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# Analysis of Past Marine Oil Spill Rates and Trends For Future Contingency Planning

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## Abstract

Analyses of thirty years of US and international marine oil spill data have revealed that spillage rates have generally decreased despite overall increases in oil production and transportation (Etkin, 2001). At the same time, occasional large spills ─ along with increasing expectations of effective spill response ─ have necessitated complex contingency planning for increasingly rare high-impact events.

Past oil spill trends for vessels from 1985-2000 and potential future spill rates in light of improvements implementation of double hulls on tankers and bunker tanks are analyzed with regard to future contingency planning needs in the US. A methodology for determining "theoretical" and "most-likely" worst-case oil spill scenarios for contingency planning for ports will be described.

## 1 Introduction

Analyses of US and international marine oil spill data reveals that rates of spillage have generally decreased worldwide and in the US despite overall increases in oil transport (Etkin, 2001). However, occasional large spills ─ along with an increasing expectation and obligation to respond effectively to such spills ─ have necessitated complex contingency planning for increasingly rare high-impact events along with more probable events. Determining what to expect and plan for in terms of worst-case discharges and most-probable discharges proves to be a challenge for contingency planners worldwide.

## 2 Methodology

### 2.1 Definitions

Terms were defined as follows:

- *Allision:* striking of a moving object into a stationary object. In the case of vessels, this includes a vessel striking a stationary object, e.g., a pier, or a vessel being struck by another vessel while the first vessel is stationary.
- *Collision:* impact of two vessels each of which is in motion.
- *Historical worst-case discharge (WCD):* spill size that represents that largest *recorded (historical)* spill size from a particular source type for a particular location.
- *Illegal discharges:* all spills due to intentional discharges, bilge pumping, or other activities, or unintentional discharges not related to accidents or failures.
- *Most-probable worst-case discharge (WCD):* largest spill size expected based on historical US national data on the maximum recorded percent cargo or fuel loss;

this volume is generally less than the theoretical worst-case discharge (WCD) unless the total loss of cargo or fuel has occurred.

- *Percentile spills: $n^{th}$* percentile spill is that spill volume larger than *n%* of spills for that source and type and is smaller than 100 - *n%* of spills; e.g., the spill size for the "10th percentile spill" is defined as the spill size larger than 10% of all spills, but smaller than 90% of all spills.
- *Potential spill sizes:* spill volumes for historical spills that represent amounts that would have spilled if theoretical worst-case discharges (WCD) had occurred.
- *Probability distribution function (PDF):* graphed curve (function) showing cumulative probabilities of spill sizes from which percentile spills can be determined.
- *Structural failure:* breaking apart of any part of a vessel that is not attributable to a collision, allision, or grounding, but rather due to weakness or wearing of the structure of the vessel, e.g., corrosion, or due to the impact of weather or waves.
- *Theoretical worst-case discharge (WCD):* size of the largest *possible* oil spill from a particular source (e.g., the total oil cargo or fuel on a vessel).

## 2.2 Vessel Spill Scenario Methodology

Vessel types included in the analyses of spill scenarios included: tankers, barges, and freighters (bulk carriers, container vessels, cargo vessels), fishing vessels, and passenger vessels over 300 GRT. Data from the Environmental Research Consulting databases for oil spills into US navigable waterways from vessels over 300 GRT during 1985-2000 were analyzed to develop probability distribution functions (PDFs) of *actual* spill volumes and *potential* spill volumes (theoretical worst-case discharges based on cargo or bunker capacity). The PDFs were analyzed to determine various percentile spills, and worst-case discharges (WCDs).

The vessel spill data were also analyzed to determine the percentage of cargo or bunker fuel spilled for each incident involving an accidental cause (collision, grounding, allision, sinking, structural failure, and/or fire/explosion). Cargo tanks were assumed to be 80% full and bunker tanks were assumed to be 70% full, based on standard methodologies employed by tanker engineers and naval architects (Michel and Thomas, 2000; Rawson, et al., 1998). The percentage of spills representing the different percent cargo or fuel losses were calculated.

*Theoretical* future oil spill volumes were determined based on application of cargo- and fuel-loss percentages and probabilities for different-sized and types of vessels from US data onto the vessel sizes/types transiting Washington waters and San Francisco Bay. This provided an analysis of the potential spill volumes that should be prepared for in Washington state waters and San Francisco Bay given current vessel traffic. The 10th -, 25th -, 50th -, 75th -, 90th, and 95th-percentile spills and most-probable worst-case discharge and theoretical worst-case discharge were determined for all vessel types (over 300 GRT) for Washington waters.

The oil spills that occurred in Washington State between 1985-2000 were analyzed to determine historical and potential PDFs and percentile spills. This analysis provides an examination of the types of spills that have occurred and the spill volumes that those incidents would have involved had there been theoretical WCDs.

*Theoretical* future oil spill volumes specifically from groundings by deep-draft vessels were determined based on application of the cargo- and fuel-loss percentages and probabilities for different-sized and types of vessels from US national and international data onto the vessel sizes and types that transit San Francisco Bay. The analysis focused on vessels drafts deep enough to ground on rock pinnacles present in San Francisco Bay.

These analyses do not provide an assessment of the actual risk of an oil spill occurring in US waters, San Francisco Bay, or Washington State waters, but only an assessment of the types of spill volumes that might be expected when spills do occur. A theoretical worst-case discharge (total loss of oil cargo) from a fully-loaded large tanker did not occur in US waters during 1985-2000, though a few such incidents (involving the sinking or hard drift groundings of fully-loaded tankers) have occurred in foreign waters and two incidents involving smaller tankers occurred in US waters prior to 1985 (Tables 1 - 2). It is theoretically possible for such a spill to occur in San Francisco Bay, Washington State and other parts of the US.

Table 1 Worst-Case Discharge Tanker Spills In Non-US Waters (1985-2000) (not including military-related incidents) (DWT>10,000)

| Date | Tanker (DWT) | Est. Cargo[1] | Amt. Spilled | % Loss | Location |
|---|---|---|---|---|---|
| Apr-88 | Athenian Venture (31,016) | 10,602,000 gal (36,061 t) | 10,602,000 gal (36,061 t) | 100% | Canada |
| Nov-88 | Odyssey (140,616) | 43,100,000 gal (146,600 t) | 43,100,000 gal (146,600 t) | 100% | Canada |
| Oct-94 | Thanassis A. (38,263) | 10,900,000 gal (37,075 t) | 10,900,000 gal (37,075 t) | 100% | Hong Kong |
| Jun-85 | Kinsei Maru (2,990) | 840,000 gal (2,857 t) | 840,000 gal (2,857 t) | 100% | Japan |
| Apr-92 | Katina P. (69,992) | 19,609,800 gal (66,700 t) | 19,609,800 gal (66,700 t) | 100% | South Africa |
| Jan-93 | Braer (89,730) | 25,000,000 gal (85,034 t) | 25,000,000 gal (85,034 t) | 100% | UK |
| Jan-94 | Cosmas A. (27,643) | 7,081,000 gal (24,085 t) | 7,081,000 gal (24,085 t) | 100% | Hong Kong |
| Jan-01 | Ife (10,671) | 3,386,292 gal (11,518 t) | 3,386,292 gal (11,518 t) | 100% | Nigeria |
| Jun-97 | Da Qing 243 (24,704) | 7,473,600 gal (25,320 t) | 5,000,000 gal (17,000 t) | 82% | China |
| Dec-92 | Aegean Sea (114,036) | 34,500,000 gal (117,343 t) | 21,900,000 gal (74,490 t) | 78% | Spain |
| Apr-91 | Haven (232,163) | 70,235,300 gal (238,896 t) | 42,336,000 gal (144,000 t) | 74% | Italy |

[1]Cargo capacity estimated from deadweight tonnage (assumed 80% full).
Source: Environmental Research Consulting

# 3 US Tanker Oil Spill Analysis

## 3.1 US Tanker Spills ─ All Spill Causes

The actual and potential (theoretical) WCD spill sizes for tanker spills in US waters, *regardless of the cause* of the spills, is shown in Figure 1. The “potential spills” represent the size of spills that would have occurred if each of the actual incidents had involved the loss of the entire tanker’s cargo contents. Excluding all spills of less than 1,000 gallons (3.4 tonnes) (which excludes most lightering, illegal spillage incidents, etc.), the same curves are shown in Figure 2.

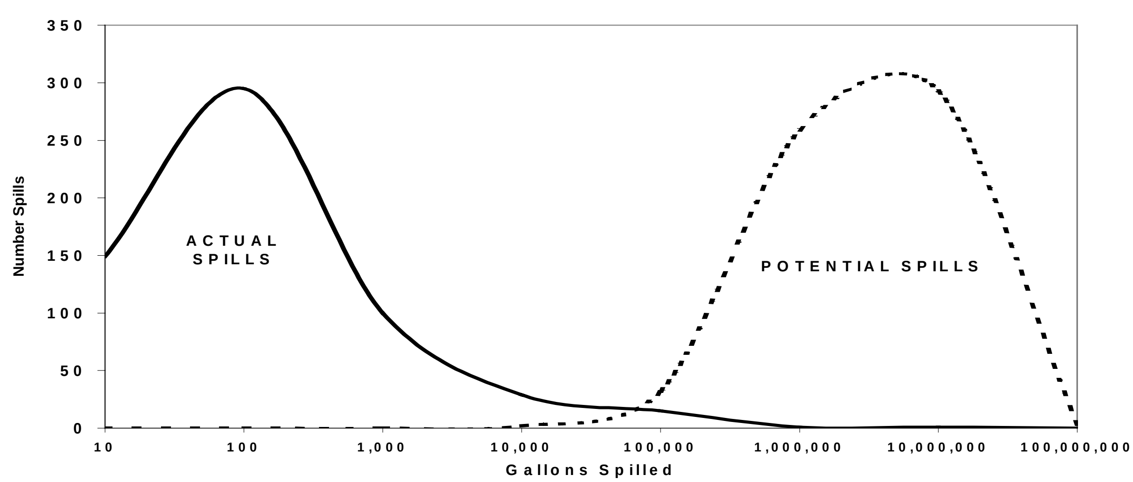
PDFs for actual spill sizes and potential (theoretical) WCDs for tanker spills in US waters produced the percentile spills shown in Table 3. This analysis shows WCDs for all types of spills regardless of cause. Since in practicality, the WCDs may not be applicable for spills related to bunkering, lightering, and loading activities, or other discharges not directly related to an accident, such as a grounding or collision. For this reason, the analyses were repeated based on spill cause.

Table 2 Worst-Case Oil Discharges From Tankers In and Near US Waters

| Date | Tanker (DWT) | Estimated Cargo[1] | Amt. Spilled | Loss | Location |
|---|---|---|---|---|---|
| Feb-77 | *Hawaiian Patriot* (101,038) | 31,185,000 gal (106,070 t) | 31,185,000 gal (106,070 t) | 100% | Pacific Ocean 595 km off Hawaii |
| Feb-68 | *Pegasus* (30,000) | 9,597,000 gal (32,643 t) | 9,597,000 gal (32,643 t) | 100% | N Atlantic Ocean off Maine |
| Feb-68 | *Mandoil II* (42,000) | 12,930,120 gal (43,980 t) | 12,930,120 gal (43,980 t) | 97% | Pacific Ocean off Oregon |
| Jan-70 | *Gezina Brovig* (16,000) | 4,925,760 gal (16,754 t) | 4,704,000 gal (16,000 t) | 95% | Caribbean Sea, off NW Puerto Rico |
| Nov-69 | *Keo* (30,000) | 9,235,800 gal (31,414 t) | 8,800,000 gal (29,932 t) | 95% | N Atlantic Ocean 200 km off Massachusetts |
| Apr-75 | *Spartan Lady* (20,724) | 6,380,091 gal (21,700 t) | 6,000,000 gal (20,408 t) | 94% | Atlantic Ocean 32 km SE New York |
| May-75 | *Epic Colocotronis* (64,000) | 19,703,040 gal (67,017 t) | 17,955,000 gal (61,071t) | 91% | Caribbean Sea 100 km NW Puerto Rico |
| Oct-66 | *Gulfstag* (20,000) | 6,157,200 gal (20,943 t) | 5,586,000 gal (19,000 t) | 91% | Gulf of Mexico off Texas |
| Mar-71 | *Texaco Oklahoma* (35,072) | 10,797,266 gal (36,725 t) | 9,450,000 gal (32,143 t) | 88% | N Atlantic Ocean off Maine |
| Dec-76 | *Argo Merchant* (28,691) | 8,832,811 gal (30,044 t) | 7,700,000 gal (26,190 t) | 87% | Atlantic Ocean 40 km ESE Massachusetts |

[1]Cargo capacity estimated from deadweight tonnage (assumed 80% full).
Source: Environmental Research Consulting Databases

Figure 1 Actual Tanker Spill Sizes Vs. Potential Worst-Case Discharge Spill Sizes For Tanker Spills in US Waters (1985-2000)



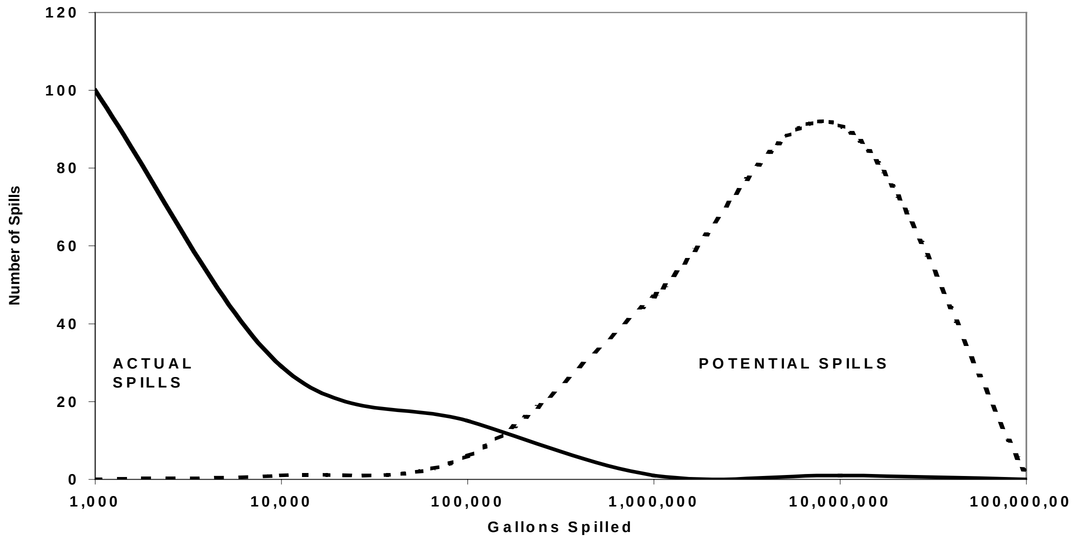



Figure 2 Actual Vs. Potential WCD Spill Sizes For Tanker Spills Over 1,000 Gallons in US Waters (1985-2000)

Table 3 Actual Vs. Potential Oil Spill Volumes From Tankers In US Waters (1985-2000) – All Causes

| Percentile Spill | Actual | Potential |
|---|---|---|
| 10th percentile | 35 gal | 1,100,000 gal |
| 25th percentile | 70 gal | 6,000,000 gal |
| 50th percentile | 125 gal | 10,000,000 gal |
| 75th percentile | 600 gal | 21,000,000 gal |
| 90th percentile | 6,000 gal | 30,000,000 gal |
| 95th percentile | 30,000 gal | 55,000,000 gal |
| Worst Case Discharge[1] | 11,000,000 gal | 108,000,000 gal |
| [1]Actual WCD = historical WCD or most-probable WCD; Potential WCD = theoretical WCD. | | |

### 3.2 US Tanker Spills ─ Accidents

The actual and potential oil spill volumes from tanker accidents involving collisions, allisions, and groundings are shown in Figure 3. The corresponding PDFs are shown in Figures 4 – 5. The "potential spills" represent the size of spills that would have occurred if the incidents had involved the loss of the entire tanker's cargo contents. The percent cargo loss (assuming 80% capacity) and the probability of each percent loss (represented by the percent total spill) are shown in Figure 6. The analysis was repeated for tanker spills involving structural failure, fires or explosions, and sinking, as shown in Figures 7 - 10.

### 3.3 US Tanker Spills ─ Lightering/Loading and Pollution Incidents

Tanker spills in US waters related to lightering, loading, and refueling were analyzed to develop the PDF shown in Figure 11. Incidents related to other causes, e.g., illegal discharges, and bilge washing, were analyzed to develop the PDF in Figure 12. Spills from lightering, loading, and refueling, as well as other pollution incidents tend to be smaller than those related to accidents.

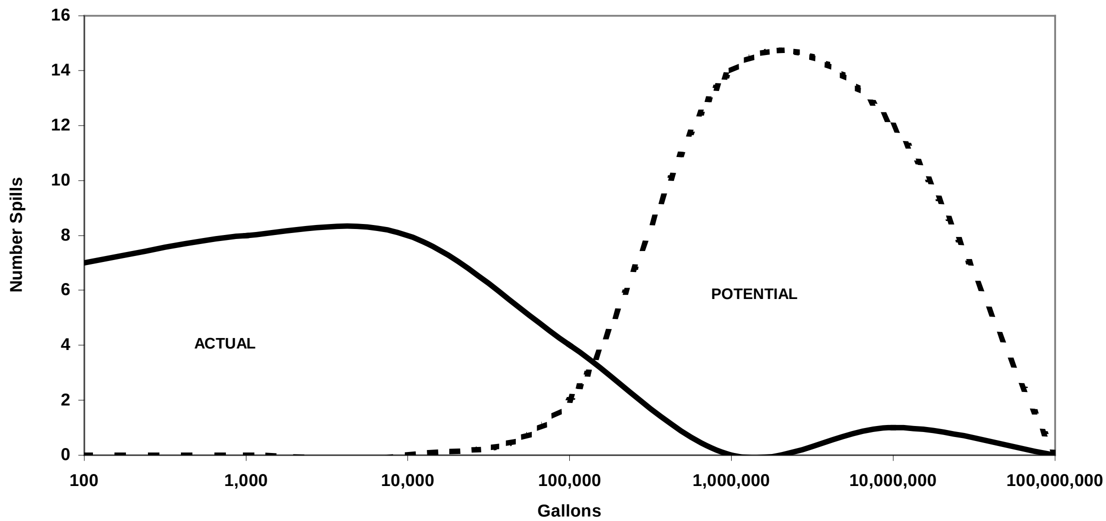



Figure 3 Actual Tanker Spills Vs. Potential Tanker Spills Due to Allisions, Collisions, and Groundings (US Waters 1985-2000)

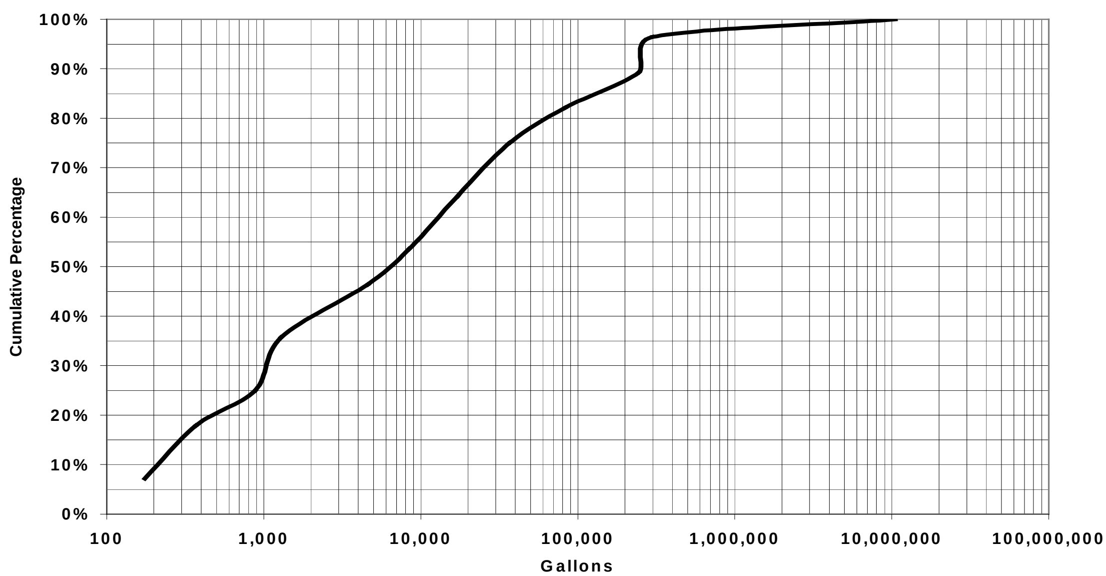



Figure 4 PDF of Actual Oil Spill Sizes
From Tanker Allisions, Collisions, and Groundings In US Waters 1985-2000

## 4. US Barge Oil Spill Analysis

### 4.1 US Barge Spills ─ Accidents

The same analyses were performed for barge spills due to accidents, again separating collisions, allisions, and groundings from other structural failures, sinking, and explosions. The results are shown in Figures 13 – 16 for accidents involving collision, allision, or grounding, and in Figures 17 – 20 for accidents involving structural failure, sinking, or explosion/fire. The smaller amount of cargo generally present on barges makes these incidents tend to be smaller than tanker spills.

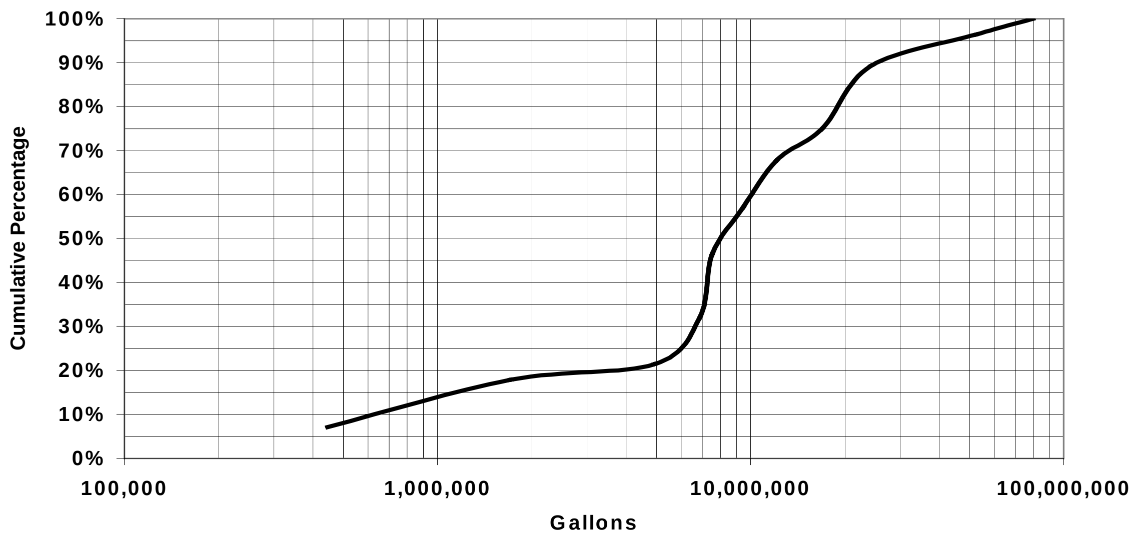



Figure 5 PDF of Potential WCD (US Tanker Allisions, Collisions, Groundings) in US Waters (1985 – 2000)

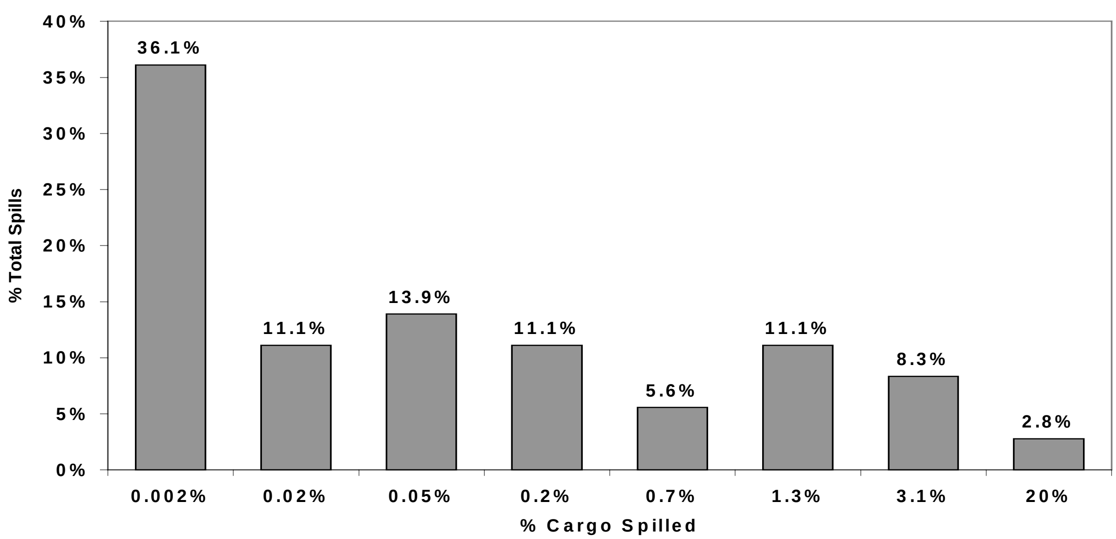



Figure 6 Percentage Cargo Spilled in Tanker Groundings, Allisions, and Collisions Resulting in Oil Spillage in US Waters 1985-2000

**4.2 US Barge Spills – Lightering/Loading and Pollution Incidents**

As with tankers, smaller incidents can occur during lightering and loading, as well as illegal discharges and other pollution events, in the spill sizes shown in the PDFs in Figures 21 – 22.

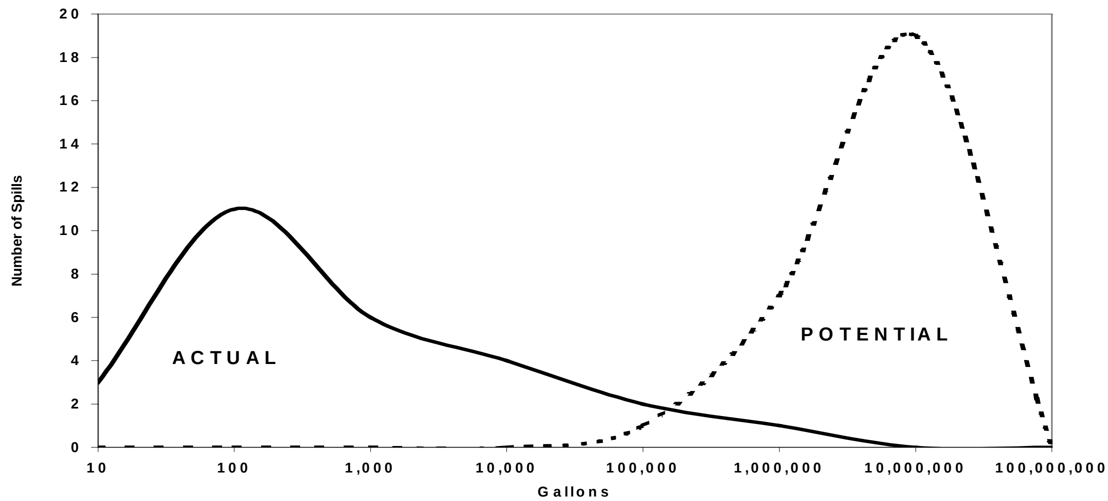



Figure 7 Actual Vs. Potential Worst-Case Discharge Spillage in Other Tanker Accidents US Waters 1985-2000 (Structural Failure, Fire, Sinking)

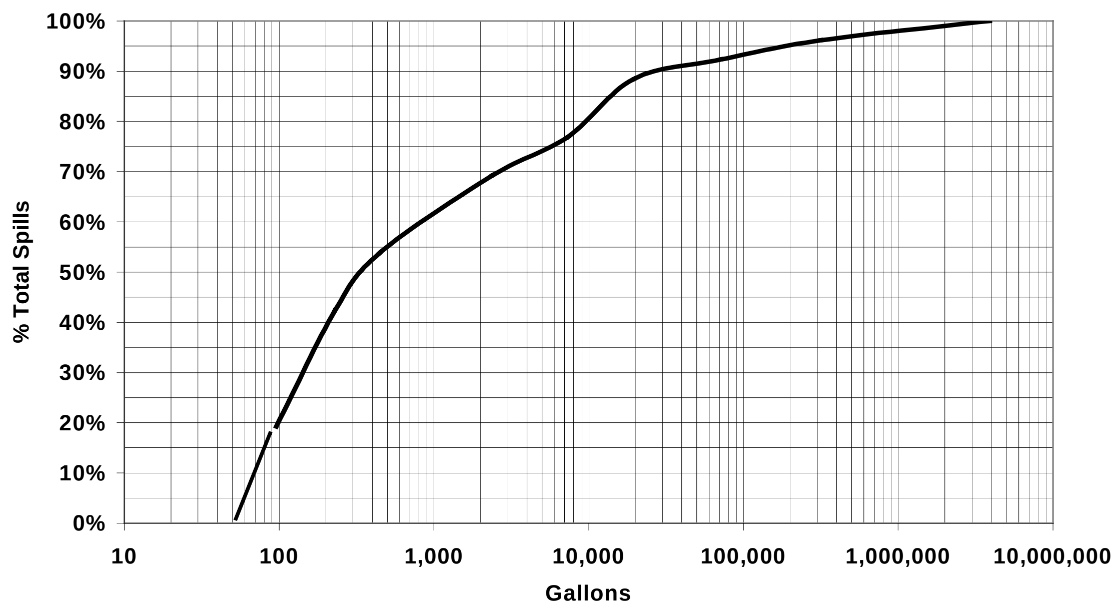



Figure 8 PDF of Oil Spillage From Tanker Accidents (Structural Failure, Fire, Sinking) In US Waters 1985-2000

# 5 US Freight Vessel Oil Spill Analysis

## 5.1 Freight Vessel Accidents

Freighters can spill oil in bunker fuel tanks in accidents. Analysis results for allisions, collisions, and groundings are shown in Figures 23 – 26, and for structural failure, explosion/fire, and sinking in Figures 27 – 30.

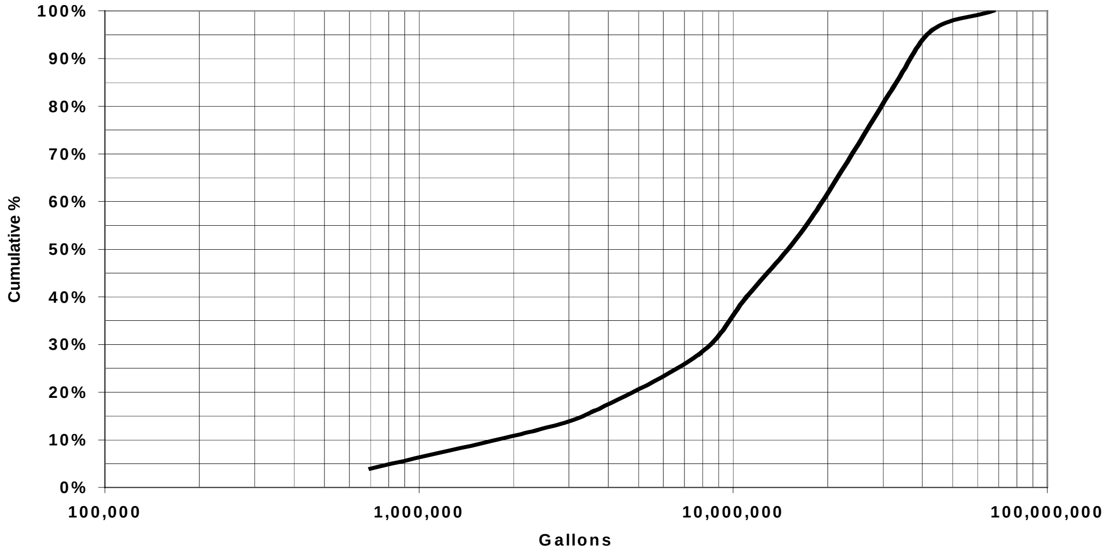



Figure 9 PDF of Potential WCD Spillage For Tanker Accidents (Structural Failure, Fire, Sinking) In US Waters (1985-2000)

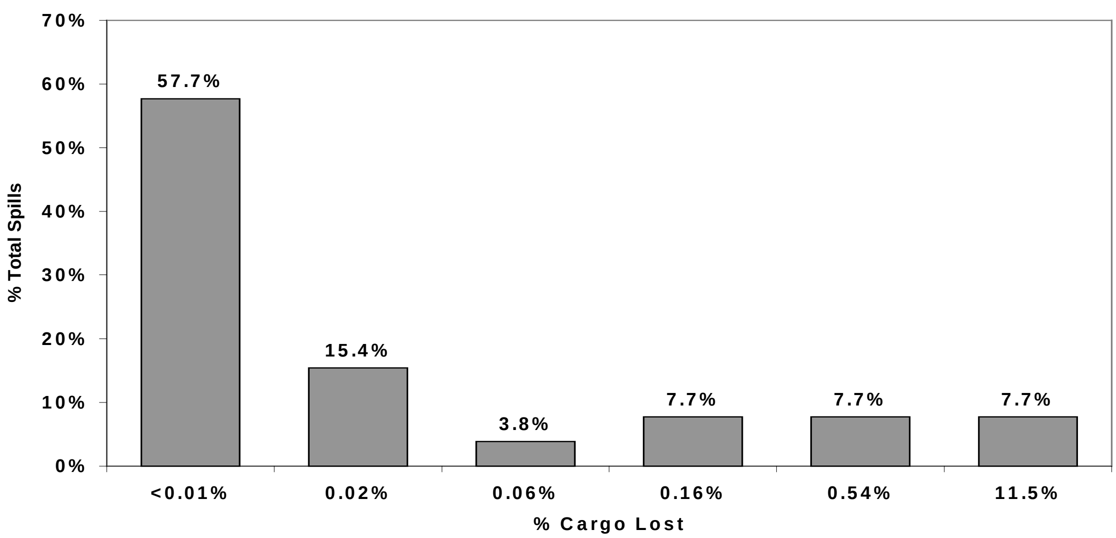



Figure 10 Percentage Cargo Spilled In Other Tanker Accidents (Structural Failure, Fire, Sinking) in US Waters (1985-2000)

## 5.2 Freight Vessel Bunkering/Fueling Incidents

PDFs of spill size for incidents involving bunkering/fueling, and illegal discharges are shown in Figures 31 – 32.


Figure 11 PDF of Oil Spill Volumes From Tanker Lightering/Loading/ Bunkering Activities In US Waters (1985-2000)

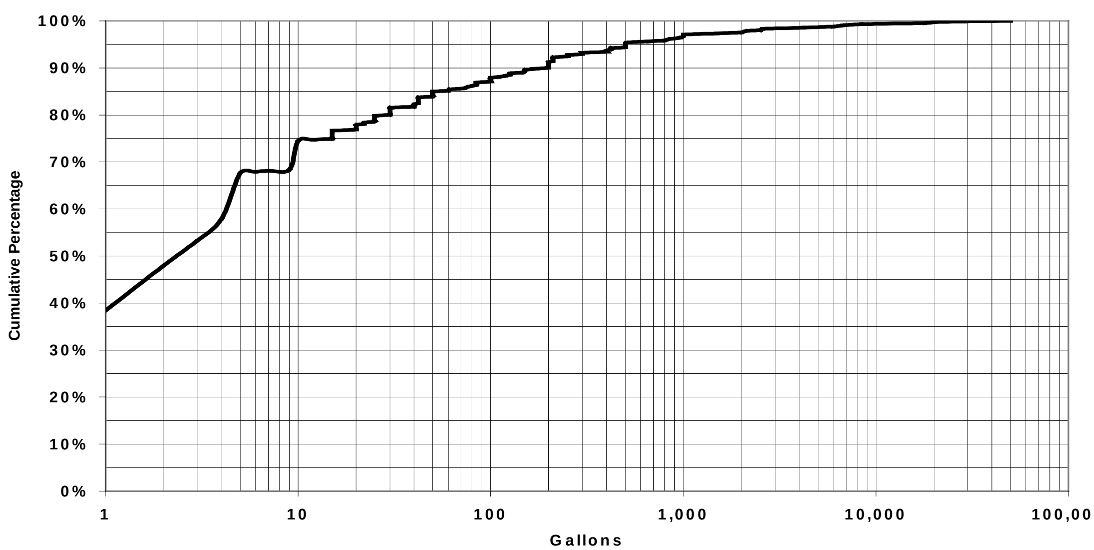



Figure 12 PDF of Oil Spill Sizes From Illegal Discharges and Other Pollution Incidents From Tankers In US Waters (1985-2000)

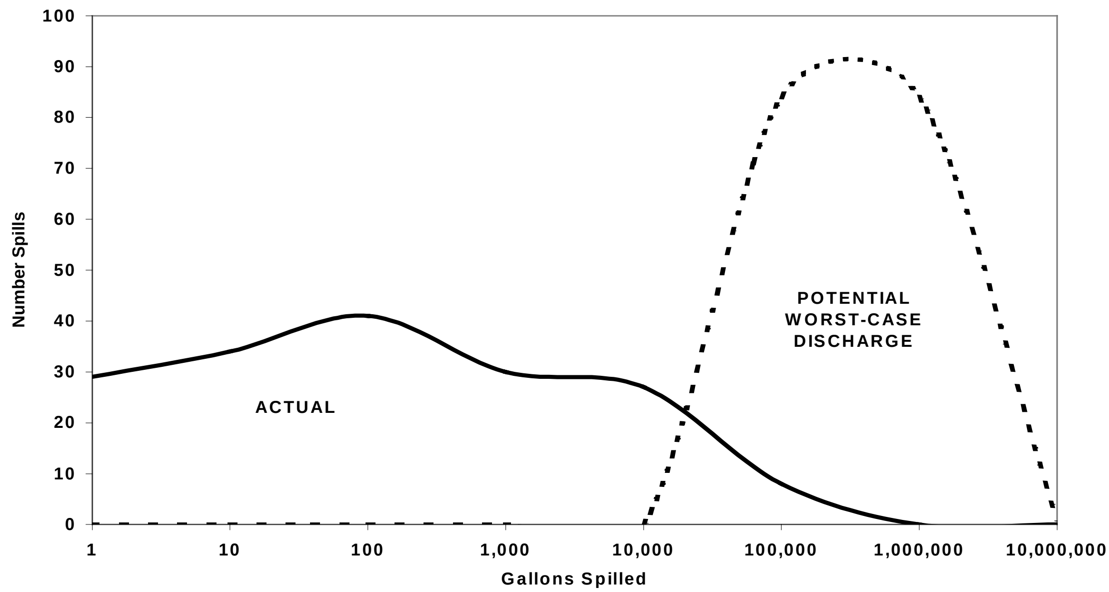



Figure 13 Actual Vs. Potential Oil Spillage From Tank Barge Accidents (Allisions, Collisions, and Groundings) In US Waters (1985-2000)

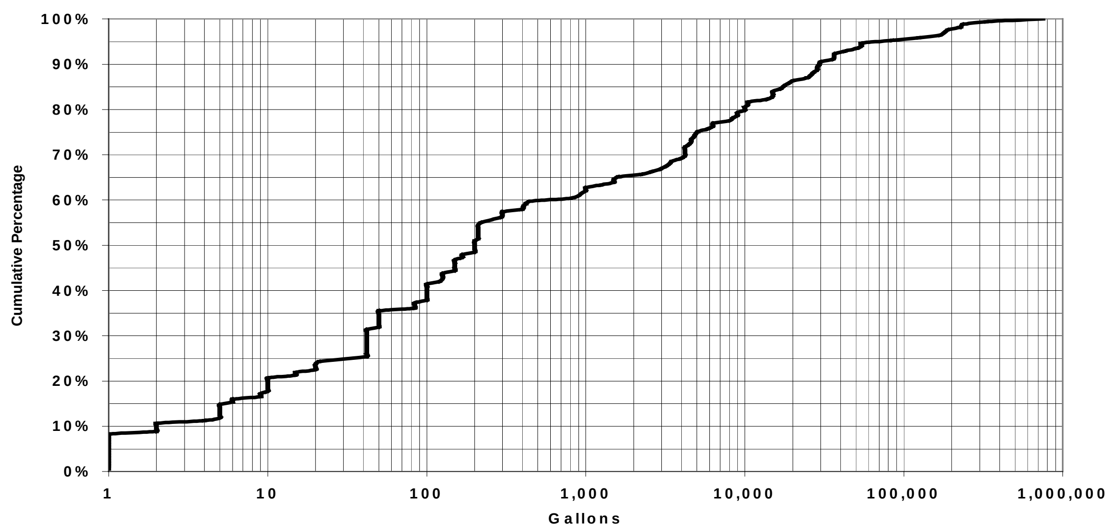



Figure 14 PDF of Oil Spill Sizes From Tank Barge Accidents (Allisions, Collisions, Groundings) In US Waters (1985-2000)

## 6 All Vessel Type Analysis

The analyses were also performed for bunkering/fueling and illegal discharge incidents for fishing vessels and passenger vessels over 300 GRT. The actual and potential spill volumes for all vessel types by spill cause are shown in Table 4. Note that there are no potential volumes calculated for fueling/bunkering or illegal discharges as it is assumed that these incidents are not likely to involve the release of the entire fuel tanks as might occur in a casualty involving allision, collision, grounding, structural failure, fire/explosion, or sinking.

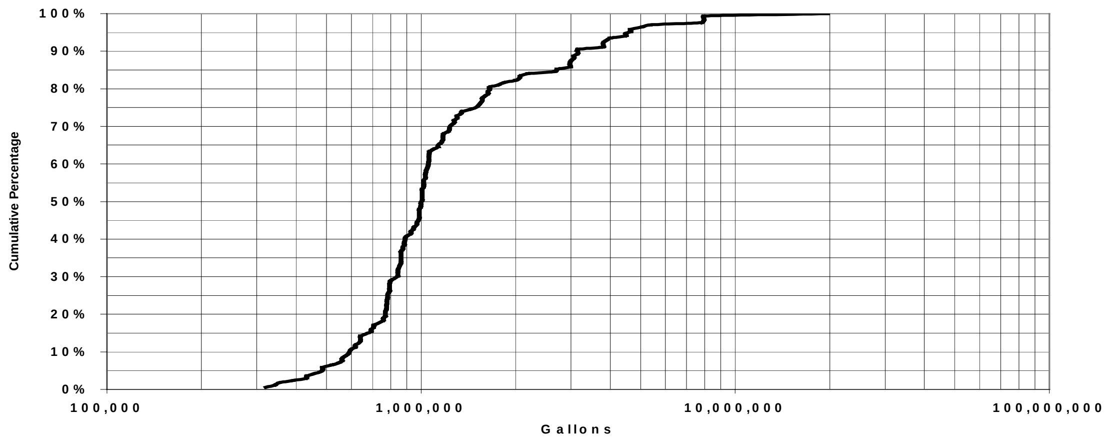



Figure 15 PDF of Potential Worst-Case Discharge Spill Volumes For Tank Barge Accidents (Allisions, Collisions, Groundings) In US Waters (1985-2000)

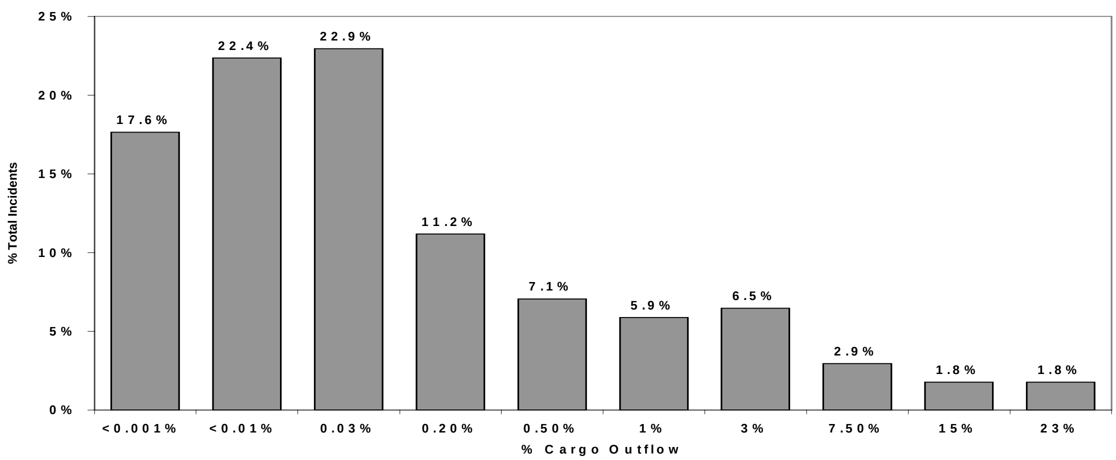



Figure 16 % Cargo Outflow From Tank Barge Accidents (Allisions, Collisions, Groundings) In US Waters (1985-2000)

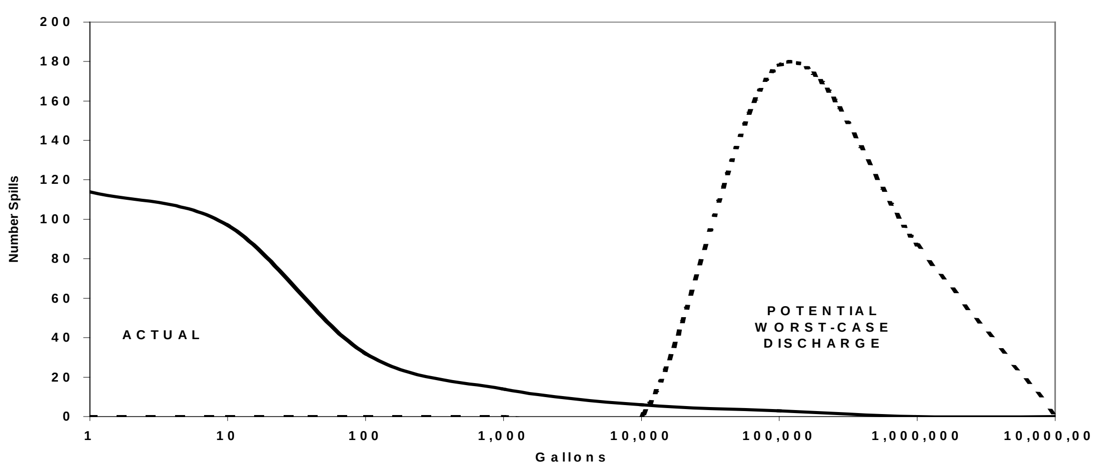



Figure 17 Actual Vs. Potential Worst-Case Discharge Oil Spill Volumes From Tank Barge Accidents (Structural Failure, Fire, Sinking) In US Waters (1985-2000)

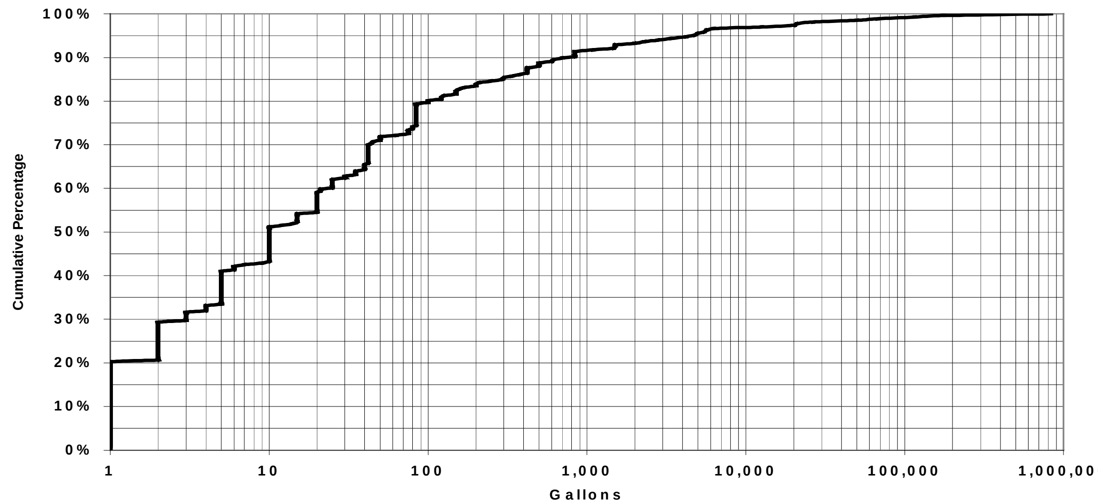



Figure 18 PDF For Actual Oil Spills From Tank Barge Accidents (Structural Failure, Fire, Sinking) In US Waters (1985-2000)

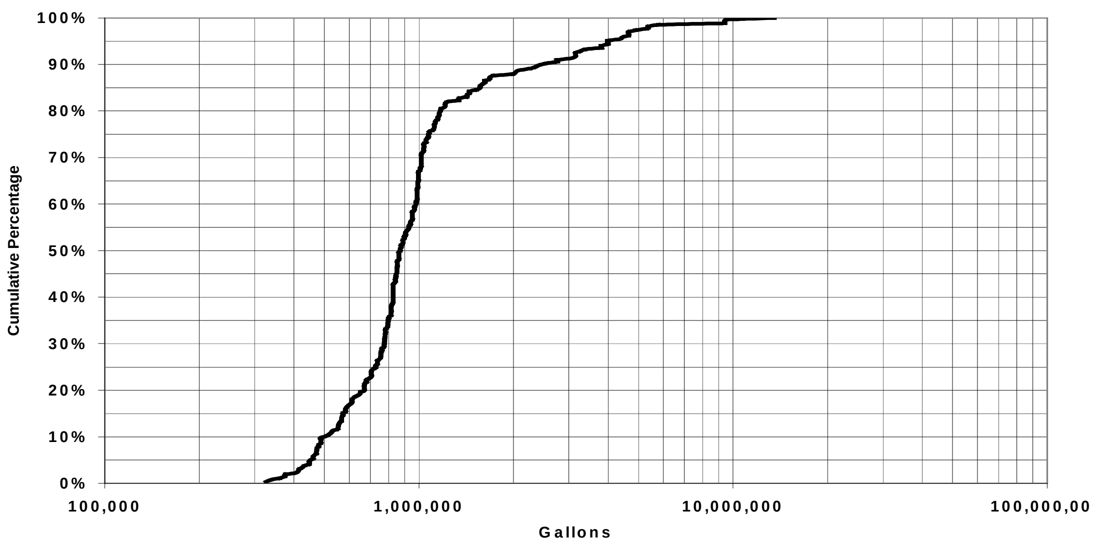



Figure 19 PDF of Potential Worst-Case Discharge Spill Volume For Tank Barge Accidents (Structural Failure, Fire, Sinking) In US Waters (1985-2000

# 7 Application to Specific Ports and Regional Circumstances

The types of spill scenarios that local or regional contingency planners should prepare for depend on local vessel traffic and the types of oils that typically are carried both by oil cargo carriers (tankers and tank barges) and as fuels by non-tank cargo vessels, and fishing and passenger vessels.

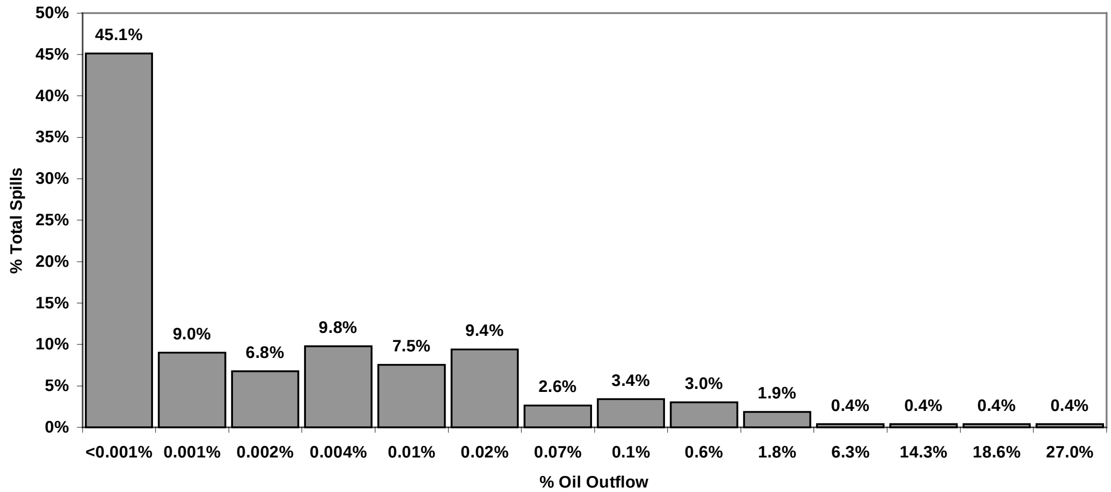



Figure 20 Percentage Oil Cargo Lost in Tank Barge Accidents (Structural Failure, Fire, Sinking) In US Waters (1985-2000)

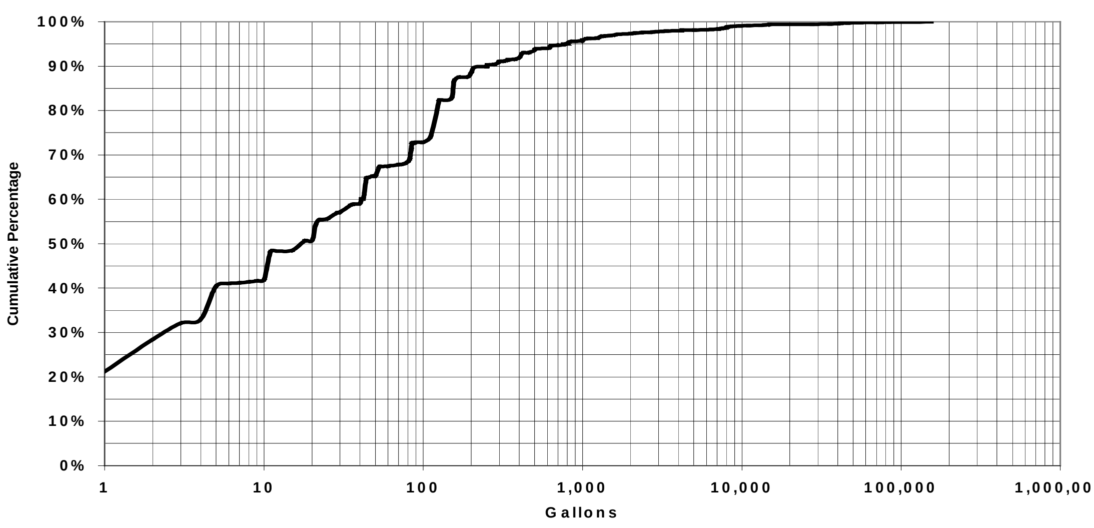



Figure 21 PDF of Barge Lightering/Loading Spills In US Waters (1985-2000)

## 7.1 Washington State Spill Scenario Planning

Typical annual vessel traffic through Puget Sound, Washington, is shown in Table 5. The calculated theoretical spill scenarios for contingency planning for this region are shown in Table 6. The sizes of the largest tanker spills are limited to just under 33 million gallons as this is the maximum oil cargo permitted in Washington state waters. The most-probable WCDs are based on the releases seen in accidents in the US. The theoretical WCDs are based on the maximum cargo sizes (assuming 80% full capacity).

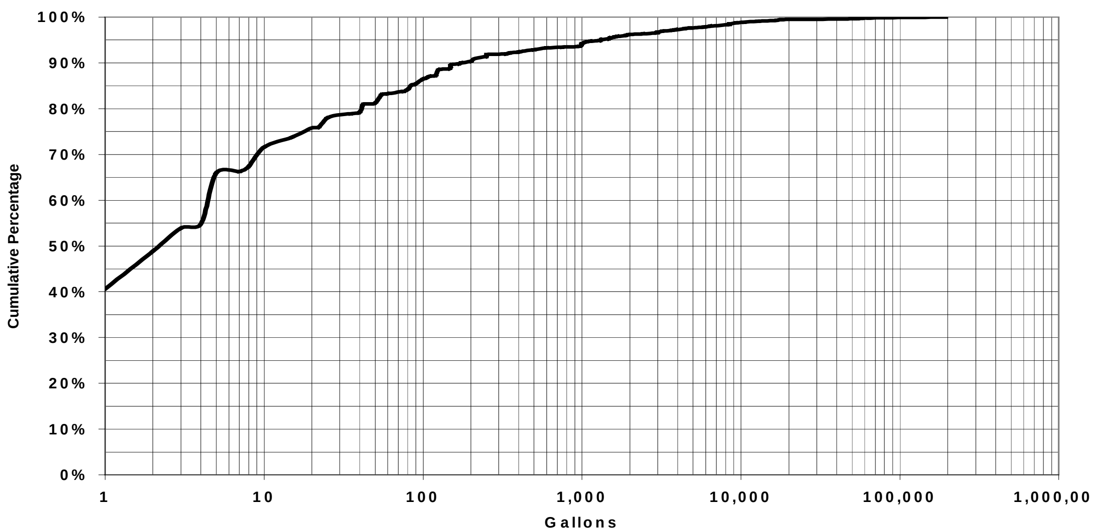



Figure 22 Volume PDF of Illegal Discharge/Pollution for US Barges (1985-2000)

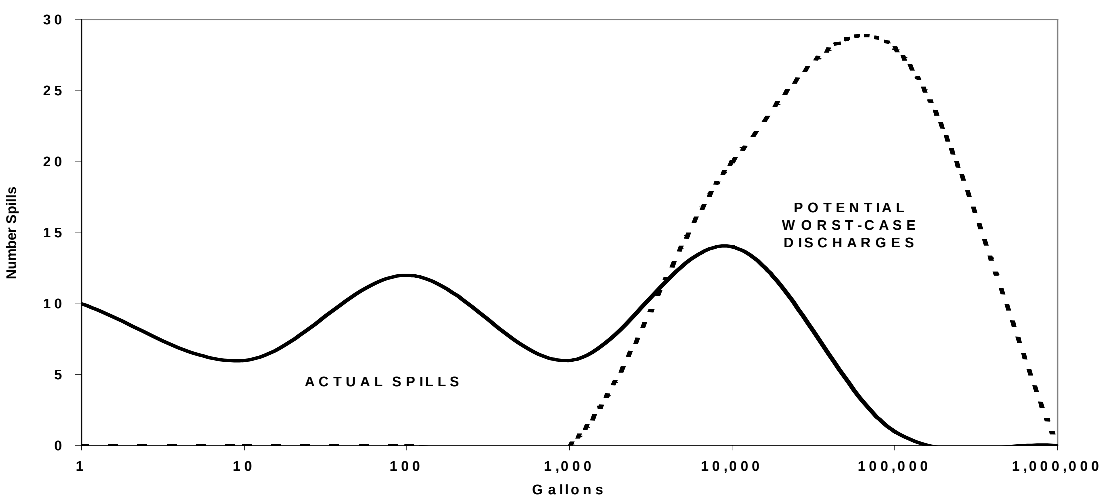



Figure 23 Actual vs. Potential Worst-Case Discharge Spill Sizes For Freighter Accidents (Allisions, Collisions, Groundings) In US Waters (1985-2000)

### 7.2 San Francisco Bay Deep Draft Vessel Groundings

For a project to determine potential spill volumes from deep draft vessel groundings in San Francisco Bay (see Etkin, et al., 2002; McCay, et al., 2002), PDFs of potential spill volumes was developed based on tanker traffic in the bay (Table 7) and the percent cargo losses and probabilities of loss specifically from tanker groundings as shown in Table 8. PDFs for spills from product tankers and crude tankers in Figures 33 and 34, respectively.

Since the project involved projecting spill volumes for the future, the impact of the implementation of double hulls was applied to these PDFs based on the

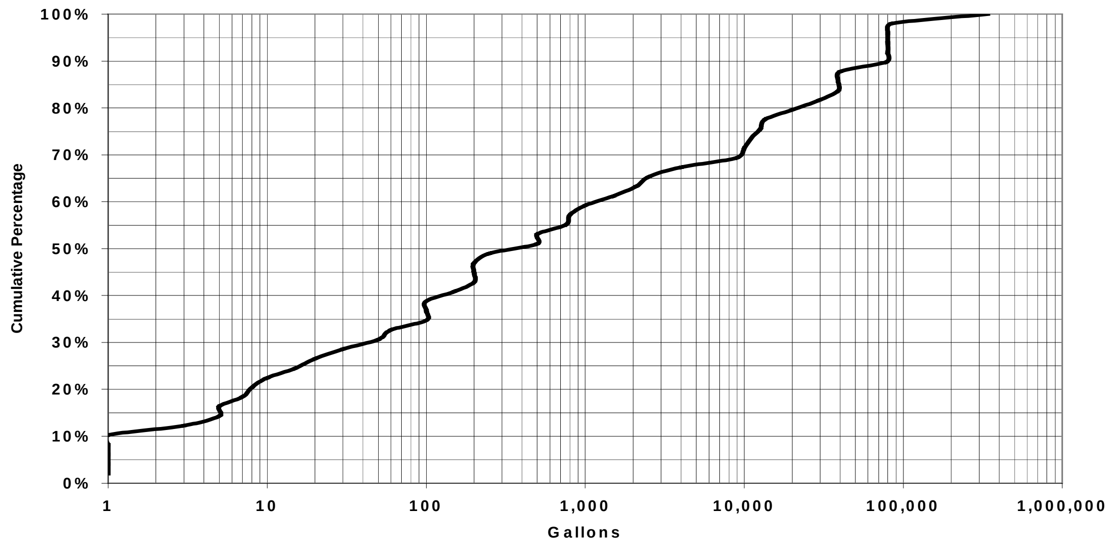



Figure 24 PDF of Oil Spill Size From Freight Ship Accidents (Allisions, Collisions, Groundings) In US Waters (1985-2000)

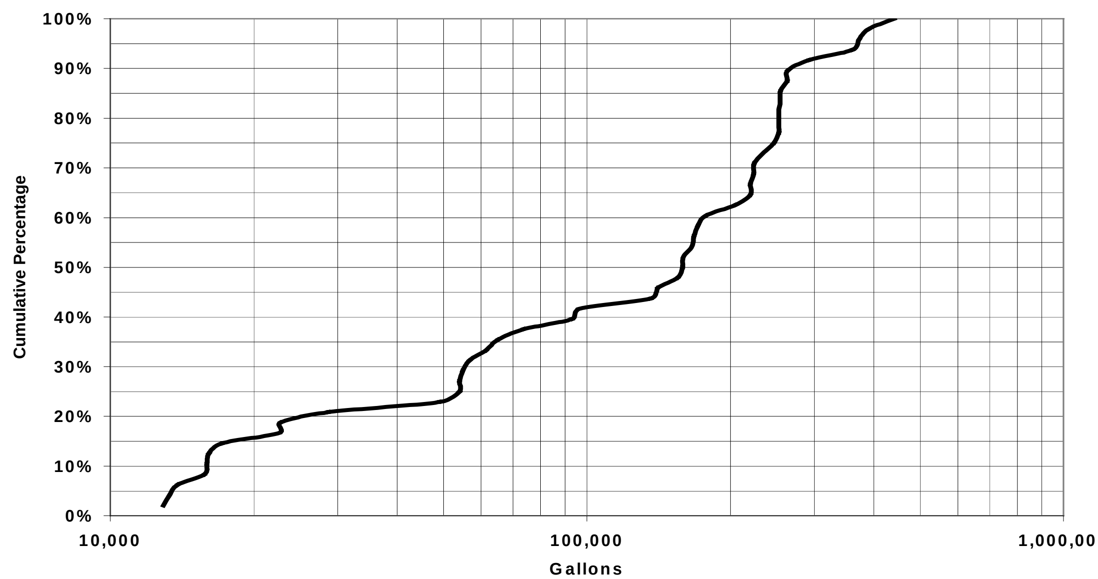



Figure 25 PDF of Potential Worst-Case Discharge Oil Spills From Freight Ship Accidents (Allisions, Collisions, Groundings) In US Waters (1985-2000)

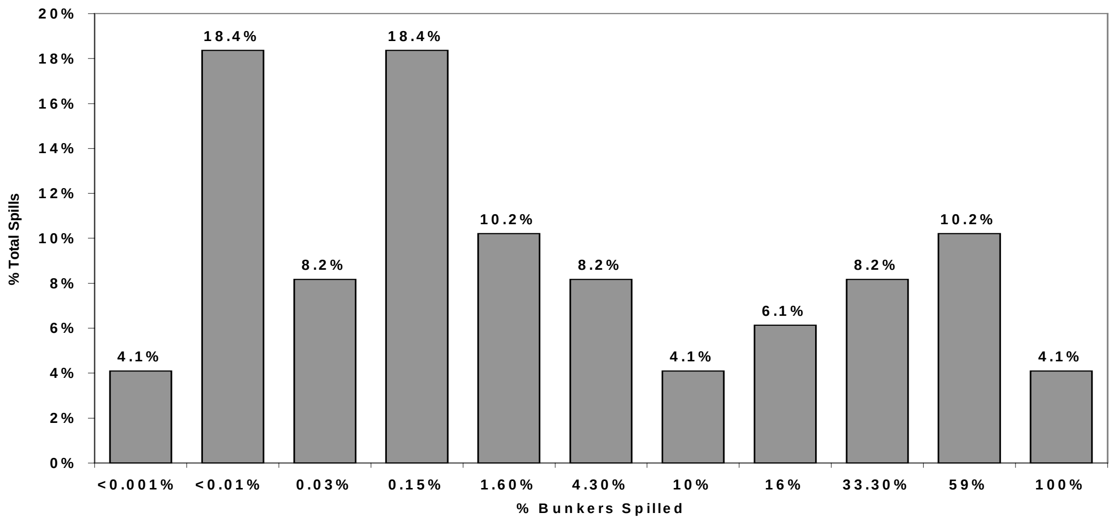



Figure 26 Bunker Fuel Spilled In Freight Ship Accidents (Allisions, Collisions, Groundings) In US Waters (1985-2000)

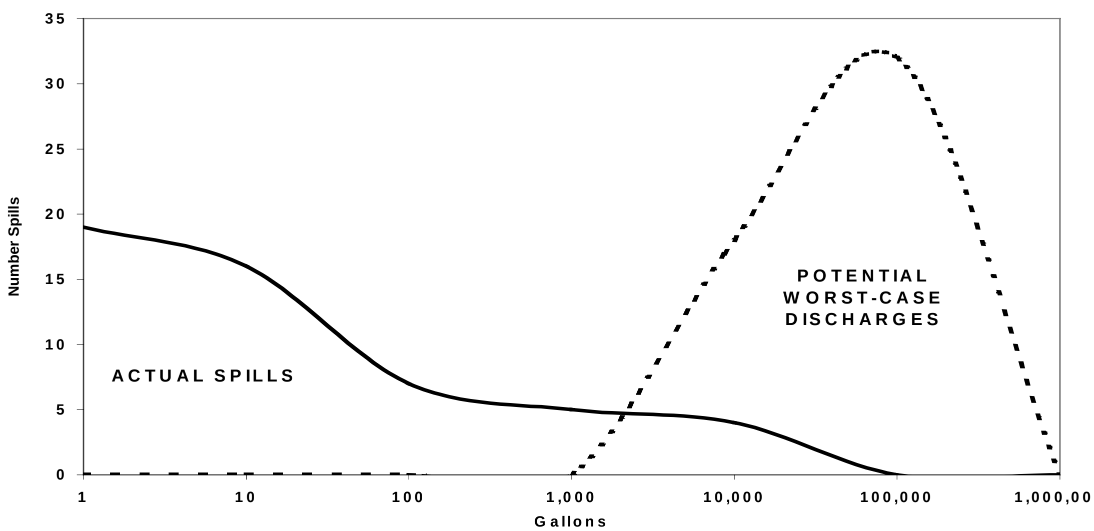



Figure 27 Actual Vs. Potential Worst-Case Discharge Oil Spill Volumes From Freighter Accidents (Structural Failure, Fire, Sinking) In US Waters (1985-2000)

principles in Table 9. The resulting spill scenarios are shown in Table 10. If this procedure were to be applied to spills from bunker/fuel tanks on non-tank vessels, adjustments to spill size would not be necessary as double hulls on bunker tanks. While decreasing the probability of spillage upon impact, double hulls on bunker tanks are likely to allow the release of just as much oil as single hulled tanks once breached (Michel and Thomas, 2000).

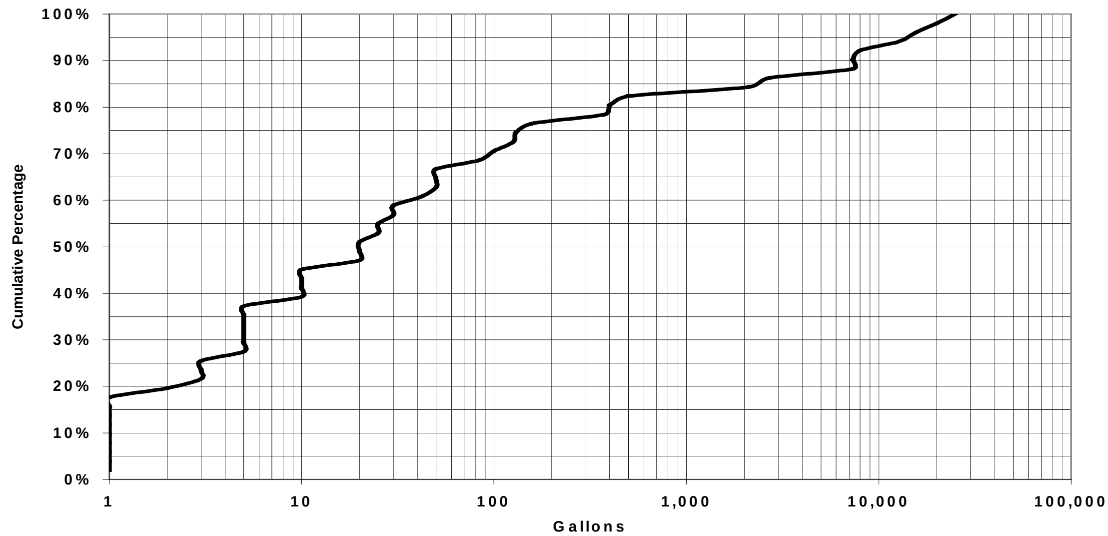



Figure 28 PDF of Oil Spill Volumes From Freighter Accidents (Structural Failure, Fire, Sinking) In US Waters (1985-2000)

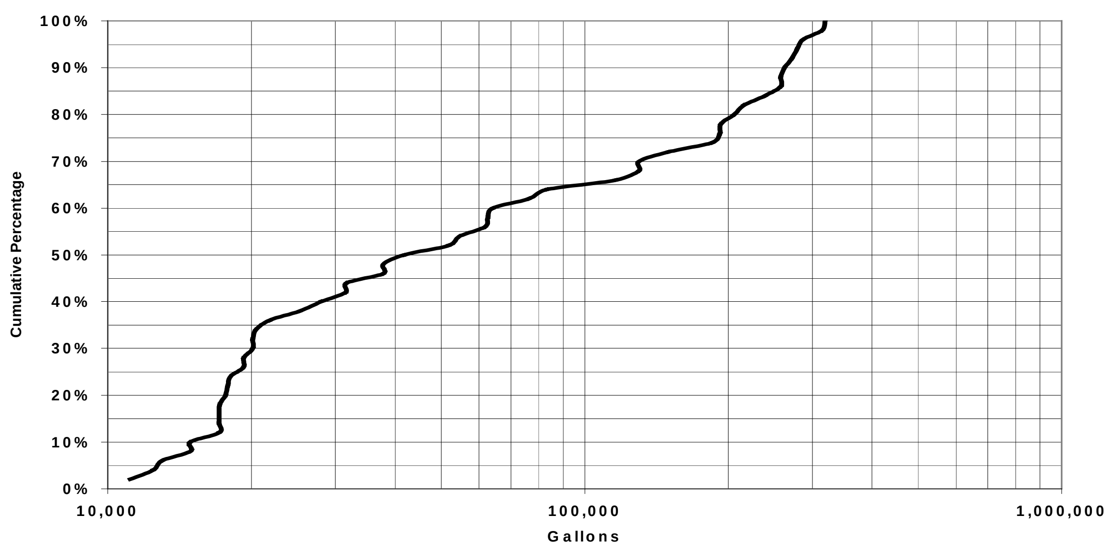



Figure 29 PDF of Worst-Case Discharge Oil Spill Volumes From Freighter Accidents (Structural Failure, Fire, Sinking) In US Waters (1985-2000)

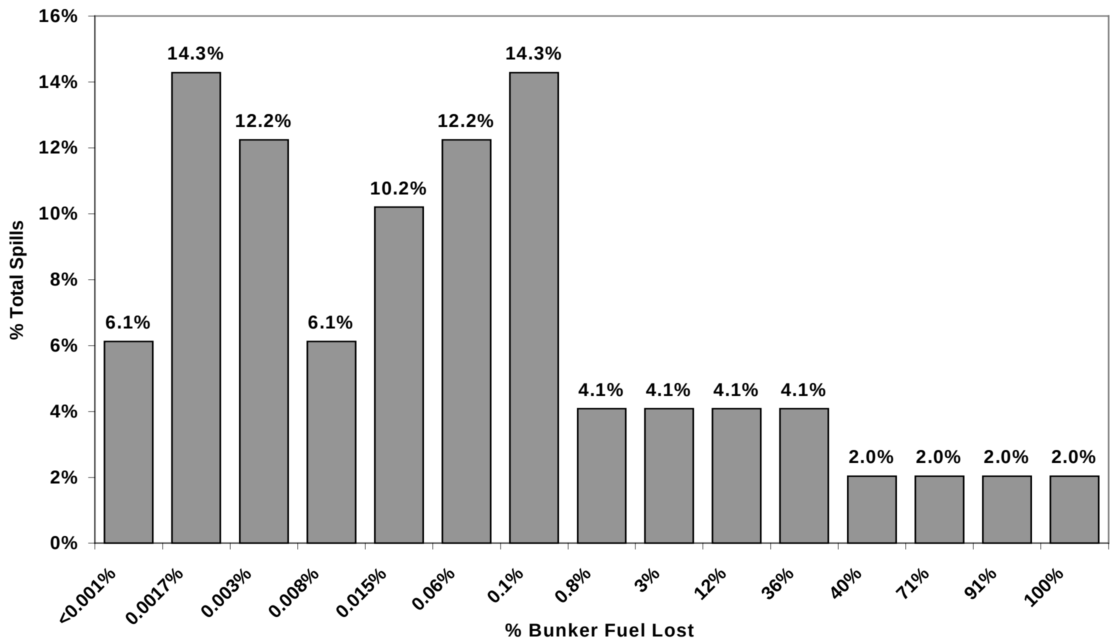



Figure 30 % Bunker Fuel Spilled In Freighter Accidents (Structural Failure, Fire, Sinking) In US Waters (1985-2000)

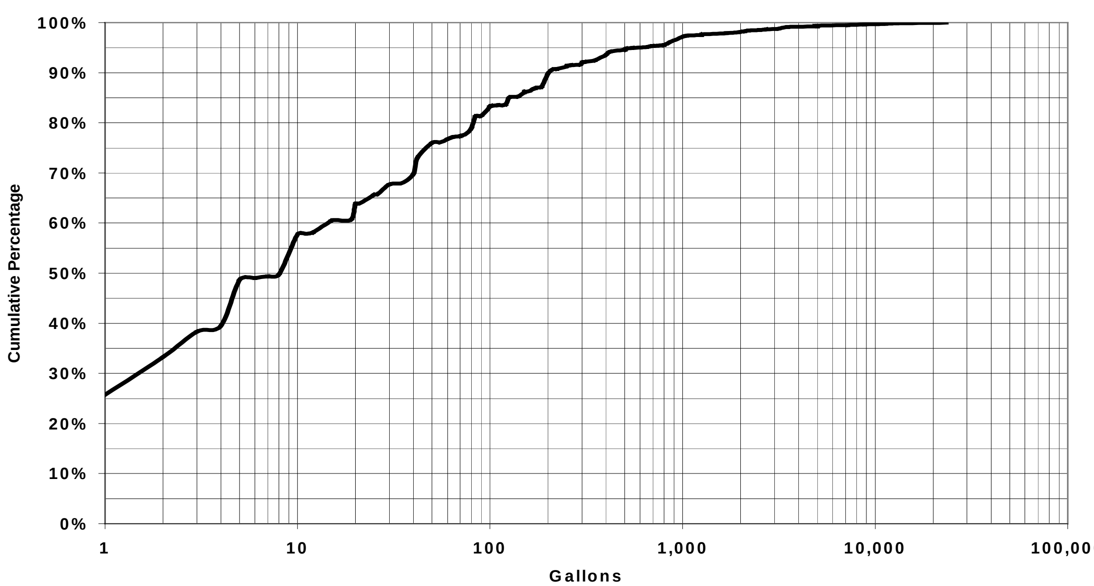



Figure 31 PDF of Oil Spill Volumes For Bunkering/Fueling Spills From Freighters In US Waters (1985-2000)

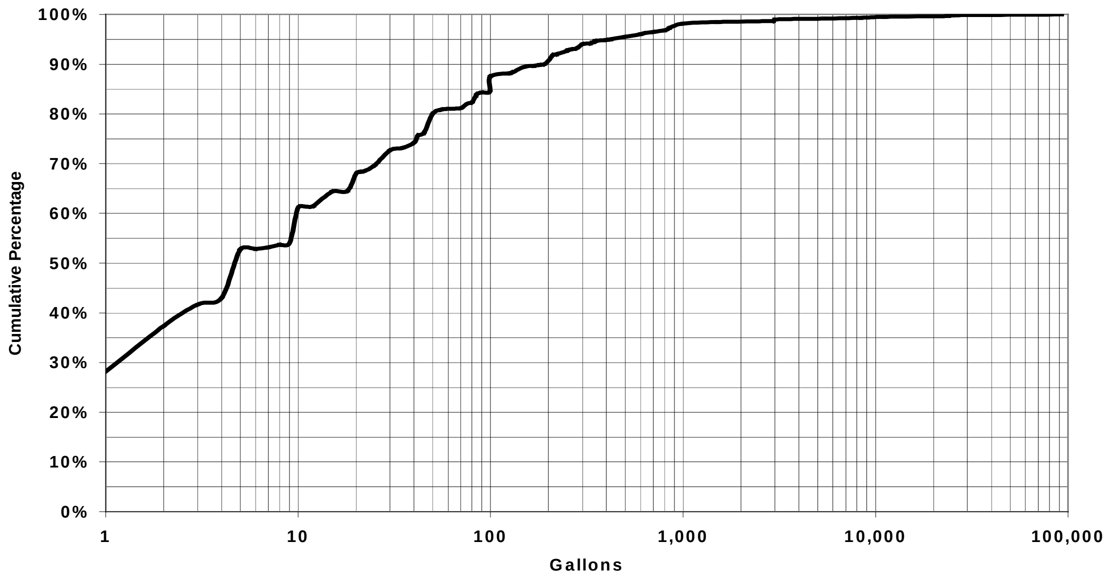



Figure 32 PDF For Oil Spill Volumes From Illegal Discharges From Freighters In US Waters (1985-2000)

## 8 Conclusions

The methodology for determining actual and potential spill volumes, as well as for developing discharge scenarios for contingency planning purposes is adaptable to a variety of situations, including those specific to circumstances in a particular port or region or for a particular vessel type or casualty cause.


## 9 Acknowledgements

This study was funded in part under contracts with Washington Department of Ecology Spills Program and US Army Corps of Engineers - San Francisco District (contract DACW07-01-R-0001). Keith Michel, Herbert Engineering, Inc., Alameda, California, USA, provided information on outflow analyses for tanker and bunker fuel tanks.

Table 4 Actual Vs. Potential WCD US Vessel Oil Spillage (1985-2000)

| Spill Type | Percentile Spills (gallons) Actual Spill Volumes/Potential Worst-Case Discharge[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10th | 25th | 50th | 75th | 90th | 95th | WCD |
| Tankers | 50 | 70 | 130 | 600 | 6,000 | 11,500 | 10,500,000 |
| ALL | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Tankers | 200 | 900 | 6,500 | 40,000 | 250,000 | 275,000 | 10,500,000 |
| Collis/All/Grou | 600,000 | 6,000,000 | 8,000,000 | 15,000,000 | 25,000,000 | 40,000,000 | 80,000,000 |
| Tankers | 70 | 120 | 350 | 6,000 | 30,000 | 200,000 | 4,000,000 |
| StructFail/Fire | 1,500,000 | 6,500,000 | 15,000,000 | 25,000,000 | 34,000,000 | 41,000,000 | 70,000,000 |
| Tankers | 1 | 2 | 6 | 50 | 300 | 1,000 | 100,000 |
| Lightering/Loading[2] | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Tankers | 1 | 1 | 3 | 10 | 200 | 500 | 50,000 |
| Illegal Discharge[2] | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Barges | 1 | 2 | 10 | 60 | 400 | 2,000 | 2,000,000 |
| ALL | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Barges | 2 | 30 | 200 | 5,000 | 30,000 | 60,000 | 800,000 |
| Coll/All/Grou | 600,000 | 800,000 | 1,000,000 | 1,500,000 | 3,100,000 | 4,500,000 | 20,000,000 |
| Barges | 1 | 2 | 10 | 85 | 700 | 4,000 | 800,000 |
| StructFail/Fire/Sink | 500,000 | 700,00 | 850,000 | 1,100,000 | 2,300,000 | 4,000,000 | 14,000,000 |
| Barges | 1 | 2 | 20 | 110 | 300 | 800 | 155,000 |
| Lightering/Loading[2] | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Barges | 1 | 1 | 2 | 20 | 200 | 1,000 | 195,000 |
| Illegal Discharge[2] | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Freighters | 1 | 1 | 8 | 50 | 200 | 1,000 | 350,000 |
| ALL | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Freighters | 1 | 15 | 300 | 10,100 | 80,000 | 82,000 | 350,000 |
| Coll/All/Grou | 15,000 | 52,000 | 120,000 | 240,000 | 270,000 | 370,000 | 440,000 |
| Freighters | 1 | 3 | 20 | 150 | 7,500 | 12,000 | 25,000 |
| StructFail/Fire/Sink | 12,000 | 18,000 | 40,000 | 180,000 | 220,000 | 280,000 | 320,000 |
| Freighters | 1 | 1 | 8 | 50 | 200 | 600 | 23,300 |
| Bunkering[2] | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Freighters | 1 | 1 | 5 | 40 | 300 | 400 | 93,000 |
| Illegal Discharges | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Fishing Vessels | 1 | 2 | 5 | 25 | 200 | 500 | 120,000 |
| ALL | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Fishing Vessels | 2 | 10 | 300 | 7,000 | 60,000 | 80,000 | 100,000 |
| Accidents | 40,000 | 45,000 | 65,000 | 85,000 | 110,000 | 140,000 | 190,000 |
| Fishing Vessels | 1 | 2 | 4 | 10 | 25 | 30 | 35 |
| Fueling[2] | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Fishing Vessels | 1 | 3 | 9 | 30 | 200 | 400 | 120,000 |
| Illegal Discharge[2] | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Passenger Vessels | 1 | 1 | 12 | 45 | 200 | 400 | 7,500 |
| ALL | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Passenger Vessels | 2 | 15 | 40 | 200 | 400 | 6,000 | 8,000 |
| Accidents | 1,000 | 3,000 | 5,000 | 70,000 | 200,000 | 225,000 | 300,000 |
| Passenger Vessels | 1 | 2 | 15 | 60 | 200 | 300 | 1,000 |
| Fueling[2] | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Passenger Vessels | 1 | 1 | 9 | 30 | 100 | 300 | 5,300 |
| Illegal Discharge[2] | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

[1]Potential WCD (complete loss) based on 80%-full cargo tanks,70%-full bunker tanks.[2]WCD not defined for pollution incidents, lightering, de-ballasting, cargo loading/unloading, intentional discharges, and discharges not accident-related. Percentile spills = % spills *smaller* than size(95th > 95% spills (5%larger; 95% spills smaller)

Table 5 Vessel and Oil Movements Through Puget Sound, Washington (2000)

| Vessel Type | Vessel Size | Oil Movement Per Transit (gallons) | | | Transits Per Year |
|---|---|---|---|---|---|
| | | Crude | Refined | Fuel | |
| Crude tanker (laden) | <75,000 DWT | 16,844,000 | -- | 352,200 | 79 |
| | 75,000-110,000 DWT | 22,000,000 | -- | 396,300 | 81 |
| | >110,000 DWT | 32,718,000 | -- | 660,450 | 138 |
| Crude tanker (ballast) | avg. 67,000 DWT | -- | -- | 352,200 | 6 |
| Product tanker (laden) | avg. 22,000 DWT | -- | 4,376,000 | 330,200 | 12 |
| | avg. 55,000 DWT | -- | 10,941,000 | 176,100 | 23 |
| Product tanker (ballast) | avg. 22,000 DWT | -- | -- | 330,200 | 20 |
| | avg. 55,000 DWT | -- | -- | 176,100 | 179 |
| Product barge (laden) | avg. 6,000 DWT | -- | 1,910,000 | 47,000 | 5 |
| | avg. 12,000 DWT | -- | 3,819,000 | 47,000 | 18 |
| Bulk carrier | <50,000 DWT | -- | -- | 143,100 | 1,913 |
| | 50,000-100,000 DWT | -- | -- | 242,200 | 501 |
| | >100,000 DWT | -- | -- | 440,300 | 122 |
| Bulk liquid carrier | -- | -- | -- | 176,100 | 186 |
| Containership | <2,500 TEU | -- | -- | 264,200 | 435 |
| | 2,500-4,000 TEU | -- | -- | 484,300 | 510 |
| | >4,000 TEU | -- | -- | 825,600 | 394 |
| Vehicle carrier | -- | -- | -- | 297,200 | 316 |
| Factory fishing vessel | 300-3,000 GRT | -- | -- | 54,000 | 59 |
| | >3,000 GRT | -- | -- | 165,100 | 112 |
| Fishing boat | >300 GRT | -- | -- | 26,400 | 167 |
| Passenger vessel | 300-3000 GRT | -- | -- | 52,800 | 16 |
| | >3,000 GRT | -- | -- | 140,900 | 11 |
| Adapted from Herbert Engineering, et al. 1999 | | | | | |

Table 6 Theoretical Potential Oil Spill Scenarios From Tankers In Washington State Waters Based on Modeling of US Spill Data

| Spill Cause(s) | Percentile Spills (gallons) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10th | 25th | 50th | 75th | 90th | 95th | Most Probable WCD | Theoretical WCD |
| Tanker Collision/ Allision Grounding | 400,000 | 500,000 | 700,000 | 900,000 | 2,000,000 | 2,400,000 | 12,000,000 | 32,718,000 |
| Tanker Structural Failure Fire/Sinking | 1,500 | 2,000 | 3,000 | 15,000 | 150,000 | 2,000,000 | 3,800,000 | 32,718,000 |
| Barge Collision Allision Grounding | 40 | 200 | 800 | 10,000 | 80,000 | 287,000 | 880,000 | 3,800,000 |
| Barge Structural Failure Fire/Sinking | 10 | 15 | 20 | 200 | 1,000 | 23,000 | 1,031,000 | 3,800,000 |
| Freighter Collision/ Allision Grounding | 10 | 60 | 310 | 5,800 | 36,000 | 54,000 | 825,600 | 825,600 |
| Freighter Structural Failure Fire/Sinking | 2 | 5 | 70 | 500 | 58,000 | 210,000 | 825,600 | 825,600 |
| Fishing Vessel Accidents | 1 | 10 | 310 | 5,800 | 36,000 | 54,000 | 165,100 | 165,100 |
| Passenger Vessel Accidents | 1 | 90 | 400 | 1,000 | 15,000 | 53,000 | 141,000 | 141,000 |

Table 7 Cargo Capacity of Tankers (> 36.7-Ft. Draft) Transiting San Francisco Bay By Deadweight Tonnage Size Class

| Deadweight Tonnage Class (DWT) | Annual Transits >36.7-Ft. Draft | Cargo Capacity tonnes (gallons) (80% full) |
|---|---|---|
| 20,000 – 45,000 DWT | 24 | 36, 700 tonnes (10,790,000 gal) |
| 50,000 – 70,000 DWT | 32 | 53,900 tonnes (15,850,000 gal) |
| 75,000 – 90,000 DWT | 17 | 68,700 tonnes (20,190,000 gal) |
| 95,000 – 110,000 DWT | 22 | 91,400 tonnes (26,880,000 gal) |
| 115,000 – 145,000 DWT | 15 | 133,400 tonnes (39,230,000 gal) |
| 150,000 – 170,000 DWT | 57 | 145,400 tonnes (42,750,000 gal) |
| 175,000 – 190,000 DWT | 42 | 155,100 tonnes (45,590,000 gal) |
| 195,000 – 215,000 DWT | 23 | 184,200 tonnes (54,160,000 gal) |

Table 8 Spill Sizes For Tanker Groundings in San Francisco Bay

| % Cargo Loss[1] | Tanker Capacity[2] | | | | Probability of Loss This Size if Spill Occurs[1] |
|---|---|---|---|---|---|
| | 14,500,000 gal *Product Tanker* | 25,000,000 gal *Product Tanker* | 44,000,000 gal *Crude Tanker* | 55,000,000 gal *Crude Tanker* | |
| 20% loss | 2,900,000 | 5,000,000 | 8,800,000 | 11,000,000 | 3.6% |
| 14% loss | 2,030,000 | 3,500,000 | 6,160,000 | 7,700,000 | 3.6% |
| 10% loss | 1,450,000 | 2,500,000 | 4,400,000 | 5,500,000 | 8.9% |
| 8% loss | 1,160,000 | 2,000,000 | 3,520,000 | 4,400,000 | 5.4% |
| 5% loss | 725,000 | 1,250,000 | 2,200,000 | 2,750,000 | 8.9% |
| 2% loss | 290,000 | 500,000 | 880,000 | 1,100,000 | 21.4% |
| 1% loss | 145,000 | 250,000 | 440,000 | 550,000 | 23.2% |
| 0.2% loss | 29,000 | 50,000 | 88,000 | 110,000 | 25.0% |
| Annual Transits[3] | 56 | 39 | 114 | 23 | 232 total transits |

[1]Based on analysis of 1980-1999 tanker groundings in US waters and 1990-1999 groundings in international waters; [2]Assuming 80% full cargo tanks
[3]Based on US Coast Guard Vessel Traffic Service data (8/2000 – 7/2001)

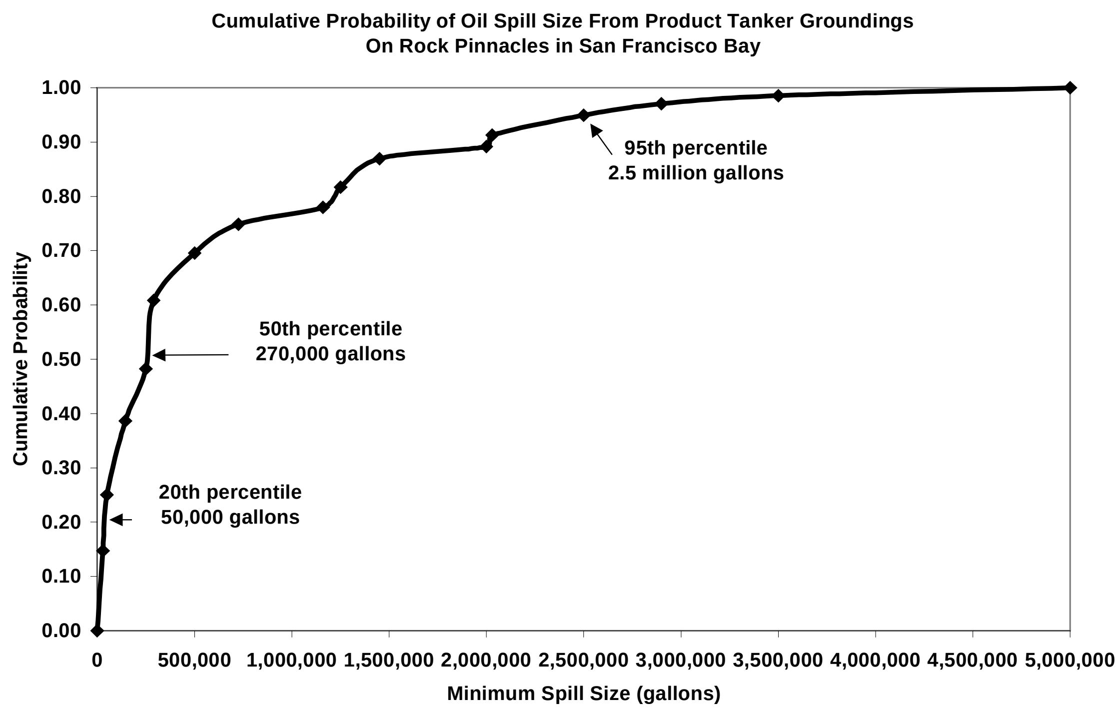



Figure 33 Cumulative Probability of Oil Spill Size From Product Tanker Groundings on Rock Pinnacles in San Francisco Bay

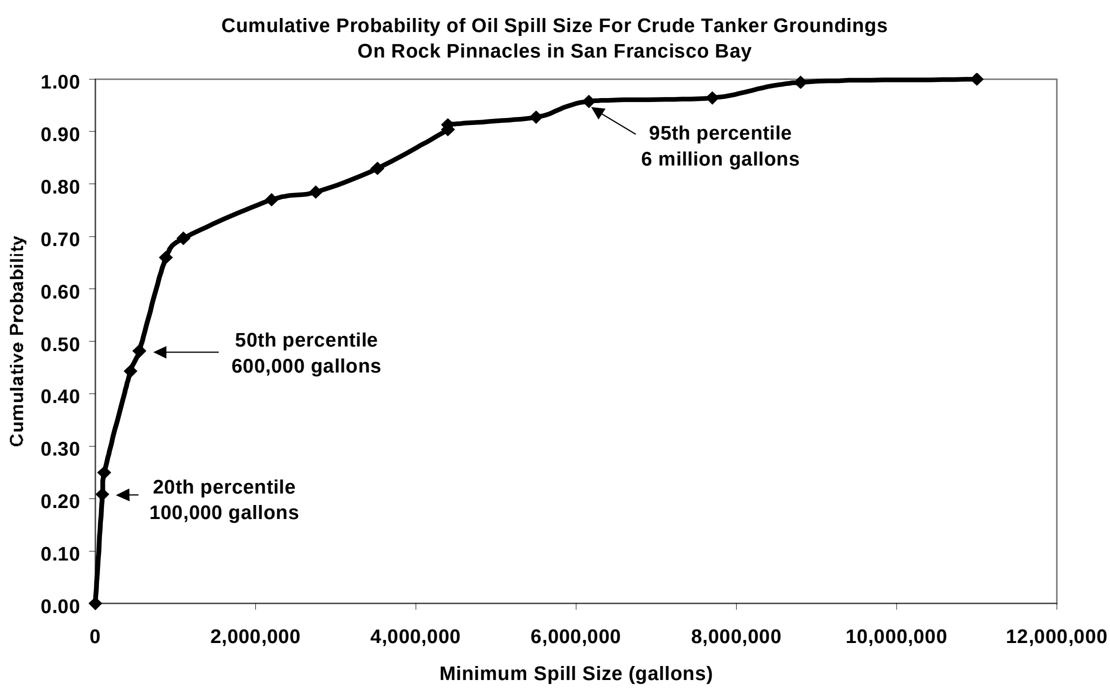



Figure 34 Cumulative Probability of Oil Spill Size From Crude Tanker Groundings on Rock Pinnacles in San Francisco Bay

Table 9 Influence of Double Hulls on Future Spill Risks

| Vessel Tank Type | Influence of Double Hulls | | |
|---|---|---|---|
| | Spill Probability Grounding/Collision/Allision | Small to Median Spill Size | Size Largest Spills |
| Tanker Cargo | Reduced | No effect | Reduce size by 50% |
| Vessel Bunker | Reduced | No effect | No effect |
| Based on Herbert Eng. et al., 1999; Michel & Thomas 2000; Rawson, et al. 1999 | | | |

Table 10 Double Hull Impact on Tanker Grounding Spills In San Francisco Bay

| Tanker Type | Expected Spill Volumes (gallons) | | | | |
|---|---|---|---|---|---|
| | $20^{th}$ % | $50^{th}$ % | $95^{th}$ % | Most-Probable WCD | Theoretical WCD |
| Single hull Product | 50,000 | 270,000 | 2,500,000 | 5,000,000 | 25,000,000 |
| Double hull Product | 50,000 | 270,000 | 1,250,000 | 2,500,000 | 25,000,000 |
| Single hull Crude | 100,000 | 600,000 | 6,000,000 | 11,000,000 | 55,000,000 |
| Double hull Crude | 100,000 | 600,000 | 3,000,000 | 5,500,000 | 55,000,000 |

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