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Update of Comparative Occurrence Rates for Offshore Oil Spills

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Abstract

Estimates of occurrence rates for offshore oil spills are useful for analyzing potential oil-spill impacts and for oil-spill response contingency planning. With the implementation of the Oil Pollution Act of 1990 (U.S. Public Law 101-380, August 18, 1990), estimates of oil-spill occurrence became 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 (U.S. OCS) platform and pipeline spill data (1964 through 1999), worldwide tanker spill data (1974 through 1999), and barge spill data for U.S. waters (1974-1999). These spill rates are expressed and normalized in terms of number of spills per volume of crude oil handled. All estimates of spill occurrence rates were restricted to spills greater than or equal to 1,000 barrels (159 m^3, 159 kiloliters, 136 metric tonnes, 42,000 U.S. gallons).

The revisions compared to the previously published rates calculated through 1992 (Anderson & LaBelle, 1994) indicate that estimates for the U.S. OCS platform spill occurrence rates continue to decline, primarily because no spills have occurred since 1980. The U.S. OCS pipeline spill occurrence rates for spills greater than or equal to 1,000 barrels remained essentially unchanged. However, the rate for larger OCS pipeline spills (greater than or equal to 10,000 barrels) has decreased significantly. Worldwide tanker spill rates, rates for tanker spills in U.S. waters, and rates for barge spills in U.S. waters decreased significantly. The most recent 15-year estimates for 1985-1999 (compared to rates for the entire data series) showed that rates for U.S. OCS platforms, tankers, and barges continued to decline.

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 chances of oil spills occurring and evaluates the potential impacts. These spills could occur at any time during the 15- to 40-year period typically associated with lease-sale- and development-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 contains 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; LaBelle & Anderson, 1985). This model is used to develop probabilistic estimates of oil-spill occurrence and contact. A realistic, objective methodology for estimating oil-spill occurrence rates 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 (Lanfear & Amstutz, 1983; Anderson & LaBelle, 1990, 1994).

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.

Units of Measurement

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 oil (35.5^{o} API gravity), 1 bbl is

equal to the following: 0.159 kiloliters, 0.159 m^3, 0.136 metric tonnes, and 42 U.S. gallons. For each spill source analyzed, spill occurrence rates are estimated for spills greater than or equal to 1,000 bbl and greater than or equal to 10,000 bbl; additionally, spill occurrence rates are estimated for worldwide tanker spills greater than or equal to 100,000 bbl. Spill occurrence rates are expressed in terms of number of spills per billion barrels (Bbbl) defined as 10^9 bbl or 1,000,000,000 bbl. In other words, for this paper, billion represents the U.S. billion (10^9), not the European billion (10^{12}).

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 number of spills per volume handled. The estimated mean number of spill occurrences is used in conjunction with the Poisson distribution to estimate the probability of spill occurrence.

Selection of Exposure Variable

Two basic criteria were used in selecting the exposure variable: the exposure variable should be simple to define, and it should be a quantity that can be estimated. The volume of oil handled was chosen as the exposure variable primarily for the following reasons: historic volumes of oil handled 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 handled, and future volumes of oil estimated to be produced and transported are routinely estimated.

Spill Rate Definition

Estimated occurrence rates for oil spills based on historic spill occurrences and associated volume of oil produced and transported, are expressed in terms of estimated mean number of spills per Bbbl of oil handled. Only large spills, those greater than or equal to 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.)

Spill occurrence rates were calculated for the entire record. In addition, they were calculated for the last 15 years of data available (1985-1999). The selection of the 15-year period was done in order to provide a time period over which all the data

sets could be compared. If spill occurrence rates have increased or decreased over time, eliminating the oldest record should make the rates more representative of spill occurrence behavior. Spill occurrence rates were examined for the last 10, 15, and 20 years. In general, for data sets for which spill rates have been shown in this paper to have declined, the rates continued to decline as the period examined was shortened. The rates that are shown in this paper to be basically unchanged (OCS pipelines) were roughly the same for all the time periods examined. The 15-year record was chosen because it appeared to represent how the rates have changed while still maintaining a significant portion of the record.

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, 1994). 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 ë 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 ët (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).

We believe that these criteria have been met since:

(a) No spills can occur when no (0 bbl) oil is produced or transported.

(b) Analysis of the record indicates that individual spill events are independent of previous spill events over time and volume handled.

(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):

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

where ë 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):

$$P(n) = \frac{(n + v - 1)!t^n \hat{o}^v}{n!(v - 1)!(t + \hat{o})^{n+v}} \quad (2)$$

where ô 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 ë estimated using equation (3) (Smith *et al.*, 1982):

$$\ddot{e} = v/\hat{o} \quad (3)$$

ANALYSIS OF SPILL OCCURRENCE DATA AND OIL MOVEMENTS

Historic oil-spill occurrences greater than or equal to 1,000 bbl and the volume in Bbbl (Bbbl = 10^9 bbl) of associated oil movements were analyzed for the types of spills discussed below.

Oil Spills from U.S. OCS Platforms and Pipelines

Although U.S. OCS spills greater than or equal to 1,000 bbl account for a very small percentage (0.05%) of the total number of U.S. OCS spills that occurred, they represent most (79%) of the volume spilled (Fig. 1). However, almost all U.S. OCS spills (94%) were less than or equal to 1 bbl in size.

Eleven platform spills (crude oil, condensate, or diesel) and 16 pipeline spills (crude oil or condensate) greater than or equal to 1,000 bbl occurred between 1964 through 1999 (Tables 1 and 2; Fig. 2). These spills make up the entire record for U.S. OCS spills greater than or equal to 1,000 bbl (the first U.S. OCS spill greater than or equal to 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 1999 was estimated to be 12 Bbbl crude oil and condensate. Historically, 95 percent or more

of the total U.S. OCS production (on an annual basis) has been transported by pipeline. (Of the remaining 5 percent, there have been no spills greater than or equal to 1,000 bbl resulting from movement of U.S. OCS oil by tanker or barge.)

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 chance of a spill occurring relative to experience elsewhere.

Crude Oil Spills from Tankers in Worldwide Coastal and Offshore Waters

From 1974 through 1999, there were 278 crude oil spills greater than or equal to 1,000 bbl from self-propelled crude oil carriers (Table 3; Fig. 3). 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; 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). 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. Worldwide movements of crude oil from 1974 through 1999 were estimated to total 239.67 Bbbl, based on crude oil imports and exports (BP Amoco, 2000 and British Petroleum Company, 1998).

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

Forty-six crude oil tanker spills greater than or equal to 1,000 bbl occurred in U.S. coastal and offshore waters (including U.S. territorial waters) from 1974 to 1999, inclusive (Table 4; Fig. 4). These are a subset of the spills included in the worldwide tanker spill rates. Estimations of crude oil movements by tanker in U.S. waters were based on foreign movements (imports + exports = 53.62 Bbbl) and domestic movements (coastal + interterritorial = 17.69 Bbbl) of crude oil for the years 1974 through 1999 (U.S. Army Corps of Engineers [COE], 2000). 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

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 percent to account for these assumptions, which resulted in an estimated 44.5 Bbbl of movements associated with tanker spills in U.S. waters (50% foreign + 100% domestic movements).

Alaska North Slope (ANS) Crude Oil Spills from Tankers

The Trans Alaska 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 1999, approximately 12.6 Bbbl of ANS crude oil were loaded onto tankers at Valdez, Alaska (U.S. Department of Commerce [DOC], 2000). Loadings peaked at 0.73 Bbbl in 1988, and dropped to 0.37 Bbbl in 1999. The bulk of these loadings (87-97%) have had destinations to either the U.S. west coast (Puget Sound, WA; San Francisco, CA; or Los Angeles, CA) or Panama. Panama destinations peaked at 43 percent of loadings in 1982, and has since tapered to zero in 1996. The destinations of the balance of the loadings were generally the Virgin Islands, Hawaii or Alaska. Eleven tanker spills greater than or equal to 1,000 bbl associated with the transportation of this ANS crude oil occurred between 1977 and 1999 (Fig. 5). These 11 spills are made up of the 240,000 bbl Exxon Valdez spill (1989) and 10 other spills which were less than or equal to 15,000 bbl in size. The earliest three spills (1978, 1980, and 1981) occurred outside of U.S. waters, and all subsequent spills occurred in U.S. waters.

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

From 1974 through 1999, 187 petroleum spills greater than or equal to 1,000 bbl (26 of which were crude oil spills) occurred from barges in U.S. coastal, offshore, and inland waters (including U.S. territorial waters) (Table 5; Fig. 6). Because the data available on barge movements in U.S. waters do not differentiate between inland and coastal/offshore movements, inland movements were included. Petroleum included crude oil and products such as 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 petroleum from 1974 through 1999 were estimated to be 43.48 Bbbl (7.32 Bbbl of which were crude oil), based on the portion of U.S. domestic petroleum movements transported by barge (COE, 2000).

RESULTS

Spill rates, expressed in terms of spills per Bbbl of oil handled, were calculated for each spill source examined for spills greater than or equal to 1,000 bbl and for spills greater than or equal to 10,000 bbl, (spills greater than or equal to 10,000 bbl being a subset of spills greater than or equal to 1,000 bbl). Spill rates for spills greater than or equal to 100,000 bbl were also calculated for crude oil spills from tankers in worldwide coastal and offshore waters, where the average spill size for spills at sea was over 100,000 bbl (112,400 bbl). In general, 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 early in the record through trend analysis (Anderson & LaBelle, 1990), the rate for spills greater than or equal to 1,000 bbl was calculated by excluding the earliest portion of the historic record (where the spill rate differed from the current trend). In this paper, spill rates for the last 15 years, 1985-1999, are also calculated.

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

Entire Record, 1964-1999

In previous work (Anderson & LaBelle, 1990), nonparametric tests (appropriate to small sample sizes) were applied to apparent random and independent observations of U.S. OCS platform and pipeline spills greater than or equal to 1,000 bbl over uniform increments of volume of U.S. OCS production from 1964 through 1987. 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 for both U.S. OCS platforms and pipeline spills. In an update continuing the analysis through 1992 (Anderson & LaBelle, 1994), it was found that the U.S. OCS platform spill trend had continued, but the trend in U.S. OCS pipeline spills was no longer evident.

As illustrated in Fig. 7, there have been no additional U.S. OCS platform spills since the U.S. OCS platform spill rate was last calculated (Anderson & LaBelle, 1994). The previously identified trend in intervals numbered 6-18 (Bbbl production intervals) has been preserved in production intervals 19-24, which represents a continued increase in the number of production intervals between observed platform spills. The revised spill rate of 0.32 spills per Bbbl handled for U.S. OCS platform spills greater than or equal to 1,000 bbl (Table 6) was based on adjustments using the last three spills that occurred over the most recent 9.5 Bbbl of production (i.e., based on production intervals 6-24). This is the same starting

point from which the previous U.S. OCS platform spill rates were calculated (Anderson & LaBelle, 1990, 1994).

Four additional U.S. OCS pipeline spills have occurred between 1993 and 1999 (Figs. 2 and 8) since the U.S. OCS pipeline spill rate was last calculated (Anderson & LaBelle, 1994). As illustrated in Fig. 8, a possible new trend within intervals 18-22 was terminated by the occurrence of three spills during intervals 23-24, the most recent 1 Bbbl of production between 1998 and 1999. The revised spill rate of 1.33 spills per Bbbl handled for U.S. OCS pipeline spills greater than or equal to 1,000 bbl was calculated based on the entire record of 16 spills over 12 Bbbl of production (Table 6).

The revised U.S. OCS platform spill rate estimate of 0.12 spills per Bbbl handled for spills greater than or equal to 10,000 bbl was calculated based on four-elevenths of the spill rate for spills greater than or equal to 1,000 bbl (Table 6). This is a conservative approach because 4 out of the 11 U.S. OCS platform spills were greater than or equal to 10,000 bbl even though all 3 spills included in the recent trend were less than or equal to 10,000 bbl. The revised U.S. OCS pipeline spill rate of 0.33 spills per Bbbl handled for spills greater than or equal to 10,000 bbl was calculated based on the 4 pipeline spills greater than or equal to 10,000 bbl over the entire record of 12 Bbbl of production (Table 6).

As illustrated in Figs. 9 and 10, the U.S. OCS platform spill rates have continued to decline since they were first calculated by Stewart (1975, 1976), and in subsequent updates by Lanfear & Amstutz (1983), and Anderson & LaBelle (1990, 1994). The U.S. OCS pipeline rates for spills greater than or equal to 1,000 bbl have remained constant since they were last calculated (Anderson & LaBelle, 1994). However, the rate for larger U.S. OCS pipeline spills (greater than or equal to 10,000 bbl) has decreased significantly.

Last 15 Years, 1985-1999

The spill rates for U.S. OCS platforms in the last 15 years could not be directly calculated because there were zero platform spills greater than or equal to 1,000 bbl during that period. It is unwise to estimate a spill rate of "zero," because if used in projections of future spill occurrence, it does not allow for any platform spills occurring--something that hasn't occurred recently, but could. One has to go back 20 years to identify the last platform spill (November 14, 1980). Therefore, the rate should be greater than 0 spills per Bbbl handled and less than 0.13 spills per Bbbl handled, the rate based on the 1980-1999 record (Table 6). This shows the U.S. OCS platform rate continues to decline in recent years, with rates for spills greater than or equal to 1,000 bbl and greater than or equal to 10,000 bbl estimated as less than 0.13 spills per Bbbl handled and less than 0.05 spills per Bbbl handled, respectively (Figs. 9 and 10).

The spill rates for U.S. OCS pipelines in the last 15 years are slightly higher than the entire record, with rates for spills greater than or equal to 1,000 bbl (estimated as 1.38 spills per Bbbl handled) and are essentially the same for spills greater than or equal to 10,000 bbl (estimated at 0.34 spills per Bbbl handled) (Table 6; Figs. 9 and 10).

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

Entire Record, 1974-1999

Data on crude oil tanker spills greater than or equal to 1,000 bbl occurring in worldwide waters from 1974 through 1999 (Fig. 3) provide a robust number of spill observations over time. The annual spill rate did not increase or decrease strictly monotonically over time (Fig. 11, Table 3). The second highest annual rate, 2.22 spills per Bbbl handled was in 1987, the middle of the data series. In general, however, the rates in the second half of the distribution were somewhat lower than those in the first half, indicating a declining rate over time. The spill rates calculated on the entire record showed a decline compared to when they were last calculated (Anderson & LaBelle, 1994). Rates for spills greater than or equal to 1,000 bbl declined from 1.30 to 1.16 spills per Bbbl handled (Table 7). This reduction to 1.16 spills per Bbbl handled is particularly significant in that the worldwide tanker spill rate had remained constant at 1.30 spills per Bbbl handled since first calculated by Lanfear & Amstutz (1983), and in updates by Anderson & LaBelle (1990, 1994). As shown in Table 7, rates for spills greater than or equal to 10,000 bbl declined from 0.72 to 0.59 spills per Bbbl handled, and for spills greater than or equal to 100,000 bbl from 0.31 to 0.24 spills per Bbbl handled.

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. It was actually the "at sea" rates that were the basis for the decreases in the worldwide tanker spill rates for all three spill sizes calculated for 1974-1999.

Last 15 Years, 1985-1999

The spill rates for crude oil spills from tankers worldwide in the last 15 years drop significantly as compared to the entire record for all three spill sizes. Spill rates for spills greater than or equal to 1,000 bbl dropped from 1.16 to 0.82 spills per Bbbl handled when looking at the last 15 years. Rates for spills greater than or equal to 10,000 bbl and greater than or equal to 100,000 bbl dropped from 0.59 to

0.37 spills per Bbbl handled and 0.24 to 0.12 spills per Bbbl handled, respectively. In these cases, both the "at sea" and "in port" rates decreased (Table 7; Figs. 9 and 10).

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

Entire Record, 1974-1999

Like tanker spills in worldwide coastal and offshore waters, data on crude oil tanker spills greater than or equal to 1,000 bbl in U.S. coastal and offshore waters (Fig. 4) provide a robust number of spill observations over time. In addition, the annual spill rate did not strictly increase or decrease monotonically over time (Fig. 11, Table 4). The highest annual rate, 4.90 spills per Bbbl handled, was in 1975 near the beginning of the data series, and the rate exceeds 2.00 spills per Bbbl handled in 1974, 1975, 1976, 1979, and 1987. In general, however, the rates in the second half of the distribution were lower than those in the first half, indicating a declining rate over time. In fact, only two spills were identified between 1992 and 1999. In Table 8, the spill rates calculated on the entire record showed a decline compared to when they were last calculated (Anderson & LaBelle, 1994). Rates for spills greater than or equal to 1,000 bbl declined from 1.21 to 1.03 spills per Bbbl handled. Rates for spills greater than or equal to 10,000 bbl declined from 0.58 to 0.43 spills per Bbbl handled. Both "at sea" and "in port" rates also declined (Table 8; Figs. 9 and 10).

Last 15 Years, 1985-1999

The spill rates for crude oil spills from tankers in U.S. coastal and offshore waters in the last 15 years drop significantly as compared to the entire record. Spill rates for spills greater than or equal to 1,000 bbl dropped from 1.03 to 0.73 spills per Bbbl handled, and spills greater than or equal to 10,000 bbl dropped from 0.43 to 0.25 spills per Bbbl handled. In these cases, both the "at sea" and "in port" rates decreased (Table 8; Figs. 9 and 10).

Estimation of Spill Rates for Spills of ANS Crude Oil Spills from Tankers

Entire Record, 1977-1999

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 9 presents the calculated spill rates for ANS crude oil transported by tanker from Valdez, Alaska. The table is based on the 11 spill observations that were distributed somewhat uniformly over

time and volume of oil moved (Fig. 5). The volume moved and spill occurrences peaked between 1987 and 1989. No spill occurrences have been observed since 1991. The spill rates calculated on the entire record showed a decline compared to when they were last calculated (Anderson & LaBelle, 1994). Rates for spills greater than or equal to 1,000 bbl declined from 1.10 to 0.88 spills per Bbbl handled. The decline was primarily in the "at sea" component. Rates for spills greater than or equal to 10,000 bbl declined from 0.33 to 0.23 (Table 9; Figs. 9 and 10). Due to the lack of any "in-port" spills greater than or equal to 10,000 bbl, only an "at sea" rate for spills greater than or equal to 10,000 bbl was estimated.

Last 15 Years, 1985-1999

The spill rates for crude oil spills greater than or equal to 1,000 bbl from ANS crude oil tankers in the last 15 years increase overall compared to the entire 1977-1999 record, from 0.88 to 0.92 spills per Bbbl handled. This is based on an increase of the "in port" rate from 0.32 to 0.46 spills per Bbbl handled and a decrease in the "at sea" rate from 0.56 to 0.46 spills per Bbbl handled. The spill rates for spills greater than or equal to 10,000 bbl increased from 0.23 to 0.34 spills per Bbbl handled (comprised entirely of an "at sea rate," since there were no "in port" spills greater than or equal to 10,000 bbl between 1985 and 1999) (Table 9; Figs. 9 and 10). These rates are slightly higher than the entire record, not because of recent spills (there have been none since 1991), but simply because the rate calculation includes the worst years, 1987 and 1989, and excludes a significant decrease in the denominator, 8.72 Bbbl as compared to 12.6 Bbbl in ANS crude movements (Table 9).

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

Entire Record, 1974-1999

Data on petroleum spills greater than or equal to 1,000 bbl from barges in U.S. coastal, offshore, and inland waters provide a robust number of spill observations over time (Fig. 6). The annual spill rate did not increase or decrease monotonically over time (Fig. 12, Table 5). The annual rate exceeded 8 spills per Bbbl handled in 1974, 1978, and 1985. However, the rates in the second half of the distribution were generally lower than those in the first half, indicating a declining rate over time. In Table 10, the spill rates calculated on the entire record showed a decline compared to when they were last calculated (Anderson & LaBelle, 1994). Rates for all petroleum spills from barges spills greater than or equal to 1,000 bbl and greater than or equal to 10,000 bbl declined from 4.81 to 4.30 spills per Bbbl handled and from 0.85 to 0.81, respectively (Figs. 9 and 10).

Crude oil barge spills are a subset of the petroleum barge spills. Rates for crude oil spills from barges for spills greater than or equal to 1,000 bbl and greater than or equal to 10,000 bbl declined from 4.32 to 3.55 spills per Bbbl handled and from 0.72 to 0.68 spills per Bbbl handled, respectively (Table 10; Figs. 9 and 10).

Last 15 Years, 1985-1999

Barge spill rates for the last 15 years declined dramatically as compared to the entire 1974-1999 record, especially for crude oil barges. The petroleum barge rates for spills greater than or equal to 1,000 bbl declined from 4.30 to 3.08 spills per Bbbl handled, with the crude oil rates declining from 3.55 to 1.23 spills per Bbbl handled. The petroleum barge rates for spills greater than or equal to 10,000 bbl declined from 0.81 to 0.52 spills per Bbbl handled, with the crude oil rates declining from 0.68 spills per Bbbl handled to less than 0.23 spills per Bbbl handled (Table 10; Figs. 9 and 10).

Average And Median Spill Size, 1985-1999

Average and median spill sizes were calculated for each spill source for spills of 1,000 bbl and greater and 10,000 bbl and greater (Tables 11 and 12; Fig. 13). Comparing both average and median spill sizes, OCS platform and pipeline spills tend to be smaller than tanker spill size. Also, tanker spills in U.S. coastal and offshore waters tend to be smaller than tanker spills worldwide. 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 (Tables 11 and 12; Fig. 13).

DISCUSSION & CONCLUSIONS

Rates for spills greater than or equal to 1,000 bbl and greater than or equal to 10,000 bbl are estimated updates of previously calculated rates based on data through 1992 (Anderson & LaBelle, 1994).

Spills Greater Than or Equal to 1,000 bbl

For spills greater than or equal to 1,000 bbl, the following conclusions can be made (Fig. 9):

- The U.S. OCS platform spill rate continued to decline from 0.45 spills per Bbbl handled (based on trend analysis for 1964-1992) to 0.32 spills per Bbbl handled (based on trend analysis for 1964-1999). The spill rate for the last 15 years, 1985-1999, was less than 0.13 spills per Bbbl handled (the rate for 1980-1999) since there were no such spills observed during this time period.

- The U.S. OCS pipeline spill rate remained essentially the same, increasing from 1.32 to 1.33 spills per Bbbl transported when the 1993-1999 data was included. The spill rate for the last 15 years shows a slight increase to 1.38 spills per Bbbl transported.

- The worldwide tanker spills rate has decreased dramatically. The spill rate had remained constant at 1.30 spills per Bbbl transported in past spill-rate updates by Lanfear & Amstutz (1983), and Anderson & LaBelle (1990, 1994). Based on the 1974-1999 data, the rate dropped to 1.16 spills per Bbbl transported. This decline was primarily a result of a decline in the "at sea" spill rate. The rate declined even further to 0.82 spills per Bbbl transported when examined for the last 15 years (1985-1999). The decline in the last 15 years was a result of reductions in both the "in port" and "at sea" spill rates.

- The rates for tanker spills in U.S. waters continued to be lower than the worldwide tanker spill rates. The spill rate for tankers in U.S. waters declined from 1.21 to 1.03 spills per Bbbl transported based on the entire 1974-1999 record. The rate declined further to 0.73 spills per Bbbl transported when only the last 15 years were examined (1985-1999). These rate reductions reflected a decline in both the "in port" and "at sea" spill rates.

- The rate for tankers carrying ANS crude oil declined based on the entire 1977-1999 record from 1.10 to 0.88 spills per Bbbl transported. This spill rate continued to be lower than the rate for tanker spills in U.S. waters. However, the ANS crude oil tanker rate increased slightly over the revised rate to 0.92 spills per Bbbl transported when calculated for the last 15 years. This rate is greater than the 0.73 spills per Bbbl transported for tanker spills in U.S. waters. This 1985-1999 period begins during the peak of ANS crude oil movements and tanker spills, and reflects the decrease in the denominator as the movements of ANS crude oil declined.

- The rate for petroleum spills (including crude oil spills) from barges in U.S. coastal, offshore, and inland waters declined from 4.81 to 4.30 spills per Bbbl transported based on the entire 1974-1999 record. This rate declined further when examining the last 15 years (1985-1999) to 3.08 spills per Bbbl transported.

- The rate for crude oil spills from barges in U.S. coastal, offshore, and inland waters declined from 4.32 to 3.55 spills per Bbbl transported based on the entire 1974-1999 record. This rate declined more dramatically in the last 15 years (1985-1999) to 1.23 spills per Bbbl transported. This spill rate continues to be significantly lower than the ratesfor all petroleum spills from barges.

Spills Greater Than or Equal to 10,000 bbl

For spills greater than or equal to 10,000 bbl, the following can be concluded (Fig. 10):

- The U.S. OCS platform spill rate continued to decline from 0.16 to 0.12 spills per Bbbl handled for the 1964-1999 record with adjustments for an improved trend after the early record. The rate dropped further to less than 0.05 spills per Bbbl handled in the 1985-1999 period where no platform spills were observed.

- The U.S. OCS pipeline spill rate decreased from 0.44 to 0.33 spills per Bbbl transported over the entire 1964-1999 record. This remained essentially the same at 0.34 spills per Bbbl transported in the last 15 years (1985-1999).

- The worldwide tanker spill rate declined from 0.72 to 0.59 spills per Bbbl transported over the entire 1974-1999 record. The rate drops to 0.37 spills per Bbbl transported when examined over the last 15 years (1985-1999).

- The spill rate for tankers in U.S. waters dropped from 0.58 to 0.43 spills per Bbbl transported for the entire 1974-1999 record, and even further to 0.25 spills per Bbbl transported in the last 15 years (1985-1999). This rate continues to be lower than the rate for tanker spills worldwide.

- The spill rate for tankers carrying ANS crude oil dropped from 0.33 to 0.23 spills per transported for the entire 1977-1999 record. The spill rate increased to 0.34 spills per Bbbl transported when examined for the last 15 years (1985-1999).

- The rate for petroleum spills (including crude oil spills) from barges in U.S. coastal, offshore, and inland waters declined from 0.85 to 0.81 spills per Bbbl transported based on the entire 1974-1999 record. This rate declined further when examining the last 15 years (1985-1999) to 0.52 spills per Bbbl transported.

- The rate for crude oil spills from barges in U.S. coastal, offshore, and inland waters declined from 0.72 to 0.68 spills per Bbbl transported based on the entire 1974-1999 record. This rate declined more dramatically in the last 15 years (1985-1999) to less than 0.23 spills per Bbbl transported with no crude oil spills from barges observed during this time period.

Spills Less Than 1,000 bbl

Spill occurrence distributions characteristically have spill occurrences decreasing logarithmically as spill size increases; that is, there are far more spills of 1 bbl than 10 bbl in size, and there are many more spills of 10 bbl than 100 bbl in size. If a spill rate for spills greater than or equal to 1,000 bbl cannot be estimated due to a lack of observations of spills greater than or equal to 1,000, but data are available to compute a spill rate for spills greater than or equal to 500 bbl, one can assume the spill rate for spills greater than or equal to 1,000 is a rate significantly less than the rate for spills greater than or equal to 500 bbl.

Also, sometimes it is necessary to estimate spill occurrences for smaller spills for impact analyses. Historical spill rates for smaller spills can be used for these purposes with the understanding that the historical data are more susceptible to underreporting. Estimates of spill occurrences, rates, and spill sizes for U.S. OCS oil spills (crude, condensate, and refined products) between 1985-1999 are presented by spill size in Table 13. This data dramatically illustrate the relationship between spill occurrences and spill size: almost 20,000 spills less than or equal to 1 bbl, almost 570 spills between 1.1 and 999 bbl, and 8 spills greater than or equal to 1,000 bbl.

Spill Rates for Onshore ANS Crude Oil Production, Spills Greater Than or Equal to 500 bbl

The MMS estimates spill rates for spills greater than or equal to 1,000 bbl for use in the OSRA modeling. Larger spills are more likely to be observed and reported so that the larger the spill size threshold, the lower the likelihood that spill occurrences will go unreported. However, sometimes spills greater than or equal to 1,000 bbl have not been observed with a particular activity, so that a lower spill size threshold has to be selected. Twenty-two crude oil spills greater than or equal to 100 bbl associated with Alaska onshore ANS production were identified between 1985 and 1998 (USDOI, MMS, 2000; State of Alaska, 2000) (Fig. 14). It is unusual that no spills occurred during the earlier start up period, 1969-1984. The State of Alaska began a database in 1985. It is possible (but not certain) that some spills occurred prior to 1985 but were not recorded. The largest spill was 925 bbl, so that spill rates for spills greater than or equal to 1,000 bbl could not be calculated. Instead, the five spills greater than or equal to 500 bbl were examined further (Table 14).

For the five spills greater than or equal to 500 bbl, the average and median spill sizes were 672 bbl and 650 bbl, respectively. Four were spills at the production facility, and one was a pipeline spill. All of these spills occurred during 1989 or later. It is unclear whether any spill greater than or equal to 500 bbl occurred prior to 1989, or whether any occurred for which records were not available. ANS

production was 12.221 Bbbl handled from 1969-1998, and 8.313 Bbbl handled from 1985-1998.

This resulted in a spill rate of 0.60 spills greater than or equal to 500 bbl per Bbbl handled for 1985-1998, comprised of a facility rate of 0.48 spills greater than or equal to 500 per Bbbl produced and pipeline rate of 0.12 spills greater than or equal to 500 per Bbbl transported. Over the entire 1969-1998 record, these rates drop to 0.41 spills greater than or equal to 500 bbl per Bbbl total, comprised of a facility rate of 0.33 spills greater than or equal to 500 per Bbbl produced, and a pipeline rate of 0.08 spills greater than or equal to 500 per Bbbl transported.

The higher spill rates for the 1985-1998 period may be a result of better spill reporting rather than an actual increase in spill rate over time. If spills actually occurred between 1969-1984, but were not reported, this resulting 1969-1998 spill rate is too low. Although a spill rate for spills greater than or equal to 1,000 bbl could not be calculated for this data, it can be assumed that such a rate is implicitly significantly less than the rates calculated for spills greater than or equal to 500 bbl.

Pipeline spills from the Trans Alaska Pipeline System (TAPS) were not included in the ANS crude production spill rates. The TAPS spills were analyzed separately in the next section.

Crude Oil Spills From the Trans-Alaska Pipeline System

Nine crude oil spills greater than or equal to 100 bbl associated with the TAPS between 1977 and 1998 (USDOI, MMS, 2000; State of Alaska 2000) (Fig. 15). Five spills were greater than or equal to 1,000 bbl, all of which occurred prior to 1982. The average spill size for spills greater than or equal to 1,000 bbl was 4,200 bbl. Only one spill occurred after 1981, an 811 bbl spill in 1996 (Table 15).

The spill rate for spills greater than or equal to 1,000 bbl was 0.40 spills per Bbbl transported through the pipeline for 1977-1998. Since no spills greater than or equal to 1,000 bbl have occurred since 1982, a rate for spills greater than or equal to 1,000 bbl was not computed for 1985-1998. The spill rate for spills greater than or equal to 500 bbl were calculated as 0.48 spills per Bbbl transported for 1977-1998, which dropped to 0.12 spills per Bbbl for 1985-1998.

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Table 1 U.S. OCS platform spills[1] greater than or equal to 1,000 bbl, 1964-1999

Spill Date	Area & Block (Water Depth, Distance from Shore)	Volume Spilled (bbl)	Cause Of Spill
April 8, 1964	Eugene Island 208 (94 feet, 48 miles)	2,559	freighter struck platform, fire
October 3, 1964	Total Event:	11,869[2]	Hurricane Hilda casualties:
	Eugene Island 208 (94 feet, 48 miles)	(5,180)	well blowouts, 3 platforms destroyed
	Ship Shoal 149 (55 feet, 33 miles)	(5,100)	well blowout, platform destroyed
	Ship Shoal 199 (102 feet, 44 miles)	(1,589)	storage oil loss, platform destroyed
July 19, 1965	Ship Shoal 29 (15 feet, 7 miles)	1,688[3]	well blowout
January 28, 1969	Santa Barbara Channel (190 feet, 6 miles)	80,000	50,000 bbl during blowout phase, subsequent seepage 30,000 bbl, considerable oil on beaches, platform destroyed
March 16, 1969	Ship Shoal 72 (30 feet, 6 miles)	2,500	storm, vessel bumped rig and sheared wellhead, well blowout
February 10, 1970	Main Pass 41 (39 feet, 14 miles)	30,000	fire, well blowout, platform destroyed, minor amount of oil on beaches
December 1, 1970	South Timbalier 26 (60 feet, 8 miles)	53,000	wire line work, well blowout, fire, platform and rigs destroyed, 4 fatalities, 36 injured, minor amount of oil on beaches
January 9, 1973	West Delta 79 (110 feet, 17 miles)	9,935	structure supporting oil storage tank bent, tank ruptured
January 26, 1973	South Pelto 23 (61 feet, 15 miles)	7,000	rough seas, stationary storage barge sank
November 23, 1979	Main Pass 151 (280 feet, 10 miles)	1,500[4]	rough seas, service vessel's propeller cut hole in hull of semisubmersible rig, damaged diesel tank
November 14, 1980	High Island 206 (60 feet, 27 miles)	1,456	Hurricane Jeanne, saltwater pump shutoff switch failed after ballasting, tank overflowed

[1]Crude oil unless otherwise indicated
[2]10/3/64 Hurricane Hilda, 11,869 bbl total spillage (treated as one spill event)
[3]Condensate
[4]Diesel
Source: MMS OCS Spill Database, October 2000

Table 2 U.S. OCS pipeline spills[1] greater than or equal to 1,000 bbl, 1964-1999

Spill Date	Area & Block (Water Depth, Distance from Shore)	Volume Spilled (bbl)	Cause Of Spill
October 15, 1967	West Delta 73 (168 feet, 22 miles)	160,638	anchor kinked pipeline, internal corrosion later caused a failure in that section (12" pipeline)
March 12, 1968	South Timbalier 131 (160 feet, 28 miles)	6,000	anchor drag damaged pipeline section (18" pipeline)
February 11, 1969	Main Pass 299 (210 feet, 17 miles)	7,532	anchor drag damaged pipeline section (4" pipeline)
May 12, 1973	West Delta 73 (168 feet, 22 miles)	5,000	internal corrosion, several small leaks discovered (16" pipeline)
April 17, 1974	Eugene Island 317 (240 feet, 75 miles)	19,833	anchor drag caused pipeline break (14" pipeline)
September 11, 1974	Main Pass 73 (141 feet, 9 mi)	3,500	Hurricane Carmen, connection torn loose (8" pipeline)
December 18, 1976	Eugene Island 297 (210 feet, 71 miles)	4,000	trawl drag pulled valve loose (tie-in between 14" and 10" pipelines)
December 11, 1981	South Pass 60 (190 feet, 4 miles)	5,100	service vessel's anchor damaged pipeline (8" pipeline)
February 7, 1988	Galveston 2A (75 feet, 34 miles)	15,576	vessel illegally dropped anchor and dragged it along bottom, ruptured pipeline (14" pipeline)
January 24, 1990	Ship Shoal 281 (197 feet, 60 miles)	14,423[2]	anchor drag, flange and valve broke off (4" pipeline)
May 6, 1990	Eugene Island 314 (230 feet, 78 miles)	4,569	trawl drag pulled off valve (tie-in between 8" and 20" pipeline)
August 31, 1992	South Pelto 8 (30 feet, 6 miles)	2,000	Hurricane Andrew, loose drilling rig's anchor drag damaged pipeline[3], moderate amount of oil on shoreline (20" pipeline)
November 16, 1994	Ship Shoal 281 (197 feet, 60 miles)	4,533[2]	trawl drag (4" pipeline)
January 26, 1998	East Cameron 334 (264 feet, 105 miles)	1,211[2]	service vessel's anchor drag damaged pipeline during rescue operation (16" pipeline)
September 29, 1998	South Pass 38 (108 feet, 6 miles)	8,212	Hurricane George, mudslide parted pipeline, small amount of oil on shoreline (10" pipeline)
July 23, 1999	Ship Shoal 241 (133 feet, 50 miles)	3,200	jackup barge sat on pipeline (12" pipeline)

[1]Crude oil unless otherwise indicated
[2]Condensate
[3]Pipeline had been shut in for hurricane, leak occurred when pipeline restarted.
Source: MMS OCS Spill Database, October 2000

Table 3 Number of worldwide crude oil spills greater than or equal to 1,000 barrels from tankers, and crude oil movements, 1974-1999

		Spills in Port			Spills At Sea				
Year	All Spills	1,000-9,999 bbl	10,000-99,999 bbl	100,000 bbl or greater	1,000-9,999 bbl	10,000-99,999 bbl	100,000 bbl or greater	Crude Oil Movements (Bbb1)	Spills Per Bbbl
1974	21	7	2	1	6	3	2	10.17	2.07
1975	21	2	2	2	6	6	3	9.33	2.25
1976	19	6	2	1	2	2	6	10.51	1.81
1977	16	2	2	1	3	3	5	10.69	1.50
1978	17	3	2	1	3	4	4	10.48	1.62
1979	23	4	2	3	4	5	5	10.96	2.10
1980	11	1	1	1	3	2	3	9.66	1.14
1981	8	3	1	0	4	0	0	8.54	0.94
1982	8	3	1	1	3	0	0	7.32	1.09
1983	13	4	1	0	1	4	3	6.86	1.90
1984	8	2	3	0	1	2	0	6.84	1.17
1985	6	1	2	0	0	2	1	6.35	0.95
1986	6	2	0	0	1	3	0	7.19	0.83
1987	15	5	1	0	5	4	0	6.76	2.22
1988	9	3	3	0	2	0	1	7.41	1.22
1989	13	2	1	0	1	6	3	8.04	1.62
1990	11	5	0	0	2	4	0	8.71	1.26
1991	9	3	0	1	2	1	2	9.18	0.98
1992	7	3	0	1	1	2	0	9.30	0.75
1993	6	0	1	0	2	1	2	9.87	0.61
1994	6	1	1	1	1	0	2	10.08	0.60
1995	6	3	0	0	3	0	0	10.29	0.58
1996	7	3	0	1	3	0	0	10.62	0.66
1997	6	1	0	1	2	2	0	11.32	0.53
1998	3	3	0	0	0	0	0	11.62	0.26
1999	3	1	0	0	1	1	0	11.57	0.26
Total	278[1]	74	28	16	62	57	42	239.67	1.16

Bbbl = 10^9 bbl

[1]278 spills totaling 26,091,500 bbl spilled; excludes inland spills.

Largest tanker spill 1,869,000 bbl

Sources: BP Amoco, 2000; BP, 1998; MMS Worldwide Tanker Spill Database, October 2000

(Note: 28 spills were added to 1974-1992 data since Anderson & LaBelle, 1994)

Table 4 Number of crude oil spills greater than or equal to 1,000 bbl from tankers in U.S. waters, and crude oil movements, 1974-1999

		Spills in Port		Spills At Sea					
Year	All Spills	1,000-9,999 bbl	10,000 bbl and greater	1,000-9,999 bbl	10,000 bbl and greater	Imports/ Exports (Bbbl)	Domestic Movements[1] (Bbbl)	Adjusted Movements[2] (Bbbl)	Spills Per Bbbl
1974	2	1	1	0	0	1.44	0.22	0.94	2.13
1975	5	1	1	1	2	1.70	0.17	1.02	4.90
1976	3	3	0	0	0	2.24	0.15	1.27	2.36
1977	3	1	1	0	1[3]	2.69	0.20	1.55	1.94
1978	1	0	0	1	0	2.58	0.59	1.88	0.53
1979	5	3	1	0	1[3]	2.52	0.64	1.90	2.63
1980	2	0	1	1	0	2.03	0.84	1.86	1.08
1981	2	1	1	0	0	1.74	0.87	1.74	1.15
1982	1	0	1	0	0	1.50	0.94	1.69	0.59
1983	1	1	0	0	0	1.21	0.99	1.59	0.63
1984	1	0	0	0	1	1.14	0.92	1.49	0.67
1985	2	1	1	0	0	1.08	1.00	1.54	1.30
1986	3	2	0	1	0	1.44	0.99	1.71	1.75
1987	4	0	0	2	2	1.58	1.06	1.85	2.16
1988	2	1	1	0	0	1.68	1.00	1.84	1.09
1989	2	1	0	0	1[3]	1.99	0.88	1.87	1.07
1990	3	1	0	0	2	2.06	0.82	1.85	1.62
1991	2	2	0	0	0	1.95	0.82	1.79	1.12
1992	1	1	0	0	0	2.14	0.76	1.83	0.55
1993	0	0	0	0	0	2.38	0.66	1.85	-.-
1994	0	0	0	0	0	2.58	0.65	1.94	-.-
1995	1	1	0	0	0	2.47	0.59	1.82	0.55
1996	0	0	0	0	0	2.68	0.56	1.90	-.-
1997	0	0	0	0	0	2.88	0.51	1.95	-.-
1998	0	0	0	0	0	2.90	0.42	1.88	-.-
1999	0	0	0	0	0	3.02[4]	0.44[4]	1.95[4]	-.-
Total	46[5]	21	9	6	10[3]	53.62	17.69	44.50	1.03

Bbbl = 10^9 bbl
Dash (-.-) indicates zero spills observed; spill rate not calculated
[1]Coastal and intraterritorial domestic movements
[2]Assumes half of exposure from U.S. imports/exports occurs outside U.S. waters
[3]Includes spill(s) greater than or equal to 100,000 bbl: 1977-1, 1979-1, 1989-1, Total-3
[4]1999 movements estimated as a 4% increase over 1998 per a COE estimate, 10/2000 (www.wrsc.usace.army.mil/ndc/wscompqr.htm)
[5]46 spills totaling 1,289,500 bbl spilled; includes spills in U.S. territorial waters; excludes inland spills. Largest tanker spill 255,000 bbl
Sources: COE, 2000; MMS Worldwide Tanker Spill Database, October 2000
(Note: 7 spills were added to 1974-1992 data since Anderson & LaBelle, 1994)

Table 5 Number of petroleum[1] spills greater than or equal to 1,000 bbl from barges in U.S. waters and petroleum[1] movements by barges in U.S. waters, 1974-1999. (The subset that refers to crude oil is in parentheses.)

	Number of Spills				Petroleum Movements	Spills[2] Per
Year	All Spills	1,000-9,999 bbl	10,000-24,999 bbl	>25,000 bbl	(Bbbl)	Bbbl
1974	14 (6)	10 (4)	2 (2)	2 (0)	1.62 (0.32)	8.64 (18.75)
1975	12 (4)	8 (3)	4 (1)	0 (0)	1.61 (0.33)	7.45 (12.12)
1976	9 (4)	9 (4)	0 (0)	0 (0)	1.75 (0.34)	5.14 (11.76)
1977	14 (0)	13 (0)	1 (0)	0 (0)	1.78 (0.33)	7.87 (-.-)
1978	15 (2)	12 (2)	3 (0)	0 (0)	1.85 (0.36)	8.11 (5.56)
1979	11 (1)	11 (1)	0 (0)	0 (0)	1.71 (0.32)	6.43 (3.13)
1980	10 (2)	10 (2)	0 (0)	0 (0)	1.72 (0.27)	5.81 (7.41)
1981	6 (0)	4 (0)	0 (0)	2 (0)	1.67 (0.22)	3.59 (-.-)
1982	5 (0)	4 (0)	0 (0)	1 (0)	1.57 (0.23)	3.18 (-.-)
1983	6 (1)	2 (0)	3 (1)	1 (0)	1.54 (0.25)	3.90 (4.00)
1984	8 (1)	5 (0)	2 (1)	1 (0)	1.64 (0.27)	4.88 (3.70)
1985	13 (2)	9 (2)	2 (0)	2 (0)	1.58 (0.30)	8.23 (6.67)
1986	6 (1)	5 (1)	1 (0)	0 (0)	1.64 (0.30)	3.66 (3.33)
1987	5 (0)	5 (0)	0 (0)	0 (0)	1.67 (0.27)	2.99 (-.-)
1988	9 (0)	7 (0)	0 (0)	2 (0)	1.74 (0.30)	5.17 (-.-)
1989	7 (0)	7 (0)	0 (0)	0 (0)	1.71 (0.28)	4.09 (-.-)
1990	10 (1)	9 (1)	1 (0)	0 (0)	1.74 (0.31)	5.75 (3.23)
1991	4 (0)	3 (0)	0 (0)	1 (0)	1.65 (0.28)	2.42 (-.-)
1992	3 (0)	3 (0)	0 (0)	0 (0)	1.60 (0.28)	1.88 (-.-)
1993	3 (0)	2 (0)	0 (0)	1 (0)	1.64 (0.28)	1.83 (-.-)
1994	1 (0)	0 (0)	1 (0)	0 (0)	1.64 (0.27)	0.61 (-.-)
1995	5 (0)	4 (0)	1 (0)	0 (0)	1.60 (0.26)	3.13 (-.-)
1996	4 (0)	3 (0)	1 (0)	0 (0)	1.61 (0.26)	2.48 (-.-)
1997	3 (0)	3 (0)	0 (0)	0 (0)	1.73 (0.26)	1.73 (-.-)
1998	1 (1)	1 (1)	0 (0)	0 (0)	1.70 (0.21)	0.59 (4.76)
1999	3 (0)	3 (0)	0 (0)	0 (0)	1.77 (0.22)[3]	1.69 (-.-)
Total	187 (26)[4]	152 (21)	22 (5)	13 (0)	43.48 (7.32)	4.30 (3.55)

Bbbl = 10^9 bbl

[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]Dash (-.-) indicates zero spills observed--not calculated

[3]1999 Movements estimated as a 4% increase over 1998 per a COE estimate, 10/2000 (www.wrsc.usace.army.mil/ndc/wscompqr.htm)

[4]187 petroleum spills totaling 1,256,500 bbl spilled; includes 26 crude oil spills totaling 175,500 bbl spilled. Largest barge spill 48,500 bbl

Sources: COE, 2000; MMS Worldwide Tanker Spill Database, October 2000

(Note: 14 spills were added to 1974-1992 data since Anderson & LaBelle, 1994)

Table 6 U.S. OCS platform and pipeline spill rates

	Old Rate, 1964 –1992[1]			Updated Rate, 1964 -1999			Last 15-Year Rate, 1985-1999		
Spill Source	Volume (Bbbl)	Number of Spills	Spill Rate	Volume (Bbbl)	Number of Spills	Spill Rate	Volume (Bbbl)	Number of Spills	Spill Rate
Spills Greater Than or Equal to 1,000 bbl									
Platforms	6.60 of 9.10[1]	3 of 11[2]	0.45[2]	9.5 of 12.00[3]	3 of 11[3]	0.32[3]	-.-[4]	0	>0 to <0.13[4]
Pipelines	9.10	12	1.32	12.00	16	1.33	5.81	8	1.38
Spills Greater Than or Equal to 10,000 bbl									
Platforms	-.-[5]	-[5]	0.16[5]	-.-[5]	-[5]	0.12[5]	-.-[5]	-[5]	>0 to <0.05[5]
Pipelines	9.10	4	0.44	12.00	4	0.33	5.81	2	0.34

Spill Rate = Spills per Bbbl handled; Bbbl = 10^9 bbl

[1]Anderson and LaBelle (1994)

[2]Based on results of trend analysis, most recent 6.60 Bbbl over which 3 spills greater than or equal to 1,000 bbl occurred.

[3]Based on results of trend analysis, most recent 9.5 Bbbl over which 3 spills greater than or equal to 1,000 bbl occurred.

[4]Zero spills 1985-1999; 1980-1999, 7.41 Bbbl production, 1 spill greater than or equal to 1,000 bbl, so rate is less than rate for last 20 years. It is best not to use a zero spill rate when a spill is still a possibility, so that an estimate of some rate greater than zero is desirable.

[5]Based on 4/11 of the spill rate for spills greater than or equal to 1,000-- 4 of the 11 spills greater than or equal to 1,000 bbl were greater than or equal to 10,000 bbl over the entire history. None of the 3 spills in the trend was greater than or equal to 10,000 bbl, and none since 1970).

Sources: MMS OCS Production Database, October 2000; MMS OCS Spill Database, October 2000

Table 7 Worldwide tanker spill rates

	Old Rate, 1974 –1992[1]			Updated Rate, 1974 -1999			Last 15-Year Rate, 1985-1999		
Spill Source	Volume (Bbbl)	Number of Spills	Spill Rate	Volume (Bbbl)	Number of Spills	Spill Rate	Volume (Bbbl)	Number of Spills	Spill Rate
Spills Greater Than or Equal to 1,000 bbl									
All Spills	164.40	213	1.30	239.67	278	1.16	138.31	113	0.82
In Port		77	0.47		117	0.49		50	0.36
At Sea		136	0.83		161	0.67		63	0.46
Spills Greater Than or Equal to 10,000 bbl									
All Spills	164.40	119	0.72	239.67	143	0.59	138.31	51	0.37
In Port		31	0.19		44	0.18		14	0.10
At Sea		88	0.53		99	0.41		37	0.27
Spills Greater Than or Equal to 100,000 bbl									
All Spills	164.40	52	0.31	239.67	58	0.24	138.31	16	0.12
In Port		12	0.07		16	0.07		5	0.04
At Sea		40	0.24		42	0.17		11	0.08

Spill Rate = Spills per Bbbl handled; Bbbl = 10^9 bbl
Crude oil spills only, excludes barges and inland spills
[1]Anderson and LaBelle (1994)
Sources: BP Amoco, 1999; BP, 1998; MMS Worldwide Tanker Spill Database, October 2000

Table 8 Spill rates for tankers in U.S. coastal and offshore waters

	Old Rate, 1974 –1992[1]			Updated Rate, 1974 -1999			Last 15-Year Rate, 1985-1999		
Spill Source	Volume (Bbbl)	Number of Spills	Spill Rate	Volume (Bbbl)	Number of Spills	Spill Rate	Volume (Bbbl)	Number of Spills	Spill Rate
Spills Greater Than or Equal to 1,000 bbl									
Tankers U.S. Waters	31.24	38	1.21	44.50	46	1.03	27.57	20	0.73
In Port		22	0.70		30	0.67		12	0.44
At Sea		16	0.51		16	0.36		8	0.29
Spills Greater Than or Equal to 10,000 bbl									
Tankers U.S. Waters	31.24	18	0.58	44.50	19	0.43	27.57	7	0.25
In Port		8	0.26		9	0.20		2	0.07
At Sea		10	0.32		10	0.23		5	0.18

Spill Rate = Spills per Bbbl handled; Bbbl = 10^9 bbl
Crude oil spills only, excludes barges and inland spills
[1]Anderson and LaBelle (1994)
Sources: COE, 2000; MMS Worldwide Tanker Spill Database, October 2000

Table 9 Alaska North Slope crude oil tanker spill rates

	Old Rate, 1977 –1992[1]			Updated Rate, 1977 -1999			Last 15-Year Rate, 1985-1999		
Spill Source	Volume (Bbbl)	Number of Spills	Spill Rate	Volume (Bbbl)	Number of Spills	Spill Rate	Volume (Bbbl)	Number of Spills	Spill Rate
Spills Greater Than or Equal to 1,000 bbl									
Alaska North Slope Oil Tankers	9.08	10	1.10	12.60	11	0.88	8.72	8	0.92
In Port		3	0.33		4	0.32		4	0.46
At Sea		7	0.77		7	0.56		4	0.46
Spills Greater Than or Equal to 10,000 bbl									
Alaska North Slope Oil Tankers	9.08	3	0.33	12.60	3	0.23	8.72	3	0.34
In Port		0	-.-		0	-.-		0	-.-
At Sea		3	0.33		3	0.23		3	0.34

Spill Rate = Spills per Bbbl handled; Bbbl = 10^9 bbl
[1]Anderson and LaBelle (1994)
Dash (-.-) indicates zero spills observed; spill rate not calculated
Sources: DOC, 2000; MMS Worldwide Tanker Spill Database, October 2000

Table 10 Spill rates for barges in U.S. coastal, offshore, and inland waters

	Old Rate, 1974 –1992[1]			Updated Rate, 1974 -1999			Last 15-Year Rate, 1985-1999		
Spill Source	Volume (Bbbl)	Number of Spills	Spill Rate	Volume (Bbbl)	Number of Spills	Spill Rate	Volume (Bbbl)	Number of Spills	Spill Rate
Spills Greater Than or Equal to 1,000 bbl									
All Petroleum Products	31.78	153	4.81	43.48	187	4.30	25.02	77	3.08
Crude Oil Only	5.56	24	4.32	7.32	26	3.55	4.08	5	1.23
Spills Greater Than or Equal to 10,000 bbl									
All Petroleum Products	31.78	27	0.85	43.48	35	0.81	25.02	13	0.52
Crude Oil Only	5.56	4	0.72	7.32	5	0.68	4.08	0	<0.23[2]

Spill Rate = Spills per Bbbl handled; Bbbl = 10^9 bbl
[1]Anderson and LaBelle (1994)
[2]Zero spills, 1985-1999 (1984-1999, volume = 4.35 Bbbl crude, 1 spill greater than or equal to 10,000 bbl)
Sources: COE, 2000; MMS Worldwide Tanker Spill Database, October 2000

Table 11 Average and median spill sizes by spill source, spill size greater than or equal to 1,000 bbl

	Entire Record through 1999[1]			Last 15 Years, 1985-1999		
Spill Source	Number of Spills	Average Spill Size (bbl)	Median Spill Size (bbl)	Number of Spills	Average Spill Size (bbl)	Median Spill Size (bbl)
OCS Platforms	3/11[2]	3,300/18,300[2]	1,500/7,000[2]	0 [3]	--[3]	-- [3]
OCS Pipelines	16	16,600	5,100	8	6,700	4,600
Worldwide Tankers, Total	278	93,900	11,300	113	70,100	7,900
In Port	117	68,300	6,300	50	56,300	3,600
At Sea	161	112,400	17,000	63	81,000	14,300
Tankers U.S. Waters, Total	46	28,000	7,000	20	22,800	5,300
In Port	30	10,000	6,000	12	5,600	4,500
At Sea	16	61,900	16,100	8	48,600	14,600
Tankers Alaska North Slope Crude, Total	11	27,900	5,000	8	37,100	7,800
In Port	4	5,600	5,300	4	5,600	5,300
At Sea	7	40,600	4,900	4	68,700	14,600
Barges U.S. Waters						
All Petroleum Products	187	6,700	3,000	77	6,900	3,000
Crude Oil Only	26	6,700	4,400	5	4,000	3,700

[1]Series start year: OCS platforms and pipelines—1964; worldwide tankers, tankers U.S. waters, barges U.S. waters—1974; tankers ANS crude—1977.
[2]Three spills left after trend analysis: average size, 3,300 bbl; median size 1,500 bbl; over the entire record, average and median spill sizes for 11 spills were 18,300 bbl and 7,000 bbl, respectively.
[3]Last 15 years, zero spills; last platform spill greater than or equal to 1,000 bbl was approximately 1,500 bbl and occurred in 1980.
Sources: MMS OCS Spill Database, October 2000; MMS Worldwide Tanker Spill Database, October 2000

Table 12 Average and median spill sizes by spill source, spill size greater than or equal to 10,000 bbl

Spill Source	Entire Record through 1999[1]			Last 15 Years, 1985-1999		
	Number of Spills	Average Spill Size (bbl)	Median Spill Size (bbl)	Number of Spills	Average Spill Size (bbl)	Median Spill Size (bbl)
OCS Platforms	0/4[2]	0/43,700[2]	0/41,500[2]	0[3]	--[3]	--[3]
OCS Pipelines	4	52,500	17,700	2	15,000	15,000
Worldwide Tankers, Total	143	178,700	66,000	51	150,800	56,900
In Port	44	175,500	49,500	14	192,300	43,000
At Sea	99	180,200	71,400	37	135,000	60,000
Tankers U.S. Waters, Total	19	62,100	20,000	7	58,000	15,400
In Port	9	23,700	20,000	2	12,900	12,900
At Sea	10	96,700	43,200	5	76,100	17,800
Tankers Alaska North Slope Crude, Total	3	89,900	15,000	3	89,900	15,000
In Port	0	--	--	0	--	--
At Sea	3	89,900	15,000	3	89,900	15,000
Barges U.S. Waters						
All Petroleum Products	35	22,500	19,700	13	25,700	20,000
Crude Oil Only	5	18,500	18,200	0	--	--

[1]Series start year: OCS platforms and pipelines—1964; worldwide tankers, tankers U.S. waters, barges U.S. waters—1974; tankers ANS crude—1977.
[2]Three spills left after trend analysis, average size, 3,300 bbl; median size 1,500 bbl, none greater than or equal to 10,000 bbl. Over the entire record, average and median spill sizes for 4 spills were
43,700 bbl and 41,500 bbl, respectively. Last platform spill greater than or equal to 10,000 bbl occurred in 1970 and was 53,000 bbl in size.
[3]Last 15 years zero spills; last platform spill greater than or equal to10,000 bbl was 53,000 bbl and occurred in 1970.
Sources: MMS OCS Spill Database, October 2000; MMS Worldwide Tanker Spill Database, October 2000

Table 13 U.S. OCS oil[1] spills, overall spill size characterization, 1985-1999

Spill Size	Number of Spills	Platform vs. Pipeline Spills	Spill Rate[2]	Average Spill Size (bbl)	Median Spill Size (bbl)
0 to 1.0 bbl	19,506	unavailable	3,357.31	0.07	unavailable
1.1 - 9.9 bbl	434	326/108	74.70	3.2	2.8
10.0-49.9	94	66/28	16.18	19.1	17.8
50.0-499.9	37	28/9	6.37	123	87
500.0-999.9	3	2/1	0.52	681	643
1,000 bbl and greater	8	0/8	1.38	6,716	4,551

Spill Rate = Spills per Bbbl handled; Bbbl = 10^9 bbl
[1]Oil spills includes crude oil, condensate, and refined petroleum products.
[2]Based on 5.81 Bbbl production
Source: MMS OCS Spill Database, October 2000

Table 14 Crude oil and condensate spills associated with onshore Alaska North Slope crude oil production, spill size greater than or equal to 500 bbl, 1969-1998

Years	Spill Source	Number of Spills	Production (Bbbl)	Spill Rate
1969-1998[1]	All Spills	5[2]	12.221	0.41[1]
	Facilities	4		0.33[1]
	Pipelines	1		0.08[1]
1985-1998	All Spills	5[2]	8.313	0.60
	Facilities	4		0.48
	Pipelines	1		0.12

Spill Rate = Spills per Bbbl handled; Bbbl = 10^9 bbl

[1]It is unusual that no spills occurred during the earlier start-up period, 1969-1984. The State of Alaska began a database in 1985. It is possible (but not certain) that some spills occurred prior to 1985 but were not recorded. If earlier spills occurred, but were not identified, this resulting 1969-1998 spill rate is too low.

[2] Average spill size 672 bbl; median spill size 650 bbl; largest spill 925 bbl.

Source: USDOI, MMS, 2000; State of Alaska, 2000

Table 15 Spills associated with Trans-Alaska Pipeline System, spill size greater than or equal to 500 bbl and greater than or equal to 1,000 bbl, 1977-1998

Years	Spill Source	Number of Spills	Throughput (Bbbl)	Spill Rate
1977-1998	Spills greater than or equal to 500 bbl	6[1]	12.492	0.48
	Spills greater than or equal to 1,000 bbl	5[2]		0.40
1985-1998	Spills greater than or equal to 500 bbl	1[3]	8.603	0.12
	Spills greater than or equal to 1,000 bbl	0		*

Spill Rate = Spills per Bbbl handled; Bbbl = 10^9 bbl

[1]Average spill size 3,635 bbl; median spill size 3,250; largest spill 7,000 bbl, 1977-1998

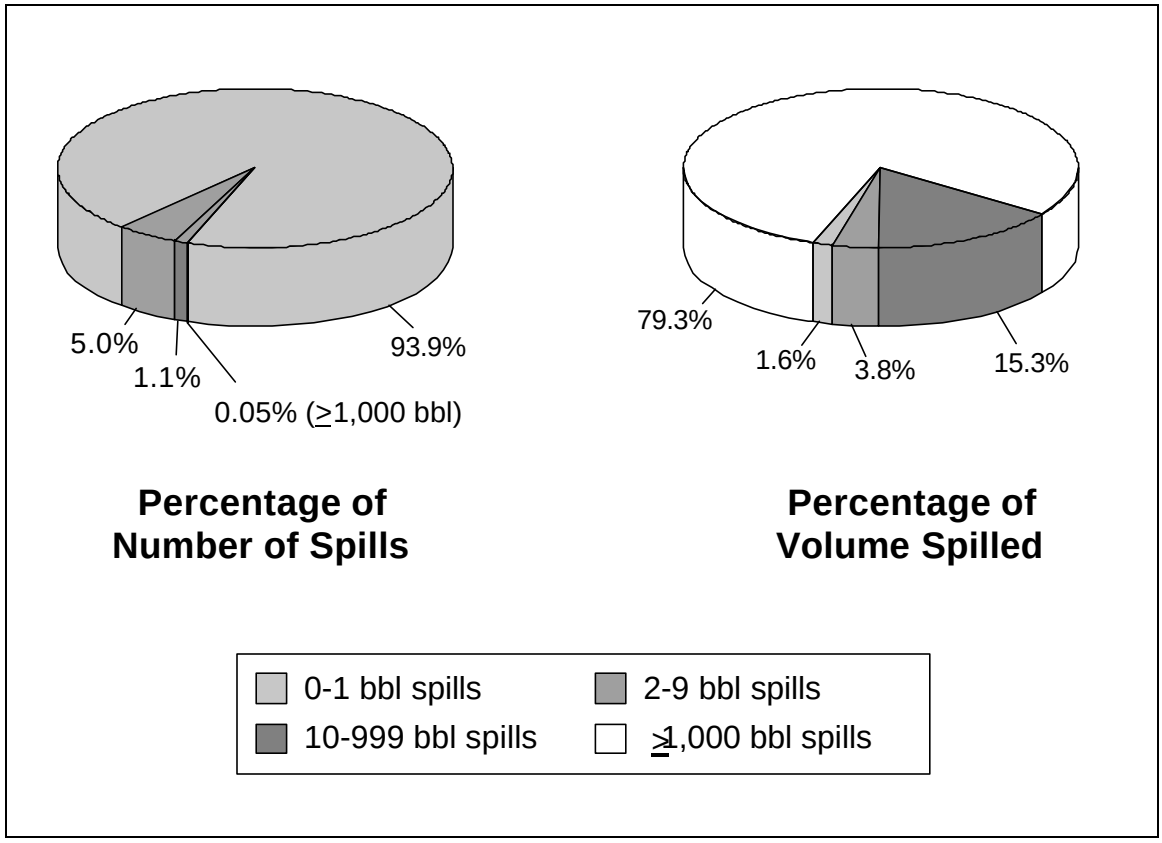
[2]Average spill size 4,200 bbl; median spill size 4,000 bbl

[3]Only one spill, 811 bbl, 1985-1998.

* No spills greater than or equal to 1,000 bbl occurred between 1985 and 1998; therefore, no rate was calculated.

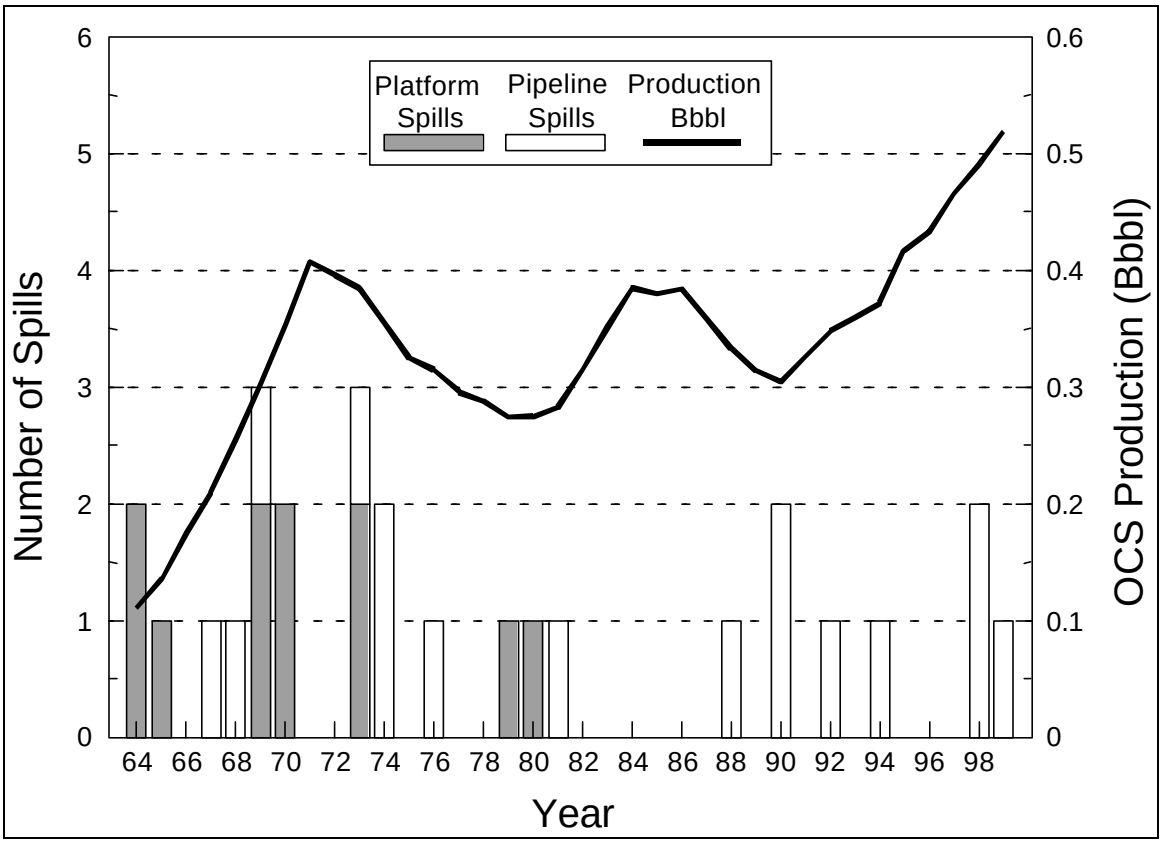
Source: USDOI, MMS, 2000; State of Alaska,2000

Figure 1 U.S. OCS spill size distribution: percent of total spills vs. volume spilled, 1971-1999



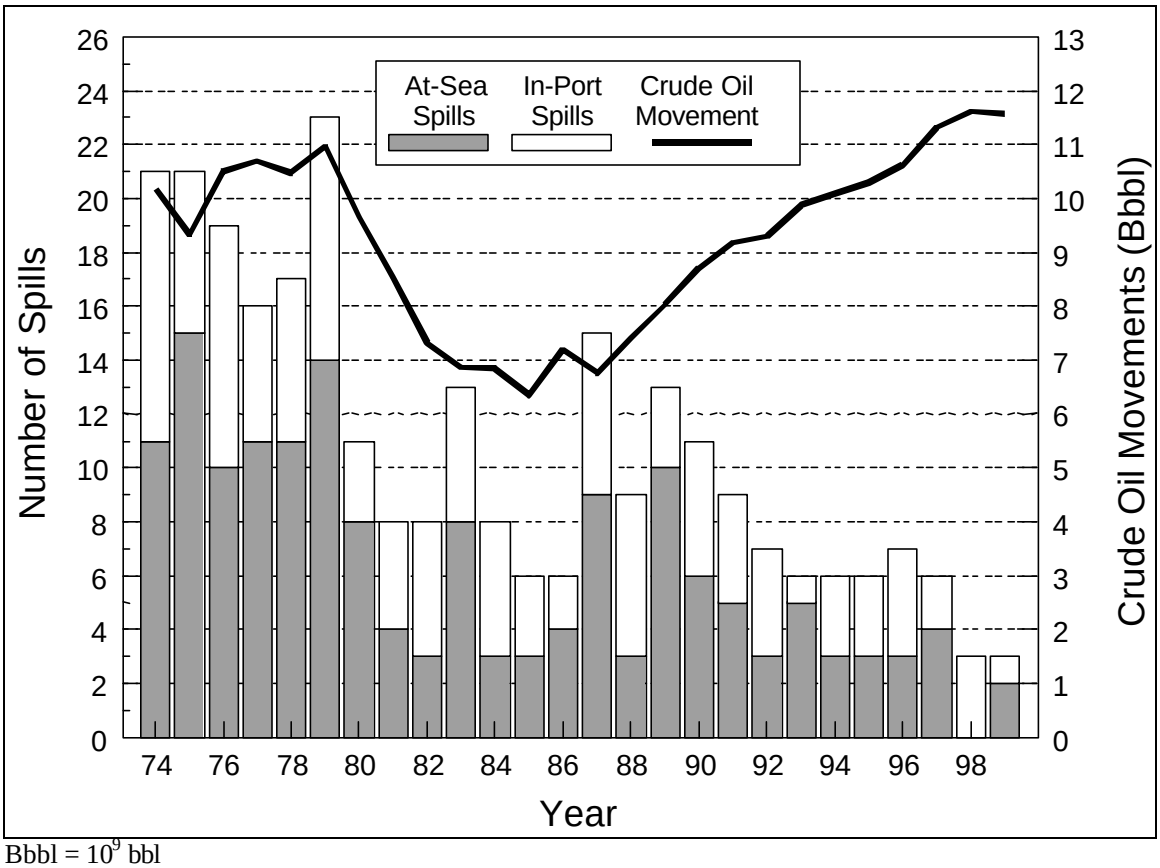
Based on 34,260 spills totaling 140,066 bbl
Source: MMS OCS Spill Database, 2000

Figure 2 Number of U.S. OCS spills greater than or equal to 1,000 bbl vs. U.S. OCS production, 1964-1999



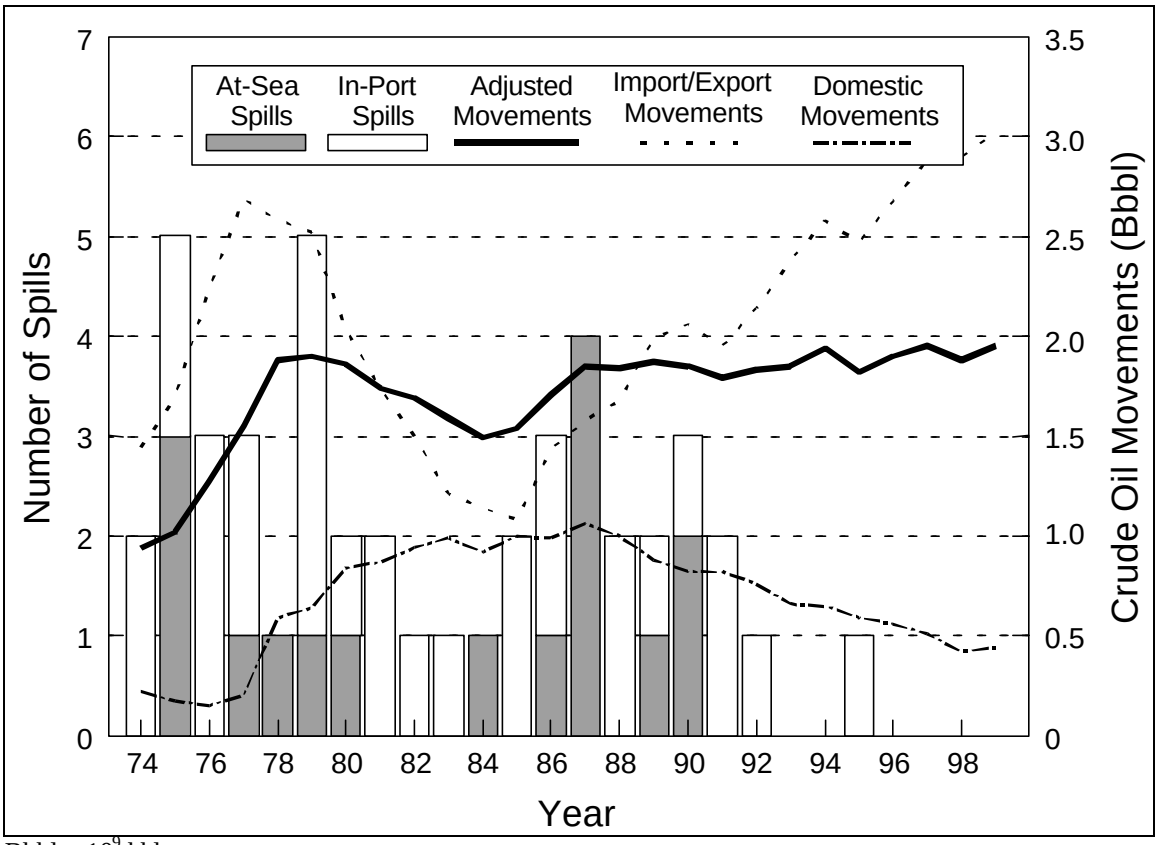
Bbbl = 10^9 bbl
Based on 27 crude oil, condensate, and diesel spills; 12 Bbbl of crude oil and condensate production
Sources: MMS OCS Production Database, 2000; MMS OCS Spill Database, 2000

Figure 3 Number of worldwide tanker spills greater than or equal to 1,000 bbl vs. worldwide crude oil movements, 1974-1999



Bbbl = 10^9 bbl
Based on 278 crude oil spills; 239.67 Bbbl of crude imports; excludes inland spills
Sources: BP Amoco, 2000; BP, 1998; MMS Worldwide Tanker Spill Database, 2000

Figure 4 Number of tanker spills greater than or equal to 1,000 bbl vs. crude oil movements in U.S. waters, 1974-1999



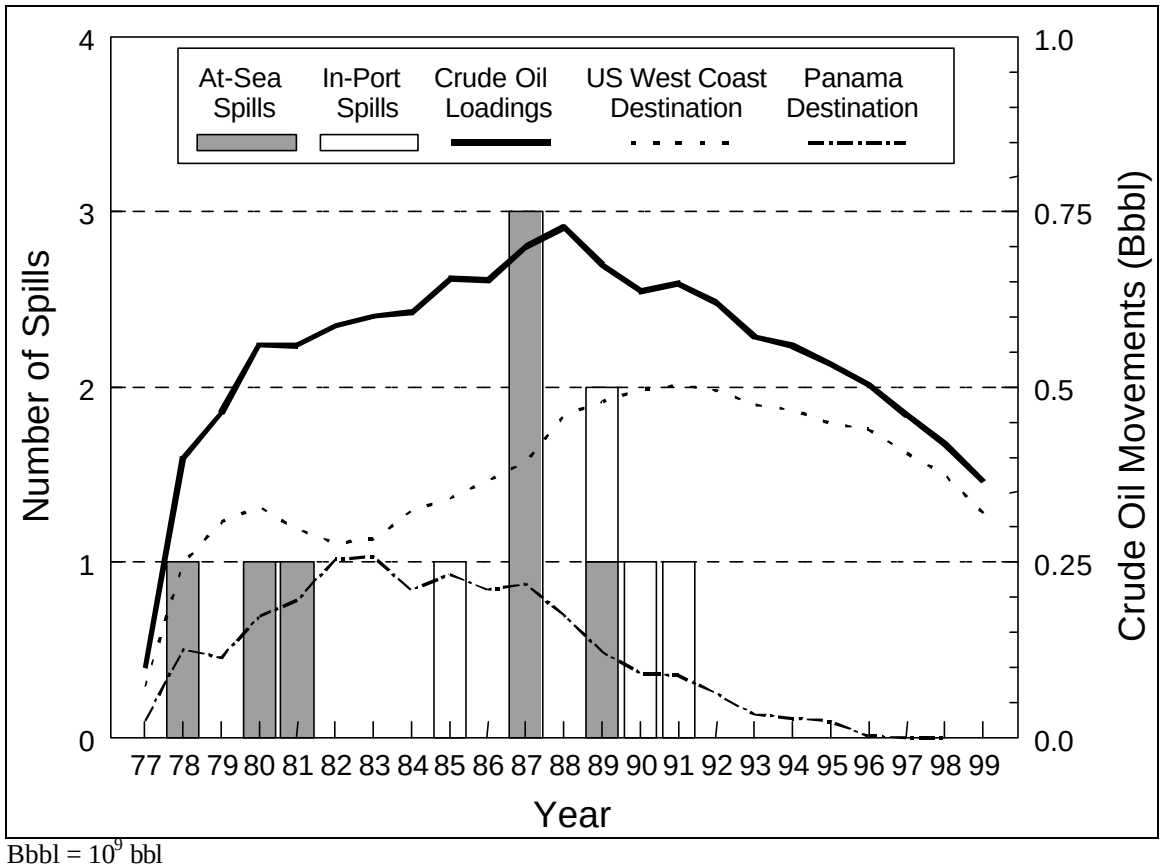
Bbbl = 10^9 bbl

Adjusted movements account for half of spills related to imports/exports assumed to occur outside of U.S. waters.

Based on 46 crude oil spills; 44.5 Bbbl adjusted movements; excludes inland spills

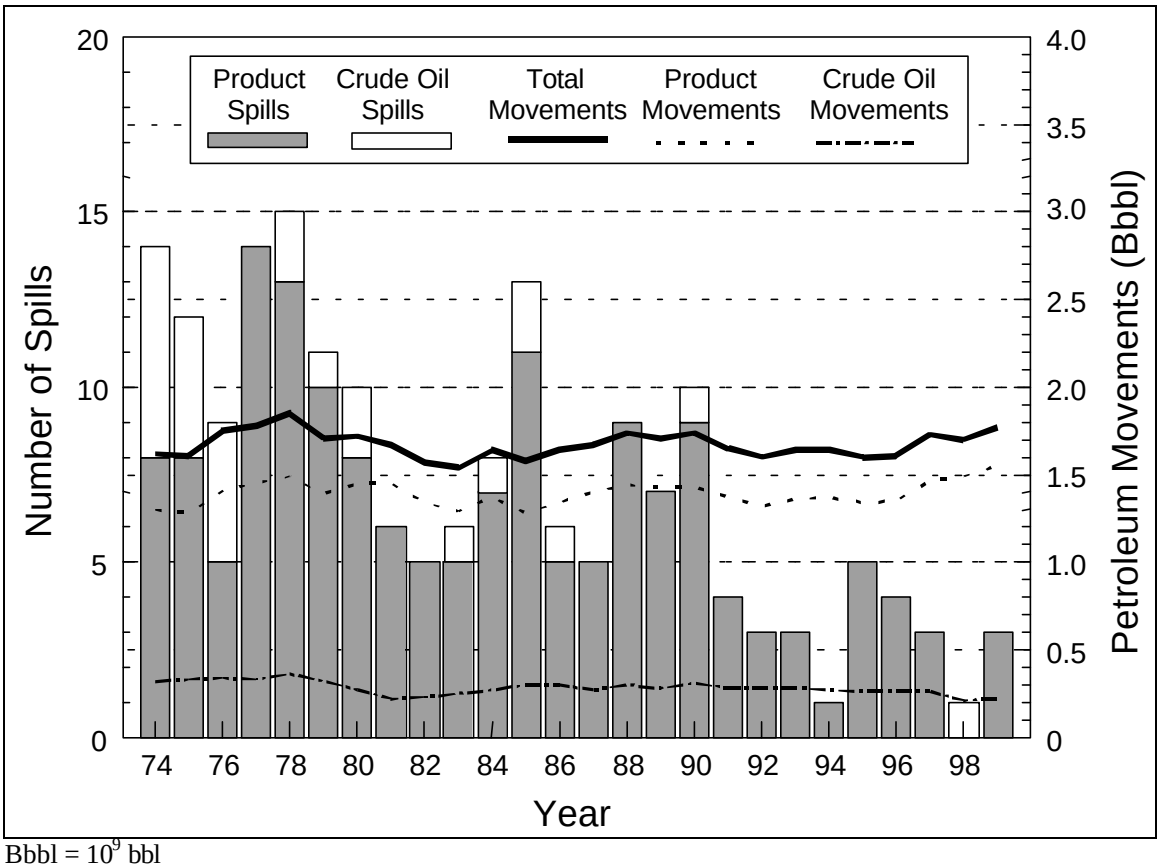
Sources: COE, 2000; MMS Worldwide Tanker Spill Database, 2000

Figure 5 Number of Alaska North Slope crude tanker spills greater than or equal to 1,000 bbl vs. total crude oil loadings at Valdez and destinations, 1977-1999



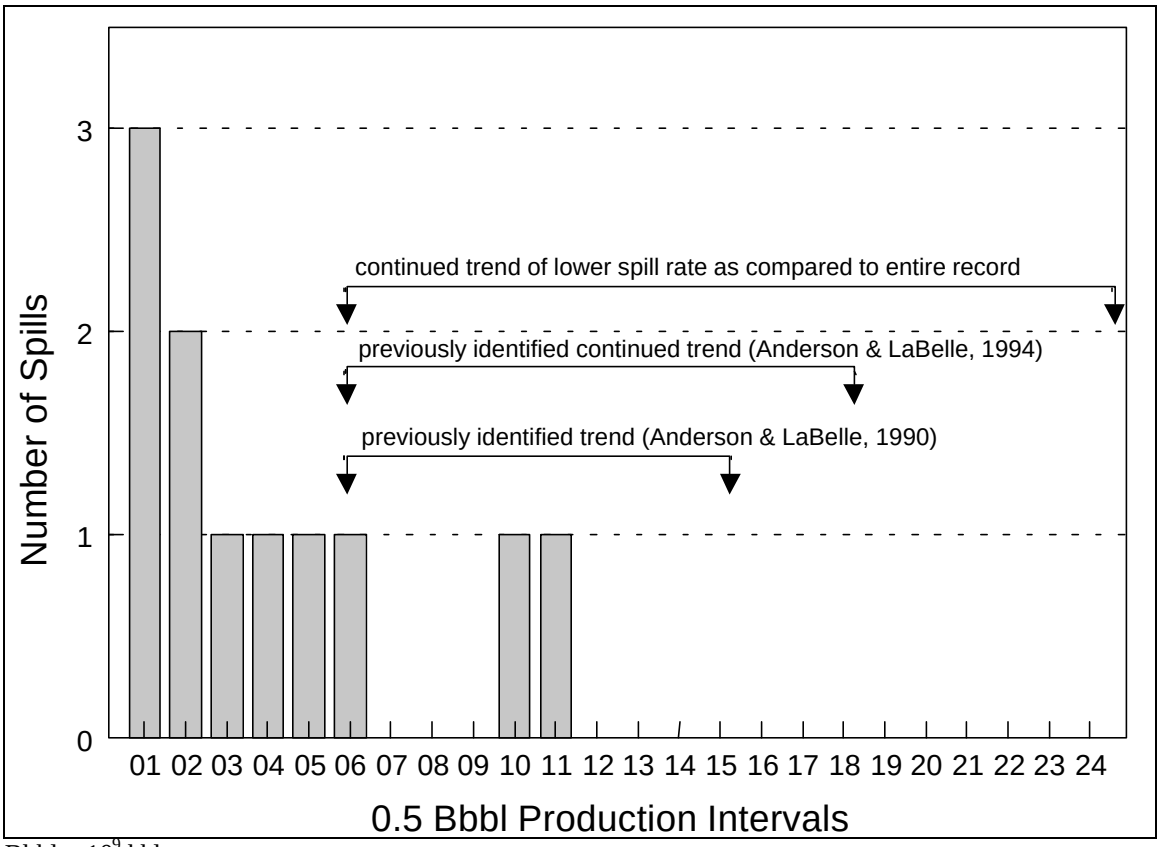
Bbbl = 10^9 bbl
Based on 11 Alaska North Slope crude oil spills; 12.6 Bbbl of loadings from Valdez
Sources: DOC, 2000; MMS Worldwide Tanker Spill Database, 2000

Figure 6 Number of petroleum spills from barges greater than or equal to 1,000 bbl vs. petroleum movements in U.S. waters, 1974-1999



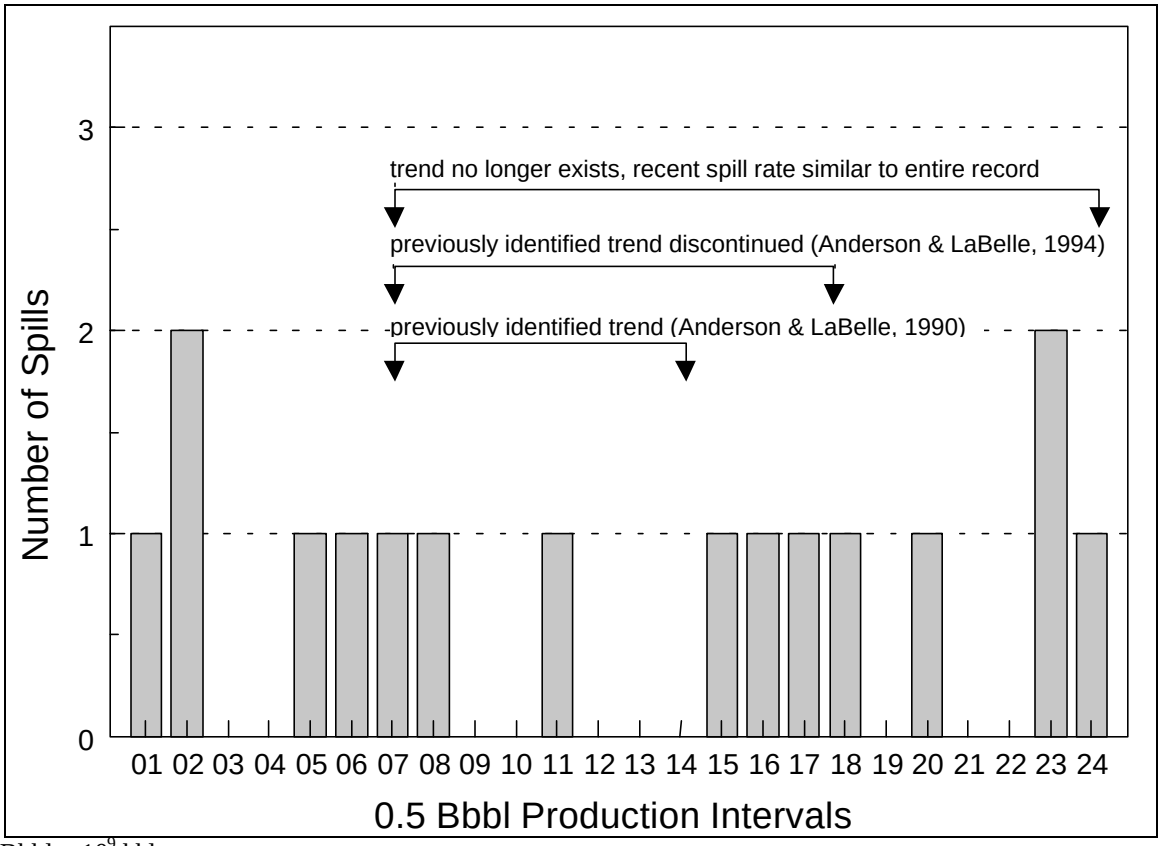
Bbbl = 10^9 bbl
Based on 187 petroleum spills (crude + product); 43.48 Bbbl movements
Sources: COE, 2000; MMS Worldwide Tanker Spill Database, 2000

Figure 7 U.S. OCS platform spills greater than or equal to 1,000 bbl within 0.5 Bbbl production intervals



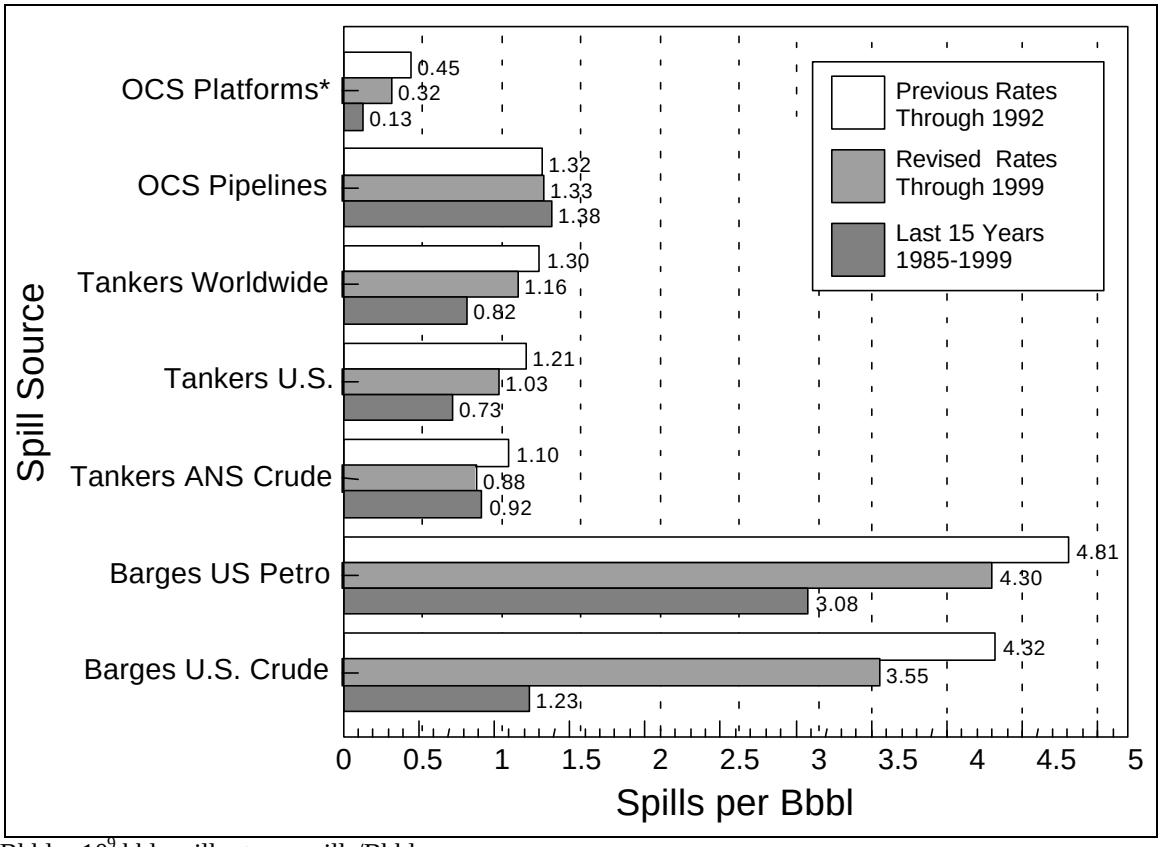
Bbbl = 10^9 bbl
Based on 12 Bbbl of crude oil and condensate production

Figure 8 U.S. OCS pipeline spills greater than or equal to 1,000 bbl within 0.5 Bbbl production intervals



Bbbl = 10^9 bbl
Based on 12 Bbbl of crude oil and condensate production

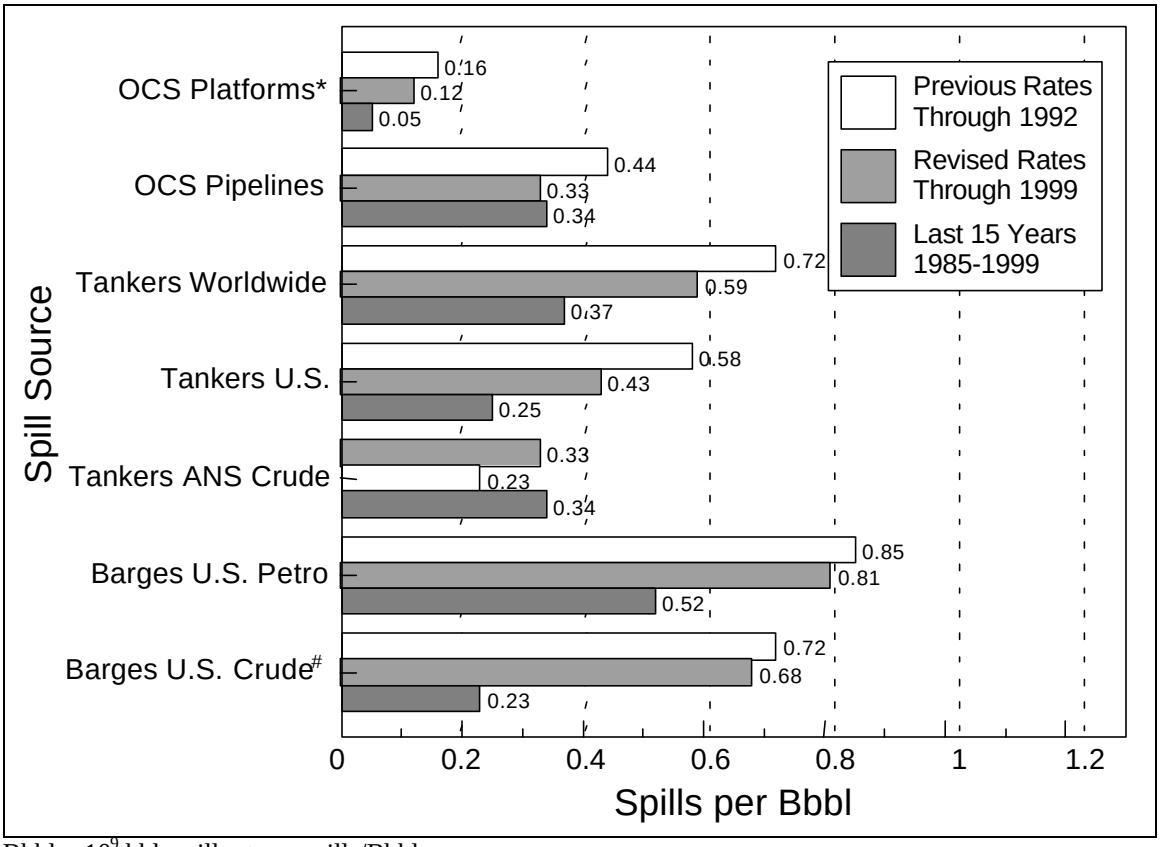
Figure 9 Comparison of historic spill rates for spills greater than or equal to 1,000 bbl



Bbbl = 10^9 bbl; spill rates = spills/Bbbl

*OCS platforms: zero spills since 1980; last 15-year (1985-1999) spill rate less than 20-year (1980-1999) rate of 0.13

Figure 10 Comparison of historic spill rates for spills greater than or equal to 10,000 bbl

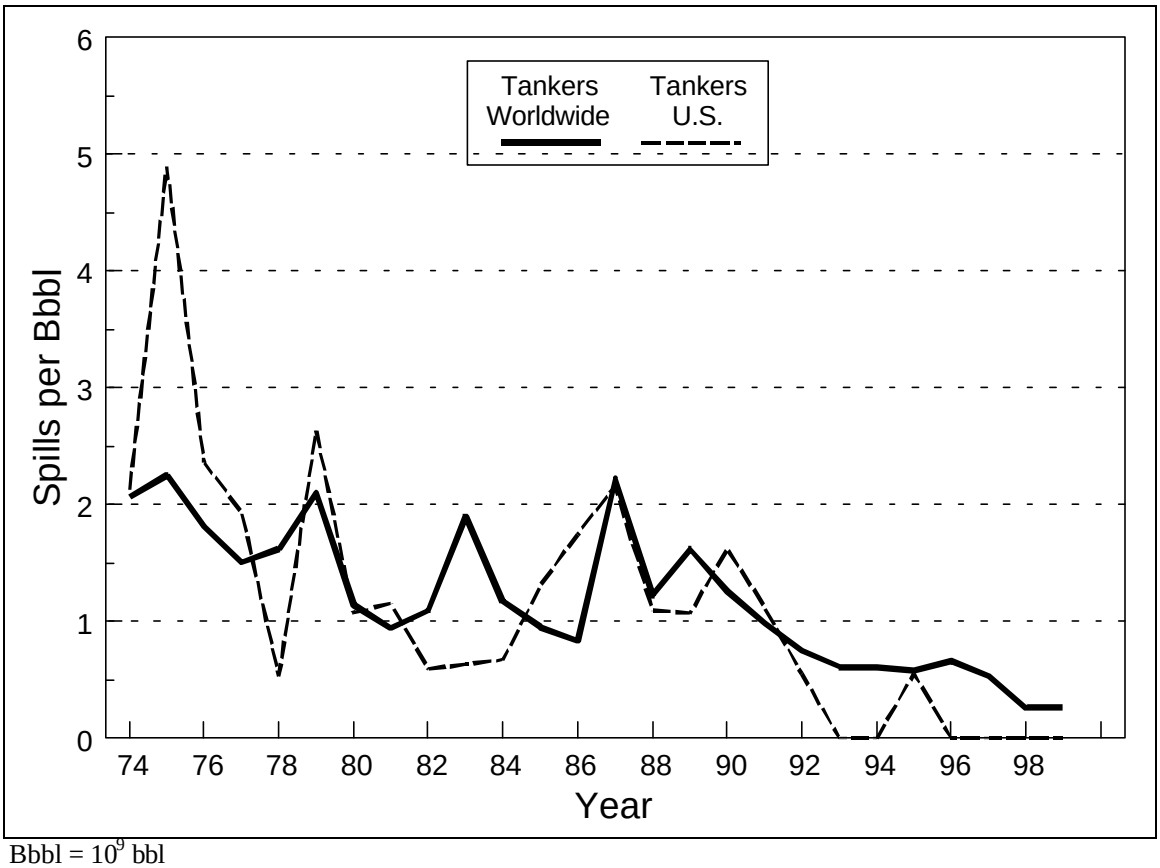


Bbbl = 10^9 bbl; spill rates = spills/Bbbl

*OCS platforms: zero spills since 1980; zero spills $\geq$10,000 bbl since 1970. Last 15-year (1985-1999) spill rate less than 0.05 spills/Bbbl

#Barges in U.S. waters: zero crude oil spills since 1984; spill rate less than 16-year (1984-1999) rate of 0.23 spills/Bbbl

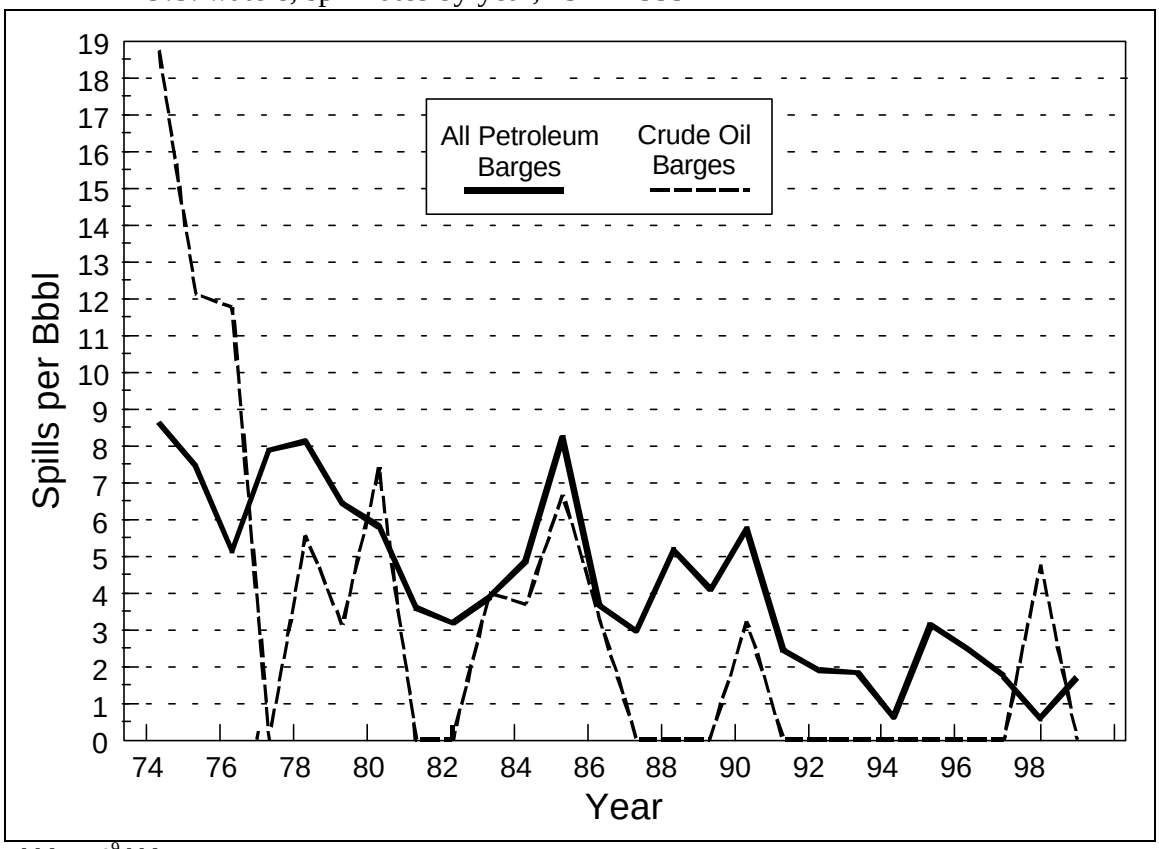
Figure 11 Worldwide tanker spills and tanker spills in U.S. waters greater than or equal to 1,000 bbl, spills rates by year, 1974-1999



Bbbl = 10^9 bbl

Sources: BP Amoco, 2000; British Petroleum Company, 1998; COE, 2000; MMS Tanker Spill Database, 2000

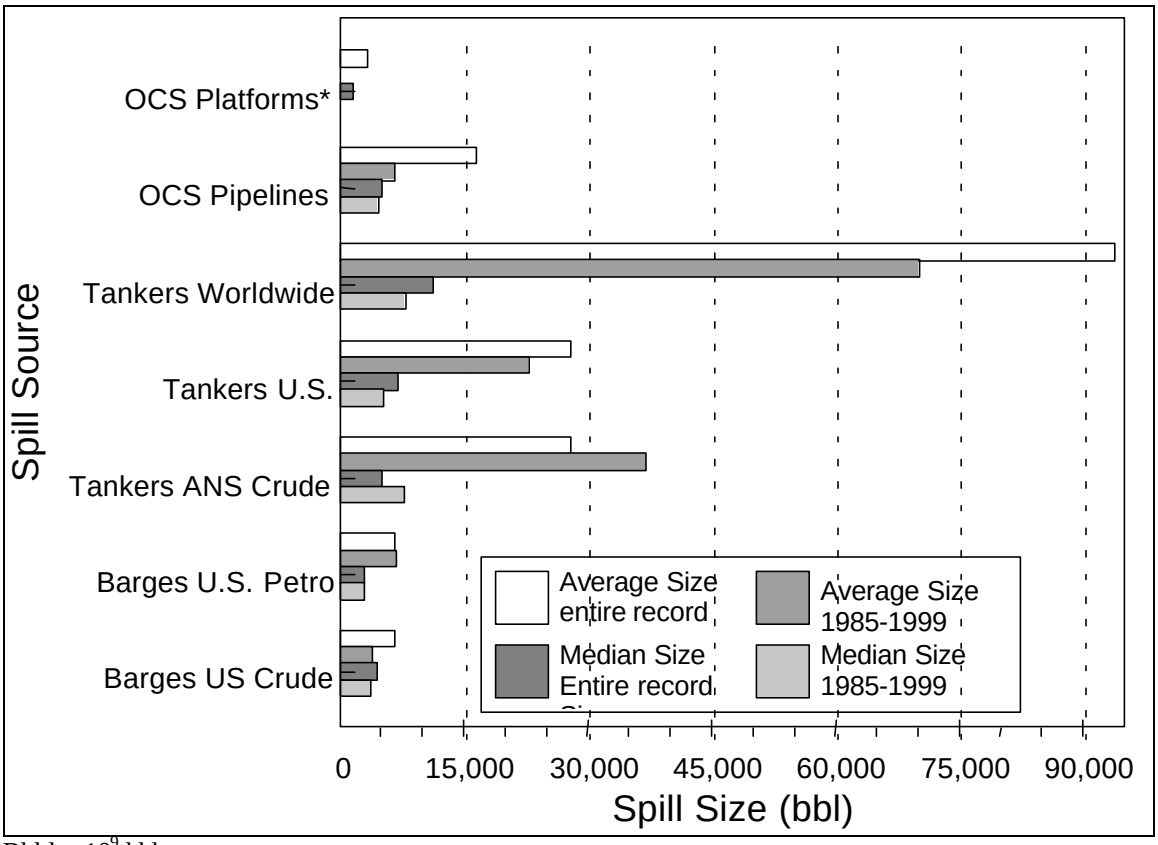
Figure 12 Petroleum and crude oil barge spills greater than or equal to 1,000 bbl in U.S. waters, spill rates by year, 1974-1999



Bbbl = 10^9 bbl

Sources: BP Amoco, 2000; British Petroleum Company, 1998; COE, 2000; MMS Tanker Spill Database, 2000

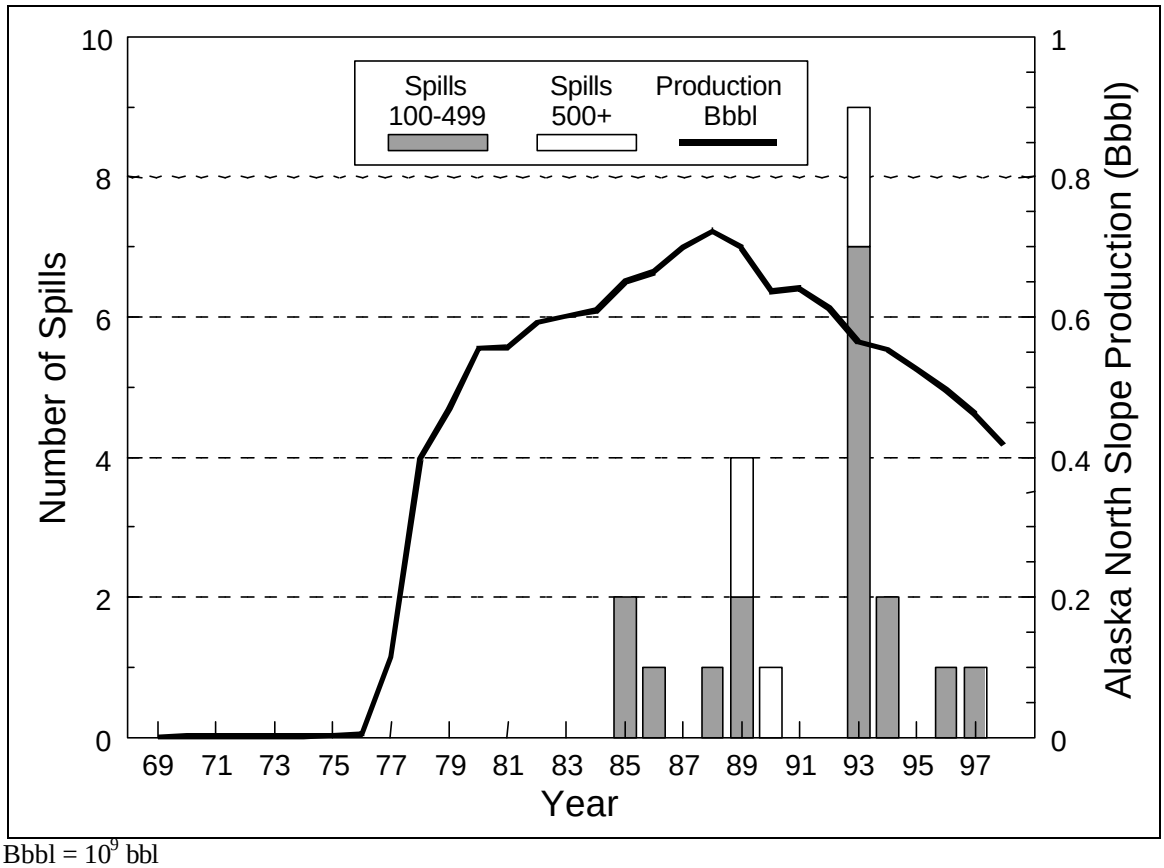
Figure 13 Comparison of average and median spill size by spill source for spills greater than or equal to 1,000 bbl, 1985-1999



Bbbl = 10^9 bbl

*OCS platforms: three spills left after trend analysis, average size, 3,300 bbl; median size, 1,500 bbl; zero spills ≥1,000 bbl since 1980, last spill approximately 1,500 bbl.

Figure 14 Number of Alaska North Slope spills greater than or equal to 100 bbl vs. Alaska North Slope production, 1969-1998

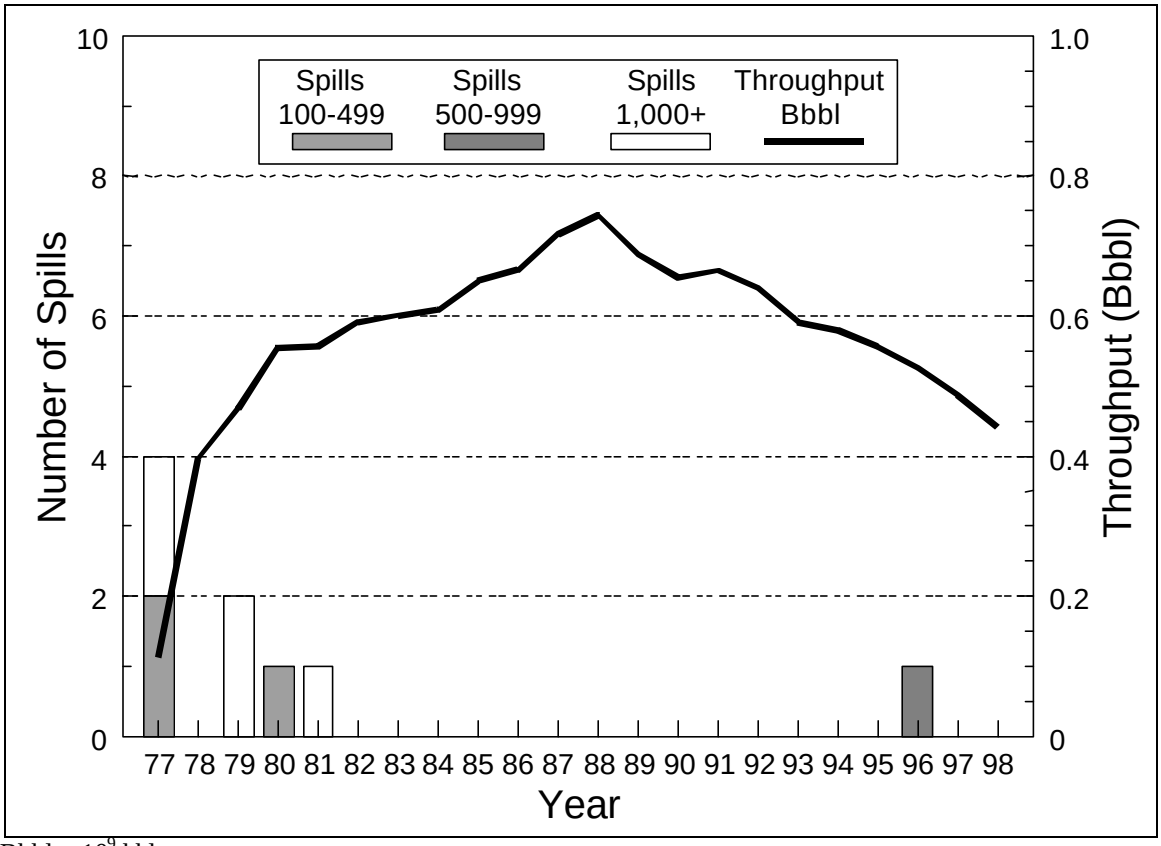


Bbbl = 10^9 bbl

Based on 22 crude oil spills; 12.21 Bbbl of crude oil and condensate production; excludes Trans-Alaska Pipeline System spills.

Sources: USDOI, MMS, 2000; State of Alaska, 2000; State of Alaska, 1999

Figure 15 Number of Trans-Alaska Pipeline System spills vs. throughput production, 1977-1998



Bbbl = 10^9 bbl
Based on 9 crude oil spills
Sources: USDOI, MMS 2000