Appendix S

Baseline Crude Oil Pipeline Spill Analysis

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Baseline Crude Oil Pipeline Spill Analysis

Line 3 Project Final Environmental Impact Statement

Prepared for

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ENVIRONMENTAL RESEARCH CONSULTING

Contents

List of Tables

List of Figures

Notes on Terminology Used in Report

Probability and Frequency

The term "probability" and "frequency" are used interchangeably in this report. The probability that something will occur is the frequency of expected events (spills or releases) in a specified time frame.

Return Periods

The results are represented in terms of expected *frequencies* and as *return periods*. (The return period is also sometimes called the "recurrence interval.") These terms express the same concepts in different ways. The expected frequency is an estimate of the likelihood or probability that an event (in this case, a pipeline spill) will occur in any given year. The inverse of this is the return period.

For example, if there is a 1% chance, or a one in 100 chance, that a large spill event will occur in one year, the "return period" for this event is 100 years. The return period is the inverse of the frequency.

$$Frequency(event) = \frac{number(events)}{year}$$

$$Return = \frac{1}{Frequency(event)} = \frac{years}{event}$$

$$Frequency(event) = \frac{0.01}{year}$$

$$Return(event) = \frac{1}{0.01} = 100$$

The return period (e.g., 100 years) is used in an attempt to simplify the definition of a specific statistically determined chance of an event occurring in any one year (1%). It does not, however, mean that it will necessarily take 100 years before this event occurs or that it will only occur once in a 100-year time frame. The return period or recurrence interval can also be viewed as the "odds" or "chances" that an event will occur in any one year.

Rounding of Numbers and Significant Digits

Calculated data from modeling and various interim analyses are shown with as many as five digits after the decimal point. This is to allow for greater accuracy in adding and other mathematical processes and to avoid rounding errors that may be confusing to the reader.

In summary tables, however, such as those providing estimates of annual frequencies of specific volumes of spills and return years, the results have been rounded to two or three significant digits, as appropriate, starting with the first non-zero digit. This is a standard methodology applied in many analyses to avoid the implication that one could be so precise in determining the frequency of spill events in the future. For example, if the calculated spill frequency is 0.00128 per year, which would bring a return period of 781.25 years, the spill frequency would be rounded to 0.0013 per year and the return period would be expressed as 780 years. Note that "significant digits" are also called "significant figures."

Baseline Crude Oil Pipeline Spill Analysis
Enbridge Line 3 Final Environmental Impact Statement

Introduction

In order to quantify the incremental risk for the Line 3 Project, the potential spills that might occur need to be compared with the baseline of spills occurring from existing pipelines in the area. This report provides an overview of pipeline spill rates and trends in the inland[1] US as a whole, as well as an analysis of historical data for existing crude oil pipelines in Minnesota.

General Analysis Inland Pipeline Spills in the US

Pipeline Spill Data

Data analyses on the crude and refined product pipeline spills were based on data available publicly from the Pipeline and Hazardous Materials Safety Administration (PHMSA).[2] A total of 10,810 spill incidents were included. Criteria for inclusion of spill incidents in the database were:

- Spillage of one gallon or more;
- Onshore/inland spill location;[3] and
- Incident occurrence during 1968 through 2015.[4]

The spill incidents were individually characterized with respect to:

- Year and date of incident;
- Location (state, county, city, latitude/longitude);
- General oil type (crude or refined);
- Detailed oil type (crude, gasoline, light oil,[5] and heavy oil[6]); and
- Amount of spillage (in barrels, bbl).

Analytical Results and Findings: Annual Spill Numbers and Volumes

Over the 48-year time period, there were a total of 6,433 crude pipeline spills and 4,377 refined product spills in inland[7] areas of the US, involving a total of over 6.7 million bbl of spillage. These figures are for spills of 1 gallon or more.[8]

The data for major pipeline spills of at least 10,000 gallons (238 bbl) were also analyzed separately. According to the National Contingency Plan,[9] a "major" oil spill is defined as one that involves a spillage of more than 100,000 gallons in coastal (marine) waters, and more than 10,000 gallons in inland waters.

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[1] In this report, the term "inland" pipeline specifically excludes any pipelines offshore in marine waters, but does not exclude pipelines that cross inland waterways.
[2] https://www.phmsa.dot.gov/pipeline/library/data-stats/raw-data
[3] Spills from offshore pipelines were excluded.
[4] These were the data that were available at the time of the preparation of this document.
[5] Light oil included: diesel, jet fuel, kerosene.
[6] Heavy oil included: heavy fuel oil, transmix.
[7] The term "inland" is used to exclude offshore and exclusively marine pipeline spill incidents.
[8] Parts of these analyses appeared in Etkin (2014) and Etkin (2017).

Five-year averages of spillage for all pipeline spills and for major spills are shown in Table 1 and Table 2, with graphical representations in Figure 1 and Figure 2, respectively. The annual numbers and total volumes are shown in Table 3 and Table 4, and Figure 3 through Figure 5.

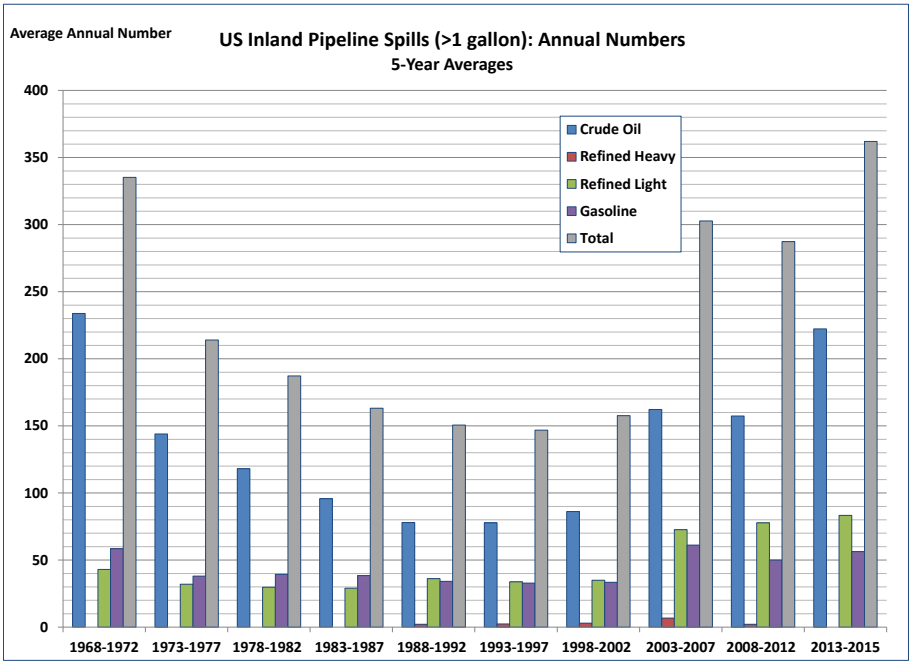

Figure 1: US Inland Pipeline Spills (>1 gallon): Five-Year Averages of Annual Spill Numbers

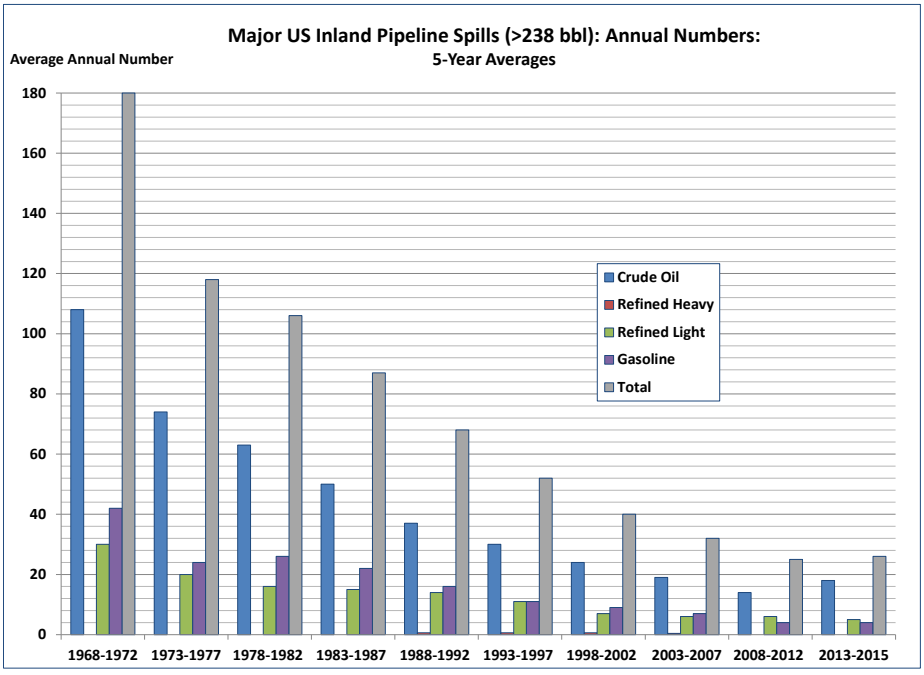

Figure 2: Major US Inland Pipeline Spills (>238 bbl): Five-Year Averages of Annual Spill Numbers

[9] 40 CFR§ 300.5

Table 1: Five-Year Average Spillage for US Inland Pipeline Spills (1968–2012)

Years	Five-Year Averages[10]														
	Crude Oil			Refined Heavy			Refined Light			Gasoline			Total		
	#	Total Bbl	Spill Bbl	#	Total Bbl	Spill Bbl	#	Total Bbl	Spill Bbl	#	Total Bbl	Spill Bbl	#	Total Bbl	Spill Bbl
1968–1972	234	225,023	994	0	0	0	43	37,076	871	58	44,517	765	335	306,616	933
1973–1977	144	136,736	932	0	0	0	32	44,341	1,380	38	31,537	848	214	212,614	983
1978–1982	118	118,949	1,016	0	0	0	30	26,640	871	39	29,959	776	187	175,547	943
1983–1987	96	111,124	1,229	0	0	0	29	22,692	796	38	46,305	1,210	163	180,121	1,129
1988–1992	78	98,026	1,265	2	1,857	361	36	19,996	579	34	19,568	561	151	139,447	937
1993–1997	78	54,063	705	2	713	190	34	20,031	596	33	29,610	979	147	104,274	733
1998–2002	86	55,856	823	3	866	362	35	13,557	622	33	13,792	560	158	84,070	733
2003–2007	162	50,073	307	7	323	42	73	9,680	128	61	9,720	166	303	69,795	233
2008–2012	157	37,308	244	2	2	0	78	7,134	92	50	7,232	139	287	51,676	181
2013–2015	222	27,177	126	0	0	0	83	4,510	54	56	7,535	127	362	39,222	110
Grand Average	**134**	**94,111**	**791**	**2**	**385**	**100**	**46**	**21,235**	**622**	**44**	**24,662**	**633**	**225**	**140,385**	**716**

Table 2: Five-Year Average Spillage for US Major[11] Inland Pipeline Spills (1968–2012)

Years	Five-Year Averages									
	Crude Oil		Refined Heavy		Refined Light		Gasoline		Total	
	#	Total Bbl	#	Total Bbl	#	Total Bbl	#	Total Bbl	#	Total Bbl
1968–1972	108	209,558	0.0	0	30	35,502	42	42,328	180	287,387
1973–1977	74	128,997	0.0	0	20	42,759	24	30,140	118	201,895
1978–1982	63	113,625	0.0	0	16	25,207	26	28,579	106	167,412
1983–1987	50	106,923	0.0	0	15	21,359	22	44,576	87	172,858
1988–1992	37	94,650	0.6	1,801	14	18,723	16	18,498	68	133,672
1993–1997	30	50,017	0.6	500	11	18,507	11	28,383	52	97,407
1998–2002	24	52,949	0.6	784	7	12,490	9	12,801	40	79,024
2003–2007	19	47,504	0.4	218	6	8,936	7	8,842	32	65,500
2008–2012	14	34,601	0.0	0	6	5,879	4	6,658	25	47,137
2013–2015	18	23,753	0.0	0	5	3,372	4	7,196	26	34,321
Grand Average	**44**	**86,258**	**0.2**	**330**	**13**	**19,273**	**17**	**22,800**	**73**	**128,661**

[10] The period 2013–2015 is a three-year average. "Total bbl" is average annual total spillage. "Spill bbl" refers to average spill volume for individual incidents.
[11] Major spills are defined as those involving at least 10,000 gallons (238 bbl).

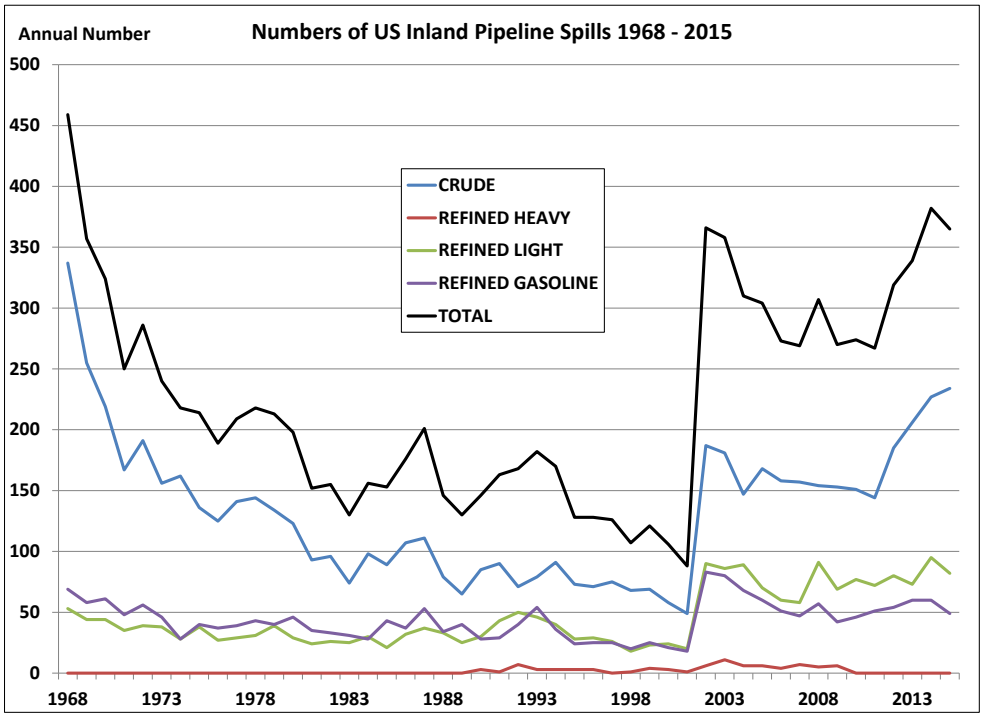

Figure 3: Annual Numbers of US Inland Pipeline Spills (>1 gallon)

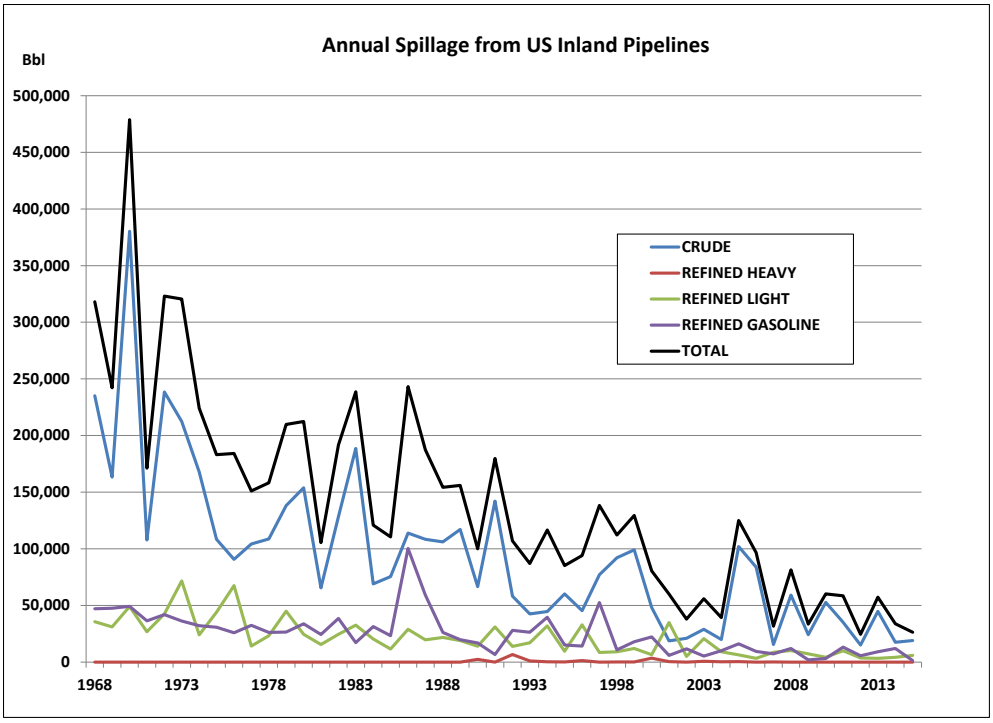

Figure 4: Annual Volume of Spillage from US Inland Pipelines

Table 3: Spill Numbers and Volumes for US Inland Pipeline Spills of One Bbl or More (1968–2015)										
Year	Crude Oil		Refined Heavy		Refined Light		Gasoline		Total	
	#	bbl	#	bbl	#	bbl	#	bbl	#	bbl
1968	337	235,196	0	0	53	35,730	69	47,075	459	318,001
1969	255	163,312	0	0	44	31,149	58	47,661	357	242,122
1970	219	380,289	0	0	44	49,096	61	49,318	324	478,703
1971	167	107,820	0	0	35	26,870	48	36,526	250	171,216
1972	191	238,500	0	0	39	42,536	56	42,004	286	323,040
1973	156	212,356	0	0	38	71,741	46	36,382	240	320,479
1974	162	167,891	0	0	28	24,187	28	32,122	218	224,200
1975	136	108,355	0	0	38	44,043	40	30,770	214	183,168
1976	125	90,709	0	0	27	67,578	37	25,870	189	184,157
1977	141	104,367	0	0	29	14,158	39	32,540	209	151,065
1978	144	108,732	0	0	31	23,338	43	26,253	218	158,323
1979	134	138,167	0	0	39	45,056	40	26,567	213	209,790
1980	123	153,901	0	0	29	24,580	46	33,913	198	212,394
1981	93	65,525	0	0	24	15,592	35	24,404	152	105,521
1982	96	128,421	0	0	26	24,632	33	38,656	155	191,709
1983	74	188,653	0	0	25	32,656	31	17,250	130	238,559
1984	98	69,025	0	0	30	20,515	28	31,457	156	120,997
1985	89	75,549	0	0	21	11,615	43	23,336	153	110,500
1986	107	113,903	0	0	32	28,958	37	100,301	176	243,162
1987	111	108,490	0	0	37	19,716	53	59,183	201	187,389
1988	79	106,130	0	0	33	21,806	34	26,318	146	154,254
1989	65	117,071	0	0	25	19,131	40	19,816	130	156,018
1990	85	66,594	3	2,507	30	14,029	28	16,987	146	100,117
1991	90	142,101	1	3	43	31,059	29	6,676	163	179,839
1992	71	58,236	7	6,775	50	13,956	40	28,041	168	107,008
1993	79	42,578	3	1,040	46	17,062	54	26,339	182	87,019
1994	91	44,715	3	302	40	32,064	36	39,642	170	116,723
1995	73	60,303	3	132	28	9,601	24	15,173	128	85,209
1996	71	45,533	3	1,378	29	32,934	25	14,206	128	94,051
1997	75	77,184	0		26	8,493	25	52,689	126	138,366
1998	68	92,134	1	149	18	9,117	20	10,814	107	112,214
1999	69	99,095	4	211	23	12,091	25	18,054	121	129,451
2000	58	48,218	3	3,484	24	6,616	21	22,252	106	80,570
2001	49	18,718	1	440	20	34,976	18	6,011	88	60,145
2002	187	21,114	6	47	90	4,983	83	11,828	366	37,972
2003	181	28,979	11	786	86	20,801	80	5,415	358	55,980
2004	147	19,943	6	258	89	9,154	68	10,072	310	39,427
2005	168	101,970	6	418	70	6,437	60	16,201	304	125,026
2006	158	83,852	4	44	60	3,311	51	9,529	273	96,737
2007	157	15,618	7	109	58	8,696	47	7,383	269	31,806
2008	154	59,253	5	6	91	10,167	57	12,033	307	81,459
2009	153	24,193	6	4	69	7,360	42	1,938	270	33,495
2010	151	52,710	0	0	77	4,362	46	3,211	274	60,283
2011	144	35,287	0	0	72	10,071	51	13,280	267	58,638
2012	185	15,099	0	0	80	3,710	54	5,697	319	24,506
2013	206	44,877	0	0	73	3,372	60	9,144	339	57,393
2014	227	17,521	0	0	95	4,254	60	12,124	382	33,899
2015	234	19,134	0	0	82	5,903	49	1,337	365	26,374
Total	**6,433**	**4,517,322**	**83**	**18,094**	**2,196**	**1,019,261**	**2,098**	**1,183,796**	**10,810**	**6,738,473**

Table 4: Spill Numbers and Volumes for Major US Inland Pipeline Spills (1968–2015)										
Year	Crude Oil		Refined Heavy		Refined Light		Gasoline		Total	
	#	bbl	#	bbl	#	bbl	#	bbl	#	bbl
1968	149	211,637	0	0	39	33,826	48	44,508	236	289,971
1969	122	146,404	0	0	28	29,162	44	45,534	194	221,100
1970	96	365,610	0	0	35	48,237	44	46,689	175	460,536
1971	74	96,363	0	0	24	25,585	34	35,004	132	156,952
1972	101	227,776	0	0	24	40,698	38	39,904	163	308,378
1973	88	204,601	0	0	27	70,264	29	34,489	144	309,354
1974	83	158,898	0	0	17	22,426	20	31,467	120	212,791
1975	63	99,623	0	0	25	42,739	23	29,223	111	171,585
1976	63	84,244	0	0	21	66,444	23	24,356	107	175,044
1977	74	97,617	0	0	10	11,921	25	31,165	109	140,703
1978	82	102,200	0	0	15	21,374	29	24,616	126	148,190
1979	65	130,623	0	0	24	43,547	22	24,860	111	199,030
1980	61	148,279	0	0	15	23,391	31	31,952	107	203,622
1981	49	61,870	0	0	12	14,517	27	23,942	88	100,329
1982	58	125,155	0	0	16	23,205	23	37,527	97	185,887
1983	45	185,962	0	0	11	30,929	20	16,025	76	232,916
1984	44	64,280	0	0	17	19,549	16	29,891	77	113,720
1985	38	70,788	0	0	10	10,550	20	21,199	68	102,537
1986	61	109,417	0	0	19	27,607	26	99,179	106	236,203
1987	61	104,168	0	0	20	18,159	26	56,585	107	178,912
1988	43	102,274	0	0	16	20,799	18	24,821	77	147,894
1989	30	113,997	0	0	9	17,908	19	18,556	58	150,461
1990	33	63,225	2	2,506	15	13,260	17	16,016	67	95,007
1991	47	138,916	0	0	14	28,867	10	6,087	71	173,870
1992	34	54,840	1	6,500	16	12,781	18	27,008	69	101,129
1993	26	38,926	1	950	9	15,056	16	24,630	52	79,562
1994	34	40,983	1	300	14	31,039	12	38,118	61	110,440
1995	30	56,843	0	0	10	7,921	9	14,422	49	79,186
1996	24	40,404	1	1,250	11	31,319	4	12,852	40	85,825
1997	34	72,930	0	0	10	7,200	13	51,891	57	132,021
1998	27	88,344	0	0	5	7,991	5	9,720	37	106,055
1999	37	96,275	0	0	10	11,144	13	17,532	60	124,951
2000	28	45,699	2	3,482	8	5,808	10	21,123	48	76,112
2001	13	16,006	1	440	7	34,187	5	5,096	26	55,729
2002	14	18,419	0	0	6	3,321	10	10,532	30	32,272
2003	22	26,149	1	725	11	19,861	7	4,349	41	51,084
2004	20	17,252	0	0	6	7,916	9	9,022	35	34,190
2005	26	99,533	1	365	6	5,501	6	15,077	39	120,476
2006	14	80,865	0	0	4	2,975	5	9,107	23	92,947
2007	14	13,720	0	0	4	8,429	6	6,655	24	28,804
2008	15	56,536	0	0	6	8,797	6	11,241	27	76,574
2009	15	22,061	0	0	6	6,123	4	1,471	25	29,655
2010	13	50,122	0	0	4	3,226	2	2,621	19	55,969
2011	16	32,679	0	0	11	9,154	5	12,761	32	54,594
2012	12	11,606	0	0	5	2,094	4	5,194	21	18,894
2013	15	41,486	0	0	4	2,393	5	8,677	24	52,556
2014	19	13,877	0	0	5	3,471	6	11,887	30	29,235
2015	19	15,897	0	0	5	4,251	1	1,025	25	21,173
Total	**2,151**	**4,265,379**	**11**	**16,518**	**646**	**956,922**	**813**	**1,125,606**	**3,621**	**6,364,425**

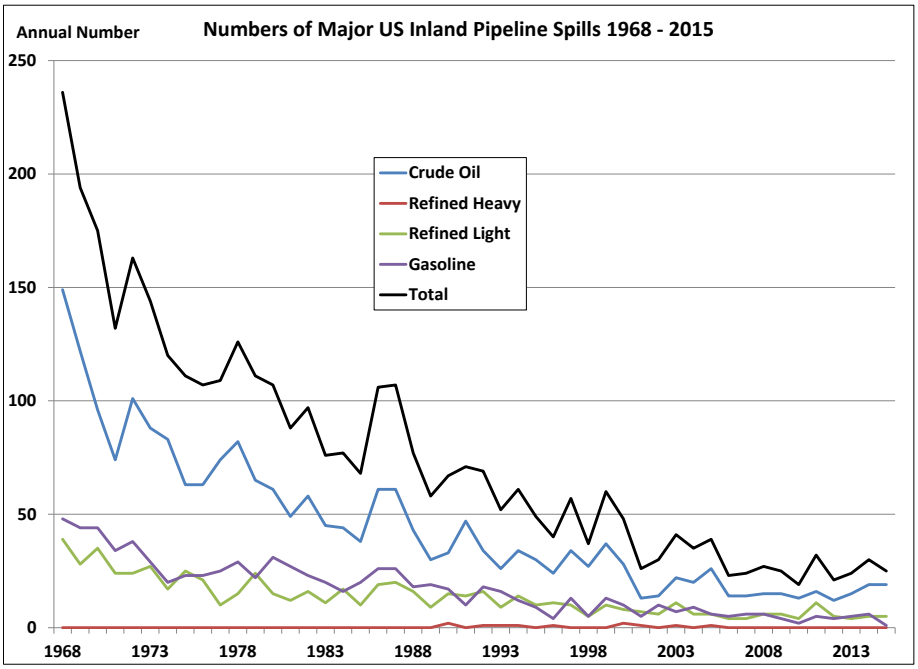

Figure 5: Annual Numbers of Major US Inland Pipeline Spills (>238 bbl)

Annual average volumes per spill incident for all spills are shown in Table 5, Table 6, Figure 6, and Figure 7. The average volume of pipeline spills has decreased significantly since the late 1960s, and particularly in the last dozen years. The average spill volume (all oil types) is now less than 50% of the average volume ten years ago, and 12% of the volume in the late 1960s.

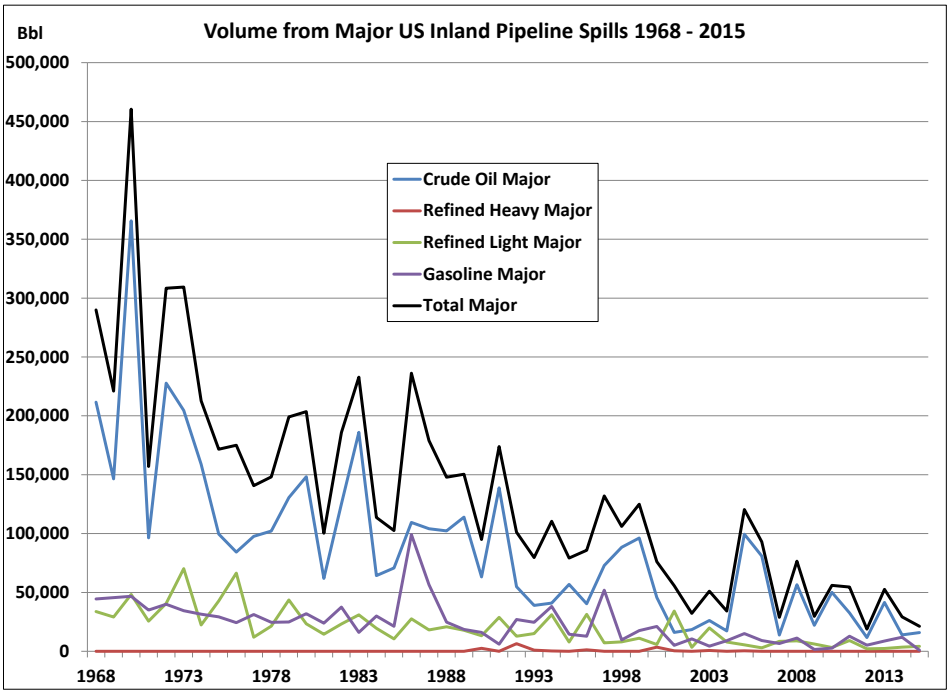

Figure 6: Volume of Spillage from Major US Pipeline Spills (>238 bbl)

Table 5: Average Volumes for US Inland Pipeline Spills of One Bbl or More (1968–2015)					
Year	Average Volume (bbl)				
	Crude Oil	Refined Heavy	Refined Light	Gasoline	Total
1968	698	0	674	682	693
1969	640	0	708	822	678
1970	1,736	0	1,116	808	1,477
1971	646	0	768	761	685
1972	1,249	0	1,091	750	1,130
1973	1,361	0	1,888	791	1,335
1974	1,036	0	864	1,147	1,028
1975	797	0	1,159	769	856
1976	726	0	2,503	699	974
1977	740	0	488	834	723
1978	755	0	753	611	726
1979	1,031	0	1,155	664	985
1980	1,251	0	848	737	1,073
1981	705	0	650	697	694
1982	1,338	0	947	1,171	1,237
1983	2,549	0	1,306	556	1,835
1984	704	0	684	1,123	776
1985	849	0	553	543	722
1986	1,065	0	905	2,711	1,382
1987	977	0	533	1,117	932
1988	1,343	0	661	774	1,057
1989	1,801	0	765	495	1,200
1990	783	836	468	607	686
1991	1,579	3	722	230	1,103
1992	820	968	279	701	637
1993	539	347	371	488	478
1994	491	101	802	1,101	687
1995	826	44	343	632	666
1996	641	459	1,136	568	735
1997	1,029	0	327	2,108	1,098
1998	1,355	149	507	541	1,049
1999	1,436	53	526	722	1,070
2000	831	1,161	276	1,060	760
2001	382	440	1,749	334	683
2002	113	8	55	143	104
2003	160	71	242	68	156
2004	136	43	103	148	127
2005	607	70	92	270	411
2006	531	11	55	187	354
2007	99	16	150	157	118
2008	385	1	112	211	265
2009	158	1	107	46	124
2010	349	0	57	70	220
2011	245	0	140	260	220
2012	82	0	46	105	77
2013	218	0	46	152	169
2014	77	0	45	202	89
2015	82	0	72	27	72
Total	**702**	**218**	**464**	**564**	**623**

Table 6: Average Volumes for US Inland Pipeline Spills (1968–2015): 5-Year Averages					
Year	Five-Year Average Spill Volume (bbl)[12]				
	Crude Oil	Refined Heavy	Refined Light	Gasoline	Total
1968–1972	994	0	871	765	933
1973–1977	932	0	1,380	848	983
1978–1982	1,016	0	871	776	943
1983–1987	1,229	0	796	1,210	1,129
1988–1992	1,265	361	579	561	937
1993–1997	705	190	596	979	733
1998–2002	823	362	622	560	733
2003–2007	307	42	128	166	233
2008–2012	244	0	92	139	181
2013–2015	126	0	54	127	110

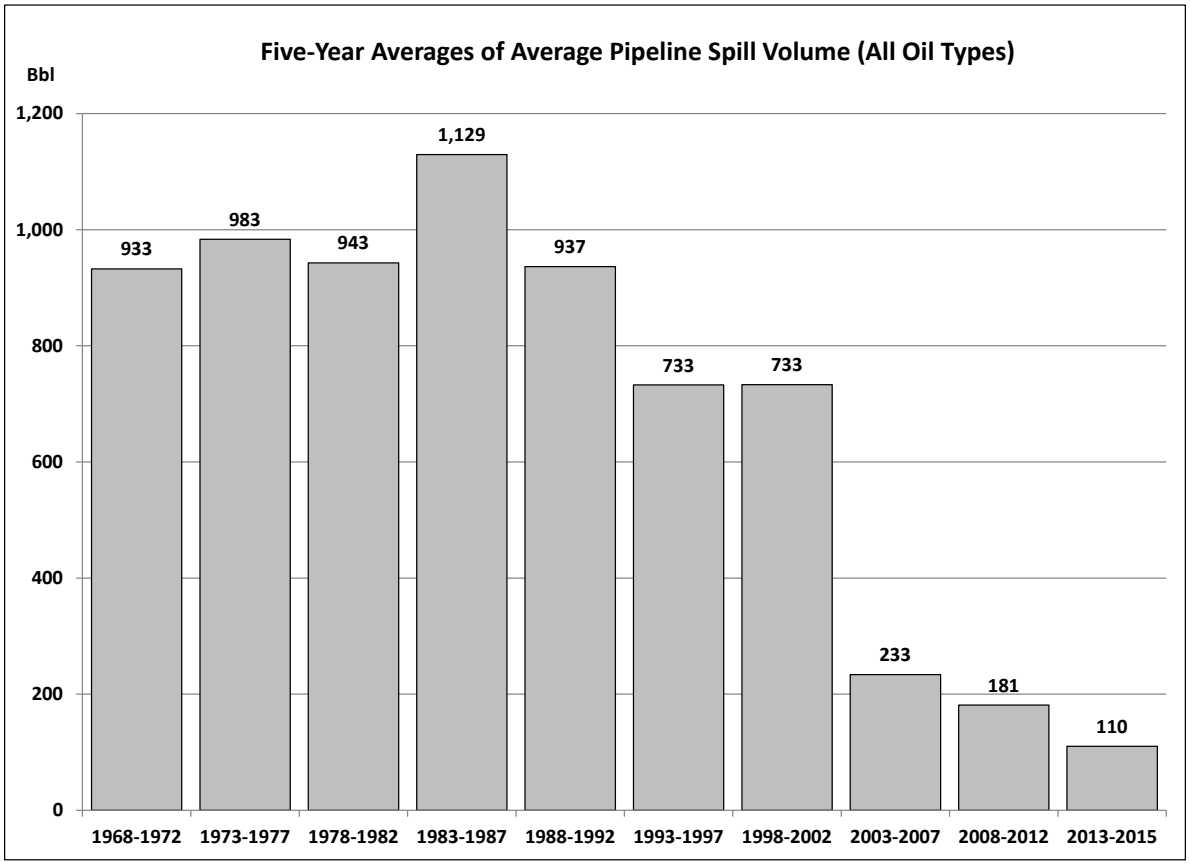

Figure 7: Average US Inland Pipeline Spill Volume (Five-Year Averages)

The vast majority of spillage is attributable to major spills (238 bbl and larger) (Figure 8 through Figure 11). Overall, 93% of the volume of spillage can be attributed to the 37% of incidents that are considered "major" by involving 10,000 gallons (238 bbl) or more.

[12] The period 2013–2015 is a three-year average.

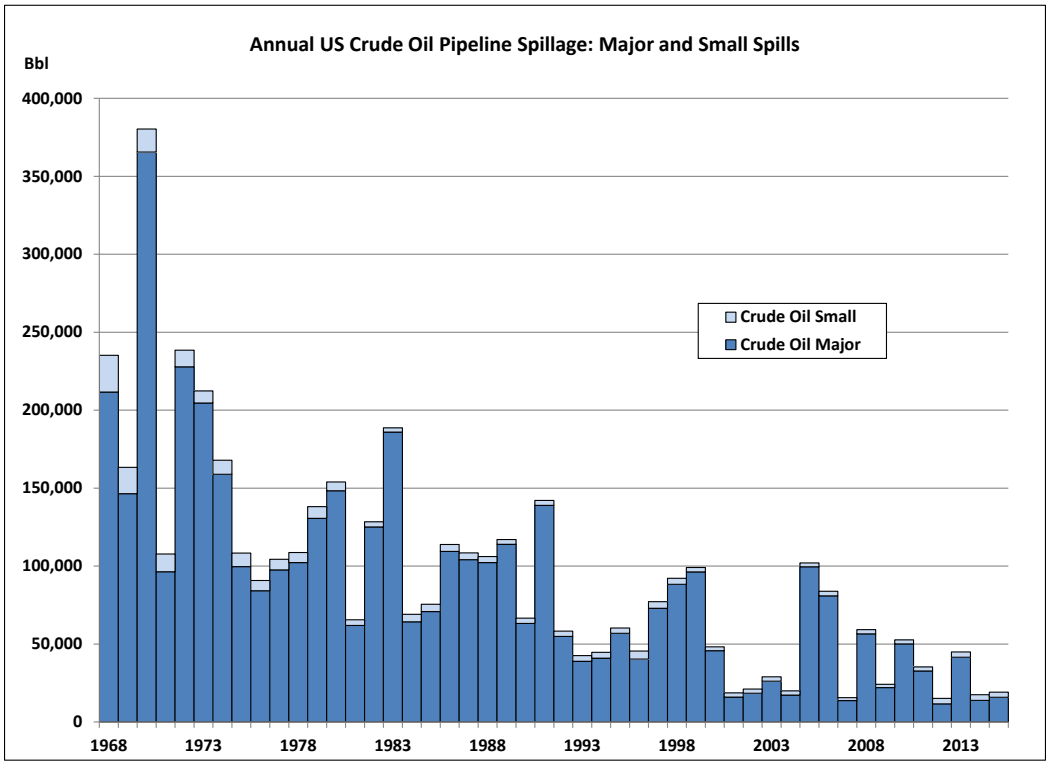

Figure 8: Annual Volume of Inland Crude Oil Pipeline Spillage (Major and Small Spills)

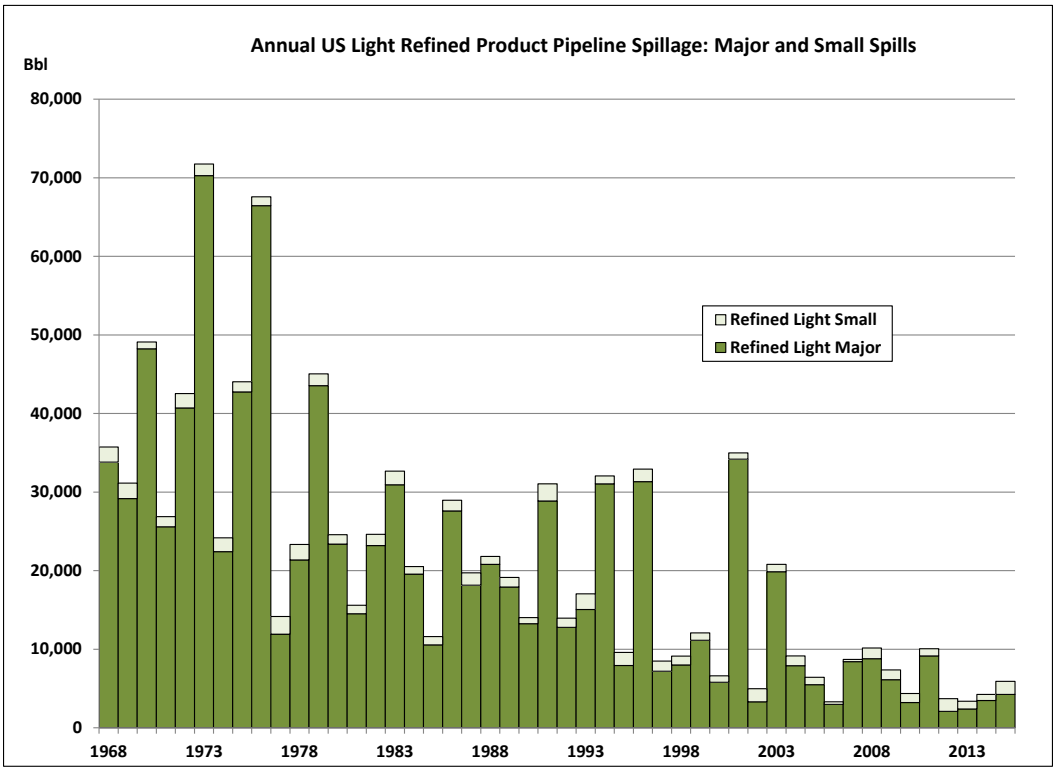

Figure 9: Annual Volume of Inland Light Refined Pipeline Spillage (Major and Small Spills)

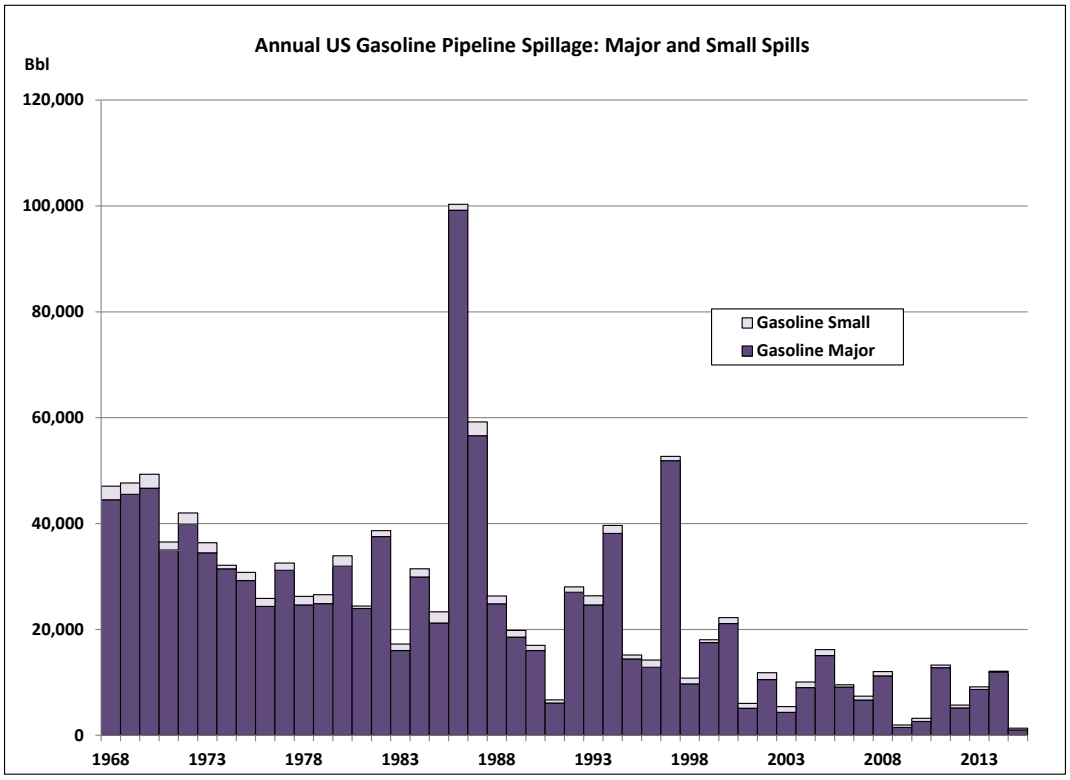

Figure 10: Annual Volume of Inland Gasoline Pipeline Spillage (Major and Small Spills)

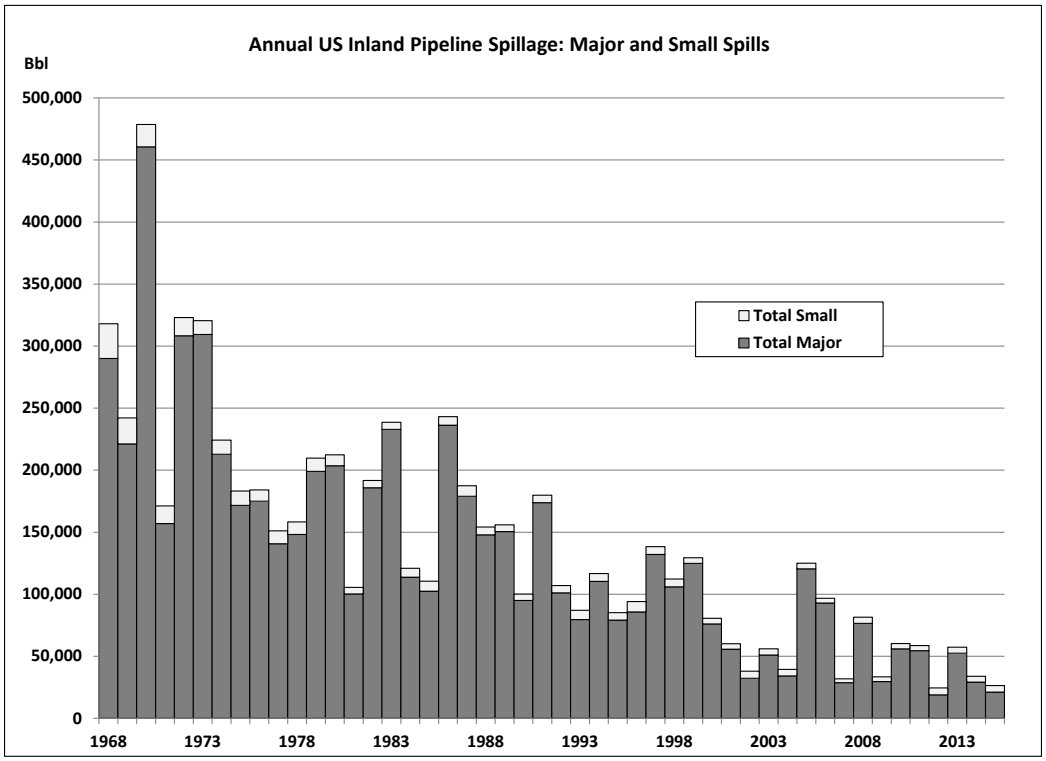

Figure 11: Annual Volume of Inland Pipeline Spillage (Major and Small Spills)–All Oil Types

Probability Distribution of Pipeline Spill Volume

The volumes of spills vary from a few drops or a small leak to a very large discharge. The distribution of volumes in the spills from inland oil pipelines over the years 1968–2015 are shown in Table 7 and Table 8. Figure 12 shows a cumulative probability density function of volume for pipeline spills.

Table 7: Probability Distribution of Spill Volumes for US Inland Pipelines (1968–2015)

Spill Volume	% Spill Incidents	Number of Incidents
<1 bbl	8.64%	934
1–9 bbl	21.99%	2,377
10–99 bbl	19.21%	2,077
100–999 bbl	37.47%	4,050
1,000–9,999 bbl	11.90%	1,286
10,000–90,000 bbl	0.78%	84
100,000+ bbl	0.02%	2

Table 8: Percentile Spill Volumes for US Inland Pipelines (1968–2015)

Percentile[13]	Volume
50th (median)	100 bbl
90th	1,100 bbl
95th	2,000 bbl
99th	6,000 bbl

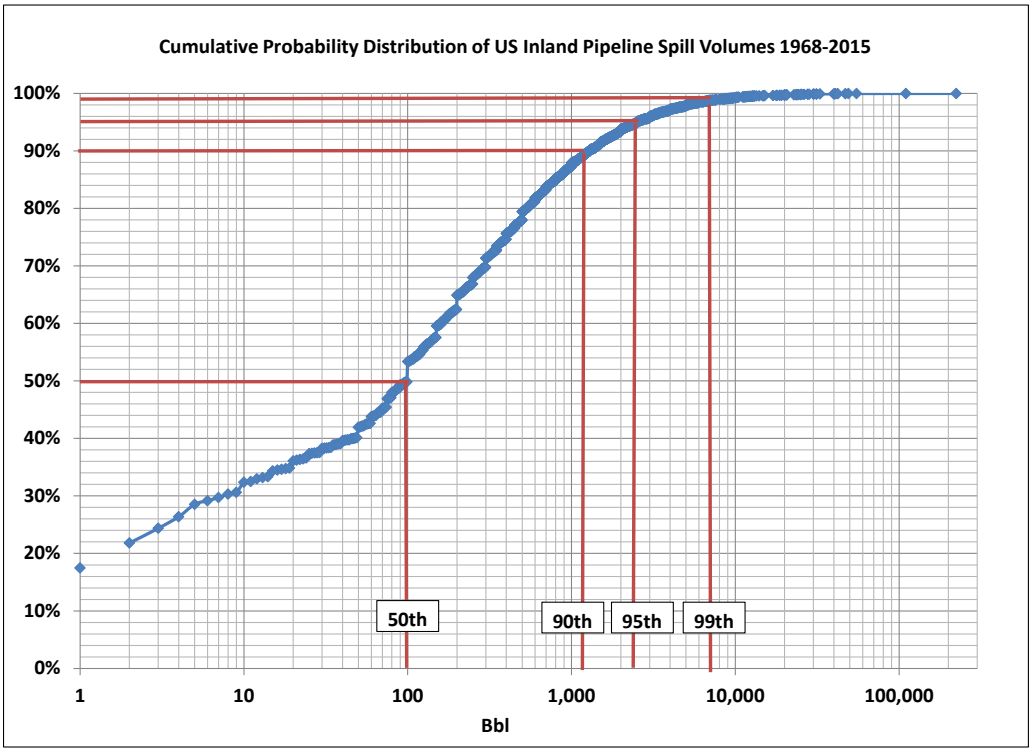

Figure 12: Cumulative Probability Distribution of US Inland Spill Volumes (1968–2015)

[13] A percentile spill volume is the percentage of spills that are that volume or less. e.g., a 90th percentile spill of 1,100 bbl means that 90% of spills are 1,100 bbl or less. Only 10% of spills are larger. The 50th percentile is the equivalent of the "median." Half of spills are smaller, half are larger.

With the trend towards smaller spills in the last decades, another cumulative probability distribution function of spill volume was developed for spills in the last decade only (2006–2015), as in Table 9, Table 10, and Figure 13. The shift towards smaller spills in the last decade can be seen in Figure 14.

Table 9: Probability Distribution of Spill Volumes for US Inland Pipelines (2006–2015)		
Spill Volume	**% Spill Incidents**	**Number of Incidents**
<1 bbl	33.51%	1,027
1–9 bbl	34.78%	1,066
10–99 bbl	18.76%	575
100–999 bbl	10.15%	311
1,000–9,999 bbl	2.58%	79
10,000–90,000 bbl	0.23%	7
100,000+ bbl	0.00%	0

Table 10: Percentile Spill Volumes for US Inland Pipelines (2006–2015)	
Percentile[14]	**Volume**
50th (median)	1 bbl
90th	100 bbl
95th	400 bbl
99th	2,500 bbl

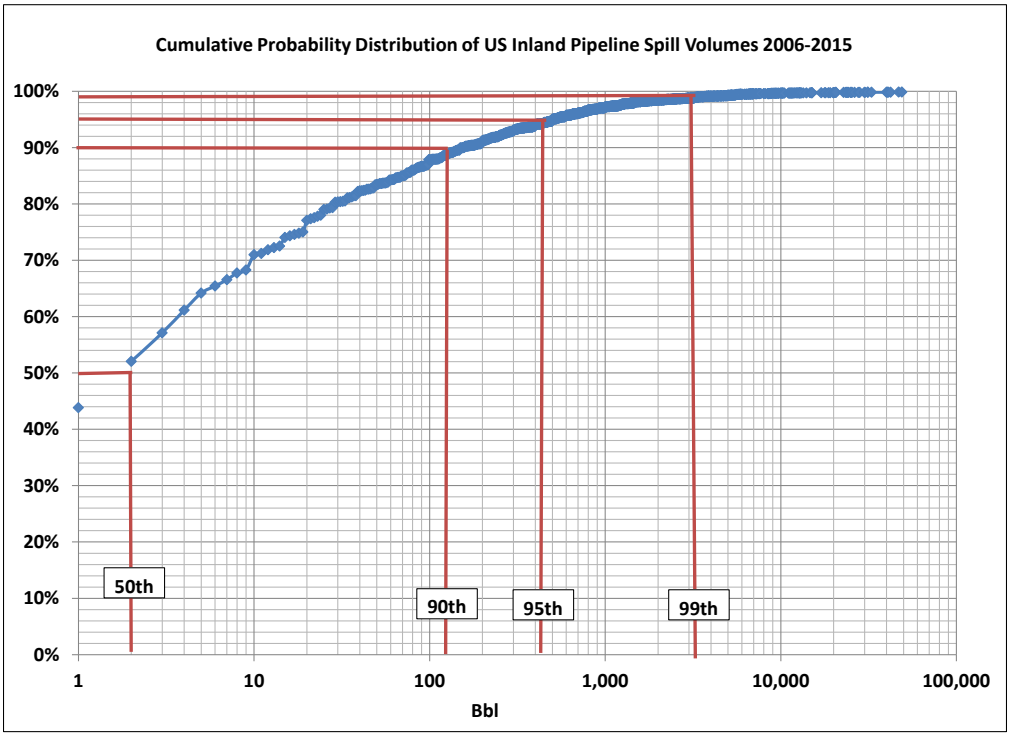

Figure 13: Cumulative Probability Distribution of US Inland Spill Volumes (2006–2015)

[14] A percentile spill volume is the percentage of spills that are that volume or less. e.g., a 90th percentile spill of 1,100 bbl means that 90% of spills are 1,100 bbl or less. Only 10% of spills are larger. The 50th percentile is the equivalent of the "median." Half of spills are smaller, half are larger.

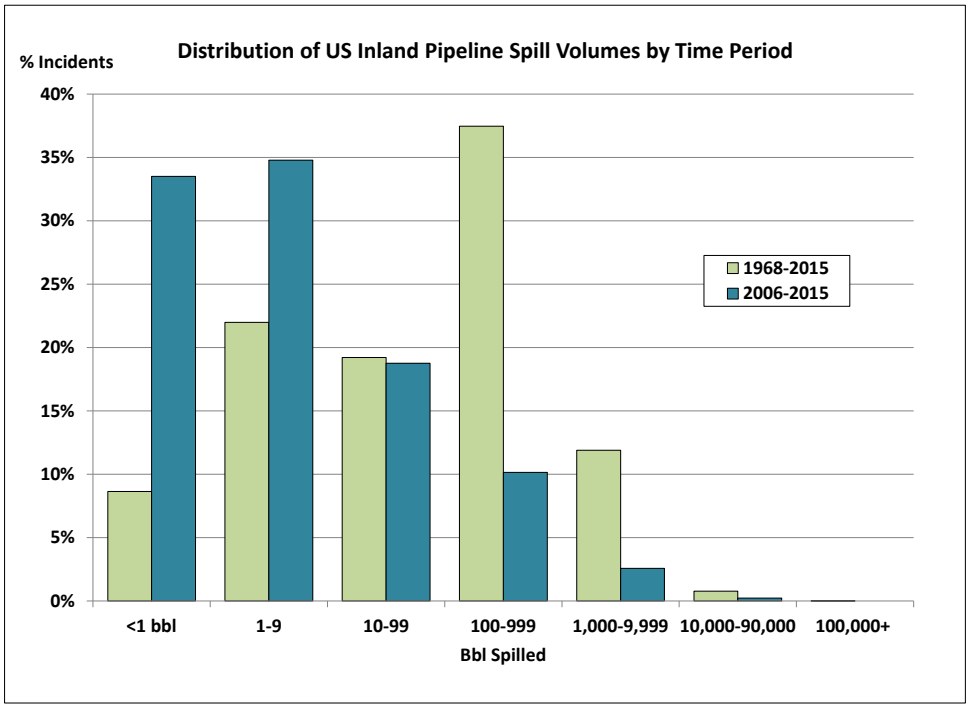

Figure 14: Distribution of US Inland Pipeline Spill Volumes by Time Period

Pipeline Spillage Rate per Volume Transmitted

Spillage should be viewed with respect to the amount of oil transported through pipelines to determine incident rates. This also allows projections for future spillage rates. Two types of incident rates analyzed—spillage rate (volume of oil spilled per unit crude or refined product transported through pipelines) and incident frequency (numbers of spills per unit crude or refined product transported through pipelines).[15] The numbers of spills (of any volume) per barrel of oil transmitted are shown in Table 11 and Figure 15. Spill numbers, particularly crude spills, have increased since 1985.

Table 11: US Inland Pipeline Spill Number per Oil Transmitted (1985–2015)

Years	Number of Spills per Bbl Transmitted Through Pipelines		
	Crude	Refined	Total
1985–1989	0.00000013	0.00000006	0.00000008
1990–1994	0.00000011	0.00000006	0.00000008
1995–1999	0.00000008	0.00000003	0.00000005
2000–2004	0.00000017	0.00000008	0.00000011
2005–2009	0.00000024	0.00000008	0.00000013
2010–2015	0.00000030	0.00000008	0.00000014
1985–2015 (All Years)	**0.00000029**	**0.00000009**	**0.00000016**

[15] Oil pipeline transmission rates are from US Energy Information Administration (EIA). In the EIA data, refined products are combined into one category. Spill incidents from the various refined product categories are combined.

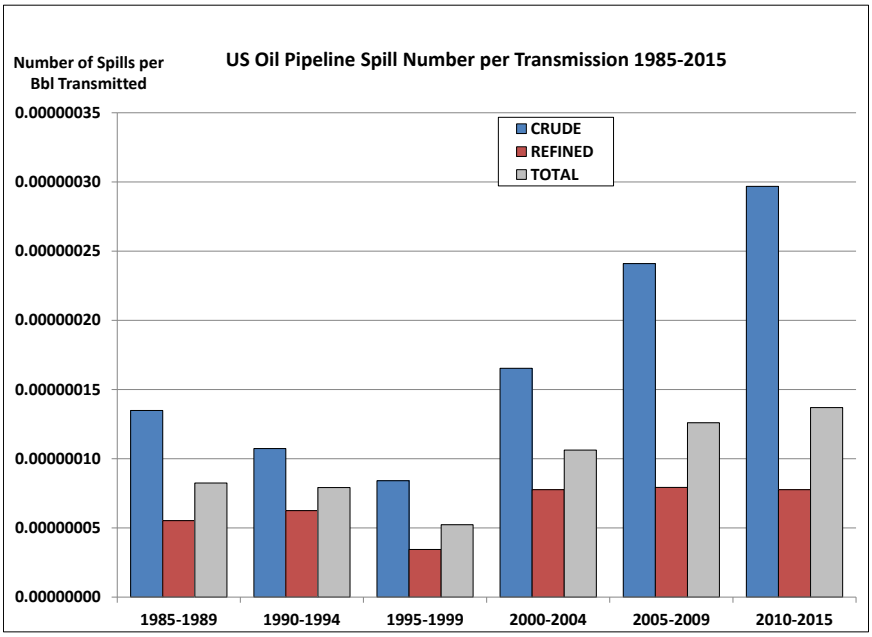

Figure 15: US Inland Oil Pipeline Spill Number per Volume Transmission (1985–2015)

Note that the values for the crude, refined, and total number of spills per bbl transmitted (the rates), as shown in Table 11 and Figure 15 are not additive. (The same holds true for Table 12 and Figure 16). The rates are derived as follows:

$$Rate_{crude} = \frac{N_{crude}}{Barrels_{crude}}$$

$$Rate_{refined} = \frac{N_{refined}}{Barrels_{refined}}$$

$$Barrels_{total} = Barrels_{crude} + Barrels_{refined}$$

$$N_{total} = N_{crude} + N_{refined}$$

$$Rate_{total} = \frac{N_{crude} + N_{refined}}{Barrels_{crude} + Barrels_{refined}}$$

$$N_{crude} = Rate_{crude} \cdot Barrels_{crude}$$

$$N_{refined} = Rate_{crude} \cdot Barrels_{crude}$$

$$Rate_{total} = \frac{(Rate_{crude} \cdot Barrels_{crude}) + (Rate_{refined} \cdot Barrels_{refined})}{(Barrels_{crude} + Barrels_{refined})}$$

$$Rate_{total} = (Barrels_{crude} + Barrels_{refined}) \cdot ((Rate_{crude} \cdot Barrels_{crude}) + (Rate_{refined} \cdot Barrels_{refined}))$$

$$Rate_{total} \neq Rate_{crude} + Rate_{refined}$$

For example, in 1985, there were 633,979,000 bbl of crude, and 1,216,670,000 bbl of refined products transmitted through pipelines, or a total 1,850,649,000 bbl. That year, there were 89 crude and 64 refined pipeline spills (of 1 bbl or more), for a total of 153 spills. The spillage rate for crude oil was

0.00000014 spills/bbl transmitted (89/633,979,000) and for refined products it was 0.00000005 spills/bbl transmitted (64/1,216,670,000). For the total spill rate (crude oil and refined products) are calculated, it would be done by dividing the total number of spills (153) by the total oil transmitted (1,850,649,000 bbl) to get a rate of 0.00000008 spills/bbl transmitted. This is not the sum of the crude spillage rate (0.0000005) and the refined product spillage rate (0.00000014), which would be 0.00000019.[16]

However, rates of major spills (238 bbl and larger) have *decreased* (Table 12 and Figure 16). This may possibly be explained by increasingly higher reporting rates for smaller spills. Crude pipelines consistently have higher spillage rates than refined product pipelines.

Table 12: Major US Inland Pipeline Spill Number per Oil Transmitted (1985–2015)

Years	Number of Spills per Bbl Transmitted Through Pipelines		
	Crude	Refined	Total
1985–1989	0.000000070	0.000000028	0.000000043
1990–1994	0.000000045	0.000000022	0.000000031
1995–1999	0.000000037	0.000000013	0.000000021
2000–2004	0.000000025	0.000000011	0.000000015
2005–2009	0.000000025	0.000000007	0.000000012
2010–2015	0.000000024	0.000000006	0.000000011
1985–2015 (All Years)	**0.000000037**	**0.000000013**	**0.000000021**

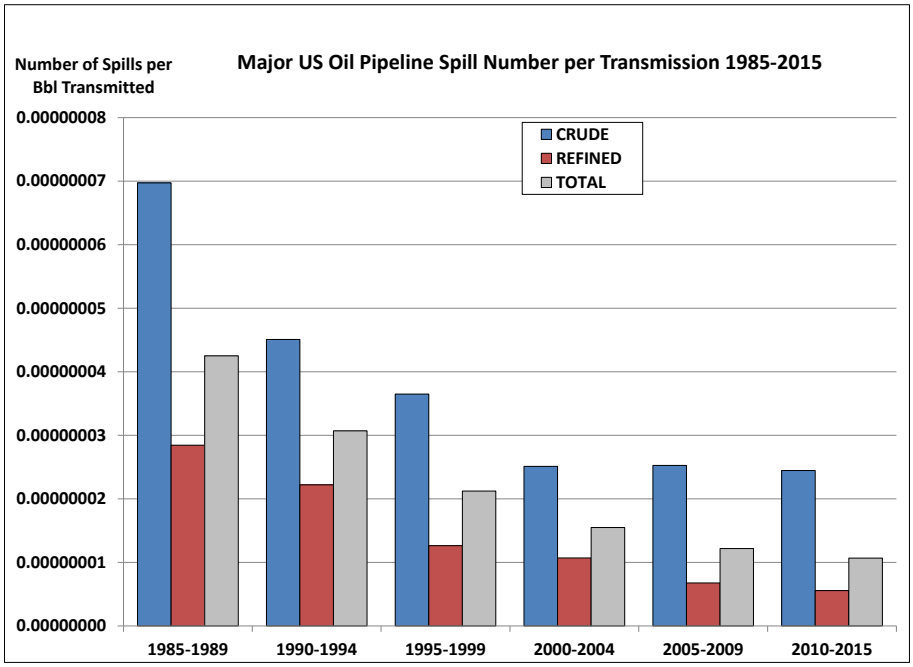

Figure 16: Major US Inland Oil Pipeline Spill Number per Volume Transmission (1985–2015)

[16] A more simple example is this: If a person eats 3 apples out of a bunch of 12 apples (1/4 or 0.25) and 4 oranges out of a group of 5 oranges (4/5 or 0.80), he can also be said to have eaten 7 pieces of fruit out of 17 (7/17 or 0.412). The rate of total *fruit* consumption is 0.412. But the rate of apple consumption is 0.25 and the rate of orange consumption is 0.80. The two rates are not added together to make 1.05.

Spillage rates per volume of pipeline transmission are shown in Table 13 and Figure 17. Again, spillage rates have generally gone down, though there was an increase in crude pipeline spillage between 2000 and 2010. Crude pipeline spillage rates are about four times the rates for refined product pipelines.

Table 13: US Inland Pipeline Volume Spilled per Oil Transmitted (19852015)

Years	Volume of Oil Spilled per Bbl Transmitted Through Pipelines		
	Crude	Refined	Total
1985–1989	0.000154	0.000051	0.000087
1990–1994	0.000092	0.000036	0.000057
1995–1999	0.000085	0.000025	0.000047
2000–2004	0.000035	0.000018	0.000024
2005–2009	0.000083	0.000010	0.000032
2010–2015	0.000051	0.000007	0.000019
1985–2015 (All Years)	**0.000083**	**0.000023**	**0.000042**

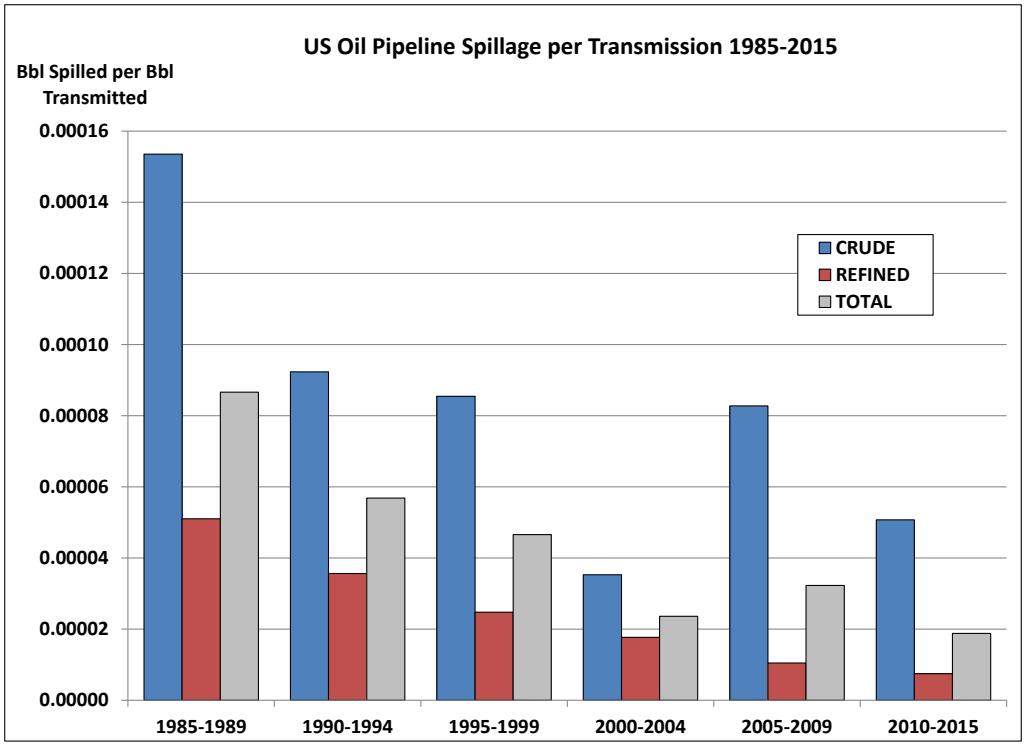

Figure 17: US Inland Oil Pipeline Spillage per Transmission (1985–2015)

Spillage per Pipeline Mile

Pipeline spillage was also analyzed by pipeline mile,[17] as in Figure 18, Figure 19, and Table 14 for spill number, and Table 15 and Figure 20 for spill volume.[18]

[17] Pipeline mileage data are from PHMSA. Transmission lines only.

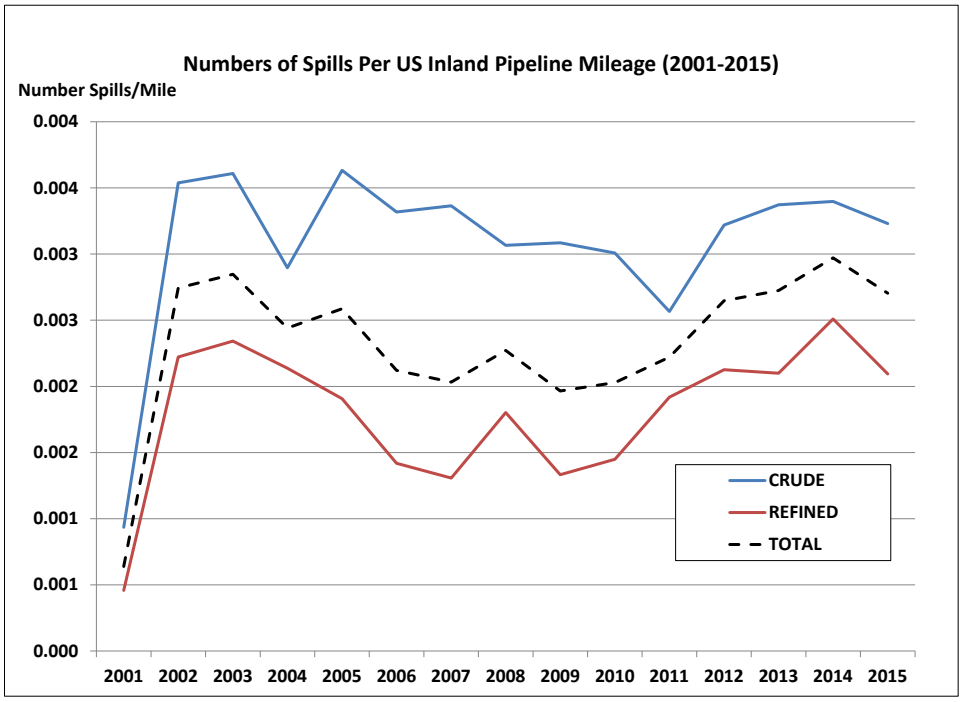

Figure 18: Number of Spills of Any Volume per US Inland Pipeline Mile

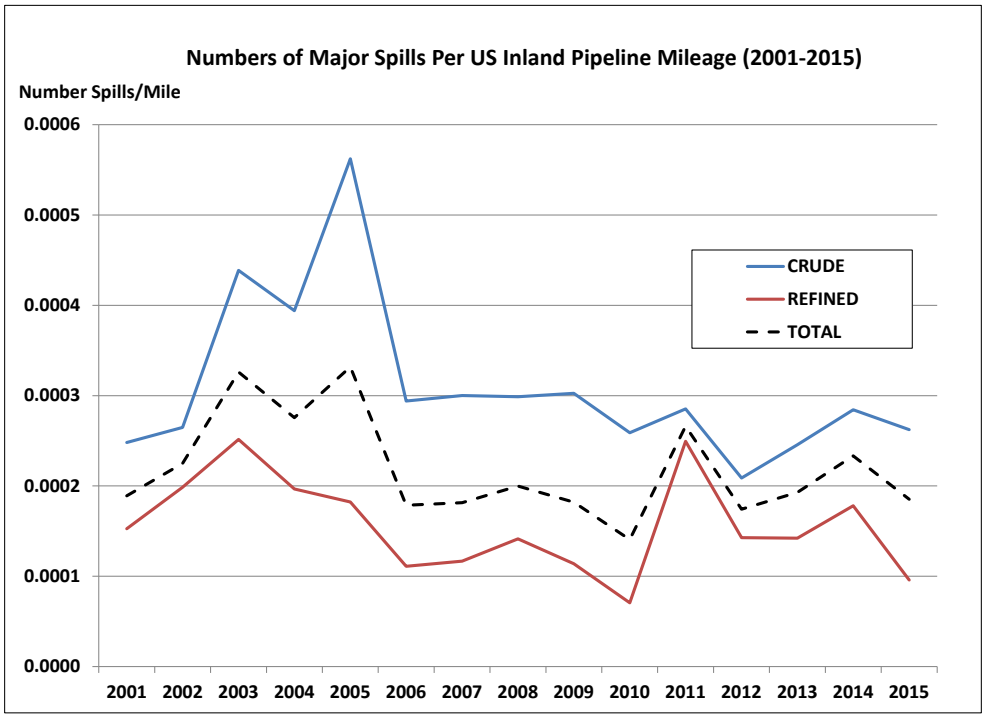

Figure 19: Number of Major Spills per US Inland Pipeline Mile

[18] As described previously, the rates are not additive. For example, the crude spillage rate for the year 2001 is 13 spills per 52,386 pipeline miles (0.00025); the refined spillage rate is 13 spills per 85,214 pipeline miles (0.00015). The total spillage rate is 26 spills for 137,600 miles or 0.00019. (0.00025 + 0.00015 ≠ 0.00019).

Table 14: US Inland Pipeline Spill Number per Pipeline Mile (2001–2015)[19]						
Year	Number of Spills per US Inland Pipeline Mile					
	Crude		Refined		Total	
	All Spills	Major Spills	All Spills	Major Spills	All Spills	Major Spills
2001	0.00094	0.00025	0.00046	0.00015	0.00064	0.00019
2002	0.00354	0.00026	0.00222	0.00020	0.00274	0.00022
2003	0.00361	0.00044	0.00234	0.00025	0.00285	0.00033
2004	0.00290	0.00039	0.00214	0.00020	0.00244	0.00028
2005	0.00363	0.00056	0.00191	0.00018	0.00259	0.00033
2006	0.00332	0.00029	0.00142	0.00011	0.00212	0.00018
2007	0.00336	0.00030	0.00131	0.00012	0.00203	0.00018
2008	0.00307	0.00030	0.00180	0.00014	0.00227	0.00020
2009	0.00309	0.00030	0.00133	0.00011	0.00197	0.00018
2010	0.00301	0.00026	0.00145	0.00007	0.00203	0.00014
2011	0.00257	0.00029	0.00192	0.00025	0.00222	0.00027
2012	0.00322	0.00021	0.00213	0.00014	0.00265	0.00017
2013	0.00337	0.00025	0.00210	0.00014	0.00272	0.00019
2014	0.00340	0.00028	0.00251	0.00018	0.00297	0.00023
2015	0.00323	0.00026	0.00209	0.00010	0.00270	0.00019
All Years	**0.00309**	**0.00030**	**0.00176**	**0.00015**	**0.00232**	**0.00022**

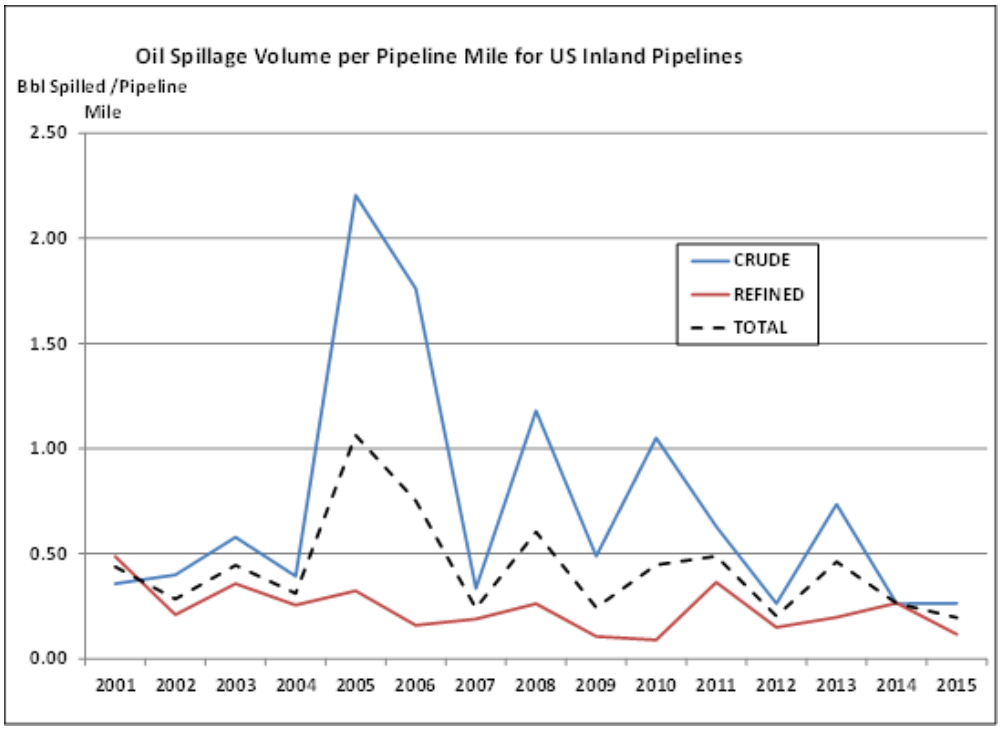

Figure 20: Volume Spilled per Pipeline Mile for US Inland Pipelines

[19] As described previously, the rates are not additive.

Table 15: US Inland Pipeline Volume Spilled per Pipeline Mile (2001–2015)			
Year	**Volume (bbl) Spilled per US Inland Pipeline Mile**		
	Crude	**Refined**	**Total**
2001	0.36	0.49	0.44
2002	0.40	0.21	0.28
2003	0.58	0.36	0.45
2004	0.39	0.26	0.31
2005	2.21	0.32	1.06
2006	1.76	0.16	0.75
2007	0.33	0.19	0.24
2008	1.18	0.26	0.60
2009	0.49	0.11	0.24
2010	1.05	0.09	0.45
2011	0.63	0.36	0.49
2012	0.26	0.15	0.20
2013	0.73	0.20	0.46
2014	0.26	0.27	0.26
2015	0.26	0.12	0.20
All Years	**0.69**	**0.23**	**0.42**

US Inland Pipeline Spillage Summary

Based on the analytical results presented above the following conclusions are reached concerning US inland pipeline spills:[20]

- Each year, it can be expected that about 360 pipeline spills (of any volume) will occur, of which:
  - About 60% (216) would be crude spills;
  - About 25% (90) would be gasoline spills; and
  - About 15% (54) would be light refined product spills.

- Heavy refined product pipeline spills are relatively rare.

- Each year, throughout the US, it can be expected that there will be about 26 major pipeline spills of at least 238 bbl (10,000 gallons), of which:
  - About 70% (18) would be crude spills;
  - About 15% (4) would be gasoline spills; and
  - About 15% (4) would be refined light product spills.

- Overall, half of the pipeline spills that do occur would be expected to involve 1 bbl or less. About 90% would involve 100 bbl or less. Only 5% would be expected to be 400 bbl or more, and only 1% would be expected to be 2,500 bbl or more.

[20] Data from analytical results have been rounded to the nearest two significant digits.

- For future projections, assuming that pipeline operations and conditions are constant, any changes in spillage could be estimated from the number of spills per oil transmission and/or volumes of spillage per oil transmission:

    - Inland crude pipeline spills occur at the rate of about one pipeline spill (of any volume) for every 3.3 million bbl transmitted;
    - A major inland crude pipeline spill of at least 238 bbl (10,000 gallons) might be expected once for every 42 million bbl of crude oil transmitted;
    - Inland refined product pipeline spills occur at the rate of about one spill (of any volume) for every 12.5 million bbl of refined product transmitted;
    - A major inland refined product pipeline spill of at least 238 bbl (10,000 gallons) might be expected once for every 28 million bbl of refined product transmitted; and
    - About half of the major refined product pipeline spills might be expected to be gasoline spills and the other half light refined product spills.

Minnesota Pipeline Spill Analysis

The data presented thus far in this report represent pipeline spills of both crude and refined products throughout the US. The following analyses specifically focus on crude pipelines that transit within and through Minnesota.

Minnesota Crude Pipeline Mileage in Comparison with Other States

According to PHMSA, the state of Minnesota currently has 2,416 miles of crude oil pipelines, making it the state with the seventh greatest crude transmission pipeline mileage (Table 16). Its pipeline mileage is exceeded only by Texas, Oklahoma, California, Wyoming, Louisiana, and Kansas. In terms of "pipeline density," i.e., the mileage of pipelines per square mile, Minnesota ranks eighth, exceeded by Oklahoma, Louisiana, Texas, Illinois, Wyoming, Kansas, and Mississippi. There is one crude pipeline mile for every 35 square miles of land in Minnesota. Oklahoma, Louisiana, and Texas—all oil-producing states—have 2.3, 2.2, and 1.8 times as many pipelines per square mile, respectively, in comparison with Minnesota.

Table 16: Crude Pipeline Spillage by Pipeline Mileage by State (as of 2015)

State	Crude Pipeline Miles[21]	Square Miles	Pipeline Density[22]
Texas	14,108	266,874	0.05286
Oklahoma	4,575	69,903	0.06545
California	3,820	158,648	0.02408
Wyoming	3,572	97,818	0.03652
Louisiana	2,951	47,720	0.06184
Kansas	2,671	82,282	0.03246
Minnesota	2,416	84,397	0.03147
Montana	2,204	147,047	0.01499
Illinois	2,089	56,343	0.03708
North Dakota	1,615	70,704	0.02284
Missouri	1,591	69,709	0.02282
Mississippi	1,416	47,695	0.02969
New Mexico	1,206	121,599	0.00992
Wisconsin	1,206	56,145	0.02148
Michigan	1,179	58,513	0.02015
Alaska	1,028	587,878	0.00175
Nebraska	672	77,359	0.00869
Utah	620	84,905	0.00730
Kentucky	538	40,411	0.01331
Ohio	530	41,328	0.01282
Arkansas	432	53,183	0.00812
Indiana	426	36,185	0.01177
Alabama	370	51,718	0.00715
Colorado	344	104,100	0.00330

[21] Data source: PHMSA. (Transmission lines only.)
[22] Pipeline miles/square mile of area in state.

Table 16: Crude Pipeline Spillage by Pipeline Mileage by State (as of 2015)			
State	**Crude Pipeline Miles[21]**	**Square Miles**	**Pipeline Density[22]**
Iowa	336	56,276	0.00597
Tennessee	275	42,146	0.00652
South Dakota	232	77,122	0.00301
Maine	148	33,128	0.00447
Vermont	117	9,615	0.01217
New York	93	49,112	0.00189
New Hampshire	68	9,283	0.00733
Washington	64	68,126	0.00094
Maryland	52	10,455	0.00497
Florida	45	58,681	0.00077
Pennsylvania	28	45,310	0.00062
West Virginia	4	24,231	0.00017
Hawaii	2	6,459	0.00031
Total	**53,043**	**3,614,743**	**0.01467**

Minnesota Crude Pipeline Spill History

During the years 1968 through 2016, there were a total of 118 crude pipeline spills (of one bbl or more) reported in Minnesota (Table 17, Figure 21, and Figure 22).[23] A total of 184,239 bbl of crude oil spilled in this time period. During this time period, there has been an average of 2.45 spills per year, though the average annual number has increased in the last 10 to 20 years (3.7 spills per year since 1997, and 3.0 spills per year since 2007). This may be an artifact of the data in that the reporting of pipeline spills was less rigorous in the earlier years. Smaller spills (of less than a few bbl) were not reported consistently.

Table 17: Crude Pipeline Spills in Minnesota (1968–2016)		
Year	**Number (1 bbl or more)**	**Bbl Spilled**
1968	1	4,000
1969	2	400
1970	0	0
1971	0	0
1972	5	11,950
1973	4	41,100
1974	3	6,975
1975	1	350
1976	0	0
1977	1	4,398
1978	1	60
1979	1	10,500
1980	2	14,247

[23] There were two spills of less than one bbl (0.21 bbl and 0.15 bbl) in 2016 and one spill of 0.76 bbl thus far in 2017 that are not included in this analysis.

Table 17: Crude Pipeline Spills in Minnesota (1968–2016)		
Year	**Number (1 bbl or more)**	**Bbl Spilled**
1981	0	0
1982	2	9,350
1983	0	0
1984	1	2,196
1985	2	6,010
1986	3	568
1987	3	626
1988	1	3
1989	3	415
1990	0	0
1991	1	40,500
1992	1	150
1993	1	2
1994	5	297
1995	1	50
1996	3	5,065
1997	1	475
1998	2	5,900
1999	2	401
2000	4	110
2001	4	57
2002	7	6,286
2003	11	286
2004	3	1,014
2005	0	0
2006	6	3,240
2007	6	340
2008	4	1,616
2009	6	5,014
2010	5	176
2011	1	10
2012	1	1
2013	2	36
2014	3	28
2015	2	30
2016	0	0
Total	**118**	**184,232**

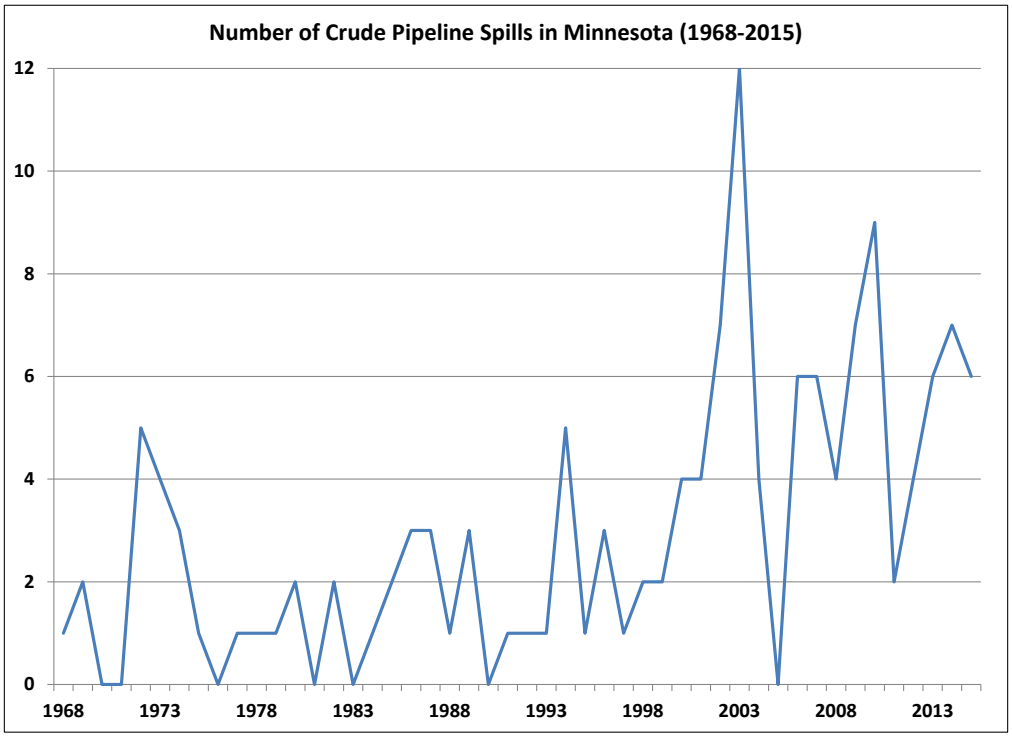

Figure 21: Annual Number of Crude Pipeline Spills in Minnesota (1968–2015)

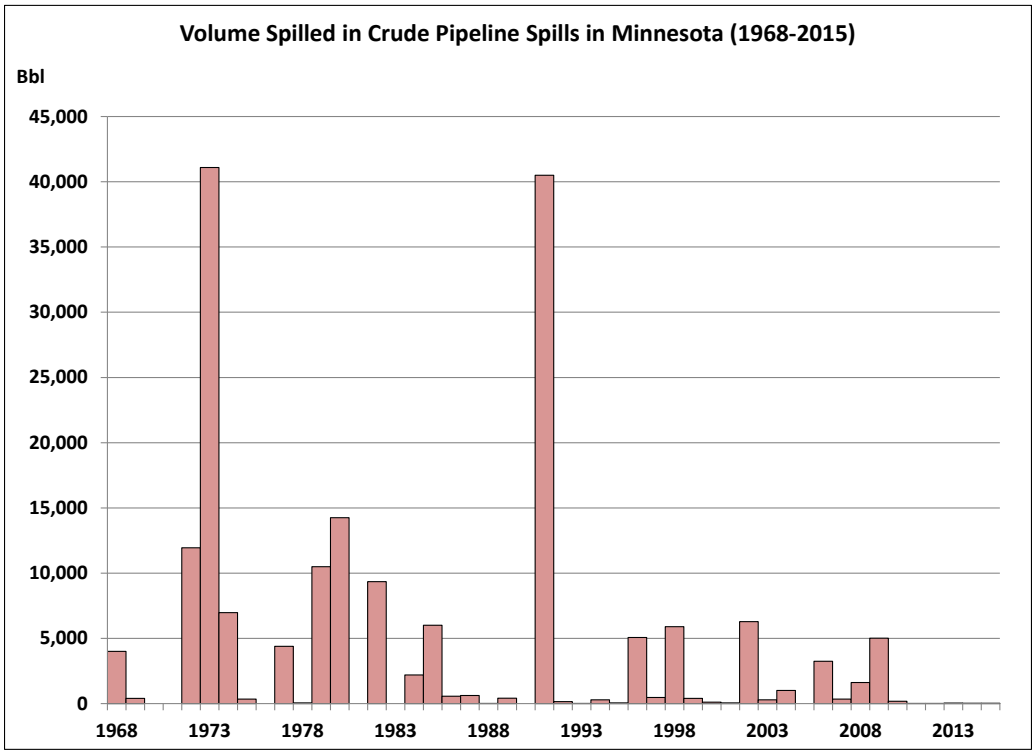

Figure 22: Volume Spilled in Crude Pipeline Spills in Minnesota (1968–2015)

The five-year average data are shown in Table 18. The average annual number of spills has increased; however, the average annual volume and the average volume per spill have both decreased.

Table 18: Five-Year Average Crude Pipeline Spill Data for Minnesota

Years[24]	Annual Number Spills (1 bbl or more)	Annual Volume Spilled	Average Volume/Spill (1 bbl or more)
1968–1972	2	3,270	1,318
1973–1977	2	10,565	3,470
1978–1982	1	6,831	4,472
1983–1987	2	1,880	1,120
1988–1992	1	8,214	8,158
1993–1997	2	1,178	455
1998–2002	4	2,551	818
2003–2007	5	976	192
2008–2012	3	1,363	257
2013–2016	2	31	14
Overall Average	**2.4**	**3,760**	**2,068**

The frequency distribution of spill volumes (volume for each individual incident) varies from 0.01 bbl (0.42 gallons, or less than two quarts) to 40,500 bbl (Table 19). Just over 69% of spill incidents involved less than 100 bbl, about 85% less than 1,000 bbl, and nearly 97% less than 10,000 bbl.

Table 19: Frequency Distribution of Spill Volumes for Minnesota Crude Pipelines (1968–2016)

Spill Volume	% Spill Incidents	Number of Incidents
<1 bbl	18.2%	26
1–9 bbl	30.1%	43
10–99 bbl	21.0%	30
100–999 bbl	15.4%	22
1,000–9,999 bbl	11.9%	17
10,000–90,000 bbl	3.5%	5
100,000+ bbl	0.0%	0

During the 49-year time frame, there were 32 major crude pipeline spills (>238 bbl), of which three occurred in the last decade and eight in the last 20 years (Table 20). These major spills account for over 98% of the total volume of spillage. There have been no major (>238 bbl) pipeline spills in Minnesota in the last six years. There have been no spills of over 10,000 bbl since 1991.

Table 20: Major Crude Pipeline Spills (>238 bbl) in Minnesota (1968–2016)

Year	Number (238 bbl or more)
1968	1
1969	0
1970	0

[24] The period 2013–2015 is a four-year average.

Table 20: Major Crude Pipeline Spills (>238 bbl) in Minnesota (1968–2016)	
Year	**Number (238 bbl or more)**
1971	0
1972	3
1973	4
1974	1
1975	1
1976	0
1977	1
1978	0
1979	1
1980	2
1981	0
1982	1
1983	0
1984	1
1985	1
1986	2
1987	1
1988	0
1989	1
1990	0
1991	1
1992	0
1993	0
1994	0
1995	0
1996	1
1997	1
1998	1
1999	1
2000	0
2001	0
2002	1
2003	0
2004	1
2005	0
2006	1
2007	1
2008	1
2009	1
2010	0

Table 20: Major Crude Pipeline Spills (>238 bbl) in Minnesota (1968–2016)	
Year	**Number (238 bbl or more)**
2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
Total	**32**

Minnesota Major Crude Pipeline Spills

Data on the 32 major crude pipeline spills (>238 bbl) in Minnesota are shown in Table 21 in chronological order. A summary of the major spills by county is shown in Table 22.

Table 21: Major Crude Pipeline Spills in Minnesota (1968–2016)				
Date	**Operator[25]**	**County (City)**	**Bbl Spilled**	**Cause**
12/8/1968	Enbridge	Red Lake	4,000	Defective weld
7/14/1972	Enbridge	Marshall	8,000	Equipment rupturing line
8/23/1972	Enbridge	Clearwater	3,000	Incorrect operation by carrier
9/9/1972	Enbridge	Carlton	700	Equipment rupturing line
8/13/1973	Enbridge	Marshall	17,000	Incorrect operation by carrier
9/5/1973	Enbridge	Kittson	400	Equipment rupturing line
9/11/1973	Enbridge	Polk	5,000	Incorrect operation by carrier
12/4/1973	Enbridge	Marshall	18,700	Other (No further information available)
7/12/1974	Enbridge	Clearwater	6,900	Defective pipe
4/3/1975	Enbridge	Clearwater	350	Other (No further information available)
11/4/1977	Koch	Todd (Staples)	4,398	Defective pipe
8/20/1979	Enbridge	Beltrami	10,500	Defective pipe
1/11/1980	Koch	Benton	11,847	Defective weld
6/26/1980	Enbridge	Kittson	2,400	Defective pipe
7/21/1982	Enbridge	Clearwater (Clearbrook)	9,200	Other (No further information available)
2/11/1984	Koch	Benton (Foley)	2,196	Defective pipe
11/7/1985	Koch	Anoka (Burns)	5,980	Other (No further information available)
2/10/1986	Koch	Dakota (Inner Grove Hts)	300	Failed weld
9/6/1986	Enbridge	Polk	265	Other (Contractor failed to tighten)
3/6/1987	Enbridge	Clearwater	500	Failed weld
3/26/1989	Enbridge	Pennington (Sanders Twp)	300	Failed weld
3/3/1991	Enbridge	Itasca	40,500	Other (Split in heat affect zone)
8/24/1996	Enbridge	Kittson (Donaldson Station)	5,000	Corrosion
1/3/1997	Marathon	Washington (Cottage Grove)	475	Other (Tank farm pipeline)

[25] Minnesota Pipeline and Wood River Pipeline are grouped under Koch; Lakehead is grouped under Enbridge.

Table 21: Major Crude Pipeline Spills in Minnesota (1968–2016)				
Date	**Operator[25]**	**County (City)**	**Bbl Spilled**	**Cause**
9/16/1998	Enbridge	Red Lake (Plummer)	5,700	Excavation damage
2/22/1999	Enbridge	Marshall (Radium)	400	Other (Loose bolts on flange)
7/4/2002	Enbridge	Itasca (Cohasset)	6,000	Material and/or weld failures
2/19/2004	Enbridge	Itasca (Grand Rapids)	1,003	Natural forces (earth movement)
6/27/2006	Koch	Morrison (Little Falls)	3,200	Other outside force damage
11/28/2007	Enbridge	Clearwater (Clearbrook)	325	Incorrect operation by carrier
3/23/2008	Koch	Clearwater (Clearbrook)	1,600	Natural forces (earth movement)
12/4/2009	Koch	Todd (Staples)	5,000	Incorrect operation by carrier

Table 22: Major Pipeline Spills by Minnesota County (1968–2016)							
County	**Square Mileage**	**Major Spill Number**			**Total Spill Volume[26]**		
		Number	**% Total Major**	**Number per Square Mile**	**Volume (bbl)**	**% Total Volume**	**Volume per Square Mile**
Anoka	432.61	1	3.1%	0.00231	5,980	3.3%	13.82
Beltrami	2,505.27	1	3.1%	0.00040	10,500	5.8%	4.19
Benton	408.28	2	6.3%	0.00490	14,043	7.8%	**34.40**
Carlton	860.33	1	3.1%	0.00116	700	0.4%	0.81
Clearwater	994.71	7	**21.9%**	**0.00704**	21,875	12.1%	21.99
Dakota	569.58	1	3.1%	0.00176	300	0.2%	0.53
Itasca	2,665.06	3	9.4%	0.00113	47,503	**26.2%**	17.82
Kittson	1,097.08	3	9.4%	0.00273	7,800	4.3%	7.11
Marshall	1,772.24	4	12.5%	0.00226	44,100	24.3%	24.88
Morrison	1,124.50	1	3.1%	0.00089	3,200	1.8%	2.85
Pennington	616.54	1	3.1%	0.00162	300	0.2%	0.49
Polk	1,970.37	2	6.3%	0.00102	5,265	2.9%	2.67
Red Lake	432.43	2	6.3%	0.00463	9,700	5.4%	22.43
Todd	942.02	2	6.3%	0.00212	9,398	5.2%	9.98
Washington	391.70	1	3.1%	0.00255	475	0.3%	1.21
Total	**16,782.72**	**32**	**100.0%**	**0.00191**	**181,139**	**100.0%**	**10.79**

Comparison of Minnesota and US for Major Crude Pipeline Spills

The rate of major crude pipeline spills (>238 bbl) in Minnesota was compared with the crude pipeline spillage in the US as a whole for the last 16 years (2001 through 2016), and for the last seven years (2010 through 2016). The latter time period was selected because this was the only time frame for which state-specific pipeline transmission rates were available from PHMSA. Overall, the Minnesota crude pipeline rate was considerably less than that of the nation as a whole, with respect to spillage per pipeline miles and barrels transmitted (Table 23).

[26] Includes only spillage from major spills, which encompasses 98% of the total spillage.

Table 23: Crude Pipeline Spillage: Minnesota vs. US Nationwide[27]						
Spill Rate[28]	Average 2001–2016			Average 2010–2016		
	MN	US	MN/US Ratio	MN	US	MN/US Ratio
Major Spills/Pipeline Mile-Year	0.00023	0.0003	0.767	0	0.00026	0.000
Bbl Spilled/Pipeline Mile-Year	0.43	0.69	0.623	0.015	0.53	0.028
Major Spills/Million Bbl Transmitted	0.0014	0.025	0.056	0	0.024	0.000
Bbl Spilled/Million Bbl Transmitted	4.3	56	0.077	0.16	51	0.003

All Crude Pipeline Spills (2000–2016)

Data for crude pipeline spills of *all sizes* that occurred since 2000 were analyzed. There were 91 spill incidents, one of which occurred in 2017.[29] A summary of these data is shown in Table 24.

Table 24: Minnesota Crude Pipeline Spills of All Sizes (2000–Present)				
Year	Number of Spills		Total Volume (bbl)	Average Volume (bbl)
	All Volumes	Major Spills (>238 bbl)		
2000	4	0	110.00	27.50
2001	4	0	57.00	14.25
2002	7	1	6,286.00	898.00
2003	12	0	286.24	23.85
2004	4	1	1,014.50	253.63
2005	0	0	0.00	0.00
2006	6	1	3,240.00	540.00
2007	6	1	340.02	56.67
2008	4	1	1,616.00	404.00
2009	7	1	5,015.31	716.47
2010	9	0	176.21	19.58
2011	2	0	10.48	5.24
2012	4	0	1.86	0.47
2013	6	0	38.69	6.45
2014	7	0	28.39	4.06
2015	6	0	30.27	5.05
2016	2	0	0.36	0.18
2017[30]	1	0	0.76	0.76
Total	**91**	**6**	**18,252.09**	**-**
Average All Years	**5.2**	**0.3**	**1,042.98**	**200.57**
Average 2010–2017	**4.9**	**0**	**38.27**	**5.57**

[27] US data is for all states inclusive of Minnesota.
[28] Pipeline mile-year is a mile of pipeline in operation for one year. Crude transmission bbl-miles for Koch and Enbridge based on PHMSA data for 2015 and mileage data.
[29] There was one crude pipeline spill incident of 0.76 bbl reported for 2017–on 5 June 2017 in Clearwater.
[30] Half year (through June 2017).

The frequency distribution of spill volumes is shown in Table 25 and Figure 23. For the years 2000 through the present (end of June 2017), there were 91 incidents, of which nearly 30% involved less than one bbl. The average spill volume was 201 bbl. The median (i.e., 50th percentile) was 2.0 bbl. For the years 2010 through the present, there were 37 incidents, of which over 81% involved less than one bbl. The average spill volume was 7.8 bbl. The median was 0.54 bbl. The spill volumes have been significantly smaller since 2010.

Table 25: Frequency Distribution of Spill Volumes for Minnesota Crude Pipelines (2000–2017)

Spill Volume Category	2000–2017		2010–2017	
	Number of Incidents	% Spill Incidents	Number of Incidents	% Spill Incidents
0.01–0.09 bbl	5	5.5%	23	62.2%
0.1–0.9 bbl	22	24.2%	7	18.9%
1–9 bbl	37	40.7%	6	16.2%
10–99 bbl	17	18.7%	1	2.7%
100–999 bbl	5	5.5%	0	0.0%
1,000–9,999 bbl	5	5.5%	0	0.0%
10,000–90,000 bbl	0	0.0%	0	0.0%
100,000+ bbl	0	0.0%	0	0.0%
Total	**91**	**100%**	**37**	**100%**
Median		**2.0 bbl**		**0.54 bbl**
Mean (Average)		**200.57 bbl**		**7.76 bbl**

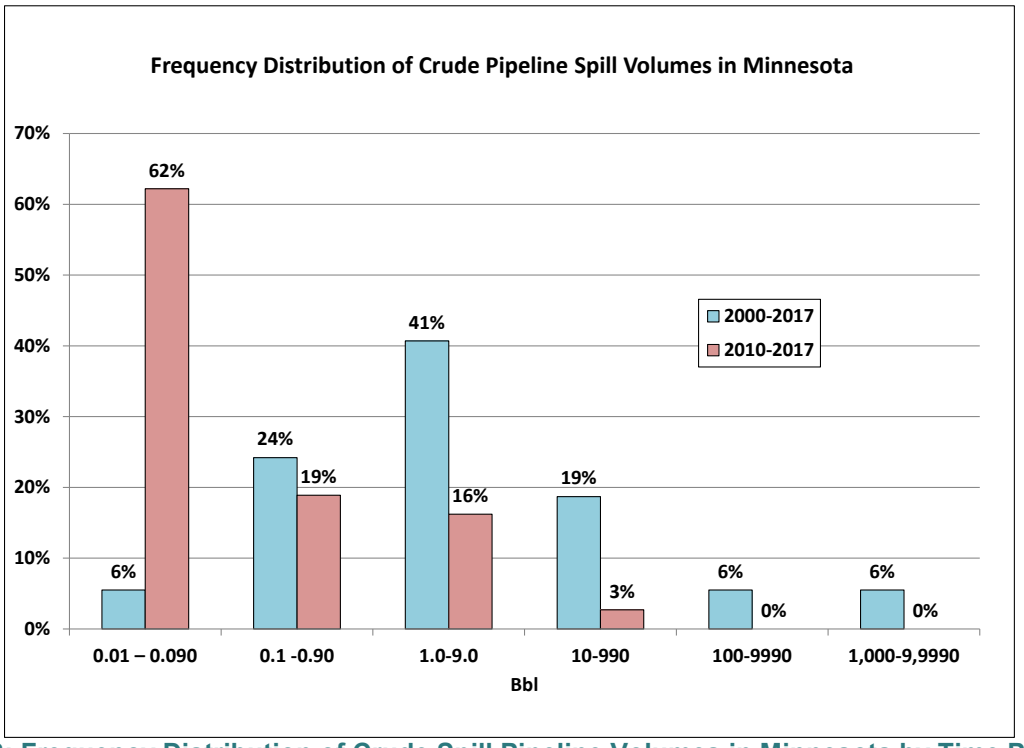

Figure 23: Frequency Distribution of Crude Spill Pipeline Volumes in Minnesota by Time Period

Benchmarking of Enbridge Line 3 Hypothetical Spill Scenarios

Hypothetical spill scenarios were modeled in the Stantec Report (Stantec et al. 2017) at seven selected sites with the spill volumes in Table 26. The volumes were benchmarked against spill volumes from past spills throughout the US and in Minnesota for different time periods. [Note that throughout this section, the hypothetical spills are referred to by their site numbers for convenience. The site itself not pertinent to the benchmarking analysis as the scenario volumes are compared to historical spills throughout the US and throughout the state of Minnesota. The sites themselves are not benchmarked in this analysis in any manner.]

Table 26: Hypothetical Pipeline Spill Scenarios Modeled in Draft Environmental Impact Statement

Site Number	Study Site	Volume (bbl)[1]
Site 1	Mosquito Creek to Lower Rice Lake	8,265
Site 2	Mississippi River at Ball Club	10,660
Site 3	Sandy River	15,374
Site 4	Shell River to Twin Lakes	13,648
Site 5	Red River	13,856
Site 6	Mississippi River at Palisades	11,840
Site 7	Mississippi River at Little Falls	15,894

Benchmarking Against US National Spills

The hypothetical spills in Table 26 were benchmarked against US pipeline spills (crude and refined) based on data from 1968 through 2015 (Table 7, Table 8, and Figure 12) and on data from 2006 through 2015 (Table 9, Table 10, and Figure 13). All of the scenarios exceeded the 99th percentile of pipeline spills regardless of spilled product. In other words, less than 1% of historical pipeline spills throughout the US over 48 years were that size or larger.

Table 27 shows the percentile value for the hypothetical spill scenarios relative only to crude pipeline spills throughout the US for different time periods.

Table 27: Hypothetical Line 3 Spills Relative to US National Crude Pipeline Incidents						
Hypothetical Spill[31]	US 1968–2015		US 2000–2015		US 2006–2015	
	Percentile[32]	% Spills Larger[33]	Percentile	% Spills Larger	Percentile	% Spills Larger
Site 1	98.82	1.18%	99.53	0.47%	99.66	0.34%
Site 2	99.19	0.81%	99.69	0.31%	99.72	0.28%
Site 3	99.52	0.48%	99.80	0.20%	99.83	0.17%
Site 4	99.44	0.56%	99.77	0.23%	99.77	0.23%
Site 5	99.52	0.48%	99.84	0.16%	99.85	0.15%
Site 6	99.27	0.73%	99.73	0.27%	99.72	0.28%
Site 7	99.52	0.48%	99.80	0.20%	99.84	0.16%

Benchmarking Against Historical Minnesota Spills

The same analyses were conducted comparing the hypothetical spill scenario volumes to historical crude pipeline spills in Minnesota, as summarized in Table 28. The data involved spills that occurred from 1968 through the present (end of June 2017). There have been no spills over 6,000 bbl since 2000. For this reason, all of the hypothetical Line 3 spill scenarios would represent the largest spills in this time period.

There have been larger spills prior to 2000. The hypothetical Line 3 scenarios represent the 96th to 99th percentiles. That means that 1% to 3.5% of crude pipeline spills during 1968 through 2015 were larger. In other words, if these hypothetical incidents had occurred, they would have fallen into the designated percentiles and only the percentage shown would have been larger. If these hypothetical Line 3 spills had occurred in 2000 or later, they would have been the largest crude pipeline spills in that time period.

Table 28: Hypothetical Line 3 Spills Relative to Minnesota Crude Pipeline Incidents						
Hypothetical Spill	Minnesota 1968–2017		Minnesota 2000–2017		Minnesota 2006–2017	
	Percentile	% Spills Larger	Percentile	% Spills Larger	Percentile	% Spills Larger
Site 1	96.45	3.55%	100.00	0.00%	100.00	0.00%
Site 2	97.87	2.13%	100.00	0.00%	100.00	0.00%
Site 3	99.01	0.99%	100.00	0.00%	100.00	0.00%
Site 4	98.87	1.13%	100.00	0.00%	100.00	0.00%
Site 5	99.15	0.85%	100.00	0.00%	100.00	0.00%
Site 6	97.87	2.13%	100.00	0.00%	100.00	0.00%
Site 7	99.08	0.92%	100.00	0.00%	100.00	0.00%

Return Period Calculation for Hypothetical Line 3 Scenario Volumes

The return periods for the volumes of the hypothetical Line 3 spills *in the entire US* were calculated based on the national data for the three time periods, with the results shown in Table 29. In other words, spills of this volume would be expected *somewhere in the US* every two to four years based on the data from the

[31] The hypothetical spills are referred to by their "site numbers" for convenience. The sites themselves are not benchmarked in this analysis in any manner.

[32] A percentile spill volume is the percentage of spills that are that volume or less. e.g., a 99th percentile spill of 1,100 bbl means that 99% of spills are 1,100 bbl or less. Only 1% of spills are larger.

[33] The percent of historical crude pipeline spills that were larger than the volume of the hypothetical scenario.

last decade. *This does not indicate that these spills would occur in Minnesota on Line 3 (or any other pipeline in Minnesota).*

Table 29: Estimated Return Periods for Hypothetical Crude Pipeline Spill Volumes in the US						
Hypothetical Spill Volume	**US 1968–2015**		**US 2000–2015**		**US 2006–2015**	
	Frequency per Year	**Return Period (Years)**	**Frequency per Year**	**Return Period (Years)**	**Frequency per Year**	**Return Period (Years)**
Site 1	1.58	0.6	0.75	1.3	0.60	1.7
Site 2	1.09	0.9	0.50	2.0	0.50	2.0
Site 3	0.64	1.6	0.32	3.1	0.30	3.3
Site 4	0.75	1.3	0.37	2.7	0.41	2.5
Site 5	0.64	1.6	0.26	3.9	0.27	3.8
Site 6	0.98	1.0	0.43	2.3	0.50	2.0
Site 7	0.64	1.6	0.32	3.1	0.28	3.5

Based on analyses of historical data for Minnesota, the frequency of a spill of large volume in the state is much lower (see Table 23). As shown in Table 28, there have been no spills of the magnitude of the volumes for the hypothetical Line 3 scenarios since prior to 2000. The last spill of this volume or greater in Minnesota was in March 1991 (see Table 21).

The return period calculation based solely on Minnesota data for the years 1968 through June 2017 is shown in Table 30. Note that for the 2000–2017 time period, the calculation returns a value of zero for the frequency as there are no historical incidents in this time period. This may be attributed to a very low likelihood or probability of a large spill incident and a short time frame.[34]

The estimated return periods based on the 1968–2017 data are over-estimates with regard to frequency, and, correspondingly, under-estimates for return periods. In other words, the frequencies would be expected to be lower and the return periods would be expected to be longer.

Table 30: Estimated Return Periods for Hypothetical Crude Pipeline Spill Volumes in Minnesota		
Hypothetical Spill Volume	**Minnesota 1968–2017**	
	Frequency per Year	**Return Period (Years)**
Site 1	0.101	9.9
Site 2	0.061	16.5
Site 3	0.028	35.5
Site 4	0.032	31.1
Site 5	0.024	41.3
Site 6	0.061	16.5
Site 7	0.026	38.2

[34] This would be analogous to rolling dice a limited number of times and never getting a particular result. With more rolls (more time), eventually the number may come up.

An alternative approach to calculating the return period for the Minnesota spills was also taken. The return periods estimated for the US as a whole (in Table 29) were used to calculate the relative reduction in frequencies for the time periods (1968–2015, to 2000–2015, to 2006–2015), as shown in Table 31.

Table 31: Reduction in Frequencies for Hypothetical Crude Pipeline Spill Volumes in the US

Hypothetical Spill Volume	US 1968–2015 Frequency per Year	US 2000–2015		US 2006–2015	
		Frequency per Year	Reduction from 1968–2015	Frequency per Year	Reduction from 1968–2015
Site 1	1.58	0.75	52.5%	0.6	62.0%
Site 2	1.09	0.5	54.1%	0.5	54.1%
Site 3	0.64	0.32	50.0%	0.3	53.1%
Site 4	0.75	0.37	50.7%	0.41	45.3%
Site 5	0.64	0.26	59.4%	0.27	57.8%
Site 6	0.98	0.43	56.1%	0.5	49.0%
Site 7	0.64	0.32	50.0%	0.28	56.3%

The reduction factors in Table 31 were applied to the frequencies in Table 30 to derive the extrapolated frequencies and return periods in Table 32. These results indicate that the expected return period of the hypothetical spills ranges from about once every 21 to 26 years for the lowest volume (Site 1) to once every 99 to 103 years for the highest volume (Site 5). Note that these return periods do not necessarily correspond to the specific sites (Table 26) for which these volumes were calculated—only these spill volumes within the state.

It is important to bear in mind that this estimation approach is conservative. That is, it is cautionary by over-estimating the probability of these incidents.

Table 32: Extrapolated Frequencies/Return Periods for Hypothetical Large Spills in Minnesota

Hypothetical Spill Volume	Minnesota 1968–2017		Minnesota 2000–2017 Extrapolated from US 2000–2015 Reduction		Minnesota 2006–2017 Extrapolated from US 20062015 Reduction	
	Frequency per Year	Return Period (Years)	Frequency per Year	Return Period (Years)	Frequency per Year	Return Period (Years)
Site 1	0.101	9.9	0.0479	20.9	0.0384	26.1
Site 2	0.061	16.5	0.0280	35.7	0.0280	35.7
Site 3	0.028	35.5	0.0140	71.4	0.0131	76.2
Site 4	0.032	31.1	0.0158	63.3	0.0175	57.2
Site 5	0.024	41.3	0.0098	102.6	0.0101	98.8
Site 6	0.061	16.5	0.0268	37.4	0.0311	32.1
Site 7	0.026	38.2	0.0130	76.9	0.0114	87.9

Return Period Calculation for Smaller Spills

Based on the data in Table 25, the return periods for smaller spills were calculated, as shown in Table 33. Since there were no spills in the larger spill categories, the frequencies were zero. However, this is merely

indicative of a lower probability and a return period that exceeds the time period for the data—17.5 years for the 2000–2017 data set, and 7.5 years for the 2010–2017 set.

Table 33: Frequencies and Return Period by Spill Volumes for Minnesota Crude Pipelines

Spill Volume Category	Based on Minnesota 2000–2017 Data		Based on Minnesota 2010–2017 Data	
	Frequency per Year	Return Period (Years)	Frequency per Year	Return Period (Years)
0.01–0.09 bbl	0.29	3.5	3.07	0.3
0.1–0.9 bbl	1.26	0.8	0.93	1.1
1–9 bbl	2.11	0.5	0.80	1.3
10–99 bbl	0.97	1.0	0.13	7.5
100–999 bbl	0.29	3.5	0.00	0.0
1,000–9,999 bbl	0.29	3.5	0.00	0.0
10,000–90,000 bbl	0.00	0.0	0.00	0.0
Total	**5.20**	**0.2**	**4.93**	**0.2**

Summary of Findings for Minnesota Crude Pipeline Spills

In order to quantify the incremental risk for the Line 3 Project, the potential spills that might occur need to be compared with the baseline of spills occurring from existing pipelines in the area. The analyses of historical data conducted in this report provide an overview of pipeline spill rates and trends in the inland US as a whole for existing crude oil pipelines in Minnesota.

US Crude Pipeline Spills

For crude oil pipeline spillage in the US as a whole, the following conclusions were reached:

- There are about 53,045 miles of crude oil pipeline throughout the US.
- The frequency of crude pipeline spills in the US has decreased significantly over the last 48 years.
- Crude pipeline spills have become increasingly lower in volume.
- Projecting into the future, half of the pipeline spills that do occur would be expected to involve 1 bbl or less, and about 90% would involve 100 bbl or less. Only 5% would be expected to be 400 bbl or more, and only 1% would be expected to be 2,500 bbl or more.
- Inland crude pipeline spills occur at the rate of about one pipeline spill (of any volume) for every 3.3 million bbl transmitted.
- A major inland crude pipeline spill of at least 238 bbl (10,000 gallons) might be expected once for every 42 million bbl of crude oil transmitted.

Minnesota Crude Pipeline Spills

For crude oil pipeline spillage in Minnesota, the following conclusions were reached:

- Minnesota currently has about 2,416 miles of crude oil pipelines.
- Since 1968, there were a total of 118 crude oil pipeline spills of one bbl or more, with a total of 184,332 bbl spilled.

- The annual number of reported pipelines has increased; however, this can be attributed to the increase in reporting of smaller spills that previously had not been reported.
- During 1968 through 2016, there were 32 major pipeline spills (>238 bbl or 10,000 gallons).
- There have been no major crude pipeline spills in Minnesota in the last six years, and no spills over 10,000 bbl since 1991.
- The rate of spillage in Minnesota has been lower than that in the US as a whole, accounting for pipeline mileage and amount transmitted.
- The rate of major spills per pipeline mile-year in Minnesota was 77% that of the US as a whole during 2001 through 2016. There were no major spills in 2010 through the present.
- The volume spilled per pipeline mile-year in Minnesota as 62% that of the US as a whole during 2001 through 2016, and 3% that of the US during 2010 through 2016.
- The number of major spills per volume transmitted in Minnesota was 6% that of the US as a whole during 2001 through 2016. There were no major pipeline spills in Minnesota since 2010.
- The volume of spillage per amount transmitted in Minnesota was 8% that of the US as a whole in 2001 through 2016, and 0.3% that of the US as a whole since 2010.
- Since 2010, 62% of crude pipeline spills have involved less than 0.1 bbl (4.2 gallons); 81% have involved less than 1 bbl.
- A spill of less than 0.1 bbl might be expected once every four months; a spill of less than 10 bbl, once every 16 months; and a spill of less than 100 bbl, once every 7.5 years.

Using a conservative (cautionary over-estimating) approach, it was estimated that the volumes of spillage in the seven hypothetical Line 3 spill scenarios might be expected once in 26 to 99 years somewhere in the state of Minnesota. *This does not indicate that the incidents would occur at the specific sites selected for modeling.*

References

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