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Toxic Nature of Crude Oil

1.1 High Risk Areas

In general, spilled oil is most harmful when shallow, productive waters, porous sediments, low-energy aquatic environments, or special-use habitats are impacted. Examples of high-risk locations include wetlands, sheltered tidal flats, shallow bays, coarse sand and gravel beaches, and sites with concentrated reproductive and migratory activities.

1.2 Potential Impacts

The impacts on local shore regions from a crude oil spill can be economically devastating. There are impacts on the fishing and tourism industries, shipping, recreation, and property values, to mention a few. In addition to the economic impacts on the coastal communities, the environmental damages can be devastating to the local ecosystems. The BP Gulf oil spill threatens to destroy an entire ecosystem, a way of life that has existed for generations, and national treasures and can possibly have global implications.

Recent computer models suggest that the ongoing spill is likely to contaminate the entire eastern shoreline and move on to the shores of foreign countries.

Crude oil and petroleum products vary in their toxicity, and the sensitivity of fish to petroleum varies according to species. The water-soluble fractions of crude oil can stunt fish growth. Negative impacts on fish are primarily seen in the eggs, larvae, and early juveniles, with varied effects on the adults.

The following are some negative impacts from oil spills:

- Pink salmon fry are affected by exposure to water-soluble fractions of crude oil, while pink salmon eggs are tolerant of benzene and water-soluble petroleum.
- Fish rapidly metabolize aromatic hydrocarbons due to their enzyme system.
- Depressed feeding, decreased swimming activity, and increased mortality occur in fish.
- The mortality of eggs and larvae increases (such as after the Argo Merchant No.6 fuel oil discharge where 20% of the cod eggs and 46% of the Pollock eggs in the discharge zone were dead). During the Torrey Canyon (Bunker C) discharge, 90% of the pilchard eggs in the discharge area were killed. Following the Amoco Cadiz (crude oil) discharge, a one-year old class of flatfish was thought to have been reduced.
- Exclusion of fishermen from the fishing grounds and other disruptions of fishing can change the population balance to date (e.g., salmon over-escapement in Prince William Sound after the Exxon Valdez (crude oil) spill).
- The fouling of costly fishing gear during the spill can set the fisherman back even after the fishing restrictions are lifted.
- The tainting of fish (such as change in flavor or smell) and the public's fear of tainting, mortality, or other effects of non-motile inshore species, such as rockfish, occurs.
- Mortality and the tainting of fish maintained in mariculture enclosures, where the escape of fish is prevented, is common (e.g., the Braer oil discharge off the Shetlands affected salmon in mariculture enclosures).

- Sublethal effects occur, such as fin erosion, ulceration of the integument, liver damage, lesions in the olfactory tissue, reduced hatching success, reduced growth, change in egg buoyancy, malformations that interfere with feeding, arrest of cell division, and genetic damage.
- The oiling of feathers is considered to be the primary cause of most bird deaths following oil spills. Oil disrupts and destroys the fine strand structure of the feathers, resulting in the loss of water repellency and body insulation. As the oiled plumage becomes matted, water penetrates the feathers and chills the animal's body. The combined results are a loss of buoyancy and hypothermia. The natural response to oil matted plumage is preening, subsequent to which oiled birds ingest the oil while attempting to remove the petroleum from their feathers. The ingestion of petroleum results in anemia, pneumonia, kidney and liver damage, stunted growth, altered blood chemistry, and decreased egg production.
- Chicks are exposed to petroleum by ingesting food regurgitated by impacted adults, and they may also be poisoned.
- Recovery from the effects of oil spills on local populations of invertebrates can require up to 10 years depending on the type of oil, the circumstances of the spill, and the organisms affected. Invertebrates (zooplankton) in the water column of large bodies of water return to pre-spill conditions much faster than invertebrates in small bodies of water (fresh-water lakes, streams); however, this is a broad generalization.
- Gulls, storm petrels, and guillemots experience elevated corticosterone, thyroxin, and increased size of adrenal glands after ingesting a single dose of 0.1% (of diet) crude oil.
- Exposure to oil by birds has been shown to lead to changes in behavior that ultimately cause reduced reproductive success. Effects include cessation or delay of egg laying, increased nesting phenology, nest abandonment, reduced feeding of young, mate switching, interruption of courtship behavior, egg rejection,

parental rejection of chicks, impairment of incubation behavior, and reduced nest attentiveness.

- Epifauna, such as mussels and bivalves, generally survive oiling as adults due to their protective shells, but they have no enzymatic system for purging. Therefore, bioaccumulation occurs, resulting in reduced feeding absorption efficiency followed by growth reductions.
- Oiling of chicks by the externally treated adult has been reported to result in the rejection of the chicks.
- Wedge-tailed shearwaters orally exposed to Santa Barbara crude oil had a laying and incubation frequency significantly lower than controls.
- Oil concentrations as low as 1 uL/egg (1.3% of the surface of a mallard egg) are toxic. This is attributed to a function of the aromatic component of crude oil rather than impaired gas exchange.
- Mallards that ingest crude oil experience delayed laying, decreased oviposition, and decreased shell thickness.
- The hatching success of herring and black-backed gull eggs decreased in response to 10 uL of crude or weathered crude oil applied externally to eggshells.
- Heron, tern, and brown pelican eggs experience reduced hatchability when oiled either directly or via the adult's feathers.
- Following the Santa Barbara oil spill, a large number of premature births were observed in sea lions.

Crude oil is toxic to humans. The industry downplays this and argues crude oil is of low toxicity to humans. Table 1.1 tabulates compositions of crude oil as reported on Material Safety Data Sheets from different suppliers. Crude oil contains both chemical toxins and carcinogens. Among the chemicals are benzene, toluene, ethylbenzene, xylene, polyaromatic hydrocarbons (PAHs), and toxic heavy metals not listed on MSDSs. While concentrations are low, when there is a spill of the magnitude of the Deepwater Horizon spill (the BP disaster of the Gulf) covering thousands of square miles of surface area, the volatile organic compounds (VOCs) rapidly evaporate accelerated by constant surface area renewal caused by waves. Personnel working on vessels that skim up the surface oil or combat the spill along shorelines and marshes are being exposed to carcinogens and other toxic chemical ingredients that are known teratogens, or systemic poisons, which are known to impair liver and kidney functions. Crude oils contain similar chemicals to coal tar pitch volatiles, or PAHs, which are a large family of toxic chemicals that are suspected and confirmed human carcinogens. When oil is burned at the surface in order to combat the spill, more carcinogenic PAHs are created as these are products of incomplete combustion.

The toxicity of crude oil involves an incredibly complex mixture of inorganic and organic chemicals. There is uncertainty in the application of dose-response relationships based on crude oil as a whole mixture to both humans and aquatic life. A simplified approach to determining toxicity is an "indicator chemical approach" which involves selecting a subset of chemicals from the whole mixture that represents the "worst case" in terms of mobility and toxicity. This approach has been used with crude oil with the subsets of chemicals being volatile organics such as benzene, toluene, ethylbenzene, and xylenes (collectively referred to as BTEX) and polycyclic aromatic hydrocarbons (PAHs).

The BTEX group is of significance because the chemicals in the family are soluble in water, highly mobile in the environment, and represent the more volatile and soluble components of crude oil. In addition, benzene is an EPA defined Class A carcinogen.

In contrast, PAHs are not highly mobile. These chemicals tend to have low solubility and vapor pressures (hence, they are referred to as semi-volatile organic chemicals or SVOCs) but they are of interest because they range from toxic to carcinogenic. These chemicals are prevalent in crude oil, representing the heavier or less volatile crude oil components. PAHs and their transformation products are among the most hazardous constituents of crude oil.

The effects of petroleum and individual PAHs on living organisms such as mammals include impaired immune systems, impaired reproduction, and reduced growth and development. Overall, the effects are immunological, reproductive, fetotoxic, and genotoxic.

The toxicity of crude oil may be affected by various factors such as "weathering" time or the addition of oil dispersants. Weathered and "fresh" crude oil may have different toxicities depending on oil type and weathering time. Oil and dispersant mixtures can be equally as toxic as crude oil alone.

Table 1.1 Compositions of crude oil reported on various MSDSs.

Concentrations as Reported on MSDS	Toluene					100 ppm	0.1–5 wt.%
	Xylene					100 ppm	0.1–5 wt.%
	Coal Tar Pitch Volatiles				0.2 wt.%		
	Pentane				1.5–2.5 vol.%		
	Isopentane				0.3–1.5 vol.%		
	Butane				0.8–1 vol.%	10 ppm	
	Hydrogen Sulfide			Varies (<1) wt.%		10 ppm	<0.5 wt.%
	n Hexane			0–1.4 wt.%	0.8–1 vol.%		
	Polycyclic aromatic hydrocarbons (PAHs)		Trace				
	Ethylbenzene						0.1–5 wt.%
	Benzene	0–0.1 wt.%	Trace	0.0–0.1 wt.%			0.1–5 wt.%
	Asphaltene Content	0–2 wt.%					
	Polars	1–5 wt.%					
	Aromatics	8–15 wt.%					
	Saturates	80–90 wt.%					
	Sulfur Compounds	0–2 wt.%	Varied				
Effective Date		7-Aug	11-Mar-08	No Date	5/13/2002	No Date	30-Jun-08
Supplier		Martin Marietta Materials	Irving	Mark West	BP West Coast Products LLC	Gibson Energy ULC	Plains Marketing, L.P.

1.3 Definitions

The following definitions are given in the NOAA HMRAD Shoreline Countermeasures Manual for tropical coastal environments:

- Light oils (diesel, No. 2 fuel oils, light crudes):
  - Moderately volatile; will leave residue (up to 1/3 of spilled amount)
  - Moderate concentrations of toxic (soluble) compounds
  - Well "oil" intertidal resources with long-term contamination potential
  - Has potential for subtidal impacts (dissolution, mixing, sorption onto suspended sediments)
  - No dispersion necessary
  - Cleanup can be very effective

- Medium oils (most crudes):
  - About 1/3 will evaporate within 24 hours
  - Maximum water-soluble fraction is 10–100 ppm
  - Oil contamination of intertidal areas can be severe and long-term
  - Impact to waterfowl and fur-bearing mammals can be severe
  - Chemical dispersion is an option within 1–2 days
  - Clean-up is most effective if conducted quickly

- Heavy oils (heavy crude oils, No. 6 fuel, bunker C):
  - Heavy oils with little or no evaporation or dissolution
  - Water-soluble fraction is likely to be <10 ppm
  - Heavy contamination of intertidal areas is likely
  - Severe impacts to waterfowl and fur-bearing mammals (coating and ingestion)
  - Possible long-term contamination of sediments
  - Weathers very slowly
  - Dispersion is seldom effective
  - Shoreline clean-up is difficult under all conditions

The following are common synonyms. Although the term "petroleum" is sometimes considered a synonym for crude oil, it more commonly refers to petroleum products as a whole and not just the crude oil from which these products are derived. Oil, both crude and refined, is a very broad topic. It has been divided into several different entries (although there is still some overlap on certain topics):

- Base oil
- Coal liquid
- Coal oil
- Crude oil, petroleum
- Crude petroleum
- Petrol
- Petroleum crude
- Petroleum oil
- Rock oil
- Seneca oil
- Naphtha

The following are terms concerning chemical composition. These terms are important from the standpoint of identifying the chemicals of exposure, environmental sampling, and assessing toxicity.

1.3.1 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a group of over 100 different chemicals that are formed during the incomplete burning of coal, oil, gas, garbage, or other organic substances like tobacco or charbroiled meat, but they are also found in oil. The simplest PAHs, as defined by the International Union on Pure and Applied Chemistry (IUPAC) (G.P. Moss, IUPAC nomenclature for fused-ring systems), are phenanthrene and anthracene. Both of these chemicals contain three fused aromatic rings. Smaller molecules, such as benzene, are not PAHs. PAHs may contain four-, five-, six-, or seven-member rings, but those with five or six are most common. PAHs composed only of six-membered rings are called alternant PAHs. Certain alternant PAHs are called "benzenoid" PAHs. The name is derived from benzene, which is an aromatic hydrocarbon with a single, six-membered ring. These can be benzene rings that are interconnected with each other by single carbon-carbon bonds and with no rings remaining that do not contain a complete benzene ring. The set of alternant PAHs is closely related to a set of mathematical entities called polyhexes, which are planar figures composed by conjoining regular hexagons of identical sizes.

PAHs that contain up to six fused aromatic rings are often known as "small" PAHs, and those containing more than six aromatic rings are called "large" PAHs. Due to the availability of samples of the various small PAHs, the bulk of research on PAHs has been on those of up to six rings. The biological activity and occurrence of the large PAHs do appear to be a continuation of the small PAHs. They are believed to derive from combustion products but at lower levels than the small PAHs due to the kinetic limitation of their production through the addition of successive rings. Also, with many more isomers possible for larger PAHs, the occurrence of specific structures is smaller.

Another aromatic compound is Naphthalene ($C_{10}H_8$ constituent of mothballs). This chemical consists of two coplanar six-membered rings sharing an edge and is another aromatic hydrocarbon. By formal convention it is not a true PAH, though it is referred to as a bicyclic aromatic hydrocarbon.

Note that aqueous solubility decreases approximately one order of magnitude for each additional ring.

Other toxic PAHs include the following:

- Benz(a)anthracene
- Benzo(a)pyrene (B(a)P)
- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Chrysene
- Dibenz(a,h)anthracene
- Indeno(1,2,3-cd)pyrene
- Acenaphthylene
- Acenaphthene
- Anthracene
- Fluorene
- Phenanthrene
- Fluoranthene
- Pyrene
- Benzo(g,h,i)perylene

1.3.2 Total Petroleum Hydrocarbons (TPH)

Individual compounds of crude oil can be classified into the following categories:

- Hydrocarbons, which include alkanes (normal and branched chains), cycloalkanes, alkenes, aromatics, and naphthenoaromatics
- Non-hydrocarbons, which include nitrogen, sulfur and oxygen (NSO) compounds, asphaltenes and resins (including NSO heterocyclics), metallo-organics, and inorganic metal salts

The toxicity of individual chemicals differs widely. Generally, the most toxic compounds are benzene, ethyl benzene, toluene, and xylenes.

1.4 Examples of Historical Oil Spills and Their Impacts

Table 1.2 lists 26 spills that have occurred over the years. The list is a sampling of the spills that have been reported. For relative comparison, while many consider the 1989 Exxon Valdez spill in Alaska one of the largest spills in history, it was actually quite small in comparison to many other spills. The Valdez spill ranks as the 34th largest spill in the world.

The Gulf War oil spill, resulting from the 1990 Iraqi invasion of Kuwait, is regarded as the largest oil spill in history. Iraqi forces opened valves at the Sea Island oil terminal and dumped oil from several tankers into the Persian Gulf in order to thwart a potential landing by U.S. Marines. The immediate reports from Baghdad said that American air strikes had caused a discharge of oil from two tankers. Coalition forces determined the main source of oil to be the Sea Island terminal in Kuwait. American air strikes destroyed the pipelines in order to prevent further spillage into the Persian Gulf. The oil spill, which began on January 23, 1991, caused considerable damage to wildlife in the Persian Gulf, especially in areas surrounding Kuwait and Iraq. Estimates on the volume spilled usually range around 11 million barrels (462 million gallons). The oil slick reached a maximum size of 101 by 42 miles (4,242 square miles) and was 5 inches thick in some areas. Marshlands and mud tidal flats still contain large quantities of oil, and full recovery is likely to take decades. The long-term effects were very significant. The salt marshes, which occur along almost 50% of the coastline, have shown the heaviest impact compared to the other ecosystem types for nearly two decades. Sand beaches are on the best way to complete recovery. The main reason for the delayed recovery of the salt marshes is the absence of physical energy (wave action) and the mostly anaerobic milieu of the oiled substrates.

Of the 26 spills noted in Table 1.2, nearly 1.2 billion gallons of oil was spilled. This is equivalent to the combined capacities of 1,848 Olympic-size swimming pools.

There are no reliable estimates of the BP oil spill in the Gulf of Mexico at the moment. This disaster began April 20, 2010 when the rig exploded and sank. News media reports as of June 19, 2010 have reported official numbers of between 35,000 and 60,000 barrels per day being released into the Gulf. As of this writing, those estimates represent a release of between 89 and 153 million gallons of oil. The BP Gulf disaster (known as the Deepwater Horizon spill) may prove to match the 1979 Ixtoc I oil rig disaster (see Table 1.2).

The damage to ecosystems and the way of life caused by oil spills is both far reaching and not fully defined because neither governments nor the industry have acted to provide adequate research funding in order to define the impacts and to devise safe and reliable technologies for offshore oil recovery. The Exxon Valdez spill of nearly 11 million gallons killed as many as 700,000 sea birds and 5,000 sea otters initially. Twenty-one years after the spill, the populations of sea otters in the areas of Prince William Sound have not recovered. The Pacific herring population all but collapsed in the aftermath of the spill. Two intensely studied pods of killer whales in the sound suffered heavy losses from the spill and never fully recovered. One of the pods no longer has a reproductive female and is therefore doomed to extinction. The oil that was spilled in Prince William Sound is in fact still sitting there.

The degradation of oil takes decades. The authors have worked on oil pipeline releases that occurred in the 1960s. The daughter products of degradation follow a pathway that is strongly dependent on the ecosystem it is attacking. While oil industry ads and government officials seek to calm public outcry and anger over the chronic impacts from the Deepwater Horizon spill by reporting that ecosystem damages will be minimized by natural attenuation, the fact remains that this is nonsense. Microbial action in a rich marine environment like the Gulf will accelerate degradation but only to a point. The microbes move on leaving large complex chemical compounds in their aftermath. These are the asphaltenes that are too difficult to digest. What remains after decades is the dense tarry material that serves one useful purpose – surfacing roadways. Estimates from 2003 show that there was as much as 21,000 gallons of crude oil remaining in Prince William Sound decades after the Exxon Valdez spill. After all of these years, the oil, the legal disputes, and the negative impacts to the environment are still there.

The Ixtoc I spill was even more devastating and even more mysterious because less documentation exists. The oil drifting north from the spill destroyed hundreds of millions of crabs on Mexican beaches and killed 80% of the segmented worms and shrimp-like crustaceans in the sand along Texas beaches.

Since 1970, there have been 1,700 spills on record from tankers alone. The smallest recorded spill is 2,100 gallons of oil. There seems to be no reliable records on how much toxic chemical dispersants have been applied over the years in response to some of these spills. After the Deepwater Horizon spill, the fact still remains that there is a lack of oversight and complacency in issuing licenses for offshore drilling without ensuring appropriate emergency response infrastructure and plans.

The International Tanker Owners Pollution Federation (ITOPF) maintains a database[1] of oil spills from tankers, combined carriers, and barges. The database reports information on accidental spillages since 1970, excluding those resulting from acts of war. The data reported includes the type of oil spilt, the spill amount, the cause and location of the incident, and the vessel involved. For historical reasons, spills are generally categorized by size: <7 tonnes, 7–700 tonnes, and >700 tonnes (<50 bbls, 50–5,000 bbls, >5,000 bbls). The actual amount spilled is also recorded. The database shows nearly 10,000 incidents, the vast majority of which (82%) fall into the smallest category, i.e., < 50 bbls (bbls stands for barrels).

In general, the incidence of large spills is relatively low. However, ITOPF has noted that detailed statistical analysis is rarely possible. Regardless, this extensive database does show that the number of

[1]http://www.itopf.com/information-services/data-and-statistics/statistics/#background

Table 1.2 Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
19-Jan-91	Persian Gulf, Kuwait	During the Gulf War, Iraqi forces, attempting to thwart a potential landing of American soldiers, opened the valves at an offshore oil terminal and dumped oil from several tankers. The oil they released created a 4-inch thick oil slick that covered 4,000 square miles. That's enough oil to cover the entire state of Rhode Island one-foot deep in oil.	520,000,000	12,380,952	802.5
3-Jun-79	Bay of Campeche off Ciudad del Carmen, Mexico (Incident lasted from June 3, 1979-March 23, 1980)	Ixtoc 1 Oil Spill – This oil spill did not involve a tanker, but rather an offshore oil well. Pemex, a state-owned Mexican petroleum company was drilling an oil well when a blowout occurred. The oil ignited causing the drilling rig to collapse. Oil began gushing out of the well into the Gulf of Mexico at a rate of 10,000 to 30,000 barrels a day for almost an entire year before workers were finally able to cap the well and stop the leak.	140,000,000	3,333,333	216.0

Table 1.2 (cont.) Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
8-Sep-94	Kolva River, Russia	Kolva River Oil Spill – A ruptured pipeline caused this enormous oil spill. The pipeline had been leaking for eight months, but the oil was contained by a dike. When the dike collapsed, it sent millions of gallons of oil into the Russian Arctic.	84,000,000	2,000,000	129.6
18-Sep-83	Persian Gulf, Iran	Nowruz Oil Field Spill – This spill was the result of a tanker collision with an oil platform. The platform tilted and was closed, but the weakened platform collapsed sending oil spewing into the Persian Gulf. Delays in getting the leak capped were caused by the ongoing Iran-Iraq War.	80,000,000	1,904,762	123.5
6-Aug-83	Saldanha Bay, South Africa	Castillo de Bellver Oil Spill – The Castillo de Bellver caught fire approximately 70 miles northwest of Cape Town, South Africa. The ship drifted before breaking in two 25 miles off the coast. The ships stern sank in deep	79,000,000	1,880,952	121.9

		water still carrying approximately 31 million gallons of oil. The bow section was towed away and deliberately scrapped.			
16-Mar-78	Portsall, France	Amoco Cadiz Oil Spill – The Amoco Cadiz was caught in a fierce winter storm that damaged its rudder. The ship put out a distress call that it was no longer able to maneuver. Several ships responded, but none were able to stop the massive ship from running aground. On March 17th, the gigantic supertanker broke in two sending all of its 69 million gallons of oil into the English Channel. The ship was later sunk by the French.	69,000,000	1,642,857	106.5
11-Apr-91	Genoa, Italy	M/T Haven Tanker Oil Spill – This oil tanker exploded and sank off the coast of Italy killing six people. The source of the explosion was alleged to be the poor state of repair the ship was in. Supposedly, the Haven was scrapped after being hit by a missile during the Iran-Iraq War and then put back into operation. The vessel continued leaking its remaining oil into the Mediterranean for 12 years after the sinking.	45,000,000	1,071,429	69.4

Table 1.2 (cont.) Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
10-Nov-88	Off the coast of Nova Scotia, Canada – This spill occurred approximately 700 nautical miles off the coast of Newfoundland.	Odyssey Oil Spill – No information on the incident was uncovered from research.	40,700,000	969,048	62.8
18-Mar-67	Scilly Isles, UK	The Torrey Canyon Oil Spill – The spill created an oil slick measuring 270 square miles. It contaminated approximately 180 miles of coastland and killed over 15,000 sea birds and enormous numbers of aquatic animals before the spill was finally contained.	36,000,000	857,143	55.6

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19-Dec-72	Gulf of Oman	The Sea Star Oil Spill – The South Korean supertanker, Sea Star, collided with a Brazilian tanker, the Horta Barbosa, off the coast of Oman.	35,300,000	840,476	54.5
Feb-96	Coast of Southwest Wales	Sea Empress Grounding – The grounding of the Sea Empress caused one of the largest and most environmentally damaging oil spills in European history. More than 100 km of coastline became seriously polluted by oil. Ecosystems of conservation, fishery, and recreational importance were affected. A massive clean-up operation was launched both at sea and onshore. The pollution was at its height during late February and early March of 1996, at which time huge slicks were at sea, and many shores were experiencing large-scale bulk oil pollution. By April, as a result of natural dispersion and the clean-up operation, little bulk oil remained at sea and many shores had regained a semblance of normality. Wave-exposed rocky shores improved quickly	21,097,436	502,320	32.6

Table 1.2 (cont.) Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
		through natural cleansing, followed by the intensively cleaned sands of the main bathing beaches, most of which were reopened for Easter. However, many shores were affected by residual oil pollution through the summer of 1996. Contamination persisted out of sight within shingle, sands, and muds and within surviving wildlife. Autumnal storms remobilized buried oil, causing the temporary reappearance of sheens and tar balls on many beaches. This storm action accelerated the natural cleansing of the coast. By spring of 1997, few shores showed visible evidence of oiling. Birds at sea were hit hard during the early weeks of the spill, resulting in thousands of casualties. The grey seal population appeared little affected and impacts to sub			

		tidal wildlife were limited. Considerable damage was caused to shorelines affected by bulk oil. Shore seaweeds and invertebrates were killed in large quantities. Mass strandings of cockles and other shellfish occurred on sandy beaches. Rock pool fish were also affected. On many shores the process of wildlife recovery began soon after the bulk oil dispersed naturally or was removed. Surviving wildlife was supplemented by plant and animal recolonizers. Recovery is likely to be protracted in the case of sheltered shores that continue to harbor deep-seated lingering residues of oil (e.g., some muddy shores in Milford Haven). As a result of the incident, fishing activity was banned. However, following intensive government testing of shellfish and finfish, the ban was lifted in stages.			
24-Mar-89	Coast of Alaska	Exxon Valdez oil – spilled 10.8 million gallons of oil along 1,100 miles of Alaskan coast. The spill could have been much worse – the Valdez was carrying 53 million gallons.	10,800,000	257,143	16.7

Table 1.2 (cont.) Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
1-Nov-79	Galveston Entrance in the Gulf of Mexico	Burmah Agate – Burmah Agate collided with the freighter Mimosa southeast of Galveston Entrance in the Gulf of Mexico. The collision caused an explosion and a fire on the Burmah Agate that burned until January 8, 1980. An estimated 2.6 million gallons of oil were released into the environment, and another 7.8 million gallons were consumed by the fire.	10,400,000	247,619	16.0
27-Apr-86	Cativa Bay – Caribbean coast of Panama	Cavity Bay Release – On May 4th, a storm broke the containment booms, releasing ~150,000 barrels of oil into the Atlantic Ocean. Winds, tides, and rain runoff washed part of the oil onto exposed shorelines. Some of the oil was carried back into Cativa Bay, and some was washed into adjacent	10,080,000	240,000	15.6

		embayments with mangrove shorelines. By May 15th, oil had spread along the coast and washed across fringing reefs and into mangrove forests and small estuaries. A total of 82 km of coastline (=11 linear km) was oiled to varying degrees. Approximately 75 ha of mangroves, primarily the red mangrove Rhizophora mangle, were killed by the discharge. Oil slicks were observed frequently in Bahia Les Minas during the 4 years following the discharge. The slicks primarily originated from fringing mangrove areas that had been impacted by the discharge. As dead red mangroves decayed and their wooden structures disappeared, erosion of the associated oiled sediment occurred, releasing trapped oil. Oil was present in mangrove sediments and continued to appear on mangrove roots during the three years following the discharge, with the highest levels of continued oiling occurring in stream habitats and the lowest levels along the open coast. Total oil concentrations remained high, up to 20% of dry weight in surface sediments, for at least the first 4 years following the discharge. Residual pools of oil in mangrove			

Table 1.2 (cont.) Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
		sediments were sufficiently fluid to flow out when sediments were cored or disturbed 5 years after the discharge. The release of oil from pools under and around the collapsed Refineria Panama storage tank and from mangrove sediments caused chronic re-oiling for at least 5 years following the discharge, and undegraded oil residues were found in some heavily oiled sediments 6 years after the discharge. Thus, the discharge site, initially injured by a single point source of oil, became a chronic source of oil contamination. Hydrocarbon chemistry confirmed the long-term persistence of crude oil in mangrove sediments, with pools of trapped oil maintaining consistent hydrocarbon composition. The frequency and amount of re-oiling differed among			

		habitats. Secondary re-oiling was heaviest in sheltered drainage systems of the mangrove environment, where oil continuously leaked from the sediment, but also occurred along the open coast and along channels. Seasonal variation in weather, water levels, and tidal flushing affected the amount of oil released. The greatest amount of re-oiling occurred between February and August 1989 and appeared to be related to the collapse and cutting of dead mangroves and to replanting efforts by the Refineria Panama.			
15-Dec-76	Southeast of Nantucket Island, Massachusetts	Argo Merchant ran aground on Fishing Rip (Nantucket Shoals) 29 nautical miles southeast of Nantucket Island, Massachusetts in high winds and ten foot seas. Six days later, the vessel broke apart and spilled its entire cargo.	7,700,000	183,333	11.9
30-Jul-84	Calcasieu River Bar Channel, LA	U.K. Tank Vessel Alvenus grounded in the Calcasieu River Bar Channel 11 miles southeast of Cameron, Louisiana. The vessel suffered a structural failure that ruptured the hull near the No. 2 tanks. Offshore recovery was hampered by rough weather and the magnitude of the spill. The spill moved slowly westward, coming ashore near High	2,751,000	65,500	4.2

Table 1.2 (cont.) Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
		Island along the Bolivar Peninsula and into Galveston Bay, Texas between August 2nd and 5th. Oil impacts were severe at Rollover Inlet and Crystal Beach, and on August 4th more oil was pushed ashore further south along the Galveston Island coast. The spill affected 90% of Galveston's West Beach, including 80% of the Galveston seawall and the associated rock groins and pilings. Oil in the seawall area was a concern due to the oil's smothering effect on marine organisms. Tourism losses were estimated at $1 million per day. Commercial shrimp fishermen filed a suit for $10 million. By October 1st, the oiled beaches of Bolivar Peninsula and Galveston Island had been cleaned by the removal of oiled sand.			

Jan-83	Louisiana	A well blow-out – Comparisons of control and affected sites one year after the discharge revealed that oil effects on vegetation were species-specific. Areas with high shading by mature trees had little or no understory, and few effects of the oil were observed on the dominant woody vegetation. Perennial plants were returning to the sunlit areas. In contrast, oiled areas formerly covered with floating vascular vegetation were devoid of any vegetation.	1,260,000	30,000	1.9
Mar-73	La Parguera, Puerto Rico	Liberian tanker Zoe Colocotronis ran aground and pumped crude oil overboard. The wind drove about 60% of the oil into Bahia Sucia in southwestern Puerto Rico, where it affected a number of marine habitats including red and black mangrove swamps. The discharge site and an un-oiled reference site were evaluated qualitatively one week, 13 weeks, and 3 years after the discharge. Observations were made of the degree of prop root oiling, of the prop root invertebrate community, and of oil in swamp sediments. After 3 years, dead mangroves were evident and oil remained in sediments. It was noted in 1990 that,	1,118,803	26,638	1.7

Table 1.2 (cont.) Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
		although most petroleum released at sea in tropical environments degrades rapidly, contamination reaching intertidal sediments may persist for decades. They observed discrete subsurface layers of petroleum hydrocarbons in intertidal sediment cores collected from the discharge site in 1990, 13 years after the discharge. The uppermost such layer contained petroleum hydrocarbon concentrations greater than 200 mg/g. A deeper layer with less concentrated petroleum hydrocarbons was believed to correspond to the earlier Argea Prima discharge in 1962. Sediments above, between, and below these layers had low concentrations of typical biogenic hydrocarbons.			

7-Jan-94	Escambron Beach in San Juan, Puerto Rico	Barge Morris J. Berman – The barge grounded on a hard bottom consisting of rocky substrate with scattered coral after its towing cable parted. The barge had a capacity of three million gallons but was reportedly only half full. The cargo, a heavy #6 fuel oil, began spilling and impacted nearby shoreline and shallow intertidal habitats immediately. No estimated leakage rate was available. Due to strong northerly winds, the surf at the grounding site was quite strong, creating a hazardous situation as they pounded the deck of the vessel. The responsible party initially assumed responsibility for the spill but very quickly expended the ten million dollar limit of their insurance policy. Full federal funding of the spill occurred at 0600 on January 14th, and it became a United States Coast Guard (USCG) directed response. Oil, in the form of large mats, accumulated on the surface and on the bottom of the lagoons. Submerged oil posed a major clean-up problem during the response. On January 15th the barge was re-floated, towed to a scuttling site 20 miles northeast of San Juan, and sunk. Impacts were primarily along 12 miles	743,400	17,700	1.1

Table 1.2 (cont.) Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
		of shoreline from Isabella to Borinquen. This oil was buried as oily sand layers and submerged as oil and sand mats in the protected areas or crenulate bays.			
13-Dec-68	Galeta Island, Canal Zone, Panama	The oil tanker Witwater broke up in heavy seas off the Atlantic coast of Panama. The breakup of the vessel and the continued leaking of the wreck spilled 14,000 barrels of bunker C and diesel oil into the water 5 miles from Galeta Island. The oil eventually impacted Galeta Island. Strong seasonal winds pushed the slick towards Galeta Island. Sand beaches, rocky coasts, and mangroves along the island were oiled. Oil collected in a small bay on the island. An estimated 8,000 barrels of oil remained in the bow section of the wreck and leaked at a rate of 50 barrels per day.	588,000	14,000	0.9

23-Oct-07	Kab Field, Bay of Campeche, Gulf of Mexico	The Usumacinta was brought into position alongside the Kab-101 platform to finish drilling the Kab-103 well. A cold weather front passed through the Gulf of Mexico bringing storm winds of 130 km/hr with waves of 6–8 m. The adverse weather conditions caused oscillating movements of Usumacinta jack-up. These movements caused the cantilever deck of the Usumacinta to strike the top of the production valve tree on the Kab-101 platform, resulting in a leak of oil and gas. The subsurface safety valves of wells 101 and 121 were closed by PEMEX personnel, but the valves were unable to seal completely, allowing the continued leaking of oil and gas. 81 personnel on the Usumacinta were evacuated by lifeboat. There were 21 reported deaths during the evacuation of the Usumacinta with one worker missing, presumed dead. Regarding the spill, PEMEX undertook measures to contain, recover, and disperse the spill. The initial spill was reported by PEMEX at circa 422 barrels per day of mostly light crude, of which 40% was estimated to have evaporated. Chemical dispersants were used	575,400	13,700	0.9

Table 1.2 (cont.) Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
		alongside sea recovery operations, with a total of 8,701 barrels recovered from the sea. By early December 2007, PEMEX estimated that around 5,000 bbls oil had been lost from the well and not recovered. There was some criticism over the use of dispersants simply causing the oil to sink to the seabed.			
6-Mar-91	Nevis Island (British)	Vista Bella – the Vista Bella sank in the Atlantic Ocean approximately 12 miles northeast of Nevis Island (British). The barge, carrying 13,300 barrels of No. 6 fuel oil, sank in approximately 2,000 feet of water. The wind speed on the day of the incident was approx. 6–10 knots. The cause of the sinking was not determined. The barge was owned by Offshore Marine Limited and operated under the Trinidad flag. Dispersant was applied from March	558,600	13,300	0.9

		9th–15th within a two-nautical mile area of the source. The U.S. Coast Guard (USCG) Atlantic Strike Team (AST) was on-scene from March 14th to the 23rd. Contractor beach clean-up began on March 27.			
20-Mar-01	Rio de Janeiro, Brasil	Ten personnel were killed when the world's largest offshore oil rig exploded and sank.	395,000	9,405	0.6
10-Aug-93	Tampa Bay, Florida	Barge Bouchard 155 – Three ships collided in Tampa Bay, Florida – the barge Bouchard 155, the freighter Balsa 37, and the barge Ocean 255.	336,000	8,000	0.5
Jul-75	Western edge of the Florida Current	The tanker Garbis discharged crude oil-water emulsion. Prevailing easterly winds drove the oil ashore along a 30 mile stretch of the Florida Keys from Boca Chica to Little Pine Key. Red mangroves with >50% of their leaves oiled were killed, and red mangrove propagules with >50% oil coverage died within 2 months. Black mangroves with >50% of pneumatophores oiled were killed. Thin oil coating left chemical burn scars, and the germination of oiled seeds decreased by 30%. Batis and Salicornia spp. died when oil coated their leaves, stems, or substrate. Lightly oiled mangrove	126,000	3,000	0.2

Table 1.2 (cont.) Examples of major oil spills ranked from largest to smallest.

Date	Location	Incident	Amount of Oil Spilled		Equivalent Number of Olympic Size Swimming pools
			In Gallons	In Barrels	
		areas appeared to exhibit normal growth 6 months after the discharge. However, young and dwarf mangroves apparently suffered permanent injury, indicated by deformed leaves, roots, and stems. The discharge site was visited in May 1980, 5 years after the discharge, and it was reported that the oil had weathered significantly.			
1993-Oct-14	Rose Island, approximately 150 miles east of America Samoa	Jin Shiang Fa ran aground on Rose Island. The crew abandoned ship and were rescued by another fishing vessel in the area. The Jin Shiang Fa, a 137-foot, Taiwanese flagged fishing vessel, was carrying 10,000 gallons of diesel in its internal fuel tanks as well as an additional 100,000 gallons (2,390 barrels) of diesel in its forward cargo holds when	110,000	2,619	0.2

		it went aground. A Coast Guard overflight reported the vessel went aground on the west side of Rose Island, south of the narrow opening into the inner lagoon. A sheen, two miles long by 200 yards wide, trailed from the vessel in a northwesterly direction away from the island. An overflight the following day indicated that the vessel had a 30 degree list to port and an 11-mile by 200-yard wide sheen trailing to the northwest.			

large spills (> 5000 bbls) has decreased significantly during the last 40 years, such that the average number of major spills for the decade (2000–2009) is about three. Excluding the BP Gulf catastrophe, the average for the decade of the 2000s is less than half of the average for the 1990s and a mere eighth of the average for the 1970s. The same is true for medium-sized spills from tankers (50–5,000 bbls) where the average number of spills occurring in the last decade was 14, and half of that was experienced during the previous decade.

It is notable that the number of large spills in the 1970s is more than half of all the spills recorded in the 40 years between 1970 and 2009. Furthermore, the average number of large spills per year during the 1990s was less than a third of that witnessed during the 1970s. This downward trend continued during the 2000s, during which only 7% of all recorded spills occurred. The ITOPF along with the industry sector report in numerous sources that oil spills, in general, have become considerably less frequent compared to a few decades ago and, in fact, further argue that the statistics reflect a safety record that has improved over time. They imply and even claim that this is a reflection of the industry acting more responsibly because, along with tracking the oil spill statistics, the industry has made efforts to identify the root causes for spill incidents and generally has attempted to devise corrective actions that reduce the risks of such incidents from occurring.

We took the data reported by the ITOPF and created the chronological bar chart of recorded spills shown in Figure 1.1. On the chart we have included the oil release into the Gulf from BP's ill-fated Macondo well blowout of April 2010. There are no reliable estimates of how much oil has been released into the Gulf from this one single event. *The New York Times*[2] has reported that the range is somewhere between BP's reported estimate of 5,000 bbls/day to as high as 60,000 bbls/day. With potential fines from the Clean Water Act, which sets a civil fine of $1,100 for every barrel of oil released in a spill, in addition to the responsibility for paying for environmental clean-up and economic loss, to as much as $4,300 a barrel in fines if the U.S. government determines that the spill was the result of gross negligence, we have no confidence that BP's own estimate is accurate. Based on the information currently available, we have assumed that the truth lies somewhere in between. Therefore, the

[2]http://www.nytimes.com/2010/07/20/us/20flow.html

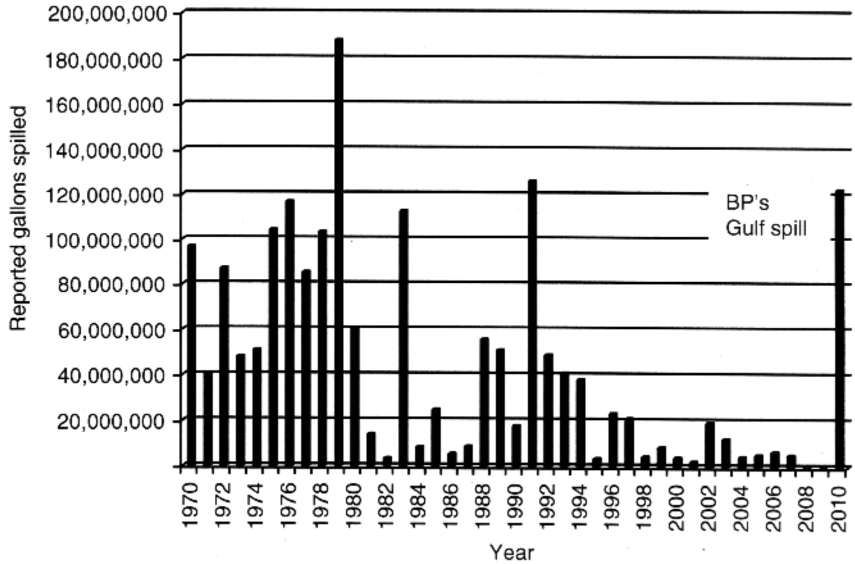

Figure 1.1 Bar chart showing reported oil spills. (Data converted from barrels to gallons from ITOPD database.)

data for the Gulf spill is shown as an average after 90 days of uncontrolled release into the Gulf.

Figure 1.1 leads one to a very different impression of the industry's safety record. While the frequency of oil spills has shown a decreasing trend since the 1970s, the chart clearly shows that for every decade since 1970 there have been catastrophic releases of oil into the environment. We don't share the same opinion as the industry sector in that it has a good track record. Nor do we believe that the industry has acted responsibly in taking steps to reduce such incidents from occurring. As explained in detail in Chapter 7, we have concluded that BP's Macondo well disaster was preventable. And while the industry sector as a whole may argue that BP's actions are not representative of the sector's checks and balances that are intended to prevent catastrophic releases of oil and the subsequent environmental damages and long-term health risks from such releases, we see more rhetoric than technical safeguards.