California Oil Spill Response Cost Study

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Executive Summary

Firms that produce, transport, or process oil and gas face the financial risk of paying for cleanup, penalties, legal services, and other expenses associated with the accidental release of product to the natural environment. Although infrequent, a large spill can be very expensive and so firms operating in California and elsewhere are required to demonstrate financial responsibility that shows they will be able to pay such costs. Under the authority of the Lempert-Keene-Seastrand Oil Spill Prevention & Response Act (CA Gov. C. §8670.1 et seq.), the Office of Spill Prevention and Response (OSPR) is required to establish financial responsibility requirements for oil spills from certain segments of industry. Senate Bill 861, among other mandates, required OSPR to establish such requirements for inland facilities. California is now considering potential revisions to these financial requirements. In Fall 2018, the Office of Spill Prevention and Response retained Catalyst Environmental Solutions Corporation (Catalyst), teamed with Environmental Research Consulting (ERC) and Greene Economics, to develop a customized oil spill cost model using current data that could be applied to spill scenarios in California for the purpose of exploring the need for revisions to current financial requirements. This report documents the background research and analysis used to develop the model and presents the results, by category of entity that is regulated by CDFW OSPR.

The current OSPR COFR amounts and RWCS volumes are based on statutory requirements or the results of the 1993 study. OSPR is currently updating its regulations. The specific objectives of this study are to:

1. Gather up-to-date spill volume and oil spill response cost data to inform development of California oil spill regulations and COFR requirements; and
2. Develop a cost model, called the CDFW Oil Spill Cost model (CDFW-OSC), that can be used as a tool by OSPR to estimate cleanup costs and damages in a variety of habitat types.

Several different sources of data were used to inform the analysis of recent spill history (1990s through 2018) and to create the relationships in the cost model developed for the study. Table ES-1 summarizes the sources of information for each category of entity regulated by OSPR regulations and indicates the section of this report where detailed analysis of spill history is described. The primary source for California spills is based on hazardous material release reporting and is publicly available on the California Office of Emergency Services website (CA OES).

ERC augmented this with a survey of inland oil producers in California. This California Operator Survey data includes 133 cases for which at least some cost data were provided. The costs were mainly for small spills at inland production facilities. Spill volumes varied from 0.25 bbl to 1,800 bbl, with an average of 44 bbl. 62% of the spills involved 5 bbl or less of spillage. Nearly a third of the spills involved produced water rather than only oil. Most of these spill cleanups would have been in a fairly limited area within the bounds of the facility. Spill costs varied from about $35 per bbl to $29,341 per bbl, with an average (mean) of $1,954.

CDFW OSPR provided data regarding vehicle spills between 2015 and 2017 to inform the analysis of mobile transfer units (MTUs).

The US Energy Information Administration (EIA) provided information on crude oil transport by rail and pipeline, and storage tank capacities gathered from oil spill contingency plans.

Finally, ERC relied on its proprietary database of oil spills and spill costs worldwide. The ERC Oil Spill Cost Database includes 443 spills from around the world, including spills from all types of sources and in different types of locations. The cases generally involve much larger spill volumes, with an average of

49,500 bbl. The range of spill volumes is from two bbl to 4.9 million bbl. The spill costs average $10,697 per bbl with a maximum of $690,255 per bbl. These spills are generally more complex than the ones captured in the CA OES data. The data on these more complex, and overall more costly, spill response operations and damages from these spills are more readily available (thought often as part of litigation) than for smaller spills. For that reason, these more "notorious" incidents make up the majority of the incidents in this database.

In general, there are significant challenges in obtaining accurate records for oil spill costs. Unless a spill's response and damage costs are part of public records (as with many non-US tanker spills funded by international funds, or in the US if the spill is federalized), the records are often confidential. The data are kept confidential by the responsible parties. Those costs that are publicized, as in media reports, are usually not broken down by cost type (response, damages, etc.), which makes it difficult to make reasonable comparisons.

Table ES-1: Summary of Spill Analysis by OSPR-Regulated Category

Category	Source of Spill Volume Data Described in Section 3	Number of Spills Included in the Dataset	Time Period of Spills Included in the Dataset	Location of Analysis of Recent Spill History in Study
Tanker	ERC Oil Spill Database	150	1968-2012	Section 4.1
	CA OES database	5	1998-2018	
Tank Barge	CA OES database	9	1998-2018	Section 4.2
Non-Tank Vessel	CA OES database	62	1998-2018	Section 4.3
Marine Facility	CA OES database	310	1998-2018	Section 4.4
Offshore Platform	ERC Oil Spill database	10	1968-2012	Section 4.5
Marine Pipeline	ERC Oil Spill database	0 (modeled)	modeled	Section 4.6
Small Marine Fueling Facility	CA OES database	22	1998-2018	Section 4.7
Mobile Transfer Unit (Marine)	CDFW OSPR data	2	2015-2017	Section 4.8
Inland Production Facility	CA OES database	4,164	1998-2018	Section 4.9
	CA Operator Survey	157 (133 with cost)	2015-2018	
Inland Pipeline	CA OES database	206	1998-2018	Section 4.10
Inland Rail	CA OES database	363	1998-2018	Section 4.11

As described in Section 6, the model results show that the per barrel costs for oil spill cleanup and response are dependent on the type of oil spilled and the spill location (inland to flowing water, or marine), rather than the spill source. As respondents with actual cost data to the operator survey only apply to inland production facilities, these data were used only to inform this category (responses from other categories of regulated entities provided modeled versus actual data).

There are differences of over an order of magnitude between the current California COFR unit costs and the unit costs for the smaller spills as estimated by the CDFW-OSC model. The California Operator Survey costs are considerably smaller (less than 100 bbl) and none of these spills reached flowing water. The spills in the survey were considerably smaller than those incorporated into the ERC Spill Cost Database upon which the CDFW-OSC depends. There is a general reduction in per-unit costs as spill volumes increase. This is largely attributable to an "economy of scale" factor. This is generally true for larger complex response operations and the damages that occur from large spills. Once the equipment, personnel, logistics, and overall response "infrastructure" and incident command systems are in place, the level of effort is spread out over a larger number of barrels of oil spilled and does not increase in direct proportion to each additional barrel that was spilled. Once the spill response becomes a complex operation, the unit costs increase sharply, but then drop off as the costs are spread over a greater volume.

However, for very small spills of less than 100 bbl or so, this relationship breaks down. For very small spills, like those reported in the California Operators Survey, the spill cleanup is relatively routine and can be handled by a smaller crew or even with on-site personnel trained in response. There is no complex incident command center with large numbers of state and federal officials in attendance. There is a relatively simple array of response equipment being employed.

Table ES-2 summarizes the per bbl response costs from the respondents

Table ES-2: Per-Bbl Response Cost Percentiles for Inland Production Facilities based on Responses to the California Operator Survey

Percentile	Response Cost/Bbl (2019 US$)
10th	$35
25th	$101
50th (Median)	$343
75th	$1,547
90th	$6,600
95th	$10,000
99th	$14,500
Maximum	$29,341
Average (Mean)	$1,954

Table ES-3 provides the results of per barrel spill costs for larger spills into water based on oil type. These results apply to spills greater than 100 bbl which occurred either offshore or in coastal areas and entered marine or large river system environments.

Table ES-3: CDFW-OSC Model Results – Range of Per Barrel Spill Costs by Oil Type for Offshore or Coastal Spills Greater than 100 bbl[1]

Oil Category	Per-Bbl Spill Cost			
	Highest Cost	High Cost	Medium Cost	Low Cost
Non-Persistent	$17,144	$13,055	$6,747	$4,615
Light Persistent	$31,764	$24,183	$12,498	$8,547
Medium Persistent	$38,805	$29,539	$15,268	$10,445
Heavy Persistent	$70,386	$53,582	$27,700	$18,943

[1] The vast majority of spill costs included in the model are marine spills which occurred in coastal and offshore environments; however, the costs also include some spills to major rivers (e.g. the Kalamazoo River spill)

SECTION 1 Introduction and Study Objectives

Firms that produce, transport, or process oil and gas face the financial risk of paying for cleanup, penalties, legal services, and other expenses associated with the accidental release of product to the natural environment. Although infrequent, a large spill can be very expensive and so firms operating in California and elsewhere are required to demonstrate financial responsibility that shows they will be able to pay such costs. Under the authority of the Lempert-Keene-Seastrand Oil Spill Prevention & Response Act (CA Gov. C. §8670.1 et seq.), the Office of Spill Prevention and Response (OSPR) is required to establish financial responsibility requirements for oil spills from certain segments of industry. Senate Bill 861, among other mandates, required OSPR to establish such requirements for inland facilities. California is now considering potential revisions to these financial requirements. In fall 2018, the Office of Spill Prevention and Response retained Catalyst Environmental Solutions Corporation (Catalyst), teamed with Environmental Research Consulting (ERC) and Greene Economics to develop a customized oil spill cost model using current data that could be applied to spill scenarios in California for the purpose of exploring the need for revisions to current financial requirements. This report documents the background research and analysis used to develop the model and presents the results.

1.1 Background

Following the 1989 *Exxon Valdez* oil spill in Alaska and the subsequent *American Trader* tanker oil spill off the coast of Huntington Beach in February 1990, the California Legislature enacted the Lempert-Keene-Seastrand Oil Spill Prevention and Response Act. The Act covers all aspects of marine oil spill prevention, preparedness, and response in California and established an Administrator that is appointed by the California State Governor and is also a Chief Deputy Director of the California Department of Fish and Wildlife (CDFW). The Lempert-Keene-Seastrand Oil Spill Prevention and Response Act (Act) mandates that certain owners and operators of vessels and facilities obtain a certificate of financial responsibility (COFR) before operating in California where a spill of oil could impact marine waters. A COFR is an official written acknowledgement issued by the OSPR Administrator that the operator has demonstrated the ability to pay for cleanup costs and damages caused by a marine oil spill. The OSPR opened in 1991 as a division of CDFW that has the responsibility for protecting California's natural resources through prevention of and response to oil spills. In 1993 OSPR commissioned a study to examine cleanup costs and monetary damages resulting from marine oil spills in order to inform requirements on the financial responsibilities of vessels and facilities.[2]

In 2014 Governor Jerry Brown expanded the OSPR program to cover all state surface waters at risk of oil spills from any source, including pipelines, production facilities, and the increasing shipments of oil transported by railroads. Senate Bill 861, adopted in June 2014, authorized the expansion and provided the additional statutory and regulatory authority for the prevention, preparedness and response activities in the new inland areas of responsibility. Senate Bill 861 expanded OSPR's jurisdiction to cover oil spills to any surface waters (i.e. waters of the State), including dry washes or ephemeral/intermittent streams (see Figure 1). Consequently, the COFR requirements were expanded to apply to inland facilities, including inland oil production facilities, and transportation of oil by rail or inland oil pipelines.

[2] Mercer Management Consulting 1993.

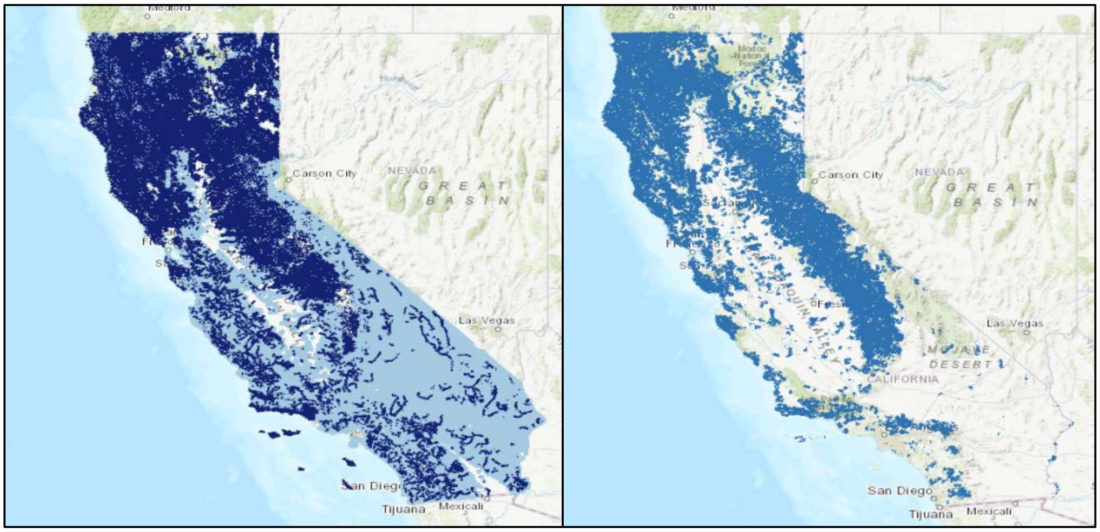

Figure 1: Ephemeral/Intermittent Streams (Left); Perennial Streams (Right) in California[3]

1.2 Current Regulations

The current OSPR COFR amounts as per California Code of Regulations (CCR), 14 CCR § 791.7, are in Table 1. Facility spills are classified with respect to risk to different types of waterways (marine, intermittent, ephemeral, or perennial). COFR amounts for the various spill sources are based on a function of the calculated Reasonable Worst-Case Spill (RWCS) volumes set by OSPR and a pre-determined per-barrel (bbl) cost. The current definitions of RWCS volumes are shown in Table 2.

1.3 Study Objectives

The current OSPR COFR amounts and RWCS volumes are either set forth in statute or based on the results of the 1993 study. OSPR is currently updating its regulations. The specific objectives of this study are to:

1. Gather up-to-date spill volume and oil spill response cost data to inform development of California oil spill regulations and COFR requirements; and
2. Develop a cost model that can be used as a tool by OSPR to estimate cleanup costs and damages in a variety of habitat types.

1.4 Model Development

The flow chart below (Figure 2) shows the process for building the model and outputs. As described in detail in this report, we gathered cost and spill data from publicly available databases and inquiries to OSPR-regulated entities, supplemented with existing cost data from spills worldwide to use as inputs to the project-specific model. As shown in the diagram, the cost model estimates the cleanup costs and potential damages by categorizing the individual database entries by the key factors that are correlated with spill costs. These factors are primarily (but not exclusively): spill volume, oil type, geographic location (jurisdiction and ecological/socioeconomic features), and OSPR Plan Type (rail, vessel, pipeline, facility, or transfer). Data are analyzed to establish statistical relationships between the spill factors and costs. The relationships can then be used to develop revised RWCS volumes and set revised COFR amounts where needed.

[3] Southwest Environmental Response Management Application (NOAA).

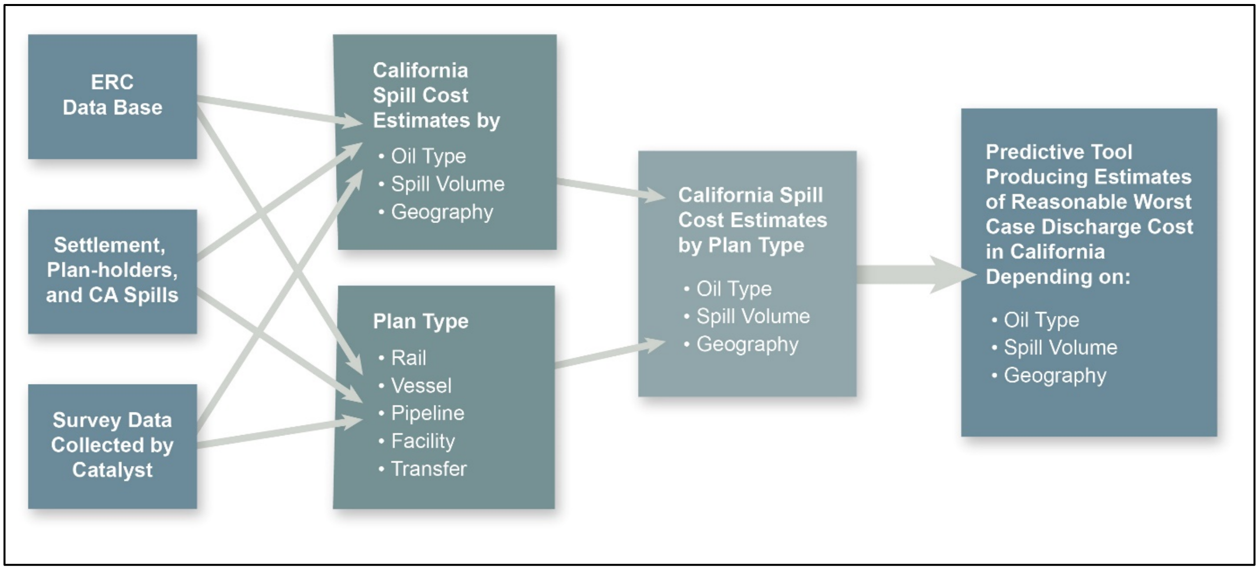

Figure 2: Flowchart of Model Development for RWCS Estimates

1.5 Report Organization

This report presents the technical documentation and results of the development of the CDFW Oil Spill Cost (CDFW-OSC) model, as follows:

- Section 2 – Previous Studies on Large California Spills – provides background and cost data for historic large spills in California history, and provides context for the analysis.
- Section 3 – Review of Data Sources – describes the sources of data used to gather information on oil spills in California and oil spill response costs.
- Section 4 – Analysis of Recent Spill History – examines recent spill history for each of the source types and uses data to calculate risk percentiles.
- Section 5 – Model Development – discussed issues and limitations in modeling oil spill costs and the algorithms used to develop the oil spill cost model
- Section 6 – Model Results – Estimating Oil Spill Costs – describes our analysis of the distribution of oil spill costs in California based on historical data and compared to worldwide data and provide the output of unit spill costs from the oil spill cost model.
- Section 7 – Discussion – provides a discussion of the results and describes the effect of spill volume and location on COFR amounts.
- Section 8 – References – provides a bibliography of sources used in this report.
- Section 9 – Acronyms and Terminology – provides an index of acronyms and abbreviations used in this report as well as a brief glossary of technical terms used in this report.
- Appendix A – ERC-CDFW Oil Spill Cost Model – provides details regarding the development of the cost model and algorithms used.

Table 1: Current OSPR Certificate of Financial Responsibility Amounts

Category	Sub-category	COFR amount/calculation	Minimum	Maximum
Tanker	all	$1B	$1B	
Tank Barge	Large (>150,000 bbl capacity)	$1B	$1B	
	Small (<150,000 bbl capacity)	$12,500 x (30% of total cargo capacity)		$562.5M
Non-tank Vessel	CA or federal >7,500 bbl total oil capacity; private >6,500 bbl	$300 M	$300 M	
	CA or federal 1,001-7,500 bbl; private 1,001-6,500 bbl	[(Total bbl capacity – 1,000) x $5,670] + $18.9M	$18.9M	$50.1M
	501-1,000	$18.9M	$18.9M	
	51-500	$10M	$10M	
	11-50	$5M	$5M	
	1-10	$2M	$2M	
Marine Facility (e.g. terminals)		$12,500 x RWCS	$1M	$300M
Offshore Platform	Not drilling	$12,500 x RWCS	$1M	$300M
	Active drilling	$12,500 x RWCS	$10M	$300M
Marine Pipeline		$12,500 x RWCS	$1M	$300M
Small Marine Fueling Facility		$12,500 x RWCS		$600K
MTU		$12,500 x (30% of max cargo capacity)		$6.3M
Inland Facility (e.g. production, pipelines, rail)	Risk to ephemeral or intermittent waterway	$6,000 x RWCS		$100M
	Risk to perennial waterway	$10,000 x RWCS		$100M
	Pipelines	$10,000 x RWCS		$100M
	Rail	$10,000 x RWCS		$100M

Table 2: Current Reasonable Worst-Case Spill Volume Definitions

Category	Sub-category	RWCS amount/calculation	Maximum of all plan holders
Tanker	all	25% of total capacity	925,000 bbl
Tank Barge	Large (>150,000 bbl capacity)	25% of total capacity	81,750 bbl
	Small (<150,000 bbl capacity)		20,950 bbl
Non-tank Vessel	Calif or federal >7,500 bbl total oil capacity; other >6,500 bbl	Total volume of single largest fuel tank	14,465 bbl
	Calif or federal 1,001-7,500 bbl; other 1,001-6,500 bbl		7,500 bbl
	501-1,000		1,000 bbl
	51-500		500 bbl
	11-50		50 bbl
	1-10		10 bbl
Marine Facility (e.g. terminals)		Function of multiple factors[1]	31,135 bbl
Offshore Platform	Not drilling	Function of multiple factors[2]	2,107 bbl
	Active drilling	Daily vol for 30 days from uncontrolled blowout	NA
Marine Pipeline	Onshore	Function of multiple factors[3]	28,267 bbl
	Offshore	(Leak detection + shutdown time) * max flow rate + additional leakage	3,134 bbl
Small Marine Fueling Facility		Function of multiple factors[4]	48 bbl
MTU		Total truck tank capacity	500 bbl
Inland Facility (e.g. production, pipelines, rail)	Production facility	10% of daily production from largest producing well	70 bbl
	Pipeline	Function of multiple factors[5]	65,856 bbl
	Other	Function of multiple factors[1]	66,861 bbl
	Rail <10mph	1% bulk oil[6]	714 bbl
	Rail <25mph	5% bulk oil	3,713 bbl
	Rail >25mph	20% bulk oil	14,994 bbl

[1] Loss of capacity of in-line, break-out, and portable storage tanks not subject to Chapter 6.67 or Chapter 6.7 of Division 20, Health and Safety Code (Aboveground and Underground Storage Tank programs administered by Certified Unified Program Agencies on behalf of CA Department of Forestry and Fire Protection, Office of the State Fire Marshal) needed for continuous operation of pipelines used to handle or transport oil; *plus* the amount of additional spillage reasonable expected to enter waters of the state during emergency shut-off, transfer, or pumping operations if hose(s) or pipeline(s) rupture or becomes disconnected, calculated as (maximum time to discover release + maximum time to shut down flow)*(maximum flow rate) + total linefill drainage volume; *plus* drainage volume from piping normally not in use.

[2] Total tank storage and flow line capacity; *plus* portion of linefill capacity subject to loss during spill, taking into account availability, location of emergency shut-off controls and hydrostatic pressure; *plus* amount of additional spillage reasonable expected to enter marine waters during shut-off, transfer, or pumping operations if a hose or pipeline ruptures or becomes disconnected; *plus* daily production for 30 days from an uncontrolled blowout of highest capacity well.
[3] (Maximum time to discover release + maximum shut-down response time)*(maximum flow rate) + (largest line drainage volume after shutdown of line section); *or* the largest foreseeable discharge for the line section(s) within a response zone based on maximum historical discharge; *or* the capacity of the single largest tank or battery of tanks within a secondary containment, adjusted for containment capacity.
[4] (Maximum time to discover release + maximum time to shut down flow)*(maximum flow rate) + total linefill drainage volume
[5] Loss of capacity of in-line, break-out, and portable storage tanks not subject to Chapter 6.67 or Chapter 6.7 of Division 20, Health and Safety Code, needed for continuous operation of pipelines used to handle or transport oil; *plus* the amount of additional spillage reasonable expected to enter waters of the state during emergency shut-off, transfer, or pumping operations if hose(s) or pipeline(s) rupture or becomes disconnected, calculated as (maximum time to discover release + maximum time to shut down flow)*(maximum flow rate) + total linefill drainage volume; *plus* drainage volume from pipelines normally not in use.
[6] All rail RWCS have a minimum of 1 tank car.

SECTION 2 Review of Previous Research on Large California Spills

In attempting to project the potential costs and impacts of a hypothetical future spill, particularly one that approaches a RWCS scenario, past cases and modeling studies provide insightful data and information. These previous case studies on historical spills and hypothetical large spill scenarios provide a perspective on the magnitude of damages and the spread of oil for large spills and make it easier to conceptualize the cleanup requirements for a large spill (i.e., many miles of shoreline, large areas of oil coverage). Modeling of spill behavior–trajectory, fate, and effects-- may also help to frame a RWCS scenario that may be larger than previous historic spills. This section reviews research to date on the costs and damages for historic and modeled large spills in California, providing comments on how these events can inform the current effort.

2.1 Noteworthy Historical Spills in California

Fortunately, very large oil spills–ones that involve millions of gallons or hundreds of thousands of barrels (bbl)–are rare events. While California did experience what is believed to be the largest on-land oil well blowout over 18 months in 1910–1911 (Lakeview Gusher Number One in Kern County) (Figure 3) and a significant offshore well blowout on 28 January 1969 (Alpha 21 Platform A off Santa Barbara), there have been no other spills over 100,000 bbl in the last 50 years. The Cymric oil field "surface expression" reported in May 2019, which is currently under investigation, spilled approximately 32,000 bbl.

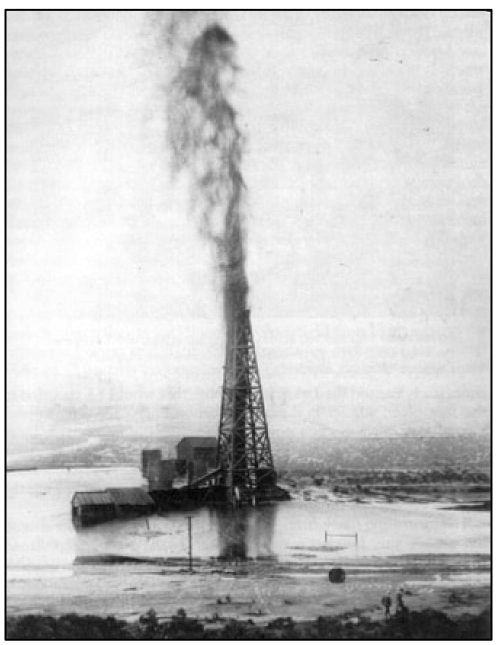

Figure 3: Lakeview No. 1 Gusher 1910[4]

In the case of the Lakeview No. 1 blowout, a pressurized oil well in the Midway- Sunset Oil Field in Kern County released 9 million bbl of crude oil over the course of 18 months. The initial flow rate was

[4] By unknown photographer, 1910 - https://www.georgetownenvironmentalhistory.org/ehg-blog/field-trip-to-the-midway-sunset-oil-field-california, Public Domain, https://commons.wikimedia.org/w/index.php?curid=77935501

reported to be 18,800 bbl per day, but peak flow reached 90,000 bbl per day. This flow rate has never been reached in any other blowouts worldwide.

In the 1969 Santa Barbara blowout Platform A, located about six miles off the coast in the Dos Cuadras Offshore Oil Field, an estimated 80,000 to 100,000 bbl of crude oil spilled over the course of three months, with the majority of the release occurring during 28 January through 7 February, and then tapering off by April 1969 (Figure 4). The flowrate was estimated to be about 9,090 bbl per day. The spill caused oiling of the coastline from Goleta to Ventura, as well as the Channel Islands. There were reports of oiled seabirds and marine mammals. This incident was noteworthy in that the public outcry and media coverage resulted in numerous pieces of significant environmental legislation, including the development of the US Environmental Protection Agency (EPA).

Figure 4: 1969 Santa Barbara Platform A Blowout[5]

In neither of these incidents, particularly for the Lakewood Gusher, did responders employ the sort of comprehensive spill cleanup measures that would be expected for a spill of this magnitude today. Nor was there any real effort to assess natural resource damages and conduct restoration, which is a vital part of the aftermath of spills currently. Hence neither of these incidents provides a predictive view into the response costs of a potential very large spill in California at present.

It is important to note that for tanker spills, there has never been a worst-case discharge spill (based on the release of the entire contents of a fully-loaded large tanker) in US waters. The 1989 *Exxon Valdez* spill of 261,900 bbl of crude oil in Prince William Sound, Alaska, which had a significant effect on large areas of Alaska, was the largest tanker spill in the US. However, the actual release only represented about 20% of the tanker's cargo.

There have been significant spills in California in the last 15 years that may provide some important insights, including the 2007 *Cosco Busan* spill in San Francisco Bay and the 2015 Refugio pipeline spill. However, it is important to note that these spills were still only relatively moderate-sized–1,276 bbl and

[5] Photo: US Geological Survey. https://response.restoration.noaa.gov/about/media/natural-seeps-historic-legacy-what-sets-apart-latest-santa-barbara-oil-spill.html

2,500 bbl, respectively–though they did both involve extensive response efforts and noteworthy environmental impacts.

The *Cosco Busan* spill culminated in a $44.4 million settlement, which included $36.8 million for natural resource damages. The spill killed 6,849 birds, impacted 14 to 29 percent of the following winter's herring spawn, and oiled 3,367 acres of shoreline habitat.[6] Response costs were estimated at $72.6 million, third party claims at $8.4 million, and fines at $12.4 million.

The 2015 pipeline break near Refugio State Beach in Santa Barbara County (Figure 5) resulted in heavily oiled beach areas and important cultural resource areas for California Native Americans. Note that the spill response operations were significantly challenged by the fact that this spill occurred in the vicinity of Coal Oil Point, which has natural seeps that release an estimated 155 to 167 bbl of oil per day.[7] Determining the source of the shoreline oil, pipeline spill or offshore oil seeps, required the incorporation of oil fingerprinting into the response operations.[8] To date, the cost associated with the Refugio pipeline spill has included $64.5 million in cleanup or response costs, $2.5 million in third party claims, and $3.35 million in fines; there is a civil proceeding ongoing currently and there will likely be more fines and penalties assessed in the future. The Natural Resource Damage Assessment (NRDA) has not yet been concluded.

Figure 5: 2015 Oil Pipeline Break at Refugio State Beach[9]

Even spills an order of magnitude larger may not provide that much more information. There were a few spills in the nearly 10,000 to 20,000-bbl range in the 1970s through early 1990s. Examples include the *American Trader* spill off Huntington Beach in 1990, involved the release of about 9,900 bbl of crude oil with impacts to thousands of birds. The 1988 Shell Oil Martinez refinery spill of 9,500 bbl had a notable impact on fish and wildlife habitat. A 1971 two tankers collided under the Golden Gate Bridge, spilling

[6] https://response.restoration.noaa.gov/about/media/36-million-natural-resource-damages-settlement-cosco-busan.html; https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=37886&inline
[7] Lorenson et al. 2011; Hornafius et al. 1999.
[8] Stout et al. 2018.
[9] Photo: NOAA. https://response.restoration.noaa.gov/about/media/natural-seeps-historic-legacy-what-sets-apart-latest-santa-barbara-oil-spill.html

20,000 bbl of heavy oil and resulting in extensive beach oiling and large wildlife impacts. The *American Trader* spill resulted in two natural resource damage settlements: the settlement for recreational impacts was $11.6 million and the settlement for environmental impacts was $3.45 million. In addition, the spill resulted in cleanup costs of $19.1 million, third party claims of $25.5 million, and fines totaling over $6.5 million.

In part because these spills are all unique, and have different costs associated with the spill characteristics and historical context, additional research has focused on modeling hypothetical very large or even "worst-case discharge" spills in California to help governments prepare for such an event.

For these reasons, studies that have involved modeling of hypothetical very large or even "worst-case discharge" spills in California may prove instructive with respect to the potential magnitude and scope of effects for these types of incidents.

2.2 US Army Corps of Engineers San Francisco Bay Spill Study

One study conducted for the US Army Corps of Engineers (USACE) involved the modeling of hypothetical tanker worst-case discharges in San Francisco Bay. The purpose of the study was to determine the potential costs and damages associated with such spills so that a cost-benefit analysis could be conducted. The USACE were investigating the potential removal of rock pinnacles that presented navigation hazards for deep-draft vessels in the bay.[10] The hypothetical releases included those shown in Table 3.

Table 3: USACE San Francisco Bay Modeling Study Oil Spill Types and Volumes[11]

Oil Type	20th Percentile	50th Percentile	95th Percentile
Gasoline (Product Tanker)	1,190 bbl	6,430 bbl	30,000 bbl
Diesel (Product Tanker)	1,190 bbl	6,430 bbl	30,000 bbl
AK Crude (Crude Tanker)	2,380 bbl	14,300 bbl	71,400 bbl
Heavy Fuel Oil (Freighter)	600 bbl	2,380 bbl	9,800 bbl

The estimated spill volumes were determined using three estimated percentile spill volumes. A percentile is developed by dividing a data set into 100 equal groups in order of the value. For example, if you had data on the height of 300 fifth graders, the first percentile would have the shortest (or tallest) three heights, the next percentile would have the next three heights and down the line to the other end. If a spill volume is the nth percentile case, it means that n% of spills will be this size or smaller. Only 100%-n% of cases will be larger. Hence the 95th percentile case for a spill volume means that the analyst anticipates that only five percent of spills will be larger than that 95th percentile spill. For example, in Table 4, showing the USACE study framework, 80 percent of spills for gasoline tankers are expected to be larger than 1,190 bbl, 50 percent are expected to be larger than 6,430 bbl, and just five percent are expected to exceed 30,000 bbl.

The 95th percentile is often used as an "almost worst-case scenario" in oil spill studies. It corresponds with the 95th percent confidence interval used in statistical analyses. The top five percent of cases are considered statistical anomalies. The volumes of hypothetical spillage modeled in the USACE study at were based on an analysis of historical tanker accident data. Note that the 95th percentile is not a worst-case discharge, which would, theoretically, involve the release of the entire tanker's cargo. Based on

[10] Etkin et al. 2002, 2003; French-McCay et al. 2002, 2003.
[11] Adapted from French-McCay et al. 2002.

tanker traffic at the time of the study (2000–2001), the largest crude tankers calling in San Francisco Bay were 215,000 deadweight tonnage (DWT). Tankers of this size would carry as much as 1.43 million bbl. Even with double hulls, which were not universal at that time (but were present on the tanker fleet entering San Francisco Bay), the worst-case discharge would be been about 700,000 bbl. (This represents 50 percent outflow from the tanker's cargo capacity, as would be expected with double hulls, which limit the outflow as well as reduce the likelihood of an oil release in an impact accident, such as a grounding or collision.) The researchers estimated that the 95th percentile was represented by a spill nearly an order of magnitude smaller, at 71,400 bbl based on the probability distribution function of tanker spill volumes. This means that the remaining five percent of incidents would be expected to exceed 71,400 bbl and range all the way up to a maximum of 700,000 bbl for that size tanker.

Trajectory, fate, and effects modeling using SIMAP[12] were conducted to determine the behavior of the spilled oil in the 12 hypothetical spills. The extent of the spread of floating oil can be seen in Figure 6 through Figure 9 by oil type. The large area of water surface and shoreline exposed to oil extends throughout San Francisco Bay and parts of the outer coast.

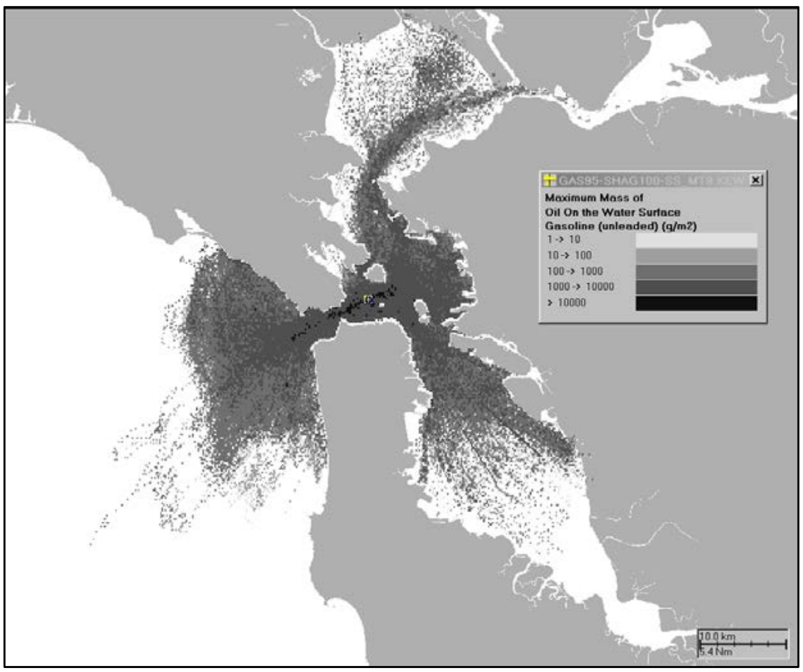

Figure 6: Maximum Possible Water Surface Exposure to Floating Oil (g/m^2): Gasoline[13]

[12] The SIMAP model is described in greater detail in: French McCay 2002, 2003, 2004; French McCay et al. 2015, 2018b. Assumptions and algorithms of SIMAP are fully documented in French et al. 1996, French McCay 2002, 2003, 2004 and French McCay et al. 2015, 2018 a, 2018b, and 2018c; French and Rines 1997; French McCay 2003, 2004; French McCay and Rowe 2004; French et al. 1997.

[13] French-McCay et al. 2002.

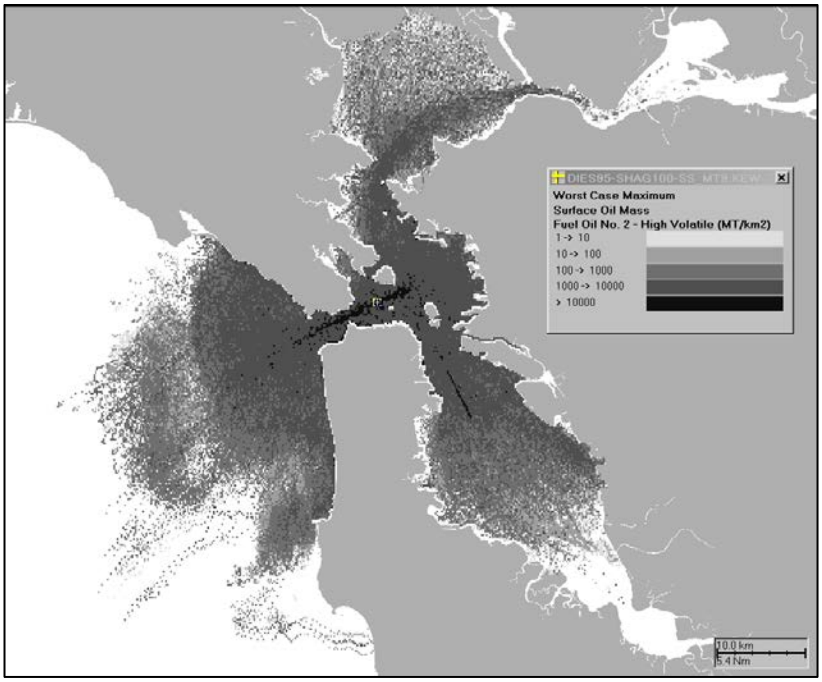

Figure 7: Maximum Possible Water Surface Exposure to Floating Oil (g/m^2): Diesel[14]

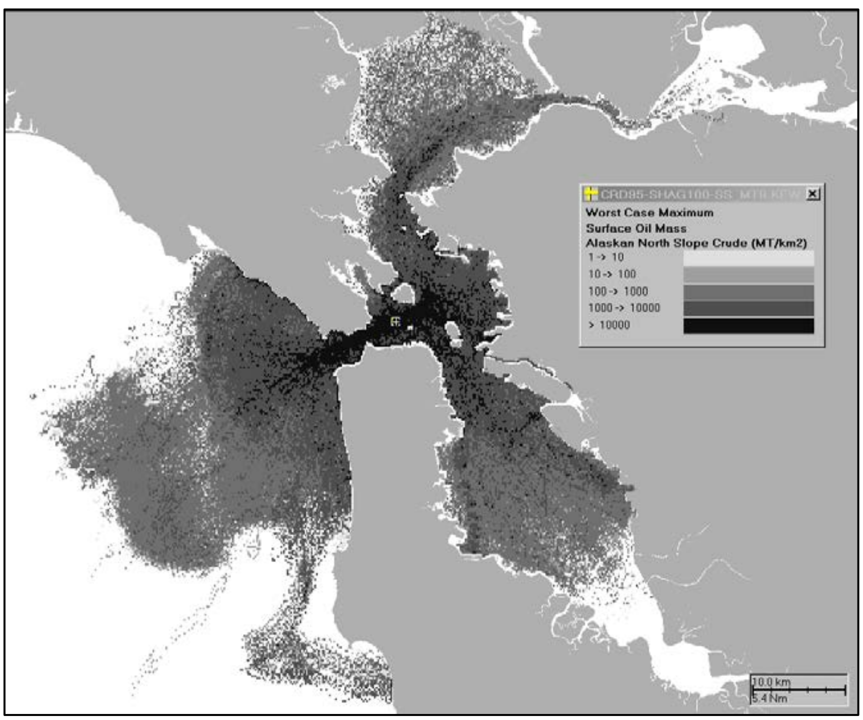

Figure 8: Maximum Possible Water Surface Exposure to Floating Oil (g/m^2): Crude[15]

[14] French-McCay et al. 2002.
[15] French-McCay et al. 2002.

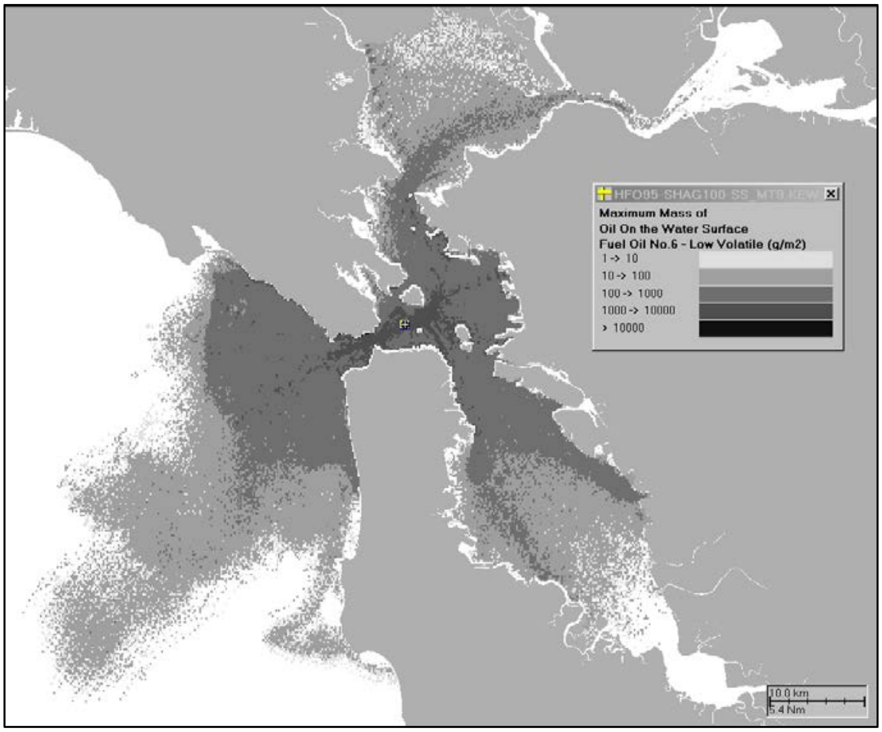

Figure 9: Maximum Possible Water Surface Exposure to Floating Oil (g/m^2): HFO[16]

The second part of the study included an analysis of potential costs associated with the cleanup response, NRDA, and socioeconomic damages (e.g., effects on port, tourism, fisheries) from the hypothetical spills. All costs were calculated based on the degree of oil impact (shoreline, surface, and water column). Response costs were calculated based on the level of effort required, estimated equipment and personnel requirements, shoreline cleanup effort, etc. NRDA costs were estimated based on Habitat Equivalency Analysis methods.[17] The total costs for the spills were calculated as shown in Table 4 (updated to 2019 US dollars).

It is important to note that these costs were based on response standards and trends in the late 1990s and early 2000s. While the data have been updated to 2019 dollars, there has been a significant increase in response costs that exceeds the inflation index. The costs in Table 4 therefore are likely under-estimates for the potential costs for these scenarios at present or in the future. Additional information on the development of the cost estimates in Table 4 is provided in Appendix A.

Table 4: Total Oil Spill Scenario Costs for USACE San Francisco Bay Study (updated to 2019 US$)[18]

Oil Type	Scenario[19]	US$ Million (2019)			
		NRDA for Ecological Damages	Socio-economic Costs	Response Costs (Mechanical)	Total Costs
Diesel	20thM	$15.0	$41.2	$17.7	$73.8
	20thW	$23.3	$37.0	$20.9	$81.1
	50thM	$44.9	$76.9	$27.2	$149.1
	50thW	$159.5	$81.2	$19.0	$259.6

[16] French-McCay et al. 2002.
[17] Etkin, pers comm?
[18] Etkin et al. 2002.
[19] Median (M) and worst (W) spread of oil.

Oil Type	Scenario[19]	US$ Million (2019)			
		NRDA for Ecological Damages	Socio-economic Costs	Response Costs (Mechanical)	Total Costs
	95thM	$100.6	$195.2	$39.0	$334.8
	95thW	$273.8	$193.2	$45.9	$512.9
Gasoline	20thM	$6.2	$31.9	$14.5	$52.6
	20thW	$27.8	$29.1	$14.5	$71.5
	50thM	$15.4	$71.0	$16.0	$102.4
	50thW	$57.8	$69.5	$16.0	$143.3
	95thM	$28.0	$160.9	$19.4	$208.4
	95thW	$113.7	$160.2	$21.8	$295.7
HFO	20thM	$1.3	$30.4	$16.8	$48.5
	20thW	$2.0	$29.8	$20.2	$51.9
	50thM	$4.4	$81.1	$50.9	$136.4
	50thW	$7.2	$75.9	$73.3	$156.4
	95thM	$5.7	$141.3	$113.2	$260.3
	95thW	$10.6	$131.6	$177.2	$319.4
Crude	20thM	$56.9	$47.2	$42.8	$225.5
	20thW	$140.7	$42.0	$52.2	$235.0
	50thM	$36.9	$117.6	$95.0	$488.3
	50thW	$36.4	$132.7	$121.4	$290.5
	95thM	$67.4	$274.5	$264.1	$606.0
	95thW	$164.8	$283.2	$333.8	$781.8

2.3 CDFW OSPR San Francisco Bay Booming Study

Another study conducted for CDFW involved the modeling of large oil spills to determine the potential effectiveness of strategically-placed large-scale exclusion booming to protect sensitive sites in San Francisco Bay. In this case, estimates of averted shoreline cleanup costs were calculated based on the use of alternative booming strategies.[20] However, the cost analyses did not include determining overall spill costs and damages, which limits the relevance to the current study. The study conclusions were that there were possibly some benefits to alternative booming strategies in some locations, however, the higher currents in San Francisco Bay would prove challenging to effective booming in many areas.

2.4 BSEE Oil spill Response Plan Capability Study

As part of a Bureau of Safety and Environmental Enforcement (BSEE) study to evaluate the potential effectiveness of various response strategies for worst-case discharge (WCD) well blowout scenarios for the US Outer Continental Shelf (OCS), scenarios for Pacific OCS blowouts were modeled and analyzed.[21] This study also did not involve cost analyses, but it provides a perspective on the potential magnitude of a WCD well blowout off California.

For a 170-day hypothetical release from an offshore well blowout releasing at the rate of 5,200 bbl/day, for a total of 884,000 bbl, about 1,620 miles of shoreline would be oiled and over 56,000 square miles of sea surface would be covered at some point with oil thick enough to remove mechanically (≥8 grams/square meter) (Figure 10). For a 10-day flow for a total of 52,000 bbl, shoreline oiling would cover about 620 miles and nearly 5,000 square miles of sea surface would be oiled at some point (Figure 11).

[20] Etkin et al. 2008; French-McCay et al. 2008; Etkin 2009a; French-McCay and Rowe 2009.
[21] Buchholz et al. 2016a, 2016b, 2016c.

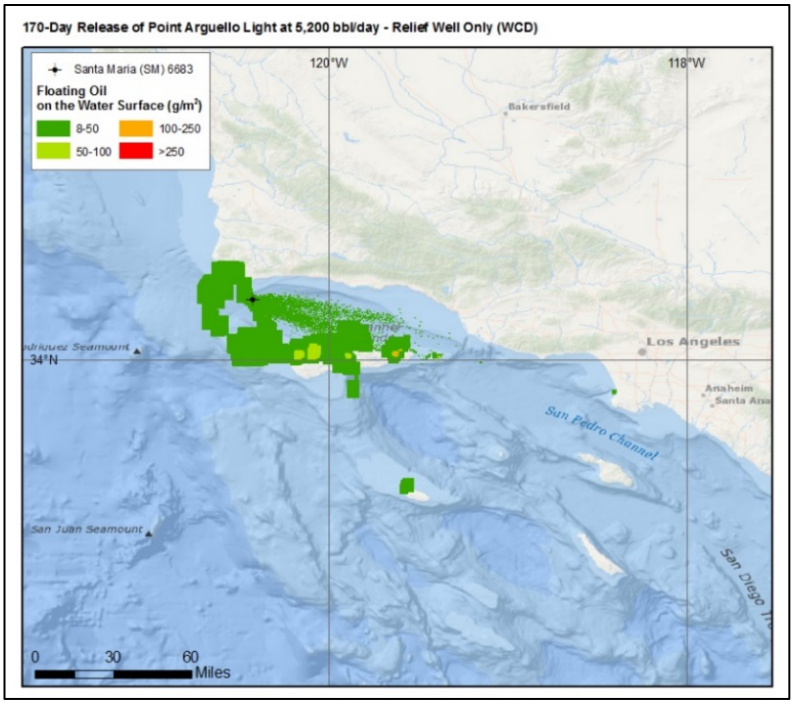

Figure 10: Maximum Concentrations of Surface Oiling in 170-Day Modeled Discharge[22]

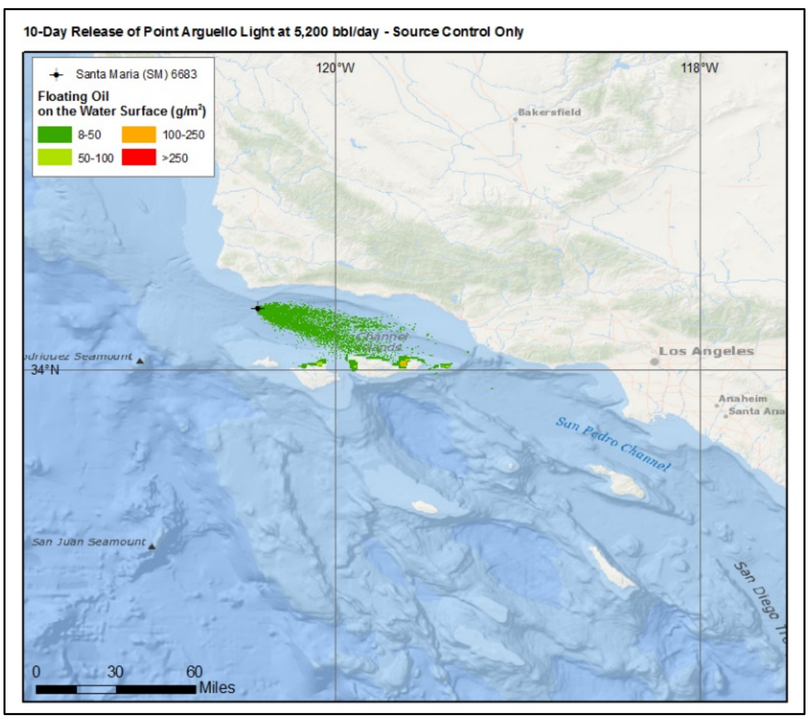

Figure 11: Maximum Concentrations of Surface Oiling in 10-Day Modeled Discharge[23]

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[22] Buchholz et al. 2016a.
[23] Buchholz et al. 2016a.

SECTION 3 Review of Data Sources

Several different sources of data were used to inform the analysis of recent spill history presented in Section 4 and to create the relationships in the cost model developed in Section 5. The first source described is specific to California and is based on hazardous material release reporting. The EIA provided information on crude oil transport by rail and pipeline, and storage tank capacities were gathered from oil spill contingency plans. A key data source is ERC's proprietary database of oil spills and spill costs worldwide. Finally, spill cost and volume data gathered directly from entities regulated by OSPR via survey for this project are described.

In general, there are significant challenges in obtaining accurate records for oil spill costs. Unless a spill's response and damage costs are part of public records (as with many non-US tanker spills funded by international funds, or in the US if the spill is federalized), the records are often confidential. The data are kept confidential by the responsible parties. Those costs that are publicized, as in media reports, are usually not broken down by cost type (response, damages, etc.), which makes it difficult to make reasonable comparisons.

3.1 California Oil Spill Volume Data

Spill data for input into the oil spill cost model was gathered from a variety of sources. The Comprehensive Environmental Response, Compensations, and Liability Act (CERCLA), Emergency Planning and Community Right-to-Know Act, and California law require responsible parties to report hazardous material releases if certain criteria is met. CERCLA requires that all releases of hazardous substances (including radionuclides) exceeding reportable quantities be reported by the responsible party to the National Response Center. These data are compiled and publicly available as MS Excel files on the California Governor's Office of Emergency Services (OES) website (https://www.caloes.ca.gov/for-individuals-families/hazardous-materials/spill-release-reporting). These data are available in individual files for each year from 1993 to October of 2018. Each year within the original data contain between 5,000 to 8,000 observations. However, approximately 60 percent of these datapoints are not related to petroleum and/or involve insignificant quantities (less than 1 gallon). The data from OES's Hazardous Material (HazMat) Spill Reports data were parsed to include only spills that met the following criteria:

- Actual spill event (i.e., not a spill drill or potential release);
- Spill that occurred from a source included in California's COFR regulations (i.e., tanker, tank barge, non-tank vessel, vessel carrying oil as secondary cargo, marine facility, marine pipeline, inland production facility, inland transmission pipeline, or railroad), but not including such sources as a residence, school, restaurant, automobile or truck (not MTUs), small boats, transformer, offshore pipeline outside of state waters, inland SPCC facility, or other source that would not be expected to have a COFR under California's regulations;
- Petroleum oil (crude and refined products or mixtures), including produced water with oil, that would generally be in a liquid state at ambient temperatures;[24] and
- Volume of at least one barrel (bbl).

[24] Spills involving liquefied natural gas, cooking oil, and chemicals or other hazardous materials were not included in our analyses.

In addition, while the original data includes a tremendous amount of additional information, the following key pieces of information were compiled for each relevant spill:

- Control No.
- Date of the Spill
- Agency (in most cases the agency responsible for cleanup)
- Substance
- Amount
- Measure (Unit)
- Source Type
- Location
- City
- County
- Waterway
- Description (more detail regarding the spill)
- Cleanup (a description of the cleanup effort, where applicable)

Incidents that involved produced water (i.e., a mixture of oil and water) were counted along with the other spills of oil. A total of 8.5 percent of the spills involved produced water or another type of oil-water mixture. The volumes of these incidents should be viewed with caution as there is generally only a small percentage of oil in these spill amounts. The produced water incidents contributed greatly to the total volume in some years. For example, in 2017, a single event involved 30,000 bbl of "oil–produced type, white colored, mixed with brine water." This produced water spill makes up over 95 percent of the total volume of spillage for the entire year. The volume of spillage for produced water and oil-water mixtures constituted 29 percent of the total spill volume for the 1998 through 2018 period.

A total of 5,141 incidents were included in the final analysis (Table 5). During the years 2014 through 2018, there was a significant reduction in the numbers of spills reported and volume of individual spills compared to earlier years in the dataset. For example, the average number of spills between 1998 and 2002 was 502 compared with the average from 2014 through 2018, which was 78. This represents a decrease of 84 percent. The volume of spills for the same two periods averaged 54 percent less, moving from 17,197 bbls to 7,895 bbls per year. The same data are shown graphically in Figure 12 and Figure 13.

Table 5: California Oil Spills 1998 through October 2018[25]

Year	Number of Spills of at Least 1 bbl			Amount Spilled (bbl)		
	Oil Only	Produced Water or Oil-Water Mixtures[26]	Total	Oil Only	Produced Water or Oil-Water Mixtures[27]	Total
1998	887	11	898	26,289	130	26,419
1999	552	12	564	19,508	240	19,748
2000	420	20	440	19,162	747	19,909
2001	208	149	357	8,396	5,523	13,919
2002	241	12	253	4,886	849	5,734

[25] From CA OES spill records.

[26] In 2001, there were 13 inland pipeline spills of oil-water mixtures and 126 oil-water incidents involving inland production facilities, as well as 10 additional oil-water spills from other sources. There is no explanation for the sudden up-tick in reports of these incidents during this year.

[27] The larger volumes reported in 2007 and 2017 are both related to a single large incident reported in the CA OES data in each of those respective years, rather than the cumulative volumes from all incidents reported. A single event in 2007 reported a volume of 10,000 bbl of produced water/oil released (Control #07-6758) and a single incident in 2017 reported a volume of 30,000 bbl of produced water/oil released (Control #17-8714).

Year	Number of Spills of at Least 1 bbl			Amount Spilled (bbl)		
	Oil Only	Produced Water or Oil-Water Mixtures[26]	Total	Oil Only	Produced Water or Oil-Water Mixtures[27]	Total
2003	198	25	223	5,856	1,587	7,443
2004	227	10	237	7,738	357	8,095
2005	220	20	240	5,674	901	6,576
2006	222	24	246	5,581	1,374	6,956
2007	216	29	245	10,995	10,960	21,955
2008	208	36	244	3,961	990	4,951
2009	145	19	164	17,241	786	18,027
2010	141	15	156	8,061	550	8,611
2011	132	14	146	2,659	751	3,411
2012	122	9	131	2,207	1,867	4,074
2013	96	20	116	1,400	654	2,054
2014	95	19	114	1,568	688	2,256
2015	80	18	98	1,061	1,405	2,466
2016	77	14	91	778	1,096	1,873
2017	76	21	97	1,271	30,369	31,639
2018	62	19	81	987	252	1,239
TOTAL	4,625	516	5,141	155,279	62,076	217,355

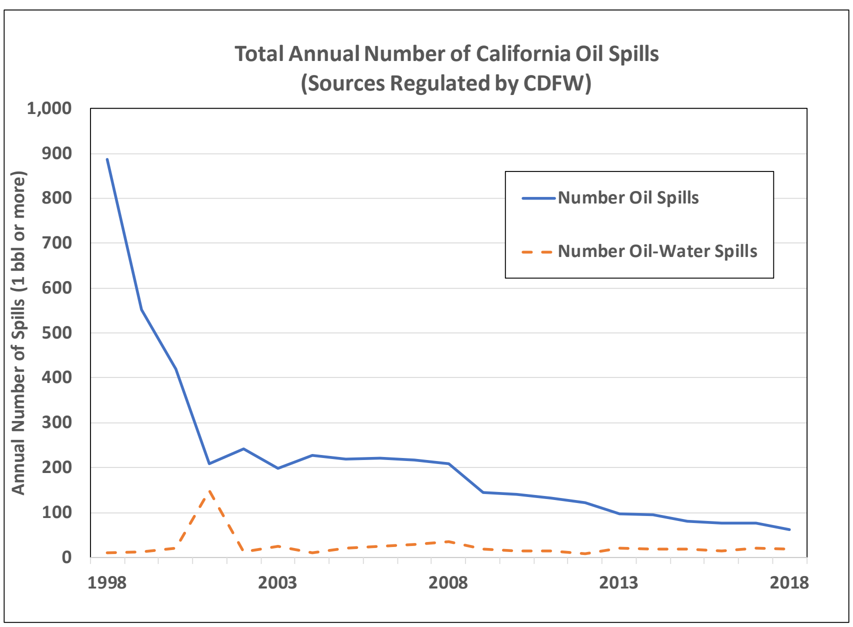

Figure 12: Number of Oil Spills of at Least 1 Barrel in California 1998–2018[28]

[28] From CA OES Hazmat Spill Records. In 2001, there were 13 inland pipeline spills of oil-water mixtures and 126 oil-water incidents involving inland production facilities, as well as 10 additional oil-water spills from other sources. There is no explanation for the sudden up-tick in reports of these incidents during this year.

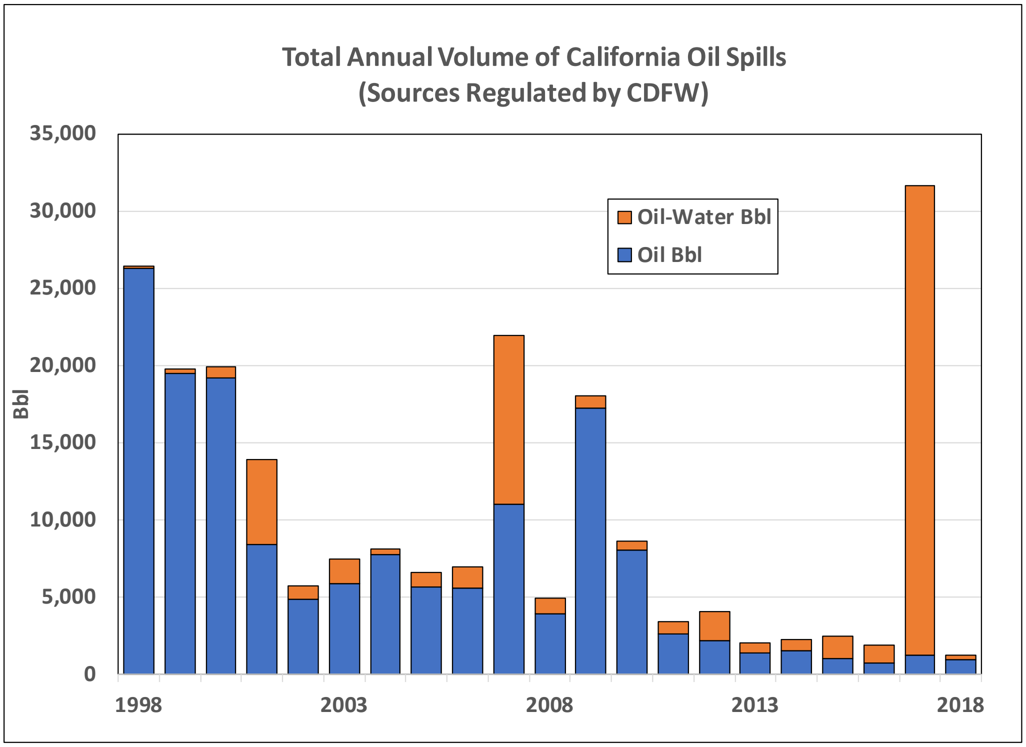

Figure 13: Total Annual Volume of Oil Spillage in California[29]

The spills (including oil and oil-water/produced water incidents) were categorized with regard to source type to correspond with the current designations in the COFR regulations. The raw CA OES Data did not contain specific designations for source type for the majority of the incident records. The categories were assigned based on the descriptive text, locations, and other details provided. Based on these designations, the total number of spills and volume of spillage (with all oil types combined) were calculated as shown in Table 6.

The capacities of the storage tanks at the facilities are only needed to find the LARGEST single tank, because that will define the maximum worst-case discharge. This is required to be in Area Contingency Plans. We reviewed the Oil Spill Contingency Plans that are accessible on the OSPR website for this data (https://www.wildlife.ca.gov/OSPR/Contingency). To obtain the data on vessel worst-case discharge volumes, we reviewed information on the largest tankers that go into California waters that is available from Marine Traffic (Automated Information System) data.

Table 6: Breakdown of California Spills by Category (Categories Regulated by CDFW-OSPR), 1998 – 2018[26]

Category	Number of Spills	% Total Number	Volume of Largest Spill in CA OES database (bbl)	Total Volume of All Spills (bbl)	% Total Volume
Tanker (Marine)	6	0.1%	9,524[1]	9,555	5.08%
Tank Barge (Marine)	9	0.2%	95	151	0.08%
Non-Tank Vessel (Marine)	60	1.2%	1,275[2]	2,240	1.19%

[29] From CA OES Hazmat Spill Records.

Category	Number of Spills	% Total Number	Volume of Largest Spill in CA OES database (bbl)	Total Volume of All Spills (bbl)	% Total Volume
Marine Facility (e.g. terminals)	307	6.0%	4,600	16,409	8.73%
Marine Pipeline	2	0.0%	2,974[3]	4,147	2.21%
Small Marine Fueling Facility	22	0.4%	71	118	0.06%
Inland Production Facility	4,164	81.0%	10,000[4]	141,406	75.18%
Railroad (Inland)	363	7.1%	1,070[5]	4,721	2.51%
Inland Pipeline	207	4.0%	3,000[6]	9,337	4.96%
TOTAL	5,140	100.00%	10,000	188,084	100.00%
Notes: 1. Dubai Star oil spill; 2. Cosco Busan oil spill; 3. Kinder-Morgan/Suisun Marsh pipeline spill; 4. Volume includes produced water and oil; 5. Compton train derailment; 6. Pyramid Lake pipeline spill					

3.2 Oil Spill Cost Data Collection

For this study, two sets of cost data were used to perform calculations. The primary datasets used to evaluate spill costs by volume, oil type, and geography are proprietary datasets in hand and held by ERC. The ERC Oil Spill Cost Database includes 443 spills from around the world, including spills from all types of sources and in different types of locations. The cases generally involve much larger spill volumes, with an average of 49,500 bbl. The range of spill volumes is from two bbl to 4.9 million bbl. The spill costs average $10,697 per bbl with a maximum of $690,255 per bbl. These spills are generally more complex than the ones captured in the CA OES data. The data on these more complex, and overall more costly, spill response operations and damages from these spills are more readily available (thought often as part of litigation) than for smaller spills. For that reason, these more “notorious” incidents make up the majority of the incidents in this database.

The second primary data set includes actual costs provided by the entities regulated by OSPR, which were surveyed as part of this study.

3.2.1 ERC Oil Spill Cost Database

Datasets provided by ERC include:

- **ERCMasterSpillCostData-v12** - This database was developed from a large number of interviews, reports, technical articles, and litigation data.
- **ERCMasterUSSpillData-v35** - This was developed during the time period 1982 through 2018 from:
  - International Oil Spill Database (Oil Spill Intelligence Report)
  - US Coast Guard (USCG) Marine Safety Information System
  - USCG Marine Information for Safety and Law Enforcement data
  - National Response Center data
  - Minerals Management/Bureau of Safety and Environmental Enforcement/Bureau of Ocean Energy Management spill data
  - Office of Pipeline Safety data
  - US EPA Emergency Notification Response System data
  - EPA Inland oil spill database (that I developed for EPA)

- State oil spill databases from: AK, AR, CA, CO, DE, GA, HI, ID, IN, LA, ME, MA, MI, MS, MO, MT, NH, NY, OR, SD, TN, TX, UT, VT, VA, WA, WV, WI
- International Tanker Owners Pollution Federation database
- US Joint Group of Experts on the Scientific Aspects of Marine Protection (GESAMP)

The ERC Oil Spill Cost Database includes 444 spill cases. Data fields included for each incident in the current database are:

- Spill name (vessel or source name, or commonly-used reference)
- Year of spill
- Source type
- Oil function (bunkers/fuel or transported/produced oil)
- Oil type (e.g., crude, diesel, heavy fuel oil)
- Oil persistence classification (non-persistent, light-persistent, persistent, heavy-persistent)
- Volume of spillage (in barrels, bbl)
- Location
- Response cost (in 2019 US dollars)
- Environmental & natural resource damage assessment (NRDA) costs (in 2019 US dollars)
- Third-party claims (in 2019 US dollars)
- Fines and penalties (in 2019 US dollars)
- International Oil Pollution Compensation (IOPC) Fund and Civil Liability Convention (CLC nation status (whether or not spill location nation is an IOPC/CLC signatory)30
- IOPC/CLC spill status (whether spill would be covered under IOPC/CLC conventions)

A breakdown of the spill cases between US and non-US data, by oil group is presented in Table 7. The regional distribution of spill cases by source type is shown in Table 8. Spill data by oil group are shown in Table 9. Spill cases by volume are shown in Table 10. The average spill volume is 51,287 bbl. The median volume is 800 bbl–i.e., only half the cases are larger than 800 bbl.

Table 7: Summary of ERC Oil Spill Cost Database Information – US vs Non-US by Oil Group, 1982-2018

Oil Persistence Category	US	Non-US	Total
Non-Persistent	8	2	10
Light Persistent	104	26	130
Medium Persistent	50	50	100
Heavy Persistent	112	92	204
Total	274	170	444

[30] These conventions have a bearing on the costs in non-US spills because there are liability limits on the spiller and a fund that pays for damages. These conventions are not applicable in the US because the US is not a signatory to these International Maritime Organization (IMO) conventions. They are mentioned here because they are data fields in the database of spills which is international.

Table 8: Data Set for Oil Spill Cost Information–Regions by Category, 1982-2018

Region	Tanker	Tank Barge	Cargo Vessel	Other Vessel	Pipeline	Rail	Facility	Well	FPSO[31]	Total
Africa	4	0	2	0	2	0	0	0	1	9
Asia	51	2	4	0	0	0	0	0	0	57
Australia	2	0	6	0	0	0	0	1	0	9
Baltic	6	0	0	0	4	0	0	1	0	11
Canada	4	0	2	1	4	2	2	0	0	15
Caribbean	2	1	0	0	0	0	0	1	0	4
Medit.	9	0	0	0	0	0	1	1	0	11
Mid. East	4	2	0	0	0	0	0	0	0	6
S America	3	0	0	1	12	0	2	1	0	19
Europe	22	1	3	0	1	0	0	2	0	29
US East	14	16	27	16	7	0	3	0	0	83
US Gulf	18	33	25	19	2	1	0	3	0	101
US West	11	3	24	38	12	0	1	0	0	89
Total	150	58	93	75	44	3	9	10	1	443

Table 9: Data Set for Oil Spill Cost Information–Regions by Oil Persistence Group, 1982-2018

Region	Oil Persistence Group (Number of Cases)					
	CLC/IOPC[32] Persistence	Non-Persistent		Persistent		Total
	Cost Factor Persistence	Non-Persistent (NP)	Light Persistent (LP)	Medium Persistent (MP)	Heavy Persistent (HP)	
Africa		0	2	3	4	9
Asia		1	3	5	48	57
Australia		0	1	2	6	9
Baltic		1	0	7	3	11
Canada		0	6	2	7	15
Caribbean		0	1	2	1	4
Mediterranean		0	5	2	4	11
Middle East		0	0	1	5	6
South America		0	2	17	0	19
UK/Europe		0	6	9	14	29
US East		3	30	9	41	83
US Gulf		3	32	21	45	101
US West		2	42	20	25	89
Total		10	130	100	203	443

[31] Floating production, storage, and offloading vessels used in offshore oil production.

[32] Civil Liability Convention and International Oil Pollution Compensation Fund oil persistence category for the purposes of determining liability limits for spills related to tanker transport of oil.

Table 10: Data Set for Oil Spill Cost Information–Regions by Spill Volume Category, 1982-2018

Region	Cases by Spill Volume Category (bbl)							Total
	1-9 bbl	10-99 bbl	100- 999 bbl	1,000-9,999 bbl	10,000-99,999 bbl	100,000 - 99,999 bbl	1,000,000-5,000,000 bbl	
Africa	0	0	2	3	4	0	0	9
Asia	0	9	21	19	7	1	0	57
Australia	0	0	2	5	0	2	0	9
Baltic	0	0	1	3	4	2	1	11
Canada	1	0	5	6	3	0	0	15
Caribbean	0	0	0	1	2	0	1	4
Mediterranean	0	0	0	4	4	2	1	11
Middle East	0	0	0	4	1	1	0	6
South America	0	0	1	5	3	10	0	19
UK/Europe	0	0	6	12	4	6	1	29
US East	0	42	16	16	9	0	0	83
US Gulf	0	33	33	24	8	2	1	101
US West	1	41	22	23	1	1	0	89
Total	2	125	109	125	50	27	5	443

3.2.2 California Inland Operator Spill Cost Survey

Recognizing the importance of including event-based data and industry input into the study, large data sets of actual costs for oil spill events in California were gathered and analyzed for this study. To gather this data, a Microsoft Excel worksheet and Instruction Sheet were developed to conduct a survey of oil spill costs with entities regulated under the Act. To identify those entities that should be solicited for input, our team reviewed the database of regulated entities provided by OSPR, "By RWCS and Plan Type 10-26-18". This database was filtered to only those entities with a Plan Status of "Approved" or "Review Pending". Table 11 shows all of the entities contacted with data requests.

Between November 25, 2018 and January 7, 2019, regulated entities were called and/or emailed to introduce ourselves and the project and ascertain their willingness to participate in the survey. For oil producers we directly contacted the President, Director of Regulatory Affairs or Director of Environmental Health and Safety at each company. For the non-oil producer entities, company websites were reviewed to identify the most applicable person likely to have authority to provide information or find a contact name, phone number and email address. Regulated entities were then contacted initially by phone to introduce ourselves and the project and, if we were able to reach a person in a decision-making capacity, followed up with an email that included the survey and information sheet. Following initial contact, follow-up was performed with each entity via phone and/or email to answer any questions and ensure responsiveness in a timely manner. Receipt for all data was requested by January 31, 2019. We received data from eight oil producers and the responses received included information on 157 spills for inland production facilities, for spills which occurred between 2015 and 2018.

Details regarding these spills are included in the tables below. It is important to note that none of the reported spills reached water; all of the spills reported entered dry creeks or washes where water was not present at the time of the spill. In addition, to those producers which provided data, we also received responses from five companies that they had not had any spills and had no data to provide. No spill data was provided from railroads, mobile transportation units (MTUs), pipelines, or marine facilities. Some respondents provided modeled estimates of costs based on various internally developed scenarios; this information was reviewed but only actual data from actual spills was used for input in the model. These data were primarily used to provide supporting information on California-specific inland spills, to alert the researchers to any issues or concerns, and to verify and ground truth information from other sources.

Table 11: Entities Provided with Survey Questionnaire

Company Name	Plan Type
Aera	Production, Inland Production
Berry Petroleum	Facility, Inland Facility
Brea Canon	Facility, Inland Facility
Breitburn	Production, Inland Facility, Inland Production
Chevron	Offshore, Marine Facility, Inland Facility, Pipeline, Inland Pipeline
CMO, Inc	Inland Production
California Resources Corporation	Facility, Inland Facility, Inland Production
E&B Natural Resources	Inland Production
ERG Operating Company	Inland Production
Freeport McMoran Oil & Gas	Pipeline, Inland Facility (withdrawn)
Hathaway, LLC	Inland Facility, Lease
Macpherson Operating Company	Inland Production
Naftex Operating Company	Inland Facility
Patriot Resources	Inland Facility
Pacific Coast Energy Company	Inland Production, Inland Pipeline
Santa Maria Energy	Inland Production
Seneca Resources	Inland Production
Sentinel Peak Resources	Inland Facility, Lease, Pipeline
Signal Hill Petroleum	Inland Production
Termo Company	Inland Production
All Star Cleaning and Preservation, Inc.	MTU
Ancon Marine	MTU
Andeavor-Marathon	Facility
Arizona and California Railroad	Rail
Asbury Environmental Services	MTU
Bakersfield Pipeline System	Pipeline
Beacon West Energy Group	Platform, Lease
Beta Offshore	Pipeline
Black Gold Industries	MTU
Blue and Gold Fleet Company	Marine Facility
BNSF Railway	Rail
California Marine Cleaning, Inc.	MTU
CE Allen Company	Inland Facility
Chemoil Refining Corporation	Marine Facility, Pipeline

Company Name	Plan Type
Conoco Phillips/Phillips 66	Marine Facility
Crimson Pipeline	Pipeline
DCOR	Marine Facility, Pipeline
Dion & Sons, Inc.	MTU
Environmental Logistics Inc.	MTU
Flyers Transportation LLC	MTU
Golden Gate Ferry	Marine Facility
Jankovich Company	MTU
KinderMorgan Energy Partners	Inland Facility, Pipeline
L & M Renner, Inc.	MTU
Matrix Oil Corp.	Inland Pipeline
NRC Environmental Services	MTU
NuStar Energy	Marine Facility
O.C. Vacuum Environmental Services	MTU
Ocean Blue Environmental Services, Inc.	MTU
Pacific Offshore LLC	Marine Facility
Pacific Pipeline System	Pipeline
Pacific Refining Company	Marine Facility
Pacific Tank Cleaning Services, Inc.	MTU
Pacific Trans Environmental Services, Inc.	MTU
Paramount Petroleum Corporation	Pipeline
Patriot Environmental Services	MTU
Plains West Coast Terminals	Pipeline
Redwood Coast Fuels	MTU
Ribost Terminal, LLC	Facility
Richmond Pacific Railroad Corporation	Rail
Safety-Kleen Systems Inc.	Marine Facility
San Diego and Imperial Valley Railroad	Rail
San Francisco bay ferry	Marine Facility
San Joaquin Valley Railroad	Rail
Shell Oil Products/Shell Pipeline	Inland Facility, Marine Facility, Pipeline
SoCo Group Inc.	MTU
South Bay Sand Blasting and Tank Cleaning Inc.	MTU
Southern California Gas Company	Inland Facility
Synergy Oil & Gas LLC	Inland Facility
TN Avenue LLC	Inland Facility
Torrance Logistics Company	Inland Pipeline
TracTide Marine Corp	Facility
TransMontaigne Operating Company	Facility
Union Pacific Railroad	Rail
Valero Inc/Valero Refining Company	Pipeline, Facility, Inland Facility, Marine Facility

The requested data for each spill incident and the number of responses in each category are summarized in Table 12. The volume of oil spilled in these incidents ranged from 0.1 bbl to 1,800 bbl. The distribution of volumes is summarized in Table 13. For five of the incidents the reported spillage was "0." These data were eliminated. The location types are summarized in Table 14. Oil types reported for the spills over 0 bbl are summarized in Table 15.

Table 12: Survey of California Regulated Entities on Oil Spill Costs

Category	Number Responses	% Incidents
Source Type	157	100%
Date	157	100%
Location Type	151	96%
Location	28	18%
Type of Oil Spilled	151	96%
Volume of Oil Spilled	157	100%
OSRO Costs	138	88%
Disposal, Decontamination, and Other Costs	6	4%
Payments to Cover Coast Guard/ Federal/State Workers	6	4%
Total Legal Fees	Non reported	0%
Total Settlement Amount	Non reported	0%
Natural Resource Damage Assessment Costs	Non reported	0%
Legal/Consultant Fees	Non reported	0%

Table 13: Survey of California Inland Oil Operators–Spill Volume Distribution

Spill Volume Category	Number Responses	% Reported Incidents
No spillage	5	3.2%
0.1–0.9 bbl	26	16.6%
1–9 bbl	85	54.1%
10–99 bbl	30	19.1%
100–999 bbl	10	6.4%
1,000–1,800 bbl	1	0.6%
Total	157	100%
Average Spill Volume: 44.1 bbl (without zeroes)		

Table 14: Survey of California Inland Oil Operators–Location Types[1]

Location Type	Number Responses	% Spill Incidents
Desert Scrub Area	16	10.5%
Facility (Inside Secondary Containment)	50	32.9%
Inland Dry Wash (Intermittent Stream, Arroyo, Gulch)	25	16.4%
Inland Soil	60	39.5%
Not Reported	6	0.7%
Total	157	100.0%

1. None of the reported spills reached water. All waterbodies were dry at the time of the reported spill.

Table 15: Survey of California Inland Oil Operators–Oil Types

Oil Type[1]	Number Responses	% Spill Incidents
Crude Oil (Assumed Medium)	28	18.4%
Heavy Crude Oil	46	30.3%
Light Crude Oil	26	17.1%
Other Oil	3	2.0%
Produced Water	48	31.6%
No Oil Type Reported	6	0.7%
Total	157	100.0%

[1]Light – API Gravity > 31.1; Medium – API Gravity between 22.3 and 31.1; Heavy – API Gravity < 22.3; Extra Heavy – API Gravity < 10.0

Note that nearly one third of the reported spill incidents involved produced water. Produced water often is generated during the production of oil and gas from onshore and offshore wells. Formation water is seawater or fresh water that has been trapped for millions of years with oil and natural gas in a geologic reservoir consisting of a porous sedimentary rock formation between layers of impermeable rock within the earth's crust.[33] Produced water contains varying amounts of hydrocarbons, as well as other components, such as ions and salts of various metals, ammonia, nitrates, nitrites, phosphates, and organic acids. The compositions differ depending on the particular formation and reservoir.[34]

With respect to calculating oil spill cleanup and damage costs, the most important components of produced water are the hydrocarbons, such as those in crude oil. These vary with both the formation and the age of the wells. In nearly depleted fields where oil production has continued for some time, there may be as little as 2% hydrocarbons in produced water. In California each year, about 3.071 billion bbl of produced water is brought to the surface in wells producing crude oil from conventional formations. Of this, approximately 197.75 million bbl of hydrocarbon is produced. Although the percentages of hydrocarbons will vary by well and formation, on average, produced water in California contains about 6.4% hydrocarbon. This factor needs to be considered when deriving unit response costs from data for oil spills from data for cleanups of produced water spills.

The response to the survey data included 133 cases for which at least some cost data were provided. The costs were mainly for small spills to land or dry washes; none involved water. The data are limited to inland production facilities. Spill volumes varied from 0.25 bbl to 1,800 bbl, with an average of 44 bbl. 62% of the spills involved 5 bbl or less of spillage. Nearly a third of the spills involved produced water rather than only oil. Most of these spill cleanups would have been in a fairly limited area within the bounds of the facility. Spill costs varied from about $35 per bbl to $29,341 per bbl, with an average (mean) of $1,954.

[33] Collins 1975.
[34] Neff et al. 2011.

SECTION 4 Analysis of Recent History of Spill Volumes by Category

Since essential parts of California's COFR regulations are based on spill volumes, an analysis of California's oil spill history was conducted. The purposes of this analysis were to:

- Determine the percentile[35] distributions of oil spills by source type in California;
- Determine the percentile distributions of oil spill by source type throughout the US based on available data;
- Determine the theoretical worst-case discharges (WCD) by source type in California; and
- Benchmark the current California RWCS volumes against both California and national data.

4.1 Recent Spill History for Tankers

In the 1998–2018 CA OES Data, there were six tanker spills recorded. They ranged in volume from 1 to 18 bbl, with an average volume of 6.2 bbl, with the exception of the *Dubai Star* oil spill in 2009. These data are insufficient to conduct any form of analysis to determine a probability distribution regarding RWCS volume. While California data might be the most appropriate, the limited sample of tanker spills reduces the ability to evaluate a broader distribution. Further, in this case, all of the spills occurred over 10 years ago and do not reflect more modern safety developments like double-hulls. The ERC data can be used in this case to broaden the tanker spill sample size and in doing so strengthen the ability to accurately estimate a complete probability distribution for California. With a larger data set, there is a better opportunity to understand what size of spill represents a small spill and what represents a larger spill. With just a few data points, it is difficult to know if they are representative of the entire distribution of possible spills. Therefore, in addition to the CA OES data, Table 16 includes data for historic spills in California provided by OSPR and the ERC Oil Spill Database.

An analysis of national oil spill data for tankers indicates that the 95th percentile spill volume is about 108 bbl for the years 1968–2012. However, the volume has become increasingly smaller over the decades, as shown in Figure 14.[36]

Table 16: Tanker Spills in California

Tanker Name	Date	Location	Bbl
American Trader	2/7/1990	Huntington Beach, CA	416,598
Arizona Standard and Oregon Standard (collision)	1/19/1971	San Francisco Bay, CA	123,076
Puerto Rican	10/31/1984	Pacific Ocean, Bodega Bay off San Francisco, CA	100,484
Sea Spirit	4/7/1974	Los Angeles harbor, CA	50,024

[35] Percentiles are defined as "each of the 100 equal groups into which a population can be divided according to the distribution of values of a particular variable." If a spill volume is the nth percentile case, it means that n% of spills will be this size or smaller. Only 100%-n% of cases will be larger. The 95th percentile case is often used as an "almost worst-case scenario" in oil spill studies (e.g., Etkin et al. 2018; Morandi et al. 2018; Symons et al. 2013; Etkin et al. 2008.

[36] National oil spill data in ERC Oil Spill Databases for the years 1968–2012. Data for the years prior to 1973 have limited information on smaller spills.

Tanker Name	Date	Location	Bbl
Apex Houston (tank barge)	1/28/1986	Offshore Marin, San Francisco, San Mateo, Santa Cruz, and Monterey Counties, CA	25,800
Dubai Star	10/3/2009	San Francisco Bay and Alameda County shoreline, CA	9,452
Andriagi Shipping	11/10/1998	Long Beach harbor, CA	18
Constitution Service	4/25/1998	Port Hueneme, CA	7
Vessel Chinborazo	2/7/2000	Long Beach harbor, CA	2
Cargo Oil Tanker	6/16/2001	Long Beach harbor, CA	1
Eagle Vermont	2009	Los Angeles harbor, CA	3

With double hulls and various other safety and spill prevention measures, the annual numbers and volumes of tanker spills have decreased significantly in the US–about 94 percent since the 1970s.[37] The vast majority of spills from tankers are small, however, the possibility of a large spill still exists.

The 95th percentile spill volumes are compared with the actual worst-case discharge volumes for the same time periods in Table 17.

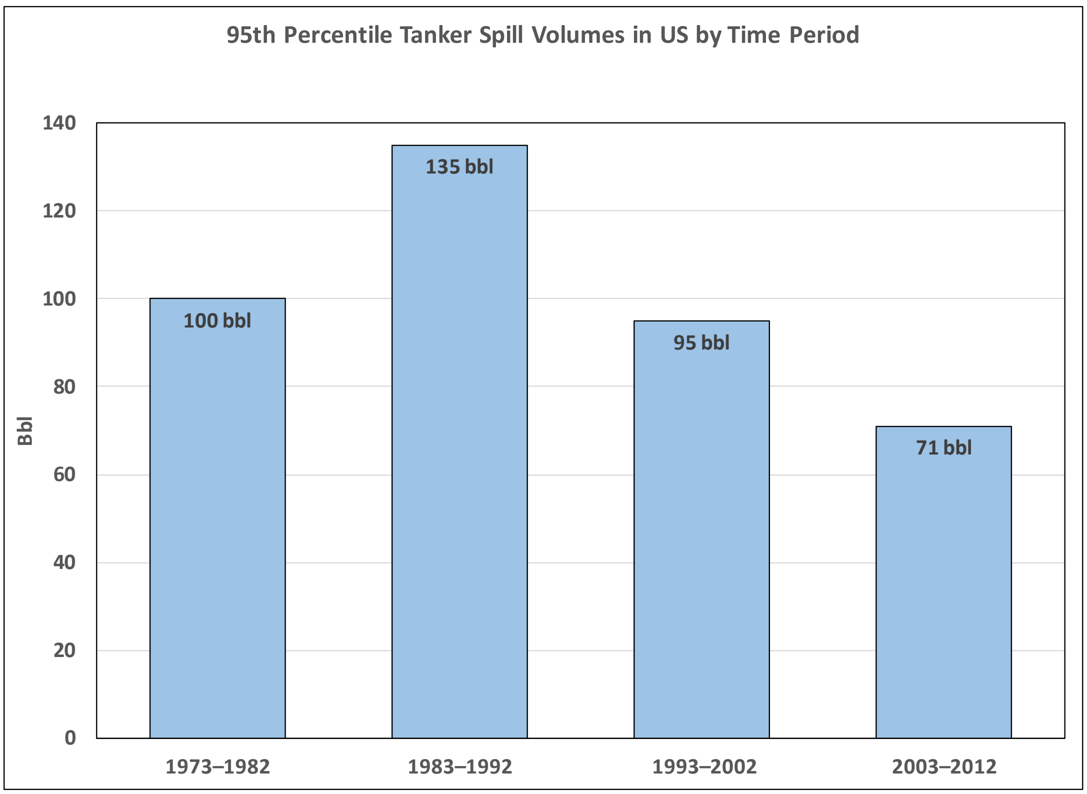

Figure 14: 95th Percentile Tanker Spill Volumes in US by Time Period[38]

[37] Based on data in Etkin 2009a, 2010a, 2010b.

[38] Based on data in Etkin 2009a.

Table 17: US Tanker Spill Volumes by Time Period[39]

Time Period	Spill Volume per Incident	
	95th Percentile	Worst-Case Discharge (WCD)[40]
1973–1982	100 bbl	247,556 bbl
1983–1992	135 bbl	250,000 bbl
1993–2002	95 bbl	19,714 bbl
2003–2012	71 bbl	6,271 bbl

The largest tanker spills that have occurred in and near US waters since 1968 are shown in Table 18. The largest worldwide incidents are shown in Table 19. Note that all of the tankers involved in these incidents were single-hulled. It is also important to note that there have not been any true "worst-case discharges" in US waters, meaning that there have been no instances when the entire oil cargo of a fully-loaded tanker have been released (the *Mandoil II* was a smaller tanker). The *Exxon Valdez* released approximately 20 percent of its cargo in Prince William Sound, Alaska, in 1989. These data are provided as a context for "worst-case discharges" from tanker spills in the US and worldwide. The historical data on tanker spills indicate that there is a significant reduction in the frequency of large tanker spills. Due to prevention measures and safety practices, tanker spills are much less likely than in decades past. In addition, the potential volume of discharge is reduced by the presence of double hulls, which are now mandatory for all tankers.

Table 18: Largest Tanker Spills in and near US Waters[41]

Tanker Name	Date	Location	Bbl
Mandoil II	2/29/1968	Pacific Ocean, off Columbia River, Warrenton, OR	300,000
Exxon Valdez	3/24/1989	Prince William Sound, Valdez, AK	261,905
Burmah Agate	11/1/1979	Gulf of Mexico, off Galveston Bay, TX	254,762
Pegasus (Pegasos)	2/8/1968	Northwest Atlantic Ocean off US east coast	228,500
Texaco Oklahoma	3/26/1971	Northwest Atlantic Ocean off US east coast	225,000
Keo	11/5/1969	Northwest Atlantic Ocean, SE of Nantucket I., MA	209,524
Argo Merchant	12/15/1976	Nantucket Shoals, off Nantucket Island, MA	183,333
Spartan Lady	4/4/1975	Northwest Atlantic Ocean off US east coast	142,857
Gulfstag	10/24/1966	Gulf of Mexico	133,000
Arizona Standard and Oregon Standard	1/19/1971	San Francisco Bay, CA	123,076
Mega Borg	6/9/1990	Gulf of Mexico, off Texas	119,048
Gezina Brovig	1/31/1970	Caribbean Sea, N of San Juan, PR	112,000
LSCO Petrochem	10/4/1976	Gulf of Mexico, off Louisiana	109,952
Puerto Rican	10/31/1984	Pacific Ocean, Bodega Bay off San Francisco, CA	100,484
Blue Ridge	7/29/1987	Gulf of Mexico, off Florida	80,000
Santa Augusta	6/1/1971	Caribbean Sea, St. Croix, US Virgin Islands	78,643
Argea Prima	7/17/1962	Caribbean Sea, PR	70,000
Alvenus	7/30/1984	Calcasieu River, off Cameron, Cameron Parish, LA	66,452
General M.C. Meiggs	1/1/1972	Strait of Juan de Fuca, off Port Angeles, WA	54,762
Sea Spirit	4/7/1974	Los Angeles harbor, CA	50,024
Ocean Eagle	3/3/1968	Caribbean Sea, San Juan, PR	47,619

[39] Based on data in Etkin 2009a.
[40] Based on actual data.
[41] Etkin 2009a.

Table 19: Largest Tanker Spills Worldwide[42]

Tanker Name[43]	Date	Location	Bbl
Atlantic Empress[44]	7/19/1979	Trinidad -Tobago	2,004,476
Castillo de Bellver	8/6/1983	South Africa	1,869,048
Amoco Cadiz	3/16/1978	France	1,634,952
Odyssey	11/10/1988	Canada	1,026,190
Haven	4/11/1991	Italy	1,008,000
Al Qadasiyah*	1/19/1991	Kuwait	977,829
Hileen*	1/19/1991	Kuwait	977,829
Torrey Canyon	3/18/1967	United Kingdom	909,000
Sea Star	12/19/1972	Oman	902,238
Irenes Serenade	2/23/1980	Greece	871,429
Al-Mulanabbi*	1/19/1991	Kuwait	820,676
Texaco Denmark	12/7/1971	Belgium	750,000
Tariq Ibn Ziyad*	1/19/1991	Kuwait	744,276
Independentza	11/15/1979	Turkey	687,786
Julius Schindler	2/11/1969	Portugal	675,000
Urquiola	5/12/1976	Spain	670,000
Braer	1/5/1993	United Kingdom	595,238
Jakob Maersk	1/29/1975	Portugal	577,524
Aegean Sea	12/3/1992	Spain	521,429
Nova	12/6/1985	Iran	508,381
Sea Empress	2/15/1996	United Kingdom	506,524
Khark 5	12/19/1989	Morocco	490,476
Prestige	11/15/2002	Spain	490,000
Wafra	2/27/1971	South Africa	480,000
Sinclair Petrolore	12/6/1960	Brazil	420,000
Assimi	1/7/1983	Oman	376,190
Yuyo Maru No. 10	11/9/1974	Japan	375,000
ABT Summer	5/28/1991	Angola	357,143
Katina P.	4/26/1992	South Africa	357,143
Heimvard	5/22/1965	Japan	350,000
Andros Patria	12/31/1978	Spain	347,619
Ain Zalah*	1/30/1991	Kuwait	346,801
World Glory	6/13/1968	South Africa	337,500
British Ambassador	1/13/1975	Japan	337,500
Pericles GC	12/9/1983	Qatar	333,333
Metula	8/9/1974	Chile	330,000
Ennerdale	6/1/1970	Seychelles	328,571
Tadotsu	12/7/1978	Indonesia	314,143
Mandoil	2/29/1968	United States	300,000

[42] Etkin 2009a.

[43] Incidents denoted with asterisk (*) were part of the 1991 Gulf War spillage. The combined volume of the tanker spills from that event was 3,867,411 bbl. Other oil sources, including coastal oil terminals and pipelines were also intentionally caused to spill, which added an additional 7,287,280 bbl, for a total of 11,154,691 bbl of spillage into the Arabian/Persian Gulf. The sum of this spillage that occurred in 1991 is often referred to as the "Gulf War spill".

[44] The Atlantic Empress spilled about half of its load near Trinidad and Tobago and the rest near Barbados when it was being towed from the site of the incident two weeks later.

Tanker Name[43]	Date	Location	Bbl
Napier	6/10/1973	Chile	270,000
Nassia	3/13/1994	Turkey	269,500
Patianna	8/26/1979	United Arab Emirates	266,000
Trader	6/11/1972	Greece	262,500
Exxon Valdez	3/24/1989	United States	261,905
Juan Antonio Lavalleja	12/29/1980	Algeria	260,952
Thanassis A.	10/21/1994	Hong Kong	259,524
Athenian Venture	4/22/1988	Canada	252,429
Borag	2/7/1977	Taiwan	247,500
St. Peter	2/6/1976	Colombia	245,700

The RWCS volume for tankers, which is set in statute by the Lempert-Keene-Seastrand Oil Spill Act, is "25 percent of total oil capacity". This is about 660,000 bbl for a 300,000-DWT Very Large Crude Carrier (VLCC). This volume of spillage has not been reached by any tanker worldwide in at least 15 years.

An important consideration in determining the RWCS volume is the potential outflow from a double-hulled tanker involved in an impact accident (grounding, collision, or allision). While tanker spills can occur for a number of reasons (e.g., bunkering, equipment failures), the largest potential volume is from impact accidents.

Outflow modeling[45] has demonstrated that the volumes of outflows for the very largest incidents involving tankers (and tank barges) would be reduced by 50% with double hulls. Double hulls on tankers accomplish two things: reduction of the probability of any spillage occurring in the first place (by reducing the likelihood that the hull will be breached), and reduction of the volume of spillage for the very largest spills by 50 percent if a breach does occur. This is not the case for double hulls on bunker tanks, for which there is a reduction in the probability of spillage occurring in an impact accident, but there is no reduction in spillage volume with large incidents. The percentage oil outflow probabilities from tankers (Table 20) is based on international studies of the amount of oil actually spilled compared with the adjusted capacity of the vessel, which was verified by existing oil outflow models developed for the International Maritime Organization (IMO).[46]

Table 20: Oil Outflow Probability for Double-Hulled Tankers in Impact Accidents[46]

% Cargo Outflow of Total Volume Held in Tanker	Probability of Oil Outflow Following an Impact Accident	Cumulative Probability	Percentile
0.002%	0.3589	0.3589	36th
0.02%	0.1400	0.4989	50th
0.05%	0.1200	0.6189	62nd
0.2%	0.1110	0.7299	73rd
0.7%	0.0900	0.8199	82nd
1.3%	0.0800	0.8999	90th
3.1%	0.0700	0.9699	97th
20%	0.0300	0.9999	99th
50%	0.0001	1.0000	100th

[45] Rawson and Brown 1998; Yip et al. 2011b; NRC 1998.

[46] Based on Etkin et al. 2018; Rawson and Brown 1998; Yip et al. 2011b; NRC 1998.

Based on the data in Table , the 95th percentile spill volume for a double-hulled tanker is about 3 percent of the total oil cargo capacity (i.e., the probability that a double-hulled tanker would spill 20 percent of the total volume of oil held in its cargo following an impact accident is 3 percent). For a 300,000-DWT VLCC, this would be 66,000 bbl. The 25th percentile spill for this tanker would be about 40 bbl. The 50th percentile spill would be about 400 bbl. The 75th percentile spill would be about 4,000 bbl.

4.2 Recent Spill History for Tank Barges

In the 1998–2018 CA OES Data, there were nine tank barge spills recorded. They all occurred prior to 2010. They ranged in volume from 1 to 95 bbl, with an average volume of 6 bbl. These data are insufficient to conduct any form of analysis to determine a probability distribution. Note the *Apex Houston* tank barge spilled over 600 bbl of crude oil in 1986, impacting thousands of birds along the California coast.

Outflow analyses for double-hulled tank barge spills, conducted using similar methodologies as for tankers, provide the outcomes shown in Table 21. Double hulls on tank barges provide a similar level of protection as for tankers. The 95th percentile spill volume for a double-hulled tank barge is about 5 percent of the total oil cargo capacity. The 25th percentile spill would be about 15 bbl. The 50th percentile spill would be 65 bbl. The 75th percentile spill would be 650 bbl. As with tankers, the RWCS volume for tank barges is set by statute at 25% of total volume. This would mean volumes of up to 98,000 bbl. This volume is about six times as large as the 95th percentile volume based on outflow data for tank barges and roughly twice the volume of the largest tank barge spill in US history.

The largest tank barge spills in US waters are shown in Table 22. (Note that these were not double-hulled tank barges).

Table 21: Oil Outflow Probability for Double-Hulled Tank Barge Impact Accidents[47]

% Cargo Outflow	Probability	Cumulative Probability	Percentile
0.001%	0.180	0.1800	18th
0.01%	0.220	0.4000	40th
0.03%	0.200	0.6000	60th
0.2%	0.110	0.7100	71st
0.5%	0.090	0.8000	80th
1%	0.070	0.8700	87th
3%	0.060	0.9300	93rd
7.5%	0.030	0.9600	96th
15%	0.020	0.9800	98th
23%	0.018	0.9980	99th
50%	0.002	1.0000	100th

[47] Based on Etkin et al. 2018; Etkin 2001; Etkin 2002; Etkin 2003; Etkin and Neel 2001; Etkin and Michel 2003; Etkin et al. 2009; Rawson et al. 1998; Yip et al. 2011; NRC 1998. (Oil outflow percentage probabilities were derived from analyses of international data on oil spillage (actual spillage versus adjusted capacity).

Table 22: Largest Tank Barge Spills in and near US Waters[48]

Date	Barge Name	Location	Bbl
1/16/1989	UMTB American 283	Pacific Ocean, south of Semidi Islands, Alaska	48,619
10/25/1972	Ocean 80	Arthur Kill Waterway, Carteret, New Jersey	47,643
8/1/1974	Barge #15	Lower Mississippi River, Bertrandville, Louisiana	46,452
3/5/1975	B-421/Barge 13/B-117	Lower Mississippi River, Vicksburg, Mississippi	37,993
10/9/1974	Bouchard 65	Atlantic Ocean, near Massachusetts	36,643
9/23/1988	n/a	Sandy Hook Channel, New York, New York	35,000
6/17/1991	n/a	Long Island Sound, Port Jefferson, New York	30,000
3/12/1964	n/a	Pacific Ocean, Moclips, Washington	29,762
3/25/1973	Barge 9	Lower Mississippi River, Louisiana	29,310
1/24/1984	n/a	Lower Mississippi River, Wilson, Arkansas	26,119
6/22/1974	ON 524331	Lower Mississippi River, New Orleans, Louisiana	24,000
6/16/1995	Apex 3603 & 3506	Vicksburg, Mississippi, Lower Mississippi River	20,205
3/3/1975	IOT-105	Lower Mississippi River, Vicksburg, Mississippi	20,000
11/22/1985	E-24	Block Island Sound, off Fishers Island, New York	20,000
1/19/1996	North Cape	Block Island Sound, near Galilee, Rhode Island	19,714
1/7/1994	Morris J. Berman	San Juan Harbor, Puerto Rico	19,000
6/24/1974	ABC 2311	Lower Mississippi River, New Orleans, Louisiana	18,238
6/1/1984	n/a	Lower Mississippi River, Louisiana	17,500
3/7/1986	Texas	Upper Mississippi River, Thebes, Illinois	17,048
7/28/1990	Barges 3417, 3503, 3510	Houston Shipping Channel, Galveston, Texas	16,476

4.3 Recent Spill History for Non-Tank Vessels

There were 60 non-tank vessel spills recorded in the 1998–2018 CA OES Data with spill volumes ranging from 1 bbl to 1,275 bbl. The most recent incident occurred in 2011. The largest non-tank vessel spills originate from bunker tanks, which are considerably smaller than the cargo tanks on tankers and tank barges. This limits the potential volume of outflow. The category of non-tank vessels includes a large variety of cargo ships and freighters.

The probability distribution of spill volumes for non-tank vessels based on the 1998–2018 CA OES Data is shown in Figure 15. The data in Figure 15 are shown in percentiles in Table 23.

[48] Etkin 2009a.

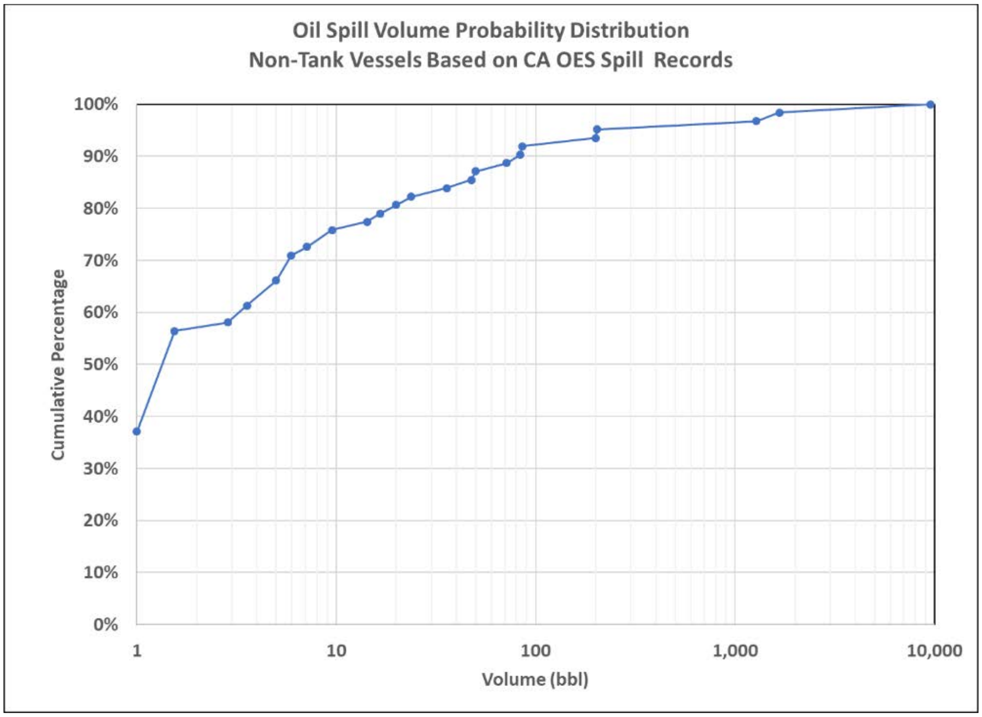

Figure 15: Oil Spill Volume Probability Distribution for Non-Tank Vessels, 1998-2018, N-60 (CA OES Data)

Table 23: Oil Spill Volume Percentiles for Non-Tank Vessels, 1998-2018, N=60 (CA OES Data)

Percentile	Volume (bbl)
25th	N/A
50th	1.5
75th	9.5
95th	1,000

Bunker tank outflow modeling conducted in a similar fashion at that for tankers and tank barges indicates that the probability distribution of outflow is as shown in Table 23. In this analysis, the percent outflow is based on the entire bunker capacity of the vessel and not on the size of any individual bunker tank. The 95th percentile outflow is about 6 percent of the total bunker capacity. For the very largest container ships, this would mean about 3,000 bbl. Note that this is more than twice the volume of the 2007 *Cosco Busan* spill in San Francisco Bay.

The RWCS for non-tank vessels is set in statute as the "total volume of the single largest fuel tank." Fuel tanks vary in volume from about 945 bbl to 22,000 bbl, depending on the size of the vessel. The volume calculated in this manner would generally be larger than the percentage calculation as shown in Table 24.

Table 24: Oil Outflow Probability for Bunker Tank Impact Accidents[49]

% Bunker Outflow	Probability	Cumulative Probability	Percentile
0.01%	0.50	0.5000	50th
0.02%	0.15	0.6500	65th
0.06%	0.11	0.7600	76th
0.16%	0.08	0.8400	84th
0.54%	0.08	0.9200	92nd
11.50%	0.08	1.0000	100th

While bunker tanks are increasingly being built or retrofitted with double hulls, the volume of outflow does not change with this measure. This is due to the engineering of the bunker tanks; they way that the bunker tanks are configured makes it less likely that they will break open with impacts. However, if the bunker tanks do open in an impact, all of the oil in the tank is likely to flow out. The double hulls merely reduce the likelihood of a spill in the event of impact by about 60 percent.[50] The implementation of double hulls on bunker tanks is continuing. Currently, about 50 percent of non-tank vessels have double-hulled bunker tanks. By 2026, it is expected that about 75 percent of non-tank vessels will have this protection.

4.4 Recent Spill History for Marine Facilities

The 1998–2018 CA OES spill data included 307 incidents involving marine facilities (e.g., refineries and storage terminals). The volumes spilled ranged from 1 bbl to 4,600 bbl[51]. The probability distribution for volume is shown in Table 25 and Figure 16. The 95th percentile spill volume was 200 bbl.

Table 25: Oil Spill Volume Percentiles for Marine Facilities, 1998-2018, N=307 (Based on CA OES Data)

Percentile	Volume (bbl)
25th	1
50th	6
75th	30
95th	200

The RWCS volume for marine facilities is defined by OSPR regulations as the “loss of entire capacity of all in-line, breakout and portable storage tanks.” Based on available information on California’s refineries and other marine oil facilities, the maximum volume of release would be 31,135 bbl.

[49] Based on Etkin et al. 2018; Etkin 2001; Etkin 2002; Etkin 2003; Etkin and Neel 2001; Etkin and Michel 2003; Etkin et al. 2009; Rawson et al. 1998; Yip et al. 2011; NRC 1998. (Oil outflow percentage probabilities were derived from analyses of international data on oil spillage (actual spillage versus adjusted capacity).

[50] Etkin and Michel 2003; Michel and Winslow 2000; Barone et al. 2007; Herbert Engineering et al. 2003.

[51] Based on CA OES database, the 4,600 bbl spill occurred in 2010 as a result of the release of naptha from a hole in the bottom of a storage tank on a marine facility.

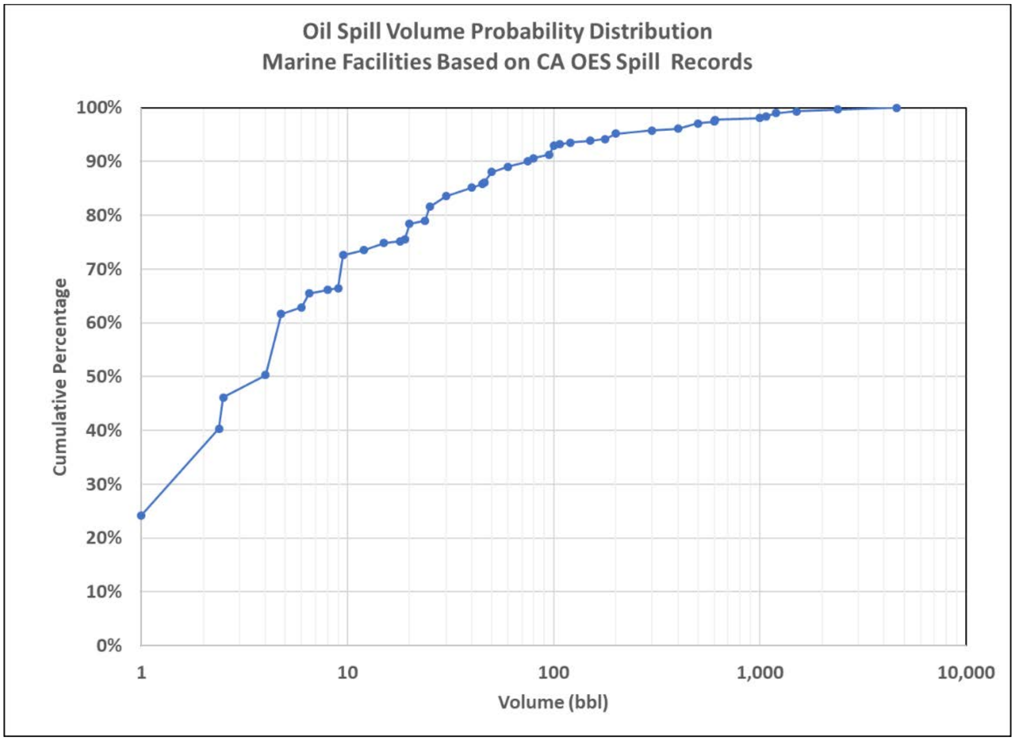

Figure 16: Oil Spill Volume Probability Distribution for Marine Facilities, 1998-2018, N=307 (CA OES Data)

4.5 Recent Spill History for Offshore Platforms

The 1998–2018 CDFW spill records contained three spill incidents involving offshore platform facilities. The incidents had occurred in 1999 and 2000. The spill volume ranged from 1 bbl to 5 bbl. These data are insufficient to conduct any form of analysis to determine a probability distribution.

The potential volume of spillage from an offshore active drilling marine facility could be very large if a blowout occurs. The volume of a blowout depends on two factors–the flowrate from the oil reservoir and the duration of the flow. The duration will be affected by the likelihood of natural bridging, which occurs roughly 84 percent of the time in blowouts,[52] and, if that does not occur, the time it takes to either cap and contain the blowout or to drill a relief well.[53] The flow rate depends on the type of well (e.g., exploration or production) and the characteristics of the well reservoir. There can also be corrosion-caused leakages in wells that are not uncontrolled blowouts. Overall, there is a series of probabilities that need to be considered with respect to a blowout or other release occurring.

The volume of a blowout or well release will vary widely and the outcomes of well blowouts in one location (e.g., the Gulf of Mexico) should not be assumed to be applicable to other locations. For California, there are reliable estimates on the potential volumes for well blowouts based on data from the Pacific Outer Continental Shelf (OCS) Region Bureau of Safety and Environmental Enforcement (BSEE).[54]

The Pacific OCS Region has 431 producing wells located offshore in federal waters. In addition, there are three platforms located in state waters with 65 producing wells, as well as the four man-made islands

[52] Danenberger 1980; Holand 2006; Scanpower 2006; Dyb et al. 2012.
[53] Etkin 2015.
[54] Buchholz et al. 2016.

located in Long Beach Harbor, known as THUMS, which have a combined total of 1,000 wells. All wells are in the region shown in Figure 17. The wells and platforms are shown in Table 26.

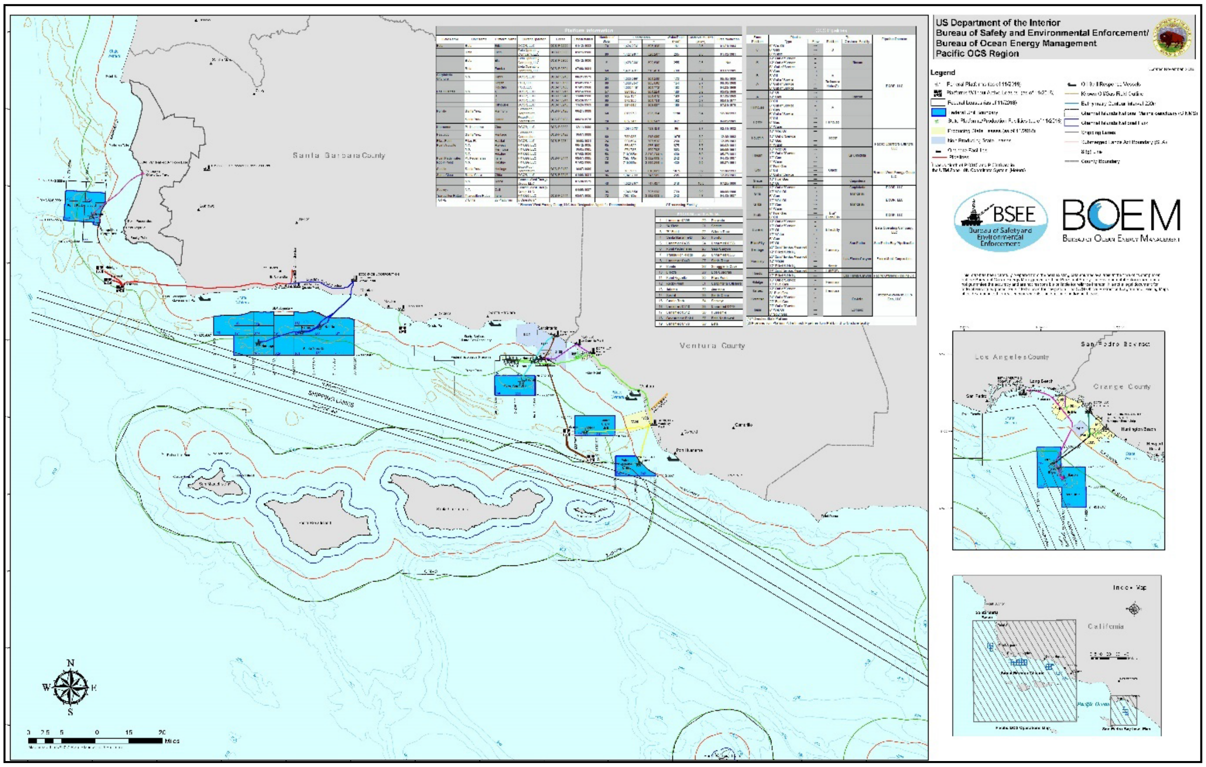

Figure 17: Pacific OCS Region Well Map[55]

Table 26: Pacific OCS Region Platform Data[56][57]

Platform	Producing Wells	Water Depth (ft.)	Annual Production (million bbl)
Edith	15	161	124
Ellen	23	265	494
Emmy	31	45	0.77
Esther	18	38	0.21
Eureka	30	700	893
Eva	16	58	0.52
Henry	20	173	135
Hogan	11	154	102
Houchin	16	163	136
A	36	188	263
B	31	190	321
C	25	192	188
Hillhouse	31	190	216
Harmony	26	1,198	3,413
Hondo	22	842	1,707

[55] Source: BSEE Pacific OCS Region (https://www.boem.gov/pacific-ocs-map/)

[56] BSEE Pacific OCS Region (POCS) Production and Development Statistics. July 2014 (Data for December 2013), as presented in Buchholz et al. 2016.

[57] California State Lands Commission Safety and Oil Spill Prevention Audits, 2016 (https://www.slc.ca.gov/oil-gas/)

Platform	Producing Wells	Water Depth (ft.)	Annual Production (million bbl)
Gina	6	95	108
Heritage	25	1,075	2,322
Habitat	5	290	0
Harvest	12	675	600
Hermosa	9	603	524
Hidalgo	6	430	346
Irene	15	242	1,654
Hildago	4	430	88
Heritage	17	1,075	3,559
Gilda	23	205	343
Grace	1	318	37
Gail	21	739	984
Irene	1	242	0
THUMS	1,000	Four man-made islands	16.79

Based on the analyses of worst-case discharge volumes for the Pacific OCS Region, the majority of flow rates in this region are low (i.e., less than 12,000 bbl/day) compared with much higher rates in the Gulf of Mexico and Arctic OCS Regions.[58] According to BSEE, average flow rates for the Pacific OCS Region range from 100 bbl/day to 9,750 bbl/day per platform. Note that there may be multiple wells connected to a particular platform. A maximum per-well rate was estimated to be 5,200 bbl/day. According to BSEE, a relief well would take about 170 days to drill and properly implement to stop a blowout. This means that there is the potential for an 884,000-bbl blowout.

A 30-day release, as per the RWCS definition for offshore active drilling marine facilities, would involve 156,000 bbl. Note that this is larger than the 1969 Santa Barbara blowout (100,000 bbl). A 30-day release would generally incorporate the time that it would take to install a capping and containment structure to stop the flow, although it may not be sufficient time to drill and implement a relief well. Based on previous analyses, the probability of requiring a relief well is about 10 percent for each blowout. A 30-day release would, therefore, cover about 90 percent of blowout cases. Relief wells may take 75 days to 170 days to be used to stop the flow of oil to the environment. The oil would continue to be released until the well is either capped or a relief well is drilled.[59]

It is important to note that the probability distributions of blowout durations, and the overall probabilities of blowouts, are based largely on historical data. There have been a number of developments in blowout interventions since the 2010 Macondo MC252 (Deepwater Horizon) blowout in the Gulf of Mexico that will reduce the risk associated with large blowouts.[60]

4.6 Recent Spill History for Marine Pipelines

There were only two records of marine pipeline spills in the CA OES Data for the 1998–2018 time period.[61] Marine pipelines are connected to offshore drilling platforms and offloading facilities to connect these oil sources to mainland terminals. In national data on marine pipeline spills, there are records of about 13 such incidents per year in the US with the average volume of 200 bbl. During the

[58] Buchholz et al. 2016b.

[59] Dyb et al. 2012; Holand 2006, 2013; Danberger 1980; Scanpower 2006; Buchholz et al. 2016b; Etkin 2015.

[60] Nedwed 2018; Nedwed et al. 2017; Caia et al. 2018.

[61] The Torch Platform Irene spill occurred in September 1997, prior to the development of the Cal OES dataset, and resulted in a release of 153 bbl.

years 1969 through 2007, a total of about 2,500 bbl spilled in the Pacific region. A total of 10 bbl spilled during 1998 through 2007.[62]

The 95th percentile spill volume for offshore pipelines based on national data is 224 bbl, with a worst-case spill of 8,212 bbl for 1998 through 2007 (Figure 18 and Table 27).

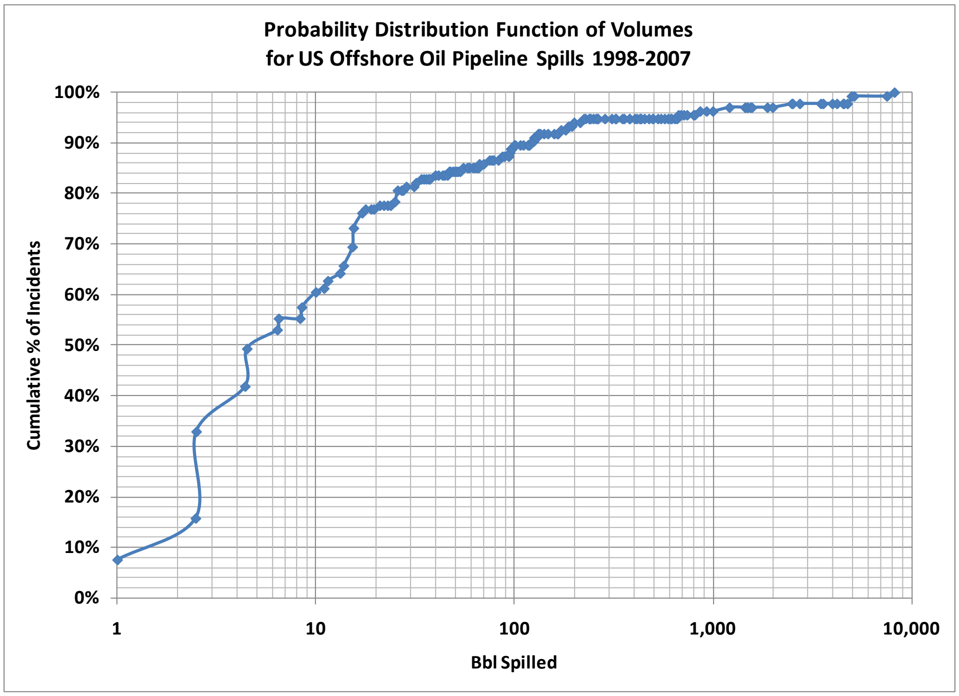

Figure 18: Probability Distribution Function for U.S. Marine Pipeline Spills 1998 – 2007, N=2,335 (from Etkin 2009a)[63]

Table 27: Oil Spill Volume Probability for U.S. Marine Pipeline Spills, 1998-2007, N=2,335 (Based on Etkin 2009a)

Percentile	Volume (bbl)
25th	3.5
50th	5.5
75th	23
95th	224

4.7 Recent Spill History for Small Marine Fuel Facilities

The 1998–2018 CDFW spill records contained 22 incidents involving small marine fuel facilities (SMFFs). The volumes ranged from 1 bbl to 71 bbl. These data are insufficient to conduct any form of analysis to determine a probability distribution, as shown in Figure 19 below. There are no definitive data on these types of facilities in the national data sets.

[62] Etkin 2009a.

[63] Note the logarithmic scale. N=2,335

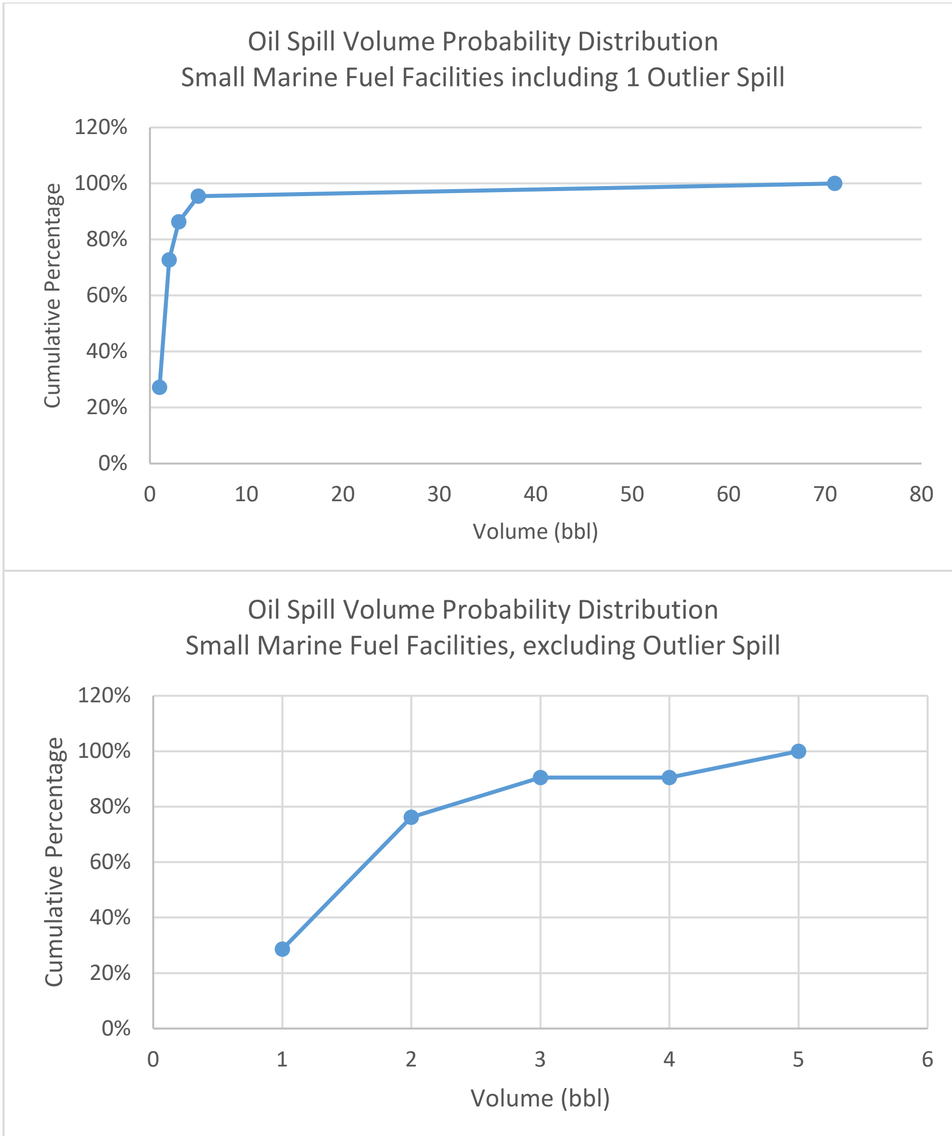

Figure 19: Probability Distribution Functions for Small Marine Fuel Facilities including and excluding the outlier spill, 1998-2018, N=22

4.8 Recent Spill History for Mobile Transfer Unit (MTU)

OSPR only regulates marine tanker trucks that deliver fuel over water. Data for these units were provided by OSPR and only includes incidents records between 2015 and 2017. In this time period, there were 28 tanker truck spills in California and of these, only two were marine fueling accidents (an incident rate of 0.7 per year). Data regarding the volume of oil spilled in these two incidents was unavailable; therefore, we evaluated the 1998–2018 CA OES spill data to examine the probability distribution for spill volume. The CA OES spill data included 98 incidents involving tanker trucks, primarily fuel delivery trucks or tanker trucks on highways. This data did not specifically focus on tanker trucks that transfer oil over water. The volumes spilled ranged from 1 bbl to 217 bbl. The probability distribution for volume is shown in Figure 20 and Table 28. The 95th percentile spill volume was 190 bbl.

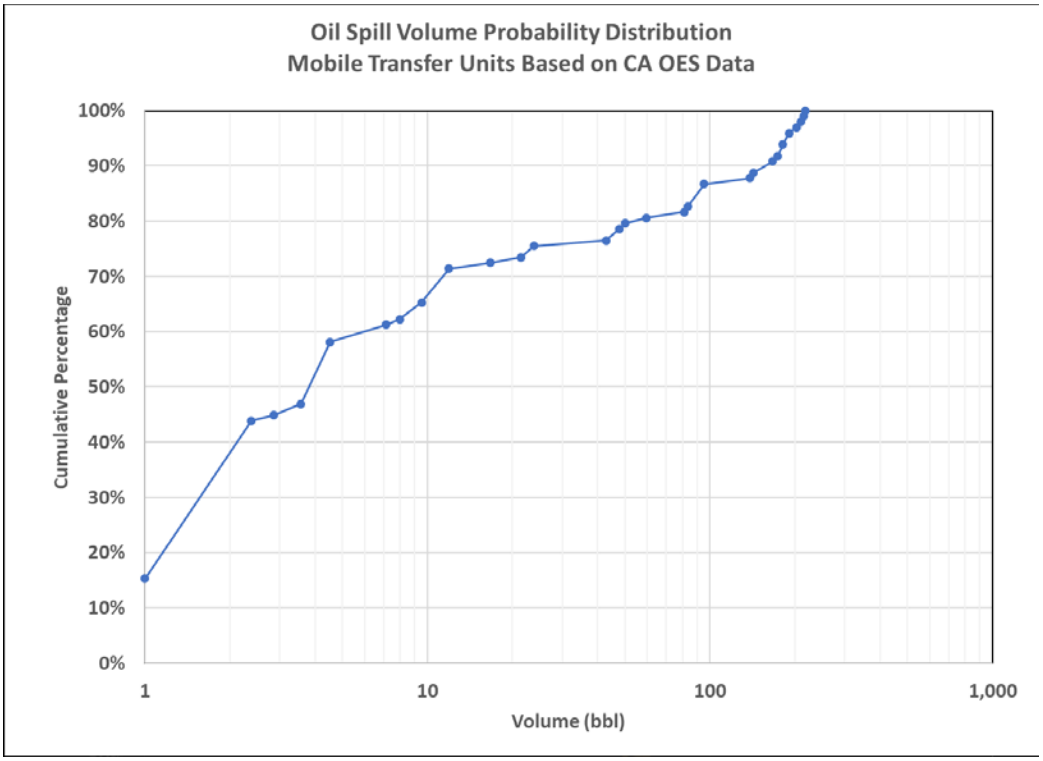

Figure 20: Oil Spill Volume Probability Distribution for Mobile Transfer Units, 1998-2018, N=98 (CA OES Data)

Table 28: Oil Spill Volume Percentiles for Mobile Transfer Units, 1998-2018, N=98 (Based on CA OES Data)

Percentile	Volume (bbl)
25th	2
50th	5
75th	40
95th	190

4.9 Recent Spill History for Inland Production Facilities

The 1998–2018 CA OES spill records include 4,164 incidents involving inland production facilities. The spill volumes ranged from 1 bbl to 10,000 bbl. (Note that many of these incidents involve produced water or other oil-water mixtures with low percentages of oil.) As described in Section 3, we also conducted a survey of California oil producers to obtain cost data for spills; the survey results presented information for 157 spills that occurred between 2015 and 2018. Given the overlap in timeframe of this dataset and CA OES records, we assume that at least a portion of the survey data is representative of spills already included in the CA OES spill records; therefore, we did not include the 157 spills reported in the survey responses as additional spills in the calculation of the probability distribution for volume. The probability distribution for volume is shown in Figure 21 and Table 29. The 95th percentile spill volume was 110 bbl.

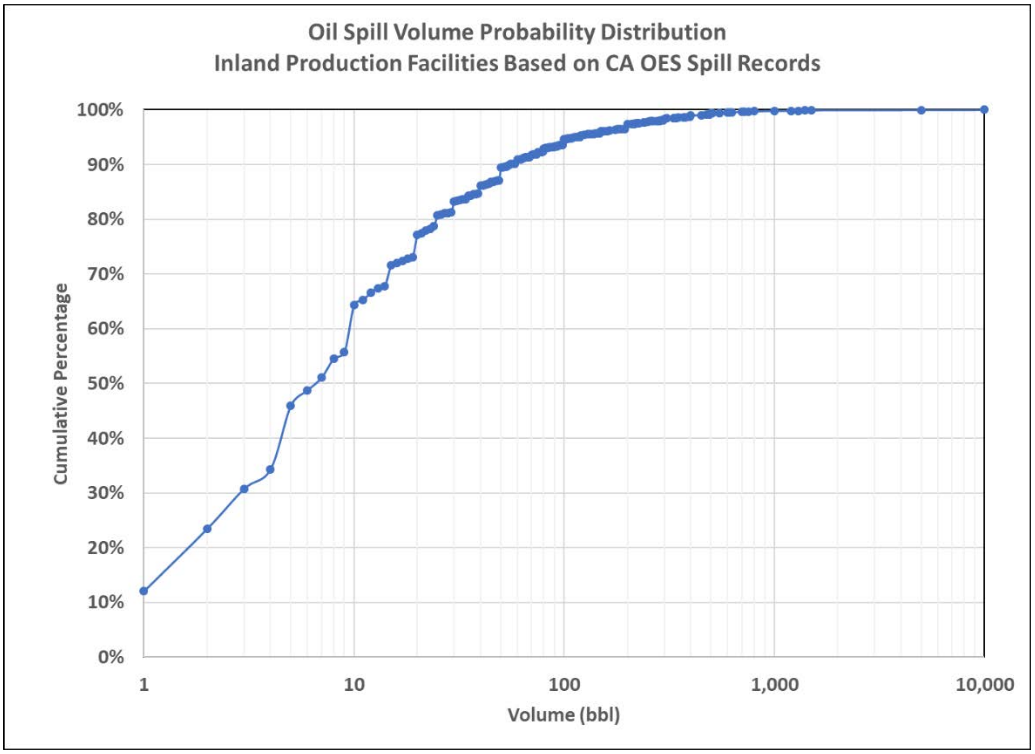

Figure 21: Inland Production Facility Spill Volume Probability Distribution, 1998-2018, N=4,164 (CA OES Data)[64]

Table 29: Oil Spill Volume Percentiles for Inland Production Facilities, 1998-2018, N=4,164 (Based on CA OES Data)

Percentile	Volume (bbl)
25th	3
50th	8
75th	35
95th	110

The RWCS volume definition for inland production facilities is “10 percent of the daily average oil and condensate production of largest producing well”. The reporting regulations, pursuant to sections 3406 and 3227 of the Public Resources Code, exclude produced water.

If the produced water and oil-water mixture incidents are removed from the CA OES Dataset, the probability distribution shifts to lower volumes, as shown in Figure 22 and Table 30. Without the produced water spills, the inland production facility spills range from 1 bbl to 5,000 bbl, with an average of 30 bbl. The 95th percentile spill volume is 100 bbl.

[64] CA OES Data

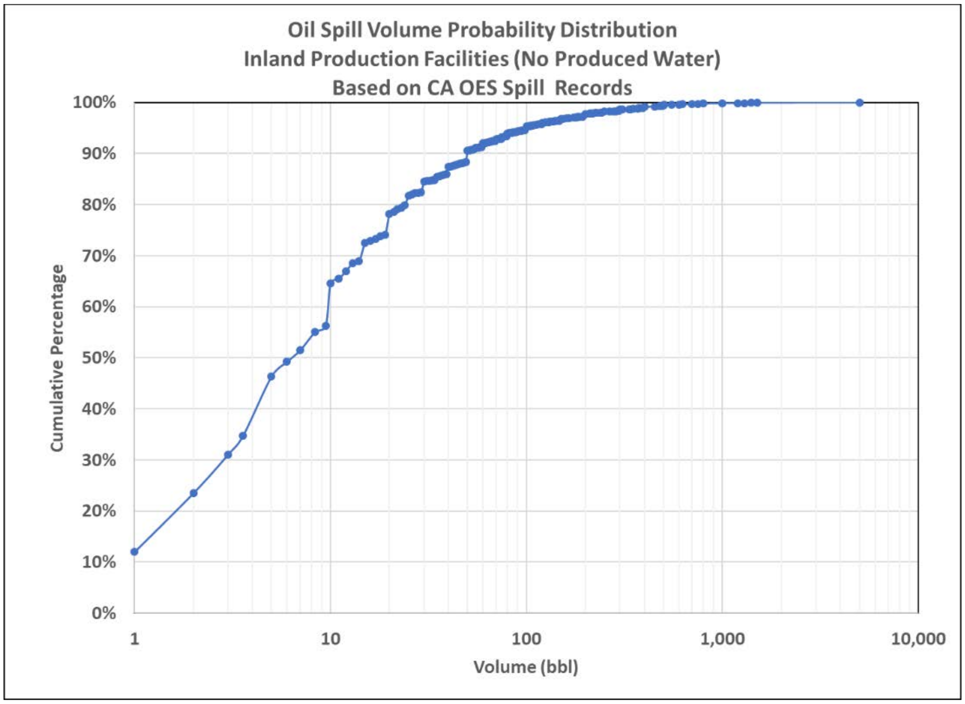

Figure 22: Inland Production Facility Spill Volume Probability Distribution (Excluding Produced Water), 1998-2018, N=3,178[65]

Table 30: Oil Spill Volume Percentiles for Inland Production Facilities (Excluding Produced Water), 1998-2018, N=3,178 (Based on CA OES Data)

Percentile	Volume (bbl)
25th	4
50th	7.5
75th	30
95th	100

4.10 Recent Spill History for Inland Pipelines

The 1998–2018 CA OES spill records contained 207 incidents involving inland pipelines. The spill volumes ranged from 1 bbl to 3,000 bbl. The probability distribution for volume is shown in Table 31 and Figure 24.

Table 31: Oil Spill Volume Percentiles for Inland Pipelines, 1998-2018, N=207 (Based on CA OES Data)

Percentile	Volume (bbl)
25th	2
50th	5
75th	21
95th	200

In an analysis of 48 years of inland pipeline spills throughout the US, including 6,433 crude pipeline and 4,377 refined product pipeline spills, it was found that half of pipeline spills involve less than one barrel, and 90 percent involve less than 100 bbl (Note that these data included spills of one gallon or more). In

[65] CA OES Data

the last decade, the 95th percentile spill volume is 400 bbl. The 99th percentile pipeline spill involves 2,500 bbl.[66] The 95th percentile volume for the US is 2.7 times larger than the volume based on the analysis of CA OES Data. The largest crude pipeline spills in the US are shown in Table 32.

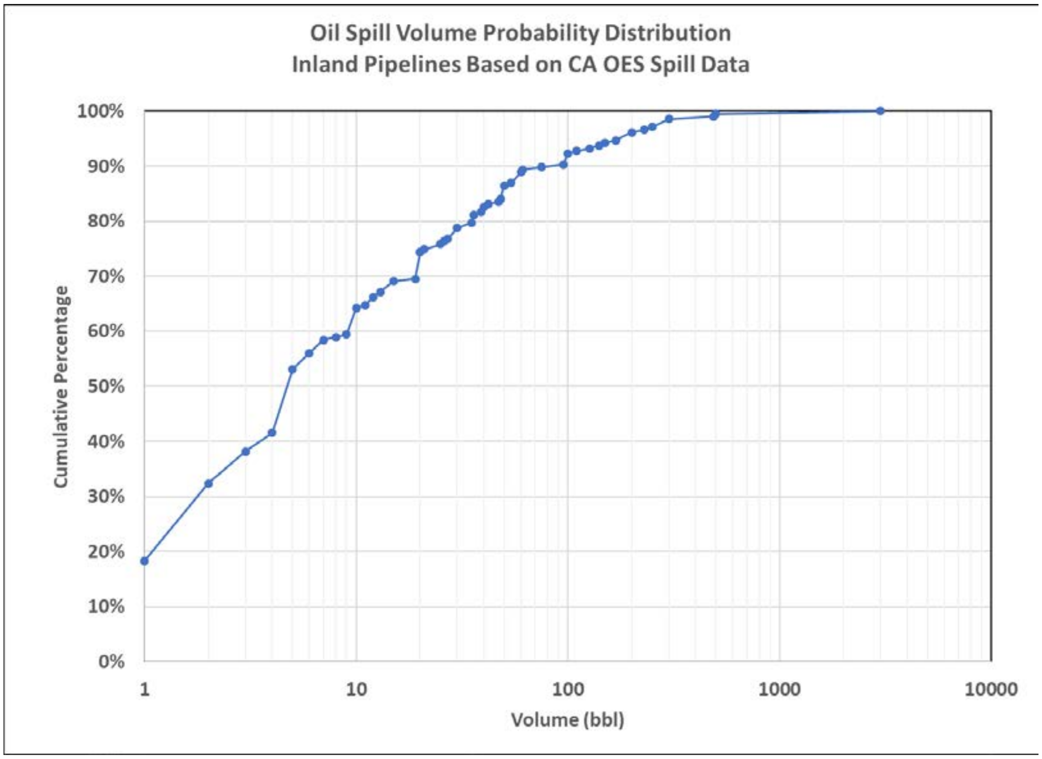

Figure 23: Oil Spill Volume Probability Distribution for Inland Pipelines, 1998-2018, N=207 (CA OES Data)

Table 32: US Crude Pipeline Spills of 20,000 bbl or Greater (1968–2012)[67]

Date	Company	State	County	City	Bbl
8/3/1970	Sunoco	TX	San Patricio	Taft	223,183
12/25/1983	Mid-Valley	OH	Allen	Lima	110,000
2/20/2006	Semcrude	OK	Payne	Cushing	49,000
8/3/1970	Humble	TX	San Patricio	Sinton	47,000
6/14/1968	Conoco-Phillips	KS	Greenwood	Eureka	41,000
3/3/1991	Lakehead	MN	Itasca	Grand Rapids	40,500
1/18/1974	Shell	LA	St. Charles	Diamond	40,000
5/14/1998	Valero	TX	Hutchinson	Phillips	32,903
1/7/2008	Conoco-Phillips	TX	Yoakum	Denver City	31,322
7/13/1989	Lakehead	ND	Pembina	Joliette	31,300
2/17/1973	Chevron-Texaco	TX	Hudspeth	Dell City	30,185
1/2/1995	Chevron-Texaco	OK	Lincoln	Lincoln City	30,000
6/30/1991	BP	TX	Yoakum	Denver City	28,200
4/6/1983	Ashland	MS	Franklin	Roxie	26,321
9/2/2005	Shell	LA	Plaquemines	Pilottown	25,435

[66] Etkin 2017.
[67] Adapted from data in Etkin 2014.

Date	Company	State	County	City	Bbl
5/4/1979	ExxonMobil	TX	Kimble	London	25,200
6/10/1980	Capline	IL	Pulaski	Karnak	25,000
8/30/2005	Chevron-Texaco	LA	Plaquemines	Buras	23,614
1/24/1989	Chevron-Texaco	TX	Winkler	Kermit	23,534
12/24/1988	Shell	MO	Maries	Vienna	20,554
7/26/2010	Enbridge	MI	Calhoun	Marshall	20,082
2/13/1990	ExxonMobil	TX	Crane	Crane	20,027
1/20/1982	Wood River	IA	Polk	Des Moines	20,000
1/20/1982	Wood River	IA	Polk	Des Moines	20,000

Overall, the annual numbers of major (>238 bbl) crude and refined product pipeline spills have decreased over the last 48 years (Figure 24). In addition, the average volume and volume probability distributions of crude pipeline spills have decreased (Figure 25).

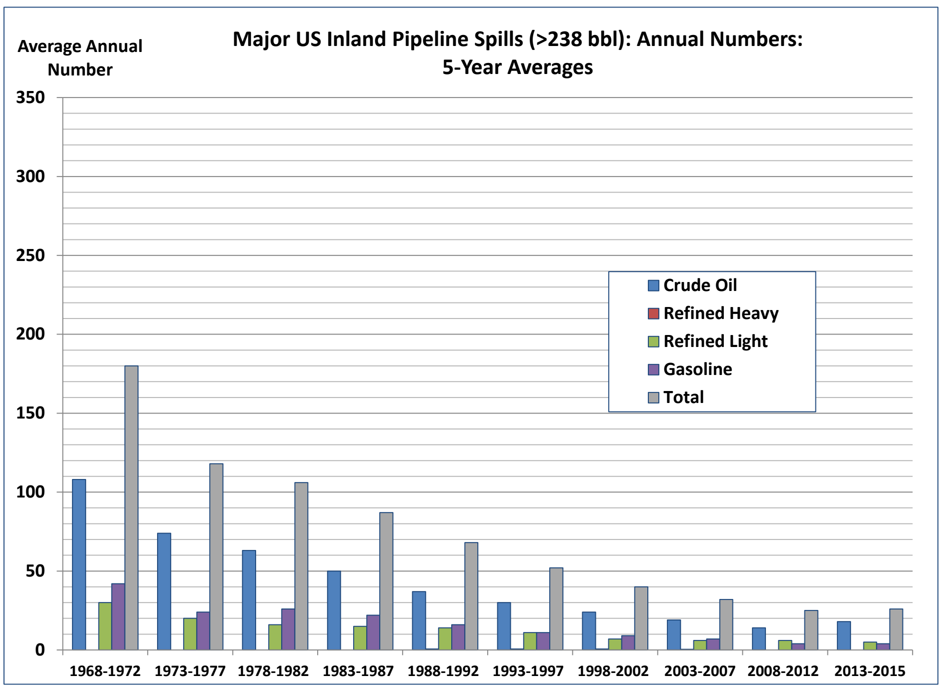

Figure 24: Major US Pipeline Spills (>238 bbl): Five-Year Average Spill Numbers[68]

[68] From: Etkin 2017.

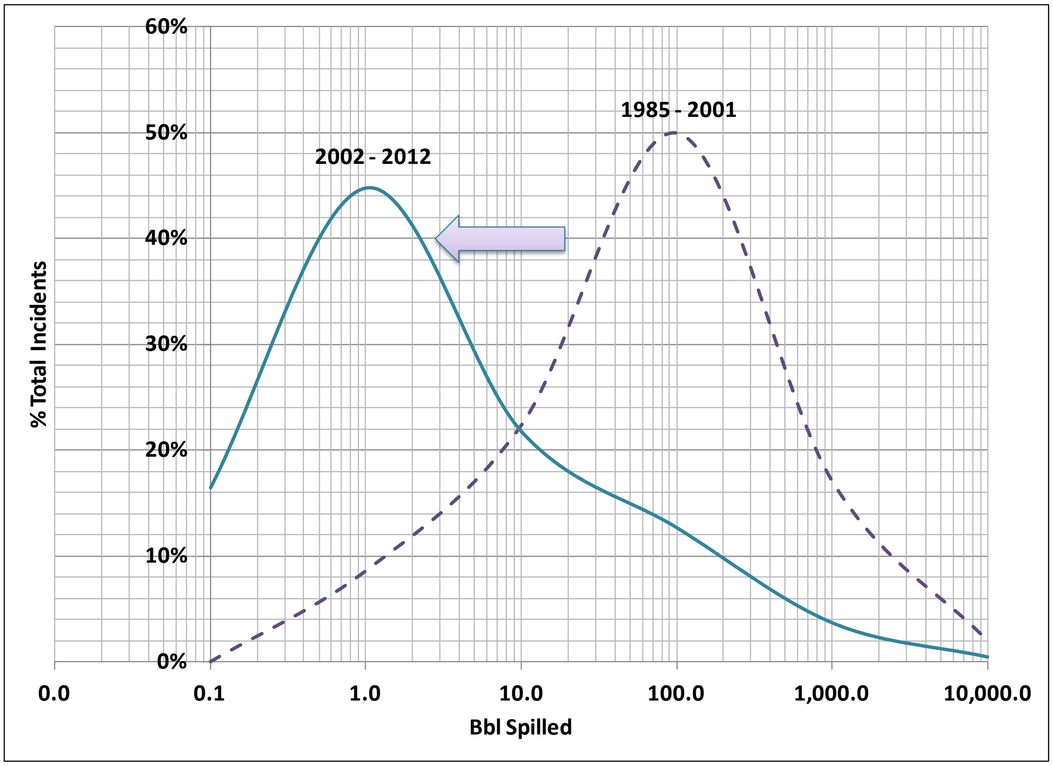

Figure 25: Crude Pipeline Spill Volume Distribution by Time Periods[69]

Pipeline spills are a particular concern for California. In a study on crude pipeline spills throughout the US for the years 1968 through 2012, Kern County, California, was the second highest county in the nation based on the number of crude pipeline spills (with an average of 2.87 spills per year with an average volume of 309 bbl), followed by Los Angeles County (with an average of 2.58 spills per year with an average volume of 253 bbl).[70] However, the reductions in pipeline spills seen throughout the US have affected California as well.

When pipeline spill data are normalized to the volume of product transferred, the total number of spills per volume transferred still declines. The refined product spills per bbl transferred decline through time, but the number of crude oil pipeline spills per barrel transferred slightly increased since the year 2000 (Figure 26). However, some of this may be due to an increase in the reporting of smaller spills (changes in reporting requirements have resulted in more frequent reports of smaller pipeline spills), because when examining the numbers of major crude pipeline spills per-volume transmission, the data show that the numbers of spills have leveled off (Figure 27). Major spills are defined by the EPA and U.S. Coast Guard as those involving greater than 10,000 gallons (238 bbl).

[69] From: Etkin 2014.
[70] Etkin 2014.

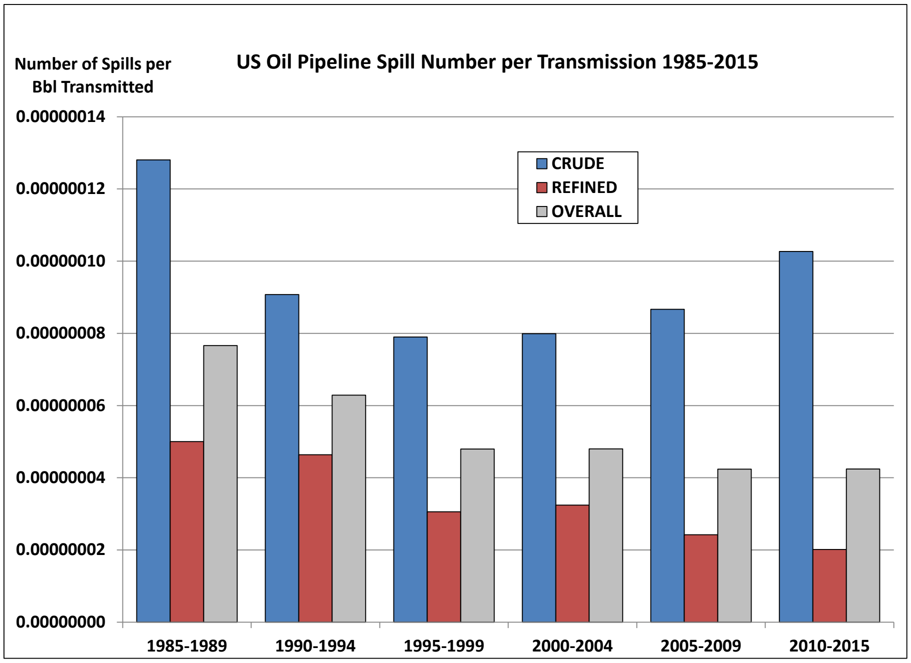

Figure 26: US Inland Oil Pipeline Spill Number per Volume Transmission (1985-2015)[71]

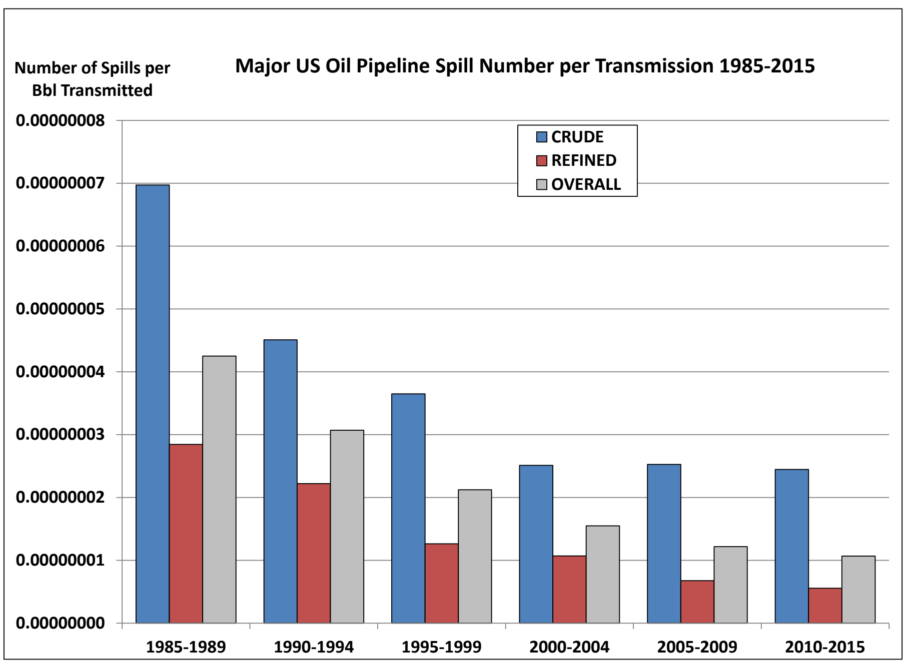

Figure 27: Major (Spills Greater than 238 bbl) US Oil Pipeline Spill Number per Volume Transmission (1985-2015)[72]

[71] From: Etkin 2017.
[72] From: Etkin 2017.

4.11 Recent Spill History for Rail

The 1998–2018 CA OES spill records contained 363 incidents involving railroads. The spill volumes ranged from 1 bbl to 1,071 bbl. The probability distribution for volume is shown in Figure 28 and Table 33. The 95th percentile spill volume was 45 bbl.

It is important to note that the majority of these incidents involve spills from locomotives that may be in transit or at railyards. There were only three incidents that involved tank cars. Since the COFR categories for railroad tank cars carrying oil at different rates of speed (10 mph, 25 mph, and over 25 mph) and not for spills of fuel from locomotives, the CA OES Data-derived volume probability distributions are not appropriate for analyzing RWCS volumes for the rail tank car category.

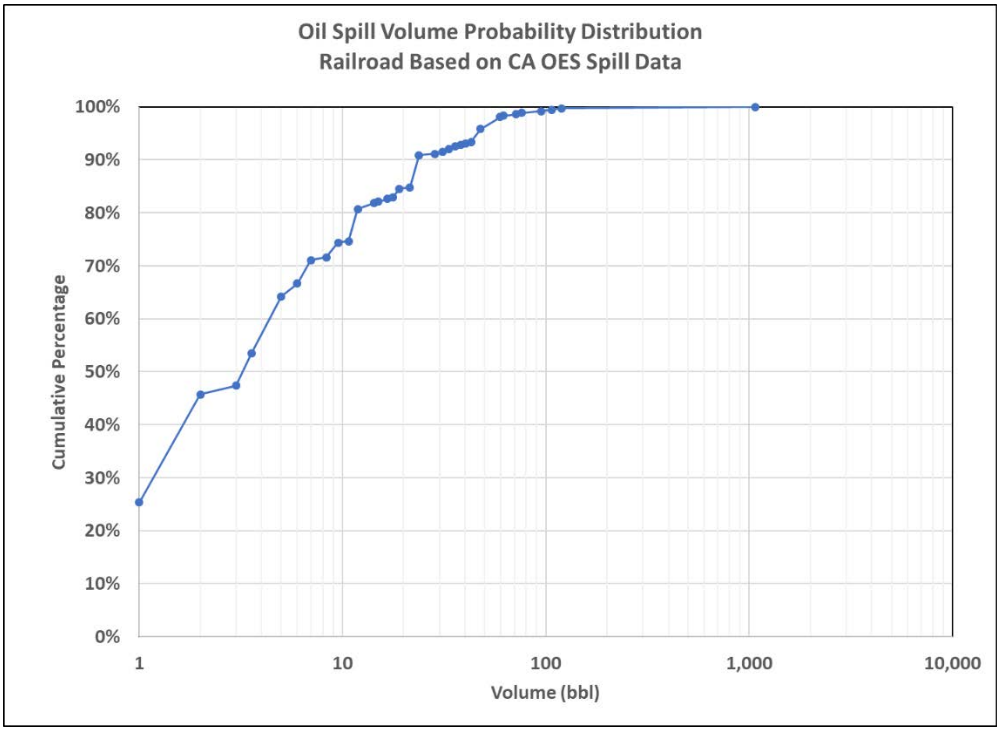

Figure 28: Oil Spill Volume Probability Distribution for Railroads, 1998-2018, N=363 (CA OES Data)

Table 33: Oil Spill Volumes for Railroad Spills, 1998-2018, N=363 (Based on CA OES Data)

Percentile	Volume (bbl)
25th	1
50th	4.5
75th	10
95th	45

While there have long been occasional smaller spills from locomotives and other railroad equipment and facilities in the US averaging 1,000 to 2,000 bbl per year,[73] a much greater concern about significant railroad oil spills developed with the sudden shift to crude-by-rail (CBR) transportation that began in 2010. Initially, some crude oil was being transported by key trains, which contained up to 20 tank cars on trains with other types of cargo. By 2011 into 2012, there was a sudden surge in CBR transportation in the form of unit trains that contained 100 to as many as 120 tank cars that contained crude oil, mainly

[73] Etkin 2009a.

Bakken crude oil from North Dakota. There was also some transport of diluted bitumen products from Alberta, Canada.[74] CBR transport peaked in early 2015 with about 70,000 crude oil carloads being transported each month in the US.[75]

The risks related to CBR spills were demonstrated in a July 2013 accident in Lac-Mégantic, Quebec, Canada, in which 63 tank cars derailed and nearly 38,000 bbl of Bakken crude were spilled. The oil ignited causing massive fire and explosions. There were 47 fatalities and extensive damage to the small town. Other notable CBR accidents in the US and Canada are listed in Table 34.

Table 34: Notable CBR US and Canadian Accidents with Crude Spillage 2013–2016[76]

Incident Location	Date	Outcome Synopsis
Paynton, Saskatchewan	1/24/2013	Collision with road grader; 16 cars derailed; 4 cars spilled oil; 667 bbl spilled.
Parkers Prairie, Minnesota	3/27/2013	14 tank cars derailed; 1 car ruptured; 714 bbl spilled; no fire; minimal damage due to frozen ground
Calgary, Alberta	4/3/2013	7 tank cars derailed; 2 tank cars released oil; fire (put out by local firefighters); 640 bbl spilled
White River, Ontario	4/3/2013	22 cars derailed; 1 car spilled oil; 393 bbl spilled
Jansen, Saskatchewan	5/21/2013	Mixed train; 5 cars derailed; 575 bbl spilled.
Lac-Mégantic, Quebec	7/5/2013	63 tank cars derailed; 37,719 bbl spilled; massive fire/explosion; 47 fatalities; 2,000 people evacuated; extensive damage to town
Aliceville, Alabama	11/7/2013	30 tank cars derailed; 12 tank cars burned; 10,846 bbl spilled; No injuries; fire; wetland impact
Casselton, North Dakota	12/30/2013	Collision; 20 crude cars derailed; explosion/fire; > 9,524 bbl spilled; 1,400 residents evacuated; no injuries
Plaster Rock, New Brunswick	2/7/2014	5 tank cars derailed; 5 tank cars burned; 45 homes evacuated; 3,000 bbl spilled; 45 homes evacuated; no injuries; no fire
Vandergrift, Pennsylvania	2/13/2014	19 tank cars derailed; 4 tank cars spilled oil; 108 bbl spilled; no fire; no injuries
Lynchburg, Virginia	4/30/2014	15 tank cars derailed; 3 tank cars burned; 1,190 bbl spilled; immediate area evacuated; some oil in river; no injuries
LaSalle, Colorado	5/9/2014	6 tank cars derailed; 1 tank car spilled oil; 155 bbl spilled; spill contained in ditch; no fire
Mount Carbon, West Virginia	2/16/2015	27 tank cars derailed; 14 tank cars burned; 9,800 bbl spilled; oil entered Kanawha River; drinking water impacts
Gogama, Ontario	2/14/2015	35 tank cars derailed; 7 tank cars caught fire; 4,900 bbl spilled
Galena, Illinois	3/5/2015	6 cars derailed; 2 cars burned; estimated 1,400 bbl spilled.
Gogama, Ontario	3/7/2015	69 tank cars derailed; 7 tank cars caught fire; 4,709 bbl spilled
Heimdal, North Dakota	5/6/2015	6 cars derailed and spilled oil; cars burst into flames; town evacuated; estimated spill 4,000 bbl.

[74] Etkin et al. 2015.
[75] Etkin 2017.
[76] Updated from Etkin 2017.

Incident Location	Date	Outcome Synopsis
Culbertson, Montana	7/17/2015	22 cars derailed; 4 cars leaked oil; 833 bbl spilled; no injuries, fire, or explosion.
Watertown, Wisconsin	11/8/2015	13 cars derailed; 1 car spilled oil; 12 bbl spilled.
Mosier, Oregon	6/3/2016	11 tank cars derailed; Several cars burned; 1,000 bbl spilled; some oil entered Columbia River
Money, Mississippi	4/29/2017	12 tank cars derailed in collision. The amount spilled is unknown. Most of the spilled oil was consumed in fire.
Plainfield, Illinois	7/1/2017	20 tank cars derailed; 2 cars released oil for a total of 1,071 bbl. No oil entered the river 1,200 ft. away.
Doon, Iowa	6/22/2018	32 tank cars derailed; 14 tank cars released some oil for a total of 5,476 bbl. Oil entered floodwaters and nearby river.

The volumes of spillage from these CBR incidents were plotted as a probability distribution, as shown in Figure 29 and Table 35. The 95th percentile spill volume is about 10,000 bbl, which represents about 14 or 15 tank cars of oil.[77] This is about the volume of the largest incident that occurred in the US–Aliceville, Alabama (Table 34).

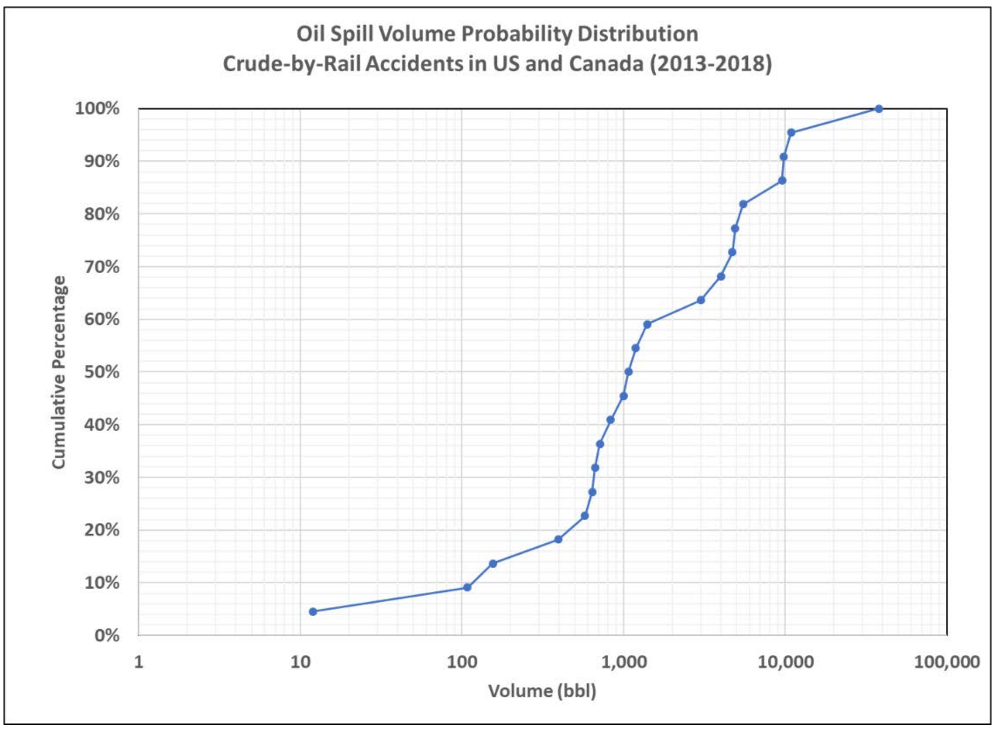

Figure 29: Oil Spill Volume Probability Distribution from US and Canadian CBR Accidents, 2013-2018, N=23

[77] Rail tank cars generally have a capacity of 714 bbl. However, they typically are only loaded to about 650 bbl to accommodate expansion.

Table 35: Oil Spill Percentile Volumes for US and Canadian CBR Accidents, 2013-2018, N=23

Percentile	Volume (bbl)
25th	750
50th	1,000
75th	6,500
95th	10,000

There are a number of safety measures that have been put into place that would reduce the likelihood of a secondary explosion due to thermal damage on tank cars and reduce the likelihood of tank cars breaking open. Based on the application of this model to trains of 100- and 120-tank cars, the probability distribution of spill volumes were calculated as shown in Table 36. The 90th percentile spill volume for a 120-car unit train is about 23,000 bbl, while for a 100-car unit train it would be 21,000 bbl. Note that these calculations assumed a more conservative approach to assumptions on the efficacy and full implementation of future safety measures. This would provide estimates that may over-estimate the extent of spillage. Full implementation of future safety measures (e.g., positive train control, DOT-117 tank cars, speed restrictions, track and equipment upgrades and maintenance) would reduce the potential volume of spillage.

Table 36: Expected CBR Spill Volume per Incident (Loaded Unit Trains)[78]

Statistical Parameter	120-Car Unit Trains		100-Car Unit Trains	
	Spill Volume (bbl)	Tank Cars Releasing	Spill Volume (bbl)	Tank Cars Releasing
Mean	11,253	17.3	10,498	16.2
0 percentile	261	0.4	249	0.4
10th percentile	2,860	4.4	2,718	4.2
20th percentile	4,219	6.5	3,984	6.1
30th percentile	5,705	8.8	5,365	8.3
40th percentile	7,375	11.3	6,918	10.6
50th percentile	9,280	14.3	8,686	13.4
60th percentile	11,507	17.7	10,756	16.5
70th percentile	14,186	21.8	13,236	20.4
80th percentile	17,655	27.2	16,452	25.3
90th percentile	22,830	35.1	21,214	32.6
100th percentile	50,201	77.2	44,455	68.4

Another consideration for the determination of a RWCS volume is the definition of "worst-case discharge" included in the Pipeline and Hazardous Material Safety Administration's (PHMSA) Final Rule regarding oil spill response planning for High-Hazard Flammable Trains (HHFTs).

On 28 February 2019, PHMSA, in coordination with the Federal Railroad Administration (FRA), issued a final rule that requires railroads to develop and submit Comprehensive Oil Spill Response Plans for route segments traveled by HHFTs. The rule applies to HHFTs transporting petroleum oil or Class 3 Flammable Liquids in a block of 20 or more loaded tank cars (key trains) and trains that have a total of 35 loaded petroleum oil or Class 3 Flammable Liquids tank cars (Docket No. PHMSA-2014-0105 (HM-251B)).

PHMSA's Final Rule defines a "worst-case discharge" of oil for response planning as *the greater of*:

- 300,000 gallons (7,143 bbl), or approximately the content of 10 tank cars; or

[78] Etkin 2017.

- 15 percent of total lading of liquid petroleum oil transported within the largest unit train consist reasonably expected to transport liquid petroleum oil in a given response zone. For a 100-car unit train, this would be 15 cars, for a 120-car unit train, this would be 18 tank cars.

The worst-case discharge calculated from tank cars exceeding 42,000 gallons (1,000 bbl) is equal to the capacity of the cargo container. OSPR's current RWCS volumes are dependent on the train speed (Table 37). Trains transiting under 10 mph would generally be moving within railyards. Trains transiting at 25 mph might include short lines that are going through high-consequence or densely-populated areas where the speed has been voluntarily reduced or regulated. Trains transiting at more than 25 mph would include most of the longer-distance routes. The various approaches to defining "worst-case discharge" are compared in Table 38.

Table 37: Current OSPR Reasonable Worst-Case Spill (RWCS) Volume Definitions for Rail Tank Cars

Rail Tank Car Speed[79]	Category	RWCS Definitions	Estimated Volumes (bbl)
10 mph	714 bbl/car[80]	Greater of: 1 tank car or 1% bulk oil[81]	714–843 bbl
25 mph	714 bbl/car	Greater of: 1 tank car or 5% bulk oil	714–4,213 bbl
>25 mph	714 bbl/car	Greater of: 1 tank car or 20% bulk oil	714–16,850 bbl

Table 38: Comparison of OSPR and PHMSA Worst-Case Discharge Spill Volumes for Rail Tank Cars

Approach	Assumption	Volume (bbl)[82]		Tank Cars[83]		% Total Load	
		100-Car Train	120-Car Train	100-Car Train	120-Car Train	100-Car Train	120-Car Train
OSPR RWCS 10 mph	1% bulk oil	650	780	1.0	1.2	1%	1%
OSPR RWCS 25 mph	5% bulk oil	3,250	3,900	5.0	6.0	5%	5%
OSPR RWCS >25 mph	20% bulk oil	13,000	15,600	20.0	24.0	20%	20%
CBR-SpillRISK-V	95th percentile	28,000	30,000	43.1	46.2	43%	38%
PHMSA	Final Rule	9,750	11,700	15.0	18.0	15%	15%
CBR Cases	95th percentile	10,000	10,000	15.4	15.4	15%	13%

4.12 Summary

Percentile spill volumes were calculated based on the most appropriate historical spill data available for the different sources types as summarized in Table 39.

Offshore production facility blowouts, the potentially largest type of spill, are dependent on the flow rate, which varies considerably between wells, and the duration of flow. For California, the average flow rates vary from 100 bbl/day to 9,750 bbl/day. (In comparison, there are wells in the Gulf of Mexico that flow at rates averaging as much as 449,000 bbl/day.[84]) The duration of flow depends on whether the

[79] Railroad maximum speeds based on the most recent Timetable submitted to the Federal Railroad Administration.
[80] Typical railroad tank car has a capacity of 714 bbl. Typically, they only actually contain 650 bbl.
[81] Crude-by-rail unit trains typically have 100 to 118 tank cars.
[82] Assuming 650 bbl per tank car.
[83] Assuming 650 bbl per tank car.
[84] Buchholz et al. 2016.

blowout naturally bridges, stopping the flow of oil, or whether an intervention measure is required. Intervention measures include capping and relief well drilling. The timing for those varies as well. According to BSEE, this would take about 170 days in California. [85] This would represent a worst-case spill scenario for California.

Applying the specific flow rates for California along with the probability distribution of duration is the most appropriate measure of potential blowout scenarios for determining reasonable worst-case spill scenarios. The 30-day flow, as currently applied in the RWCS definition is about the 90th percentile case based on historical data.[86]

Table 39: Oil Spill Volume Summary by Category

Category	Data Applied	Largest Spill Volume (bbl)	Number of Spills	95th Percentile Volume (bbl)
Tanker	Outflow modeling for 300,000 DWT tanker	Spill volume modeled based on tanker size	This is a modeled outcome. There are no specific spills.	66,000
Tank Barge	Outflow modeling for 327,000-bbl capacity tank barge	Spill volume modeled based on tank barge size	This is a modeled outcome. There are no specific spills.	16,000
Non-Tank Vessel	CA OES	1,275	60	1,000
	Outflow modeling for 22,000-bbl bunker capacity vessel	Spill volume modeled based on non-tank vessel size	This is a modeled outcome. There are no specific spills.	1,320
Marine Facility	CA OES	4,600	310	200
Offshore Platform	National and worldwide data (Etkin et al 2015)	Spill volume modeled based on maximum per well rate.	This is a modeled outcome. There are no specific spills.	Not calculated
Marine Pipelines	National data (Etkin 2009a)	8,212	13	224
Small Marine Fuel Facility	CA OES	71	22	
Mobile Transfer Units	CA OES[87]	217	98	190
Inland Production Facility	CA OES	10,000	4,164	110
Inland Production Facility (No Produced Water)	CA OES	10,000	3,767	100
Inland Pipelines	CA OES	3,000	206	150
Inland Railroads[88]	CA OES	1,071	363	45
Railroad Tank Cars	US and Canadian data	37,719	23	10,000
	Modeled CBR data (Etkin 2017)	Modeled data	Modeled data	25,000

[85] Buchholz et al. 2016.

[86] Dyb et al. 2012; Holand 2006, 2013; Danberger 1980; Scanpower 2006; Buchholz et al. 2016b; Etkin 2015.

[87] These data represent MTUs traveling on highways. Based on data provided by CDFW-OSPR, only 2 spills from MTUs transferring oil over water occurred between 2015 and 2017 and spill volume is unknown.

[88] These data are for all railroad-related spills, not necessarily only spills from tank cars in unit trains.

SECTION 5 Model Development

Each oil spill is a unique event, the outcome of which depends on the particular circumstances that caused the release into the environment, the characteristics of the receiving environment, and actions taken to mitigate effects. Calculation of the costs of hypothetical future spill events requires making assumptions that the potential incidents will follow the patterns of past cases. A complete description of the oil spill cost model developed for this project is included in Appendix A of this report.

5.1 General Issues Regarding Prediction of Oil Spill Costs

Estimation of costs for hypothetical future oil spill scenarios–including those potentially incurred for cleanup response operations, third-party damages, natural resource or environmental damage assessments, and fines and penalties–has numerous practical applications, such as:

- Conducting spill risk assessments to quantify risk exposure for potential responsible parties in their oil operations;
- Conducting cost-benefit analyses for spill prevention or risk mitigation measures; and
- Determining insurance coverage requirements or setting liability limits.

Clearly, the more precise the cost estimates for the various aspects of an oil spill, the more valuable the estimates are for practical application. At the same time, ideally, the calculation method is simple–for example, a single cost per barrel (bbl) value that can easily be applied to any hypothetical (or actual) spill of a set or known volume.

The limitation to this level of precision and simplicity is that there are many interrelated and variable factors that determine the costs of a spill. Each spill presents a unique situation with factors that will affect the ultimate costs to the responsible party. The spill volume, oil properties, geographic and environmental features of the location, sensitive socioeconomic and ecological resources in proximity to the spill site, wind directions, currents, and weather conditions all affect the costs of cleanup. In addition, the type of cleanup response strategy, which may be limited by jurisdictional regulations and practical considerations, also affect cleanup costs. The effectiveness of the cleanup response operations, which will be affected by the conditions, as well as the skill of the operators and the condition and amount of equipment available, will have an overall effect on the cleanup costs, as well as on mitigating any ecological and socioeconomic damages. In some cases, the cleanup response operations themselves may cause damages, even when there is a net environmental benefit to the operations.

The same spill (i.e., a certain volume of a particular type of oil spilling in a certain location under the same environmental conditions) can result in different cost outcomes depending on the efficacy of the response operation.[89] Spill costs are also affected by the jurisdiction in which they occur, which will determine the liability regime that is in effect, as well as the spill response measures that may be applied.

These limitations apply in calculating the costs for specific hypothetical spill scenarios. When applied to a large potential array of hypothetical spills, there is a larger degree of imprecision and uncertainty in spill cost estimates. However, it is possible to calculate cost estimates for potential future spills based on general characteristics of spills that have the greatest effect on costs, recognizing that there will be

[89] As demonstrated in Etkin et al. 2006.

some variation in the costs for specific spills. Including a "risk tolerance factor" in the estimate allows for potentially higher costs to be factored into a risk exposure analysis.

5.2 Limitation in Predicting Oil Behavior, Fate, and Effects

Nearly all oil spill costs are related in one way or another to the ultimate behavior, fate, and effects of the spilled oil in the particular location in which it spills, and the way in which the spill response operations are conducted under the prevailing environmental conditions, regulations, and decision-making processes. While studying previous case studies is very instructional in noting patterns that may be applied in a model, the most effective way to predict spill costs with respect to oil behavior, fate, and effects, as well as the applied response, for hypothetical future spills is to use modeling to simulate hypothetical spills and response operations. Absent these data for specific spill scenarios, a large number of assumptions need to be made on the way in which these factors will affect the outcome of a spill and its costs.[90]

5.3 Estimating Unit Spill Costs

The response costs of the worldwide spills analyzed were adjusted in a number of ways to derive a country-specific unit base cost. These adjustments were based on a correction for "outliers," the exponential increase in response costs over time (taking into account inflation corrections by year), oil type (persistence) factors, and volume factors. These unit costs were then further adjusted for more geographic-specific factors that would change the potential magnitude of costs–including environmental sensitivity, dispersant response policy, and–on a geographic basis. These adjustments are summarized in the schematic drawing in Figure 30.

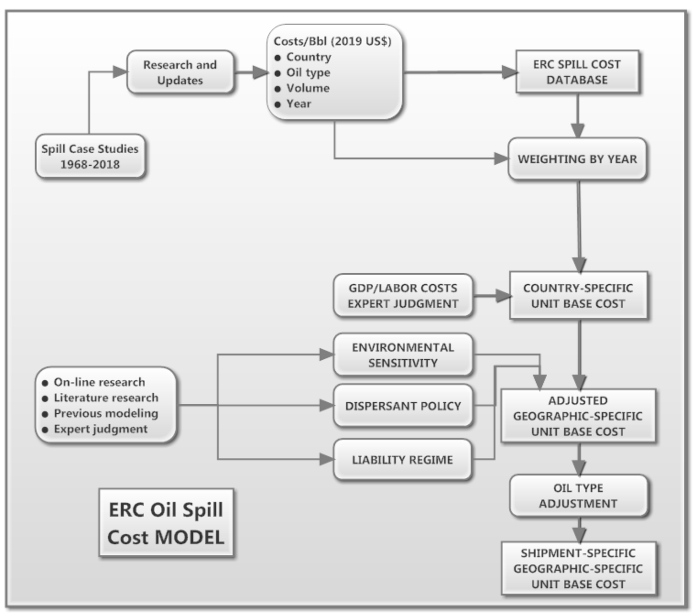

Figure 30: CDFW-OSC Model Derivation of Geographic Unit Base Costs

[90] For example: Buchholz et al. 2016b; Etkin et al. 2002, 2003, 2006; French-McCay et al. 2005, 2006.

The overall methodological approach to the development of the CDFW-OSC Model involved:

1. Calculation of average per-bbl response costs by overall Region, and Nations represented in the data from worldwide spills;
2. Calculation of per-bbl response costs with time-scaling to take into account the overall increases in response costs beyond adjustments for inflation;
3. Analysis to determine "outlier" cases;
4. Development of four different approaches to estimating per-bbl response cost–Highest (based on time-scaled data including outliers), High (based on time-scaled data excluding outliers), Medium (based on original data in 2019 US dollars including outliers), and Low (based on original data in 2019 US dollars excluding outliers), so as to provide costs for different levels of risk tolerance;
5. To adjust for over-representation of US cases in the calculation of averages, the grand averages by Region were used rather than the overall average from the worldwide spills;
6. The Region averages were then adjusted for the individual regions by applying a GDP PPP correction factor to allow for general economic differences between the regions and subregions;
7. These averages were then further adjusted to take into account differences in dispersant response policy, which would have a significant effect on overall costs and damages (dispersants tend to reduce shoreline oiling, cleanup, and damage costs);
8. The Region dispersant adjusted averages were then further modified based on oil type; and
9. An optional ecological sensitivity index was provided to allow for unusually high costs based on the presence of certain types of ecological receptors in some areas.

In applying the OSC model, the proximity to shoreline (nearshore/in-port versus offshore) needs to be considered. The basic steps in applying the OSC model are in Figure 31. The per-bbl unit costs are found in look-up tables (or "key tables") or can be incorporated into a simple spreadsheet calculator.

The four calculation approaches–Highest, High, Medium, and Low–result in a range of potential costs. The costs that would be realized in an actual spill scenario would be dependent on the factors of the incident itself. There will be circumstances in which the costs are particularly high due to extenuating circumstances, making the incident an "outlier" case. The Highest and Medium approaches take these outliers into consideration. The Highest and High approaches additionally take into account that there has been an over-arching trend towards increased costs for spills, even after adjustments for inflation. This is likely attributable to increased public concern about the effects of spills and higher standards for cleanup, as well as a good measure of "punitive" measures with regard to costs that are incorporated into response and damage costs.

Four different approaches were taken to calculate the regional response costs, as summarized in Table 40. The inclusion of outliers tends to drive the costs up by a factor of 1.6; time-scaling (year-adjustment) tends to drive costs up by a factor of about five. These approaches may be considered as degrees of "maximization" for costs that can be applied with respect to the degree of risk tolerance for management purposes. For application in this study, the different levels of risk can be viewed as the degree to which it may be "acceptable" to potentially under-estimate the costs of a RWCS incident in setting COFR levels.

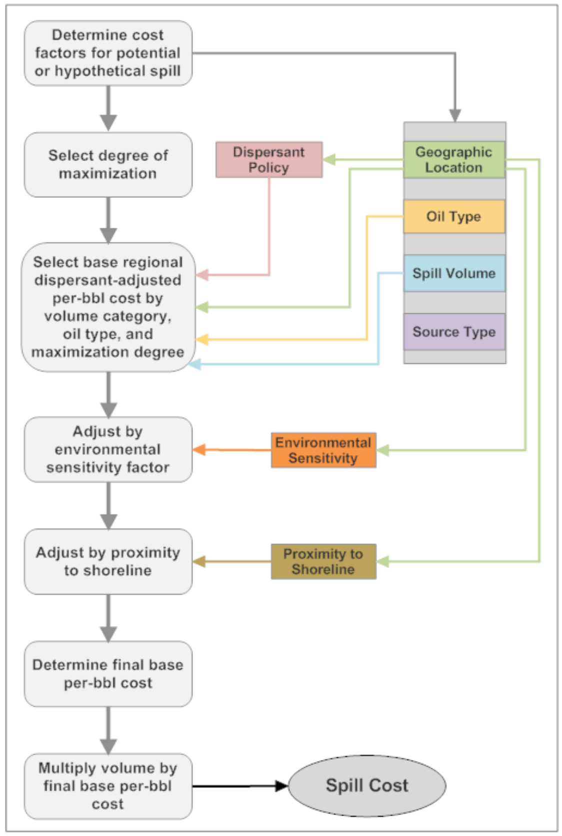

Figure 31: Basic Algorithm of CDFW-OSC Model

Table 40: Different Approaches to Calculation of Per-Unit Base Response Costs

Calculation Approach	Degree of Cost Maximization	Year Adjustment	Outliers Included
Time-Scaled with Outliers	Highest Cost	YES	YES
Time-Scaled without Outliers	High Cost	YES	NO
Non-Time Scaled (Original) with Outliers	Medium Cost	NO	YES
Non-Time Scaled (Original) without Outliers	Lowest Cost	NO	NO

While all costs are adjusted to current dollars (2019 dollars), there are additional adjustments that are made to reflect the fact that oil spill costs (i.e. response costs) have increased at a rate faster than overall inflation. The Lowest-Cost category and the Medium-Cost category do not adjust for this increase (called “time-scaling”). Since this phenomenon has been demonstrated for US spills (see Figure in Appendix A), it is highly recommended that this type of year adjustment be incorporated into the CDFW-OSC model.

In analyzing the cost data, it was also found that there are several oil spill cases that represent “outliers” in that the unit costs are significantly higher than costs for the rest of the cases by as much 11 to 14 standard deviations about the mean (average). Generally, statisticians regard data that are two standard deviations from the mean as being significantly different from the rest of the dataset. Including or eliminating these incidents from the data analysis, as was done for the Lowest-Cost and High-Cost approaches, represents a stance of less concern about missing a potential “outlier” case. Outliers were defined as spills for which the per-bbl response costs were more than three standard deviations from the mean. There were five such cases in the international dataset. Of these five, three cases occurred in

California. The California outlier cases included: two spills that involved less than 25 bbl, and one case that involved less than 110 bbl. They all involved non-tank vessels spilling heavy persistent oil into marine waters. Therefore, incorporating the Highest-Cost approach may be appropriate for California. Overall, it is recommended that either the time-scaled approaches with outliers (Highest-Cost) or without outlier (High-Cost) be applied for the CDFW-OSC model.

Two major classifications of per-unit costs were made–oil type and spill volume. General categories of oils were developed based on persistence–non-persistent, low-persistent, medium-persistent, and heavy-persistent, as summarized in Table 41.

Table 41: Oil Type Classifications for CDFW-OSC Model

Oil Type Classification	Classification Abbreviation	Example Oils
Non-Persistent	NP	Gasoline, jet fuel, kerosene
Light Persistent	LP	Diesel, No. 2 fuel, condensate
Medium Persistent	MP	Medium crude oil
Heavy Persistent	HP	Heavy crude, heavy/intermediate fuel, bunker fuel

SECTION 6 Model Results - Estimating Oil Spill Costs

This section presents the results of our analysis estimating oil spill costs. As described in this section, the costs of an oil spill vary depending on where the spill occurs, and the type of oil that is spilled, rather than the source of the spill. For spills greater than 100 bbl, the greatest per barrel costs occur with a spill of heavy persistent oil ..These costs are not appropriate to apply to spills under 100 bbl. In determining COFR amounts, or applying costs to specific regulated entities, the source and recent spill history (as presented in Section 4) can be used to determine the RWCS that can be multiplied by the per barrel unit spill costs presented in this section.

6.1 General Distribution of Spill Costs Based on Historic Worldwide Data

The costs reflected in the ERC Spill Cost Database, described in Section 3, (adjusted to 2019 dollars) include response costs, third-party damage claims, environmental (natural resource) damage claims, and fines and penalties assessed. Only response costs were analyzed at this point as this is the most complete set of cost data. The reasoning for this is that response costs would generally always be incurred in the event of a spill. The degree of response (the amount of work and resources required for cleanup) is also generally correlated with the environmental and socioeconomic (third-party) damages, as well as fines and penalties imposed. There may be circumstances when damage claims, and fines and penalties, are disproportionate to response costs. This might happen when the spill occurs in a particularly environmentally-, culturally-, and/or politically-sensitive location. This is taken into consideration in later sensitivity adjustment factors.

The per-bbl response costs range from less than $1 per bbl to as much as $670,000 per bbl–varying by five orders of magnitude. This range roughly represents a log-normal distribution (Figure 32 and Figure 33). These costs include worldwide spills. They also need to be adjusted before application in a cost model.

The cumulative probability distribution of per-bbl response costs and the percentile values are shown in Figure 34 and Table 42.

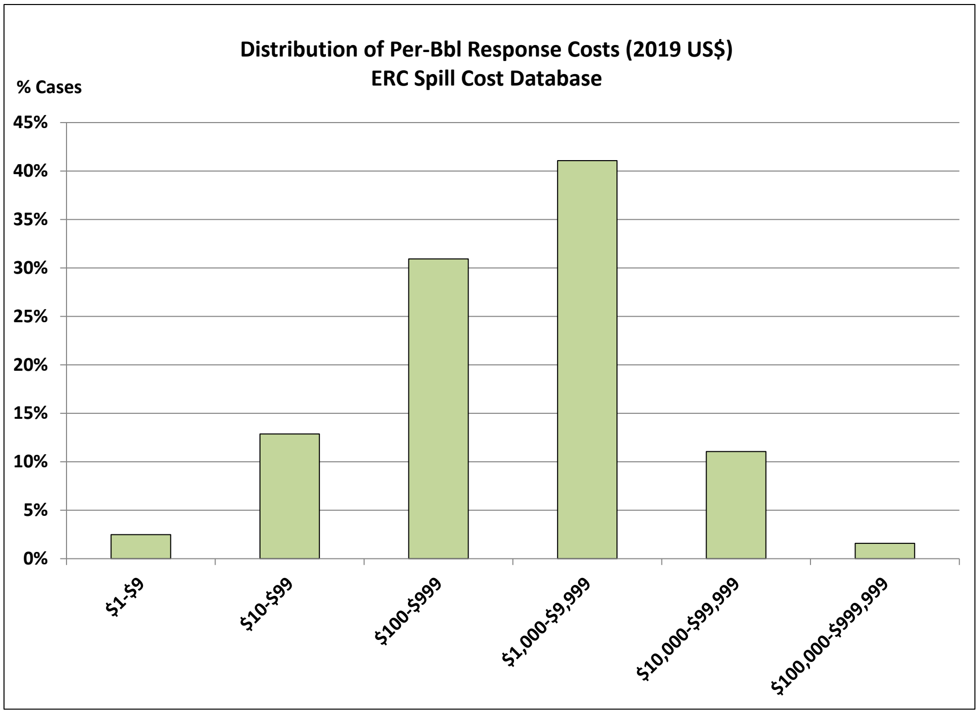

Figure 32: Distribution of Per-Bbl Response Costs

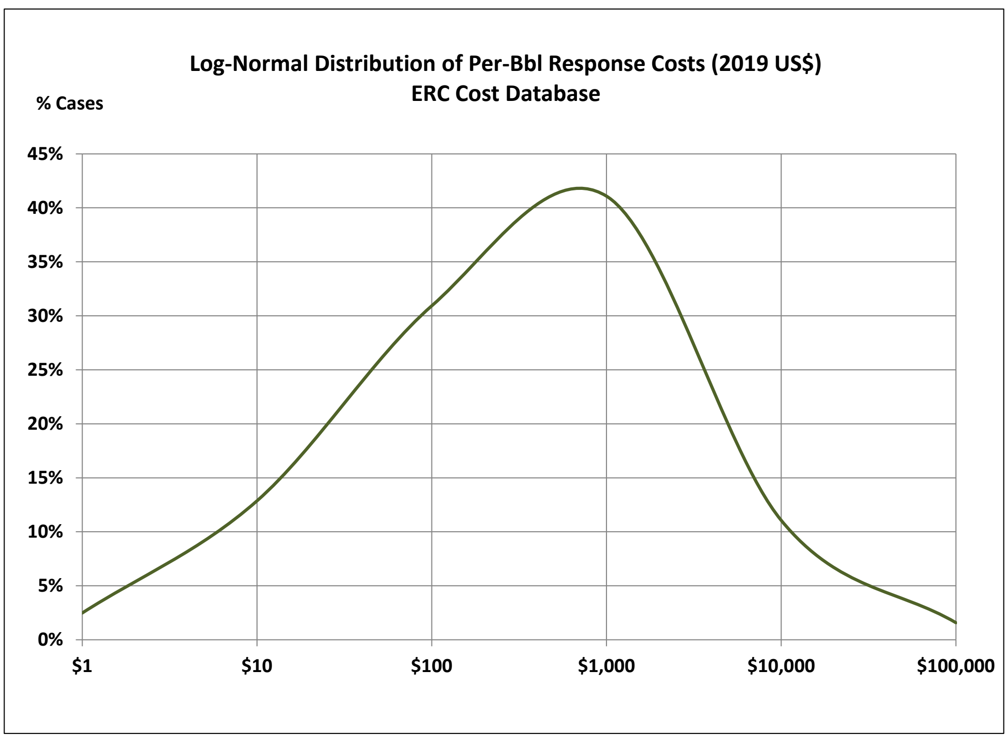

Figure 33: Log-Normal Distribution of Per-Bbl Response Costs

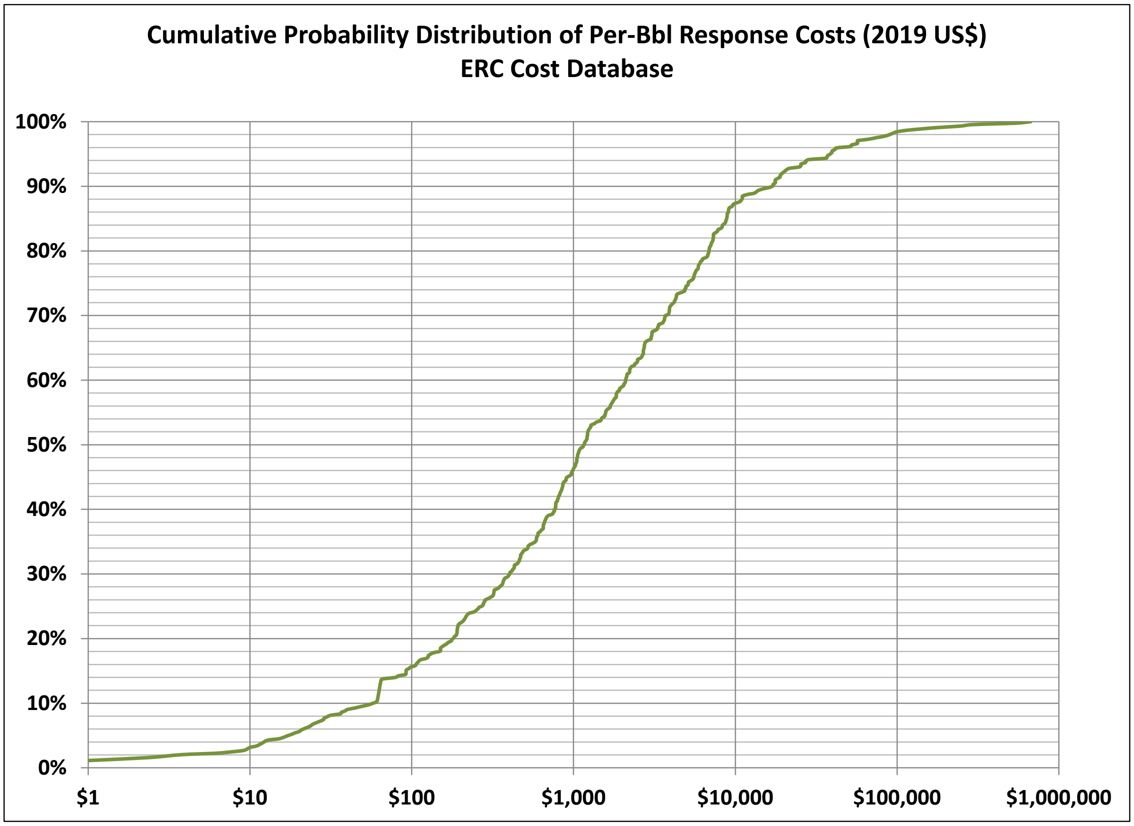

Figure 34: Cumulative Probability Distribution of Per-Bbl Response Costs

Table 42: Per-Bbl Response Cost Percentiles based on data available from 443 Spills Worldwide

Percentile	Response Cost/Bbl (2019 US$) (Worldwide)
10th	$62
25th	$280
50th (Median)	$1,206
75th	$5,284
90th	$17,527
95th	$40,054
99th	$184,549
Maximum	$690,255
Average (Mean)	$10,697

6.2 Distribution of Spill Costs in California Oil Operator Survey

The data collected in the survey are an important addition to the existing data from worldwide spills for the following reasons:

- The spill cases cover relatively small spills for which there is often little data; and
- The incidents occurred under the circumstances that would be applicable to the specific conditions for inland California spills–i.e., desert scrub areas, as well to dry washes and soil. It is important to note that none of the spill cases for which data were provided went to

waterbodies with water present. This is in contrast to the ERC data included in the model which is nationwide and includes a lot of marine spills.

- Based on the responses to the survey, all of the data provided is applicable to Inland Production Facilities.

Per-bbl spill response (cleanup) costs varied from $1 to over $29,000 per bbl. There were 20 incidents for which spill costs were reported to be $0, which were removed from the dataset, leaving 133 incidents. All costs were adjusted to 2019 dollars. The distributions of costs are shown in Figure 35 and Figure 36.

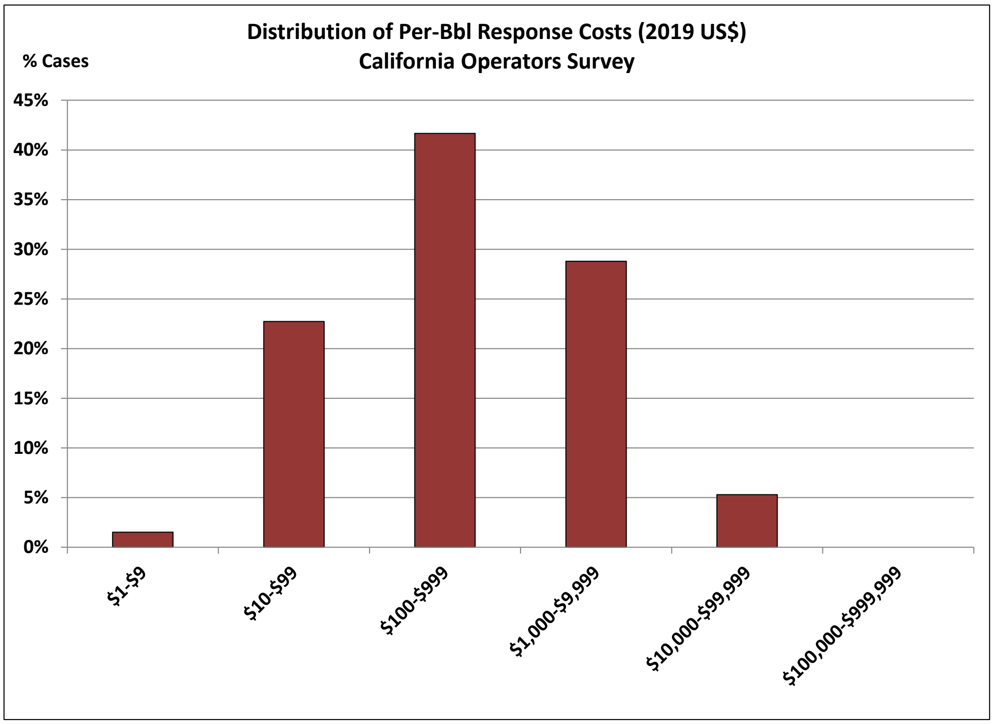

Figure 35: CA Survey Distribution of Per-Bbl Response Costs

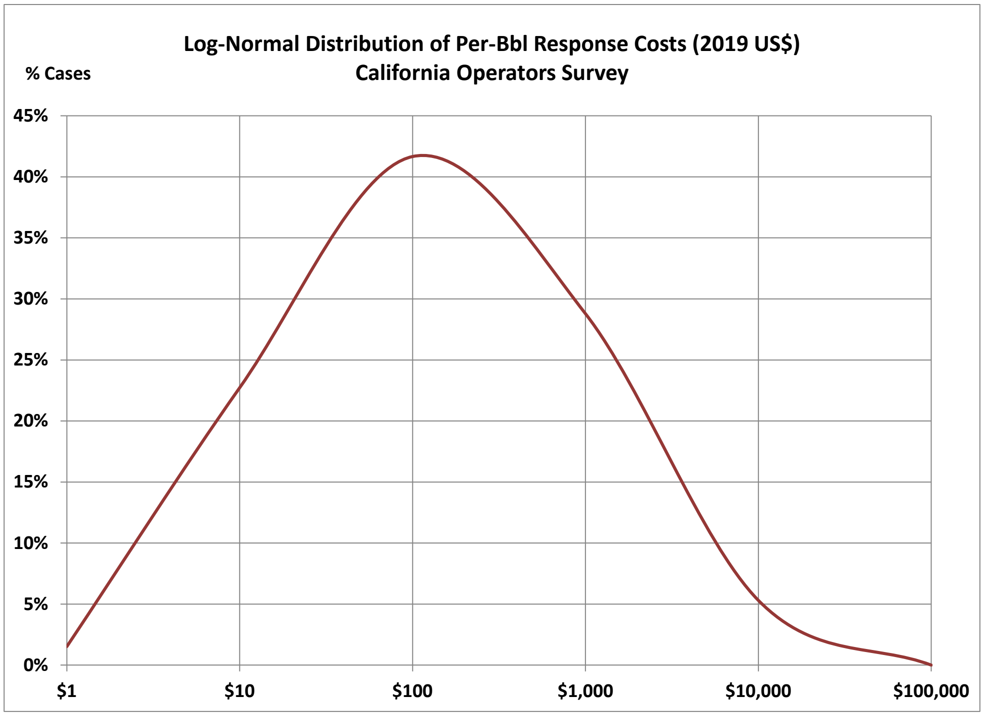

Figure 36: CA Survey Log-Normal Distribution of Per-Bbl Response Costs

The cumulative distribution of per-bbl response costs is shown in Figure 37. The percentile costs are shown in Table 43. If the produced water spills are eliminated from the dataset, the overall costs increase, as shown in Table 44.

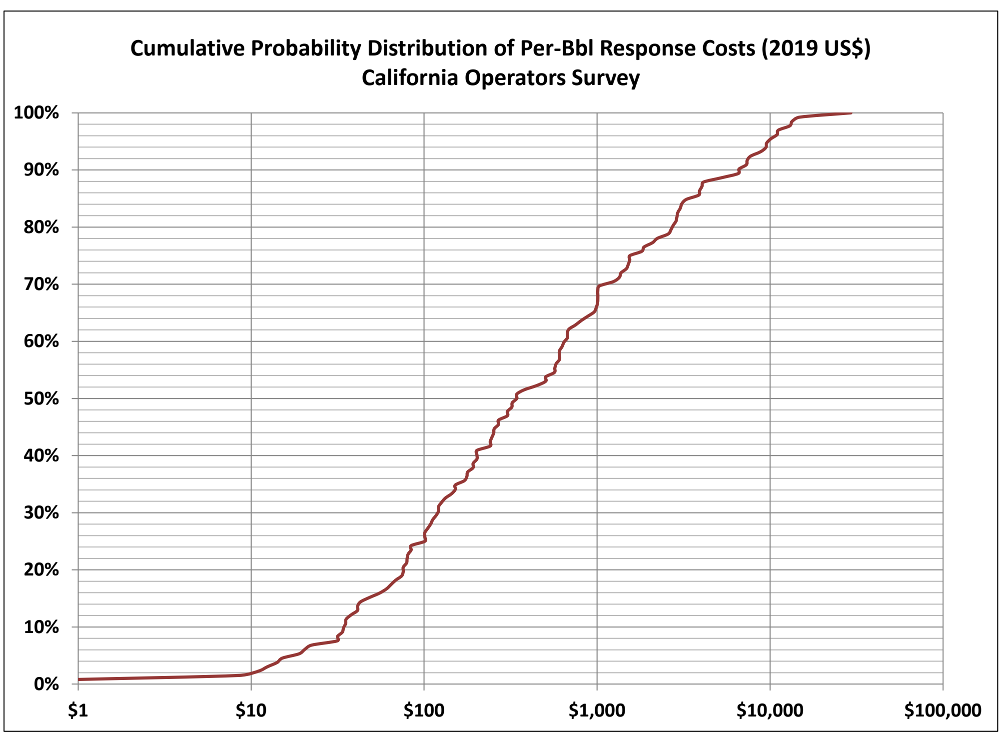

Figure 37: California Operator Survey Cumulative Probability Distribution of Per-Bbl Response Costs

Table 43: Per-Bbl Response Cost Percentiles in California Operators Survey

Percentile	Response Cost/Bbl (2019 US$)
10th	$35
25th	$101
50th (Median)	$343
75th	$1,547
90th	$6,600
95th	$10,000
99th	$14,500
Maximum	$29,341
Average (Mean)	$1,954

Table 44: California Survey Per-Bbl Response Cost Percentiles (without Produced Water)

Percentile	Response Cost/Bbl (2019 US$)	
	California Operators Survey Including Produced Water Incidents	California Operators Survey Excluding Produced Water Incidents
10th	$35	$101
25th	$101	$241
50th (Median)	$343	$670
75th	$1,547	$3,000
90th	$6,600	$9,200
95th	$10,000	$11,100
99th	$14,500	$15,000
Maximum	$29,341	$29,341
Average (Mean)	$1,954	$2,800

6.3 Unit Spill Costs from Oil Spill Cost Model

The CDFW-OSC cost model is most applicable to marine spills and larger inland spills to water, in contrast to the spill costs described in Section 6.2 which are generally smaller spills to dry areas. As described above, the costs of an oil spill are dependent less on the source of the oil and more on where the spill occurs, and the type of oil that is spilled. For spills greater than 100 bbl, the greatest per barrel costs occur with a spill of heavy persistent oil to marine environments (e.g. oceans, coastline, bays) and larger inland waterbodies (rivers and lakes) (Table 45). These costs are not appropriate to apply to spills under 100 bbl, and are most applicable to spills greater than 10,000 bbl. To map these unit costs to a specific category as defined by CDFW-OSPR regulations (Table 2), the per bbl cost would need to be multiplied by the RWCS.

Table 45: CDFW-OSC Model Results – Per Barrel Spill Costs by Oil Type for Spills Greater than 100 bbl

Oil Category	Per-Bbl Spill Cost			
	Highest Cost	High Cost	Medium Cost	Low Cost
Non-Persistent	$17,144	$13,055	$6,747	$4,615
Light Persistent	$31,764	$24,183	$12,498	$8,547
Medium Persistent	$38,805	$29,539	$15,268	$10,445
Heavy Persistent	$70,386	$53,582	$27,700	$18,943

SECTION 7 Discussion of Spill Costs

There are differences of over an order of magnitude between the current California COFR unit costs and the unit costs for the smaller spills as estimated by the CDFW-OSC model. The California Operator Survey costs are considerably smaller. The spills in the survey were considerably smaller than those incorporated into the ERC Spill Cost Database upon which the CDFW-OSC depends.

As detailed in Appendix A, there is a general reduction in per-unit costs as spill volumes increase. This is largely attributable to an “economy of scale” factor. This is generally true for larger complex response operations and the damages that occur from large spills. Once the equipment, personnel, logistics, and overall response “infrastructure” and incident command systems are in place, the level of effort is spread out over a larger number of barrels of oil spilled and does not increase in direct proportion to each additional barrel that was spilled.

However, for very small spills of less than 100 bbl or so, this relationship breaks down. For very small spills, like those reported in the California Operators Survey, the spill cleanup is relatively routine and can be handled by a smaller crew or even with on-site personnel trained in response. There is no complex incident command center with large numbers of state and federal officials in attendance. There is a relatively simple array of response equipment being employed.

A schematic representation of the per-unit volume spill cost relationship is shown in Figure 38. Once the spill response becomes a complex operation, the unit costs increase sharply, but then drop off as the costs are spread over a greater volume.

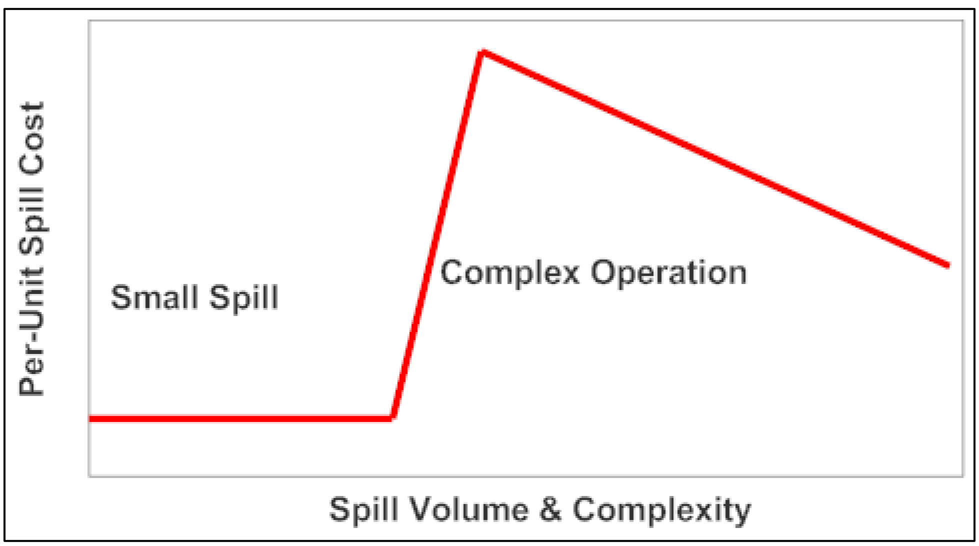

Figure 38: Hypothetical Per-Unit Volume Spill Cost Relationship with Volume and Complexity

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SECTION 9 Acronyms and Terminology

bbl: barrels (the equivalent of 42 US gallons)

CDFW-OSC: California Department of Fish & Wildlife Oil Spill Cost (model)

DPAC: dispersant policy-adjusted cost

DWT: deadweight tonnage

ERC: Environmental Research Consulting

ES: Environmental Sensitivity

g/ml: grams per milliliter

GDP: Gross Domestic Product

GT: gross tonnage

HFO: heavy fuel oil

HP: heavy persistent

IFO: intermediate fuel oil

LP: light persistent

Mobile transfer unit (MTU): a vehicle, truck, or trailer, including all connecting hoses and piping, used for transferring oil at a location where a discharge could impact Waters of the State.

MP: medium persistent

MPA: Marine Protected Area

Marine facility: an oil storage, production, or processing facility located in marine waters or where a discharge could affect marine waters.

Inland facility: an oil storage, production, or processing facility located in non-marine waters or where a discharge could affect non-marine waters.

Ephemeral stream: stream (or portion of stream) which flows briefly in direct response to precipitation in the immediate area, and whose channel is at all times above the groundwater reservoir. (Depicted in Southwest Environmental Response Management Application (ERMA) on National Oceanic and Atmospheric Administration (NOAA) website).

Intermittent: stream where portions flow continuously only at certain times of the year, for example when it receives water from a spring, groundwater sources, or from a surface source, such as melting snow (seasonal); at low flow there may be dry segments alternating with flowing segments. (Depicted in Southwest Environmental Response Management Application (ERMA) on National Oceanic and Atmospheric Administration (NOAA) website).

Perennial stream: a stream or portion of a stream that flows year-round is considered a permanent stream, and for which base flow is maintained by ground-water discharge to the streambed due to the ground-water elevation adjacent to the stream typically being higher than the elevation of the streambed.

NRDA: Natural Resource Damage Assessment

PPP: Purchasing Power Parity

RWCS: reasonable worst-case spill

WCD: worst-case discharge

Appendix A

CDFW OIL SPILL COST MODEL



Appendix A: CDFW Oil Spill Cost Model

The response costs in the 2019 ERC Spill Cost Database were adjusted in a number of ways to derive a country-specific unit base cost. These adjustments were based on a correction for "outliers," the exponential increase in response costs over time (taking into account inflation corrections by year), oil type (persistence) factors, and volume factors. These unit costs were then further adjusted for more geographic-specific factors that would change the potential magnitude of costs–including environmental sensitivity, dispersant response policy, and liability regime–on a geographic basis. These adjustments are summarized in the schematic drawing in (Figure A-1).

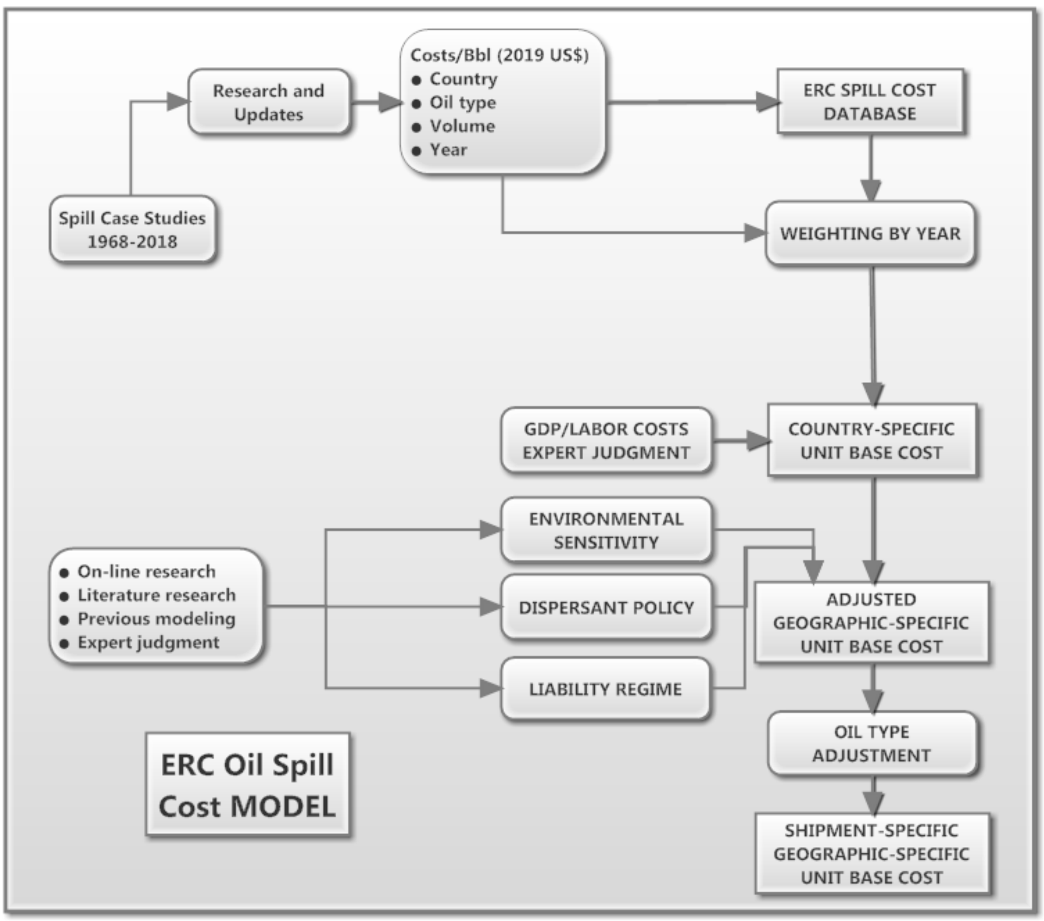

Figure A-1: ERC Oil Spill Cost Model Algorithm Adjustments

Consideration of "Outliers"

There are clearly spill incidents for which the per-unit response costs are extremely high. This is usually due to extenuating circumstances, such as occurrence near particularly sensitive resources or a politically-charged environment, which can both necessitate response operations that call for extremely high cleanup endpoint standards or unusual measures.

For the whole dataset there are five (1.1%) incidents that are more than three standard deviations from the mean (average), including two that are 11.25 and 13.91 standard deviations from the mean. If these five incidents are removed from the dataset, the mean per-bbl response cost decreases from $10,697/bbl to $6,272/bbl. The probability distribution of response costs now shifts as shown in Table A-1 and Figure A-2.

Table A-1: Per-Bbl Response Cost Percentiles in ERC Spill Cost Database (w/o Outliers)

Percentile	Response Cost/Bbl (2019 US$)	
	Whole Dataset	Without 1% Outliers
10th	$62	$59
25th	$280	$268
50th (Median)	$1,206	$1,138
75th	$5,284	$5,052
90th	$17,527	$13,919
95th	$40,054	$28,868
99th	$184,549	$91,759
Maximum	$690,255	$144,340
Average (Mean)	$10,697	$6,272

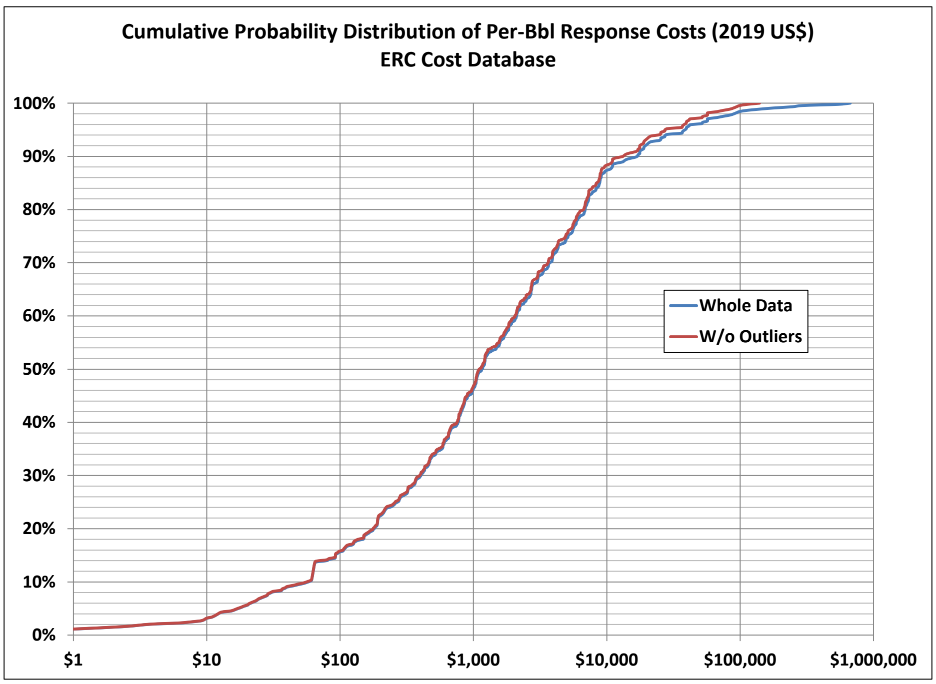

Figure A-2: Per-Bbl Response Cumulative Probability Distribution Costs without Outliers

For the purposes of providing a *conservative* predictor of spill costs, the data were considered by including and excluding all outliers. Including the outliers would tend to increase the estimate of costs, but allow for the possibility that there would be an “outlier” situation for a particular future spill incident.

Weighting by Year (Time-Scaling)

The response cost for spills has increased over five decades, even when adjusted to current values (2019 US dollars). The average per-bbl response cost by decade is shown in Figure A-3. The increase is exponential. Note that outliers have been removed, as described above.

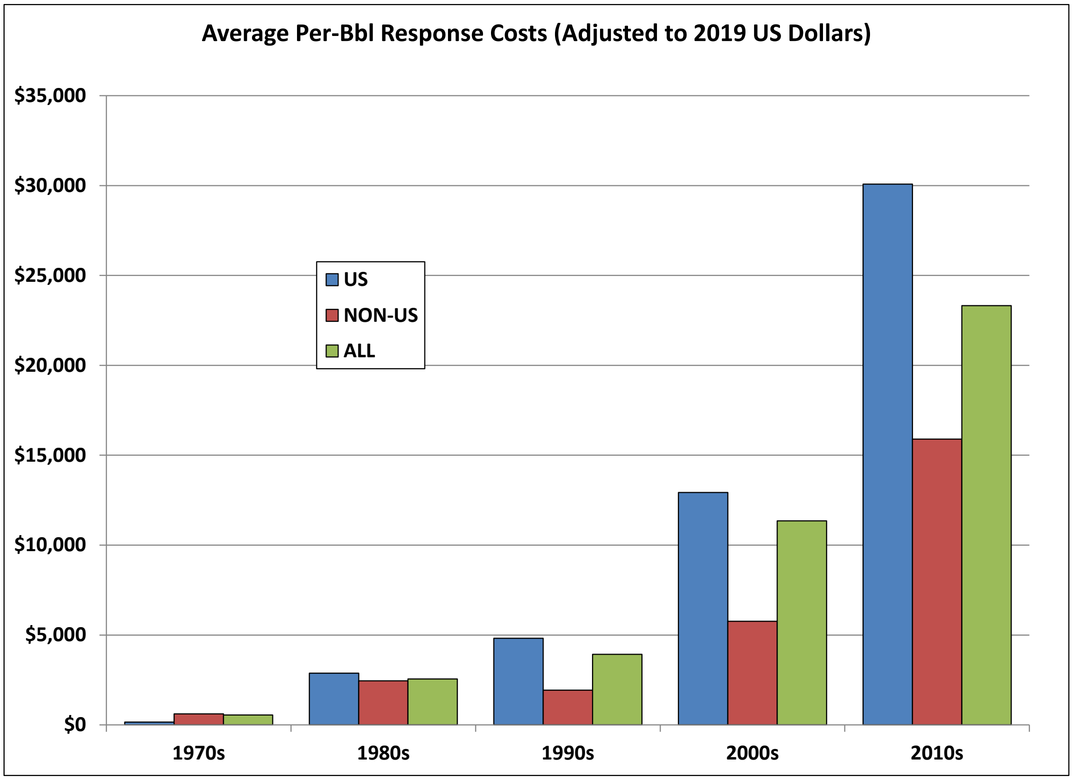

Figure A-3: Average Per-Bbl Response Cost by Decade

Taking into account the exponential cost increase by decade, the unit response cost ($/bbl) for all nations, $\boldsymbol{C_{R\text{-}ALL}}$, can be expressed as:

$$C_{R-ALL} = 281.38e^{0.8984d} \qquad [1]$$

Where: ***d*** = the decade in numbers with the 1970s as "1"and the 2010s as "5."

On an annual basis, this increase can roughly be expressed as [Figure A-4]:

$$C_{R-ALL} = 281.38e^{0.08984x} \qquad [2]$$

Where: ***x*** = the year in numbers after the year 1969 (1970 = year 1)

$\boldsymbol{C_{R\text{-}ALL}}$ = the unit response cost for all nations in 2017 $/bbl

The annual increase (after the year 1970) is expressed as:

$$\Delta C_{R-ALL} = 281.38e^{0.0.08984x} - 308 \qquad [3]$$

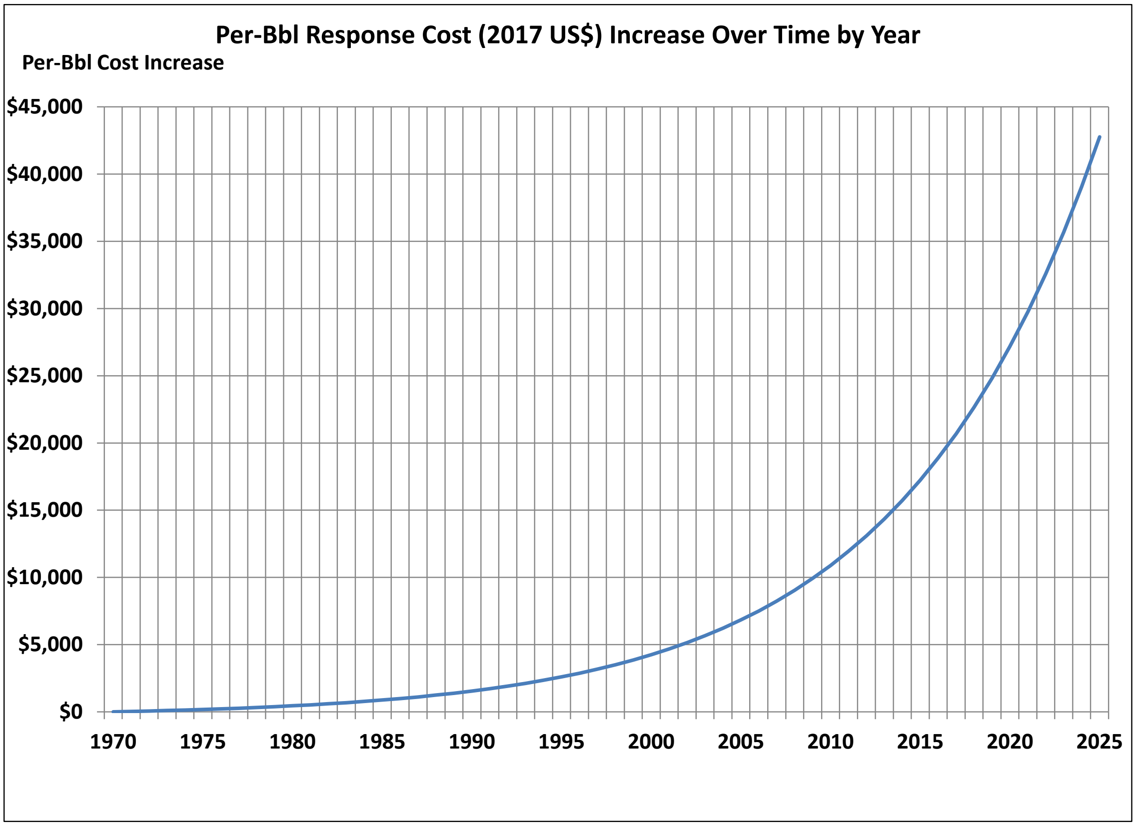

Figure A-4: Annual Increase in Per-Bbl Response Costs (All Nations)

Since the "year factor" or time-scaling displayed such a significant relationship, it was used to adjust all of the response cost data in the ERC Spill Cost Database. Equation 3 was applied to these data.[91] A second approach did not apply time-scaling for response costs. In both approaches,[92] the time-scaling factor was not applied to the other costs (fines and penalties, third-party damages, environmental damages, and oil loss), because these categories of costs have not generally increased in the same manner. Response cost increases reflect the greater efforts that are being taken and the more complex operations that have developed to satisfy public demand for higher standards of cleanup.

Year-Adjusted Data Summary

Once the data in the ERC Spill Cost Database were all adjusted by year (and all outliers included), the overall picture of costs changed considerably, as summarized in Table A-2 and Figure A-5. Clearly, the adjustments by year and the inclusion of the outlier cases, significantly increases the per-bbl response costs so that the average is nearly six times the average of the original data, and nearly 10 times the value of the original data without outliers. The per-bbl response costs shift about an order of magnitude (Figure A-6).

[91] Note: Time-scaling was not applied to oil loss in that that cost was already specific to the year of each incident.

[92] Each time-scaling approach was further divided into subcategories of with- and without outliers (see Table A-2).

Table A-2: Per-Bbl Response Costs in ERC Spill Cost Database after Year Adjustments

Percentile	Response Cost/Bbl (2019 US$)		
	Original Data		Data with Year Adjustment (Including Outliers)
	Whole Dataset (Original)	Without 1% Outliers	
10th	$62	$59	$510
25th	$280	$268	$2,433
50th (Median)	$1,206	$1,138	$11,584
75th	$5,284	$5,052	$45,739
90th	$17,527	$13,919	$122,591
95th	$40,054	$28,868	$221,955
99th	$184,549	$91,759	$681,611
Maximum	$690,255	$144,340	$3,898,954
Average (Mean)	$10,697	$6,272	$60,523

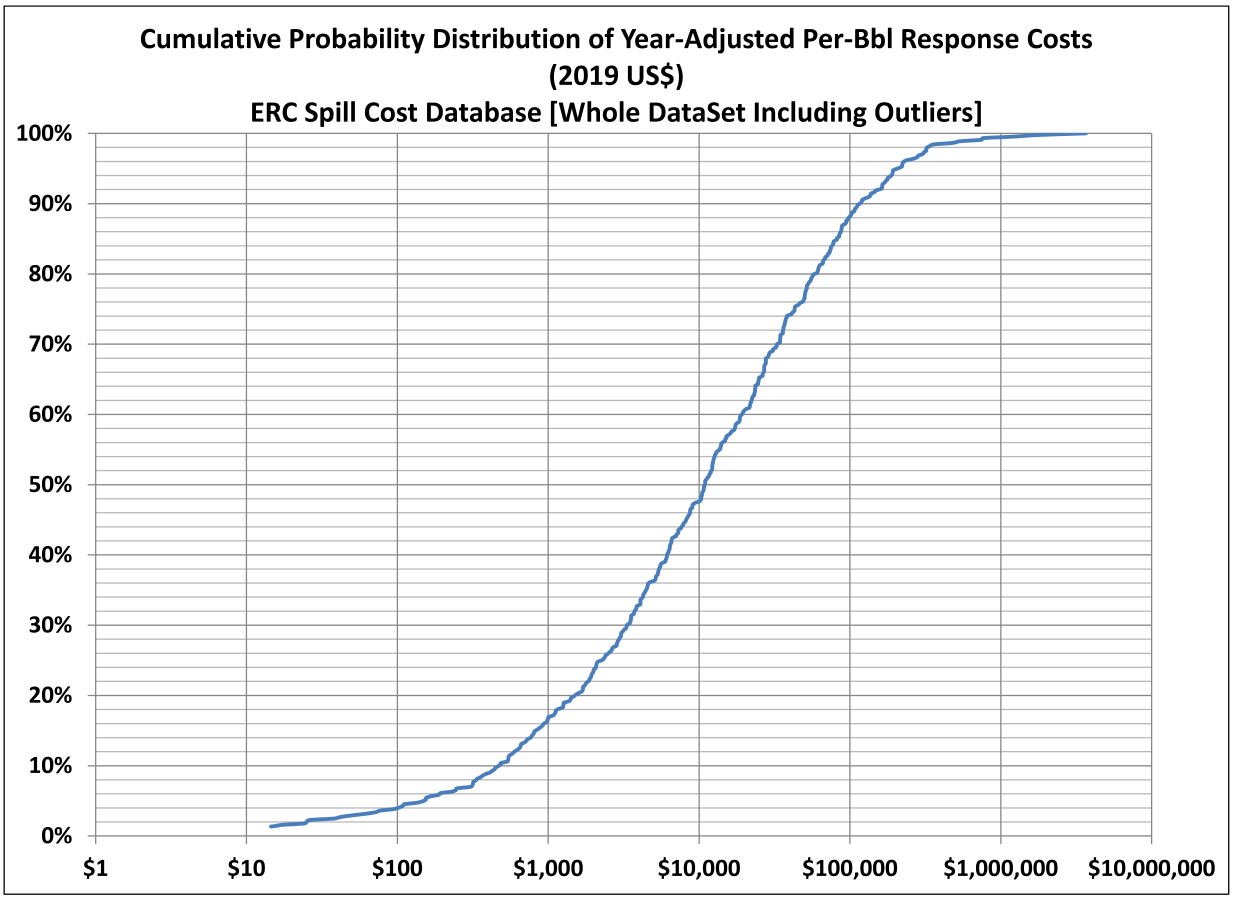

Figure A-5: Year-Adjusted Per-Bbl Response Cumulative Probability Distribution of Costs

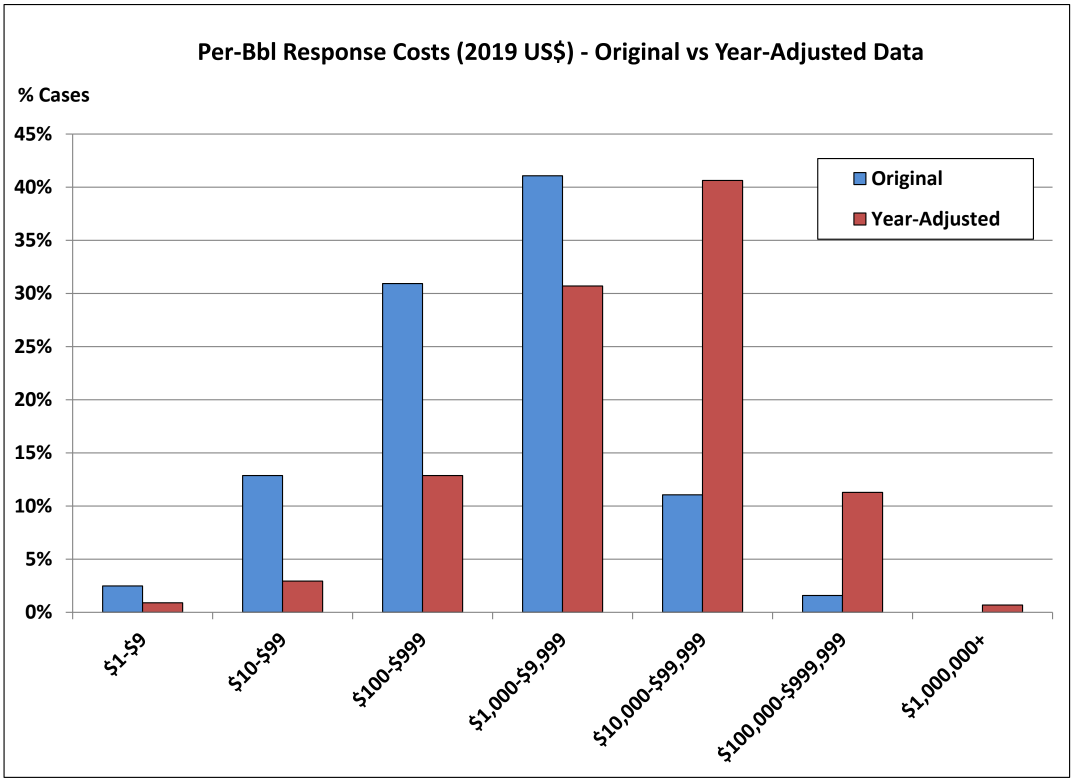

Figure A-6: Distribution of Per-Bbl Response Costs: Original vs. Year-Adjusted Data

Oil Type Cost Adjustment

The properties of the spilled oil, particularly with respect to persistence, will affect response costs. The more persistence and adherent the oil, the more work required to remove it. In addition, heavier oils tend to undergo less evaporation due to the lower concentrations of lighter components. The average unit year-adjusted response costs by oil type are shown in Table A-3 and Figure A-7.

Table A-3: Average Response Costs by Oil Type/Persistence Category

Oil Persistence Category	Average Year-Adjusted Response Cost/Bbl	Cost Factor Relative to Medium Persistent
Non-Persistent	$19,600	0.5
Light Persistent	$40,400	1.0
Medium Persistent	$40,400	1.0
Heavy Persistent	$81,300	2.0

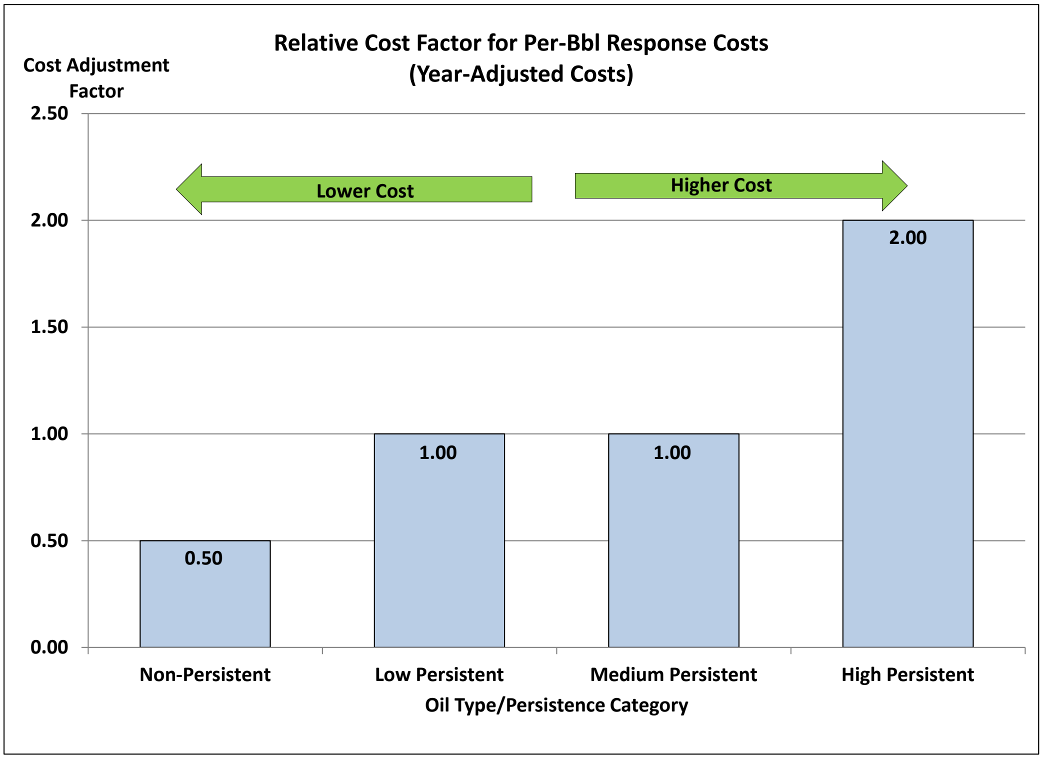

Figure A-7: Relative Cost Factor for Per-Bbl Costs Based on Oil Type/Persistence

Based on this analysis, the Light Persistent (LP) and Medium Persistent (MP) categories have approximately the same unit response cost. In the analyses for costs, they can be combined. However, for the purposes of determining whether a particular hypothetical spill would be covered under the CLC/IOPC conventions with respect to liability limits, the oil persistence is of consequence. This would only apply to spills outside of the US.

Adjustment of Per-Bbl Costs based on Spill Volume

Anecdotally, it has been recognized that there is a very rough negative correlation of spill volume and per-bbl response cost in that larger spills tend to involve lower per-bbl response costs. This is generally attributable to "economy of scale" factors in the response operations. A number of researchers have examined this relationship.[93] For example, one study showed the regression of spill response costs (per tonne) and spill volume, as shown in Figure A-8 and the equation: [94]

$$Log(CCT) = -0.9507 \cdot Log(t) + 15.387 \quad [4]$$

Where, ***CCT*** = spill response cost per tonne

t = tonnes of spilled oil

[93] Kontovas et al. 2010; Nyman 2011; Yamada 2009; Psarros et al. 2009; Skjong et al. 2005; Liu and Wirtz 2009; Monnier 1994.

[94] Liu and Wirtz 2009.

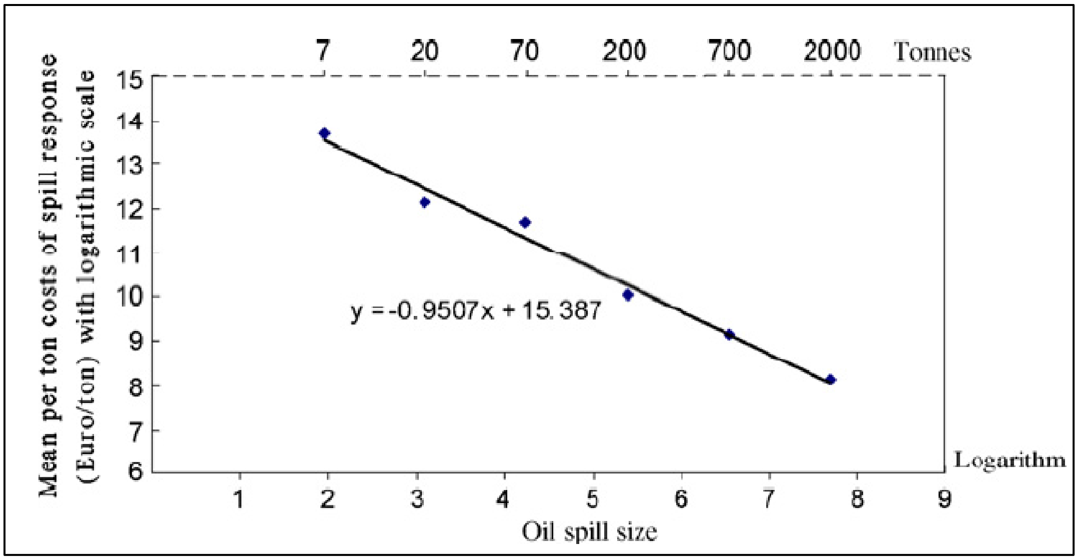

Figure A-8: Liu-Wirtz Regression between Spill Response Costs/Tonne and Spill Size[95]

In earlier work, conducted by ERC, the relationships in Figure A-9 through Figure A-11 were noted. In all cases, the per-unit cost tends to go down with spill volume. The values in Figure A-10 and Figure A-11 were converted into 2019 US dollars and bbl as in Figure A-12. There is a general downward trend, though the correlations are not significant for either the US or Non-US costs. It is interesting to note that all of these regression models were based on empirical data that included a significantly smaller datasets (each less than 100 incidents) than that currently being analyzed in the ERC Spill Cost Database.

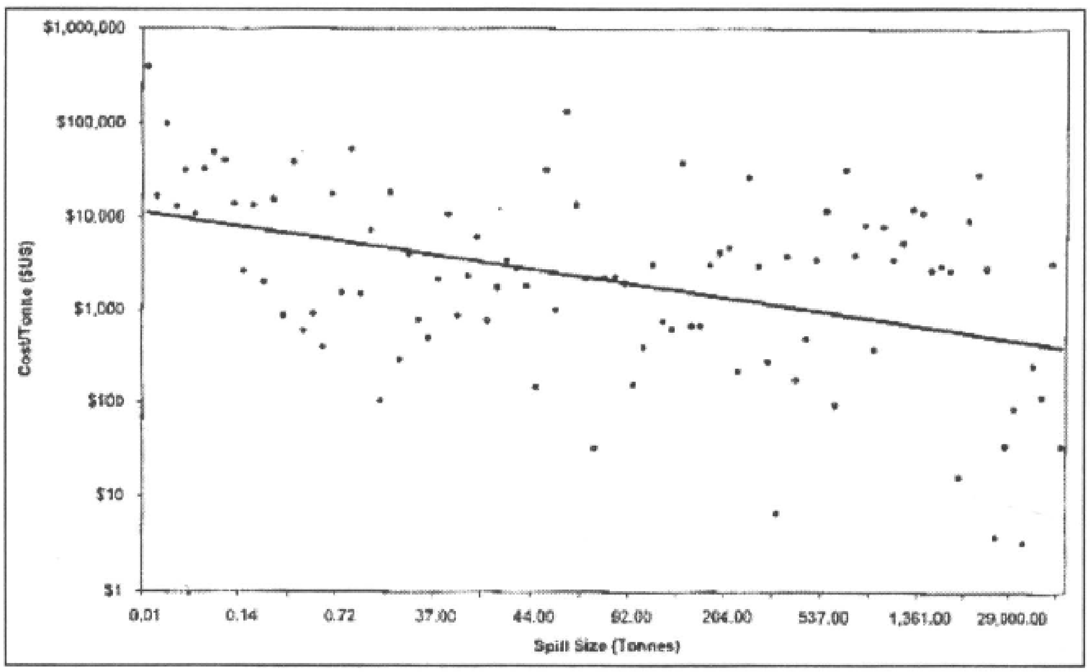

Figure A-9: Etkin 1999 Relationship between Spill Volume and Unit Response Cost[96]

[95] Liu and Wirtz 2009.

[96] Etkin 1999.

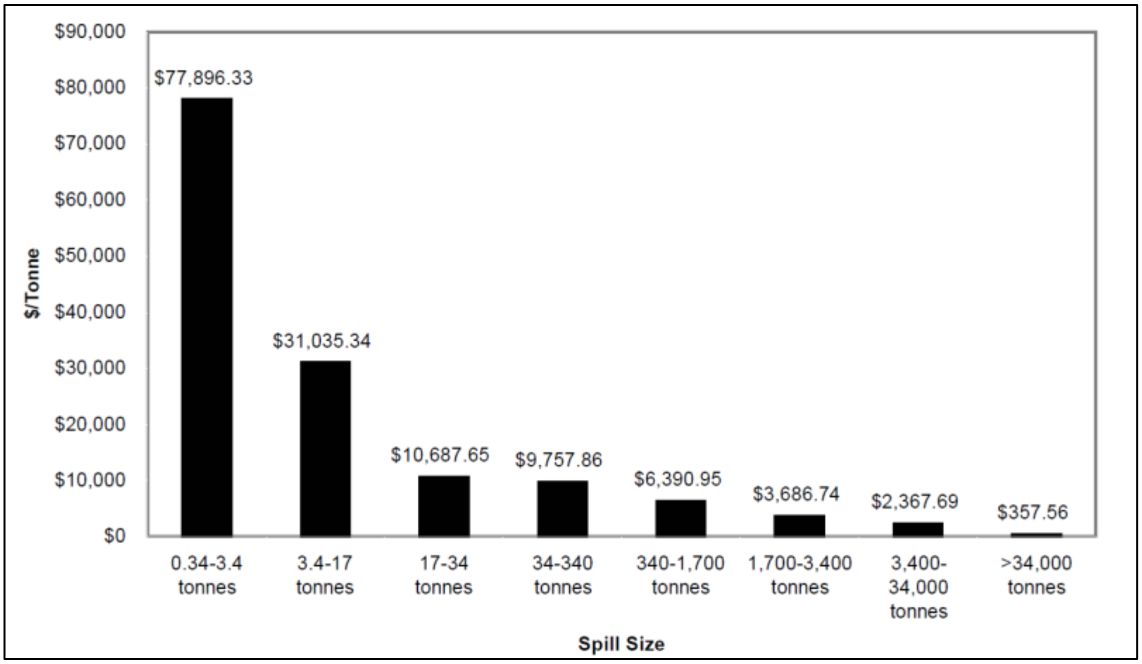

Figure A-10: Etkin 2000 Per-Unit Marine Oil Spill Response Costs for Non-US Spills[97]

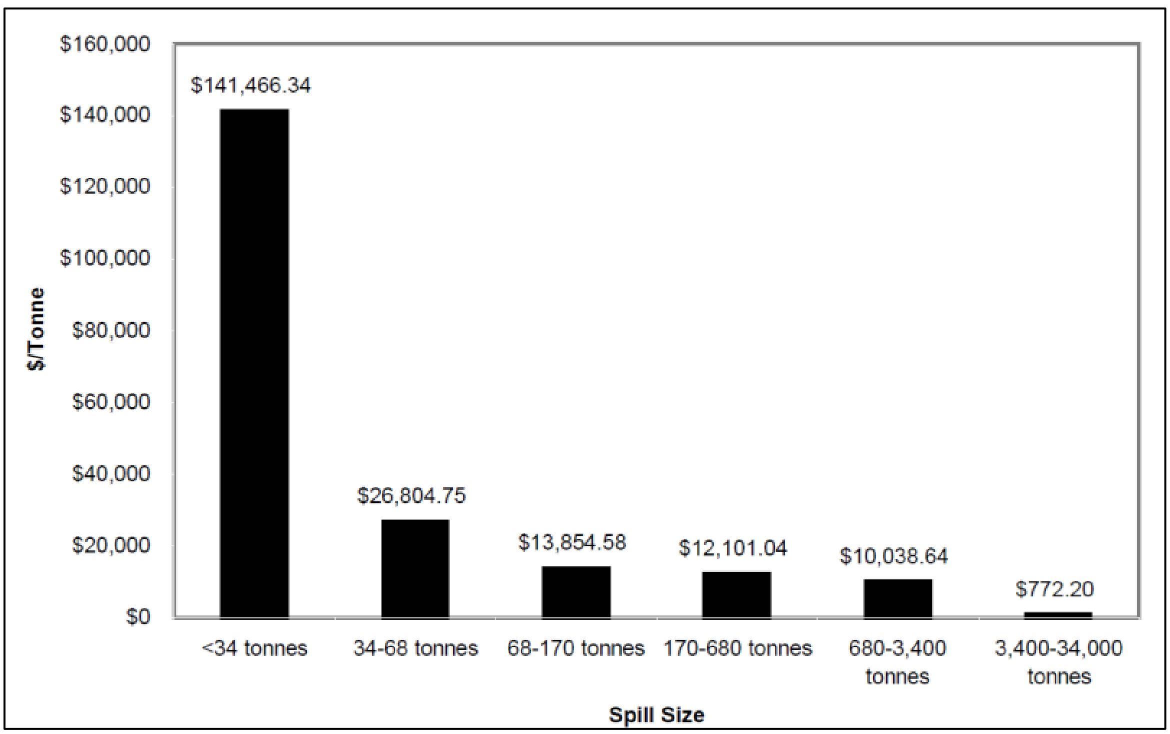

Figure A-11: Etkin 2000 Per-Unit Marine Oil Spill Response Costs for US Spills[98]

[97] Etkin 2000 (1999 US$)
[98] Etkin 2000 (1999 US$)

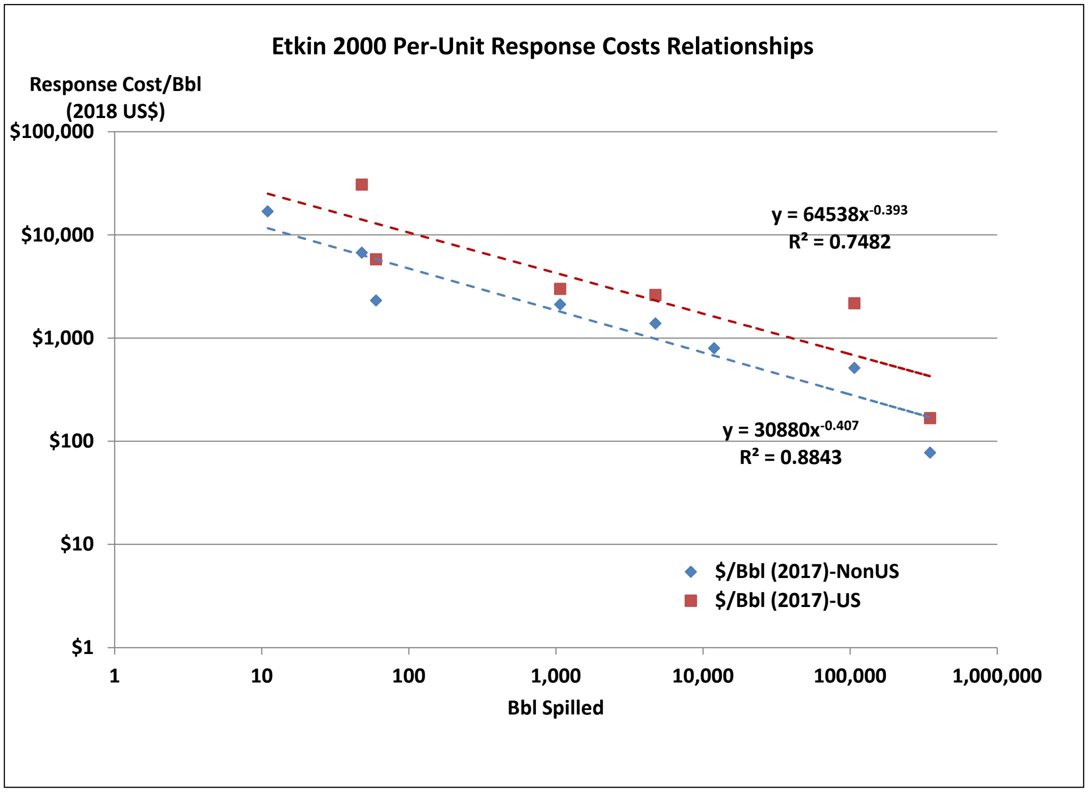

Figure A-12: Etkin 2000 Relationships Converted to 2019 US$ and Bbl

However, based on the data in the ERC Spill Cost Database, which includes 443 data points, the correlation is not significant (Figure A-13)[99] even applying a double logarithmic transformation,[100] and when only one nation's (US) data minus outliers are used (Figure A-14).[101]

[99] $R^2 = 0.20$

[100] As suggested in: Friis-Hansen and Ditlevsen 2003.

[101] $R^2 = 0.03$

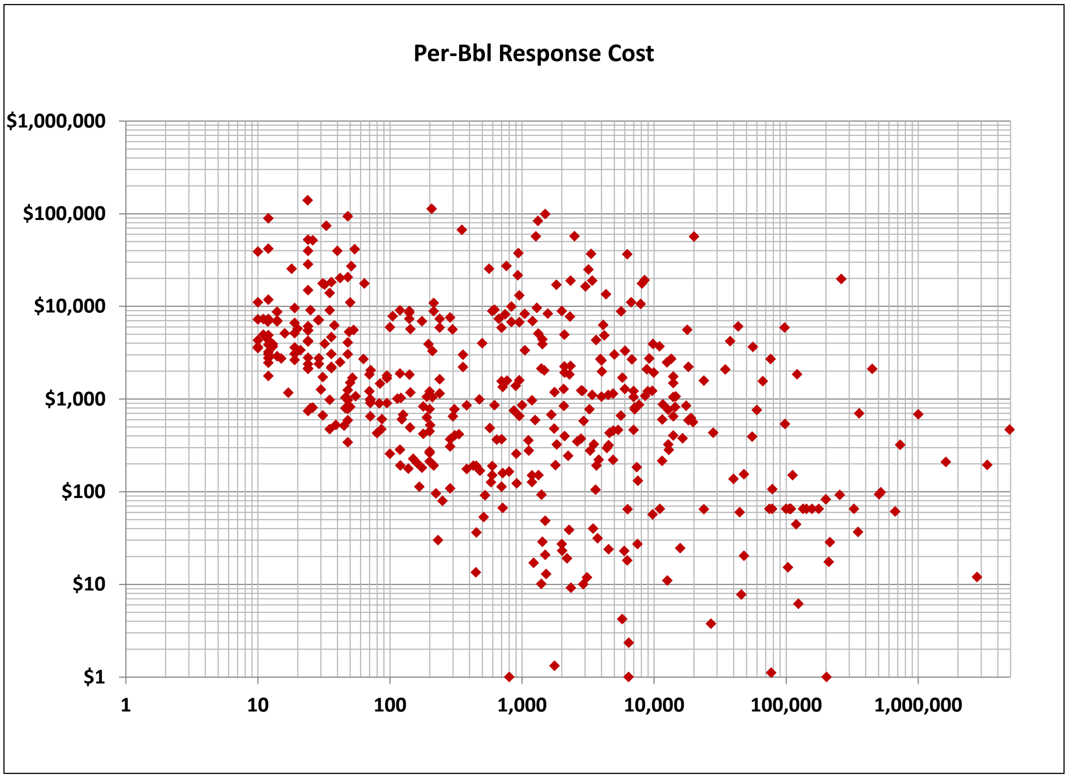

Figure A-13: Per-Bbl Response Cost by Spill Volume (All Cases Minus Outliers)

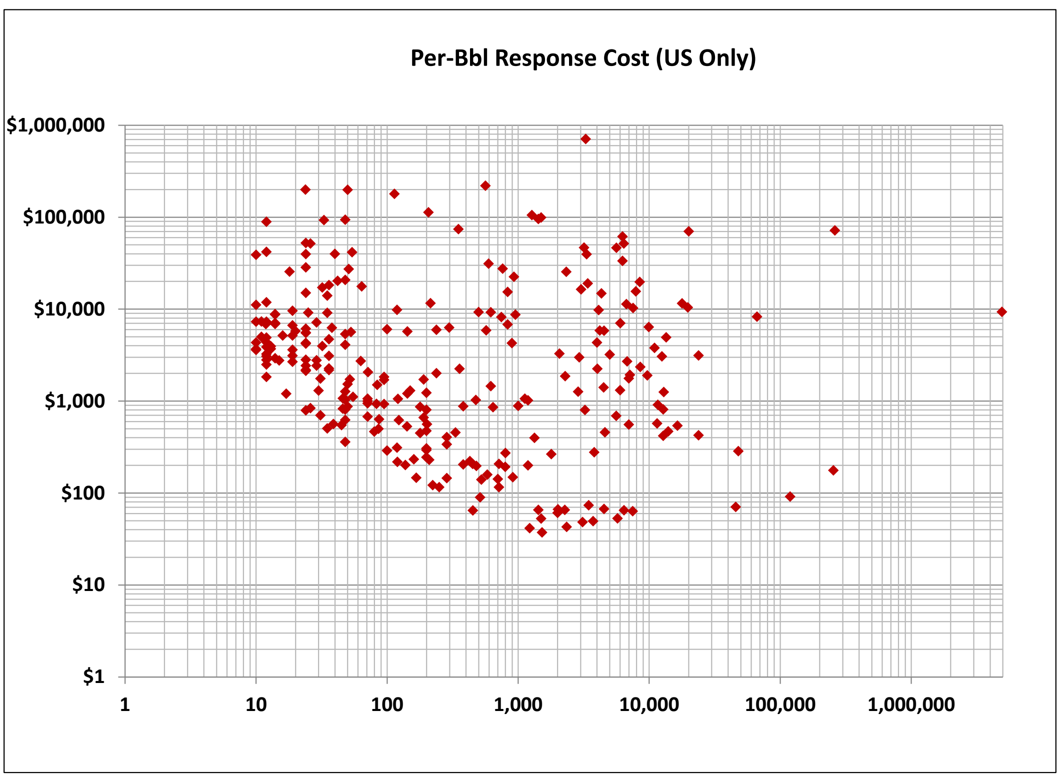

Figure A-14: Per-Bbl Response Cost by Volume (All US Cases Minus Outliers)

After the Year Adjustments were made, the same relationships were again plotted using the adjusted data (including outliers), as shown in Figure A-15 and Figure A-16 for all the data and for the US only, respectively. While the costs are shifted higher, there is still considerable scatter in the plots.

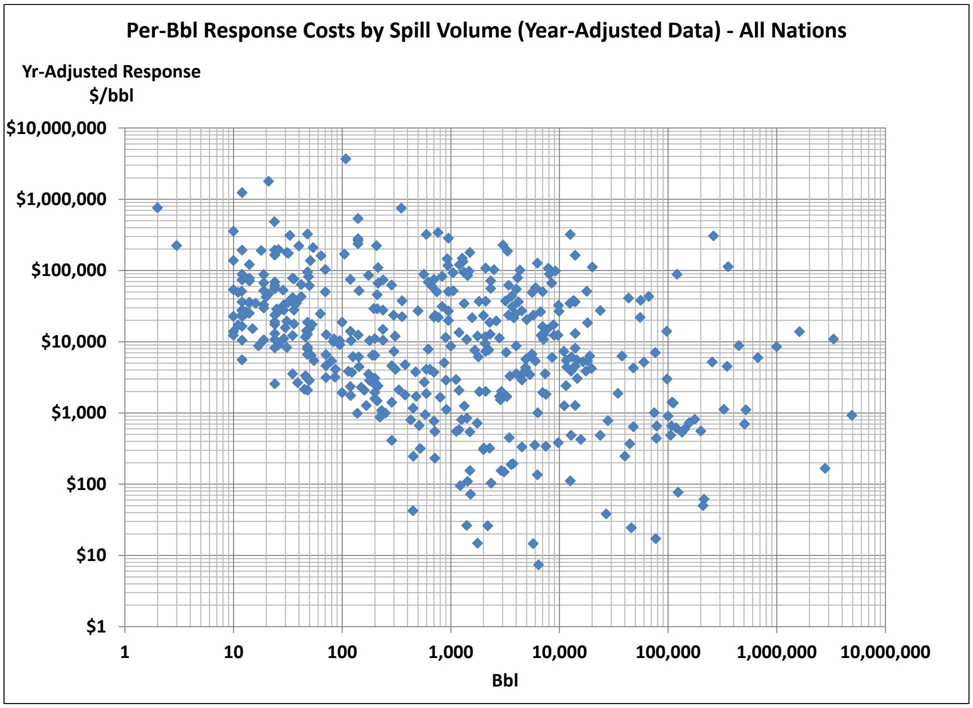

Figure A-15: Per-Bbl Response Cost by Volume (Year-Adjusted Data + Outliers)–All Nations

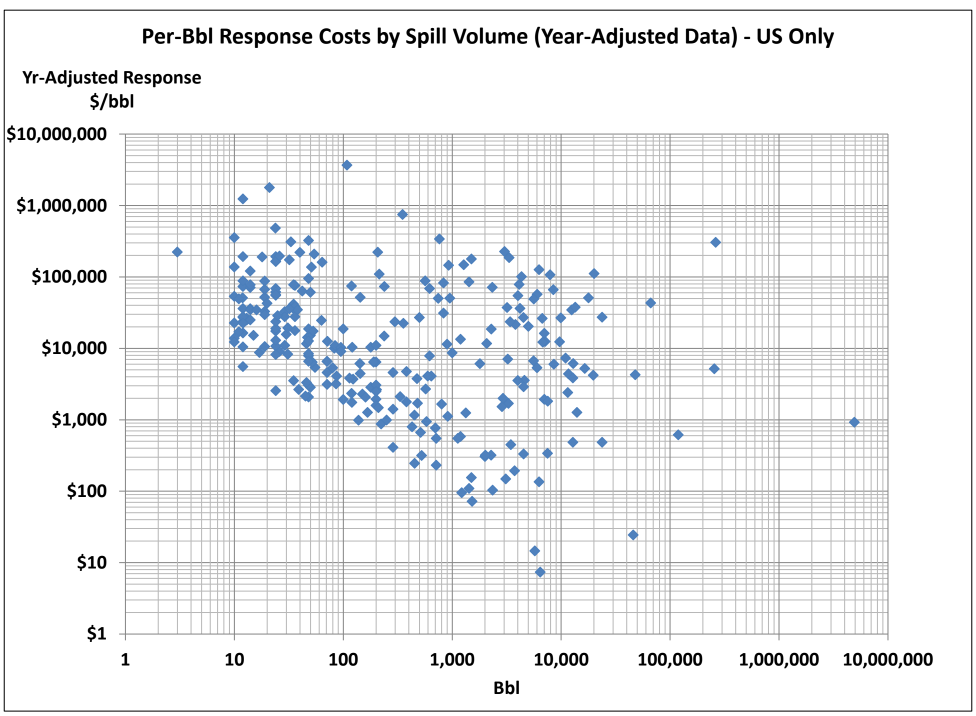

Figure A-16: Per-Bbl Response Cost by Volume (Year-Adjusted Data + Outliers)–US Only

Another researcher[102] found that the per-unit cost of spills decreased with spill volume, but leveled off when the spill was larger than about 2,000 tonnes (84,000 bbl). However, as a rough calculation, the data in Figure A-16 might be expressed as the relationship shown in Figure A-17. For spills of 10 bbl to 10,000 bbl, the relationship is:

$$\frac{C_{response}}{v} = 1000000v^{-1} \qquad [5]$$

where: $C_{response}$ = per-bbl response cost; and

v = volume in bbl (up to 10,000 bbl).

After 10,000 bbl, the per-bbl costs level off.

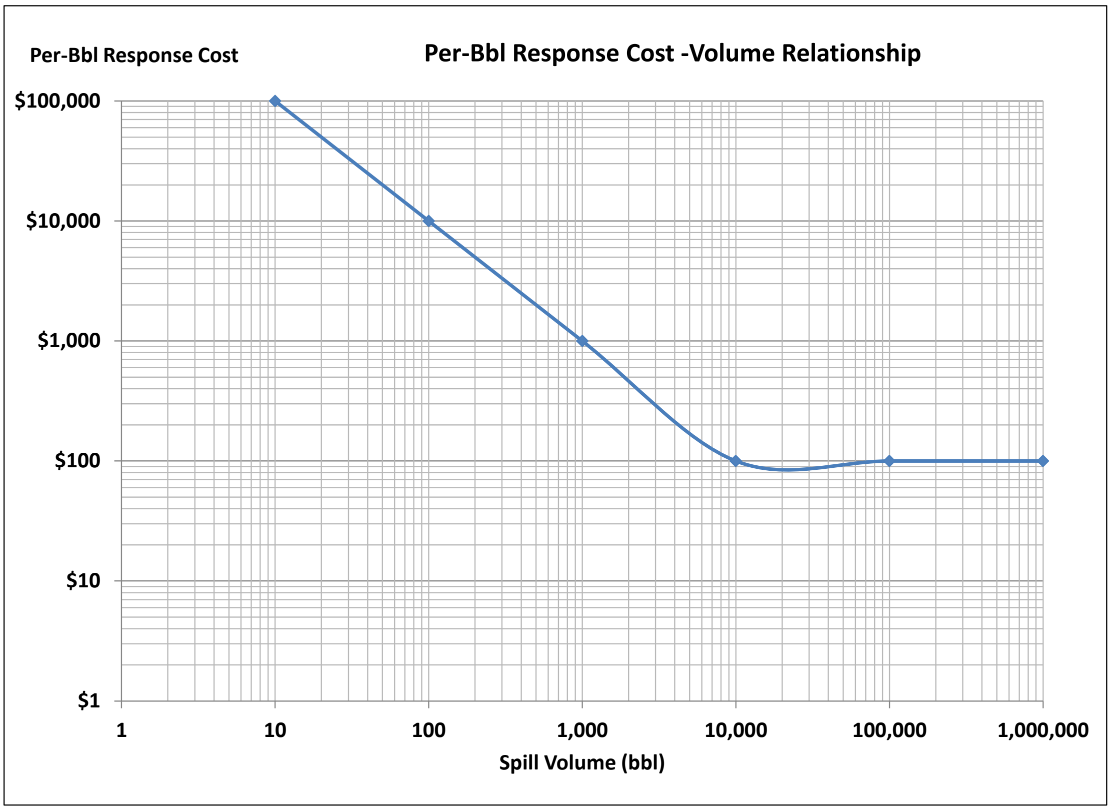

Figure A-17: Proxy Per-Bbl Cost-Volume Relationship

Since the worldwide average response cost per bbl is in the thousands of dollars, per-bbl response costs are more appropriate for spills of 1,000 bbl and smaller. For specific model applications, it is recommended that the per-bbl costs should be adjusted by an order of magnitude (i.e., divided by 10) for spills of 10,000 bbl or more. Very small spills may have even higher per-bbl costs.

Variations in Response Cost Calculation Approach

Four different approaches were taken to calculate the regional response costs, as summarized in Table A-4. The inclusion of outliers tends to drive the costs up by a factor of 1.6; time-scaling (year-adjustment) tends to drive costs up by a factor of about five. These approaches may be considered as

[102] Yamada 2009.

degrees of "maximization" for costs that can be applied with respect to the degree of risk tolerance for management purposes.

Table A-4: Different Approaches to Calculation of Per-Unit Base Response Costs

Calculation Approach	Degree of Cost Maximization	Year Adjustment	Outliers Included
Time-Scaled with Outliers	Highest Cost	YES	YES
Time-Scaled without Outliers	High Cost	YES	NO
Non-Time Scaled (Original) with Outliers	Medium Cost	NO	YES
Non-Time Scaled (Original) without Outliers	Lowest Cost	NO	NO

Region-Specific Per-Unit Base Response Costs

Average and maximum per-bbl response costs by region were calculated based on the current ERC Spill Cost Database using all four approaches in Table A-4. The results for the US regions are shown in Table A-5 with comparisons to the grand average of costs for regions around the world.

Table A-5: Average Response Cost/Bbl by Region (2019 US$)

Region	Average Response Cost/Bbl by Approach				Average Response Cost/Bbl by Approach Compared to Grand Average			
	Highest	High	Medium	Low	Highest	High	Medium	Low
US Gulf	$17,798	$17,798	$2,740	$2,740	0.442	0.603	0.298	0.691
US East	$49,435	$49,435	$8,678	$8,678	1.229	1.676	0.943	2.188
US West	$144,402	$81,356	$25,187	$13,901	3.590	2.758	2.737	3.504
Grand World Average	$40,222	$29,499	$9,203	$3,967	1.0	1.0	1.0	1.0

Average response costs by US region, as reflected in the ERC Spill Cost Database, are shown in Table A-6. Costs are shown based on all four calculation approaches.

Table A-6: Average Response Cost by Nation (Represented in ERC Spill Cost Database)

Region	Average Response Cost/Bbl by Maximization Approach				Number of Cases
	Highest Cost	High Cost	Medium Cost	Low Cost	
US East	$49,435	$49,435	$8,678	$8,678	83
US Gulf	$17,798	$17,798	$2,740	$2,740	101
US West	$144,402	$81,356	$25,187	$13,901	86
Global Average	$37,900	$34,071	$5,514	$3,611	443

Nation Classifications Based on GDP and Labor Costs

With such a small dataset for most of the individual nations, and a large number of coastal nations not represented in the ERC Spill Cost database, as shown in Table A-6, it will be necessary to make assumptions about the costs for individual nations, as well as for some of the geographic regions.

For individual nations, there are two different approaches to determining the general level of expected spill response costs–the per-capita Gross Domestic Product, GDP, as reflected by per-capita Purchasing

Power Parity (PPP).[103] In addition, per-capita GDP PPP adequately reflects the variation in the potential costs for providing the services required for spill response operations by nation. For this reason, the per-capita GDP PPP was used as a means to classify different nations with respect to the potential base costs of response. There is clearly a regional variation in per-capita GDP PPP, as shown in Figure A-18. However, there is also variation between nations within each geographic region.

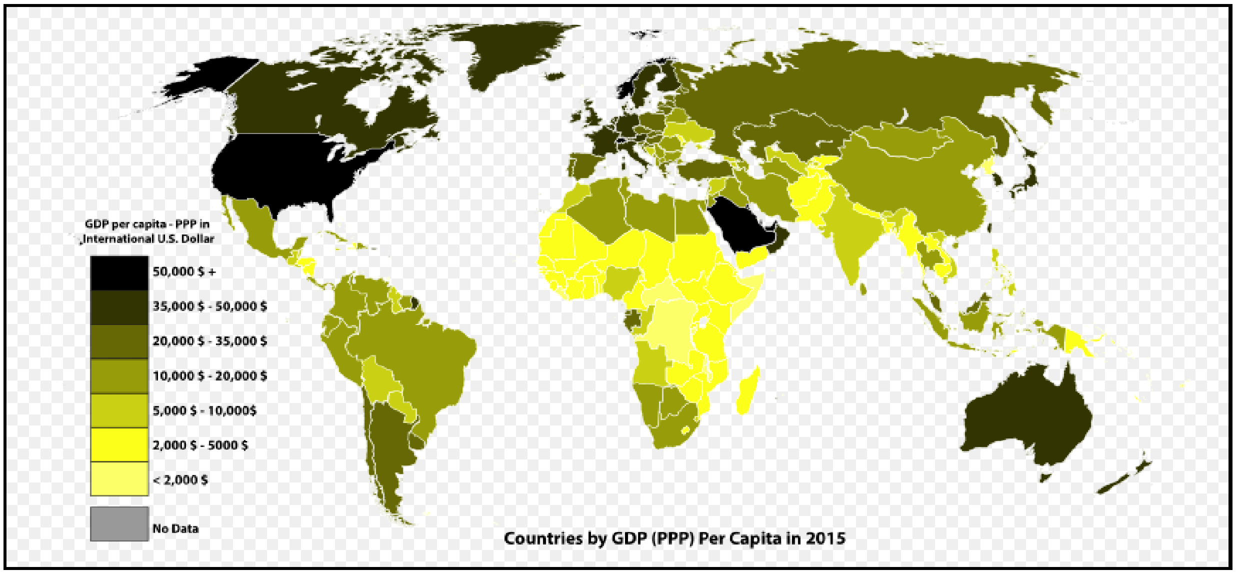

Figure A-18: Gross Domestic Product (Purchasing Power Parity) per Capita in 2015[104]

Based on a comparison of the per-capita PPP by coastal nation to the average per-capita PPP of all the coastal nations, each nation and each geographic region were classified into cost categories on a five-point scale.[105]

The results by region are summarized in Table A-7. Note that in some regions, there are specific nations that could present much higher costs than the regional average indicates. Higher costs will be expected to come into play if the oil impacts the shorelines, waters, and resources of these nations. (Note that the individual nation data can be used to classify costs based on specific ports or transits). The GDP PPP-per capita/Coastal PPP Average values in Table A-7 can be applied as multipliers of the average unit response cost to derive the base unit response costs by region. For this purpose, an "average" unit response cost is required.

Table A-7: Region Economic Classifications

Region	Average 2016 GDP PPP/Capita	Average GDP PPP per Capita/PPP	Nations with Higher Costs than Regional per Capita/PPP Average
Africa	$6,409	0.30	Gabon (0.84); Eq. Guinea (1.21); Mauritius (0.98)
Australia	$42,919	1.99	-

[103] Purchasing Power Parity (PPP) is measured by finding the values (in US dollars) of a basket of consumer goods that are present in each country (such as orange juice, pencils, etc.). If that basket costs $100 in the US and $200 in the United Kingdom, then the purchasing power parity exchange rate is 1:2.

[104] Based on International Monetary Fund data for 2015.

[105] Color-coded classifications of potential spill costs are based on Regional classifications are based on the average PPP-per capita/coastal nation average of the nations in each region: Blue (lowest cost) = <0.7; green (low cost) = 0.7-0.9; yellow (moderate cost) = 1.0 – 1.8; orange (high cost) = >1.9 to <2.5; red (highest cost) = >2.50.

Region	Average 2016 GDP PPP/Capita	Average GDP PPP per Capita/PPP	Nations with Higher Costs than Regional per Capita/PPP Average
Baltic	$23,702	1.10	-
Canada	$44,025	2.04	-
Caribbean	$16,048	0.74	Bermuda
China	$37,105	1.72	Hong Kong (2.72)
India	$6,938	0.32	Sri Lanka (0.57)
Mediterranean	$22,115	1.02	Cyprus (1.51); France (1.92); Israel (1.75); Italy (1.78); Malta (1.76); Spain (1.69)
Middle East	$43,230	2.00	Kuwait (3.44); Qatar (5.91); Saudi Arabia (2.52); UAE (3.36)
Sea of Japan	$38,614	1.79	Japan (1.92)
Southeast Asia	$18,429	0.85	Malaysia (1.28) Brunei Darussalam (3.59); Singapore (4.07); Macao SAR (4.83)
South America	$16,780	0.78	Chile (1.11); Uruguay (1.00)
UK/Europe	$46,516	2.15	Denmark (2.31); Ireland (3.31); Norway (2.75)
US (East/West Gulf)[106]	$57,638	2.67	-

Appropriate Average (Mean) for Base Unit Cost Determination

The data in the ERC Spill Cost Database is merely a sampling of the actual set of spill costs for the thousands of incidents that have occurred. The incidents are not a random sampling of all spill incidents that have occurred, but rather are ones for which cost data was available. There are a disproportionate number of incidents in the US due to the fact that the cost data are more readily available. For this reason, the average (mean) of this data set is skewed towards the more expensive US spill costs, even when the outliers are removed (Table A-4). There are a number of ways to calculate the "average" or mean response cost, as shown in Table A-8.

TableA-8: Average/Median Response Costs by Sampling Method and Calculation Approach

CDFW-OSC Sampling Method (Data Set)	Average (Mean) by Maximization Approach				Median (50th Percentile) by Maximization Approach			
	Highest Cost	High Cost	Medium Cost	Low Cost	Highest Cost	High Cost	Medium Cost	Low Cost
Whole Database	$58,703	$42,959	$10,697	$6,272	$11,288	$11,089	$1,206	$1,138
Regions	$40,222	$29,499	$9,203	$3,967	$31,365	$21,756	$1,882	$1,882
Nations[107]	$37,900	$34,071	$5,691	$3,412	$9,756	$9,756	$851	$298

Given that there is a fairly good coverage of regions of the world in the ERC Spill Cost Database, the average costs of the Regions or of the individual nations represented in the ERC Spill Cost Database represents a more reasonable estimate of the true average costs internationally. The use of the national data rather than the individual incident data shifts the distribution curve to the left (i.e., lower costs) by an order of magnitude. This also corrects for the over-representation of certain nations, particularly the US, in the ERC Spill Cost Database.

[106] Costs in each of the three US regions would likely differ given regional differences in Consumer Price Indices (Northeast = 1.04; Western = 1.02; Southern = 0.97). The GDP PPP data average across the whole nation.

[107] US data is divided into US East, US Gulf, and US West.

The distributions of per-bbl response costs for the sampling methods in Table A-8 are shown in Figure A-19–Figure A-24 based on the calculation approach. The shift towards higher costs is apparent in the Highest Cost and High Calculation Approaches, which are influenced by the time-scaling.

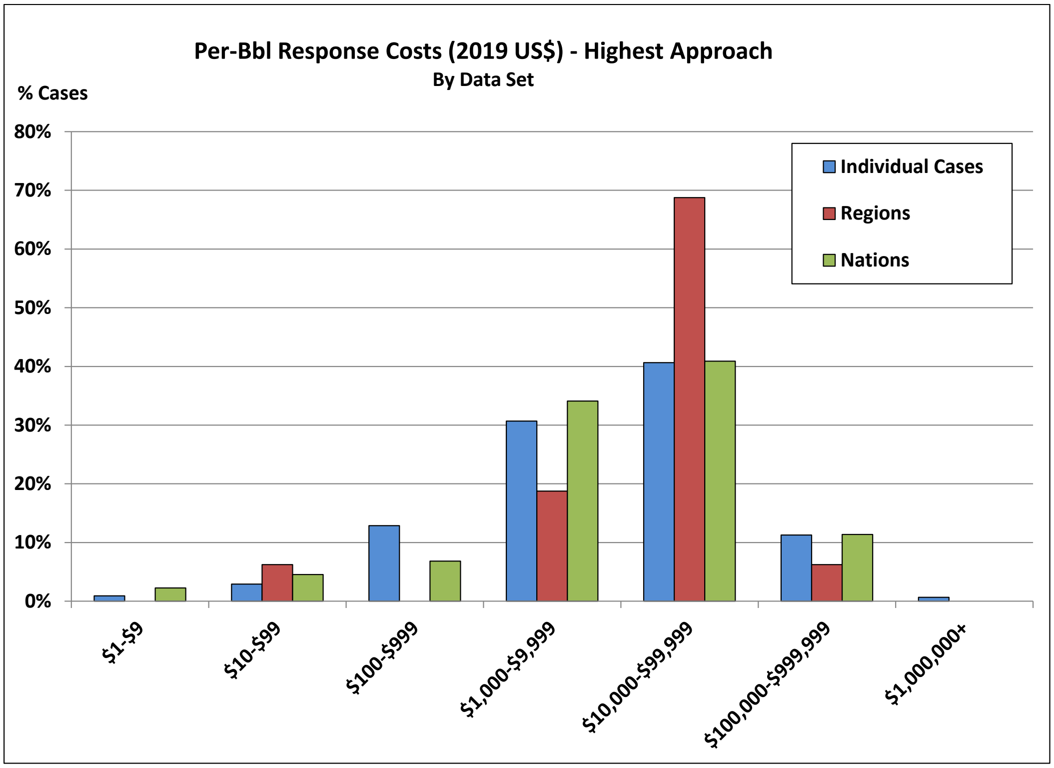

Figure A-19: Distributions of Per-Bbl Response Costs (Highest Approach)

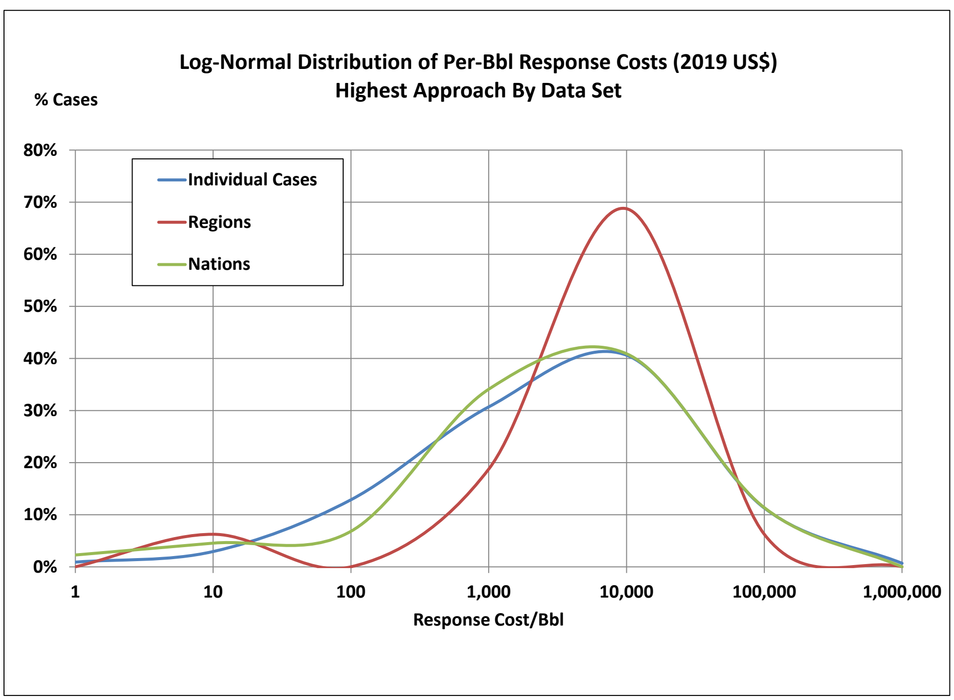

Figure A-20: Log-Normal Distributions of Per-Bbl Response Costs (Highest Approach)

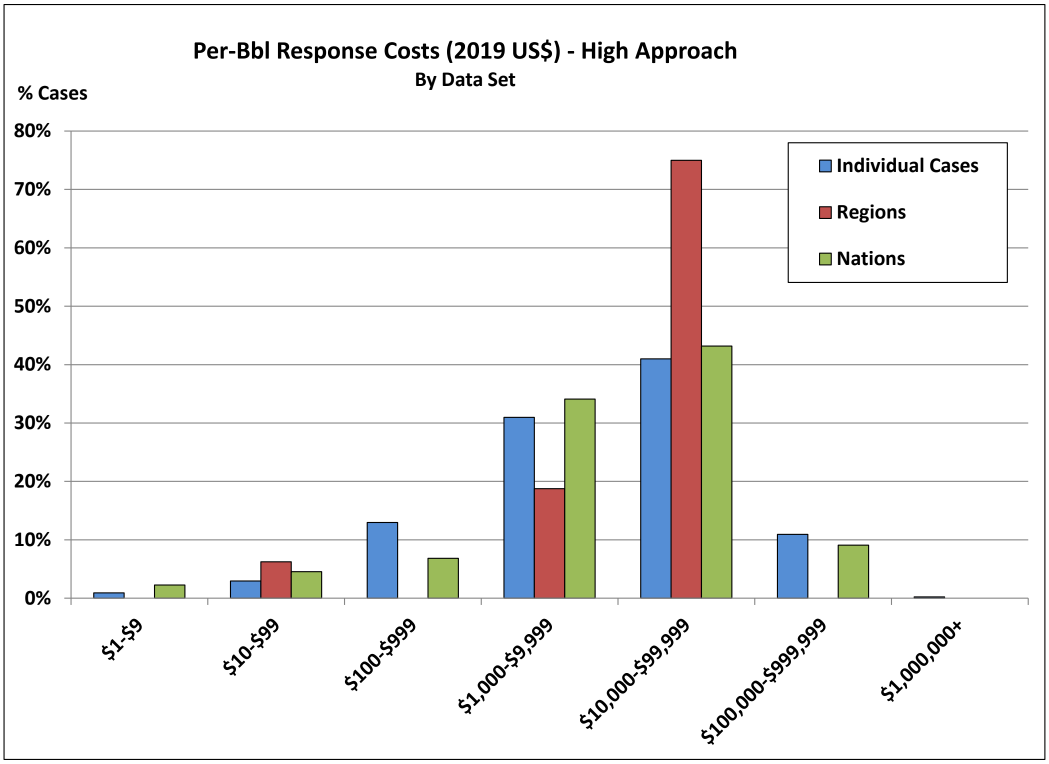

Figure A-21: Distributions of Per-Bbl Response Costs (High Approach)

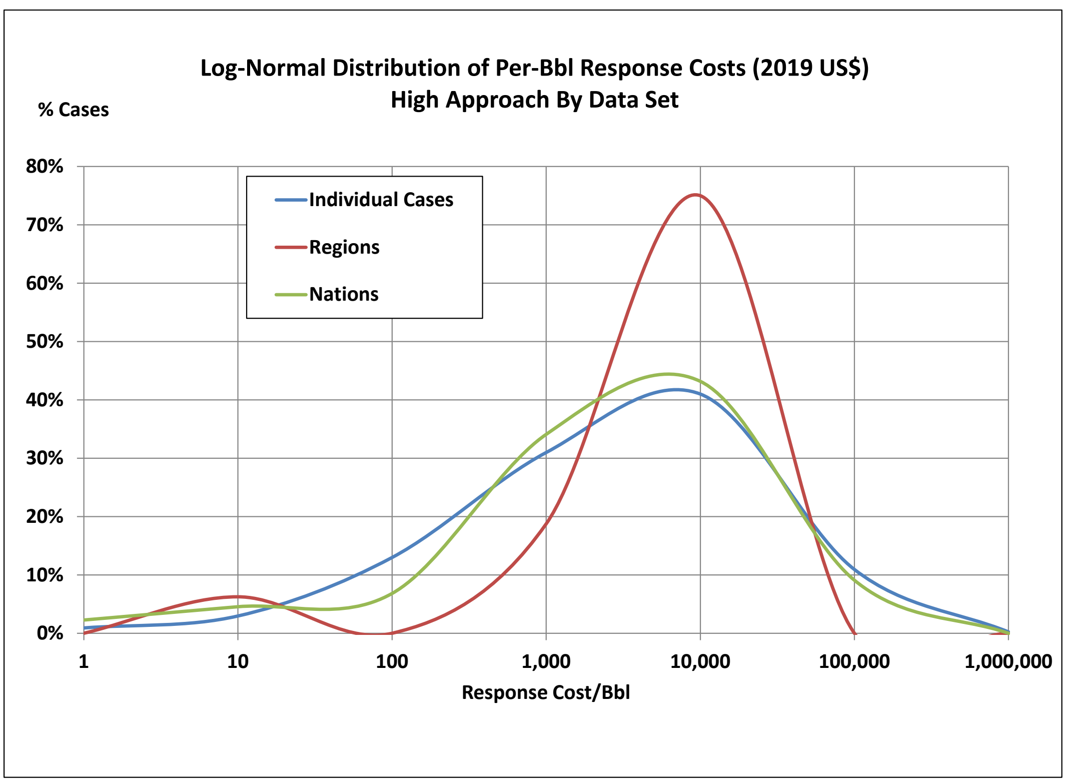

Figure A-22: Log-Normal Distributions of Per-Bbl Response Costs (High Approach)

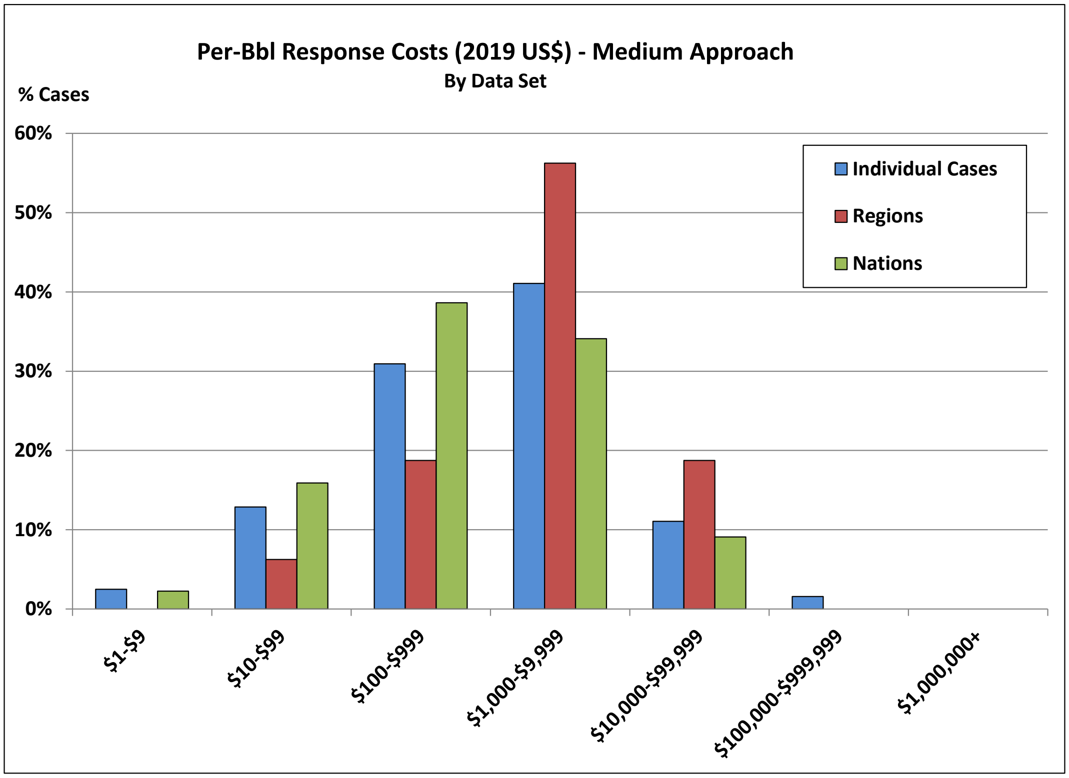

Figure A-23: Distributions of Per-Bbl Response Costs (Medium Approach)

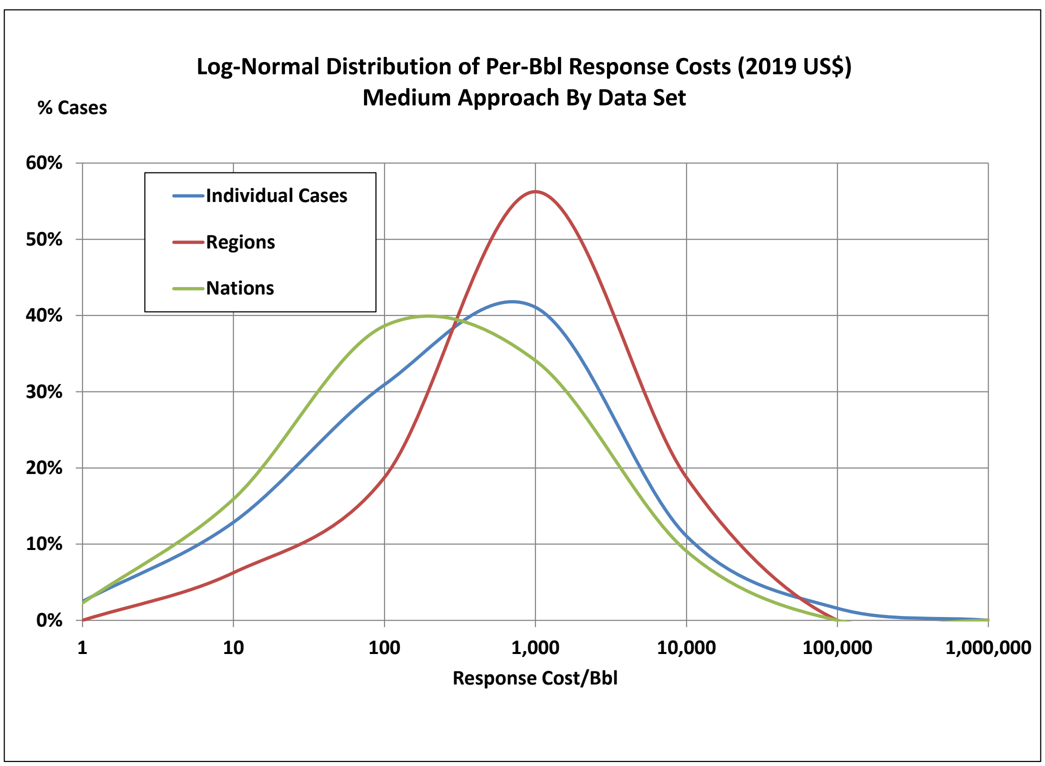

Figure A-24: Log-Normal Distributions of Per-Bbl Response Costs (Medium Approach)

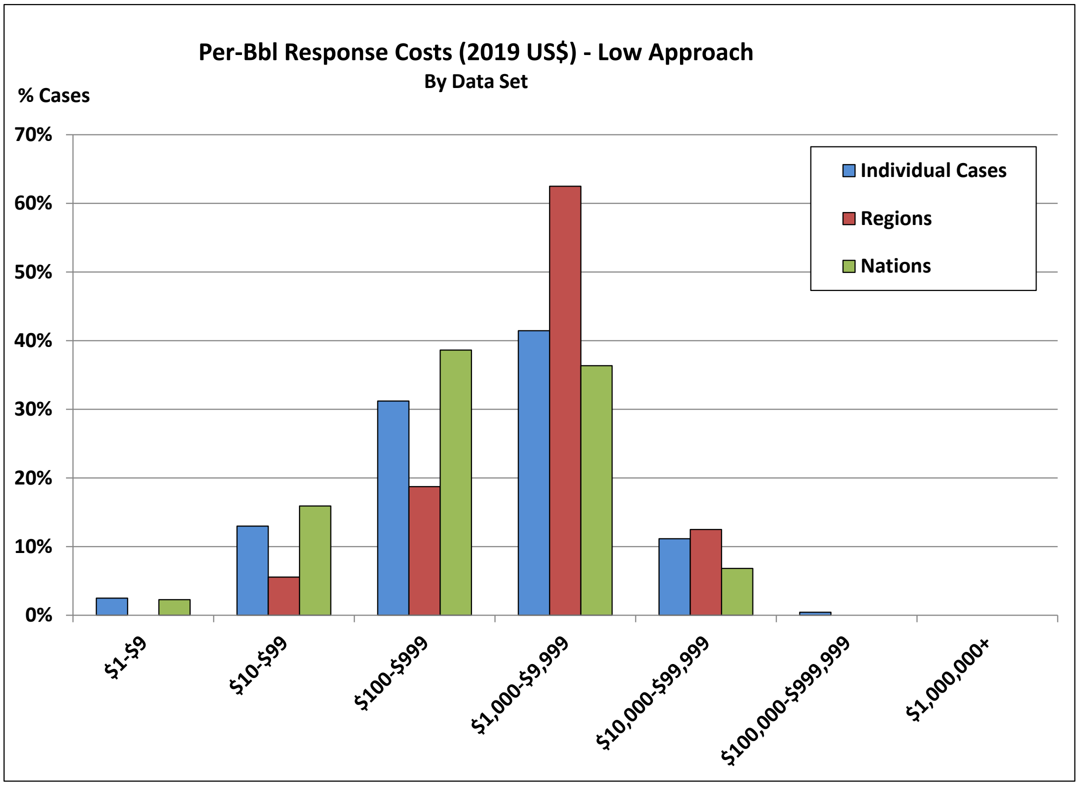

Figure A-25: Distributions of Per-Bbl Response Costs (Low Approach)

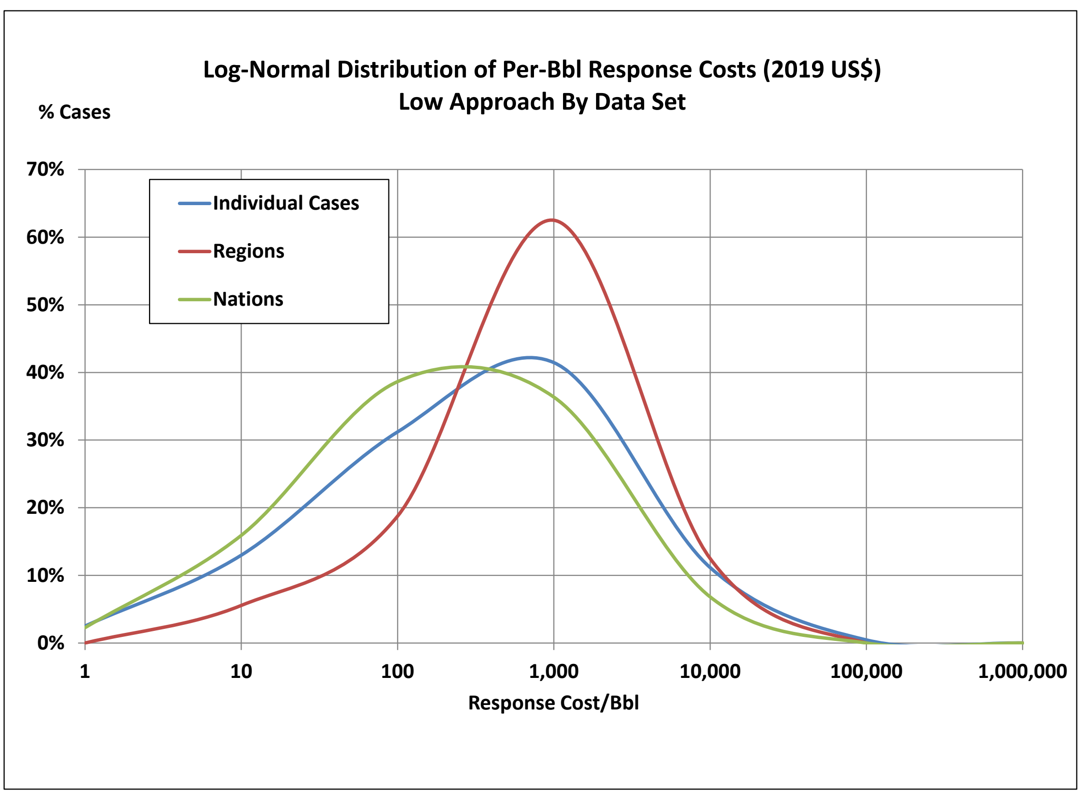

Figure A-26: Log-Normal Distributions of Per-Bbl Response Costs (Low Approach)

Calculation of Per-Bbl Response Cost by GDP PPP Method

Another approach to calculating regional per-bbl response costs is to take the global average and then adjust it based on the Gross Domestic Product at Purchasing Power Parity (GDP PPP).[108] This corrects for economic differences between nations. However, it does not correct for differences in approaches to spill cleanup response (e.g., standards of completion).

The per-bbl response costs calculated by taking the GDP PPP multiplier and applying it to the ERC Spill Cost Database region average was compared with the actual averages for the cases for each region in the database (Table A-9). In some cases, the costs were higher or lower than expected. Potential reasons for those differences were noted. More information about the potential factors that could affect per-unit response costs is discussed in the next section.

Table A-9: Region Base Per-Bbl Response Cost (GDP PPP Method)

Region	GDP PPP per-capita Multiplier[109]	Per-Bbl Response Cost		CDFW-OSC Cost /GDP PPP Response Cost Comparison	
		By GDP PPP[110]	CDFW-OSC Highest Approach	CDFW-OSC/ GDP PPP	Potential Reason(s) for Difference in Cost Estimation
Africa	0.3	$12,067	$22,180	1.84	Political and environmental sensitivity; logistics challenges
Australia	1.99	$80,042	$80,147	1.00	-
Baltic	1.1	$44,244	$51,176	1.16	-
Canada	2.04	$82,053	$87,351	1.06	-
Caribbean	0.74	$29,764	$6,714	0.23	IOPC/CLC limits; impacts to lower-economic areas
China	0.72	$28,960	$10,040	0.35	Impacts to lower-economic areas; IOPC/CLC limits
India	0.32	$12,871	$27	0.00	Impacts to lower-economic areas; IOPC/CLC limits
Mediterr.	1.02	$41,026	$13,010	0.32	IOPC/CLC limits
Middle East	2	$80,444	$3,167	0.04	Impacts to lower-economic areas; IOPC/CLC limits
Sea of Japan	1.79	$71,997	$55,213	0.77	Impacts to lower-economic areas; IOPC/CLC limits
South America	0.78	$31,373	$12,110	0.39	Impacts to lower-economic areas; IOPC/CLC limits
Southeast Asia	1.56	$62,746	$20,707	0.33	Impacts to lower-economic areas; IOPC/CLC limits

108 GDP per capita (PPP-based) is gross domestic product converted to international dollars using purchasing power parity rates and divided by total population.

109 For the three US regions, the GDP PPP multiplier 2.67, was multiplied by regional differences in Consumer Price Indices [Northeast (East) = 1.04; West = 1.02; Southern (Gulf) = 0.97]. For all multi-national regions, only the coastal nations were considered in the calculation of the average GDP PPP (per capita) Multiplier.

110 Average by Regions ($40,222) multiplied by the GDP PPP Multiplier.

Region	GDP PPP per-capita Multiplier[109]	Per-Bbl Response Cost		CDFW-OSC Cost /GDP PPP Response Cost Comparison	
		By GDP PPP[110]	CDFW-OSC Highest Approach	CDFW-OSC/ GDP PPP	Potential Reason(s) for Difference in Cost Estimation
UK/Europe	2.15	$86,477	$40,550	0.47	IOPC/CLC limits; dispersant policy
US East	2.78	$111,817	$49,435	0.44	Lower environmental sensitivity of locations of spills
US Gulf	2.59	$104,175	$17,798	0.17	Dispersant application; oil behavior offshore (lighter oil)
US West	2.72	$109,404	$144,402	1.32	Political sensitivity

Limitation of Sample Sizes

The significant deviation of many of the ERC Spill Cost Database-derived average response costs from those predicted by the GDP PPP, as evidenced by the ER/GDP PPP value in Table A-9 indicate that there are simply too few cases for some of the regions in the ERC Spill Cost Database to calculate any meaningful averages. While there are more data in this database than have been used in previous spill cost modeling studies, there are still so many factors affecting the costs in each particular case. Small samples (often only one or two) in many Regions mean that there could be some anomalous factors making a particular spill more or less expensive than would be expected. Larger sample sizes provide a more robust estimate of the average per-bbl costs. This would advocate for the use of the *global* average adjusted by factors that make some areas more expensive than others–including the GDP PPP, and the other factors described in the next section.

Geographic-Specific Adjustment Factors

Certain region-specific factors can affect the per-unit response cost, most notably environmental sensitivity, dispersant policy, and liability regimes.

Environmental Sensitivity Adjustment

The environmental factors that are most likely to drive up response and damage costs are: the presence of coral reefs, the presence of mangroves; the presence of Marine Protected Areas (MPAs); and aquaculture and commercial fisheries.

Coral reefs are a particular concern with respect to environmental damages from oil spills, as well as response costs. A worldwide distribution map of coral reefs is shown in Figure A-27. Note that impacts to coral reefs are not an issue for oil spills in California.

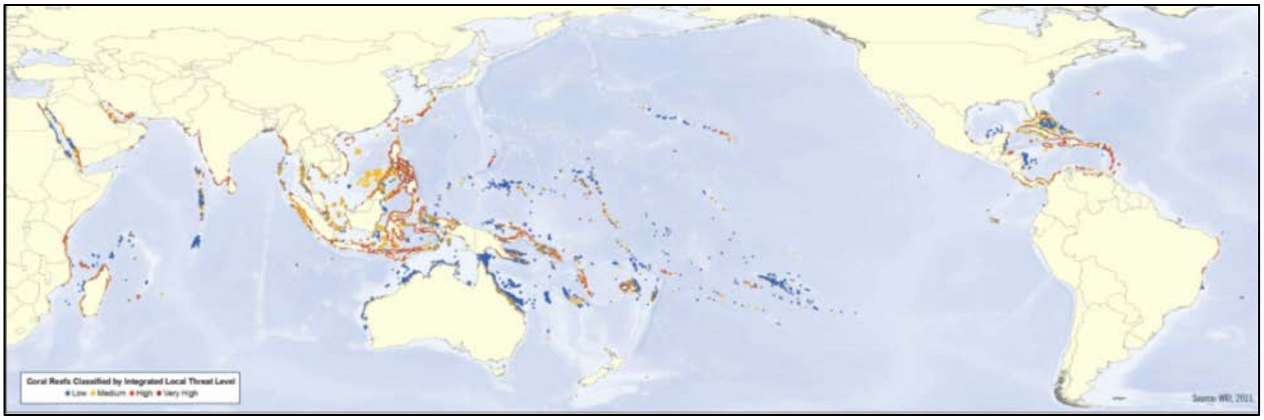

Figure A-27: Worldwide Map of Reefs at Risk[111]

World Wildlife Fund (WWF) uses the term Marine Protected Area (MPA) as an overarching description of an area designated and effectively managed to protect marine ecosystems, processes, habitats, and species, which can contribute to the restoration and replenishment of resources for social, economic, and cultural enrichment (Figure A-28 and Figure A-29). These areas would generally be ones that would be identified as environmentally-sensitive with respect to potential spill costs as well. There are some MPAs off the California coast that could potentially be affected by a larger coastal or offshore spill.

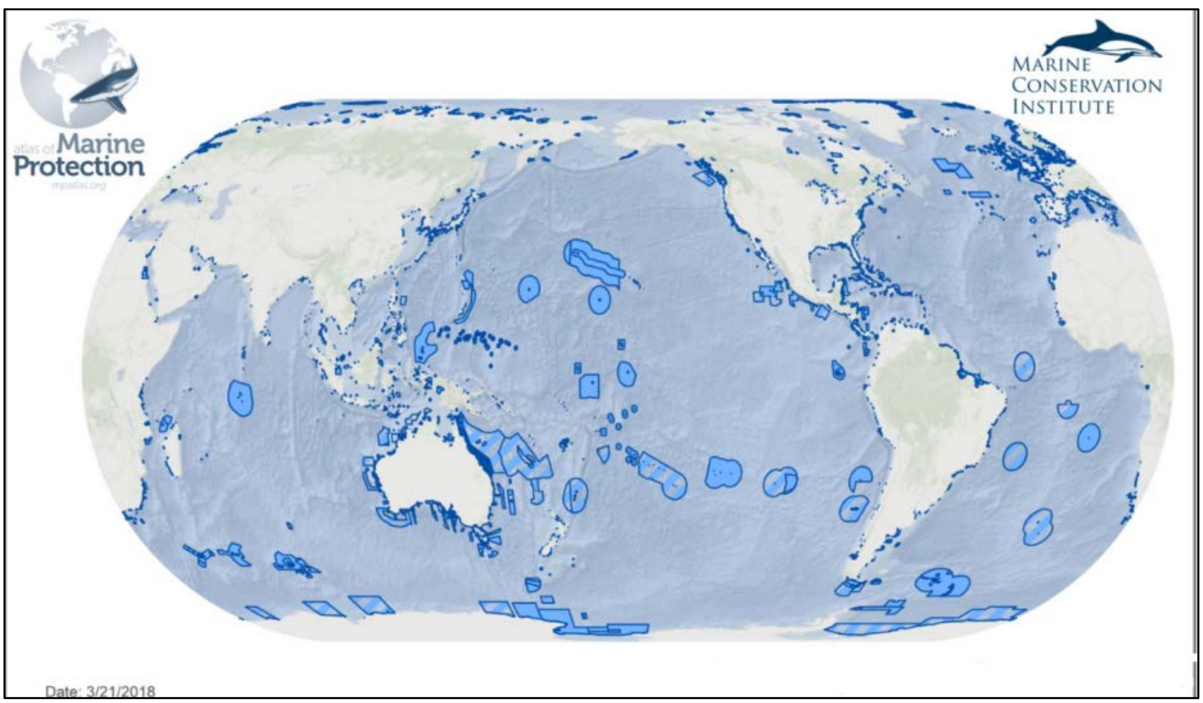

Figure A-28: Marine Protected Areas[112]

[111] Burke et al. 2011.
[112] Source: Marine Conservation Institute Atlas of Marine Protection (www.mpatlas.org) March 2018.

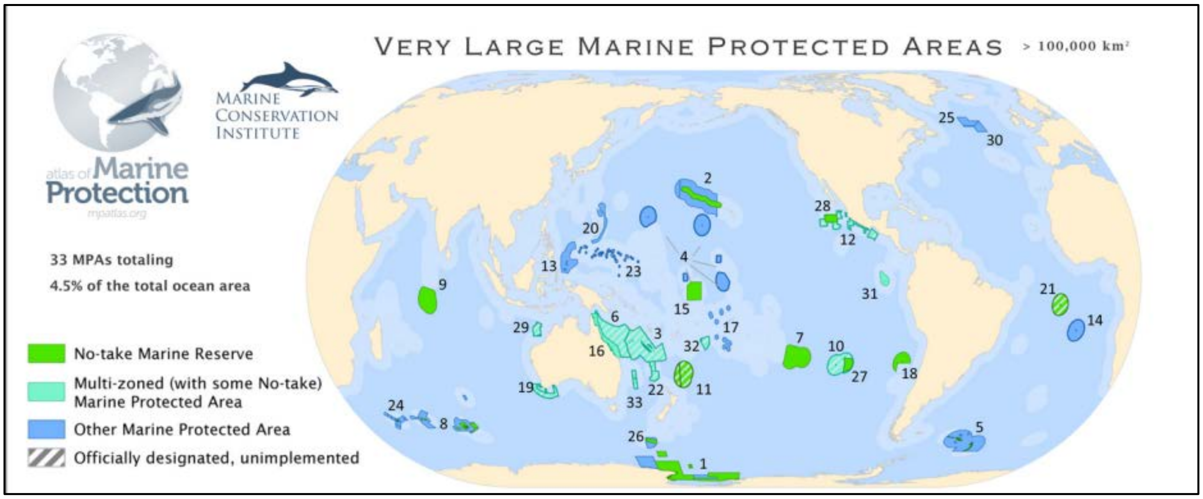

Figure A-29: Very Large Marine Protected Areas[113]

Mangroves are another particularly sensitive type of habitat with respect to oil spills.[114] The global distribution of mangroves is shown in Figure A-30.

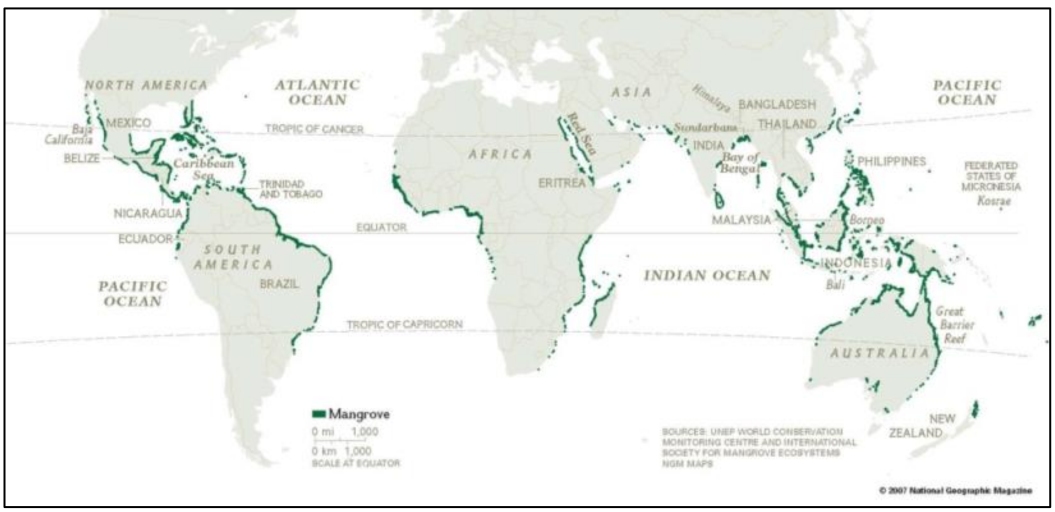

Figure A-30: Worldwide Mangrove Distribution[115]

Fisheries and aquaculture areas (Figure A-31 and Figure A-32) are also particularly sensitive to the effects of oil spills with respect to potential damages, which would drive up costs. The use of chemical dispersants in cleanup response operations may be limited in aquaculture areas due to the potential effects of chemical dispersants on fish. There are mangrove areas on the Pacific coast of Mexico, including on Baja California, that may potentially be affected by a larger coastal or offshore spill in southern California.

[113] Source: Marine Conservation Institute Atlas of Marine Protection (www.mpatlas.org) December 2017.
[114] Hoff et al. 2014.
[115] Sources: UNEP World Conservation Monitoring Centre and International Society for Mangrove Ecosystems NGM Maps; Map Copyright: National Geographic Magazine.

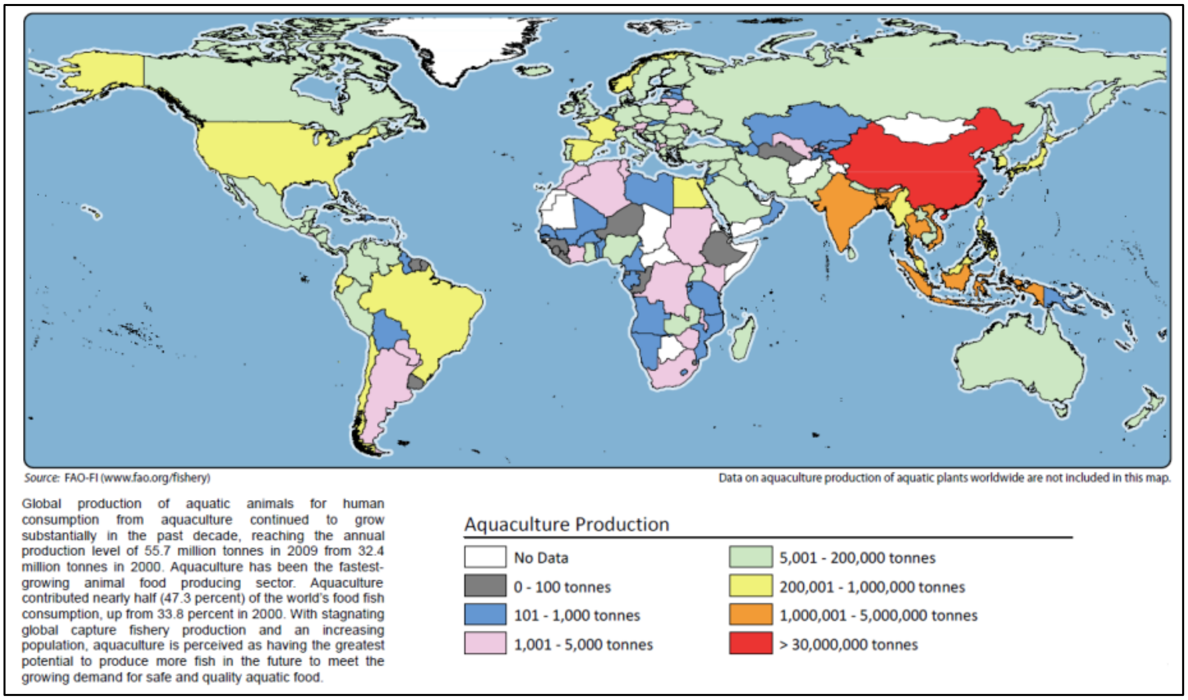

Figure A-31: Worldwide Aquaculture Production[116]

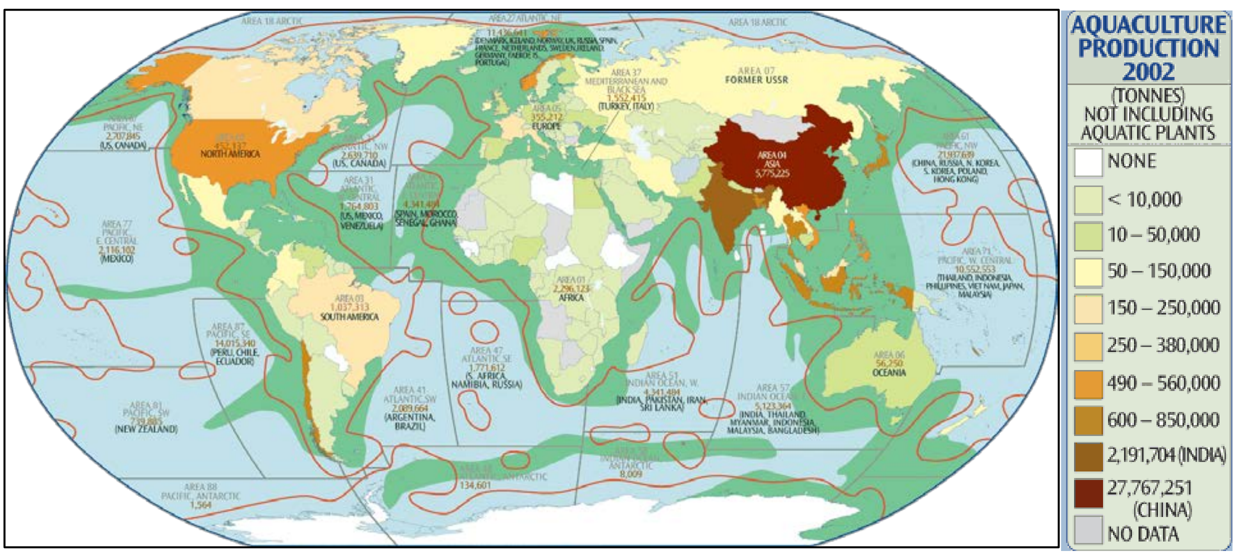

Figure A-32: Worldwide Fisheries[117]

The ecological consequences of oil spills on ecosystems and populations of organisms are based on a complex interaction between the characteristics of the oil and the characteristics of the ecosystems or organisms. There is no simple linear relationship between the impacts of a spill and the volume of oil spilled. Ecosystems and organisms react differently to toxicity, adherence and coating effects, and persistence of different types of oils. The behavior of the oil in a spill varies with environmental factors such as temperature, wave energy, and wind direction, as well as with response measures applied.

116 Source: Food and Agriculture Organization of the United Nations (FAO) (www.fao.org)

117 Source: The Global Education Project (http://www.theglobaleducationproject.org/earth/fisheries-and-aquaculture.php)

Spill response operations can mitigate oil impacts to some degree by removing oil or preventing oil from reaching particularly sensitive or valued resources through the use of effective dispersant application, mechanical recovery, in situ burning, or preventive and deflective booming. At the same time, some response operations can exacerbate spill impacts, such as aggressive shoreline treatment or heavy foot and vehicular traffic in marshes. Dispersant applications often involve a tradeoff between impacts to water column organisms (e.g., fish, invertebrates) and impacts to surface-dwelling birds and shoreline habitats.

Quantifying or even qualifying the environmental sensitivity with respect to oil spills is complex, involving the environmental sensitivity of the receptor environment (e.g., mangrove, coral reef) in terms of irreplaceability, vulnerability, and influence on larger ecosystems. At the same time, duration, scale, and intensity of impacts need to be considered. Effects differ by oil type. Various factors can affect the ecological consequences of a spill (Figure A-33).

Figure A-33: Flow Chart of Factors Influencing Ecological Consequences of Spills[118]

A summary of the combined environmental sensitivity and vulnerability (threatened, endangered, etc.) of different ecosystems in response to impacts from different oil types is shown in Table A-10. Coral reefs, mangroves, and salt marshes rank particularly high.

[118] Source: Environmental Research Consulting.

Table A-10: Comparison of Ecosystem Sensitivity and Vulnerability by Oil Type[119]

Ecosystem or Shoreline Type	Combined Environmental Sensitivity and Ecosystem Vulnerability			
	Volatile Distillates (Non-Persistent)	Light Oil (Light Persistent)	Medium Oil (Medium Persistent)	Heavy Oil (Heavy Persistent)
Arctic	insufficient data	insufficient data	Medium-High	Medium-High
Antarctic	insufficient data	Medium-High	insufficient data	insufficient data
Tropical	insufficient data	Medium-High	Medium-High	Medium-High
Coral Reef	insufficient data	High	High	Medium-High
Estuarine	insufficient data	Medium	Medium	Medium
Riverine	insufficient data	Medium	Medium-High	Medium
Intertidal	Medium	Medium-High	Medium-High	Medium
Sublittoral	Medium	Medium	Medium-High	Medium
Pelagic	insufficient data	Low-Medium	Medium	Medium
Benthic	insufficient data	Medium	Medium-High	Medium
Demersal	insufficient data	insufficient data	Medium	Medium
Kelp	insufficient data	Medium	Medium-High	insufficient data
Exposed Rocky	Medium	Medium	Medium-High	Medium
Rocky Platform	insufficient data	insufficient data	Medium-High	Medium
Fine Sand	insufficient data	insufficient data	Medium	Medium
Coarse Sand	insufficient data	Medium	Medium-High	Medium
Sand/Gravel	insufficient data	insufficient data	Medium-High	Medium
Gravel	insufficient data	insufficient data	Medium-High	Medium-High
Riprap	insufficient data	Low	Low	Low
Exposed Tidal	insufficient data	Medium	Medium-High	Medium
Sheltered Rocky	insufficient data	Medium	insufficient data	Medium
Sheltered Solid	insufficient data	insufficient data	insufficient data	insufficient data
Sheltered Tidal	insufficient data	Medium	Medium-High	insufficient data
Salt Marsh	insufficient data	Medium-High	High	High
Fresh Marsh	insufficient data	insufficient data	Medium	Medium
Swamp	insufficient data	insufficient data	insufficient data	insufficient data
Mangrove	insufficient data	Medium-High	High	High
Sub-Arctic	insufficient data	Medium	Medium-High	Medium-High

The degree to which these environmental sensitivity factors would affect spill costs overall is complex. Response costs would generally reflect the degree of labor, resources, and duration of effort involved. For responses in particularly environmentally-sensitive locations, all of these components would be increased due to the greater care and thoroughness that would be required in the operations. At the same time, the costs for environmental or natural resource damage claims, where those are likely to be assessed–i.e., primarily in the US, spills in more environmentally-sensitive locations would result in higher costs. Even if environmental damage claims per se are not permitted, there may be an increase in fines and penalties, not to mention the more intangible damage to public relations and reputation for spills in these locations.

[119] Based on literature review of 922 technical reports, scientific journal articles, and conference papers, as well as 217 oil spill case studies, conducted by ERC in 2013.

Socioeconomic and third-party claims would be another potential cost consideration. Spills that affect mangroves and coral reefs would generally cause environmental or natural resource damages, which would not usually translate into third-party claims, except, perhaps if these areas are considered to be integral to regional tourism. For spills that occur in commercial fishery and aquaculture areas, there would be clear effects on the degree of third-party claims.

The degree to which environmental sensitivity should be applied in calculating base per-unit response costs is summarized in Table A-11 based on oil type. The values indicate the degree to which the average base unit response cost would be increased if these environmentally-sensitive resources were to be affected in a spill. (e.g., "0" means no change. "0.2" means a 20% increase.) Note that coral reefs are not included as they are not a factor for California spills.

Table A-11: Environmental Sensitivity Adjustments Based on Receptor Type

Presence in Region	Mangroves				Fisheries				MPAs			
	NP	LP	MP	HP	NP	LP	MP	HP	NP	LP	MP	HP
Very Low	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low	0.0	0.1	0.1	0.2	0.1	0.3	0.2	0.1	0.0	0.1	0.1	0.2
Medium	0.1	0.2	0.3	0.4	0.2	0.6	0.5	0.3	0.1	0.2	0.2	0.4
High	0.2	0.4	0.5	1.0	0.3	0.9	0.8	0.4	0.2	0.4	0.4	0.8
Very High	0.3	0.6	0.8	1.6	0.6	1.6	1.5	0.8	0.3	0.6	0.6	1.2

Environmental Sensitivity Adjustments by Region

The regions were rated on a five-point scale for environmental sensitivity and a three-point scale for dispersant policy (Table A-12). The multipliers for the sensitivity factors by region are in Table A-13. The sensitivity multipliers are added to create a single sensitivity multiplier for each region:

$$ES_{total} = ES_{coral} + ES_{mangrove} + ES_{fishery} + ES_{MPA} \quad [6]$$

Table A-12: Factor Ratings for Sensitivity Factors by Region

Region	Presence of Environmental Sensitivity Factors			
	Coral Reefs	Mangroves	Fisheries	MPAs
US East	L	L	H	VL
US Gulf	L	L	H	H
US West	VL	VL	H	VL

Table A-13: Environmental Sensitivity Adjustments by Region and Oil Type

Region	Environmental Sensitivity Factors Based on Oil Type[120]																			
	Mangrove				Fisheries				MPAs				Total				Relative Rank			
	NP	LP	MP	HP	NP	LP	MP	HP	NP	LP	MP	HP	NP	LP	MP	HP	NP	LP	MP	HP
US East	0.0	0.1	0.1	0.2	0.3	0.9	0.8	0.4	0.0	0.0	0.0	0.0	0.4	1.3	1.2	0.8	L	M	M	VL
US Gulf	0.0	0.1	0.1	0.2	0.3	0.9	0.8	0.4	0.2	0.4	0.4	0.8	0.6	1.7	1.6	1.6	L	M	M	L
US West	0.0	0.0	0.0	0.0	0.3	0.9	0.8	0.4	0.0	0.0	0.0	0.0	0.3	0.9	0.8	0.4	VL	L	L	VL

[120] Multiplier factors from Table A-11.

Application of Environmental Sensitivity Adjustments

The Total Environmental Sensitivity Factor can be used as an increase factor for all costs. Response costs will increase in these environmentally-sensitive areas in that particularly high end-point standards need to be applied. There also are generally more complex and tedious operations involved. Damage claims may also be particularly high.

The environmental sensitivity adjustment should be applied as:

$$UnitCost_{total-ES} = UnitCost_{total} + (UnitCost_{total} \cdot ES_{total})$$
$$UnitCost_{total-ES} = (1 + ES_{total}) \cdot (UnitCost_{total}) \quad [7]$$

Not all spills that occur in a particular region will necessarily impact the environmentally-sensitive areas. The actual costs will be determined by the specific location of the spill within the larger region and the behavior, fate, and effects of the oil in each spill scenario. The environmentally-sensitive areas in a Region may only represent a small geographic area. The Total Environmental Sensitivity Factor can be applied based on percentage of area covered or likelihood of spill occurring in the sensitive areas based on the specific tanker routes, for example.

Dispersant Policy Adjustment

The type of spill response conducted will be an important factor in determining the cost of the response. While most large spills require a complex array of response strategies, having the option to apply chemical dispersants has a significant effect on costs, generally lowering them. The option to use dispersants in a particular area would generally be determined by the policies of the nations involved, as well as any specific environmental conditions in the location or at the time of the spills. This provides a general sense of the geographic distribution of dispersant-permissible areas. The dispersant policies of coastal nations are summarized in Figure A-34.

The degree to which the use of dispersants can affect response cost has been examined in several studies.[121] The recommended cost adjustment factors by dispersant policy are shown in Table A-14. The dispersant adjustment factor should be applied to the base average response cost as a multiplier. The response cost maximum cost, as calculated by the Highest Approach (i.e., time-scale adjusted and with outliers) should not be adjusted for dispersant policy. In most cases in which there are extremely sensitive resources, particularly coral reefs, mangroves, and fisheries, the use of dispersants would likely be limited even if policy allows for their use. Table A-15 shows the dispersant-adjusted base response costs applying the Highest and Low-calculated response costs as examples.

$$RC_{base-disp} = RC_{base} \cdot D_{adjust} \quad [8]$$

[121] Etkin 2000; Etkin 2003; Etkin and Tebeau 2003; Etkin et al. 2003; Etkin et al. 2002; French-McCay et al. 2002.

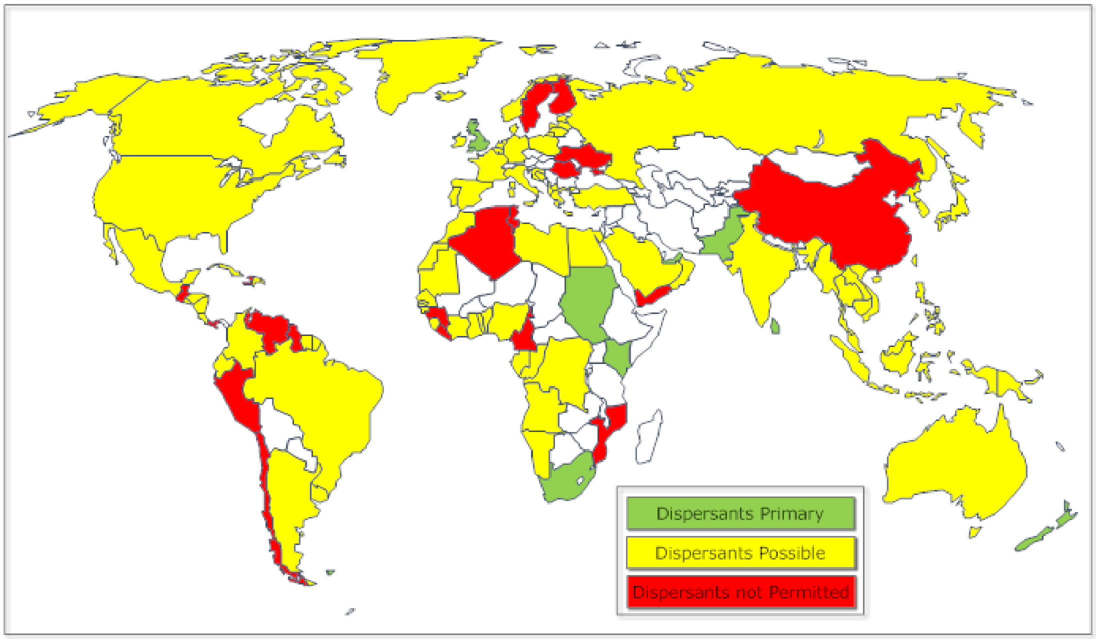

Figure A-34: Dispersant Policy Map

Table A-14: Dispersant Policy Adjustment Factors

Dispersant Policy	Dispersant Adjustment Factor
Dispersants as Primary Response Method	0.35
Dispersants Permitted but with Restrictions (Secondary/Tertiary Response)	0.60
No Dispersants Allowed (Mechanical/Manual Methods Only)	1.00

Table A-15: Dispersant Policy Adjustment by Region

Region	Dispersant Policy	Applied Dispersant Adjustment Factor	Base Per-Bbl Response Cost			
			GDP PPP Method		Dispersant-Policy Adjusted	
			Highest Cost	Low Cost	Highest Cost	Low Cost
US East	Possible	0.6	$123,664	$12,528	$74,199	$7,517
US Gulf	Possible	0.6	$115,212	$11,672	$69,128	$7,004
US West	Possible	0.6	$120,995	$12,258	$72,597	$7,354

Proximity to Shore

For *individual* spill incidents, the proximity to shore is a very important determinant of response (and damage) costs. Many of the most sensitive and socioeconomically-valuable resources are on the shoreline or in close proximity to the coast in nearshore waters. A significant portion of response costs can usually be attributed to shoreline cleanup operations, which are labor-intensive.[122] Most cleanup response strategies are aimed at keeping oil off the shorelines in one manner or another. The amount of oil that ends up on shorelines and in sensitive nearshore waters depends on the location of the spill and the directions of surface winds, and, to a lesser extent, currents. Onshore winds can drive oil spilled in

[122] Peck et al. 1996.

an offshore location onto the shoreline. The oil type and environmental conditions at the time of the spill will determine the degree of evaporation that occurs before the remaining oil reaches the shore.

The effect that the degree of shoreline oiling has on response costs was examined in a previous ERC study, as shown in Table A-16 and Figure A-35.

Table A-16: Per-Bbl Response Costs by Degree of Shoreline Oiling[123]

Shoreline Length Oiled	Per-Bbl Response Costs (2019 US$)		
	US Spills	Non-US Spills	All Spills
0–1 km	$572	$1,197	$1,101
2–5 km	$1,297	$1,332	$1,255
8–15 km	$2,282	$1,365	$1,253
20–90 km	$3,284	$1,486	$1,432
100 km	$5,912	$1,962	$2,468
500 km	$11,250	$2,253	$3,560

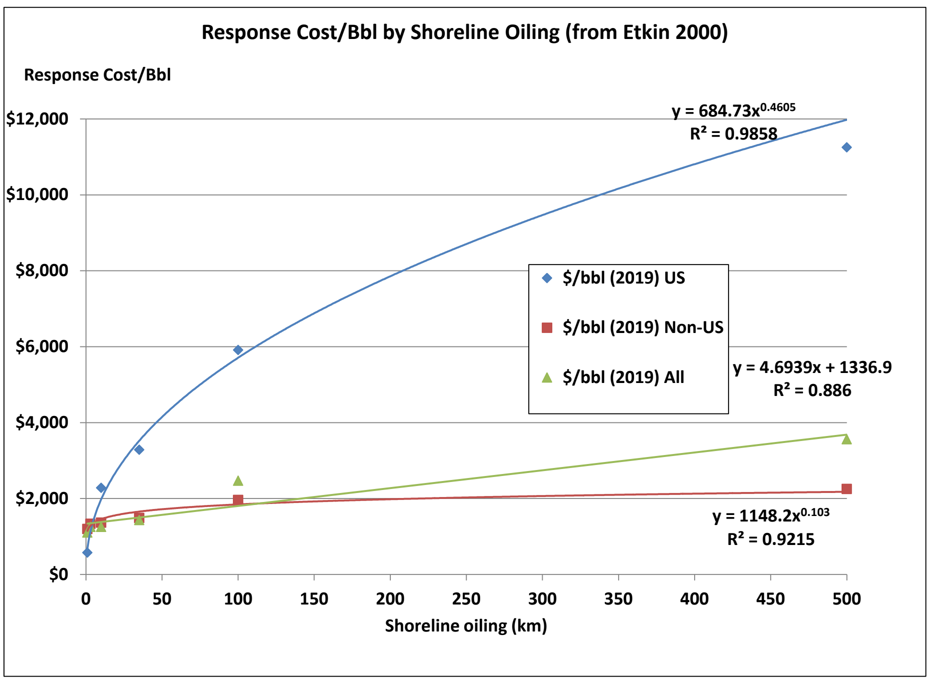

Figure A-35: Per-Bbl Response Cost by Shoreline Oiling (Based on Etkin 2000)

This study also quantified response costs by location type, as shown in Table A-17. Nearshore and in-port spills have higher per-bbl response costs than offshore spills.

[123] Based on Etkin 2000. All costs have been updated to 2019 US dollars and spillage volume units converted to bbl.

Table A-17: Per-Bbl Response Costs by Location Type[124]

Location Type	Per-Bbl Response Costs (2019 US$)		
	US Spills	Non-US Spills	All Spills
In-Port	$7,381	$2,811	$4,260
Nearshore	$5,427	$3,882	$4,859
Offshore	$1,488	$1,856	$1,796

[Note that the costs in Table A-16 and Figure A-35 are generally lower than those calculated in the ERC Spill Cost Database. This is due to the fact that the data in Etkin 2000 are based on pre-2000 spills and have not been year-adjusted.]

Nearshore or in-port spills would generally have per-bbl response costs about 2.5 times the cost of spills in offshore locations.[125] The Shoreline Proximity Multiplier (SPM) of 2.5 can be applied on a case-by-case basis if there are specific routes (or portions of routes nearshore or in ports). The definition of "nearshore" is imprecise in that it is based on an assumption that a large portion of the spilled oil would come ashore. This is dependent on wind direction and currents, as well as the volume of spillage and oil properties with respect to evaporation rates. However, as a general rule of thumb, "nearshore" might be defined as within 5 km of the coast.

Note that in applying the Shoreline Proximity Multiplier in addition to the Environmental Sensitivity Multiplier, they should be applied additively as in:

$$Adjustment_{total} = ESM + SPM \quad [9]$$

For nearshore spills, the SPM is 2.5. For offshore spills it is set as 0 so that the ESM is the only adjustment.

Incorporating Other Non-Response Costs

While response cost is a good overall indicator of spill costs and can be used to compare the relative costs between regions or between nations, there are additional costs that should be considered in determining the absolute cost. These costs would include the NRDA costs in the US, as well as fines and penalties that may be assessed (note that COFR requirements by CDFW OSPR do not incorporate potential fines and penalties). Liability generally only includes response costs and third-party damages.

For the spill cases in the ERC Spill Cost Database, there is an average of $681 per bbl in fines and penalties–or an additional 1.2% above the worldwide average year-adjusted per-bbl response cost.

For US NRDA (environmental or natural resource damage costs), the average NRDA cost per bbl is $3,096–or about 4.5% above the US average year-adjusted per-bbl response cost. Third-party damage claims will also play an important role in determining overall final costs. Average per-bbl third-party damage claims are $10,907, or about 18.6% above the worldwide average year-adjusted response cost.

The additional costs that should be added to the base unit response costs (adjusted for dispersant policy) for each region are summarized in Table A-18–Table A-21 based on the calculation approaches.

[124] Based on Etkin 2000. All costs have been updated to 2019 US dollars and spillage volume units converted to bbl.
[125] Calculated by taking the average of the in-port and nearshore unit costs and dividing by the offshore unit costs for the All Spills category in Table A-17.

Table A-18: Total Per-Bbl Costs by Region–Highest Approach

Region	Per-Bbl Costs				
	Highest Dispersant-Policy Adjusted Response Cost	Additional Costs			Total
		NRDA	Fines	3rd Party	
US East	$74,199	$3,339	$891	$13,801	$92,229
US Gulf	$69,128	$3,111	$830	$12,858	$85,926
US West	$72,597	$3,267	$871	$13,503	$90,238

Table A-19: Total Per-Bbl Costs by Region–High Approach

Region	Per-Bbl Costs				
	High Dispersant-Policy Adjusted Response Cost	Additional Costs			Total
		NRDA	Fines	3rd Party	
US East	$52,183	$3,339	$891	$13,801	$70,214
US Gulf	$48,617	$3,111	$830	$12,858	$65,415
US West	$51,056	$3,267	$871	$13,503	$68,698

Table A-20: Total Per-Bbl Costs by Region–Medium Approach

Region	Per-Bbl Costs				
	Medium Dispersant-Policy Adjusted Response Cost	Additional Costs			Total
		NRDA	Fines	3rd Party	
US East	$18,263	$3,339	$891	$13,801	$70,214
US Gulf	$17,015	$3,111	$830	$12,858	$65,415
US West	$17,869	$3,267	$871	$13,503	$68,698

Table A-21: Total Per-Bbl Costs by Region–Low Approach

Region	Per-Bbl Costs				
	Low Dispersant-Policy Adjusted Response Cost	Additional Costs			Total
		NRDA	Fines	3rd Party	
US East	$6,791	$3,339	$891	$13,801	$24,822
US Gulf	$6,327	$3,111	$830	$12,858	$23,125
US West	$6,645	$3,267	$871	$13,503	$24,286

Summary of CDFW-OSC Cost Algorithm Components

The total per-bbl costs in Table A-19–Table A-21 for each Region can be used to estimate total per-bbl costs for expected spills by geographic region. The different approaches–Highest, High, Medium, and Low–should be selected based on the degree of caution appropriate in the risk assessment process. That is, if there is concern about maximizing the potential costs (e.g., for insurance coverage), the Highest or High figures should be applied.

However, the costs still need to be adjusted for five situations:

- When spills involve non-persistent, low-persistent, or heavy-persistent oils;
- When spills involve particularly large volumes;
- When spills occur in nearshore or port areas;
- When there are specific ecological sensitivity factors involved; and

- When spills are large and costs exceed applicable liability limits, although this applies only to tanker transport of oils and/or the bunkers on tankers during transport.

Adjustment by Oil Type

The base total costs assume a spill that involves a medium-persistent oil, which covers most crude oils. It can be used as a generic of default cost value. However, if the spill involves oil that is clearly much more persistent or less persistent, the costs need to be adjusted. Heavier oils are more expensive to clean up and tend to cause more damage claims and fines and penalties due to their persistence. For this reason, the adjustments are made to all cost categories.

Note that dispersants are also generally not effective on non-persistent oils. Therefore, the dispersant adjustment cannot be applied to these oils. This means that the response cost adjustment for dispersants are not applicable to non-persistent oils. The adjustments by oil type are summarized in Table A-22.

Table A-22: Summary of Oil Type Adjustments

Oil Type	Base Total Cost Adjustment	Dispersant Adjustment
Non-Persistent	0.5	Not Applicable
Light Persistent	0.8	Applicable
Medium Persistent	1.0	Applicable
Heavy Persistent	2.0	Applicable

Adjustments for Very Large Spill Volumes

Based on the analyses presented, an adjustment should be made for spills that exceed 10,000 bbl[126] in total volume. Since the worldwide average response cost per bbl is in the thousands, per-bbl response costs for spills of 10,000 bbl and higher should be adjusted by an order of magnitude (i.e., divided by 10).

The "key tables" (Table A-23 through Table A-27) would apply (on a per-bbl basis) to spills of up to 1,000 bbl total volume. Spills of 10,000 bbl or more would, therefore, contain values that are 10% of the per-bbl costs in those tables, as in Table A-23–Table A-27.

Note that small spills (less than 100 bbl to 1,000 bbl) may be more expensive on a per-bbl basis, especially if in particularly sensitive areas, or if there are particular political situations that make the spill a "high-profile" event.

Table A-23: Key Table: Highest Total Per-Bbl Costs for Regions by Oil Type/Volume

US Region	Non-Persistent		Low- Persistent		Medium-Persistent		Heavy-Persistent	
	Per-Bbl DPAC		Per-Bbl DPAC		Per-Bbl DPAC		Per-Bbl DPAC	
	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl
East	$46,115	$4,612	$73,784	$7,378	$92,229	$9,223	$184,458	$36,892
Gulf	$42,963	$4,296	$68,741	$6,874	$85,926	$8,592	$171,851	$34,371
West	$45,119	$4,512	$72,191	$7,219	$90,238	$9,024	$180,477	$36,096

[126] 10,000 bbl = 420,000 gallons ≈ 1,600 m^3 ≈ 1,430 tonnes.

Table A-24: Key Table: High Total Per-Bbl Costs for Regions by Oil Type/Volume

Region	Non-Persistent		Low- Persistent		Medium-Persistent		Heavy-Persistent	
	Per-Bbl DPAC		Per-Bbl DPAC		Per-Bbl DPAC		Per-Bbl DPAC	
	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl
East	$35,107	$3,511	$56,171	$5,617	$70,214	$7,021	$140,428	$14,043
Gulf	$32,708	$3,271	$52,331	$5,233	$65,415	$6,542	$130,830	$13,083
West	$34,349	$3,435	$54,958	$5,496	$68,698	$6,870	$137,395	$13,739

Table A-25: Key Table: Medium Total Per-Bbl Costs for Regions by Oil Type/Volume

Region	Non-Persistent		Low- Persistent		Medium-Persistent		Heavy-Persistent	
	Per-Bbl DPAC		Per-Bbl DPAC		Per-Bbl DPAC		Per-Bbl DPAC	
	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl
East	$18,147	$1,815	$29,035	$2,903	$36,294	$3,629	$72,589	$7,259
Gulf	$16,907	$1,691	$27,050	$2,705	$33,813	$3,382	$67,625	$6,762
West	$17,756	$1,776	$28,408	$2,840	$35,511	$3,551	$71,021	$7,103

Table A-26: Key Table: Low Total Per-Bbl Costs for Regions by Oil Type/Volume

Region	Non-Persistent		Low- Persistent		Medium-Persistent		Heavy-Persistent	
	Per-Bbl DPAC		Per-Bbl DPAC		Per-Bbl DPAC		Per-Bbl DPAC	
	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl	<1,000 bbl	>10,000 bbl
East	$12,411	$1,242	$19,858	$1,986	$24,822	$2,483	$49,645	$4,964
Gulf	$11,563	$1,157	$18,500	$1,850	$23,125	$2,313	$46,251	$4,625
West	$12,143	$1,215	$19,429	$1,942	$24,286	$2,429	$48,572	$4,857

Additional Adjustments for Ecological Sensitivity

The region- specific costs can be adjusted even further to take into account particular environmental sensitivities of certain areas within a larger region.

The Total Environmental Sensitivity Factor can be applied to all costs. Response costs will increase in these environmentally-sensitive areas in that particularly high end-point standards need to be applied. There also are generally more complex and tedious operations involved. Damage claims may also be particularly high. Fines and penalties tend to be very high when there are damages to these highly-sensitive areas.

The environmental sensitivity adjustment should be applied as:

$$
\begin{aligned}
UnitCost_{total-ES} &= UnitCost_{total} + (UnitCost_{total} \cdot ES_{total}) \\
UnitCost_{total-ES} &= (1+ES_{total}) \cdot (UnitCost_{total}) \\
ESM &= (1+ES_{total})
\end{aligned}
\quad [10]
$$

The Environmental Sensitivity Multiplier (ESM) is shown in the right column of Table A-27.

Note that in applying the Shoreline Proximity Multiplier in addition to the Environmental Sensitivity Multiplier, they should be applied additively as in:

$$Adjustment_{total} = ESM + SPM \qquad [11]$$

For nearshore spills, the SPM is 2.5. In the offshore, the SPM is 0. (The ESM is the only adjustment.)

Table A-27: Environmental Sensitivity Adjustments by Region and Oil Type

Region	ES Adjustment Factor			Environmental Sensitivity Multiplier		
	LP	MP	HP	LP	MP	HP
US East	1.3	1.2	0.8	2.3	2.2	1.8
US Gulf	1.7	1.6	1.6	2.7	2.6	2.6
US West	0.9	0.8	0.4	1.9	1.8	1.4

Not all spills that occur in a particular region will necessarily impact the environmentally-sensitive areas. The actual costs will be determined by the specific location of the spill within a larger region and the behavior, fate, and effects of the oil in each spill scenario. The environmentally-sensitive areas in a Region may only represent a small geographic area. The Total Environmental Sensitivity Factor (in Table A-28) can be applied based on percentage of area covered or likelihood of spill occurring in the sensitive areas based on the specific tanker routes. Alternatively, very specific routes and areas can be evaluated for the presence of coral reefs, mangroves, fisheries/aquaculture, and Marine Protected Areas (e.g., by studying Figure through Figure , or other more-detailed and geographic-specific source material, if available) to adjust costs based on Table A-28.

Table A-28: Environmental Sensitivity Multipliers by Receptor and Oil Type[127]

Presence in Region	Coral Reefs			Mangroves			Fisheries			MPAs		
	LP	MP	HP	LP	MP	HP	LP	MP	HP	LP	MP	HP
Very Low	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low	1.3	1.3	1.2	1.1	1.1	1.2	1.3	1.2	1.1	1.1	1.1	1.2
Medium	1.6	1.6	1.5	1.2	1.3	1.4	1.6	1.5	1.3	1.2	1.2	1.4
High	1.9	1.9	1.7	1.4	1.5	2.0	1.9	1.8	1.4	1.4	1.4	1.8
Very High	3.0	3.0	2.7	1.6	1.8	2.6	2.6	2.5	1.8	1.6	1.6	2.2

Oil Type Impacts

The tables below demonstrate the general environmental injury ranking scores and environmental effects of oils by type which were factored into the environmental sensitivity multipliers in the previous section.

[127] Note that non-persistent (NP) oil has a very low effect on oil receptor types because it evaporates so readily.

Table A-29: Environmental Injury Ranking Scores by Oil Type[128]

Oil Type	CDFW-OSC Oil Category	Relative Ranking[129]		
		Acute Toxicity[130]	Mechanical Injury[131]	Persistence[132]
Crude Oil[133]	MP	0.9	3.6	5.0
No. 6 Fuel Oil (Bunker)	HP	2.3	5.0	5.0
No. 2 Fuel Oil (Diesel)	LP	2.3	3.2	2.0
Gasoline	NP	5.0	1.0	1.0
No. 1 Fuel Oil (Jet Fuel)	NP	1.4	2.4	1.0

Table A-30: Properties of Different Oils and Environmental Effects[134]

Oil Type	CDFW-OSC Oil Category	Relative Ranking[135]				
		Plant Toxicity	Water Threat	Viscosity	Adhesion	Penetration
Gasoline	NP	5	5	1	1	5
No. 2 Fuel Oil (Diesel)	LP	2	3	2	2	4
Light Crude	MP	4	4	3	3	3
Heavy Crude	HP	3	2	4	4	2
No. 6 Fuel Oil (Bunker)	HP	1	1	5	5	1

Additional Adjustments for Shoreline Proximity

The values in Table A-23 through Table A-26 assume a mix of nearshore, coastal, and offshore impacts (i.e. all considered "marine" under current CDFW OSPR regulations and not applicable to inland spills to dry water). If a spill occurs in a nearshore area or within a port, the costs can be multiplied by a factor of 2.5 to take into account the greater costs that may be incurred due to greater shoreline oiling. In addition, impacts to ports tend to cause particularly high damage claims as there are clear economic impacts of blocking port activities during response operations.

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[128] Based on Washington Administrative Code 1992.

[129] Relative ranking scores range from 1 to 5, where 1 represents the least harmful effect and 5 represents the most harmful effect.

[130] Acute toxicity score determined by summing weighted averages of the 1-, 2-, and 3-ringed aromatic compounds and dividing this sum by 107, where aromatic compound composition is determined by the solubility of the aromatic compounds.

[131] Mechanical injury is equal to (SP-0.688)/0.062, where SP = specific gravity of the spilled oil. (Mechanical injury is related to the adherence and heaviness of the oil on bird feathers, fur, and other environmental receptors.)

[132] Persistence ranking is based on: 5 = persistence of 5 – 10 years or more; 4 = 2 – 5 years; 3 = 1 – 2 years; 2 = 1 month to 1 year; and 1 = days to weeks.

[133] Based on Prudhoe Bay crude oil. Other crude oils may be heavier or lighter and have different characteristics.

[134] Based on Fingas 2001.

[135] Relative ranking scores range from 1 to 5, where 1 represents the lowest degree and 5 represents the highest degree.

Summary of Methodological Approach

The overall methodological approach to the development of the CDFW-OSC Model involved (Figure):

1. Calculation of average per-bbl response costs by overall ERC Spill Cost Database (all cases), Region, and Nations represented in the ERC Spill Cost Database;
2. Calculation of per-bbl response costs with time-scaling to take into account the overall increases in response costs beyond adjustments for inflation;
3. Analysis to determine "outlier" cases;
4. Development of four different approaches to estimating per-bbl response cost–Highest (based on time-scaled data including outliers), High (based on time-scaled data excluding outliers), Medium (based on original data in 2019 US dollars including outliers), and Low (based on original data in 2019 US dollars excluding outliers), to provide costs for by risk tolerance level;
5. To adjust for over-representation of US cases in the calculation of averages, the grand averages by Region were used rather than the overall ERC Spill Cost Database average;
6. The Region averages were then adjusted for the individual regions by applying a GDP PPP correction factor to allow for general economic differences between regions worldwide;
7. These averages were then further adjusted to take into account differences in dispersant response policy, which would have a significant effect on overall costs and damages (dispersants tend to reduce shoreline oiling, cleanup, and damage costs);
8. The Region dispersant adjusted averages were then further modified based on oil type; and
9. An optional ecological sensitivity index was provided to allow for unusually high costs based on the presence of certain types of ecological receptors in some areas.

The four calculation approaches–Highest, High, Medium, and Low–result in a range of potential costs. The costs that would be realized in an actual spill scenario would be dependent on the factors of the incident itself. There will be circumstances in which the costs are particularly high due to extenuating circumstances, making the incident an "outlier" case. The Highest and Medium approaches take these outliers into consideration. The Highest and High approaches additionally take into account that there has been an over-arching trend towards increased costs for spills, even after adjustments for inflation. This is attributable to increased public concern about effects of spills and higher standards for cleanup.

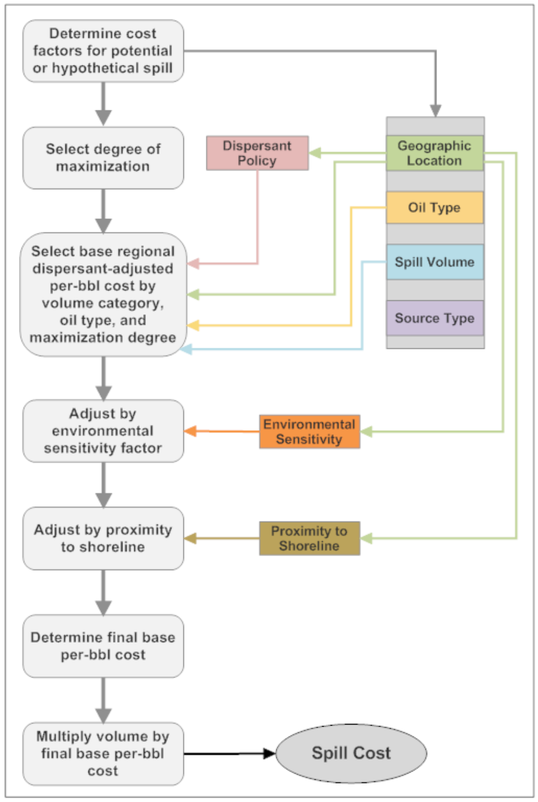

Figure A-36: Basic Algorithm of CDFW-OSC Model

Summary of Costs by Global Geographic Zones

Total per-bbl costs (adjusted for environmental sensitivity, shore proximity, and dispersant policy) are shown by US region and shoreline proximity by oil type in Table A-31 through Table A-34 for large spill volumes.

Table A-31: Ranked Total Per-Bbl Costs by Region and Shoreline Proximity (NP Oil)

Region	Shore Proximity	Per-Bbl DPAC w/ ESM by Maximization Approach (Large Volume)			
		Highest Cost	High Cost	Medium Cost	Low Cost
US East	Nearshore	$17,707	$13,481	$6,968	$4,766
US East	Offshore	$8,485	$6,459	$3,339	$2,284
US Gulf	Nearshore	$17,872	$13,607	$7,034	$4,809
US Gulf	Offshore	$9,280	$7,065	$3,653	$2,497
US West	Nearshore	$15,882	$12,092	$6,249	$4,274
US West	Offshore	$2,193	$1,650	$814	$531

Table A-32: Ranked Total Per-Bbl Costs by Region and Shoreline Proximity (LP Oil)

Region	Shore Proximity	Per-Bbl DPAC w/ ESM by Maximization Approach (Large Volume)			
		Highest Cost	High Cost	Medium Cost	Low Cost
US East	Nearshore	$35,414	$26,961	$13,936	$9,532
US East	Offshore	$16,969	$12,918	$6,678	$4,567
US Gulf	Nearshore	$35,743	$27,213	$14,068	$9,618
US Gulf	Offshore	$18,559	$14,130	$7,305	$4,994

Region	Shore Proximity	Per-Bbl DPAC w/ ESM by Maximization Approach (Large Volume)			
		Highest Cost	High Cost	Medium Cost	Low Cost
US West	Nearshore	$31,764	$24,183	$12,498	$8,547
US West	Offshore	$4,385	$3,299	$1,627	$1,061

Table A-33: Ranked Total Per-Bbl Costs by Region and Shoreline Proximity (MP Oil)

Region	Shore Proximity	Per-Bbl DPAC w/ ESM by Maximization Approach (Large Volume)			
		Highest Cost	High Cost	Medium Cost	Low Cost
US East	Nearshore	$43,349	$32,999	$17,057	$11,669
US East	Offshore	$20,291	$15,446	$7,984	$5,462
US Gulf	Nearshore	$43,821	$33,363	$17,247	$11,794
US Gulf	Offshore	$22,340	$17,008	$8,792	$6,013
US West	Nearshore	$38,805	$29,539	$15,268	$10,445
US West	Offshore	$16,243	$12,365	$6,391	$4,372

Table A-34: Ranked Total Per-Bbl Costs by Region and Shoreline Proximity (HP Oil)

Region	Shore Proximity	Per-Bbl DPAC w/ ESM by Maximization Approach (Large Volume)			
		Highest Cost	High Cost	Medium Cost	Low Cost
US East	Nearshore	$79,316	$60,386	$31,215	$21,347
US East	Offshore	$33,202	$25,278	$13,067	$8,936
US Gulf	Nearshore	$87,642	$66,725	$34,488	$23,588
US Gulf	Offshore	$44,680	$34,017	$17,582	$12,026
US West	Nearshore	$70,386	$53,582	$27,700	$18,943
US West	Offshore	$25,267	$19,234	$9,944	$6,799

Selection of Risk Tolerance Approach

The different approaches to the calculation of the per-bbl base response costs upon which the total costs rely are outlined in Table A-35. The main drivers are the adjustment for year, which takes into account the fact that costs for spills overall appear to be increasing in excess of expected inflation rates, and the inclusion of outliers. The outliers are particular cases that, on a per-bbl basis, are extremely high compared with all the other cases. These cases represent peculiar circumstances that would drive costs extremely high. On average, the Highest base response costs are nearly four times greater than the Low costs.

Table A-35: Different Approaches to Calculation of Per-Unit Base Response Costs

Calculation Approach	Relative Result Degree of Cost Maximization	Year Adjustment	Outliers Included
Time-Scaled with Outliers	Highest Cost	YES	YES
Time-Scaled without Outliers	High Cost	YES	NO
Non-Time Scaled (Original) with Outliers	Medium Cost	NO	YES
Non-Time Scaled (Original) without Outliers	Lowest Cost	NO	NO

With respect to selection of Risk Tolerance Approach for estimating potential spill costs, a number of factors should be considered. There does appear to be a trend of increasing costs for spills that exceeds the expected inflation adjustments. This is likely due to heightened public concern and awareness about spills, which would tend to call for increased cleanup response standards, as well as a certain measure of punitive measures against spillers. The outliers are relatively rare cases that appear to increase the average costs by category due to peculiar circumstances. However, there may also be a measure of punitive measures involved depending on the location of the spill and political circumstances.

The Highest-Cost category incorporates both of these cost increase factors. It would, therefore be the most "conservative" or "precautionary" approach in that it would take into account unlikely, but possible, extreme costs. For risk management purposes, this might best reflect the potential cost risk exposure.

The High-Cost category incorporates the reasonable assumption of general cost increases, but omits the outlier cases. This approach can be characterized as the most "reasonable" approach in that it most likely takes into account expected cost increases, but does not maximize the costs. For risk management purposes, this might best reflect the most likely cost risk exposure. This may be appropriate for planning purposes when coupled with a spill probability analysis.

The Medium-Cost category assumes that there is no general cost increase over time but that there may be outlier cases that should be considered. This is a relatively optimistic perspective on spill costs.

The Low-Cost category assumes that there is no general cost increase and omits outlier cases from the calculations. This approach most likely grossly underestimates costs and may be considered to be overly optimistic.

The term "risk tolerance approach" refers to the degree of cost maximization. Depending on the application of the cost modeling for the user, the "risk tolerance" may have different implications. If it is vitally important not to risk under-estimating the cost, for example for the purpose of determining insurance or financial responsibility levels to cover all potential contingencies, it may be prudent to rely on the "Highest-Cost" estimates. This may be appropriate for catastrophic risk insurance purposes. Note that the outlier cases that are reflected in the Highest-Cost category would most likely affect highly politicized cases. These would most likely be in places that have a particularly high environmental sensitivity (e.g., affecting sensitive wetlands or endangered species habitats), cultural sensitivity (e.g., affecting indigenous lands), or socioeconomic value (e.g., beach-front real estate or tourist areas).

Generally, the recommended approach is the High-Cost category for most planning purposes. This would cover the expected costs for oil spills under most reasonable circumstances.