Comparative Occurrence Rates for Offshore Oil Spills

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Abstract

Estimates of occurrence rates for offshore oil spills are useful for analysis of potential oil spill impacts and for oil spill response contingency planning. As the Oil Pollution Act of 1990 (U.S. Public Law 101-380, August 18, 1990) becomes fully implemented, estimates of oil spill occurrence will become even more important to natural resource trustees and to responsible parties involved in oil and gas activities. Oil spill occurrence rate estimates have been revised based on U.S. Outer Continental Shelf platform and pipeline spill data (1964 through 1992) and worldwide tanker spill data (1974 through 1992). These spill rates are expressed and normalized in terms of number of spills per volume of crude oil handled. The revisions indicate that estimates for the platform spill occurrence rates declined, the pipeline spill occurrence rates increased, and the worldwide tanker spill occurrence rates remained unchanged. Calculated for the first time were estimates of tanker and barge spill rates for spills occurring in U.S. waters, and spill occurrence rates for spills of North Slope crude oil transported by tanker from Valdez, Alaska. All estimates of spill occurrence rates were restricted to spills greater than or equal to 159 m^3 (1,000 barrels).

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INTRODUCTION

Background

The 1989 *Exxon Valdez* spill in Alaska's Prince William Sound was a primary focus for developing legislation for the Oil Pollution Act of 1990 (U.S. Public Law 101-380, August 18, 1990). Implementation of this act continues to focus concern on oil spill prevention and contingency planning, both of which have increased the levels of interest in oil spill occurrences by Federal and State government, industry, public, and environmental groups.

The Minerals Management Service (MMS) of the U.S. Department of the Interior (DOI) conducts and regulates oil and natural gas leasing, development, and production activities on the U.S. Outer Continental Shelf (hereafter referred to as U.S. OCS). Prior to holding a U.S. OCS lease sale, the MMS assesses the risks of oil spills occurring and evaluates the potential impacts. These spills could occur at any time during a 15- to 40-year period associated with lease sale-specific activities. The MMS also analyzes proposed development and production plans and oil spill contingency plans for individual production and transportation sites. Each of these plans has varying levels of information that may influence the ability to estimate the risk of oil spills occurring at a particular site.

The Oil Spill Risk Analysis (OSRA) model, developed in 1975 by the DOI, is a tool that evaluates offshore oil spill risks (Smith *et al.*, 1982). This model is used to develop probabilistic estimates of oil spill occurrence and contact. A realistic, objective methodology for estimating occurrence rates for oil spills is required for the model's application. The MMS developed and maintains oil spill databases on U.S. OCS spills and tanker spills, which are used to support these estimations.

Many unknown factors could affect the likelihood of an oil spill occurring during the life of the lease sale activities: timing of exploration, development, and production; volume of production; type and location of drilling rigs; mode of product transportation and loading; weather and other external factors. Such data limitations preclude using elaborate spill-prediction techniques.

This paper presents a simple approach for estimating oil spill occurrence, normalized as a function of the volume of oil handled. For this paper, volume is reported in barrels (bbl) to assist policy and decisionmakers in government and industry. Based on average Arabian light crude (35.5° API gravity), 1 bbl is equal to the following: 42 U.S. gallons, 0.159 m^3, 0.136 metric tonnes. Spill occurrence rates are estimated for spills $\geq$ 159 m^3 (1,000 bbl), and for spills $\geq$ 1,590 m^3 (10,000 bbl) and, in the case of tanker spills occurring in worldwide waters $\geq$ 15,900 m^3 (100,000 bbl). Spill occurrence rates are expressed in terms of spills per 159,000,000 m^3 (10^9 bbl).

METHODS & ASSUMPTIONS

The method used in revising occurrence rates involved three basic steps (1) data on historical spill occurrences and on volume of oil handled were examined, (2) volume was chosen as the exposure variable, and (3) spill occurrence rates were estimated and normalized based on spills per volume handled. The estimated mean number of spill occurrences are used in conjunction with the Poisson distribution to estimate the probability of spill occurrence.

Analysis of Spill Occurrence Data and Oil Movements

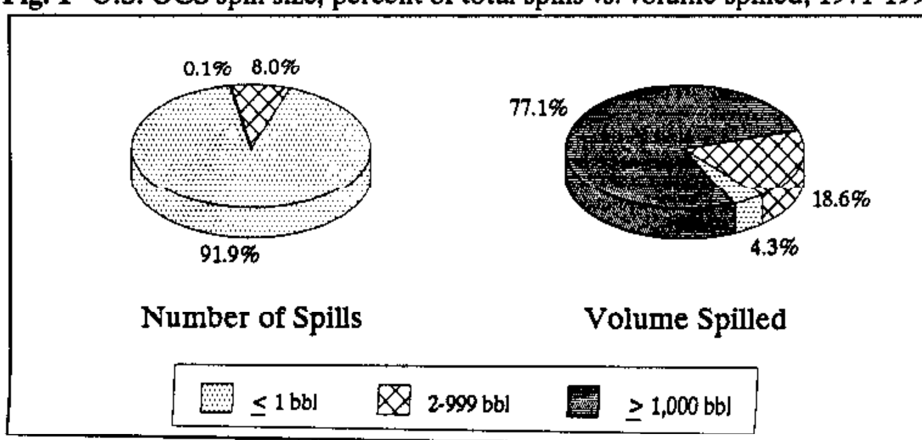
Historic oil spill occurrences ≥ 159 m^3 (1,000 bbl) and the volume of associated oil movements, in units of 159,000,000 m^3 (10^9 bbl), were analyzed for the types of spills discussed below.

Petroleum Spills from U.S. OCS Platforms and Pipelines

Although U.S. OCS spills ≥ 1,000 bbl account for a very small percentage (0.1%) of the total number of U.S. OCS spills that occurred, they represent most (77%) of the volume spilled (see Fig. 1). However, almost all U.S. OCS spills (92%) were ≤ 1 bbl in size.

Eleven platform spills and 12 pipeline spills ≥ 1,000 bbl occurred from 1964 through 1992 (see Table 1). These spills make up the entire record for U.S. OCS spills ≥ 1,000 bbl (the first U.S. OCS spill ≥ 1,000 bbl was reported in 1964). Platform spills are classified as blowouts and other spills occurring on the platform, including those resulting from damage to storage tanks. Total U.S. OCS production from 1964 through 1992 was estimated to be 9.1×10^9 bbl of crude oil and condensate (MMS, 1993). Historically, 95% or more of the total U.S. OCS production (on an annual basis) has been transported by pipeline. (Of the remaining 5%, there have been no spills ≥ 1,000 bbl resulting from movement of U.S. OCS oil by tanker or barge.)

Fig. 1 U.S. OCS spill size, percent of total spills vs. volume spilled, 1971-1992



Based on U.S. OCS spills in Gulf of Mexico (1971-1992) and Pacific (1976-1992); 21,963 spills totalling 121,300 bbl. Source: MMS OCS Spill Database, 1994

Table 1 U.S. OCS Oil Spills[1] ≥ 1,000 bbl, 1964-1992

Spill Date	U.S. OCS Area & Block	Volume Spilled (bbl)	Cause of Spill
PLATFORM SPILLS			
April 1964	Eugene Island 208	2,559	Freighter struck platform, fire
October 1964	Ship Shoal 149 & 199 /Eugene Island 208	11,869[2]	Platforms in hurricane, blowout
July 1965	Ship Shoal 29	1,688[3]	Well blowout
January 1969	Santa Barbara Channel	80,000	Well blowout
March 1969	Ship Shoal 72	2,500	Ship struck platform during storm, blowout
February 1970	Main Pass 41	30,000	Well blowout, fire
December 1970	South Timbalier 26	53,000	Well blowout, fire
January 1973	West Delta 79	9,935	Structural failure, storage tank rupture
January 1973	South Pelto 23	7,000	Stationary storage barge sank
November 1979	Main Pass 151	1,500[4]	Vessel collided with semisubmersible
November 1980	High Island 206	1,456	Pump failure, tank overflow
PIPELINE SPILLS			
October 1967	West Delta 73	160,638	Anchor damage to pipeline
March 1968	South Timbalier 131	6,000	Anchor damage to pipeline
February 1969	Main Pass 299	7,532	Anchor damage to pipeline
May 1973	West Delta 73	5,000	Pipeline corrosion
April 1974	Eugene Island 317	19,833	Anchor damage to pipeline
September 1974	Main Pass 73	3,500	Hurricane damage to pipeline
December 1976	Eugene Island 297	4,000	Trawl damage to pipeline
December 1981	South Pass 60	5,100	Anchor damage to pipeline
February 1988	Galveston 2A	15,576	Anchor damage to pipeline
January 1990	Ship Shoal 281	14,423[3]	Anchor damage to pipeline
May 1990	Eugene Island 314	4,569	Trawl damage to pipeline
August 1992	South Pelto 8	2,000	Hurricane damage to pipeline

1 bbl = 0.159 m^3
[1]Crude oil unless otherwise identified
[2]Five platforms; includes 1,589 bbl storage oil
[3]Condensate
[4]Diesel tank of semi-submersible drilling rig damaged
Source: MMS OCS Spill Database, 1994

The advantages of limiting the analysis to spills from U.S. OCS platforms and pipelines are that rates will better reflect the magnitude of spill occurrence under U.S. regulatory and operational controls, and the individual spill and production records are readily accessible. A disadvantage is that there are a small number of observations. This limited number of observations also precludes statistical analysis of possible spill rate variations that may exist between the northern Pacific or Alaska waters vs. the Southern California and the Gulf of Mexico waters (where most of the OCS experience in the United States has occurred). We believe that the rates should not be adjusted based on the intuition that more hostile environments are riskier. The more hostile environments have more stringent engineering and operational regulations, which may offset or even reduce the risk of a spill occurring relative to experience elsewhere.

Crude Oil Spills from Tankers in Worldwide Coastal and Offshore Waters

From 1974 through 1992, there were 213 crude oil spills ≥ 1,000 bbl from self-propelled crude oil carriers (see Table 2). Prior to this time, international spill occurrences were recorded on an irregular basis; more stringent reporting requirements were introduced in 1973 (Intergovernmental Maritime Consultative Organization International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL); Federal Water Pollution Control Act, U.S. Public Law 92-500, October 18, 1972; amended by U.S. Public Law 93-207, December 28, 1973).

Worldwide movements of crude oil from 1974 through 1992 were estimated to total 164.4 x 10^9 bbl, based on crude oil imports and exports (British Petroleum Company (BP), 1993). Inland spills (those in rivers, canals, etc.) and spills from barges were specifically excluded from the calculations under the assumption that international transportation of crude oil is performed by tanker to and from coastal ports.

Crude Oil Spills from Tankers in U.S. Coastal and Offshore Waters

Thirty-eight crude oil tanker spills ≥ 1,000 bbl occurred in U.S. coastal and offshore waters (including U.S. territorial waters) from 1974 to 1992, inclusive. These are a subset of the spills included in the worldwide tanker spill rates (see Table 2, numbers in parentheses).

Estimations of crude oil movements by tanker in U.S. waters were based on foreign movements (imports + exports—34.72 x 10^9 bbl) and domestic movements (coastal + interterritorial—13.88 x 10^9 bbl) of crude oil for the years 1974 through 1992 (U.S. Army Corps of Engineers [COE], 1994). Comprehensive data on locations of all individual vessel routes, the volumes moved over each route, and the oil spills associated with each specific route are generally unavailable. Therefore, a simple assumption regarding spills associated with foreign movements (U.S. crude oil imports and exports) was made that half of the spills related to foreign movements occurred in U.S. waters, and the other half occurred in international or foreign waters at the other end of the trip. In the spill rate calculation, the volume of foreign movements was adjusted by 50% to account for these assumptions, which resulted in an estimated 31.24 x 10^9 bbl of movements associated with tanker spills in U.S. waters (50% foreign + 100% domestic movements).

Table 2 Number of Worldwide Crude Oil Tanker Spills[1] ≥ 1,000 bbl and Crude Oil Movements, 1974-1992

		Spills In Port			Spills At Sea				
Year	All Spills	1,000-9,999 bbl	10,000-99,999 bbl	100,000 bbl and greater	1,000-9,999 bbl	10,000-99,999 bbl	100,000 bbl and greater	Crude Oil Movements (10^9 bbl)	Spills per 10^9 bbl
1974	19 (2)	5 (1)	2 (1)	1 (0)	6 (0)	3 (0)	2 (0)	10.2	1.9
1975	19 (6)	2 (1)	0 (0)	3 (1)	5 (1)	7 (2)	2 (1)	9.3	2.0
1976	18 (2)	3 (1)	0 (0)	1 (0)	4 (1)	4 (0)	6 (0)	10.5	1.7
1977	15 (3)	1 (1)	2 (1)	1 (0)	3 (0)	3 (0)	5 (1)	10.7	1.4
1978	17 (1)	3 (0)	1 (0)	0 (0)	3 (1)	4 (0)	6 (0)	10.5	1.6
1979	22 (4)	3 (2)	2 (1)	2 (0)	4 (0)	5 (0)	6 (1)	11.0	2.0
1980	11 (2)	1 (0)	1 (1)	1 (0)	3 (1)	2 (0)	3 (0)	9.7	1.1
1981	7 (2)	3 (1)	1 (1)	0 (0)	3 (0)	0 (0)	0 (0)	8.5	0.8
1982	6 (0)	2 (0)	0 (0)	1 (0)	3 (0)	0 (0)	0 (0)	7.3	0.8
1983	13 (1)	4 (1)	1 (0)	0 (0)	1 (0)	4 (0)	3 (0)	6.9	1.9
1984	6 (1)	1 (0)	3 (0)	0 (0)	1 (0)	1 (1)	0 (0)	6.8	0.9
1985	5 (2)	1 (1)	2 (1)	0 (0)	1 (0)	0 (0)	1 (0)	6.4	0.8
1986	6 (3)	2 (2)	0 (0)	0 (0)	1 (1)	3 (0)	0 (0)	7.2	0.8
1987	11 (3)	3 (0)	1 (0)	0 (0)	4 (1)	3 (2)	0 (0)	6.8	1.6
1988	6 (1)	1 (0)	3 (1)	0 (0)	1 (0)	0 (0)	1 (0)	7.4	0.8
1989	12 (2)	3 (1)	0 (0)	0 (0)	1 (0)	5 (0)	3 (1)	8.0	1.5
1990	8 (2)	5 (1)	0 (0)	0 (0)	1 (0)	2 (1)	0 (0)	8.7	0.9
1991	6 (0)	0 (0)	0 (0)	1 (0)	2 (0)	1 (0)	2 (0)	9.2	0.7
1992	6 (1)	3 (1)	0 (0)	1 (0)	1 (0)	1 (0)	0 (0)	9.3	0.6
Total	213 (38)[2]	46 (14)	19 (7)	12 (1)	48 (6)	48 (6)	40 (4)	164.4	1.3

1 bbl = 0.159 m^3

[1]Number of spills in U.S. waters are shown in parentheses

[2]213 spills ≥ 1,000 bbl totalling 22,191,000 bbl; includes 38 spills in U.S. waters totalling 1,868,800 bbl; excludes inland spills

Sources: BP, 1993; MMS Worldwide Tanker Spill Database, 1994

Tanker Spills of North Slope Crude Transported from Valdez, Alaska

The Alyeska Pipeline System is the main transportation artery carrying crude oil and some natural gas liquids from Alaska's Arctic Subregion to Valdez, an ice-free port on the southern coast of Alaska. Transportation began in August 1977. From 1977 through 1992, approximately 9.08 x 10^9 bbl of North Slope crude were loaded onto tankers at Valdez (U.S. Department of Commerce [DOC], 1993). Roughly 95% of this crude oil has been shipped by tanker to the U.S. West Coast and Panama, with 10 associated tanker spills ≥ 1,000 bbl occurring during this time. These 10 spills are made up of the 240,500 bbl *Exxon Valdez* spill and 9 other spills which were 15,000 bbl or less in size.

Petroleum Spills from Barges in U.S. Coastal, Offshore, and Inland Waters

From 1974 through 1992, 153 petroleum product spills ≥ 1,000 bbl (24 of which were crude oil spills) occurred from barges in U.S. coastal, offshore, and inland waters (including U.S. territorial waters) (see Table 3). Because the data available on barge movements in U.S. waters do not differentiate between inland and coastal/offshore movements, inland movements were included. All petroleum products included crude oil, gasoline, jet fuel, kerosene, distillate fuel oil, residual fuel oil, lubricating oils and greases, naphtha, petroleum solvents, asphalt, tar and pitches, and liquified gases. Movements of these products from 1974 through 1992 were estimated to be 31.78 x 10^9 bbl (5.56 x 10^9 bbl of which was crude oil), based on the portion of U.S. domestic petroleum movements transported by barge (COE, 1994).

Selection of Exposure Variable

Two basic criteria were used in selecting the risk exposure variable: the exposure variable should be simple to define, and it should be a quantity that can be estimated. The volume of oil produced or transported was chosen as the exposure variable, primarily for the following reasons: historic volumes of oil produced and transported are well documented, using these volumes makes the calculation of the estimated oil spill occurrence rate simple—the ratio of the number of historic spills to the volume of oil produced or transported, and future volumes of oil production and transportation are routinely estimated.

Spill Rate Definition

Estimated occurrence rates for oil spills (hereafter referred to simply as "spill rates"), based on historic spill occurrences and associated oil movements, are expressed in terms of estimated mean number of spills per 10^9 bbl of oil handled. Only spills ≥ 1,000 bbl are addressed because spills smaller than that may not persist long enough to be simulated by trajectory modeling. Another consideration is that a large spill is likely to be identified and reported; therefore, these records are more comprehensive than those of smaller spills. (Small, chronic spillage is addressed in MMS's environmental analyses without the use of trajectory modeling.)

Table 3 Barge Spills ≥ 1,000 bbl and Petroleum[1] Movements by Barges in U.S. Waters, 1974-1992

Year	Number of Spills[2]				Petroleum[3] Movements (10^9 bbl)	Spills[3] per 10^9 bbl
	All Spills	1,000-9,999 bbl	10,000-24,999 bbl	25,000 bbl and greater		
1974	13 (5)	9 (3)	2 (2)	2 (0)	1.62 (0.32)	8.0 (15.6)
1975	12 (4)	8 (3)	4 (1)	0 (0)	1.61 (0.33)	7.5 (12.1)
1976	8 (4)	8 (4)	0 (0)	0 (0)	1.75 (0.34)	4.6 (11.8)
1977	12 (0)	11 (0)	1 (0)	0 (0)	1.79 (0.33)	6.7 (-.-)[4]
1978	15 (2)	12 (2)	3 (0)	0 (0)	1.85 (0.36)	8.1 (5.6)
1979	10 (1)	10 (1)	0 (0)	0 (0)	1.71 (0.32)	5.8 (3.1)
1980	10 (2)	10 (2)	0 (0)	0 (0)	1.72 (0.27)	5.8 (7.4)
1981	6 (0)	4 (0)	0 (0)	2 (0)	1.68 (0.22)	3.6 (-.-)
1982	5 (0)	4 (0)	0 (0)	1 (0)	1.57 (0.23)	3.2 (-.-)
1983	6 (1)	3 (1)	2 (0)	1 (0)	1.54 (0.25)	3.9 (4.0)
1984	7 (1)	5 (0)	1 (1)	1 (0)	1.64 (0.28)	4.3 (3.6)
1985	11 (2)	7 (2)	2 (0)	2 (0)	1.58 (0.30)	7.0 (6.7)
1986	6 (1)	5 (1)	1 (0)	0 (0)	1.64 (0.30)	3.7 (3.3)
1987	4 (0)	4 (0)	0 (0)	0 (0)	1.67 (0.27)	2.4 (-.-)
1988	8 (0)	7 (0)	0 (0)	1 (0)	1.74 (0.30)	4.6 (-.-)
1989	7 (0)	7 (0)	0 (0)	0 (0)	1.71 (0.28)	4.1 (-.-)
1990	10 (1)	9 (1)	1 (0)	0 (0)	1.74 (0.31)	5.7 (3.2)
1991	3 (0)	3 (0)	0 (0)	0 (0)	1.65 (0.28)	1.8 (-.-)
1992	0 (0)	0 (0)	0 (0)	0 (0)	1.60 (0.28)	-.- (-.-)
Total	153 (24)[5]	126 (20)	17 (4)	10 (0)	31.78 (5.56)	4.8 (4.3)

1 bbl = 0.159 m^3

[1]Petroleum includes crude oil, gasoline, jet fuel, kerosene, distillate fuel oil, residual fuel oil, lubricating oils and greases, petroleum solvents, asphalt, and liquified gases

[2]Number of crude oil spills are shown in parentheses

[3]Columns may not add to total due to rounding

[4]Dash indicates zero spills observed; not calculated

[5]153 spills ≥ 1,000 bbl totalling 973,500 bbl; includes 24 crude oil spills totalling 147,600 bbl (including those in U.S. territorial waters); includes coastal, offshore, and inland movements and spills; largest spill less than 50,000 bbl

Sources: COE, 1994; MMS Worldwide Tanker Spill Database, 1994

The U.S. OCS platform and pipeline spill rates and the worldwide tanker spill rates are updates of previously published rates (Anderson & LaBelle, 1990). The tanker and barge spill rates in U.S. waters and the tanker spill rate for spills of North Slope crude oil transported by tanker from Valdez, Alaska, are introduced in this paper.

Poisson Distribution for Estimating Oil Spill Occurrence

Spill occurrence has been modeled previously as a Poisson process (Smith *et al.*, 1982; Lanfear & Amstutz, 1983; Anderson & LaBelle, 1990). A stochastic process, $N(t)$, is a counting process if $N(t)$ represents the total number of events that have occurred up to time t. To determine if the counting process of spill occurrence is a Poisson process, with volume of oil exposure t and where λ is the true rate of spill occurrence per unit exposure, the occurrence of spills must meet the following three criteria (Ross, 1985):

(a) N(0) must equal zero with a probability equal to 1.

(b) The process must have independent increments (i.e., the number of spill occurrences for any given interval does not depend on the previous or following intervals).

(c) The number of events in any interval of length t must be Poisson distributed with a mean of λt (i.e., this process must have stationary increments where the number of spills that occur in any interval depends only on the length of the interval).

These criteria have been met since

(a) No spills can occur when no (0 bbl) oil is handled.

(b) Analysis of the record indicates that individual spill events are independent of previous spill events over time and production/transportation.

(c) In the situation where the data indicated that there was a decrease in the frequency of spill events over time and production, a sensitivity analysis was performed to identify where the increments became relatively stationary. The spill rate was then calculated from that point forward.

Because spill occurrences meet the criteria for a Poisson process, the following equations were used in our estimation of spill rates. The estimated volume of oil handled is the exposure variable. Smith *et al.* (1982), using Bayesian inference techniques, presented a derivation of this process, assuming the probability of n spills over some future exposure t is expected to occur at random with a frequency specified by equation (1):

$$P[n \text{ spills over future exposure } t] = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \qquad (1)$$

where λ is the true rate of spill occurrence per unit exposure.

The predicted probability takes the form of a negative binomial distribution specified by equation (2):

$$P(n) = \frac{(n + v - 1)!t^n\tau^v}{n!(v - 1)!(t + \tau)^{n+v}} \tag{2}$$

where τ is past exposure and v is the number of spills observed in the past. The negative binomial is then shown to converge over time to the Poisson, with λ estimated using equation (3) (Smith *et al.*, 1982):

$$\lambda = v/\tau \tag{3}$$

RESULTS

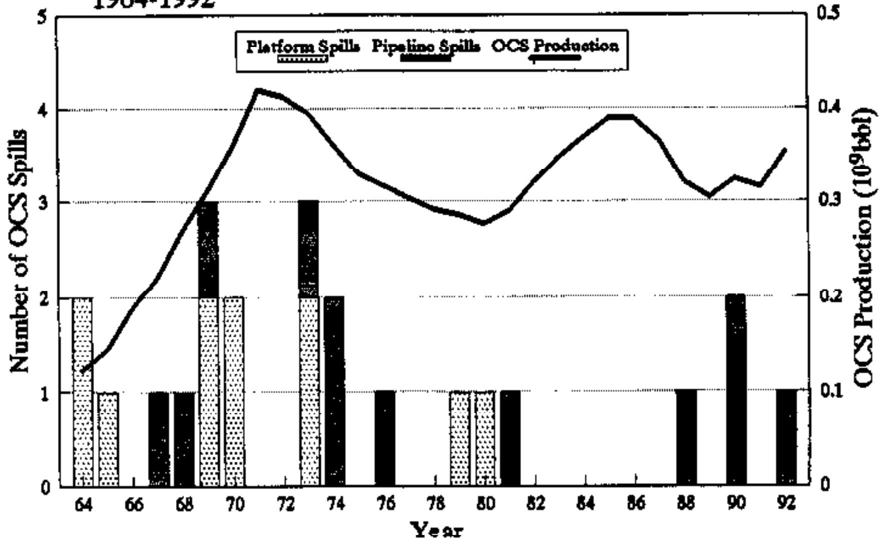
Spill rates, expressed in terms of spills per 10^9 bbl of oil handled, were calculated for each spill source examined for spills $\geq$ 1,000 bbl and for spills $\geq$ 10,000 bbl, (spills $\geq$ 10,000 bbl being a subset of spills $\geq$ 1,000 bbl). Spill rates for spills $\geq$ 100,000 bbl were also calculated for crude oil spills from tankers in worldwide coastal and offshore waters, where the average spill size was greater than 100,000 bbl (104,200 bbl). As a rule, the rates were calculated using the entire record of observed spills and oil movements, and were normalized in terms of spills per volume of crude oil handled. For U.S. OCS platforms, where a decline in the spill rate was identified through trend analysis, the rate for spills $\geq$ 1,000 bbl was calculated by excluding the earliest portion of the historic record (where the spill rate differed from the current trend).

Estimation of Spill Rates for Petroleum Spills from U.S. OCS Platforms and Pipelines

In previous work, nonparametric tests (appropriate to small sample sizes) were applied to apparent random and independent observations of U.S. OCS platform and pipeline spills $\geq$ 1,000 bbl over uniform increments of volume of U.S. OCS production from 1964 through 1987 (Anderson & LaBelle, 1990). Test results indicated a significant increase in the number of uniform production intervals between the observed spills over time. The increase translated to a statistically significant reduction, or decreasing trend, in the overall spill rates between the earlier and latter parts of the historic record.

As illustrated in Fig. 2, there have been no additional U.S. OCS platform spills since the U.S. OCS platform spill rate was last calculated (Anderson & LaBelle, 1990). The previously identified trend in intervals numbered 6-15 (0.5 x 10^9 bbl production intervals) has been preserved in production intervals 16-18, which represents a continued increase in the number of production intervals between observed platform spills (see Fig. 3). The revised spill rate of 0.45 spills per 10^9 bbl handled for U.S. OCS platform spills $\geq$ 1,000 bbl (Table 4) was based on adjustments using the last three spills that occurred over the most recent 6.6 x 10^9 bbl of production (i.e., based on production intervals 6-18). This is the same starting point from which the previous U.S. OCS platform spill rate was calculated (Anderson & LaBelle, 1990).

Fig. 2 Number of U.S. OCS spills ≥ 1,000 bbl vs. U.S. OCS production, 1964-1992



Based on 23 spills; 9.1 x 10^9 bbl of crude oil and condensate production.
Sources: MMS, 1993; MMS OCS Spill Database, 1994

Table 4 U.S. OCS Platform and Pipeline Spill Rates, 1964-1992

U.S. OCS Spills	Number of Spills	Average Spill Size (bbl)	Median Spill Size (bbl)	Spill Rate (spills per 10^9 bbl)
≥ 1,000 bbl				
Platforms	11	18,300	7,000	0.45[1]
Pipelines	12	20,700	5,600	1.32[2]
≥ 10,000 bbl				
Platforms	4	43,700	41,500	0.16[3]
Pipelines	4	52,600	17,700	0.44[2]

1 bbl = 0.159 m^3

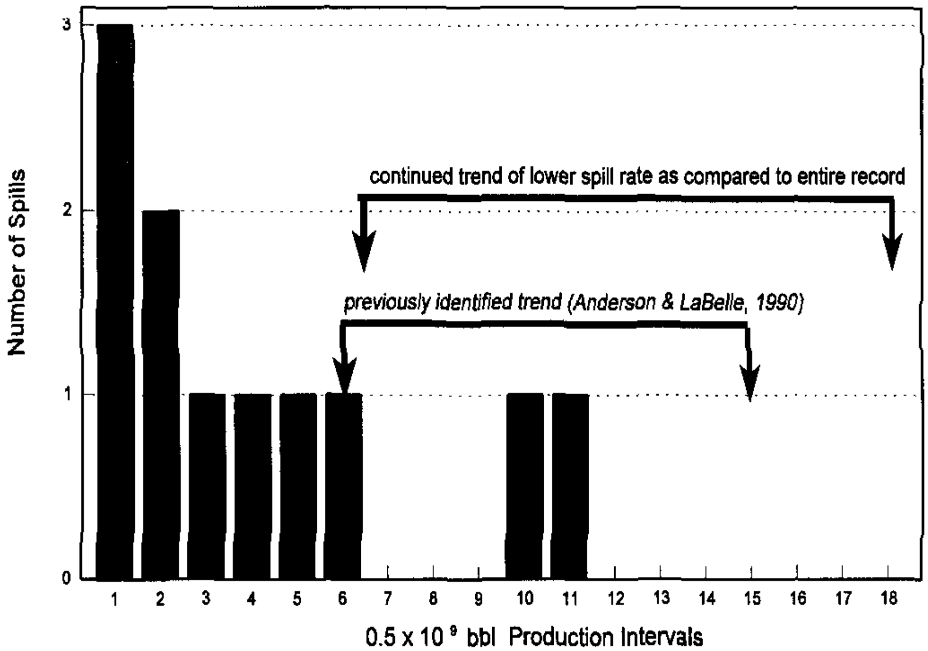
[1]Based on trend analysis, most recent 6.6 x 10^9 bbl over which 3 spills ≥ 1,000 bbl occurred (earlier portion of record not included in spill rate)

[2]Based on entire transportation record of 9.1 x 10^9 bbl crude oil, 1964-1992

[3]Based on 4/11 of the spill rate for spills ≥ 1,000 bbl--4 of the 11 spills ≥ 1,000 bbl were also ≥ 10,000 bbl between 1964 and 1992. None of the 3 spills in the current trend was ≥ 10,000 bbl

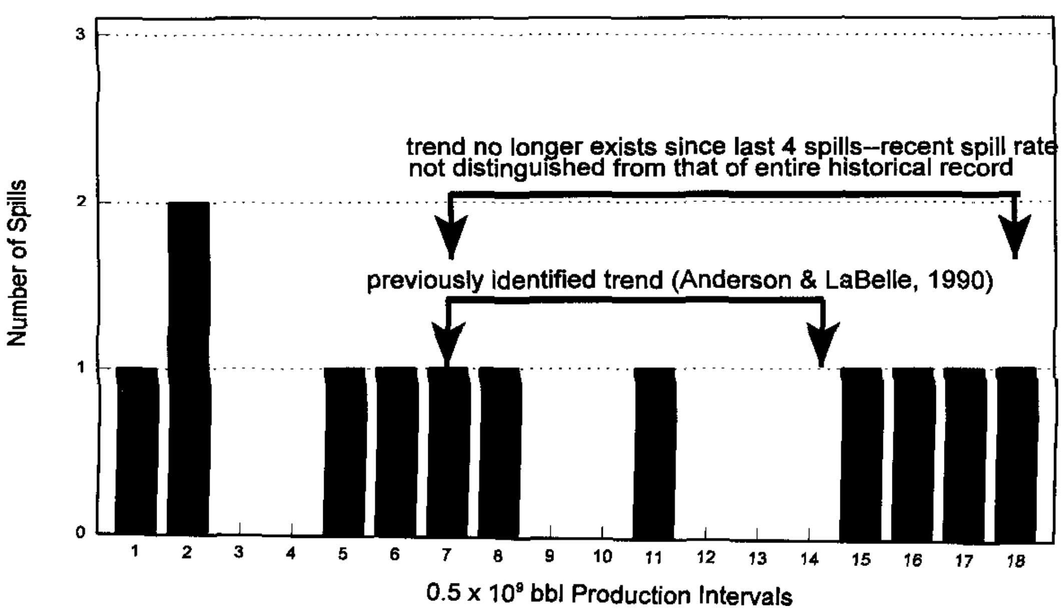
Sources: MMS, 1993; MMS OCS Spill Database, 1994

Fig. 3. U.S. OCS platform spills ≥ 1,000 bbl within 0.5 x 10 ^{9} bbl production intervals, 1964-1992



Based on 9.1 x 10 ^{9} bbl of crude oil and condensate production.

Fig. 4 U.S. OCS pipeline spills ≥ 1,000 bbl within 0.5 x 10 ^{9} bbl production interva 1964-1992



Based on 9.1 x 10 ^{9} bbl of crude oil and condensate production.

Four additional U.S. OCS pipeline spills have occurred (see Fig. 2) since the U.S. OCS pipeline spill rate was last calculated (Anderson & LaBelle, 1990). As illustrated in Fig. 4, the occurrence of these spills during the most recent 2.0 x 10^9 bbl of production (intervals 15-18) between 1988 and 1992 eliminated the trend of increased production between spill observations previously identified after the first 3.0 x 10^9 bbl of production (intervals 1-6) in the U.S. OCS pipeline spill record. As such, the spill rate for intervals 7 through 18 is no longer significantly different from the entire pipeline spill record. The revised spill rate of 1.32 spills per 10^9 bbl handled for U.S. OCS pipeline spills ≥ 1,000 bbl was calculated based on the entire record of 12 spills over 9.1 x 10^9 bbl of production (see Table 4).
The revised U.S. OCS platform spill rate estimate of 0.16 spills per 10^9 bbl handled for spills ≥ 10,000 bbl was calculated based on four-elevenths of the spill rate for spills ≥ 1,000 bbl (Table 4). This was because 4 out of the 11 U.S. OCS platform spills were ≥ 10,000 bbl even though all 3 spills included in the recent trend were less than 10,000 bbl. The revised U.S. OCS pipeline spill rate of 0.44 spills per 10^9 bbl handled for spills ≥ 10,000 bbl was calculated based on the 4 (out of 12) pipeline spills over the entire record of 9.1 x 10^9 bbl of production (see Table 4).

Estimation of Spill Rates for Crude Oil Spills from Tankers in Worldwide Coastal and Offshore Waters

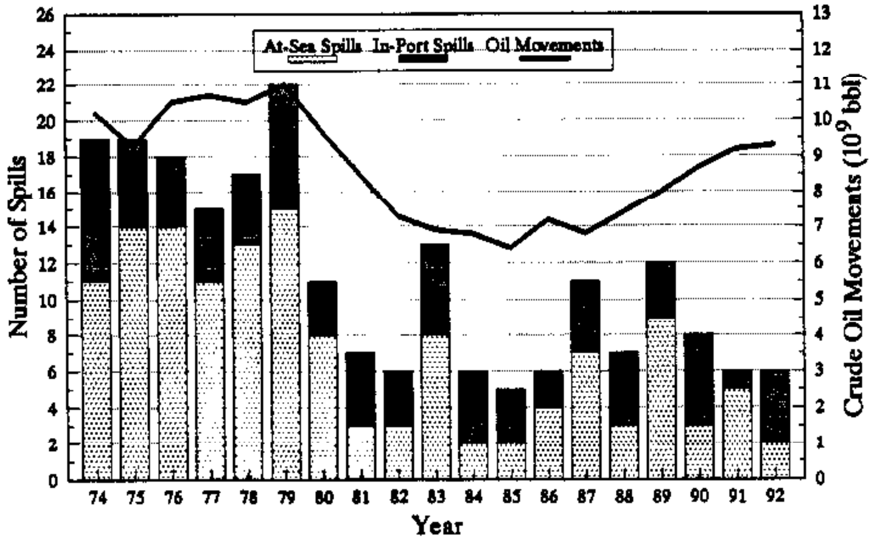
Data of crude oil tanker spills ≥ 1,000 bbl occurring in worldwide waters from 1974 through 1992 (see Fig. 5) comprised substantially more observations than the U.S. OCS platform and pipeline data. In addition, the annual spill rate did not appear to increase or decrease monotonically over time (see Table 2). For these reasons, the spill rates for spills ≥ 1,000 bbl, 10,000 bbl, and 100,000 bbl were calculated based on the entire record (Table 5).

Rates for spills that occur offshore ("at sea") were analyzed separately from those occurring in harbors or at piers ("in port"). This separation was necessary, since only spills occurring offshore are simulated as trajectories by the OSRA model, using the "at-sea" rate. (In-port spills are assumed to contact land.) Inland tanker spills were excluded from this analysis because they are beyond MMS purview.

Estimation of Spill Rates for Crude Oil Spills from Tankers in U.S. Coastal and Offshore Waters

Like tanker spills in worldwide coastal and offshore waters, data of crude oil tanker spills ≥ 1,000 bbl in U.S. coastal and offshore waters (Fig. 6) comprised substantially more observations than the U.S. OCS platform and pipeline data. In addition, the annual spill rate did not appear to increase or decrease monotonically over time. For these reasons, the spill rates for spills ≥ 1,000 bbl and 10,000 bbl were calculated based on the entire record (Table 6).

Fig. 5 Number of worldwide tanker spills ≥ 1,000 bbl vs. worldwide crude oil movements, 1974-1992



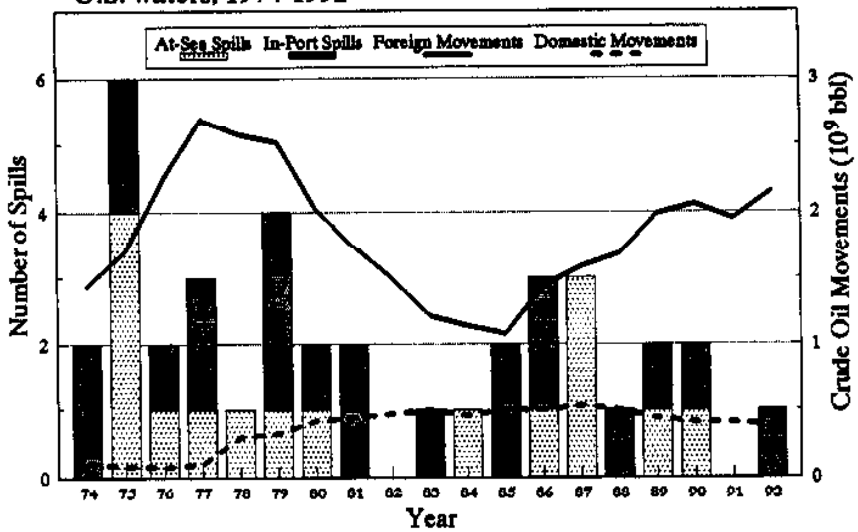
Based on 213 crude oil spills; 164.4×10^9 bbl of crude imports; excludes inland spills.
Sources: BP, 1993; MMS Worldwide Tanker Spill Database, 1994.

Table 5 Worldwide Tanker Spill Rates, 1974-1992

Tanker Spills[1]	Number of Spills	Average Spill Size (bbl)	Median Spill Size (bbl)	Spill Rate[2] (spills per 10^9 bbl)
≥ 1,000 bbl				
In Port	77	58,300	6,400	0.47
At Sea	136	130,100	22,000	0.83
All Spills	213	104,200	15,000	1.30
≥ 10,000 bbl				
In Port	31	139,500	50,000	0.19
At Sea	88	198,700	88,400	0.53
All Spills	119	183,300	73,300	0.72
≥ 100,000 bbl				
In Port	12	310,300	251,000	0.07
At Sea	40	392,900	243,600	0.24
All Spills	52	373,800	243,600	0.31

1 bbl = 0.159 m^3
[1]Crude oil spills only, excludes barge and inland spills
[2]Based on movement of 164.4×10^9 bbl crude oil
Sources: MMS Worldwide Tanker Spill Database, 1994; BP, 1993

Fig. 6 Number of tanker spills ≥ 1,000 bbl vs. crude oil movements in U.S. waters, 1974-1992



Based on 38 crude oil spills; 34.7×10^9 bbl foreign movements; 13.9×10^9 bbl of domestic movements; excludes inland spills.
Sources: COE, 1994; MMS Worldwide Tanker Spill Database, 1994

Table 6 Spill Rates for Tankers in U.S. Coastal and Offshore Waters, 1974-1992

Tanker Spills[1]	Number of Spills	Average Spill Size (bbl)	Median Spill Size (bbl)	Spill Rate[2] (spills per 10^9 bbl)
≥ 1,000 bbl				
In Port	22	22,100	6,800	0.70
At Sea	16	86,500	16,000	0.51
All Spills	38	49,200	9,200	1.21
≥ 10,000 bbl				
In Port	8	53,600	20,000	0.26
At Sea	10	136,200	79,700	0.32
All Spills	18	99,500	26,000	0.58

1 bbl = 0.159 m^3
[1]Crude oil spills only (including those in U.S. territorial waters); excludes barge and inland spills
[2]Based on adjusted movements of 31.24×10^9 bbl crude oil
Sources: COE, 1994; MMS Worldwide Tanker Spill Database, 1994

Table 7 North Slope Crude Oil Tanker Spill Rates, 1977-1992

Tanker Spills	Number of Spills	Average Spill Size (bbl)	Median Spill Size (bbl)	Spill Rate[1] (spills per 10^9 bbl)
≥ 1,000 bbl				
In Port	3	5,600	5,700	0.33
At Sea	7	40,200	4,000	0.77
All Spills	10	29,800	4,900	1.10
≥ 10,000 bbl				
In Port	0	--[2]	--	--
At Sea	3	89,900	15,000	0.33
All Spills	3	89,900	15,000	0.33

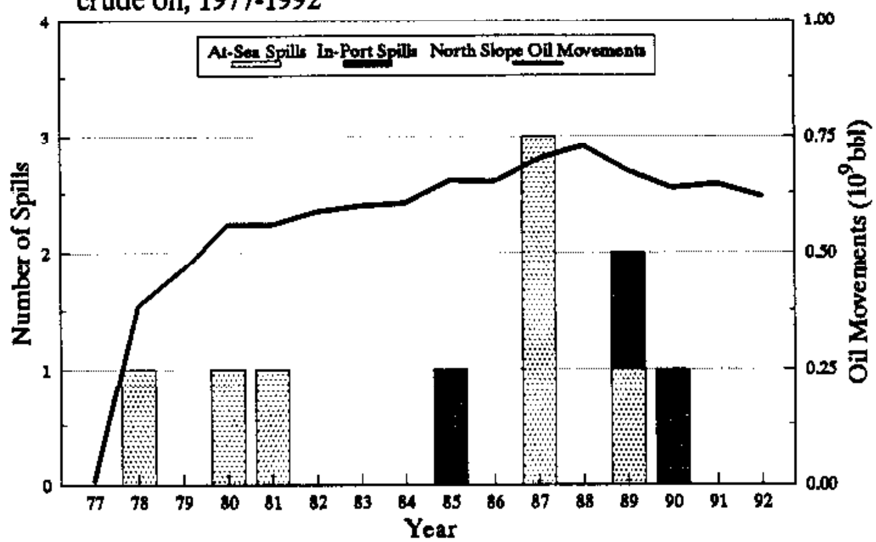
1 bbl = 0.159 m^3

[1]Based on movements of 9.08 x 10^9 bbl of North Slope crude oil

[2]Dash indicates zero spills observed; not calculated

Sources: DOC, 1993; MMS Worldwide Tanker Spill Database, 1994

Fig. 7 Number of tanker spills ≥ 1,000 bbl vs. movements of North Slope crude oil, 1977-1992



Based on 10 spills; 9.1 x 10^9 bbl of North Slope Crude moved by tanker.
Sources: DOC, 1993; MMS Worldwide Tanker Spill Database, 1994.

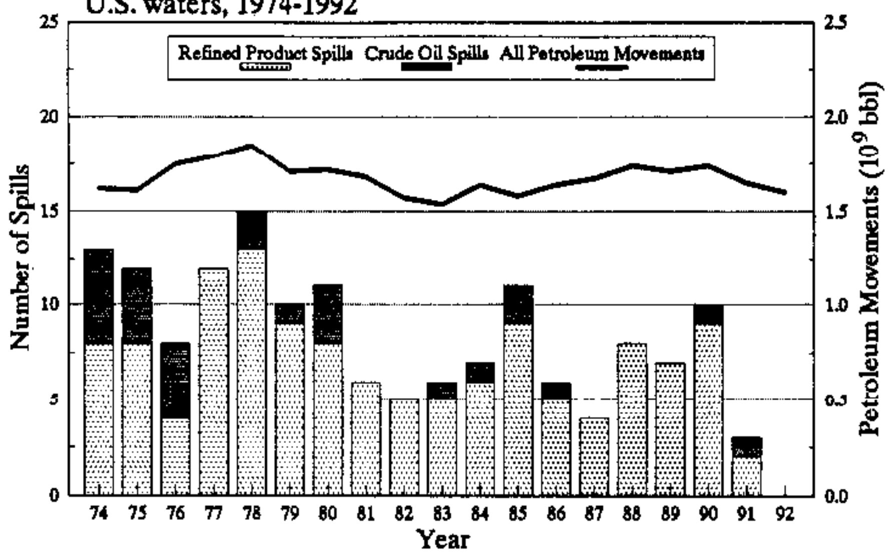
Estimation of Spill Rates for Spills of North Slope Crude Oil Transported by Tanker from Valdez, Alaska

U.S. law requires that marine transportation of domestic products be performed by U.S. flagships. These U.S. flagships must be owned by U.S. companies, built in the United States, and manned by U.S. crews. Table 7 presents the calculated spill rates for North Slope crude oil transported by tanker from Valdez, Alaska, based on the 10 spill observations that were distributed uniformly over time and volume of oil moved (see Fig 7). Due to the lack of any "in-port" spills ≥ 10,000 bbl, only an "at-sea" rate for spills ≥ 10,000 bbl was estimated.

Estimation of Spill Rates for Petroleum Spills from Barges in U.S. Coastal, Offshore, and Inland Waters

Data of petroleum spills ≥ 1,000 bbl from barges in U.S. coastal, offshore, and inland waters comprised substantially more observations than the U.S. OCS platform and pipeline data (see Fig. 8). In addition, the annual spill rate did not appear to increase or decrease monotonically over time (see Table 3). For these reasons, the spill rates for spills ≥ 1,000 bbl and 10,000 bbl were calculated based on the entire record (Table 8). Although the estimated rate for barge spills in U.S. waters is relatively high in comparison to the other estimated spill rates, the average and median spill sizes are comparatively small.

Fig. 8 Number of barge spills ≥ 1,000 bbl vs. petroleum movements in U.S. waters, 1974-1992



Based on 153 petroleum spills; 31.8 x 10^9 bbl of domestic movements; includes coastal, offshore, and inland spills and movements.
Sources: COE, 1994; MMS Worldwide Tanker Spill Database, 1994

Table 8 Spill Rates for Barges in U.S. Coastal, Offshore, and Inland Waters, 1974-1992

Barge Spills[1]	Number of Spills	Average Spill Size (bbl)	Median Spill Size (bbl)	Spill Rate[2] (spills per 10^9 bbl)
≥ 1,000 bbl				
All Petroleum Products	153	6,400	3,000	4.81
Crude Oil Only	24	6,200	4,100	4.32
≥ 10,000 bbl				
All Petroleum Products	27	21,900	20,000	0.85
Crude Oil Only	4	19,100	19,300	0.72

1 bbl = 0.159 m^3
[1]Includes spills in U.S. territorial waters
[2]Based on movements of 31.78 x 10^9 bbl petroleum products, 5.56 x 10^9 bbl were crude oil
Sources: COE, 1994; MMS Worldwide Tanker Spill Database, 1994

CONCLUSIONS & DISCUSSION

The U.S. OCS platform and pipeline spill rates and the worldwide tanker spill rates are estimated updates of previously calculated rates.

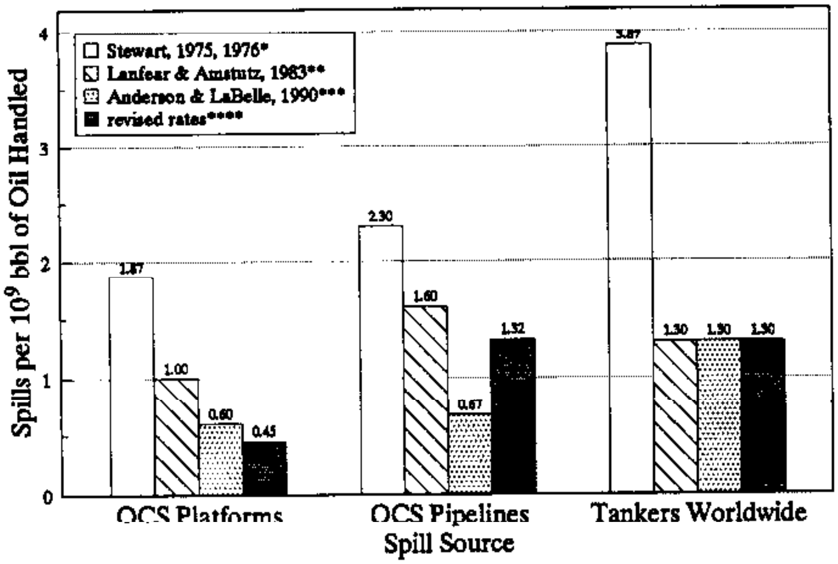
For spills ≥ 1,000 bbl, the following conclusions can be made (see Fig. 9):

- The U.S. OCS platform spill rates continued to decline from 0.60 per 10^9 bbl of production (based on trend analysis for 1964-1987) to 0.45 spills per 10^9 bbl of production (based on trend analysis for 1964-1992).
- The U.S. OCS pipeline spill rate increased from 0.67 per 10^9 bbl transported (based on trend analysis for 1964-1987) to 1.32 spills per 10^9 bbl transported (based on the entire record for 1964-1992).
- The worldwide tanker spill rates stayed constant at 1.30 spills per 10^9 bbl transported (for 1974-1985 as well as 1974-1992).

For spills ≥ 10,000 bbl, the following can be concluded (see Fig. 10):

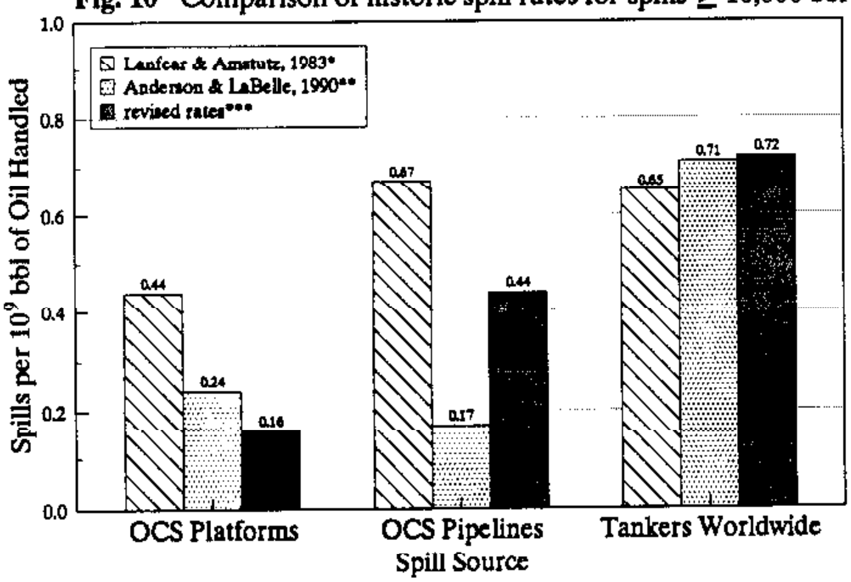
- The U.S. OCS platform spill rates continued to decline from 0.24 to 0.16 spills per 10^9 bbl of production.
- The U.S. OCS pipeline spill rates increased from 0.17 to 0.44 spills per 10^9 bbl transported.
- The worldwide tanker spill rates basically stayed constant, with a minor increase from 0.71 to 0.72 spills per 10^9 bbl transported.

Fig. 9 Comparison of historic spill rates for spills ≥ 1,000 bbl



* U.S. OCS data 1964-1975, tanker data 1969-1973.
** U.S. OCS data 1964-1980, tanker data 1974-1980.
*** U.S. OCS data 1964-1987, tanker data 1974-1985.
**** U.S. OCS data 1964-1992, tanker data 1974-1992.

Fig. 10 Comparison of historic spill rates for spills ≥ 10,000 bbl



* U.S. OCS data 1964-1980, tanker data 1974-1980.
** U.S. OCS data 1964-1987, tanker data 1974-1985.
**** U.S. OCS data 1964-1992, tanker data 1974-1992.

Figure 11 compares the spill rates for crude oil spills ≥ 1,000 bbl for worldwide tanker spills, tanker spills in U.S. waters, and spills of North Slope crude oil transported by tanker from Valdez, Alaska. Although the tanker spills in U.S. waters and the spills of North Slope crude are subsets of worldwide tanker spills, different sources were used for the volume of oil spilled (BP, 1993 for worldwide movements; COE, 1994 for U.S. waters; and DOC, 1993 for movement of North Slope crude). The resulting tanker spill rates for spills ≥ 1,000 bbl ranged from 1.30 to 1.10 spills per 10^9 bbl transported—a reasonably close grouping. However, the distributions of in-port spills vs. at-sea spills varied notably.

The in-port vs. at-sea ratios for worldwide and North Slope crude oil tanker spills contrast with the ratio for tanker spills occurring in U.S. waters. One reason is that the data for in-port tanker spills are not subject to international reporting requirements. As such, in-port spill data for U.S. waters are more accessible to U.S. agencies than are data for in-port spills occurring outside U.S. waters. Therefore, the U.S. in-port spill data may be more comprehensive. The in-port tanker spills in U.S. waters may also be overstated because they may include some spills from inland oil movements (movements which were intentionally excluded from the tanker spill rate calculations) that occurred at a terminus in a coastal port. Also, the estimated rate for at-sea spills in U.S. waters may be relatively low because it includes only those spills that occurred within the 322-km (200-mile) limit, as compared to the worldwide tanker spill rate and the North Slope crude oil spill rate that include spills occurring in much larger extents of open ocean.

Fig. 11 Comparison of tanker spill rates for spills ≥ 1,000 bbl

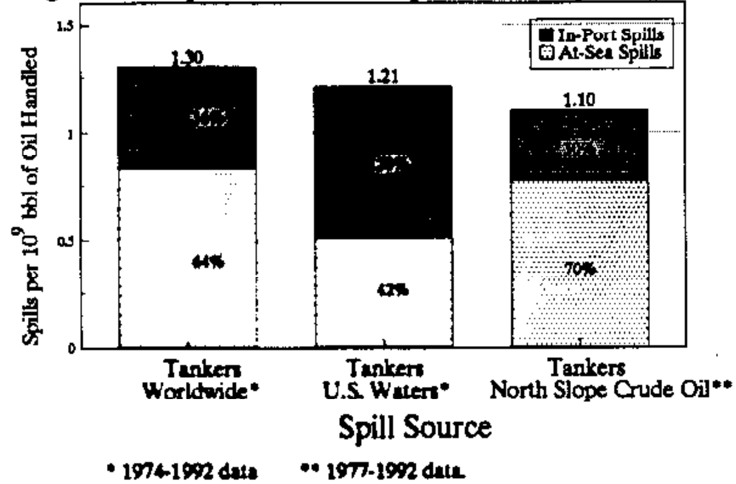
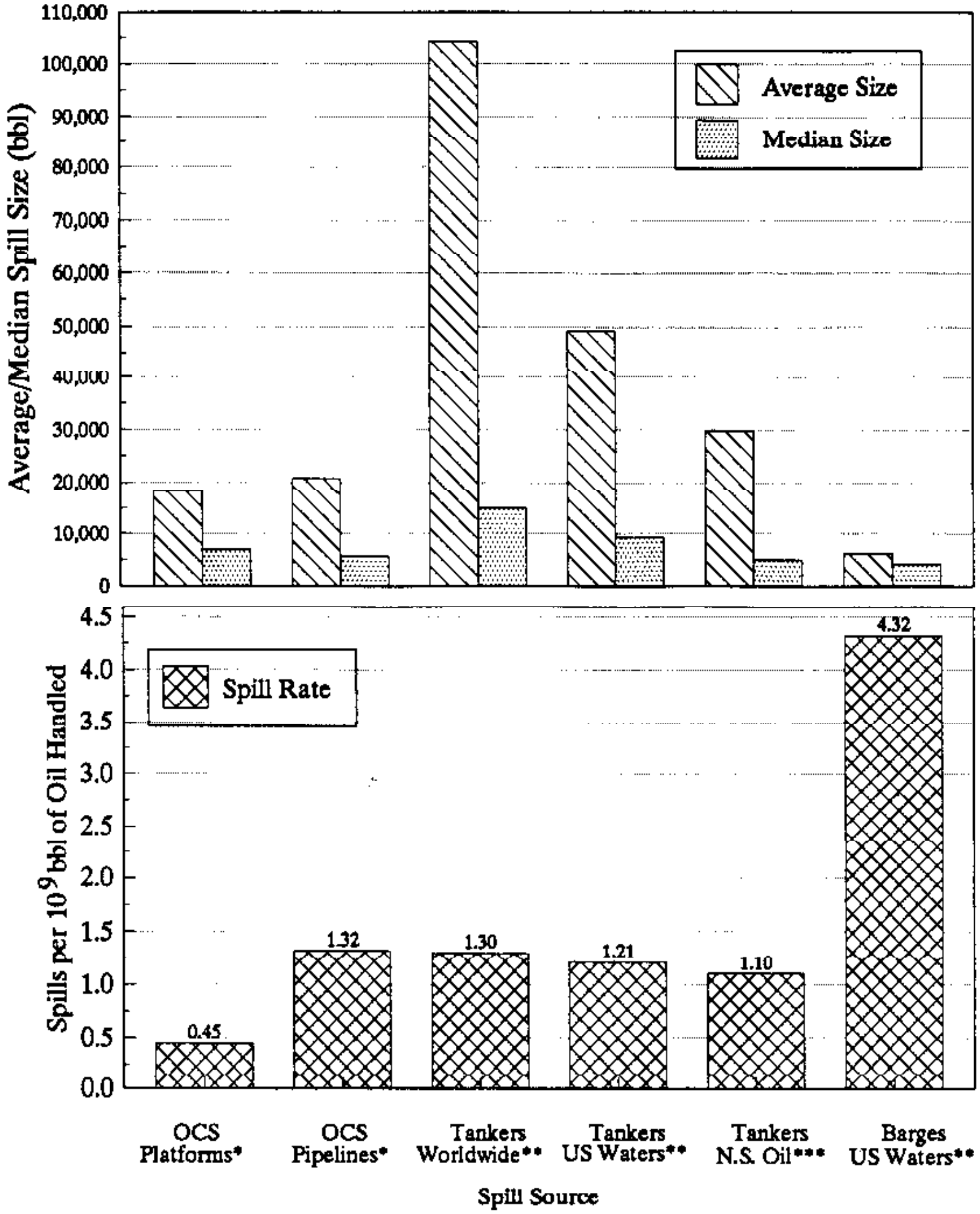


Figure 12 compares the various spill sizes with the estimated occurrence rates for spills ≥ 1,000 bbl. On average, spills from barges were the smallest spills—the average size of crude oil spills from barges was only 6,200 bbl. The largest average spill size was for tanker spills in worldwide waters (104,200 bbl), which can be compared to the average spill size for tanker spills in U.S. waters (49,200 bbl) or the average North Slope crude oil tanker spill size (29,800 bbl). However, the highest spill rates calculated were for barges in U.S. waters, where the rate for crude oil spills ≥ 1,000 bbl was 4.32 spills per 10^9 bbl moved. The lowest calculated rate was for U.S. OCS platforms (0.45 spills per 10^9 bbl moved), which demonstrated a declining trend in that spill rate.

Fig. 12 Comparision of spill size and spill rates by spill source for spills ≥ 1,000 bbl



* 1964-1992 U.S. OCS data.

** 1974-1992 tanker and barge data (crude oil spills only).

*** 1977-1992 North Slope crude data.

Sample Calculation of Spill Occurrence Probability

Since this information is used in public policymaking, it useful to provide an example of how MMS uses the spill rate and the Poisson distribution (see Poisson Distribution for Estimating Oil Spill Occurrence). Table 9 presents such an example.

Using the spill rate (λ) for worldwide tanker spills of 1.30 spills $\geq$ 1,000 bbl per 10^9 bbl transported, and an estimated movement (t) of 0.75 x 10^9 bbl of oil by tanker over the next 10 years, it is estimated that a mean number (λ x t) of 0.98 spills $\geq$ 1,000 bbl will occur over that 10-year period as a result of the movement of oil by tanker, or

(1.30 spills per 10^9 bbl x 0.75 x 10^9 bbl = 0.98 spills)

The estimated probability of zero (0) spills (P(0)) occurring over that 10-year period as a result of moving the 0.75 x 10^9 bbl by tanker is calculated by substituting 0 for n and 0.98 for λt in equation (1), or

$$P(0) = \frac{(0.98^0 \text{ X } e^{-0.98})}{0!} = \frac{(1 \text{ X } 0.38)}{1} = 0.38 \text{ or } 38\%$$

Therefore, the estimated probability of 1 or more spills occurring is equal to 1.00 minus the probability of 0 spills occurring, or

1.00 - P(0) = 1.00 - 0.34 or 0.62 (62%)

Again, using the worldwide tanker spill rates (see Table 5) and assuming the movement of 0.75 x 10^9 bbl of oil, it can be shown that the estimated probability of 1 or more spills $\geq$ 10,000 bbl occurring is 0.42 (42%), and the estimated probability of 1 or more spills $\geq$ 100,000 bbl occurring is 0.21 (21%) (see Table 9). It should be noted that spills $\geq$ 10,000 bbl and spills $\geq$ 100,000 bbl are subsets of spills $\geq$ 1,000 bbl. The mean number of spills can be subtracted (i.e., using the previous example (see Table 9), the estimated mean number of spills $\geq$ 1,000 bbl but less than 10,000 bbl is (0.98 - 0.54) or 0.44). The probabilities, however, cannot be subtracted, and must be recalculated using the estimated mean of 0.44 spills in the Poisson distribution (i.e., the estimated probability of 1 or more spills $\geq$ 1,000 bbl and < 10,000 bbl occurring is 0.36 (36%), and is not equal to (62% - 42%)).

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Table 9 Sample Calculation of Estimated Probability of Spill Occurrence[1] Using 1974-1992 Worldwide Tanker Spill Rate

Spill Size	Assumed Volume Handled (10^9 bbl)	Estimated Spill Rate (spills per 10^9 bbl handled)	Estimated Mean Number of Spills	Probability of zero (0)[2] spills occurring (%)	Probability of 1 spill occurring (%)	Probability of 2 spills occurring (%)	Probability of 3 or more spills occurring (%)
≥ 1,000 bbl	0.75	1.30	0.98	38	37	18	7
≥ 10,000 bbl	0.75	0.72	0.54	58	32	9	1
≥ 100,000 bbl	0.75	0.31	0.23	79	18	2	1

1 bbl = 0.159 m^3

[1]Assumes the movement of 0.75×10^9 bbl oil, applies a Poisson probability distribution

[2]To calculate the probability of 1 or more spills occurring, subtract the probability of 0 spills occurring from 1.00

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