A REEXAMINATION OF OCCURRENCE RATES FOR ACCIDENTAL OIL SPILLS ON THE U.S. OUTER CONTINENTAL SHELF

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ABSTRACT: *The Department of the Interior is required to evaluate the risks of oil spills from outer continental shelf (OCS) oil leasing and must compare these risks to those of other oil sources, such as importing oil. Past practice has been to treat spill occurrence as a Poisson process, with a rate proportional to the amount of oil produced or transported. U.S. oil production and accident data and worldwide tanker data were used. Criticism of this approach has centered on the validity of using oil volume as an exposure variable, and the applicability of existing accident data to frontier OCS areas.*

To examine these questions, the Interior Department recently sponsored several studies on OCS oil spill occurrence rates. One study compiled an extensive listing of all known oil spills of recent years and is believed to be the most complete database on oil spills available to the public. Another study looked at trends in oil spills from U.S. OCS platforms and discovered a statistically significant decrease in the spill rate since 1974. Other studies examined oil spill data for Cook Inlet and Prudhoe Bay, Alaska, and found that spill rates for these areas could not be shown to be significantly different from the U.S. OCS platform spill rate based on trend analysis.

Studies are continuing to ensure that oil spill rates used by the Interior Department reflect the latest data and analyses.

The Minerals Management Service (MMS) of the U.S. Department of the Interior conducts oil and gas leasing on the U.S. outer continental shelf (OCS) and supervises leases which are sold. The leasing process is subject to the National Environmental Policy Act (NEPA), which requires that MMS evaluate the risks of oil spills occurring and damaging environmentally sensitive resources.

To address this important question, an oil spill trajectory analysis (OSTA) model was developed.[10] A central portion of the OSTA model deals with the likelihood of spill occurrence associated with producing and transporting offshore oil. A realistic, objective methodology for estimating oil spill occurrence rates is essential for properly balancing the benefits and risks of OCS leasing.

Intuitive notions regarding exactly what affects oil spill risks abound and often conflict with one another. For example, one can make an intuitively reasonable argument that risks should decline as the industry gains experience. An equally reasonable intuitive argument, however, can be made that drilling in deeper water or in the presence of sea ice should be riskier. Who is to say which effect predominates?

To address such questions in an objective manner, the oil spill risk analyses performed by the Interior Department have followed the principles of basing oil spill occurrence rates on historical records, updating records to reflect recent experience, and using trend analysis, where appropriate, to expedite adjustments for recent experience. Following this approach, intuitive notions are treated as hypotheses, which must be tested against the data, and accepted only if they meet objective tests. Claims of improved or decreased safety for certain operations are held to the test of experience, to fail or succeed on their own record. Updating and trend analysis ensures that obsolete data eventually will be purged from the record. Spill occurrence must be predicted over two to three decades, the estimated time to complete production from an offshore lease, so, it is reasonable to examine a comparably long record of experience.

The primary concern of the OSTA model has been with accidental spills of 1,000 barrels (bbl) or larger, and which could originate from OCS leasing or (for comparison) from alternatives to OCS leasing, such as importing oil.[10] All aspects of OCS production, including transportation of the oil to the shore, have been considered, so that spill rates are needed for production platforms, pipelines, and tankers.

The 1,000 bbl cutoff was selected to limit evaluations to those spills large enough to travel long distances on the ocean surface and to do serious damage under the right circumstances, though it is recognized that not all spills have serious environmental impacts. Another consideration is that a 1,000 bbl spill is serious enough not to go unnoticed, so reporting records tend to be reliable.

Some of the more recent analyses also have looked at spills of 10,000 bbl or greater,[8, 9] and there is increasing interest in obtaining a frequency distribution for spill size, so that more detailed examinations of impacts can be made. Frequency distributions also are necessary for stochastic oil spill simulations using spreading algorithms, as the initial spill volume is a critical parameter. These new demands on the OSTA model reflect the increasing sophistication of users in interpreting its results.

Oil spill occurrence has been treated as a Poisson process, with the estimated volume of economically recoverable oil as the exposure variable. Thus, the expected number of spills resulting from a proposed sale is directly proportional to the estimated amount of oil to be gained as benefits from the proposed sale. However, other exposure variables have been suggested as better predictors of oil spill occurrence.

Although the literature abounds with studies of oil spill occurrence statistics, many are applicable only in limited circumstances. Sponsoring agencies often have different requirements. The U.S. Coast Guard, for example, may be interested only in spills from carriers of crude oil. Researchers rarely have made their databases readily available to the scientific community, so it is difficult to reproduce or verify results, and nearly impossible to adapt the results to different situations.

To help update its own estimates of spill rates, the Interior Department contracted with The Futures Group, Glastonbury, Connecticut, to prepare a database of historic oil spills and to perform a preliminary analysis of spill rates.[14, 15] Completed in September 1982, the database contains detailed records of platform, pipeline, and tanker spills. It is available in hard copy or electronic format from the MMS for the cost of reproduction. Records are in a readable format that also is suitable for convenient input with most modern computer languages. The entire database used by the Interior Department is,

Table 1. Oil spills of 1,000 bbl or more from platforms on the U.S. outer continental shelf, 1964–1980

Date	MMS Database ID No.	Location	Size (bbl)	Cause
8 April 64	200	Eugene Island 208	5,108	Collision
3 Oct. 64	220–280	(7 Platforms)	17,500	Hurricane
19 July 65	360	Ship Shoal 29	1,688	Blowout
28 Jan. 69	990	Santa Barbara	77,000[1]	Blowout
16 March 69	1,060	Ship Shoal 72	2,500	Blowout, weather
17 Aug. 69	1,220	Main Pass 41	16,000	Tank spill, weather
10 Feb. 70	1,430	Main Pass 41	30,500	Blowout
1 Dec. 70	1,580	South Timbalier 26	53,000	Blowout
20 July 72	2,000	(Unspecified, Gulf of Mexico)	4,300	Unspecified
9 Jan. 73	2,130	West Delta 79	9,935	Tank spill
23 Nov. 79	4,230	Main Pass 151	1,500	Tank spill
17 Nov. 80	4,590	Galveston	1,500	Tank spill

1. Estimates vary[1]

Table 2. Oil spills of 1,000 bbl or more from pipelines on the U.S. outer continental shelf, 1964–1980

Date	MMS Database ID No.	Location	Size (bbl)	Cause
17 Oct. 67	20	West Delta 73	160,638	Anchor dragging
12 March 68	30	South Timbalier 131	6,000	Anchor dragging
11 Feb. 69	60	Main Pass 299	7,532	Anchor dragging
12 May 73	280	Grand Island 73	5,000	Corrosion
18 April 74	320	Eugene Island 317	19,833	Anchor dragging
11 Sept. 74	350	Main Pass 73	3,500	Environmental
18 Dec. 76	440	Eugene Island 297	4,000	"Damaged"
17 July 78	530	Eugene Island 215	1,000	Anchor dragging

therefore, available to the scientific community for examining the spill rates now used or for testing new hypotheses.

Spills from OCS platforms

Before 1981, OSTA model runs used OCS platform spill rates based on Stewart:[11] 10 spills of 1,000 bbl or more in handling 5.338 billion bbl of oil, for a rate of 1.87 spills per billion barrels.

Samuels and others,[8] using U.S. Geological Survey (USGS) accident records[16, 17] which reported nine spills of 1,000 bbl or more from 1964 to 1979, and using a 1964–1980 federal OCS oil production of 4.386 billion bbl,[18] computed a rate of 2.05 spills per billion barrels and a rate of 0.91 spills per billion barrels for spills of 10,000 bbl or more.

Nakassis[7] examined the spill record and concluded that a trend existed. Using a maximum likelihood approach, he estimated that the present spill rate for U.S. OCS platforms should be 0.79 spills per billion barrels. This rate has been applied in all OSTA models since late 1981.

The Futures Group and World Information Systems database[19] contains records of 462 platform accidents worldwide from 1955 through 1980, including 12 spills of 1,000 bbl or more in U.S. waters (Table 1). The USGS data for spills before 1973[18] contain several discrepancies but do not negate the conclusions of Nakassis. Ten of the 12 spills occurred before 1974, reaffirming the existence of a trend. Using the same methodology as Nakassis, we compute a spill rate of 1.0 spills per billion barrels for spills of 1,000 bbl or more.

Exposure variables other than volume of oil have been proposed. Stewart and Kennedy[13] suggested platform-years. Well-years, wells drilled, and frequency of hurricanes also have been suggested. Large spills, fortunately (for the environment, not the statisticians), are not very common, and it is difficult with only 12 spills to compare exposure variables to see which is a significantly better predictor than volume of oil. To complicate the analysis further, many proposed exposure variables are closely correlated with volume of oil, and, as shown by Nakassis, the spill rate, at least on a volume basis, has changed with time. Volume of oil has been used primarily because most other exposure variables are derived from predictions of oil resources.

The implication of using volume of oil as the exposure variable is that past and future OCS production will be similar. One intuitive notion is that this assumption will not hold in parts of Alaska, where production may occur on gravel islands. This notion can be tested as follows.

Using data from Prudhoe Bay,[3, 4] Samuels and others[8] tested the hypothesis that the spill rate for Prudhoe Bay was the same as the spill rate for the U.S. OCS. They concluded that the spill record of Prud-

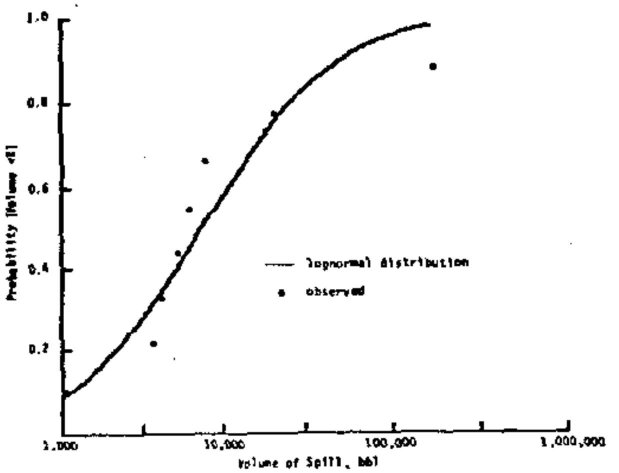

Figure 2. Log-normal cumulative frequency distribution of spill size for spills of 1,000 bbl or more from pipelines on the U.S. OCS

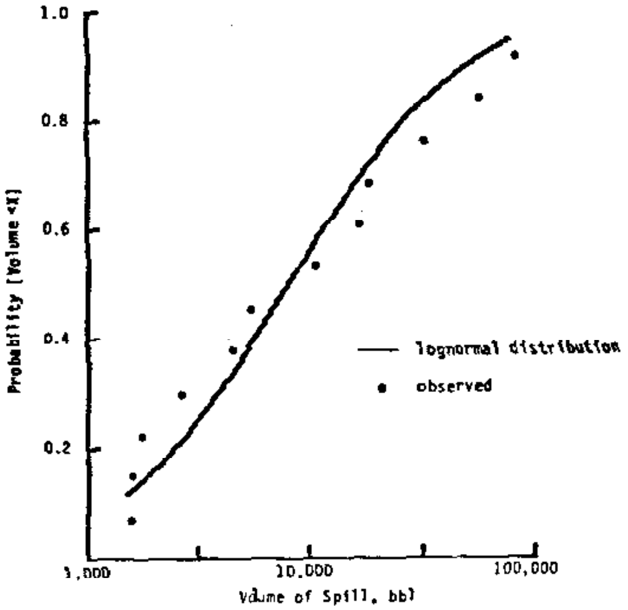

Figure 1. Log-normal cumulative frequency distribution of spill size for spills of 1,000 bbl or more from U.S. OCS production platforms

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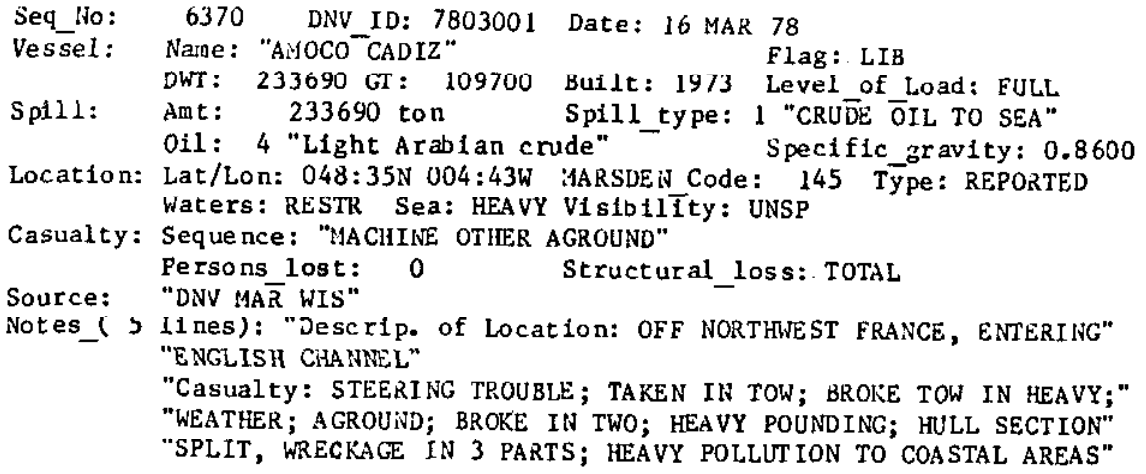
1. Approximately the total U.S. federal and state offshore oil production from 1964 to 1974.



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Seq_No:      6370     DNV_ID: 7803001  Date: 16 MAR 78
Vessel:      Name: "AMOCO CADIZ"                  Flag: LIB
             DWT:  233690 GT:  109700  Built: 1973  Level_of_Load: FULL
Spill:       Amt:    233690 ton        Spill_type: 1 "CRUDE OIL TO SEA"
             Oil:  4 "Light Arabian crude"        Specific_gravity: 0.8600
Location:    Lat/Lon: 048:35N 004:43W  MARSDEN_Code:  145  Type: REPORTED
             Waters: RESTR  Sea: HEAVY Visibility: UNSP
Casualty:    Sequence: "MACHINE OTHER AGROUND"
             Persons_lost:   0         Structural_loss: TOTAL
Source:      "DNV MAR WIS"
Notes_( 5 lines): "Descrip. of Location: OFF NORTHWEST FRANCE, ENTERING"
             "ENGLISH CHANNEL"
             "Casualty: STEERING TROUBLE; TAKEN IN TOW; BROKE TOW IN HEAVY;"
             "WEATHER; AGROUND; BROKE IN TWO; HEAVY POUNDING; HULL SECTION"
             "SPLIT, WRECKAGE IN 3 PARTS; HEAVY POLLUTION TO COASTAL AREAS"
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Figure 3. Example of a tanker accident record

hoe Bay, one spill (60,000 gallons of fuel oil) in producing 1.8 billion bbl of oil, was not likely to have resulted from a Poisson process with a spill rate of 2.05 spills per billion barrels (the rate used, at that time, for the OCS). However, using a spill rate of 1.0 spills per billion barrels, there is a 0.46 probability of observing zero to one spill in producing 1.8 billion bbl of oil. In other words, the record of Prudhoe Bay is very much what we would expect, given its production. Prudhoe Bay indeed could be safer, but there is not a long enough record to prove so, and we cannot reject the hypothesis that the spill rate for gravel islands is the same as for platforms.

Figure 1 shows the cumulative frequency distribution for the 12 platform spills of more than 1,000 bbl. A log-normal distribution, with a mean $\log_{10}$ volume of 3.905 and a standard devaition $\log_{10}$ of 0.608 provides a useful approximation for most oil spill modeling purposes. Note that the distribution is truncated at its lower end due to the 1,000 bbl cutoff.

Oil spills from U.S. OCS pipelines

Spill rates for pipelines on the U.S. OCS were, like platform rates, taken from Stewart.[11] The rates changed little when Samuels and others,[8] using USGS accident data from 1964 through 1979 and basing exposure on U.S. OCS production (almost all U.S. OCS oil is transported by pipeline), computed a rate of 1.82 spills per billion barrels for spills of 1,000 bbl or more.

The new database contains records of 64 OCS pipeline accidents worldwide from 1967 through 1980. Of these, eight spills of 1,000 bbl or more occurred on the U.S. OCS (Table 2). These are the same spills used by Samuels and others.[8] The spill rate, updating for 5.01 billion bbl of oil and condensate production from 1964–1980,[19] is 1.6 spills per billion barrels. Unlike platform spills, no trend in the rate is apparent.

A cumulative frequency distribution for pipeline spills is shown in Figure 2. A log-normal distribution with a mean $\log_{10}$ volume of 3.875 and a standard deviation $\log_{10}$ of 0.648 provides only an approximate fit. This must be applied with some caution as a single event, one 160,000 bbl spill, has a great influence.

Anchor dragging is the most frequent cause of pipeline spills; with corrosion, it accounts for 75 percent of the large pipeline spills in Table 2. Both of these causes appear to have a relationship to length of the pipeline, implying that kilometer-years (km-yr) may be a more accurate exposure variable. With an exposure in the U.S. Gulf of Mexico from 1969 to 1980 of 24,140 km-yr,[15] the spill rate would be 0.086 spills per 1,000 km-yr. Table 3 compares km-yr and volume of oil as exposure variables.

On a likelihood basis, volume of oil is better than km-yr in explaining the spill record. The length of pipelines has increased more than threefold since 1969, with no corresponding increase in spill occurrences. Perhaps km-yr, adjusted for some experience factor, may yet prove to be a superior exposure variable. However, such an adjustment would cost a statistical analysis at least two degrees of freedom (for shape and parameter value), making its superiority very difficult to demonstrate with only eight spill occurrences.

Table 3. Analysis of U.S. OCS pipeline spills of 1,000 bbl or more from 1969 to 1980, comparing km-yr and volume of oil as exposure variables

Year	Pipelines[1] (10^3km)	Volume of oil and condensate[2] (billion bbl)	Spills observed
1969	1.15	0.313	1
1970	1.23	0.361	0
1971	1.33	0.419	0
1972	1.56	0.412	0
1973	1.70	0.395	1
1974	1.84	0.361	2
1975	1.97	0.330	0
1976	2.39	0.317	1
1977	2.50	0.304	0
1978	2.60	0.292	1
1979	2.88	0.286	0
1980	2.99	0.277	0
Spill rate: (1969–1980)	0.25/10^3km-yr	1.79 per billion bbl	
Likelihood:	1.2e-5	1.9e-5	

1. Gulf of Mexico only, diameter greater than six inches[15]
2. U.S. Geological Survey[19]

Oil spills from tankers

The Interior Department did not maintain a database of tanker accidents as it did for platforms and pipelines. All tanker spill rates were derived from published studies. Devanney and Stewart,[2] examining spills on major trade routes, reported 99 spills of 1,000 bbl or more occurred in transporting 29.326 billion bbl of oil. Stewart[12] reported 178 spills in transporting 45.941 billion bbl of oil, for a rate of 3.87 spills per billion barrels; all of these spills occurred before 1976.

The Futures Group and World Information Systems database provides the Interior Department with the first opportunity since 1976 to review and update the tanker spill rates. Because of the difficulty and expense of collecting spill data, primary emphasis was placed on

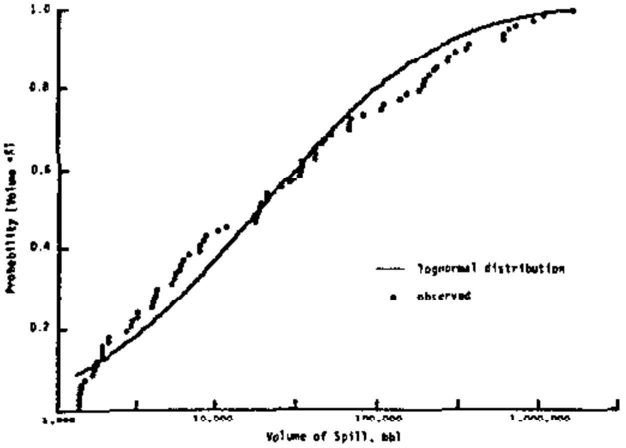

Figure 4. Log-normal cumulative frequency distribution of spill size for crude oil spills of 1,000 bbl or more from tankers worldwide

collecting data on spills of 1,000 bbl or more occurring since 1974, although spills of all dates and sizes were included. Data from the U.S. Coast Guard Pollution Incident Reporting System (PIRS), for example, were included beginning in 1973. The data summarized in Table 4 contain 885 records of accidents, involving vessels engaged in transporting oil as a product. The format of a typical record (Figure 3) includes such details as type of oil, location, and type of water (pier, harbor, restricted, or open), as well as room for comments.

Spills of crude oil of 1,000 bbl or more, from tankers worldwide are shown in Table 5. That at least 31 percent of the spills occurred in harbors or at piers is particularly important for evaluating environmental impacts, as these spills would not be subject to the same advective and weathering effects of winds and currents as spills on the OCS. Earlier analyses did not make this important distinction. Using an exposure of approximately 88 billion bbl of oil transported between 1974 and 1980,[15] the new spill rates become 0.90 spills per billion barrels for spills at sea (open, restricted or unknown waters) and 0.40 spills per billion barrels for spills in port (harbors or piers), for a total of 1.3 spills per billion barrels. Spills in port must be assumed to be divided evenly between the inbound and outbound portions of the voyage, as the database does not make this distinction.

The tanker spill rate since 1974 appears to be only a third of that before 1973. Stewart[12] reports more spills before 1976 than are contained in The Futures Group and World Information Systems database, but this could be due to lack of collection success (emphasis was on years 1974 and later) in the earlier years. Goldberg and others[5] also report more incidents for years before 1972, but about the same number for later years. (Their classification scheme, however, is not exactly the same, and individual records are not available, so the comparison is only approximate.) Unless the databases are very much in error, it appears that the tanker spill rate for spills of 1,000 bbl or more dropped significantly sometime between 1972 and 1974.

Table 4. Summary of data on oil spills from vessels carrying petroleum as a cargo

Year	Number of spills Any size	≥ 1,000 bbl
pre-1969	49	33
1969	20	13
1970	40	22
1971	47	19
1972	89	44
1973	78	49
1974	82	30
1975	67	27
1976	57	26
1977	88	34
1978	81	27
1979	111	43
1980	76	27
Total	885	394

The cumulative frequency distribution for crude oil spills of 1,000 bbl or more is shown in Figure 4. Although distorted by truncation at the lower end, a log-normal distribution gives a reasonable fit, even at the upper ends. Using a Kolmogorov-Smirnov test,* we fail to reject the hypothesis that the distribution is log-normal, with a mean $\log_{10}$ volume of 4.294 and a standard deviation $\log_{10}$ of 0.872. A minimum volume of 1,000 bbl should be used because of the truncation.

Do the worldwide rates apply to U.S. waters? From 1974 to 1980, 14 crude oil spills of 1,000 bbl or more occurred at sea near the United States, while 23.1 billion bbl of oil were delivered.[15] Allowing for half of the spills occurring on the outbound portion of the journey (that is, from the oil exporting countries), and assuming movement of crude oil between U.S. ports is small, we would expect to have observed 10 or 11 spills in this period, with a 0.17 probability of observing 14 or more. Although the U.S. rate seems a little high, we cannot reject the hypothesis that it is the same as the worldwide rate.

Discussion

The statistical evidence now points to a sharp drop in oil spill occurrences from production platforms and tankers sometime around 1974. Although the statistics do not explain why this drop occurred, any number of intuitive theories could claim credit, including greater industry concern, increased public pressure, stricter government regulations, and better technology. Ironically, this better safety record, particularly in the case of production platforms, has made it difficult to predict accurately the lower spill rates for spills of 1,000 bbl or more. This is an uncertainty we should be happy to accept.

When should the trend have been detected? Hindsight tells us that the spill rate has been over-predicted since 1974, but trends take time to become apparent. Assuming a Poisson process, with a rate estimated as the total number of spills since 1964 divided by total OCS oil and condensate production, we can calculate the probability of observing zero spills from 1974 onward. Not until 1977 would this probability become less than 5 percent.

Table 5. Crude oil spills of 1,000 barrels or more from tankers worldwide, by location

Year	At sea (Open/restricted)	In port (Harbor/pier)	Unspecified	Totals
1974	10	8	2	20
1975	9	4	3	16
1976	16	4	1	21
1977	12	4	0	16
1978	8	1	2	11
1979	11	9	1	21
1980	3	5	1	9
Total	69	35	10	114

Table 6. Summary of occurrence rates for accidental oil spills now used in the OSTA model

	Spills/billion bbl ≥ 1,000 bbl	≥ 10,000 bbl
Platform	1.0	0.44
Pipeline	1.6	0.67
Tanker, total	1.3	0.65
at sea	0.90	0.50
in port	0.40	0.15

Thus, one could have only begun tentatively to detect the trend in platform spills sometime in 1978. Allowing time for data collection, analysis, and review—and admitting to some caution against reporting a false trend—it is not surprising that the OSTA model's spill rate did not reflect the trend until 1981.

Estimating occurrence rates for accidental oil spills does not, of course, completely describe the risks of OCS leasing, as mere occurrence does not necessarily imply that environmental impacts occur. These risks only can be studied with models such as the OSTA model, which consider not only spill occurrence, but also movement of spills and contact with environmental resources.

Conclusions

Predictions of oil spill occurrence rates from OCS production platforms, OCS pipelines, and tankers have been revised and updated to reflect experience through 1980. The statistical evidence points to a sharp drop, sometime around 1974 in the oil spill occurrence rates from OCS production platforms and from tankers. The new rates, recommended for predicting the impacts of OCS leasing, are given in Table 6. All data in support of these rates are readily available to the scientific community through the MMS.

Volume of oil produced or transported remains the most practical exposure variable for predicting oil spill occurrences as a Poisson process. Although intuitive arguments exist for using other variables, it is difficult to demonstrate, particularly in the case of platforms and pipelines, that these exposure variables are superior to volume of oil, because there have been few spills from these sources. The new database, however, provides opportunities for researchers to examine other exposure variables for tankers.

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