4.1 Mechanisms of Impact

Section 4.1 examines the mechanisms by which continued operation of TAPS may cause environmental and socio-economic effects. Section 4.1.1 describes possible ground-impacting maintenance actions, including excavations for investigating corrosion of below-ground pipe, maintenance of slopes and the workpad, potential pipe replacement projects, valves maintenance, remediation of cathodic protection, maintenance and repair of river crossings and training structures, surveillance actions, maintenance and repair of the fuel gas line, and gravel mining.

Section 4.1.2 presents a summary analysis of oil spill potential during the ROW renewal period. This analysis includes potential spills from North Slope exploration and production activities, TAPS operation, and marine tanker transportation. Appendix B contains the full detail of the spill analysis.

4.1.1 Ground-Impacting Maintenance Actions

By J.D. Norton and J. Harle

Ongoing maintenance activities will occur during the ROW renewal period (2004-2034) as TAPS operation continues. Significant activities affecting the environment are summarized in the following sections. For each activity, typical maintenance expectations based on historical data are covered and the project scale estimated.

Alyeska Pipeline Service Company

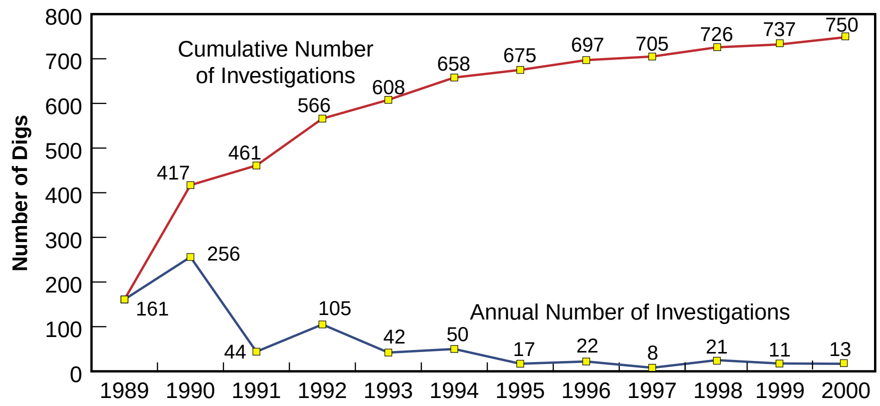
Photo 4.1-1. *Typical TAPS corrosion investigation project.*

4.1.1.1 Corrosion Repair of Below-Ground Mainline Pipeline

External corrosion investigations ("digs") of buried mainline pipe occur annually based on review of data gathered from instrumented-pig runs. Mainline pipe sections where pipe-wall thinning is detected are excavated and examined. Pipe coatings and cathodic protection systems are repaired to arrest additional wall thinning from corrosion. In some cases, full-encirclement pipe sleeves are installed to reinforce the pipe where anticipated hydraulic pressures require additional measures of safety.

Uncovering mainline buried pipe for examination and repair usually results in an engineered excavation of about 60 linear feet of pipe (Tart and Hughes, 1998). The excavations usually disturb a surface area of about 50 by 200 feet within the existing workpad area. Depth of cover of soil over the top of the pipe varies from 4 to 20 feet, with side slopes generally at a ratio of 2 to 1. For personnel safety, the slopes are no steeper than 1.5 to 1. Some corrosion problems are detected in wet areas, and these excavations are more complex and are carried out in winter to reduce the need for dewatering excavations. Dewatering may be required at any time of the year, and ditch water is discharged in accordance with state and federal permits. At approximately two sites each year, the dewatering discharge is expected to exceed 500,000 gallons (gal) total for both sites.

Impacts from this activity are localized and of short duration and include equipment noise, water quality changes from discharges, and excavation fill and regrading of the site. An estimated 15 digs will initially occur each year, potentially increasing to 20 by the end of 2034 (Flanders, 2000, pers. comm.). Figure 4.1-1 shows the numbers of Alyeska corrosion investigation digs since 1989.



Source: Flanders (2000, pers. comm.)

Figure 4.1-1. *TAPS corrosion investigation projects for underground mainline pipe.*

4.1.1.2 Slope/Workpad Maintenance

Slopes must be monitored for adverse movement, and occasional maintenance and repair of the slopes or the affected sections of mainline pipe are necessary. Fifty slopes are monitored every two years for change. Five areas are currently instrumented and monitored for movement and ground temperature change: Squirrel Creek, Klutina, Tazlina, Pump Station 11, and Treasure Creek.

Maintenance activities include workpad regrading, revegetation, clearing of drainage structures, adjustment of above-ground pipeline elevation, and installation of passive thermal-transfer devices (heat pipes) to maintain slope stability. This activity generates noise, requires use of heavy equipment on the slope or workpad, and creates the potential for erosion runoff.

4.1.1.3 Potential Pipeline Replacement

Mainline pipe replacement is rare since most pipe repair work is accomplished by installation of full-encirclement pipe sleeves over damaged sections. In addition, ongoing refurbishment of pipeline coatings and cathodic protection systems reduces pipeline repairs or replacements. Four pipeline reroutes/replacements have occurred since 1977:

- 3,600 linear feet at MP 200 near the Dietrich River in 1985,
- 234 linear feet at MP 166 at Atigun Pass in 1987,
- 200 linear feet at Pump Station 3 in 1990, and
- 8.5 miles at MP 157 to MP 165 near the Atigun River in 1991.

These projects were initiated because pipe replacement was determined to be a more economical solution than the expected number of site-specific repairs in these areas.

Impacts from pipeline replacements are greater than those from normal maintenance activities. Pipeline replacements are major construction projects that approach original construction impacts in scale for a localized area. Costs range from $1 million to $10 million per mile. Because of pipeline integrity monitoring, major reroutes due to corrosion are not expected during the ROW renewal period.

Less significant pipeline rehabilitation efforts may be required at mechanically refrigerated sites. The impacts would be similar to those from below-ground corrosion investigations. Small excavations may be needed at the three mainline refrigeration sites. The refrigeration units or pipeline insulation at all three sites may need to be replaced in order to maintain pipe support.

4.1.1.4 Mainline Below-Ground Valve Maintenance

Mainline valves undergo extensive performance testing, and increased maintenance efforts are expected (Jackson and White, 2000). Forty mainline valves are in below-ground pipe, and all may be excavated for inspection and repair — at a rate of about 5 valves per year (Aus, 2000, pers. comm). Vaults are likely to be installed at each site to provide access for future inspections. Impacts expected are similar to those from below-ground corrosion investigations.

Some below-ground valves may be replaced and refurbished, as was done with three valves in 1990, one in 1998, and one in 2000 (Pomeroy, 2000, pers. comm.).

4.1.1.5 Remediation of Mainline Cathodic Protection

Cathodic protection mitigates corrosion of buried mainline pipe. Alyeska monitors cathodic protection by "coupon" testing, close interval survey, and test stations. Remedial action is taken if cathodic protection is determined to be inadequate.

If remediation is required, impressed-current cathodic protection or sacrificial galvanic cathodic protection is installed. Impressed-current cathodic protection has been applied by installation of deep-well anodes, linear anodes, or horizontally distributed anode beds.

At remote sites, one of the most difficult problems with an impressed-current system is obtaining electrical power. Commercial power is normally available at pump stations and for areas south of Fairbanks. Where commercial power is not available, a generator is needed to operate an impressed-current system.

Deep-well ground beds are installed vertically from the surface and may be several hundred feet deep. The beds are effective in areas where the surface soil resistivity is high. Deep-well impressed-current systems can affect cathodic protection for several miles on each side of the ground bed. Deep-well ground beds are often installed remote from the pipeline and therefore require additional right-of-way.

Linear anodes are placed near the pipeline and distribute current effectively to the pipeline in the vicinity of the anode. Trenching near the pipeline is required, and a rectifier must be installed.

Horizontally distributed anode ground beds, such as those at pump stations, can affect the pipeline for several miles in each direction. Because the anodes are distributed relatively near the surface, the ground bed is larger than a deep-well ground bed.

Impacts from remedial cathodic protection of any kind are localized and include noise and potential minor lubricant spills from support equipment. The need for remediation is determined by evaluating a combination of cathodic-protection data, corrosion-pig data, and mitigation history. During the period 2004-2034, the addition of 20 to 30 new impressed-current rectifiers can be expected. Each year, 6 to 10 anode ground beds will need to be repaired, replaced, or improved (Williams, 2000, pers. comm.).

Alyeska Pipeline Service Company

***Photo 4.1-2**. Coating mainline pipe.*

As the pipeline ages, the coating degrades, more bare metal is exposed, and greater demands on the cathodic protection system result. The system may ultimately not be able to supply sufficient corrosion protection to TAPS. At this point, either additional protection must be added or the coating must be refurbished. Coating refurbishment requires excavation of the pipeline one segment at a time to allow placement of a new coating (Photo 4.1-2). It is estimated that rehabilitation of less than 5 miles of pipeline will occur during the ROW renewal period (Klechka, 1999, pers. comm.).

4.1.1.6 River Crossings and River Training Structure Repairs

During design, it was anticipated that maintenance of existing river-training structures would be necessary and that new structures might be needed in response to major floods or stream migration. Some repair and new structures are required almost every year. A typical repair may involve adding riprap to a washed-out spur nose or to bank riprap.

Impacts from maintenance or construction of river training structures are primarily noise, dust, gravel and rock mining (either local or remote), and sediment generation from instream activities. All work is done in accordance with environmental permits. Emergency or temporary repair work is done in accordance with methods practical at the time for the specific location with oversight by regulatory agencies.

In addition to maintenance of river training structures to ensure pipeline integrity, repairs or additions may also be made to facilitate right-of-way access. For example, a dike was constructed along McCallum Creek in 1999 to mitigate workpad overflows caused by icings. In the Atigun River floodplain, repairs to the workpad were necessary in the 1990s to maintain access to a check valve.

4.1.1.7 Surveillance Actions

Surveillance has minimal ground-impacting mechanisms, because surveillance uses conventional vehicles on established work areas. Much of the surveillance during summer is by helicopters or by four-wheel-drive trucks on the workpad and access roads. In winter, snow vehicles and helicopters are used.

4.1.1.8 Fuel Gas Line Maintenance and Repair

Annual regrading and backfilling of the cover over the fuel gas line are required because of seasonal temperature variations and water runoff. Sections of the line are subject to thermal uplifting (jacking) each year due to cold gas temperatures. These sections are analyzed for stress and corrosion, and evaluated using an integrity-based approach. Several hundred feet of the line are reburied each year (Sorenson, 2000, pers. comm.).

Rectifiers located at Pump Stations 1, 2, 3, and 4 provide cathodic protection for the fuel gas line, and the 74 test stations are monitored annually. Remediation of this system is based on a risk assessment and U.S. Department of Transportation requirements.

Impacts result from excavation equipment, trucks, and vehicles on the right-of-way of the fuel gas line. After repairs are complete, the right-of-way is regraded and revegetated. Impact is minimized by performing most work in the winter. Most of the fuel gas line was built from snowpads, and no permanent gravel workpad exists. However, the fuel gas line runs adjacent to the oil pipeline workpad or adjacent to the Dalton Highway, both of which provide access.

4.1.1.9 New Material Sites/Rock Quarries

Gravel materials will be needed for the maintenance and repair of the ROW. Rock quarries produce riprap to maintain and repair river and floodplain bank-protection dikes and levees. The impact mechanisms are earth-moving equipment removing vegetation and soil overburden from the area of the site and construction of access roads. Heavy trucks will travel the access road to deliver materials to the maintenance areas. After the material sites and access roads are no longer needed, these sites will be contoured and revegetated in accordance with permit requirements. For additional discussion on the impact of gravel/rock mining, see Section 4.3.1.1.

4.1.2 Spill Analysis

By IT Corporation staff, L.D. Maxim, and R. Niebo

Of the possible adverse impacts of continued operation of TAPS, a large oil spill is potentially of greatest concern. This section summarizes the results of an historical analysis of oil spills from North Slope oil production and transportation Operations[1] from 1977 to 1999 and uses these data, together with estimates of possible improvements in spill prevention measures, to estimate probable spill volumes and the likelihood of large [>1,000-barrel (bbl)] spills occurring for the ROW renewal period (2004-2034). See Appendix B for a more comprehensive technical analysis.

Since the statistical characteristics of oil spills differ among the activities that produce or transport oil, data are provided for each of four distinct segments of Operations:

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

Based on the definition of TAPS in the Federal Grant (Stipulation 1.1.1.22), neither E&P nor marine transportation is part of TAPS. However, these are elements in the production and transportation system and are included for use in the impact discussions in Section 4. Table 4.1-1 identifies the spill potential associated with each segment.

Past Operations have resulted in spills of various materials, including the following:

- Crude oil.
- Refined products (“product”), such as aviation fuel, diesel fuel, gasoline, turbine fuel, motor oil, lubrication (lube) oil, and hydraulic oil.
- Other substances, such as acetone, mercury, propane, antifreeze, Therminol, Halon, and corrosion inhibitor.
- Water (e.g., ballast water, oily water, saltwater).

In accord with the spill analyses presented in recent documents such as the environmental assessment (EA) for the Alpine Development (USACE, 1997), the environmental evaluation documents for NPR-A (BLM and MMS, 1998), and the Beaufort Sea and Chukchi environmental impact statements (EISs) prepared by the Minerals Management Service (MMS, 1987a, b, 1990, 1996a), this spill analysis focuses on crude spills, although data and projections are given for both crude and product spills. Crude spills result from some loss of system integrity in events such as a tank valve failure, pipeline cracks, and tanker

[1]The term *Operations* is capitalized in this discussion and refers to North Slope oil production and transportation.

Table 4.1-1. *North Slope production and transportation system segments employed in oil spill analysis.*

Segment	Segment Boundary	Where Spilled	Sample Major Spill Events	Principal Data Sources
Exploration and Production (E&P)	North Slope oil fields to Pump Station 1	North Slope oil wells, feeder pipelines, and other Alaska North Slope facilities	• Leaks on pads • Well workover/ maintenance spills • Loading/unloading spills at crude oil topping units	BP/ARCO; ADEC
Pipeline	Pump Station 1 to metering station at VMT	Distributed along length of pipeline, at pump stations, associated tanks farms, and access roads	• Steele Creek sabotage incident • Atigun Pass pipe settlement • Tank valve failure at Pump Station 10 • Check Valve 92 failure	APSC; ADEC
Valdez Marine Terminal (VMT)	Metering station to loading arm(s)	Within VMT	• 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)	• *Thompson Pass* hull crack • *Exxon Valdez* grounding • Loading/unloading spills	APSC; ADEC; USCG

groundings leading to penetration of crude tanks. Product spills generally result from ancillary or supporting activities — e.g., diesel spills from fueling vehicles.

4.1.2.1 Data Sources and Compilation

IT Corporation compiled a master database of spills for all segments from 1977 when the first oil flowed through TAPS until the cutoff date for this analysis (August 1999)[2]. This database includes spills of crude, product, "other," and water. The principal sources of E&P spill data are spill databases maintained by ARCO Alaska, Inc., BP Exploration (Alaska) Inc., and Alyeska Pipeline Service Company. The principal source of pipeline and VMT spill data is the Alyeska database. The principal sources of marine transportation spill data are databases maintained by Alyeska for Valdez and Prince William Sound (PWS) and by the U.S. Coast Guard (USCG) for U.S. waters. These data were augmented by and checked against data available from other agencies, including the Alaska Department of Environmental Conservation (ADEC), U.S. Environmental Protection Agency (EPA), and the Office of Pipeline Safety (OPS), Research and Special Programs Administration, U.S. Department of Transportation. Likewise, tanker spills at U.S. destination ports (not originally contained in the Alyeska database) available from the USCG were included. Consistency checks among the various databases enabled deletion of duplicate records and other adjustments.

The database contains information on the number and volume of spills. Many spills — particularly small ones — occurred inside buildings, within secondary containment structures, or on gravel pads, and/or were otherwise contained. The size threshold for spill reporting varies with the segment (see Appendix B), but many spills in the database are less than 1 teaspoon.

4.1.2.2 Data Analysis

Appendix B presents several statistical analyses of historical crude and product spills, including a study of the number and volume of spills by segment, the development of descriptive statistics, comparisons of spill volumes with original estimates and various benchmarks, evaluation and characterization of the size distribution of spill volumes, and an examination of relevant time trends.

Since spills are accidental events that are probabilistic rather than deterministic, it is essential to characterize them in statistical terms. This analysis provides estimates of the average spill volume either for the entire duration of the ROW renewal period or on an annual basis. The spill histories of Operations and other oil production and transpor-

[2]Since August 1999, no large oil spills have been associated with TAPS; the last large (>1,000 bbl) spill occurred in 1990 (Table 4.1-2). 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 (Figure 4.1-5), 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.

tation systems exhibit substantial year-to-year variability in spill volumes. Even though future spill volumes are likely to decrease in aggregate, largely as a result of prevention measures applicable to the marine transportation segment, such variability is likely to continue.

The statistical analysis reflects current knowledge about oil spill statistics found in applicable literature (see, e.g., Amstutz and Samuels, 1984; Anderson, C.M. and LaBelle, 1990, 1994; CONCAWE, 1998; LaBelle and Anderson, 1985; Lanfear and Amstutz, 1983; Smith, Slack et al., 1982). Key findings are highlighted below.

Aggregate Spill Totals and Distribution by Operations Segment

For all Operations segments, approximately 10,600 spills occurred involving a total volume of approximately 327,100 bbl (14,870 bbl/yr) of either crude or products over 22 years. The total spill volume is dominated by a single catastrophic event, the *Exxon Valdez* oil spill (EVOS) in 1989. This single event accounts for 78.6 percent of the total volume of crude and product spilled.

Figure 4.1-2 shows how the spill *volume* varies with material spilled (crude and product) by segment, and Figure 4.1-3 presents similar information for the *number* of spills. The respective shares of the total volume of crude and product spilled by segment are:

- E&P, 3.36 percent (50.87 percent of total number);
- Pipeline, 9.56 percent (29.94 percent of total number);
- VMT 1.26 percent (11.16 percent of total number); and
- The marine transportation link, 85.82 percent (8.04 percent of total number).

Product spills are more numerous (77.1 percent of the total number of spills), but because these typically involve smaller spills, account for only 3.21 percent of the total volume of crude and product spilled.

Figure 4.1-4 shows a histogram of the total number of crude and product spills in gallons for all Operations segments. The class intervals are shown in orders of magnitude. About 32 percent (3,338 of 10,577 spills) fall in the range of 0 to 1 gal. Another 43 percent of these spills fall into the 1 to 10-gal range. Beyond this, the number and percentage of spills fall off rapidly with spill size. Small spills are thus most numerous. However, while few in number, large spills account for most of the total volume spilled.

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 4.1-2 shows summary information about the 10 largest oil spills, including both crude and product spills, over the operating history of TAPS. MMS uses a threshold of 1,000 bbl for a large spill. Expanding this list by one additional spill (Table 4.1-2, bottom) includes all spills greater than or equal to 1,000 bbl. 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 bbl (the *Thompson Pass* spill) to 257,143 bbl (the EVOS) and account for approximately 93.5 percent of the total volume spilled. If all spills greater than 1,000 bbl are included, the 11 largest spills account for 94 percent of the total volume. As noted above, there are 10,577 recorded spills from 1977 to 1999. Thus, only 11 out of 10,577 (0.1

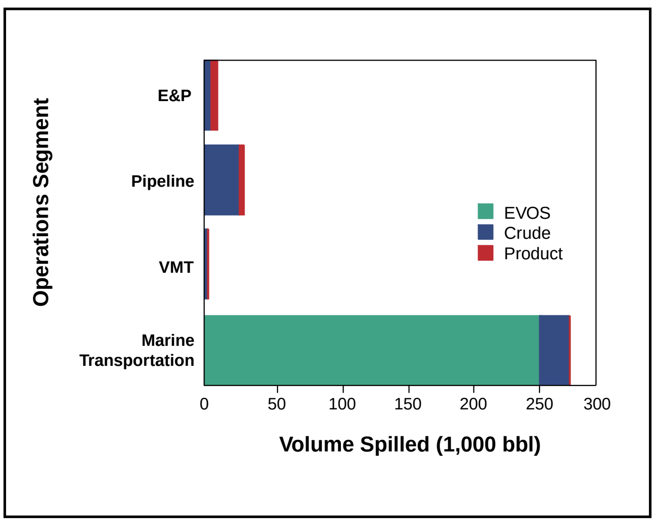


Figure 4.1-2. *Distribution of total spill volume by segment for both crude and product spills (1977-1999).*

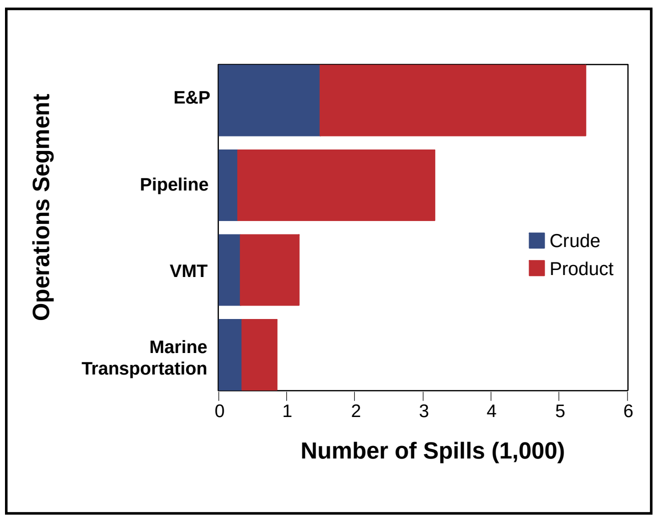


Figure 4.1-3. *Distribution of total number of spills by segment for both crude and product spills (1977-1999).*

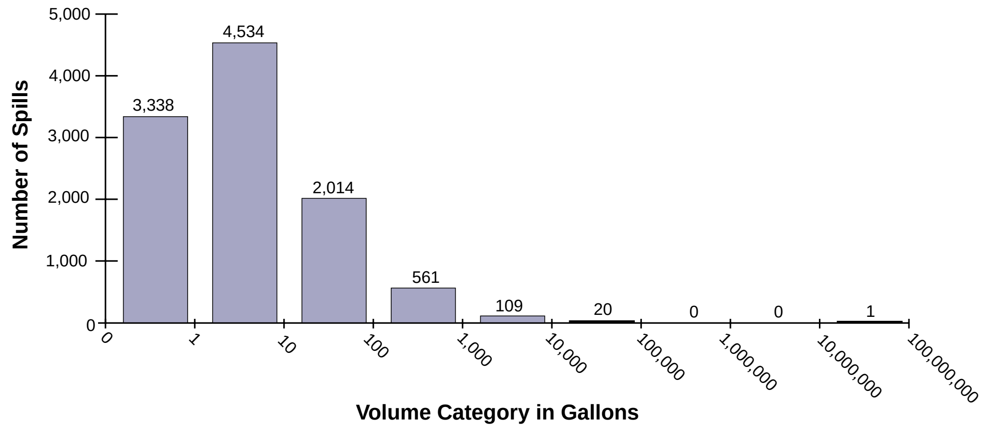


Figure 4.1-4. *Number of spills by volume category (1977-1999). Total spills=10,577. Spills include ANS, TAPS, VMT, and marine transport.*

percent) of the spills account for 94 percent of the total spill volume. Figure 4.1-5 shows the fraction of total crude and product spills accounted for by the largest spill, next largest 10 spills, 100 spills, 1,000 spills, and the remaining 9,466 spills.

- Five of the largest ten spills (EVOS, *American Trader, ARCO Anchorage, Glacier Bay,* and *Thompson Pass)* occurred on the marine transportation segment. There were four large pipeline spills (five >1,000 bbl) 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 occurred in Port Valdez or Prince William Sound. 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 without TAPS, but when oil is being handled, the statistical chance of oil spills exists.

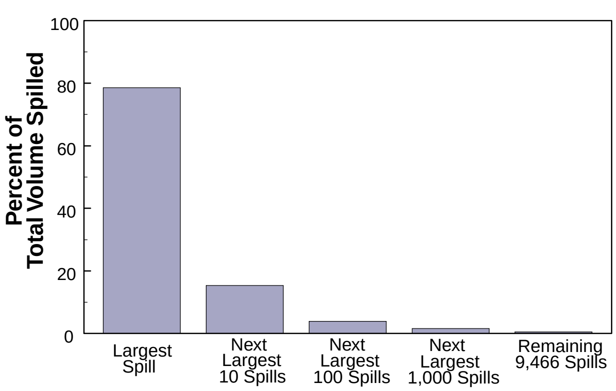


Figure 4.1-5. *Fraction of total volume (crude and product) spilled accounted for by largest spills.*

Operations Spills in Context

While the total volume of crude and product spilled since TAPS operation started is substantial, it is much lower than estimated in the original TAPS EIS (BLM, 1972). The authors of the original EIS did not consider E&P spills and lacked the data to project pipeline or VMT spills. Instead, they estimated a range of values for marine-transportation spill volumes. When adjusted for year-to-year variations in throughput and totaled over the 22-year period, the original estimate would range from 2.6 million to 5.9 million bbl, substantially greater than the 0.33 million bbl actually spilled.

The total volume of crude and product spilled in Operations is small compared to the amount of material produced and handled. One measure often used to characterize spill performance is the *volumetric spill rate,* defined as the number of barrels of material spilled divided by the barrels handled. These rates are typically calculated in units of bbl spilled per million bbl of throughput. Volumetric spill rates are as follows:

- All segments, 25.6;
- E&P, 0.86;
- Pipeline, 2.45;
- VMT, 0.323; and
- Marine transportation, 22.03.

Table 4.1-2. *Crude or product spills >1,000 bbl for Operations (1977-99).*

Event	Date Material Spilled	Quantity Spilled (bbl)	Material Spilled	Operations Segment	Description
Exxon Valdez	March 24, 1989	257,143	Crude oil	Marine	Tanker went aground on Bligh Reef, Prince William Sound
Steele Creek, MP 473.53	February 15, 1978	16,000	Crude oil	Pipeline	Leak caused by sabotage
American Trader	February 7, 1990	9,458	Crude oil	Marine	Vessel grounded on own anchor during mooring at Golden West Marine Terminal off Huntington Beach, CA.
ARCO Anchorage	December 21, 1985	5,690	Crude oil	Marine	Tanker ran aground in Port Angeles, WA
Glacier Bay	July 2, 1987	4,942	Crude oil	Marine	Tanker struck rock and went aground in Cook Inlet
MP 734	June 15, 1979	4,000	Crude oil	Pipeline	Pipe wrinkled and cracked due to settlement
Valdez Marine Terminal (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
Thompson Pass	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 Operations oil spill data base 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)Spill volume was 1,500 barrels per Alyeska records, but 2,000 barrels per JPO records. The larger volume was used in this analysis.
For additional material on marine spills, see the following:
Exxon Valdez: ADEC (1993), Nadler (1994), NRC (1991, 1998), Davidson (1990), Keeble (1991), NTSB (1990)
American Trader: NRC (1991), Nadler (1994), Epler (1990)
Glacier Bay: Davidson (1990), Nadler (1994), Little (1999), Wohlforth (1991), Bernton (1987a, b), Chappel (1987), Foster (1987), Kizzia (1990)
ARCO Anchorage: Nadler (1994)
Thompson Pass: Nadler (1994), Davidson (1990), Keeble (1991), Epler (1989a, b)

Operations spill experience can also be put in context by another measure. To project spills, MMS uses a spill rate defined as the number of >1,000-bbl spills per billion bbl of throughput. Because no large E&P spills have occurred, the spill rate for this segment is 0. For the pipeline and VMT together, the combined spill rate is 0.47. For the marine transportation link, this spill rate is 0.39. In analyzing outer continental shelf platforms and pipelines, MMS developed estimates of spill rates of 0.45 for platforms and 1.32 for pipelines (Anderson and LaBelle, 1994). Both rates are considerably greater than those for corresponding segments of Operations (Figure 4.1-6). These comparisons help provide quantitative perspective.

As noted above, small spills are most numerous, but large spills account for the vast majority of the total spill volume. This is true in aggregate and on a segment-by-segment basis (see Appendix B). A brief summary of relevant spill statistics for each segment from 1977 to 1999 is pre-

sented below.

E&P Spills. Spills from this segment range from 0.0015 to 925 bbl for crude and 0.0006 to 450 bbl for product. Fifty percent (the median) of E&P crude spills are ≤0.238 bbl (slightly less than 10 gal), while 50 percent of E&P product spills are ≤0.119 bbl (slightly less than 5 gal).

The smallest 90 percent of E&P crude spills account for approximately 13 percent of the total volume spilled, while the smallest 90 percent of product spills account for 16 percent of the total volume spilled.

The cumulative distribution function (CDF) provides another perspective on spill volumes. Figure 4.1-7 shows the CDFs for E&P crude and product spills. 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). Because of the large variability of spill volumes, only a portion of the CDF is plotted in Figure 4.1-7: that for spills ≤2 bbl. For E&P spills, 84.1 percent of crude spills and 92 percent of product spills are <2 bbl.

Pipeline Spills. Spills from this segment range from essentially zero to 16,000 bbl for crude and zero to 238 bbl for products. Fifty percent (the median) of pipeline crude spills are ≤0.0476 bbl (2 gal), while 50 percent of the pipeline product spills are ≤0.071 bbl (3 gal).

The smallest 90 percent of pipeline crude spills account for approximately 0.25 percent of the crude volume spilled, while the smallest 90 percent of product spills account for 6.2 percent of the product volume spilled.

Figure 4.1-8 shows the CDFs for crude and product pipeline spills. For pipeline spills, 88.0 percent of crude spills and 96.3 percent of product spills are <2 bbl.

VMT Spills. Spills from this segment range from essentially zero to 32,100 bbl for crude and zero to 29 bbl for products. Fifty percent of VMT crude spills are ≤0.0238 bbl (1 gal), while 50 percent of VMT product spills are ≤0.00595 bbl (0.25 gal).

The smallest 90 percent of VMT crude spills account for approximately 0.81 percent of the total volume of crude spilled for this segment, while product spills account for 4.2 percent of the total volume of product spilled.

Figure 4.1-9 shows the CDFs for VMT spills, of which 95.3 percent of crude spills and 97.4 percent of product spills are <2 bbl.

Marine Transportation Spills. Spills from this segment range from essentially zero to 257,143 bbl for crude and zero to 681 bbl for products. Fifty percent of marine transportation crude spills are ≤0.0476 bbl (2 gal), while 50 percent of marine transportation product spills are ≤0.006 bbl (0.25 gal).

The smallest 90 percent of marine transportation crude

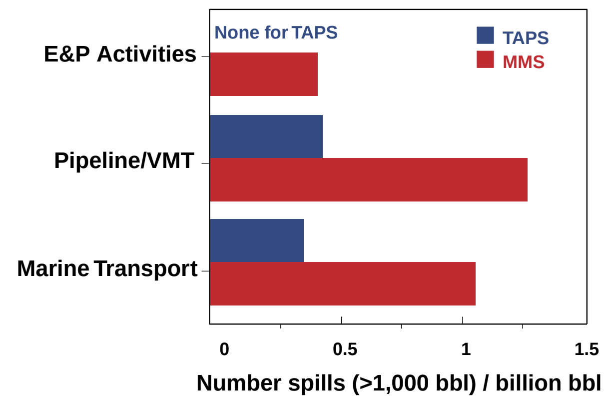


Figure 4.1-6. *Number of large (>1,000 bbl) spills per billion bbl throughput for Operations segments compared to MMS data.*

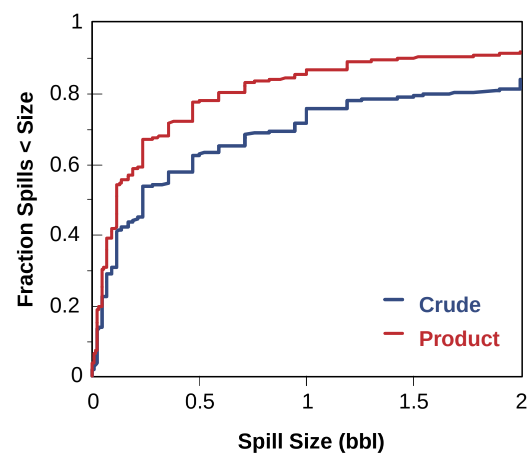


Figure 4.1-7. *Cumulative distribution function for E&P spills (1977-1999).*

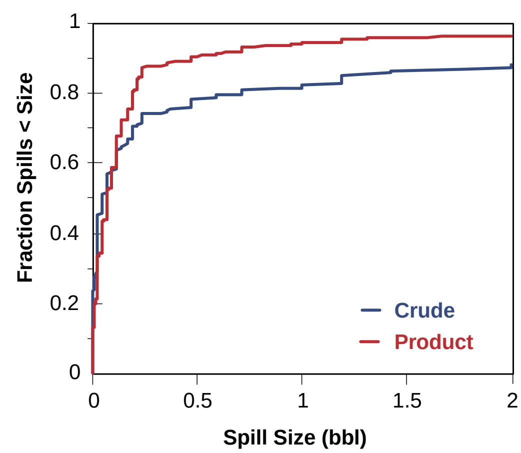


Figure 4.1-8. *Cumulative distribution function for pipeline spills (1977-1999).*

spills account for 0.03 percent of the total volume of crude spilled on this segment, while the smallest 90 percent of product spills account for 0.87 percent of the product volume spilled.

Figure 4.1-10 shows the CDFs for marine transportation spills: 87.2 percent of crude spills and 95.4 percent of product spills are <2 bbl.

Conclusion. The large spill rates for various segments of Operations compare favorably with MMS estimates for outer-continental-shelf platforms and pipelines. Analyses of spill data from both sources indicate that the *total number of spills* is not a statistic of particular relevance. Rather, analytical effort should be focused on large (defined by MMS as >1,000 bbl) spills and/or on the total volume of material spilled. Small spills, though numerous, do not account for an appreciable fraction of the volume spilled.

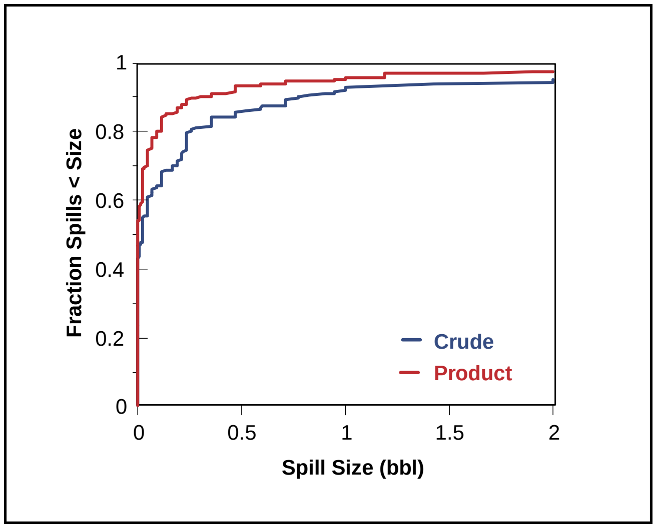


Figure 4.1-9. *Cumulative distribution function for VMT spills (1977-1999).*

4.1.2.3 Projections of Future Spill Volumes

Time Trends

This section analyzes spill rates, based on spill volumes per million barrels handled, to see if there are trends over time. Time trends provide a useful basis for making informed projections of future spill volumes associated with continued operation of TAPS if the ROW is renewed. Consequences of the no-action alternative are discussed in a later section.

This analysis develops conservative projections of spill volumes over the period of ROW renewal (2004-2034). Management of Alyeska and E&P operators have expressed commitment to reducing spill volumes. To the extent that these efforts are successful, future spill volumes will be less than those estimated here.

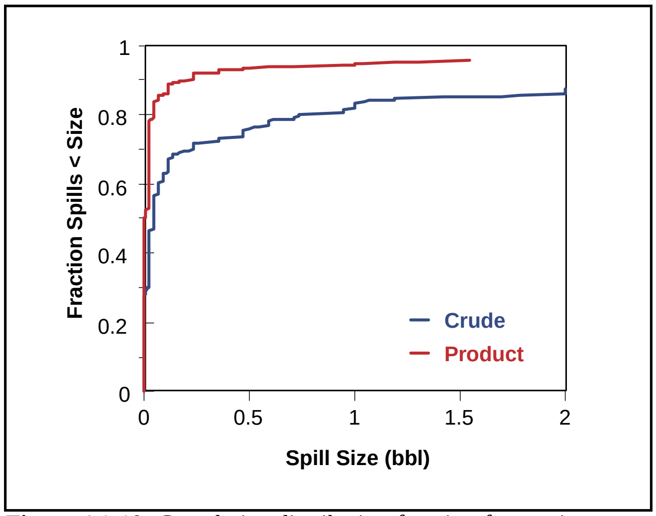


Figure 4.1-10. *Cumulative distribution function for marine transportation spills (1977-1999).*

E&P

Figure 4.1-11 presents volumetric spill rates in bbl spilled/million bbl throughput by year for the E&P segment from 1977 to 1999. The y-axis is the volumetric spill rate defined as the total annual volume of crude and product spilled divided by the total annual crude throughput. There is substantial variability (approximately one order of magnitude) in year-to-year volumetric spill rates over this period and little apparent trend — an impression supported by statistical regression analysis. Absent a trend or persuasive evidence of a step change, the historical average volumetric spill rate provides the best estimate of future spills for this segment. Dividing the total amount spilled by the total throughput from 1977 to 1999 yields an average annual spill rate of 0.86 bbl/million bbl throughput.

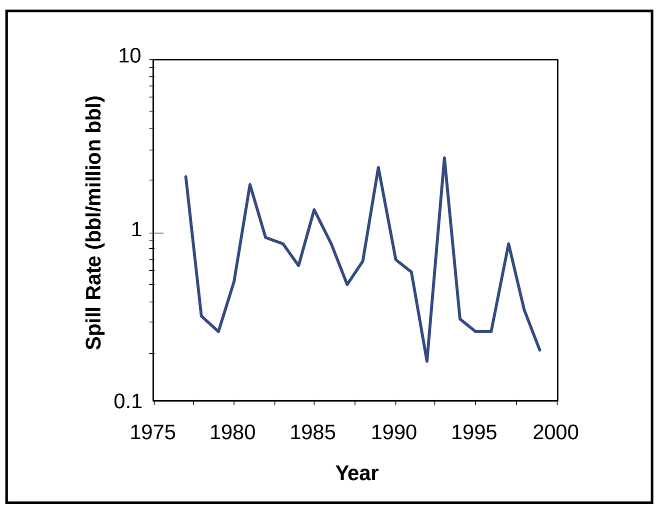


Figure 4.1-11. *Volumetric spill rate for ANS E&P operations (1977-1999).*

Because TAPS throughput volumes are projected to de-

crease in the future (see Appendix A), the assumption of a constant average volumetric spill rate (per million bbl throughput) means that future E&P spills will decrease in proportion to throughput. Based on the baseline future TAPS throughput assumption from the year 2004 to 2034 of 7.02 billion bbl, the projected volume of E&P crude and product spills is approximately 6,050 bbl for the period — an average of 202 bbl/year.

Pipeline

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

Figure 4.1-12 presents volumetric spill rates by year for the pipeline segment. As with the data from all other segments, there is substantial variability (approximately three orders of magnitude for this segment), but evidence of a downward trend in volumetric spill rates in later years. (All large pipeline spills occurred during first five years of operation of TAPS. None has occurred since 1987). A linear regression line (the dashed line in Figure 4.1-12) has a negative slope, which is significantly different from zero ($p = 0.001$), confirming the visual impression offered by Figure 4.1-12. Nonetheless, the predictive power of the linear trend model 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.

The average volumetric spill rate of crude and product is 2.45 bbl spilled/million bbl throughput. From the baseline throughput assumption, 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.

VMT

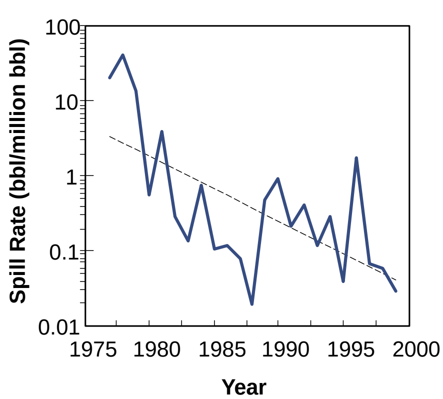
Figure 4.1-13 presents calculated volumetric spill rates for the VMT segment. Volumetric spill rates are highly variable (about four orders of magnitude), and there is no evident time trend. The annual average spill rate is 0.32 bbl crude and product spilled/million bbl throughput, which translates to a total spill volume of 2,270 bbl and an average of 76 bbl/year over the ROW renewal period.

Marine Transport

Figure 4.1-14 presents comparable rates for the marine transportation segment. Variability is nearly six orders of magnitude, and there is no statistically significant time trend, although the post-1990 decrease is believed to be real. The annual average volumetric spill rate for this segment is 22 bbl crude and product spilled/million bbl crude throughput — for a projected spill volume of approximately 154,400 bbl (5,147 bbl/year) over the ROW renewal period. Because marine transportation spills are potentially so important, this projection is examined in more detail.

Future Marine Transportation Spills

The historical importance of marine transportation spills justifies a more careful examination of the prospects of future spills than 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 reasonable to claim that it is impossible for



Note: Dashed line is linear regression line.

Figure 4.1-12. *Volumetric spill rate for pipeline (1977-1999).*

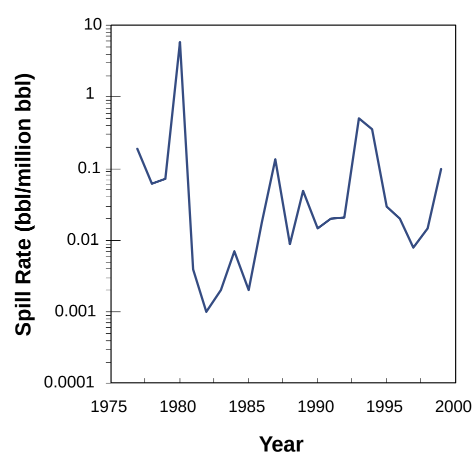


Figure 4.1-13. *Volumetric spill rate for VMT (1977-1999).*

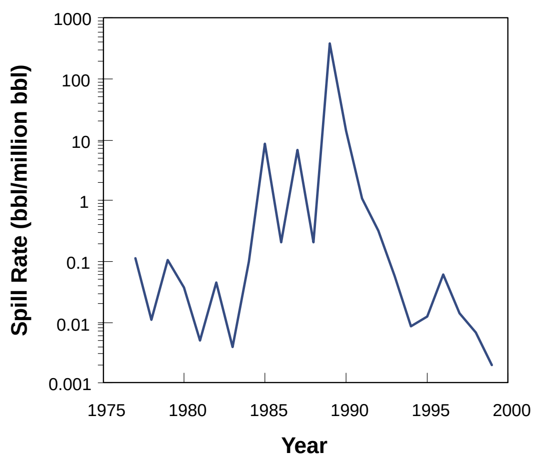


Figure 4.1-14. *Volumetric spill rate for marine transportation (1977-1999).*

a very large tanker spill to occur during the period covered by the ROW renewal. However, based on lessons learned from the 1989 EVOS, on new legislation such as the Oil Pollution Act of 1990 (OPA 90), and on new regulations, numerous improvements have been made that are likely to reduce the probability of a major marine transportation accident and/or the projected spill from one. Marine transportation companies have used detailed risk assessments to identify critical areas for improvement. These measures fall into two main classes:

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

Key spill-prevention measures include provision of tanker escorts, an enhanced USCG-staffed Vessel Traffic Service, more stringent weather constraints on tanker operation, use of ice routing measures, and mandatory alcohol testing of tanker officers. Other measures are discussed in Section 4.2.3.3. Collectively, these measures are designed to substantially reduce the likelihood of a tanker accident and subsequent spill.

Among other things, OPA 90 established a schedule for closing U.S. ports to single-hull tankers. By 2014, all tankers calling at the VMT will have double hulls. Thus, for the final 20 years of the 30-year ROW renewal period, the tanker fleet for transporting Alaska North Slope (ANS) crude oil will consist exclusively of double-hull tankers. Of 26 tankers now serving VMT, three are double-hull, 13 have double bottoms, and an additional seven double-hull tankers are on order and scheduled to enter service before the existing 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 4.1-3 provides several estimates of the benefits of double-hull tankers in terms of a reduced probability of an oil spill and/or reduced outflow from a spill. Of these, the most 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. 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 between 3 and 4.

Taken together, improvements in spill prevention measures and phase-in of double-hull tankers should appreciably reduce spill probabilities and spill outflows in PWS. There is already statistical evidence from other parts of the world that tanker spills are becoming less likely. USCG 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, this analysis assumes a range of possible spill-reduction factors. 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.

Spill Projections

Projections of the likelihood and volume associated with large spills during the ROW renewal period were developed based on the spill projection methodology employed by MMS, on TAPS experience, on estimates of the possible reduction of spill rates brought about by Alyeska measures taken in PWS, and on the benefits of replacing the existing fleet of single-hull tankers with double-hulls. In brief, the methodology is as follows:

- Marine transportation data 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

Table 4.1-3. 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.	National Research Council (NRC,1998)
"After the Exxon Valdez 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 Exxon Valdez 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.	Exxon Valdez Oil Spill Trustee Council web site (www.oilspill.state.ak.us)
"If the Exxon Valdez 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 (1999)
"A risk assessment study done in 1995 found the risks of another spill have been reduced by 75%, according to Michelle Brown, Commissioner 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)

the ROW renewal period is multiplied by the base-case spill rate to determine the projected number of large spills.

- This estimate is multiplied by several possible improvement factors to reflect the changes made to the spill prevention and response systems to calculate a revised estimate of the projected number of future spills.
- The Poisson model is employed to calculate the probability of any number of spills over the ROW renewal period based on the revised estimates of the mean number of spills.
- Estimates of the average size of the large spills are presented.

The Poisson model has been found applicable for oil spill statistics (Smith, Slack et al., 1982) and is employed in the standard MMS methodology for projecting spill probabilities. 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 projected number of large spills, μ, is equal to λT. Given μ, the probability of exactly k spills (k = 0, 1, 2, etc.) over the future production period is:

$$p[k, \mu] = e^{-\mu} \frac{\mu^{-k}}{k!}$$

Figure 4.1-15 shows the probability of 0, 1, 2 . . . large spills 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 is nearly 94 percent over the ROW renewal period. The corresponding probabilities for improvement fac-

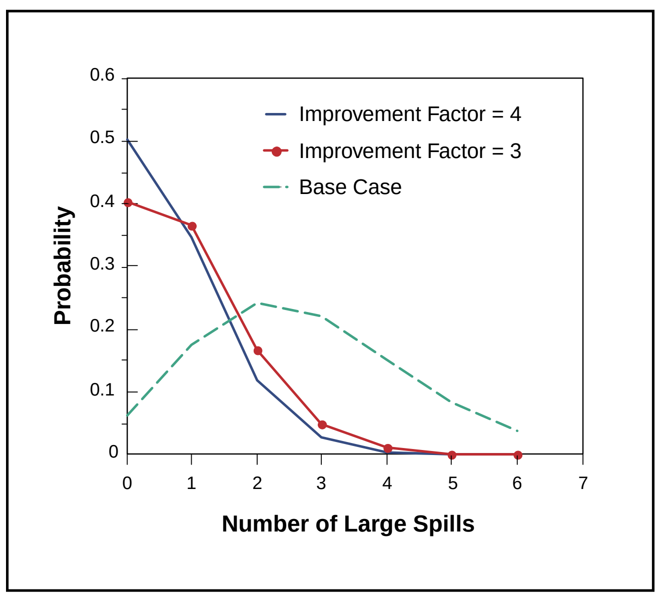


Figure 4.1-15. *Probability distribution of number of large spills in ROW renewal period (2004-2034).*

tors of 3 and 4 are 60 percent and 50 percent, respectively.

Although a large spill is defined as >1,000 bbl, the average volume of such spills is greater than this threshold. Based on observed marine-transportation spills for Operations from 1977 to 1999 (including EVOS), the average size of all spills >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. For example, a recent EIS posits an average large spill volume of 30,000 bbl for ANS tankers (MMS, 1996a).

Based on the MMS oil spill methodology and conservative estimates of possible improvement, this analysis concludes that over the ROW renewal period from 2004 through 2034:

- 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 projected 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 over the ROW renewal period ranges from 20,700 bbl (0.69*30,000) to 82,500 bbl (2.75*30,000). Spread over 30 operating years, the average volume spilled over the marine transportation segment ranges from 690 to 2,750 bbl/yr.

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

Future Small Spills

Because large spills account for the vast majority of the oil spilled in the marine transport segment, 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. Nonetheless, for the sake of completeness, these are included.

Figure 4.1-16 shows a time series of the annual volumetric spill rate (crude and product total) from 1977 to 1999 for spills <1,000 bbl. There is no statistically significant time trend, although it is possible that these have decreased since 1991. Some of the post-1990 measures discussed above, though targeted at large spills, may also reduce the frequency and/or volume of small spills. These potential benefits are disregarded in this analysis.

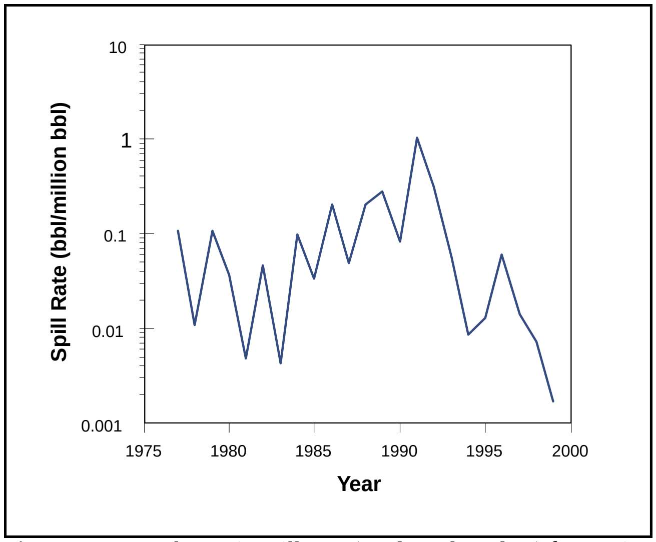


Figure 4.1-16. *Volumetric spill rate (crude and product) for marine transportation spills <1,000 bbl.*

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 renewal period, the total volume of small spills is estimated to be approximately (1000*0.1404*7.02) = 987 bbl, or 32.9 bbl/yr. As expected, this is very small compared to the projections for large spills (690 to 2,750 bbl/yr).

Spill Projections

Tables 4.1-4 and 4.1-5 summarize the above quantitative analysis and present estimates of the future spill volumes from the proposed action. Table 4.1-4 is based solely on historical data, while Table 4.1-5 is based on historical data and an allowance for the effects of preventive measures implemented in recent years.

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

The estimate of 6,000 bbl/yr does not reflect any allowance for improvements to the system. As noted in Section 4.2.3.3 and Appendix B, since 1990 there have been many changes made to the marine transportation system — and more in prospect — that are designed to reduce the likelihood of an accident and/or the amount of oil spilled in the event of an accident. Some of these were implemented as early as 1990, others throughout the 1990s, and yet others are scheduled to be implemented during the ROW renewal period. For example, Sections 4.2.3.2 and 4.2.3.3 provide information on the measures used to control spill frequency and amount at VMT and along various segments of the ma-

Table 4.1-4. *Estimates of future oil spills based on historical data only.*

Segment	Total Volume 2004-2034 (bbl)	Average per Year 2004-2034 (bbl)	Remarks
E&P Operations	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 4.1-5. *Estimates 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 4.1-4 above

rine transportation link.

One way to estimate the impact of these spill prevention and response measures is to partition the data set into time segments (i) 1977 to 1989 and (ii) 1990 to 1999 (the post-EVOS period). This partition is designed to reflect the effects of the enhancements made to various Operations segments made from 1990 onwards.

Using the same methodology described above but limiting data to the period from 1990 to 1999 results in a revised projection of the annual spill volume (all segments) for the ROW renewal period of approximately 750 bbl/yr (see Appendix B, Table B-9) rather than the 6,000 bbl/yr estimate shown in Table 4.1-4 — an 88 percent reduction. This difference is largely accounted for by a substantial reduction in the spill volume projection for the marine transportation link. To avoid any possible understatement of future spill volumes, this projection is not used elsewhere in this Environmental Report. Nonetheless, it is plausible and provides some idea of the possible conservatism in the estimates given in Table 4.1-4.

Another approach for factoring in the possible improvements made — particularly in the marine transportation segment — is used in this analysis. Projections for E&P, pipeline, and VMT spills are based on volumetric spill rates derived above. However, projections for the marine transportation link are based on methodology used by MMS for large (>1,000 bbl) spills and volumetric spill rates for small spills. This approach uses data for the entire time period (1977 to 1999), but makes allowance for the system enhancements using a range of possible improvement factors based on literature estimates of the benefits of new technology. For all segments of Operations, the estimated annual spill totals for the ROW renewal period range from approximately 1,600 to 3,600 bbl (Table 4.1-5). These estimates represent the average annual spill volume (all segments) based on conservative assumptions:

- No improvements are reflected in the estimates for E&P, pipeline, and VMT.
- A range of possible improvement is assumed for the marine transportation link, which translates into a corresponding range of average annual spill volumes from 723 to 2,783 bbl. The upper end of this range assumes very conservatively that no system improvements result, the lower end reflects plausible (but still conservative) estimates of possible improvement. Thus, not all values in this range should be thought of as equally likely. Values at the lower end are more likely.

The analysis of historical large (>1,000 bbl) spill frequency (number of large spills per billion bbl throughput), future throughput projections (Appendix A), and estimates of the average size of large spills leads to the following:

- Based on a range of improvement factors, there is a 50 to 94 percent probability of one or more large spills during the ROW renewal period. The lower end of this range is more probable.
- The average size of a large spill (MMS, 1996a) is assumed to be 30,000 bbl. Both this and the above estimates are also conservative. If the historical database is limited to those marine transportation spills that have occurred from 1990 to 1999, both the estimated probability of one or more spills and the projected size of a large spill decrease substantially (Appendix B). For example, based on the number of large spills since 1990 and estimates of possible improvement resulting from double hulls and other measures, the probability of one or more large spills during the ROW renewal period ranges from 28 to 73 percent. A precise estimate of the projected spill volume per large spill is difficult because only one large spill *(American Trader*, a single-hull vessel) occurred during this period and also because it is believed that much less (and possibly no) oil would have spilled in this accident if this vessel were double-hulled.

As discussed in Appendix B, annual spill rates in this analysis are conservative when compared to a study by Det Norske Veritas et al. (1996) for the tanker trade and a study sponsored by MMS (Hart Crowser Inc., 2000) for ANS production and TAPS transportation.

Choice of the no-action alternative will lower but not eliminate the estimated spill volume in Alaska because TAPS, VMT, and North Slope E&P activities will be shut down. However, the no-action alternative will only displace these spills to other production and distribution systems — perhaps those with fewer environmental safeguards. The Cook Inlet refinery, for example, does not have a SERVS fleet to escort tankers, nor a VTS. Most E&P and pipeline spills would be displaced to the country of origin of U.S. crude oil imports. Shutting down ANS operations may lower, but will not eliminate spills in Alaskan waters, because either crude oil or refined products would have to be imported to Alaska to satisfy internal demand. Additionally, there would be some product spills during dismantlement, removal, and restoration of the North Slope production facilities, pipeline, and VMT.

Moreover, spills occurring at U.S. destination ports (e.g., refineries in Hawaii or the West Coast) would not be eliminated if ANS operations were terminated. As shown in Table 4.1-2, three of five of the largest marine spills for ANS tankers occurred at destination ports.