened that authorities undertook a major oil salvage operation in 2001.

III. LEGAL AND FINANCIAL POLICIES

Background

The question of how to deal with vessel wrecks with potentially damaging pollution consequences has increasingly become more of a social and political issue over the last 30 years. The international community has struggled with a policy regarding wreck removal and began officially considering a comprehensive Draft Wreck Removal Convention (DWRC) in 1998.[7] The DWRC, which continues to be debated within the International Maritime Organization (IMO), remains controversial.

In the United States, on the other hand, the laws governing responses to polluting or potentially polluting wrecks are more established and typically require vessel owners and responsible parties to take certain actions or face civil and criminal liability for inaction. Even in the United States, however, there are circumstances when the course for timely and appropriate action is obstructed.

One of the major hurdles that remain, and the most difficult to answer both domestically and internationally, is determining the source of funds to pay for the proper treatment of these wrecks and their pollution-related damages. This chapter discusses the current legal and financial policies governing both U.S. and international treatment of potentially polluting wrecks. It is not intended to be a comprehensive discussion answering all of the outstanding questions, but rather an overview that highlights the current state of issues and makes recommendations for possible future actions.

Treatment of Wrecks in the United States

The primary statutes in the United States under which wreck removal can be required are triggered when sunken or partially submerged vessels result in a hazard to navigation or the vessel is an abandoned barge. In addition, other statutes deal with oil or hazardous substance pollution or wrecks that pose a substantial threat of the discharge of such pollution. The focus of this chapter will be on the latter, but the former warrants a brief discussion.

Treatment of Vessels Under the Wreck Act

The removal of sunken vessels located in navigable channels (interpreted broadly by the courts to not be limited only to dredged or buoy marked channels) are dealt with under the Wreck Act, which is incorporated in the Rivers and Harbors Act of 1899, 33 U.S.C. §§ 409, *et seq*. The Wreck Act is intended to safeguard against obstructions or endangerments to navigation. Specifically, under the Wreck Act, owners and operators are responsible for immediately marking a sunken vessel with a buoy or beacon during the day and a lighted lantern at night. The markings must remain until the vessel is removed or abandoned. In addition, the owner or operator is responsible under the Wreck Act to "diligently" commence "immediate" removal of the wreck. Failure of the owner or operator to commence or diligently prosecute such removal will be considered abandonment and the U.S. Army Corps of Engineers (USACE), acting on behalf of the federal government, may take action to remove the vessel from the navigable channel.

Specifically, whenever a wrecked vessel exists for longer than 30 days as an obstruction or endangerment to any waterway, the wrecked vessel may be "broken up, removed, sold or otherwise disposed of by the United States without any liability to the owner of the wreck for such action." 33 U.S.C §414. The determination of whether a wreck poses an obstacle to navigation rests initially with the USACE and a reviewing court will only overturn the determination if the decision is found to be arbitrary and capricious.[8]

In addition, in the event the government determines that the existence of the submerged or wrecked vessel in the navigable waters of the United States is creating an emergency situation, the vessel owner, lessee, or operator will be given 24 hours to begin removal of the vessel using the most expeditious method available. If the vessel is not removed or steps are not taken in an expeditious manner to secure the vessel's removal, the government may intercede to remove or destroy the vessel to alleviate the situation. The vessel owner, lessee, or operator will then be liable to the United States for all costs associated with the government's action. If the owner fails or refuses to reimburse the government within 30 days after notification, the vessel may be sold with the proceeds going to the Treasury of the United States. *Id*. § 415(a) - (c). Penalties for knowingly obstructing a navigable channel range from fines to imprisonment and mariner license revocation. *Id*. §§ 411, 412. Accordingly, the Wreck Act is triggered when a vessel poses a hazard to a navigable waterway but would not apply to sunken wrecks located in open waters that pose no risk to navigation.

Treatment of Vessels Under the Abandoned Barge Act

Separate authority exists to remove sunken barges that are abandoned in the navigable waters of the United States under the Abandoned Barge Act of 1992 (ABA) 48 U.S.C. §§ 4701, *et seq*. Whereas the primary focus of the Wreck Act is on hazards to navigation, the ABA was primarily enacted out of the concern that abandoned barges were essentially being used as dump sites for hazardous wastes. In order to prevent so-called "midnight dumping" and to make the abandoned barge owner liable for removal costs, the ABA made it illegal to abandon barges greater than 100 gross tons in the navigable waters of the United States. Specifically, if barges are sunk, moored, stranded, or wrecked for longer than 30 days in violation of the ABA, the owner or operator is liable for up to $1,000 per day of the violation. The government is authorized to remove the barge, after public notice in either a notice to mariners or an official journal in the county in which the barge is located, at the owner's expense.

Accordingly, the authority of the ABA may be used to remove wrecks posing a pollution risk to the environment. The ABA authority is triggered as long as the wreck is an abandoned barge located in the navigable waters of the United States but would not apply in a situation involving a barge located beyond three miles from the U.S. coastline.

Treatment of Wrecks under the Oil Pollution Act of 1990

More importantly, for the purposes of this analysis, are sunken vessels that pose an environmental risk from a discharge or threat of a discharge of oil or hazardous substances. The Federal Water Pollution Control Act (FWPCA), as amended by OPA 90, governs removal[9] actions when a sunken wreck is discharging, or threatens to discharge, oil or hazardous substances to the waters of the United States including the Exclusive Economic Zone (EEZ). The FWPCA provides a procedure to remove or otherwise mitigate the discharge or threat of discharge from a wreck, or to remove the wreck in order to mitigate the discharge, or threat of discharge, when it is determined to be absolutely necessary.

In short, the FWPCA authorizes the FOSC to take response measures deemed necessary to protect the public health or welfare or environment from discharges. 40 C.F.R. § 300.130. As discussed in more detail below, except in cases in which the FOSC is required to direct the response to a discharge or threat of discharge that poses a substantial threat to the public health or welfare of the United States (*i.e.*, a "substantial threat spill), the FOSC may allow the responsible party to voluntarily and promptly perform removal actions provided the FOSC determines such actions will ensure an effective and immediate removal of a discharge, or mitigation or prevention of a threat of a discharge (*i.e.* a "general removal spill"). *Id.* § 300.305(d).

General Removal Requirement. Under this general removal spill authority, the federal government, through a designated FOSC, has the *discretion* to (1) remove or arrange for the removal of a discharge, and mitigate or prevent a substantial threat of a discharge at any time; (2) direct or monitor all actions to remove a discharge; and (3) remove, and if necessary, destroy a vessel discharging or threatening to discharge by whatever means are available. This authority applies to discharges either into or on the navigable waters, on the adjoining shorelines, into or on the waters of the EEZ, or that may affect natural resources of the U.S. 33 U.S.C. § 1321(c)(1). Actions taken by the FOSC, other federal agencies, states, owners or operators, or any other person participating in the response must be in accordance with the National Oil & Hazardous Substances Pollution Contingency Plan (NCP), 40 C.F.R. Part 300. In accordance with the NCP, the FOSC may allow the responsible party to voluntarily and promptly perform removal actions (with adequate FOSC monitoring) provided the FOSC determines such actions are effective and immediate. The FOSC must take appropriate response actions if the responsible party does not take effective actions to eliminate the threat or if removal is being done improperly. *Id.* § 300.305(d).

Discharge Posing Substantial Threat to Public Health or Welfare. Under this substantial threat authority, when a discharge, or a substantial threat of a discharge, of oil is determined to be of such a size and character to pose a substantial threat to the public health or welfare of the United States (including but not limited to fish, shellfish, wildlife, other natural resources, and the public and private beaches and shorelines of the United States), the FOSC *must* direct all federal, state, and private actions to remove the discharge or to mitigate or prevent the threat of the discharge. *33 U.S.C.* §1321(c)(2)(A). Removal actions in substantial threat cases, including removal of a wreck if deemed necessary, are exempt from government contracting procedures or employment of personnel by the federal government in order to facilitate emergency response.

For the purposes of this paper, the first important point is that if the threat of a discharge or an actual discharge of oil does not affect U.S. waters, then there is no removal authority and federal funds are not be available to finance the removal. The second important point is that, in every situation, regardless of whether it involves a general removal spill or a substantial threat spill, the FOSC is responsible for ensuring that immediate and effective removal actions are undertaken by monitoring the removal actions of the responsible party, or directing all response activities, including removal of a wreck if deemed necessary in a particular situation, in order to protect the environment.

It should be noted that federal funds are available whenever the government monitors or directs a spill response. There is no requirement to "federalize" a spill *per se*. The specific response actions actually employed for a particular incident will depend on the circumstances surrounding the incident. With regard to wrecks, the response goal will be to solely stop or mitigate oil pollution or the threat of pollution. Generally, in view of the cost and complexity, actual removal of a wreck will be reserved for cases when other removal actions will not adequately stop or mitigate pollution from the vessel posing an unacceptable pollution threat.

Owners and operators of wrecked vessels are liable for the costs of cleanup and, if deemed necessary, the physical removal of their vessels. In the event the owner or operator refuses to respond or takes inadequate action, is unable to pay, or is unable to be located and the situation dictates immediate action, the U.S. Coast Guard will likely take over the response effort and the Oil Spill Liability Trust Fund (OSLTF) will be relied on to "fund" the removal activities. It is important to note, however, that the OSLTF is only used for the removal of the wreck if it is deemed necessary to accomplish that goal. See the case study of *Jacob Luckenbach* in this chapter. There may be instances where the removal of the entire wreck may be more cost effective than just the removal of the pollutants—although this is more likely to be the case for smaller vessels.

The National Pollution Funds Center (NPFC) manages the OSLTF. Upon completion of removal actions, the NPFC may pursue an action against the responsible parties to recover removal costs incurred by the OSLTF. However, even assuming that the responsible parties can be located, there are various defenses and limitations on the liability of the owner and operator that may result in the OSTLF ultimately bearing all or a significant amount of the financial burden associated with a pollution incident.[10]

In a similar sense, in the event hazardous substances need to be removed, the NCP authorizes the FOSC to access funds available under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to protect public health and environmental quality including natural resources. The FOSC can submit a request to the NPFC and the CERCLA fund would be available on a reimbursable basis to fund the clean up of the hazardous substance if the responsible party is not available or willing to take appropriate action.[11] Materials covered under the OSLTF are not covered under CERCLA because they are not "solid wastes", and thus not "hazardous wastes."

Vessel Name: SS *Jacob Luckenbach*

Location: 27 km (17 mi) southwest of entrance to San Francisco Bay, California, USA

History of the Wreck: From 1992-2002, thousands of oiled birds washed up in winter on beaches along central California without observation of oil slicks. In 2002, nearly 2,000 birds were collected, instigating efforts to locate the source of these "mystery" spills. Fingerprint analysis of oil samples showed a match with mystery spills starting in 1992, thus a passing vessel source was unlikely. The oil did not match natural seeps. Hindcast modeling, satellite imagery, and overflights were used to narrow the source area. Shipwreck databases contained information on over 700 shipwrecks in the region. After analysis, eight vessels were targeted for assessment; first on the list was *Jacob Luckenbach*. Anecdotal information obtained from recreational divers confirmed that *Jacob Luckenbach* was known to leak oil. During the initial assessment, oil was observed rising from the wreck. Oil collected from within the hold (by recreational divers) was a match to that on the oiled birds. The vessel, a C-3 freighter fully laden with 1950 tonnes of fuel oil, sank in 56 m of water on 24 July 1953 as a result of a collision.

Oil Pollution Risk: The wreck is located in a highly sensitive area with seasonally very large numbers of marine birds and mammals, as well as being within the waters of the Gulf of the Farallones National Marine Sanctuary and adjacent to two National Marine Sanctuaries, Cordell Banks and Monterey Bay. Seabird mortalities over the 10 years of mystery spills were estimated to be in the tens of thousands, and hundreds of miles of beaches were oiled.

Other Special Issues: Vessel is a historic resource under the National Historic Preservation Act, as well as a protected resource under the National Marine Sanctuaries Act (NMSA) 16 U.S.C. 1431 *et seq*. The NMSA regulations 15 CFR Part 922.2(e) delineates NOAA's responsibility for protection historic resources under National Historic Preservation Act (NHPA). The Gulf of the Farallones National Marine Sanctuary also has specific regulations (§922.82) prohibiting the discharge or deposit of any materials and prohibiting the removal or damage of any historical or cultural resources.

Legal, Policy, and Financial Issues: The owners, charterers, and insurers had signed consent degrees with the U.S. in 1954 that settled any and all claims resulting from the collision with the federal government. There was no Responsible Party under the Oil Pollution Act of 1990, the National Marine Sanctuary Act, or any other liability statute. As this wreck did constitute an ongoing pollution threat, the Oil Spill Liability Trust Fund, was used to fund the recovery work.

Salvage Operations Summary: In May 2002 the U.S. Coast Guard contracted with a commercial salvage firm to conduct a vessel assessment and remove available oil. Mobilization took 21 days, and the oil removal operations were completed in 123 days. The salvage platform was a 120 by 30 m work/accommodation barge with oil cargo tanks. The barge was secured in a six-point mooring and could remain on-station in all but the worst weather. Problems encountered included extended cold-water saturation diving at depths to 55 m, strong reversing currents, adverse weather, and poor underwater visibility. Many fuel tanks were found to have badly corroded vent pipes which allowed oil to slowly leak into the cargo holds (Figure JL-1). These vents were the primary sources of the oil releases. During the assessment, 26 tanks and spaces on the wreck were documented as containing about 540 tonnes of heavy fuel oil. The heavy residual oils in the deep tanks and double bottoms also proved to be a pumping challenge, because some tanks contained oil with a viscosity of well over 200,000 centistokes (cSt) at 6C. To be able to pump out the oil, the tanks had to be hot-tapped and heated to more than 78C with special steam lances and purpose-built heat exchangers Figure JL-2). This was necessary in order to allow adequate oil migration to the pump suction at the side shell of the tank. Annular Water Injection techniques were used to cool the pumps and lubricate the internal periphery of the discharge hoses in order to pump the oil to the surface. In total, 350 tonnes of heavy fuel oil were recovered.

To maximize operational conditions, this operation had to occur during the summer months, which coincided with the Gulf of the Farallones National Marine Sanctuary's most biologically active and sensitive season. The sanctuary has thousands of seals and sea lions, and it is home to the largest concentration of breeding seabirds in the continental United States. The site was directly in the path of the endangered marbled murrelet father and chick pairs that would be swimming from the Farallon Islands to the coast. Observers were placed on the barge to minimize impacts from operations to wildlife.

Costs: $19,200,000 for all salvage and spill-response related work; does not include U.S. Coast Guard or NRDA claims, nor does it include costs for cleanup of the previous "mystery spills".

Lessons Learned: The *Jacob Luckenbach* project was successful in removing all accessible oil and relieving the potential for catastrophic oil release. The project was more difficult and extended longer than originally planned. This was due to many factors, including poor weather conditions, exposed location, poor condition of the wreck, and extremely viscous oil. Information on the bottom conditions, the structural conditions and the ship's cargo were particularly important to plan the recovery operation.

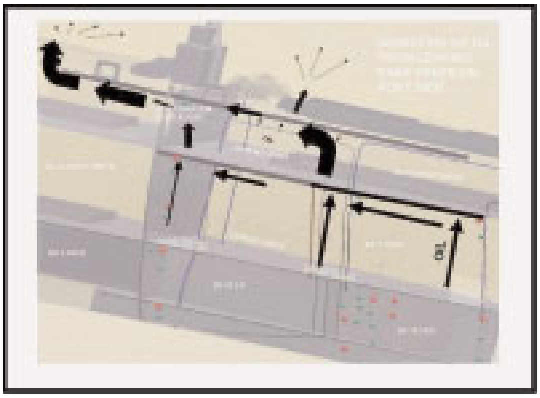

FIGURE JL-1. DIAGRAM SHOWING HOW THE HEAVY FUEL OIL LEAKED THROUGH THE TANK VENT PIPES INTO THE CARGO HOLDS (COURTESY OF PCCI, INC.).

FIGURE JL-2. PHOTOGRAPH OF THE HEAT EXCHANGER UNIT INSERTED THROUGH THE 6-INCH HOT TAP (PHOTOGRAPH COURTESY OF PCCI, INC.).

The OSLTF, originally established under the Internal Revenue Code of 1986 at 26 U.S.C. § 9509, was one of several trust funds set up to provide for costs of pollution-related incidents. OPA 90 generally consolidated the liability and compensation schemes of these funds and authorized use of the OSLTF to replace the various funds previously used to support financial liability regimes. The predominant rationale was to ensure that adequate federal resources would be available to respond immediately and appropriately to *Exxon Valdez*-type spills.

The OSLTF has two major components: (1) The Emergency Fund for removal activities (including pollution incidents involving wrecks) and the initiation of natural resource damage assessments; and (2) the Principal Fund for all other authorized uses. The Emergency Fund ensures rapid response and up to $50 million is available each year to fund removal activities without Congressional appropriation. Funds not used in a fiscal year are available until expended.

The primary source of revenue for the OSLTF was a five-cents per-barrel fee on imported and domestic oil paid by the oil industry. This fee ceased in 1994 as a result of a sunset provision in the law. Today, the largest source of income for the fund comes from interest on the fund principal from Treasury investments. Other sources include costs recovered from the parties responsible for the spills, and any fines or civil penalties collected under the FWPCA, the Deepwater Port Act of 1974, or section 207 of the Trans-Alaska Pipeline Authorization Act. The maximum expenditure from the fund is $1 billion per incident and a limit of $500 million for natural resource assessments and claims stemming from the incident.

As an example of the use of the OSLTF, federal funds were used in 1999 to remove wrecks off a reef flat in Pago Pago Harbor, American Samoa (Sifling et al., 2001). Nine fishing vessels were wrecked and grounded following Typhoon Val in 1991. By 1999, it was determined that, based on the on-going discharges of petroleum products from the vessels and the other known hazardous substances (*i.e.* anhydrous ammonia from refrigeration systems) onboard the vessels, further cleanup actions were necessary. The FOSC recommended that the OSLTF be used to for oil and hazardous materials removal because efforts to locate the Korean owners of the vessels were unsuccessful. Through this OSLTF funding, the U.S. Coast Guard hired contractors and removed the oil and hazardous materials, but not the wrecks. The response plan was to cut up the wrecks as needed to access and remove the oil and hazardous materials, but leave the remaining pieces secured in place. The U.S. Coast Guard was not willing to remove the wrecks or restore injured natural resources resulting from clean up actions, so the natural resource Trustees made a claim to the OSLTF for damages that would result from the cleanup actions (construction of causeways across the reef flat to access the wrecks), with the restoration action being the complete removal of the wrecks (Michel et al., 2001; NOAA et al., 2001). The costs for the nine-month cleanup action removing nearly 125 tonnes of oil and 0.3 tonnes of hazardous materials were over US $12 million, and the costs for the restoration (complete vessel removal) were approximately US $3 million. This case serves as a good example demonstrating that, based on previous practice, the U.S. Coast Guard will likely fund wreck removal only when absolutely necessary for oil or hazardous materials removal.

In Puerto Rico, where there are over 100 known abandoned vessels (mostly recreational boats), the U.S. Coast Guard has used the OSLTF for removal of oil and hazardous materials from those vessels that posed environmental or human-health threats. They used the OSLTF in June 2002 for the complete removal and scrapping of *Dutchman* as a continuing pollution threat because it had been used repeatedly for illegal dumping of hazardous materials. This is a good example demonstrating that removal of a vessel can prevent the need for future cleanups in particular circumstances (Michel et al., 2002).

Another recent example of the OSLTF dollars at work in wreck removal was in the Commonwealth of Northern Mariana Islands in July 2004.[12] A fishing vessel, *Mwaalil Saat*, reportedly containing 170 tonnes of fuel oil sank in Tanapag Harbor, Saipan when her bowlines parted during the passage of Typhoon Ting Ting. The owner of the vessel did not have insurance and refused to carry out any removal actions. Because the wreck was located adjacent to the port of Saipan's bulk oil facility and a sensitive area, the FOSC determined that the wreck was a direct threat to cargo operations, public safety, marine environment and the OSLTF was authorized for use. Final cost for this response was US $3.4 million. Total expenditures to support this removal effort were about US $3.5 million.

In certain situations, even if a wreck is determined to be a substantial threat, there may be additional obstacles to cleanup efforts. For example, *USS Arizona* has been leaking oil into Pearl Harbor, Hawaii for over 60 years. However, *Arizona* is listed on the National Register and any actions to disturb the vessel would need to be in accordance with the National Historic Preservation Act (NHPA). The NHPA requires that prior to the approval of any federal funds, the Advisory Council on Historic Preservation shall be given a reasonable opportunity to comment on the potential effect of the proposed undertaking. 16 U.S.C. § 470f.

In summary, the Clean Water Act, as amended by OPA 90 provides the primary legal authority for the federal government to remove wrecks in order to stop or mitigate discharges or substantial threats of pollution affecting waters of the United States. Funding for such cases is available through the OSLTF. Generally, the OSLTF will be used to fund the removal or destruction of a wreck only when other removal actions are deemed inadequate to stop or mitigate an unacceptable pollution threat to the public health or welfare of the United States.

Treatment of Wrecks Under the Domestic Law of Other States

Generally speaking, the domestic laws of other States tend to focus on the issue of physical wreck removal. A survey conducted by IMO found that the law relating to wreck removal in different countries has developed to differing degrees of sophistication. The survey notes that, of the 30 countries analyzed, the United States probably has the most sophisticated regime, and there are a number of countries with a limited wreck removal regime. However, the survey concludes that the law in the various countries generally share the following similar elements: 1) wrecks are defined; 2) when a wreck constitutes a hazard is defined; 3) the onus is on the owner of the wreck to remove it; 4) in the event the owner fails to do so, the State can take action to remove the wreck; and 5) the owner remains liable for the wreck removal expenses and that State can generally reimburse itself by selling the salved property (IMO Legal Committee 75/6/2, February 14, 1997, Draft Convention on Wreck Removal).

Treatment of Wrecks Under International Law

The international community, under the auspices of the IMO, has been working on a DWRC for several years. Individual concepts and ideas have traditionally circulated throughout the international community, but there were no serious deliberations regarding the draft until 1998. Following its introduction that year, there have been numerous meetings of the IMO Legal Committee to further develop appropriate provisions.

The DWRC is intended to provide international rules on the rights and obligations of States and shipowners in dealing with wrecks and drifting or sunken cargo that may pose a hazard to navigation and/or pose a threat to the marine environment. The DWRC is intended to clarify rights and obligations regarding the identification, reporting, locating and removal of hazardous wrecks, in particular those found beyond territorial waters. In general, the DWRC covers:

- Reporting and Locating Ships and Wrecks—which covers reporting of casualties to the nearest coastal State; warnings to mariners and coastal States about the wreck; and action by the coastal State to locate the ship or wreck;
- Determination of Hazard—provides guidelines for assigning responsibility for determining whether a hazard exists when the wreck or ship is beyond territorial waters, based on a list of specific criteria, including depth of water above wreck and proximity of shipping routes;
- Rights and Obligations to Remove Hazardous Ships and Wrecks—sets out when the shipowner is responsible for removing the wreck and when a State may intervene;

- Financial Liability—for locating, marking and removing ships and wrecks;
- Time-bar—sets a time limit for claims for compensation;
- Jurisdiction—sets out jurisdiction(s) where actions for compensation may be brought;
- Financial Security—sets out security required to cover liabilities regarding claims for compensation under the Convention; and,
- Settlement of Disputes.

Based on the drafts from the IMO legal committee, the DWRC contains some provisions similar to those in U.S. statutes, with differences that are discussed below. Probably the most important element missing from the DWRC is a mechanism to provide for the source of the funds to take care of the potentially polluting or polluting wrecks if the registered owner or operator is unavailable or unable to pay for such action. This has been, and will no doubt continue to be, a major point of contention going forward and, if not resolved on an international level, will likely result in a "paper tiger" DWRC that will not be triggered to clean up or mitigate a polluting wreck if the owner of the wreck can not be found or is unwilling to take mitigating action.

In the international arena, the equivalent to the U.S. standard related to posing a substantial threat to public health and welfare, as in the FWPCA, takes the form of a threat that "may reasonably be expected to result in major harmful consequences to the marine environment, or damage to the coastline or related interests of one or more States" (DMRC, Annex 1, Article 1(5)(b)).

While these standards are arguably similar, they both are equally ambiguous when it comes to defining the actual trigger for such a determination. In the case of OPA 90, each FOSC is given broad discretion to make that determination, compared to the over one hundred different countries with presumably many different opinions as to what constitutes "major harmful consequences to the marine environment." Moreover, Parties to the DWRC (as currently drafted) will be hesitant to take action under the Convention, absent an owner or operator taking action, because there is no associated funding mechanism.

The geographic area covered by the DWRC is out to the limits of an individual State's EEZ, but in no case extending more than 200 nautical miles from the shoreline of that State.[13] Inside this area, the States whose interests are most directly threatened by the wreck have a responsibility to take action to remove wrecks that pose a hazard. This action is limited to what is only "reasonably necessary" to remove the immediate risk that the wreck creates. The DWRC does not apply to any warships or other vessels owned or operated by a State for non-commercial service.[14]

Before any State action can be taken, the DWRC provides that owners and operators of any wrecked vessel must immediately report such a vessel to the State that is most threatened by the situation. This report must include, among other things, the precise location of the wreck, the size, type, and construction of the wreck, the nature of the damage, and the amount and type of cargo and bunker/lubricating oil on board the vessel and the damage likely to result should the cargo or oil be released into the environment. Based on this report, the threatened State will determine whether or not the reported wreck poses a hazard based on a list of criteria.

These criteria include meteorological and hydrological conditions such as tidal patterns and currents, traffic density, and the vulnerability of port facilities. Once a State is notified that a wreck exists, it shall use all practical resources to notify other mariners of the location of the wreck and, if a determination is made that the wreck poses a hazard, the State must establish the precise location of the wreck and mark the wreck with the internationally accepted system of buoyage. After the wreck is determined to be a hazard and appropriately marked, the removal process can begin.

Once a coastal State determines that a wreck poses a hazard, it will immediately inform the flag state and the registered owner of the vessel. Upon notification, the registered owner must provide evidence to the threatened State of insurance or other financial security. The DWRC requires either compulsory insurance or other financial security such as a bank guarantee for vessels over a certain length[15] to cover liability in the event removal procedures are warranted. A State that becomes Party to this Convention would be prohibited from permitting vessels to register under its flag unless it is certified as meeting the requirements of the financial security provisions. Once financial security is verified, the registered owner may contract with any salvor to perform the removal operations. Before the removal commences, however, the threatened State may stipulate conditions under which the removal operations should be carried out to ensure that safety and protection of the marine environment is taken into account.

To prevent the "out of sight, out of mind" mentality that a sunken wreck may foster, the threatened State will set a deadline for the removal operations and will notify the registered owner of the deadline in writing. This notification will also indicate that in the event the registered owner does not undertake the removal before the deadline, the State most threatened will intervene and remove the wreck at the registered owner's expense. In any event, the threatened State may choose to intervene under the DWRC if the potential hazard caused by the wreck becomes particularly severe.

If the threatened State determines that immediate action must be taken to confine the hazard that the wreck poses, then it will undertake the most practical and expeditious means available to remove the wreck. All States that become Party to the DWRC will be required to ensure that registered owners of wrecked vessels comply with the DWRC based upon its own implementing national laws and regulations.

The DWRC thus provides a good framework to identifying, locating, and dealing with wrecked vessels. The most significant problem, however, is the funding to remove the wreck in the event that the registered owner is neither available nor sufficiently solvent to deal with the potential threat. Initially, the idea was forwarded to make the flag state responsible for all costs associated with the removal. This idea was quickly rejected by most of the participating countries.

It has taken several years to get the DWRC to this point, and it is likely that several more years will be needed to work out the details because of the number of contentious issues such as financial responsibility, as well as powerful countries in the international community that quietly object to its implementation. The DWRC legal committee has requested that the International Group of P&I Clubs get together with their colleagues in the insurance industry, as well as other sectors of the shipping industry, to see whether the issues concerning financial liability can be worked out. The DWRC is slated to be discussed as early as the next biennium of the IMO in 2004-2005. If the international community fails to accept a funding mechanism satisfactory to IMO Member States, there is a risk that the DWRC, when and if adopted, will result in a phantom framework rather than a workable solution in those circumstances when removal action is left to the coastal state. It is noble to suggest what needs to be done and how to do it, however, it is more important to explain who will pay and how they will pay for what could potentially be a multi-million dollar endeavor.

Ultimately, the success of the DWRC depends greatly on the number of States that become Parties and, to a lesser extent, whether the States that become Parties are also States that register ships. If the IMO is unable to get a significant number of States to agree to the DWRC provision, then this could result in a convention with no substance and sporadic applicability throughout the world.

IV. TECHNOLOGICAL FEASIBILITY OF OIL REMOVAL FROM WRECKS

Introduction

The removal of oil from wrecks is not a new practice, but salvors and offshore service companies are increasingly being called upon to accomplish more difficult removal tasks. Most oil removal is accomplished by the salvor at the surface. Underwater oil removal is more complex and occurs less frequently; however, there is growing experience with improved techniques in deeper water. In the last decade, very challenging salvage operations for *Kursk* (Russian submarine), T/V *Erika*, F/V *Ehime Maru*, T/V *Prestige* and SS *Jacob Luckenbach*, among others have demonstrated the extent of engineering and salvage skills available to work in deep water and exposed sea conditions.

A typical oil removal operation includes the following phases:

- Initial Mobilization
- Wreck Assessment / Leak Prevention
- Removal Mobilization
- Oil Removal
- Wreck Stabilization
- Disposal and Demobilization

The successful removal of oil from wrecks requires as complete an understanding of the wreck conditions as possible and the application of different technologies. The technical issues, methods, and costs involved in oil removal from wrecks are discussed in the following sections.

Factors Influencing Salvage Planning

Mobilization Distance

The location of the wreck establishes the mobilization points of likely salvage and oil recovery resources. The need for large or unique equipment may involve long mobilization distances, time, and cost. Mobilization, and subsequent demobilization, costs of equipment and personnel could be a significant part of the direct removal operations. If the anticipated removal costs rise because of a long mobilization/demobilization, the possibility of simpler alternative response options will become more attractive. Such alternatives may employ local marine capability in diving and support vessels providing a smaller but longer recovery effort, perhaps over several seasons (Jolma, 2002). Additionally, oil disposal can become a significant demobilization cost problem if local oil reception and processing options are limited.

Sea Conditions

The expected weather and sea conditions at the wreck site must be considered for proper planning and mobilization, since they directly affect the selection of work platforms and the time window in which to safely accomplish the work. Tropical storm seasons, winter weather, and seasonal currents may help establish the time window, particularly in exposed sea conditions. Heavier work platforms and more powerful tools, including large work-class remotely operated vehicles (ROV), can extend the weather window, but with a corresponding increase in cost and mobilization time.

Currents, tides, water temperature, and clarity also impact the selection of work platforms, work methods, and safety. Water temperature and oil viscosity impact the selection of the tools and time needed to remove the oil. Poor water clarity impedes both diver and ROV operations, and tidal currents can limit direct work to periods of slack water.

Mooring of work platforms over, or adjacent to the wreck, must be properly planned and executed. An analysis of mooring forces against expected wind and sea conditions must be completed early in the planning process. This requires a bottom survey of the ground conditions near the wreck, statistical wind and wave data, and platform descriptive data. A mooring load analysis can then be conducted to establish the type and size of anchors, mooring wire, and deck gear needed. Dynamic positioning systems on work vessels are becoming more common and can be used in many extreme conditions, but are not without increased cost and operational complexity. For submerged wrecks, the support platform, no matter how moored, must be able to be moved quickly and accurately over the wreck to support the work. The use of sonar tracking systems between the wreck and the support platform are used to provide real-time relative locations.

Working in more protected or restricted waters has many benefits, allowing the use of smaller work platforms and simpler mooring options. The work's impact on local vessel traffic, seasonal fishing, resources at risk, or beach use, however, may add significantly to the cost of working in protected waters. Local laws also can impact the selection and use of foreign salvors, labor, equipment, and vessels.

Oil Type

Understanding the type of oil on board a wreck is critical to successful salvage planning. Direct sampling of oils from the wreck is important because sampling of released oil may result in a false conclusion as to oil characteristics. The use of oil on ships, either as cargo or bunkers, is a relatively recent phenomenon as compared to the total history of maritime wrecks. The type, volume, and location of oil on a wreck will vary depending on the type of vessel, its construction age, propulsion, trade route, and other factors. Therefore, an understanding of the history of marine oils can be useful when assessing the relative risk from several wrecks.

A History of Maritime Oil. Other than the ancient shipment of amphorae containing olive oil, the practical transport of oil by sea began shortly after the common use of refined oils in the middle of the nineteenth century. Oil tankers began as converted coal ships with a few early oil tankers built for specific trade routes, such as the Baku - Caspian Sea tanker in 1877. The use of oil as ship's fuel became more common in the early 20th century. The world's first oil-fueled battleship, USS *Oklahoma*, was built in 1912 and few if any coal-fueled warships were built subsequently (Jane's Fighting Ships, 1998). The First World War involved the use of both coal and oil-fueled war ships. Military conversion to all oil bunkers occurred by the middle of the 1920s. Commercial ships followed, with timing dependant on specific trade routes and the availability of coal in remote ports: many coal-fueled cargo ships were still in service well into the 1930s. Relatively few new ships were being built as the worldwide depression grew.

Bunker oil was first used in the Gulf of Mexico and in trade with Mexico. Coal was used extensively in the Great Lakes for many years, as coal was easily available. On the U.S. East Coast both oil and coal were used for coastwise and foreign trade cargo ships. Well into the 1940s, harbor craft such as tugs continued to burn coal to meet local air pollution ordinances through the use of clean-burning anthracite coal rather than oil (Seward, 1962).

In the 1920s the use of diesel engines in European and Asian cargo ships was common. In the U.S., steam engines using bunker oil were preferred. By 1932, ninety-five percent of all newly constructed European and Asian large cargo ships were diesel, while in the U.S. only steam plants were being built to power similarly sized ships (King, 1932). European and Asian builders continued in the development of larger diesel, low-speed engines that used a light or heavy diesel marine fuel. These diesel fuels are of low viscosity and are relatively non-persistent.

Military and commercial steam-powered ships for many years used a common fuel-high-viscosity residual "bunker" oil. Such oil was cheap and a suitable burner fuel for steam boilers when heated. Its high viscosity requires constant heating to allow it to be pumped. Ship and shore bunker tanks were fitted with heating coils, and the fuel was kept hot at all times. Often bunker oil could be used on some older ships interchangeably with coal as necessary. The quality and specifications of this oil often varied by location. Prior to the Second World War, U.S. Navy ships converted to a somewhat lighter viscosity black oil, Navy Special Fuel Oil (NSFO). In the 1960s the Navy then converted to use a diesel fuel that could be used for both boilers and diesel engines. Heavy bunker fuel can still be found onboard some cargo ships as either fuel for older steam plants or in tankers as cargo for shore power plants.

Modern residual fuel oils are described by ISO Standard 8217. Heavy marine fuel oils are defined as Intermediate Fuel Oil (IFO) with a numerical suffix giving the oil's viscosity at 50°C, such as "IFO 390." This oil is designated as ISO oil RHM 55 that has a viscosity of 390 cSt at 50°C and exceeds 200,000 cSt at 6°C.

A marine wreck can contain a variety of other oils, such as oil cargo, engine lubrication oil, or hydraulic oil. Some oil and ship heating systems may have used polychlorinated biphenyls (PCBs) as oil stabilizers in closed-loop heating systems or in electrical components. Many cargo ships were built with the ability to carry a bulk, liquid cargo, including oil in "deep tanks", and some could be converted to hold dry or liquid cargo.

Oil Viscosity. Viscosity plays an important part in wreck oil recovery operations. Lighter oils that can flow easily at ambient water temperature generally present a simpler removal solution. Everything from sampling, pumping, and disposal are easier with light oils which are often refined products, although many crude oils have light to moderate viscosity. If the wreck is lying near upright, light oils are more readily lost through tank vents or through hull cracks. The possibility, therefore, of finding significant volumes of light oil on such a wreck may be low. A good survey of the wreck is essential to understand the flow and possible loss of oil within the hull. The true orientation of the hull, as it twists and bends, and assessment of the venting, sounding, and piping system must be well understood.

Heavy, persistent oils can cause the most environmental and visual damage. These oils can remain in most tanks or compartments, particularly in cold water. Bunker oil can present a wide range of oil viscosity (Figure 7). Even within a single ship, different types of bunker fuel oil can be found. Also, stratification of oil from varying density may occur within a tank resulting in sludge and water/oil emulsion layers.

Oil Weathering. Although oil properties are subject to weathering effects such as evaporation and emulsification, the properties of oil in closed, quiet tanks of wrecks change slowly. Stratification of oil from varying oil density may occur within a tank resulting in sludge and water/oil emulsion layers. With heavy oils, some limited emulsification of oil with water will occur at the water/oil interface but does not seem to spread. Oil wax may result at low temperatures near the oil's pour point. Marine growth on the oil surface and biological activity can occur under certain conditions.

The challenge to the salvor is how to move the oil, in whatever form, out of the wreck. Although lighter oils can be removed relatively easily, direct pumping of the heavy oil can be limited both by the slow flow of the oil to the pump inlet and by the back-pressure as it is pushed through a discharge hose to the surface. It is, therefore, important to know the type, viscosity, and location of oil in the wreck to properly select pumping, tapping, and hose options. Also, it will provide for a realistic estimate of the time and effort needed for the job. The effective flow rate of pumping a tank includes all the time required to prepare, tap, heat, pump, and secure a given tank or space.

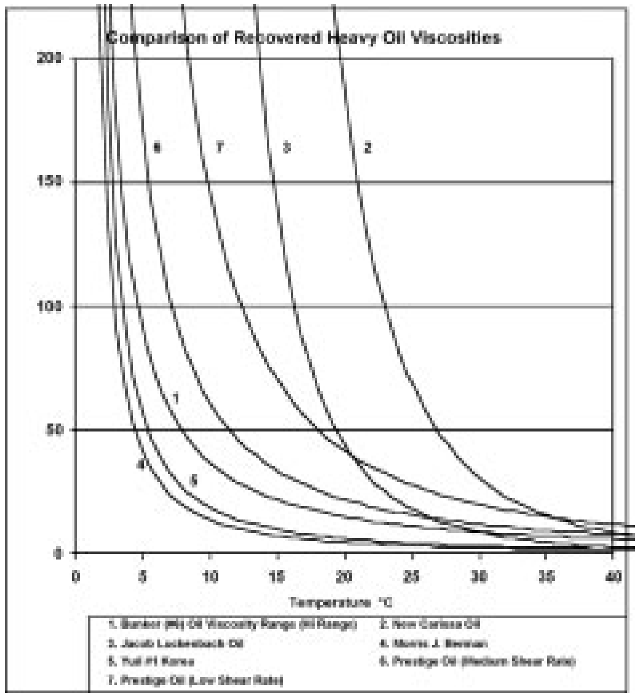

FIGURE 7. OIL VISCOSITY OF HEAVY FUEL OILS.

Residual Oil Volume in the Wreck. After removal operations some oil will remain in the tanks and spaces of the wreck. Oil will remain in various ways:

- Clinging to inner tank surfaces
- Trapped behind tank and hull structures
- Remaining in inaccessible tanks and spaces
- Remaining in cargo and fuel piping
- Coating debris and cargo

The initial wreck assessment should include an estimate of the potential residual oil volume using the geometry of the tanks and spaces, the viscosity of the oil, and the procedures that can be used to remove the oil. Complete oil removal from a tank will require several cycles of pumping and settling within a tank to minimize the percentage of water recovered with the oil. A procedure of oil discharge sampling and analysis is needed to establish the most efficient stripping procedures and to document each final tank stripping and closure. A consistent procedure is necessary for all closed tanks to establish the removal of all pumpable oil throughout the wreck. Final permanent plugging and closing of tank openings will secure the tanks from residual leaks and possible tampering by curious divers.

Wreck Conditions

Does a wreck contain oil or not? If so, how much and of what type? Is the wreck safe to work on? These are the key questions to be answered when assessing a wreck and determining the type and extent of oil removal. The characteristics of the ship's fuel and cargo oil and initial tank loading should point to where the oil should be found in the wreck. Bunker oil fuel tanks are usually located in double-bottom tanks formed by the ship's bottom and side-shell hull plating. The hull shell plating forms most tanker cargo oil tanks built prior to recent tanker double-hull construction. Therefore, cargo and fuel oil tanks of wrecks should be generally accessible directly through the hull shell plating. This simplifies survey sampling and tapping the tanks for pumping.

Double-hull configurations present additional complexity by having to penetrate through the outer empty tank to sample or open and remove oil. The design of oil piping systems also can effect oil removal. Some piping systems can provide for more direct access to individual tanks. In some ships, deck mounted pumping and piping systems can provide easier tank access. Some piping designers are offering to install emergency piping runs in each tank to facilitate oil removal in the event of an accident.

There are multiple fuel tanks or cargo tanks in a wreck. Cargo ship bunker tanks are found along the bottom of the ship. Some bottom tanks may be used for water ballast and fresh water. Each tank usually has port and starboard halves. A mid-sized tanker may have nine to twelve tank bulkheads, forming three independent tanks across the hull. Several tanks throughout the ship will be dedicated to water ballast. For example, refer to Figure M-3 showing the tank arrangement of the wreck of *Mississinewa*.

Marine ship casualties incur damage not only from the initial event (e.g., collision, explosion, or hull failure) but also from hitting the sea bottom. The motion of the vessel during these events can cause a significant, immediate oil loss to the sea or internally. Hot oil may continue to flow freely until it is completely cool which may take hours to weeks. The wreck's orientation and remaining hull condition are the most important factors affecting possible oil recovery. Wrecks lying upright with bunker tanks buried are likely to have lost, or continue to lose oil from tanks through tank vent piping or hull cracks. Wrecks lying upside down may have much of the oil contained in intact tanks offering relatively easy access directly to the tank through the hull. The final orientation of a wreck can have many causes including the slope of the bottom. Cargo vessels, because of their superstructure and cargo gear, seem to land more upright, whereas tankers, because of the relative buoyancy of the cargo, may tend to land upside-down.

The general condition of a wreck is a result of initial structural damage, hull corrosion, and, later, structural collapse. Together, these factors result in low remaining hull strength and the cracking of hull tanks. The hull condition will likely vary throughout the wreck. The deterioration of the superstructure, cargo gear, and piping may have little similarity to the condition of the hull and oil tanks. Hull structure is made of significantly thicker steel than the superstructure and piping components.

Military vessels, particularly heavy combatant ships, are often made of heavier steel plate and piping than commercial or auxiliary military vessels, and for similar structural damage, non-combatant shipwrecks would tend to deteriorate more rapidly than military combatants. However, military vessels may have a greater likelihood of leaking as they are more likely to have sunk from combat damage to main hull structure as opposed to non-combatant vessels.

The mechanisms of steel and iron rates of corrosion in underwater wrecks are reasonably well understood (MacLeod, 2002). Corrosion will occur under marine growth related to the level of dissolved oxygen, which is in turn affected by salinity and water temperature. Other factors affecting corrosion rates include water depth, burial in bottom sediment, and marine growth. Disturbance of the wreck from various activities including divers, salvage efforts, water currents, or fishing activity can cause corrosion rates to increase. The fact that oil is still contained in a tank may affect the rate of local corrosion of a relatively intact oil tank. Hull oil tanks containing oil with marine growth outside protecting the loss of hull paint have shown little or no steel loss after many years underwater. This effect has been observed in both warm and cold-water locations and in shallow to moderate (50 m) water depths (Moffatt et al., 2003; Moffatt, 2004).

The potential for tank failure from corrosion is, therefore, probably dependent on the condition of the wreck's hull paint. A survey of the status of the hull paint, particularly over and around the oil tanks, along with an overall measurement of the wreck's galvanic corrosion potential, would be critical in establishing the relative risk of the wreck.

Wreck Location Factors

A wreck's location will establish several parameters that impact the relative condition of the vessel. Such factors include:

- Water depth
- Protected or unprotected waters
- Sea and storm characteristics of the location
- Sea temperature
- Biological activity
- Chemical characteristics of the water

Water depth and local sea conditions combine to have a large effect on a wreck. If a vessel sinks in open, fairly deep water, the hull's impact on the bottom may cause further structural damage. The velocity at impact is a function of relative hull buoyancy as it falls to the bottom. The hull may reach a terminal velocity, and thus highest impact, if there is sufficient water depth. Every case is different since hull shape, attitude, cargo, and other factors vary, but the terminal velocity is probably reached within the first 100-300 m of fall.

In shallow water, particularly in water depths significantly less than the length of the vessel, hull impact ground reactions can cause significant hull stress and cracking of the hull, particularly as part of the hull is raised above the water before it sinks. In such wrecks it would not be unusual to see significant forward or aft damage, and hull and deck cracks.

The scouring of a wreck by wave, tidal or other currents is also a function of water depth. For example, a typical wave's underwater pressure has influence to a depth of about half of the wave's length. In some exposed settings, where wavelengths of 75 to 150 m may be common during storms, wrecks at 35 to 75 m would experience wave-pulse water scouring. Scouring can result in more rapid steel deterioration as coatings and bio-coatings are removed. Scouring currents can entrain trapped oil, releasing the oil from the wreck. Scouring also causes movement of bottom soil and debris, causing further movement and breaking of the hull, or burying the hull and making it less accessible to oil removal. In shallow water, breaking waves with entrained oxygen may increase the rate steel deterioration, as the water of the dissipated waves is flushed through the wreck. Protected locations, with smaller waves and currents, would limit scouring effects to the wreck.

The prevailing seasonal water temperatures are well known for most ocean and coastal regions. Variations in temperature can change the oil viscosity within a wreck. Oil leaks may, therefore, be observed as a seasonal or weather-induced phenomenon.

Water depth is also a significant factor in the overall cost of conducting oil removal, because it can limit options in selecting work platforms and intervention techniques. The choice between moored or dynamically positioned vessels occurs at about 150 m of water, because the size and complexity of a ground (anchor) mooring system becomes difficult to mobilize and handle.

Water depth will also affect the selection of the intervention method, whether by air, mixed-gas, saturation diving, or the use of ROVs. The utility of each method and relative cost is discussed later, but the use of divers is generally limited by the available work and decompression times. ROVs have fewer work-time limitations than divers, but the size and relative costs of ROVs can increase significantly in deeper depths or in high-current environments.

State-of-the-art Capabilities and Limitations

Wreck Inspection

Proper wreck assessment is critically important to determine the best removal plan. A thorough assessment of the wreck before the complete mobilization to the site will save time and improve the chances of overall project success. The goal of a wreck inspection is to determine the condition of the wreck, the amount and locations of oil, and if oil can or should be removed. The assessment will require the use of several inspection methods, including:

- Diver or ROV observations
- Measuring the orientation of each section of the wreck
- Sampling of oil, marine life, and metals
- Mapping and locating the wreck and its debris field
- Mapping of adjacent and area bottom profiles and sediment conditions

Ship construction drawings of the wrecked vessel should be obtained. If drawings of the actual vessel are not available, drawings of a vessel of the same or similar class are also useful. Government, classification societies, or shipyard archives may be a source for such drawings. Documentation should include:

- Construction drawings of vessel or class
- Drawings of similar vessels from the building yard
- Contemporary accounts and photos of the sinking
- Documentation of the voyage, cargo, bunkering reports, etc.
- Previous wreck surveys and reports

Sonar mapping systems coupled with a global positioning system (GPS) can provide detailed wreck mapping and three-dimensional overviews. Divers or ROVs, and sometimes both, provide direct observations. These are combined with drawings and architectural plans.

Locating and sampling individual tanks is an important and time-consuming effort. Locating individual tank bulkheads can require extensive growth cleaning and hit-or-miss techniques. Low-tech solutions include using a hammer to sound for internal bulkheads and hull frames. Tank sampling can consist of a drill and sampling tube. Newer solid, magnet based drills can speed drilling and sampling. ROVs can perform drilling if power and total thrust is sufficient. Heating of the sample before it is taken may be necessary for very heavy oils, but a standard tool for this kind of sampling is not available. Drilling multiple holes is necessary to establish lower limits of tank oil to calculate the contained oil volume, and because of stratification of oil within a tank, several representative samples should be obtained. Sampling can also be accomplished through sounding tubes or vents, if accessible or unbroken.

Ultrasonic devices can be used to sample hull plate thickness but have proven to be less useful for determining the level of oil inside of a submerged tank. In recent years, a nuclear back-scatter, density and chemical detector has been used to find oil through underwater tank hull plating. Such an instrument is suitable for ROV use. This, or similar techniques, can provide rapid wreck oil tank assessments.

Wreck surveys can be conducted by a variety of organizations including the government agency, the salvor, or other interested parties for different purposes. Often these surveys use different methods and look at different aspect of the wreck. Coordination and use of this different survey data is often difficult and may require repeated surveys.

Oil Removal

The wreck condition, location, and oil contained will largely establish the removal techniques and tools to be used. For relatively intact wrecks, re-floating or complete wreck removal may be the most practical option (Brown et al., 1997). This has some advantages in that all of the obstruction is removed, no oil remains, and other pollutants are removed. If only oil is to be removed, various types of tapping and pumping techniques can be used, including:

- Hot-tap cutting tools
- Vacuum pumping
- Submersible hydraulic pumps
- ROV operated cutting and pumping tools
- Heating equipment

Hot-tap cutting refers to the method of cutting an access hole into a pressurized pipe or tank to install a pipe flange or “tap.” Several versions of these tools that have been adapted to underwater use can install a pipe flange and cut a hole into oil tanks without spilling oil. Flanges can be mounted onto the hull using drilled bolts or by welding. Lightweight cutting tools have been developed allowing one diver to install and operate the hot tap (Fig. 8). Several hot-tap flanges and holes must be installed in a tank to mount the pump, provide make-up water, and insert heating coils (see Figure JL-2 in *Jacob Luckenbach* case study).

FIGURE 8. LIGHTWEIGHT HOT-TAP.

Specialized ROV operated underwater tools have been developed for tapping and removing oil from underwater wrecks. Examples of these machines include the Frank Mohn Company (FRAMO) Remote Offloading System (ROLS) and the Hot Tapping Machine developed by Repsol for the *Prestige* oil offloading (see case study this chapter). The ROLS has been used successfully on several wreck oil removal operations, including *Estonia*, *Ievoli Sun*, *Yuil No. 1*, and *Osung No 3.*, *Bow Mariner*, and others. The Repsol machine was used at 3,850 meters. These machines allow for the removal of oil at water depths unsafe or impossible for divers. Use of these tools can provide for more efficient operations than diving by allowing work in poor weather conditions, higher current, and providing 24-hour operations. Powerful ROVs and large support platforms are necessary for successful operations.

Low viscosity oils can be removed by using a vacuum pump. The use of a vacuum and long suction hose can simplify the rigging and equipment to be handled by a diver or a salvage crew. Various types of vacuum pumps are available, ranging from a simple diaphragm pump to high-volume rotary vacuum pumps. Clogging of the suction hose can be a problem if oil viscosity is high or debris is encountered.

Vessel Name: M/V *Prestige*

Location: Approximately 160 km off the coast of Northwest Spain.

History of the Wreck: M/V *Prestige* was a 26-year old, single-hulled oil tanker that was owned by the Liberian entity Mare Shipping, Inc. and operated by the Greek entity Universe Maritime Ltd. On 13 November 13 2002, while enroute from Latvia to Singapore in heavy seas and high winds, *Prestige* suffered hull damage and developed a 25-degree starboard list in the region of Cape Finisterre, approximately 50 km off the coast of Northwest Spain. On board *Prestige* at the time were approximately 78,000 metric tonnes of heavy fuel oil. The vessel drifted to within 8 km of the coast before being taken under tow by a Spanish coast guard vessel. Safe havens were denied in Spain and Portugal, and the ship was directed to be towed further out to sea, in an attempt to avoid a dramatic impact on the economically and socially sensitive upper and lower "rias" (= indented estuaries) of the Galician coastline, at the risk of extending the pollution beyond Galicia. Six days later, after enduring heavy seas and spilling more than 10,000 tonnes of fuel oil, *Prestige* broke in two and both parts sunk 270 km offshore Spain in 3,500 m of water. In February 2003, the Spanish authorities estimated that some 35,000 tonnes of fuel remained in the wreck, implying that 43,000 tonnes had been spilled. That spill estimate proved later to be far below reality. Detailed investigations of the wreck in late 2003 showed that about 15,000 tonnes remained onboard at that time, increasing the spill estimate to some 63,000 tonnes. More than 400 km of the Spanish coastline were oiled, often heavily by the thick, emulsified oil, but most of the rias were spared. Tarballs also washed upon the French Atlantic coast.

Oil Pollution Risk: In spite of sealing operations undertaken in early 2003 with the French scientific submarine *Nautile*, the highly persistent oil continued to leak (Figure JL-1) at rates estimated by a few tonnes per day, and it had been hypothesized that *Prestige* would continue to leak until at least the year 2006 without oil removal. No risk assessment study was implemented. The only information available was that a quantity of oil close to the amount that had already spilled remained in the wreck and could surface sometime; this was considered more than sufficient by the Spanish public to request that action would be undertaken. Public pressure did not reduce when it appeared that the amount trapped in the wreck was in fact only a quarter of what had been already spilled.

Other Special Issues: Salvage operations in very deep water (3,500 m) forced development of innovative technologies.

Legal, Policy, and Financial Issues: Because of high public pressure, the Spanish government committed to remove the pollution hazard based on the initial estimate of 35,000 tonnes of heavy fuel oil in the sunken wrecks and stood by its decision when the estimate was reduced to 15,000 tonnes. The Protection & Indemnity Club of the shipowner made clear that it had no intention to do more than meet its duties by the international conventions in force, i.e. putting up a limitation fund of US $78 million. That amount and the additional compensation available through the International Oil Pollution Compensation Fund (IOPC Fund) summed up at US $184 million as the total money available for all consequences of the *Prestige* pollution. Much more money had already been spent in response costs when the Spanish government committed to deal with the wreck hazard. It was made clear that oil recovery from the wreck would be undertaken at public expense and that repayment could be sought later from those judged responsible of the pollution.

Salvage Operations Summary: The Ministry of Transport with the French deep-sea submarine *Nautile*, and later the Spanish national oil company Repsol YFP with deep ROVs, conducted leak-sealing operations on the *Prestige* wreck in the first half of 2003. Eleven tank leaks were plugged using a variety of tools and materials inserted by a ROV, significantly reducing the leak rate. The contents of the tanks were sounded using several innovative techniques including a neutron chemical detection tool. One problem was to design sensors that could withstand the extreme pressure (6,000 psi). In late 2003, a test oil recovery operation was implemented, using ROV hot-tap cutting tools to make a 70 cm diameter hole and using a 25-m tall soft 500 m^3 cylinder-shaped tank to collect the oil as it floated out through the holes in the tank, then to shuttle it to the surface for recovery in a floating dock. Difficulties encountered in the shuttle recovery led to changes in the recoverable soft-tank option to a 350 m^3 aluminum shuttle designed to be emptied 50 m below sea surface by pumping the oil into a waiting tanker with water annulus pumps. Operations started in May 2004. Operations continued through mid October 2004 with approximately 13,600 tonnes removed at the end, leaving only an estimated 700 tonnes adhered to the inner walls of the wreck.

Costs: Spanish claims for cleanup costs and damages to local individuals and businesses, as presented to the IOPC Funds at the end of 2003, amounted to Euros 538 million. French costs and damages amounted to Euros 7.2 million. Further claims are expected and damages estimates in excess of Euros 1 billion have been announced by non-governmental organizations. The costs for oil recovery from the sunken bow part are estimated at US $120 million, pre-financed by the Spanish national oil company, Repsol YPF and repaid by the Spanish government. Both the ship owner and the P&I Club have stated that these costs were unreasonable, considering the potential pollution hazard.

Lessons Learned: Many lessons have been learned from this unique operation. It has been demonstrated that a scientific deep-sea submarine can be rapidly adapted to implement urgent leak-sealing operations on a deep-water wreck and that ROVs can seal a leaking wreck at almost any depth. Initial estimates of the oil trapped in a wreck proved once more far above the reality. Dramatic decisions based on that first, erroneous assessment were not revised afterwards. The final assessment, which proved right, was undertaken with a technology never used in such circumstances. Hot tapping of an exceptional size (70 cm diameter) and recovery efforts were dramatically reduced through successful simultaneous operation of up to 3 ROVs on the same wreck, at depths over 3,500 m. Highly innovative shuttle filling, moving, and pumping technologies were tested and successfully implemented. As a whole, the successful recovery of the fuel trapped in the *Prestige* wreck demonstrated that any oil recovery from a wreck has become technically possible at almost any depth.

FIGURE P-1. ROV ATTEMPTING TO SAMPLE OIL LEAKING FROM *PRESTIGE* AT 3,500 M.

FIGURE P-2. AN ALUMINUM SHUTTLE BEING TOWED TO THE PRESTIGE SITE.

FIGURE P-3. HOT-TAPPING MACHINE

Submersible hydraulic pumps are now commonly used for most surface and underwater salvage operations. Centrifugal and positive-displacement submersible pumps are available in many different sizes. Centrifugal pumps have the advantage of being lighter-weight with higher flow rates than positive displacement pumps, and they cannot over-pressurize the discharge hose beyond a shut-off pressure limit. These pumps are not suitable for heavy oils, and emulsification is likely to be high, which may degrade the quality of the recovered product for sale. Such pumps were used to offload *Mississinewa* of relatively light viscosity oil (U.S. Navy Salvage Report, 2004).

There are several types of positive-displacement pumps, but the most commonly now used for underwater pumping are screw pumps. These come in various configurations and sizes from several manufacturers. Flow rates of approximately 1,600 liters per hour are possible with the larger pumps. These pumps have good suction characteristics, capable of drawing heavy oil to the pump. Pump inlets have cutters to help chop and clear debris. New versions of these pumps are fitted with annular water injection rings, to help the pumping of heavy oils and lubricate the discharge hoses to prevent clogging. Pumping of heavy oil (bitumen) with a viscosity over 100,000 cSt has been accomplished with these modified pumps, but the primary limitation remains the flow rate of the heavy oil into the pump inlet.

Despite the use of heavy-oil pumps and water injection techniques, the application of heat to individual oil tanks may be necessary. Direct heating of the oil in a tank could be accomplished by using the ship's tank heating coils in most heavy oil tanks. If the heating coils could be tapped, hot water or steam could be circulated until the oil viscosity is low enough to easily pump. Often, however, the orientation of the wreck or the condition of the steam piping precludes their use, because heating-coil piping tends to waste away relatively quickly as compared to hull plating.

Two other types of direct oil heating can be accomplished by providing localized heating near the pump inlet, or complete tank heating. The usual source of external heat is portable boilers with steam delivered to the wreck through hoses. This is an old technique largely unchanged since heavy oil has been used. The steam can either be directly injected into the tank thus "wasting" the condensed steam into the tank, or with heating coils inserted into the tank and the waste-steam returned to the boiler. Depending on the ambient temperature and the geometry of the tank, multiple heating points may be established to fully warm the tank oil. The oil discharge hoses can also be heated by inserting a smaller steam hose.

Viscosity Lowering Techniques

Heating is the most commonly used viscosity-lowering technique, but other techniques could be considered. One approach often discussed is to increase the viscosity of the oil until it behaves as a solid and then leave it in the wreck. Oil solidifiers, when mixed with oil, form a rubbery semi-solid substance. Usually solidifiers are dry substances that are "mixed well" into the oil. A practical problem remains of how to inject the solidifier into a closed oil tank and provide sufficient mixing energy. Also, the stability of such solid mixtures is unknown over long periods. These limitations seem to make the use of solidifiers to stabilize large volumes of trapped submerged oil impractical, but they may be useful for small applications.

Oil viscosity can be reduced by mixing with light oil. Light oil, such as diesel, could be injected into a submerged oil tank to improve pumping. This is possible, but it may also require significant mixing energy and time to reach throughout the tank, and may result in further oil leaks. A version of this technique was used for the oil recovery from *Erika* (Bocquillon et al., 2001; Bocquillon and Guyonnet, 2002).

Limits of Diving Operations

Oil has been removed from underwater wrecks using divers or robotic tools, and sometimes a combination of both. Each technique has its limitations and advantages, as discussed below.

Diving operations can be conducted in relatively deep water. However, the diving technique will vary as to depth, working conditions, duration, and other factors. Most U.S. commercial divers conduct their diving in accordance with U.S. Navy Diving Manual and its limits for air and mixed-gas diving. Other countries may follow these standards or use similar standards developed by industry. Most commercial diving will be conducted using surface-supplied air or mixed-gas systems. This is the safest method that provides surface control of the diver and his gas and can provide surface voice and visual control. The range of surface-supplied compressed air diving is generally to about 65 m. The working bottom time at that depth would preclude extensive work. The use of mixed-gas, helium-oxygen and other gas mixes, can extend diving to about 90 m and extend bottom work-time in shallower depths. Saturation diving is the preferred method for diving in about 45 to 365 m of seawater. Saturation diving can require fewer diving personnel and results in more efficient bottom work time. Mobilization and topside support costs are higher for these complex systems, and thus may be more suitable for long duration and complex operations.

Today ROVs are capable of performing a wide variety of inspection and underwater tasks and are the obvious choice at depths beyond 300 m. They are used frequently, however, at shallower depths for surveys or to assist divers. In poor visibility, ROVs have limitations in not being able to feel their way like a diver, but their long endurance makes them practical for simple repetitive tasks, often using purpose-built tools. There is great variety in their size and capability: light, inexpensive, ROVs can offer a "flying eye" to inspect or observe work; heavy-work ROVs have sufficient power systems to overcome currents and power large work tools. Manned atmospheric diving systems (ADS), such as manned ROVs and articulated pressure suits, combine some advantages of a swimming diver and a ROV.

Assessing the Cost of Oil Removal Operations

Predicting the cost of oil removal operations in advance is difficult. If commercial salvors are to do the work, the competitive environment at the time of the bid is hard to predict. The availability of vessels, divers, or special tools may be quite limited, particularly for deep-water work. Cost factors can be placed into four categories:

- **Mobilization**—The time and costs associated with obtaining and moving support vessels, personnel, and equipment to and from the job site.
- **Equipment, tools, and diving operations**—The fixed or day costs for equipment and personnel will be driven by many factors including:
  - Viscosity of oil—is heating required?
  - Water depth—size of mooring system, use of divers or ROVs
  - Sea and weather conditions—size of vessels
  - Condition and type of wreck—complexity of underwater work
  - Volume of oil to be recovered—size and number of oil transport vessels
  - Number of oil tanks—tank or void penetrations needed
  - Extent of stand-by oil recovery required—other vessels and labor required
- **Days required on site**—time necessary to accomplish the recovery including working days and standby days for delays such as bad weather.
- **Net disposal cost of oil recovered**—total cost of oil disposal can likely exceed the value of oil, unless it is in good condition.

These factors describe the relative complexity of the recovery operation. In general, oil recovery costs are directly related to the complexity of the site, not to the volume of oil to be pumped. For example, over 6,000 tonnes of a heavy fuel oil were removed from *Mississinewa* at a cost of US $3-4 million (see case study in Chapter III). The site was shallow, the water was warm and clear, the tanks were readily accessible, and the oil was readily pumped. The costs would have been even lower if it had not been such a remote site that required extensive mobilization costs. In contrast, removal of 350 tonnes from *Jacob Luckenbach* off California cost at least US $20 million because of extensive weather delays, the oil was in many different compartments, the viscous oil had to be heated to be pumpable, extended cold-water saturation diving at depths to 55 m, strong currents, and poor visibility. A range of relative costs for oil recovery from an average size merchant shipwreck with multiple tanks, excluding government oversight and support costs, is shown in Table 7, based on best professional judgment and recent operations. The figures in Table 7 could be used to generate first-order estimates for removal of priority wrecks, as part of the process of risk assessment and cost analysis.

Table 7. Range of Relative Costs for Oil Recovery from an Average Wreck.

Relative Complexity	Impact Factors on Cost	Cost Range (US $ million)
Simple	Shallow depth (<20 m)	<1 - 3
	Low viscosity oil	
	Protected water	
	Local mobilization	
Moderate	Moderate depth (20-50 m)	2 - 5
	Moderate viscosity oil	
	Weather & sea restrictions	
	Regional mobilization	
Complex	Deep depth (50-250 m)	5 - 20+
	High viscosity oil	
	Poor wreck condition	
	Open water	
	Weather limitations	
	Long mobilization	
Highly complex	Extreme depth (>250 m)	20 - 100+
	High viscosity oil	
	Poor wreck condition	
	Open water	
	Weather limitations	
	Long mobilization	

V. ASSESSING THE RISKS OF POTENTIALLY POLLUTING WRECKS

Historical accounts in the literature and contemporary cases, such as those discussed in Chapter III, illustrate that sunken shipwrecks can and do leak oil. The chronic leaks of oil from the sunken tanker *Prestige* demonstrated that even heavy residual fuel oil in wrecks in cold and deep-water environments can eventually rise to the surface and contaminate the coastline. There may be more leaking wrecks than records indicate, because chronic or intermittent oil spills from sunken wrecks historically have been confused with "operational discharges" of oil wastes from shipping. Significant financial resources, personnel, and time have been wasted in the search for the culprits of this intermittent oil pollution. An example of this is *SS Jacob Luckenbach* which was finally determined to be the source of mystery spills observed for over 10 years on the US coast (see Case Study in Chapter III).

The decision to salvage oil from a sunken vessel must be based upon a sound risk assessment and a well-developed cost-benefit analysis because any salvage effort is usually expensive, time-consuming, and risky. Cost-benefit analysis must assess the potential environmental and biological impacts of any pollution from the wreck as well as the socioeconomic implications of any spill and remediation costs. Based on past experience, two considerations should be at the forefront of any decision to carry out remedial activities, whether they be off-load or salvage of remaining oil cargo from any sunken vessel or removal of the wreck:

1. The potential environmental impact and risks posed by the oil contained within the sunken vessel outweighs the cost of the mitigation action.
2. The potential combination of environmental impact/risk, economic damage, and social unrest that could be caused by repetitive spills of oil contained in the sunken vessel outweighs the cost of the mitigation action.

The obvious difficulty is that the valuation of "real" potential costs (e.g., ship time, fuel, pay for salvors, and even loss of fisheries) is much easier than valuation of "perceived" potential costs (e.g., aesthetics, environmental integrity, non-commercial species loss). These perceived costs are either poorly considered, or excluded from the evaluation process because they cannot be adequately valued. Therefore, the decision on overall benefits and costs has to be based on a qualitative, but consistent approach.

Environmental Risk Assessment for Sunken Wrecks

Assessing the environmental threat posed by sunken wrecks is complex. Each shipwreck type and location is unique and must be assessed, analyzed, and handled on a case-by-case basis. There are two basic purposes of environmental risk assessment of wreck sites:

- Provide environmental pre-assessments for determining the risk posed by the potential release of oil from a shipwreck; and
- Gather vital information required to undertake and manage any spill response in the event of a release occurring before pollution mitigation of the wreck has taken place.

The volume of oil lost or potentially lost during a spill incident is not necessarily the most important factor in determining the seriousness of an oil spill event or possible risk posed by a sunken vessel. The location of the incident/vessel, behavior and weathering characteristics of the released oil, prevailing sea and weather conditions, as well as the sensitivities of the environmental resources in the surrounding area are often the important considerations. Therefore, there is a value in undertaking assessments of the areas under threat and determining the resources at risk before an emergency occurs. This will lead to a better understanding of the consequences of any spill event, both spatially and seasonally, and costs and benefits can be estimated for possible spill response strategies, contingency arrangements, and cleanup operations.

A general methodology for the assessment of environmental risk posed by sunken shipwrecks, modified from that first proposed by the South Pacific Regional Environment Programme (SPREP, 2002; Nawadra and Gilbert, 2002; Gilbert, 2003), is presented in Table 8. Many of these activities can be carried out concurrently, but some tasks will need to be completed prior to others being commenced. The tasks within the methodology are not presented in any order of importance.

There are seven main steps proposed for a local environmental assessment both before and during a spill incident (Table 9). This process was detailed in Gilbert (2001) and Gilbert and Nawadra (2002).

In assessing the potential risk posed by an individual wreck, it is necessary to examine the potential impacts of the spill by incorporating the following information (Gilbert et al., 2003):

- Description of the environment immediately adjacent to and surrounding the area of the wreck.
- Modeling of the possible oil release scenarios, oil fate and oil impact zones using seasonal oceanographic and meteorological data. This spill trajectory and impact modeling should also incorporate the influence and fluctuations of under-water currents that affect oil rising from deep-sea wrecks.
- Wreck location, orientation, and estimated distance to nearest coastline or sensitive shallow sub-tidal habitats, as well as seasonality factors relating those environments.
- Information on the cargo types and their location including presence/absence of munitions and/or explosives.
- Diagrams of the machinery, compartments, piping, and tank layout for the vessel and integrity of fuel/oil tanks.
- Type and extent of debris around the wreck site that may interfere with offloading operations or pose a safety hazard.
- Description of the regional environment likely to impacted by a catastrophic release of oil from the sunken wreck, including assessment of the wildlife, habitats, and marine and coastal resources within the region, including seasonal fluctuations.
- Description and assessment of the potential socioeconomic impacts of oil spills from the wrecks.

In general terms the threat and range of oil impacts during and after an oil spill can range from biological to socioeconomic considerations, including:

- Physical and chemical alteration of natural habitats, both short- and long-term
- Physical smothering effects on wildlife and plants
- Lethal and sub-lethal toxic effects on fish, wildlife, and plants
- Short- and long-term changes in biological communities resulting from oil effects on key organisms (e.g., food chain interruptions)
- Tainting of edible species, notably fish and shellfish
- Loss of use of amenity areas and tourism
- Loss of market for fisheries
- Fouling of boats, fishing gear, boat ramps, jetties, etc.
- Temporary interruption of any marine-based industries

Potential Economic of Impacts on Fisheries and Tourism

The populations of developing countries frequently have strong cultural ties with the sea and rely heavily on subsistence fishing in lagoons and coastal regions. Commercial fishing is also one of the main sources of income for many coastal nations of the world.

Table 8. Generalized Methodology and Task Description for Assessment of Risk Posed by Sunken Shipwrecks.

Task	Task Description
	Information Gathering
1.	Develop an accurate sunken vessel database by the collation of existing historical data on wreck (military and private sources)
2.	Identify the ownership (sovereignty) of individual wrecks and which jurisdictional responsibility for each vessel (e.g., international waters, EEZ, territorial waters, etc.)
3.	Confirm and map locations of sunken vessels in the region
4.	Confirm the identity of vessels and cargo quantities and types
5.	Determine if any reports of previous oil releases in the area have occurred from the vessels
6.	Collect information on vessel history such as damage prior to sinking
	Implications/Consequences
7.	Assess likely scenarios for impact of any released oil (e.g., possible release scenarios, spill trajectory modeling, oil fate, and oil weathering patterns)
8.	Determine the ecological and human-use resources at risk in the area of the spill and any impacts that may have already occurred
9.	Estimate the ecologically important sea/coastal/land uses of the region
10.	Document the physio-ecological character (and any oiling) of the surrounding shorelines
11.	Determine and assess the impacts of an oil spill from the wreck on wildlife and fisheries in the region
12.	Determine possible consequences of oil release scenarios (e.g., environmental sensitivities, economic risks, subsistence fishing, recreation, etc.)
	Assessment of Risk Priority/ Actions
13.	Select priority sites or wrecks to employ mitigation strategies and oil cargo and/or wreck salvage
14.	Determine which sites/wrecks require regular pollution surveillance or monitoring by local or remote techniques
15.	Carry out site investigations, inspections, and assessments of vessel integrity and tank soundings where possible (e.g., integrity of hull, ships fastenings, metal thickness measurements, pipe-work deterioration)
16.	Assess the accessibility issues related to the wreck and potential oil cargo off-loading strategies
17.	Determine contingency arrangements for offloading of oil cargos including spill containment, oil recovery, and waste disposal options
18.	Assess any physical or ecological constraints on salvage activities or cleanup operations
19.	Provide an overall recommendation on any necessary actions related to the remaining oil

Most international seafood safety laws include a requirement that seafood consumed by its population is not injurious to health, unfit, or so contaminated that it would be unreasonable to expect it to be eaten. It is normal international practice to close fisheries or place exclusion zones in the location of an oil spill until the source has been secured and checks can be carried out on the

Table 9. Main Steps in Environmental Assessment for Oil Spill Impacts.

Activity	Description
1	Collate and cross check existing environmental data and reports
2	Identify the major types of habitats/ecosystems and their value
3	Assess intertidal biota - character/health - state of indicator species on shores - mortality.
4	Assess health of nearshore, sub-tidal areas
5	Observe and assess wildlife - species - abundance - seasonality
6	Assess any ecological constraints on response or cleanup operations
7	Provide photo documentation or video surveys

safety and marketability of seafood from the incident scene. This precautionary measure not only protects the health of consumers but the reputation of the fisheries.

Any ban on fishing within subsistence areas could mean great hardship to regional populations and possibly the need for government assistance or food aid. It also places an extra risk of human safety if required to then fish in the unfamiliar or rougher waters away from usual fishing areas. This was a major concern during the chronic oil spills from *Mississinewa* in Micronesia. (see Case Study this Chapter).

Using Spill Trajectory Modeling in Risk Assessment for Oil Spills from Wrecks

It is necessary to understand where the oil might move at sea under seasonal conditions for an effective assessment of environmental risk of catastrophic oil spills or chronic seeps from sunken vessels, as well as marine and coastal resources that may be at threat. An oil plume rising from deep water can travel long distances due to subsurface currents prior to surfacing, which could be many kilometers from the wreck site, and the currents and wind patterns may differ by season.

When an oil spill occurs at sea, the first and primary concern of response planners is to predict where the oil will go. They consider the slick direction, speed of movement, weathering, and spreading characteristics of the oil under the influence of prevailing currents and winds. Tracking of oil spills in nearshore marine environments, which are likely to impact the shoreline, is also of prime importance in the effective deployment of oil spill response personnel and equipment to protect environmentally sensitive areas and in response planning. Similarly, models provide a means of running different spill scenarios from known positions of wrecks in order to determine where and when likely oil seeps or spills may impact sensitive marine or coastal resources (Symons and Hodges, 2004). Oil spill trajectory analysis played a key role in the planning for the oil removal from *Mississinewa* in Ulithi Lagoon (see case study).

Spill models can also be used to determine the source of intermittent (mystery) oil spills from sunken wrecks. By operating the numerical spill models in hindcast mode, oil slicks can be backtracked to their source. This technology is being used by a number of regulatory agencies worldwide to identify the sources of illegal oil discharges from vessels at sea.

To undertake this modeling, it is essential that accurate 3-dimensional currents and detailed meteorological observation data are available for the region of study, including geostrophic current models. Complex nearshore environments tidal driven currents require detailed digital bathymetry data and tidal constituents for accurate hydrodynamic modeling.

Vessel Name: USS *Mississinewa*

Location: Ulithi Lagoon, Yap, Federated States of Micronesia

History of the Wreck: On 20 November 1944, USS *Mississinewa* (AO-59), a U.S. Navy oil tanker fully loaded with 12,900 tonnes of petroleum products (fuel oil, aviation gasoline, and diesel fuel) was struck by a Kaiten (Imperial Japanese Navy manned suicide torpedo), became engulfed in flames, and sank with a loss of 63 U.S. Sailors and one Japanese. Several forward fuel tanks were damaged in the explosion and subsequent fire, and an unknown amount of oil was released and burned as the tanker capsized. Oil was observed leaking from the vessel in August 2001 (Figures M-1 and M-2). Navy teams patched leaks in September 2001 and again in February 2002.

Oil Pollution Risk: The volume of oil remaining onboard in 2002 was estimated to be 6,600-9,300 tonnes of mostly Navy Special Fuel Oil, which is a heavy and persistent oil. Ulithi Lagoon is highly sensitive with abundant natural and socioeconomic resources. Biological resources include: nesting and migratory green and hawksbill sea turtles (endangered worldwide); nesting and migratory seabirds; coral reefs and seagrasses with associated fish and shellfish resources; and whales. The local population depends heavily on seafood for protein. There is a nascent sport diving industry. Chronic or catastrophic oil spills would have significant biological and socio-economic impacts.

FIGURE M-1. OIL SLICK FROM THE LEAK OF NAVY SPECIAL FUEL OIL FROM *MISSISSINEWA* IN ULITHI LAGOON. TAKEN ON 9 AUGUST 2001 (PHOTOGRAPH COURTESY OF NOAA).

FIGURE M-2. OIL LEAKING FROM *MISSISSINEWA*. TAKEN IN SEPTEMBER 2001 (PHOTOGRAPH COURTESY OF SUPSALV).

Other Special Issues: *Mississinewa* is a war grave. Because the vessel was upside down (Figure M-3), the offloading operation did not require entry into any spaces that may contain human remains.

A compete ban on fishing within the lagoon area had been imposed by the Environment Protection Agency and Marine Resources Department of Yap State in July 2001, resulting in great hardship for the local population. On recommendations by the South Pacific Regional Environment Program (SPREP) during the environmental assessment in early September 2001, the fishing ban in Ulithi lagoon was lifted by the Governor of Yap (Gilbert, 2001).

Legal, Policy, and Financial Issues: The wreck was a U.S. vessel in the water of another country, FSM, although there is a Compact of Free Association between the US and FSM. The decision to remove the oil involved issues of sovereignty and the liability from future pollution. An Environmental Assessment was conducted, leading to a Finding of No Significant Impacts from the planned removal actions.

Salvage Operations Summary: To prevent the possibility of both chronic and catastrophic oil releases, the U.S. Navy decided to conduct operations to offload as much of the remaining oil as feasible. Figure M-3 shows the tank locations and condition. Water depth at the vessel was 38 m; water temperatures were 80°F at the bottom. Currents were weak to moderate.

Based on the recommendations in the Environmental Assessment, offloading operations were conducted in the winter because:

- It was important to avoid the risk of a spill during the nesting season (spring and summer) when there would be large numbers of birds and sea turtles present in Ulithi Lagoon;
- Trajectory analyses indicated that any oil releases during the northeast trade wind pattern would quickly be transported to the west-southwest. Statistical analysis based on actual wind data for 1995-1998 showed that the bulk of any spilled oil would pass outside the limits of the lagoon within 12 hours after the release under the trade wind pattern. In contrast, during the southwest monsoon climatic pattern, any spilled oil would tend to remain within the lagoon for a longer period of time.

Support tug and tank barge were anchored in a four-point moor to limit damage to possible exposed coral and hard bottom areas. The oil was removed using divers with surface-supplied air using pumps and hoses, manifolds, and a modified version of the Light-Weight Hot-Tap system. Oil was pumped directly into a receiving barge. During tank stripping operations there was no discharge of decanted water. Oil was removed from sixteen tanks or other spaces.

Divers cut large assess holes into fuel oil tanks to reach the engine room spaces. No oil was found in these spaces. The bow section was separated from the stern and laying on its side (Figure M-3) preventing direct access to the forward fuel oil tanks. Divers cut an access hole and subsequent sampling holes in adjacent tanks.

Most of the pumping was accomplished using a four-inch Hydrasearch centrifugal pump. These lightweight hydraulic pumps could be easily moved by a diver and helped to reduce rigging time. The relatively low viscosity fuel oil at 80°F allowed for pumping rates of 1-2 tonnes per minute.

After pumping each tank or space, it was recorded as “closed” only after several sequences of settling and stripping. Stripping cycles could take several days for some tanks. When no pumpable oil was observed the hose was removed and a pipe cap was installed. The cap and all bolts were then covered by a larger cap and epoxied in place. No bolts or flanges were left exposed to prevent removal of the caps.

All project solid waste, sewage, and recovered oil were stored on the recovery barge. All sewage was processed through portable sewage treatment plants, meeting IMO/USCG requirements. Solid waste was stored in deck containers for disposal in Singapore. The recovered oil and water mixture was sold in Singapore. The quality of the oil varied as to tank, with some delivered of good quality and others with high water content disposed of as sludge. Approximately 6,000 tonnes of oil were delivered, with only 0.15 million gallons of water. This low water-to-oil ratio was the result of good pumping discipline and the relatively high viscosity of the oil which promoted tank stripping.

Oil does remain in the wreck in piping, some spaces and in tanks. Overall the residual oil volume is probably less than 50 tonnes.

Oil spill recovery containment and recovery equipment were stationed at the site for potential pumping accidents. No oil spills occurred during the recovery operation, except for some minor deck-equipment hydraulic leaks of less than a few liters.

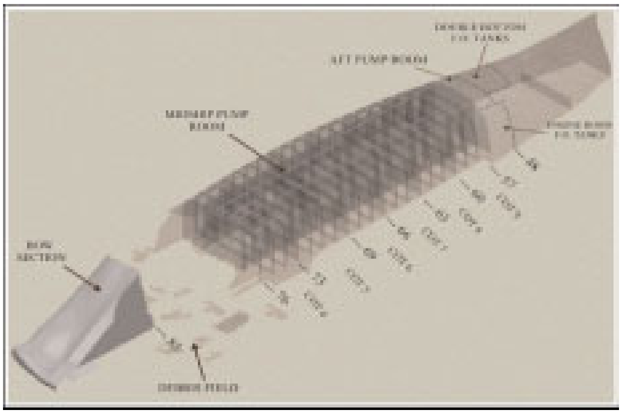

FIGURE M-3. DIAGRAM OF *MISSISSINEWA* SHOWING TANK LOCATIONS AND CONDITION. THE VESSEL IS UPSIDE DOWN AND BROKEN INTO TWO SECTIONS (NAVSEA, 2002).

Costs: Total recovery costs were US $4-5 million.

Lessons Learned: Other than the long distances required for mobilization to Ulithi, the oil recovery operation was relatively straightforward. The remote location required the operation to be mostly self sufficient with large working platforms moored in an exposed location in often poor sea conditions. The relatively shallow depth, good visibility, and warm water provided nearly ideal work conditions. The use of lightweight cutting and pumping tools simplified the diver work and allowed extra time to be taken to assure complete tank pumping and stripping. Earlier visits to the wreck provided valuable planning information and helped assure local government cooperation.

War Graves, Nautical Heritage, and Conservation Issues related to Shipwrecks

“ Over a seaman’s grave no roses ever bloom”

— old mariners saying

Many of the sunken war wrecks are also war graves for lost mariners and other military personnel and civilians. Despite beliefs to the contrary, a ship abandoned at the bottom of the sea is not without proprietorship. The depth of water does not transfer title of either the ship or its cargo to an enterprising profiteer or souvenir hunter.

US military vessels, for example, are never abandoned simply through the passage of time; they must be officially stricken from the Navy list. They remain fully commissioned ships, in effect a piece of US sovereignty and a monument honoring the dead on board just like a war cemetery on land. The remains of crew members from ships of any flag deserve respect and should remain undisturbed unless proper retrieval and burial becomes necessary and endorsed by the wrecks sovereign owner. Removing bones or skeletons from a World War II shipwreck is equivalent to grave robbing in the eyes of the military and their governments. Under no circumstances should the salvage or retrieval of human remains take place without the specific and written consent of the sovereign countries involved. The 1989 Salvage Convention does not apply to warships entitled to sovereign immunity under generally recognized principles of international law, unless that State decides otherwise.

It is clearly necessary to preserve these significant historical shipwreck sites for their cultural values as well as for their status as war graves. Multilateral agreements and relationships among governments need to be developed to control access to wreck sites, share confidential information, and seize recovered artifacts to restrict profiteering and commercial exploitation of sites.

It is essential to avoid the indiscriminate exploitation of sunken wartime shipwrecks once they have been identified. Treasure and souvenir hunters along with unsupervised recreational divers could disturb and destroy these heritage sites by taking mementoes and objects for interest or commercial gain. Before any fieldwork is undertaken, a site management plan should be developed to stop the looting and destruction of important archaeological shipwreck sites.

In any part of a wreck mitigation strategy, recovered underwater cultural heritage items should be deposited, conserved, and managed in a manner that ensures its long-term preservation. There is a need to include the curatorial aspects and conservation methodology for any recovered artifacts to ensure they do not degrade, are archived correctly, and are not lost. A well-developed and agreed wreck salvage plan needs to address the ownership of and ultimate disposition of any artifacts recovered.

Categorization of Sunken Wrecks

To assist in classifying the information available concerning sunken wrecks a three level categorization could be used in any wreck database: locations are evaluated, known, or suspected (Table 10).

Oil Cargo, Fuel Quantities, and Estimations

Accurate documentation of the remaining oil quantities as cargo or in bunkers of sunken vessels is difficult to access. The lack of accurate oil volumes and locations for sunken wrecks can be due to a number of factors that include:

- Inaccurate estimates of tanks/holds that were ruptured prior to sinking or how much oil has already leaked;

Table 10. Categorization of Sunken Wrecks.

Category	Category Description
Evaluated	Sunken wreck site has been accurately determined and wreck has been inspected and evaluated by divers and/or remotely operated vehicles
Known	Wreck site has been accurately located but not physically inspected
Suspected	Sunken wreck site location is based upon documented information but actual location is not known nor inspected

- Fires and explosions on some vessels may have continued for long periods and sometimes after crews were taken off prior to sinking;
- Records of fuel loaded, usage, and remaining stocks were not kept or lost with the vessel; and
- High explosives, shells, depth charges, and other munitions may have continued to explode while the vessel sank due to water pressure rupturing further holds and tanks.

In Chapter II, both high and low estimates were calculated using a standard approach. This or similar methods should be used to create a range of likely volumes onboard, which more appropriately reflects the potential risks and the uncertainties. When actual on-site wreck assessments are completed, more accurate oil estimates would be forthcoming.

Wreck Risk Assessment Criteria and Matrix

A three-level ranking can assist in the determination of whether a particular sunken wreck poses a threat of pollution and whether intervention, removal, remedial, or mitigation action is required, such as:

- High risk—action or mitigation required

Table 11. Site Wreck Risk Assessment Criteria and Ratings.

Site Assessment Criteria			
Risk Assessment Criteria and Questions	**High Risk**	**Medium Risk**	**Low Risk**
What is the size, type, and construction of the sunken vessel?	>10000 tonnes	1000-10000 tonnes	<1000 tonnes
What is the likely quantity of oil on board?	High; >1000 tonnes	Moderate; 100-1000 tonnes	Low; <100 tonnes
How accessible is the wreck to shore?	Nearshore or Lagoonal	Offshore but accessible	Open sea
How deep is the water where the wreck rests?	Access by conventional SCUBA	At limit of diving capability	Deep water Submersible access only
Has the wreck a history of previous oil releases?	Documented history of oil leaks	Occasional oil leaks or not known	None
What oil types are contained in the wreck? Are they persistent oils once spilt at sea?	Very persistent oil	Medium grade oils	Non-persistent oil
Is the wreck subject to severe weather events, such as storms, monsoons, hurricanes, typhoons?	High degree of severe weather possible	Moderate degree of severe weather possible	Low degree of severe weather possible
What is the stability of the seabed and what are the sediment effects on the wreck movement and integrity?	Unstable and/or high degree of movement	Relatively stable or not known	Known to be a stable seabed
What is condition of the wreck, degree of deterioration, and its fragility to natural disturbance effects?	Significant deterioration	Moderate deterioration	Mostly intact
Is the wreck subject to high level of hydrodynamic forces on the seabed?	High level of sub-sea currents	Medium level of hydrodynamic forces	Low level of currents and driving forces

Table 12. Environmental Assessment Criteria and Ratings for Sunken Wrecks.

Environmental Assessment Criteria			
Risk Assessment Criteria and Questions	**High Risk**	**Medium Risk**	**Low Risk**
Are there areas of high environmental sensitivity in the region? Consider distribution of sensitive habitats such as marshes, mangroves, seagrasses, coral reefs, mud flats, and kelp beds.	High level of environmental sensitivity	Medium level of environmental sensitivity	Low level of environmental sensitivity
Does spill trajectory modeling indicates significant environmental resources at risk from oil releases?	High probability of impact	Moderate probability of impact	Low probability of impact
How unique, rare or diverse is the ecology of the area likely to be affected?	High	Medium	Low
Are rare or endangered wildlife located within the region or potential spill impact zones?	High level of protected species in region	Low level of protected species in impact zone	No protected species in impact zone
What sensitive wildlife species are at risk? Consider the diversity, number, locations, and seasonality.	High number and diversity	Medium number and diversity	Low number and diversity
Are there routes for transitory species, such as migratory birds and marine mammals?	High abundance	Occasional	None
What is the preservation or protection status of the area at risk? Considerations include: marine park, wilderness, world heritage, and conservation status?	High level of protection and preservation	Moderate level of protection and preservation	Low or no level of protection and preservation
Are there any historical, cultural or archaeological resources in the area at risk, including war graves?	Significant resources and high value	Moderate level of resources	Low level or not present
Does the area at risk have subsistence fishing, traditional hunting/gathering or fish traps in the wreck area?	High degree of subsistence living in region	Medium level of dependency on subsistence	Low level or no dependency on subsistence
What is the extent of scientific, educational, or research interest in the area at risk?	High degree of interest	Occasional interest	Low or no interest

- Medium risk—monitor and reassess if conditions change
- Low risk—no action is required

In the analysis of risk, it is important to take a holistic view and not focus on one resource or economic consideration. There must be a balance between ecological, social, cultural, and economic criteria. Preliminary risk assessment criteria matrices are shown in Table 11, 12 and 13, together with a simple rating using high, medium or low risk. The criteria and associated risk ratings have been organized into three main categories related to site, environ-

Table 13. Economic Assessment Criteria and Ratings for Sunken Wrecks.

Economic Assessment Criteria			
Risk Assessment Criteria and Questions	**High Risk**	**Medium Risk**	**Low Risk**
Are licensed commercial fisheries, fish farms, aquaculture, pearl farming etc in the area at risk?	High level of economic value	Moderate level of economic value	Low level of economic value
What other significant industrial uses, economic resources or important uses of the sea are present in the area at risk (e.g., water intakes, aquaria, salt-pans)?	High level of economic use and dependency	Medium level of economic use and dependency	Low level of economic use and dependency
What important recreational or tourism activities are carried out in the area at risk (e.g., sport fishing, diving, snorkeling, boating, sightseeing, surfing, coastal recreational use)?	High level and/or high degree of economic value	Medium level and/or moderate degree of economic value	Low level and/or low degree of economic value
What level of marine use occurs within the area of the wreck?	High degree and range of marine uses	Medium degree and range of marine uses	Low degree and range of marine uses
Is the region used as a marine transport corridor?	High degree of use	Medium level of use	Low level of use
Does the wreck contain sufficient quantities of unexploded ordnances (UXOs) or other dangerous goods (DGs) that would pose a safety hazard or require exclusions zones near the wreck?	High quantities of UXOs and/or DGs known on wreck	Moderate or unknown quantities of UXOs and/or DGs on wreck	Low or no UXOs/DGs on wreck

mental and economic criteria. The assessment criteria are not listed in any order of importance or sequence.

The matrices provided in Tables 11, 12 and 13 provide preliminary guidance how determining the level of risk of potentially polluting wrecks. Political, security, cultural, and social factors may, in some cases, override environmental and economic concerns. For example, USS *Arizona* has been leaking oil into Pearl Harbor since 7 December 1941 and still contains an estimated 1,700 tonnes of heavy fuel oil within the corroding hull (Russell et al., 2004). Because of it's status as a National Historic Landmark, a war grave for more than 1,000 sailors and marines, and a war memorial visited by more than 1.5 million people annually, the National Park Service has initiated an *Arizona* Preservation Project. This work involves detailed studies of the rates of hull corrosion, oil release rates, oil degradation, etc. as part of an overall management strategy designed to assess the future risks of a catastrophic release and provide the basic research required to make informed management decisions for long-term preservation (Russell et al., 2004).

As a general guide, if the magnitude of the risk and the likelihood of extensive environmental damage are significant, then the oil should be removed, where appropriate. Removal of oil from a wreck is in most cases is significantly less costly than removing oil from the environment after release, damaging fisheries, wildlife, and other natural resources. Also, it is generally more cost effective to have a planned removal action, rather an emergency removal effort in response to a sudden leak.

VI. CONSIDERATIONS FOR REDUCING THE RISKS OF POTENTIALLY POLLUTING WRECKS

Problem Definition

One of our major efforts was to compile a worldwide dataset on potentially polluting wrecks, as the first step of problem definition. The result was the identification of 8,569 potentially polluting wrecks, with 1,583 tank vessels greater than 150 GT and 6,986 non-tank vessels greater than 400 GT. These numbers are staggering, considering that they represent only a subset of the total number of shipwrecks. Even more staggering is the volume of oil estimated to remain onboard these wrecks: a low estimate of 2.5 million tonnes (757 million gallons) and a high estimate of 20.4 million tonnes (6 billion gallons). There is always concern about a catastrophic release from these wrecks, however, the experience is that these wrecks leak slowly or episodically. Even small, periodic leaks can have significant impacts; *SS Jacob Lukenbach* is a classic example where many thousands of birds were killed over a period of ten years of mystery spills that were eventually connected to the wreck.

Uncertainty appears to be the most immediate problem. Despite all that is known about potentially polluting wrecks, disturbing gaps remain in our ability to definitively articulate the environmental threat beyond a nagging sense that the issue warrants earnest attention.

We find ourselves at a crossroads. Do we invest time and resources into sufficiently characterizing the pollution threat in order to support decisions on mitigating actions? Or, do we gamble on the capacity of the marine environment and its inhabitants, as well as our respective economies, to withstand any eventual release of oil pollution these wrecks may produce? The discussion below summarizes our findings and offers a number of considerations in navigating the path ahead.

Risk Assessment of Potentially Polluting Wrecks

It is clear that most of the oil remaining on these wrecks will eventually be released. More than 75 percent of the wrecks date back to World War II (thus have been underwater for 55-65 years), so there is added concern that corrosion, particularly of the piping, will lead to increased oil releases. It is also clear the consequence of such releases, when they occur, will vary greatly. Under the constraint of limited funds, it is important that oil removal efforts be prioritized according to the likelihood and consequence of oil releases. Therefore, there is a need for a systematic risk assessment of potentially polluting wrecks to characterize the pollution threat well enough to support decisions regarding appropriate mitigation.

Herein lies a problem. While there are data on wreck locations, there are very little reliable data on the quantities of oil and other pollutants aboard these vessels. In addition, it can be difficult to ascertain structural integrity of an historic wreck and its ability to contain any oil that may still be aboard. A good many wrecks are remotely located and cannot be easily accessed to examine their condition.

The following steps may deserve consideration:

1. Conduct a coordinated worldwide collection and collation of data on sunken wrecks, their locations, and potential pollutant loadings. This effort could be coordinated through regional associations that deal with oil pollution risk prevention and planning.
2. Create an integrated geospatial database of information related to sunken wrecks and make it available to all jurisdictions. The issues associated with protection of wreck sites from vandalism will need to be addressed.
3. Conduct systematic assessments using the best data sources and methods to identify those wrecks that pose significant environmental risks. The assessments should be updated as new information is made available.
4. Support research that will improve our understanding of the potential problem areas for oil leakage related to wrecks of different vessel types, such as:
   a. Improved ability to predict rates of corrosion and degradation of sunken wrecks for different seawater conditions; and
   b. Knowledge of the physical properties and behavior of heavy oils in deep water, cold water, and high-pressure seawater environments.

Improving the Legal Regimes for Wreck Removal

The United States has fairly structured wreck removal and pollution response regimes under the Wreck Act and OPA 90. In addition, OPA 90 includes a source of funds should an owner of a wrecked vessel either not be found, is unwilling, or does not take appropriate response and/or removal action. The major issue with the U.S. regime revolves around how to make determinations as to whether a wreck must be removed in order to abate the discharge of its oil polluting contents under OPA 90.

Removing oil from sunken wrecks often involves politically and publicly sensitive situations because of the potentially continuing threat of a discharge from a sunken wreck that may contain significant amounts of bunkers or oil cargo that could pose an ongoing threat to the environment unless the vessel is actually removed. The U.S. Coast Guard currently assesses situations on whether or not to remove a wreck on a case-by-case basis. There are no established national guidelines to assist a particular FOSC in determining what factors to take into account in making a determination of when a wreck should be removed in a particular situation.

It is, therefore, suggested that the United States consider adopting the following to improve the U.S. regime.

1. *Wreck Removal Guidelines*: Develop guidelines that take into account various factors to determine when a wreck needs to be removed in order to abate the discharge or the substantial threat of discharge of its polluting contents. For example, factors such as depth of water, amount of oil onboard, amount leaking, the vessel's condition, and the environmental resources threatened could be established through public notice and comment. Similar factors may be currently considered by individual FOSCs on a case-by-case basis, but a standardized national policy would be better to ensure a consistent use of the OSLTF in all situations.
2. *Financial Responsibility*: Require financial responsibility for wreck removal. In order to ensure financial security from a shipowner, vessels operating in U.S. waters could be required to demonstrate financial responsibility for wreck removal should an incident result in a vessel becoming a sunken wreck. In this manner, funding by the owner could be ensured to remove a wreck in a timely manner thus preserving the OSLTF for those occasions when there are no other options to remove a potentially polluting wreck.

Internationally, States have various pollution-related wreck removal authorities, but as a general rule, based on an IMO study, such regimes are less sophisticated then in the United States and in many cases are, for all practical purposes, quite weak or non-existent.

Based on an identified need for a widely accepted international standard, the IMO initiated deliberations on the DWRC in 1998. Much work has been put into the DWRC, however, there are a few outstanding issues that are under negotiation. It is too early to forecast how the DWRC will continue to develop.

Adoption of the DWRC, even in its present form, would greatly improve the current gap internationally with regard to mitigating polluting or potentially polluting wrecks. Clearly, the establishment of universally acceptable international rules on the rights and obligations of States and shipowners in responding to wrecks with dangerous cargoes and posing a threat to navigation and/or the environment would be a great improvement to the current situation.

The inclusion of a financial security regime is an important aspect to ensure that, should an incident occur, the owner of the sunken vessel is primarily liable and responsible for marking and removing the polluting wreck and that there will be funds available through insurance or other financial means to ensure that mitigation action is taken. This is a sound principal and may arguably take care of a great percentage of the international removal efforts. However, it is critical that an international fund be established to provide funding in case the owner cannot be found or such funds are insufficient. This has been a major issue in the development of the DWRC. No country wants to commit to unlimited liability for the removal of wrecks. However, there needs to be a fund established which would provide a stable source of funding for international removal in the absence of comprehensive insurance coverage.

A fund similar to the International Oil Pollution Compensation Funds (IOPC) could be established. Financing for the IOPC funds is limited to oil cargoes. [16] A fund for wrecked vessels would require broader funding because ships with large quantities of bunkers, for example, could pose a significant threat to the environment. However, consideration could be given to having, for example, Parties making a contribution based upon flag-state safety data and volume of registered vessels or some other agreed to criteria. In the alternative, the DWRC could require Parties to establish domestic funds similar to the OSLTF based on contributions from certain entities as a prerequisite to allowing a vessel to operate in that State's waters.

In any event, it is important for the world community to move forward with the DWRC and produce a universally accepted convention that will be widely and quickly ratified as soon as practicable. Failure to attract wide acceptance will result in no effective mechanism to mitigate and respond to pollution threatening wrecks in many places worldwide.

Lastly, there is a need for international agreement on how to address the lingering problem of sunken war wrecks, which are typically entitled to sovereign immunity and thus excluded from coverage under most legal regimes. Indeed, sunken war tonnage represents approximately 75 percent of the total number of known potentially polluting wrecks. There are obviously a number of maritime nations with a vested interest in this issue.

Improving Technology for Wreck Assessment and Oil Removal

Recent cases such as *Prestige* and *Jacob Luckenbach* have shown that there are few technological limitations to oil recovery from wrecks, even under very difficult conditions (deep water, strong currents, poor visibility). As long as there are funds available, salvors will come up with innovative solutions for wreck assessment and oil removal. Some considerations for improving the technological capabilities include:

1. The installation of emergency offloading piping and other technical design innovations of new vessels may assist with oil removal from a sunken vessel. Ship hull, piping and machinery design standards could be investigated to include simple requirements to assist in oil detection, containment, and recovery within a wreck. The increasing use of double-hull oil cargo tanks may increase the difficulty and risk of oil recovery operations. Drilling of double-hulls has been done using remote vehicles but at increased cost and risk.
2. A standard method of surveying the condition of wrecks to determine the relative risk of pollution should be developed. Such a method should consider:
    a. Oil Survey and Sampling. The advent of non-destructive oil sensing instruments, such as gamma-ray or neutron back-scatter meters, may allow for rapid assessment of oil volumes of a wreck. The increased use of this technique may now allow for a relatively low-cost survey of potentially polluting wrecks. Techniques for direct sampling of oils should also be developed and formalized for light and very heavy oils.
    b. Structural Condition. Further analysis of wreck corrosion rates could be used to develop a more complete understanding of the rate of hull and superstructure failure. Such data could become the basis of a wreck, risk stability model. A standard survey technique to measure and report on hull, piping and superstructure condition should be developed so that salvors and government authorities can share common data formats. Standard guidance and some basic training on the issues of wreck surveys, risks, and recovery techniques would be useful in assuring common approaches and evaluation techniques.
    c. Quality Control. Standard procedures should be developed to document the volume of oil recovered, to estimate the remaining oil volume, and to verifying tank close-out procedures.
3. The use of heat and/or fluidizers for removing heavy oils from tanks will remain an essential technique even with the use of pump annular water injection. Improved heat exchangers and similar techniques to fluidize oil should be developed to reduce the time, cost, and reliability of heavy oil recovery operations.

VII. REFERENCES CITED

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ENDNOTES

1 Sunken vessels that have no pollutants on board (e.g., pollution threat has been removed through salvage and/or lightering, or having spilled completely in the accident) were not included. Cargo is a petroleum-based marine pollutant (i.e., edible oils, fish catch, non-oil cargo, such as grain or ores, are not included).

2 "Marsden introduced this numbering system in the early nineteenth century as a means of identifying the geographic location of oceanographic and meteorological data. The Marsden square grid consists of 10° latitude-longitude boxes. The numbering begins at the intersection of the equator and the zero or Greenwich meridian. The square between 0° and 10° West longitude and 0° and 10° North latitude is numbered 001 and numbering continues westward through 360° of longitude to Marsden square 036. Marsden square 037 is directly north of Marsden

square 001, Marsden square 073 is directly north of Marsden square 037, etc.; this continues up to 80° North latitude with the last 10° Marsden square in the 70° - 80° latitude band numbered 288. The 10° squares between 80° - 90° North are numbered sequentially from 901 beginning at the Greenwich meridian and proceeding westward as before." (Information from National Climatic Data Center)

3 This can occur when the ship was recently or "posthumously" renamed. Renaming sometimes occurs when the vessel is being salvaged or scrapped after being sold to a new owner. The vessel under its original name would appear in the database as an existing shipwreck and not be linked to its being removed after being renamed by its new owner.

4 SPREP data was provided only with Marsden squares for location and without vessel names to protect the identity and location of the vessels to prevent the data being used to foster pillaging of artifacts and destruction at historically- or environmentally-significant wrecks, or to preserve the dignity of the humans who died in the vessel sinking (in the case of war graves).

5 Based on methodology in: International Maritime Organization (IMO), 1995. Interim Guidelines for Approval of Alternative Methods of Design and Construction of Oil Tankers under Regulation 13F(5) of Annex I of MARPOL 73/78. Resolution MEPC.66(37). Adopted September 14, 1995; Michel, K. and Winslow, T., 2000. Cargo Ship Bunker Tankers: Designing to Mitigate Oil Spills. SNAME Marine Technology, October 2000; Rawson, C., 1998. Assessing the Environmental Performance of Tankers in Accidental Grounding and Collision. SNAME Transactions, 1998.

6 US Pacific Fleet Commander-in-Chief. 2001. Ehime Maru: Environmental Assessment. June 2001. US Pacific Fleet, Oahu, Hawaii, USA.

7 77th Session, 20-24 April 1998.

8 Wolder v. United States, 613 F. Supp. 1139 (1985).

9 "Removal" as defined by OPA 90 "means containment and removal of oil or a hazardous substance from water and shorelines or the taking of other actions as may be necessary to minimize or mitigate damage to the public health and welfare, including, but not limited to, fish, shellfish, wildlife, and public and private property, shorelines, and beaches." 33 U.S.C. § 2701(30).

10 Complete defenses exist when an owner or operator can prove that a "discharge was caused solely by (A) an act of God, (B) an act of war, (C) negligence on the part of the United States Government, or (D) an act or omission of a third party without regard to whether any such act or omission was or was not negligent." 33 U.S.C. § 2703. In addition, liability is limited to certain amounts unless it can be shown that the incident was (A) proximately caused by gross negligence or willful misconduct, or a violation of an applicable Federal safety, construction or operating regulation, or (B) if the responsible party fails or refuses to report the incident, provide all reasonable cooperation and assistance in connection with removal activities, or comply with an order. Id., § 2704.

11 Initial CERCLA requests are limited to $250,000 per incident but can be increased with additional authority.

12 The Mariana Islands are a territory of the United States and therefore removal efforts funded by the OSLTF are authorized in its waters.

13 The DWRC does not apply to wrecks located in a State's territorial waters unless that particular State makes a formal declaration notifying the IMO Secretary General that the Convention will apply in its territorial waters.

14 However, if a State decides that it is going to take action against its own warships, the State must notify the IMO Secretary General of its decision.

15 As of May 2004, the exact length had not been determined.

16 The IOPC funds are financed by levies on certain types of oil carried by sea. The levies are paid by those that receive oil after sea transport, and normally not by States.