



Appendix B

Oil Spill Analysis for North Slope Oil Production and Transportation Operations

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B.1 Introduction

This appendix contains more detailed descriptions and supporting analyses of the oil spill data summarized in the conclusions and estimates presented in Section 4.1.2 of this environmental report. This appendix:

- Describes the oil spill database prepared by IT Corporation,
- Presents summary spill statistics by source and material spilled,
- Provides a statistical analysis of oil spill frequency and volume,
- Summarizes relevant time trends, and
- Develops probabilistic estimates of possible future oil spills associated with the continued operation of the Trans Alaska Pipeline System (TAPS) and related facilities from 2004 through 2034.

Because the statistical characteristics of oil spills differ among the various components of North Slope oil production and transportation Operations, separate spill projections are provided for each of the four segments:

- Alaska North Slope (ANS) exploration and production (E&P),
- The pipeline,
- The Valdez Marine Terminal (VMT), and
- The marine transportation (tanker) link.

Strictly speaking, neither the E&P operations nor the marine transportation system is part of TAPS¹, and environ-

¹Stipulation 1.1.1.22 of the Federal Grant (1974) defines “pipeline system” as “all facilities located in Alaska used by Permittees in connection with the construction, operation, maintenance or termination of the Pipeline. This includes, but is not limited to, the Pipeline, storage tanks, Access Roads, communications sites, airfields, construction camps, materials sites, bridges, construction equipment and facilities at the origin station and at the Valdez terminal. *This does not include facilities used in connection with production of oil or gathering systems, nor does it include such things as urban administrative offices and similar facilities which are only indirectly involved.*” [Emphasis added.] Note that aside from the VMT, there is no mention of tankers or destination ports in this definition.

mental impacts of these operations should be treated in the discussion of cumulative effects. However, these are elements in the production and transportation system and are included for completeness.

As the term is used here, “oil spills” are unintentional, accidental releases of oil or other pollutants. Accidents are fundamentally probabilistic, rather than deterministic, events. Accordingly, it is appropriate to analyze accident data in statistical terms. Therefore, statistical methods are used in this appendix to analyze the frequency and volume of oil spills.

B.2 Oil Spill Data

The quality of any statistical analysis is critically dependent on the accuracy, completeness, and validity of the input data. Thus, it is appropriate to begin with a description of these data and the procedures used for editing and validation. For most environmental impact statements (EISs) designed to estimate impacts of a project still in the design stage, it is necessary to rely on surrogate spill data (e.g., Minerals Management Service [MMS] data on outer continental shelf [OCS] oil spills) that are presumed to be representative of expected spill experience for the project being analyzed. The original TAPS EIS, which was prepared by a special interagency task force for the Federal Task Force on Alaskan Oil Development (BLM, 1972, Vol. 1, p. 29), recognized this data problem and declined to develop quantitative estimates of pipeline spills from TAPS. Rather, it concluded that “the available record of accidental loss from liquid pipelines in the United States is not an adequate base for the prediction or modeling of spills that could occur as a result of the operation of the proposed trans-Alaska pipeline...”

Since spill data have been collected throughout the 22-year history of TAPS and it is not necessary to use surrogate data, the realism of the analysis is materially increased.



Where noteworthy, other spill estimates are included for comparison with the statistics presented here.

Historical oil spill data are collected as part of the environmental stewardship activities of the companies engaged in the exploration, production, and shipment of ANS crude oil. Spill data are collected in conformity with federal, state, and local spill reporting requirements. In order to understand the types of spill information available, it is helpful to examine briefly the framework of these requirements. Spill reporting requirements applicable to Operations include federal and state regulations, as well as spill reporting obligations under the terms of the TAPS right-of-way (ROW) State Lease and Federal Grant.

The Clean Water Act of 1972 (CWA) provides the federal foundation for regulations detailing specific requirements for pollution prevention and response measures. Section 311 of the CWA addresses pollution from oil and hazardous substance releases, providing the U.S. Environmental Protection Agency (EPA) and the U.S. Coast Guard (USCG) with the authority to establish a program for preventing, preparing for, and responding to oil spills in navigable waters of the U.S. Provisions of the CWA are embodied in a variety of regulations, including the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) and the oil pollution prevention regulations.

The NCP is the federal government's blueprint for responding to oil spills and hazardous substance releases. The first NCP was developed and published in 1968 following the *Torrey Canyon* oil spill off the coast of England. The 1968 NCP provided the first comprehensive system of accident reporting, spill containment, and cleanup, and established a response headquarters, a national reaction team, and regional reaction teams (precursors to the current National Response Team and Regional Response Teams). Over the years, additional revisions were made to the NCP in accord with new legislation. The latest revisions were made final in 1994 to reflect the oil spill provisions of the Oil Pollution Act of 1990 (OPA 90). OPA 90 increased penalties for regulatory noncompliance, broadened the response and enforcement authorities of the federal government, and preserved state authority to establish laws governing oil spill prevention and response.

Under the NCP, the EPA and USCG established requirements to report spills to navigable waters or adjoining shorelines. EPA requires owners or operators of facilities that discharge oil in quantities that may be harmful to public health or welfare, or to the environment, to report the spill to the federal government. This requirement stems from the EPA "Discharge of Oil" regulation (40 CFR Part 110.3). Under this regulation, *reporting* oil spills to the federal

government does not depend on the specific amount of oil spilled, but instead on the presence of a visible sheen, sludge, emulsion, or discoloration created by the spilled oil. Spills are required to be reported to the National Response Center, the federal government's centralized reporting center staffed 24 hours a day by USCG personnel. The NRC maintains all reports of hazardous substance releases and oil spills made to the federal government. The National Response Center records and maintains all reports in the Emergency Response Notification System computer database.

In addition to federal requirements, the State of Alaska requires operators to notify the Alaska Department of Environmental Conservation (ADEC) of the following types of releases:

- Immediately notify ADEC of any discharge or release of oil to water, or any discharge or release (including a cumulative discharge or release) of oil in excess of 55 gallons solely to land outside an impermeable secondary containment area or structure; and
- Notify ADEC within 48 hours after discovery (including a cumulative discharge) of oil discharged solely to land in excess of 10 gallons, but 55 gallons or less, or in excess of 55 gallons, if the discharge or release is the result of the escape or release of oil from its original storage tank, pipeline, or other immediate container into an impermeable secondary containment area or structure.

ADEC also requires all operators to maintain records and submit a monthly report of each discharge or release, including a cumulative discharge or release, of 1 to 10 gallons of oil solely to land.

A third type of spill reporting is required by the TAPS ROW agreements, which require Alyeska Pipeline Service Company to report spills that are required to be reported to other agencies, and to maintain records of for spills below reporting thresholds. This data set contains the most extensive information on spills throughout the history of TAPS operations.

B.3 Data Sources and Compilation

Historical spill records associated with Operations are assembled and analyzed to characterize spill frequency and volume, normalize data to relevant exposure metrics, assess possible time trends, and make projections of future spill frequencies and volumes. The occurrence of Operations spills may be a function of several factors, including pipeline throughput and the level and types of operations at



pipeline facilities and along the pipeline.

Data are analyzed separately for ANS E&P, the pipeline, the VMT, and the marine transportation link (tanker trade). As noted above, E&P and marine transportation spills are properly regarded as cumulative, rather than direct, effects of TAPS, but are included in this section for completeness.

B.3.1 Data Sources

IT Corporation compiled oil spill data from a number of databases, most of which are maintained to satisfy regulatory reporting requirements. The validity of the spill analysis is directly related to the accuracy and coverage of the data [see USCG (1997a) for a description and evaluation of several government data sources]. Quality spill data from the following reliable sources were sought for each segment of crude oil transportation:

- Alyeska spill database,
- ADEC database,
- U.S. Department of Transportation, Research and Special Programs Administration, Office of Pipeline Safety (OPS) database,
- Emergency Response Notification System database,
- USCG database,
- BP Exploration (Alaska) database,
- ARCO Alaska database, and
- North Slope crude oil shippers database.

(The word *database* is used in the singular form in this analysis. Some agencies maintain spill information in more than one database.)

Although all data sources are potentially useful and were consulted, the spills reported in each are not necessarily identical. This is true because of differences in reporting requirements for the segments of Operations, volume thresholds, whether or not all spills (e.g., including third-party spills) are included, and other reasons.

Alyeska has maintained spill data since 1974. Yearly variations in the types of information contained in the database reflect changes in regulatory reporting requirements, changes in operating practices, the incorporation of evolving knowledge about the quantitative characteristics of oil spills, and evolving environmental sensitivities.

For completeness and accuracy, IT Corporation compared Alyeska spill data with other agency-maintained data for consistency and coverage.

ADEC maintained a spills database in Fairbanks between 1971 and 1995. This database is commonly referred to as the “Fairbanks Data.” The database contains records of reported spills from areas north of Tok, Alaska. ADEC now maintains a statewide spills database that records the

reported spills of oil and hazardous substances in Alaska from mid-1994 to March 1999. The statewide database is considered more complete than the Fairbanks Data.

The OPS database (Little, 1999, pers. comm.), termed the Hazardous Liquid Pipeline Accident Database, includes pipeline spills that meet any of the following reporting criteria: (1) any spill volume greater than 50 bbl, (2) any spill resulting in personal injury, (3) any spill resulting in death, or (4) any spill resulting in an unintentional fire. The OPS database was downloaded via the Internet. Upon review, it was decided that Alyeska and ADEC data were more useful, in part because the higher threshold for recording in the OPS database led to the exclusion of potentially relevant spills. This choice does not reflect a judgment on the suitability of the OPS database for other analytical purposes.

The Emergency Response Notification System database is a compilation of notifications made to the federal government of releases of oil and hazardous substances. Data were downloaded from the system website, including data from 1987 to 1999. These data are not useful for this study because of the absence of accurate location data.

USCG data were obtained through the National Technical Information Services library. The data were located in the Marine Casualty and Pollution Database, part of USCG’s Marine Safety Management System. These data were obtained to identify spills of ANS crude oil along tanker transport and delivery routes.

Spill data in electronic format from ARCO Alaska and BP Exploration (Alaska) were obtained and evaluated. These data were combined into a unified database to analyze spill data specific to the North Slope E&P activities.

Spill data were requested from the shipping companies of ANS crude. These data were used to identify spills occurring between Prince William Sound and the domestic delivery points. These data may be limited to spills within the waters of the United States. Table B-1 identifies the data sources used for the specific transportation segments.

Exploration and Production

Spill data associated with E&P activities, crude stabilization, and feeder pipelines available in electronic format were obtained from ARCO Alaska, Inc. and BP Exploration (Alaska) Inc. These data were compared with Alyeska data for redundancies and with the ADEC databases for completeness. Duplicate entries were eliminated and the resulting data included in the oil spill database.

Pipeline

A number of sources provide information on pipeline spills. The Alyeska data are judged to be the most accurate



Table B-1. Operations spill data sources and data utilization.

Data Source	E&P	Pipeline	Valdez Marine Terminal (VMT)	Tanker Trade
Alyeska Pipeline Service Company		√	√	
ADEC Statewide database	√	√	√	√
ADEC Fairbanks database	√	√	√	
Office of Pipeline Safety databases	√	√		
ERNS databases				√
United States Coast Guard databases				√
BP Exploration (Alaska) databases	√			
ARCO Alaska databases	√			
North Slope crude oil shippers database				√

and complete data for the pipeline. Data from the ADEC database were used to validate and supplement information contained in the Alyeska database. The ADEC database was also used to locate spills logically associated with TAPS operations but not contained in the Alyeska database. This does not reflect reporting errors in the Alyeska database. For example, Alyeska is not obligated to report third-party spills. However, the Alyeska database did contain *known* third-party spills which occurred in the vicinity of the pipeline. These included spills along the Dalton Highway and third-party spills that may have been reported by organizations other than Alyeska — such as trucking companies and tank-truck operators. Because these spills are logically related to TAPS operations, they have been added to the database. ADEC data from the statewide database also provided more detailed information regarding spill causes.

Few records from the other data sources could be correlated to specific locations along the pipeline. The Alyeska database was judged the most complete source of spill data and was supplemented as necessary with data from the ADEC database.

Valdez Marine Terminal

The Alyeska and the statewide ADEC databases were judged sufficiently complete for this analysis.

Marine Transportation Link

The two principal sources for the tanker-trade transportation segment are: Alyeska records of spills in Prince William Sound and the USCG database of reported spills into navigable waters of the United States.

Spill data from the ANS crude-oil shipping companies were used to identify spills between the VMT and the delivery points. These data were limited to spills within the waters of the United States and the U.S. Virgin Islands. In recent years, ANS crude has been exported to some desti-

nations in the Orient, but the vast majority of TAPS throughput has been shipped to the United States, principally California, Washington state, Hawaii, and the U.S. Virgin Islands.

For completeness and accuracy, USCG spill data for vessels engaged in the ANS trade in all U.S. waters were included in the database. These data include spills of ANS crude occurring en route or in the vicinity of destination ports. For example, the 1985 spill from the grounding of the *ARCO Anchorage* near Port Angeles, Washington, is included in the spill database because this vessel was transporting ANS crude. As noted, inclusion of all marine transportation spills through the first destination port provides a more complete picture of spills associated with production and distribution of ANS oil. However, halting operation of this production-distribution link — a consequence of adopting the no-action alternative — would not eliminate all spills. Rather, crude oil imports would replace ANS production. These imports would be carried in tankers from foreign ports with attendant possibilities for spills en route and at destination ports.

B.3.2 Data Compilation

Data collected from the sources listed above were compiled into one master database by IT Corporation. Spills in this database include those occurring from the beginning of TAPS operations in 1977 through August 1999². This is believed to be the most complete and accurate database available for Operations. Because of inclusion of additional

²Since August 1999, no large oil spills have been associated with TAPS; the last large (>1,000 bbl) spill occurred in 1990 (Table B-4). The oil spill analysis has not been updated to include small spills that may have occurred since August 1999. Since small spills account for only a minor portion of the total volume spilled over the life of TAPS, it is not useful to repeat the analysis after each small spill. These small spills have little or no material impact on the outcome of the analysis.



data, elimination of redundant information, and other data checks, the analyses based on these data may differ from those presented in other documents [such as Alpine (USACE, 1997), Beaufort Sea Sale 144 (MMS, 1996), NPR-A (BLM and MMS, 1998), and Northstar (USACE, 1999)].

Information fields unique to each individual source were preserved to the largest extent possible. Data fields were included to ensure that the data analysis would be consistent with available knowledge from the literature and/or prior analyses of oil spills. Table B-2 summarizes relevant propositions, hypotheses, and findings regarding oil spill

Table B-2. Prior knowledge tested/incorporated in present spill analysis.

Proposition	Source(s)	Implications for Analysis
Poisson process describes spill frequency distribution for spills in fixed size class.	Smith et al. (1982) also used as basis for all MMS EIS projections	Model reasonable, a priori, and supported by empirical data. Argues for retention of spill numbers as well as spill volumes.
Summary statistics to describe spill frequency must be chosen to reflect the shape of the probability distribution.	Smith et al. (1982)	Distribution of spill size should be examined and quantified.
Oil spills of different magnitudes have different damage potentials and may be expected to exhibit different statistical properties. Small spills are not usually a major concern.	Alpine EED (USACE, 1997) Beaufort Sea Sale 124 EIS (MMS, 1990) Beaufort Sea Sale 97 EIS (MMS, 1987a) Smith et al. (1982)	Analysis should focus on important spills. Larger spills are potentially more relevant.
Large spills occur relatively rarely, but account for a high proportion of the total amount spilled.	Beaufort Sea Sale 144 EIS (MMS, 1996) Chukchi Sea Sale 109 (MMS, 1987b) CONCAWE (1998) Northstar EIS (USACE, 1999) Smith et al. (1982)	Lorenz curves and empirical cumulative distribution functions (CDFs) should be plotted. Finding underscores the importance of volume data as well as number of spills.
It is reasonable to expect that spill occurrence rates will differ for the various modes of production and transport.	Amstutz and Samuels (1984) Smith et al. (1982) All ANS EISs	Separate spill analyses may be appropriate for various TAPS elements. Database should retain information on segments.
Spill forecasts should be keyed to an exposure variable such as volume of oil handled, pipeline length, port calls, number of tanker years, etc. Exposure variable should be simple and predictable in the future.	Beaufort Sea Sale 124 EIS (MMS, 1990) Beaufort Sea Sale 97 EIS (MMS, 1987a) CONCAWE (1998) Smith et al. (1982)	Spill forecasts should be keyed to reasonable exposure variable. Oil production/throughput is one reasonable basis for normalization. Past and projected system throughputs are important ancillary data.
Experience with Federal outer continental shelf may be a useful surrogate for Alaska.	Amstutz and Samuels (1984)	Hypothesis to be tested. ANS experience should be principal source of data.
ADEC database integrity as it pertains to ANS is most reliable for the period after 1989.	NPR-A EIS (BLM and MMS, 1998)	Estimates based upon post-1989 data may be preferable for analyses of ANS data. All data retained for this analysis.
Overall, there is no evidence to show that the aging of pipeline systems poses any greater level of risk.	CONCAWE (1998) based on analysis of European pipeline spill data.	Hypothesis to be tested. Predictions should be based upon actual ANS/TAPS experience.
Conclusions regarding spill performance may depend upon definitions of "spill" and volume cutoffs.	Observation based upon comparison of Alpine EED (USACE, 1997) and Northstar EIS (USACE, 1999).	Definitions should be made explicit. Comparisons among analyses should consider this factor.



frequencies and volumes from the literature. Though focused on implications for analysis, this material is also relevant to database design. For example, one of the findings reported in this table is that spill occurrence rates are likely to differ among the various modes of production and transport (e.g., Smith et al., 1982). Therefore, it is appropriate to include data fields describing the system element (i.e., stage in the production and transportation chain) associated with the oil spill to permit source-specific analyses. As a second example, larger spills are expected to account for the majority of the spilled volume — as shown by the data as discussed below — but no arbitrary spill threshold was imposed on the spill data included in the database. The operative principle is that any deletions should be keyed to the purposes and results of analysis, rather than determined a priori.

Spill data fields are included in the database to support the intended statistical analyses of the data. For example, because time trends are potentially important, it is necessary to retain information on the date of the spill.

Data are analyzed for each segment of the production and transportation system including North Slope E&P, the pipeline, the VMT, and the marine transportation link. Table B-3 summarizes the segments included, boundaries, spill locations, illustrative spill types, and data sources consulted in preparing the database. In fact, spill data are coded and can be retrieved by specific location and operation/equipment. For example, it is possible to identify all spills associated with a particular pump station, or facility (e.g., tank in tank farm), or individual piece of equipment (e.g.,

valve) associated with this pump station.

Although a natural focus of this analysis is crude oil spills, Operations include a number of materials that might also be spilled. For example, gasoline or other refined products are spilled in various transfer operations and as a result of valve or other failures at holding tanks, vehicle accidents, etc. Prior analyses have indicated that both spill frequency and volume vary with the material spilled. Therefore, it is appropriate to include fields that identify the various materials spilled. The database contains spill data for the following substances:

- Crude oil;
- Refined oil products (“product”), including aviation fuels, gasoline, diesel fuel, turbine fuel, motor oil, and lube oil;
- Other substances, including acetone, mercury, propane, antifreeze, Therminol, Halon, corrosion inhibitor, and “other” (undefined substances); and
- Water, including ballast water, oily water, and brine.

In accord with the spill analyses presented in recent environmental evaluation documents and EISs [e.g., all of the Beaufort Sea and Chukchi Sea EISs (MMS, 1987a, b, 1990, 1996)], this oil spill analysis focuses on crude spills, although data and analyses are presented for both crude and product spills.

Spill causes are potentially relevant for analysis. Therefore, reported spill causes are included in the database. Causes are categorized in the database as mechanical failure, operator error, corrosion, third-party activity, other, and unknown. Other information related to cause, source, and

Table B-3. Operations segments employed in oil spill analysis.

Segment	Segment Boundary	Where Spilled	Sample Major Spill Events	Principal Data Sources
ANS E&P	North Slope oil fields to Pump Station 1	North Slope oil wells, feeder pipelines (flowlines), and other ANS facilities	<ul style="list-style-type: none"> • Leaks on pads • Well workover/maintenance spills • Loading/unloading spills at crude oil topping units 	BP/ARCO; ADEC
Pipeline	PS 1 to metering station at VMT	Distributed along length of pipeline, at pump stations, associated tanks farms, and access roads	<ul style="list-style-type: none"> • Steele Creek sabotage incident • Atigun Pass pipe settlement • Tank valve failure at PS 10 • Check Valve 92 failure 	APSC; ADEC
VMT	Metering station to loading arm(s)	Within VMT	<ul style="list-style-type: none"> • Valve leak at East Tank Farm • Sump bleed line spill from fuel offloading rack 	APSC; ADEC
Marine Transportation	Tankers	At loading dock, harbor, harbor approaches, and domestic destination ports (e.g., California, Hawaii, Washington state)	<ul style="list-style-type: none"> • <i>Thompson Pass</i> hull crack • <i>Exxon Valdez</i> grounding • Loading/unloading spills 	APSC; ADEC; USCG



description of the spills is retained in the database.

Reports of recent spill events are typically more detailed than reports of older events. This may be due to changes in the regulatory reporting requirements, changes in the operations and procedures, advances in the technology and capability of spill detection, and the experience level of the reporting organizations. Increased requirements in OPA 90 are reflected in spill data after 1990.

B.3.3 Perspectives on Reliability, Accuracy, and Completeness

The spill data included in the database are believed to be both accurate and complete. The quality of the environmental stewardship activity, penalties for failure to report spills, and public sensitivity and scrutiny of Operations reduce the likelihood of reporting errors. Moreover, the systematic comparisons among data sets and inclusion of additional spill data (from third-party spills associated with Operations and tanker spills at destination ports) by IT Corporation contributed materially to the accuracy and completeness of the oil spill database used in this analysis. As noted above, the oil spill analyses are based on actual operating experience, rather than potentially imperfect surrogates.

Since volumes for some spills are estimated, rather than measured, error is introduced. Because some small spills are discovered after the fact and/or by indirect means (e.g., a stain on a pad or soils after snowmelt), it is possible that some spills were not detected and therefore not included in this database. However, it is very unlikely that an oil spill of appreciable volume would not be detected. Since small spills are not likely to have environmental significance and large spills account for nearly all the spilled volume, the effects of possible under-reporting are unlikely to be material. One analysis of Operations spill data (BLM and MMS, 1998) concluded that oil spill data are probably more reliable for the period after 1989 as a result of heightened public and regulatory agency concern following the *Exxon Valdez* oil spill (EVOS). Although not stated explicitly, the operative hypothesis is that data on post-1989 oil spills are less subject to reporting bias than are those that might have occurred earlier.

Finally, it is important to note that the number of spills and volumes shown in the accompanying figures and tables are for *all spills*, even though many of the spills did not reach the natural environment. Many of the reported spills (particularly smaller spills) occurred inside buildings, within secondary containment structures, or onto gravel

pads and, therefore, were contained. Other spills occurred in winter months when the ground was frozen and were cleaned up before the spring breakup. These are potentially relevant (but unquantified) considerations in terms of assessing potential spill-related environmental impacts.

B.3.4 Ancillary Data

It was also necessary to collect some ancillary data such as on candidate *exposure variables*. As noted in Smith et al. (1982):

Fundamental to the spill occurrence forecasting method is the notion of an exposure variable. An exposure variable is some quantity related to oil production or transportation, which has a precise statistical relationship to spill occurrence. In the past, the exposure variable used in the model has been volume of oil handled. Predicted probability distributions have been constructed by utilizing past rates of spills per volume of oil handled and the projected volume of oil to be handled.

Other exposure variables could be used. In the case of tankers, for example, number of port calls and numbers of tanker years have been contemplated...

Figure B-1 shows the number of tankers loaded annually at VMT by year — one candidate exposure variable for the marine transportation link. These data are available from Alyeska. The volume of oil handled is another candidate exposure variable. TAPS throughput volumes are also available from Alyeska. As a practical matter, the number of tankers loaded is directly proportional to throughput for any assumed tanker fleet composition. As Figure B-2 shows, the number of tankers loaded and the volumes of crude shipped are highly correlated ($R^2 = 0.95$), indicating that the fleet size composition has not varied appreciably over the years. Based on the regression of tankers loaded on throughput volume, the average volume of oil carried per tanker over the years from 1977 to 1999 was $1/1.3 = 0.769$ million bbl, or approximately 109,000 tons (figured at 7.07 bbl/ton). Figure B-3 shows a time trend of the average quantity of crude loaded per tanker by year from 1977 to 1999. As implied by the regression analysis shown in Figure B-2, this quantity has been relatively constant over the years. In the future, as tankers in the present fleet are phased out and replaced by double-hull tankers, this average may increase somewhat. (Three of ARCO's Millennium class tankers, carrying 125,000 tons, are on order and may serve as models for future new tanker construction for the ANS trade.)

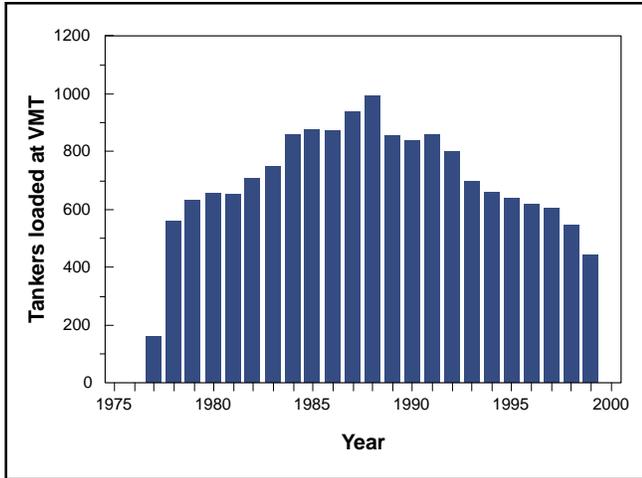


Figure B-1. Tankers loaded at VMT by year, 1977 to November 1, 1999.

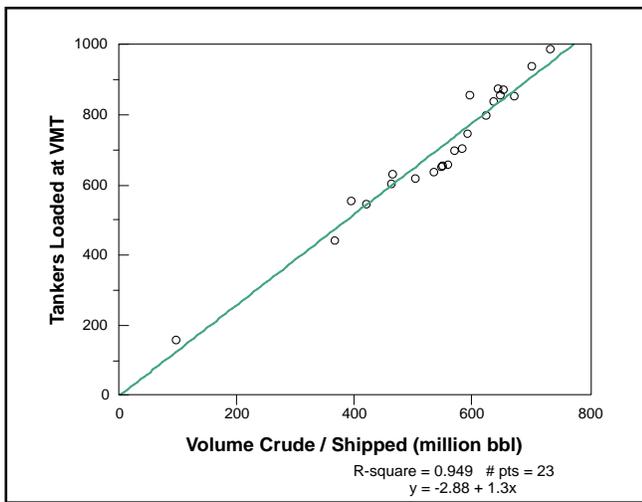


Figure B-2. Tankers loaded at VMT as a function of the volume of crude shipped, 1977 to 1999.

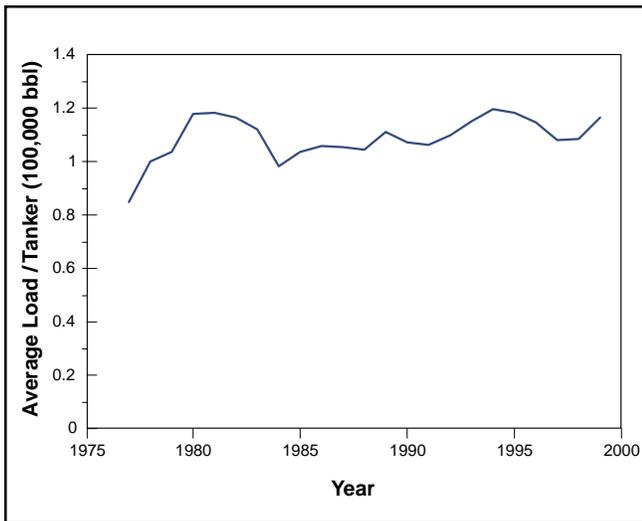


Figure B-3. Average load per tanker by year (1977 to 1999) for the ANS trade.

B.4 Summary Spill Statistics

This section highlights summary oil spill statistics, showing how spill frequency and volume vary with material spilled, Operations segment, and time. Although statistics on the number of spills are presented, the environmental consequences of oil spills are likely to depend more on the volume than the number of oil spills. Moreover, a few relatively rare spills account for the vast majority of the spill volume, which underlies the analytical focus of various government agencies (e.g., MMS) on larger spills. The analyses presented in this and later sections reflect the available knowledge and hypotheses distilled from the available literature summarized in Table B-2.

B.4.1 Spill Totals by Segment

For all Operations segments, approximately 10,600 spills occurred, for a total volume of approximately 327,100 bbl of either crude oil or products from 1977 until August 1999. This is equivalent to 480 spills/year, with an annual spill volume (crude and product) of 14,870 bbl.

The total spill volume is dominated by a single catastrophic event, the EVOS, which accounts for approximately 257,100 bbl or 78.6 percent of the total volume of crude and product spilled. The annual average is likewise dominated by the contribution of the EVOS. The annual average was exceeded in only two years out of TAPS 22-year history, 1989 (the year of EVOS) and 1978, when a single incident of sabotage to the pipeline at Steele Creek resulted in a spill of approximately 16,000 bbl.

The aggregate quantity spilled is certainly substantial, but accounted for only a small proportion of the system throughput throughout its 22-year history. From 1977 to 1999, TAPS throughput totaled nearly 13 billion bbl, so the total volumetric spill rate (including EVOS) over this period was approximately 25.6 bbl per million bbl throughput. (Excluding EVOS, the volume of crude and product spilled was 5.48 bbl/million bbl throughput. This was distributed among the various segments as follows; E&P, 0.86; pipeline, 2.45; VMT, 0.323; and the marine transportation link, 1.85.)

B.4.2 Statistics on Large Oil Spills

Perhaps the most striking feature of the Operations oil spill data is the relative importance of large oil spills. Table B-4 shows summary information about the ten largest oil spills (including both crude and product spills) over the operating history of TAPS. Several features of this table are



noteworthy:

- Collectively, these spills account for a very large percentage of the total volume of oil spilled. The “top ten” range in size from 1,700 to 257,143 bbl and account for approximately 93.5 percent of the total volume spilled. As noted above, there were a total of approximately 10,600 recorded spills over the period from 1977 to 1999. Thus, only 10 of a total of 10,600 spills (0.094 percent) accounted for 93.5 percent of the spill volume.
- If the large-spill threshold were set at 1,000 bbl (as is typical in MMS analyses), the number of large TAPS

spills would increase to 11 (as a result of inclusion of a 1979 pipeline spill of 1,500 bbl at Atigun Pass) and would account for 94 percent of the total volume of oil spilled. These statistics clearly justify an analytical focus on large spills.

- Five of the largest 10 spills occurred on the marine transportation segment. There were four large pipeline spills and one large VMT spill. E&P spills, though most numerous, accounted for only 3.4 percent of the total spill volume.
- Of the marine transportation spills, the EVOS and *Thompson Pass* spills were unique to TAPS opera-

Table B-4. The ten largest oil spills (1977 to 1999).

Rank Event	Date Material Spilled	Quantity Spilled (bbl)	Material Spilled	Operations Segment	Description	
<i>Exxon Valdez</i>	March 24, 1989	257,143	Crude oil	Marine	Tanker went aground on Bligh Reef, Prince William Sound	
Steele Creek, MP 457.53	February 15, 1978	16,000	Crude oil	Pipeline	Leak caused by sabotage	
<i>American Trader</i>	February 7, 1990	9,458	Crude oil	Marine	Vessel grounded on own anchor during mooring at Golden West Marine Terminal off Huntington Beach, CA.	
<i>ARCO Anchorage</i>	December 21, 1985	5,690	Crude oil	Marine	Tanker ran aground in Port Angeles, WA	
<i>Glacier Bay</i>	July 2, 1987	4,942	Crude oil	Marine	Tanker struck uncharted rock and went aground in Cook Inlet	
MP 734	June 15, 1979	4,000	Crude oil	Pipeline	Pipe wrinkled and cracked due to settlement	
VMT East Tank Farm	February 11, 1980	3,200	Crude oil	VMT	Leaking valve, East Tank Farm	
Check Valve 23	January 1, 1981	2,000 ^a	Crude oil	Pipeline	Leak due to drain connection failure	
Check Valve 7	July 19, 1977	1,800	Crude oil	Pipeline	Front-end loader accidentally broke check valve	
<i>Thompson Pass</i>	January 3, 1989	1,700	Crude oil	Marine	Crack in tanker hull at Valdez, AK	
					Cumulative volume of ten largest crude or product spills	305,933 bbl
					Total volume of crude and product spilled	327,107 bbl
					Cumulative volume of ten largest crude or product spills as percent of total spilled	93.5 percent
Note: The TAPS oil spill database lists 11 spills larger than 1,000 bbl. These spills include the 10 listed above and the spill listed below:						
Milepost 166.433 Atigun Pass	June 10, 1979	1,500	Crude oil	Pipeline	Pipeline support loss	
					Cumulative volume of 11 largest crude or product spills	307,433 bbl
					Total volume of crude and product spilled	327,107 bbl
					Cumulative volume of 11 largest crude or product spills as percent of total spilled	94.0 percent

(a) According to JPO records. Spill volume is 1,500 bbl in Alyeska records. The larger volume is used in this analysis. Source: Operations oil spill database compiled by IT Corporation, Inc. (1999).



tions. The *American Trader*, *ARCO Anchorage*, and *Glacier Bay* spills occurred at destination ports. The likelihood of oil spills at destination ports is proportional to the volume of oil imported, not to TAPS throughput. Even if TAPS were not in operation, import-related spills would still occur. It cannot be said that these three specific spills would have occurred were TAPS not in operation, but as long as oil is being handled, there is the statistical chance of oil spills.

B.4.3 Historical Aside: Comparison of Spill Volume Total with Original Estimates

The original TAPS EIS did not consider oil spills associated with ANS exploration and production activities and did not develop a quantitative estimate of pipeline spills, although it noted that spills were likely. Instead, marine transportation spills were the sole focus of study, and several estimates of spill volumes were presented.

Two bounding estimates are given in Volume 4 of the EIS (BLM, 1972, p. 484). These were intended to bracket probable spill rates and ranged from 402 bbl/day to 929 bbl/day assuming that the pipeline was operating at or near its maximum throughput of 2 million bbl/day. (The majority of the spill total was estimated based on an analysis of worldwide casualty losses. Ballast water treatment discharges were included in this total, but accounted for only 13 to 26 bbl/day.) Table B-5 reconstructs these estimates, making adjustments for possible spills at West Coast ports (most of which are included in the database) and for variable levels of TAPS output over the years — assuming (as in the original analysis) that spill volumes are directly proportional to throughput. Adding the estimated annual spill volumes for each year, the lower and upper bounds on estimated spills for the marine transportation link over the period from 1977 until 1999 are 2.56 million bbl and 5.91 million bbl, respectively.

At another place in the original EIS (BLM, 1972, Volume 1 Summary Sheet), it is stated that in an “average year” marine spills would be expected to be 140,000 bbl, equal to a total of slightly more than 3 million bbl over a 22-year period.

In fact, considering Operations spills from *all segments* (not just marine transportation), the actual spill volume total was 0.33 million bbl, lower than the lower bound by a factor of 7.7 and the upper bound by a factor of nearly 18.

Thus, actual Operations spill performance (large spills notwithstanding) was substantially better than expected when the system was constructed. (More recent benchmarks are included below.)

B.4.4 Number and Volume of Spill by Operations Segment

The number and volume of spills vary with material spilled and Operations segment. Figure B-4 shows the distribution of the *volume of crude and product spilled* for E&P, the pipeline, VMT, and marine transportation link. Figure B-5 shows the comparable distribution of the *number of crude and product spills* over the same period. The respective shares of total spill volume (and spill numbers shown in parentheses), including both crude and product, of the various system elements are; E&P, 3.36 percent (50.87 percent); pipeline, 9.56 percent (29.94 percent); VMT 1.26 percent (11.16 percent); and the marine transportation link (reflecting the contribution of EVOS), 85.82 percent (8.04 percent). Product spills are more numerous

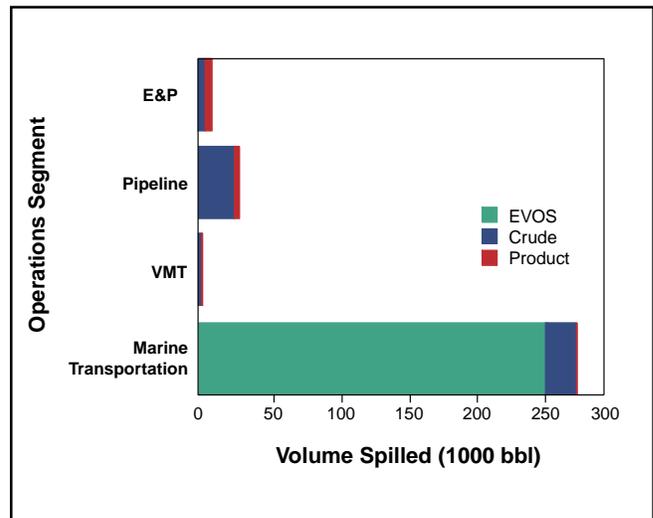


Figure B-4. Distribution of total spill volume among segments for both crude and product spills (1977-1999).

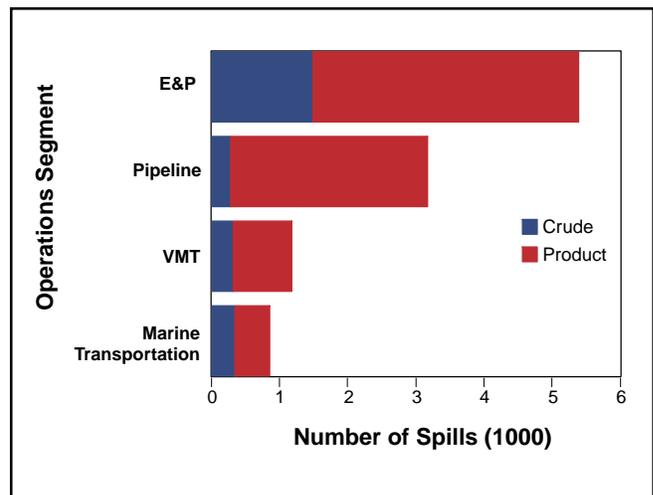


Figure B-5. Distribution of total number of spills among segments for both crude and product spills (1977-1999).



Table B-5. More exact calculation of original EIS estimates of spill volumes. The planning-basis TAPS throughput assumed in EIS is 2 million bbl/day, or 730 million bbl/year.

Year	EIS Predictions At Full Capacity		Less Amount Spilled At West Coast Harbors		Net Amount Spilled In Alaska and High Seas		Actual		
	Lower (bbl/day)	Upper (bbl/day)	Lower (bbl/day)	Upper (bbl/day)	Lower (bbl/day)	Upper (bbl/day)	TAPS Annual	Throughput Adjusted EIS Annual Projection	
							Throughput (million bbl)	Lower (1000 bbl)	Upper (1000 bbl)
1977	402	929	1.05	2.25	400.95	926.75	112.30	12.51	52.04
1978	402	929	1.05	2.25	400.95	926.75	397.01	79.59	183.96
1979	402	929	1.05	2.25	400.95	926.75	467.78	93.78	216.76
1980	402	929	1.05	2.25	400.95	926.75	554.93	111.25	257.14
1981	402	929	1.05	2.25	400.95	926.75	556.07	111.48	257.67
1982	402	929	1.05	2.25	400.95	926.75	591.14	118.51	273.92
1983	402	929	1.05	2.25	400.95	926.75	600.86	120.46	278.42
1984	402	929	1.05	2.25	400.95	926.75	608.84	122.06	282.12
1985	402	929	1.05	2.25	400.95	926.75	649.89	130.29	301.14
1986	402	929	1.05	2.25	400.95	926.75	665.43	133.40	308.35
1987	402	929	1.05	2.25	400.95	926.75	716.66	143.67	332.08
1988	402	929	1.05	2.25	400.95	926.75	744.11	149.18	344.80
1989	402	929	1.05	2.25	400.95	926.75	688.06	137.94	318.83
1990	402	929	1.05	2.25	400.95	926.75	654.55	131.22	303.30
1991	402	929	1.05	2.25	400.95	926.75	665.17	133.35	308.23
1992	402	929	1.05	2.25	400.95	926.75	639.36	128.18	296.26
1993	402	929	1.05	2.25	400.95	926.75	591.22	118.53	273.96
1994	402	929	1.05	2.25	400.95	926.75	579.32	116.14	268.44
1995	402	929	1.05	2.25	400.95	926.75	555.94	111.45	257.61
1996	402	929	1.05	2.25	400.95	926.75	525.51	105.35	243.51
1997	402	929	1.05	2.25	400.95	926.75	487.09	97.65	225.71
1998	402	929	1.05	2.25	400.95	926.75	440.50	88.31	204.12
1999	402	929	1.05	2.25	400.95	926.75	267.00	53.53	123.72
Total							12,758.7	2,557.8	5,912.1
Source/ Basis	BLM (1972) Vol. 4, Table 26, p 484, for Case II	BLM (1972) Vol. 4, Table 26 p 484, for Case IV	BLM (1972) Vol. 4 Table 26 Line 6 less Valdez	BLM (1972) Vol. 4, Table 26 Line 5 less Valdez	Subtraction Column 4 from Column 2	Subtraction Column 5 from Column 3	APSC (1999a) for 1977-1998, 1999 estimated.	Calculation prorated on output keyed to lower est. and converted to 365 days	Calculation prorated on output keyed to upper est. and converted to 365 days

Note: 1999 throughput estimate is through August 1999.

(77.1 percent of the total number of spills) but, because these typically involve smaller spills (see below), these account for only a small fraction (3.21 percent) of the spilled volume.

The dominance of a single event complicates the statistical analysis of the data. The EVOS spill is so large that it is appropriate to evaluate the likelihood of a recurrence of such an event as a separate meta-statistical question. A special section addressing marine transportation spills is included following the statistical analysis.

B.4.5 Contribution of Larger Spills (Lorenz Diagrams)

As noted above, a key conclusion of this analysis is that smaller spills (though more numerous) account for only a small proportion of the total spill volume. This is best shown by a *Lorenz diagram*, which displays the fraction of the spilled volume versus the fraction of the number of spills. (Lorenz diagrams were first developed by economists studying the distribution of incomes or wealth of vari-



ous populations (see, e.g., Baumol, 1982; Samuelson, 1980; or Aitchison and Brown, 1969). This concept has also been applied to geographic (see, e.g., King, 1969) and mineralogical data (see, e.g., Koch and Link, 1971), and (without attribution) to oil spill data (CONCAWE, 1998.)

A Lorenz diagram is constructed as follows. First, the spill data are sorted in ascending order of spill volume. Next, the cumulative fraction of the volume spilled (y-axis) is plotted as a function of the cumulative fraction of the number of spills (x-axis). Figure B-6 provides a hypothetical illustration of a Lorenz plot. If all spills are exactly the same size, the fraction of the spill volume will correspond exactly to the fraction of the number of spills. The 45° line “AB” in Figure B-6 depicts this situation. If some spills are larger than others (as is to be expected from experience and the literature summarized in Table B-2), then the fraction of the spilled volume will be less than the fraction of the number of spills, as shown by the curve “AB” beneath the 45° line in Figure B-6. The area between the curve and the straight line (the shaded area in Figure B-6) provides an indication of the degree of inequality in spill size distribution. Dividing the shaded area by the area of the triangle (“ABC”) provides a normalized index or coefficient, denoted L, of the variability in spill volumes. L ranges from 0 (all spills the same size) to 1.

The Lorenz diagram shown in Figure B-6 is hypothetical, included solely to illustrate the concept. The actual Lorenz curves for Operations components are more extreme. Figure B-7 shows Lorenz plots for crude and product spills that occurred as a result of E&P activities from 1977 to 1999. As can be seen, there is very substantial curvature in these plots (the computed Lorenz coefficients are 0.911 and 0.883 for crude and product, respectively).

The Lorenz plots provide an important characterization of E&P (and, as shown below, for other Operations segments) spills. The clear message is that a few relatively large spills account for the majority of the spill volume. Most spills are relatively small. For E&P spills:

- Fifty percent (the median) of crude spills were less than or equal to 0.238 bbl (slightly less than 10 gal). Fifty percent of product spills were less than or equal to 0.119 bbl (slightly less than 5 gal).
- The smallest 90 percent of crude spills accounted for approximately 13 percent of the total volume spilled in this segment and the smallest 95 percent of the spills accounted for approximately 20 percent of the spilled volume. The corresponding percentages for product spills were 16 percent and 25 percent, respectively.
- Another perspective on spill volumes is provided by

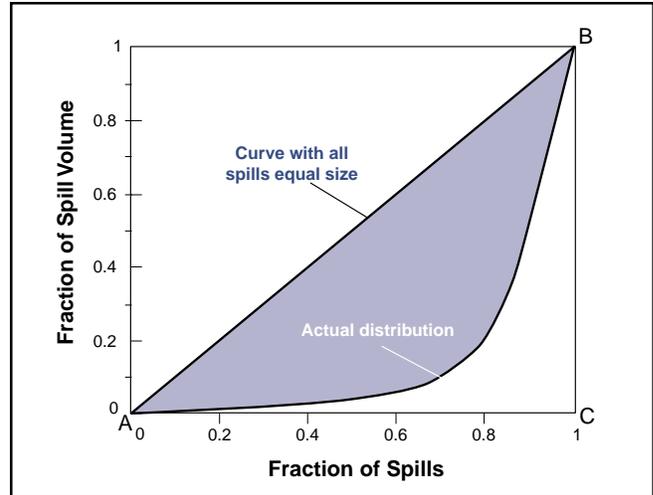


Figure B-6. A hypothetical Lorenz diagram: the size of the area between the line of perfect quality and the Lorenz curve as a fraction of the bounding triangle is used as a measure of inequality.

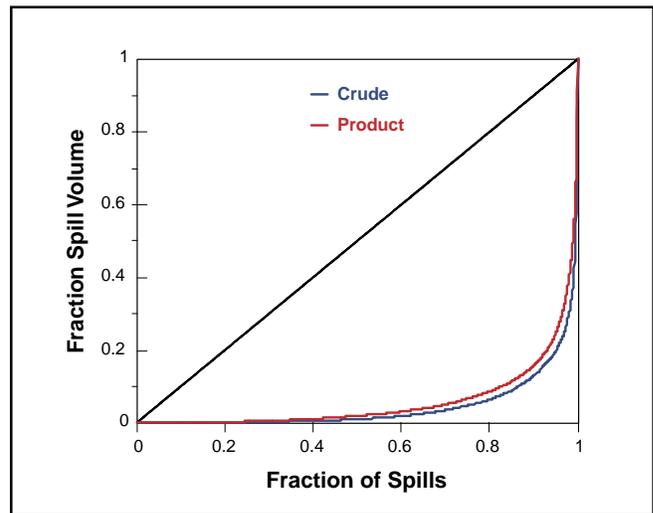


Figure B-7. Lorenz curve for E&P spills (1977–1999).

the cumulative distribution function (CDF). Figure B-8 shows the CDF for E&P spills (crude and product) over the period from 1977 to 1999. The CDF plots the fraction of spills with a volume less than or equal to a specified value V (on the y-axis) against the value of V (on the x-axis); crude spills are shown in green, product spills in red. Because of the large variability in spill volumes, only a portion of the CDF is plotted in Figure B-8; that for spills less than or equal to 2 bbl. The picture presented in Figure B-8 clearly shows that most spills are of relatively small volume. For E&P spills, 84.1 percent of crude spills and 92.2 percent of product spills are less than 2 bbl. Small spills (many measured in teaspoons) are quite diverse (fueling vehicles, leaking drums, splashes, etc.).



Spills along other segments of Operations have similar characteristics. For example, Figure B-9 shows Lorenz curves for pipeline crude and product spills over the same time period. Here the curves are even more “bowed,” a visual impression reflected in the computed Lorenz coefficients (0.986 and 0.945 for crude and product spills, respectively).

For pipeline spills:

- Fifty percent (the median) of crude spills were less than or equal to 0.0476 bbl (2 gal). The median product spill was 0.071 bbl (3 gal).
- The smallest 90 percent of crude spills accounted for approximately 0.25 percent of the total crude volume spilled in this segment and the smallest 95 percent of the spills accounted for 0.8 percent of the volume spilled. The corresponding percentages for pipeline product spills were 6.2 and 9.3 percent, respectively.
- Figure B-10 shows the CDFs for pipeline spills (crude and product) less than 2 bbl over the period from 1977 to 1999. These CDF resembles those for E&P spills. For pipeline spills, 88.0 percent of crude spills and 96.3 percent of product spills are less than 2 bbl.

VMT spills can be characterized in this same way as follows:

- Fifty percent (the median) of VMT crude spills were less than or equal to 0.0238 bbl (1 gal). The median product spill was 0.00595 bbl (0.25 gal).
- The smallest 90 percent of VMT crude spills accounted for approximately 0.81 percent of the total crude volume spilled in this segment and the smallest 95 percent of the spills accounted for 1.38 percent of the volume spilled. The corresponding percentages for VMT product spills were 4.2 and 8.2 percent, respectively.
- Figure B-11 shows the CDFs for VMT spills (crude and product) over the period from 1977 to 1999. For VMT spills, 95.3 percent of crude spills and 97.4 percent of product spills are less than 2 bbl.

Despite the large total volume of marine transportation spills, similar results are found for this segment:

- Fifty percent (the median) of marine crude spills were less than or equal to 0.0476 bbl (2 gal). The median product spill was 0.006 bbl (0.25 gal).
- The smallest 90 percent of marine crude spills accounted for only 0.03 percent of the total crude volume spilled in this segment and the smallest 95 percent of the spills accounted for 0.07 percent of the volume spilled. The corresponding percentages for marine product spills were 0.87 percent and 2.17 per-

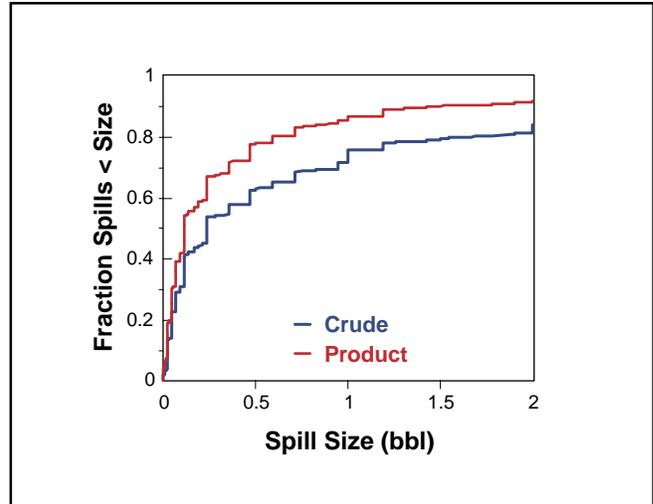


Figure B-8. Cumulative distribution function for ANS E&P spills less than 2 bbl (1977-1999).

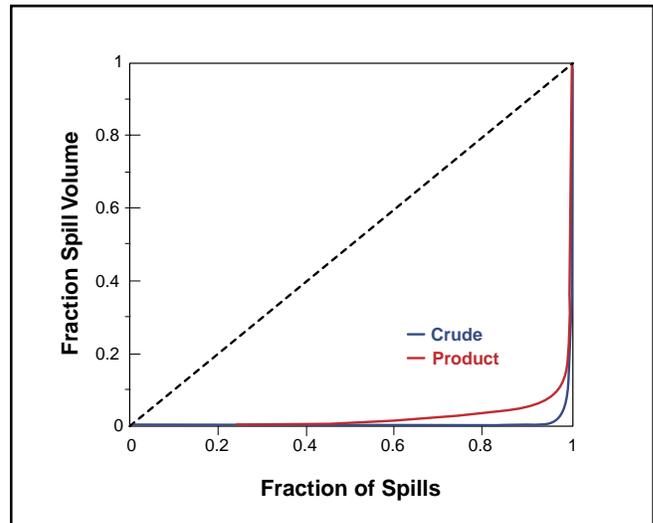


Figure B-9. Lorenz curve for pipeline spills (1977-1999).

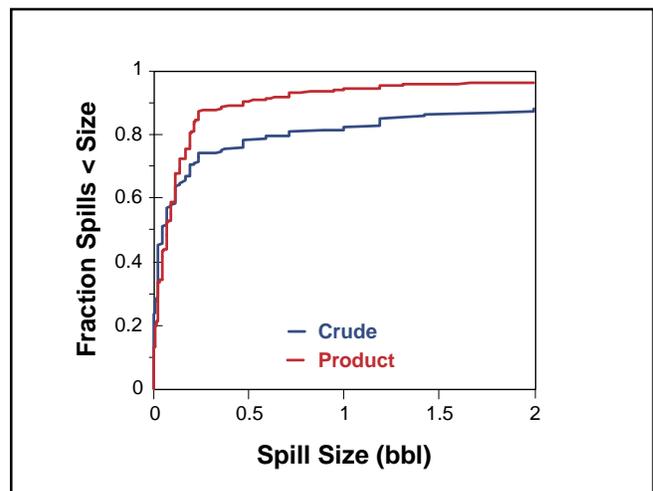


Figure B-10. Cumulative distribution function for pipeline spills less than 2 bbl (1977-1999).

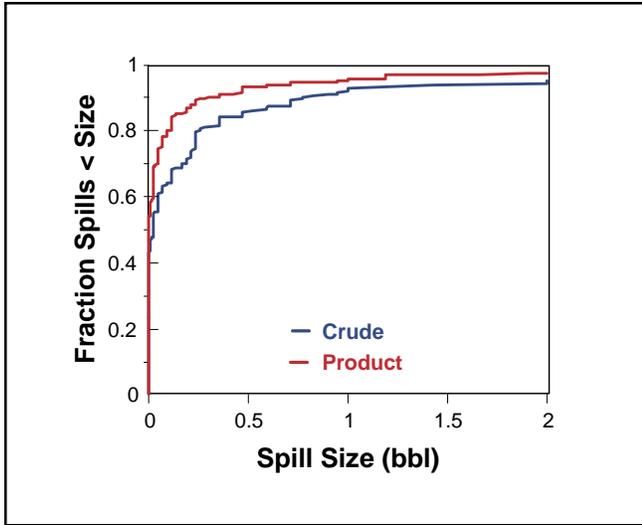


Figure B-11. Cumulative distribution function for VMT spills less than 2 bbl (1977-1999).

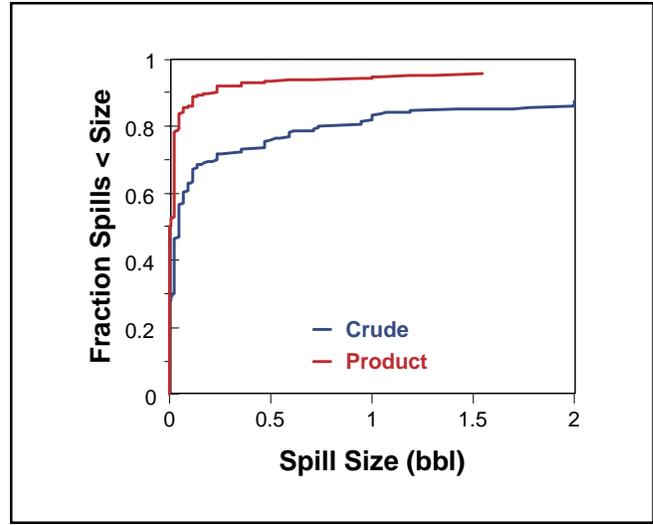


Figure B-12. Cumulative distribution function for tanker spills less than 2 bbl (1977-1999).

cent, respectively.

- Figure B-12 shows the CDFs for marine transportation spills (crude and product) over the period from 1977 to 1999. For marine transportation spills, 87.2 percent of crude spills and 95.4 percent of product spills are less than 2 bbl. Leaks in hoses, valves, and other minor operational problems are illustrations of small spills.

In this regard, Operations spill characteristics are similar to those that occur with other oil production and transportation systems (see Table B-2 for literature references). Small spills are inherently of less concern than larger spills for the following reasons:

- Small spills are more likely to be contained on site.
- Small spills have a lower potential to produce significant adverse environmental impacts.
- Small spills collectively (see Table B-2 and above) account for only a small proportion of the total volume spilled. Thus, any prediction bias introduced by an exclusive focus on large spills is small.

For these (and other reasons) the spill prediction methodology employed by the government concentrates on large spills, typically spills greater than 1,000 bbl or 100,000 bbl [see EISs for Beaufort Sea Planning Area Lease Sale 124 (MMS, 1990) and Lease Sale 97 (MMS, 1987a)]. Although this methodology is applicable in principle to Operations, a smaller threshold is necessary because very few “megaspills” have been observed. The largest observed spills for Operations are as follows: E&P, 925 bbl; pipeline, 16,000 bbl; VMT, 32,100 bbl; and marine transportation, 257,143 bbl.

Table B-6 shows the number of spills that exceeds a

stated threshold size (e.g., >1,000 bbl) by Operations segment over the period from 1977 to 1999. The MMS methodology is based on the mean number of large spills per billion bbl throughput. To use this methodology for all segments of Operations (based on actual data) would require that the size threshold be no greater than 750 bbl, otherwise the estimated mean number of spills for E&P operations will be zero (a point explored below). However, it is interesting to take the data as given and compare large spill frequencies with those based on outer-continental-shelf and other experience.

These computations are also shown in Table B-6. The empirical large spill rate, expressed as the observed number of spills >1,000 bbl per billion bbl of throughput, is calculated for each of the segments and compared with the most recent MMS estimates (Anderson and LaBelle, 1994). Excluding E&P operations (which cannot be estimated because there have been no spills >1,000 bbl), the empirical spill rates for Operations compare favorably with MMS experience. For example, pooling pipeline and VMT spills results in a spill rate of 0.47 large spills per billion bbl.

This rate is only about 36 percent of the rate (1.32) based on MMS analysis of outer-continental-shelf data — that is; Operations experienced 65 percent fewer large pipeline and terminal spills than would be expected. We are unable to determine whether or not terminal spills were included in the MMS rate of 1.32 large spills/billion bbl throughput for pipelines shown in Table B-6. The data presented in the paper on which the analysis is based (Anderson and LaBelle, 1994) do not include any terminal spills, which may mean that no large spills occurred or that these spills were not counted as pipeline spills. In any event, the spill



Table B-6. Number of crude spills greater than or equal to specified spill threshold (1977-1999) by Operations segment and comparison with MMS estimates.

Segment	Assumed Threshold					
	250 bbl	500 bbl	750 bbl	1,000 bbl	10,000 bbl	100,000 bbl
E&P	4	2	1	0	0	0
Pipeline	8	6	6	5	1	0
VMT	1	1	1	1	0	0
Marine Transportation	5	5	5	5	1	1
Total	18	14	13	11	2	1

Comparison with MMS Data for Spill Threshold >1,000 bbl (TAPS throughput to date: 12.758 billion bbl)			
Segment	Empirical Spill >1,000 bbl (rate as number/billion bbl)	MMS Rate (as number/billion bbl)	Remarks
E&P	0.00	0.45	Figure at left for platforms
Pipeline	0.39	1.32	May include terminals
VMT	0.08		
Subtotal pipe and VMT	0.47		
Marine Transportation	0.39	1.1	Combination of 0.33 (in port) and 0.77 (at sea)

Source: MMS data from Beaufort Sea Planning Area Lease Sale 144 (1996)

rate for pipelines alone (1.32) is significantly greater than that for the Operations pipeline (0.39). Inspection of the spill events in the MMS database (Table 1 of Anderson and LaBelle, 1994) suggests that a greater spill rate for outer-continental-shelf pipelines compared to TAPS would be plausible. Although some accidents/failures leading to outer-continental-shelf spills are similar to those that might occur on TAPS (e.g., corrosion), most are quite different (illustrative causes of outer-continental-shelf spills are hurricane damage, anchor damage to pipeline, trawl damage to pipeline, etc.). Thus, there may be sound reasons why TAPS (an onshore pipeline throughout its length) has a lower spill rate than OCS pipelines.

Figure B-13 summarizes these comparisons. As noted above, there were no spills >1,000 bbl for E&P operations over the period from 1977 to 1999. The estimated large spill rate per billion bbl throughput is less than the MMS data would indicate.

Another benchmark that has been used for E&P activities is the number of blowouts per 1,000 wells drilled. Mallery (1998) analyzed ANS E&P activities over the period from 1974 to 1997. "Loss of secondary well control with a drilling rig on the well" (a blowout) can occur in one of two ways:

- A failure of a rig's blowout prevention equipment to contain a hydrocarbon influx in the well, which results in a surface blowout.
- A failure of the cemented casing in a well, which re-

sults in a subsurface blowout or annular migration of hydrocarbons to the surface.

From 1974 to 1997, there were six documented cases of loss of secondary well control, two surface blowouts and four subsurface blowouts. Over this same time period an estimated 3,336 wells were drilled by ARCO, BPXA, and other operators. Thus, the estimated blowout rate over this period was 1.8/1,000 wells drilled. This figure is slightly larger than, but comparable to, the reported rate (1.2/1,000 wells drilled) for Gulf Coast well drilling over the period 1960 to 1996 (Skalle and Podio, 1998).

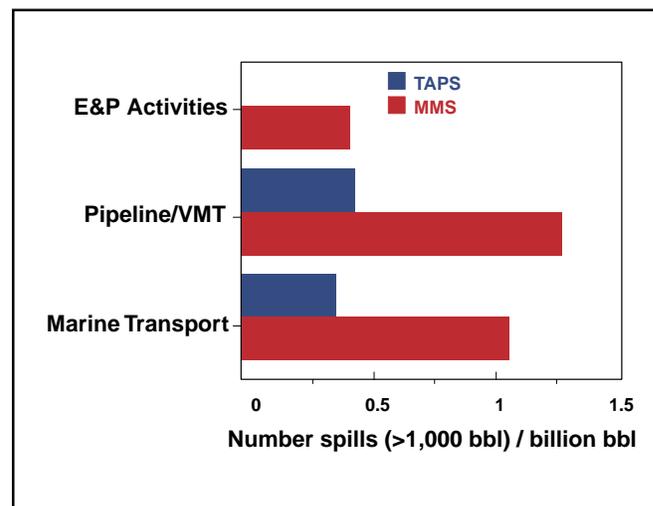


Figure B-13. Number of large (>1,000 bbl) spills per billion bbl throughput for Operations compared to MMS data.



Notwithstanding the EVOS, the observed rate of occurrence of large marine transportation spills (0.39/billion bbl throughput) is only 35 percent of that (1.1 large spills/billion bbl) expected on the basis of MMS data. The spill rate for marine transportation estimated by MMS is derived from data on ANS tankers over the period from 1977 to 1992 (Anderson and LaBelle, 1994). Part of the reason why the estimate presented here is lower is that few spills (and no spills >1,000 bbl) occurred in the marine transportation segment between 1992 and 1999.

Relative to a “zero defects” goal, any spill rate (however calculated) greater than zero is of concern. However, in terms of expectations based on actual data, Operations spill performance is better than reasonable benchmarks. Operations spills may be large in aggregate, but not relative to the quantity of oil handled.

B.4.6 Relevant Descriptive Statistics

Table B-7 provides relevant descriptive statistics for Operations spills by segment and material spilled. The number of spills, and minimum, maximum, median, and mean (arithmetic average) spill volumes are given in this table. Also presented are the Lorenz coefficients, standard deviations of spill size, the coefficients of variation (ratios of standard deviations to means), the skewness of the distribution (measured by the coefficient of skewness, G1, see, Kendall and Stuart, 1963), various percentiles of the CDF, and the 90 and 95 percent points of the Lorenz curves. As indicated by the facts that the median spill size is significantly less than the mean (arithmetic average) spill size, Lorenz coefficients are close to unity, and coefficients of variation and skewness are also large, these spill distribu-

Table B-7. Characteristics of TAPS crude and product spills (1977-1999).

Attribute/Item	Units	E&P Material Spilled		Pipeline Material Spilled		VMT Material Spilled		Marine Transportation Material Spilled		
		Crude	Product	Crude	Product	Crude	Product	Crude	Product	
Number of spills 1977-1999		1,482	3,898	276	2,891	322	858	345	505	
Average number of spills/year	spills/yr	67.36	177.18	12.55	131.41	14.64	39.00	15.68	22.95	
Volume of spills 1977-1999	bbl	5,779	5,220	27,573	3,697	3,535	580	279,727	997	
Average volume/year	bbl/yr	263	237	1,253	168	161	26	12,715	45	
Spill size characteristics										
Lorenz coefficient, L	N/A	0.911	0.883	0.986	0.945	0.992	0.969	0.996	0.985	
Minimum	bbl	0.001488	0.000628981	0.00007738	0.000030952	0.00007738	0.00000619	0.000061905	0.00000967	
Maximum	bbl	925	450	16,000	238	3,200	298	257,143	681	
Median	bbl	0.23800	0.11900	0.04760	0.07143	0.02380	0.00595	0.04762	0.00600	
Mean	bbl	3.90	1.34	99.90	1.28	10.98	0.68	810.80	1.98	
Standard deviation		33.88	10.02	1008.46	11.42	178.63	10.52	13856.07	30.82	
Coefficient of variation		8.69	7.48	10.10	8.93	16.27	15.57	17.09	15.61	
Skewness (G1)		20.08	28.53	14.62	14.24	17.84	26.64	18.51	21.45	
Percentiles of spill volume CDF	0.05	bbl	0.0238000	0.0119000	0.0007420	0.0014857	0.0000310	0.0000310	0.0001000	0.0000310
	0.10	bbl	0.023800	0.023800	0.001490	0.005950	0.000093	0.000062	0.000743	0.000100
	0.20	bbl	0.04760	0.03570	0.00595	0.01190	0.00070	0.00037	0.00298	0.00074
	0.50	bbl	0.23800	0.11900	0.04760	0.07143	0.02380	0.00595	0.04762	0.00600
	0.80	bbl	1.6190	0.5952	0.7143	0.1905	0.2619	0.0952	0.7381	0.0476
	0.90	bbl	4.000	1.429	4.000	0.476	0.774	0.357	3.000	0.236
	0.95	bbl	7.55	4.00	25.00	1.19	2.00	1.00	11.90	1.19
	x	y	y	y	y	y	y	y	y	
Smallest x% of spills	90.00	12.98	15.75	0.25	6.20	0.81	4.15	0.03	0.87	
account for y% of spill volume	95.00	19.76	24.66	0.80	9.28	1.38	8.17	0.07	2.17	



tions are not symmetrical, but rather have long right tails (extreme values) for each of the Operations segments. Because of these characteristics, the familiar normal (bell shaped) distribution is not a suitable statistical model for description of spill volume data (more below).

B.4.7 The Distribution of Spill Volume

This section examines the statistical distribution of spill volumes. There are two reasons for this analysis:

- First, the distribution of spill volumes is of intellectual and practical interest. Knowledge of this distribution, among other things, enables selection of appropriate models for projection of the volume of future spills.
- Second, knowledge of the appropriate statistical distribution of spill volumes enables a more parsimonious representation of the data. Additionally, the statistical estimates may be more efficient than sample estimates.

This analysis concludes that the lognormal distribution provides an adequate (although not exact) representation of the spill volume data.

Several statistical models are appropriate candidates for describing the size distribution of spills. One obvious choice is the lognormal distribution (Rappaport, 1991,

Maxim et al., 1994, 1997). As Table B-8 shows, the lognormal distribution has found wide applicability in a variety of fields. The lognormal distribution applies to variables constrained to take on only positive values and, depending upon its parameters, can assume a variety of shapes — including distributions with long right tails. It is defined mathematically as follows:

Let x be the random variable denoting the size of the spill. The distribution function for the lognormal variable x is given (Gilbert, 1987; Johnson and Kotz, 1970; Aitchison and Brown, 1969) by the equation:

$$(Eq. 1) \quad f(x) = \frac{1}{x\sigma_y\sqrt{2\pi}} \exp\left[-\frac{1}{2\sigma_y^2}(\ln x - \mu_y)^2\right],$$

where x is the size of the spill, μ_y is the mean, and σ_y is the standard deviation of the *log-transformed* spill size y (i.e., $y = \ln x$).

The density function of the random variable y is given by,

$$(Eq. 2) \quad f(y) = \frac{1}{\sigma_y\sqrt{2\pi}} \exp\left[-\frac{1}{2\sigma_y^2}(y - \mu_y)^2\right].$$

Table B-8. Wide applicability of the lognormal distribution.

Field	Examples	References
Physics	<ul style="list-style-type: none"> • Small particle statistics • Radionuclide data sets 	Aitchison and Brown (1969) Gilbert (1987) Johnson and Kotz (1970)
Geology	<ul style="list-style-type: none"> • Gold and mineral assays 	Aitchison and Brown (1969) Koch and Link (1971)
Economics	<ul style="list-style-type: none"> • Income or wealth distributions • Expenditures on particular commodities 	Aitchison and Brown (1969)
Biology	<ul style="list-style-type: none"> • Size of organisms • Abundance of species 	Aitchison and Brown (1969) Kendall and Stuart (1963)
Engineering	<ul style="list-style-type: none"> • Distribution of throughput before failure, time of failure • Flood flows 	Aitchison and Brown (1969) Johnson and Kotz (1970)
Astronomy	<ul style="list-style-type: none"> • Distribution of stars 	Aitchison and Brown (1969)
Industrial Hygiene	<ul style="list-style-type: none"> • Distribution of workplace toxic concentrations • Air quality data 	Maxim et al. (1994, 1997) Rappaport (1991) Gilbert (1987)
Environmental Contaminant Data	<ul style="list-style-type: none"> • “Most commonly used probability density model for environmental contaminant data” 	Gilbert (1987)
Geography	<ul style="list-style-type: none"> • City size distributions • Distances between towns and nearest neighbors 	King (1969)



Thus, the random variable $y = \ln x$ follows a normal (bell-shaped) distribution.

Analysis of the distribution of spill volumes by segment indicates that the lognormal distribution provides an approximate fit. To illustrate, Figure B-14 (left) shows a histogram of observed crude spills from *E&P activities* over the period from 1977 to 1999. A logarithmic spill size axis is given. Superimposed on this histogram is the fitted lognormal distribution (which appears bell-shaped when plotted on a logarithmic axis) corresponding to these data (green curve). Although the match between the empirical frequencies and fitted frequencies is not exact, the lognormal

distribution provides an approximate fit. Statisticians often use a “probability plot” to judge fit accuracy. The axes of this plot are designed so that, if the assumed distribution is correct, the points will plot as a straight line. Figure B-14 (right) shows the lognormal probability plot for these data (*Systat*, 1997). There is some slight curvature evident in the plot, but it suggests that the lognormal distribution provides an adequate fit to the E&P spill data.

Figure B-15 provides similar plots (to those shown in Figure B-14) but for the *pipeline* segment. As is the case with E&P spills, the lognormal distribution provides an approximate fit to the observed spill data.

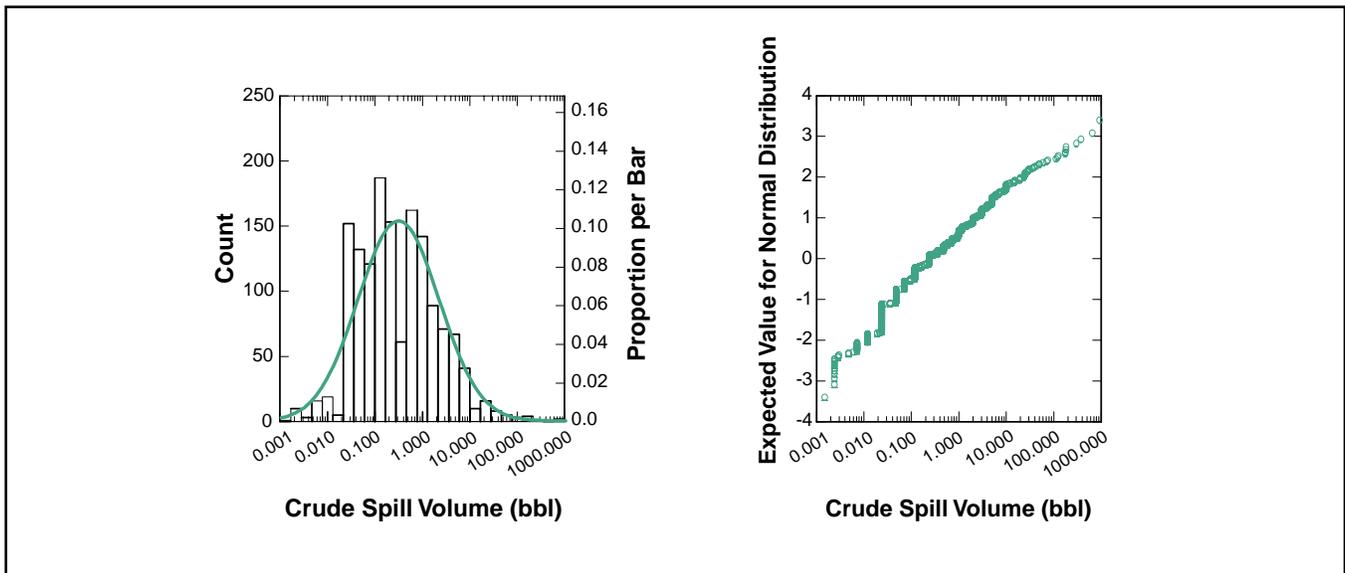


Figure B-14. Observed histogram of E&P crude spills (log scale) and fitted normal distribution (left-hand side) and normal probability plot of same data (right-hand side) confirm approximate lognormality of spill volume distribution.

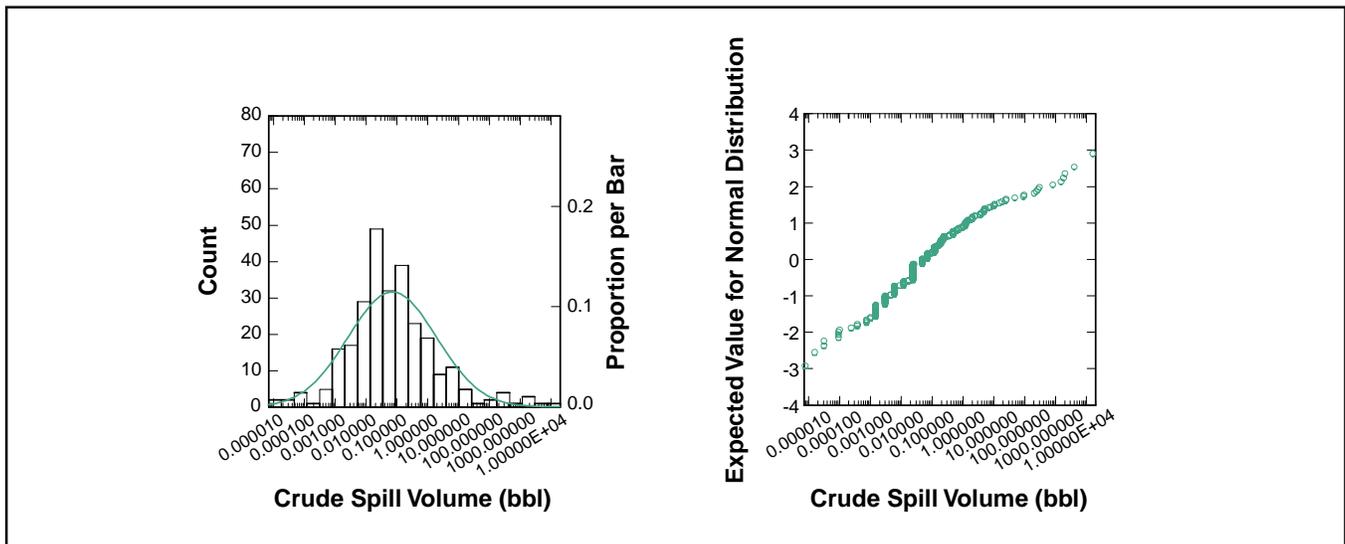


Figure B-15. Observed histogram of pipeline crude spills (log scale) and fitted normal distribution (left-hand side) and normal probability plot of same data (right-hand side) confirm approximate lognormality of spill volume distribution.



“Bumps” in the probability plots (right-hand sides of Figures B-14 and B-15) could arise as a result of rounding estimates of spill volumes (see e.g., Anderson and LaBelle, 1990). The slight curvature evident in the probability plots could indicate that the statistical characteristics of small and large spills differ and, therefore, that the observed distribution of spill volumes are a mixture of two separate distributions. Some analysts (see e.g., Smith et al., 1982) have suggested that oil spills of different magnitudes “. . . may be expected to exhibit different statistical properties in their occurrence.” “Bowed” probability plots can result from mixtures of distributions (Koch and Link, 1971, see especially p. 247).

Analysis of VMT and marine transportation spills support the above findings for E&P and pipeline spills. All probability plots confirm that the lognormal distribution provides an approximate description of the distribution of spill volumes.

B.5 Time Trends

This section examines time trends of crude and product spills from various Operations segments. It is necessary to consider time trends to develop informed projections of possible future spills associated with continuing Operations if the ROW is renewed.

In accord with modern spill analysis methodology (see Table B-2) it is reasonable to normalize spill volumes in relation to an *exposure variable*. Several bases for normalization have been suggested in the literature. The exposure variable typically used in MMS studies is the volume of material produced or handled. Therefore, an appropriate statistic is the *volumetric spill rate* expressed as the volume of crude and product spilled divided by the volume of material produced or transported.

The following sections provide what are believed to be conservative projections of spill volumes over the period (2004-2034) of the ROW renewal. Alyeska management and those of ANS E&P operators and shippers are committed to reducing spill volumes (indeed, spill volumes are elements of various performance contracts). To the extent that these efforts are successful, future spill volumes will be less than those estimated here. Possible progress in reducing the frequency of large marine spills is presented below.

B.5.1 E&P Activities

Figure B-16 presents volumetric spill rates by year for the E&P segment of Operations from 1977 to 1999. The y-

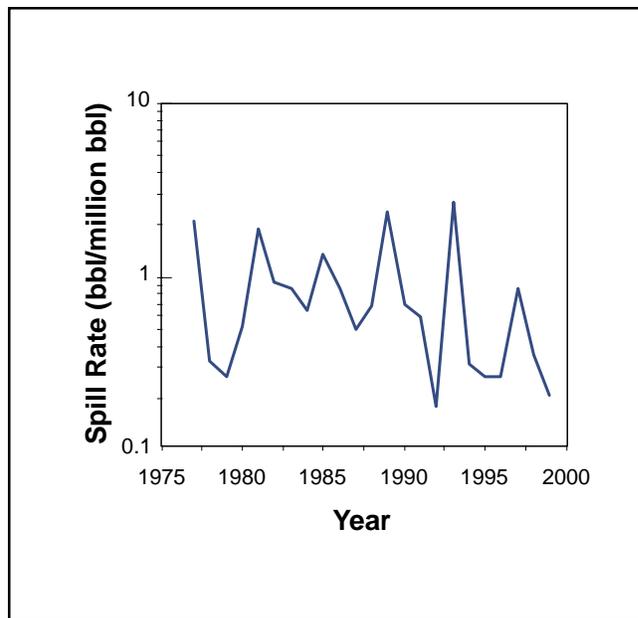


Figure B-16. Volumetric spill rate for E&P activities (1977-1999).

axis is the volumetric spill rate defined as the total annual volume of crude and product spilled divided by the total annual crude throughput. Convenient units are bbl spilled per million bbl throughput. The x-axis is time in years.

There is a substantial variability of approximately one order of magnitude in year-to-year volumetric spill rates over this period and little apparent time trend. A linear regression (fitted by ordinary least squares) has a negative slope, suggesting that volumetric spill rates have declined slightly on average, but the percentage variation explained by this regression is small ($R^2 = 0.114$) and the 95 percent confidence limits on the slope (change in rate over time) include zero, indicating that there is no statistically significant time trend.

Since there is no persuasive evidence of a time trend based on actual data, the historical average volumetric spill rate provides the best estimate of future spills for this segment. Dividing the total amount spilled in E&P activities by the total TAPS throughput from 1977 to 1999 yields an average annual spill rate of 0.86 bbl/million bbl throughput. Because TAPS throughput volumes are projected to decrease in the future (see Appendix A), the assumption of a constant average spill rate (per million bbl throughput) means that future E&P spills will decrease in proportion to throughput. The baseline future TAPS throughput assumption over the period from the year 2004 to 2034 totals approximately 7.02 billion bbl (Appendix A). Therefore, the projected average volume of ANS crude and product spills is approximately 6,050 bbl over the period from 2004 to 2034, an average of 202 bbl/year.

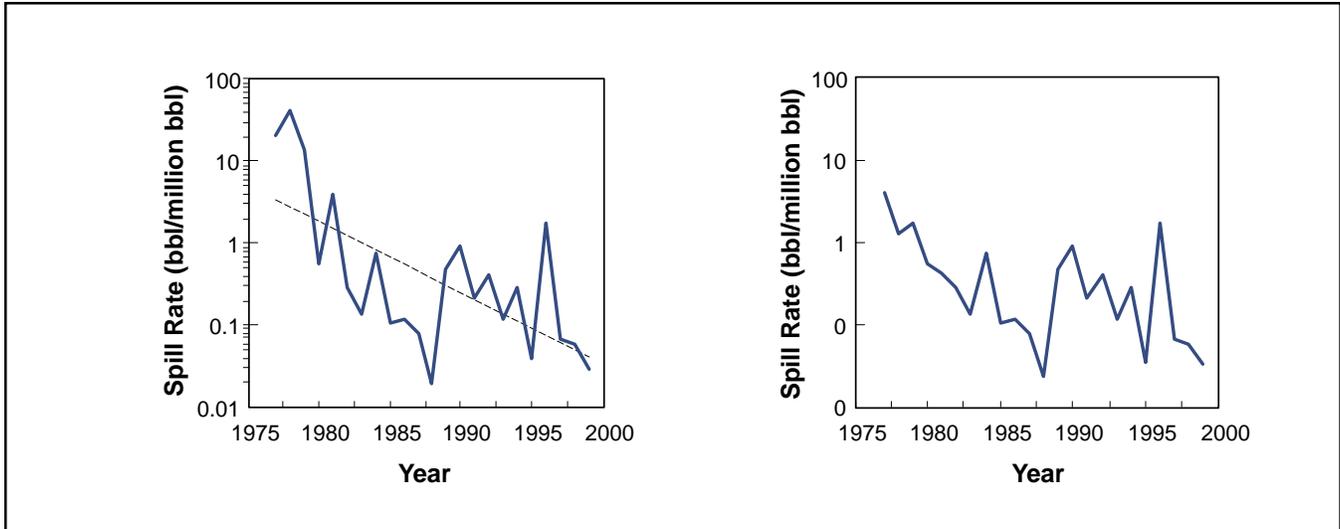


Figure B-17. Left-hand side: Volumetric spill rate for pipeline (solid line) and ordinary-least-squares trend (dashed line) (1977-1999). Right-hand side: Same data with five largest pipeline spills removed.

B.5.2 Pipeline

There is some debate about the magnitude of future pipeline spills as TAPS ages. Available evidence from European pipelines (CONCAWE, 1998) suggests that older pipelines have the same spill rates as newer pipelines. However, some TAPS critics have expressed the concern that pipeline spills may be more likely in the future (Fineberg, 1997) as the system ages.

Figure B-17 (left) presents volumetric spill rates by year for the pipeline. As with the E&P data (and data from all segments), there is substantial variability (approximately three orders of magnitude for this segment), but evidence of a trend toward decreasing volumetric spill rates in later years. (This conclusion is strengthened if it is believed (see Table B-2) that pre-1989 data may have been understated.) An ordinary-least-squares linear regression line [the dashed line in Figure B-17 (left)] has a negative slope, which is significantly different from zero ($p = 0.001$), confirming the visual impression offered by Figure B-17 (left). Nonetheless, the predictive power of the linear trend model ($R^2 = 0.431$) is not high, indicating that year-to-year variability is large relative to any time trend. For this reason, it is conservatively assumed that the volumetric spill rate is constant over time. Figure B-17 (right) plots pipeline spill rate through time but excludes the effects of the five largest pipeline spills. These larger spills occurred in the earliest years of TAPS (1977 to 1981) and represent 19 percent of the total volume spilled from the pipeline segment. Even with these points deleted, there is visual evidence of a trend, particularly in the early years.

The average volumetric spill rate (crude and product) is 2.45 bbl spilled/million bbl throughput. From the baseline throughput assumption (see above), the estimated average future pipeline spill volume is 17,200 bbl over the ROW renewal period, an average annual spill volume of 573 bbl. If the observed time trend persists, the actual volume spilled would be substantially lower.

B.5.3 VMT

Figure B-18 presents calculated volumetric spill rates for the VMT segment. Spill rates are highly variable (about four orders of magnitude) and there is no evident time

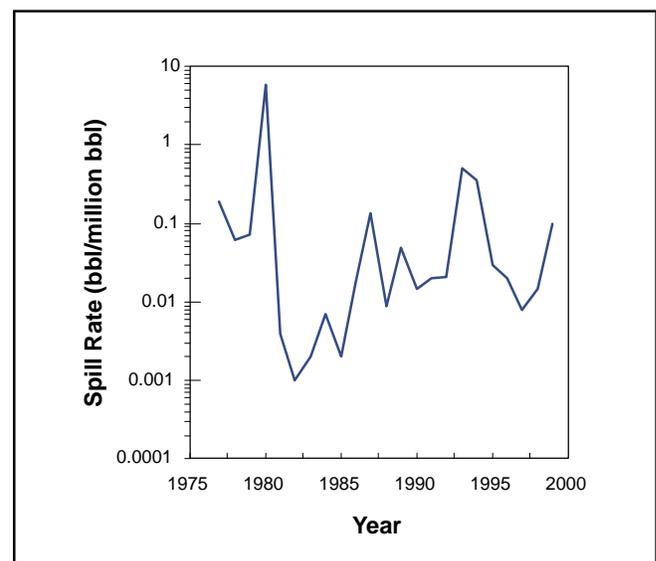


Figure B-18. Volumetric spill rate for VMT (1977-1999).



trend. The annual average spill rate is 0.32 bbl crude and product spilled/million bbl throughput, which translates to a total spill volume of 2,270 bbl (average 76 bbl/year) over the ROW renewal period.

B.5.4 Marine Transportation

Figure B-19 presents comparable rates for the marine transportation segment. Variability is nearly six orders of magnitude and there is no statistically significant time trend. The annual average volumetric spill rate for this segment is 22 bbl crude and product spilled/million bbl crude throughput, which translates to an expected spill volume of approximately 154,400 bbl (average 5,147 bbl/year) over the ROW renewal period. Because marine transportation spills are potentially so important, this projection is examined in more detail in following sections.

B.6 Choice of Data Set

The above estimates of future spill volumes over the ROW extension period 2004 to 2034 are based on the entire data set of spills occurring on all TAPS segments for the period from 1977 to 1999. As noted, there are clear time trends in volumetric spill rates for the pipeline segment and, because of the contributions of the EVOS volume to the total, an evident step-change in spill volumes for the marine transportation segment for the post-1990 period. If there are real trends in volumetric spill rates, then it is appropriate to base spill volume estimates upon more recent data. The year 1990 serves as a useful point to partition the data. Following the EVOS in 1989, numerous enhancements were made to spill response capabilities and other measures were implemented (see below) to reduce the likelihood and/or consequences of a marine transportation accident. Table B-9 shows the projected total and annual spill volumes (by segment and in aggregate) calculated using volumetric spill rates (as illustrated above) based on all (1977 to 1999) data and upon the subset of most recent data for the period from 1990 to 1999. Figure B-20 shows these same results graphically.

As can be seen, projections of future spill volumes are quite sensitive to the historical period used to estimate volumetric spill rates. If the 1990 to 1999 period were chosen, projected spill volumes are approximately 88 percent lower than if the entire operating period were chosen — largely because of very substantial drops in projected pipeline and marine transportation spills. Data used for spill volume projection cannot be chosen arbitrarily or merely

because the results provide greater comfort to the stakeholders. There must be some objective reason(s) to justify the deletion of any potentially relevant data. With regard to the TAPS system, such reasons include:

- The 1990 to 1999 period is more recent. In the presence of time trends, the choice of more recent baseline is preferable. Of course, selecting the more recent data set also reduces the number of years of data, which reduces the possible precision of the projections.

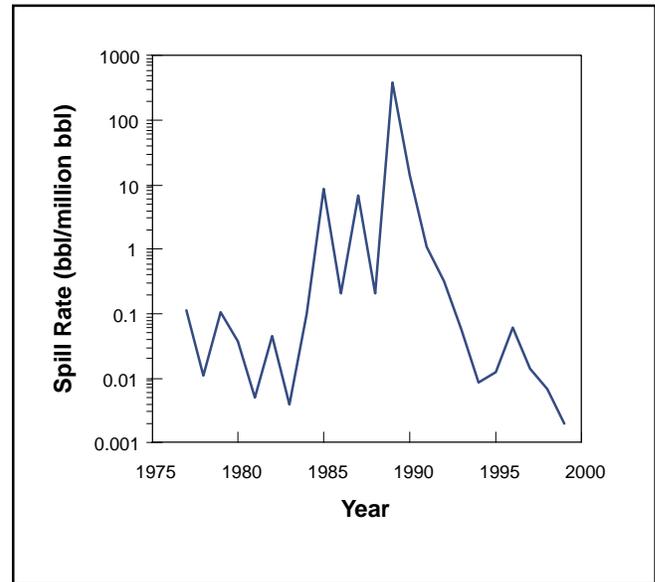


Figure B-19. Volumetric spill rate for marine transportation (1977-1999).

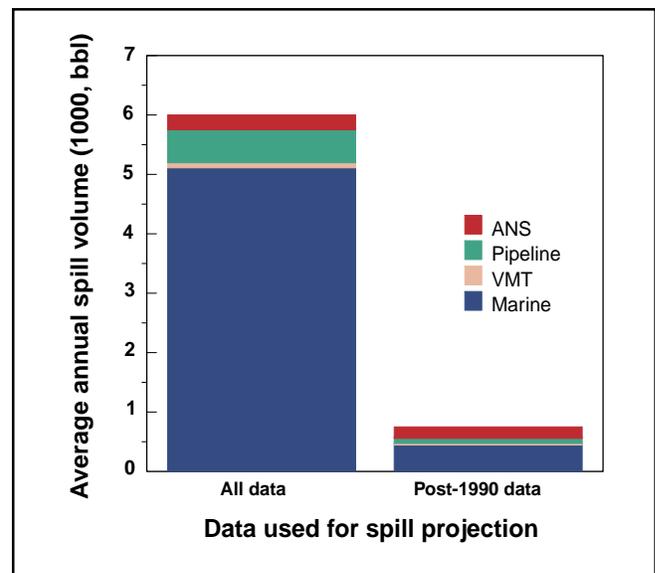


Figure B-20. Projected total and annual spill volumes (by segment and in aggregate) calculated using volumetric spill rates (as illustrated above) based on all (1977-1999) data and upon the subset of most recent data for the period from 1990 to 1999.



Table B-9. Spill projections based on different data sets.

Operations Segment	1977-1999 Data Set		1990-1999 Data Set		Percent Change
	Total Volume 2004-2034 (bbl)	Average/Year 2004-2034 (bbl)	Total Volume 2004-2034 (bbl)	Average/Year 2004-2034 (bbl)	
E&P (ANS)	6,050	202	4,806	160	-20.8
Pipeline	17,200	573	3,045	102	-82.2
VMT	2,270	76	801	27	-64.4
Marine Transportation	154,400	5,147	13,658	455	-91.2
Total	179,920	5,998	22,310	744	-87.6

Note: Estimated spill volumes based on average volumetric spill rates

- There have been many enhancements made (see below) to the marine transportation system following the EVOS and other marine spills in order to reduce the likelihood of future accidents and expected volume of oil spilled given an accident.

B.7 Future Marine Transportation Spills

The historical importance of marine transportation spills justifies a more careful examination of the prospects of future spills than merely concluding (based solely on the lack of an obvious time trend in spill data) that “the future will be like the past.”

It is not impossible for a very large tanker spill to occur during the period covered by the ROW extension. However, based on lessons learned as a result of the EVOS, new legislation (e.g., OPA 90), and new regulations, numerous improvements have been made that will reduce the likelihood of a major marine transportation accident and/or the expected outflow given such an accident. These measures fall into two main classes:

- Improvements in spill prevention and response capability for Prince William Sound (PWS) made by Alyeska, including the creation of the Ship Escort Response Vessel System (SERVS).
- Phase-in of double-hull tankers under OPA 90.

Table B-10 provides a summary of the major changes made by Alyeska between 1989 (pre-EVOS) and the present relevant to PWS. Key spill prevention measures include provision of tanker escorts, and enhanced USCG-staffed Vessel Traffic Service (VTS), more stringent weather constraints on tanker operation, use of ice routing measures, and mandatory alcohol testing of tanker officers. Collectively, these measures (costing approximately \$60 million annually) are designed to reduce the likelihood of a tanker accident and the size of any subsequent spill sub-

stantially. Shown also in Table B-10 are a series of measures that are designed to improve response capability. [Many of these were developed from a Coast Guard study of “lessons learned” during the EVOS cleanup (USCG and DOT, 1993)]. These measures should reduce the environmental impacts of a spill.

Among other things, OPA 90 established a schedule for closing U.S. ports to single-hull tankers. By 2015 at the latest, all tankers calling at VMT will have double-hulls. In fact, according to projections made by the U.S. General Accounting Office (GAO, 1990, 1999) the last of the present tanker fleet will be phased out in 2013. Thus, for at least 20 years of the 30-year ROW renewal period (2014 to 2034), the ANS tanker fleet will consist exclusively of double-hull tankers. (Of 26 tankers now serving VMT, 3 are double-hull, 13 have double sides, and an additional 3 double-hull tankers are on order, scheduled to enter service before the existing TAPS ROW expires.)

Shortly after the EVOS, a National Transportation Safety Board report (NTSB, 1990) stated that had the *Exxon Valdez* been fitted with a double hull, “the risks of oil spills owing to collision or grounding would have been significantly reduced.”

Table B-11 provides several estimates of the benefits of double-hull tankers in terms of a reduced probability of an oil spill and/or reduced outflow in the event of a spill. Of these, the recent National Research Council study (NRC, 1998) offers the most authoritative estimates of measures of effectiveness of double-hull tankers compared to existing single-hull tankers. As can be seen, this study estimates that the probability of a spill would be reduced by an “improvement factor” ranging from 4 to 6, and the expected spill outflow reduced by an improvement factor of between 3 and 4. Together, improvements in prevention and phase-in of double-hull tankers should reduce spill probabilities and spill outflows at PWS appreciably.

There have been (and will be) many additional improve-



Table B-10. Prince William Sound spill prevention and response.

Category	Before March 1989*	Fall 2000*
Tanker, Escort, Tracking, and Operations	<ul style="list-style-type: none"> • Vessel escort only through Valdez Narrows • USCG radar tracking to pilot station (past Valdez Narrows) • No drug and alcohol testing for tanker crews 	<ul style="list-style-type: none"> • 3 prevention and response tugs (PRTs), 2 enhanced tractor tugs (ETTs), and 4 conventional tugs • USCG Vessel Traffic Service; enhanced radar coverage; automated vessel tracking in Prince William Sound (PWS) • Tanker officer alcohol testing prior to sailing; weather restrictions on tanker operations; ice routing measures; tankers boomed during loading at Valdez Marine Terminal (VMT)
Oil Spill Recovery and Nonmechanical Response Systems	<ul style="list-style-type: none"> • 13 oil-skimming systems with recovery capability of 27,000 bbl of oil in 72 hours • 1 barge with 12,000 bbl storage for recovered oil • Approximately 5 miles of containment boom; no fire boom/igniter systems • Limited dispersant and application systems in place 	<ul style="list-style-type: none"> • Major SERVVS response equipment on 24-hour standby. • Over 70 skimming systems with recovery capability of 300,000 bbl of oil in 72 hours • 7 barges with 818,000 bbl storage for recovered oil • At least 35 miles of containment boom plus over 3,000 ft of fire-resistant boom with 2 helicopter igniter systems • Dispersant stockpile of over 60,000 gallons with fixed-wing, helicopter, and vessel-based application systems
Spill Planning, Management, and Training	<ul style="list-style-type: none"> • Contingency plan developed for “most likely” spill scenario of 4,000 bbl • Drills conducted every few years outside Port Valdez • Response team in place resembled a command system • Valdez Terminal employees provided response personnel; no SERVVS organization 	<ul style="list-style-type: none"> • State-approved comprehensive Oil Discharge Prevention and Contingency Plan developed by shippers and Alyeska for response planning standard of 300,000 bbl • Major tanker drill conducted annually with frequent smaller drills • Weekly drills and training exercises • Unified Incident Command System structure with USCG, Alyeska, shippers, and state for incident response • Alyeska SERVVS is the dedicated, trained spill response organization with over 200 personnel and contractors
Community Involvement, Response, and Training	<ul style="list-style-type: none"> • No organized citizen involvement in plan development and oversight • No community response centers • No community training programs • Approximately 10 fishing vessels at Port Valdez under contract for spill response 	<ul style="list-style-type: none"> • PWS Regional Citizens’ Advisory Council budget for 2000 is \$2.5 million • 5 Community Response Centers in PWS • Community training programs in PWS and Kodiak • Program trains and integrates fishing vessels in oil spill response plans; over 300 fishing vessels under contract
Wildlife and Resource Protection	<ul style="list-style-type: none"> • No specific fish hatchery protection plans • No specific wildlife rescue programs 	<ul style="list-style-type: none"> • Hatchery protection plans with pre-staged equipment for all hatcheries in PWS • Wildlife response plan with hazing, capture, and rehabilitation equipment on site and ready for rapid deployment
Communications	<ul style="list-style-type: none"> • Radio communications for spill response from scene to command center only 	<ul style="list-style-type: none"> • Fixed radio repeater system with communications capability to cover PWS
Government Oversight	<ul style="list-style-type: none"> • State oversight at Valdez Terminal and tanker operations by 3 on-site state employees 	<ul style="list-style-type: none"> • Comprehensive oversight of VMT and tanker operations by federal and state agencies, including the Joint Pipeline Office; 7 specially trained on-site state personnel
Spill Prevention and Response Budget	<ul style="list-style-type: none"> • Approximately \$1 million annual for VMT and PWS 	<ul style="list-style-type: none"> • Approximately \$60 million annually

*Based on oil spill contingency plans reviewed and approved by ADEC and by the USCG for 1999. Note: ADEC (www.state.ak.us/dec/) offers a similar list (Feb. 1999) titled “Then and Now.”

Source: APSC (1999c) with slight modification.



Table B-11. Potential benefits of double-hull tankers.

Statement	Summary	Source
"If a vessel experiences a collision or grounding that penetrates the outer hull, double-hull tankers are four to six times less likely than single-hull tankers to spill oil. Expected or average outflow is three to four times less with a double-hull compared to a single-hull tank vessel."	Probability of spill reduced by factor of 4 to 6. Expected spill volume reduced by factor of 3 to 4.	NRC (1998)
"After the <i>Exxon Valdez</i> grounded on Bligh Reef, the Coast Guard estimated that 25 to 60 percent of the spilled oil . . . could have been contained if vessel had a double hull."	Expected spill volume reduced by factor of 1.33 to 2.5.	Davidson (1990)
"It is estimated that if the <i>Exxon Valdez</i> had had a double-hull structure, the amount of the spill would have been reduced by more than half."	Expected spill volume reduced by factor >2.	<i>Exxon Valdez</i> Oil Spill Trustee Council (www.oilspill.state.ak.us)
"If the <i>Exxon Valdez</i> tanker had been protected by a double hull, 80% less oil would have spilled . . . a marine architect told a house panel . . ."	Expected spill volume reduced by factor of 5.	Whitney (1990)
"A risk assessment study done in 1995 found the risks of another spill have been reduced by 75%, according to Michelle Brown, Commission of the State Department of Environmental Conservation."	Probability of spill reduced by factor of 3.	Clark (1999) Det Norske Veritas et al. (1996)
"Oil outflow for a double-hull tanker for composite accident reduced to 29% for large tankers."	Expected spill volume reduced by factor of >3.	NRC (1991)

ments beyond those summarized in Table B-10 that should reduce the probability of an accident and/or the expected volume of crude spilled in the event of an accident. As noted above, double-hull tankers will replace single-hull tankers. However, the new tankers will be different in other respects as well. For example,

- New tankers should have a reduced probability of developing hull cracks compared to the older tankers presently in service. In addition, the USCG has instituted a Critical Area Inspection Program for all tankers in the TAPS trade (APSC, 1999b). This program is intended to reduce the likelihood of undetected hull fractures, which could result in crude oil discharges.
- Present tankers have been retrofitted with and new tankers will be equipped with more modern navigation receivers. Since the EVOS, both the satellite-based Global Positioning System (GPS) and Differential Global Positioning System (DGPS) systems have been placed into service (NRC, 1994). GPS offers a significant improvement in absolute accuracy compared to Loran-C (the system in use during the 1980s) and DGPS (a system operated by the Coast Guard that operates by broadcasting correction signals to be applied to the GPS position) offers yet greater improvement (10 meters absolute accuracy). There are three DGPS sites that provide coverage of the Valdez-Cape Hinchinbrook area, located at Cape

Hinchinbrook, Kenai, and Potato Point (USCG, 2000a). With the recent decision (implemented May 1, 2000) to eliminate selective availability (SA, an intentional degradation of the GPS signal implemented originally out of national security concerns), DGPS accuracy will be significantly greater — perhaps 3 to 5 meters according to some sources (Queeney, 2000).

- New tankers will be able to maintain “position awareness” to a significantly greater degree. These will use Electronic Chart Display and Information Systems (ECDIS), a navigation system that displays real-time position information (from DGPS) on an electronic chart, replacing time-consuming position plotting on paper charts (NRC, 1994) and facilitating navigation and avoidance of charted hazards to navigation.
- New tankers will be equipped with Automatic Identification Systems (AIS), transponder-based systems that will transmit such ship information as identification, position, heading, ship length, beam, type, draught, and hazardous cargo information, to ships and shore (USCG, 1997b; Petterson, 2000; USCG, 2000b; Elfring, 2000). GPS/DGPS and radar are used to answer the question, “Where am I?” ECDIS is used to answer the question, “Where am I in relation to charted objects (e.g., reefs, aids to navigation, landmarks, etc.)?” Radar and Automatic Radar Plotting



Aids are used to answer the question, “Where are other vessels?” AIS is/will be used to answer a much more complete set of questions, including, “Where am I?” “Where are they?” “Who are they?” “Which way are they headed?” What is their course and speed?” “What is the closest point of approach and time to the closest point of approach?” AIS information can be presented as an ECDIS overlay, radar overlay, or on a personal computer (PC). Portable AIS systems, small enough to be carried by pilots, have been produced. Enhanced AIS (EAIS, see Elfring, 2000) will integrate this information with services available from VTS and non-USCG sources to provide waterway information (e.g., weather, currents, depth, ports, etc.). Once consigned to the realm of science fiction, the technology is now available. The 72nd Session of the International Maritime Organization Maritime Safety Committee has established a timetable for carriage requirements (USCG, 2000b) and prototype systems have been implemented (USCG, 1997b) in some areas to solve specific local problems (e.g., VTS Prince William Sound incorporates a ship-to-shore AIS for tank ships only).

Other mitigating actions (APSC, 1999b) include the implementation of new training and improved loading procedures to minimize tank overflow problems. Tankers are fitted with automatic or remote gauging systems and high-level alarms to minimize the possibility of tank overflow. Ship auditing practices, preventive maintenance, and inspections are designed to identify defects that could result in a spill.

Table B-12 provides a discharge history of all spills greater than 55 gallons from either VMT or the marine transportation link (APSC, 1999b, augmented with marine spills outside of the Valdez area). Hull cracks/corrosion leaks and overflowing tanks, for example, account for several of these spills. The likelihood of these failures should be reduced by the Critical Area Inspection Program, use of automatic/remote gauging systems, and high-level alarms. Improved training and preventive maintenance should also reduce the probability of these accidents.

Collectively, there have been numerous major and minor changes made to the marine transportation system since the EVOS. Many occurred almost immediately as “lessons learned” were assimilated, some have arisen out of a process of continuous improvement during the 1990s, and some (e.g., switch to double-hull tankers) will occur during the renewal period.

There is already statistical evidence (from other parts of the world) to support the fact that tanker spills are becoming

less likely. Coast Guard Commandant Admiral James Loy recently reported to Congress that the number of major tanker spills has dropped by two-thirds since passage of OPA 90 (Whitney, 1999).

For these and other reasons, future marine transportation spills are expected to be less likely — perhaps much less likely — than past experience would indicate. For illustrative purposes, we have assumed a range of possible spill reduction factors in this analysis. Double-hulls alone should reduce spills by more than 80 percent (NRC, 1998). To be conservative and reflect the fact that single-hull tankers will be used for a portion of the ROW renewal period, *it is assumed that the future spill rate* (expressed as the number of spills of volume >1,000 bbl/billion bbl throughput) *will be less than that observed by an improvement factor ranging between 1 and 4*. The lower end of the range (improvement factor = 1) represents the status quo, the upper-end (improvement factor = 4) a conservative estimate of the benefits of double-hulls and other measures.

B.8 Spill Projections

This section develops projections of the likelihood and volume associated with both small and large spills over the period of the ROW extension based on the spill projection methodology employed by MMS, Operations experience, and estimates of the possible reduction of spill rates brought about by Alyeska measures taken at PWS and benefits of replacing the existing fleet of single-hull tankers with modern double-hulled equivalents.

B.8.1 Future Large Spills

In brief, the methodology for large (>1,000 bbl) spills is as follows:

- Marine transportation data for Operations are analyzed to estimate the base case spill rate (number of spills >1,000 bbl/billion bbl throughput).
- The base-case assumption of future throughput over the ROW renewal period is multiplied by the base case spill rate to determine the expected number of large spills in this period.
- This estimate is multiplied by several possible improvement factors to reflect the changes made to the spill prevention and response system to calculate a revised estimate of the expected number of future spills over the ROW renewal period.
- The Poisson model is employed to calculate the probability of any number of spills over the ROW renewal



Table B-12. Discharge history of all spills greater than 55 gallons from either VMT or the marine transportation link.

Date	Tanker	Cause/Description	Spill Volume (bbl)
11/28/77	Glacier Bay	Crack in port side of tanker	12
07/29/78	American Independence	Ballast water discharge	3
09/05/78	Tonsina	Tanker overflow	5
10/17/78	Aquila	Unknown	10
11/09/78	Manhattan	Tank overflow	2
01/03/79	Mobil Arctic	Crack between ballast tank and crude tank	50
02/08/79	Exxon San Francisco	Tank overflow	5
02/03/80	Mobil Oil	Tank overflow	5
04/14/80	Bay Ridge	Ballast valve left open while pumping crude	29
07/08/80	BT San Diego	Connection flange on loading arm	4
09/11/80	Exxon San Francisco	Contaminated ballast water	10
08/16/82	Bay Ridge	Fault in line to ballast tank	2
10/01/82	Brooklyn	Leak in segregated ballast line	25
12/30/83	ARCO Alaska	Manifold overflow	1
08/26/84	ARCO Alaska	Corroded inert gas deck seal drain	60
12/21/85	ARCO Anchorage	Tanker ran aground in Port Angeles, WA	5,690
04/13/86	BT San Diego	Failure of slop tank valves	24
05/18/86	Thompson Pass or ARCO Fairbanks	Unknown origin (insufficient information to attribute to either tanker)	2
06/20/86	Thompson Pass	Hull crack	2
02/03/87	Mobil Meridian	Leak in upper rudder bearing	5
07/02/87	Glacier Bay	Tanker struck uncharted rock and went aground in Cook Inlet	4,942
01/11/88	Exxon Benicia	Unknown	3
02/12/88	Exxon Benicia	Hull corrosion leak	7
01/03/89	Thompson Pass	Hull crack	1,700
01/16/89	Cove Leader	Hull fracture-mechanical	60
03/11/89	St. Lucia	Overflow of tank compartment	3
03/24/89	Exxon Valdez	Ran aground on Bligh Reef	257,143
04/10/89	Keystone Canyon	Cracked overboard discharge line	2
02/07/90	American Trader	Vessel grounded on own anchor during mooring at Gold West Marine Terminal off Hunting Beach, CA	9,458
05/21/94	Eastern Lion	Corrosion hole in #1 port cargo tank	200

Source: APSC (1999b) as augmented with data for marine transportation spills outside of PWS.

period based on the revised estimates of the mean number of spills.

- Estimates of the average size of the large spills are presented.

Several investigators have found the Poisson model suitable for oil spill calculations (see e.g., Smith et al., 1982; Anderson and LaBelle, 1990, 1994). The Poisson model is used in the MMS oil spill models in several EISs. More generally, the Poisson model has been shown to be appli-

cable to the areal distribution of objects (Clarke, 1946; Clark and Evans, 1954), queuing theory (Fry, 1965), reliability theory (Shooman, 1968), accidents (Wadsworth and Bryan, 1960; Parzen, 1960), acceptance sampling (Duncan, 1965), and other miscellaneous applications (e.g., Wallis, 1936).

The Poisson model is used as follows: denoting the spill rate (spills >1,000 bbl/billion bbl throughput) by λ and the estimated future throughput over the ROW renewal period



by T (billion bbl), the expected number of large spills, μ , is equal to λT . Given μ , the probability of exactly k large spills ($k = 0, 1, 2$, etc.) over the future production period is,

$$(Eq. 3) \quad p[k, \mu] = e^{-\mu} \frac{\mu^k}{k!}$$

The probability of at least one large spill is, therefore,

$$(Eq. 4) \quad p[k \geq 1, \mu] = 1 - p[k=0, \mu] = 1 - e^{-\mu}$$

Table B-13 shows the calculated probability of any number of large spills over the ROW renewal period for various possible values of μ . Possible reductions in the historical

large spill rate are quantified by an assumed improvement factor ranging from 1 (no improvement) to 6 (the upper end of the National Response Center estimate). Figure B-21 shows these probabilities graphically for improvement factors of 1 (base case — no improvement), 3 (67 percent reduction in spill rate), and 4 (75 percent reduction in spill rate).

For the base case, the probability of one or more spills >1,000 bbl (see Table B-13) is nearly 94 percent over the ROW renewal period. The corresponding probabilities for improvement factors of 3 and 4 are 60 and 50 percent, respectively

What is the expected size of a large spill? Although a large spill is defined as one >1,000 bbl, the average volume of such spills is greater than the threshold value. Based on

Table B-13. Probability calculations for future marine spills over ROW renewal period.

Quantity	Units	Value	Source/remarks					
Observed number of spills >1,000 bbl	NA	5	see Table B-4					
Total TAPS throughput (1977-1999)	billion bbl	12.758	ASPC (1999a) updated					
Spill rate for these data	spills/billion bbl	0.391911	Ratio spills/throughput					
Baseline TAPS throughput in ROW period	billion bbl	7.02	Appendix B					
Expected # spills in ROW period	# spills	2.751	Calculation					
Probability of indicated number of spills >1,000 bbl over renewal period If actual spill rate is this fraction of observed TAPS marine transportation spill rate								
Assumed improvement factor relative to historical rate								
	1	1.5	2	2.5	3	3.5	4	6
	Resulting mean number of spills (2004-2034)							
	2.751	1.834	1.376	1.100	0.917	0.786	0.688	0.459
Number of Spills	Probability	Probability	Probability	Probability	Probability	Probability	Probability	Probability
0	0.0639	0.1598	0.2527	0.3327	0.3997	0.4556	0.5027	0.6322
1	0.1757	0.2930	0.3476	0.3661	0.3665	0.3582	0.3457	0.2899
2	0.2416	0.2687	0.2391	0.2015	0.1681	0.1408	0.1189	0.0665
3	0.2216	0.1643	0.1096	0.0739	0.0514	0.0369	0.0273	0.0102
4	0.1524	0.0753	0.0377	0.0203	0.0118	0.0072	0.0047	0.0012
5	0.0839	0.0276	0.0104	0.0045	0.0022	0.0011	0.0006	0.0001
6	0.0385	0.0084	0.0024	0.0008	0.0003	0.0001	0.0001	0.0000
7	0.0151	0.0022	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000
8	0.0052	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0016	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14 or more	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1 or more	0.9361	0.8402	0.7473	0.6673	0.6003	0.5444	0.4973	0.3678

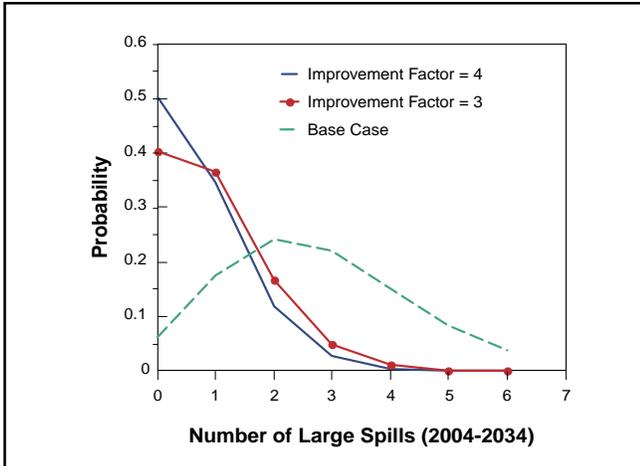


Figure B-21. Probability distribution of number of large spills in ROW renewal period (2004-2034) for various improvement factors.

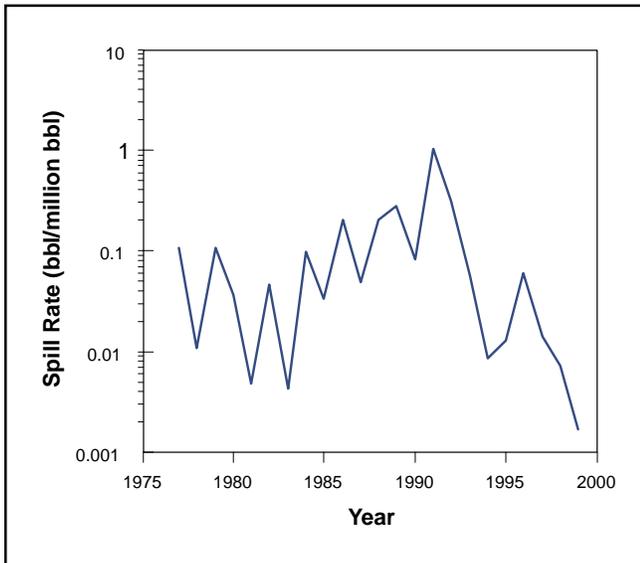


Figure B-22. Volumetric spill rate (crude and product) for marine transportation spills <1,000 bbl.

observed marine transportation spills for Operations over the period from 1977 to 1999 (including EVOS) the average size of all spills greater than 1,000 bbl (the conditional mean) was approximately 55,800 bbl. However, as noted above, it is likely that the size of any large spill would also be reduced by the same measures that reduce the spill probability. A recent (MMS, 1996) EIS, for example, posits an average large spill volume of 30,000 bbl for ANS tankers.

Based on the MMS oil spill methodology and conservative estimates of possible improvement, this analysis concludes that:

- The likelihood of one or more large (>1,000 bbl) crude spills for the marine transportation link ranges from 50 percent (improvement factor 4) to 94 percent (no improvement).

- The expected number of large spills ranges from 0.69 (improvement factor 4) to 2.75 (no improvement).
- The estimated volume of a large tanker spill is 30,000 bbl.
- The estimated total volume of oil spilled as a result of large spills over the ROW renewal period ranges from 0.69 (30,000) = 20,700 bbl to 2.75 (30,000) = 82,500 bbl. Spread over 30 operating years the average volume spilled over the marine transportation segment ranges from 690 bbl/yr to 2,750 bbl/yr.

These projections present a more optimistic picture of future marine transportation spills than that determined solely from historical data. The specific improvement factors assumed here are arbitrary, but conservative relative to the range of improvement factors reported in the literature.

B.8.2 Future Small Spills

Because large spills account for the vast majority of the oil spilled in the marine transport segment of Operations, the consequences of omitting small spills from the analysis are likely to be negligible in terms of projections of the volume of future oil spills from Operations. Nonetheless, for the sake of completeness, these are included. To begin, Table B-14 shows the spill volumes (crude, product, and total) associated with spills less than or equal to 1,000 bbl for the marine transportation link over the period from 1977 to 1999. This table was prepared by deleting all marine transportation crude or product spills >1,000 bbl from the database and recalculating yearly totals for crude, product, and total spills. The combined volumetric spill rate (bbl crude and product spilled/million bbl throughput) for these small spills is calculated from the yearly totals and TAPS throughput.

Figure B-22 shows a time series of the annual volumetric spill rate (crude and product total) from 1977 to 1999 for these small spills. Over this entire time period there is no statistically significant time trend, although it is possible that these have decreased since 1991. Though targeted at large spills, some of the post-1990 measures discussed above may also reduce the frequency and/or volume of small spills. These potential benefits are disregarded in this analysis.

The average volumetric spill rate for the period from 1977 to 1999 (0.1404 bbl/million bbl) is used to project future spills. Based on future projected throughput of 7.02 billion bbl (Appendix A) over the ROW extension, the total spill volume (small spills) is estimated to be approximately (1000*0.1404*7.02) equal to 987 bbl, or 32.9 bbl/yr (see Table B-14). As expected, this is very small com-

**Table B-14.** Annual and total volumes for marine spills less than 1,000 bbl by material spilled, spill rate, and projected future small spills.

Year	Marine Transport Crude (bbl)	Product (bbl)	Total (bbl)	TAPS Annual Throughput (million bbl)	Volumetric Spill Rate (bbl/million bbl)
1977	12.02	0.41	12.43	112.30	0.1107
1978	3.91	0.49	4.40	397.01	0.0111
1979	50.44	0.50	50.94	467.78	0.1089
1980	19.46	1.08	20.54	554.93	0.0370
1981	2.04	0.71	2.75	556.07	0.0049
1982	27.61	0.07	27.68	591.14	0.0468
1983	1.51	1.07	2.58	600.68	0.0043
1984	61.33	0.02	61.35	608.84	0.1008
1985	2.22	19.66	21.88	649.89	0.0337
1986	133.24	6.16	139.39	665.44	0.2095
1987	29.24	6.95	36.19	716.66	0.0505
1988	144.34	11.11	155.45	744.11	0.2089
1989	178.29	18.26	196.56	688.06	0.2857
1990	12.81	42.96	55.77	654.55	0.0852
1991	11.07	697.79	708.86	665.17	1.0657
1992	68.81	137.03	205.83	639.36	0.3219
1993	19.41	14.78	34.18	591.22	0.0578
1994	1.05	3.98	5.03	579.32	0.0087
1995	0.00	7.15	7.15	555.94	0.0129
1996	11.17	20.78	31.95	525.51	0.0608
1997	2.21	4.73	6.94	487.10	0.0143
1998	2.12	1.08	3.20	440.50	0.0073
1999	0.00	0.45	0.45	267.00	0.0017
Subtotal	794.29	997.22	1,791.52	12,758.58	0.1404
Future Projections:					
	Quantity	Units	Value	Remarks	
	Volumetric spill rate	bbl/million bbl	0.1404	spills < 1,000 bbl	
	Total throughput	billion bbl	7.02	Appendix A	
	Projected spill volume	bbl	985.72	Multiplication	
	Years ROW	years	30.00	Proposed renewal	
	Average annual spill volume	bbl/yr	32.86	Division	

pared to the projections for large spills (690 to 2,750 bbl/yr) and could be neglected for practical purposes.

B.8.3 Spill Volumes Based on Data Since 1990

As noted above, it may be appropriate to partition the spill data, at least for the marine transportation link, into two periods: (i) 1977 to 1989 and (ii) 1990 to 1999. This section summarizes the results of applying the above methodology to the 1990 to 1999 data.

Over the period from 1990 to 1999 the number of large (>1,000 bbl) marine transportation spills was only one, the *American Trader* crude oil spill, which occurred off the

coast of California in 1990 when this single-hull vessel drifted over and was punctured by its own anchor when mooring. TAPS throughput over the period from 1990 to 1999 totaled 5.41 billion bbl, so the estimated number of large spills per billion bbl for this period was 0.18. Applying this rate to the estimated 7.02 billion bbl of TAPS throughput over the renewal period, 1.3 large spills (absent any adjustments) would be projected to occur. For comparison, basing the analysis on the entire 1977-1999 period results in 2.75 projected large spills (see Table B-13), absent any adjustments for other possible improvements. The probability of one or more large spills during the renewal period given that 1.3 are expected can be calculated from



the Poisson distribution to be approximately 0.73, rather than the 0.94 value shown in Table B-13. If the future spill rate were reduced by a factor of four, as was done in the above computations, the probability of one or more large spills during the renewal period would be 0.28, rather than 0.50 as shown in Table B-13.

It is also necessary to estimate the expected volume of oil spilled per large spill based on data for the period 1990 to 1999. Estimating this quantity from the data alone is problematic, because there is only one sample, the *American Trader*, which spilled 9,458 bbl.

However, this data point is interesting, because many analysts (see selected quotations contained in Table B-15) believe that substantially less (and possibly no) oil would have spilled as a result of this accident if the *American Trader* had been equipped with a double hull. Indeed, coming as it did on the heels of the EVOS, the *American Trader* spill created significant political impetus for the passage of legislation (ultimately incorporated into OPA 90) mandating use of double hulls. This information is certainly relevant. It is more difficult to decide how to integrate this into the spills analysis based on 1990 to 1999 data. Were such an accident to occur in the future (assuming a double-hull), the spill volume would be quite small, and possibly zero — implying a zero rate for large spills. Alternatively, the presence of a double-hull might be reflected in the assumed spill volume given an accident, which would certainly be smaller than the 30,000 bbl estimate assumed above.

Because a large spill rate that is *exactly zero* is unrealistic and because basing an estimate of the expected volume

spilled on only one data point creates an estimate of unknown precision, we do not base spill volume estimates upon data from 1990 to 1999. *However, this analysis certainly implies that the estimates based on the entire data set (Table B-13) — even when adjusted to reflect improvements — are conservative.*

B.9 Comparisons with Other Analyses

B.9.1 Det Norske Veritas et al. Analysis

Det Norske Veritas et al. (1996) completed a very comprehensive risk analysis of possible spills in PWS. A series of models was used to estimate the likelihood of various possible accidents (including collisions, powered grounding, drift grounding, structural failure, and fire and explosion) in various segments of PWS and environs. Accident probabilities were quantified as the expected number of accidents per year and the “return period” or mean number of years between accidents, which is numerically equal to the reciprocal of the number of accidents per year. Table B-16 (top) provides a summary of these probability estimates as of 1995. For all accidents considered as a group, the likelihood as determined from these models ranged from approximately 2.9×10^{-2} (corresponding to a return period of 34 years) to 5.6×10^{-2} (a return period of 18 years).

Each accident type differed with respect to the fraction of accidents with the potential for oil outflow and the ex-

Table B-15. The American Trader crude spill; several comments on the protective effect of double hulls.

Statement	Source
“If the American Trader had had a double bottom or hull, this accident wouldn’t have spilled any oil, it wouldn’t have made a blip in the news.”	Arthur McKenzie, former Exxon official and president of the Tanker Advisory Center in New York quoted in Rempel (1990)
“Rep. Dean A. Gallo...said, the Huntington Beach spill ‘would never have happened’ with his proposal [requiring double hulls or double bottoms almost immediately on all new tankers and a retrofitting program on all existing tankers] in force.”	Rep. Dean A. Gallo (R–NJ) quoted in Rempel (1990)
“...on an inspection of the spill site Thursday, Coast Guard Commandant Paul A. Yost, Jr., acknowledged that the American Trader probably...would have lost less oil if (it) would have had a double bottom.”	Rep. Dean A. Gallo (R–NJ) quoted in Rempel (1990)
“In that [i.e., the American Trader] case — a clear argument for double bottoms — the Coast Guard captain in charge of the cleanup was none other than [James] Card himself. ‘It makes you wonder,’ said Card, who attained the rank of Admiral shortly afterward.”	Nalder (1994), p. 216
“There is not all that much water out there,” he said, adding that a swell apparently lifted the tanker up as it attempted to moor and when it came down, ‘it hit the anchor,’ and punctured the hull.”	Stanford Schmidt, president of New York-based American Trading and Transportation Co., owner of the American Trader, as quoted in Churm (1990)



pected outflow given a release. Table B-16 also shows the estimates of the fraction of accidents of each type with the potential for oil outflow.

For each possible accident type, an oil outflow model was used to project spill volumes. Based on these inputs, it was possible to estimate the expected annual oil outflow associated with each accident type. When summed over all accident types, the projected average annual oil spill volume ranged from approximately 1,830 to 3,690 bbl/yr.

The analysis was conducted by an independent study group, provided with external input (e.g., the Regional Citizens Advisory Council), and peer-reviewed. For this reason, the DNV analysis should be considered authoritative. The oil spill estimates were based on conditions prevailing in 1995 and specific initiatives under consideration at that time. For example, throughputs will be different as will the

composition of the tanker fleet. In 1995 only three tankers were equipped with double-hulls, another ten with double-bottoms or double-sides. After 2014, all tankers engaged in the ANS trade will have double hulls. The effects of this fleet change need to be included in the analysis.

The effect of throughput can be adjusted for by expressing the estimated annual spill volume in terms of a volumetric spill rate and using this spill rate, together with future production estimates, to project future spills. These calculations are made in Table B-16 (bottom). The resulting annual spill volume (averaged over the 30-year TAPS ROW renewal period) ranges from approximately 770 bbl/yr to 1,555 bbl/yr — a geometric mean value of 1,095 bbl/yr. Allowance for the protective effects of double hulls would lower these projections substantially.

Thus, the Det Norske Veritas analysis is broadly consis-

Table B-16. Risk-related estimates developed by Det Norske Veritas et al. (1996).

Accident type	Accident Frequency Statistical Accidents Per Year		Return Period (yrs)		Percent of Accident Type with Potential for Oil Outflow	Estimated Average Annual Oil Outflow for Outbound Tankers (bbl)	
	Lower	Upper	Lower	Upper		Lower	Upper
Collisions	1.60 x 10 ⁻⁰²	4.10 x 10 ⁻⁰²	24	63	26.00%	530.2	1,272.6
Powered Grounding	5.92 x 10 ⁻⁰³	7.20 x 10 ⁻⁰³	139	169	68.00%	353.5	912.0
Drift Grounding	4.60 x 10 ⁻⁰³	5.50 x 10 ⁻⁰³	182	217	69.00%	473.7	855.5
Structural Failure	1.54 x 10 ⁻⁰³	1.63 x 10 ⁻⁰³	615	648	95.00%	190.9	367.6
Fire and Explosion	9.40 x 10 ⁻⁰⁴	9.40 x 10 ⁻⁰⁴	1,064	1,064	100.00%	282.8	282.8
Total	2.90 x 10⁻⁰²	5.63 x 10⁻⁰²	18	34	75.00%	1,831.1	3,690.5
					Throughput basis (million bbl/day)	1.522	1.522
					Throughput basis (million bbl/yr)	555.5	555.5
					Volumetric spill rate (bbl/million bbl)	3.30	6.64

Notes:

- Fire and explosion calculated by one model only.
- Estimated annual outflow calculated from accident frequency using oil outflow model.
- Annual oil outflows calculated from original estimates in tons assuming 7.07 bbl/ton.
- Total annual oil outflow calculated as sum from all accident types, there are minor discrepancies from original totals presented in report.
- Figures shown are for outbound tankers, summed over seven subareas from Gulf of Alaska to Port Valdez, summed over all seasons.
- Calculations based on 1995 throughput of 1.522 million bbl/day.

Future Spill Projections Based on This Analysis:					
Quantity	Units	Lower	Upper	Source	Note
Volumetric Spill Rate	bbl/million bbl	3.30	6.64	See above	Estimated volumetric spill rate based on system as it existed in 1995 as adjusted for throughput differences. Estimates do not reflect improvements post 1995 or phase-in of double-hull tankers.
Future Throughput	billion bbl	7.02	7.02	Appendix A	
Projected Spill Volume	bbl	23,139	46,636	Multiplication	
Duration of ROW Renewal	years	30	30	Proposal	
Annual Spill Rate	bbl/yr	771	1,555	Division	
Geometric Mean of Lower and Upper Estimates	bbl/yr	1,095			



tent with the spill volume projections — particularly those with an improvement factor of 4 — presented in this analysis. Moreover, the Det Norske Veritas analysis identified a number of risk management options (for training, bridgemanning levels, escort/response vessel positioning, speed limits on various segments of the route) that have ultimately been incorporated into the marine transportation system (APSC, 1999b). Taken together, these improvements would lower spill probabilities/volumes beneath those summarized in Table B-16.

B.9.2 MMS Analysis

Hart Crowser Inc. (2000) recently conducted an oil spill analysis for the ANS and TAPS on behalf of the U.S. Minerals Management Service. This study was based on a data set that included spills greater than 100 bbl from activities associated with oil production and transportation in Alaska and Arctic Canada. Hart Crowser concluded that the data collected from Alaska operations for the years 1980 onward were the most reliable and pertinent, and statistical analyses were performed on that data set. They estimated that between 52 gallons (1.2 bbl) and 66 gallons (1.6 bbl) of oil would be spilled per million barrels of oil produced and transported.

Although the data set used by Hart Crowser differed from that used in this analysis, the projected spill volumes for the period from 2004 to 2034 are similar. Based on future production and transportation of 7 billion barrels of oil over the renewal period, the Hart Crowser spill rates from E&P and pipeline operations would result in a projected spill volume ranging from 8,700 to 11,000 barrels. Table B-9 shows total spill volume estimates of 7,851 bbl (sum of E&P and Pipeline volumes for 1977 to 1999 data set) and

23,250 barrels (sum of E&P and Pipeline volumes for 1990 to 1999 data set) for these same two segments over the renewal period.

Table B-17 compares actual spill rates with those projected in the original TAPS EIS, the Det Norske Veritas et al. analysis, and the Hart Crowser study.

B.10 Spill Projections for the No-Action Alternative

Selection of the no-action alternative would eliminate spills that occur at the North Slope, pipeline spills, and VMT spills. (*Displace* is a more accurate term than *eliminate* because the United States would import additional oil to make up for the shortfall caused by shutting down TAPS. E&P and pipeline spills would be displaced to the country of origin of U.S. crude oil imports.) Additionally, there would be some product spills during the period of dismantling, removal, and restoration of the North Slope production facilities, pipeline, and VMT.

Opting for the no-action alternative would not eliminate tanker crude oil spills, because additional oil would be imported to U.S. refineries to compensate for the lack of ANS crude. To be sure, no further spills associated with TAPS would occur at Valdez. *However, spills at West Coast ports would not be affected.*

B.11 Estimates

Tables B-18 and B-19 summarize the above quantitative analysis and presents estimates of the future spill volumes associated with the recommended action alternative. These

Table B-17. Comparison of spill rates by Operations segment (bbl/million bbl throughput)

Segment	TAPS EIS Forecast (a)	Actual Operations 1977-99 (b)	Forecast for 2004-2034 (b)			
			Based on 1977-99 data	Based on 1990-99 data	DNV Forecast (c)	MMS Forecast (d)
E&P (ANS)	*	0.9	0.9	0.7	*	*
Pipeline	*	2.5	2.5	0.4	*	*
E&P + Pipeline	*	3.4	3.4	1.1	*	1.2 - 1.6
VMT	1.5	0.3	0.3	0.1	*	*
Marine	192	22	3.0(e) - 22.0	2	3.3 - 6.6	*

*Not forecast in study.

(a) Normalized from BLM (1972) (based on estimated spill rates of 3 bbl/day for transfers at VMT and 384 bbl/day for marine spills at a throughput of 2 million bbl/day).

(b) From this report, Table B-9.

(c) From Det Norske Veritas et al. (1996) risk assessment of marine operations only (see Table B-16, this report).

(d) From Hart Crowser Inc. (2000); study addressed potential spills from E&P and TAPS combined; VMT was not included.

(e) Includes expected improvements attributable to SERVS and double-hull tankers (see Table B-18, this report).

**Table B-18.** Estimates of future Operations oil spills based on historical data only.

Segment	Total Volume 2004-2034 (bbl)	Average per Year 2004-2034 (bbl)	Remarks
E&P	6,050	202	Based on average volumetric spill rate and projected throughput
Pipeline	17,200	573	Based on average volumetric spill rate and projected throughput
VMT	2,270	76	Based on average volumetric spill rate and projected throughput
Marine Transportation	154,400	5,147	Based on average volumetric spill rate and projected throughput
TOTAL	179,920	5,998	Sum of above

Table B-19. Estimate of future marine transportation spills based on allowance for mitigating measures.

Segment	Total Volume 2004-2034 (bbl)	Average per Year 2004-2034 (bbl)	Remarks
Marine Transportation	20,700 to 82,500	690 to 2,750	Based on analysis of large (>1,000 bbl) spills, range results from use of various improvement factors
	986	33	Based on average volumetric flow rate (small spills) and projected throughput
Subtotal	21,686 to 83,486	723 to 2,783	Sum of small and large spill estimates
TOTAL ALL SEGMENTS	47,206 to 109,006	1,573 to 3,634	Sum of marine transportation and other segments taken from Table B-17 above

are partitioned into estimates based solely on historical data (Table B-18) and those based on historical data and an allowance for the effects of preventative measures implemented in recent years (Table B-19).

Based solely on historical data, the average annual spill volume over the ROW renewal period for all Operations segments is approximately 6,000 bbl/yr. The marine transportation segment accounts for nearly 74 percent of this annual total.

The estimate of 6,000 bbl/yr does not reflect any allowance for improvements made to the system. As noted, the cost of these improvements has been substantial. SERVS alone costs \$60 million annually. Three new Millennium-class double-hull tankers, each costing approximately \$166 million, are already on order, and six other tankers will be required in the future to replace existing single-hull tankers under terms of OPA 90. The total cost (\$ billions in money of the day) of these two improvements alone over the 30-year renewal period is nearly \$3.3 billion. To base spill estimates solely upon past history is to assume that these costly improvements have no identifiable benefits.

A second set of spill estimates is provided, which is

based on historical experience for E&P, pipeline, VMT, and improved performance for the marine transportation segment. These estimates are expressed as a range, based on literature estimates of the benefits of new technology. For all Operations segments, the estimated annual spill totals over the ROW renewal period range from approximately 1,600 to 3,600 bbl. These estimates represent the average annual total based on conservative assumptions (e.g., no improvement to E&P, pipeline, or VMT spill rates). Spill totals have been highly variable in the past. In particular, this analysis indicates that there is a probability, ranging from 50 to 94 percent, that there will be one or more large spills throughout the duration of the ROW renewal period. The 50 percent probability is based on historical data for the entire period of TAPS operations, adjusted to reflect the effects of improvements made since 1990, whereas the 94 percent estimate assumes no improvement. The facts brought out in the discussion of these estimates — and the analysis based on data for the period 1990 to 1999 — indicate that even the lower probability is likely to be a conservative estimate. The upper value, which assumes no real improvement over historical experience, is virtually certain



to be highly conservative. The expected spill volume given that a large (>1,000 bbl) spill occurs, 30,000 bbl, is based on MMS (1996) analysis. Although this estimate is smaller than actually observed over the operating history of the marine transportation system, it too is likely to be conservative.

Choice of the no-action alternative will lower the estimated spill volume *in Alaska* (because TAPS, VMT, and the associated ANS fields will be shut down), but will only displace these spills to other production and distribution systems — perhaps with fewer safeguards. The Cook Inlet refinery, for example, will likely continue to operate, and does not have a SERVS fleet to escort tankers. Other Alaska refineries at North Pole and Valdez would either be shut in or have to import crude oil by other modes of transportation. If the refineries are shut in, refined products would have to be imported to supply areas previously serviced by these refineries. Spills would continue under any scenario. Moreover, spills occurring at U.S. destination ports (e.g., refineries in Hawaii or the West Coast) would not be eliminated. As shown in Table B-4, three of five of the largest marine spills for ANS tankers were at destination ports.

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