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# Clean Up Techniques Used for Coastal Oil Spills: An Analysis of Spills Occurring in Santa Barbara, California, Prince William Sound, Alaska, the Sea Of Japan, and the Gulf Coast

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This Master's Project

# CLEAN UP TECHNIQUES USED FOR COASTAL OIL SPILLS: AN ANALYSIS OF SPILLS OCCURRING IN SANTA BARBARA, CALIFORNIA, PRINCE WILLIAM SOUND, ALASKA, THE SEA OF JAPAN, AND THE GULF COAST

by

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## Acronyms and Abbreviations

| **Term** | **Abbreviation** | **Description** |
|---|---|---|
| Clean Water Act | CWA | Federal Law in the United States that governs water pollution |
| Environmental Protection Agency | EPA | The United States agency that protects human health and the environment. |
| Environmental Sensitivity Index maps | ESI | A map of coastal resources at risk by oil spills. The map assesses |
| Incident Command System | ICS | Established to standardize on scene incident management for potential disasters. |
| International Petroleum Industry Environmental Conservation | IPECA | Addresses environmental and social issues internationally relating to oil |
| National Oceanographically and Atmospheric Association | NOAA | Understands and predicts climate, weather, and ocean behavior. |
| Net Environmental Benefit Analysis | NEBA | An analysis that evaluates if oil spill response improves or damages. |
| National Damage Resource Assessment | NRDA | Displays the extent of damage to resource due to an oil spill, and provides an assessment of for oil spill response. |

| | | |
|---|---|---|
| Oil Pollution Act of 1990 | OPA 90 | Improved the United States strategy for preventing and responding to oil spills. |
| Office of Response and Restoration | OR&R | responds to oil spills disasters, |
| Resources at Risk | RAR | Resources which would become effected by potential oil spills. |

# 1.0 Introduction

## 1.1 Oil in the Ocean

The world has become more and more dependent upon oil based products, derived from petroleum. These products are used to fuel automobiles, heat homes, produce energy, and are used for machinery in various industries. Some of the products that come from petroleum are gasoline, diesel, motor oil, kerosene, jet oil, heating oil, asphalt, and plastics. Oil is primarily stored and transported in large volumes via tankers because populous countries use large quantities of oils, and it is more cost effective to transport oil this way. However, while in storage or in transport, oils are sometimes spilled onto land or into waterways. Oil spills are a continuing problem throughout the world. Disasters such as the Deep Water Horizon oil spill and the Exxon Valdez oil spill, provide evidence that coastal oil spills pose danger to the economy and natural resources, and could directly affect the public's health (Boufadel, Bobo, & Xia, 2011).

## 1.2 Spill Response Overview

Potential oil spill volumes have been categorized by the National Oil Spill Contingency Plan, where they are broken down into three categories: a Minor Spill which is a discharge of oil less than 10,000 gallons, a Moderate Spill which is a discharge of oil of 10,000 to 100,000 gallons, and a Major Spill defined by a discharge of oil of more than 100,000 gallons (Samudro & Mangkoedihardjo, 2012). Spill containment technology methods used currently to clean up oil in coastal environments are: the use of booms, hard booms, sorbent booms, fire booms, skimmers, vacuum trucks, in situ burning, dispersants, and chemical cleaners. However, many variables can directly and indirectly affect the cleanup response, and it is important to have a clear understanding of what these variables are. These oil spill response variables include water temperature, size of spill (#barrels or #of US gallons), duration of time to clean up, wind speed, resources at risk, habitats at risk, public at risk, economics at risk, public interest, responsible party, and having enough money to carry out a successful operation (Azevedo, Oliveira, Fortunato, Zhang, & Baptista, 2014). These variables will affect the incident command system's worker response duration as well. An incident command system is a structure of policies and personnel created to improve emergency response. Within the incident command system there are groups such as operations, planning, logistics, and finance, whom are all overseen by the incident commander. Working with the incident commander are personnel such as the safety officer, the liaison officer, intelligence, and the public information officer. This team must work quickly and efficiently together and is an important factor in achieving a positive oil spill response.

The goal of my research is to examine reported data and information from oil spill responses in historical spills. I will be focusing on large bodies of ocean waters near Santa Barbara, California, Prince William Sound, Alaska, the Sea of Japan, and the Gulf of Mexico. I will also assess the oil response method as detailed above, and how it was implemented. This oil spill research will also examine available statistical data to examine if the oil spill response method was successful, while also looking at the lessons learned. I will conclude with recommendations for future oil spill cleanups based on my findings and examine new ways to respond to a spill that are available today.

### 1.3 Historical Spill Review

The first oil spill case study I will examine occurred in Santa Barbara, California. In January of 1969, the Union Oil Company workers were drilling from an offshore drilling platform stationed six miles off of Santa Barbara California's coastline at approximately 3,000 feet below the ocean floor ("Lessons Learned from Santa Barbara Spill : NPR," n.d.). Union Oil, which is now called Unocal, was granted a waiver by the United States Geological Survey, which allowed them to use a shorter casing on the pipe that went into the sea floor than Federal Standards had originally prescribed (Clarke, Hemphill, & Student, 2002). When underwater pipes ruptured, the blow out spewed more than three million gallons of crude oil ("Lessons Learned from Santa Barbara Spill : NPR," n.d.). The spill killed marine animals and blackened beaches.

The second oil spill to be examined is the Exxon Valdez oil spill which occurred in 1989 in Alaska on the coastal reef of the Prince William Sound (PSW). The oil spill occurred due to the ship going off course from the main shipping lane to avoid icebergs in the ships path (Haycox, 2012). However, the ship could not get back on track and struck the Bligh Reef. The Exxon Valdez spilled approximately 11 million gallons of crude oil, one mile off the shore into the ocean (Haycox, 2012). The oil spill eventually covered a total of 1100 miles of the Alaskan Peninsula's shoreline (Xia & Boufadel, 2011). Wildlife such as sea otters, sea birds, bald eagles, killer whales, and harbor seals were all effected from the oil spill (Brannon et al., 2012).

The third oil spill to be examined occurred in the Sea of Japan off the Oki Islands of Shimane Prefecture, on Jan 2, 1997. The Russian tanker Nakhodka carrying a cargo of about 5 million gallons of heavy oil, in route from Shanghai, China to Petropavlovsk, Russia, broke into two pieces and began to sink (K & Sciences, 2000). The stern section of the tanker sank soon after the incident down to the seabed at a depth of about 2,500 meters with an estimated 3.3 million of oil cargo on board (K & Sciences, 2000). The upturned bow section continued to drift in the ocean and eventually made land near the shore of Antou, Mikuni town, the Fukui Prefecture (Symposium, 1997). The Russian tanker incident resulted in an estimated 1.6 million gallons of oil spilled in the Sea of Japan (Kasai, Kishira, & Syutsubo, 2001).

Finally, the fourth oil spill that I will examine is The Deepwater Horizon oil spill. This oil spill that occurred on April 20, 2010 in the Gulf of Mexico, It is considered the largest marine oil spill in the history of the petroleum industry (Mary, Rose, & Hunt, 2012). The Deepwater Horizon oil rig exploded and gushed oil until it was finally capped on July 15, 2010, but the oil well was not completely sealed until September 19, 2010 (Mccormick, 2012). The total discharge of oil was estimated at 4.9 million barrels which is equal to approximately 210 million gallons of oil (Kurtz, 2013).

## 1.4 Overview

My research will contrast techniques used for oil spill clean-up by reviewing historical oil spills. I will provide a comparative analysis for response to oil spills that occurred in Santa Barbara, California in 1969; the 1989 Exxon Valdez Oil Spill; a 1997 spill that occurred in the Sea of Japan; and the 2010 Deep Water Horizon spill that occurred in the Gulf of Mexico. I will use these four spills as case studies to illustrate the methods used in the past for oil spill responses with the aim of contrasting oil spill remediation techniques used in each instance and to examine the outcomes of the response effort. Another goal of this research is to provide a review that summarizes cleanup techniques and strategies, and to determine under what conditions they are most effective. An additional goal is to assess what progress has been made in spill response and remediation technology.

In the following chapter, I will address oil spill risk assessment and response planning. Following chapter 2, I will provide information in Chapter 3 on Oil Spill response methods used in the field for coastal incidents. In Chapter 4, I will provide an assessment on four historical oil spills that have occurred within the past 50 years. Finally, in Chapter 5, I will assess oil spill tradeoffs and different types of considerations that are involved when responding to an oil spill. I will conclude my research with recommendations for past oil spill's responses.

## 2.0 Oil Risk Assessments and Response Planning

Response organizations understand that oil spills can be of all different sizes and shapes. Understanding the risks of potential spills will help responders to create a universal plan for management and operational tasks for events in sensitive areas. Oil spill response planners categorize the risk of spills into three levels, Tier 1, Tier 2, and Tier 3, which is the worst case for a spill. These levels are categorized by the capability of clean up organizations to respond to an incident, and the estimated volume of oil spilled. The four incidents that I will outline all are level Tier 3 oil spill incidents due the volume of their spills (EPA, n.d.) As we continue to examine the severity of potential oil spills, we are able to use risk assessment tools and new computer aided technologies to display models for better understanding of the risks involved.

The volume of oil spilled and the type of petroleum being processed have a direct correlation with the risk involved. Oil spill responders need to have all the appropriate data for the volume and types of petroleum that different facilities produce and transport (Prendergast & Gschwend, 2014) . Responders need to understand the risks involved for all facilities handling petroleum, so they can prepare for a spill if it does happen. Oil spill responders and planners need to understand all potential environmental impacts, and make human health always first priority.

## 2.1 Understanding Risks

Response planning involves understanding oil risk assessments, comprehending environmental sensitivity maps, being able to predict how spilled oil will weather, predicting oil's fate by reading trajectories, learning the different types of response actions, choosing appropriate associated plans, and being able to have personnel and equipment ready and capable for an oil spill response. As will be discussed below, after learning many lessons from past incidents, planning for oil spills has progressed for the better within the last few decades.

Oil spill contingency plans involve a rigorous amount of knowledge and preparation about potential oil spill sites. Responders have to determine what factors are present within the potential spill location, while planning for the worst case scenario in the event of an oil spill. Oil spill contingency plans are created using details of the spill risk, estimated oil spill sizes, oil spill trajectories models, information about surrounding habitats at risk and surrounding economic resources such as fisheries, spill response methods, weather patterns and seasonal changes, and ocean tides and currents . The results of these factors are then used to create an actionable plan for this specific vulnerable area. The actionable plan is designed to address all spill scenarios including the oil spill consequences involved. Environmental Sensitivity maps are used to help determine what resources at risk are present at a potential oil spill location. In the following section I will describe Environmental Sensitivity Mapping.

### 2.1.1 Environmental Sensitivity Mapping

An effective oil spill response plan involves understanding the environmental, biological, social and economic impacts in the location of potential oil spills. There are many things that oil spills pose a threat to, and knowing what is there to be potentially harmed helps responders to understand the resources at risk. The National Oceanic and Atmospheric Administration (NOAA), provides response planners with Environmental Sensitivity Index (ESI) maps on their web site, for all of the coastal regions in the United States ("Environmental Sensitivity Index (ESI) Maps | response.restoration.noaa.gov," n.d.) Figure 1 shows an example of an environmental sensitivity index map for San Diego, California.

These environmental sensitivity index maps show the types of resources at risk in an area that can be potentially affected by a future oil spill. ESI maps show all the habitats, plants, animals, type of shoreline, historical sites, and recreational areas that need to be measured before creating a spill response plan for a potential spill site. If a future oil spill is to occur, ESI maps allow oil spill planners to prioritize their response efforts. Seasonal sensitivities for species near a potential spill site are displayed on ESI maps. ESI maps also provide information on particular species which are most vulnerable (Environ, 2014), and also include all contact information for emergency personnel that would manage a spill in the potential area.

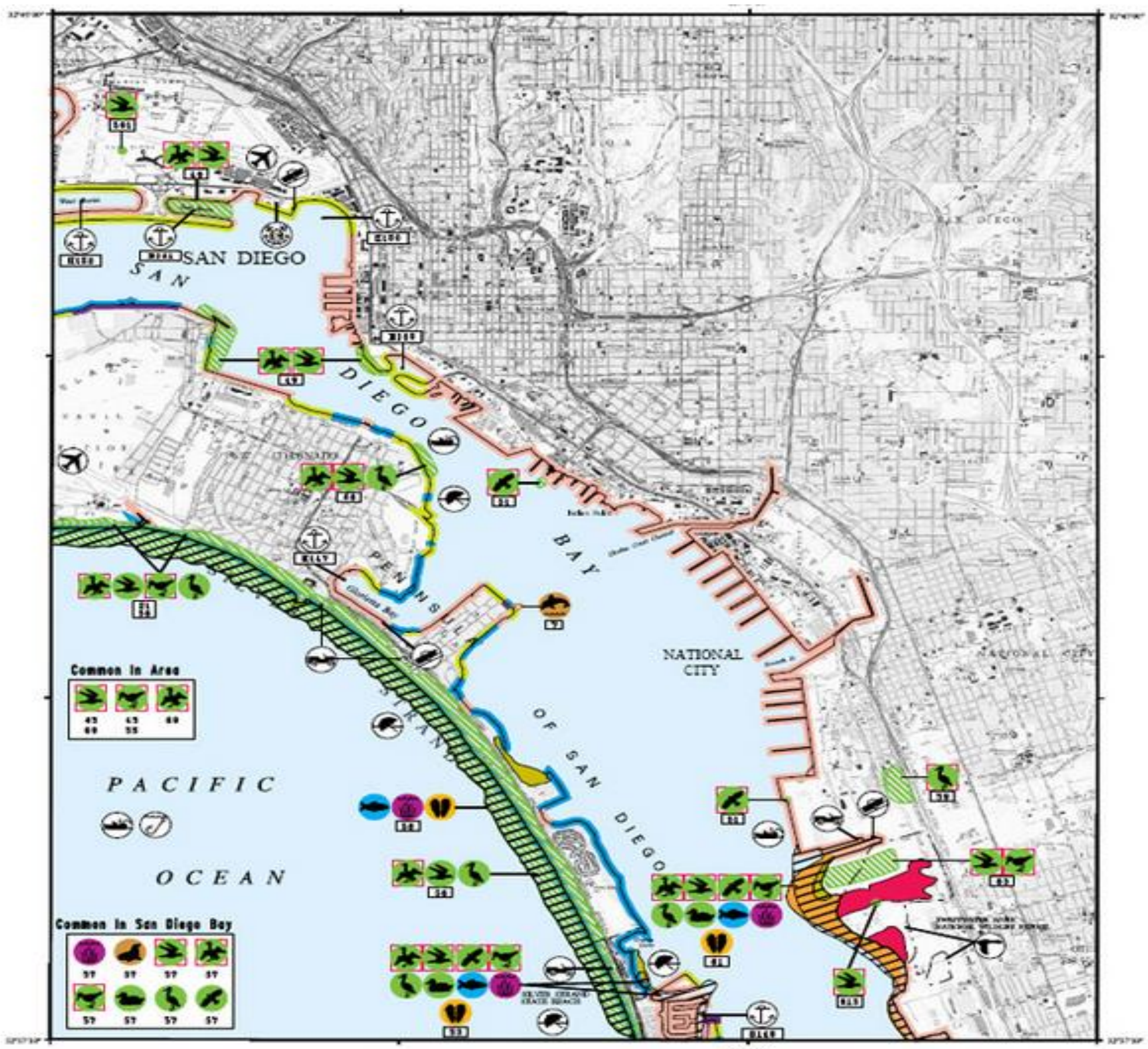


***Figure 1****: Environmental Sensitivity Map of San Diego, California. (US Department of Commerce, n.d.). Potential resources at risk are displayed on the map.*

*US Department of Commerce, N. O. and A. A. (n.d.). Transformations: Spill Response. Retrieved from http://celebrating200years.noaa.gov/transformations/spill_response/image3.html*

2.1.2 Weathering Preparation

All oil spilled in the ocean will eventually begin to change physically in a process called weathering. When oil weathers, it changes the way oil behaves. Weathering can occur at many different levels and there are a robust amount of variables that effect the weathering of oil in the ocean. These variables include; temperature of the ocean, sunlight on the spill site, behavior of the sea, and the amount of microbes available to consume the oil (Xhelilaj, Sinanaj, Qemali, Sheshi, & Vlore, 2010). Spill responders need to have a clear understanding of how spilled oil will weather, in order to choose the best response plan and technology for cleaning up the oil.

Some examples of oil weathering are: evaporation, dissolution, dispersions, absorption, emulsification, and photo oxidation (Figure 2). A common type of oil weathering is emulsification where the oil mixes with water and grows up to five times its actual volume, creating a type of mousse like texture on the ocean's surface. Mousse oil is extremely difficult to clean and can sometimes leave response strategies ineffective because of its inability to smother (Xia & Boufadel, 2011). Once responders have an understanding of the weathering process, they then try to determine the vulnerable areas that can be potentially impacted by referring to the previous discussed ESI maps.

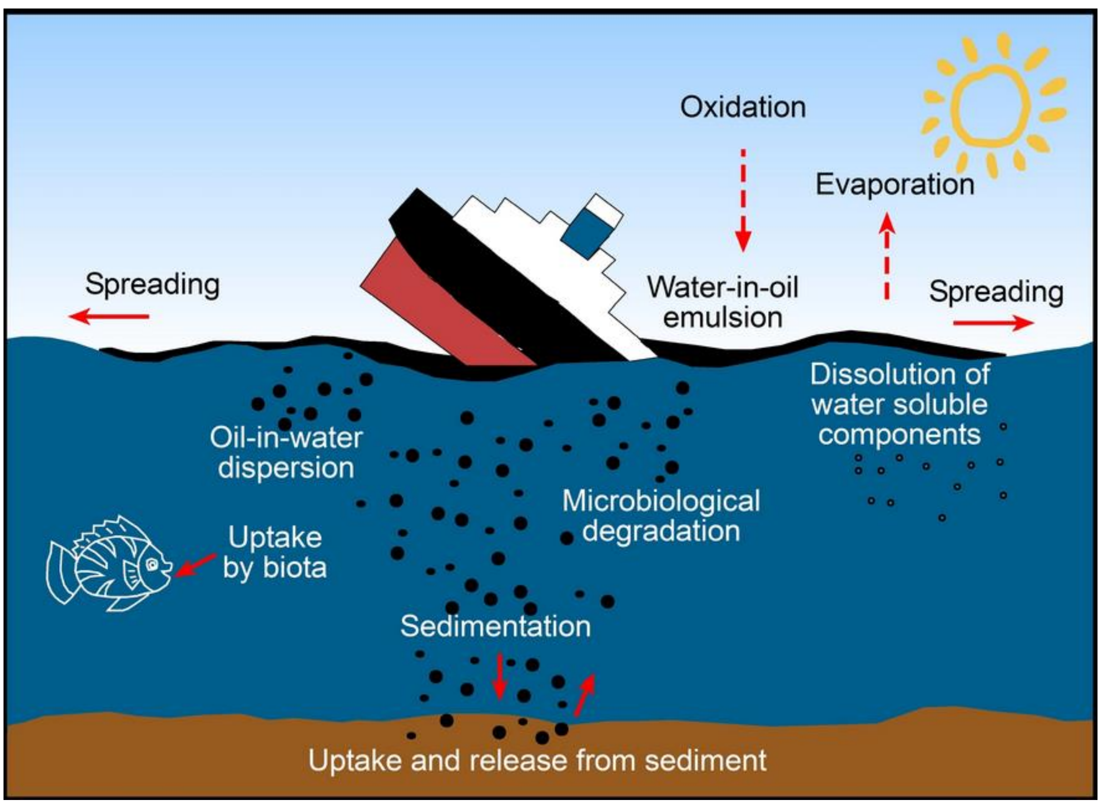


***Figure 2**: The fate of oil in marine environments. The Weathering Process of Oil*
("oil_weathering_900.jpg (2142×1551)," n.d.)

### 2.1.3 Trajectories

When an oil spill event has occurred and continues to release oil, responders need to know where the oil will end up. After oil spill responders understand the types of sources that can potentially spill oil and how much oil those sources can actually spill, then the responders use trajectories to determine where spilled oil could end up.

Oil spill responders use trajectories to better understand how spilled oil might behave under a vigorous amount of changing circumstances (Cekirge & Arabia, 2013). Trajectory modeling can factor in many elements to help responders determine the fate of the oil, such as: wave energy, weather, currents, winds, and season. Responders in the United States use programs such as: General NOAA Operational Modeling Environment (GNOME) (Figure 3); Wireless Information System for Emergency Responders (WISER); Computer-Aided Management of Emergency Operations (CAMEO); Areal Locations of Hazardous Atmospheres (ALOHA); and MARPLOT GIS mapping. (Oceanic, Administration, & Response, 2012). If unique locations are not able to be displayed using response programs, and data is unavailable likewise, then responders need to rely on local knowledge about ocean behavior.

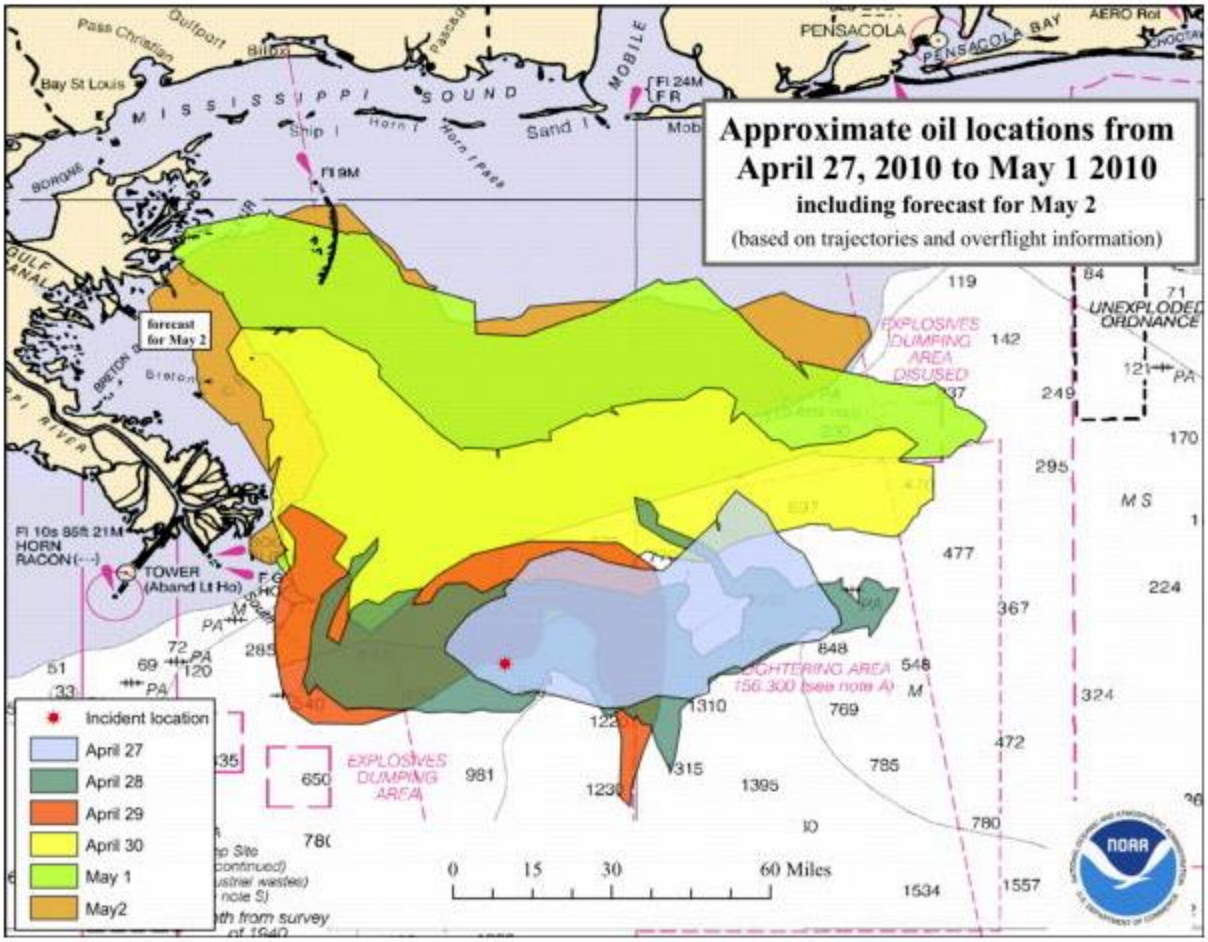


***Figure 3**: Oil Spill Trajectory Map of the Deep Water Horizon Incident. ("The Map Room - Mapping the Gulf of Mexico Oil Spill," n.d.). The Map Room - Mapping the Gulf of Mexico Oil Spill. (n.d.). Retrieved October 18, 2014, from http://www.maproomblog.com/2010/05/mapping_the_gulf_of_mexico_oil_spill.php*

Variables, such as the weight of the petroleum product and the physical conditions of the sea at the time of the oil spill, impact the behavior of an oil spill's projected path. Understanding what type of petroleum oil is spilled is crucial because heavy oils and light oils behave different. A heavy oil has an increased density and boiling point, and usually has high viscosity. A light oil has a decreased density and boiling point, and usually is low in viscosity. Light oils evaporate much faster than heavy oils do, and will create a different trajectory path, resulting in different response strategies for both types of oil (Wilson, n.d.).

New technology for oil spill response continues to improve. Barker recently said that many oil tanks are now using murphy switch gages that are linked to a program by ScadaLynx, which views oil tank levels. The newer technology allows responders to view flowing tube pressures, and can display the rates of gases within the system. He says that responders can now turn a 3000 barrel oil spill into a 1 barrel oil spill with the click of a button. If there is a system failure detected, responders can shut down wells from a computer or smart phone with this progressing technology (Barker, 2014).

## 2.2 Response Actions

Many response methods and strategies are considered for an effective oil spill response. The primary goal of any response action is to not let oil reach the shoreline where it will create the most amount of destruction. Not all oil spilled needs to be cleaned up, because the majority of oil biodegrades in the water column due to dispersion. When oil spill responders know that oil can potentially reach the shoreline, they will plan to deploy containment boom to create a barrier between the shoreline and the floating oil. Manual oil removal techniques are used when booming strategies become ineffective, and oil stands and fouls beaches. If the spilled oil is not heavy oil and is not smothering the shoreline, oil spill planners believe it is best to not respond to the spilled oil, and to leave the spilled oil where it is (Sylves & Comfort, 2012). There are many positive tradeoffs for leaving the light oil in place, one being that, it allows for natural processes to break down the oil.

Oil spill response planners contemplate all available and appropriate response actions. They consider all possible scenarios for oil spills within their response plan. Therefore, all responders are aware that no two oil spills ever the same, and all response plans are unique for every situation. For every oil spill event, responders will reassess the oil spills conditions, to determine which response action is most appropriate for a positive tradeoff. NOAA has created a list of five factors that need to be considered when determining a spill response: the first is to determine if there is any potential for human exposure by eating contaminated seafood by having direct contact with the oil; the second is what is the degree and duration of environmental impacts, if the oil is not removed; third, what are the natural removal rates for oil in this effected area; fourth, what is the potential for remobilized oil to affect other sensitive resources; and fifth, what is the chance that the cleanup response could cause greater harm than the oil alone (Oceanic et al., 2012). Although not require by NOAA, responders will also consider political influence for the affected community, perception of the public, and economic interests such as tourism and historical sites, when determining a spill response. Considerations such as political influence and its outcome of changing the way political decisions are made for a cleanup response pose difficulties at times between responders and locals in the affected community. The perception of the public in the affected community plays a role in the cleanup process because every day activates will be disrupted by the cleanup response. Tourism and historical sites in the affected community will be considered as well because economic interests are an important factor when determining how long the response duration will be. The following section will assess response plans for oil spill clean ups.

## 2.3 Response Plans

An effective oil spill response plan will depend on a group of different plans that must be appropriately ordered before a response can be carried out. These organizational plans are coordinated with local contractors and service providers to meet the needs of both the responders and the response activities.

The amount of organizational plans can vary depending on the size of the spill, and the appropriate number of oil spill cleanup personnel will be unique. All oil spills differ in size and their geographical location will pose different strategies for response, which in return will determine the correct amount of responders. Response tools/materials and technologies will be different for every spill as well. Organizational and response plans are determined within an incident command system. There are many position titles within an incident command system for hazardous waste operations for emergency oil spill response. Some of these positions include: Operations Section, Planning Section, Logistics Section, Finance/ Administration Section, Public Information Officer, Liaison Officer, Safety Officer, and Incident Commander (Orr, 2014) (Figure 4).

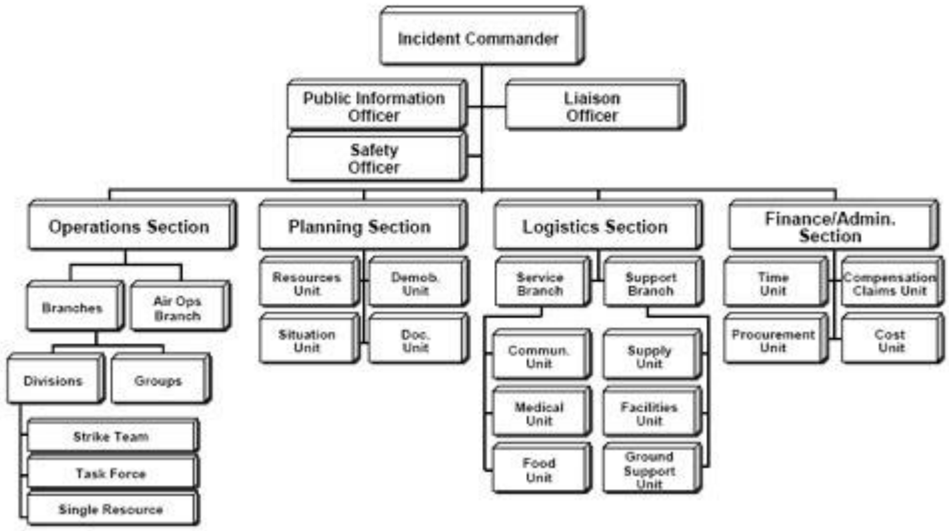


***Figure 4****: Incident Command System Roles for Hazardous Waste Operations for Emergency Response. (“Management - Oil Spill Solutions,” n.d.). Management - Oil Spill Solutions. (n.d.). Retrieved October 18, 2014, from http://www.oilspillsolutions.org/management.htm*

There are various organizational plans needed to support an oil spill response. They include: communications plan, catering and hospitality plan, decanting plan (for oiled water), demobilization plan, medical plan, notification plan, oiled wildlife plan, Post-response monitoring plan, Sampling Plan, Social Services and Humanitarian Aid Plan, Transportation plan, volunteer management plan, and finally a waste management plan. These are typical plans created for oil spill response.

## 2.4 Spill Response Readiness and Capability

Once all risks and strategies for a particular location are assessed and understood, oil spill responders prepare for response actions by frequently developing and/or improving response readiness and capability. Readiness and capability includes training all response personnel, continuously practicing response exercises, and maintaining supplies and equipment inventory used for spill responses. Any training that involves oil spill personnel needs to address any possible spill situation for a given location.

All oil spill response training exercises are coordinated with government, local stakeholders, and oil spill response organizations (OSROs). Some ORSO's that are currently helping to respond to disasters are: Clean Harbors; Clean Seas; National Response Corporation (NRC); Marine Express; Marine Spill Response Corporation (MSRC); and Patriot Environmental Services (Chang, Stone, Demes, & Piscitelli, 2014). Best practices for responders is to complete their training on all relevant response strategies for a given oil spill scenario, and then practice the response skills in the field. Responders then practice these skills in the location at risk from an oil spill.

Response supplies and equipment that are used for an oil spill response are determined based on the strategies outlined in response plans. The amount of supplies and equipment needed for an oil spill response is based on the possible spill scenarios of whether the oil spill event is a Tier 1, Tier 2, or Tier 3. Equipment and supplies are stored near locations that are easily accessible to responders. It is most crucial that oil spill responders keep equipment and supplies close to the sites where it will be used for response.

## 2.5 Summary

The Oil Pollution Act of 1990, signed by President George Bush, mandated the need for oil spill contingency planning. This type of contingency planning includes a set of actionable plans for a certain potential spill location, and provides data on spill risk analysis. These plans are set so that oil spill responders understand various spill scenarios within a vulnerable area. Different types of spill scenarios are developed based upon the size of the spill, the estimated trajectory of the spilled oil, and potential risk associated with the oil spill. Variables such as local weather, tidal patterns, ocean currents, type of season, and coastal geography are variables that can effect spill. These variables for oil spills are tested with data from past historical spills, and provide recommendations for response to potential spills. These recommendations provide strategies for identifying and protecting resources at risk such as vulnerable habitats, historical sites, and economic interests.

The understanding of spill response tactics by oil spill responders is crucial for a successful oil spill cleanup, and responders need to stay up to date with trainings and certifications. The response team is responsible for knowing where equipment is for potential spill clean ups and the equipment used for response needs to be in an easily accessible location. Oil spill response planning is considered useless if a response team is lacking in capability and readiness. Response teams need to have an adequate amount of cleanup crew ready to respond to a disaster, or chances of being successful will not be great. We have seen in the past from historical oil spills that although oil spill responders have a plan to tackle an oil spill, sometimes the response team is lacking responders or equipment. Oil spill response teams should review their plans for potential spills and continue to update their response plans to reflect new research on spill response strategies for local resources. The following chapter presents an overview of different types of oil spill response methods used in a spill response plan for coastal conditions.

## 3.0 Oil Spill Response Methods

Oil spill response methods continue to evolve and research is constantly ongoing due to the constant impact of environmental factors and how they interact with oil spills. Many improvements for response methods currently being used continue to be tested and redeveloped. Furthermore, each spill response can bring understanding of new ways of cleaning up oil. The Deep Water Horizon oil spill that occurred in the Gulf of Mexico in 2010 reinforced the need for responders to understand in situ burning and dispersants in a new way (Dana, 2011).

There are many different types of response methods including: passive removal, manual removal, and mechanical techniques. Some of the techniques used are: natural attenuation, sorbents, booms, bioremediation, chemical techniques such as dispersants, in situ burning, flushing and flooding, and high pressure hot water flushing (Environmental & Analysis, n.d.). Oil spill cleanup methods pose environmental impacts because not only is there oil in a place where there shouldn’t be, but now there is a cleanup crew there as well. Some cleanup methods are effective at removing oil but can result in environmental stressors to the coastlines and natural habitat. Some of these environmental stressors include: trampling the shoreline by response crews, vehicle degradation, and equipment overloading the shoreline (Reader & O'Connor, 2014).

The following section describes how response options and the physical characteristics of coastlines interact. Not all coastlines have the same characteristics, and the types of response strategies used typically depends on many of the coastline characteristics. The following sections also provide a brief summary of the most commonly used response options for coastal oil spills.

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## 3.1 Coastal Conditions

Coastal conditions vary around the world and determine how oil spill responders clean up the oiled beach. There are different environmental impacts that oil spills pose to shorelines, all of which are unique. Oil is carcinogenic and responders exposed to it become at risk for illness (Meo et al., 2009). Mammals, crustaceans, birds, plants, and fish all are directly affected by the duration of time it takes for an oil spill to reach the coastline and to be cleaned up (Morse, 2012). Oil can smother and foul shorelines eliminating the need for fisheries, and can damage local business and economies. Historic resources such as beaches and marinas all suffer from economic and social impacts brought on by the oil spill, which in return can dramatically decrease property values. Coastal conditions play a key role in determining response and removal strategies.

## 3.2 Passive Oil Removal

Passive oil removal is a cleanup method that does not use a manual or mechanical cleaning technology. Therefore, passive oil removal uses a method where the technology is simply the use of natural absorbent material. Oil spill responders choose to use this type of passive oil removal method if they do not want to disrupt the coastline that they are cleaning the oil from. This method of using absorbent to collect oil is also useful for puddles and small pools of oil. If determined that the disturbance to ocean plants and wildlife from cleanup activities will be present during a response, than oil spill responders will choose to use passive oil removal techniques.

### 3.2.1 Natural Attenuation

Crude oil under the right condition, will naturally break down in the environment. The process of natural attenuation for spilled oil involves the steps of oxidation, digestion, and biodegradation. This three step process does not involve any help from oil spill responders or remediation experts; it is a natural process within the ocean environment. Natural attenuation should be the preferred cleanup method when animal habitats are not at risk from the spreading of oil during the duration of this environmental process. However, the rate at which the oil is eliminated by this natural process is uncertain, due to how many different variables are involved with the ocean. Oil spill responders have understood how wave energy naturally disperses spilled oil evenly to make the oil more bioavailable to feed microorganisms which naturally process crude oil (Street, n.d.). Public opinion can sometimes become flawed by this natural process due to the fact that you are leaving the oil alone and not doing anything about the spilled oil. Natural attenuation method of cleaning up oil often is rejected even though it might possibly be the best method for an oil spill cleanup (Out, 2012).

### 3.2.2 Sorbent

A primary passive removal of oil is with the technology of absorbents and adsorbents. Sorbents are used very much like you would use a sponge. Some sorbents are even reusable making them sustainable. There are many unique types of sorbent; sorbent pads, sheets of sorbent, sorbent boom or sausage boom, snare boom, pom poms, hay and straw, and peat moss (Street, 2011e). The use of sorbent is selected if the spills location is accessible without disturbing the natural habitat. This is important because responders are going to be laying down sorbent to collect oil, and then they have to pick up the sorbent, and remove offsite, the oil that has been absorbed. The oil and sorbent is then properly decontaminated or disposed of by a hazardous response team. The goal of the response team using this form of passive oil removal is to not disrupt the natural environment when collecting the sorbent. Sorbent has proved to be good at collecting oil that has been trapped in coastal rocks, oil laying at the surface of the ocean, or even oil in small pools by the shoreline.

### 3.2.3 Containment Booms and Barriers

A primary way to contain and collect oil is by the use of containment boom and barriers. The oil can then be recovered by a skimmer or even by the use of sorbent. When oil is spilled, responders can see if it is floating on top of the ocean water, and if it is on the top layer of ocean water, it can be contained and collected easier than if the oil were to sink to the ocean floor. Booming can also be used to simply create a barrier in between the coastline and spilled oil. Booming is also an effective technique if oil is continuing to spill out of a tanker or a vessel. For instance, oil spill responders can surround the vessel with boom using a circle coral technique, which in return with trap the spilling oil in between the boom and the vessel. This is a useful technique especially if ocean waters are calm which would eliminate the chance of oil spilling over the containment boom barriers. Berm barriers can be made into any form and can be used on the sandy coastline for instance, to prevent oil from spreading into a sensitive wetland area where oil has not reached. By protecting these beaches with the use of barriers, responders can decrease the chance of disrupting multiple habitats, and minimize the effects the oil has on the intertidal zone, shoreline, and beach.

## 3.3 Manual Oil Removal

Manual oil removal uses oil spill laborers and quite often many laborers at once depending on the length of oiled coastline. Oil spill labor workers use many tools such as; sorbents, rakes, scrapers, pitch forks, brooms, scrubbers, shovels and buckets, tractors, bulldozers, trucks, and high pressure water hoses (Street, 2011b). Manual labors use these tools to physically removal oil that is stranded on shorelines. Manual labor can often disrupt the natural environment at the site of the spill by continual trampling by oil spill response workers.

### 3.3.1 Oil and Debris Removal

Labor workers use tools to remove oiled debris, oiled vegetation, oiled wildlife, oiled sediment, and oiled gravel along the coastline. The hazardous oiled solids are taken by a hazardous response team for decontamination at a hazardous waste disposal center. After the oiled debris is collected, new material such as sand or gravel can replace the old oiled shoreline surface. Sandy shorelines or beaches that cannot be manually accessed by heavy clean up equipment, often benefit by using the technique of oil and debris removal. Removing so much oiled debris from a contaminated shoreline can disrupt the shorelines natural habitat.

### 3.3.2 Cleaning and Scrubbing

Manmade structures and variations in shoreline can benefit from scrubbing and cleaning of oiled shores when the use of other technology can be insufficient at removing or collecting the oil. When scrubbing and cleaning shorelines, using detergents to help remove oil is extremely common (Street, 2011e). For instance if you were cleaning up cooking oil at home, you would want to use some detergent soap to help eliminate all of the oil in your kitchen. When using detergent on the shoreline oil spill responders have to understand the effects that the detergent will have on the wildlife's habitat close to the shoreline they are responding to. For instance lichens, algae, and limpets are all effected with the use of oil clean up detergents because they get scrubbed off rocks and manmade structures. Trampling the shoreline by labor workers also will have a negative effect on the environment due to the large amount of workers needed for some oil spill responses.

## 3.4 Mechanical Oil Removal

Mechanical oil removal is used when physical labor isn't enough help to remove oil. Mechanical oil removal uses equipment to remove oil from the surface of the ocean water. It also uses equipment to remove oiled material from the shoreline where manual labor is insufficient. Technicians are required to have proper training for the use of specialized equipment specific for oil spill cleanup. Mechanical removal can be very strenuous on a shorelines habitat's likelihood for survival. The environment around the oil spill cleanup site endures destruction from response trucks and conveyer belt loaders throughout the duration of the response. Therefore, before responding with the use of mechanical oil removal techniques, responders need to evaluate the likelihood for the shoreline to survive the type of stress. For rocky shorelines mechanical oil removal is not the first choice due to how hard it is to access them. However, sandy beaches benefit from this type of response method because this technique allows easy access to the shoreline and allows for large amounts of weathered oil to be collected with a minimal effect on the environment in return.

### 3.4.1 Vacuuming

Vacuuming systems used for cleaning up oil uses a suction technology to gather oil that has puddled on a shore or is in a pooled type setting. If used at the beginning of an oil spill response, vacuuming can prevent the settling of oil underneath rocky coasts or coasts with heavily oiled debris(“FIELD GUIDE : Shoreline Clean-up Assessment Technique ( SCAT ),” n.d.). The use of vacuum systems on oiled shorelines requires responders to not disrupt existing habitats around the contaminated site with heavy equipment being used to respond. Easy access to shoreline is important for response because responders will be making several trips to haul away oil that has been vacuumed up. Vacuum technology collects everything from oiled vegetation and wildlife, to oiled gravel and rocks. Therefore, the need to not disturb the natural habitat and preserve the natural environment around the contaminated site becomes crucial for an ecosystems survival. When a vacuum unit has been exhausted and needs to be emptied, typically it contain more water than debris. The need for large decanting containers to separate oily water for separation and disposal is then utilized by oil spill responders.

### 3.4.2 Shoreline Surface Material / Debris Removal

If oil is spilled in an area where it can naturally break down, it will eventually be eliminated naturally, without the need for manual removal. However, if this is not the case, and the oil cannot be broken down natural, once an oil spill event has fouled a coastline, the damage will continue until we remove the oiled debris. The goal is to achieve an effective cleanup and eliminate oiled debris such as soil and sand physically removing them. In order for cleanup crews to achieve this goal, they have to be able to access the beach that they are responding to. The method of mechanical removal of oiled debris on fouled beaches results in the need to backfill in the sediment, sand, or soil on the beach to its original form. This process can involve replacing the sediment, sand, or soil with new or decontaminated product (Strategic, 2013). Although effective for oil spill response, this method for shoreline surface debris removal can be troublesome to existing shoreline habitats. By altering an existing habitat during the cleanup can have a directly affect the habitat and involve a longer duration for complete environmental to recovery.

### 3.4.3 Flooding and Flushing

Flooding and flushing oil away with low pressure water can be an effective way at redirecting oil that has fouled the shoreline. By using the method of low pressure water, responders can collect the oil easily for removal, or they can simplify direct it back into the ocean to be remobilized and eliminated by the surf (Street, 2011a). However, the environment is always prone to stress, and this method can disrupt the natural habitat of the shoreline (Brannon et al., 2012). The stress on the environment is a result from responders hoses used for flooding, or simply because a responder flooded or flushed an area for too long resulting in over saturation of a particular area. Sediments that responders are not wanting to flush or flood, sometimes gets lost or displaced. Responders also have to be aware that if they are going to remobilize oil rather than removing the oil that they need to be sure that they are using sorbent boom to collect the oil. If they do not have sorbent boom properly placed when they are remobilizing the oil, then responders put the shoreline again at risk with the chance of oil re attaching itself to the shore. Oil spill responders have to plan when they are going to flush and flood certain areas depending upon whether it is high tide or low tide (Palinkas, 2012). The environment around the shoreline has evolved to handle the ocean tides, waves, and surf, therefore, making this technique useful in rock and gravel shoreline types.

### 3.4.4 High-Pressure, Hot Water Flushing

High- pressure hot water flushing and flooding is considered in situations where the environmental impact is not applicable, meaning that all wildlife and habitat would not be affected. A process has been developed for the response method of high pressure hot water flushing for oil fouled shorelines. The water is transported to the site by work trucks and is heated and pressurized on site. The water which is heated and pressurized on the work trucks, response boats, or cleanup barges, then it is sent through water hoses to the shore. The use of this oil spill response method is highly effective when there is not wildlife or habitats at threat. Primarily, this method is used on marinas or rip rap areas, where public opinion and economic pressure are a high priority. The method of hot water high pressure will typically eliminate any remaining plants and animals that have been scared with oil.  Hot water high pressure flushing can also push and pull oil deeper into rocks, making the shoreline environmental recovery have a longer duration than expected. (Street, 2011b). This happens because we are spraying the oil off with pressured water and the oil does not get absorbed by sorbent boom. Therefore, the oil gets trapped into the sediment before getting absorbed/collected for disposal. This method does harm plants directly, and can cause native plants to be eliminated without the chance of future survival.

### 3.5 Chemical

The use of chemicals for cleaning up oil, is used often due to how effective these methods can be for shoreline oil spills. Bioremediation, shoreline cleaners, dispersants, solidifiers, and surface washing agents, have all proven to be successful at removing oil from coastlines and restoring natural habitats (Street, 2011c). However there are tradeoffs involved with each method and its appropriateness is based on environmental analysis.

#### 3.5.1 Bioremediation

Bioremediation is an oil spill treatment option that will augment the natural biodegradation process of the ocean. Bioremediation requires the addition of nutrients or microorganisms to augment the natural breakdown of the petroleum. Bioremediation is most effective once the vast amount of oil that has reached shore has been cleaned up. Bioremediation methods such as refining the sediment or oiled soil makes for an effective catalysis to enhance the rate of microbial biodegradation (Street, 2011a). Although bioremediation can be effective, due to its slow recovery time, it is not always considered. Bioremediation is not only economical, but it is an effective technique for sensitive shorelines, due to being non aggressive to the shorelines habitat.

#### 3.5.2 Shoreline Cleaners

Shoreline cleaners help to divert oil that has become weathered or immobile. When flushing and flooding oil that has reached the shoreline becomes ineffective, the use of shoreline cleaners is considered to remove the oil ("FIELD GUIDE : Shoreline Clean-up Assessment Technique ( SCAT )," n.d.). The shoreline cleaners help to break up and release oil, which is then be contained by boom and collected by sorbent. The use of sorbent is necessary so that the oil isn't again released into the ocean. Regional response teams will typical approve the use of shoreline cleaners to an oil contaminated shoreline before they are used by cleanup crews.

3.6 In Situ Burning/ Controlled Burning


***Figure 5**: Controlled burning process: before, during, and after.*

("Controlled Burning - Oil Spill Solutions," n.d.)

In situ burning is a technique used by oil spill responders which involves the controlled burning of oil that has spilled from an oil source. As seen in Figure 5, oil spill responders surround the floating oil with fire containment boom, and preform a controlled burn to eliminate the oil on top of the ocean water's surface. Some different types of oil/gas will burn uniquely and release different properties into the air (Table 1). This chemical/physical process turns the liquid phase of spilled oil, into the gas phase of oil. When In situ burning conducted properly, in situ burning significantly reduces the amount of oil on the water and minimizes the adverse effect of the oil on the environment. The method of In situ burning is used once responders consider if there are communities nearby that can become affected from the emissions from the burn, and what is the risk of secondary fires present. If both of these circumstances are not present than in situ burning is considered. Weather forecasting is extremely important so we know the wind will not shift and endanger local populations. In situ burning a useful strategy in remote locations or when storage and disposal of the oil will be too costly and difficult to removal. Safety concerns involving the emissions from the controlled burns prose concern. The main health problems from emissions come from; Carbon monoxide (CO), Sulfur dioxide (SO2), Nitrogen dioxide (NO2), Poly aromatic hydrocarbons (PAHs), Particulate matter (PM), Carbonyls (aldehydes and ketones), and Volatile Organic Compounds (VOCs). Controlled burning has been used in many past historical oil spills, including the Exxon Valdez oil spill of 1989, and the most recent Deep Water Horizon Oil Spill of 2010.

***Table 1**: Burning Properties of Various Fuels. Table 1 displays data on potential spilled oil that can be removed by in-situ burning.*

("Controlled Burning - Oil Spill Solutions," n.d.)

**Burning Properties of Various Fuels**

| Fuel | Burnability | Ease of Ignition | Flame Spread | Burning Rate* (mm/min) | Sootiness of Flame | Efficiency Range (%) |
|---|---|---|---|---|---|---|
| Gasoline | very high | very easy | very rapid through vapours | 4 | medium | 95-99 |
| Diesel Fuel | high | easy | moderate | 3.5 | very high | 90-98 |
| Light Crude | high | easy | moderate | 3.5 | high | 85-98 |
| Medium Crude | moderate | easy | moderate | 3.5 | medium | 80-95 |
| Heavy Crude | moderate | medium | moderate | 3 | medium | 75-90 |
| Weathered Crude | low | difficult, add primer | slow | 2.8 | low | 50-90 |
| Crude oil with ice | low | difficult, add primer | slow | 2 | medium | 50-90 |
| Heavy Fuel Oil | very low | difficult, add primer | slow | 2.2 | low | 40-70 |
| Waste Oil | low | difficult, add primer | slow | 2 | medium | 30-60 |

** typical rates only — to get the rate in Litre/m2/hour multiply by 60*

*Ref:* Dr Merv Fingas of Spill Science

3.7 Summary

There are two classifications for oil spill response methods. These classifications are either non aggressive removal or aggressive removal. The first classification is nonaggressive removal, which includes methods such as, vacuum removal which used vacuum trucks to collect standing oil; physical removal such as using machinery to remove oiled debris form fouled coastlines; manually removing the spilled oil by using sorbent materials like straw to absorb the oil; low pressure washing of the coastlines, with the use of non-hot water; and finally the use of bioremediation to eliminate the oil by adding oil eating organisms in the affected area. (Environmental & Analysis, n.d.). The second classification is aggressive removal, which includes methods such as: relocating oil fouled sediments by using trucks, bulldozers, and heavy machinery that tramples and causes disruption to the natural coastline; the use of water with high temperature that is sprayed at high pressure to remove the oil; chemical cleaning to remove the oil, which in return will harm the natural environment by introducing toxic chemicals, and finally sand blasting the coastline to remove the oil (Environmental & Analysis, n.d.).

Oil spill response methods differ along coastlines because of the vast amount of variables that influence the spilled oil's direction and destination. Methods such as flooding and flushing, high-pressure hot water flushing, in situ burning, booming and sorbent, dispersants, bioremediation, and other chemical treatments have been used and prove to be effective along shorelines (Table 2). When responders decide what technique to use when responding to an oil spill they have to consider many factors such as; keeping the responder safe on the job site, shoreline accessibility, availability of response equipment for cleaning oil, the weather currently at the coastline while still factoring in wave and tidal predictions, how deep the water is, and finally what is the physical state of the weathered oil at the time of the response. Equipment such as: booms, skimmers, sorbents, chemical and biological agents, vacuums, and shovels are used to collect oil (Table 3). The goal of these response methods is to remove the spilled oil from the fouled coastline, and to create a catalyst for the natural environment to recover from an oil spill. Incident command systems have to factor in a number of tradeoffs for social and economic interests when considering what response method to use for an oil spill cleanup, so it is not always a straightforward decision.

***Table 2****: Methods for cleaning up spilled oil. Adapted from :* (Strategic, 2013)

| **Methods for cleaning up oil** | **Pros and Cons** | **When to Use** |
|---|---|---|
| Bioremediation; *which is the use of biological agents to break down or remove spilled oil.* | Inexpensive, effective, but hard to control and still poses risks on human health | bacteria needs to be readily available, when other methods will cause harm to natural environments |

| | | |
|---|---|---|
| Controlled burning/ In-situ Burning | Reduces oil but can cause wind pollution | Large oil slick, when human health is not at risk |
| Dispersants; *which cause the oil slick to break up and disband.* | Separates the oil slick, but still pollutes the water | Large oil slick, bacteria needs to be readily available |
| Vacuum and centrifuge; *which collects and separated the oil and water* | Effective method, but can disturb the natural environmental with heavy clean up machinery | When oil is floating, when oil can easily be collected, when location allows access |
| Natural Attenuation; is a method of allowing the natural environment to | Used in ecological sensitive areas like wetlands | When other methods will disrupt the natural environment |
| Dredging; used for oil that is dispersed with detergents. | Eliminates oil by physical removal, but can only be used for oils denser than water and can disrupt the surrounding environment. | When the environment allows access, when oil has been removed from the top layer of sediment but still exists below. |
| Skimming; which traps spilled oil for later separation | Effective method, but requires calm waters at all times during the process of skimming | When oil is floating, easy to surround the oil, clam winds and ocean current |

***Table 3****: Equipment used for Cleanup operations. Adapted from :* (Strategic, 2013)

| **Oil Spill Clean Up Equipment** | **Description** |
|---|---|
| Booms | floating connected barriers that gather the oil for easy collection, can relocate oil floating on ocean's surface, can be used as a sorbent as well |
| Oil Skimmers | Skims the oil floating on the ocean's surface for collection and separation. |
| Oil Sorbents | large solid absorbents that absorbs oil, can be chemical and natural forms |
| Chemical and biological agents | helps to break down the slick oil, and disperse the oil for later collection |
| Vacuums | Removes spilled oil from fouled coastlines and the ocean surface. |
| Rakes, shovels, tractors, bulldozers, conveyor belts, and other road equipment | Manual labor tools used to clean up/collect oil on beaches |

## 4.0 Historical Spill Incidents

There have been many oil spill events that have occurred in the past and damaged coastlines throughout the world. Some spills are larger than others, and some spills although not as large as, have a greater environmental impact. I researched four different oil spill events that have occurred over the past 50 years: the Santa Barbara oil spill of 1969 in Santa Barbara, California; the Exxon Valdez oil spill of 1989 in Prince Williams Sound, Alaska; the Sea of Japan oil spill of 1997; and the Deep Water Horizon oil spill of 2010 in the Gulf of Mexico. What follows is a summary of each incident, the different types of response methods used during each cleanup, any long term impacts that arose during the oil spill cleanup, and lessons learned after the response.

### 4.1 Santa Barbara Oil Spill 1969

One of the biggest oil spills in United States history was an oil spill in Santa Barbara, California which occurred on January 29, 1969. An off shore oil rig, Oil Platform A, suffered a blowout. This oil rig blowout spilled 3 million gallons of oil. The largest reported oil slick along the Santa Barbara coast was 800 square miles, with a total of 300 miles of shoreline oiled (figure 6). The responsible party for the oil spill was Union Oil, and the estimated cost of this oil spill 25 million dollars. The following section provides a summary on the Santa Barbara oil spill of 1969 (table 4).

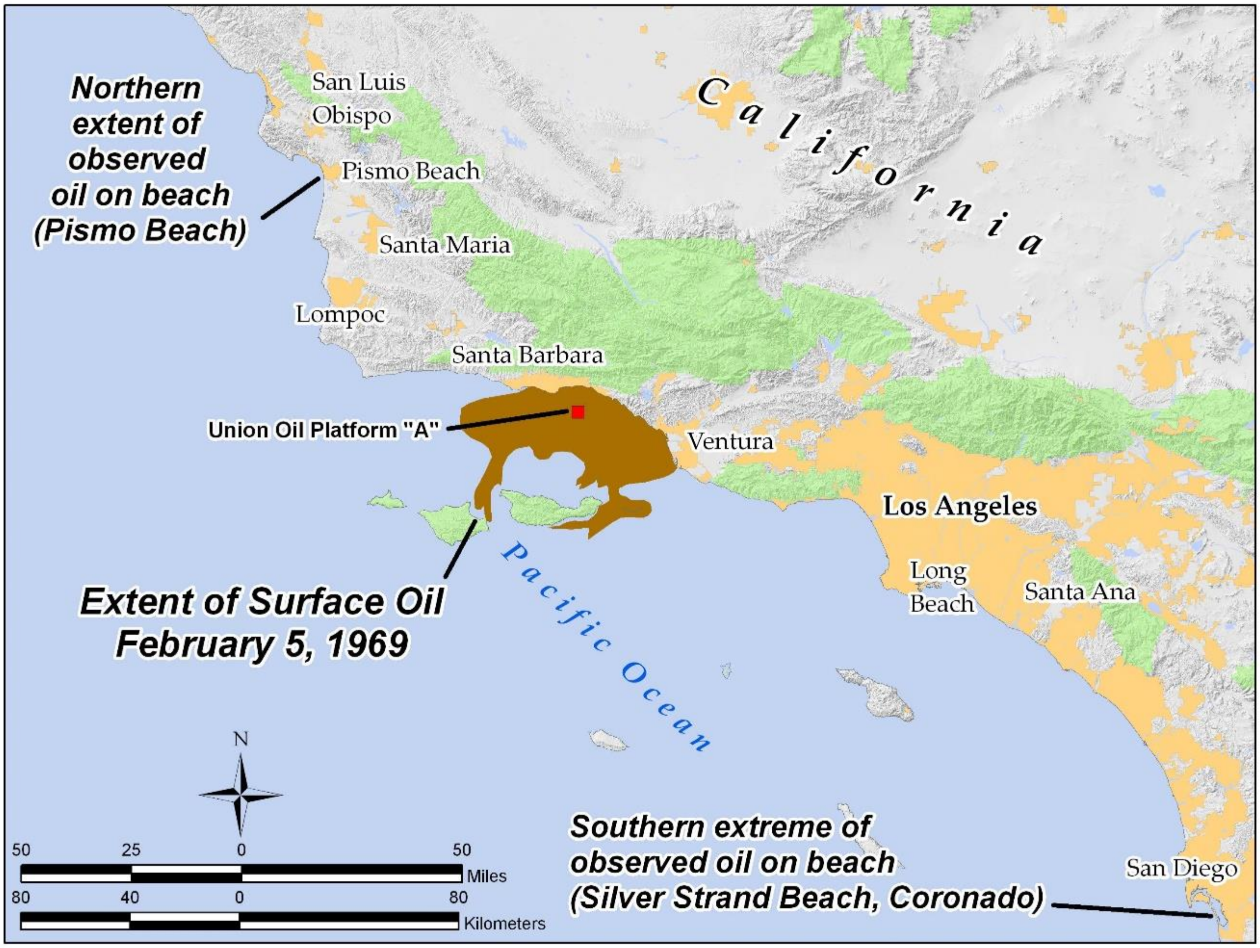


***Figure 6****: Map of the Santa Barba oil spill of 1969, displaying the extent of oil that spilled from Platform A.* ("The Hinge Years: Countries versus Companies | EGEE 120: Oil: International Evolution," n.d.)

4.1.1 Incident Summary

The Santa Barbara Channel was where the first offshore oil drilling took place in the world. On January 28 1969, a 3,500-foot deep well had a disastrous pressure increase 5 miles off the coast of Santa Barbara California. Union oil which is now called Unocal, was granted a waiver by the United States Geological Survey (USGS), which allowed Unocal to use a shorter casing than required on the pipe that went into the sea floor than Federal Standards had originally prescribed to use (Clarke et al., 2002). A casing on a well is the part on the well that prevents blowouts. In this incident, the seafloor underneath the well cracked, causing oil and natural gas to disperse from the sea floor. On the eleventh day of the oil spill the well cracks were sealed by chemical mud, however shortly thereafter, more oil escaped, approximately 3 million gallons more (Foster, n.d.). Oil reached the seawall in many instances (Figure 7).

All wildlife in the incident area was affected by the toxicity of the oil. Following the spill, close to 3,500 dead coastal birds were removed from the coastline along with many seals and dolphins (Clarke et al., 2002). Many bird populations were disrupted due to the incident, and many of them were endangered already. The oil spill incident also killed intertidal invertebrates and fish. Coastal kelp became disrupted as well and indirectly choked out food chains (Clarke et al., 2002). Oil spill clean ups began immediately following the oil spill. Much of the response help came from the local communities of Santa Barbara. Many responders used boom made of straw piles to absorb the oil. The contaminated boom was bulldozed and trucked off location for proper hazardous material disposal. The use of skimmers also helped to gather the oil that was on the top layer of the ocean's surface.

***Figure 7****: A photo of Santa Barbara sea wall fouled with oil from Platform A.* ("Santa Barbara Oil Spill | CounterSpill," n.d.)

### 4.1.2 Response Methods

The main response methods used for the Santa Barbara oil spill were sorbents and boom. Responders also used the method of steam cleaning of rocks and used bulldozers to remove oiled debris from the shoreline. The media reported average citizens volunteering their time at Carpinteria State Beach. They used straw to soak up oil, and steam cleaned boulders (Blackened & Beaches, 2010). Volunteers also collected oil encrusted birds from beaches such as Carpinteria State Beach and took them to makeshift rescue centers. Oil that had come on shore during the initial stages of the Santa Barbara oil spill was documented by aerial photos and samples were taken from intertidal waters. Aerial photo estimates of the spill were used to determine by color, the amount of oil in the polluted area (Foster, Neushul, & Zingmark, n.d.). Factors such as the color and shade of oil were important determinants in this assessment and could be obtained by aerial photos.

After 11 days, expert's calculated the flow rate of oil to be roughly 5000 barrels per day of spilled oil. Kelp beds in Santa Barbara showed that they held large amounts of oil. Intertidal waters held the spilled oil due to the direction of waves, water temperature, wind direction, and tides. (Foster, Neushul, & Zingmark, n.d.). A past oil spill incident which occurred in England, named the Torrey Cannon disaster, helped Santa Barbara oil spill responders determine the direction in which the oil would move. Responders were able to calculate the relative wind vector, which shows the direction in which the oil is spreading with respect to the currents in the oceans and wind directions in the spill's location (Foster, n.d.). A winter current from southern California pushes up to northern California; from Los Angeles towards the Bay Area. Experts predicted that this current, the Davidson Current, was the reason or the oil reaching the California coastlines from Platform A (Foster et al., n.d.)

An additional sampling method employed during this spill used a coffee can to estimate core depths of oil. This core method used in the study only provided an estimate for the amount of oil that was actually in tidal zone samples. The aerial photos obtained did not have the same time line, as the measurements obtained using the coffee can method, however, both had similar results. For example, both showed a high amount in the ocean kelp (Foster, n.d.). Evidence suggests that the oil held in this kelp contributes to the overall net amount of oil distributed.

Oil which once covered intertidal areas, washed away immediately, however, rocky areas on the coastline were covered with oil (Foster, n.d.). This was because the rocky areas dry during intertidal periods, making it harder for the natural environment to remove the oil. The effects on marine organisms from the spilled oil were not uniform during this study. Along the beach, rocky surfaces and land that had interaction during high tide were covered with the most oil (Foster et al., n.d.). Middle and lower inter tidal zones were not as effected. Results from sampling stations differed greatly in oil pollution concentration.

### 4.1.3 Impacts on Fish

The major difference between Platform A blowout, and tanker disasters, is that the crude oil release from the blowout extended over a period of time, where a tanker accident would only have a short term release. With the constant release of oil from platform A in Santa Barbara, California, fish were impacted. Sighting records from 1963-1988 for the Santa Barbara Channel and Islands areas indicate that the summer to winter period has a greater abundance of northern anchovy, pacific bonito, and jack mackerel (Merchant, 1992). About 15 days after the initial oil spill occurrence in Santa Barbara, the California Department of Fish and Game sampled pelagic species for population data. There was no evidence of starvation from the northern anchovy that could have happened due to the impairment of the phytoplankton food chain. No supportive analysis was given relative to the changes in abundance before during or after the oil spill. The same study concluded that the reduction of fish catch was due to the problem of fishing in oil waters, and was not due to the lack of fish (Merchant, 1992). Data would indicate that pelagic fish resources did not suffer short term debility from the localized oil spill.

At the end of January 1969, after the spill, the northern anchovy was absent in February but was observed at higher abundance levels in the late spring. The northern anchovy in early summer months showed a higher abundance level than that observed either in 1968 or 1970. The abundance level for northern anchovy did show a decline in 1970 (Merchant, 1992). The Jack Mackerel has a distribution of older adults generally offshore from which the younger year classes recruit into the southern California fishery. The Jack Mackerel tonnages decreased after the spill but overall increased slightly in 1969, then decreased in 1970 (Merchant, 1992).

The Pacific Bonito fishing season in the Santa Barbara channel usually extends from the summer months into months of February or March. Starting in August 1968 prior to the oil spill occurrence some of the highest abundance of Pacific Bonito were recorded. This high abundance of Pacific Bonito extended through January 1969. After the spill Pacific Bonito were not observed, but were once again observed to increase in abundance in July/August 1969. The levels of Pacific Bonito were just around the same levels observed initially in 1968 (Merchant, 1992). As in previous years the Pacific Bonito were absent from February until May.

The oil spill had some immediate short term negative effects on the apparent abundance of Pacific Bonito and Jack Mackerel, however, northern anchovy were relatively stable from 1968 through 1971. Observations during the oil spill indicate that the Northern Anchovy, Pacific Bonito, Jack Mackerel sighting of schools or school groups were in normal geographical areas of distribution within the Santa Barbara Channel and Islands. The fish behavior below the oil slick was normal relative to depth, movement and school shape (Merchant, 1992).

4.1.4 Impacts on Plants

A study on intertidal organisms were studied in Santa Barbara area. 10 survey stations extended from Santa Barbara to Los Angeles were studied immediately after the disaster (Foster et al., n.d.). Early surveys after the oil spill showed that the most significant biological change at a survey station showed a loss of 16 plant species. Prior to and after the Santa Barbara oil spill, was an occurrence of several severe storms which may have contributed to the loss of the species. Native species were not severely affected, however barnacles and grass in the intertidal zone were damaged (Foster et al., n.d.)

The survey study from Los Angeles County to Santa Barbara County had exposed that increased flora disruption in the areas were due to the oil disaster, however, these survey areas already had prior disruptions due to being exposed to smog, pollution from sewage, and recreation. (Foster et al., n.d.) Researchers concluded that weather, oil damage, and a variability of other factors, contributed to species changes in the Los Angeles Country area to Santa Barbara Country area. Nevertheless, there were factors that influenced the existence of intertidal organisms. After the oil spill, intertidal variables such as tidal levels, existing biota, habitat location, kelp beds, and substrate all had an influence of protecting intertidal organism's survival. Also, the ability of the spilled oil to evaporate before it reached the California coastline assisted organisms survival (Foster et al., n.d.). Due to these circumstances, the cleanup method of detergents was used during the oils spill response. Continuing oil pollution through natural seepage and wells will continue to long term impact the environment in the Santa Barbara region. The study concluded that there was no extensive ecological damage on the coastline (Foster et al., n.d.).

4.1.4 Other Outcomes

The Santa Barbara Oil spill showed how much of an ecological threat offshore drilling was to not only the California coastline but the entire United States. After the oil spill event in Santa Barbara, California occurred, a significant environmental movement was founded, which would eventually led to the creation of the first Earth Day in November of 1969. Get Oil Out, GOO, started a petition to ban offshore drilling. GOO eventually collected 100,000 signatures for their petition (Clarke et al., 2002). The Environmental Defense Center (EDC) was created for the first environmental science program was started at The University of California at Santa Barbara. The California Coastal Commission (CCC) was also created to influence impacts on the California coastline. After the oil spill, for a duration of 16 years, The State Land Commission (SLC) banned offshore drilling. After the Reagan Administration was in Washington, they vetoed to stopped the ban on offshore oil drilling and to continue oil drilling in the Santa Barbara Area (Clarke et al., 2002).

In Washington, President Richard Nixon signed the National Environmental Policy Act (NEPA) of 1969. NEPA was the catalyst of establishing the Environmental Protection Agency (EPA) in 1970. President Nixon’s observations of the Santa Barbara channel led to a 34,000 acre expansion of the Department of Interior buffer zone in the channel to prevent future disruption (Blackened & Beaches, 2010). The California Environmental Quality Act (CEQA), was also created and became a federal and state regulation. The federal government founding the Civil Applications Committee (CAC). The CAC coordinates with the military for national response emergencies (Clarke et al., 2002). New laws in 1972 were based on the Federal Water Pollution Control Act’s Amendments. The Clean Water Act of 1977 became implemented. In 1980, the superfund law known as the Comprehensive Environmental Response Compensation Liability Act was created, which eventually created in 1987 the Water Quality Act (Friant, 2007).

***Table 4****: Santa Barbara California Oil Spill (1969)*

| | |
|---|---|
| Oil Spill amount (Gallons) | 3 million gallons |
| Occurrence | Oil Platform A blowout |
| Response Method | Sorbent, Boom, Manual removal |
| Resources at Risk (RAR) | Amenity, Beaches, Fish |
| Clean up Cost $ | $25 million |

4.2 Exxon Valdez Oil Spill 1989

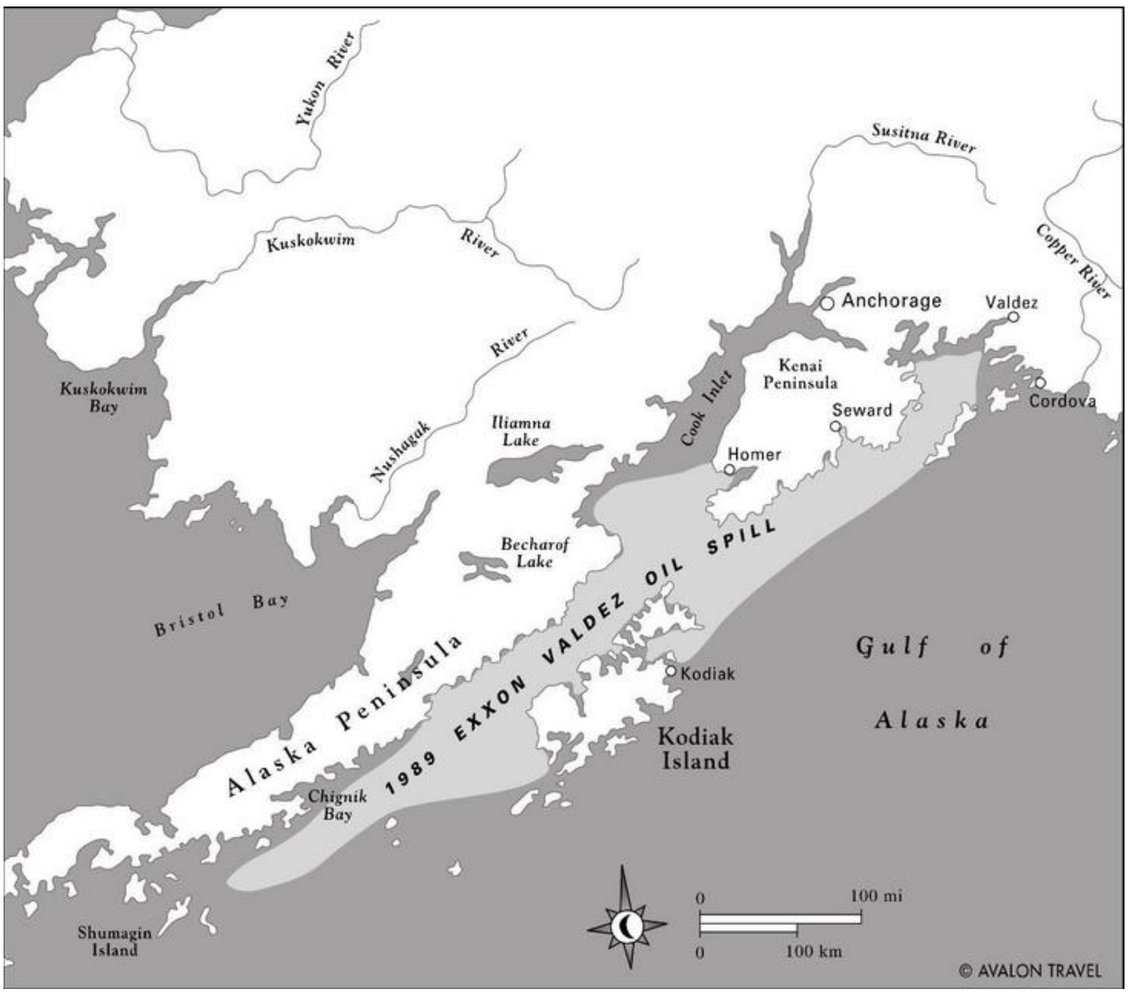


***Figure 8****: Map of the Exxon Valdez oil spill of 1989, displaying the extent of spilled oil.*
("ALAS_04_Exxon-Valdez-Oil-Spill.jpg (1351×1185)," n.d.)

### 4.2.1 Incident Summary

The Exxon Valdez oil spill disaster occurred on March 23, 1989 in Prince William Sound, Alaska. This oil spill at the time was the largest in United States history. The Exxon Valdez tanker ran off course and grounded on Bligh Reef. An estimated 11 million gallons of oil was spilled during the disaster's duration. The responsible party for the oil spill was the Exxon Corporation. The oil spill resulted in an estimated 2.1 billion dollar cost. The largest spread of oil from the spill was 460 miles (Palinkas, 2012) (figure 8). The following section provides a summary on the Exxon Valdez oil spill of 1989 (table 5).

### 4.2.2 Response Methods

The Coast Guard were on the oil spill response team with the help of other federal agencies such as the Environmental Protection Agency (EPA). Methods such as burning, mechanical cleanup, and chemical dispersants were used in the effort to clean up the spill. The response team started trial burns during early stages of the spill. Boats towed fire retardant boom behind them, moving oil in a safe zone for in-situ burning (Street, 2011d). Due to weather at the location of the spill, controlled burning did not continue and the use of mechanical cleanup followed. Skimmers and booms were used shortly after for response but posed difficulty while transferring the oil into permanent storage containers for disposal. However, skimmers were not available until one day after the oil spill incident, which slowed recover efforts (Haycox, 2012). Skimmers often became damaged due to being clogged by oiled kelp and in return slowed down response time as well. Weather challenges also made recovery difficult.

Dispersants were used at the beginning of the spill response as well but because of the calm waters in the ocean, the dispersants were ineffective at diverting the oil away from the shore (Palinkas, 2012). The responders used heavy machinery and hot high pressured water to flush the oil off rocky/gravely beaches (figure 9). Bioremediation was also used on beaches that were not as heavily impacted with spilled oil (Boufadel et al., 2011). The Exxon Valdez spill taught responders that they needed better universal contingency planning and more effective spill prevention measures.

Three more local organizations also helped respond to the disaster. These organizations included: the Interagency Shoreline Cleanup Committees (ISCC), which helped clean up and monitor the coastline; the International Bird Rescue Research Center (IBRRC), which helped oiled wildlife; and the Alaska Department of Environmental Conservation (ADEC), which stopped local fisheries from operating (“Implications for Spill Response | response.restoration.noaa.gov,” n.d.).

***Figure 9****: Oil spill responders using the technique of Hot water, high pressure flooding of oiled rocks along the shore line of Alaska.* (“Exxon Valdez Oil Spill | CounterSpill,” n.d.)

### 4.2.3 Long-Term Impacts

The amount of oil spilled and the geography of the area in which the Exxon Valdez oil spill occurred made this oil spill the most destructive of its time. The United States Fish and Wildlife service estimated 350,000 birds were harmed by the Exxon Valdez oil spill (Haycox, 2012), resulting in food chains being disrupted as a consequence from the oil spill ("Implications for Spill Response | response.restoration.noaa.gov," n.d.). Other wildlife that were killed due to the disaster included: killer whales, bald eagles, pigeons, sea otters, harbor seals, and sea ducks (Xia & Boufadel, 2011). An oil spill of this size made responders realize that they were not at all prepared for a cleanup of this nature. This oil spill led to the development of more strict rules and regulations for oil spill response.

After the 1989 Exxon Valdez oil tanker disaster, the herring population crashed within a few years. After almost 25 years later, the herring population has still not recovered. Other wilflife within the intertidal communities such as barrows goldeneyes, oystercatchers, harlequin ducks, killer whales, sea otters, clams, mussels, have also not fully recovered in the past 25 years since the spill. There are also many human services that are still impaired 25 years after the oil spill such as commercial fishing, recreation usage, and tourism.

### 4.2.4 Other Outcomes

There were a hand full of lessons learned from the Exxon Valdez spill. According to NOAA, the Alaskan coastline's ecosystem suffered due to the use of aggressive cleanup methods such as hot water high pressure flooding used for cleanup. ("Implications for Spill Response | response.restoration.noaa.gov," n.d.) The use of this type of oil spill recovery method on gravely beaches can result in long duration for recovery ("Implications for Spill Response | response.restoration.noaa.gov," n.d.). Flushing of an fouled shoreline can also remove beneficial sediments and nutrients that small organisms rely on for survival within their habitats ("Implications for Spill Response | response.restoration.noaa.gov," n.d.).

As a response to the Exxon Valdez oil spill, George H. Bush signed the Oil Pollution Act of 1990 (OPA 90), which expanded oil spill prevention measures and established new requirements for oil response by the federal government and oil spill industry (Friant, 2007). The act improved the nation's ability to prevent and respond to oil spills, increased government responsibilities, and provided the money and resources necessary to respond to oil spills. This led to the creation of the National Oil Spill Liability Trust Fund, which provides up to one billion dollars per spill incident for oil spill response (Friant, 2007).

***Table 5****: Exxon Valdez Oil Spill (1989)*

| | |
|---|---|
| Oil Spill amount (Gallons) | 11 million gallons |
| Occurrence | Tanker crashed into Reef |
| Response Method | Hot washing, Sorbent, Mechanical reworking |
| Resources at Risk (RAR) | Coastlines, Fish |
| Clean up Cost $ | $2.1 Billion |

4.3 Sea of Japan Oil Spill 1997

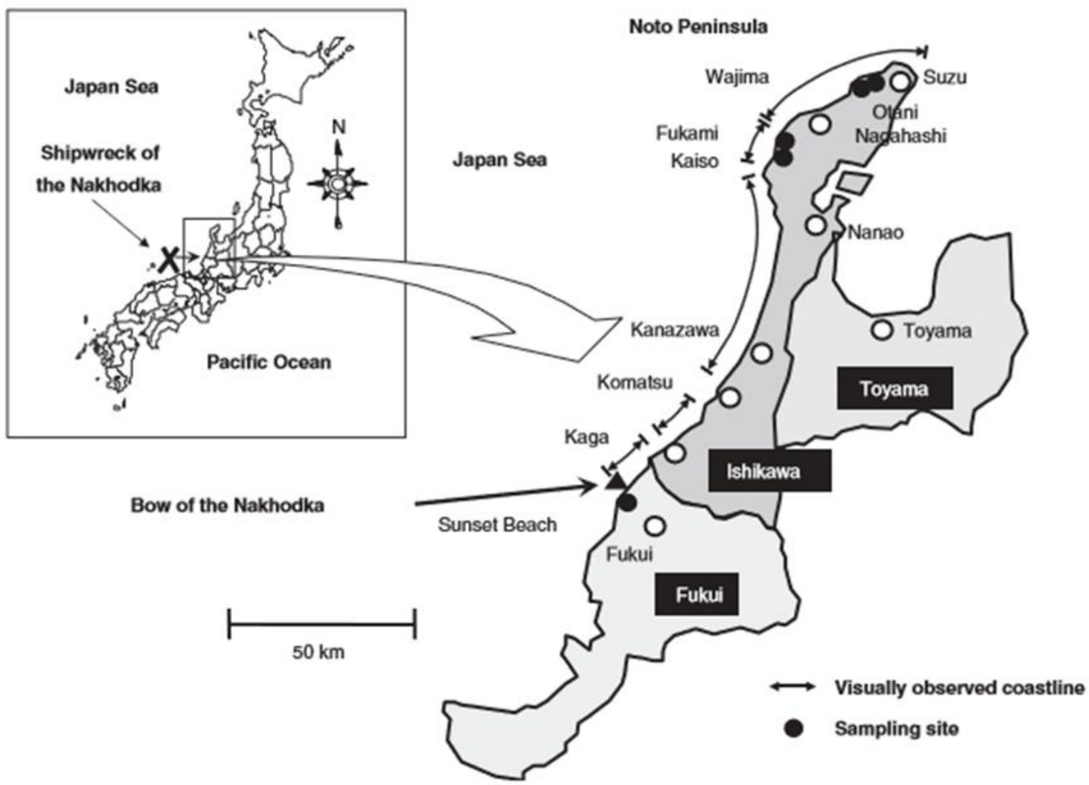


***Figure 10****: Map of the Nakhodka oil spill of 1997 in the Sea of Japan.* (Hayakawa et al., 2006)

4.3.1 Incident Summary

The shipwreck of the Russian tanker Nakhodka, occurred along its journey from Shanghai to Russia. The oil spill disaster occurred on January 2, 1997 in the Sea of Japan, off the Island of Honshu. The oil tanker broke into two while carrying 6 million gallons of fuel oil. Initially, 1.9 million gallons of oil spilled out of the tanker with the remaining oil left in the bow of the ship (Sciences, 2000). When the bow of the tanker reached the Japanese coastline, it released the remaining amount of oil and fouled the beaches. An estimated 300 km of coastline was fouled with oil (Varlamov, Yoon, Hirose, Kawamura, & Shiohara, 1999) (figure 10). The following section provides a summary on the Sea of Japan oil spill of 1997 (table 6).

### 4.3.2 Response Methods

Response methods used for cleanup were, skimmers, coastal boom, dispersant, and portable storage tanks. An estimated total of 200,000 people recovered all of the oil that reached the shore in 1 month (Sciences & Futami, 2000). The oil was removed from the shore by the hands of innumerable volunteers, and the oil was also treated with chemical agents such as oil dispersants (Figure 11).

The Nakhodka Oil spill posed many threats to the Sea of Japan. After the spill in Japan, the Maritime Safety Agency (MSA) leaded the cleanup operations. The owner of the tanker provided equipment and man labor. (Varlamov, Yoon, Hirose, Kawamura, & Shiohara, 1999). Almost 100 vessels from MSA and the Japan Self Defense Force were used for cleanup operations. The Petroleum Association of Japan (PAJ) help with cleanup operations by providing training for operation crews and delivered clean up equipment’s such as skimmers, sorbent, boom, and storage tanks. (Varlamov et al., 1999). More assistance from the Russian Ministry of Merchant Marine (MNS) helped to recovery the oil as well. Also, hundreds of fishing boats from eight of Japan’s prefectures were used to collect oil manually using drums. Helicopters were used as well to spray a limited amount of dispersant to help with the oil escaping from the bow section (Varlamov et al., 1999).

The results of a 2000 study examining the cleanup operations of the Nakhodka spill show that a petroleum degrading bacteria,  TerraZyme, which is used for microbiological dispersants, was able to significantly enhance the biodegradation of oil in the field (Sciences & Futami, 2000). Therefore, as long as the degradation of oil occurs naturally by the process degradation, oil pollution will have a long duration unless treated.(Sciences & Futami, 2000).

***Figure 11**: Oil spill cleanup methods used by the Anto district's local community.* (Morita et al., 1999)

4.3.3 Long-Term Impacts

Coastal microbial communities are influenced by oil spills (Bacteria, 2006). The breakdown of hydrocarbons by microorganisms is one of the main ways by which oil spills are cleaned up from sites that have fouled by petroleum.  The breakup of the tanker Nakhodka, resulted in a viscous sticky fluid fouling the coast and associated natural habitats. After 9 years of bioremediation, the oil from the tanker started to become a hard solid and subsequently formed a surface of crystalline paraffin wax along with bits of graphite and calcite. On the anaerobic under side of the crust many bacteria associated with halite formed (Bacteria, 2006). During the 9-year bioremediation, evidence suggests that after finding the paraffin wax and the hydrocarbon degrading bacteria in the oil's crust, these may have had a significant effect on the type of weathering processes that the Nakhodka tanker's oil spill underwent (Bacteria, 2006).

The Nakhodka oil spill was examined for a 9 year period to assess the weathering of it. Samples of oil at the beginning of the spill indicated that Si, S, Ti, Cr, Ni, Cu, and Zn were present. However, heavy metals and Sulfur were not present after 9 years of weathering (Bacteria, 2006). The data also showed how these metals in the Nakhodka oil spill affected the biodegradation of heavy oil during the 9-year bioremediation. The results also provided information that the Nakhodka oil spill resulted in not only organic pollutants but also heavy metal pollutants along the coastal areas of the Sea of Japan (Bacteria, 2006).

The research showed that both heavy metals and hydrocarbons would influence the composition of microbial communities. The genus *Pseudomonas* was a dominant member at all contaminated coastal sites.(Bacteria, 2006). Genus *Pseudomonas* is able to cope with hydrocarbon toxicity and could serve as a primary catalyst for aliphatic hydrocarbon degradation in the Sea of Japan during the duration of the bioremediation (Bacteria, 2006).

#### 4.3.4 Other Outcomes

There has still not been a legitimate explanation for why the Russian tanker broke into two, except for according to the Japanese, it was 26 years old. Russia however denies that the tanker broke into two due to being old or due to negligence from the crew or captain. Russia believes that their tanker broke into 2 due to a submerged ship or was targeted by military drills. It is important to know how the tanker broke into two because it is important to determine who should pay for the cleanup. After the oil spill, bad weather mixed with the slow response time by the Japanese Government, allowed for the spilled oil to reach inland and contaminate the Japanese coastline. The Japanese fishing industry was effected along with several historical resources/beaches. Even though oil never reached the 15 nuclear reactors in Wakasa Bay, the oil spill did threaten them due to the fact that the oil could have seeped into the reactors intake pipes. However due to clean up efforts oil never reached the nuclear reactors. Environmental planning and response time for the oil spill directly threatened the Japanese coastline.

*Table 6*: *Nakhodka Oil Spill in the Sea of Japan (1997)*

| | |
|---|---|
| Oil Spill amount (Gallons) | 1.9 million gallons |
| Occurrence | Tanker broke into 2 |
| Response Method | Labor, Boom, Sorbent |
| Resources at Risk (RAR) | Historical Sites, Fish, Beaches |
| Clean up Cost $ | Undetermined |

4.4 Deep Water Horizon Oil Spill 2010

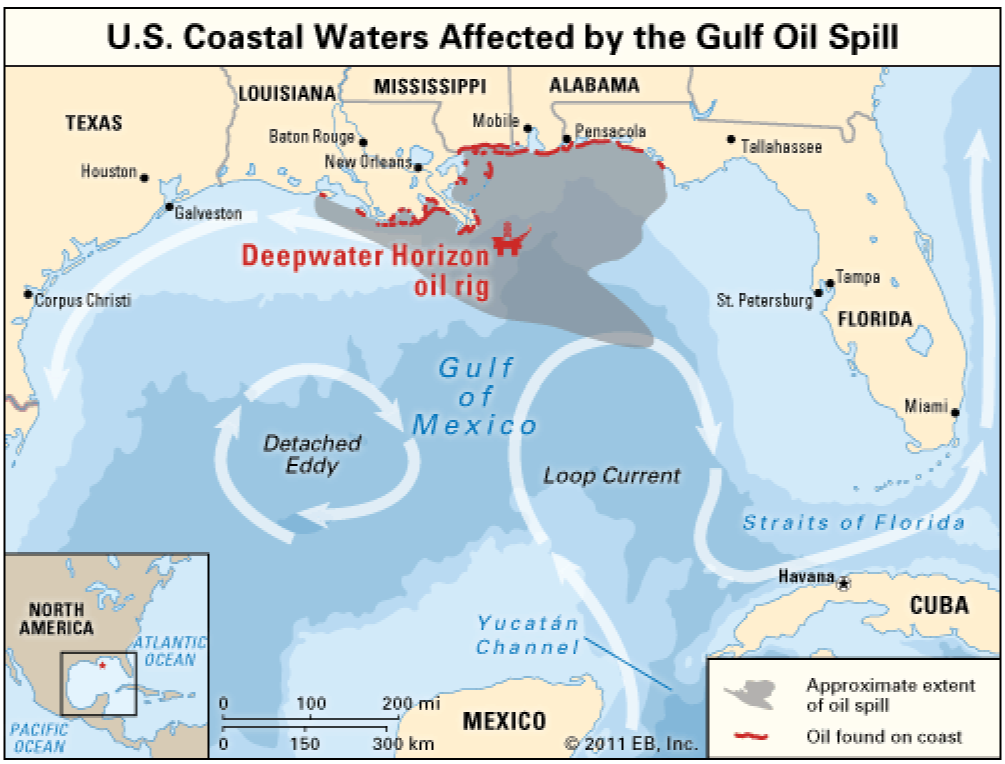


***Figure 12***: *Map of the Deep Water Horizon Oil Spill in 2010 that occurred in the Gulf of Mexico.* ("Deepwater Horizon oil spill of 2010: coastal waters affected by the oil spill -- Kids Encyclopedia | Children's Homework Help | Kids Online Dictionary | Britannica," n.d.)

4.4.1 Incident Summary

The following section provides a summary on the Deep Water Horizon oil spill of 2010 (Table 7).

The Deep Water Horizon oil spill occurred on April 20, 2010 in the Gulf of Mexico and lasted for 87 days (Figure 12). This oil spill was rated the largest oil spill in United States history. The oil spill happened due to an explosion on an oil rig which resulted in 11 initial deaths, 2 response deaths, and 17 injured (Wilson, n.d.) (Figure 13). The oil rig was near the states of Louisiana, Alabama, Mississippi, and northern parts of Florida. The largest reported slick was 24,435 square kilometers (Kurtz, 2013). The coastline was fouled with a reported 1665 kilometers of shoreline oiled (Kurtz, 2013). The oil spill resulted in an estimated 4.9 million barrels of oil spilled. The responsible party involved with the disaster was British Petroleum BP. Clean up costs for the incident ran close to 11.6 billion dollars (Wilson, n.d.).

### 4.4.2 Response Methods

An estimated 30,000 people responded to the spill in the Gulf Coast. These responders worked at collecting oil, beach cleanup, animal care and performing various other duties (Sylves & Comfort, 2012). Methods for response included dispersants, booms, skimmers, and controlled burning. Using the method of eliminating the oil spill by in situ burning or controlled burning, is the process of burning oil in a contained area rather than collecting it for disposal. The oil on the surface of the water burns away, however this method of response has negative effects on the environment, primarily, air quality concerns affecting the health of workers. Responders also used a total of 5.5 million feet of boom to contain the oil (Kurtz, 2013). Boom created a barrier in the water and allowed responders to collect and absorb oil that was sitting on the water’s surface and couldn’t be disposed of by controlled burning.

***Figure 13****: Clean up response for the Deep Water Horizon Oil Rig with is still on fire from the original explosion, and continuing to leak oil.* ("BP Oil Spill | CounterSpill," n.d.)

4.4.3 Long-Term Impacts

Many long term impacts from the Deep Water Horizon oil spill are going to continue to be researched. An estimated of 8,000 animals were reported deceased after only half of a year after the spill and many species were on the endangered species list (Morse, 2012). An estimated 16,000 total miles of coastline have been fouled along the coastlines of Alabama, Florida, Louisiana, Mississippi, and Texas (Wilson, n.d.).

The Deep Water Horizon oil well explosion occurred approximately 5,000 feet below the surface. The damage caused by the oil and the 2 million gallons of chemical dispersants used on the spill may not be known for many years after the spill. Wildlife that was affected due to the event were the Bluefin tuna, brown pelican, the reddish egret, the snowy plover, the sea turtle, the royal tern, and the sperm whale. All of these affected wildlife will continue to be researched in the coming years as more consequences become evident.

Although oil is no longer visible on the ocean surface in the Gulf of Mexico, it is still there. Mass amounts of oil have been found on the gulf coast's ocean floor. Presently, oil continues to wash into wetlands and beaches, making clean up and restoration difficult. Tracked slick dolphins and sea turtles have been linked to being stranded due to the oil spill. Factors in the Gulf of Mexico such as imbalances in food webs and decreased fish and wildlife populations, create a long process for ecosystem recovery. The decline in recreation and commercial fishing due to the oil spill continues to pose a treat for the gulf coast's economy.

#### 4.4.4 Other Outcomes

Oil dispersant, skimmer ships, floating boom, and control burns were chosen for the appropriate clean up response method for the Deep Water Horizon oil spill (Reader & O'Connor, 2014). The Deepwater Horizon oil spill has provided us with methods for response and well containment strategies for deep water wells. New research in the future will teach us about the success or lack of success from the choices responders made to this oil spill event, and as of 2012, the Gulf was still polluted with oil (Mary et al., 2012). President Obama stated that the government would provide a $20 billion spill response fund for future oil spill disasters (Mccormick, 2012). British Petroleum, the responsible party for the oil spill disaster, paid close to $40 billion in cleanup costs, fines for insubordination, and lawsuit settlements (Dana, 2011).

***Table 7****: Deep Water Horizon oil spill in the Gulf of Mexico (2010)*

| | |
|---|---|
| Oil Spill amount (Gallons) | 210 million gallons |
| Occurrence | Oil Well Explosion |
| Response Method | In-situ Burning, Dispersants, Sorbent, Boom |
| Resources at Risk (RAR) | Historical Sites, Fish, Beaches, |
| Clean up Cost $ | $11.6 Billion |

## 4.5 Case Study Summary

Four oil spill disasters were studied: The Santa Barbara oil spill of 1969 in Santa Barbara, California; the Exxon Valdez oil spill of 1989 in Prince Williams Sound, Alaska; the Sea of Japan oil spill of 1997; and the Deep Water Horizon oil spill of 2010 in the Gulf of Mexico (table 8). The Santa Barbara spill introduced the perils of a large spill and led to the creation of an environmental awareness not present before the spill. The Exxon Valdez oil spill in Prince Williams Alaska for instance, sent off a reaction within congress and eventually lead to the creation of the oil pollution Act of 1990 (OPA90) (EPA, n.d.). The OPA90 has improved the United States ability to prevent oil spills and respond to oil spills if an incident does occur by mandating that regional governments create spill contingency plans (EPA, n.d.). Another outcome of the OPA90 was the creation of the national Oil Spill Liability Trust Fund which will provide one billion dollars per spill incident (Morris, Incident, & Kurtz, 2008). The Sea of Japan spill taught us the importance of bioremediation tools. After the Deep Water Horizon oil spill, the need for better spill coordination between government, contractors, and responsible parties is still present. Past events have shaped the way we respond to oil spill planning. However, the Deepwater Horizon, a deep water well, also showed us what we don't know.

## 4.6 Summary of Case Studies

***Table 8****: Summary of Historical Oil Spills; Santa Barbara 1969, Exxon Valdez 1989, Sea of Japan 1997, Deep Water Horizon 2010.*

| | **Santa Barbara** | **Exxon Valdez** | **Sea of Japan** | **Deep Water Horizon** |
|---|---|---|---|---|
| **Gallons of oil** | 3 million gallons | 11 million gallons | 1.9 million gallons | 210 million gallons |
| **Occurrence** | Oil Platform A blowout | Tanker crashed into Reef | Tanker broke into 2 | Oil Well Explosion |

| | | | | |
|---|---|---|---|---|
| **Clean up Cost $** | $25 million | $2.1 Billion | Undetermined | $11.6 Billion |
| **Resources at Risk** | Amenity<br>Beaches<br>Fish<br>Recreation | Economy<br>Fish<br>Tourism | Historical Sites<br>Fish<br>Beaches<br>Recreation | Fish<br>Beaches<br>Recreation<br>Economy |
| **Response method(s)** | Sorbent, Boom, Manual removal, Pressure Washing | Hot washing, High Pressure Washing, Boom Sorbent, Mechanical reworking | Labor, Boom, Sorbent, Dispersants | In-situ Burning, Dispersants, Sorbent, Boom, Skimmers, Vacuums |
| **Effectiveness** | Effective due to spill occurring almost 50 years ago. | Oil still present and ecosystem has not fully recovered | Effective, recovered ecosystem and coastline | Undetermined, More research needed in the future. |

## 5.0 Oil Spill Analysis

Oil spills can also be examined from a Net Environmental Benefit Analysis perspective, and in this last section of my paper, I will discuss that perspective and how it can help with response planning and cleanup efforts. Oil spill responders collect data such as; the ecology of the site, physical characteristics, resources at risk, and relevant response operations. Oil spill responders combine this collected data with statistics from the spill response plan. Spill response plans assess oil types under considerations, and the probable weather patterns for the site. Responders use these results to create environmental sensitivity index maps that will help to prepare universal area contingency plans for possible oil spills. The following sections highlight the process of evaluating Net Environmental Benefit Analysis, while examining how oil can effect resources at risk.

5.1 Net Environmental Benefit Analysis (NEBA)

The best scenario is to never have an oil spill. The key to minimizing the impact of an oil spill is to respond quickly by carefully pre-selecting response tools before an incident occurs. Net Environmental Benefit Analysis (NEBA) provides a navigational guide for selecting the right response tool in consideration of the effectiveness, feasibility, specific environmental sensitivities, and community impacts (Efroymson, Nicolette, & Suter, 2004). Recovery options such as physical removal, natural removal, mechanical removal, in-situ burning, or the use of dispersants, are compared and eventually selected to maximize NEBA for an oil spill event. As resources are delivered around the world's oil supply chain, environmental managers have to strategize and work together to protect the shared things that people value. Some valuable resources include sensitive ecosystems, local business, health and safety, tourism and recreation, and regional industries. Then it must be determined if the response chosen complies with regulations. Four steps used in NEBA (figure 14) include: first, to evaluate data; second, to predict outcomes; third, to balance tradeoffs; and fourth, to then select best options for clean-up (Efroymson et al., 2004).

Before a spill occurs, NEBA requires the identification and prioritizing of environmental and community assets based on environmental sensitivities and social values. Some of these include looking at local populations, sensitive shorelines, local industries, sensitive species that could be affected, and local infrastructures that could be put in danger (Efroymson et al., 2004). Outcomes are predicted by reviewing and comparing previous spill cases to see how restoration occurred, and what the environmental impacts were. Decisions are based upon looking at different tradeoffs. Some tradeoffs include shoreline protection versus water column protection; impact on fisheries versus impact on tourism; and impact on wildlife verses impact on local community (Efroymson et al., 2004). NEBA allows proactive pre-selection and planning to inform a response. This improves organization and communication within communities, and plays an important role in protecting the environment.

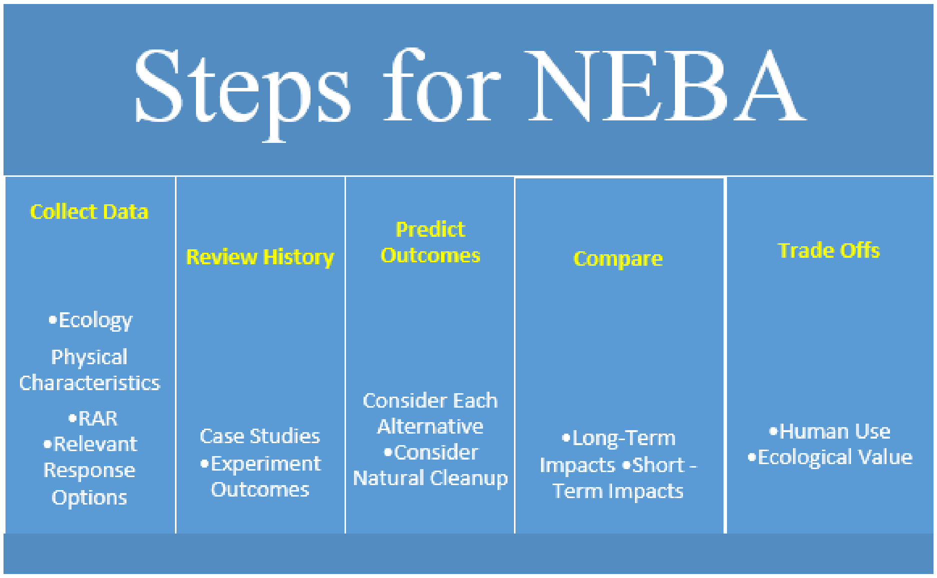


**Figure 14**: Steps for assessing Net Environmental Benefit Analysis (NEBA). This examines the following elements: Collect Data; Review History; Compare; Predict Outcomes; Tradeoffs. (Baker, 1999)

5.2 Data for Oil Response

In 1997, the United States Environmental Protection Agency implemented an ecological risk assessment which is based on estimating the risks and protection involved with the environment (Friant, 2007). In 1999, an ecological risk assessment and risk management assessment for hazardous waste sites was established. These assessments provided strategies on managing risks and impacts of remediation. (Friant, 2007). Finally, most recently in 2006, the United States Environmental Protection Agency issued its ecological benefits assessment strategic plan. The United States Environmental Protection Agency overall goal is to use existing policies to help improve new oil spill response decisions through understanding the ecological benefits. (Friant, 2007).

In addition, the International Petroleum Industry Environmental Conservation Association (IPIECA), has been guided by a set of principles that encourage organizations involved with oil to consider three things. First, they need to concentrate on preventing spills, because otherwise, spills will continue to occur and will affect the local environment. Second, response to spills should seek to minimize the severity of environmental damage and urge the recovery of any damaged ecosystems. Third, the response should always seek to complement and make use of natural forces to the fullest extent practicable (Environmental & Analysis, n.d.).

The Environmental Protection Agency (EPA), has developed a 7 steps process for responding to a potentially hazardous site, such as an oil spill disaster; first, is to state the problem; second, is to identify the study goals; third, is to identify the information inputs; fourth, is to define the study boundaries; fifth, is to develop the analytical approach (what are the decision rules); sixth, is to specify performance of acceptance criteria (tolerance for decision goals); and finally, seventh, is to develop the plan for obtaining data and optimize the sampling plan.

### 5.3 Predictions Based on Historical Outcomes

Historical spills that have re-occurred in the same location help responders to predict what type of response could possibly be used: site archeological, the social/economical influence on oil within that location, how many people live in these vulnerable areas, knowing what type of shoreline, already being able to predict how to protect the shoreline and with type of boom, and knowing rock/gravel/sand spread with this shoreline.

Responders and planners understand that oil primarily never stays in the same location that it was spilled. Understanding the possibility that spilled oil can penetrate the shoreline deeply, causing long term chronic exposure as the oil is released over time, makes response options limited in many spill locations. Responders consider three environmental effects from oil movement; first, will keytone species be impacted by oil exposure, disrupting the entire ecosystem? Second, will low food chain species be impacted by oil movement and exposure, increasing the exposure levels in high chain species? Third, will oil movement and exposure cause significant economic harm?

The oil which spilled from the Nakhodka tanker was a heavy oil and had a high viscosity. The Nakhodka oil had a high vanadium content which means produced through the addition of large amounts of distillation residues.(K & Sciences, 2000). The Nakhodka oil was researched to be a conglomerate of half aromatics and half of the heavy oil was made up of resin, asphaltum and saturated hydrocarbon (K & Sciences, 2000). The oil from the Nakhodka spill is very similar to the common bunker C heavy oil.

After an oil spill, oil will start to break down naturally by degrading bacteria. When an oil spill incident occurs the degrading bacteria levels in the areas increase and will control the whole community of bacteria (Leahy & Colwell, 1990). These bacteria will only biodegrade the easiest parts of oil, such as small aromatics and saturated hydrocarbons.  Large molecules of aromatics will in return degraded slow in the natural degradation process (K & Sciences, 2000). Concluding that once oil pollution occurs in the field its concentration will remain for a long time if we only rely on the natural degradation process alone (Leahy & Colwell, 1990).

## 5.4 Comparison of Long Term/Short Term Tradeoffs

Reviewing history from past oil spills to predict probable outcomes of future oil spills is a tool used for planning a response. Responders consider each alternative clean up options while also considering natural clean up options. Depending on the oil spills location, not always do responders need to clean the oil up. By examining the comparisons and tradeoffs for spill sites, responders look at long term impacts vs. short term impacts. They examine tradeoffs such as human use and ecological value. Other considerations that oil spill managers enforce are that responders make use of labels and compliance posters at the jobsite, and that medical examinations for responders are completed before any responder enters the hot zone.

One of the first considerations for cleaning up oil, is to see if the site accessible by land. It is considered if response workers would be able to safety enter and exit the spill site. An analysis is also conducted to see if responders would be able to haul waste way from the site, because vacuuming oil and water for example is heavy haul.  Response to oil spills requires responders to understand responsibilities associated with: Personal Protective Equipment (PPE), Medical First Aid, Fire Protection, Compressed Air, and Material Handling and Storage. After an oil spill occurs, environmental quality and human health are put at risk. Human health is the most important factor when dealing with oil clean ups, however, a large number of research studies are inconclusive when addressing offsets on toxicity to humans (Baker & Towns, n.d.). The exposure levels are very hard to determine for humans, because there are so many variables that can offset the allowable levels for humans. Therefore, all efforts need to be made to prevent oil spills, and if a spill does happen, to clean the spill up rapidly and reduce the overall environmental impact.

During the Nakhodka oil spill, many residents in Anto, had worked daily to remove the destructive oil. Due to the coastal conditions where the oil spilled, machines could not access the area (Morita et al., 1999). Therefore, workers had to use ladles and buckets to clean up the spill. This cleanup job was very difficult because of continuing stormy weather. The health status of the Anto residents from the Anto district in Fukui prefecture, which resided nearest to the coast were studied. Two hundred eighty two men and women were involved in the cleanup activities between January 7 and January 20 were examined by public health nurses to see if they had suffered any effects after being exposed to the oil (Morita et al., 1999). The principal symptoms included, headache, low back and leg pain, and irritation of the throat and eyes. Among the responders that underwent urine analysis tests to show toxicity, only three people showed an elevated level of hippuric acid. However, the responders that did test positive for high levels, returned to normal by the second examination for hippuric acid (Morita et al., 1999). Accordingly, the exposure to the oil and the subsequent cleanup efforts were suggested to inflict acute health problems on local residents.

## 6.0 Conclusions and Recommendations

Oil spills into coastal waters have impacts on the environment, animal and their habitats, economic interests, and social resources. The cycle process for petroleum poses a spill risk at every point; from exploration to find the petroleum, drilling, production/refining the petroleum, transporting the product, and consumption of the product. Those who produce, refine, and transport petroleum products are responsible for responding to spills quickly in order to accelerate the natural recovery process. The goals for an effective oil spill response is first, for the environmental impacts from the spilled oil to be reduced or eliminated, and second, for response activities to not disrupt the environment further.

There are many factors that affect oil spill responses and many considerations need to go into decision plans before responding to a spill. Factors such as; potential spill risk for the vulnerable location, probable spill scenarios for the vulnerable location, sensitive sites and species that can be affected, understanding the broader resources that can be at risk like social or economic interest and recreational activities. Effective spill response planning requires continuous training and exercise practice for response teams. Having sufficient spill readiness such as appropriate response supplies, and organization structure and framework, is required for an effective spill response as well.

First responders to an oil spill incident have to rapidly asses the spill situation, determine what clean up resources are available, and determine what response method will be used to protect resources at risk. Oil spill planning has to consider tradeoffs decisions on where to deploy their response team for cleanup while still ensuring that the environment does not become more disrupted.  These tradeoff decisions are based on many factors, many which are not available until the oil event occurs. Often times, reevaluating spill response assumptions made prior to an oil spill occur, because ever incident is unique and possesses many different factors that alter a response plan.  Decisions that are made at the time of an oil spill incident need to be explained and documented for the reasoning used in making the choice. The documentation is completed so responders can determine if the appropriate response method was used, and can then be used to help determine future oil spill responses. Responders also rely on lessons learned from oil spills to understand how oil behaves in different environments. Responders also use lessons learned to understand how effective oil spill techniques were, and to better understand how the environment responds to spilled oil and cleanup activities.

Response plans made several years ago may not be sufficient in the future due to sea level rise and changing weather patterns. Responders will have to reconsider assumptions that have been made for sensitive environments and protective areas. Higher sea levels and weather changes could increase the risk of exposure to oil. Some areas that could be affected by changing weather patterns and rising sea levels are: wetlands, coastal habitats, estuaries, intertidal zones, and splash zones.

Oil spill response strategies will continue to evolve and improve as responders gain knowledge through lessons learned from past response incident experiences. The Santa Barbara oil spill of 1969, taught us that we lacked environmental policy to regulate for spill disasters. The Exxon Valdez oil spill of 1989, taught responders that they needed a national contingency plan for disasters, and better spill prevention measures. The oil spill disaster which in the Sea of Japan, exposed the need for better communication between oil transporting countries, and the need for more efficient tanker auditing and maintenance. Finally, the Deep Water Horizon oil spill of 2010, taught responders new methods with response techniques for well containment in deep water. Every organization and individual involved in the petroleum lifestyle, including consumers, needs to be responsible for ensuring safe and effective petroleum management.

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