Risk Assessment Modeling Approach for the Prioritization Of Oil Removal Operations from Sunken Wrecks

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Introduction

An international survey (Michel et al., 2005) has identified over 8,500 sunken shipwrecks in marine waters, including more than 1,500 sunken tank vessels (≥150 gross tons) and nearly 7,000 sunken non-tank vessels (≥400 gross tons) (Figure 1). These wrecks may contain as much as 2.5 to 20 million tonnes (17.5 to 140 million barrels) of oil and other hazardous materials. Sporadic or continuous leakages, or potential sudden massive spillages from these wrecks, 75 percent of which stem from World War II (WWII), pose a continual risk across the globe.

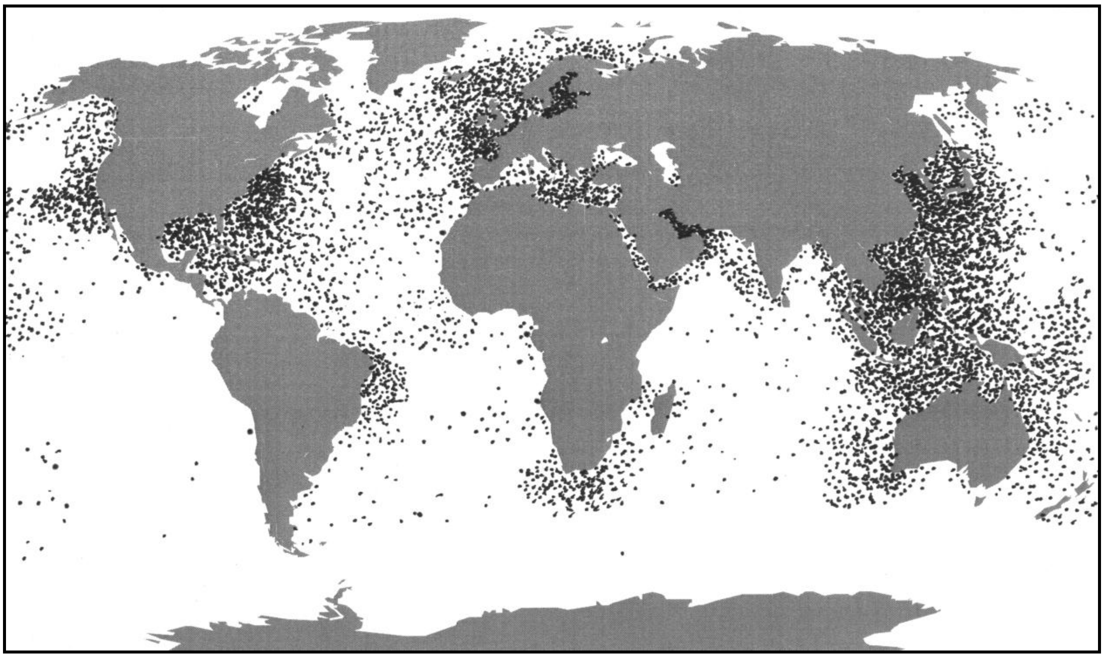


Fig. 1: Approximate positions of wrecks of oil tankers and non-tank vessels ≥400 GRT

Reactive strategies in addressing this threat, once releases occur, have proven to be ineffective and costly, as evidenced by the *Jacob Luckenbach* project. The *Jacob Luckenbach* sank in 1953 after suffering a collision 27 kilometers southwest of the Golden Gate Bridge off of San Francisco, California, USA. This wreck was identified as the cause of "mystery" oil spills that impacted wildlife and the California coastline since 1992. The decade-long release of heavy fuel oil from the wreck not only caused the death of over 51,000 seabirds and eight sea otters along the coast of California, but also impacted over 10,000 square kilometers of the Pacific Ocean along with near-shore tidal flats, wetlands, rocky inter-tidal areas, coastal beaches, sub-tidal reefs, kelp forests, and underwater canyons over more than a ten-year period – more damage than caused by the 2007 M/V *Cosco Busan* spill in San Francisco Bay. In the end, it cost the US more than US$20 million to remove the oil from this one sunken wreck and US$21 million to restore the impacted environment (Luckenbach Trustee Council 2006).

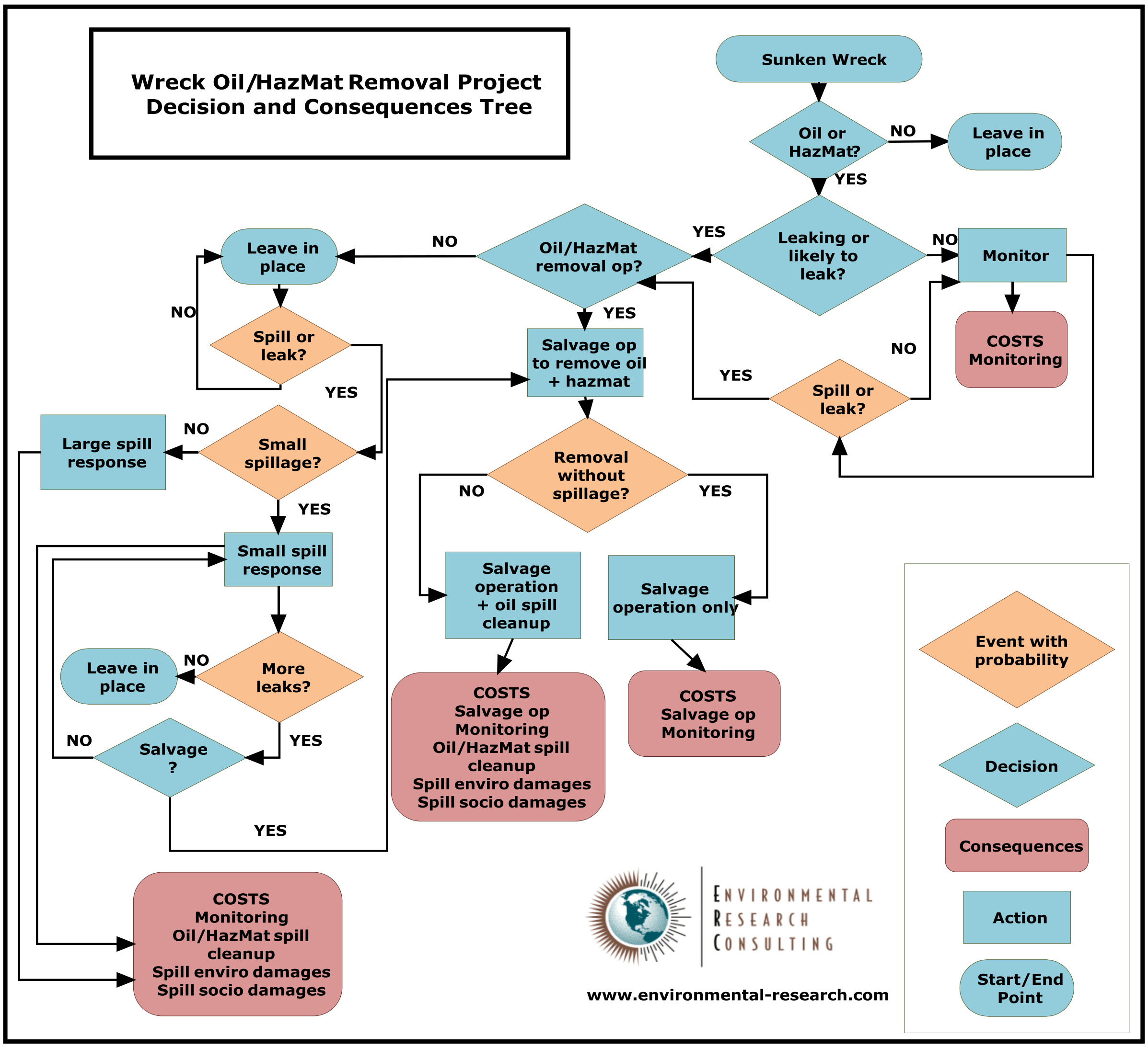
Responses to continuous oil leakage episodes that appear as “mystery spills”, or to a massive oil release, from one or more of these wrecks will cost *hundreds of millions of dollars*, probably significantly more. Because on-water oil response efforts are rarely highly-effective, the damages when environmentally-sensitive and economically-valuable wildlife habitats, shorelines, and coastal and marine waters are oiled will be extensive. The response costs and damages will be significantly greater when the responses occur on a *reactive* basis than the costs that would be associated with planned and controlled *proactive* oil removal operations. In other words, implementing a proactive strategy will mitigate damage and costs *before* there is an emergency and the oil is in our waters and on our shorelines.

Yet, it is *impractical* and *economically unfeasible* to remove oil and hazardous materials from *all* these vessels. Each wreck presents a unique situation with regard to the probability of leakage and the potential impacts of oil leakage. This paper presents a strategic modeling approach to prioritizing the wrecks with regard to their risk potential. The model takes into account both aspects of oil pollution *risk* – the *probability* that leakage will occur and the potential *impacts* of that leakage.

Methodological Approach

The overall approach to the risk assessment process as it would be applied to a decision-making process is shown in Figure 2. The first step is to determine the probability of leakage from a submerged wreck. This leakage potential depends on a number of factors such as cargo and fuel tank configurations, including the type of vessel and where build, the structural integrity of the particular vessel by design, its condition with regard to breakage and damage (particularly for WWII vessels that may have suffered torpedo or other damage), the depth at which the vessel lies, water temperature and salinity, and exposure to currents.

The nature of the leakage that might occur depends on the vessel condition, as well as the actual amount of oil on board the vessel, its cargo and fuel tank configuration, and the type and condition of oils on board. Tankers contain oil as cargo (in the form of crude oil or refined products), as well as bunker, lubricating, and engine oils. Non-tank vessels contain various types of bunker, lubricating, and engine oils. The condition of the oil is dependent on chemical and physical properties, as well as vessel depth i.e. the temperature. The oil may leak continuously or sporadically in relatively small amounts, or may be spilled into the marine environment in a single massive release.



The potential range of leakage scenarios – from continuous or sporadic small releases through a sudden massive release of most or all of the oil – presents a broad range of potential consequences. The impacts of oil spillage, including environmental and socio-economic damages, as well as response costs, vary tremendously depending on oil type and condition, spill volume, seasonal timing of the release, and duration, and, most importantly, *location*. The location of a spill with respect to its proximity to sensitive environmental, wildlife, economic, and cultural resources, the influence of prevailing winds, tides, and currents, and political jurisdiction has a great effect on the costs and damages that may result. The seasonal timing of a release can have a significant impact on the extent of wildlife impacts, particularly for migratory bird populations.

While cases studies and observations of the impacts of specific leaking wrecks provide some insights into the potential scenarios that might result from a spill from one of the many “potentially polluting wrecks” on the ocean floor, there are too many variables involved with each individual wreck to make any reasonable future predictions. The massive number of wrecks in some areas, particularly the South

Pacific, presents a logistical and economic challenge to policymakers and response officials. It is simply impossible for all of the potentially polluting cargo and fuels from all these wrecks to be removed. The wrecks need to be evaluated in a systematic and scientifically-based manner to prioritize the risk. The combination of a technically-sound leakage probability assessment with state-of-the-art modeling of potential spill impacts results in a comprehensive risk assessment approach that can be applied to prioritize wrecks for oil removal based on estimated risk.

Sunken vessels suspected of containing oil and/or other dangerous cargoes are evaluated with regard to the potential for leakage. Those vessels deemed highly likely to leak (or already leaking) are then considered for a risk assessment process. The costs associated with spill response for actual or hypothetical potential spills, as well as the environmental and socioeconomic damages associated with those spills are then compared with the costs of the salvage operations. The decision to remove the oil and other contaminants in a salvage operation is based on the outcome of the cost-benefit analysis of costs of the salvage operations in comparison with the *averted* costs and damages for spills.

Inventory of Wrecks

As the first step in this proactive process, the project must systematically assess the complex problem of undersea threats and account for the many wrecks that exist within the coastal waters of nations that are concerned with this issue, especially in areas of greatest environmental concern. This process will entail the further development of a comprehensive inventory of underwater wreck sites for incorporation into a specialized database (e.g., ERC's Wreck Database) that can be used to track vital wreck information. The critical information needed for the database shall consist of the location of the vessel, the true identification and historical significance of the vessel, the type of cargo and vessel specifics, the water depth the vessel resides in, the casualty date, and known evidence of oil leakage or survey descriptions of wreck. These wreck case-studies will be used to assess the pollution potential with regard to the likelihood of spillage and the potential volume of release and prioritize the vessels for proactive and preventive oil removal operations.

Determining the Probability of Leakage

The probability of leakage can be determined by defined screenings of the wreck through on-site/underwater surveys to determine the exact position and wreck and site conditions. A preliminary desk study can determine the vessel history and possible cargo and fuel contents, voyage history, drawings, and yard- and building details. An on-site survey can be used to verify or obtain on-site conditions in order to assess the potential pollution risk. Each survey is site-specific and will validate critical information to include: the verification of location information, prevalent weather and current patterns, assessment of historical condition, water depth, physical condition and position (e.g., lying on a particular side, upside down, sunk into the mud, etc.), type of steel used, effects of steel corrosion, site vulnerability, and inspection of tanks for remaining product.

Studies on steel corrosion are valuable for determining the probability and time involved before leakage could start to occur due to the disintegration of tank compartments and to predict any structural failure. Corrosion tests have shown the rate of corrosion penetration to be approximately 0.064 – 0.074 mm/year, and field studies have shown even higher rates of up to 0.115 mm/year (Wrubel 2007).

Use of State-of-the-Art Modeling to Simulate Spill Scenarios

The state-of-the-art capability of the oil fate and impact assessment model SIMAP™ (Applied Science Associates, Inc.) is ideally suited to this purpose (French et al. 1996; French McCay and Rowe 2004; French McCay et al. 2004). SIMAP uses wind data, current data, and transport and weathering algorithms to calculate the mass of oil components in various environmental compartments (water surface, shoreline, water column, atmosphere, sediments, etc.), oil trajectory over time, surface oil distribution, and concentrations of the oil components in water and sediments. SIMAP also contains physical fate and biological effects models, which estimate exposure and impact on each habitat and wildlife species (or species group) in the area of the spill. Environmental, geographical, physical-chemical, and biological databases supply required information to the model for computation of fates and effects. Seasonal and spatial variations in wildlife populations, particularly migratory birds, are incorporated into the modeling databases when available.

A preliminary assessment will involve running the SIMAP oil fate model in probabilistic mode. Model inputs are varied to provide a statistical characterization of likely consequences from each wreck: volume and timing of oil release (catastrophic release of entire contents over several hours; chronic leakage for days or weeks); and environmental conditions: randomize date and time of release to sample from a long record of environmental data (i.e., winds and currents, temperature).

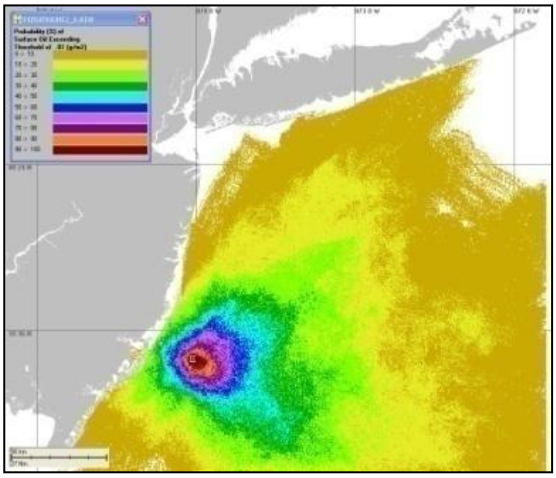


Figure 2: Probability of exposure map for surface oil greater than sheen thickness in SIMAP.

The model outputs are summarized in plots mapping the following exposure indices: surface slick or floating oil thickness; shoreline: average oil loading over the shore segment; subsurface oil concentration (entrained in water); dissolved aromatic concentrations in water (indicating toxicity to aquatic biota); and total hydrocarbons on/in bottom sediments. Maps (e.g., Figure 2) summarize the probability of exposure greater than thresholds of concern, the time (hours) of first exposure greater than the threshold of concern at each location, and maximum potential exposure (thickness, volume, or concentration) at any time after the spill. This preliminary set of model runs will identify wrecks worthy of further analysis because of the combined risk of oil release and impact on resources.

For those wrecks known or suspected to contain chemical hazards, the model CHEMMAP™ (Applied Science Associates, Inc.) (Figure 3) (French McCay 2001) can be applied to simulate spills and measure impacts.

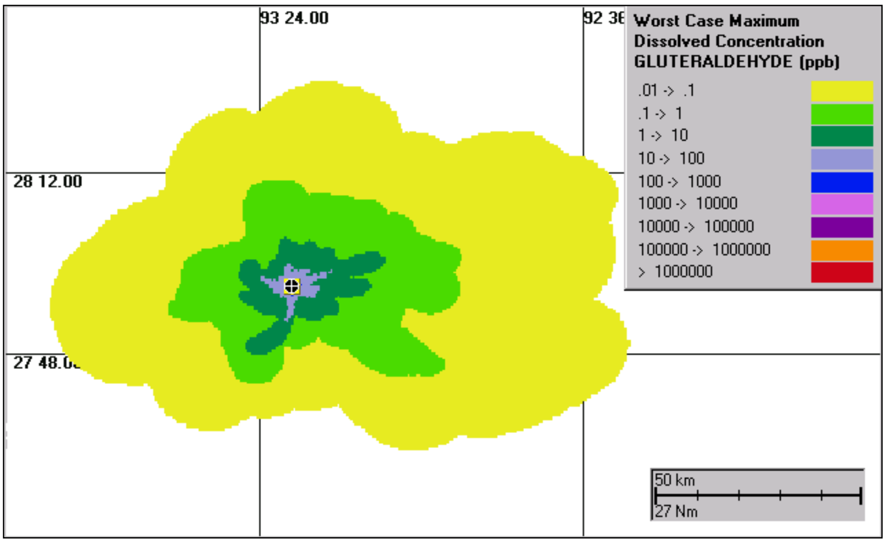


Figure 3: Maximum potential exposure concentrations for an example spill of gluteraldehyde in CHEMMAP.

Estimating Potential Costs and Damages from Spills

Using the data from the trajectory, fate, and effects modeling in SIMAP and CHEMMAP, with the addition of the appropriate spill response within the model simulation, the costs and damages from the resulting oil and chemical spills are then calculated. This methodology has been applied in several studies (Etkin et al. 2006; Etkin et al. 2003; French McCay et al. 2005).

Environmental damages (referred to as “natural resource damages” in the US) would be assessed for any spill of significant quantity to impact biological and recreational resources. Injuries to biological resources must be estimated using biological abundance and life history data for the area. Thus, a biological database for the area will be developed. For the biological impacts, environmental costs are based on cost of restoration of ecological services. For the risk assessment, estimation of environmental costs will be performed utilizing methods, where restoration costs are based on compensatory habitat creation. The scale of the restoration project is calculated using a food web modeling approach, based on the net increase in production provided by the new habitat. This approach has been used in a number of NRD cases in the US and is consistent with standard practice. Outside of the US, a similar approach will be applied, though the valuation of environmental damages will be commensurate with local practice. Modeling data outputs also include estimates of the numbers of individuals or biomass of various wildlife populations that would be affected by a hypothetical release of oil and/or chemicals from the wreck.

In addition to assessing impacts from oil and chemical spills to the environment (i.e., shorelines and biota in the water column, on the water surface and on the shorelines), the consequence assessment will also include assessment of response costs and socioeconomic costs (e.g., tourism, fishing, vessel/port traffic). The cost impact estimation should include costs for containment and clean-up. The environmental risk assessment should include a description of the resources available to respond to and contain an oil release. It should also take into account the amount of time needed to respond to a release. In the process of performing a response cost analysis, it could also be determined how to mitigate the risk of chemical spills by reducing the potential for spills with various prevention measures.

The cost of the hypothetical spill response that would be required are also calculated for the equipment, labor, and resources required for on-water operations (e.g., mechanical recovery and/or dispersant application) based on the behavior and trajectory of the oil on the water (Etkin and Welch 2005; Etkin 2001) . Shoreline oil and chemical removal costs are calculated based on the efforts required for removal by shoreline type, oil and chemical type, and degree of deposition as determined by the SIMAP and CHEMMAP simulations (Etkin 2003).

Prioritization of Wrecks

The “risk” from any particular wreck is the product of the probability of spillage and the impact of that spillage. Initial studies to “triage” wrecks in a particular region of concern based on the proximity of the wrecks to known sensitive resources and knowledge of prevailing currents that would likely cause significant coastal impacts, along with preliminary impact modeling could be used to narrow the scope of a more rigorous assessment. The wrecks could then be ranked with regard to risk based on detailed impact modeling and cost estimations studies.

Estimating Costs of Environmental Salvage Operations

Environmental salvage and oil removal technologies have improved dramatically over time making for more effective and safe removal operations. With today’s salvage and wreck oil removal technologies, combined with the availability of both moored and dynamically-positioned (DP) project support vessels, it is possible to work for extended periods of time at position and to deploy divers or remote operated tools without being hampered by mooring systems and the water-depth limitations of surface and saturation diving. Remote-operated vehicles (ROVs) are common tools in the oil and gas industry that allow the execution of very complex subsurface engineering and construction tasks. A variety of ROVs are available within the industry for either observation purposes or doing installation and construction work. The new work-class ROVs can go to 4,000 meters of water depth and beyond. Remote-controlled offloading systems (ROLS) can be used to gain pollution-free access from the outside of a ship’s hull into cargo and bunker tanks. Small portable modular hot-tap systems are available for use either by divers or in connection with a ROV.

Subsea oil heating systems for local installation close to the oil outflow valve are well developed. These systems are powered either by steam or high-frequency electricity and are meant to reduce the often high-viscosity of the oil to increase pumping rates. Alternatively, water injection at the outflow valve to decrease friction in transport hoses or mixing of oil residues with biological degradable oils at the outflow valve to reduce viscosity can both be used to aid in pumping.

Non-invasive identification of oil and emulsions has a great advantage over invasive techniques by reducing the risk of accidental leakage. An example of this technology is the neutron back scattering system (NBS), which measures changes in the density of hydrogen contained in water, oil, or other emulsions. The NBS is able to detect oil and emulsions through up to eight cm of steel walls.

Advances in oil/water separation capabilities are also now more developed, which makes it possible to have larger quantities of oil stored on board of the support vessels without the interruption of going back to port to discharge collected product.

The response community (environmental salvage companies, oil industry support companies, and diving companies) are able to address the threats of potentially-polluting submerged wrecks as never before. However, the required technology generally needs to be tailored to fit each job individually. Each operation will have its unique challenges and operations costs, many of which may not be predictable before the surveys and operations commence, as is the case for all spill response operations.

At the same time, the approximate costs of the necessary removal operations would need to be estimated as part of determining the outcome of a cost-benefit analysis of a hypothetical operation. In estimating the costs of the removal, water depth is the primary driving factor, though other site-specific factors need to be considered as well. Removal operations costs can be controlled by:

- *Pre-planning:* An oil removal job should be planned well in advance on the basis of an in-depth desk study and on-site surveys to develop the most cost-effective removal plan.
- *Informed contracting:* Costs can be controlled by defining a clear scope of work, and using market mechanisms such as tendering, clever contracting of sub- contractors inclusive of performance criteria.
- *Effective project management:* The establishment of proper management for the preparations and executions of projects is important in determining costs.
- *Executing at the right time of the year:* The timing of oil removal should be planned to fall into the best available season in order to avoid as much as possible down time and maximize working windows.
- *Work with proven technology:* Technology and equipment intended to be used should be tested by contractors and accepted by project management prior commencement of any contracts.

As part of the cost of salvage operations, the cost of precautionary spill preparedness resources needs to be considered. In addition, the cost of any spill (and the low probability of that event) needs to be taken into account.

Cost-Benefit Analysis of Removal Operations

The "benefit" of a proactive removal operation is the amount of damage and cost *averted* through the removal of the pollution threat. These damages and costs are quantified in the modeling and cost analysis phases of the assessment. These averted costs – i.e., the benefit – must then be compared to the costs of the removal operation to complete the cost-benefit analysis. In some cases, qualitative factors, such as the need to preserve cultural, historical, or natural resources that are difficult to quantify need to be considered in this process. It is also often important to consider the extent of biological impacts – on both habitats and specific wildlife populations. In some cases, there are potential impacts to rare and endangered species that cannot be adequately quantified in financial terms.

In some wreck cases, the a cost-benefit analysis may ultimately lead to a conclustion that a "leave alone and monitor" policy may be appropriate rather than an actual removal. In other cases, the benefits of removing a substantial threat will far outweigh the costs of the removal operations.

Conclusions

Many nations around the world have recognized the environmental threat posed by the cargo and/or bunker oils and chemical cargoes remaining onboard shipwrecks located in their respective waters, and that the time had long since come when action must be taken to deal with those pollution threats. Now, in light of the need to provide for a heightened level of marine environmental protection, and with the benefit of today's capabilities, there exists the capability to address the threat to the world's coastal and ocean environment posed by the aging population of shipwrecks by employing a proactive, rational, scientifically-based strategy. The use of a scientifically-based risk assessment process using state-of-the-art modeling capabilities provides authorities with rigorous data that can be used to make *informed* decisions on wreck oil and chemical removal.

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