ALASKA
North Slope Spills Analysis

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Research & Planning Group, LLC.

PUBLICATION INFORMATION

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EXECUTIVE SUMMARY

This analysis considers the frequency, volume, and causes of oil spills resulting from loss-of-integrity of existing crude oil piping infrastructure on the North Slope. In 2010, Nuka Research and Planning Group, LLC developed a North Slope Spills Analysis (Nuka Research, 2010) for the Alaska Department of Environmental Conservation. That study investigated vulnerabilities to the crude oil infrastructure by compiling available spill data from 1995-2009, identifying causal factors, and identifying trends in loss-of-integrity spills from crude oil piping infrastructure on the North Slope. This study provides an update to the previous analysis, incorporating spill data from 2010-2011.

Focus of Spills Analysis

The geographic scope of this analysis was contained within the North Slope Region as defined in 18 AAC 75.495(a)(9) and limited to oil production infrastructure, which includes wells and associated piping, flowlines, process centers and their associated piping and above ground storage tanks, and crude oil transmission lines. This study does not include spills from the Trans-Alaska Pipeline System (TAPS), beginning with Pump Station 1 and including associated infrastructure south to Valdez.

It should be noted that the method for calculating leak rate was modified for this update. The original method for calculating leak rate included all materials spilled such as seawater. This update excludes seawater spills and only calculates leak rate based on crude oil and produced water spills.

Data Compilation and Analysis

A database was developed in 2010 for the original North Slope Spills Analysis, which contained a final set of 640 loss-of-integrity spills. Forty-one (41) loss-of-integrity spills were added from the years 2010 – 2011. Spill data was compiled from a combination of the state's SPILLS database; the operator's Oil Discharge Prevention and Contingency Plan; the state's Oil Discharge Prevention and Contingency Plan database; pipeline parameter information provided by operators, the state, incident reports; and online production statistics maintained by the Alaska Oil & Gas Conservation Commission (AOGCC).

Data completeness was judged to be poor. Many case files did not contain the information necessary to complete the record for the spill. This lack of data hampered the ability to analyze loss-of-integrity spills. Spill cause and method of leak detection are noted as areas where better data would be useful.

Once compiled, the data was analyzed by regulatory category (storage tank, oil transmission pipeline, flowline, facility oil piping, process piping, and well) and primary cause of failure (valve/seal failure, operator error, internal corrosion, thermal expansion, external corrosion, overpressure, erosion, construction/installation/fabrication, vibration, or third-party action). In each analysis the frequency of spills, total volume, spill size class, primary cause of failure, temporal trends, and spatial trends were considered. Other sections of the analysis consider leak rates, age of pipeline at failure, leak detection, and impacts. All spill volumes are reported in gallons. The analysis considers whether the frequency and volume of loss-of-integrity spills from North Slope oil and gas operations are changing over time by looking for trends in the number and total volume of reported spills.

Results

A total of 681 loss-of-integrity spills from North Slope crude oil production infrastructure resulted in the release of a reported 1,215,413 gallons from July 1, 1995 - December 31, 2011.

As with the previous study on these data, spill volume has a highly skewed distribution. The majority (65%) of loss-of-integrity spills are less than 100 gallons, but a few (14) very large spills greater than 10,000 gallons account for the majority of the volume spilled (80%). This abnormal distribution makes interpretations of data associated with spill volume difficult. The mean spill size of 1,784 gallons does not represent a typical or a probable spill and is therefore not a useful statistic. The volume of oil spilled per year is highly variable and there is no statistically meaningful trend over time. However, it should be noted that 2010 and 2011 represent the two lowest years in the dataset. There was only one spill greater than 1,000 gallons in 2010 and none in 2011, also minimums across all years studied.

The number of spills per year is more normally distributed and therefore more meaningful statistically. The average number of spills for the 14 complete years of data was 47 spills per year. There were 20 and 21 spills per year in 2010 and 2011 respectively. A linear regression of spills per year over the study period shows a statistically significant downward trend. The number of spills per year is trending down for these fields.

The largest quantity of oil was spilled from flowlines (268,358 gallons) as compared to other regulatory categories. Facility oil piping (259,163 gallons), storage tanks (247,137 gallons), and oil transmission pipelines (217,439 gallons) resulted in the second, third, and fourth largest quantities spilled. At the other end of the spectrum, wells accounted for just 66,672 gallons of oil spilled during the time period studied. Since 1995 the data show a decrease overall in the number of facility oil piping, flowline, and process piping spills and an increase in the number of well spills. However when controlling for the number of new wells the increase in this category is not significant. During the two-year data update period there were no spills from the regulatory categories of oil transmission pipelines and above ground storage tanks.

When examining the data related to the cause of the spills that occurred, statistical analysis is challenged by the subjectivity of the assignment of cause and the fact that more than one cause of failure may be assigned to a single spill. However, overall valve/seal failure is the most frequent cause of oil spills on the North Slope (especially among spills from wells), while corrosion is the most frequent cause of all spills over 1,000 gallons. Corrosion also causes an unusually high percentage of flowline spills, and is indicated to be of greater concern at Kuparuk as compared to Prudhoe Bay.

Leak rates are used to compare different oil fields and changes over time. Leak rates were calculated by volume and numbers of spills per barrels of oil production. Leak rates associated with the volume of an oil spill were too variable for use, but leak rates associated with the number of spills were useful for comparisons among fields. The Kuparuk River, Northstar, and Prudhoe Bay oil fields had rates very close to two spills per one hundred million barrels of oil produced. The Milne Point field exhibits a leak rate of more than twice this value and the Endicott field's leak rate is less than half of this value.

Leak rates were also calculated for flowlines and oil transmission pipelines as the number and volume of spills per year per thousand miles of flowline. As with other statistics, the volumetric leak rate was not useful and the sample size for oil transmission pipelines was too small to make a valid comparison. However the flowline comparison did prove useful between the Prudhoe Bay and Kuparuk River fields. The Prudhoe Bay leak rate (1.50 spills per year per thousand miles of flowline) and the Kuparuk River leak rate (1.87 spills per year per thousand miles of flowline) are consistent with studies of other facilities, which typically have fewer than two spills per year per thousand miles of pipeline.

A logistic regression model showed that flowline spills are significantly correlated to the pipeline length and age. Older pipelines and longer pipelines are more likely to have had a spill. A survival analysis shows a similar correlation between pipeline age and length and likelihood of a failure. However, the survival analysis indicates that the probability of a leak tends to stabilize after about 20 years. This indicates that once pipelines have survived the initial burn-in period, they may operate at least another 15 years without a significant increase in the probability of a leak.

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1 INTRODUCTION

In 2010, Nuka Research and Planning Group, LLC developed a North Slope Spills Analysis for the Alaska Department of Environmental Conservation (ADEC). This study provides an update to the previous data analysis. The update includes incorporating two additional years of data from 2010-2011 for loss-of-integrity spills into the core data set. The analysis includes identifying causal factors and trends in loss-of-integrity spills from crude oil piping infrastructure on the North Slope. The same methodologies used for the prior study were applied to this update.

1.1 Statement of Problem

Critical to the success of ongoing oil production from the existing North Slope crude oil infrastructure is the ability to continue reliable and safe operation of that infrastructure.

1.2 Project Goal

The goal of the 2012 North Slope Spills Data Analysis project is to evaluate the frequency and volume of spills from the North Slope crude oil piping infrastructure by continuing to analyze North Slope spill data. The 2010 study investigated risks to the crude oil infrastructure by compiling available spill data from 1995-2009. This study provides an update by incorporating spill data from 2010-2011. This study continues to consider whether spill trends over time suggest any relationship to infrastructure aging, while also looking for other trends in historic spill occurrences that could be linked to future prevention activities.

1.3 Project Scope

The scope of this project was to update the original North Slope Spills Analysis data set and Geospatial Platform by including data from January 1, 2010 to December 31, 2011. The original study analyzed available data from North Slope oil production operators during the period of July 1, 1995 to December 31, 2009.

The project approach is consistent with the 2010 North Slope Spills Analysis study and considers leaks due to loss-of-integrity, which is defined as a failure that leads to a reportable spill of any fluids in the production stream, including mechanical failures and human errors. This analysis considers the frequency, volume, and causes of North Slope oil spills by regulatory category. The following regulatory categories and definitions in state regulations provide for the basis for categorizing spills in this analysis:

- Well—Regulated by the Alaska Oil and Gas Conservation Commission- 20 AAC 25
- Facility Oil Piping—18 AAC 75.080, 75.990 (171)

- Flowline—18 AAC 75.047, 75.990(173)
- Above Ground Oil Storage Tank—18 AAC 75.065, 75.990 (165)
- Process Piping—Not regulated by Alaska Department of Environmental Conservation

As shown in Figure 1-1, oil production on the North Slope begins at the well, which is located on the well pads that are typically constructed of gravel and may be located onshore or offshore on islands. Each well produces oil, gas, and water in varying proportions. Flowlines carry this three-phase mixture from the drill site to the processing center. The processing center contains a variety of equipment, including three-phase separators and gas conditioning equipment. Oil is filtered to remove any sediment and is then routed through a crude oil transmission pipeline for delivery to Pump Station 1 of the Trans-Alaska Pipeline (TAPS). Natural gas is processed to remove liquids, then compressed and reinjected into the reservoir or used as a fuel supply for production operations. Produced water is chemically treated and also injected into the reservoir. The reinjected gas and water help to maintain reservoir pressure.

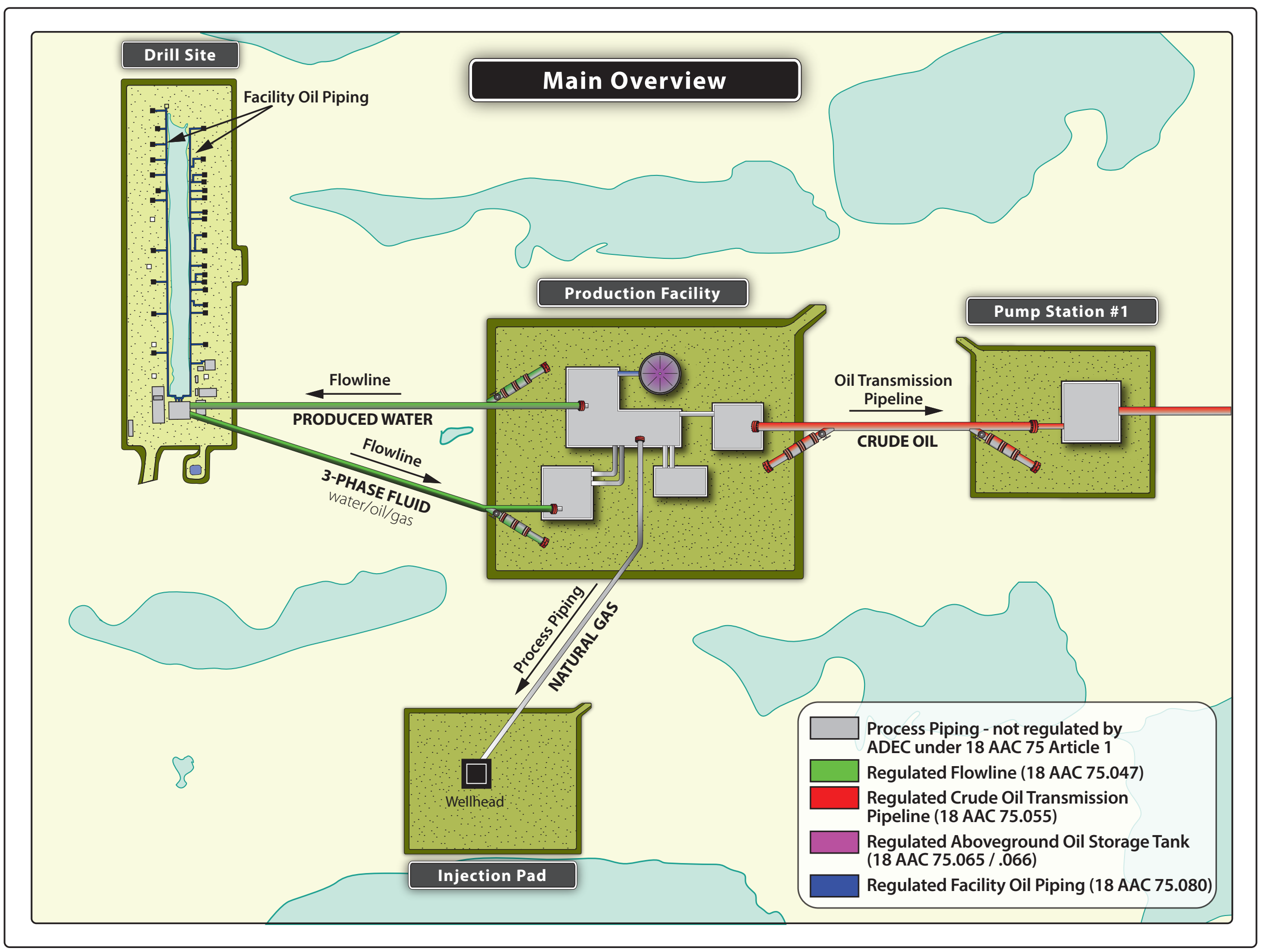

Figure 1-1. Overview of typical North Slope crude oil infrastructure components

As shown in Figure 1-2, the geographic scope of this analysis was contained within the North Slope Region as defined in 18 AAC 75.495(a)(9) and limited to oil production infrastructure, which includes wells and associated piping, flowlines, process centers and their associated piping and above ground storage tanks, and crude oil transmission lines. Pump Station 1 of the Trans-Alaska Pipeline System (TAPS) and the associated pipeline infrastructure south to Valdez was specifically excluded from this analysis.

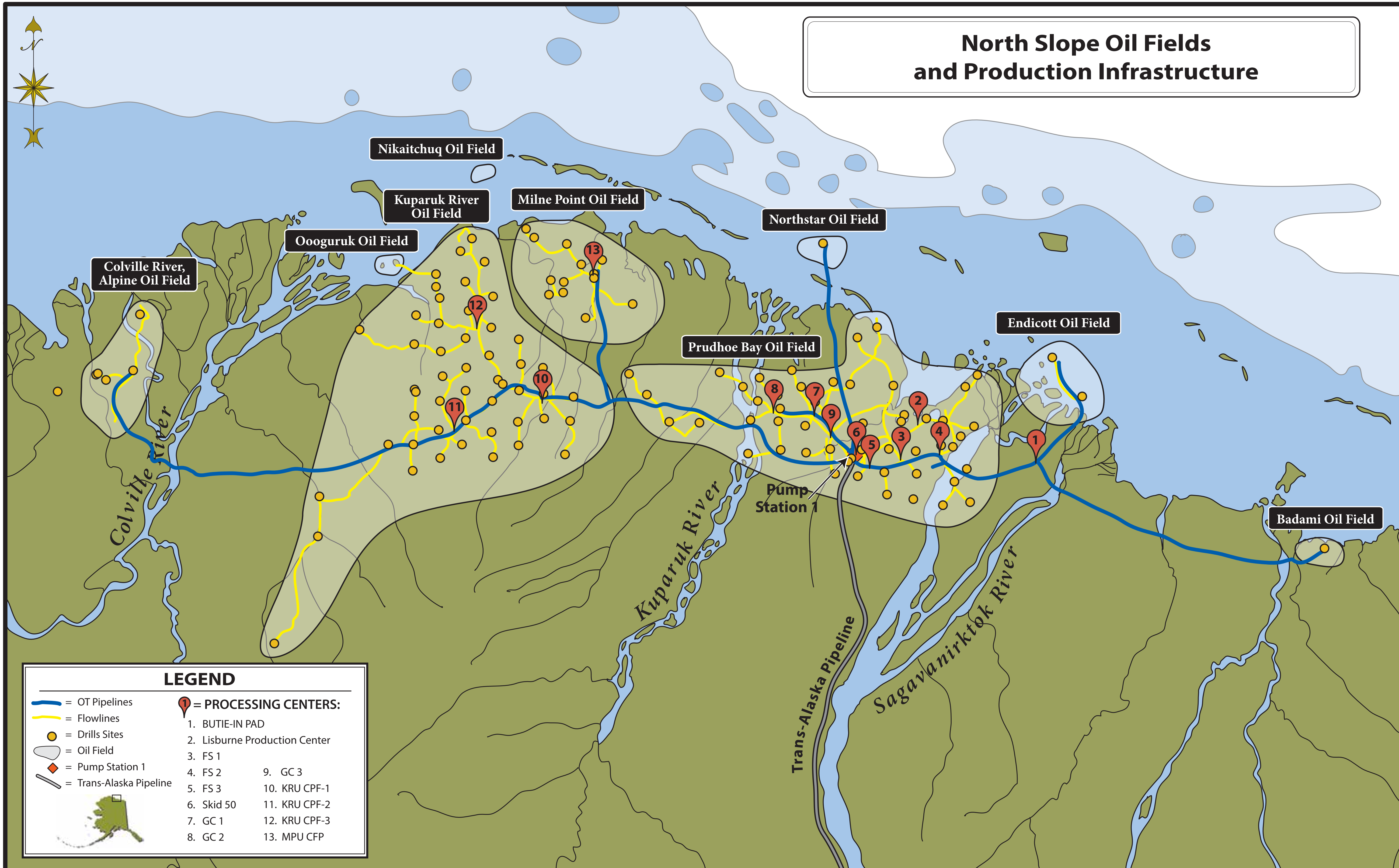

Figure 1-2. North Slope oil fields and production infrastructure.

METHODS 2

2.1 Analysis Design

The State has a continued interest in understanding spill trends over time, causal factors, spill impacts, spill detection methods or timing, and infrastructure characteristics. A database was developed in 2010 for the original North Slope Spills Analysis, which contained a final set of 640 loss-of-integrity spills. This project continues to build and update the database by including spills reported to the ADEC from North Slope oil production operators from the time period of January 1, 2010 to December 31, 2011. The analysis is limited by the quality and quantity of data. The data sources are discussed in Section 2.2 and the analysis of data is presented in Section 3.

2.2 Data Sources and Collection Procedures

Documents and databases available through public records were used to review data on spills, oil production, and pipelines. Spill records from the ADEC SPILLS database, records associated with North Slope oil field spills, the operator's approved Oil Discharge Prevention and Contingency Plan, pipeline parameter information provided by operators to ADEC, and on-line production statistics maintained by the Alaska Oil & Gas Conservation Commission (AOGCC) were primary sources used in this analysis.

The information collected through both the initial and final reports on all spills meeting the reporting thresholds is compiled in the SPILLS database, which is managed by ADEC's Prevention and Emergency Response Program. This database was the source for the data set used for this updated analysis.

The ADEC Industry Preparedness Program maintains an Oil Discharge Prevention and Contingency Plan (C-Plan) database, which is linked to the ADEC SPILLS database allowing spill data to be analyzed for facilities regulated by the State of Alaska. Within the C-Plans, operators report information about the discharge history and prevention programs for the life of the facility or operation. The Milne Point and Endicott-Badami Production facility C-Plans operated by BP were submitted for renewal during the study period. The spill histories were reviewed to validate relevant data associated with in-scope oil spills. The other operator C-Plan spill histories had not changed since the original study and were not reviewed.

AOGCC maintains monthly production reports for each active oil field in Alaska. These reports are available online and they include data on the amount of: crude oil, produced water, and natural gas production summarized by oil field and production pool. Production data was collected from AOGCC from January 1, 2010 to December 31, 2011 to update the data set for this study.

Spill investigation information for only two incidents during this study period were reviewed to gather additional detailed data. The spill cause investigations were conducted by the operators and submitted to ADEC as part of the record.

2.3 Compilation and Sorting of Data for Analysis

The 2010 study data set consisted of 640 loss-of-integrity spills. A total of 41 loss-of-integrity spills were identified for this study period and added to the data set. Data for these 41 new spills were compiled from the ADEC SPILLS database. The data were sorted and reviewed to identify cases considered out of scope based on the following conditions:

- The spill case did not come from the oil production train; or
- The pipeline was out of service at the time of the spill; or
- The spill originated from something other than the oil production infrastructure (such as drilling or work-over operations, vehicles, portable tanks, etc.)

The second step was to assign the case to a regulatory category. The regulatory categories and subcategories are described in Table 2-1. Subcategories are not based in regulation but were derived based on the service of the facility/pipeline where the spill occurred.

Table 2-1. Pipeline regulatory categories and subcategories[1].

Regulatory Category	Subcategory	Regulation
Wells	No subcategory	AOGCC – 20 AAC 25
Facility Oil Piping	Well pad/drill site Processing Center, module to oil storage tank	18 AAC 75.080, 18 AAC 75.990(171)
Flow Line	Cross-Country 3-Phase pipeline Produced Water pipeline Operational activities, such as pigging	18 AAC 75.047, 18 AAC 75.990(173)
Oil Transmission Pipeline	Cross-country crude oil pipeline Operational activities, such as pigging	18 AAC 75.055, 18 AAC 75.990(134)
Above Ground Oil Storage Tank	No subcategory	18 AAC 75.065, 75.990(165)
Process Piping Not Regulated by State	Manifold building (interconnection) Processing center (interconnection) Seawater pipeline Natural gas pipeline	N/A

A spill case research team traveled to the ADEC Fairbanks Office and examined all available documentation for cases determined to be in-scope. Case files were scanned as a PDF file and posted on an internal website for additional review. The case reviewers utilized the case files to:

- Validate regulatory categorization and correlating sub-categorization;
- Determine the primary and major contributing causal factors;
- Assess the extent of environmental impact;
- Review the types of corrective actions; and
- Capture any available pipeline design and operating parameters (e.g. nominal wall thickness, outside diameter, installation date, throughput, maximum allowable operating pressure, etc.)

1 Regulatory Categories as defined by the Alaska Administrative Code (AAC) and the AOGCC regulations, and through collaboration with ADEC staff subject matter experts.

The availability and quality of data noted during this case-by-case review varied greatly based on the level of detail captured in each case file.

The primary or immediate cause of an incident is defined as the action or inaction that immediately preceded and led to the spill and/or event or near miss. The ADEC SPILLS database has five cause types and thirty-two cause identifications. A contributing cause is any cause that is not self-sufficient. Each of the necessary causes to explain the nature, magnitude, and timing of adverse consequences are contributing causes. Contributing causes are not collected and entered into the ADEC SPILLS database. They are typically identified through a type of root cause analysis, which is usually part of an investigation.

2.4 Geospatial Referencing

As part of the 2010 study, a Geospatial Platform was developed using Google Earth to display each loss-of-integrity spill. The geospatial data parameters included oil field, regulatory categories, service, start point, end point, pipeline length, nominal wall thickness, outside diameter, yield strength, grade, installation date, throughput, and maximum allowable operating pressure. These same parameters and referencing methods were used to update the geospatial platform with the 41 additional loss-of-integrity spills from the period of January 1, 2010 to December 31, 2011.

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ANALYSIS 3

The North Slope spill data analysis is organized by first examining combined data from all loss-of-integrity spills (July 1, 1995 to December 31, 2011), then examining spills by both regulatory category and primary cause of failure. In each analysis the frequency of spills, total volume, spill size class, primary cause of failure, temporal trends, and spatial trends are considered. Other sections of the analysis consider leak rates, age of pipeline at failure, leak detection, and impacts. All spill volumes are reported in gallons. The analysis considers whether the frequency and volume of loss-of-integrity spills from North Slope oil and gas operations are changing over time by looking for trends in the number and total volume of reported spills.

3.1 Analysis of Combined Loss-of-Integrity Spill Data

Forty-one (41) loss-of-integrity spills were reported in the past two years bringing the total North Slope Spills database to 681 loss-of-integrity spills during total analysis time period from July 1, 1995 to December 31, 2011. Figure 3-1 depicts the distribution of the number and volume of spills across the regulatory categories utilized for this report. Table 3-1 presents the number and total volume spilled each year. All oil fields were considered together when examining number and volume data. Oil fields are compared in Section 3.4 on leak rates. The average spill frequency was 40 loss-of-integrity spills per year. The total volume of crude oil and produced water spilled was 1,215,143 gallons. Spill sizes ranged from less than one gallon to 241,038 gallons. Overall, the average spill volume per spill was 1,784 gallons over the entire study period. The average spill volume per year was 71,479 gallons.

Figure 3-2 depicts the number of loss-of-integrity spills per year across all oil fields and all regulatory categories. As reported in 2010, statistical analysis of annual loss-of-integrity spills across all North Slope oil infrastructure from 1996 to 2009 shows no significant trend. The inclusion of 2010 and 2011 data changed that conclusion, with the additional two years data, there is a statistically significant downward trend in spill numbers at a 95% confidence level. This is further supported by the five-year moving average.

Figure 3-3 depicts numbers of spills greater than 1,000 gallons plotted by year. The average number of spills greater than 1,000 is 4.3 per year. Even when considering the 69 largest spills (> 1,000 gallons) over a 16-year period, the number of spills shows only a downward trend from 2010 to 2011 with only one spill greater than 1,000 gallons.

Figure 3-4 depicts a bar graph of total spill volume by year with an overlaid scatter plot of actual spill events plotted over the same time period. Note that the two largest spill events occurred in 2006 and 8 of the 12 spills greater than 10,000 gallons occurred in the years 2004 to 2009. This graph shows evidence of a trend of increasing spill quantity from the period of 1996 to 2006 and a decreasing spill quantity from the period of 2007 to 2011.

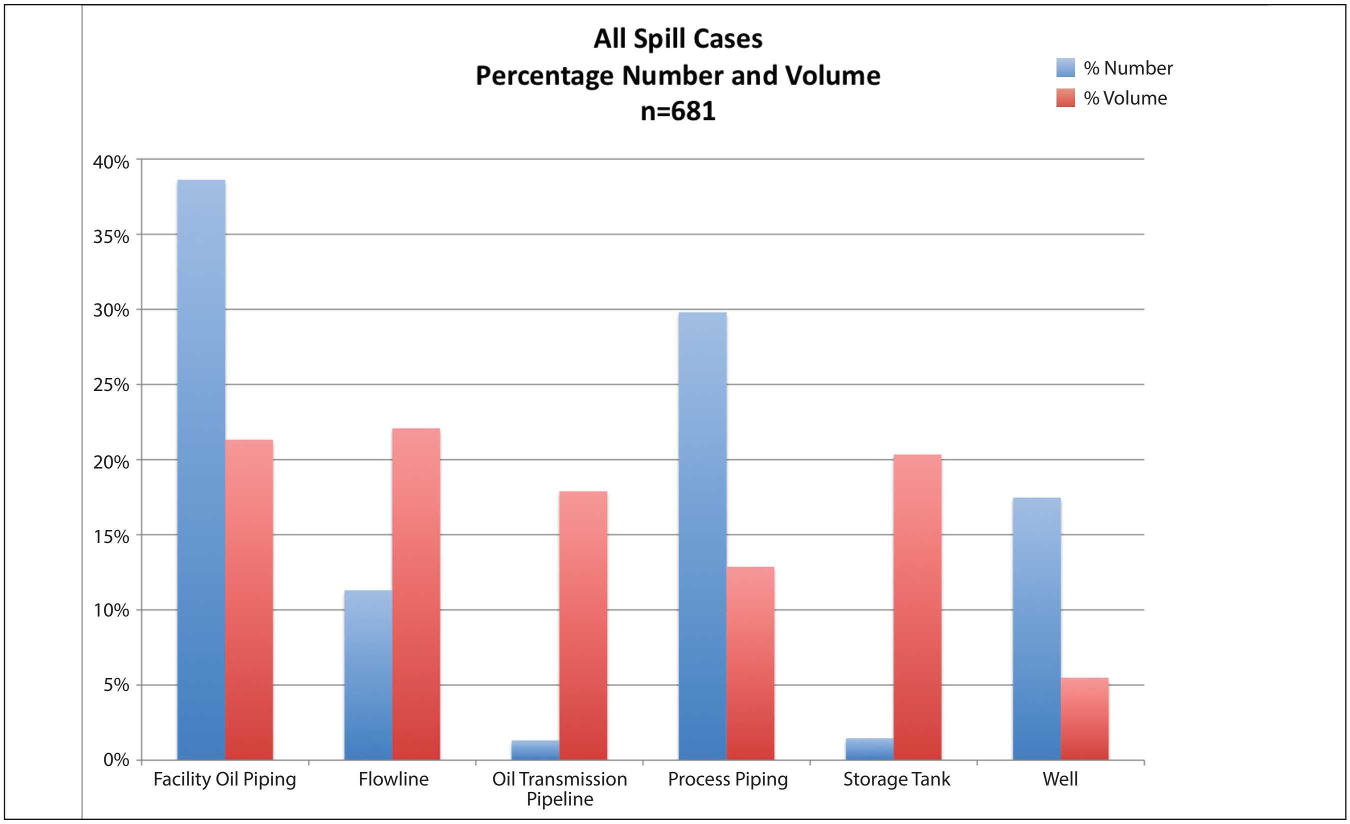

Figure 3-1. Percentage of spill number and total volume of loss-of-integrity spills from the North Slope oil production infrastructure by regulatory category.

Table 3-1. Number and total volume (gallons) of loss-of-integrity spills reported from North Slope oil operations across all fields and regulatory categories.

Year	Number of Spills	Total Volume (gallons)
1995	21	14,944
1996	51	26,843
1997	46	18,098
1998	52	87,506
1999	35	16,642
2000	41	12,577
2001	40	105,071
2002	40	33,158
2003	50	24,452
2004	45	42,493
2005	44	62,179
2006	55	469,311
2007	35	54,583
2008	47	162,522
2009	38	70,413
2010	20	11,617
2011	21	2,734
Grand Total	**681**	**1,215,143**

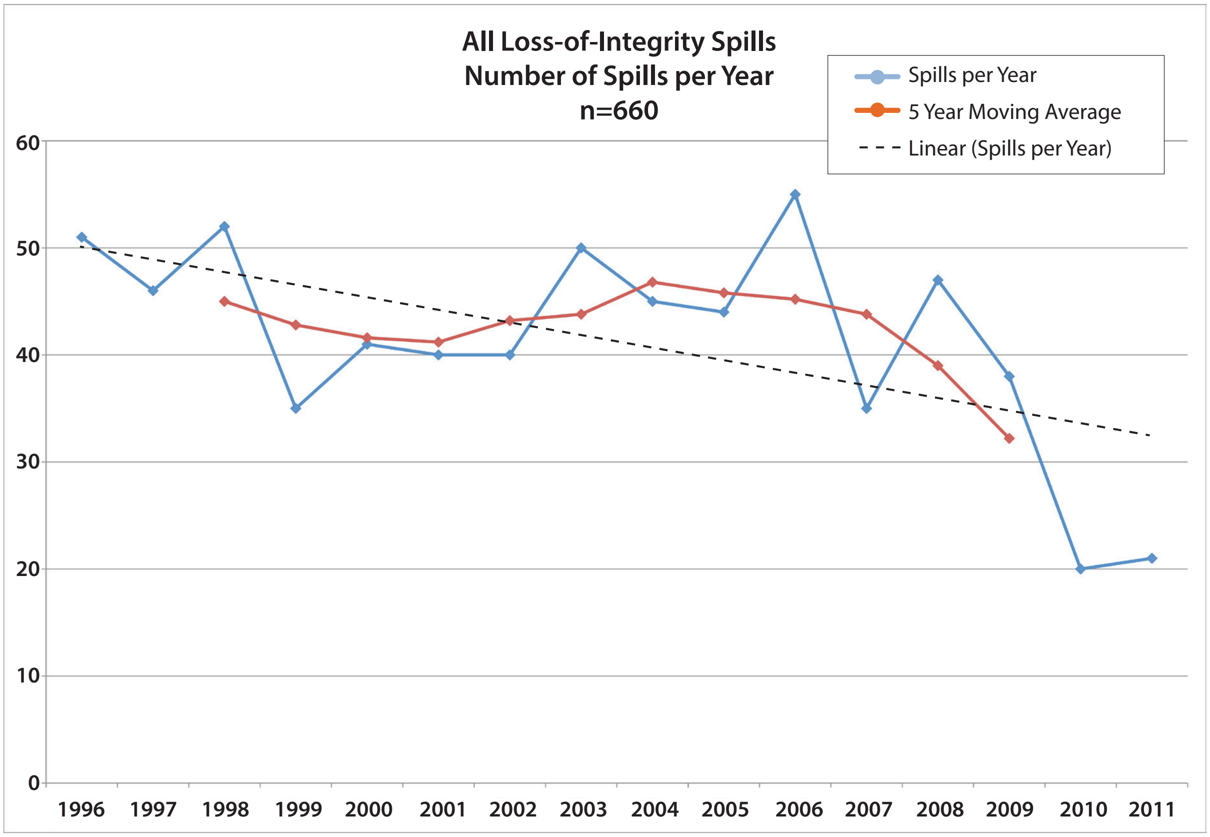

Figure 3-2. Annual number of loss-of-integrity spills for all regulatory categories reported by North Slope oil and gas operators across all years.[1]

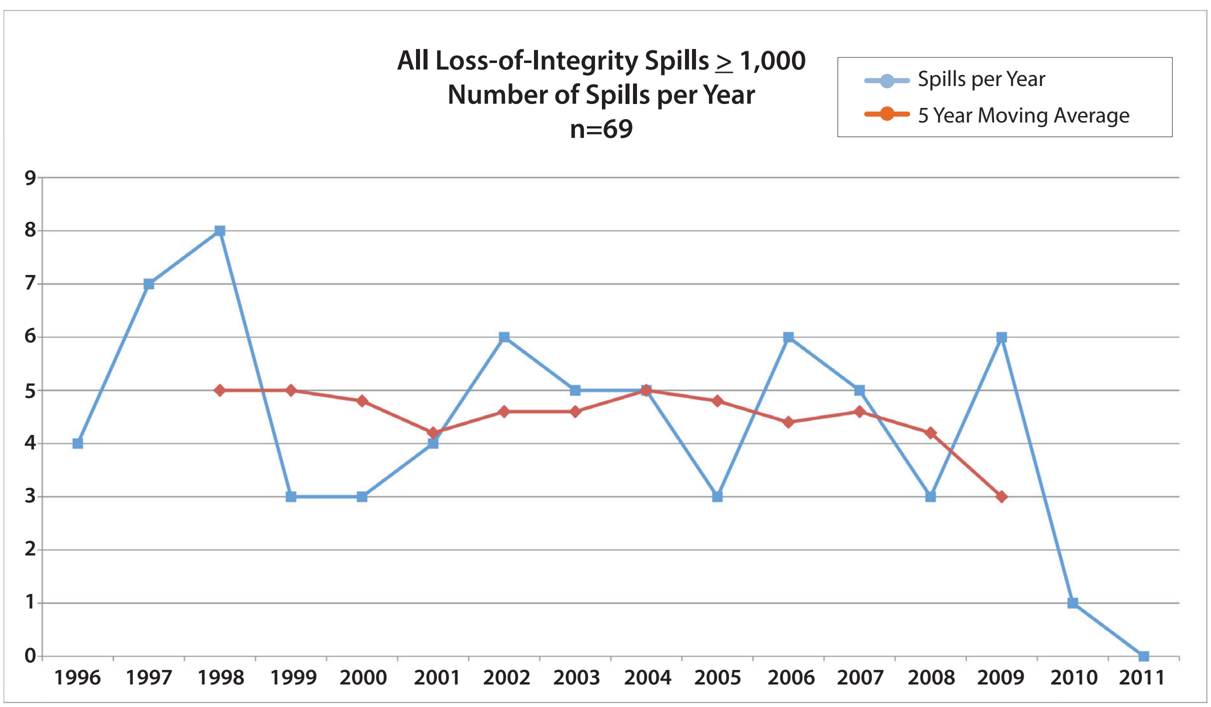

Figure 3-3. Annual number of loss-of-integrity spills > 1,000 gallons reported by North Slope oil and gas operators across all years.

1 Because spills from 1995 were recorded only from July until December, yearly graphs do not show 1995 and thus have different n values than the complete dataset.

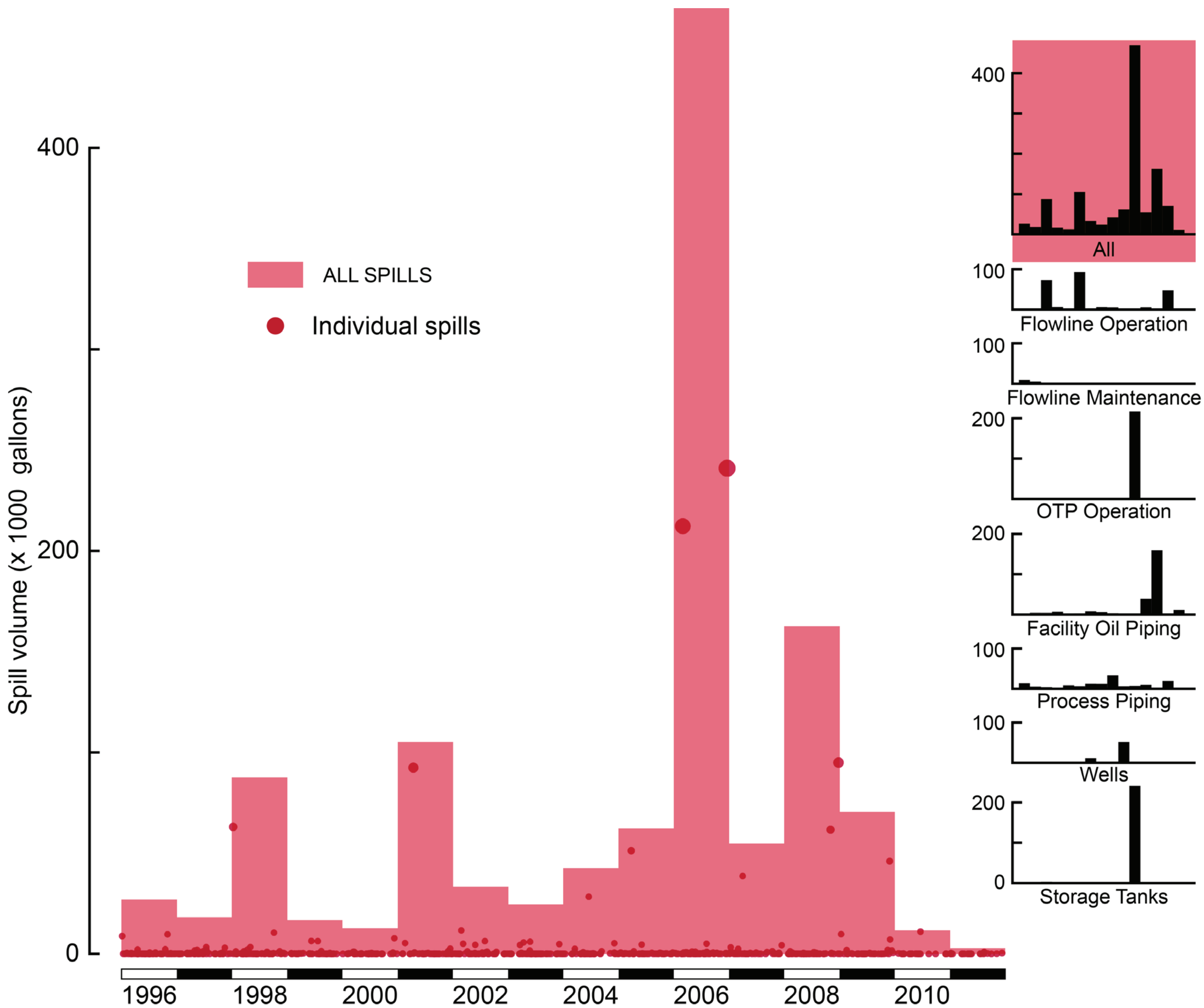

Figure 3-4. Bar graph of total spill volume (gallons) by year of actual spill events for all North Slope loss-of-integrity spills.

Examining reported spills by size class assists with understanding the severity of spills. Table 3-2 presents the number and total volume of spills by spill size categories. Figure 3-5 depicts the same data, which shows that a few large spills account for the majority of the total volume spilled. The two spills over 100,000 gallons are just 0.3% of the total number of spills and account for 37% of the total volume spilled. The 12 spills greater than 10,000 gallons represent nearly 2% of the number of spills and account for 43% of the total volume spilled.

Table 3-2. Percentage of total volume (gallons) of loss-of-integrity spills reported by size class from North Slope oil operations across all fields and regulatory categories.

Size Class (gallons)	≤ 10	≥ 10 – < 100	≥ 100 – < 1,000	≥ 1,000 - < 10,000	≥ 10,000 - < 100,000	≥ 100,000	Total
Number	237	211	162	57	12	2	681
Percent	34.8%	31.0%	23.8%	8.4%	1.8%	0.3%	
Volume (gallons)	725	7,818	49,957	181,613	521,740	453,290	1,215,143
Percent	0.1%	0.6%	4.1%	14.9%	42.9%	37.3%	

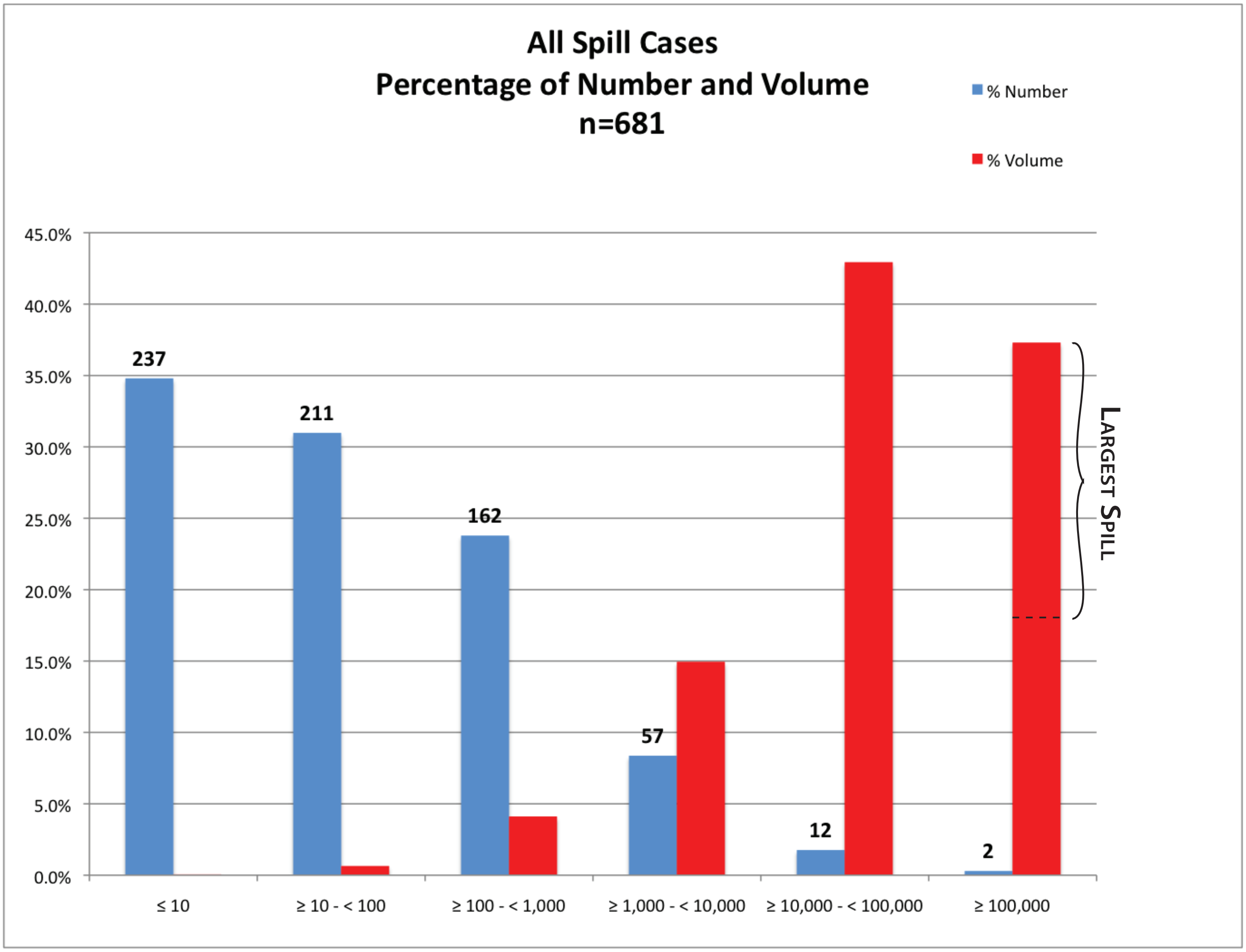

Figure 3-5. Percentage of number and total volume (gallons) of spill cases from loss-of-integrity spills by spill size class.

Table 3-3 presents the number and total volume by year of the 71 largest spills (> 1,000 gallons) from July 1995 to 2011. The 71 spills represent 10% of the number of spills and account for 95% of the total volume spilled.

Table 3-3. Number and total volume (gallons) of loss-of-integrity spills greater than 1,000 gallons reported from North Slope oil operations across all fields and regulatory categories.

Year	Number of Spills	Total Volume (gallons)
1995	2	13,860
1996	4	22,933
1997	7	14,364
1998	8	83,680
1999	3	14,034
2000	3	9,754
2001	4	101,604
2002	6	29,629
2003	5	22,592
2004	5	38,380
2005	3	57,058
2006	6	461,502
2007	5	49,935
2008	3	157,806
2009	6	68,577
2010	1	10,935
2011	0	0
Grand Total	**71**	**1,156,643**

Table 3-4 presents the recorded cause[2] of three spill sets from the loss-of-integrity spills where cause was recorded. The first set contains all spill cases, the second set contains spill cases greater than or equal to 1,000 gallons, and the third set contains spill cases greater than or equal to 10,000 gallons. Figure 3-6 depicts the relative frequency of selected primary causes to each set of spill sizes. The relative frequency of valve/seal, material failure of pipe or weld, and operator error decreases as spill size increases and the relative frequency of failures due to corrosion and internal corrosion increases as spill size increases. These data shows that spill size varies by cause. The conclusion drawn from this analysis is that valve/seal remains the most frequent cause of loss-of-integrity spills overall and external and internal corrosion are the most frequent cause of larger spills, especially spills > 10,000 gallons.

Figure 3-7 maps the distribution of all loss-of-integrity spills across the North Slope. Taken together, loss-of-integrity spills across all regulatory categories and oil fields do not exhibit an increase in the number or volume of spills over time.

2 It should be noted that the consistency and quality of characterizing cause in this data set is generally poor and has changed over the 16 years of data.

Table 3-4. Primary cause of three spill size sets for loss-of-integrity spills reported from North Slope oil operations across all fields and regulatory categories.[3]

	All Cases n=534		All Cases ≥ 1,000 gallons n=62		All Cases ≥ 10,000 gallons n=10	
Primary Cause	Number	%	Number	%	Number	%
Valve/Seal Failure	261	48.9%	21	33.9%	3	25.0%
Operator Error	87	16.3%	5	8.1%	0	0.0%
Internal Corrosion	57	10.7%	12	19.4%	6	50.0%
Thermal Expansion	39	7.3%	5	8.1%	1	8.3%
External Corrosion	27	5.1%	9	14.5%	1	8.3%
Overpressure	26	4.9%	2	3.2%	1	8.3%
Erosion	20	3.7%	4	6.5%	0	0.0%
Construction, Installation or Fabrication Related	11	2.1%	2	3.2%	0	0.0%
Vibration (wind-induced/slugging)	5	0.9%	2	3.2%	0	0.0%
3rd Party Action	1	0.2%	0	0.0%	0	0.0%

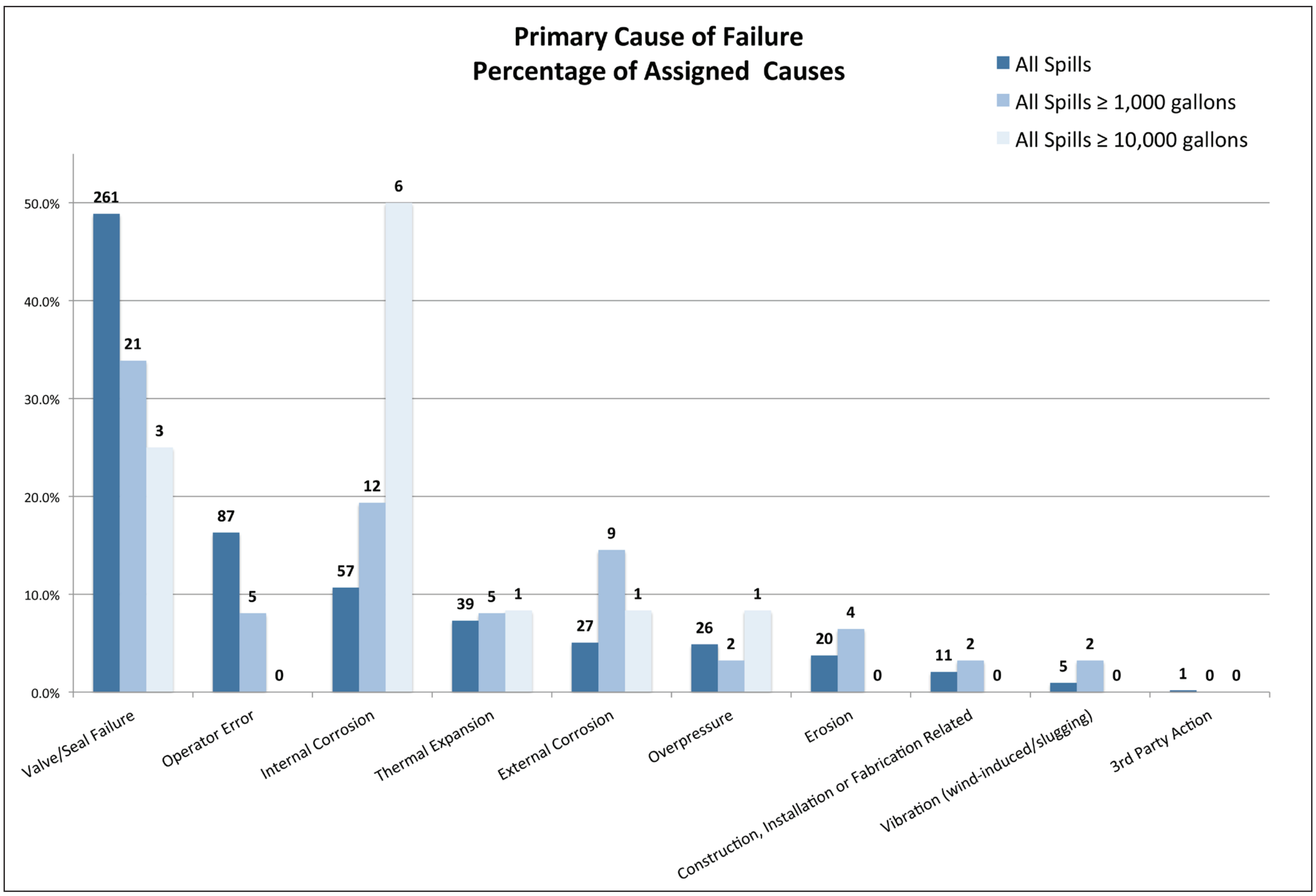

Figure 3-6. Primary cause of failure assigned to three sets of spill size classes from loss-of-integrity spills reported by North Slope oil and gas operators.

3 Note that n is the number of spill cases. Some cases have more than one primary cause, so the number of cause assignments exceeds the number of cases.

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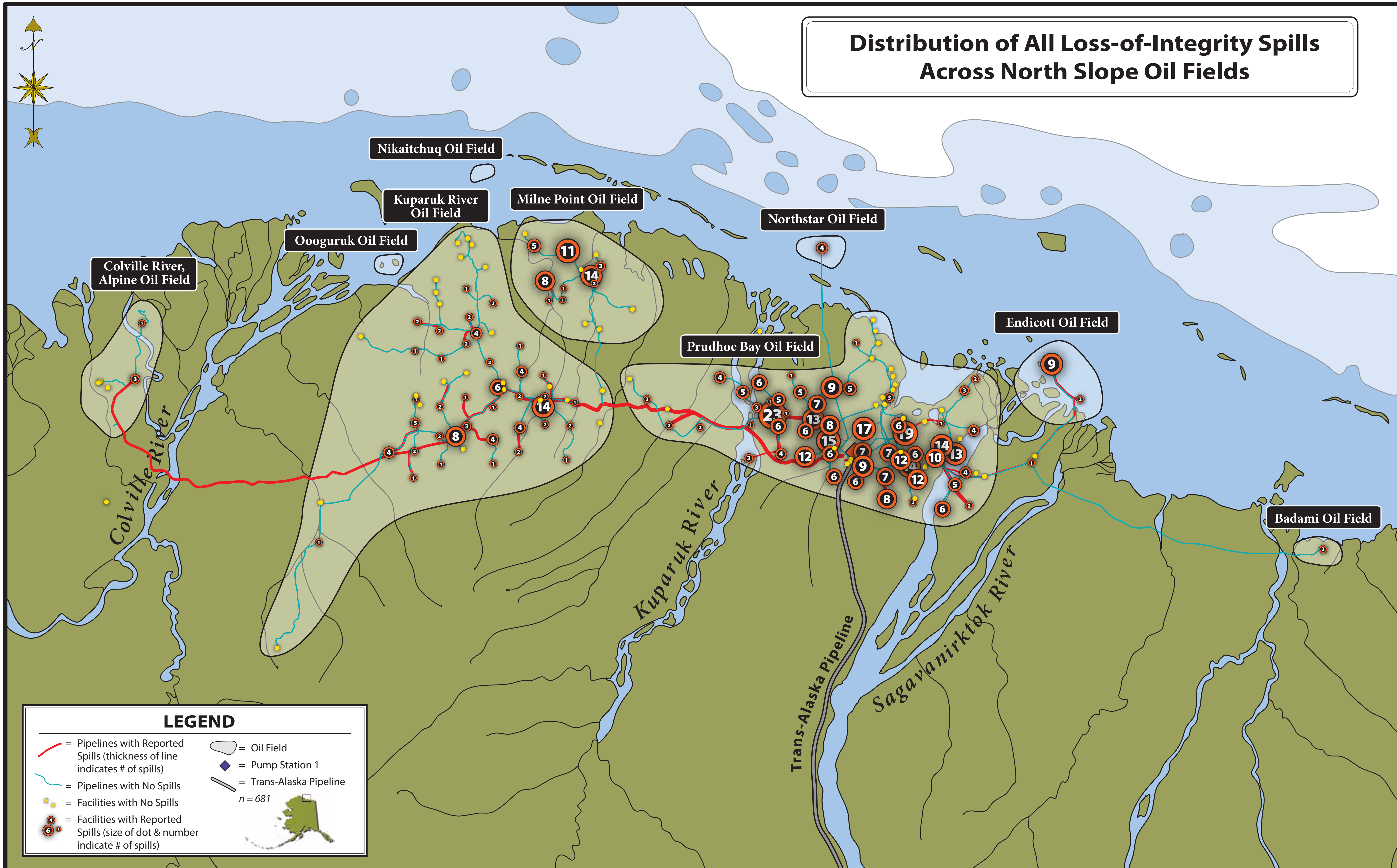

Figure 3-7. Map of distribution of all loss-of-integrity spills across the North Slope oil fields.

3.2 Analysis of Spill Data by Regulatory Category

The six regulatory categories used for this analysis are defined in Table 2-1. All spill cases were assigned to the appropriate regulatory category based on a review of the final spill report and the researcher's best professional judgment. Table 3-5 presents the number and total volume of 681 loss-of-integrity spills by regulatory category. Figure 3-8 depicts the percentage number and percentage total volume spilled by regulatory category. Figure 3-9 depicts the distribution of spills per year by regulatory category and Figure 3-10 represents the 5-year moving average of spills per year by regulatory category. Trends across time are discussed in Section 3.2.1 through 3.2.6.

Table 3-5. Number of spills and total volume (gallon) released by regulatory category for North Slope loss-of-integrity spills.

Regulatory Category	Number of Spills	Total Volume (gallons)
Storage Tank	10	247,137
Oil Transmission Pipeline	9	217,439
Flowline	77	268,358
Facility Oil Piping	263	259,163
Process Piping	203	156,375
Well	119	66,672
Grand Total	**681**	**1,215,143**

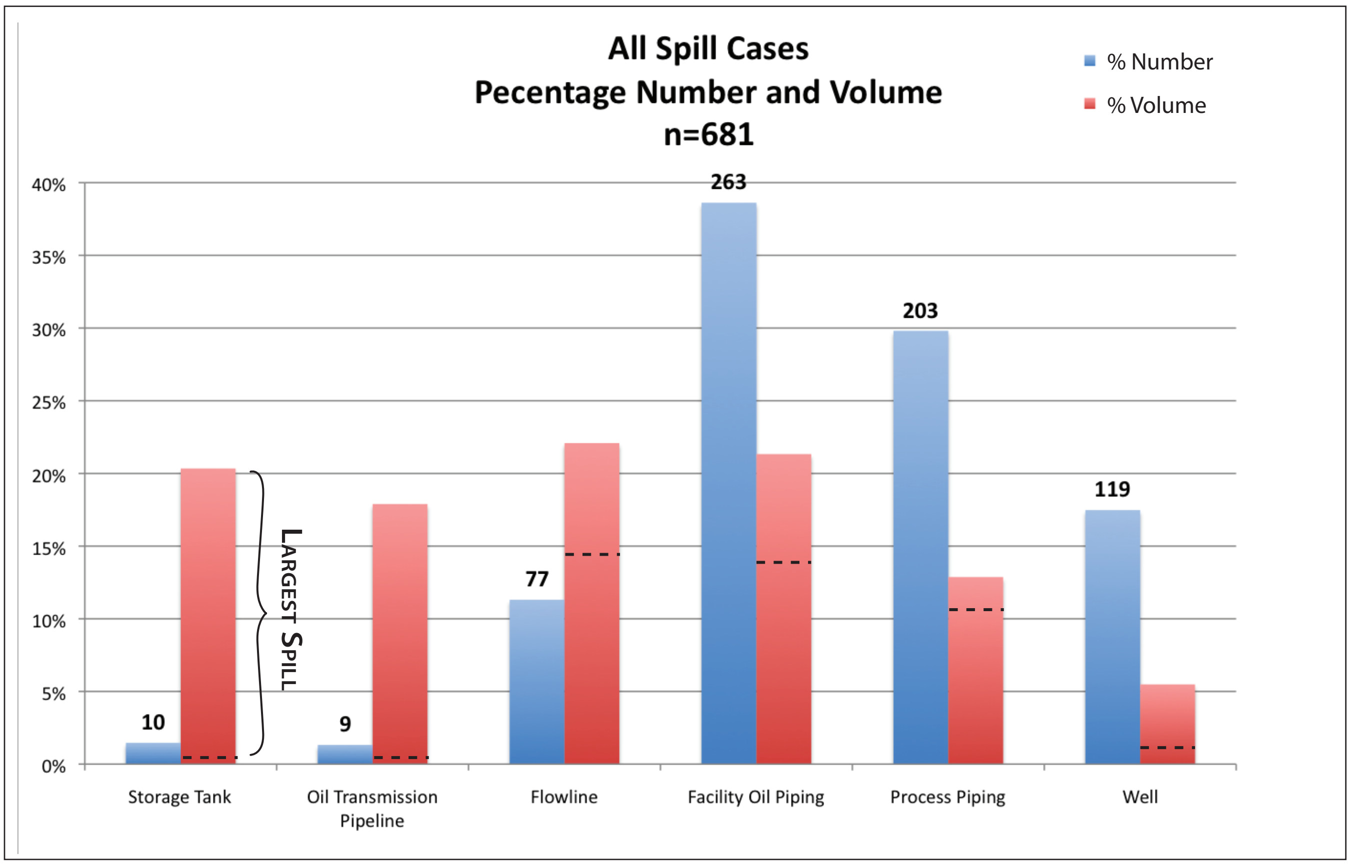

Figure 3-8. Percentage of number and total volume (gallons) of spill cases from loss-of-integrity spills by regulatory category.

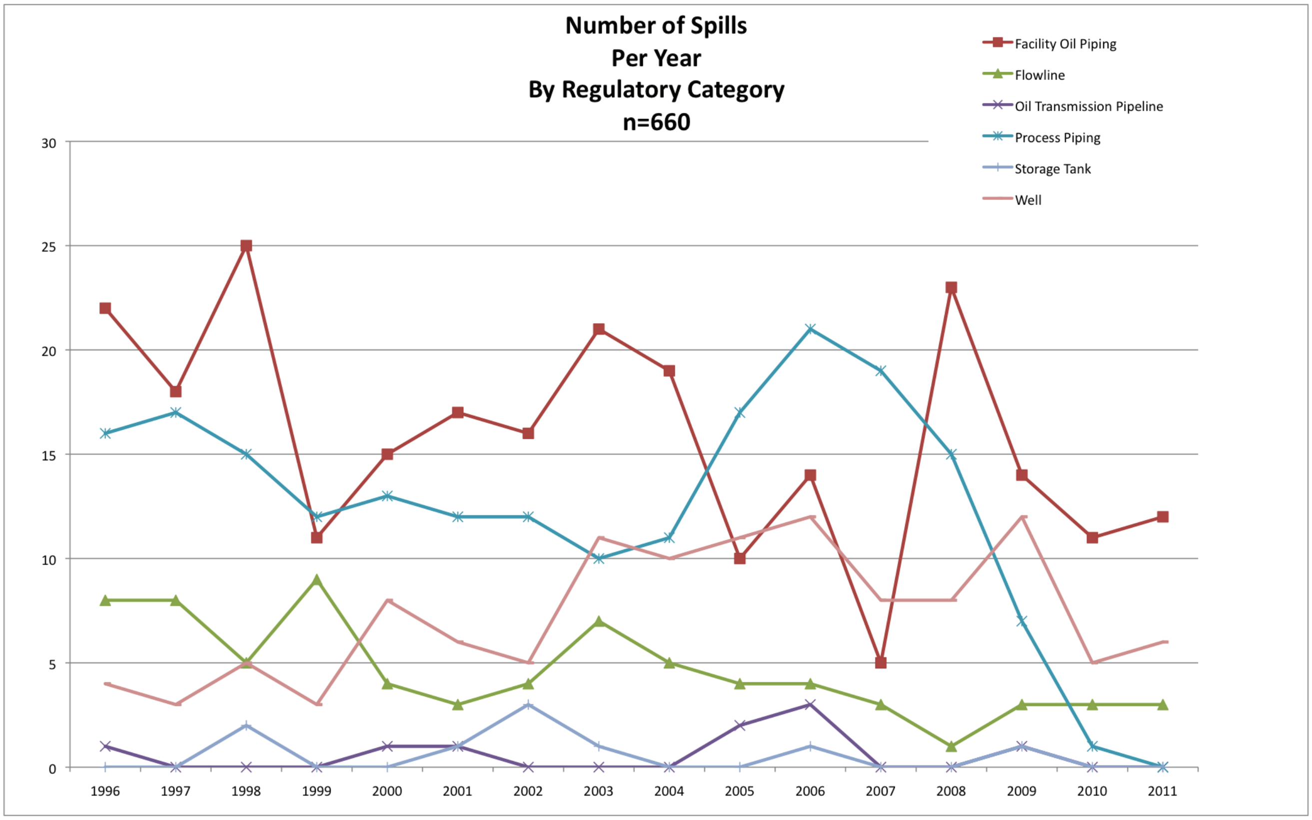

Figure 3-9. Number of loss-of-integrity spills reported by North Slope oil and gas operators by year by regulatory category.

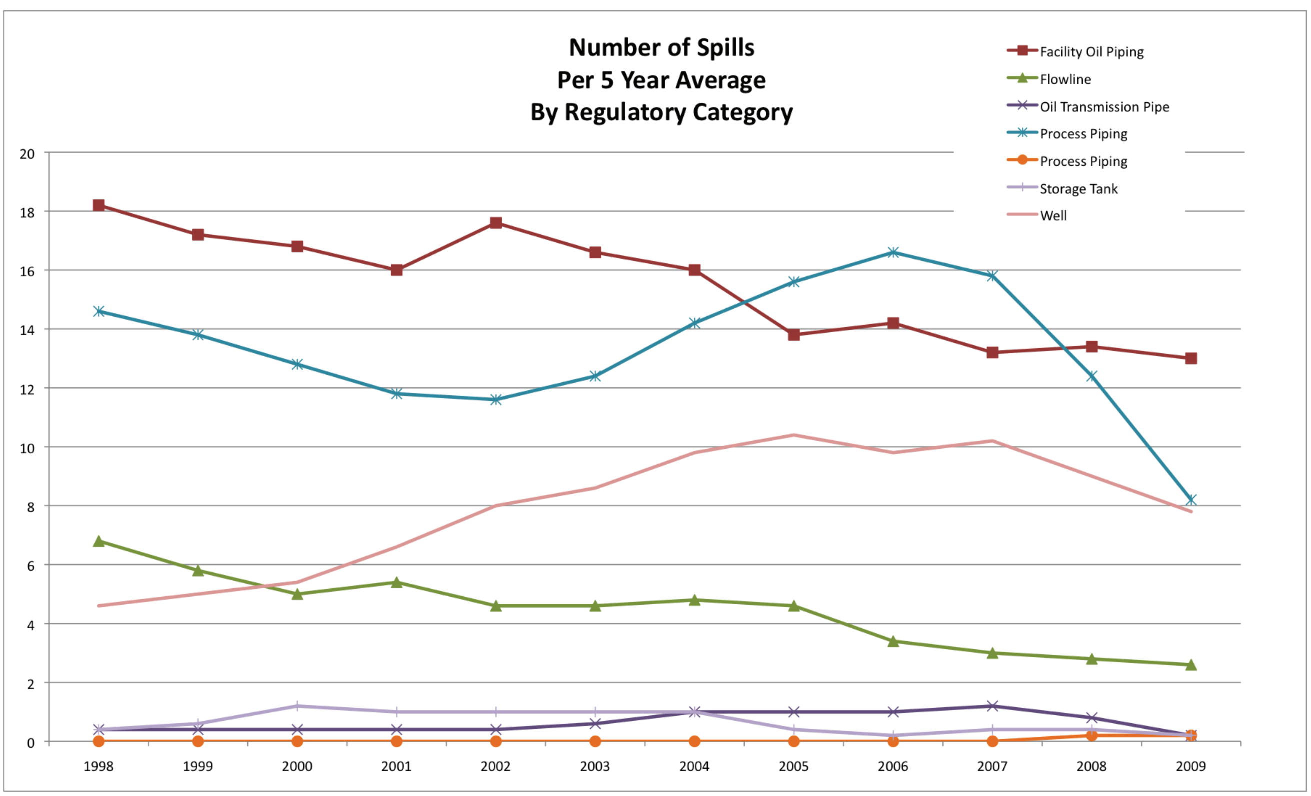

Figure 3-10. Five-year average of the number of loss-of-integrity spills reported by North Slope oil and gas operators per year and by regulatory category.

3.2.1 Flowlines

Flowlines account for the most mileage of pipelines on the North Slope, with 378 pipelines extending more than 800 pipeline miles. These lines range from 6" to 36" in diameter. Figure 3-11 maps the distribution of flowline loss-of-integrity spills across the North Slope. A total of 77 loss-of-integrity flowline spills were identified from July 1995 to 2011. There were an average of 4.8 spills per year. Flowlines remain the largest contributor (22%) with 268,358 gallons to the total volume spilled.

Flowline spills were further divided by service type into the following-categories.

- Operational spills from three-phase flowlines (3P FL) carrying oil, gas, and produced water;
- Operational spills from produced water flowlines (PW FL) carrying produced water or seawater; and
- Maintenance activity spills for either three-phase or produced water flowlines, usually related to pigging activities.

Table 3-6 presents the annual number of spills and total volume from each of these categories. Figure 3-12 depicts the percentage of the number and total volume for each of these flowline sub-categories. These data indicate that 36 (46%) of the flowline spills are related to maintenance activities, yet these maintenance spills account for only 11% of the total volume spilled. Thirty-seven percent of the flowline spills fall under the three-phase category and account for 24% of the total volume of flowline spills. Produced water flowline category (12%) accounts for 61% of the total volume of flowline spills. Statistical analysis demonstrates that the number of spills is significantly different between these three sub-categories.

Table 3-6. Number of spills and total volume (gallons) released by flowline subcategory by year for North Slope flowline loss-of-integrity spills.

	MAINTENANCE ACTIVITY		THREE-PHASE		PRODUCED WATER	
Year	Number of Spills	Total Volume (gallons)	Number of Spills	Total Volume (gallons)	Number of Spills	Total Volume (gallons)
1995	2	549	1	25	0	0
1996	2	8,946	4	78	2	2,271
1997	5	5,511	3	2,009	0	0
1998	3	2,186	0	0	2	73,500
1999	8	2,603	0	0	1	6,300
2000	2	650	2	635	0	0
2001	1	2	1	420	1	92,400
2002	2	97	2	970	0	0
2003	2	194	4	6,093	1	5
2004	2	282	2	155	1	5,250
2005	3	1,327	1	16	0	0
2006	2	290	1	700	1	5
2007	1	105	2	5,586	0	0
2008	0	0	1	0	0	0
2009	0	0	3	47,942	0	0
2010	0	0	2	253	1	8
2011	1	950	0	0	2	45
Grand Total	**36**	**23,692**	**29**	**64,882**	**12**	**179,784**

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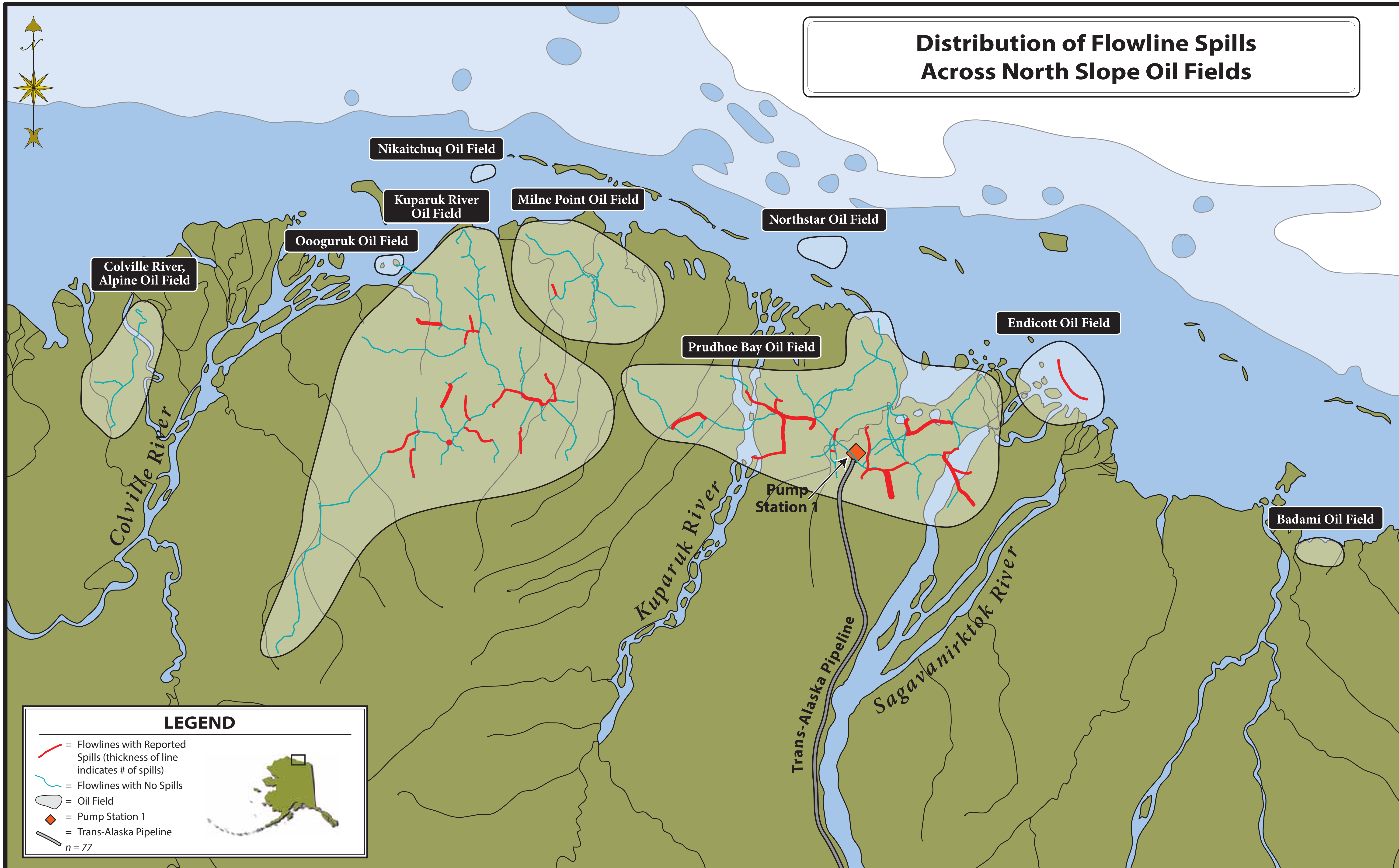

Figure 3-11. Map of distribution of loss-of-integrity spills from flowlines across the North Slope.

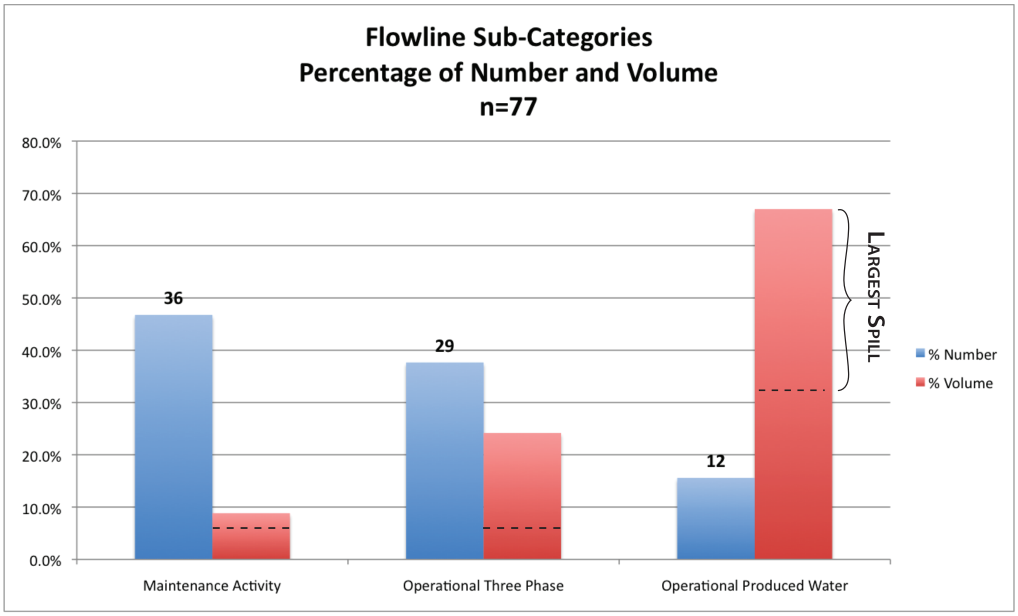

Figure 3-12. Percentage of the number and total volume (gallons) for three flowline categories: maintenance activity, three-phase, and produced water.

Due to the limited amount of data and similarity of service, three-phase and produced water data flowline spills were combined into a operational flowline spill sub-category and examined separately from maintenance activity data. The operational flowline spill sub-category includes all spills except those that occurred during a maintenance activity.

Operational Flowline Spills

Operational flowline leaks are spill cases that were not associated with maintenance activities, such as pigging. There were 41 (51%) operational leaks resulting in 91% of the total spill volume of flowline spills. Figure 3-13 depicts operational spills ranked by spill size class. Data shows that four spill cases more than 10,000 gallons account for 87% of the total volume spilled.

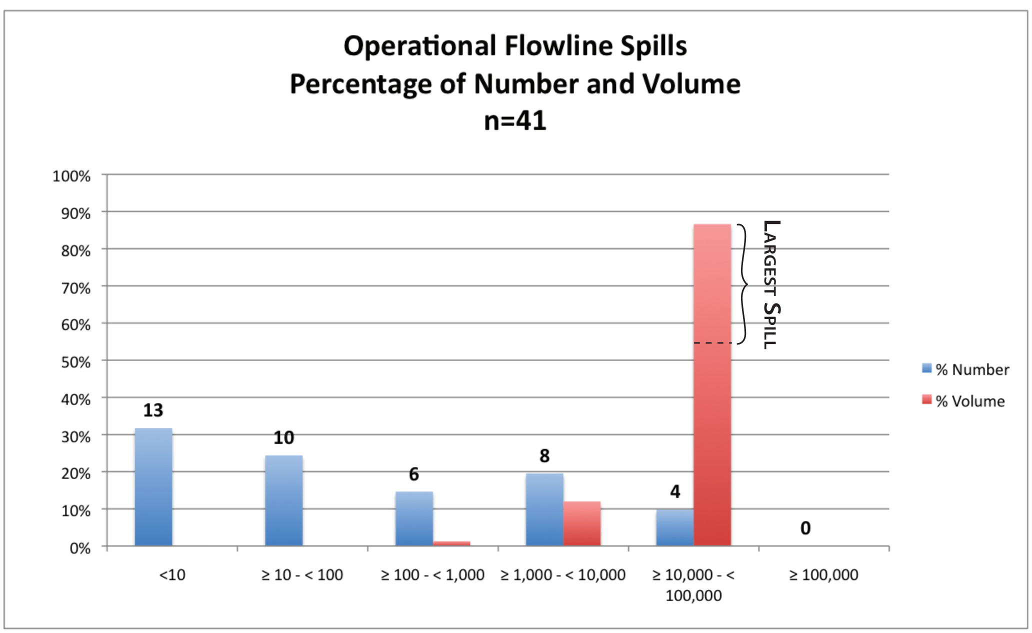

Figure 3-13. Number and volume of operational flowline spills by spill size class.

Table 3-7 presents the primary cause of failure breakdown of operational flowline spills. External corrosion remains the most common cause attributed to operational flowline leaks (17), followed by valve/seal failure (10), and thermal expansion (5).

Table 3-7. Primary cause of failure for operational flowline spills.[4]

OPERATIONAL FLOWLINE SPILLS n=46	
Major Contributing Cause	**Number**
External Corrosion	17
Valve/Seal Failure	10
Thermal Expansion	5
Internal Corrosion	4
Overpressure	4
Vibration	3
Operator Error	2
Construction	1
Erosion	0

Figure 3-14 shows the number of flowline spills by year. The average number of spills from this subcategory is 2.5 spills per year. Figure 3-15 depicts a bar graph of total spill volume by year with an overlaid scatter plot of actual spill events plotted over the same time period. Graphical analysis of the number of spills and the total volume spilled for operational flowlines continues to indicate no trend over the entire analysis time period.

Spills from this subcategory occur at a relatively low frequency, but can have a high volume when they do occur.

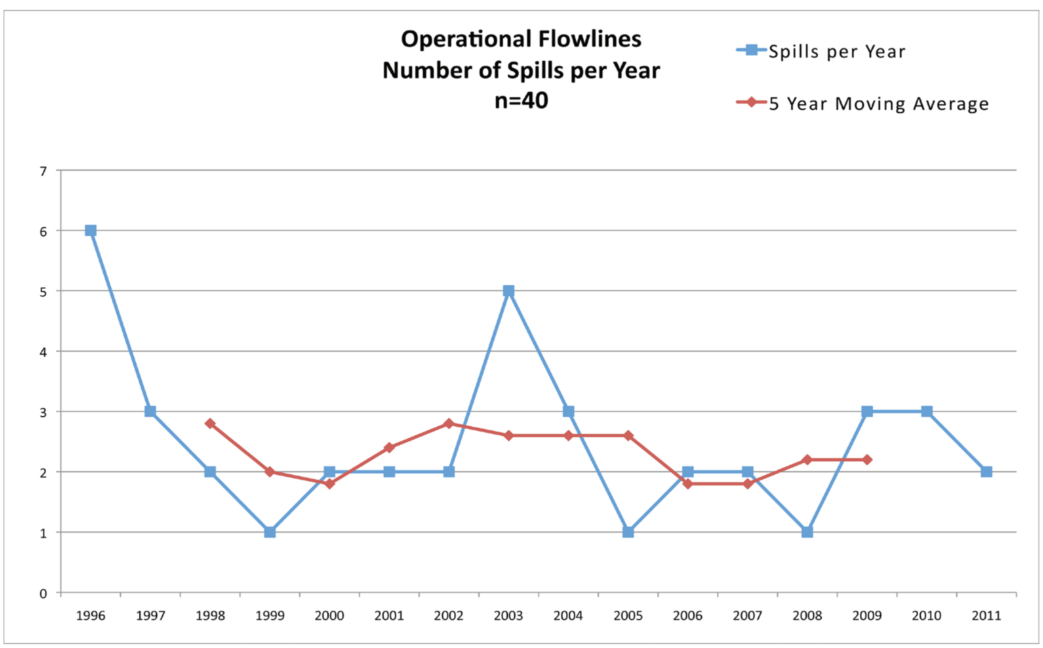

Figure 3-14. Number of operational flowline loss-of-integrity spills reported by North Slope oil and gas operators by year with the average across all years.

4 Note that n is the number of spill cases. Some cases have more than one primary cause, so the number of cause assignments exceeds the number of cases.

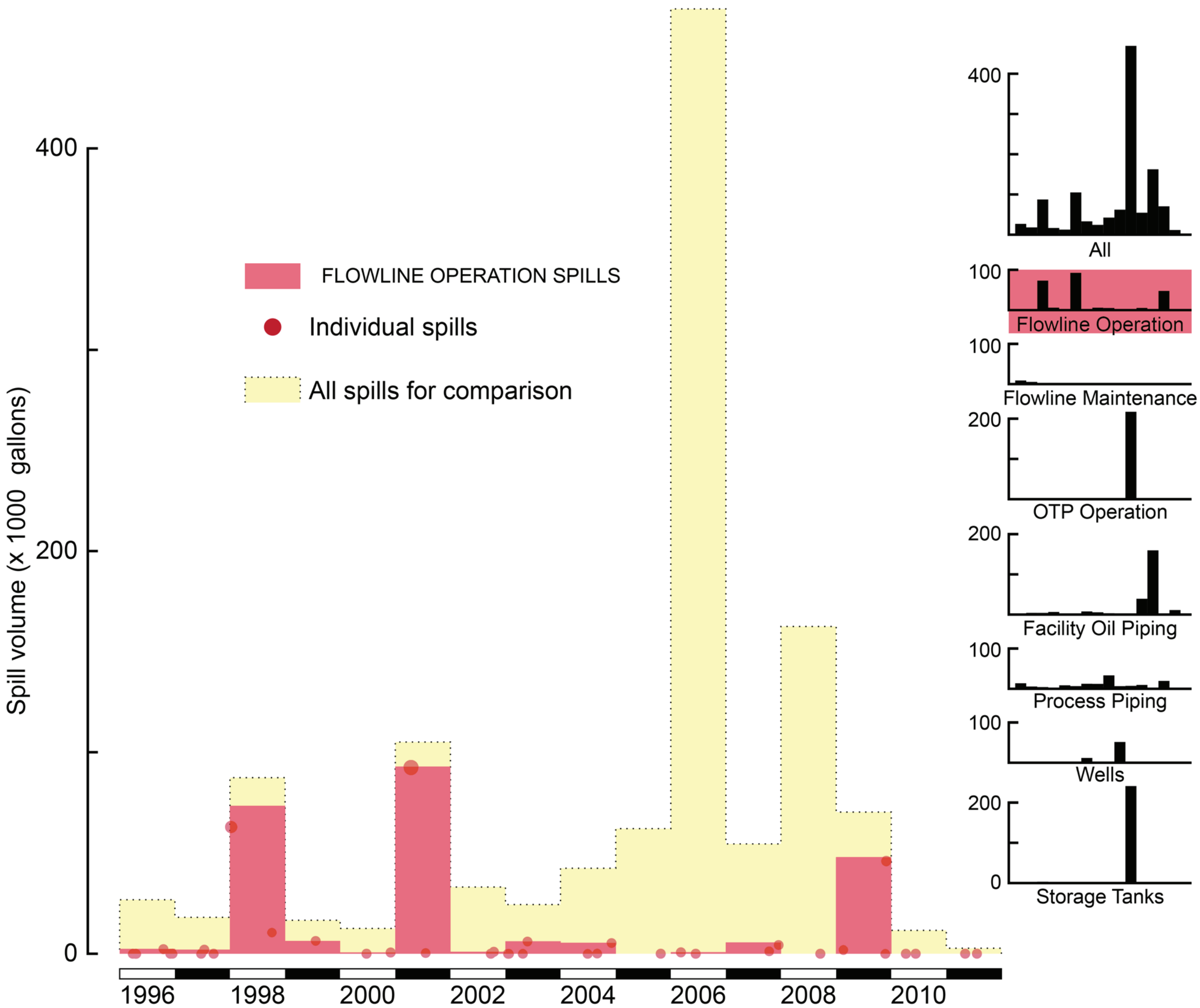

Figure 3-15. Bar graph of total spill volume (gallons) by year and scatter plot of actual spill events, all operational flowline loss-of-integrity spills.

Maintenance Activity Flowline Spills

Maintenance activity flowline spill cases are associated with maintenance activity, such as pigging. There were 36 maintenance activity flowline releases resulting in a total spill volume of 23, 692 gallons. Figure 3-16 depicts operational maintenance activity flowline spills assigned by spill size class. The data reveals that there are no spill cases over 10,000 gallons and that five cases over 1,000 gallons account for 74% of the total volume. Flowline maintenance activity spills are broadly distributed across size classes.

Table 3-8 presents the primary cause breakdown of maintenance activity flowline spills. Valve/ seal failure continues to be the greatest cause of spills (25), followed by operator error (6), internal corrosion (4), and overpressure (3).

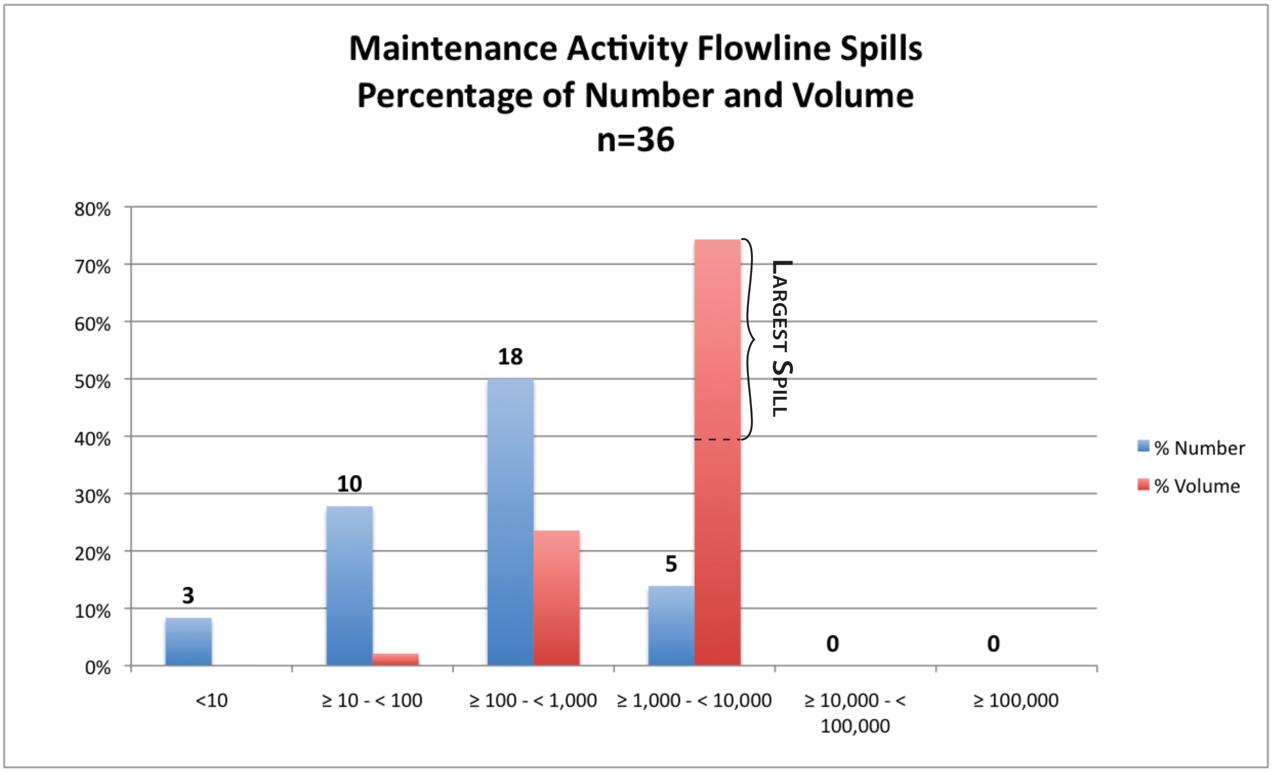

Figure 3-16. Number and volume of maintenance activity flowline spill cases by spill size class.

Table 3-8. Primary cause of failure for maintenance activity flowline spills.[5]

MAINTENANCE ACTIVITY FLOWLINE SPILLS n=40	
Primary Cause	**Number**
Valve/Seal Failure	25
Operator Error	6
Internal Corrosion	4
Overpressure	3
Erosion	1
Construction, Installation or Fabrication Related	1
External Corrision	0
Thermal Expansion	0
Vibration (wind-induced/slugging)	0
3rd Party Action	0

Figure 3-17 depicts the number of maintenance activity flowline spills by year. The average number of spills from this sub-category is 2.1 spills per year. Figure 3-18 depicts a bar graph of total spill volume by year with an overlaid scatter plot of actual spill events plotted over the same time period. Graphical analysis of the number of spills and the total volume spilled for maintenance activity flowlines indicates a downward trend over a 16-year period. This category continues to contribute little to the frequency or volume of spills.

5 Note that n is the number of spill cases. Some cases have more than one primary cause, so the number of cause assignments exceeds the number of cases.

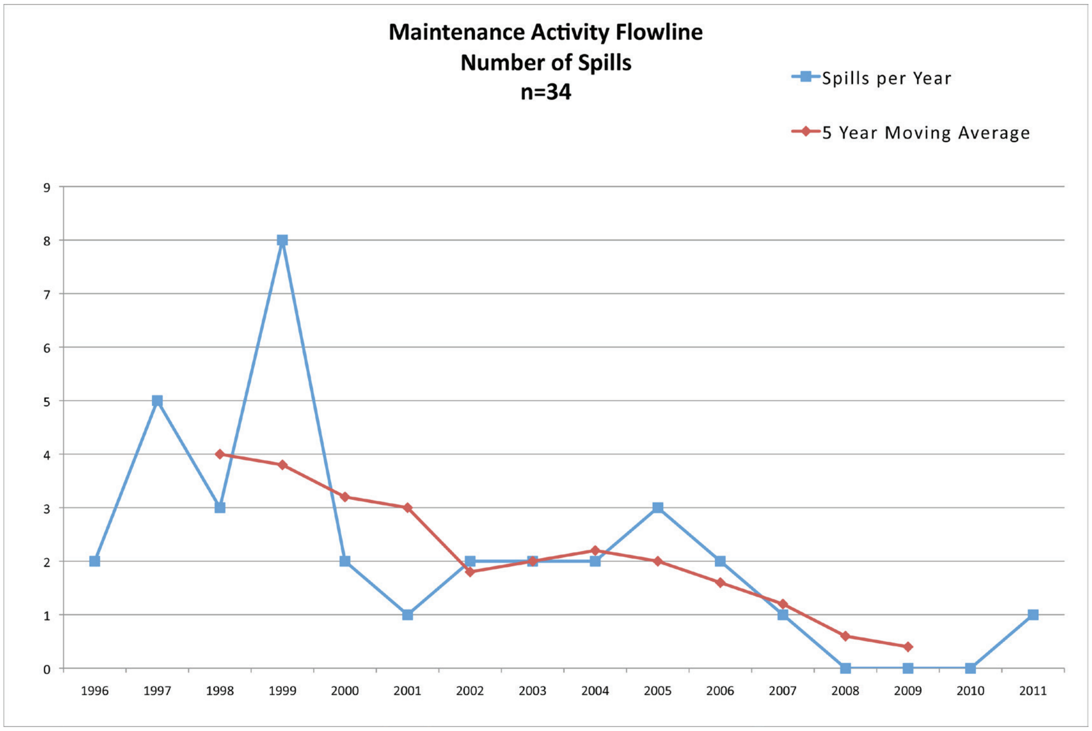

Figure 3-17. Number of maintenance activity flowline loss-of-integrity spills reported by North Slope oil and gas operators by year with the five-year moving average.

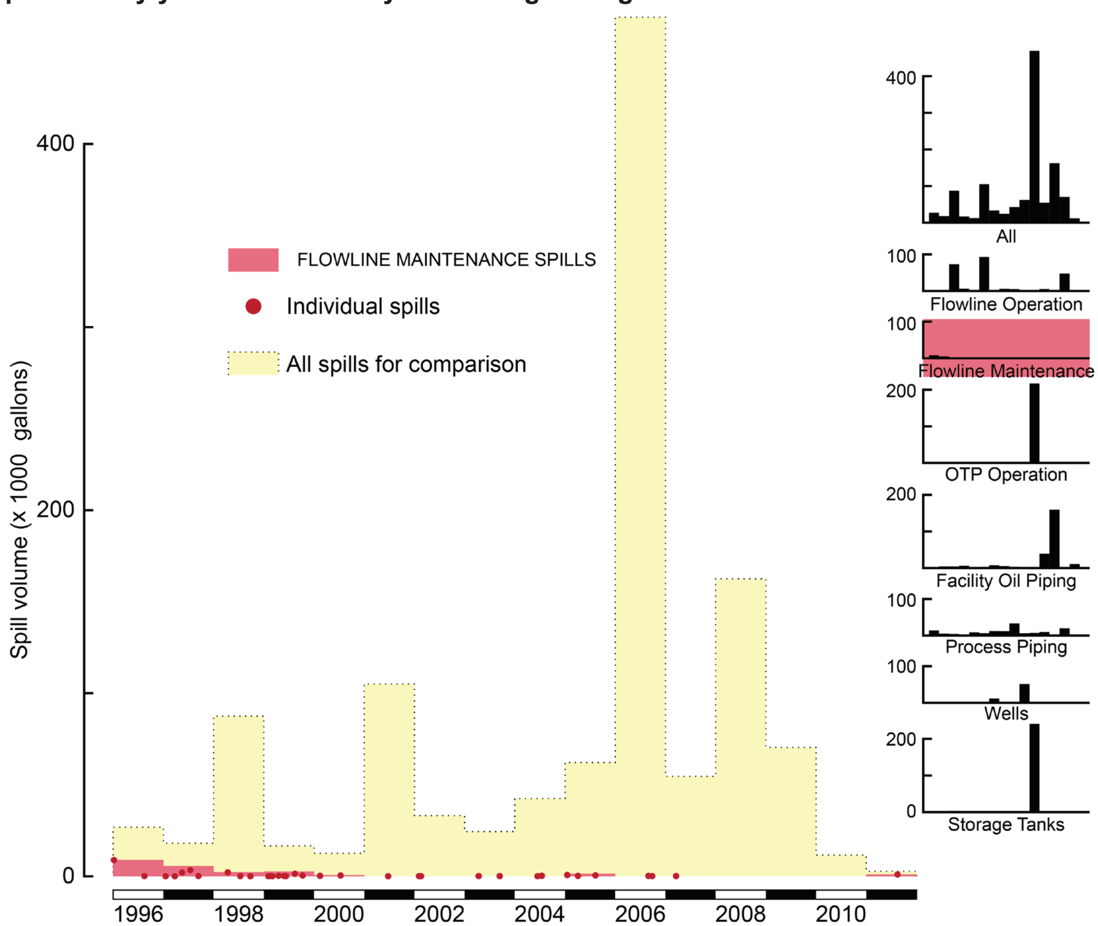

Figure 3-18. Bar graph of total spill volume (gallons) by year and scatter plot of actual spill events, all maintenance activity flowline loss-of-integrity spills.

3.2.2 Oil Transmission Pipelines

There are 16 oil transmission pipelines extending over 177 pipeline miles on the North Slope. These lines range from 6" to 34" in diameter. Figure 3-19 maps the distribution of oil transmission pipeline loss-of-integrity spills across the North Slope. A total of 9 loss-of-integrity oil transmission pipeline spills were identified during the analysis timeframe resulting in total volume of 217,351. There were an average of 0.56 spills per year from oil transmission pipelines. There were no oil transmission pipeline spills in 2010 and 2011, thus reducing the average of spills from the original study period.

Oil transmission pipeline spills were further divided by service type into the following subcategories:

- Operational spills; and
- Maintenance activity spills (related to pigging).

Table 3-9 presents the annual spill number and total for both of these categories. Figure 3-20 depicts the number and total volume of spills for each of these categories. One oil transmission pipeline spill (volume) accounts for 99.9% of the total volume spilled; the second largest spill in this regulatory category was 5,040 gallons, the other 7 spills were less than 100 gallons each.

Table 3-9. Annual number of spills and total volume (gallons) for maintenance activity and operational oil transmission pipeline categories.

	OPERATIONAL		MAINTENANCE ACTIVITY	
Year	Number of Spills	Total Volume (gallons)	Number of Spills	Total Volume (gallons)
1995	0	0	0	0
1996	0	0	1	84
1997	0	0	0	0
1998	0	0	0	0
1999	0	0	0	0
2000	1	2	0	0
2001	1	1	0	0
2002	0	0	0	0
2003	0	0	0	0
2004	0	0	0	0
2005	1	1	1	4
2006	3	217,342	0	0
2007	0	0	0	0
2008	0	0	0	0
2009	1	5	0	0
2010	0	0	0	0
2011	0	0	0	0
Grand Total	**7**	**217,351**	**2**	**88**

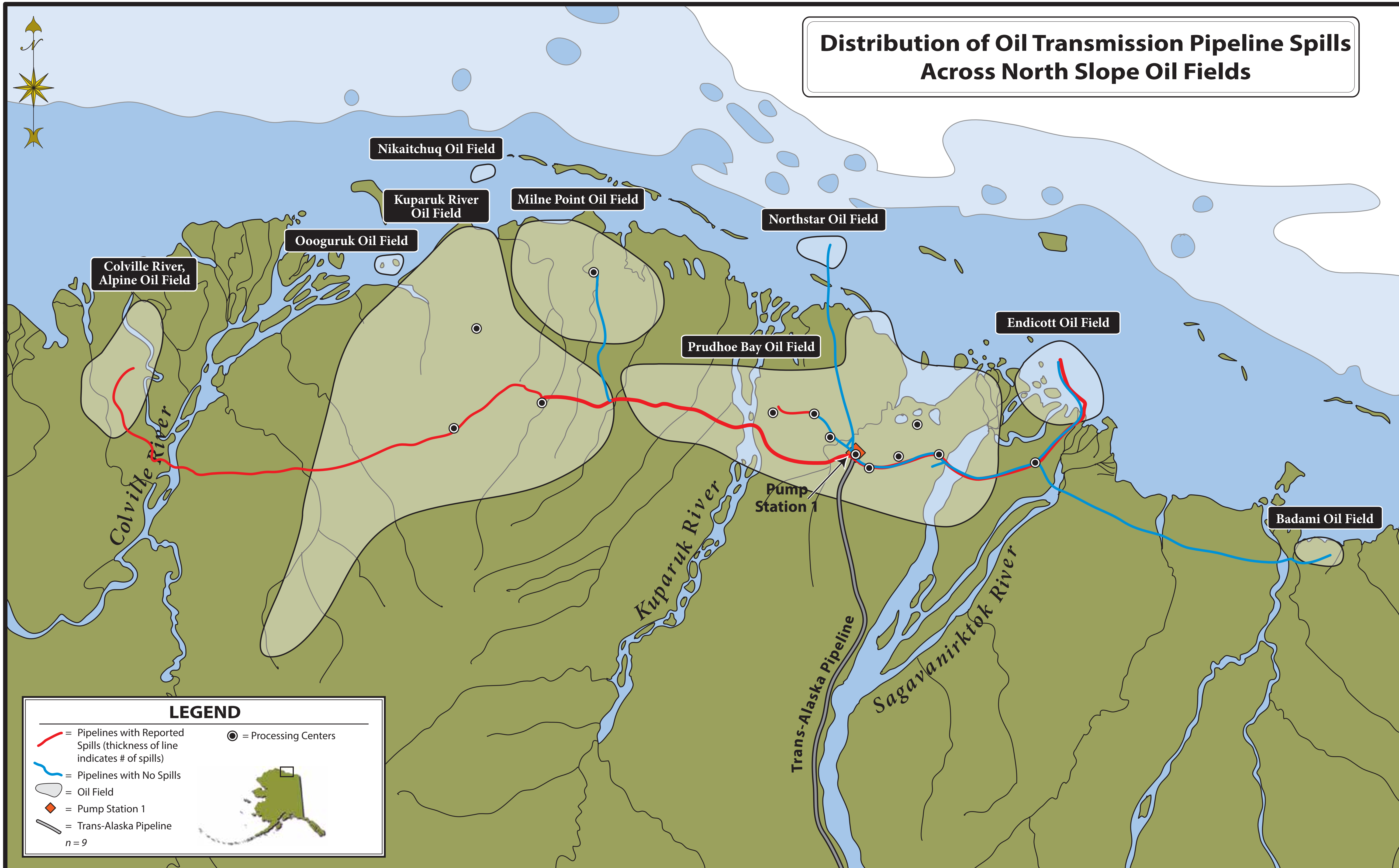

Figure 3-19. Map of distribution of loss-of-integrity spills from oil transmission pipelines across the North Slope.

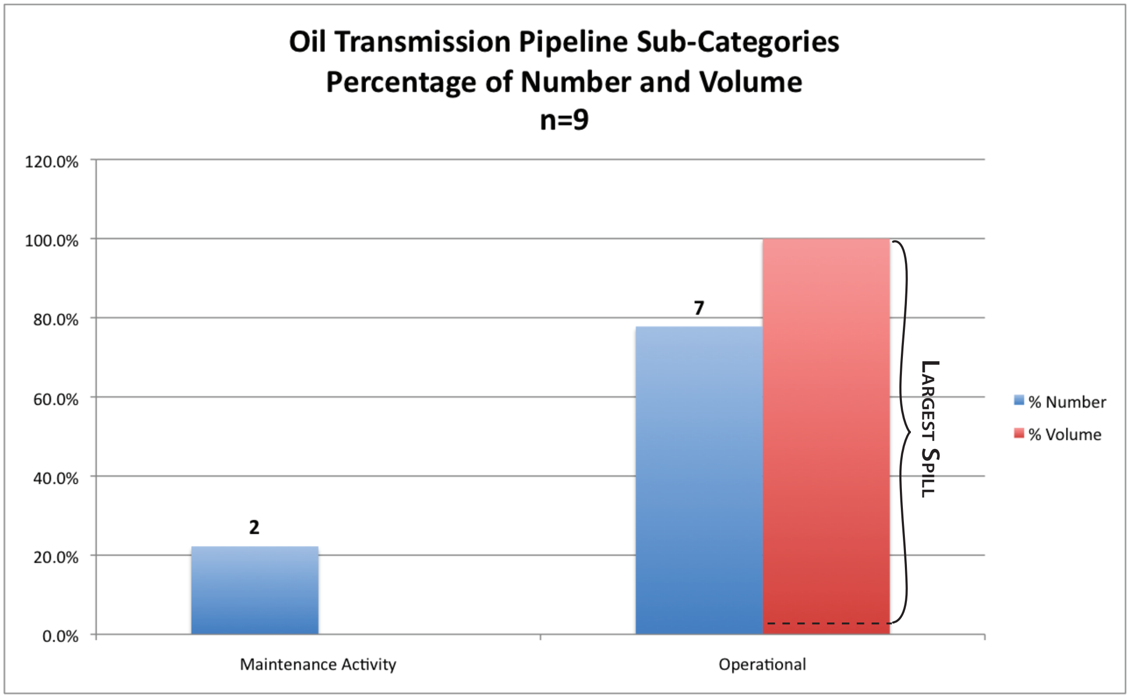

Figure 3-20. Percentage of number and volume of spills from oil transmission pipelines, maintenance activity, and operational.

Operational Oil Transmission Pipeline Leaks

Oil transmission pipeline leaks are spill cases that were not associated with maintenance activities, such as pigging. There were seven oil transmission pipeline leaks from 16 pipelines and no pipeline has experienced more than a single spill. Figure 3-21 depicts the percentage of the number and total volume of operational oil transmission pipeline leaks. Nearly the entire total volume of operational oil transmission pipeline leaks are accounted for by a single spill in 2006 of 212,252 gallons.

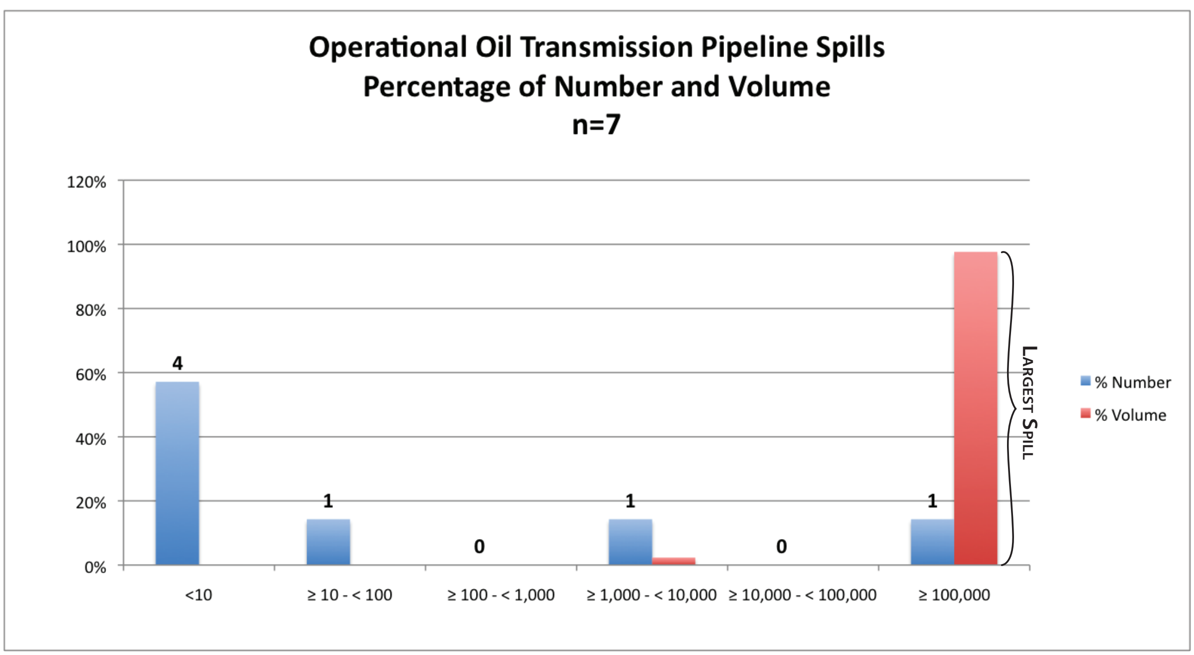

Figure 3-21. Number and volume of operational oil transmission pipeline spill cases by spill size class.

Table 3-10 presents the primary cause breakdown of oil transmission pipeline leaks. Valve/seal failure was the greatest cause of spills (4), followed by internal corrosion (2), and operator error (2). Material failure, thermal expansion, and construction related failure account for one spill each. The single largest spill of 212,252 gallons was caused by internal corrosion.

Figure 3-22 depicts the number of operational oil transmission pipeline spills by year. The average number of spills from this subcategory is 0.4 spills per year. Figure 3-23 depicts a bar graph of total spill volume by year with an overlaid scatter plot of actual spill events plotted over the same time period. Graphical analysis of the number of spills and the total volume spilled for operational oil transmission pipelines indicates no trend over the analysis time period. The single large spill in 2006 is a major contributor to the volume of spills, but the frequency and volume of all other spills for this regulatory category has been very low.

Table 3-10. Primary cause of failure for operational oil transmission pipeline spills.[6]

OPERATIONAL OIL TRANSMISSION PIPELINE SPILLS n=10	
Primary Cause	**Number**
Valve/Seal Failure	4
Internal Corrosion	2
Operator Error	2
Thermal Expansion	1
Construction, Installation or Fabrication Related	1
External Corrosion	0
Erosion	0
Vibration (wind-induced/slugging)	0
Overpressure	0
3rd Party Action	0

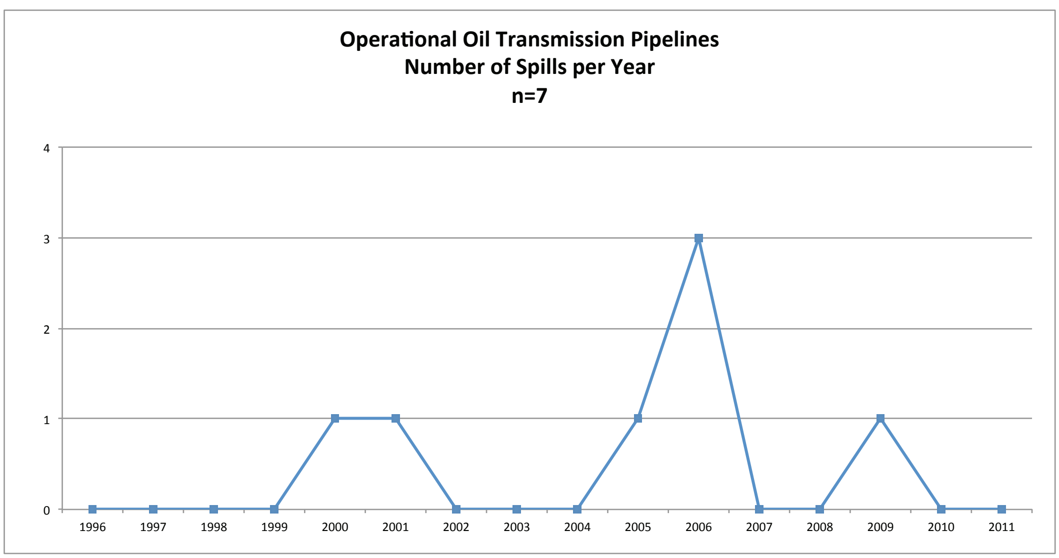

Figure 3-22. Number of operational oil transmission pipeline loss-of-integrity spills reported by North Slope oil and gas operators by year.

6 Note that n is the number of spill cases. Some cases have more than one primary cause, so the number of cause assignments exceeds the number of cases.

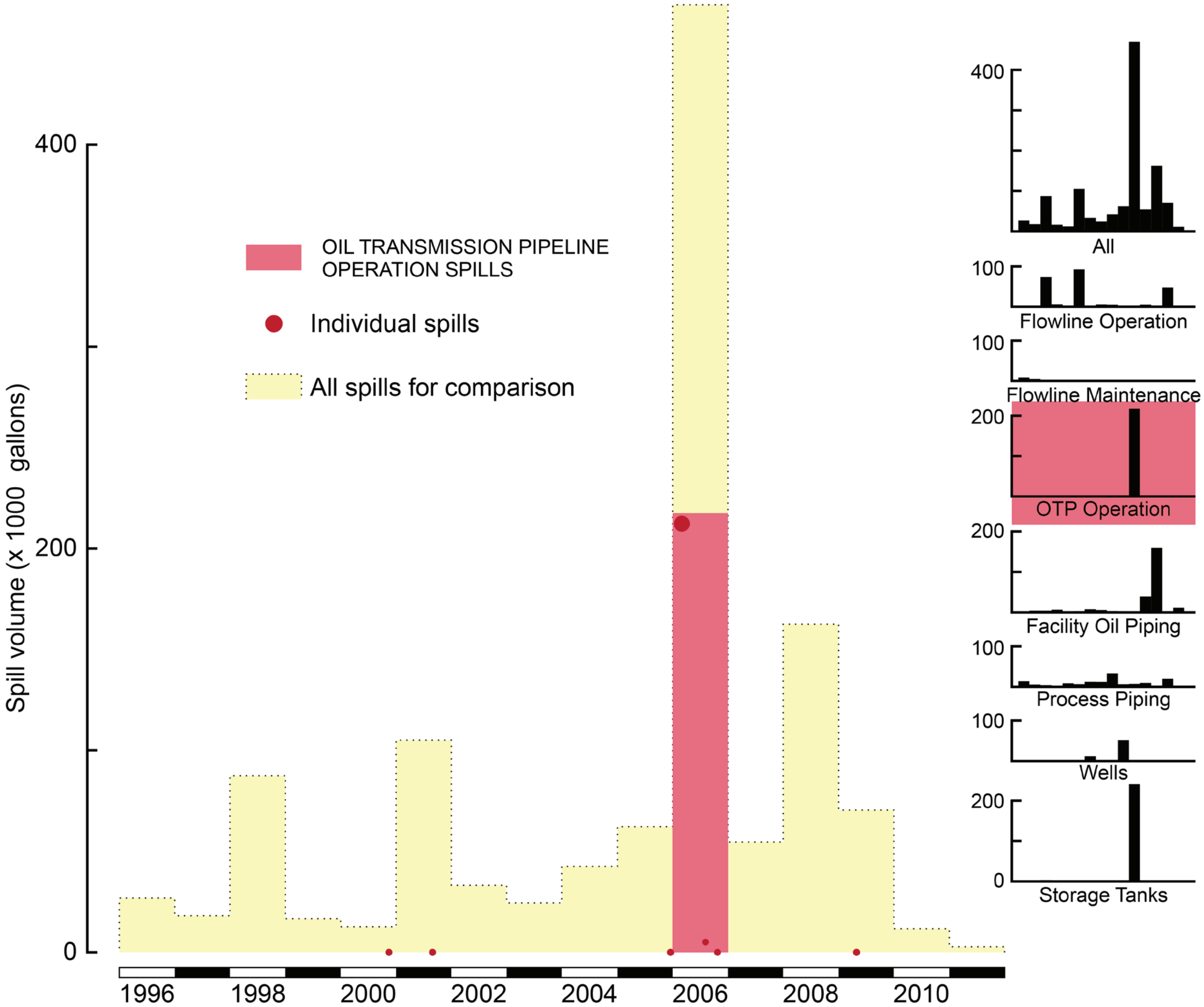

Figure 3-23. Bar graph of total spill volume (gallons) by year and scatter plot of actual spill events, all operational oil transmission pipeline loss-of-integrity spills.

<u>**Maintenance Activity Oil Transmission Pipeline Spills**</u>

Maintenance activity oil transmission pipeline spill cases are associated with maintenance activities such as pigging. Only two spill cases occurred in this sub-category, so summary statistics are not meaningful. One spill of 84 gallons in 1996 was the result of operator error and the other spill of four gallons in 2005 was the result of a valve/seal failure. Maintenance activity oil transmission pipeline spills are not a significant contributor to either frequency or volume of loss-of-integrity spills on the North Slope.

3.2.3 Facility Oil Piping

Table 3-5 shows that the regulatory category with the largest number of spill cases is facility oil piping with 260 spill cases, which represents 39% of the total number of loss-of-integrity spills. The volume spilled from facility oil piping was 259,163 gallons or 21% of the total volume spilled across all spills in the study. Facility oil piping is second to flowlines in the total volume spilled. Facility oil piping also exhibits the highest spill frequency of 16 spills per year. Figure 3-24 maps the spatial distribution of facility oil piping spills. Table 3-11 presents the annual spill number and total volume of loss-of-integrity spills in the facility oil piping category.

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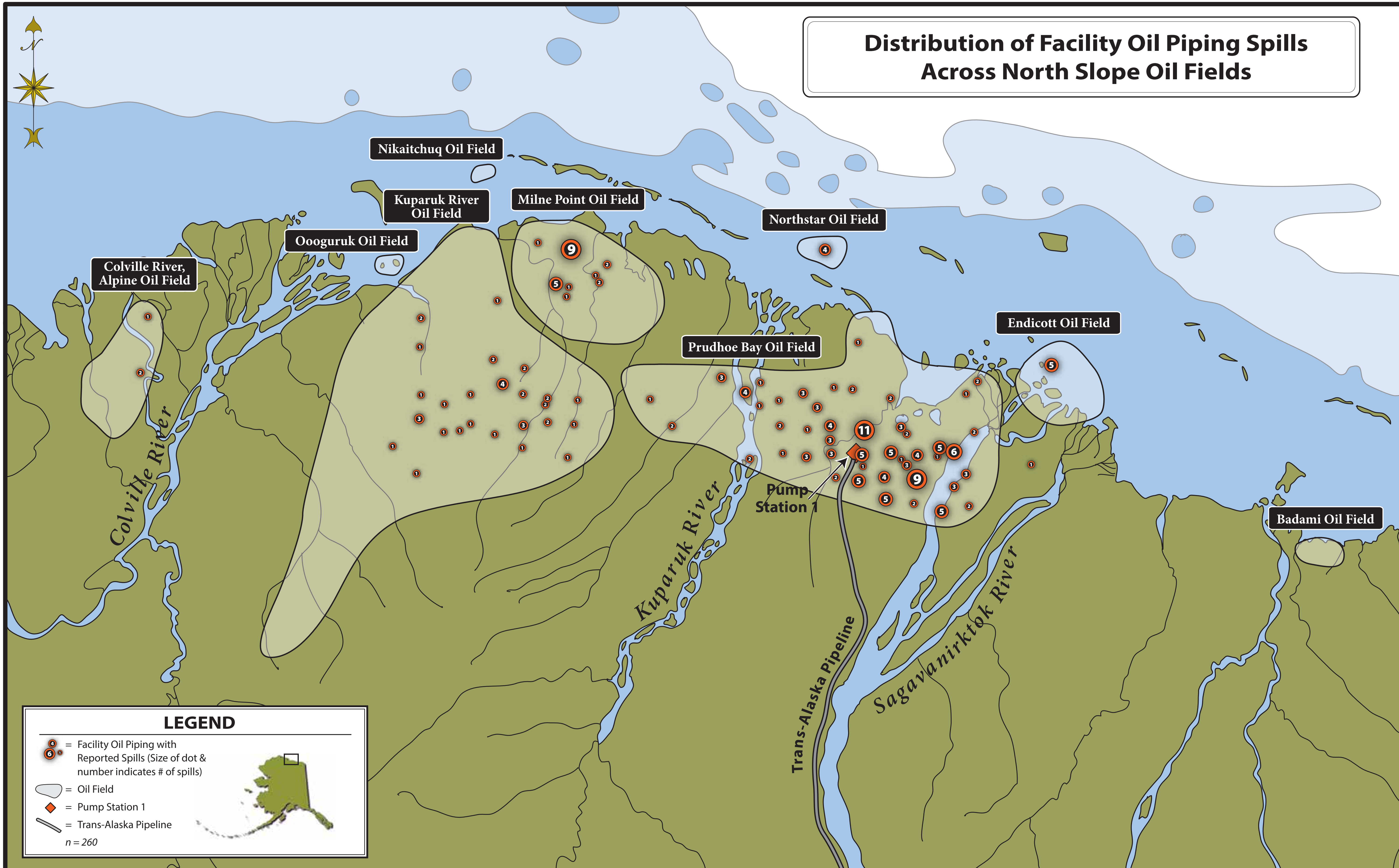

Figure 3-24. Map of distribution of loss-of-integrity spills from facility oil piping across the North Slope.

Table 3-11. Annual spill number and total volume (gallons) for loss-of-integrity spills in the facility oil piping category.

FACILITY OIL PIPING		
Year	Number of Spills	Total Volume (gallons)
1995	10	1,338
1996	22	1,668
1997	18	4,235
1998	25	4,202
1999	11	6,523
2000	14	2,330
2001	17	2,983
2002	14	7,743
2003	21	5,714
2004	19	3,227
2005	10	2,778
2006	14	1,873
2007	5	39,294
2008	23	159,642
2009	14	2,567
2010	11	11,309
2011	12	1,722
Grand Total	**260**	**259,147**

Table 3-12 presents the number and total volume of spills by spill size category. Figure 3-25 depicts the same data, which shows that a few large spills account for the majority of the total volume spilled. The four spills over 10,000 gallons are just 2% of the total number but account for 80% of the total volume spilled. The 15 spills greater than 1,000 gallons represent 6% of the number of spills and account for 13% of the total volume spilled.

Table 3-12. Number and total volume (gallons) of facility oil piping loss-of-integrity spills by size category.

Size Class	< 10	≥ 10 – < 100	≥ 100 – < 1,000	≥ 1,000 - < 10,000	≥ 10,000 - < 100,000	≥ 100,000	Total
Number	110	79	52	15	4	0	260
Percent	42.3%	30.4%	20.0%	5.8%	1.5%	0.0%	
Volume (gallons)	324	3,050	15,902	33,790	206,081	0	259,147
Percent	0.1%	1.2%	6.1%	13.0%	79.5%	0.0%	

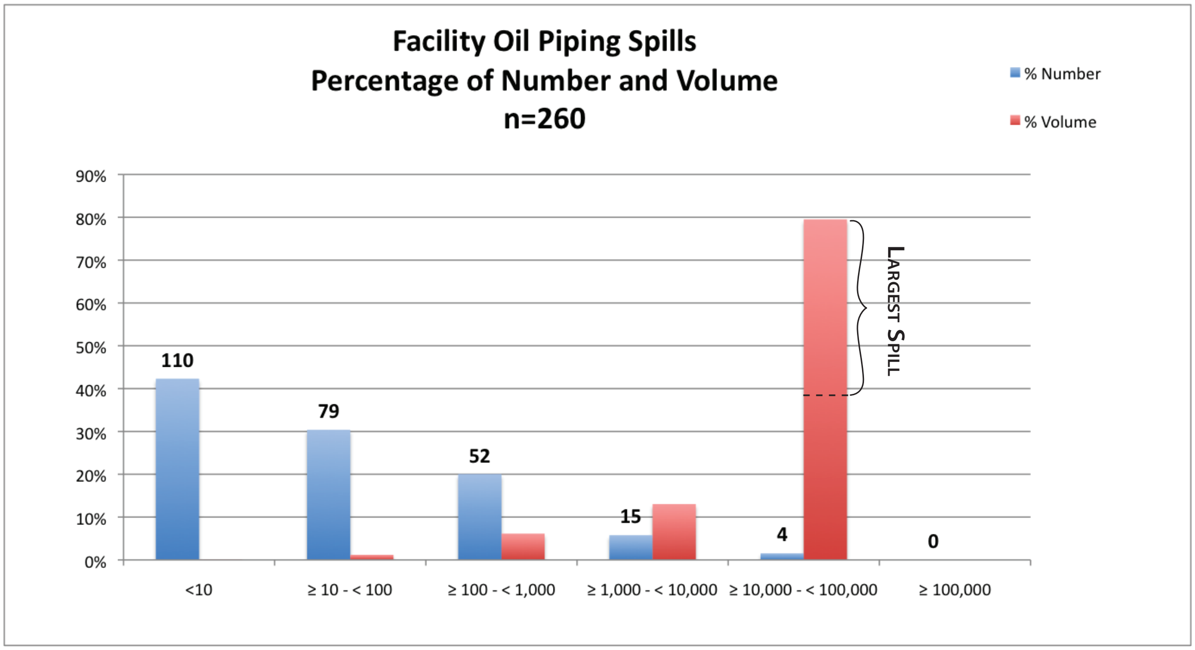

Figure 3-25. Percentage of number and total volume (gallons) of loss-of-integrity spills by size.

The facility oil piping category includes pipelines that run from individual wells to the manifold connected to the flowline as well as pipelines connected to above ground oil storage tanks. For the purpose of this study, the facility oil piping category was divided into two sub-categories based on service: well lines and tank lines. Well lines account for 94% (245 cases) and tank lines account for only 6% (15 cases) of the facility oil piping spills. The average spill volume for well lines (1,005 gallons) was larger than the average spill for tank lines (862 gallons).

Table 3-13 presents the primary cause breakdown of facility oil piping spills. Valve/seal failure was the greatest cause of spills (104), followed by operator error (35), internal corrosion (23), and thermal expansion (18). The single largest spill of 94,920 gallons was caused by internal corrosion.

Table 3-13. Primary cause of failure for facility oil piping spills.[7]

FACILITY OIL PIPING SPILLS n=205	
Primary Cause	**Number**
Valve/Seal Failure	104
Operator Error	35
Internal Corrosion	23
Thermal Expansion	18
Overpressure	9
Erosion	8
External Corrosion	3
Construction, Installation, or Fabrication Related	3
Vibration (wind-induced/slugging)	1
3rd Party Action	1

7 Note that n is the number of spill cases. Some cases were not assigned a primary cause, so the number of cause assignments is smaller than the number of cases.

Figure 3-9 depicts the number of facility oil piping spills by year. Figure 3-26 depicts a bar graph of total spill volume by year with an overlaid scatter plot of actual spill events plotted over the same time period. Statistical analysis does not indicate a significant trend in the number of facility oil piping spills over time.

Spills from facility oil piping continue to occur at the highest frequency of any regulatory category and the spill volume has increased over the study period. The majority of facility oil piping leaks occurs on well pads between the well and the flowline manifold and are caused by valve/seal failure.

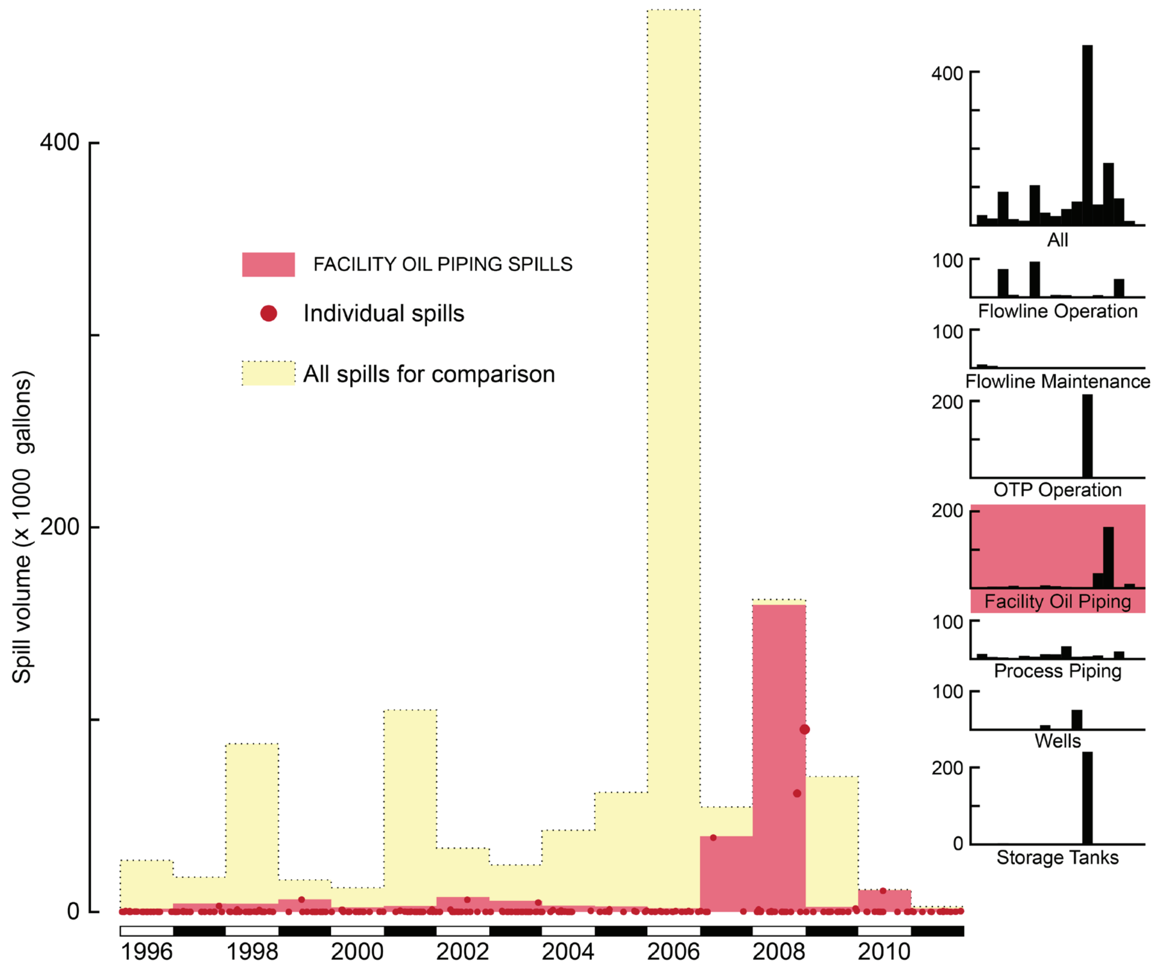

Figure 3-26. Bar graph of total spill volume (gallons) by year and scatter plot of actual spill events, all facility oil piping loss-of-integrity spills.

3.2.4 Process Piping

Table 3-5 shows that the regulatory category with the second largest number of spill cases is process piping, with 203 spill cases. These spills represent 30% of the total loss-of-integrity spills. The volume spilled from process piping was 156,374 gallons or 13% of the total volume spilled. Process piping exhibits the second highest frequency of 12.8% per year. Process piping is responsible for a large number of relatively small spills. Figure 3-27 maps the spatial distribution of process piping spills. Table 3-14 presents the annual number of spills and total volume for loss-of-integrity spills in the process piping category.

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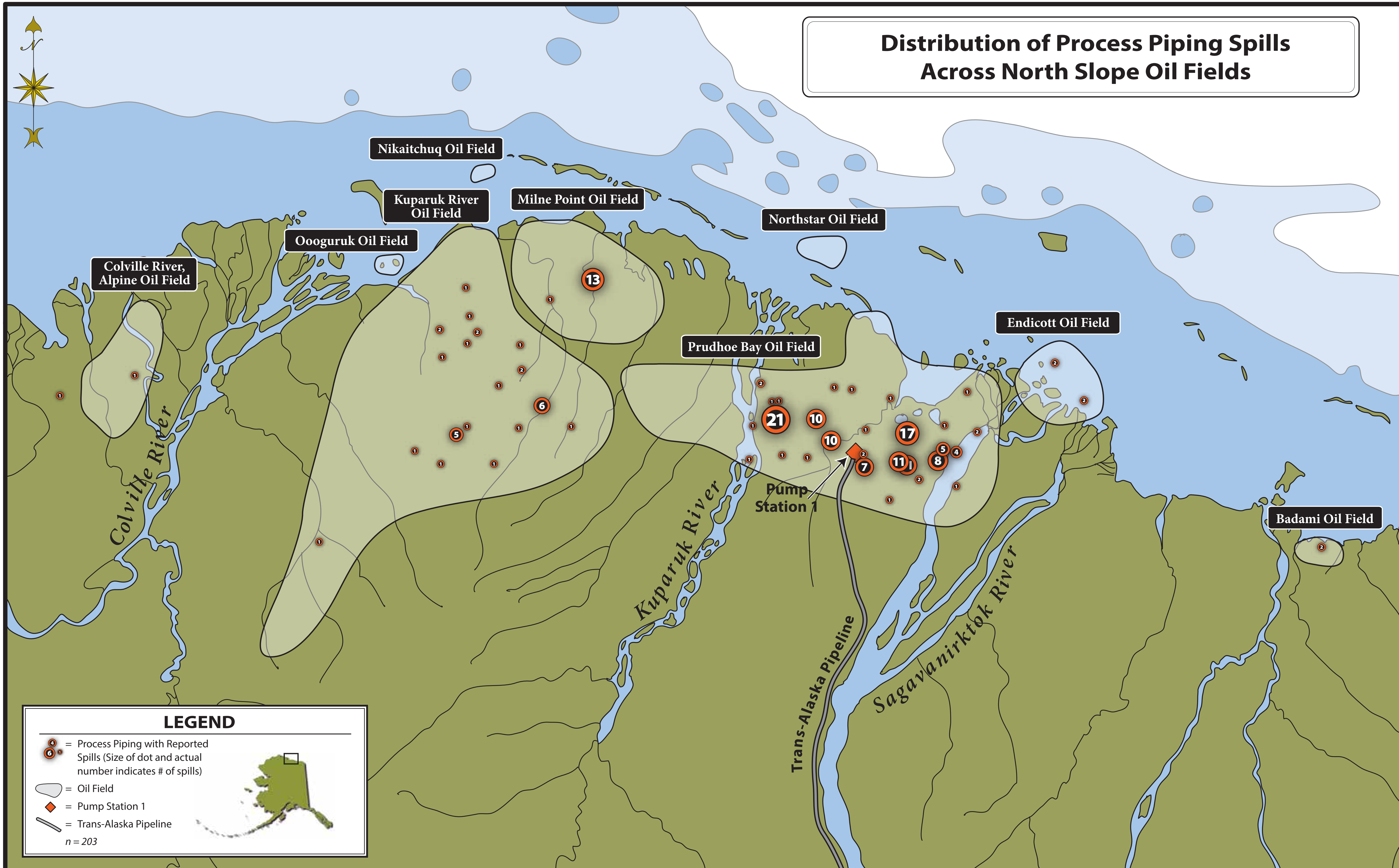

Figure 3-27. Map of distribution of loss-of-integrity spills from process piping across the North Slope.

Table 3-14. Annual number of spills and total volume (gallons) for process piping loss-of-integrity spills.

PROCESS PIPING		
Year	Number of Spills	Total Volume (gallons)
1995	5	13,005
1996	16	13,742
1997	17	5,578
1998	15	4,176
1999	12	1,202
2000	13	8,656
2001	12	6,629
2002	12	12,415
2003	10	12,194
2004	11	33,300
2005	17	6,477
2006	21	7,261
2007	19	9,572
2008	15	2,545
2009	7	19,593
2010	1	30
2011	0	0
Grand Total	**203**	**156,375**

Table 3-15 presents the number and total volume of spills by spill size category. Figure 3-28 depicts the same data. Two spills over 10,000 gallons make up less than 1.0% of the total number of spills and account for 26% of the total volume spilled. The 26 spills greater than 1,000 gallons represent 13% of the number of spills and account for 58% of the total volume spilled. The number of spills from process piping is much more broadly distributed across the size classes than other regulatory categories.

Table 3-15. Number and total volume (gallons) of process piping spills by size category.

PROCESS PIPING							
Size Class	< 10	≥ 10 – < 100	≥ 100 – < 1,000	≥ 1,000 - < 10,000	≥ 10,000 - < 100,000	≥ 100,000	Total
Number	31	71	73	26	2	0	203
Percent	15.3%	35.0%	36.0%	12.8%	1.0%	0.0%	
Volume (gallons)	89	2,961	22,492	89,883	40,950	0	156,375
Percent	0.1%	1.9%	14.4%	57.5%	26.2%	0.0%	

The process piping category includes pipes inside flowline manifold buildings, inside modules at the processing centers, and seawater pipelines. For the purpose of this study, the process piping category was divided into three sub-categories: well manifolds, processing center modules, and seawater pipelines. Table 3-16 presents the number of total volume for each of the process piping sub-categories. Process piping at processing centers account for 74% (148) of the cases and no increase of spills in the past two years. Process piping spills at processing centers are more frequent and severe than spills from well manifolds or sea water lines.

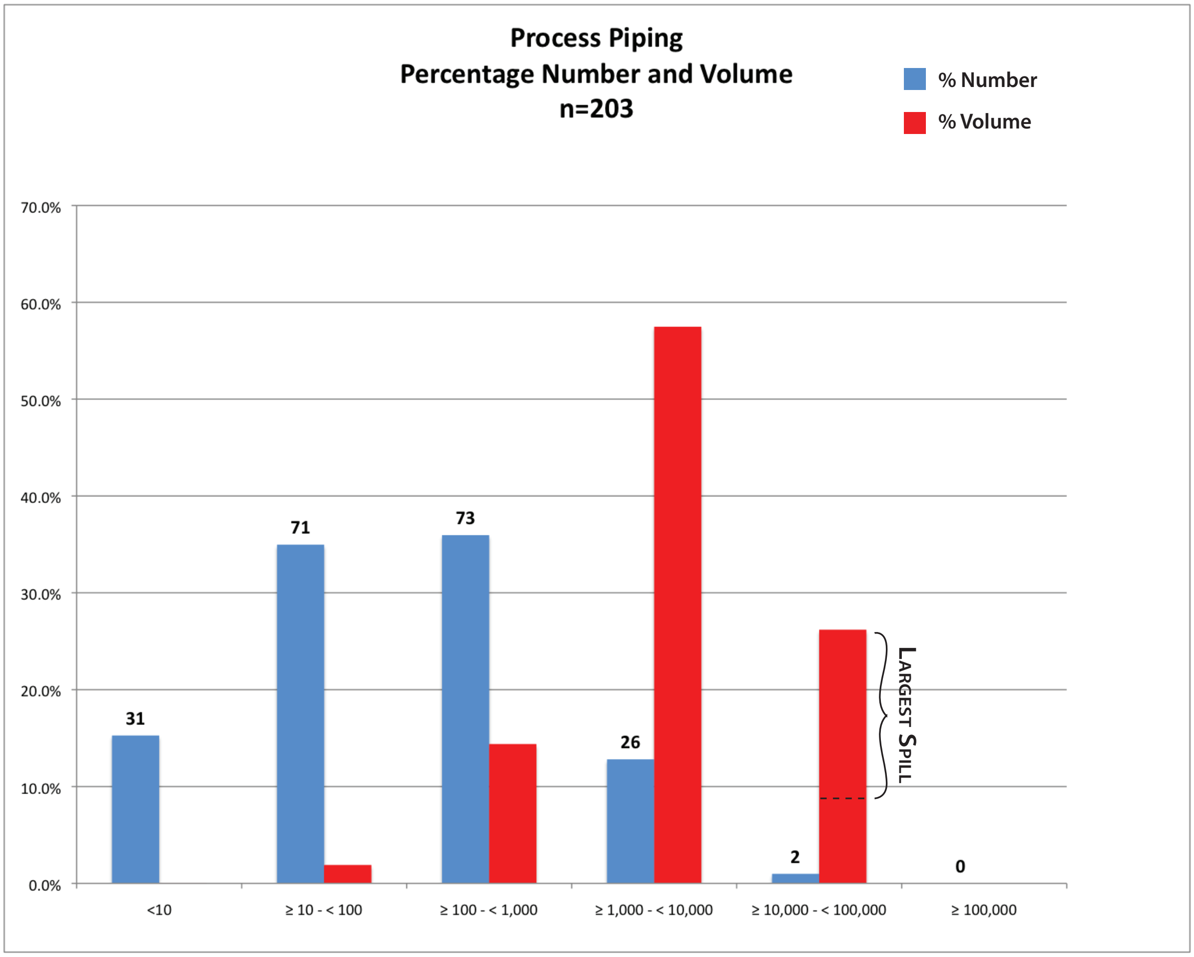

Figure 3-28. Number and total volume (gallons) of process piping spills by size category.

Table 3-16. Number and total volume (gallons) of process piping spills by sub-category.

PROCESS PIPING				
Sub-Category	**Well Manifold**	**Processing Centers**	**Sea Water**	**Total**
Number	7	148	46	201
Percent	3.5%	73.6%	22.9%	
Volume (gallons)	1,899	121,435	32,759	156,093
Percent	1.2%	77.8%	21.0%	

Table 3-17 presents the primary cause breakdown of process piping spills. Valve/seal failure was the greatest cause of spills (67), followed by operator error (34), internal corrosion (21), erosion and thermal expansion (10 each), and external corrosion (7). The two largest spills were caused by valve/seal failure and internal corrosion.

Table 3-17. Primary cause of failure for process piping spills.[8]

PROCESS PIPING SPILLS, n=156	
Primary Cause	**Number**
Valve/Seal Failure	67
Operator Error	34
Internal Corrosion	21
Erosion	10
Thermal Expansion	10
External Corrosion	7
Overpressure	4
Construction, Installation or Fabrication Related	2
Vibration (wind-induced/slugging)	1
3rd Party Action	0

Figure 3-9 presents the number of process piping spills by year. Figure 3-29 depicts a bar graph of total spill volume by year with an overlaid scatter plot of actual spill events plotted over the same time period. Statistical analysis does not indicate a significant trend in the number of process piping spills over time.

Spills from process piping occur at the second highest frequency of any category and neither spill count nor average spill volume show any trend over the study period. Spills from this sub-category have a high frequency and a relatively low volume.

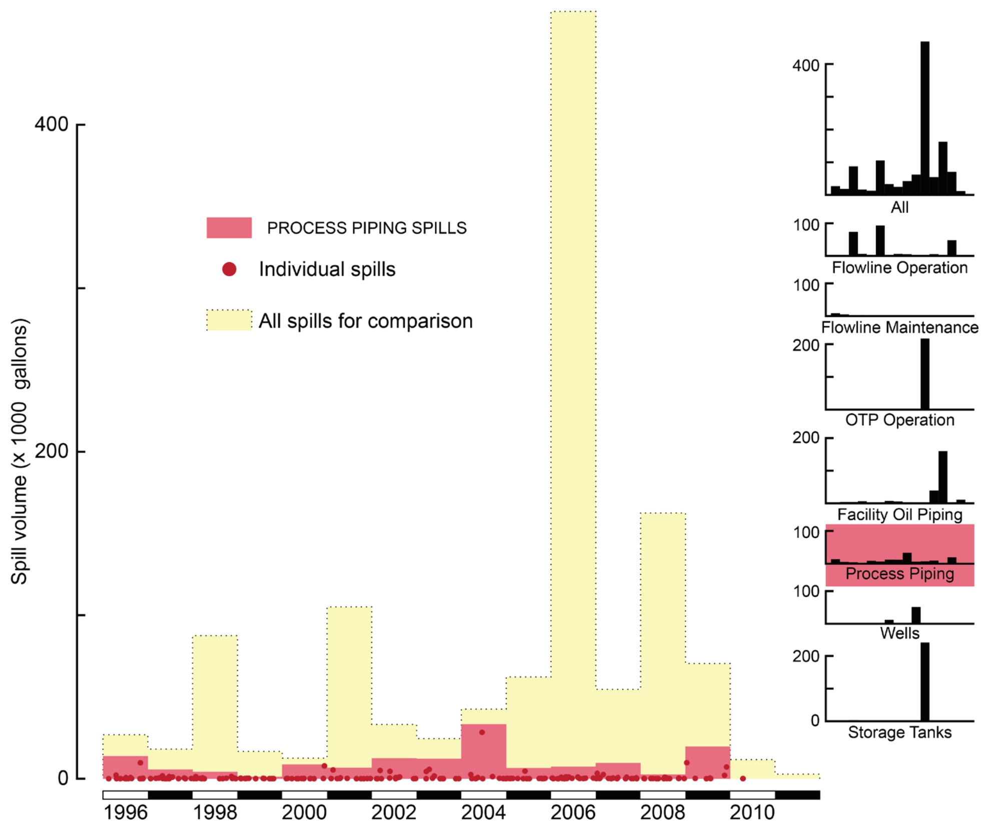

Figure 3-29. Bar graph of total spill volume (gallons) by year and scatter plot of actual spill events, all process piping loss-of-integrity spills.

8 Note that n is the number of spill cases. Some cases were not assigned a primary cause, so the number of cause assignments is smaller than the number of cases.

3.2.5 Wells

Spills from the wells category are the result of leaks from the well head or the well casing during normal production operations. Table 3-5 shows that the regulatory category with the third largest number of spill cases is wells, with 119 spill cases. The frequency of spills from wells remains unchanged from the 2010 study at 7.4 spills per year and represents 5% (66,672 gallons) of the total volume spilled across all spills in the study. The average volume of 560 gallons per spill is the lowest of all spill categories. Figure 3-30 maps the spatial distribution of well spills. Table 3-18 presents the annual spill number and total volume for loss-of-integrity spills in the wells category.

Table 3-18. Annual number of spills and total volume (gallons) for loss-of-integrity spills in wells category.

WELLS		
Year	Number of Spills	Total Volume (gallons)
1995	2	25
1996	4	54
1997	3	765
1998	5	72
1999	3	14
2000	8	301
2001	6	36
2002	5	11,816
2003	11	232
2004	10	279
2005	11	51,576
2006	12	802
2007	8	27
2008	8	336
2009	12	304
2010	5	17
2011	6	17
Grand Total	**119**	**66,672**

Table 3-19 presents the percentage of number and total volume of spills by spill size category. Figure 3-31 depicts the same data, which shows that two spills over 10,000 gallons represent only 1.7% of the total number of spills, but account for 94% of the total volume spilled. A majority of the well spills (58%) are less than ten gallons.

Table 3-19. Number and total volume (gallons) of well spills by size category.

WELLS							
Size Class	< 10	≥ 10 – < 100	≥ 100 – < 1,000	≥ 1,000 - < 10,000	≥ 10,000 - < 100,000	≥ 100,000	Total
Number	69	36	12	0	2	0	119
Percent	58.0%	30.3%	10.1%	0.0%	1.7%	0.0%	
Volume (gallons)	228	872	2,763	0	62,809	0	66,672
Percent	0.3%	1.3%	4.1%	0.0%	94.2%	0.0%	

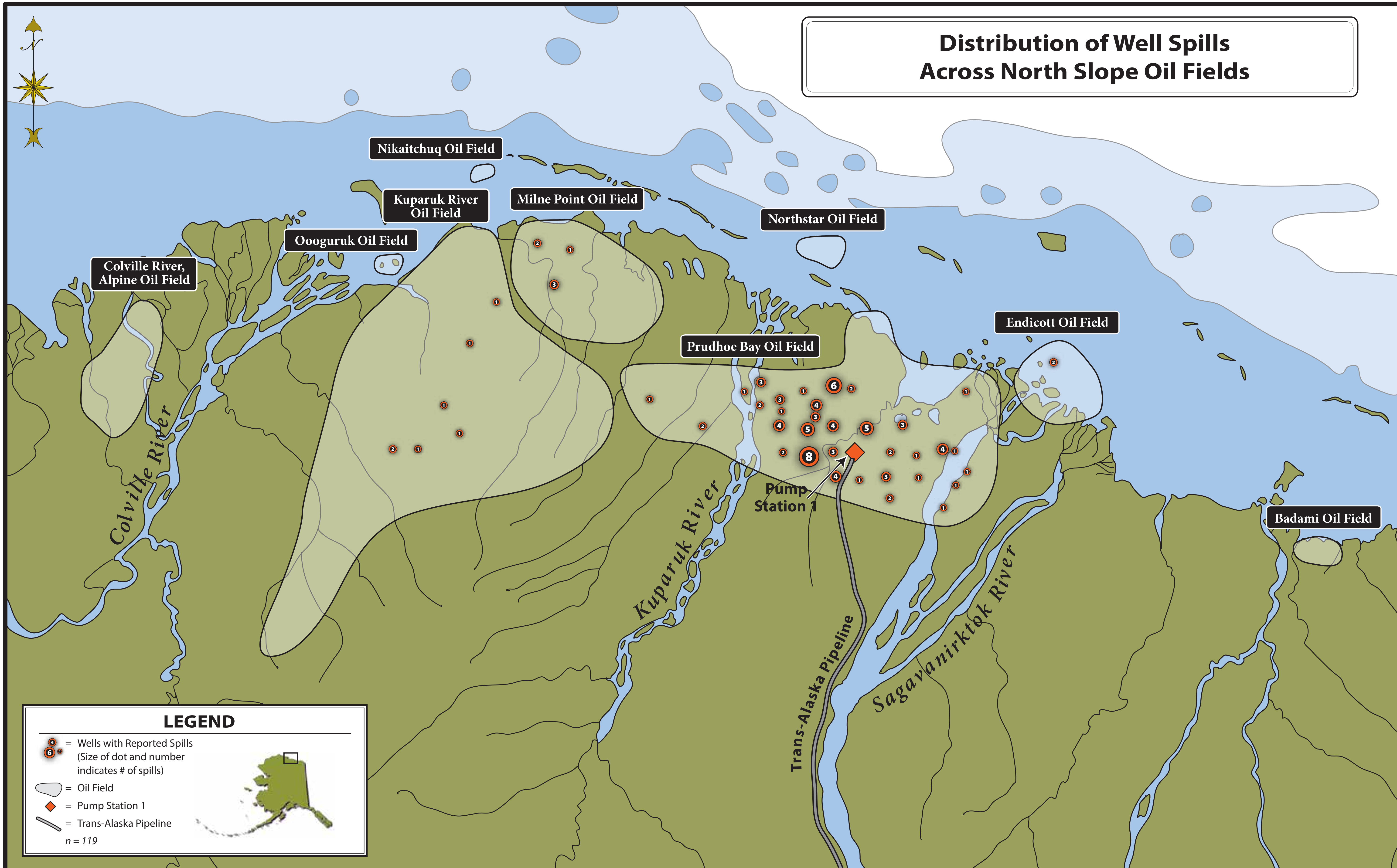

Figure 3-30. Map of distribution of loss-of-integrity spills from wells across the North Slope.

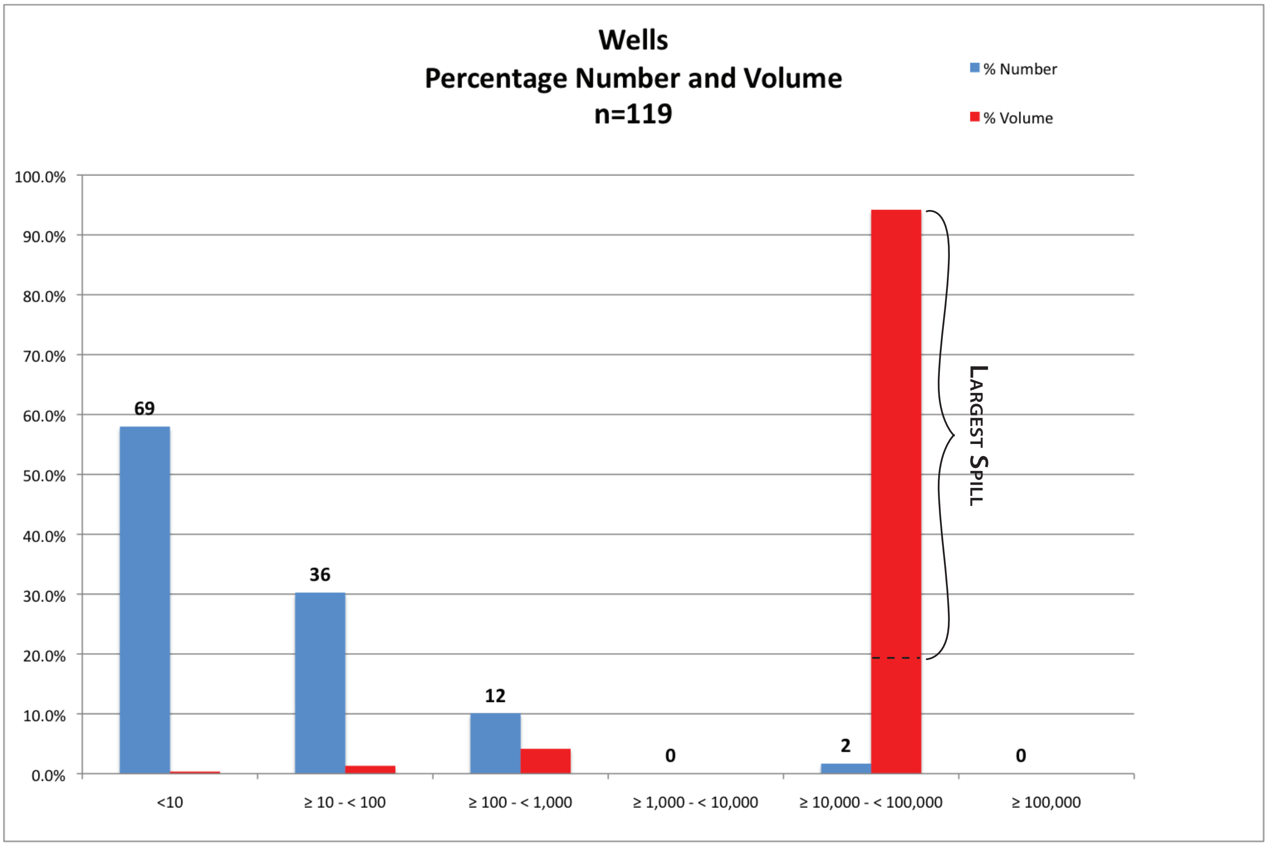

Figure 3-31. Number and total volume (gallons) of well spills by size category.

Table 3-20 presents the primary cause breakdown of well spills. Valve/seal failure was the dominant cause of spills (67%), followed by overpressure (9%), thermal expansion and operator error (6% each), internal corrosion (4%) and construction installation or fabrication (4%). The largest spill of 51,198 gallons was caused by internal corrosion.

Table 3-20. Primary causes of failure for well spills.[9]

WELL SPILLS n=67	
Primary Cause	**Number**
Valve/Seal Failure	46
Overpressure	6
Thermal Expansion	4
Operator Error	4
Internal Corrosion	3
Construction, Installation or Fabrication Related	3
Erosion	1
External Corrosion	0
Vibration (wind-induced/slugging)	0
3rd Party Action	0

9 Note that n is the number of spill cases. Some cases were not assigned a primary cause, so the number of cause assignments is smaller than the number of cases.

Figure 3-32 depicts a bar graph of total spill volume by year with an overlaid scatter plot of actual spill events plotted over the same time period. Statistical analysis indicates that there is an upward trend over time for spills from wells.

When no other factors are considered, the number of spills from this sub-category have shown a statistically significant increase over time. However, the number of wells have also increased over time. When controlling for number of wells, there is no apparent increase in spill rate for this category. Spills from the well sub-category have a low average volume when they do occur.

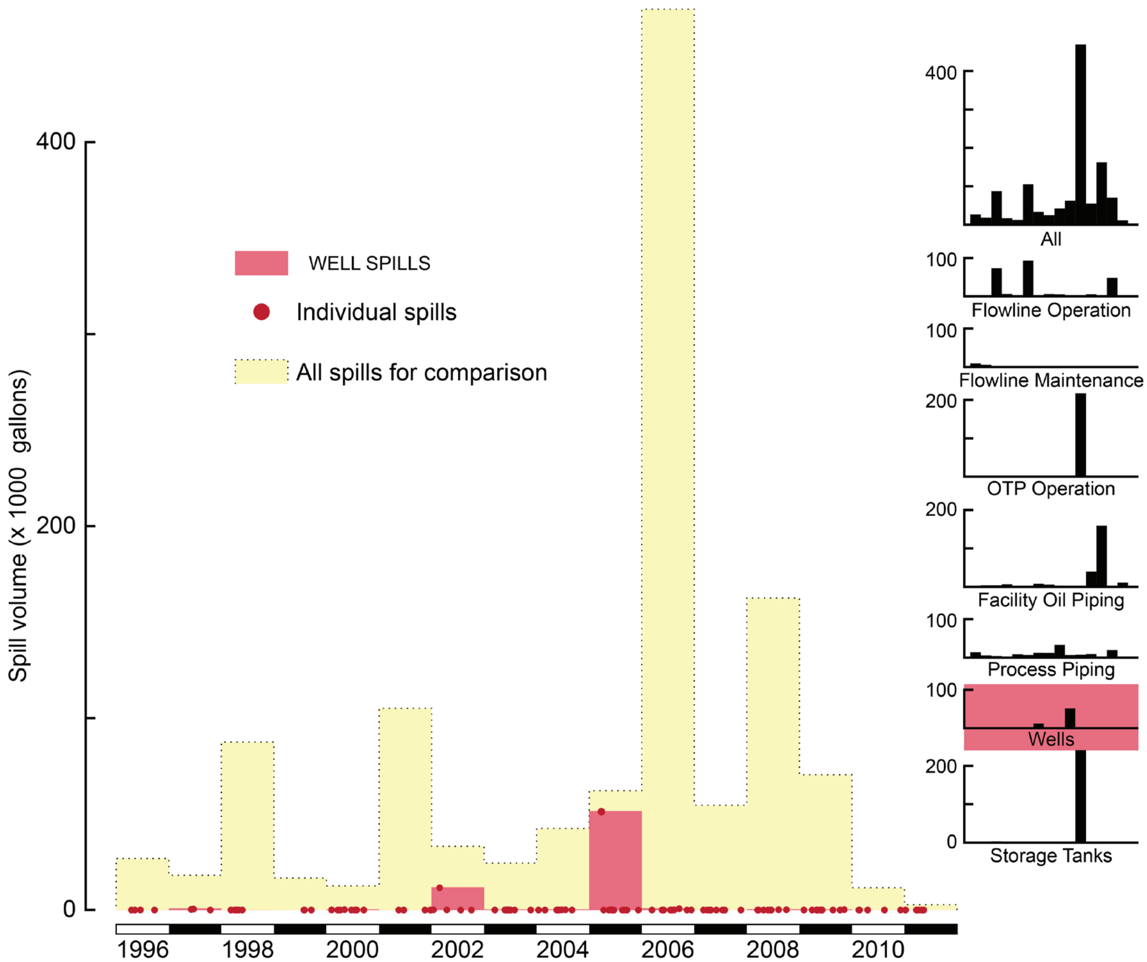

Figure 3-32. Bar graph of total spill volume (gallons) by year and scatter plot of actual spill events, all well loss-of-integrity spills.

3.2.6 Above Ground Oil Storage Tanks

The largest spill of 214,038 gallons in 2006 was from an above ground oil storage tank. Table 3-5 shows that this regulatory category has the second lowest frequency of spills with 10 spill cases, an average of 0.6 spills per year. There were no spills reported by North Slope operators for this category in 2010 and 2011. The 10 spills represent 1% of the total number of loss-of-integrity spills, however the total volume spilled from above ground oil storage tanks was 247,137 gallons representing 20% of the total volume spilled across all spill categories. Figure 3-33 maps the spatial distribution of above

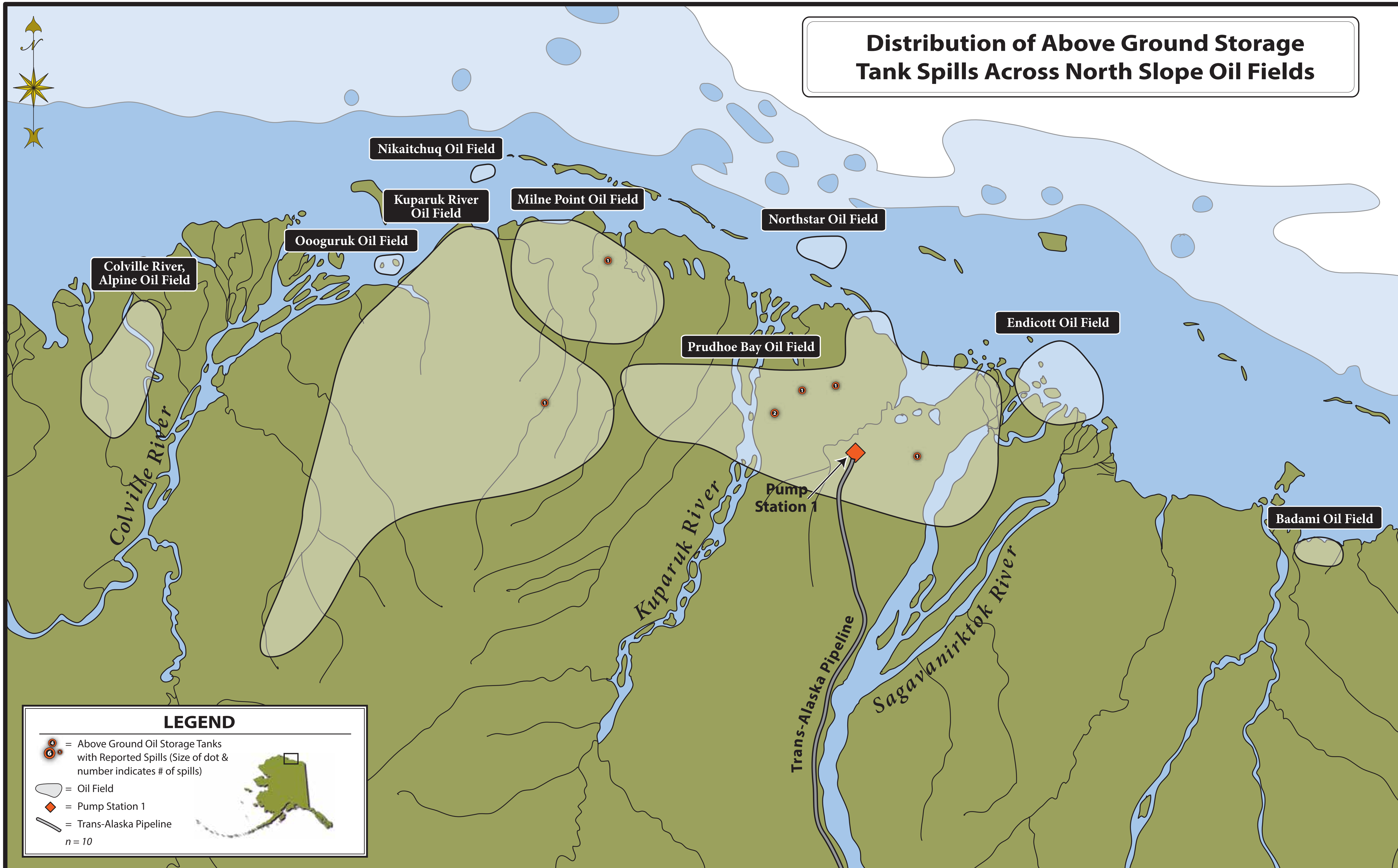

Figure 3-33. Map of distribution of loss-of-integrity spills from above ground oil storage tanks across the North Slope.

ground oil storage tank spills. Table 3-21 presents the annual spill number and total volume for loss-of-integrity spills in the above ground oil storage tank category.

Table 3-21. Annual number of spills and total volume (gallons) for loss-of-integrity above ground oil storage tanks category.

ABOVE GROUND OIL STORAGE TANK		
Year	Number of Spills	Total Volume (gallons)
1995	1	2
1996	0	0
1997	0	0
1998	2	3,370
1999	0	0
2000	0	0
2001	1	2,600
2002	3	104
2003	1	20
2004	0	0
2005	0	0
2006	1	241,038
2007	0	0
2008	0	0
2009	1	3
2010	0	0
2011	0	0
Grand Total	**10**	**247,137**

Table 3-22 presents the number and total volume of above ground oil storage tank spills by spill size category. Figure 3-34 depicts the same data, which shows that the single large spill in 2006 accounts for the vast majority (98%) of the total volume spilled.

Table 3-22. Number and total volume (gallons) of above ground oil storage tank spills by size category.

ABOVE GROUND OIL STORAGE TANKS							
Size Class	< 10	≥ 10 – < 100	≥ 100 – < 1,000	≥ 1,000 - < 10,000	≥ 10,000 - < 100,000	≥ 100,000	Total
Number	4	2	1	2	0	1	10
Percent	40.0%	20.0%	10.0%	20.0%	0.0%	10.0%	
Volume (gallons)	9	30	100	5,960	0	241,038	247,137
Percent	0.0%	0.0%	0.0%	2.4%	0.0%	97.5%	

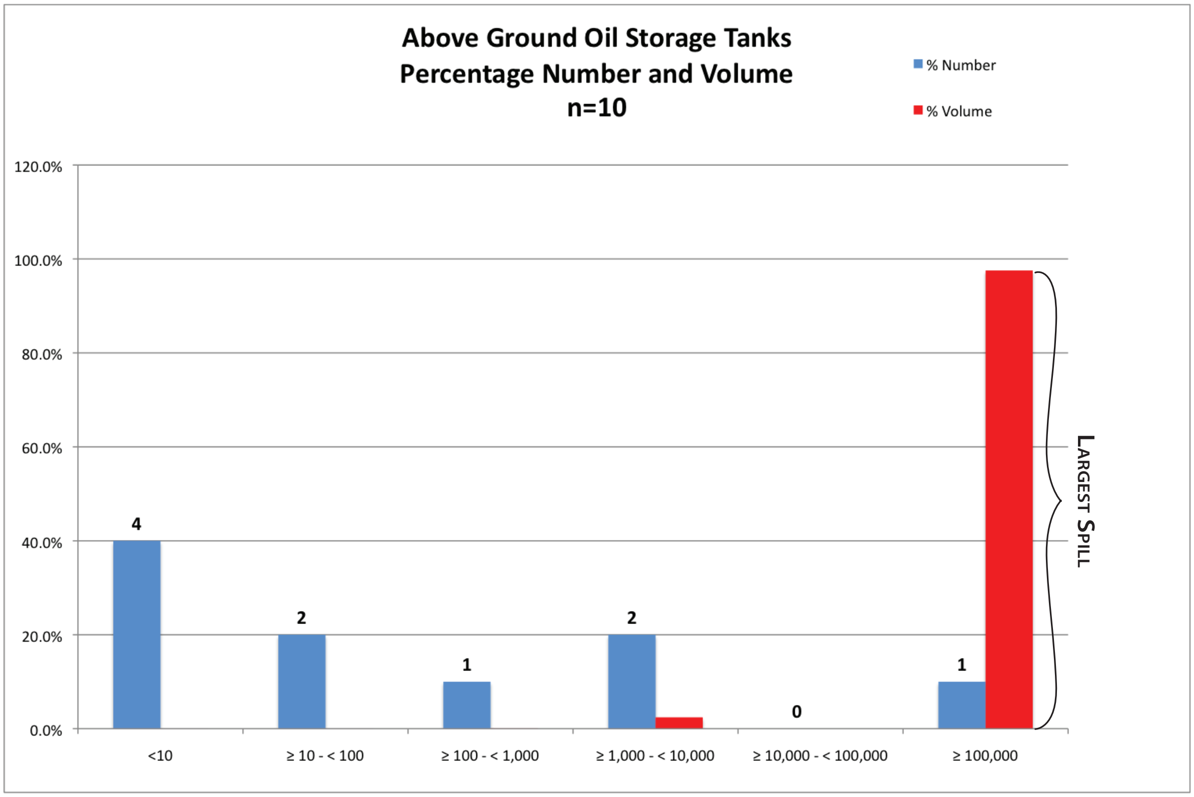

Figure 3-34. Number and total volume (gallons) of above ground oil storage tank spills by spill size category.

Table 3-23 presents the primary cause breakdown of above ground oil storage tank spills. Operator error was the most frequent cause of spills. The largest spill of 241,038 gallons was caused by material failure.

Table 3-23. Primary cause of failure for above ground storage tank spills.[10]

ABOVE GROUND OIL STORAGE TANK SPILLS n=4	
Primary Cause	**Number**
Operator Error	3
Valve/Seal Failure	1
External Corrosion	0
Internal Corrosion	0
Erosion	0
Thermal Expansion	0
Construction, Installation or Fabrication Related	0
Vibration (wind-induced/slugging)	0
Overpressure	0
3rd Party Action	0

10 Note that n is the number of spill cases. Some cases were not assigned a primary cause, so the number of cause assignments is smaller than the number of cases.

Figure 3-35 depicts a bar graph of total spill volume by year with an overlaid scatter plot of actual spill events plotted over the same time period. Graphical analysis reveals no trend in number or volume across the study period. The single large spill in 2006 is a major contributor to the volume of spills, but the frequency and volume of all other spills from this category has been very low.

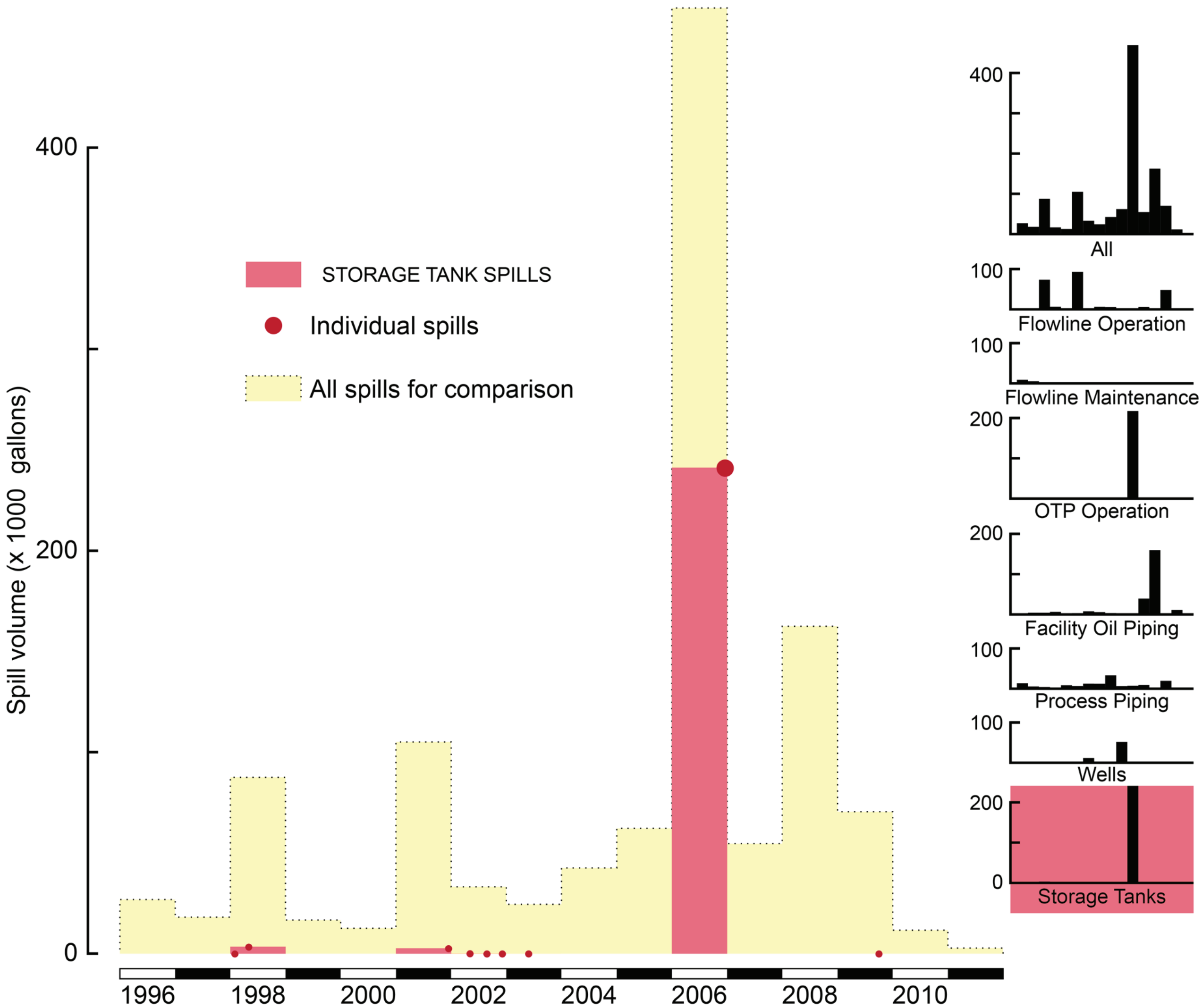

Figure 3-35. Bar graph of total spill volume (gallons) by year and scatter plot of actual spill events, all above ground oil storage tank loss-of-integrity spills.

3.2.7 Comparison Across Regulated Categories

Figure 3-36 presents a binning of regulated categories by the spill frequency and volume. The colors of the matrix are meant to indicate the relative risk of that cell. Colors are based on the best professional judgment of the authors. The volume scale is logarithmic, meaning each cell is ten times greater than the adjacent cell. Thus, moving one cell left or right represents a much greater change than moving one cell up or down. Each cell contains any relevant regulatory category followed by the number of spills in that category during the analysis time period. Facility oil piping, process piping and well spills occur at the highest frequencies. All regulated categories – oil transmission pipelines, above ground oil storage tanks, facility oil piping, flowlines, process piping and wells – have contributed spills that are in the top two volume categories.

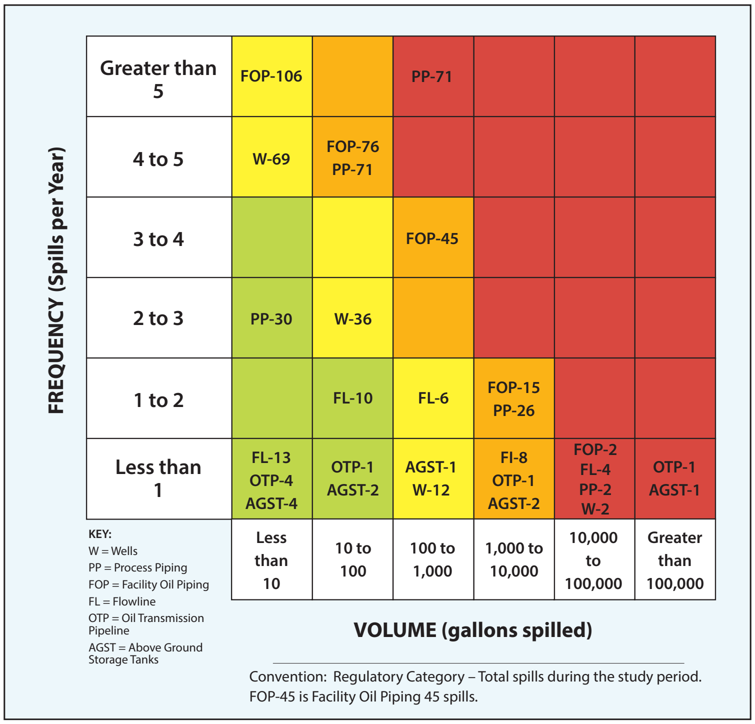

Figure 3-36. Matrix of frequency and volume of spills showing relative contribution of each regulated category during the study period.

Figure 3-37 shows the linear trends in spill frequency over the study period. While not all these trend lines are statistically significant, the graph illustrates a decrease in the number of spills in almost all regulatory categories. The decrease in number of flowline spills is statistically significant at the 95% confidence level. While there is an apparent increase in the well spill category, this trend line is not statistically significant, when well spills are normalized by the number of operating wells (e.g. spills per operating wells).

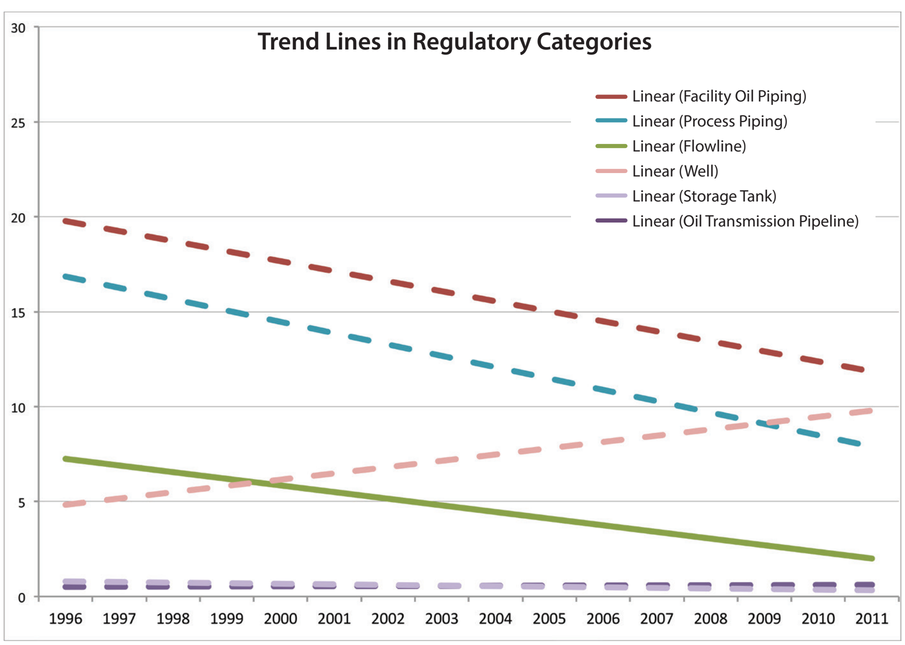

Figure 3-37. Linear trends in annual number of spills for each regulated category from 1996 to 2011. Solid line represent statistically significant linear relationships at a 95% confidence level. Dashed lines are not statistically significant but are representative of trends.

Examination of these data reveals above ground storage tanks and oil transmission pipelines have a very low spill frequency, less than one per year. Each account for about 20% of the total volume spilled which is due to the two large spills in 2006.

3.3 Analysis of Spill Data by Primary Cause of Failure

Data on the primary cause of failure was reviewed to identify common causes of failures that resulted in loss-of-integrity leaks. To understand the data it is important to understand the relationships between causes and how the data are coded in the NSS database. Causes are not mutually exclusive, so more than one cause can be assigned to a spill case. Cause can be interactive; corrosion may weaken a pipeline enough that wind induced vibration causes a material failure of the pipe or weld, which leads to a spill. Causes can be hierarchical, in that some causes are sub-sets of others. Internal corrosion is a subset of Corrosion and in turn, Corrosion could be a subset of Material Failure of Pipe or Weld. The causes used for this study were assigned to standard cause categories developed after an initial review of the database, spill case files, and cause investigation methodologies. Cases were assigned to one or more primary causes based on information obtained from the SPILLS database, case file, C-Plans, and interpretation based on the best professional judgment of the reviewer. The following illustrates the hierarchical relationship of the cause categories:

- Material Failure of Pipe or Weld
    - Corrosion
        - External Corrosion
        - Internal Corrosion
    - Erosion
        - External Erosion
        - Internal Erosion
    - Thermal Expansion
    - Construction, Installation or Fabrication Related
    - Original Manufacturing-Related
    - Vibration (wind-induced/slugging)
    - Overpressure
- Valve/Seal Failure
- Operator Error
- 3rd Party Action

Figure 3-38 presents a binning of selected primary causes of failure by the spill frequency and volume. The colors of the matrix are meant to indicate the relative risk of that cell. Colors are based on cause category assignments that reflect the best professional judgment of the authors and the volume scale is logarithmic, meaning each cell is ten times greater or lesser than the adjacent cell. Each cell contains any relevant primary cause followed by the number of spills in that category during the analysis time period. Valve/seal failures occur at the highest frequencies. Internal corrosion, external corrosion, valve/seal failure, and thermal expansion are primary causes of failure that occur in the top two volume categories.

Because more than one primary cause of failure can be assigned to a single case, statistical analysis required some simplifying assumptions. However the following facts are apparent in the data:

- Valve/seal failure is the most frequent cause of all spills;
- Corrosion is the most frequent cause for spills greater than 1,000 gallons;
- Valve/seal failures account for an unusually high percentage of well spills;
- Operator error accounts for an unusually high percentage of storage tank spills;
- Corrosion accounts for a high percentage of flowline spills; and
- Corrosion is a larger problem for Kuparuk than for Prudhoe Bay.

FREQUENCY (Spills per Year)	Less than 10	10 to 100	100 to 1,000	1.000 to 10,000	10,000 to 100,000	Greater than 100,000
Greater than 5	VS-104	VS-80				
4 to 5						
3 to 4			VS-57			
2 to 3		OE-31				
1 to 2	OE-30	CI-17	CI-22 OE-22	VS-21		
Less than 1	TE-13 CU-6 CE-5 CI-4	TE-11 CE-7 CU-5	TE-10 CE-6 CU-2	CE-9 CI-12 TE-5 OE-5 CU-2	CI-6 VS-3 CE-1 TE-1	CI-1

VOLUME (gallons spilled)

KEY:
CU = Corrosion (Unknown)
CI = Internal Corrosion
CE = External Corrosion
VS = Valve/Seal Failure
TE = Thermal Expansion
OE = Operator Error

Convention: Cause Category – Total Spills
CE-4 is External Corrosion - 4 spills during the study period.

Figure 3-38. Matrix of frequency and volume of spills showing relative contribution of selected primary causes of failure during the study period.

Table 3-24 shows the primary cause of loss-of-integrity spills for each regulatory category and the total volume spilled. Individual spills may have been assigned more than one cause by ADEC staff in the SPILLS database. In some cases, a spill may not have been assigned to a cause category.

Table 3-24. Reported primary cause of loss-of-integrity spills for each regulatory category and the total volume (gallons) spilled.

Actual Number of Spills: 681

ACTUAL # OF SPILLS & VOLUMES:	FLOWLINE		WELL		PROCESS PIPING		OIL TRANS-MISSION PIPELINE		STORAGE TANK		FACILITY OIL PIPING	
	Number	Volume	Number	Volume	Number	Volume	Number	Volume	Number	Volume	Number	Volume
	77	268,358	119	66,672	203	156,346	9	217,439	10	247,137	263	259,163
Reported Primary Causes	Individual spills may have multiple primary causes. Therefore, the totals below exceed the actual spill incidences and volumes (above).											
Unidentified Cause	1	126	12	305	5	5,678	0	0	2	5	12	5,130
Corrosion	25	126,026	4	51,482	35	49,472	2	217,292	1	10	32	171,106
External Corrosion	9	6420.1	0	0	7	8,199	0	0	0	0	2	6584
External Corrosion at or near weld joints	8	107,161	0	0	0	0	0	0	0	0	1	13
Internal Corrosion	8	12,445	3	51,482	21	39,029	2	217,292	0	0	23	162,624
Erosion	1	150	1	115	10	12,913	0	0	0	0	8	2,933
External Erosion	0	0	0	0	1	84	0	0	0	0	1	1,259
Internal Erosion	1	150	1	115	8	7,831	0	0	0	0	7	1,674
Thermal Expansion	5	46,680	4	9	11	15,030	1	5	0	0	18	3,769
Material Failure of Pipe or Weld	8	64,628	41	13,281	41	11,565	1	1	3	243,738	35	6,827
Construction, Installation or Fabrication Related	2	85	3	25	2	955	1	1	0	0	3	2,020
Original Manufacturing-Related	0	0	0	0	0	0	0	0	0	0	0	0
Vibration (wind-induced / slugging)	3	1,497	0	0	1	1,000	0	0	0	0	1	600
Valve/Seal Failure	35	29,797	46	1,097	68	59,182	5	62	1	2	106	64,112
Overpressure	7	47,950	6	251	4	22	0	0	0	0	9	1,417
Operator Error	8	2,066	4	55	34	10,992	3	136	3	3,382	35	4,740
3rd Party Action	0	0	0	0	0	0	0	0	0	0	1	15
Other (Recorded in Comments/Notes)	16	52,293	3	105	10	4,880	1	5	2	2,700	22	4,265
Not Recorded by Operator	0	0	0	0	0	0	0	0	0	0	1	3
Total Listed Causes:	**137**		**128**		**258**		**16**		**12**		**317**	

Contributing causes are typically identified through a root cause analysis, which is usually part of an investigation. Contributing causes were collected based on record review and information provided by the operator. This information is not included in the ADEC SPILLS database. Only a limited number of contributing causes was identified from the record review and more than one contributing cause can be assigned to an individual spill.

Table 3-25. Matrix of reported contributing causes distributed across reported primary causes.

PRIMARY CAUSE	CONTRIBUTING CAUSE										TOTAL
	Not Identified	Lack of Procedure/Policy	Inadequate Procedure/ Policy	Inadequate Implementation of Procedure/Policy	Lack of Training	Poor Oversight of Personnel	Insufficient Personnel	Lack of Planned Mainte-nance Program	Poor Engineering Design	Other, Explained in Notes	
Corrosion	85	1	4	6	0	0	0	11	9	10	126
External Corrosion	13	1	1	0	0	0	0	2	3	2	22
External Corrosion at or near weld joints	6	0	0	3	0	0	0	1	2	3	15
Internal Corrosion	51	0	3	3	0	0	0	8	4	3	72
Erosion	19	0	0	0	0	0	0	2	0	0	21
External Erosion	2	0	0	0	0	0	0	0	0	0	2
Internal Erosion	16	0	0	0	0	0	0	2	0	0	18
Thermal Expansion	34	1	3	5	1	2	0	1	2	10	59
Material Failure of Pipe or Weld	123	0	1	1	0	0	0	0	5	42	172
Construction, Installation or Fabrication Related	8	0	1	1	0	0	0	0	4	4	18
Original Manufacturing-Related	0	0	0	0	0	0	0	0	0	0	0
Vibration (wind-induced/slugging)	4	0	0	0	0	0	0	0	1	2	7
Valve/Seal Failure	247	2	7	8	3	4	0	7	0	32	310
Overpressure	21	0	3	4	0	0	0	1	4	4	37
Operator Error	77	3	4	9	4	3	0	3	1	22	126
3rd Party Action	1	0	0	1	0	0	0	0	0	0	2
Other (Recorded in Comments/Notes)	46	1	3	6	1	1	0	4	1	14	77
Not Recorded by Operator	1	0	0	0	0	0	0	0	0	0	1
TOTAL	**754**	**9**	**30**	**47**	**9**	**10**	**0**	**42**	**36**	**148**	**1085**

Total number of unidentified contributing causes exceeds the total number of spills (681) because multiple primary causes are assigned to individual spills.

This leads to double-counting of contributing causes.

This matrix reveals the association of primary with contributing causes, not the actual number of spills occuring.

More than 80% of the contributing cause observations were either "Not Identified" or characterized as "Other." This greatly limits the ability to draw conclusions from the contributing cause data.

3.4 Comparison of Leak Rates

Leak rates can be calculated by normalizing the number and/or volume of leaks by production throughput or by pipeline length for pipeline spills. Leak rates can be useful to compare one oil field with another, but these rates still have the underlying problems associated with the number and volume data. Volumetric leak rates based on amount spilled will still have the large variations caused by the few very large spills.

This updated analysis only considers leaks of crude oil and produced water spills. Spills of seawater and other substances have been excluded. Also, since the original 2010 spill data analysis two oil fields have come into production on the North Slope, Nikaitchuq, and Oooguruk. The volumetric leak rate for these two new oil field is zero since there have been no loss-of-integrity spills during the study period.

3.4.1 Leak Rates Based on Total Production

One way to analyze loss-of-integrity leak rates across the entire oil production infrastructure is to consider the production volumetric leak rate, which is the proportion of produced oil and water that eventually spills. This is the ratio between the total amount of oil and produced water spilled at each oil field during the study period and the total amount of oil and water produced from that field, expressed as barrels per million barrels (bbl/mm bbl). These data, which include spills across all six regulatory categories included in the study, are presented by oil field in Table 3-26 and Figure 3-39.

Table 3-26. Amount of oil and produced water spilled vs. oil and produced water throughput by oil field with corresponding volumetric leak rate.

Oil Field	Volume Oil Spilled (gallons)	Volume Produced Water Spilled (gallons)	Total Volume Spilled (gallons)	Volume of Produced Oil (gallons)	Volume of Produced Water (gallons)	Total Produced Oil & Water (gallons)	Volumetric Leak Rate (bbl per mm bbl)	Largest Spill (gallons)	Percent Contribution of Largest Spill to Leak Rate
Badami	285	10	295	233,408,994	0	233,408,994	1.264	200	67.8%
Colville River	169	2	171	16,845,455,298	2,510,121,390	19,355,576,688	0.009	170	100.0%
Endicott	1,554	5,107	6,661	19,696,136,250	50,906,672,964	70,602,809,214	0.094	4,410	66%
Kuparuk River	11,972	347,466	359,437	102,138,710,646	162,868,364,778	265,007,075,424	1.356	94,920	26.4%
Milne Point	5,728	16,838	22,566	12,537,733,824	26,650,403,640	39,188,137,464	0.576	9,760	43.2%
Nikaitchuq	0	0	0	45,136,266	6,519,702	51,655,968	0	n/a	n/a
Northstar	98	0	98	6,349,403,382	1,578,266,298	7,927,669,680	0.012	84	91.7%
Oooguruk	0	0	0	366,621,906	44,187,528	410,809,434	0	n/a	n/a
Prudhoe Bay	271,398	370,028	641,426	511,152,692,946	440,465,347,686	951,618,040,632	0.674	241,038	37.5%
ALL	**291,204**	**739,450**	**1,030,654**	**669,365,299,512**	**685,029,883,986**	**1,354,395,183,498**	**0.761**	**241,038**	

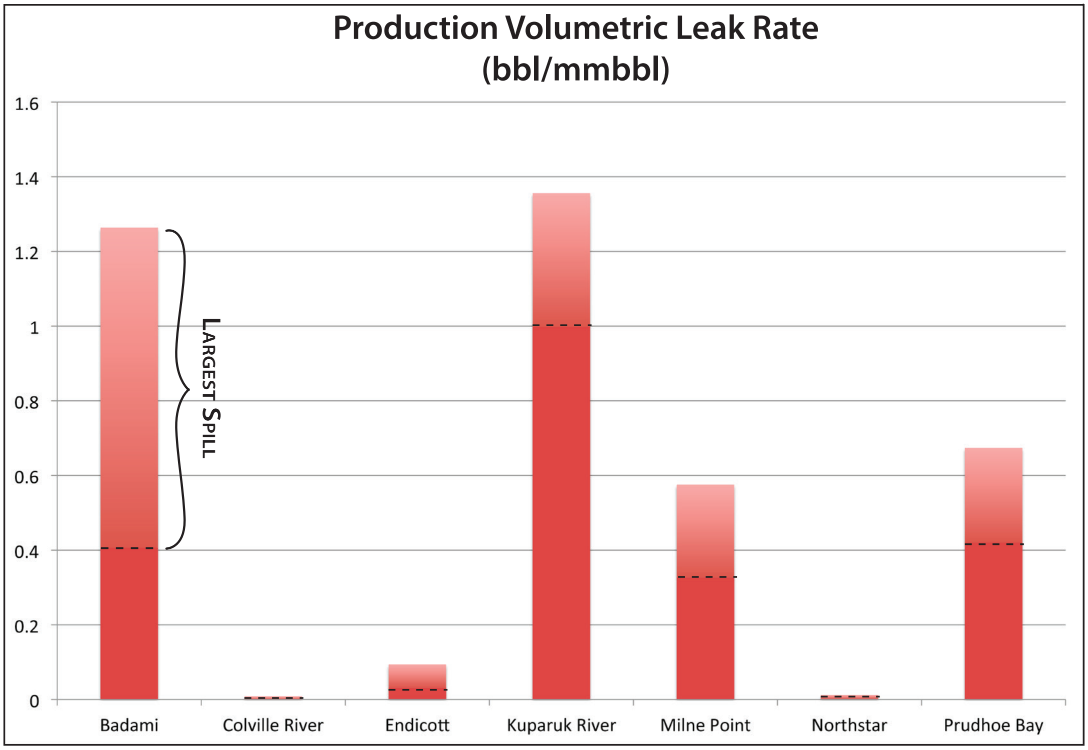

Figure 3-39. Production volumetric leak rate expressed as ratio of spilled volume to total volume (gallons) of oil and water produced, by oil field.

The production volumetric leak rate varies dramatically across North Slope oil fields. The combined leak rate for all oil fields on the North Slope was 0.761 bbl/mm bbl.[11]

This variability may not reflect actual systematic variations between the operations at these different fields. Since the largest spills account for a substantial portion of all the leak rate measurements, it is possible that the field Endicott, which has a proportionately lower leak rate measurement, has had few of the high volume spills that dominate the data. For Kuparuk (146 spills) and Prudhoe Bay (467), the largest spill is a substantial contribution to the total leak rate.

The numeric leak rate is the ratio between the number of spills at each oil field during the study period and the total amount of oil and water produced from that field, expressed as spill per million barrels (spills/mm bbl). The numeric leak rate is presented by oil field in Table 3-27 and Figure 3-40 for all crude oil and produced water loss-of–integrity spills greater than or equal to 1,000 gallons. The numeric leak rate for all fields is 0.02 spills/mm bbl of production and the rate for spills greater than 1,000 gallons is 0.0016 spills/mm bbl. Note that the Badami and Nikaitchuq data shows a disproportionately large number of spills compared to the total volume produced relative to other oil fields. Endicott and Milne Point are roughly the same age and have similar pipeline lengths, however the leak rate for Milne Point is nearly seven times larger than the leak rate for Endicott. Endicott stands out as a field with a consistently low production leak rate. Overall Kuparuk River and Prudhoe Bay appear to be roughly equivalent in production leak rate.

11 Another study of North Slope exploration and production oil spills calculated a different volumetric leak rate of 0.86 bbl/mm bbl of crude production from 1977 to 1999 (Maxim and Niebo 2001). This statistic is not directly comparable to the number calculated for this study, because the Maxim and Niebo study included spills from sources other than loss-of-integrity and their study considered the ratio of oil and produced water spilled to crude oil produced.

Table 3-27. Numeric leak rate expressed as spills per million barrels for all North Slope loss-of-integrity spills and all North Slope loss-of integrity spills greater than or equal to 1,000 gallons by oil field.

Oil Field	Number of Spills	Number of Spills ≥ 1,000 gallons	Total Produced Oil and Water (bbls)	Numeric Leak Rate (spills per mm bbl)	Numeric Leak Rate for Spills ≥ 1,000 gallons (spills per mm bbl)
Badami	4	0	5,557,357	0.720	0.000
Colville River	6	0	460,847,064	0.013	0.000
Endicott	10	2	1,681,019,267	0.006	0.001
Kuparuk River	146	17	6,309,692,272	0.023	0.003
Milne Point	43	4	933,050,892	0.046	0.004
Nikaitchuq	1	0	1,229,904	0.813	0.000
Northstar	4	0	188,754,040	0.021	0.000
Ooguruk	0	0	9,781,177	0.000	0.000
Prudhoe Bay	467	29	22,657,572,396	0.021	0.001
ALL	**681**	**52**	**32,247,504,369**	**0.021**	**0.002**

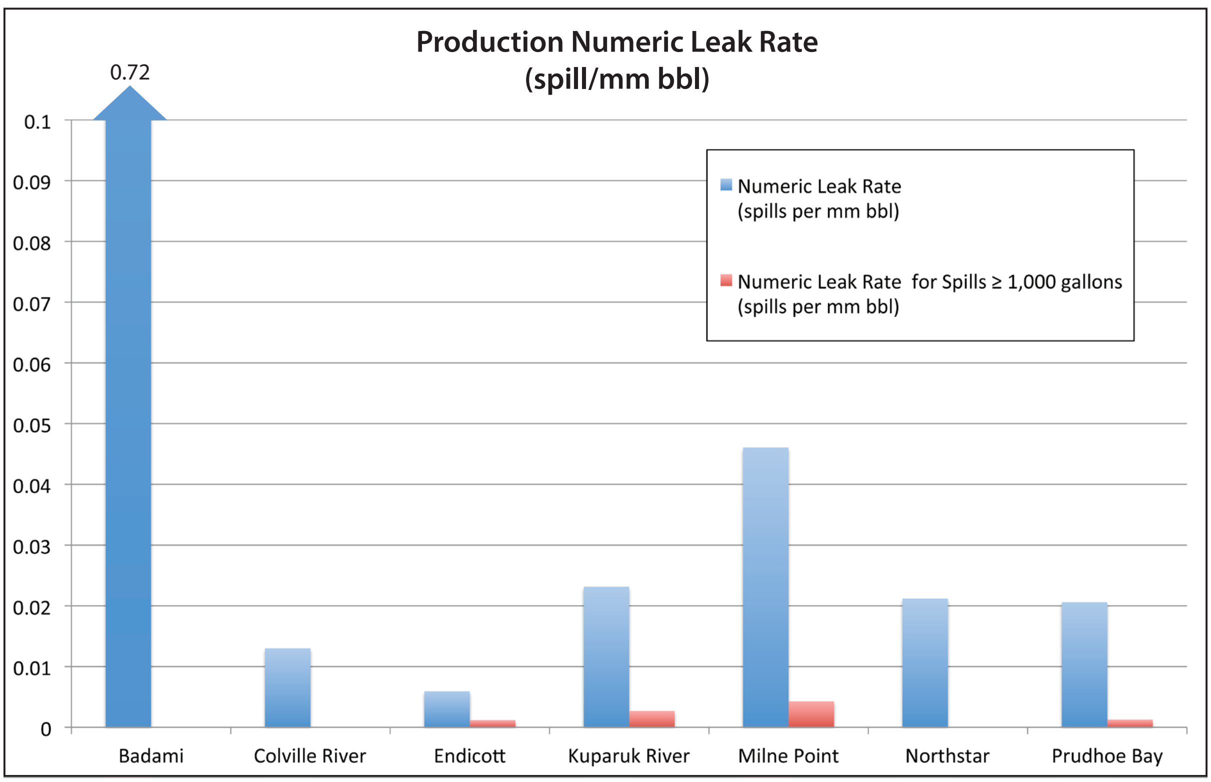

Figure 3-40. Production numeric leak rate expressed as spills per million barrels for all North Slope loss-of-integrity spills and all North Slope loss-of-integrity spills greater than or equal to 1,000 gallons.

Figure 3-41 and 3-42 depict plots of the volumetric leak rate and numerical leak rate (respectively) versus oil to water ratio for each oil field.[12]

12 The Badami oil field was excluded for these plots because of the erratic leak rates associated with this field.

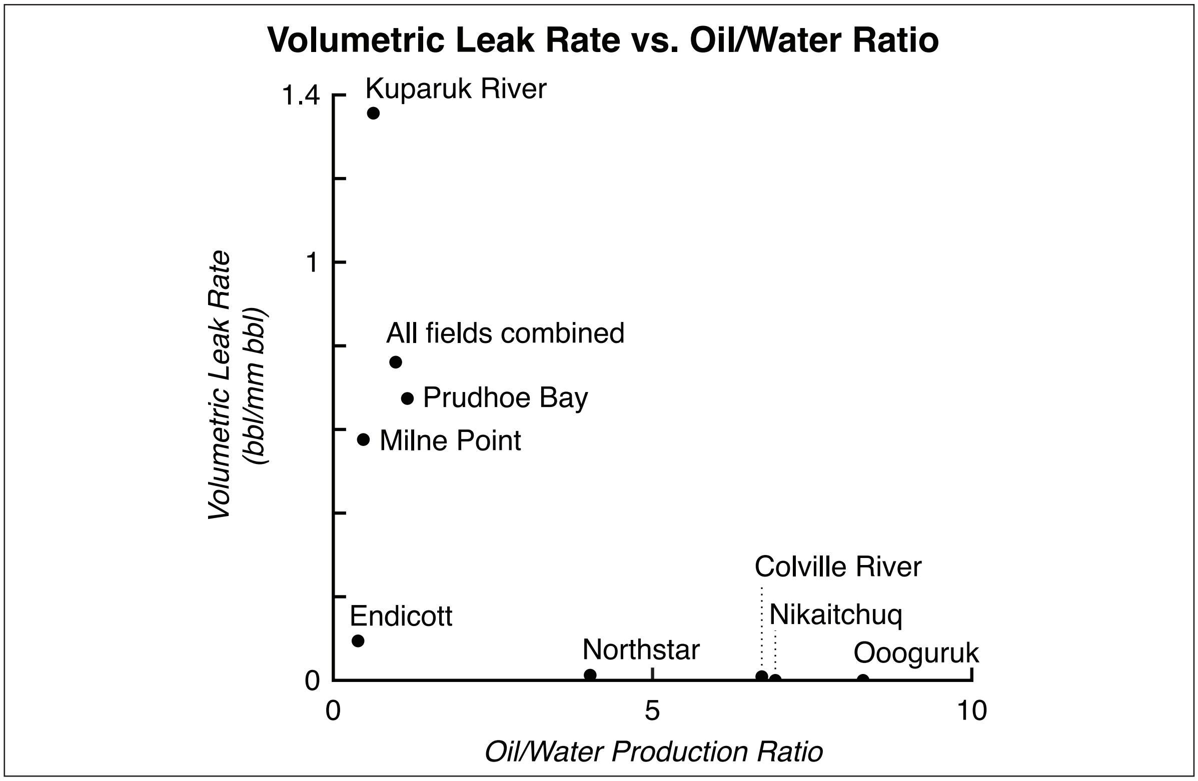

Figure 3-41. Volumetric leak rate expressed as barrels per million barrels versus oil to water ratio by oil field.

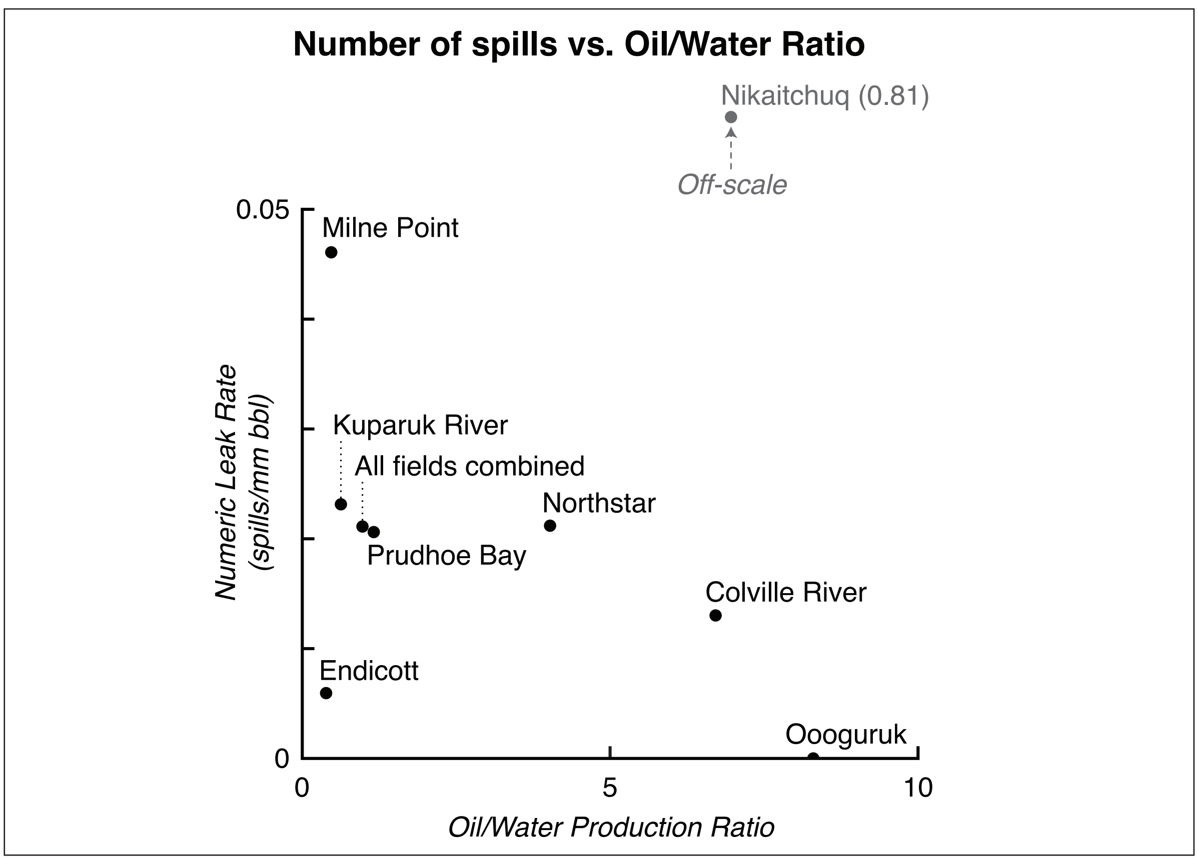

Figure 3-42. Numeric leak rate expressed as spills per million barrels versus oil to water ratio by oil field.

3.4.2 Leak Rates Based on Pipeline Length

For flowlines and oil transmission pipelines, mileage leak rates were also considered based on pipeline length. The mileage volumetric leak rate is the amount of oil spilled per mile per year expressed as gallons per year per mile. The mileage numeric leak rate is the number of spills per year per 1,000 miles, expressed as spills per year per 1,000 miles. Table 3-28 contains the mileage volumetric and numeric leak rates for operational oil transmission pipeline spills and flowline spills for the Kuparuk River and Prudhoe Bay oil fields. There was insufficient data to calculate these rates for other fields.

Table 3-28. Mileage volumetric leak rate and mileage numeric leak rate, by oil field and pipeline category.

Oil Field	OTP Volumetric Leak Rate (gallons per year per mile)	OTP Numeric Leak Rate (spills per year per 1,000 miles)	Number of OTP Spills	Flowline Volumetric Leak Rate (gallons per year per mile)	Flowline Numeric Leak Rate (spills per year per 1,000 mile)	Number of Flowline Spills
Kuparuk River	0.003	1.802	2	19.724	1.870	17
Prudhoe Bay	214.135	3.941	4	4.117	1.500	23

Figures 3-43 and 3-44 depict the mileage volumetric and numeric leak rates for operational flowline and oil transmission pipeline spills for the Kuparuk River and Prudhoe Bay oil fields. Kuparuk flowlines (19.72 gallons per mile per year) had a higher volumetric rate than Prudhoe Bay flowlines (4.12 gallons per mile per year). The numeric leak rates for Kuparuk River flowlines is 1.87 spills per year per 1,000 miles and for Prudhoe Bay is 1.50 spills per year per 1,000 miles. The Kuparuk River oil transmission pipeline (0.003 gallons per mile per year) volumetric leak rate was very low compared to the Prudhoe Bay oil transmission pipeline (214.1 gallons per mile per year) leak rate, which was dominated by the single 2006 spill of 212,252 gallons. The Prudhoe Bay oil transmission pipeline (3.941 spills per year per 1,000 miles) numeric leak rate was twice as high as the Kuparuk oil transmission pipeline (1.802 spills per year per 1,000 miles). The Prudhoe Bay and the Kuparuk River flowline mileage numeric leak rates are consistent with other studies, which were typically less than two spills per year per 1,000 miles (Guevarra 2010, Anderson and Misude 1983, Hill and Catmur 1994, Lyons 2002).[13]

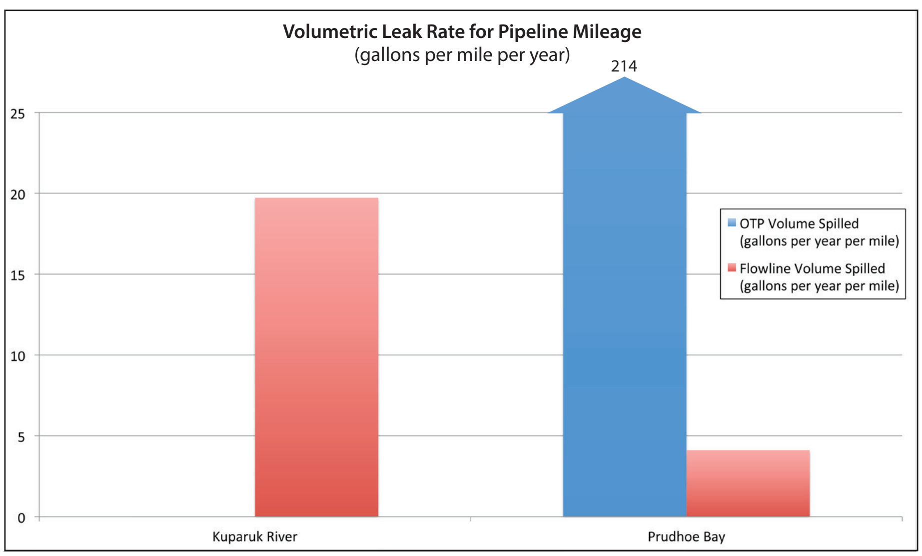

Figure 3-43. Volumetric leak rate expressed as gallons per mile per year for operational flowline and oil transmission pipeline spills at Kuparuk River and Prudhoe Bay oil fields.

13 It should be noted that these studies are not based on 3-phase pipelines, but product and crude oil pipelines.

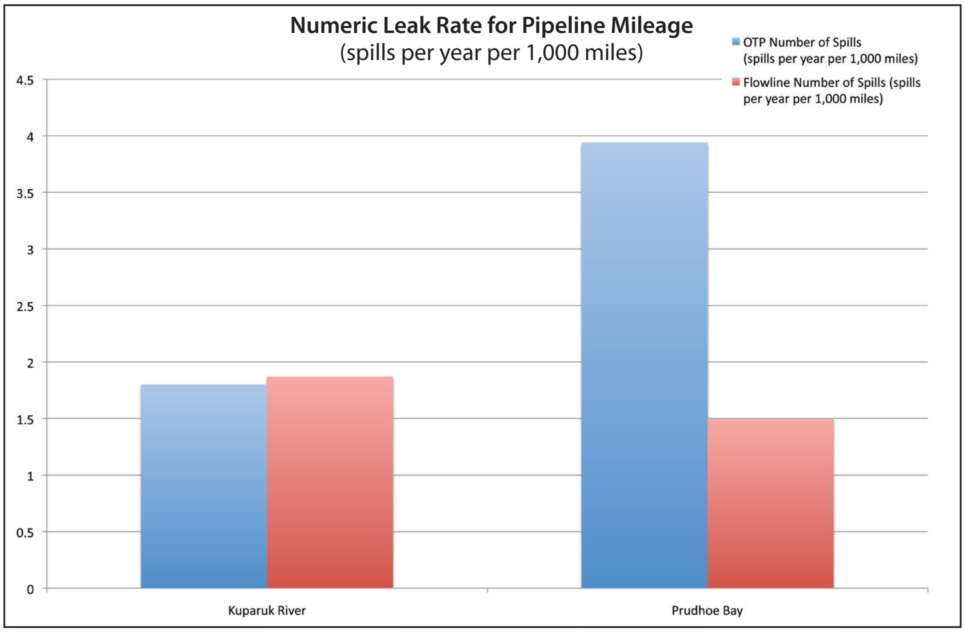

Figure 3-44. Numeric leak rate expressed as spills per year per 1,000 miles for operational flowline and oil transmission pipeline spills at Kuparuk River and Prudhoe Bay oil fields.

3.5 Flowline Spills as a Function of Pipeline Age and Length

After updates to the flowline (FL) catalogue and the inclusion of data from flowline spills in 2010 and 2011, there are 366 identified flowlines for which both the year it was placed in service and the year of failure resulting in a spill, if any, are known. There were eight flowlines listed for which the year in service was not given, so as in the previous report, these records were deleted. Additionally, there were two data records for which the reported spill year was earlier than the reported year in service. Evidently, the flowline was replaced at some point after the spill. Because the information was not included on the age of the pipe at the time of the spill, these records were also deleted.

There were a total of 45 spills reported in the final data set. For 328 of the identified flowlines (89%), no spills were reported. For 31 flowlines (8.5%) there was one spill reported, and for 7 flowlines (1.9%) there were two spills reported. Table 3-29 below details the number of spills by oil field and regulatory category. The largest number of spills (23) occurred in the Prudhoe Bay 3-phase category. The second largest number of spills (13) occurred in the Kuparuk three phase category.

Table 3-29: Summary of flowline spills by oil field and regulatory sub-category.

Oil Field	Flowline Sub-categories	Number of Spills	Total Hydraulic Length	Mean Hydraulic Length	Mean Age
Endicott	3F FL	0	18,715	18,715.00	25
Endicott	PW FL	1	18,648	18,648.00	25
Kuparuk River	3F FL	13	821,250	9,661.80	24.2
Kuparuk River	PW FL	4	724,067	13,924.40	20.8
Milne Point	3F FL	0	130,564	8,160.30	11.4
Milne Point	PW FL	1	73,535	9,191.90	9.8
Prudhoe Bay	3F FL	23	1,734,022	10,200.10	27.2
Prudhoe Bay	PW FL	3	528,981	16,029.70	23.9

Spills are broken down by operator and regulatory category in Table 3-30. BP operates the Endicott, Milne Point, and Prudhoe Bay oil fields, while ConocoPhillips operates only Kuparuk River oil field. The largest number of spills was three phase spills for BP with the second largest number of spills occurring in the three phase piping for ConocoPhillips. Tables 3-29 and 3-30 suggest that the number of spills can be explained by hydraulic length and age.

Table 3-30: Summary of flowline spills by operator and regulatory sub-category.

Operator	Flowline Sub-categories	Number of Spills	Total Hydraulic Length	Mean Hydraulic Length	Mean Age
BP	3F FL	23	1,883,301	10,071.10	25.9
BP	PW FL	5	621,164	14,789.60	21.3
ConocoPhillips	3F FL	13	821,250	9,661.80	24.2
ConocoPhillips	PW FL	4	724,067	13,924.40	20.8

Figure 3-45 is a histogram of all flowlines for the year placed in service. It reveals that the largest percentage of flowlines were placed in service in the 1980s.

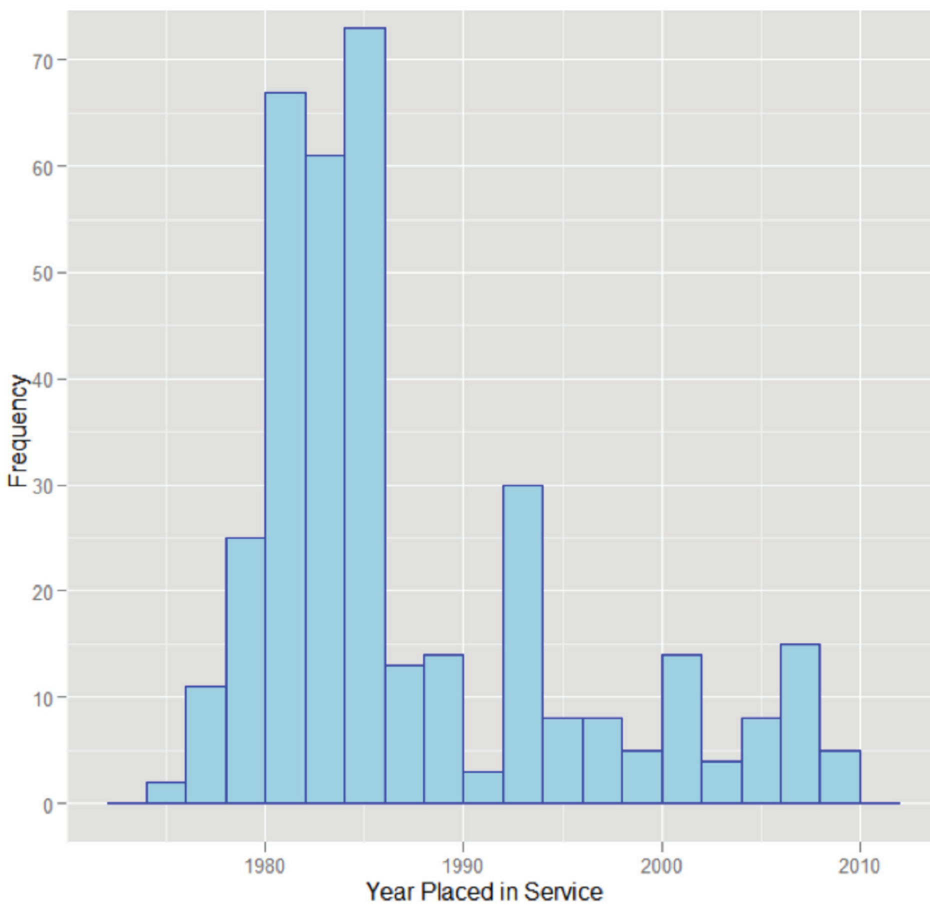

Figure 3-45. Distribution of the year flowlines were placed in service (n=366).

For those flowlines that experienced a failure resulting in a spill, the mean age at the time of failure was 17.8 years with a standard deviation of 6.3 years. The median age at failure was 19, and the modal age was 20 years. Figure 3-46 shows a histogram on the age at which flowlines failed.

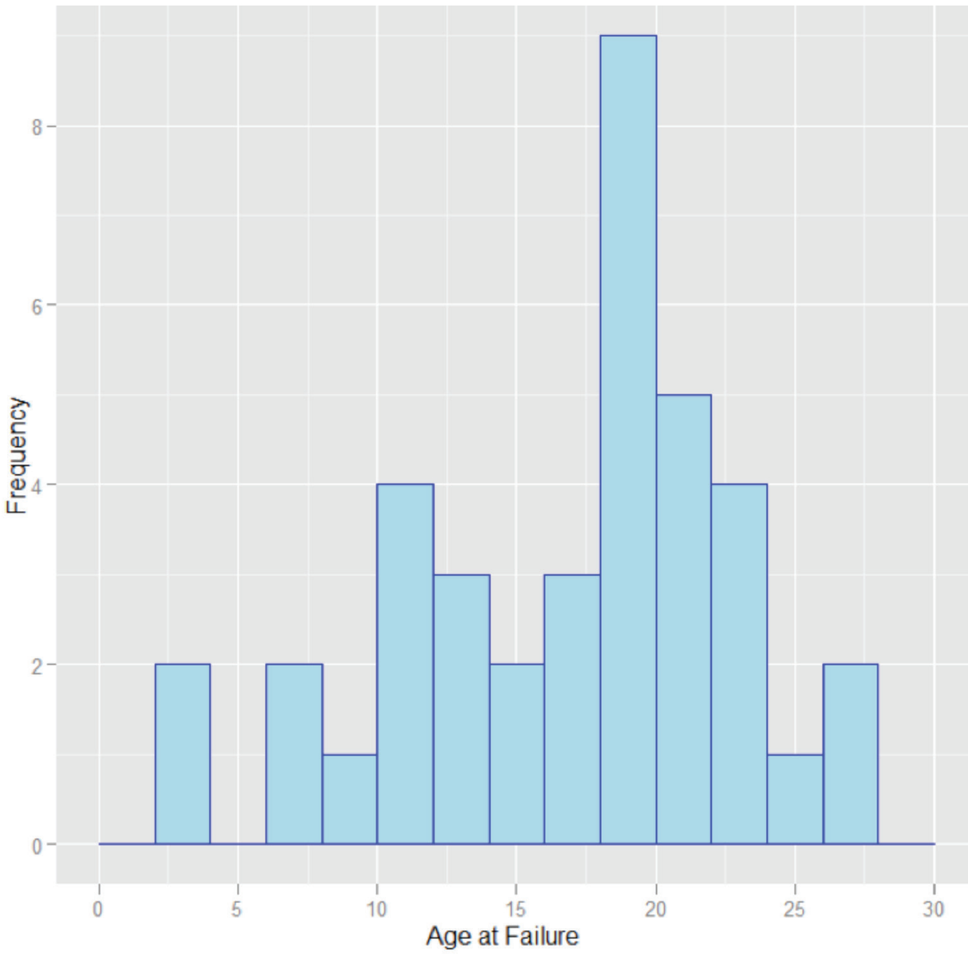

Figure 3-46. Distribution of the age flowlines failed resulting in a spill (n=366)[14].

The two variables that have proven to be significantly related to the odds of a spill occurring in past studies were age of the pipe and hydraulic length of a section. Table 3-30 suggests these continue to explain the likelihood of a spill. Table 3-31 provides summary statistics for these two variables.

Table 3-31: Summary Statistics for Independent Variables.

N =	Pipe Age (years)	Pipe Length (miles)
Mean	24.22	2.095
Min	2	0.002
Max	37	21.504
Median	27	1.718
1st Quartile	19	1.015
3rd Quartile	30	2.981

Figures 3-47 and 3-48 show how pipe age and pipe length are distributed. Pipe age is negatively skewed and pipe length is positively skewed.

14 Some flowlines experienced more than one spill, so the number of observations exceeds the number of flowline have experienced a spill.

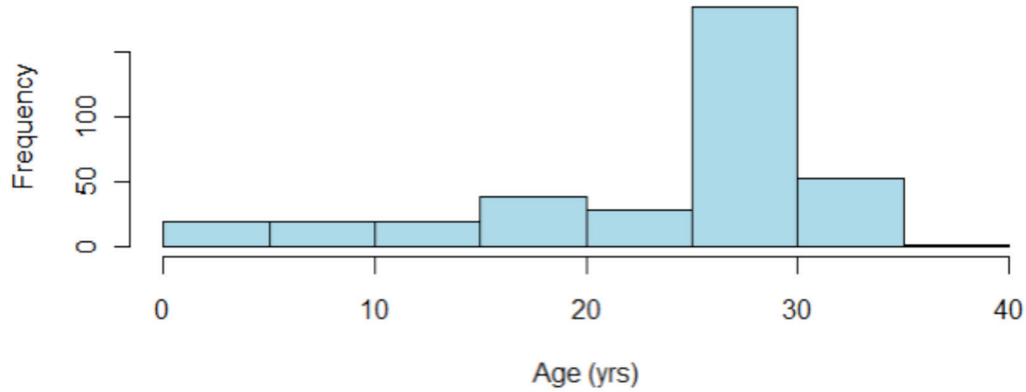

Figure 3-47. Distribution of the age of flowlines in service at the Endicott, Kuparuk River, Milne Point, and Prudue Bay oil fields.

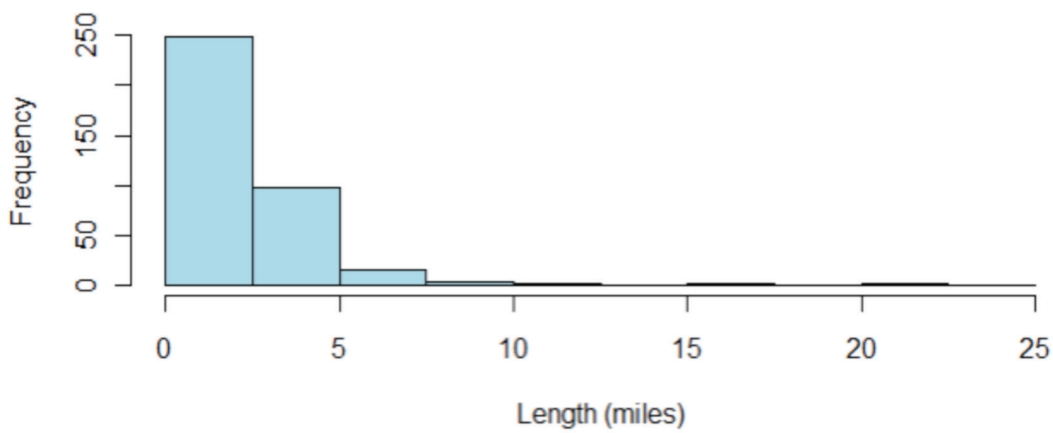

Figure 3-48. Distribution of the pipeline length of flowlines in service at the Endicott, Kuparuk River, Milne Point, and Prudue Bay oil fields.

These variables were used as the predictors in a logistic regression model. Both variables prove to be significant at a 95% confidence level. The model says that on average, when controlling for pipe length, every one year increase in the age of the pipe increases the odds that the pipe has experienced a spill by a factor of 1.09. Stated another way, every one year increase in age is associated with a 9% increase in the odds of the pipe having been involved in a spill.

Similarly, the model says that when controlling for pipe age, every one mile increase in the hydraulic length of a pipe increases the odds of it having been in a spill by a factor of 1.20 or a 20% increase in the odds.

$$\log\left(\frac{p_{spill}}{1-p_{spill}}\right) = -4.81 + 0.09(pipe\_age) + 0.18(pipe\_length)$$

Solving for probability:

$$p_{spill} = \frac{\exp(-4.81 + 0.09(pipe\_age) + 0.18(pipe\_length))}{1+\exp(-4.81 + 0.09(pipe\_age) + 0.18(pipe\_length))}$$

Two graphs of probability that a spill has occurred versus first pipe age and then pipe length are shown below in Figures 3-49 and 3-50. In the case of pipe age, the length was controlled at two miles, which is roughly the mean length. For the pipe length graph, the age was controlled at 24 years. The 95% confidence intervals have been added to the graphs. As with any other model, this model is only valid over the time range for which the data were collected. Any change in the operation, maintenance or inspections of the pipeline system will change the conditions use to derive the model.

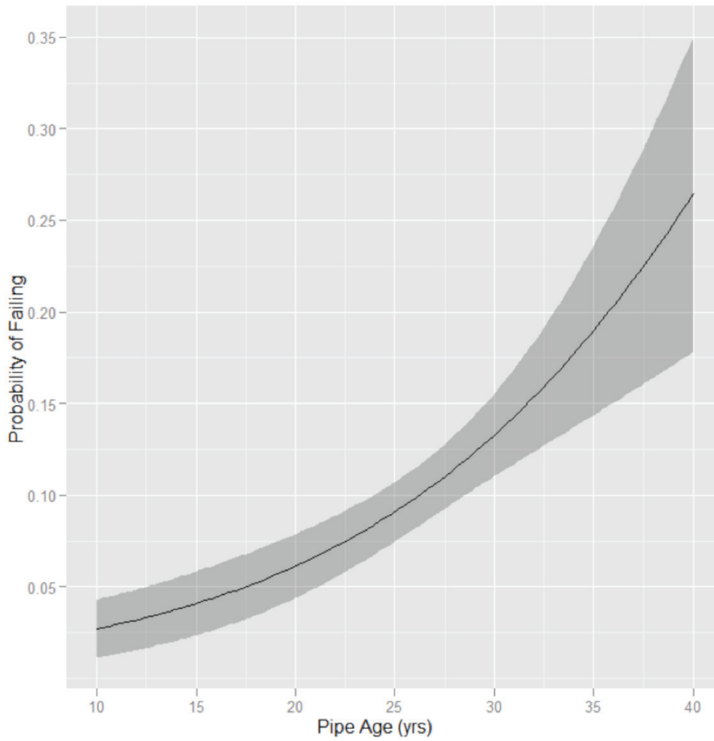

Figure 3-49. Probability of a flowline failure resulting in a spill vs age, when flowline length is controlled at two miles.

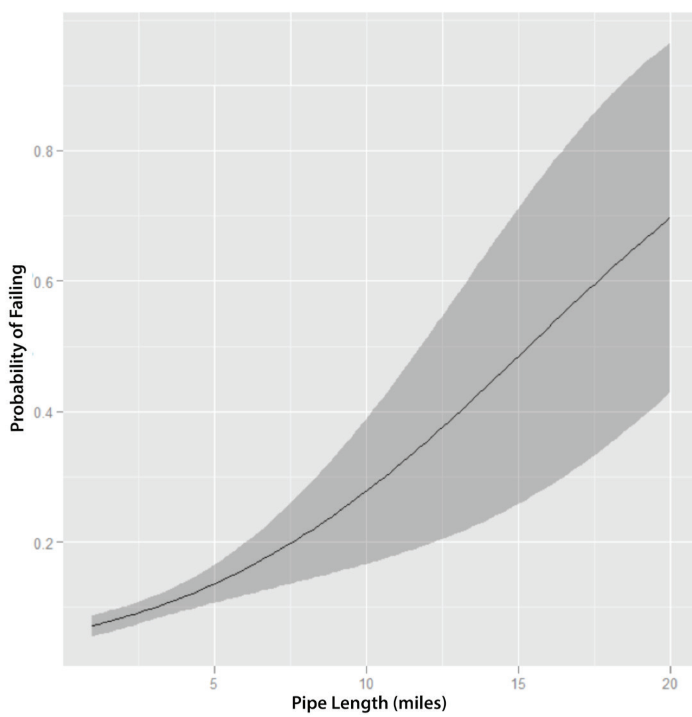

Figure 3-50. Probability of a flowline failure resulting in a spill vs length, when flowline age is controlled at 24 years.

3.6 Analysis of Survival

An alternate approach to studying age at failure is called survival analysis.[15] Survival analysis is used to study deaths in biology or medicine and failures in mechanical systems. This statistical technique models 'burn-in' periods during which relatively new pipe sections may fail because of factors such as a fault in the materials of construction, an installation problem, and/or a design flaw in the system. These issues manifest themselves in leaks early on. Those pipes for which none of these faults occurred may experience a much longer time period in which they operate problem free. In some cases where pipelines have recently been placed into service, there are no data available when a pipe actually fails because its time in the study is very short. For this reason, a 'survival' analysis has some merit.

Figure 3-51 is a Kaplan Maier survival curve for the pipe failure data. The solid line is the survival curve and the dotted lines represent the 95% confidence interval. The figure shows, at various ages, the probability that a given pipe section did not leak. Note that the line flattens after about 20 years, indicating that older pipelines have a constant probability of no leaks.

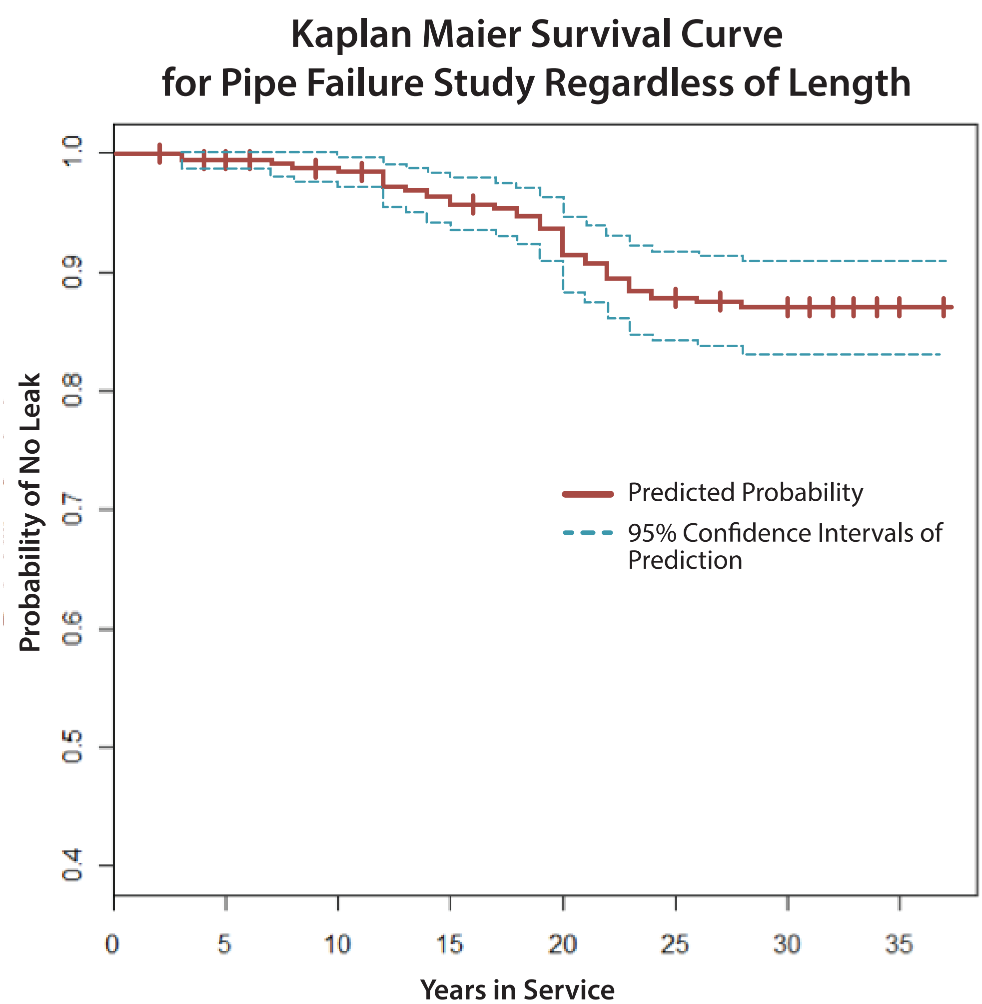

Figure 3-51. Probability of a flowline not having experienced a failure resulting in a spill vs flowline age.

15 Survival analysis is also known as reliability analysis.

Pipeline length can also be added as an independent factor in the survival analysis model. Figure 3-52 shows survival curves for pipeline grouped by hydraulic length. The categories are:

- Less than 2 miles,
- 2 miles to less than 4,
- 4 miles to less than 6, and
- Greater than 6 miles.

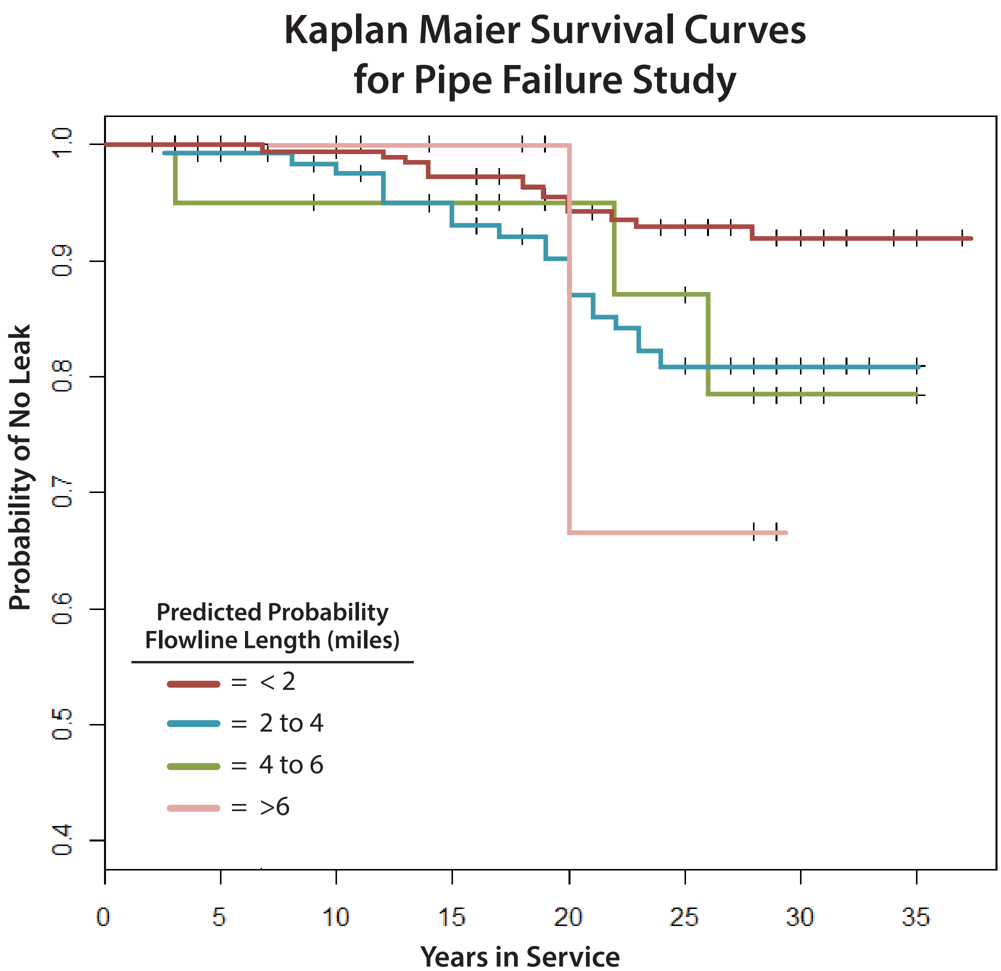

Figure 3-52. Probability of a flowline not having experienced a failure resulting in a spill (shown for four age classes) vs flowline age.

There is a strong indication that pipe length is a significant predictor of the probability that a leak has occurred. Note that for a section of length greater than 6 miles, the probability that no leak has occurred after 20 years is only 65%.[16] The results are essentially the same as for the logistic regression.

16 It should be noted that this estimate is based on a very small sample size.

3.7 Analysis of Leak Detection

There were only 6 loss-of-integrity flowline and zero oil transmission pipeline spills during this two-year update period. No information was gathered or found in the files indicating how these leaks were detected. Due to the lack of data no analysis was conducted for this update.

3.8 Analysis of Spill Impacts

The 2010 North Slope Spills Analysis study considered the use of five metrics to examine the environmental impacts from flowline and oil transmission pipeline spills. The metrics considered were: total volume spilled, number of spills impacting tundra, total volume spilled to tundra, square footage of tundra impact and number of spills that entered water. The timing of spills related to frozen conditions was also considered. In reviewing case files for the 41 additional loss-of-integrity spills the data was extremely limited since only 6 flowline spills had occurred in the past two years and no oil transmission pipeline spills were reported. Available data was limited to 3 flowline spills to tundra with an increase in total volume by only 34 gallons and impacting 552 square feet of tundra. No additional data was collected to examine the impact of spills to gravel pads. Table 3-32 presents the updated numbers, total volume, average volume, and square footage of impact to tundra. Tundra was impacted in 37% (31) of the total 83 cases studied, with 78% of the total volume spilled (379,395 gallons) impacting tundra. A total of 226,490 square feet or 5.2 acres were impacted by these spills.

Spills to frozen tundra and snow generally have less impact than spills during the thawed period. Assuming the tundra is frozen and at least partially covered with snow during the eight months from October 1 through May 31st, the spill impacting tundra are categorized as spills during the frozen period. Of the three flowline spills where data was available, two occurred during the frozen period and one during the thawed period. There were no spills that impacted water bodies during this two-year update.

Table 3-32. Summary of spill impacts to tundra.

FLOWLINE AND OIL TRANSMISSION PIPELINE SPILLS			
	Number	Total volume (gallons)	Square Footage
Spilled on Tundra	31	379,395	226,490
Percentage	37%	78.3%	
Spilled on Gravel Pads	52	105,180	Unchanged
Percentage	62%	21.7%	Unchanged
Grand Total	**83**	**484,575**	

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DISCUSSION 4

4.1 Significance of the Analysis

This report provides an update to the original North Slope crude oil infrastructure spill data analysis conducted and completed in 2010. The same methodologies, definitions, and metrics used for the 2010 study were applied to this update and may be used in the future to judge performance of the North Slope oil production infrastructure.

4.2 Overall Spill Trends

Six hundred and eighty one (681) loss-of-integrity spills were reported for the total analysis time period from July 1, 1995 through December 31, 2011. Forty-one (41) loss-of-integrity spills were reported in the last two years. An average of 44 loss-of-integrity spills was noted to occur each year in the original study. A downward trend is observed from the period of 2009 through 2011 with 41 loss-of-integrity spills during this two-year period, reducing the overall average to 41.25 loss-of-integrity spills per year. Data shows that from 2008 (n=47) through 2011 (n=21) there was a 45% decrease in the number of loss-of-integrity spills across all of the oil fields and regulatory categories from the North Slope oil and gas infrastructure. Corresponding with the decrease in the number of spills per year is a decrease in the total volume (gallons) of material spilled.

The data on spill volume continues to show that a few large spills account for the vast majority of the total volume spilled from the North Slope oil production infrastructure. The two largest spills comprise 0.3% of the total number, but account for 37% of the total volume spilled. The 12 spills greater than 10,000 gallons represent 2% of the number of spills, yet account for 43% of the total volume spilled. The 57 spills greater than 1,000 gallons represent 8.4% of the number of spills, and account for 15% of the total volume spilled. The average number of spills greater than 1,000 is 4.3 per year. A downward trend was noted from the period of 2009 through 2011 with only one spill greater than 1,000 gallons. Because of this non-normal distribution of the volume data, an average volume statistic does not represent a typical or a probable spill and is therefore not useful to report.

4.3 Spill Trends by Regulatory Categories

Six regulatory categories of infrastructure were analyzed for this analysis.

4.3.1 Flowlines

Flowlines carry either three-phase fluid or produced water between well pads and the processing center. Flowlines account for the most mileage of pipeline on the North Slope and most of the large diameter pipelines are flowlines. This regulatory category continues to account for 11% of the number of spills and 22% of the total volume spilled. There were 77 flowline spills over the past 16-years or

4.8 spills per year. There were only 6 loss-of-integrity flowline spills reported during this two-year update period. For this analysis flowline spills were divided into two sub-categories: maintenance activity flowline spills (related to pigging) and operational flowline spills (not related to pigging). This data indicates that over half (51%) of the flowline spills are related to operational factors, and that these spills account for 87% of the volume spilled in the flowline regulatory category. Four severe spills make up most of the total volume of operational flowline spills. External corrosion was the common primary cause of failure leading to operational flowline spills. There is no significant trend in frequency or volume of operational flowline spills during the 16-year study period. It is apparent that spills from this sub-category have a relatively low frequency, but a high consequence when they do occur.

In contrast, the frequency of maintenance activity-related flowline spills have shown a downward trend since 2005 with an average of one loss-of-integrity spill reported per year from 2005 to 2011. Valve/seal failure was the leading primary cause of spills for this sub-category.

4.3.2 Oil Transmission Pipelines

Oil transmission pipelines carry sales quality crude oil from production centers toward Pump Station 1 on the Trans-Alaska Pipeline. There were no reported loss-of-integrity spills from oil transmission pipelines during this two-year update period. There have been only 9 spills from oil transmission pipelines during the 16-year period equating to 0.56 spills per year. Seven of those spills were less than 100 gallons, one was approximately 5,000 gallons, and one was the second largest spill across all categories (214,000 gallons). Since there were no additional spills reported from the original study period of July 1, 1995 to December 31, 2009, there was no change in the contributing cause to the volume of spills, and the frequency of spills remains very low.

4.3.3 Facility Oil Piping

The facility oil piping category includes pipelines that run from individual wells to the manifold connected to a flowline, and pipelines connected to above ground oil storage tanks. There were 260 facility oil piping spills over the 16-year period, which equates to 16 spills per year. Facility oil piping spills have the highest frequency of spills of any category. The volume spilled from facility oil piping was 21% of the total volume spilled across all spills in the analysis, making this category third in total volume spilled. Four large facility oil piping spills account for the vast majority of the total volume spilled in this category.

Facility oil piping spills were divided into two sub-categories based on service: well lines and tank lines. Well lines account for 94% of the facility oil piping spills. The average spill volume for well lines was much larger than the average spill for tank lines. Valve/seal failure is the leading primary cause. The single largest spill of 94,920 gallons was caused by internal corrosion.

4.3.4 Process Piping

Process piping is piping internal to buildings and modules and is not regulated by ADEC. There were 203 process piping spills, equating to 12.7 spills per year. This regulatory defined category has the second highest frequency of spills. The volume spilled from process piping was 13% of the total volume across all categories. Like most of the other categories, a few large spills account for the vast majority of the total volume spilled and are relatively evenly distributed across the size classes as compared to other categories.

The process piping category was divided into the following three sub-categories based on service: well manifolds, processing center modules, and sea water piping. Processing center spills account for 74% of all spill cases, and were both more frequent and more severe than spills from well manifolds or sea water lines. The leading primary cause of failure was valve/seal failure. Neither spill frequency nor volume show any trend over the 16-year study period. Spills from this category have a high frequency and relatively low volume when they do occur.

4.3.5 Wells

There were 119 spills from well equipment, equating to 7.4 spills per year, making this regulatory category the third largest in terms of number of spills and representing 5% of the total volume spilled across all categories. The average volume per spill is the lowest of all regulatory categories. Two spills greater than 10,000 gallons account for 94% of the total volume spilled.

Similar to the other regulatory categories, valve/seal failure is the leading cause of leaks. The two largest spills were caused by internal corrosion and material failure respectively. Spills from wells continue to occur at a moderate frequency compared to the other categories.

4.3.6 Above Ground Storage Tanks

There were no loss-of-integrity spills reported by North Slope operators for this category in 2010 and 2011. Only 10 spills have occurred from above ground oil storage tanks over the 16-year study period, equating to 0.6 spills per year. This category has the second lowest frequency of spills, however the volume spilled from above ground storage tanks accounts for 20% of the total volume spilled. Ninety-eight percent of the total volume spilled was from the single largest spill in the analysis.

The most prevalent primary cause of failure for above ground oil storage tank spills is operator error, however the largest spill in this category was caused by material failure. Spills from above ground storage tanks occur at a very low frequency, but can be severe.

4.4 Primary Cause of Failure

Analysis of the primary cause of failure data is hampered by data quality and the cause categorization scheme. Over the life of the ADEC SPILLS database, there is known variability in the quality of cause interpretation and recording. In some cases, the operator determined primary cause, while in other cases ADEC personnel made the determination. The degree and type of investigation varies over time and by case. The cause characterization scheme is also problematic: the ADEC scheme does not match the schemes used in the root cause analysis methodology when investigating leaks. A discussion is merited among the users of the ADEC SPILLS database and the creators of the data.

Analysis of the primary cause of failure continues to show that valve/seal failure is the most frequent cause of all spills and corrosion is the most frequent cause of spills greater than 1,000 gallons. Primary cause of failure varies depending on the regulatory category. Corrosion is a dominant cause of failure for flowlines, specifically operational leaks.

4.5 Leak Rates

Leak rates are useful to compare different oil facilities or examine a single facility over time. However, when comparing leak rates differences in reporting requirements should be considered.

Leak rates were calculated in two ways:

- **Production leak rates**—as a proportion of total throughput (spillage from all 6 regulatory categories as a function of total volume of crude oil and process water) and
- **Mileage leak rates**—as a proportion of linear pipeline length (which applies only to oil transmission pipelines and flowlines).

In both instances numeric leak rates and volumetric leak rates were calculated. The data were broken out by oil field for internal comparisons. The data were also compared to reported leak rates from oil and gas production infrastructure in other regions. The Badami, Nikaitchuq, and Oooguruk oil fields, have been excluded from this discussion since there have been few or no loss-of-integrity spills for these fields. This updated analysis also excludes seawater and other substance spills, which were included in the 2010 report for calculating leak rates.

Volumetric leak rate vary dramatically across oil fields and this variability is due to the dominance of a few large spills within the data. Overall, Kuparuk River showed the poorest performance at 1.36 bbl of oil spilled per million barrels of oil produced, while Northstar exhibited the best performance at 0.01 bbl of oil spilled per million barrels of oil produced. This range may reflect the differences in the size and complexity of the infrastructure between these two fields. Overall, the combined volumetric leak rate was 0.76 bbl of oil spilled per million barrels of oil produced

Numeric leak rates exhibit more consistency between fields. Numeric leak rates range from 0.6 spills per one hundred million barrels of oil produced at Endicott to 4.6 spills per one hundred million barrels of oil produced at Milne Point. Once again this range may reflect the differences in the age, size, and complexity of the infrastructure between these two fields. Overall, the combined numeric leak rate was 2.1 spills per one hundred million barrels of oil produced. Kuparuk River, Northstar, and Prudhoe Bay oil fields had rates very close to 2 spills per one hundred million barrels of oil produced.

Mileage leak rates were calculated for flowline and oil transmission pipeline categories for the Prudhoe Bay and Kuparuk River fields. As with other volumetrics, the mileage volumetric leak rates were highly influenced by a few large spills. Data remains sparse for oil transmission pipeline spills, which reduces the confidence in the rates calculated for this category. The Prudhoe Bay flowline (1.50 spills per year per thousand miles of flowline) and the Kuparuk River flowline (1.87 spills per year per thousand miles of flowline) are consistent with studies of other facilities, which were typically less than two spills per year per thousand miles of flowline.

4.6 Flowline Spills as a Function of Pipeline Age and Length

A logistic regression model showed that flowline spills are significantly correlated to the pipeline length and age. When controlling for pipeline length, every one year in pipeline age increases the likelihood of the pipeline having a spill by 9%. Similarly, when controlling for age, every one-mile increase in pipeline length increases the likelihood of a spill by 20%. Older pipelines and longer pipelines are more likely to have had a spill. Similarly, a survival analysis shows a correlation between pipeline age and length and likelihood of a failure. Nevertheless, the survival analysis indicates that probability of a leak tends to stabilize after about 20 years. This indicates that once pipelines have survived the initial burn-in period, they may operate at least another 15 years without a significant increase in the probability of a leak.

4.7 Leak Detection

Analysis of both the time required detecting leaks and the detection methods used is limited because of missing data. Although there were only 6 loss-of-integrity flowline and zero oil transmission pipeline spills during this two-year period, no information was gathered or found in the files indicating how these leaks were detected. Past data analysis has indicated that almost all spills were detected visually and no spills were detected solely by a leak detection system. Due to the lack of data no analysis was conducted for this update. This is an area where data collection procedures for loss-of-integrity spills can be improved significantly.

4.8 Spill Impacts

Limited data were available to assess the types of environments impacted by North Slope spills in the updated data set. Of the 83 flowline and oil transmission pipeline spills, 37% impacted tundra and 62% were spilled to gravel pads. There were no spills that impacted water bodies during this two-year update. Insufficient data were available to detect trends in spill impacts.

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CONCLUSIONS 5

The goal of periodically analyzing and reviewing North Slope pipeline spill data is to identify measures to reduce the frequency and volume of future spills from oil and gas production facilities on the North Slope. The process selected to achieve this goal involves analyzing the data for trends in loss-of-integrity spills from crude oil piping infrastructure. The analysis presented in Section 3 and discussed in Section 4 considers trends in the frequency and volume of spills from the entire 681 loss-of-integrity spills in the data set, based on infrastructure regulatory category, leak rates, age at failure (pending), leak detection, spill impacts, and spill causes.

A downward trend of the number of loss-of-integrity spills was observed from 2009 through 2011 and these new data confirm a general downward trend in number of spills per year across all regulatory categories. Corresponding with the decrease in the number of spills per year is a decrease in the total volume of material spilled. Overall, the number and volume of loss of integrity spill from the North Slope infrastructure has decreased.

The two largest spills in the data set continue to complicate some of the statistical tests, and also skewed some of the analysis regarding which infrastructure components contribute most significantly to spill volume. The two largest spills came from storage tanks and oil transmission pipelines, so that any volumetric analysis tended to show those two infrastructure categories as problematic. During this two-year update there were no spills reported by North Slope operators for either of these regulatory categories.

The frequency of spills from facility oil piping, process piping, and wells are higher than the other regulatory categories. Efforts to reduce the number of spills should focus on these three categories. Flowlines continue to remain the largest contributor of total volume spilled, although the number of flowline spills is decreasing. Based on indicators of past spill occurrences, flowlines and facility oil piping have a higher spill volume released and therefore warrant additional measures to reduce spill volume.

Data quality remains an obstacle to analysis of spill risk. The completeness of data for each spill did not increase over the two years of new data gathered for this update. ADEC should develop procedures to ensure that all relevant data are collected for those spills determined to be due to loss-of-integrity. In addition, ADEC should review cause terminology and categorization with the goal of developing standards that are congruent with the cause investigation techniques used by the North Slope operators.

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APPENDICES 7

Appendix A:

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APPENDIX A

A.1 Acronyms and Abbreviations

3P	Three-phase
AAC	Alaska Administrative Code
ADEC	Alaska Department of Environmental Conservation
AGST	Above-ground storage tank
AK	Alaska
AOGCC	Alaska Oil and Gas Conservation Commission
ARA	Alaska Risk Assessment
ARCO	Atlantic Richfield Company
BAT	Best available technology
bbl	barrel
BLM	Bureau of Land Management
BPXA	BP Exploration, Alaska
C-Plan	Oil spill contingency plan
CE	Corrosion, external
CI	Corrosion, internal
CIC	Corrosion Inspection & Chemicals
CP	ConocoPhillips
CPAI	Conoco Phillips Alaska, Inc.
CU	Corrosion, unknown
CUI	Corrosion under insulation
DCF	Data collection form
DNR	Department of Natural Resources
DOT	Department of Transportation
EPA	Environmental Protection Agency
FL	Flowline
FOP	Facility oil piping
GIS	Geographic information systems
GKA	Greater Kuparuk Area
ID	Identification
ILI	In-line inspection
LDS	Leak detection system
LLC	Limited Liability Company
mm bbl	Million barrels
MOC	Management of change
n	Number
NSS	North Slope Spills
OE	Operator error

OSHA	Occupational Safety and Health Administration
OTP	Oil transmission pipeline
PFD	Process flow diagram
PHMSA	Pipeline and Hazardous Materials Safety Administration
PID	Piping and instrumentation diagram
PP	Process piping
PSIO	Petroleum Systems Integrity Office
PW	Produced water
QA/QC	Quality assurance/quality control
QRA	Quantitative Risk Analysis or Assessment
RDS	Research and Development Solutions
SPCC	Spill Prevention, Control and Countermeasures
TAPS	Trans-Alaska Pipeline System
TE	Thermal expansion
US	United States
VMT	Valdez Marine Terminal
VS	Valve/seal failure
W	Well
WNS	Western North Slope

A.2 Glossary of Terms

Aboveground Storage Tank {18 AAC 75.065; 18 AAC 75.990(165)}: For the purpose of 18 AAC 75.065, 18 AAC 75.066, and 18 AAC 75.075, means a container, including a storage and surge tank, that is used to store bulk quantities of oil and that has a capacity greater than 10,000 gallons; with the exception of a field-constructed underground storage tank, "aboveground oil storage tank" does not include a process pressure vessel or underground storage tank within the meaning of AS 46.03.450.

Contributing Cause: Those factors that contribute or lead to the immediate cause and sometimes referred to as "root cause."

Corrosion {18 AAC 75.990(168)}: Means the deterioration of metal from the loss of positive charged metal ions from the metal's surface into an electrolyte. Sub-categories include:

Internal corrosion,

External corrosion.

Facility Oil Piping {18 AAC 75.080; 18 AAC 75.990(171)}: Piping and associated fittings, including all valves, elbows, joints, flanges, pumps, and flexible connectors, originating from or terminating at

(A) An aboveground oil storage tank regulated under 18 AAC 75.065 or 18 AAC 75.066 up to the

(i) union of the piping with a fuel dispensing system;

(ii) marine header;

(iii) fill cap or fill valve;

(iv) forward pump used to transfer oil between facilities, between adjacent pump stations, or between a pressure pump station and a terminal or breakout tank; or

(v) first flange or connection with a tank truck loading area or with a loading rack containment area, or;

(B) An exploration or production well, up to the:

(i) choke or valve interconnection with a flowline; or

(ii) first valve or flange inside a processing unit boundary

Failure: Refers to the state or condition of not meeting a desirable or intended objective. For the purpose of this analysis through-wall pipe damage that causes loss of product.

Flowline {18 AAC 75.047; 18 AAC 75.990(173)}:

(A) Piping and associated fittings, including all valves, elbows, joints, flanges, pumps and flexible connectors,

(i) containing liquid oil;

(ii) located at a production facility; and

(iii) that is installed or used for the purpose of transporting oil between a well pad or marine structure used for oil production and the interconnection point with a transmission pipeline; and

(B) Includes all piping between interconnections, including multi-phase lines and process piping, except

(i) facility oil piping, and

(ii) transmission pipelines.

Flow Rate: The maximum production rate below which the production of solids along with the produced fluid is uniform.

Immediate Cause: Action or inaction that immediately preceded and led to the spill and/or event or near miss. Also referred to as proximate cause and primary cause.

Loss-of-integrity: A failure that leads to leakage of any fluids in the production stream, including mechanical failures and human errors.

North Slope Oil Fields: The oil production and transportation locations within the North Slope Region.

North Slope Region {18 AAC 75.495(a)(9)}: That area encompassed by the boundaries of the North Slope Borough, including adjacent shorelines and State waters, and having as its seaward boundary a line drawn in such a manner that each point is 200 nautical miles from the baseline from which the territorial sea is measured.

Oil transmission pipeline: See Transmission pipeline.

Oil Well {20 AAC 25.990(45)}: A well that produces predominately oil at a gas-oil ratio of 100,000 standard cubic feet (scf)/stock barrel tank (sbt) or lower, unless the commission establishes another ratio on a pool-by-pool basis.

Pigging: The act of forcing a device called a pig through a pipeline for the purpose of displacing or separating fluids, and cleaning or inspecting the line.

Pipe or Piping {18 AAC 75.990(177)}: Any hollow cylinder or tube used to convey oil.

Primary cause of failure: Action or inaction that immediately preceded and led to the spill and/or event or near miss. Also referred to as immediate cause.

Process Piping: Piping that is not otherwise regulated by the State of Alaska.

Process Water (Oil Exploration and Production Operations): Process water includes seawater (and occasionally freshwater) and produced water. Seawater is injected into a formation to pressurize the reservoir and force the oil toward the oil production wells. Gelled water is seawater and freshwater that is mixed with a gelling substance to increase the viscosity of the fluid for a number of purposes. Seawater is also used to maintain the existing wells or to detect leaks in pipelines. Produced water is the water mixture consisting of oil, gas, and sand that is pumped from oil production wells.

Spills In-Scope: Any reported spill of crude oil, produced water, sea water, or process water that was a result of loss-of-integrity during normal production operations.

Spills Out-of-Scope: Any spill of crude oil, produced water, sea water, or process water that resulted from drilling, workovers, construction, or out-of-service maintenance. Also any spill of any other substance except crude oil, produced water, seawater, or process water.

Transmission Pipeline {18 AAC 75.055; 18 AAC 75.990(134)} or Oil Transmission Pipeline: A pipeline through which crude oil moves in transportation, including line pipe, valves, and other appurtenances connected to line pipe, pumping units, and fabricated assemblies associated with pumping units; "transmission pipeline" does not include gathering lines, flow lines, or facility oil piping.

Well {20 AAC 25.990(73)}:

(A) A hole penetrating the earth, usually cased with steel pipe, and

- (i) from which oil or gas, or both, is obtained or obtainable; or
- (ii) that is made for the purpose of finding or obtaining oil or gas or of supporting oil or gas production; and,

(B) Includes a well with multiple well branches drilled to different bottom-hole locations.

Workover: The repair or stimulation of an existing production well for the purpose of restoring, prolonging, or enhancing the production of hydrocarbons.

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