Analysis of US Oil Spill Trends to Develop Scenarios For Contingency Planning

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ABSTRACT

A method for using past US oil spill data to project potential future vessel spill sizes was demonstrated including methods for taking into account vessel type and local factors (e.g., vessel traffic, navigational hazards, and regulations) and implementation of spill prevention measures (*e.g.*, tanker double-hulls). A methodology for determining "theoretical" (OPA 90-defined) *vs*. "most-likely" worst-case oil discharge scenarios was also demonstrated. Past vessel spills were analyzed for vessel- and spill cause-specific percent cargo or fuel outflow. Distributions of outflow percentages were then imposed on various annual vessel traffic patterns to determine the probability distribution functions of spill types that would be expected if there *were* spills.

INTRODUCTION

Oil spillage worldwide has generally decreased despite increases in oil transport (Etkin 2001). At the same time, occasional large spills – along with increasing obligations to respond effectively – have necessitated complex contingency planning for increasingly rare high-impact events. Analyses of past spill trends to forecast potential future spills rates, coupled with foreseen changes in risk factors, *e.g.,* increases in vessel traffic or implementation of prevention measures, form the backbone of spill risk assessment and contingency planning. Response planners need strategies to determine spill scenarios for planning in terms of "most-probable" incidents and "worst case discharge" (WCD) scenarios. In the US, WCD scenarios are defined under the Oil Pollution Act of 1990 (OPA 90) as "the discharge in adverse weather conditions of entire cargo" for tank vessels, and "largest foreseeable discharge in adverse weather conditions" for facilities. Facility WCDs are defined by operators and usually involve the entire contents of a storage tank or contents of a particular pipeline length (between shut-off valves). Though not encompassed in

OPA 90, WCDs for non-tank vessels can be defined as "complete loss of bunkers/fuel" for practical purposes. Based on these criteria, the US has not experienced an actual WCD from a large tanker *since 1977*, though WCDs (involving sinking or hard drift groundings of fully-laden tankers) have occurred elsewhere, as shown in Table 1. The US *has* experienced WCDs from tank barges in recent years – notably the Morris J. Berman and North Cape spills. Two incidents involving smaller tankers occurred in US waters prior to 1985 (Table 2). It is still possible for such a spill to occur in the future in the US.

Determining WCD and most-probable discharge scenarios proves challenging for US contingency planners. While OPA 90 mandates preparedness for *theoretical* WCDs, response planners often seek guidance on "most likely" scenarios for planning in particular locations – including *most likely* WCD scenarios. This paper demonstrates a method to determine "most-likely" location-specific scenarios for vessel spills, including most likely WCDs.

METHODOLOGY

Terms were defined as: *illegal discharge* (intentional discharge, bilge pumping, or unintentional discharge unrelated to accident or structural failure); *most-probable worst-case discharge (WCD)* (largest spill expected based on historical data of maximum percent cargo/fuel loss); *percentile spills* (n^{th} percentile spill > than *n%* of spills, < 100 - *n%*); *potential spill sizes* (spill volumes for historical spills had theoretical WCD occurred); *probability distribution function (PDF)* (graphed curve with cumulative probabilities of spill size to determine percentile spills); *structural failure* (breaking apart of vessel not attributable to impact); *theoretical worst-case discharge (WCD)* (largest *possible* spill from source - *e.g.*, total cargo or fuel on vessel).

Environmental Research Consulting data for 1985-2000 US oil spills from vessels over 300 gross tons (GT) were analyzed to develop PDFs of *actual*- and *potential* spill volumes (theoretical WCDs based on cargo/bunker capacity). Data were analyzed to determine percent cargo/fuel spilled for incidents involving accidents (collision, grounding, allision, sinking, structural failure, fire). Cargo tanks were assumed 80% full and bunker tanks 70% full, based on tanker engineering modeling methods (Michel and Thomas, 2000; Rawson, *et al*., 1998). The percentage of spills representing different percent cargo or fuel losses were calculated.

Theoretical future spill volumes were determined based on application of cargo/fuel loss percentages and probabilities from US data projected onto US, Washington state, and San Francisco Bay water vessel traffic. This produced estimates of potential spill volumes for local planning given current vessel traffic. Percentile spills and most-probable- and theoretical-WCDs were determined by vessel type. Scenarios were adjusted for tanker cargo limits for Washington state waters (33 million gallons). For San Francisco Bay, scenarios were adjusted to include only spills from *deep-draft* vessel groundings on specific navigational hazards. Future US tanker spill distributions were determined, including double hull implementation. The results do *not* predict the probability of spill occurrence but rather most-probable size distributions if spills *do* occur.

RESULTS

PDFs for US tanker spills due to impact accident (collision, allision, grounding) are in Fig. 1 – 2. Analyses were repeated for tanker spills from non-impact related accidents, (structural failure, fires, explosions, sinking) as in Fig. 3 – 4. Percent cargo loss (assuming 80% capacity) and probabilities of each percent loss are in Table 3. Tanker spills with other causes, (*e.g.,* bilge washing) were analyzed to develop PDFs in Fig. 5 - 6. Lightering, loading, and refueling spills tend to be smaller than accident-related ones. The analyses were repeated for barge accidents, separating impact-related incidents from other accidents. The smaller barge cargo tends to make these spills smaller than for tankers. As with tankers, smaller spills can occur during lightering, loading, and illegal discharges. Percent outflow from tank barges by spill cause is in Table 4. [barge spill PDFs are in Etkin (2002)]. Actual *vs.* potential spills for tank vessels are in Table 5. Freighters, fishing vessels, and passenger ships (>300 GT), can spill bunker/fuel oil in accidents. Analyses were conducted for impact-related accidents, other accidents, incidents involving bunkering/fueling, and illegal discharges. *Potential* volumes were not calculated for fueling/ bunkering or illegal discharge, assuming these incidents were unlikely to involve total release of fuel tanks. Percent outflow by spill cause for freighters, fishing vessels, and passenger ships is in Tables 6 - 7. Actual *vs*. potential spills are in Table 8. [Freighter spill PDFs are in Etkin (2002).]

Spill scenarios for local contingency planning depend on local vessel traffic and cargo and fuels typically carried by oil cargo carriers (tankers, barges), other cargo vessels, fishing vessels, and passenger ships. This methodology can be adapted to determine location-specific scenarios.

Typical vessel traffic through Puget Sound, Washington, (Herbert Engineering, *et al.* 1999) was analyzed to calculate theoretical spill scenarios giving results in Table 9. The largest tanker spills are limited to 33 million gallons as this is the maximum cargo permitted in 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).

To determine potential spills from deep-draft vessel groundings in San Francisco Bay (Etkin *et al*. 2002; French-McCay *et al*. 2002), PDFs of potential spills were developed based on local vessel traffic and national percent cargo loss and loss probability in tanker groundings (Table 10). PDFs for spills from product and crude tankers are shown in Fig. 7 - 8. To project *future* spills, impacts of double-hulls were applied to the PDFs based on principles in Table 11, to give spill scenarios in Table 12. Double-hulls on tankers (and barges) reduce the *probability of spillage with impact* (Table 13) and *reduce the size of large spills by 50%* (Rawson *et al.* 1998).

With mandated double-hull implementation nearing 2015, there will be corresponding reductions in potential WCDs, a trend that can be factored into contingency planning. Future US tanker grounding WCDs are in Table 14 (and Fig. 9 – 10), based on past *US tanker groundings* and *international groundings*. The latter group includes catastrophic drift groundings (with high cargo loss percentages, as in Table 1) unlike any that have been experienced thus far in US waters after 1977. In estimating potential spills of bunker/fuel from *non-tank* vessels, adjustments to spill size are unnecessary. 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).

ACKNOWLEDGEMENTS

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

BIOGRAPHY

Dagmar Schmidt Etkin received her B.A. in Biology from University of Rochester, and her A.M. and Ph.D. in Biology (specializing in population biology, ecology, and statistical analysis) from Harvard University. She has analyzed and modeled oil spill data and impacts for 15 years.

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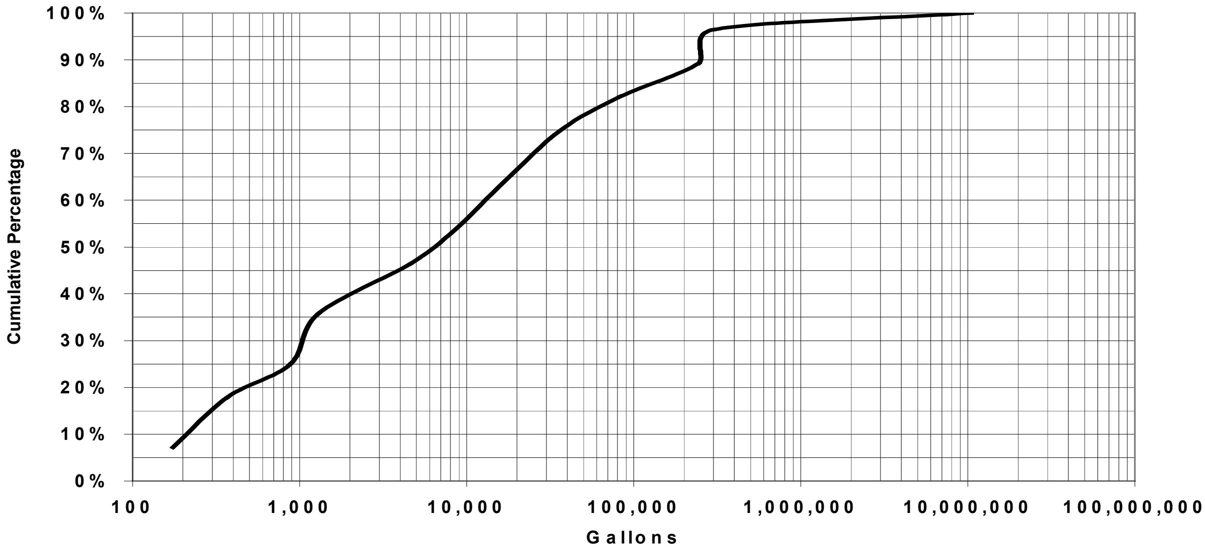
Table 1: Tanker (DWT>10,000) Worst-Case Discharges Worldwide[1] (1985 – 2000)				
Tanker	**Date**	**Amt. Spilled[2]**	**Loss**	**Location**
Athenian Venture	Apr 88	10,602,000 gal (36,061 t)	100%	Canada
Odyssey	Nov 88	43,100,000 gal (146,600 t)	100%	Canada
Thanassis A.	Oct 94	10,900,000 gal (37,075 t)	100%	Hong Kong
Kinsei Maru	Jun 85	840,000 gal (2,857 t)	100%	Japan
Katina P.	Apr 92	19,609,800 gal (66,700 t)	100%	South Africa
Braer	Jan 93	25,000,000 gal (85,034 t)	100%	UK
Cosmas A.	Jan 94	7,081,000 gal (24,085 t)	100%	Hong Kong
Ife	Jan 01	3,386,292 gal (11,518 t)	100%	Nigeria
Da Qing 243	Jun 97	5,000,000 gal (17,000 t)	82%	China
Aegean Sea	Dec 92	21,900,000 gal (74,490 t)	78%	Spain
Haven	Apr 91	42,336,000 gal (144,000 t)	74%	Italy

[1]Excluding war-related incidents. [2]Cargo capacity estimated from deadweight tonnage (80% full).
Source: Environmental Research Consulting databases.

Table 2: Worst-Case Oil Discharges From Tankers In and Near US Waters				
Tanker	**Date**	**Amt. Spilled**	**Loss**	**Location**
Hawaiian Patriot	Feb 77	31,185,000 gal (106,070 t)	100%	Pacific, 595 km off Hawaii
Pegasus	Feb 68	9,597,000 gal (32,643 t)	100%	Atlantic, off Maine
Mandoil II	Feb 68	12,930,120 gal (43,980 t)	97%	Pacific, off Oregon
Gezina Brovig	Jan 70	4,704,000 gal (16,000 t)	95%	Caribbean, off NW Puerto Rico
Keo	Nov 69	8,800,000 gal (29,932 t)	95%	Atlantic, 200 km off Mass.
Spartan Lady	Apr 75	6,000,000 gal (20,408 t)	94%	Atlantic, 32 km SE NY
Epic Colocotronis	May 75	17,955,000 gal (61,071t)	91%	Caribbean, off Puerto Rico
Gulfstag	Oct 66	5,586,000 gal (19,000 t)	91%	Gulf of Mexico, off Texas
Texaco Oklahoma	Mar 71	9,450,000 gal (32,143 t)	88%	Atlantic, off Maine
Argo Merchant	Dec 76	7,700,000 gal (26,190 t)	87%	Atlantic, 40 km ESE Mass.

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

Table 3: % Cargo Outflow in Tanker Accidents in US Waters 1985 - 2000					
Accident	**% Outflow**	**% Incidents**	**Accident**	**% Outflow**	**% Incidents**
Impact Accidents **Groundings, Allisions, Collisions**	0.002%	36.1%	***Non-Impact Accidents*** **Structural Failure, Fire, Sinking**	<0.01%	57.7%
	0.02%	11%		0.02%	15.4%
	0.05%	13.9%		0.06%	3.8%
	0.2%	11.1%		0.16%	7.7%
	0.7%	5.6%		0.54%	7.7%
	1.3%	11.1%		11.5%	7.7%
	3.1%	8.3%	Based on Environmental Research Consulting databases		
	20%	2.8%			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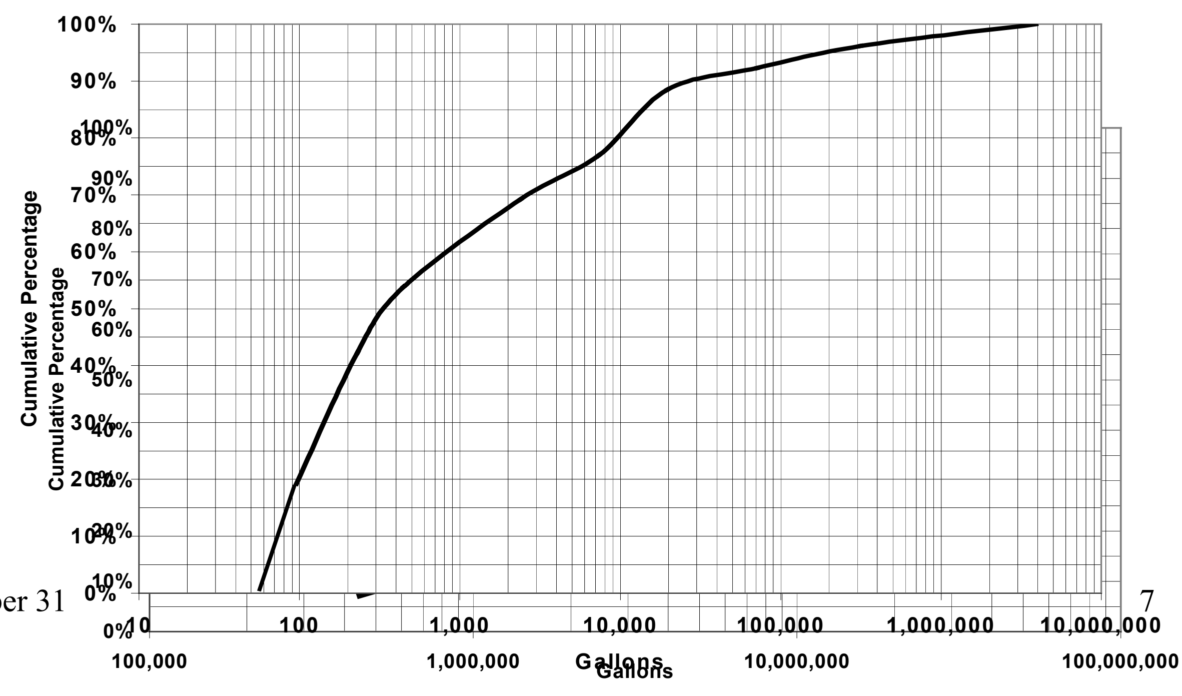
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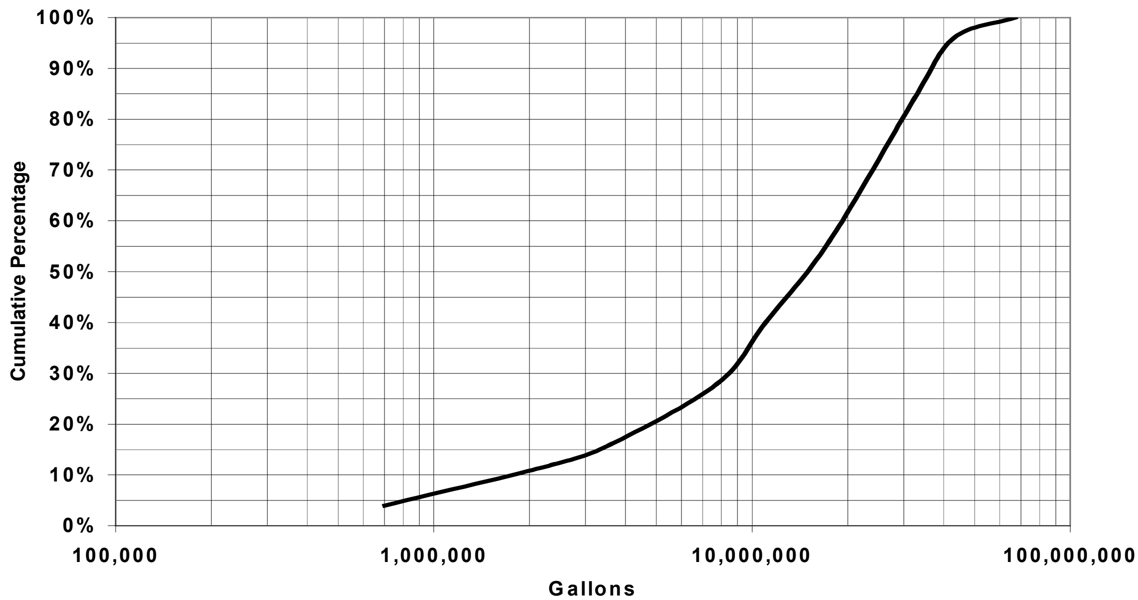
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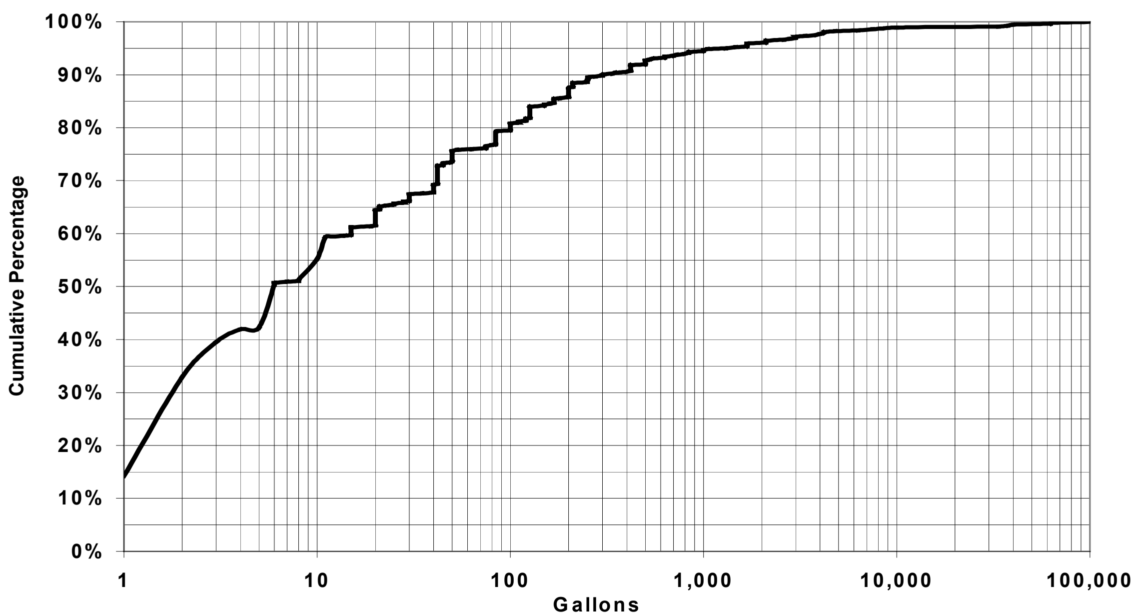
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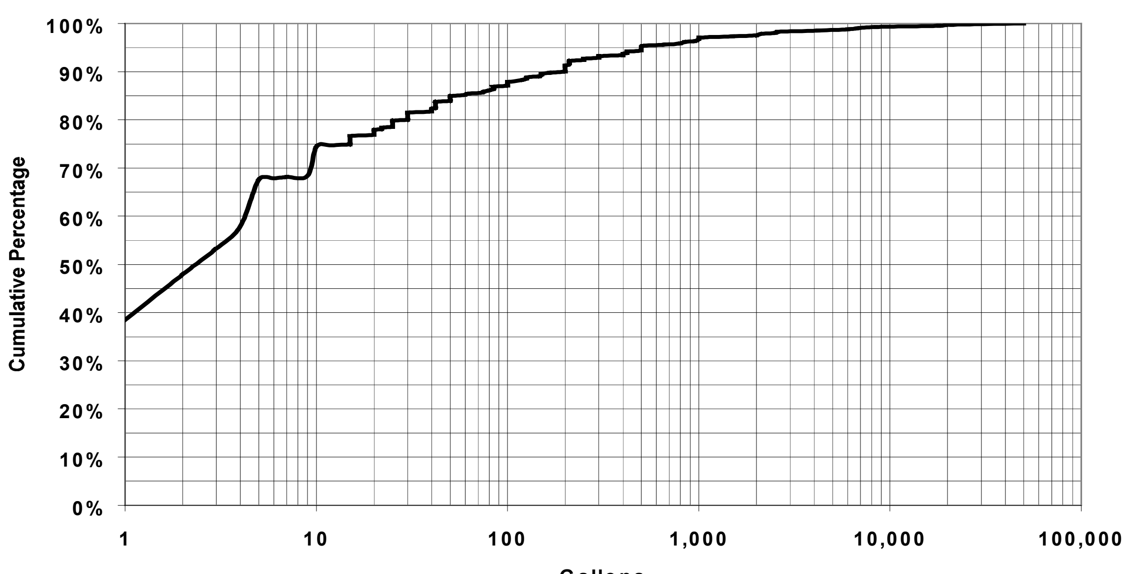
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Table 4: % Cargo Outflow From US Tank Barge Accidents (1985 – 2000)					
Accident	**% Outflow**	**% Incidents**	**Accident**	**% Outflow**	**% Incidents**
***Impact-Related* Collisions, Allisions, Groundings**	<0.001%	17.6%	***Non-Impact Related* Structural Failure, Fire, Sinking**	<0.001%	45.1%
	<0.01%	22.4%		0.001%	9.0%
	0.03%	22.9%		0.002%	6.8%
	0.20%	11.2%		0.004%	9.8%
	0.05%	7.1%		0.01%	7.5%
	1.0%	5.9%		0.02%	9.4%
	3.0%	6.5%		0.07%	2.6%
	7.5%	2.9%		0.1%	3.4%
	15%	1.8%		0.6%	3.0%
	23%	1.8%		1.8%	1.9%
Based on Environmental Research Consulting databases				6.3%	0.4%
				14.3%	0.4%
				18.6%	0.4%
				27.0%	0.4%

Table 5: Actual *vs.* Potential WCD US Tank Vessel Oil Spillage (1985 – 2000)							
Spill Type[2]	**Percentile Spills Actual Spill /Potential Spill[1] (gallons)**						
	10th	**25th**	**50th**	**75th**	**90th**	**95th**	**WCD**
Tankers ALL	50	70	130	600	6,000	11,500	10,500,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Tankers CAG	200	900	6,500	40,000	250,000	275,000	10,500,000
	600,000	6,000,000	8,000,000	15,000,000	25,000,000	40,000,000	80,000,000
Tankers STF	70	120	350	6,000	30,000	200,000	4,000,000
	1,500,000	6,500,000	15,000,000	25,000,000	34,000,000	41,000,000	70,000,000
Tankers LL[3]	1	2	6	50	300	1,000	100,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Tankers ILD[3]	1	1	3	10	200	500	50,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Barges ALL	1	2	10	60	400	2,000	2,000,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Barges CAG	2	30	200	5,000	30,000	60,000	800,000
	600,000	800,000	1,000,000	1,500,000	3,100,000	4,500,000	20,000,000
Barges STF	1	2	10	85	700	4,000	800,000
	500,000	700,00	850,000	1,100,000	2,300,000	4,000,000	14,000,000
Barges LL[3]	1	2	20	110	300	800	155,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Barges ILD[3]	1	1	2	20	200	1,000	195,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a

[1]Complete loss of 80%-full cargo tanks. [2]CAG = collisions, allisions, groundings; STF = structural failure, sinking, fire; LL = lightering, loading, refueling; ILD = illegal discharges; ALL = all causes. [3]WCD not defined for LL, ILD.

Table 6: % Cargo Outflow From Freighter Accidents					
Accident	**% Outflow**	**% Incidents**	**Accident**	**% Outflow**	**% Incidents**
Impact-Related **Collisions, Allisions, Groundings**	<0.001%	4.1%	***Non-Impact Related*** **Structural Failure, Fire, Sinking**	<0.001%	6.1%
	<0.01%	18.4%		0.0017%	14.3%
	0.03%	8.2%		0.003%	12.2%
	0.15%	18.4%		0.008%	6.1%
	1.6%	10.2%		0.015%	10.2%
	4.3%	8.2%		0.06%	12.2%
	10.0%	4.1%		0.1%	14.3%
	16.0%	6.1%		0.8%	4.1%
	33.3%	8.2%		3.0%	4.1%
	59%	10.2%		12.0%	4.1%
	100%	4.1%		36.0%	4.1%
Based on Environmental Research Consulting databases				40.0%	2.0%
				71.0%	2.0%
				91.0%	2.0%
				100%	2.0%

Table 7: % Cargo Outflow From Other Vessel Accidents					
Vessel	**% Outflow**	**% Incidents**	**Vessel**	**% Outflow**	**% Incidents**
Fishing Vessel >300 GT (All Accidents)	0.001%	7.4%	**Passenger Vessel >300 GT (All Accidents)**	0.001%	7.7%
	0.005%	7.4%		0.02%	15.4%
	0.01%	3.7%		0.17%	15.4%
	0.03%	14.8%		0.64%	15.4%
	0.2%	11.1%		0.75%	7.7%
	0.6%	7.4%		1.4%	15.4%
	1.2%	14.8%		10.5%	7.7%
	2.7%	3.7%		11.8%	7.7%
	8%	3.7%		100%	7.7%
	22%	7.4%	Based on Environmental Research Consulting databases		
	32%	3.7%			
	68%	7.4%			
	100%	7.4%			

Table 8: Actual *vs.* Potential WCD US Other Vessel Oil Spillage (1985 – 2000)							
Spill Type[2]	**Percentile Spills Actual Spill /Potential Spill[1] (gallons)**						
	10th	**25th**	**50th**	**75th**	**90th**	**95th**	**WCD**
Freighters ALL	1	1	8	50	200	1,000	350,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Freighters CAG	1	15	300	10,100	80,000	82,000	350,000
	15,000	52,000	120,000	240,000	270,000	370,000	440,000
Freighters STF	1	3	20	150	7,500	12,000	25,000
	12,000	18,000	40,000	180,000	220,000	280,000	320,000
Freighters BR[3]	1	1	8	50	200	600	23,300
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Freighters ID	1	1	5	40	300	400	93,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Fishing ALL	1	2	5	25	200	500	120,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Fishing ACC	2	10	300	7,000	60,000	80,000	100,000
	40,000	45,000	65,000	85,000	110,000	140,000	190,000
Fishing Fueling[3]	1	2	4	10	25	30	35
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Fishing ID[3]	1	3	9	30	200	400	120,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Passenger ALL	1	1	12	45	200	400	7,500
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Passenger ACC	2	15	40	200	400	6,000	8,000
	1,000	3,000	5,000	70,000	200,000	225,000	300,000
Passenger BR[3]	1	2	15	60	200	300	1,000
	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Passenger ID[3]	1	1	9	30	100	300	5,300
	n/a	n/a	n/a	n/a	n/a	n/a	n/a

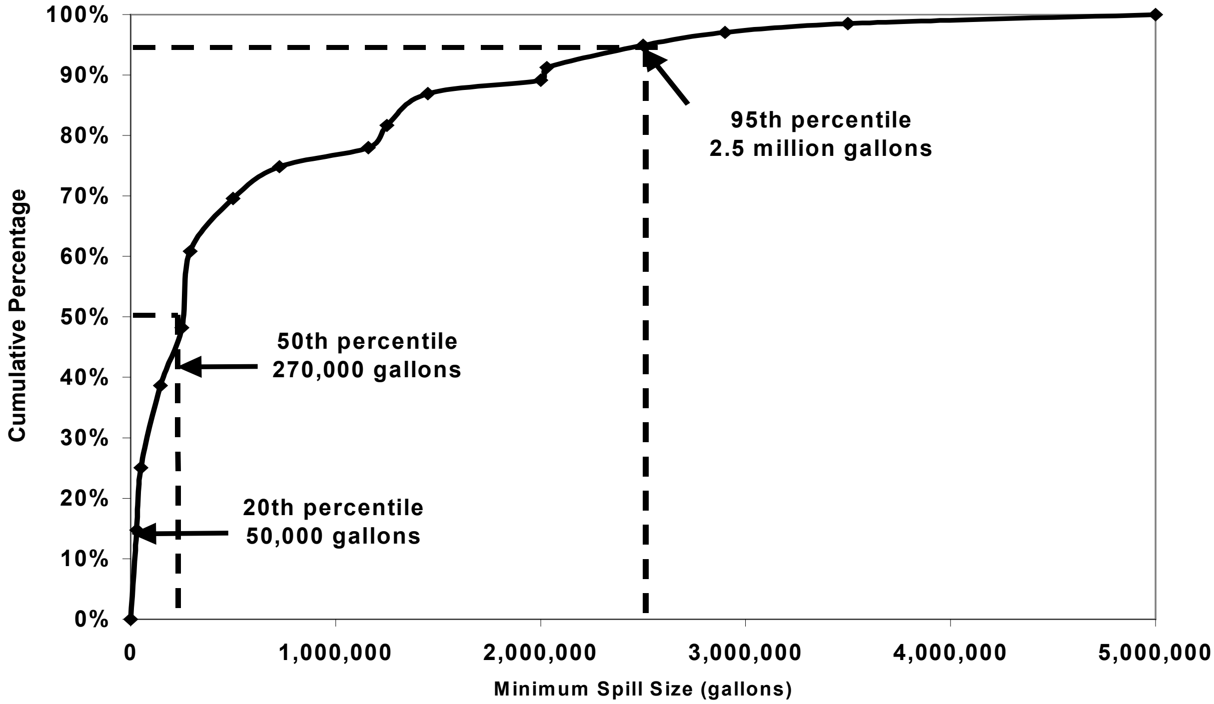
[1]Complete loss based on 70%-full bunker tanks. [2]CAG = collisions, allisions, groundings; STF = structural failure, sinking, fire; BR = bunkering, refueling; ILD = illegal discharges; ACC = all accidents, structural failure; ALL = all causes; [3]WCD not defined for ILD, BR.

Table 9: Potential Oil Spill Scenarios From Vessels In Washington State Waters								
Spill Cause[1]	**Percentile Spills (gallons)**							
	10th	**25th**	**50th**	**75th**	**90th**	**95th**	**Most Likely WCD**	**Theoretical WCD**
Tanker CAG	400,000	500,000	700,000	900,000	2,000,000	2,400,000	12,000,000	32,718,000
Tanker STF	1,500	2,000	3,000	15,000	150,000	2,000,000	3,800,000	32,718,000
Barge CAG	40	200	800	10,000	80,000	287,000	880,000	3,800,000
Barge STF	10	15	20	200	1,000	23,000	1,031,000	3,800,000
Freighter CAG	10	60	310	5,800	36,000	54,000	825,600	825,600
Freighter STF	2	5	70	500	58,000	210,000	825,600	825,600
Fishing ACC	1	10	310	5,800	36,000	54,000	165,100	165,100
Passenger ACC	1	90	400	1,000	15,000	53,000	141,000	141,000

[1]CAG = collision, allision, grounding; STF = structural failure, sinking, fire. ACC = all accidents, structural failure; ALL = all causes

Table 10: Spill Sizes For Tanker Hard Groundings in San Francisco Bay					
% Cargo Loss[1]	**Tanker Capacity (gallons)[2]**				**Probability Loss This Size[1]**
	14.5 mil *Product*	**25 mil *Product***	**44 mil *Crude***	**55 mil *Crude***	
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%**
Transits/yr[3]	**56**	**39**	**114**	**23**	**232 transits**

[1]1980-99 US,1990-99 international data. [2]80%-full tank. [3]US Coast Guard Vessel Traffic data Spills under 1,000 gallons eliminated due to their most likely being caused by *soft* groundings (Rawson, *et al.* 1998)



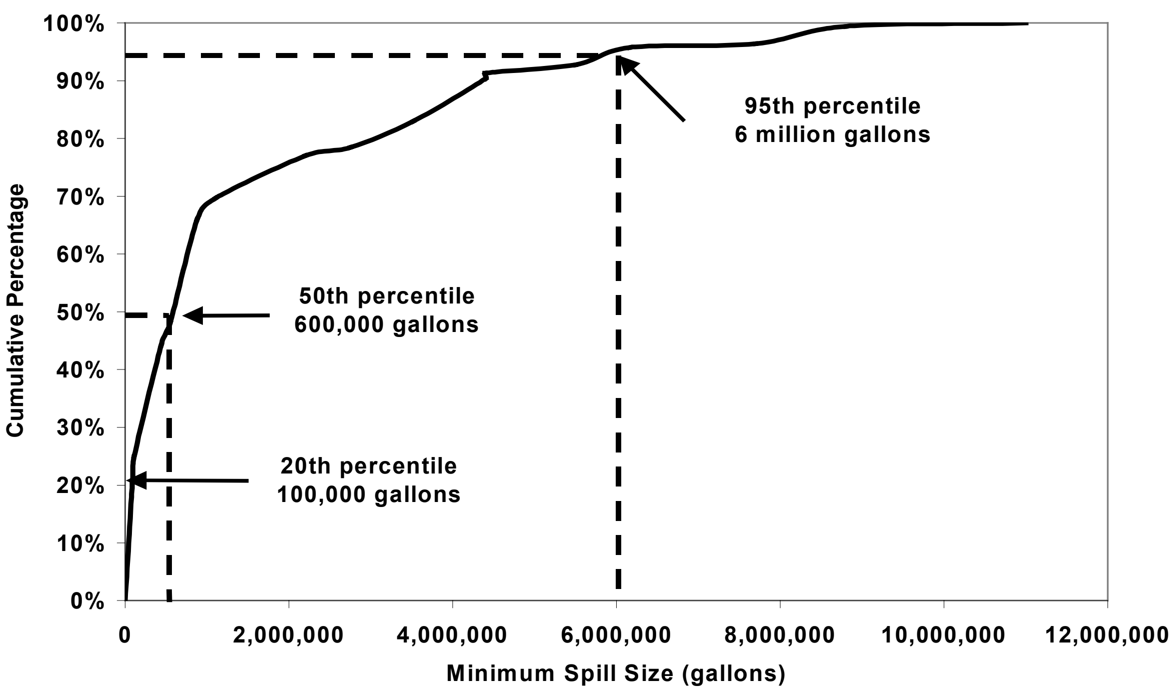


Table 11: Influence of Double Hulls on Future Spill Risks			
Tank Type	**Influence of Double Hulls**		
	Spill Probability at Impact	**Small-Median Spill Amt.**	**Large Spill Amt.**
Tanker Cargo	Reduced	No effect	Reduced 50%
Vessel Bunker	Reduced	No effect	No effect

Table 12: Double Hull Impact on Tanker Grounding Spills In San Francisco Bay					
Tanker Type	Expected Spill Volumes (gallons)				
	20th %	50th %	95th %	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

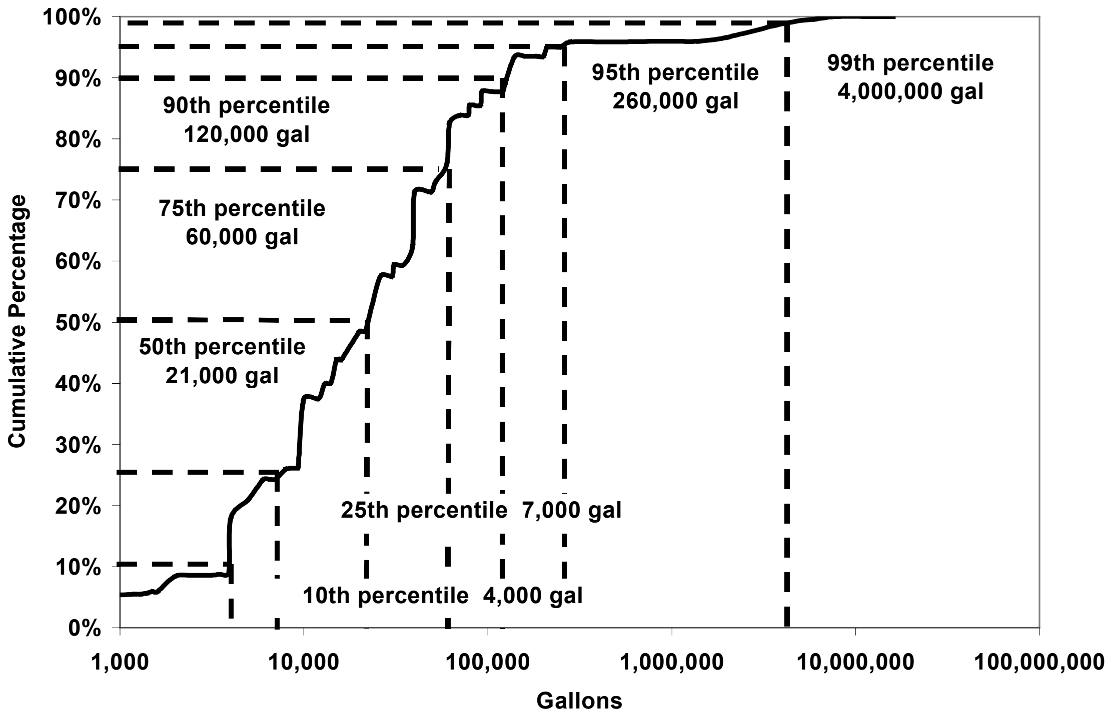
Based on Herbert Eng. et al., 1999; Michel & Thomas 2000; Rawson, et al. 1999

Table 13: Worldwide Oil Tanker Casualties Resulting in Spills 1978-1998			
Tanker Type	Collisions	Allisions	Groundings
Single Hull	6.30%	7.10%	7.20%
Double Hull	4.20%	2.60%	0
Double Bottom	7.00%	3.40%	2.40%
Double Side	0.00%	0.00%	7.70%

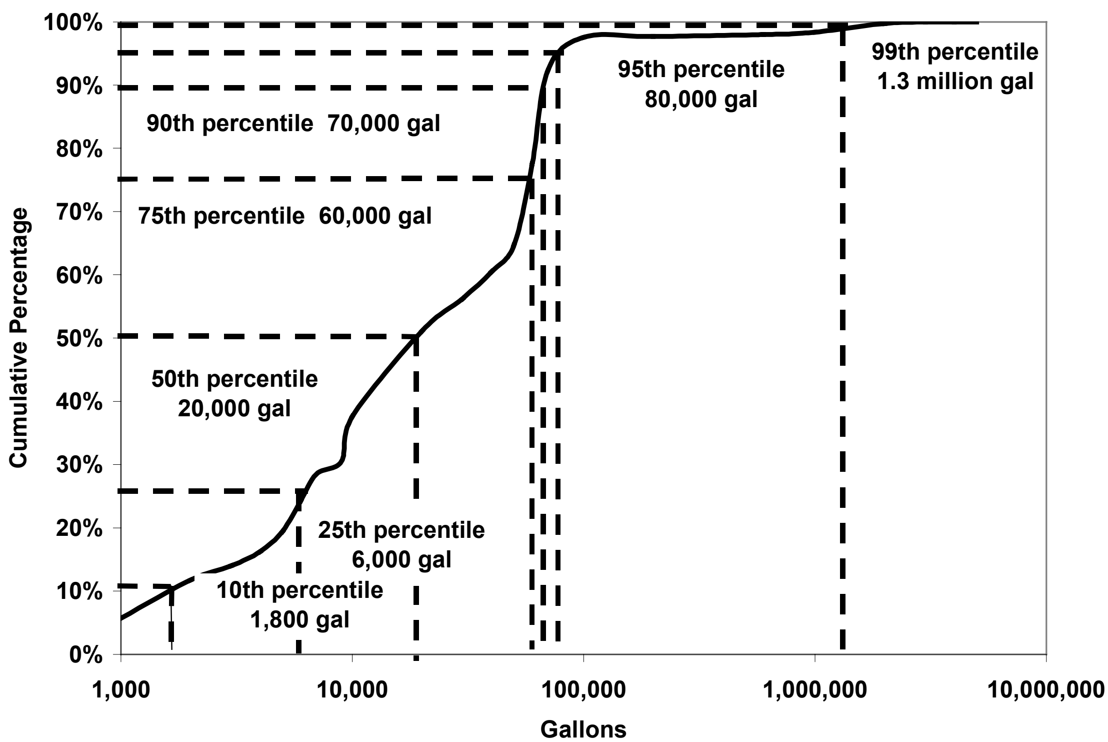
Source: Environmental Research Consulting databases (2,601 casualties)

Table 14: Future Most-Probable Scenarios for US Tanker Hard-Grounding Spills[1]								
Percentile Spill	Outflow (Gallons) By Tanker Type							
	Single Hull Crude		Double Hull Crude		Single Hull Product		Double Hull Product	
	US data only[2,3]	Intl data[3,4]	US data only[2,3]	Intl data[3,4]	US data only[2,3]	Intl data[3,4]	US data only[2,3]	Intl data[3,4]
10%	4,000	100,000	4,000	100,000	1,800	50,000	1,800	50,000
25%	7,000	180,000	7,000	180,000	6,000	100,000	6,000	100,000
50%	21,000	400,000	21,000	400,000	20,000	120,000	20,000	120,000
75%	60,000	1.8 mil.	60,000	900,000	60,000	1 mil.	60,000	500,000
90%	120,000	4.5 mil.	120,000	2.25 mil	70,000	4.5 mil	70,000	2.25 mil.
95%	260,000	10 mil.	260,000	5 mil.	80,000	6.5 mil	80,000	3.25 mil
99%	6 mil.	20 mil.	3 mil.	10 mil.	1.3 mil.	10 mil.	650,000	5 mil.
Most-Probable WCD[5]	16 mil.	76 mil.	8 mil.	38 mil.	4.8 mil.	22.8 mil	2.4 mil.	11.4 mil.
Theoretical WCD[6]	80 mil.	80 mil.	40 mil.	40 mil.	24 mil.	24 mil.	12 mil.	12 mil.

[1]1999 tanker traffic (Maritime Administration 2000). [2]Based on cargo loss % in US groundings (Table 3). [3]Spills < 1,000 gal. eliminated as most likely caused by *soft* grounding (Rawson, *et al.* 1998) [4]Based on US/international cargo loss%: 1% loss (48% incidents), 2% loss (16.2%), 5% loss (5.4%), 8% loss (5.4%), 10% (5.4%), 14% (8.1%), 20% (2.7%), 60% (5.4%), 95% (2.7%). [5]Based on largest % loss on largest cargo (20% US; 95% international). [6]Based on total mass of 80% full cargo tanks on largest tanker.



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative Percentage
90th percentile
120,000 gal
75th percentile
60,000 gal
50th percentile
21,000 gal
95th percentile
260,000 gal
99th percentile
4,000,000 gal
25th percentile 7,000 gal
10th percentile 4,000 gal
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
Gallons



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative Percentage
95th percentile
80,000 gal
99th percentile
1.3 million gal
90th percentile 70,000 gal
75th percentile 60,000 gal
50th percentile
20,000 gal
25th percentile
6,000 gal
10th percentile
1,800 gal
1,000
10,000
100,000
1,000,000
10,000,000
Gallons

Fig. 1: PDF of Actual Spill Sizes for Tanker Impact Accidents in US Waters 1985-2000

Fig. 2: PDF of Potential WCD from US Tanker Impact Accidents (1985 – 2000)

Fig. 3: PDF of Actual Oil Spillage for US Tanker Non-Impact Accidents 1985-2000

Fig. 4: PDF of Potential WCD for US Tanker Non-Impact Accidents 1985-2000

Fig. 5: PDF of Oil Spill Amounts for US Tanker Lighter/Load/Bunkering 1985-2000

Fig. 6: PDF of Oil Spill Amounts for US Tanker Illegal Discharge Incidents 1985-2000

Fig. 7: PDF of Oil Spill Size for Product Tanker Groundings in San Francisco Bay

Fig. 8: PDF of Oil Spill Size for Crude Tanker Groundings in San Francisco Bay

Fig. 9: Projected PDF of Crude Spills from Tanker Groundings in US Waters (US Grounding Data Only)

Fig. 10: Projected PDF of Oil Product Spills from Tanker Groundings in US Waters (US Grounding Data Only)

(Note: Tables are numbered at the top of each table. These figure captions correspond to the graphs only.)