Technical Review of the Spill Risk Analyses in the Sea Port Oil Terminal Deepwater Port Project Draft Environmental Impact Statement (SPOT DEIS)

Executive Summary

1. The SPOT Draft Environmental Impact Statement ("DEIS") does not show spill risk in a way that is meaningful for estimating environmental impact.

2. The SPOT DEIS relies on two different oil spill size, frequency, and fate models. The results from and inputs into the two models do not match one another and are both used in different contexts in the DEIS with no explanation for the disparate treatment.

   a. The Environmental Resources Modeling ("ERM") (2020) and Risknology (2019) analyses had different assumptions, data sources, and results.
   b. The ERM (2020) and Risknology (2019) analyses were cited in different sections of the SPOT DEIS.
   c. The ERM (2020) report has technical flaws.
   d. The Risknology (2020) report has technical flaws.

3. The SPOT DEIS contains fate modeling exercises, but the Maritime Administration ("MARAD") and the U.S. Coast Guard ("USCG") do not clearly explain for what analysis they used the exercises. The exercises use an offshore spill volume based on a Bureau of Ocean Energy Management ("BOEM") (2012) estimate of 2,200 bbl as a median large offshore spill volume. This value is unjustified because it only used data from 1996-2010, which is both too short a time frame for characterizing the size and frequency of large spills and does not use current spill data. This report section shows the consequences of using longer data sets, aggregating volumes from spills attributed to hurricanes, and adding the most recent data available. When data from 1972-2017 are used and volumes from spills caused by the same hurricane are aggregated, the median spill size (n = 31 spills >1,000 bbl) is 3,489 bbl.

4. Current data from the Pipeline Hazardous Materials and Safety Administration ("PHMSA") show that offshore and onshore pipeline spills of many sizes and substances are common but discrepancies between federal agency records are common.

5. Comparing risk estimates across settings and agencies is difficult because BOEM, the Bureau of Land Management ("BLM"), and the USCG all use different spill size class definitions. The USCG has different size classes for inshore and coastal spills.

6. Based on the amount of oil that SPOT expects to handle at its DWP per year, recent estimates of spill risk rates (ABS 2016), and the most recent spill data summary (BOEM 2018), the number of offshore pipeline spills in several different spill size categories can be calculated for different percent capacities and years of operation. Given the number of spills that may be expected and noting that the calculated offshore pipeline spills only account for one potential spill source, the potential environmental impacts need to be re-evaluated.

7. Although the expected number of spills in different size classes were not included in the DEIS, some worst credible scenario calculations and general impact analyses were included. I checked the calculations of worst credible discharges for subsea and onshore pipelines and found that the onshore pipeline volume did not account for flow rates when drag reducing agents are present.

1. The SPOT DEIS does not show spill risk in a way that is meaningful for estimating environmental impact.

In the DEIS, MARAD and the USCG cite to and rely on two different oil spill risk analyses in different parts of the DEIS: an analysis that the applicant, SPOT Terminal Services, LLC, completed and submitted with its application (Risknology) (2019) and an analysis that an independent consultant, Environmental Resources Management ("ERM"), completed for the agencies (ERM (2020)). The Risknology (2019) and ERM (2020) reports answered questions which are only part of the relevant information that would be needed in this DEIS. The two reports tried to answer the question: "What are the biggest spills we need to have engineering, response, safety, and protocols for?" They defined those by making the spill exceedance curves to find the estimates of 100-year and 500-year spill volumes and then the lower flammability limits and 12.5 kW/m^2 thresholds. ERM (2020) and Risknology (2019) also calculated worst credible discharges and modeled where those oil spills would go.

Spill frequency per isolatable section and the magnitudes of the 100- and 500-yr spills may have purpose as engineering tools for determining safety protocols, but they do not answer the fundamental question: "How many spills are expected?"

The DEIS should not include just the 100-year spill or the 500-year spill sizes, but also the spill frequencies of spills in different size classes and the numbers of spills in each size class that would occur over the life of the project. The DEIS does not include this vital information. In Section 6, I used data from the DEIS along with information available from relevant agencies to calculate the expected number of spills in various sizes over the life of the SPOT Project.

The objectives from ERM (2020) included "calculat[ing] oil spill risks for SPOT DWP onshore sections" and "calculat[ing] oil spill risks for SPOT DWP offshore sections" (DEIS, Appendix H, p. 2). Similarly, Risknology (2019) "assembled a data dossier containing oil spill probability failure rate data and estimates to be used as basic event data for qualifying oil spill release probabilities" (DEIS, Appendix H, p. 2) for isolatable onshore and offshore sections of the SPOT DWP. Both ERM (2020) and Risknology (2019) presented calculated spill frequencies and volumes for isolatable sections of the project, but neither attempted to characterize the overall probability of a spill. This is not a useful way to present the probability of an oil spill, as a failure by *any* section of the entire oil export system of the SPOT Project will result in a spill. Therefore, a more appropriate model would address the overall spill probability, not just the individual spill probabilities from each isolatable section.

As an example, consider a simplified system that has 3 components that might fail. Let

p_1 = probability that component 1 fails,

p_2 = probability that component 2 fails, and

p_3 = probability that component 3 fails.

Similarly,

$1 - p_1$ = probability that component 1 doesn't fail,

$1 - p_2$ = probability that component 2 doesn't fail, and

$1 - p_3$ = probability that component 3 doesn't fail.

We are interested in P, which is the probability that at least one component in the system fails. There are lots of ways P occurs and at least one component in the system fails:

Component 1 fails alone;
Component 2 fails alone;
Component 3 fails alone;
Components 1 and 2 fail;
Components 1 and 3 fail;
Components 2 and 3 fail; and
Components 1, 2 and 3 all fail.

If the failure probabilities (p_i's for each event) are independent, we can calculate this in two ways, which yield the same result.

Method 1: Adding up all the ways that there can be at least one failure:

Probability(Scenario) =	Mathematical expression
P(Component 1 fails alone) =	$p_1(1 - p_2)(1 - p_3)$
P(Component 2 fails alone) =	$p_2(1 - p_1)(1 - p_3)$
P(Component 3 fails alone) =	$p_3(1 - p_1)(1 - p_2)$
P(Components 1 and 2 fail) =	$p_1p_2(1 - p_3)$
P(Components 1 and 3 fail) =	$p_1p_3(1 - p_2)$
P(Components 2 and 3 fail) =	$p_2p_3(1 - p_1)$
P(Components 1, 2, and 3 all fail) =	$p_1p_2p_3$
P(At least one component fails) =	$p_1(1 - p_2)(1 - p_3) + p_2(1 - p_1)(1 - p_3) + p_3(1 - p_1)(1 - p_2)$ $+ p_1p_2(1 - p_3) + p_1p_3(1 - p_2) + p_2p_3(1 - p_1) + p_1p_2p_3$
P =	$p_1 + p_2 + p_3 - p_1p_2 - p_1p_3 - p_2p_3 + p_1p_2p_3$

Method 2: Finding the probability that no component fails = $1 - P$:

$$1 - P = (1 - p_1)(1 - p_2)(1 - p_3)$$

$$= 1 - p_1 - p_2 - p_3 + p_1p_2 + p_1p_3 + p_2p_3 - p_1p_2p_3,$$

so we see again that the probability that at least one component fails is:

$$P = p_1 + p_2 + p_3 - p_1p_2 - p_1p_3 - p_2p_3 + p_1p_2p_3$$

which matches the result in *Method 1*.

This is the simplest mathematical case where the three component failure probabilities are independent of one another.

The calculations get more complex, however, when more components are added and there are correlations in the failure probabilities. Risknology (2019) estimated failure probabilities of 12 onshore and 5 offshore isolatable sections. ERM (2020) estimated failure probabilities of 29 onshore and 6 onshore isolatable sections. Both Risknology (2019) and ERM (2020) also considered several hole diameters for each isolatable section, which increased the number of p_i's they estimated. In total Risknology (2019) showed 61 p_i's and ERM (2020) showed 302 different p_i's.

Neither model, however, calculated the overall probability of a spill occurring anywhere along the Project. ERM (2020) and Risknology (2019) only estimated per component failure frequencies (p_i's), which does not lead to an estimate of P per year nor to an overall number of spills for the life of the Project. ERM (2020) and Risknology (2019), therefore, are not reliable models to understand the frequency of spills that would result from the operation of the SPOT Project. Furthermore, if Risknology or ERM had attempted to calculate P, it would only have been as accurate as the p_i's contributing to it and how well the relationships (variance and covariance) of those discrete probabilities were known. This is a separate concern that MARAD and the USCG must address.

2. The SPOT DEIS relies on two different spill size, frequency, and fate models. The results from and inputs into the two models do not match one another and are both used in different contexts in the DEIS with no explanation for the disparate treatment.

a. The ERM and Risknology analyses had different assumptions, data sources, and results.

In the DEIS, MARAD and the USCG cited to both the Risknology (2019) and the ERM (2020) spill analysis in different sections and contexts. However, the DEIS did not reconcile the different outcomes of the two analyses or explain its choice of which oil spill risk analysis to cite in the different portions of the DEIS. In Table 1, I include a detailed chart comparing and contrasting the components of the two spill risk analyses. The chart demonstrates how different the inputs and results are for the two analyses.

Table 1. ERM (2020) and Risknology (2019) spill risk analyses.

Aspect	*ERM (2020) (DEIS Appendix H)*	*Risknology (2019) (Application Appendix M)*
	100- and 500-year spill volumes	
Condensate - 100 year volume	15,936 bbl	194,700 bbl
Condensate - 500 year volume	434,612 bbl	194,700 bbl
West Texas Intermediate Crude oil - 100 year volume	16,271 bbl	15,500 bbl (for crude oil)
West Texas Intermediate Crude - 500 year volume	434,612 bbl	48,500 bbl (for crude oil)
Western Canadian Select Crude – 100 year volume	17,174 bbl	15,500 bbl (for crude oil)
Western Canadian Select Crude – 500 year volume	547,278 bbl	48,500 bbl (for crude oil)
	Distance to lower flammability limit (LFL) for 100- and 500- year spill volumes	
Condensate - 100 year volume distance to LFL	1.442 km	0.13 km
Condensate - 500 year volume distance to LFL	7.912 km	0.13 km
West Texas Intermediate Crude oil - 100 year volume distance to LFL	1.964 km	0.78 km (for crude oil)
West Texas Intermediate Crude - 500 year volume distance to LFL	9.753 km	3.16 km (for crude oil)
Western Canadian Select Crude – 100 year volume distance to LFL	2.007 km	0.78 km (for crude oil)
Western Canadian Select Crude – 500 year volume distance to LFL	10.863 km	3.16 km (for crude oil)

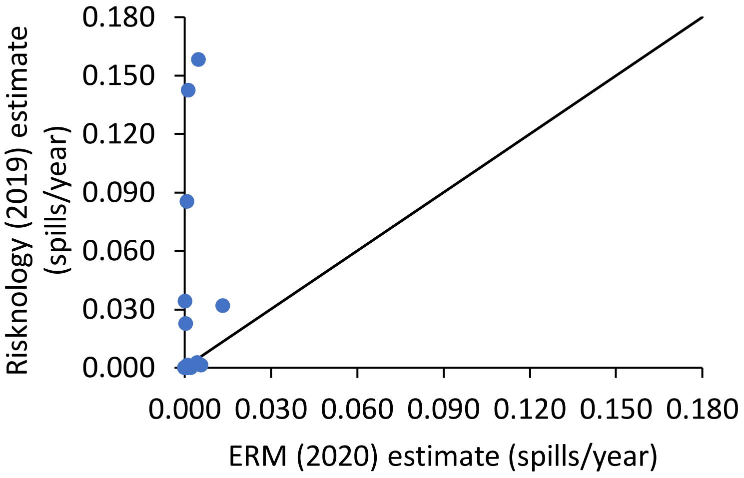
Aspect	*ERM (2020) (DEIS Appendix H)*	*Risknology (2019) (Application Appendix M)*
Distance to $12.5 kW/m^2$ for 100- and 500- year spill volumes		
Condensate - 100 year volume distance to $12.5 kW/m^2$	0.284 km	0.25 km
Condensate - 500 year volume distance to $12.5 kW/m^2$	1.195 km	0.25 km
West Texas Intermediate Crude oil - 100 year volume distance to $12.5 kW/m^2$	0.291 km	0.78 km (for crude oil)
West Texas Intermediate Crude - 500 year volume distance to $12.5 kW/m^2$	1.178 km	3.16 km (for crude oil)
Western Canadian Select Crude – 100 year volume distance to $12.5 kW/m^2$	0.398 km	0.78 km (for crude oil)
Western Canadian Select Crude – 500 year volume distance to $12.5 kW/m^2$	1.579 km	3.16 km (for crude oil)
Offshore weather conditions		
Station used	NOAA buoy Station 42019, 60 nm south of Freeport, Texas	Cited Fugro 2018 for wind speeds; generic Gulf of Mexico data for temperature and relative humidity
Offshore wind speed	6.5 m/sec = 14.5 miles per hour (average)	95% of wind speeds are > 1.3 m/sec (2.9 miles per hour); 5% of wind speeds are > 5.0 m/sec (11.2 miles per hour)
Sea surface temperature	25.4 °C (78 °F)	65-95 °F
Relative humidity	75%	75%
Hurricane wind speed	60 m/sec = 134 miles per hour	
Onshore weather conditions		
Station used	Angleton Lake Jackson Brazoria County Airport	
Offshore wind speed	7.6 m/sec = 17 miles per hour (average)	
Air temperature	21.3 °C (70 °F)	
Relative humidity	81%	

Aspect	*ERM (2020)* *(DEIS Appendix H)*	*Risknology (2019)* *(Application Appendix M)*
SPOT Project Isolatable Sections		
Onshore	29 identified, with volume (m^3), pipeline length, pressure (psig), and temperature (°C) given	12 identified, with volume (ft^3), pressure (psi), and temperature (°F) given
Offshore	6 identified, with volume (m^3), pipeline length, pressure (psig), and temperature (°C) given	5 identified, with volume (ft^3), pressure (psi), and temperature (°F) given
Release scenarios		
Onshore terminal equipment hole diameters	5, 25, 90mm and full bore Spill freq's: Table 3.8 (p. 25)	10, 50, 150mm and full bore Spill freq's: Table 3-3 (page 16)
Onshore storage tank failure hole diameters	5, 10, 50, 150mm and full bore Spill freq's: Table 3.7 (p. 24)	10, 50, 150mm and full bore Spill freq's: Table 3-3 (page 16)
Platform Equipment release hole diameters	5, 25, 90mm and full bore	10, 50, 150mm and full bore Spill freq's: Table 3-3 (page 16)
Onshore pipeline release hole diameters	5, 10, 50, 150mm and full bore Spill freq's: Table 3.5 (p. 23)	10, 50, 150mm and full bore Spill freq's: Table 3-3 (page 16)
Offshore pipeline release hole diameters	5, 10, 50, 150mm and full bore Spill freq's: Table 3.9 (p. 26)	10, 50, 150mm and full bore Spill freq's: Table 3-3 (page 16)
Riser release hole diameters	5, 10, 50, 150mm and full bore Spill freq's: Table 3.10 (p. 27)	10, 50, 150mm and full bore Spill freq's: Table 3-3 (page 16)
Data source(s) for spill frequency calculations	PHMSA (2020) IOGP (2019) RIVM (2009)	PHMSA (2008) Spouge (2006) (citing HCR database) OREDA (1984) Garber (2000) AME (1998)
VLCC tank breach due to ship collision		
Data source(s)	USCG (2019)	Moffat and Nichol (2018)

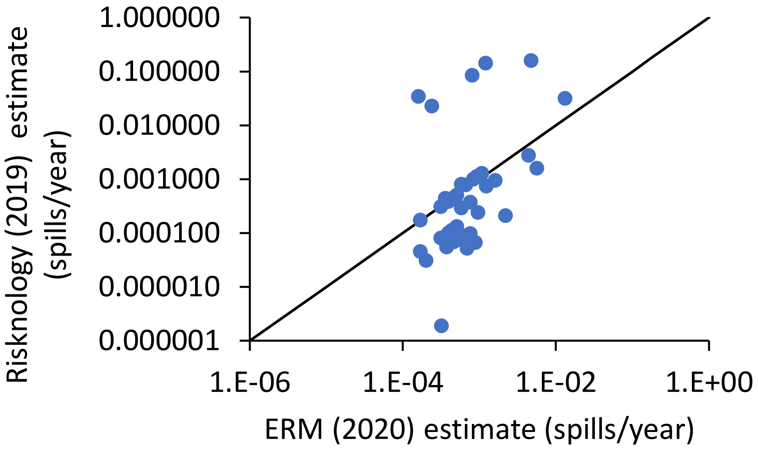
Aspect	*ERM (2020) (DEIS Appendix H)*	*Risknology (2019) (Application Appendix M)*
Marine traffic dead weight tonnage by vessel type (metric tons)		
Fishing	1000	322
Passenger	240,000	1,401
Pleasure craft	4	115
Tanker	350,000	391,932
Tug tow	500	2,116
Cargo	80,000	49,062
Other	5,000	7,494
SPOT DWP supply vessel	500	
VLCC visiting SPOT DWP	320,000	
Marine traffic mean speed (knots)		
Fishing	5.4	8.0
Passenger	14.7	16.9
Pleasure craft	13.7	17.7
Tanker	8.2	7.7
Tug tow	5.0	10.5
Cargo	10.2	12.2
Other	5.6	8.6
SPOT DWP supply vessel	5	
VLCC visiting SPOT DWP	8.2	
Marine traffic number of vessels per year		
Blocks considered	425, 426, 427, 462, 463, A56-A59	425, 426, 462, A56-A59; A59 designated as anchorage
Fishing	120 in 2019	22
Passenger	9 in 2019; 27 in 2050	25
Pleasure craft	18 in 2019	15.5
Tanker	25 in 2019; 27 in 2050	17
Tug tow	2 in 2019	2.5
Cargo	12 in 2019; 24 in 2050	11
Other	22 in 2019	24
SPOT DWP supply vessel	3 in 2019	
VLCC visiting SPOT DWP	156 in 2019	
Collision impact energy calculations		
Model cited	CMPT (1999)	
Powered and drifting impact energies	Table 3.15 on p. 32; calculations verified; ship types did not include VLCC visiting SPOT DWP	Table 3.5 on p. 18; ship types included passenger, tanker, tug tow, other, and cargo

Aspect	*ERM (2020)* *(DEIS Appendix H)*	*Risknology (2019)* *(Application Appendix M)*
	Collision frequency calculations	
Model cited	CMPT (1999)	Lewison (1980)
Collision frequency	Table 3.16 on p. 34; ship types considered = passing tankers, cargo ships, and cruise ships	Table 3.5 on p. 18; frequencies given for releasing 10% and 20% of cargo

Risknology (2019) and ERM (2020) did not estimate the same numerical values for the same isolatable sections-hole size pi's, so at least one of the estimates is incorrect (Figure 1).



a.



b.

Figure 1. Graphical comparison of first and third party spill rate estimates for the same hole diameters for the same isolatable segments on a) a linear scale and b) a log-log scale to allow the individual estimates more visual separation at the smallest spill frequency estimates. If the ERM (2020) and Risknology (2019) estimates for the same isolatable section and hole diameter match, they would fall on the 1:1 line. The more they differ from that line, the less confidence we have in at least one of them.

As both Table 1 and Figure 1 demonstrate, the Risknology (2020) and ERM (2020) analyses are wildly divergent and unreliable. Yet, the DEIS relied on both models indiscriminately throughout the DEIS.

b. MARAD and the USCG cited ERM (2020) and Risknology (2019) in different sections of the SPOT DEIS.

The DEIS relies on two separate oil risk analyses in separate sections without explanation. And it is unclear, in some sections, which analysis the agencies used. Chapter 3 is an analysis of environmental impacts and seems to lean on Risknology (2019). Chapter 4 of the DEIS is an analysis of safety considerations and says it relies on ERM (2020) but refers to both analyses. Unless the DEIS makes it clear which source they are citing (and why the agencies favor one over the other), it seems like the decision was arbitrarily made. The DEIS should explicitly compare the methodologies and results of the two and explain why one was preferred over the other.

c. ERM (2020) has technical flaws.

ERM calculated spill volumes for a specific hole diameter in a range. While using a 5 mm hole size to model the volume possible for a leak from a hole ranging from 0-5 mm in size is conservative, the same cannot be said when using a 10 mm hole size as representative of hole diameters ranging from 5-20 mm, or 50 mm to capture the spill volume of hole diameters from 20-80 mm (ERM 2020, Tables 3.5, 3.9, and 3.10 for onshore crude oil pipelines, offshore crude oil pipelines, and risers, respectively). ERM modeled onshore equipment leaks at 5, 25, and 90 mm representative hole diameters, as well as full bore ruptures (ERM 2020, Table 3.8).

ERM and Risknology also used a 0.5 hour shut down time to calculate worst credible spill sizes. The DEIS does not justify its use of a 0.5 hour shut down time, nor are there any considerations of variability around that value. My questions include: What is a reasonable range of values for emergency shut down times? Where did the 0.5 hour come from? I suggest that the PHMSA database, which includes incident times and shut down times, could be used to characterize the range of actual values and assess how realistic 0.5 hours is. If this value was given to ERM and Risknology by the Applicant, then the Applicant should explain how they arrived at it.

ERM used hole size as a measure of observed spill size. I am not convinced that hole size and observed spill size are directly related or that it should be assumed that future spills would show a strong relationship between those two variables alone. Obviously, for spills that go unchecked for the same length of time under otherwise identical circumstances, a bigger hole means a greater loss of oil, but I do not think it can be assumed that all spills will get detected (or stopped) at the same speed. (Again, this calls for an evaluation of the assumption of a shut down time of exactly 30 minutes.)

ERM (2020) explicitly ties hole diameter to spill size class (Table 3.7 on p. 24). As a counterexample, "[i]n March of 2006, approximately 201,000 gallons [4,786 bbl] of crude oil was spilled from the GC-2 Oil Transit Pipeline at the BP Exploration, Alaska (BPXA) Western Operating Area. The spill was a result of internal corrosion, which caused a 0.25-inch [6.35 mm] hole in the pipeline" (BLM 2018, Vol. 1, p. 474). Thus, a large spill (greater than 1,000 bbl) can result from a small hole (between 5-20mm) in a pipeline.

ERM (2020) showed three different exceedance curves and included the calculated spill frequencies and volumes for each fuel type separately in Attachment D. I confirmed that the spill frequency calculations remained consistent across Condensate, West Texas Intermediate, and Western Canadian Select crude, and that the differences in the exceedance curves are due only to the different spill volumes which result from the physical properties of the specific fuel types. ERM (2020) did not show how they calculated spill volumes to make the exceedance curves, but the volumes are included in its report.

I am also uncomfortable with the way ship collision frequencies were modeled. The lack of consideration that the very large crude carriers ("VLCCs") (and other carriers) using the DWP could also be collision risks to ships at the DWP may be an important omission.

d. Risknology (2019) has technical flaws.

Risknology (2019) just listed the spill rates per isolatable segment without the accompanying volumes and no formulae whatsoever, which makes it very hard to confirm either the spill frequency or size calculations are correct, although various data sources and modeling programs are cited.

As shown in Table 1, the Risknology (2019) oil spill risk analysis suffers in comparison to the one by ERM (2020). For example, ERM (2020) included weather conditions on and offshore, but Risknology (2019) only gave offshore winds, and did not include hurricanes in its discussion of weather. Risknology (2019) used older data and models than ERM (2020) did in its spill frequency calculations. Risknology (2019) did not account for any increases in marine vessel traffic over the life of the Project. Like ERM (2020), Risknology (2019) calculated spill volumes for a specific value hole diameter in a range but used a more limited set of hole diameters (10, 50, and 150 mm and full bore, p. 16, Table 3.3). The same concerns raised about how representative the hole diameters are and shut down times raised for ERM (2020) apply to Risknology (2019).

3. The fate modeling exercises use an offshore spill based on a BOEM (2012) estimate of 2,200 bbl as a median large offshore spill volume. This value is unjustified.

The median estimate of 2,200 bbl for an oil spill in the DEIS is unjustified. Below, I show the consequences of more properly using longer data sets, aggregating volumes from spills attributed to hurricanes, and adding the most recent data available. My analysis demonstrates that the DEIS should have considered a larger median spill volume as the most likely scenario spill.

BOEM’s calculation of median offshore spill volume that the DEIS relies upon included large spills from 1996 to 2010 (BOEM 2012) (Table 2). “The median size of spills ≥1,000 bbl that occurred during 1996-2010 is 2,240 bbl. The size was calculated based on the nine spills (both platform/rigs and pipelines) that occurred during this timeframe and included the DWH oil spill” (BOEM 2012, p. 3-59). Oddly, BOEM (2017) cites Anderson et al. (2012) and separates offshore spills into pipeline and platform groups, which have median large spill volumes of 1,720 and 5,066 bbl, respectively, using the same data as BOEM (2012). BOEM (2012) and BOEM (2017) use the same data to present an overall offshore median large spill volume in the first case and source-specific median large spill volumes in the latter.

Table 2. Spills included by BOEM (2012) to define median offshore spill volume.

Spill date	Source type	Volume (bbl)	Rank by volume
January 26, 1998	Pipeline	1,211	9
September 29, 1998	Pipeline	8,212	2
July 23, 1999	Pipeline	3,200	4
January 21, 2000	Pipeline	2,240	5 = median
September 15, 2004	Pipeline	1,720	6
September 24, 2005	Platform/rig	5,066	3
September 13, 2008	Pipeline	1,316	8
July 25, 2009	Pipeline	1,500	7
April 10, 2010	Platform/rig	4,900,000	1

ABS Consulting, Inc. (2016) pointed out that using 15 years of data is insufficient for calculating large spill occurrence rates. For offshore continental shelf ("OCS") pipeline spills, there were "no major trends identified that would limit the applicable data" to a short (15 year) time period (ABS 2016). It would follow that 15 years of data is also insufficient to characterize the distribution of large spills volumes (central tendency using the mean or median, or dispersion characteristics) using a short time frame.

If we extend available spill data to include information from 1974 to 2012 (a date range commonly used in BOEM reports and easily accessible from the BOEM and BSEE websites), there were 20 large spills. The spills volumes ranked tenth and eleventh were 4,000 and 3,500 bbl, respectively, for a median spill volume of 3,750 bbl (Table 3).

Table 3. Spills from 1974 to 2012 used to define median offshore spill volume. Spills in the shaded entries are also present in Table 2. Large hurricane spills are denoted with the storm name.

Spill date	Source type	Volume (bbl)	Rank by volume
April 17, 1974	Pipeline	19,833	2
September 11, 1974 (Carmen)	Pipeline	3,500	11
December 18, 1976	Pipeline	4,000	10
November 23, 1979	Platform/rig	1,500	17
November 14, 1980 (Jeanne)	Platform/rig	1,456	18
December 11, 1981	Pipeline	5,100	6
February 7, 1988	Pipeline	15,576	3
January 24, 1990	Pipeline	14,423	4
May 6, 1990	Pipeline	4,569	8
August 31, 1992 (Andrew)	Pipeline	2,000	14
November 16, 1994	Pipeline	4,533	9
January 26, 1998	Pipeline	1,211	20
September 29, 1998 (Georges)	Pipeline	8,212	5
July 23, 1999	Pipeline	3,200	12
January 21, 2000	Pipeline	2,240	13
September 15, 2004 (Ivan)	Pipeline	1,720	15
September 24, 2005 (Rita, 3 spills)	Platform/rig	5,066	7
September 13, 2008 (Ike)	Pipeline	1,316	19
July 25, 2009	Pipeline	1,500	16
April 10, 2010	Platform/rig	4,900,000	1

The volume for Hurricane Rita in Tables 2 and 3 is the total for three large spills, with individual volumes of 1,494 bbl, 1,572 bbl, and 2,000 bbl. Those spills cannot be considered independent events, so they are added together as a cumulative volume. However, if we do that for large spills for one hurricane, we should also do that for all spills caused by the same storm for all hurricanes (See Lubetkin (2020), Table 4).

If all composite hurricane-caused spill volumes from 1974 to 2012 were included, the list of spills in Table 3 would change to include more spills, and some of the hurricane-caused spills listed above would have more oil volume attributed to them. Of 26 spills, the 13th and 14th ranked spills had volumes of 3,445 and 3,200 bbl, respectively, which would result in a median spill size of approximately 3,320 bbl (Table 4).

Table 4. Spills from 1974 to 2012 used to define median offshore spill volume. Spills in the shaded entries are also present in Table 2. Large hurricane spills are denoted with the storm name and total number of spills contributing to the total volume if the volume differs from Table 3. New total spill volumes from aggregating hurricane spills are in **bold**.

Spill date	Source type	Total Volume (bbl)	Rank by volume
April 17, 1974	Pipeline	19,833	2
September 11, 1974 (Carmen)	Pipeline	3,500	11
December 18, 1976	Pipeline	4,000	10
November 23, 1979	Platform/rig	1,500	20
November 14, 1980 (Jeanne)	Platform/rig	1,456	21
December 11, 1981	Pipeline	5,100	7
February 7, 1988	Pipeline	15,576	3
January 24, 1990	Pipeline	14,423	4
May 6, 1990	Pipeline	4,569	8
August 31, 1992 (Andrew)	Pipeline	2,000	18
November 16, 1994	Pipeline	4,533	9
January 26, 1998	Pipeline	1,211	25
September 29, 1998 (Georges)	Pipeline	8,212	5
July 23, 1999	Pipeline	3,200	14
January 21, 2000	Pipeline	2,240	16
October 3, 2002 (Lili, 2 spills)	Platform/rig	**1,238**	23
September 15, 2004 (Ivan, 8 spills)	Pipeline	**3,445**	13
September 15, 2004 (Ivan, 7 spills)	Platform/rig	**1,125**	26
June 29, 2005 (Katrina, 5 spills)	Pipeline	**1,247**	22
June 29, 2005 (Katrina, 21 spills)	Platform/rig	**3,067**	15
September 24, 2005 (Rita, 5 spills)	Pipeline	**1,212**	24
September 24, 2005 (Rita, 17 spills)	Platform/rig	**7,997**	6
September 13, 2008 (Ike, 6 spills)	Pipeline	**2,025**	17
September 13, 2008 (Ike, 18 spills)	Platform/rig	**3,489**	12
July 25, 2009	Pipeline	1,500	19
April 10, 2010	Platform/rig	4,900,000	1

Still, Table 4 ignores any spills that occurred since 2012. While BOEM online spill statistics[1] list Excel sheets for 2013-2018, those sheets do not include spills volumes. The 2013 BSEE metadata list includes 71 types of data that should be part of the sheet, but 11 columns are missing: Spill/Release, Spill Volume, Event Other Type, Event Other Type Description, Oil,

---

[1] https://www.bsee.gov/stats-facts/offshore-incident-statistics

Diesel, Condensate, Hydraulic, Natural Gas, Other Type, and Other Type Description. Therefore, the most recent oil spill data with volumes listed is from BOEM's 2018 Oil Spill Risk Study (BOEM 2018), which revisited OCS oil spill statistics using data from 1972-2017. I used that information to define median offshore spill volume from 1972 to 2017 in Table 5. Spills listed in Table 5 with only the year noted are from Appendices B and D (BOEM 2018). The spills >1,000 bbl from pipelines and platforms (Table 5) can be used to find the most up-to-date and comprehensive version of the median offshore large spill volume. Using these 31 offshore spills, the median size for spills >1,000 bbl is 3,489 bbl (Table 5), much larger than the median spill size (2,200 bbl) MARAD and the USCG consistently rely upon in the DEIS.

Table 5. Spills from 1972 to 2017 used to define median offshore spill volume. Spills in the shaded entries are also present in Table 2.

Spill date	Source type	Total Volume (bbl)	Rank by volume
1973	Pipeline	5,000	11
1973	Platform/rig	9,935	6
1973	Platform/rig	7,000	9
April 17, 1974	Pipeline	19,833	2
September 11, 1974 (Carmen)	Pipeline	3,500	15
December 18, 1976	Pipeline	4,000	14
November 23, 1979	Platform/rig	1,500	25
November 14, 1980 (Jeanne)	Platform/rig	1,456	26
December 11, 1981	Pipeline	5,100	10
February 7, 1988	Pipeline	15,576	4
January 24, 1990	Pipeline	14,423	5
May 6, 1990	Pipeline	4,569	12
August 31, 1992 (Andrew)	Pipeline	2,000	23
November 16, 1994	Pipeline	4,533	13
January 26, 1998	Pipeline	1,211	30
September 29, 1998 (Georges)	Pipeline	8,212	7
July 23, 1999	Pipeline	3,200	18
January 21, 2000	Pipeline	2,240	21
October 3, 2002 (Lili, 2 spills)	Platform/rig	1,238	28
September 15, 2004 (Ivan, 8 spills)	Pipeline	3,445	17
September 15, 2004 (Ivan, 7 spills)	Platform/rig	1,125	31
September 24, 2005 (Rita, 5 spills)	Pipeline	1,212	29
September 24, 2005 (Rita, 17 spills)	Platform/rig	7,997	8
June 29, 2005 (Katrina, 5 spills)	Pipeline	1,247	27
June 29, 2005 (Katrina, 21 spills)	Platform/rig	3,067	19
September 13, 2008 (Ike, 6 spills)	Pipeline	2,025	22
September 13, 2008 (Ike, 18 spills)	Platform/rig	3,489	16
July 25, 2009	Pipeline	1,500	24
April 10, 2010	Platform/rig	4,900,000	1
2016	Pipeline	2,900	20
2017	Pipeline	16,152	3

4. Current data from the Pipeline Hazardous Materials and Safety Administration ("PHMSA") show that offshore and onshore pipeline spills of many sizes and substances are common but discrepancies between federal agency records make comparable analyses from different data sources difficult.

The individual components of the expected number of spills associated with this project can be calculated from data available from several Federal agencies. For each type of potential spill source, the number of spills expected will be the product of the rate of spill occurrence and the exposure variable (e.g., number of years, length of pipeline, number of ships, etc.). That is

$$N = RT$$

where

N = number of spills of a given size

R = occurrence rate of spills of that size

T = exposure variable.

There are four system components in the DEIS that should have had estimated spill numbers: onshore pipelines, offshore pipelines, the DWP itself, and ship collisions with the DWP or ships moored there. Previous data about N and T should be used to estimate R for each infrastructure component. Those are all do-able (if only roughly) from publicly available data about number of incidents at each of those types of infrastructure or transportation and the number of BBO handled, pipeline miles, platform years, or ship years in the same time frame. Those data are how the occurrence rates (R for specific spill sources and size classes) can be calculated. Then the occurrence rates can be used with the project specific details (T_{SPOT}) to find the number of spills (N) each source would be expected to have and the total number for the project over a given number of years. A detailed example for offshore pipeline spills is given below in Section 6.

I complied the PHMSA data for spills from 2008-2018, using data available on the PHMSA database[2] to compare against the data shown in DEIS Section 4.8.2. Offshore Pipeline Incident Data and Table 4.8-1. I sorted the data by spill substance, whether the spills were on- or offshore, and spill volume.

Table 6. Offshore crude oil spill incidents by size class, 2008-2018.

	Size class name and volume range				Total
	Very small	Small	Medium	Large	
Substance	<10 bbl	≥10-100 bbl	≥100-1000 bbl	≥1000 bbl	
Crude oil	33	2	1	1	37

---

[2] accident_hardardous_liquid_jan2002_dec2009.zip and accident_hardardous_liquid_jan2010_present.zip

Table 6 matches the total spills shown in Chapter 4 of the SPOT DWP DEIS, Section 4.8.2, Table 4.8-1 on p. 4-65.

Federal agencies do not consistently report oil spills, which makes the use of their data challenging. For example, while PHMSA data show 37 offshore crude oil spills between 2008 and 2018 (DEIS, p. 4-65), that list does not match the spills shown by BOEM (2018). PHMSA's public data included one large oil spill from 2008 and 2018, a spill of 1,500 bbl from Shell pipeline on July 25, 2009. BOEM (2018) also lists spills of 1,316 bbl on September 13, 2008 as part of the releases due to Hurricane Ike, the 2016 spill of 2,900 bbl, and the 2017 release of 16,152 bbl. Section 4.8.2 Offshore Pipeline Incident Data (p.4-65) of the DEIS cites the PHMSA data rather than the BOEM (2018) data.

Three kinds of spills were listed for onshore pipeline spills: crude oil; refined and/or petroleum product (non-HVL) which is a liquid at ambient conditions (hereinafter "refined"); and HVL or other flammable or toxic fluid which is a gas at ambient conditions (hereinafter "HVL/flammable/toxic") (Table 7). The PHMSA databases also had entries for incidents involving biofuel/alternative fuels and carbon dioxide, which I did not catalog.

Table 7. Onshore spill incidents by substance and size class, 2008-2018.

Substance	Size class name and volume range				Total
	Very small <10 bbl	Small ≥10-100 bbl	Medium ≥100-1000 bbl	Large ≥1000 bbl	
Crude oil	1,362	426	241	63	2,092
Refined	57	145	70	52	837
HVL/flammable/toxic	902	210	114	40	1,266
Total	2,834	781	425	155	4,195

More than half of the total spill incidents onshore involved crude oil (2,092 of 4,195 listed spills). One difference between Tables 6 and 7 is the number of crude oil spills that occurred on land (2,092) as compared to offshore (37) between 2008 and 2018. The number of incidents needs to be placed in the context of the number of pipeline miles and/or volume of oil transported (available from the National Transportation Safety Board or the Energy Information Administration), but clearly there are non-zero risks for transporting oil by pipeline on land. It would be possible to calculate spill risk from these data by dividing these totals by an exposure variable such as total pipeline mile-years or billions of total billions of barrels transported. Similarly, Anderson et al. (2012), ABSG Consulting, Inc. (2016), and BOEM (2018) provide spill rates for spills >1,000 and >10,000 bbl for barges and tankers. However, MARAD and the USCG did not provide those calculations as part of the DEIS.

5. Comparing risk estimates across settings and agencies is difficult.

a. <u>BOEM, BLM, USCG all use different spill size class definitions. The USCG has different size classes for inshore and coastal spills.</u>

In Table 8, I show the spill size class names and volumes in the original units (barrels or gallons) used by the USCG and other agencies and then converted to the other using the relationship 1 bbl = 42 gallons. While this DEIS defines large spills as those over 1,000 bbl, that class size limit is dramatically larger than (and will thus undercount) the spills that qualify as major inland spill but is lower than the cut off for a major coastal spill (shaded cells).

Table 8. A comparison of spill size categories by agency.

Agency	Very small	Small	Medium	Large	Very large or huge
BOEM	<50 bbl	≥50-100 bbl	≥100-1,000 bbl	≥1,000 - 10,000 bbl	≥10,000 bbl
	<2,100 gallons	≥2,100-4,200 gallons	≥4,200 to 42,000 gallons	≥42,000 to 420,000 gallons	≥420,000 gallons
BLM - Coastal Plain DEIS 2018 (Solid and Hazardous Waste)	<10 gallons	≥10 to 99.5 gallons	≥100 to 999.5 gallons	≥1,000 to 100,000 gallons	≥100,000 gallons
	<0.238 bbl	≥0.238 to 2.38 bbl	≥2.38 to 23.8 bbl	≥23.8 to 2,381 bbl	≥2,381 bbl
BLM – Coastal Plain DEIS 2018 (Petroleum Resources)		<500 bbl		≥500 bbl	
		<21,000 gallons		≥21,000 gallons	

	Minor	Medium	Major
USCG - inland	<1,000 gallons	1,000- 10,000 gallons	>10,000 gallons
	<23.8 bbl	23.8-238 bbl	>238 bbl
USCG – coastal	<10,000 gallons	10,000-100,000 gallons	>100,000 gallons
	<238 bbl	238-2,380 bbl	>2,380 bbl

In DEIS Section 3.2.1.4 (p. 3-2) the terms negligible, minor, moderate, or major are defined relative to one another. The DEIS (p. 3.2) states that “Major impacts, based on their context and intensity (or severity), have the potential to meet the thresholds for significance set forth in CEQ regulations (40 CFR § 1508.27). Major impacts warrant additional attention in a NEPA analysis."

The DEIS (p. 3-66) further states that "the Applicant provided modeling of a most likely scenario spill of 2,200 bbl of oil released over 1 hour for heavy crude (WCS), lighter crude (WTI), and condensate." That oil spill scenario was listed again in reference to the minimum time for a spill to reach shore and maximum surface area of floating oil (DEIS, p. 3-67), potential impacts on oyster reefs (DEIS, p. 3-9), polycyclic aromatic hydrocarbons (DEIS, pp. 91-92), and effects on marine and coastal birds (DEIS, p. 3-113), among others. Not only are all of those stated impacts in Chapter 3 of the DEIS based on an estimated large spill median volume (2,200 bbl as reported in BOEM 2012) that is too small, the actual median volume of 3,489 bbl qualifies as a major coastal spill based on the USCG definition.

6. Based on the amount of oil that SPOT expects to handle at its DWP per year, recent estimates of spill risk rates (ABS 2016), and the most recent spill data summary (BOEM 2018), the number of offshore pipeline spills in several different spill size categories can be calculated for different percent capacities and years of operation.

The DEIS does not calculate the number of pipeline or other types of spills of different sizes that could occur over the life of the Project. This is a critical piece of information that is missing from the DEIS. While only spills >1,000 bbl are tracked in oil spill fate modeling exercises, spills less than 1,000 bbl will also have environmental impacts, and those impacts should be considered based not only on the median volume of a single spill from each category, but also based on the expected total number of spills in each size class. While one spill of 108 bbl (median spill size for the 50-999 bbl class shown in Table 25 on p.48 of ABSG Consulting, Inc. (2016)) could potentially be characterized as having a relatively small environmental impact, the evaluation of expecting 28-56 such events over a 30-year project lifespan is quite different.

Below I calculated the number of differently sized spills that will occur using spill data and occurrence rates reflecting different time periods.

First, I show the rates calculated using data from 2001-2015 (Anderson et al. 2012) (Table 9), which included an estimate that 0.38 spills >1,000 bbl would be expected per billion barrels of oil ("BBO") produced. These are the rates used in BOEM (2012). "The most recent, published analysis of trends in OCS spills was used to project future spill risk for this EIS… This report presents an analysis of the most recent 15 years of data (1996-2010 data) as well as the previous 15 years (1985-1999 data). Data for the most recent period reflect spill prevention and occurrence conditions. The 15-year record was chosen because it reflects how the spill rates have changed while still maintaining a significant portion of the record" (BOEM 2010, p. 3-57).

Table 9. Calculating spill occurrence rate based on data from 2001-2015. Data in italics are from Table 27 of ABSG Consulting, Inc. (2016).

Volume (bbl)	*Number of spills*	*Percent of spills*	Occurrence rate per BBO handled
1-9 bbl	*77*	*56.6*	9.77
10-49 bbl	*35*	*25.7*	4.44
50-999 bbl	*21*	*15.4*	2.66
>1,000 bbl	*3*	*2.2*	0.38
Total	*136*	*100.0*	17.27

Statistically speaking, it is best to use the longest time series possible to have the most robust data set. Since BOEM (2012 and 2017) rely on constant spill occurrence rates, it is important to test for the stability of the rate over varying time windows. Anderson et al. (2012) concluded that data from 1974 to 2010 had higher spill rates than rates that only used the spills using the last 15 or 20 years of data. ABSG Consulting, Inc. (2016) re-evaluated the best time ranges for calculating spill rates for pipeline, platform, barge, and tanker spills. For pipeline spill data, ABSG Consulting, Inc. (2016) performed several tests of trends (Kendall's test; runs-up, runs-down; Spearman rank correlation) over different time periods and found that for pipeline spills "the number of spills per 0.5 [billion barrels] of oil produced has exhibited very little trend . . . Over the whole period, no statistical trend was discernible. . . . [T]he general conclusion of this analysis was that the pipeline data exhibited no compelling trends" (ABS 2016, pp 45-46).

Based on Table 41, in ABSG Consulting, Inc.'s report (ABSG Consulting, Inc. (2016), p. 71), the best data period for estimating the rate of outer continental shelf oil spills is the full data record from 1974-2015, during which time the occurrence rate of large (>1,000 bbl) spills was 0.89 per billion barrels of crude oil ("BBO") (ABSG Consulting, Inc. (2016), Table 21, p. 46 and Fig. 39, p. 72) handled through offshore pipelines (Table 10).

Table 10. Calculating spill occurrence rate (from offshore pipelines) based on data from 1974-2015. Data in italics are from Table 26 of ABSG Consulting, Inc. (2016). This assumes 17.9 BBO were handled (ABSG Consulting, Inc. (2016) Table 21).

Volume (bbl)	*Number of spills*	*Percent of spills*	Occurrence rate per BBO handled
1-9 bbl	*307*	*67.9*	17.27
10-49 bbl	*84*	*18.6*	4.73
50-999 bbl	*45*	*10.0*	2.54
>1,000 bbl	*16*	*3.5*	*0.89*
Total	*462*	*100.0*	25.43

To update the oil spill occurrence rate to the years 1972-2017, I needed to update the spill record and the BBO handled to the same years. I did this by first confirming that the BBO reported in ABSG Consulting, Inc. (2016) was reproducible (within the limits of accessible oil production records) (*Step 1*) and then adding the BBO produced in 1972, 1973, 2016, and 2017 for the Gulf of Mexico, Alaska and Pacific regions, to the extent the data were available (*Step 2*).

Step 1. ABSG Consulting, Inc. (2016) uses an estimate of 17.9 BBO handled from 1974-2015. I compiled data regarding the amount of oil handled in the Gulf of Mexico compiled from BSEE reports,[3] which showed the data in year ranges 1971-1976, 1977-1982, 1983-1988, 1989-1994,

---

[3] https://www.data.bsee.gov/Main/HtmlPage.aspx?page=annualRegion

1995-1999, 2000-2004, and 2005-present separately and from annual data for oil production in the Alaska and Pacific regions,[4] which were only available for 2010-2019 (Table 11).

Table 11. Oil production by year and region collated from BSEE reports.

Year	GoM Region	Year	GoM Region	Alaska	Pacific
1971	375,808,909	1996	368,830,338		
1972	373,306,660	1997	411,594,479		
1973	365,976,015	1998	444,225,186		
1974	338,138,486	1999	495,127,788		
1975	309,839,434	2000	522,996,889		
1976	300,545,977	2001	558,113,553		
1977	283,671,320	2002	566,978,518		
1978	275,969,407	2003	560,991,048		
1979	263,264,455	2004	534,745,349		
1980	264,610,822	2005	466,925,700		
1981	263,280,715	2006	472,077,444		
1982	286,089,617	2007	468,008,677		
1983	320,227,013	2008	423,394,331		
1984	354,642,427	2009	570,309,328		
1985	350,338,291	2010	566,628,383	1,337,999	21,707,342
1986	355,532,013	2011	481,697,356	1,057,866	19,820,270
1987	327,549,054	2012	464,791,806	627,108	17,678,493
1988	301,201,970	2013	458,988,197	669,148	18,565,833
1989	280,625,084	2014	510,468,339	625,303	18,506,540
1990	274,551,708	2015	553,006,948	609,912	11,451,040
1991	294,675,668	2016	585,353,426	546,340	6,142,614
1992	304,809,714	2017	613,315,401	517,002	5,713,059
1993	308,579,344	2018	642,062,930	498,216	4,873,812
1994	313,936,376	2019	686,452,909	479,711	4,389,575
1995	345,038,860				

The total of 16.73 BBO I found using the annual production (Table 12) is not exactly 17.9 BBO. The difference of roughly 1.2 BBO may be due to not including data about the production in Alaska or the Pacific from 1974 to 2009. (If the combined production of the Alaska and Pacific regions was averaged approximately 33 million bbl per year for those intervening 36 years, the discrepancy would be fully explained.) Based on the general agreement between total BBO produced from the ABSG Consulting, Inc. (2016) and the volume shown in Table 12, I felt confident that I was using the correct data to supplement ABSG Consulting, Inc. (2016) to BBO handled from 1972-2017.

---

[4] https://www.data.bsee.gov/Production/OCSProduction/Default.aspx

Table 12. The total barrels of oil from 1974-2015 (shaded values in Table 11) from each region individually and combined from Table 11 add to 16.73 BBO.

Total oil production for 1974-2015	Regional production in barrels			Total (bbl)	Total (BBO)
	GoM	Alaska	Pacific		
	16,617,017,412	4,927,336	107,729,518	16,729,674,266	16.73

Step 2. I added data from 1972, 1973, 2016, and 2017 to compute new spills occurrence rates per BBO produced (Table 13). Note that unlike Table 11, which showed volumes in bbl, this table uses BBO.

Table 13. Estimating the total offshore oil production from 1972-2017 by supplementing an existing estimate.

BBO	Source
17.9	Total given in ABSG Consulting, INC. (2016) for 1974-2015 (in BBO)
0.373	GoM 1972
0.366	GoM 1973
0.585	GoM 2016
0.613	GoM 2017
0.0005	Alaska 2016
0.0005	Alaska 2017
0.0061	Pacific 2016
0.0057	Pacific 2017
19.85	Total estimate for all regions, 1972-2017

Once I found the total BBO produced, I used that with the updated spill record to find spill occurrence rates for different spill size classes (Table 14). The size classes do not match those in earlier tables because BOEM (2018) used different volume thresholds for grouping spills. No data were given for spills <50 bbl. The rates of pipeline spills 100-999 bbl can be compared across Tables 9, 10, and 14 directly. The rate of spills ≥1,000 bbl from 1972-2017 is 0.76 + 0.20 = 0.96 per BBO produced.

Table 14. Data from Table 8 (p. 14) of BOEM (2018) using spills from 1972-2017; assume 19.85 BBO handled.

Volume (bbl)	*Number of spills*	*Percent of spills*	Occurrence rate per BBO handled
1-49 bbl	*No data*		
50-99 bbl	*16*	*22.9*	0.81
100-999 bbl	*35*	*50.0*	1.76
1,000-10,000 bbl	*15*	*21.4*	0.76
≥10,000 bbl	*4*	*5.7*	0.20
Total spills ≥ 50 bbl	*70*	*100.0*	3.53

According to the DEIS, the maximum flow rate will be 85,000 bbl/hr, which is the same as 2,040,000 bbl/day, which is the same as 744,600,000 bbl/yr (0.7446 BBO/yr) if it were to run at 100% capacity. That is more oil than has been produced in any year in the entire Gulf of Mexico region.

It is possible that the SPOT DWP would not function at 100% capacity all the time, so this represents a maximum rate of oil handling per year. I calculated the expected number of spills in different size classes using the occurrence rates in Tables 9, 10, and 14 for 50%, 75%, and 100% oil capacity use for one year and for 30 years of operations (Tables 15-20).

I used BBO as the exposure variable because, according to ABS (2016, p. 10): "Oil handled has long been used as an exposure variable for estimating spill rates. It is easily and intuitively defined, can be easily computed from historical production and commerce data, and can be estimated for future periods. Each of these factors makes it particularly applicable." Both BOEM (2012) and BOEM (2017) also use BBO as the exposure variable to calculate the expected number of large oil spills. "The mean number of future spills … is calculated by multiplying the spill rate … by the volume of oil estimated to be [handled] as a result of a proposed action … Spill rates were calculated based on the assumption that spills occur in direct proportion to the volume of oil handled and are expressed as number of spills per billion barrels of oil handled (spills/BBO)" (BOEM 2012, p. 3-59). "The estimation process uses a spill rate constant, based on historical accidental spills… expressed as a mean number of spills per billion barrels of oil handled (BOEM 2017, p. 3-123).

Just as with the calculations of the median volume of large offshore spills, the spills rates of occurrence are sensitive to the length of time oil spill data are included. For consistency, the same data should be used in both the calculation of the large spill median volume and any other analyses.

To show the importance of selecting the appropriate data range, I have included three sets of spill size class occurrence rates in Tables 15-17. Table 15 uses occurrence rates based on data from 2001-2015, shown in Table 9 of this report. Table 16 uses the longer "full record" cited in ABSG Consulting, Inc. (2016), and uses data from 1974-2015, as shown in Table 10 of this report.

Finally, Table 17 uses the same data range as I used to find the median volume of large spills, data from 1972-2017, as shown in Table 14.

Using different data sets to calculate spill occurrence rates leads to significantly different numbers of expected spills, even in a single year (Tables 15-17).

Table 15. Number of expected spills by size class spills using occurrence rates based on data from 2001-2015 from Table 9 and 1 year of operation (ABSG Consulting, Inc. 2016).

		Percent capacity		
		50	75	100
BBO handled in 1 year		0.3723	0.55845	0.7446
Spill size range	Spill rate per BBO handled	Expected numbers of spills		
1-9 bbl	9.77	3.64	5.46	7.27
10-49 bbl	4.44	1.65	2.48	3.31
50-999 bbl	2.66	0.99	1.49	1.98
>1,000 bbl	0.38	0.14	0.21	0.28
Total	17.25	6.42	9.63	12.84

Table 16. Number of expected spills by size class spills using occurrence rates based on data from 1974-2015 from Table 10 and 1 year of operation (ABSG Consulting, Inc. 2016).

		Percent capacity		
		50	75	100
BBO handled in 1 year		0.3723	0.55845	0.7446
Spill size range	Spill rate per BBO handled	Expected numbers of spills		
1-9 bbl	17.27	6.43	964	12.86
10-49 bbl	4.73	1.76	2.64	3.52
50-999 bbl	2.54	0.95	1.42	1.89
>1,000 bbl	0.89	0.33	0.50	0.66
Total	25.43	9.47	14.20	18.94

Table 17. Number of expected spills by size class spills using occurrence rates based on data from 1972-2017 from Table 14 and 1 year of operation. Note the difference in size class volumes from Tables 15 and 16.

		Percent capacity		
		50	75	100
BBO handled in 1 year		0.3723	0.55845	0.7446
Spill size range	Spill rate per BBO handled	Expected numbers of spills		
50-99 bbl	0.81	0.30	0.45	0.60
100-999 bbl	1.76	0.66	0.98	1.31
1,000-10,000 bbl	0.76	0.28	0.42	0.57
>10,000 bbl	0.2	0.07	0.11	0.15
Total	3.53	1.24	1.86	2.48

Using the most comprehensive and up-to-date data with an estimate of the amount of oil to be handled at the SPOT DWP shows that there could be as many as 10 to 21 spills >1,000 bbl associated with the project over 30 years (Table 20).

Table 18. Number of expected spills by size class spills using occurrence rates based on data from 2001-2015 (ABSG Consulting, Inc. 2016) from Table 9 and 30 years of operation.

		Percent capacity		
		50	75	100
BBO handled in 30 years		11.169	16.7535	22.338
Spill size range	Spill rate per BBO handled	Expected numbers of spills		
1-9 bbl	9.77	109.12	163.68	218.24
10-49 bbl	4.44	49.59	74.39	99.18
50-999 bbl	2.66	29.71	44.56	59.42
>1,000 bbl	0.38	4.24	6.37	8.49
Total	17.25	192.67	289.00	385.33

Table 19. Number of expected spills by size class spills using occurrence rates based on data from 1974-2015 (ABSG Consulting, Inc. 2016) from Table 10 and 30 years of operation.

		Percent capacity		
		50	75	100
BBO handled in 30 years		11.169	16.7535	22.338
Spill size range	Spill rate per BBO handled	Expected numbers of spills		
1-9 bbl	17.27	192.89	289.33	385.78
10-49 bbl	4.73	52.83	79.24	105.66
50-999 bbl	2.54	28.37	42.55	56.74
>1,000 bbl	0.89	9.94	14.91	19.88
Total	25.43	284.03	426.04	568.06

Table 20. Number of expected spills by size class spills using occurrence rates based on data from 1972-2017 from Table 14 and 30 years of operation.

		Percent capacity		
		50	75	100
BBO handled in 30 years		11.169	16.7535	22.338
Spill size range	Spill rate per BBO handled	Expected numbers of spills		
50-99 bbl	0.81	9.05	13.57	18.09
100-999 bbl	1.76	19.66	29.49	39.31
1,000-10,000 bbl	0.76	8.49	12.73	16.98
>10,000 bbl	0.2	2.23	3.35	4.47
Total	3.53	37.19	55.79	74.39

Given the number of spills that may be expected (i.e., between 74 and 568 total spills can be expected at 100% capacity over 30 years) and noting that the calculated offshore pipeline spills only account for one potential spill source, the potential environmental impacts need to be re-evaluated.

The numbers of expected spills in Table 20 are based on the method that BOEM has used in other EISs. Still, it is important to know that the simplistic model of $N = RT$, where T = number of BBO handled and R is a constant, is not always the right one to use. I am showing what the conclusions would be if it were applied because BOEM typically wants to base spill occurrence on BBO handled. Since that is the method applied in BOEM (2012), which is cited in this DEIS for other reasons, it is logically consistent to apply it here. I am not saying that the numbers are any good, because as with all models, “Garbage in, garbage out.”

An alternative method for calculating spill occurrence is to use the amount of physical infrastructure and time of use as the exposure variable. For example, spills risks could be measured against the number of pipeline miles in use each year (Table 21). For this project, “A total of two collocated 36-inch O.D. 46.4-mile long crude pipelines would be constructed” (ERM 2020). This is a total of 92.8 mi, or 149.3 km of subsea pipeline.

Table 21. 90% Confidence intervals for GoM and Pacific OCS offshore pipeline, platform, and loss of well control (LOWC) hydrocarbon spills statistics (1972 to 2017). Data compiled from Tables 11, 12, and 13 (pp. 18-19 of BOEM 2018).

Source	Spill Size (bbl)	Lower bound	Mean Frequency	Upper bound	Unit
Pipeline	50-1,000	8.77	11.46	14.61	per 10^5 km-yr
	>1,000	2.70	4.27	6.29	
Platform	50-1,000	4.97	5.13	6.64	per 10^4 well-yr
	>1,000	0.12	0.29	0.61	
LOWC	50-100	0.04	0.18	0.40	per 10^4 well-yr
	100-1,000	0.07	0.22	0.44	
	1,000-1,0000	0.00	0.00	0.04	
	>10,000	0.00	0.04	0.20	
	LOWC Total	0.22	0.44	0.73	

Eschenbach and Harper (2006) computed the amount of oil produced and handled and the amount of infrastructure used to extract and transport it in the Gulf of Mexico and Pacific regions from 1972-2005 (Table 22, adapted from Table A12 in Lubetkin (2020)).

Table 22. A comparison of the offshore pipeline length used and oil volume produced in the Gulf of Mexico and Pacific from 1972-2005 and the expected yearly production for the SPOT DWP.

Source	Exposure variable: Pipeline	BBO handled	Infrastructure required Pipeline/BBO
Eschenbach and Harper (2006)	2.603 x 10^5 km-yr	13.535	19,232 km-yr/BBO
SPOT DEIS	149.3 km	0.7446 per year	200.5 km-yr/BBO

Before just blindly applying these rates per 10^5 km-yr (Table 21) of offshore pipeline to the SPOT DWP offshore pipeline length, it is important to recognize that the amount of oil moving that would move through those pipeline would do so at nearly 96 times the load per km-yr than in other projects in the Gulf of Mexico (Table 22).

7. **Although the expected number of spills in different size classes were not included in the DEIS, some worst credible scenario calculations and general impact analyses were included. I checked the calculations of worst credible discharges for subsea and onshore pipelines and found that the onshore pipeline volume did not account for flow rates when drag reducing agents are present.**

ERM (2020) (p. 38) uses a worst case discharge of 687,272 bbl for a subsea release. This is due to 30 minutes of release at 1.5 times the maximum flow rate and the volume in the pipeline that would drain after the pipeline is shut down:

0.5 hr x 1.5 x 85,000 bbl/hr + 623,522 bbl in the line =

63,750 bbl + 623,522 bbl =

687,272 bbl.

As I noted above, the DEIS's choice to assume a shut down time of 0.5 hours was unjustified and problematic. In Table 23, I show spill discharge volumes that could occur if it takes longer than 0.5 hours to shut down the offshore pipeline.

Table 23. What if it takes longer to shut down the pipeline?

Time to shut down pipeline (hrs)	x 1.5 x 85,000 bbl per hour	+ Volume in the pipeline (bbl)	= Discharge (bbl)
0.5	63,750	623,522	687,272
1	127,500	623,522	751,022
2	255,000	623,522	878,522
4	510,000	623,522	1,133,522
8	1,020,000	623,522	1,643,522
16	2,040,000	623,522	2,663,522
24	3,060,000	623,522	3,683,522
48	6,120,000	623,522	6,743,522

ERM (2020) (p. 41) uses a worst case discharge of 82,208 bbl on land from a pipeline or 600,000 bbl from a storage tank based on its working capacity.

The on-land pipeline is assumed to have 0.5 hours until shut down, a flowrate of 42,500 bbl/hr and a standing volume of 60,958 bbl:

0.5 hr x 42,500 bbl/hr + 60,958 bbl =

21,250 bbl + 60,958 bbl = 82,208 bbl.

Although I was able to reproduce the worst credible discharge calculations shown, I believe ERM (2020) missed an important detail. The flow rate for onshore pipelines could be up to 63,025 barrels per hour ("bph") when a drag reducing agent is used (DEIS p. 4-47), instead of the 42,500 bph used in the calculations shown thus far. If we account for that larger flow rate, the worst credible discharge from a pipeline on land is:

> 0.5 hr x 63,025 bbl/hr + 60,958 bbl =
>
> 31,512.5 bbl + 60,958 bbl = 92,470.5 bbl

and thus the value used in the DEIS is more than 10,000 bbl too small.

Summary

The SPOT DWP DEIS did not adequately model the risks of oil spills or consider its environmental impacts.

The oil spill risk analyses by Risknology (2019) and ERM (2020) were necessary but not sufficient for examining potential oil spills. Further, the two analyses relied on in the DEIS had technical flaws and results that differed from one another substantially.

The median volume for large spills used in the DEIS is based on data that are too limited in scope and not current, leading to an estimated median volume that is too small.

It is possible to calculate expected numbers of spills in different size categories using methodology used in previous work (BOEM 2012 and BOEM 2017) and updated spill and exposure data. As an example, I showed calculations of the number of spills expected in several size classes from offshore pipelines. As many as 21 large offshore spills (of greater than 1,000 bbl of oil) could be expected if the model applied in other settings (BOEM 2012 and BOEM 2017) is appropriate here. This is only a partial estimate of the number of spills that could occur because it only accounts for one infrastructure component.

The worst credible discharge estimate for pipelines on land did not use the flow rate achievable with a drag reducing agent. The worst credible scenario, and other scenarios, rely on spill volume modeling that assumes that the isolatable section that failed can be shut down in 30 minutes, for which no data were shown to justify how accurate or precise that figure is.

Given the number of offshore spills that may be expected (Table 20) and noting that the calculated offshore pipeline spills only account for one potential spill source, the environmental impacts of more spills of all sizes need to be considered, using updated occurrence rates and median volumes.

As a way of putting the size of the SPOT DWP oil volume ambitions in context, consider that the estimated 100% capacity barrels of oil that could be handled per year (7,446,000 bbl) exceeds the largest annual production amount ever recorded in the Gulf of Mexico (Table 11). Further, the potential for handling up to 22 BBO over 30 years is approaching the magnitude of cumulative OCS oil high production scenario (25.806 BBO) forecast for the entire Gulf of Mexico from 2017-2086 (BOEM 2017, p. 3-124, Table 3-19). For the Gulf of Mexico region, 29.29 oil spills >1,000 bbl are expected in that time frame. If the risks per BBO are similar for the SPOT DWP, the expected number of spills would also be similar, but in a compressed time frame (30 years instead of 70) and in a much smaller geographic area.

References cited

ABSG Consulting Inc. 2016. Update of Occurrence Rates for Offshore Oil Spills. Arlington, VA: Prepared by ABS Consulting Inc. for USDOI, BOEM/BSEE. 95 pp.

Anderson, C. M., Mayes, M, and LaBelle, R. 2012. Update of occurrence rates for offshore oil spills. OCS Report BOEM/BSEE 2012-06.

BLM. 2018. Alpine Satellite Development Plan for the Proposed Greater Mooses Tooth 2 Development Project Final Supplemental Environmental Impact Statement.

BLM. 2019. Coastal Plain Oil and Gas Leasing Program Final Environmental Impact Statement.

BOEM. 2012. Gulf of Mexico OCS Oil and Gas Lease Sales: 2012-2017. Western Planning Area Sales 229, 233, 238, 246, and 248; Central Planning Area Lease Sales 227, 231,235, 241 and 247. Final Environmental Impact Statement. OCS EIS/EA BOEM 2012-019.

BOEM. 2017. Gulf of Mexico OCS Oil and Gas Lease Sales: 2017-2022. Gulf of Mexico Lease Sales 249, 250, 251, 252, 253, 254, 256, 257, 259, and 261. Final Multi-sale Environmental Impact Statement. OCS EIS/EA BOEM 2017-009.

BOEM. 2018. US Outer Continental Shelf Oil Spill Statistics. OCS Study BOEM 2018-006. 44 pp.

BSEE. Spill Summaries OCS Spills ≥ 50 Barrels CY 1964 – 2013. https://www.bsee.gov/stats-facts/offshore-incident-statistics/spills-archive, https://www.bsee.gov/sites/bsee.gov/files/reports/incident-and-investigations/spills-greater-than-50-barrels1964-2012-as-of-august-3-2012.pdf

BSEE. Data Center: Annual Production for Entire Region. https://www.data.bsee.gov/Main/HtmlPage.aspx?page=annualRegion

BSEE. Data Center: Production: OCS production. Outer Continental Shelf Oil and Gas Production. https://www.data.bsee.gov/Production/OCSProduction/Default.aspx

ERM. 2020. Spill Risk Analysis. Appendix H of MARAD and USCG (2020).

Eschenbach, T. G. and Harper, W. V. 2006. Alternative oil spill occurrence estimators for the Beaufort/Chukchi Sea OCS (statistical approach). DOI, MMS, Alaska Outer Continental Shelf Region. OCS Study MMS 2006-059.

Lubetkin, S.C. 2020. The tip of the iceberg: Three case studies of spill risk assessments used in environmental impact statements. *Marine Pollution Bulletin.* https://doi.org/10.1016/j.marpolbul.2019.110613

MARAD and USCG. 2020. Sea Port Oil Terminal Deepwater Port Project Draft Environmental Impact Statement. MARAD 2019-0011.

PHMSA. Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data https://www.phmsa.dot.gov/data-and-statistics/pipeline/distribution-transmission-gathering-lng-and-liquid-accident-and-incident-data; accident_hardardous_liquid_jan2002_dec2009.zip and accident_hardardous_liquid_jan2010_present.zip; last accessed on March 19, 2020.

Risknology. 2019. Sea Port Oil Terminal Spill Risk Analysis. Sea Port Oil Terminal Project Offshore Brazoria County, Texas Application, Volume IIA, Appendix M.

SUSAN C. LUBETKIN, PhD

922 Nob Hill Ave N, Seattle, Washington 98109 (206) 719-4730
susan.c.lubetkin@gmail.com

SUMMARY

Environmental statistician interested in the intersections of science and policy, with specific focus and experience in climate change and ocean health.

Areas of expertise include:

- Experimental design, linear and nonlinear regression, bootstrap methods, mixed effects models, longitudinal models, non-parametric multiplicative regression, fault trees, risk analysis
- Statistical software, especially R Studio
- Communication of research results to both specialists and non-specialists, either in small groups or larger presentations
- Ability to see and find interconnections across disparate areas

RECENT EXPERIENCE

Independent analyst June 2015-present

- Research the data sets, assumptions, and statistical models contracted by and used within the Bureau of Ocean Energy Management to estimate the likelihood of substantial spills ($\geq$1,000 barrels) in the Chukchi and Beaufort Seas in environmental impact statements/environmental assessments related to oil drilling on the outer continental shelf (draft environmental impact statement (DEIS) review requested by Alaska Wilderness League)
- Critique the spill risk analysis in the Bureau of Land Management's (BLM's) Coastal Plain DEIS (review requested by Alaska Wilderness League) and the BLM's NPR-A DEIS
- Analyze and critique the transportation corridor spill risks of diesel, ore concentrate, and chemical reagents in the US Army Corps of Engineers Pebble Mine Draft Environmental Impact Statement as part of a team of scientists and attorneys collaborating with Salmon State; subject matter expert and associate producer on *The Wild*

Executive Director: Terra Nostra*, a multi-media symphony about climate change* July 2013-present

- Commissioned a symphony about climate change from Christophe Chagnard, which was performed by the Lake Union Civic Orchestra in June of 2015 at Meany Hall, University of Washington
- Laid the groundwork for starting *Terra Nostra* as a non-profit, showing the effectiveness of using music and images to illustrate the contemporary and local effects of climate change
- Led a successful $55,000 fundraising effort to professionally record the revised version of the score in January 2019 and create the next film version of the work to be shown in August 2019
- Oversaw getting the film version of *Terra Nostra* produced and submitted to film festivals around the country. Honors include *Best Original Score* (Top Shorts, October 2019), *Honorable Mention - Experimental Film* (Independent Shorts, November 2019), *Award of Merit - Nature/Environment/Wildlife* (Best Shorts Competition, December 2019), *Award of Merit - Documentary Short* (Impact DOCS, January 2020), inclusion in the American Documentary and Animation Film Festival (Palm Springs, California, March 2020)

Instructor, University of Washington January-December 2014

- Nomination for a Distinguished Teaching Award, December 2014, University of Washington
- Quantitative Science (QSci) 482: Statistical Inference in Applied Research I: Hypothesis Testing and Estimation for Ecologists and Resource Managers (Fall 2014, Summers 1999, 2000)
- Quantitative Ecology and Resource Management (QERM) 514: Analysis of Ecological and Environmental Data (Spring 2014)
- QSci 486: Analysis of Designed Experiments (Winter 2014)

RESEARCH POSITIONS

September 2011- February 2013
University of Washington Seattle, Washington

Post-doctoral research assistantship with Evelyn Lessard (School of Oceanography) using nonparametric multiplicative regression to characterize the environmental variables best for predicting harmful algal blooms of *Pseudo-nitzschia* spp. and the production of domoic acid in the Pacific northwest.

September 2008 – May 2010
University of Washington Seattle, Washington

Post-doctoral research assistantship with Judith Zeh (Department of Statistics) modeling bowhead whale baleen length and body length at age with several canonical growth models. This involved fitting nonlinear models to multivariate data and using bootstrapping procedures to then estimate the ages of whales with known baleen and/or body lengths.

September 1997- June 1998
National Oceanographic and Atmospheric Administration Seattle, Washington

Research assistantship with Sarah Hinckley modeling nutrient-phytoplankton-zooplankton dynamics along the coastal Gulf of Alaska

EDUCATION

2008 University of Washington Seattle, Washington

Ph.D., Quantitative Ecology and Resource Management (QERM): Using annual cycles of stable carbon isotope ratios with baleen and body length data from bowhead whales (*Balaena mysticetus*) to estimate whale age and explore anomalous years

My dissertation was focused on modeling the growth of bowhead whales, using stable isotope patterns in non-linear mixed effects (NLME) models and nonlinear regression techniques.

1997 University of Washington Seattle, Washington

M.S., QERM: Multi-source mixing models: food web determination using stable isotope tracers

I developed a model to use stable isotopes to estimate primary production and other nutrient flows through estuarine food webs.

1994 Harvey Mudd College Claremont, California

B.S., Biology

PUBLICATIONS

Peer reviewed articles and book chapters

Lubetkin, S.C. 2020. The tip of the iceberg: three case studies of spill risk assessments used in environmental impact statements. *Marine Pollution Bulletin*. Available online January 31, 2020. https://doi.org/10.1016/j.marpolbul.2019.110613

Lubetkin, S. C., Zeh, J. E., and George, J. C. 2012. Statistical modeling of baleen and body length at age in bowhead whales (*Balaena mysticetus*). *Canadian Journal of Zooloogy*. 90: 915-931.

Lubetkin, S. C., Zeh, J. E., Rosa, C., and George, J. C. 2008. Age estimation for young bowhead whales (*Balaena mysticetus*) using annual baleen growth increments. *Canadian Journal of Zooloogy*. 86: 525-538.

Lubetkin, S. C. and Simenstad, C. A. 2004. Two multi-source mixing models using conservative tracers to estimate food web sources and pathways. *Journal of Applied Ecology 41*: 996-1008.

Schindler, D. E. and Lubetkin, S. C. 2004. Using stable isotopes to quantify material transport through food webs. Pp. 25-42 in Gary A. Polis, Mary E. Power, and Gary R. Huxel, eds., *Food Webs at the Landscape Level*. University of Chicago Press.

Schindler, D.E., Chang, G. C., Lubetkin, S. C., Abella, S. E. B., and Edmondson, W. T. 2002. Rarity and functional importance in a phytoplankton community. Pp. 206-220 in Peter Kareiva and Simon A. Levin, eds., *The Importance of Species*. Princeton University Press.

In preparation

George, J.C., S. C. Lubetkin, H. Thewissen, J. E. Zeh, and G. Givens. Age estimation in bowhead whales. Forthcoming chapter in the second edition of *The Bowhead Whale*.

Lubetkin, S. C., Zeh, J. E., Rosa, C., and George, J. C. Evidence of a decadal scale shift in the carbon sources for the Beaufort and Bering Seas from stable isotopic records in bowhead whale (*Balaena mysticetus*) baleen.

Lubetkin, S. C., Zeh, J. E., Rosa, C., and George, J. C. Bowhead whale (*Balaena mysticetus*) migration pattern changes in response to changing ice dynamics in the Arctic.

Lubetkin, S. C., Zeh, J. E., Rosa, C., and George, J. C. Stable isotopic evidence of bowhead whales (*Balaena mysticetus*) not migrating from the Bering Sea to the Beaufort Sea: frequency, characteristics, and ecological implications.

MEETING PRESENTATIONS, WORKSHOPS

Lubetkin, S.C. 2020. The tip of the iceberg: three case studies of spill risk assessments used in environmental impact statements. Poster at the Alaska Marine Sciences Symposium, January 27-30, 2020.

September 22-23, 2016, Washington, DC. Science and Tools for Developing Arctic Marine Protected Area Networks: Understanding Connectivity and Identifying Management Tools. Invited participant to the Arctic Council, Protection of the Arctic Marine Environment (PAME) scientific working group.

Lubetkin, S. C., and Lessard, E. J. 2013. Habitat modeling of *Pseudo-nitzschia* distribution and toxicity in the coastal waters of the northwest Pacific using non-parametric multiplicative regression. Poster at the 7th Annual Harmful Algal Bloom Symposium, Sarasota, Florida, October 2013.

Lubetkin, S. C., and Lessard, E. J. 2013. Habitat modeling of *Pseudo-nitzschia* distribution and toxicity in the coastal waters of the northwest Pacific using non-parametric multiplicative regression. Oral presentation at the Association for the Sciences of Limnology and Oceanography meeting, New Orleans, Louisiana, February 2013.

Lubetkin, S. C., and Zeh, J. E. 2006. Deriving age-length relationships for bowhead whales (*Balaena mysticetus*) using a synthesis of age estimation techniques. Paper SC/58/BRG14 presented to the International Whaling Commission Scientific Committee, June 2006.

Lubetkin, S. C., Zeh, J. E., Rosa, C., and George, J. C. 2004. Deriving von Bertalanffy age-length relationships for bowhead whales (*Balaena mysticetus*) using a synthesis of age estimation techniques. Paper SC/56/BRG3 presented to the IWC SC, June 2004.

Lubetkin, S. C. 2000. Bowhead whale age determination: extending estimates from baleen stable isotope signatures. Oral presentation at the 4th Meeting of the Society of Marine Mammalogy Northwest Student Chapter. University of Washington, Seattle, Washington, April 29, 2000.

Lubetkin, S. C. and Simenstad, C. A. 1997. Food web determination using a multiple stable isotope mixing model. Poster at the 14th Biennial Estuarine Research Federation International Conference: The State of Our Estuaries. Providence, Rhode Island, October 12-16, 1997.

November 7-9, 1996, Savannah, Georgia. Land Margin Ecosystems Research Program Workshop. (Participant with Charles Simenstad.)

February 3-6, 1996, Woods Hole, Massachusetts. Land Margin Ecosystems Research Program Workshop. (Participant with Charles Simenstad.)

COMMUNITY INVOVLEMENT AND SERVICE

Alaska Wilderness League Leadership Council (charter member, January 2019-present)

Social Venture Partners (partner from 2005-present)
- Inaugural cohort of the Conservation Philanthropy Fellowship Program in Autumn 2013
- Service on the Environment Collective Action Team (EnviroCAT) (October 2015-present, co-chair June 2017-present)

Lake Union Civic Orchestra (cello, 1995-present)

Sustainable Seattle Board of Directors (October 2015-October 2017)