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Independent Risk Analysis for the Straits Pipelines

A Multi-organizational Initiative Led by Michigan Technological University for the State of Michigan - Project ID: 1801011

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Acronym and Abbreviated Phrase List

ACGIH	American Conference of Governmental Industrial Hygienists
ACP	Area Contingency Plan
ADIOS	Automated Data Inquiry for Oil Spills
AGI	Adjusted Gross Income
AIChE	American Institute of Chemical Engineers
ALOHA	Areal Locations of Hazardous Atmospheres
AQM	Actuarial QNRA Methods
ARPA	Archaeological Resources Protection Act of 1979
AT	Averaging Time
ATC	American Transmission Company
ATSDR	U.S. Agency for Toxic Substances and Disease Registry
B[a]P	Benzo[alpha]pyrene
BBL, bbl	Oil Barrel (42 U.S. gallons)
BRFS	Behavioral Risk Factor Survey
BRFSS	Behavioral Risk Factor Surveillance System
BTC	Baku-Tbilisi-Ceyhan (pipeline)
BTEX	Benzene, Toluene, Ethylbenzene and Xylene

BTU	British Thermal Unit
BW	Body Weight
CCPS	Center for Chemical Process Safety
CDC	U.S. Centers for Disease Control and Prevention
CDE	California Department of Education
CEAA	Canadian Environmental Assessment Act of 1992/2012
CEAM	Consumer Energy Alliance
CFR	Code of Federal Regulations
CNS	Central Nervous System
CoPC	Chemicals of Potential Concern
COPD	Chronic Obstructive Pulmonary Disease
CPM	Computational Pipeline Monitoring
CR	Contamination Rate
CSF	Cancer Slope Factor
CXPA	Semi-volatile Aromatic Compounds
CXVO	Volatile Organic Compounds
DARP	Damage Assessment and Restoration Plan
DED	Explosion Duration (in one year)
DEQ	Department of Environmental Quality

DNR	Department of Natural Resources
DOJ	U.S. Department of Justice
DOT	U.S. Department of Transportation
DR	Dynamic Risk Assessment Systems, Inc.
ED	Exposure Duration
EF	Ecological Factor
EIA	U.S. Energy Information Administration
EMS	Emergency Medical Services
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ET	Exposure Time
ETA	Event Tree Analysis
EVOSTC	Exxon Valdez Oil Spill Trust Council
FDA	U.S. Food and Drug Administration
FEMA	Federal Emergency Management Agency
FNMI	First Nations, Métis, and Inuit communities or persons (Canadian usage)
FOSC	Federal On-Scene Coordinator
FVCOM	Finite Volume Community Ocean Model

GAO	Government Accountability Office
GDM	Gaussian Dispersal Model
GIS	Geospatial Information Systems
GLAHF	Great Lakes Aquatic Habitat Framework
GLERL	Great Lakes Environmental Research Laboratory/NOAA
GLSLA	Great Lakes Submerged Lands Act
GNOME	Generalized NOAA Oil Modeling Environment
H_2S	Hydrogen Sulfide
HHRA	Human Health Risk Assessment
HQ	Hazard Quotient
HRRR	High-Resolution Rapid Refresh
IAP	Incident Action Plan
IARC	International Agency for Research on Cancer (WHO)
IBA	Audubon Society Important Bird Areas
ICMS	Incident Control Management System
ICP	Incident Command Protocol
ICS	Incident Command System
IDHL	Immediately Dangerous to Life or Health
ILCR	Incremental Lifetime Cancer Risk

IR	Inhalation Rate
IRIS	Integrated Risk Assessment System
JFO	Joint Field Office
LARA	Department of Licensing and Regulatory Affairs
LD	Leak Detection
LFL	Lower Flammability Limit
Line 5	Enbridge Pipeline Located in the Straits of Mackinac, Enbridge Energy Limited Partners' Line 5 pipeline system
LMAS	Luce, Mackinac, Alger, and Schoolcraft Counties (Health region)
LMHOFS	Lake Michigan-Huron Operational Forecast System
LOC	Level of Concern
LP	Lower Peninsula of Michigan
LTBB	Little Traverse Bay Bands of Odawa Indians
MAE	Michigan Agency for Energy
MCM	Monte Carlo Method
MDCH	Michigan Department of Community Health
MDEQ	Michigan Department of Environmental Quality
MDHHS	Michigan Department of Health and Human Services
MDNR	Michigan Department of Natural Resources

MH	General fishery management area in Lake Huron
Michigan Tech	Michigan Technological University
MIKE/OS	Range of proprietary software products that permit the analysis, modeling, and simulation of a variety of hydrologic and hydrodynamic scenarios
MM	General fishery management area in Lake Michigan
MNFI	Michigan Natural Features Inventory
MOSSFA	Marine Oil Snow Sedimentation and Flocculent Accumulation
MSG	Michigan Sea Grant
MSHP	Mackinac State Historic Parks
MTRI	Michigan Tech Research Institute
NEPA	National Environmental Policy Act of 1970
NGDC	National Geophysical Data Center
NGL	Natural Gas Liquids
NHPA	National Historic Preservation Act of 1966 (16USC470)
NIMS	National Incident Management System
NLH	Northern Lake Huron
NLM	Northern Lake Michigan
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration

NOAA ESI	NOAA Environmental Sensitivity Index
NPDWR	National Primary Drinking Water Regulations
NRDA	Natural Resource Damages Assessment
NRF	National Response Framework
NRS	National Response System
OEHHA	Office of Environmental Health Hazard Assessment
OHWM	Ordinary High Water Mark
OPA	Oil Pollution Act
OPS	Office of Pipeline Safety
OSHA	Occupational Safety Health Administration
OSLTF	Oil Spill Liability Trust Fund
OSRO	Oil Spill Removal Organization
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PEC	Probable Effect Concentration
PHMSA	Pipeline and Hazardous Materials Safety Administration (U.S. Department of Transportation)
PPB	Parts Per Billion
PPE	Personal Protective Equipment

PPM	Parts Per Million
PQM	Predictive Quantitative Risk Analysis Method
PRA	Population Risk Analysis
PRI	Population Risk Indicator
PSAB	Pipeline Safety Advisory Board
PSI	Pounds per Square Inch
PTSD	Post-Traumatic Stress Disorder
QLRA	Qualitative Risk Analysis
QNRA	Quantitative Risk Analysis
RAP	Rational Action Paradigm
RfD	Reference Dose
RL	Risk Level
RMP	Risk Management Plan
ROC	Response Options Calculator (Genwest modeling software)
ROW	Right of Way
RR	Relative Risk
RUM	Random Utility Maximization
SAV	Submerged Aquatic Vegetation
SCADA	Supervisory Control and Data Acquisition

SCAT	Shoreline Cleanup Assessment Technique
SDS	Safety Data Sheet
SEF	Socioeconomic Factor
SHPO	State Historic Preservation Office
SLO	Social License to Operate
SONS	Spill of National Significance
SOW	Scope of Work
SPCC	Spill Prevention, Control, and Countermeasure (EPA rules)
SQG	Sediment Quality Guidelines
SQM	Synthesis QNRA Methods
SSX	Shell Synthetic Light
State	Collectively, Michigan Departments of Environmental Quality and Natural Resources, the Michigan Agency for Energy, and the Michigan Office of Attorney General
TEC	Threshold Effect Concentration
TEF	Toxicity Equivalency Factor
THPO	Tribal Historic Preservation Office
TIR	Total Individual Risk
TLV	Threshold Limit Value
TPH	Total Petroleum Hydrocarbons

TRP	Tactical Response Plan
TVOC	Total Volatile Organic Carbons
UAC	Unified Area Command
UCL	Upper Confidence Limit
UFL	Upper Flammability Limit
UP	Upper Peninsula of Michigan
UR	Unit Risk
USCG	U.S. Coast Guard
USDOT	U.S. Department of Transportation
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USG	Unified Coordination Group
USGS	U.S. Geological Survey
UVCE	Unconfined Vapor Cloud Explosion
VCE	Vapor Cloud Explosion
VOCs	Volatile Organic Compounds
WFH	Whitefish Fisheries Management Areas in Lake Huron
WFM	Whitefish Fisheries Management Areas in Lake Michigan
WHO	World Health Organization

WQS	Water Quality Standard
WRF	Weather Research and Forecasting
WTP	Willingness to pay (total willingness to pay less in expenditures, which is an economic measure of net benefit often referred to as consumer surplus)
ZOPE	Zone of Potential Exposure

Introduction

The Straits of Mackinac hydraulically link Lakes Michigan and Huron (Figure 1), and are wide and deep enough (average depth 20 m) to permit the same average water level in both water bodies, technically making them two lobes of a single large lake. The combined Michigan–Huron system forms the largest lake in the world by surface area and the fourth largest by volume, containing nearly 8% of the world's surface freshwater. The Straits of Mackinac also provide an important recreation and tourism area, fishing ground (including part of the 1836 treaty-ceded waters to which several tribes retain fishing rights), and waterway for commercial shipping.

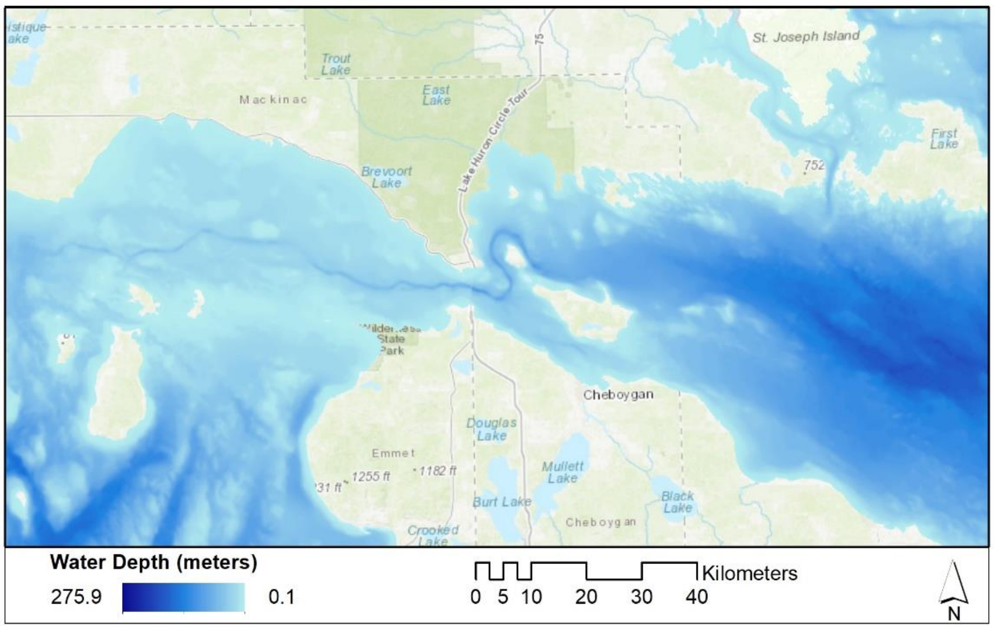

Figure 1. Straits of Mackinac and the surrounding area. Bathymetry provided by the Great Lakes Aquatic Habitat Framework (glahf.org)

This report provides an assessment of the potential costs of a worst-case hydrocarbon spill from Enbridge Energy Limited Partners' Line 5 pipeline system (Line 5) in the Straits of Mackinac. This assessment was conducted over the first half of 2018 by Michigan Technological University and its subcontractors, and was performed for the Michigan Departments of Environmental Quality and Natural Resources, the Michigan Agency for Energy, and the Michigan Office of Attorney General (collectively the State) as recommended in the Michigan Petroleum Task Force Report of July 2015. As discussed in pp 40-50 of that report, the Straits Pipelines are a segment of Line 5, which transports light crude oil and natural gas liquids. They consist of two 20" outside diameter pipelines submerged at the Straits of Mackinac. The Straits Pipelines were constructed in 1953 and operate under the terms of a 1953 Easement granted by the State to Enbridge's predecessor. They form part of a line that runs for 645 miles from Wisconsin, under the Straits of Mackinac, and through Michigan to Sarnia, Ontario. This assessment was limited to the potential impacts of spills specifically from the Straits Pipelines segment of Line 5, though other portions of the line are also located near Great Lakes shorelines and cross navigable waters.

As specified in the State of Michigan's Request for Proposals, the Scope of Work (SOW) for this project requires completion of an independent risk analysis for the Straits Pipelines as described in the Task Force Report. Recommendation 2.a. of the Task Force Report includes assessments of the duration and magnitude of a worst-case spill, the likely transport and fate of released products, the timeline for cleanup, the impacts on public health and safety, the short- and long-term ecological impacts, the options for mitigating and restoring damage to ecological and cultural resources, and the economic costs (private, public and governmental) for all damages that can be thus quantified. To perform this assessment, Michigan Technological University (Michigan Tech) assembled a team of recognized experts from Michigan Universities and beyond in subjects including engineering, hydrodynamics, public health, ecology/environmental science, economics, resource management, and social science. The abovementioned areas of interest were described as separate tasks in the scope of work, and a team of relevant experts was assigned to each task. The following reports summarize the scope, methods, and findings for each task.

Due to the uniqueness of the Straits of Mackinac and the Great Lakes, no historical spill presents a comparable case study from which impacts of a Straits spill could be estimated directly. The July 2010 spill from Enbridge's Line 6B into a tributary of Michigan's Kalamazoo River represents the best model in some respects, the dilbit that was released from Line 6B is much heavier than the products that are transported in Line 5, leading to significantly different impacts and cleanup requirements. Additionally, that spill did not reach the waters of the Great Lakes. More broadly, most previous studies have focused on the impacts of spills on saltwater marine and coastal environments, leading to gaps in our knowledge regarding the impacts and effective cleanup methods for oil spills on freshwater systems. Inland freshwater oil spills differ from coastal or marine spills in several respects. Inland spills have a much higher potential to contaminate drinking water supplies, to affect areas of concentrated populations, and to impact manmade structures and human activities. Additionally, currents are the driver of oil dispersal and transport in a Great Lakes spill, whereas the wave and tidal action that drives transport and shoreline oiling along ocean coasts are less important. Therefore, some assumptions based on the best available information were necessary to estimate the potential impacts of a worst-case spill from Line 5. These include the location and size of the leak; weather and current conditions; the immediate and longer-term response timelines; public exposure to spilled materials; duration of water intake, beach and coastal area closures; and market recovery times.

This assessment serves to complement the Alternatives Analysis for the Straits Pipeline commissioned by the State in 2017. The original intent was that this independent risk analysis would be completed at the same time; however, the first attempt at such an assessment was halted in June 2017 by the State of Michigan. The State subsequently identified Michigan Tech as a potential project lead for a multi-institution team to take over the risk analysis. Michigan Tech was identified because of the faculty's extensive knowledge of the complex flows in the Straits of Mackinac region. The director of Michigan Tech's Great Lakes Research Center, Dr.

Guy Meadows, served on the State's Pipeline Safety Advisory Board (PSAB) as the representative of state universities at that time and therefore he recused himself of voting on the matter. The other members of the PSAB voted unanimously to recommend that the State of Michigan contract with Michigan Tech. Subsequently, Dr. Meadows resigned from the PSAB to lead the new risk analysis proposal development.

The worst-case approach implemented here is based on the accumulation of worst-case assumptions, consistent with the federal definition of "the largest foreseeable discharge of oil" in 40 CFR 194.5, to yield, in theory, the maximum possible loss level. As such, it intentionally does not involve any notion of probability (Fidler and Wennersten, 2007). As a result, this assessment extends to risks with low probabilities of occurrence but large consequences. This differs in aim from the "most credible major accident" scenario laid out in the 2017 Alternatives Analysis, as summarized in the final report,

> *the risk and economic consequence estimates [in the Alternatives Analysis] do not correspond to those that would be derived by layering extreme worst-case assumptions pertaining to failure probability and consequence upon one another. To do so would result in unquantifiable levels of risk amplification, leading to results that are inconsistent with expected outcomes. This would be an ineffective basis for comparison of risk among multiple alternatives, which is the chief objective of the analysis. Instead, as described in this Final Report, risk, and the economic consequence evaluation that is based on those estimates of risk, are best characterized as being based on a most credible worst-case scenario. Prediction of the extreme worst-case scenario applies more accurately to the scope of the Risk Analysis that was contracted by the State under Michigan's Request for Information and Proposals on that subject as presented in the following: https://mipetroleumpipelines.com/document/risk-analysis-final-rfp.* (Dynamic Risk, 2017, p. PR-4)

The "worst-case scenario" for a Straits Pipelines spill has a federal definition concerning the spilled volume, but the seasonal timing that would result in the most severe impacts varies across the subtasks of this assessment. For example, a winter spill would be the most difficult to respond to safely and effectively; a spring spill would generate the highest economic costs, as outlined in the report for Tasks G and I; and a summer spill would pose the highest risks to public health and safety due to the seasonal changes in population in the Straits area, as described in the report for Task D. To effectively capture the worst foreseeable scenario for each of these areas that the State described as a subtask in the assessment scope of work, the same spill volume and location was carried across all tasks, but the spill timing assumed for evaluation varied depending on the worst outcome for that particular task's focus area. Worst case spills occurring at different times of year were assumed to affect different geographic areas based on actual seasonal weather conditions modeled as part of Task B. The specific scenarios used as case studies for each task, and the rationales for selecting them, are provided in Table 1 below. This variation among tasks was intended to allow the assessment to capture the worst-case damages in each of these independent and important spheres, but it is important to understand that due to these seasonal differences, no single spill could cause all of the worst-case impacts described throughout this report. The spring scenario adopted by Tasks G and I is used as the representative scenario to estimate the overall liability from a worst-case scenario spill at the Straits.

Table 1. Summary of the specific spill scenarios that were selected as the case studies for each task of the assessment. The fate and transport of oil for each time and location was modeled as part of Task B using actual current and weather data for the year 2016. Related tasks (E and F; G, H and I) focused on the same scenarios for consistency. 'Release location' refers to the three locations along the pipeline modeled as spill origin sites (see Figure A3).

Assessment Task(s)	Simulation Date	Release location	Map	Rationale
C	12/27	Center (Loc. 3)	Figure C5	Longest oiled shoreline 6 hours into spill, difficult winter conditions
D	7/25	North (Loc. 2)	Figure D2	Largest area of floating oil 12 hours after the spill begins during the month of July
E and F Scenario 1	4/3	Center (Loc. 3)	Figure E2	Longest oiled shoreline in Lake Michigan after 10 days
E and F Scenario 2	2/3	North (Loc. 2)	Figure E2	Longest oiled shoreline in Lake Huron after 10 days
E and F Scenario 3	3/12	South (Loc. 5)	Figure E3	Longest oiled shoreline in Lake Michigan after 60 days
E and F Scenario 4	1/19	North (Loc. 2)	Figure E3	Longest oiled shoreline in Lake Huron after 10 days
G, H and I Scenario 1	3/1	Center (Loc. 3)	Figure GI7	Longest oiled shoreline for a March spill (a spring spill has the greatest effect on resource use)
G, H and I Scenario 2	4/24	South (Loc. 5)	Figure GI7	Longest oiled shoreline for a April spill (a spring spill has the greatest effect on resource use)
G, H and I Scenario 3	5/12	Center (Loc. 3)	Figure GI7	Longest oiled shoreline for a May spill (a spring spill has the greatest effect on resource use)

References

Fidler, J., & Wennersten, R. (2007). What is a worst case scenario for a potential accident and how can it be used? In *IChemE SYMPOSIUM SERIES* (No. 153).

Dynamic Risk Assessment Systems, Inc. (2017). Alternatives Analysis for the Straits Pipelines – Final Report, p. PR-4. Document number SOM-2017-01-RPT-001. Retrieved from https://mipetroleumpipelines.com/document/alternatives-analysis-straits-pipeline-final-report

Task A: Identifying and analyzing the duration and magnitude of a "worst-case" spill or release of oil or other product from the Straits Pipelines into the environment

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A.1 Introduction

Recent large-scale incidents such as the Deepwater Horizon and Kalamazoo River oil spills have underlined the need for oil and gas operators to demonstrate to the satisfaction of all interested stakeholders that they are operating safely and can respond promptly and effectively to any plausible spill. To instill such confidence, the duration and magnitude of the maximum plausible spill must be estimated, grounded as well as possible on facts and calculations derived from the best available information. The purpose of this task was to develop an independent estimate of the magnitude of the maximum plausible spill at the Enbridge Line 5, Straits of Mackinac crossing based on site conditions, pipeline specifications, and discrimination by domain experts as to what scenarios should be considered plausible. In particular, Task II-A of the State's SOW specifies "Identifying and analyzing the duration and magnitude of a "worst case" spill or release of oil or other products from the Straits Pipelines into the environment." This would include identifying the "worst case discharge" consistent, at a minimum, with the definition of that term in 40 CFR 194.5 as "the largest foreseeable discharge of oil, including a discharge from fire or explosion, in adverse weather conditions." The identification of the "worst case" should also consider, consistent with best practices in high-hazard industries, the maximum potential release, before applying engineering and procedural controls intended to minimize releases. The identification of the "worst case" also calls for the most adverse foreseeable weather conditions including, but not limited to, storms and/or ice cover. The analysis should include, but not be limited to, consideration of the following:

1. The design and placement of the existing pipelines, control systems, leak detection methods, and shut-off valves to determine the various types of physical or operational failures or other potential hazards that could result in releases of oil or other products, including both sudden releases and longer-term releases that could be undetected using the existing systems;

2. The types of products being transported and the maximum design flow rate;

3. The potential failure of release detection methods, control systems, or shut-off valves to operate as intended;

4. The quantity of the oil or other products that could be released at the maximum design flow rate before the flow is cut off; and

5. The quantity and fate of oil or other products remaining in the affected pipeline(s) at the maximum design flow rate after the flow is cut off.

A worst-case scenario is understood to be a sequence of events/actions/accidents for a certain location and time that causes the worst possible magnitude of an accident. However, the particulars of estimating such a scenario vary across agencies and industries. In a US EPA (Environmental Protection Agency) Risk Management Plan (RMP), a worst-case scenario would entail a complete failure in which no safety equipment works except for passive measures such as drains, dikes, and basins, with weather conditions, assumed to be the worst possible (USEPA 2009). The US Coast Guard's Area Contingency Plan for Sector Sault Sainte Marie, which includes the Straits, specifies that the worst-case discharge from a pipeline "would be its entire contents between two automatic shut-off locations as the pipeline transits along, over, under or through a navigable water or adjacent shoreline." In the US, the oil and gas pipeline industry is governed by US Department of Transportation PHMSA (Pipeline and Hazardous Materials Safety Administration) regulations but is not regulated by the Occupational Safety Health Administration (OSHA) or EPA RMP. Under PHMSA's definition of worst-case discharge volume (49 CFR 194.105), pipeline operators can claim credit for spill prevention measures such as active controls, maintenance, testing, and secondary containment, reducing the worst case discharge volume on a percentage basis.

The current assessment was not required to adhere to the regulatory standards of any particular agency apart from the 40 CFR 194.5 definition of the worst case as "the largest foreseeable discharge of oil, including a discharge from fire or explosion, in adverse weather conditions". Therefore, this assessment began from the above definition and considered a number of plausible scenarios assuming different primary causes, combined with secondary failures of various engineering and procedural controls. Prevention measure credits such as those allowable under PHMSA standards were not considered, but realistic assumptions were made regarding the physical processes that would limit the release and movement of the materials transported in Line 5 in the event of an underwater breach.

Previous assessments to which these results could be compared include the scenario developed by Enbridge to meet PHMSA regulatory requirements; the memo "Defining a Worst Case Release Scenario for the Enbridge Crude Oil Pipelines Crossing the Straits of Mackinac – Line 5", submitted to the PSAB by Richard Kane in 2017 on behalf of the 501(c)3 nonprofit FLOW (For Love Of Water); and the spill consequence analysis performed for the 2017 "Alternatives Analysis for the Straits Pipelines" prepared by Dynamic Risk, Inc. The assumptions made for all three of these assessments and the current work are summarized in Table A1. The Enbridge scenario was calculated to meet specific regulatory requirements rather than identify the maximum plausible spill volume. The 2017 Alternatives Analysis estimated the average consequences of a spill based on the mean shoreline oiling from 120 modeled spills for comparison with the risks of alternatives to Line 5, and so was also not, and was not intended to be, a true worst-case scenario. This table is referenced several times going forwards in this section to communicate the reasons for the differences between the results presented here and those previous works.

Table A1: Comparison of assumptions for this and previous estimates of spill volumes at the Straits.

	Enbridge Maximum Potential Release Volume	**FLOW May 2018 Straits Spill Damages Memo**	**Dynamic Risk Alternatives Analysis (2017)**	**Michigan Tech-led Independent Assessment (this report)**
Flow rate	600,000 bbl/day (Based on commercial capacity + 10%; ~3,975 m^3/hr) and assumes full design flow rate through one 20" pipeline	Not defined	1,789 m^3/hr per 20"pipeline (total 3578 m^3/hr, 540,000 bbl/day), assumes flow is split evenly between east and west lines	614,238 bbl/day (max flow rate in Enbridge-provided operational data + 5%; ~4,069 m^3/hr), assumes flow is split evenly between east and west lines
Leak size and location	Full-bore rupture of one pipeline	Rupture within the Straits crossing, detailed scenario not provided	4 scenarios: Full-bore rupture of either west or east pipeline at the bottom of shipping channel; 3" leak at either north or south end of east pipeline	Tier 1: 36 scenarios: 3" leaks and full-bore ruptures modeled at 6 critical locations along each pipeline; Tiers 2-5: 6 scenarios: double rupture at same 6 critical locations
CPM detection	Immediate	Not defined	Immediate for rupture cases; 20 min for 3" leak cases	Immediate for rupture and 5 minutes for a 3" or larger hole leak detection

	Enbridge Maximum Potential Release Volume	**FLOW May 2018 Straits Spill Damages Memo**	**Dynamic Risk Alternatives Analysis (2017)**	**Michigan Tech-led Independent Assessment (this report)**
Valves	Assumed to be operational	Assumes that automated and remote valve closing mechanisms fail, requiring manual closing of valves	Assumed to be operational	Tier 1: Assumed to be operational; Tier 2: Primary valves fail; Tier 3: Tiers 3 and 4: primary and secondary valves fail; Tier 5: all automated/remote valve closure fails and primary/secondary valves are manually closed
Shutdown time	Valves are remotely closed in 3 minutes	Remote valves do not work; manual valve closing occurs 2 hours after the spill begins, assumes full flow until shutdown	Valves are remotely closed in 3.5 minutes	Valves are remotely closed in 3.5 minutes except Tier 5 manual closure (2 hours)
Decision time	10 minute decision time after leak detection	Not defined	10 minute decision time after leak detection	10 minute decision time after leak detection
Drain-down	Accounts for backpressure and specific gravity differences limiting the release volume	Not defined	Accounts for backpressure and specific gravity differences limiting the release volume	Accounts for backpressure and specific gravity differences limiting the release volume
2-phase flow	Not mentioned	Not mentioned, though a 2017 memo from FLOW assumed that depressurization of NGL upstream could drive crude down the line	Not mentioned	Incorporated by assuming a minimum release of at least 15% of the crude oil remaining in the pipeline after isolation regardless of location
WCS volume(s)	6,428 bbl if valves close properly, 19,164 bbl if they do not close in the designed time frame	59,500 bbl	Approx 2,600 bbl for rupture case and 2,900-4,500 bbl for north or south shore 3" leak	Between 4,400 and 58,000 bbl

A.1.1 Guiding Requirements

As required by the Code of Regulations, Title 49, Volume 3, Part 194 - Response Plans for Onshore Oil Pipelines, as cited below, the worst case maximum release must include the maximum shutdown response time in hours at the maximum flow rate.

“TITLE 49--TRANSPORTATION

CHAPTER I--RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION, DEPARTMENT OF TRANSPORTATION

PART 194--RESPONSE PLANS FOR ONSHORE OIL PIPELINES

Subpart B--Response Plans

Sec. 194.105 Worst case discharge.

Each operator shall determine the worst case discharge for each of its response zones and provide the methodology, including calculations, used to arrive at the volume.

The worst case discharge is the largest volume, in barrels, of the following:

The pipeline's maximum release time in hours, plus the maximum shutdown response time in hours (based on historic discharge data or in the absence of such historic data, the operator's best estimate), multiplied by the maximum flow rate expressed in barrels per hour (based on the maximum daily capacity of the pipeline), plus the largest line drainage volume after shutdown of the line section(s) in the response zone expressed in barrels; or

The largest foreseeable discharge for the line section(s) within a response zone, expressed in barrels, based on the maximum historic discharge, if one exists, adjusted for any subsequent corrective or preventive action taken; or

If the response zone contains one or more breakout tanks, the capacity of the single largest tank or battery of tanks within a single secondary containment system, adjusted for the capacity or size of the secondary containment system, expressed in barrels."

As described in the Introduction to this report, in contrast with the probability-based "worst case" presented in Dynamic Risk's Alternatives Analysis, the worst case approach presented in this report is based on the accumulation of worst-case assumptions and does not involve a probabilistic assessment of the risk of pipeline failure. Given this premise, the spill volumes estimated here are larger than would be expected in the spill scenarios that are most likely to occur. For context, Appendix A-2 summarizes the largest pipeline spills that have occurred in the last several years in the US.

A.2 Input Data and Assumptions

A.1.2 Basic Information

As defined in 49 CFR 194.105(b), the worst case discharge in barrels for a pipeline spill is the maximum spill detection time plus the maximum response time required to shut down the pipeline in hours, multiplied by the maximum flow rate expressed in barrels per hour, plus the largest possible line drainage volume after shutdown of the line. These values were calculated based on public information, some of which is summarized in Table A2 below, combined with confidential pipeline data (3-D location of the pipeline, specifications, operations data) provided directly to the team by Enbridge.

Table A2: Basic Information of Straits Crossing Pipelines

Outer Diameter	20"
Inner Diameter	18.376"
Wall Thickness	Minimum 0.812"
Length (West Straits Segment)	3.9 miles
Material Grade	API 5L Grade A
Maximum Operation Pressure	425 psi
Manufacturing Process	Seamless
Year of Installation	1953
Station at North Side	North Strait Station
Station at South Side	Mackinaw Station

Based on adding a conservative margin to the operations data provided by Enbridge, the maximum flow rate ever expected is approximately 25,591 bbl/h. The provided data also indicates that the pipeline's average flow rate in winter is slightly higher than the flow rate in summer, hence in this analysis winter conditions are assumed.

A.2.2 Isolation Valves

At each end of the Line 5 Straits crossing, there are isolation valves on each 20 " pipeline (Primary Valves) as well as on the 30" pipeline close to where the 20" lines meet (Secondary Valves) (Figure A1).

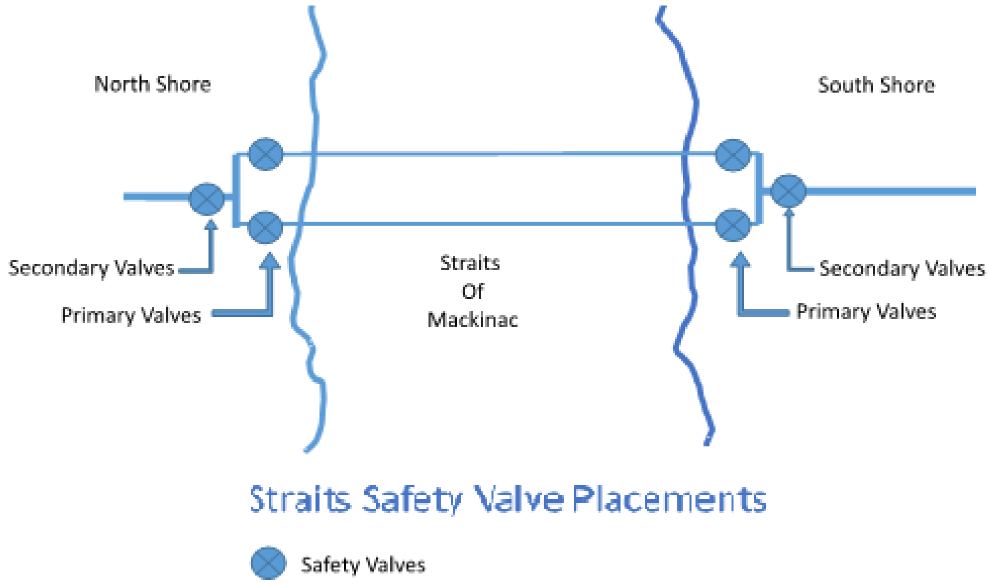

Figure A1: Locations of isolation valves north and south of the Straits crossing.

A.2.3 Elevation Profile and Critical Locations

The elevation profile of the Straits crossing pipelines is shown below in Figure A2.

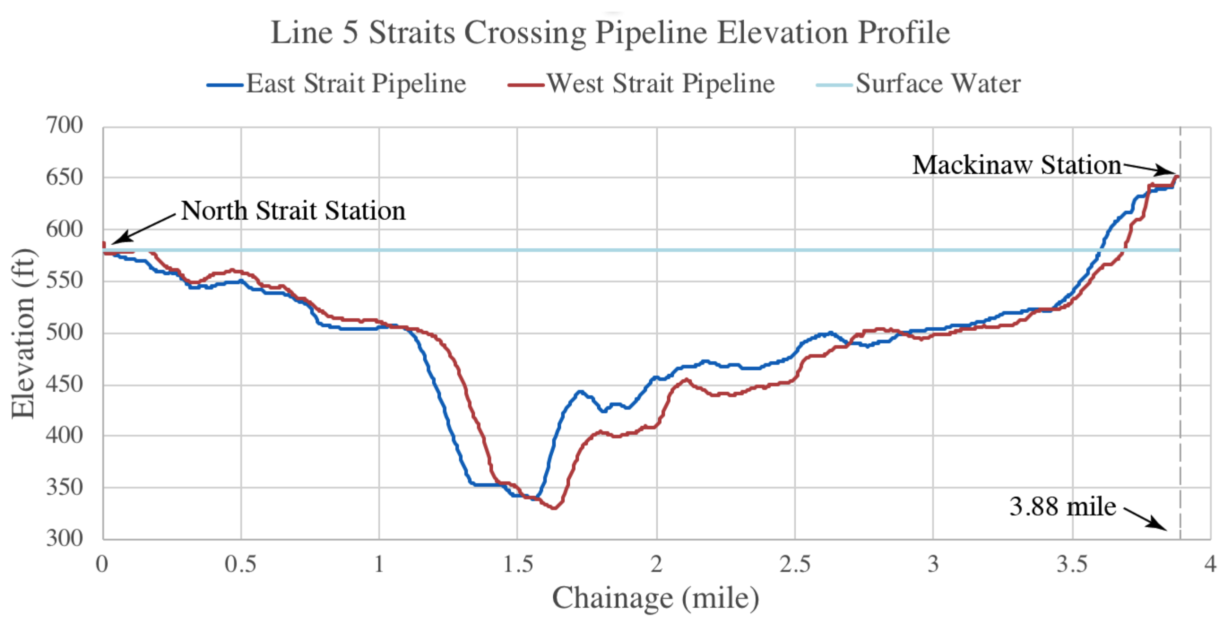

Figure A2: Elevation Profile of Straits Crossing Pipeline

The location of a leak or rupture along the pipeline and its corresponding relative elevation will affect the maximum possible line drainage volume after the shutdown of the line section.

Based on this, six critical locations, shown in Figure A3, were identified for modeling, which includes both onshore endpoints, the deepest point in the shipping channel, and three additional inflection points in the pipeline elevation profile. In detail, Locations 1 and 6 are the north and south ends of the Straits Pipelines, respectively, and are located above water at the primary valves on each shore. Locations 2, 3, 4, and 5 are all located under water and exposed. Location 3 is located at the lowest elevation of each line (the bottom of the shipping channel). Table A3 provides the details on the distances of each selected location from the primary isolation valve at North Straits Station (Location 1) and the lowest elevation point.

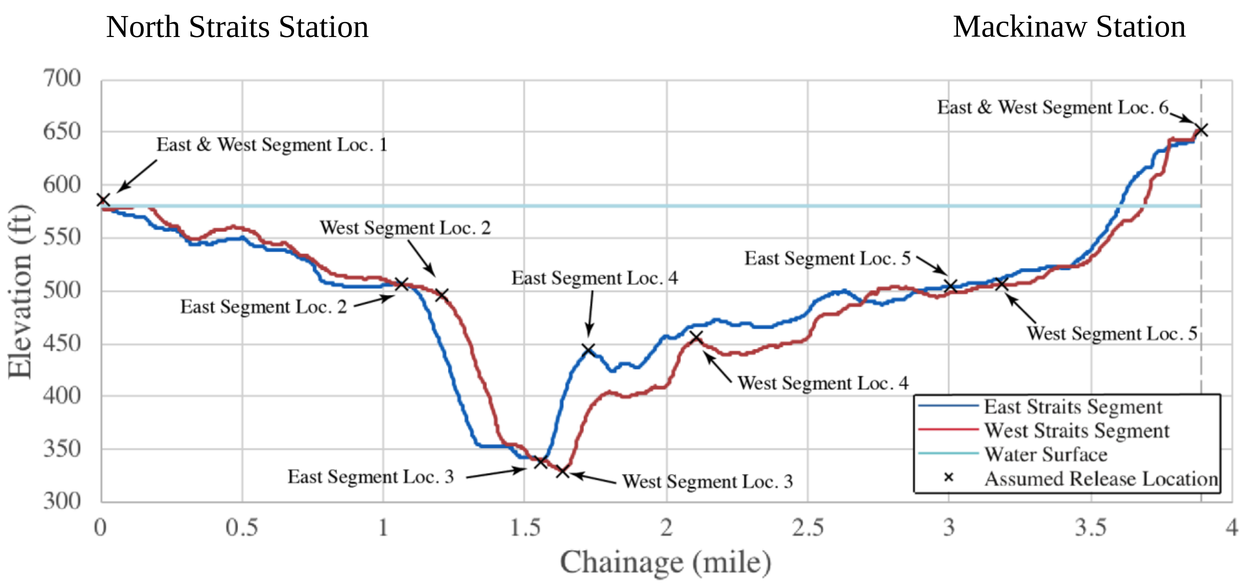

Figure A3: Line 5 Straits crossing profiles with modeled critical locations.

Table A3: Line 5 Straits Crossing Critical Locations

Location Name and Elevation	Mileage from the East Seg. Loc. 1. (mile)	Distance to the lowest elevation point (mile)	Location Name and Elevation	Mileage from the West Seg. Loc. 1. (mile)	Distance to the lowest elevation point (mile)
East Seg. Loc. 1 (586.38 ft)	0.00	1.56	West Seg. Loc. 1 (586.84 ft)	0.00	1.63
East Seg. Loc. 2 (491.34 ft)	1.14	0.42	West Seg. Loc. 2 (484.09 ft)	1.24	0.39

East Seg. Loc. 3 (339.40 ft)	1.56	0.00	West Seg. Loc. 3 (330.68 ft)	1.63	0.00
East Seg. Loc. 4 (443.11 ft)	1.73	0.17	West Seg. Loc. 4 (454.72 ft)	2.10	0.47
East Seg. Loc. 5 (504.49 ft)	3.01	1.45	West Seg. Loc. 5 (506.17 ft)	3.17	1.54
East Seg. Loc. 6 (651.71 ft)	3.88	2.32	West Seg. Loc. 6 (651.15 ft)	3.88	2.25

A.2.4 Potential Causes of Failure

The possible causes of a maximum worst-case spill from Line 5 in the Straits include corrosion, construction and material defects (cracking and fatigue), natural hazards, third party damage (accidental or sabotage), and operational errors. The Alternatives Analysis identified third party damage and incorrect operations as the principal threats to the pipeline. In line with the understood definition of a worst-case scenario, potential causes were considered if they were plausible, even if very unlikely.

The following assessment includes both pinhole leak and full-bore rupture failure modes. A pinhole leak could plausibly be caused by corrosion, defects, fatigue or third party damage, with fatigue being most likely. In 2017, Enbridge provided an interim report of coating damage found during inspections (Figure A4). Coating gaps were confirmed at three locations with an inconclusive result reported for one additional location. Coating gaps were confirmed to cause bare pipe metal to be exposed to the environment. Even though no evidence of metal loss was found to date, the absence of coating increases the probability of corrosion and thus could plausibly contribute to future pinhole leakage.

Figure A4: Coating damage found during a pipeline inspection

A rupture scenario could be caused by incorrect operation, such as accidental over-pressurization or improper closing or opening of valves; spanning-related stress such as fatigue caused by vortex-induced vibration or excessive unsupported span length; or mechanical damage (including accidental damage, such as anchor drag or damage during maintenance, and malicious third-party damage). The possibility of malicious damage was not addressed in the Alternatives Analysis, but pipeline systems are recognized as a physical target for terrorist groups and have been the focus of numerous plots intended to cause significant damage, as Dancy & Dancy recently summarized:

> *In 2005, a U.S. citizen sought to conspire with Al Qaeda to attack a major natural gas pipeline in the eastern region of the United States. In 2006, federal authorities discovered a posting on a website purportedly linked to Al Qaeda that encouraged attacks on U.S. pipelines using weapons or hidden explosives. In 2007, the U.S. Department of Justice arrested members of a terrorist group planning to attack jet fuel pipelines and storage tanks at the John F. Kennedy International Airport. In 2011, an individual planted a bomb, which did not detonate, along a natural gas pipeline in Oklahoma. In 2012, a man who reportedly had been corresponding with "Unabomber" Ted Kaczynski unsuccessfully attempted to bomb a natural gas pipeline in Plano, Texas. Canadian pipelines have also been targeted by physical attacks. Natural gas pipelines in British Columbia, Canada, were bombed six times between October 2008 and July 2009 by unknown perpetrators in acts classified by authorities as environmentally motivated "domestic terrorism.* (2016, p. 589)

Table A4 summarizes the possible threats considered in this assessment and the related potential failure modes of the pipeline.

Table A4: Primary Line 5 Threats and Associated Failure Modes.

Threats	Mode	Pipes Likely Affected
Corrosion	Pinhole leak	One 20"
Cracking (defects and fatigue)	Larger area hole	One 20"
Spanning-related stress	Guillotine rupture	One 20"
3rd Party damage	Any hole size	One or both 20"
Incorrect Operation (over pressure/hammer shock)	Guillotine rupture	One or both 20"

A.2.5 System Detection and Response Time

The total response time to an incident equals the spill detection time plus the time required to decide how to respond and to isolate the affected pipeline section, as shown below:

$$\text{Total Response Time} = \text{Spill/Leak Detection Time} + \text{Decision/Isolation Time} \qquad (1)$$

A.2.5.1 Spill/Leak Detection Time

Based on real-time transient model sensitivity performance testing on Line 5 following API 1130 conducted in fall of 2017, the Computational Pipeline Monitoring (CPM) system can detect a rupture immediately, and a small leak in 30 minutes or less. Exact detection times are confidential but have been provided for this analysis.

A scenario where either the loss of containment is not detected by the CPM or a detected leak is ignored due to human error, leading to a longer than expected detection time, is also plausible. Leak detection systems complemented by a Supervisory Control and Data Acquisition (SCADA) and CPM, such as those in place at the Straits crossing, are used by the pipeline industry to reduce both the frequency and volume of liquid (oil and natural gas liquids) and gas spilled. In addition to aiding in leak detection, SCADA and CPM systems are capable of quickly closing valves and shutting down the pumps. Leak Detection (LD) and monitoring systems are essential tools for any pipeline operator. The primary purpose of an LD system is to detect and provide the approximate location of the leak. A system that is automated could provide for a timely warning and could prevent a major spill by closing valves and stopping the flow in a pipe.

There are two major categories of LD, internal and external; both of them use technologies such as sensors detecting hydrocarbons, acoustic, temperature variation, pressure drop and material balance. Operators install a combination (hybrid) of these systems because the pipeline is used to transport various products such as crude, refined and Natural Liquid Gas (NLG) using the same conduit according to seasonal needs. These detections systems are only accurate for steady-state operations. A pipeline under transient conditions (start-up and shut-down) produce additional background noise which results in inaccurate detection. It is critical for operators to have exact procedures to minimize the potential for error during start-up and shut-down.

However, a PHMSA-funded review (Shaw et al., 2012) of pipeline right-of-way incidents between 2010 and 2012 found that these automated systems were not responsible for most of the leak detections. Instead, the largest number of incidents were reported by a pipeline company employee and/or contractor (in some cases because the contractors themselves accidentally caused the leak.) The public ranked second in reporting leaks, with SCADA and CPM programs coming in third. Of 197 reviewed incidents, 87 had a CPM in place and functional at the time of the incident, but CPM information only contributed to the detection of the leak in 17 incidents. For a more recent example of human error defeating technology, in the 2015 3,400 barrel Refugio spill, a SCADA was operating, but the pressure alarms were configured incorrectly, and the controller did not recognize the information reported by SCADA as indicative of a problem (PHMSA, 2016).

Based on historical data on pipeline leaks, the volume of a liquid leak from pipelines equipped with a SCADA or CPM system is greater than the volume leaked from pipelines not so equipped. This volume difference is because these systems are installed on larger pipelines, and leaks/ruptures from large pipelines result in large spills. Also, there is an unjustified belief that an automated system is less susceptible to an accidental leak. Additionally, due diligence is not as vigorous when an automated system is present (Sulaima et al., 2014).

A.2.5.2 Decision and Isolation Time

Based on the operating procedures provided by Enbridge, if a leak indication is identified, the operator has a 10-minute window within which to determine the nature of the situation and decide upon a response. The designed pump and valve shutdown times once a decision is made, and the shutdown command is received are 0.5 and 3 minutes, respectively. So, the total expected isolation time once a leak is identified is between 3.5 minutes (if the decision to shut down is made immediately) and 13.5 minutes (if the full allotted decision-making time is used).

A.2.5.3 Manual Valve Closing Time

The valves on either side of the Straits are designed to close automatically in response to pressure drops that may indicate a leak or rupture, and can also be closed remotely from the control room from which the pipeline is monitored 24 hours a day. Redundant power and communication systems at the Straits ensure that it is unlikely that valves would not close automatically as designed or that the control center would be unable to close them remotely, but it is not implausible. The equipment necessary to monitor and actuate automatic shutoff and remotely controlled valves may be susceptible to physical and cybersecurity issues and sabotage such as intrusion into computer systems, communications links, breaching of physical security at valve locations and vandalism (American Gas Association, 2011).

On August 6, 2008, the Baku-Tbilisi-Ceyhan (BTC) pipeline running from the Caspian Sea to the Mediterranean ruptured near Refahiye, Turkey, resulting in an explosion. The BTC pipeline was monitored via a state-of-the-art leak detection system with alarms as well as real-time data acquisition that should have been providing pressure and flow readings that would have alerted control room operators, but according to reporting, the control room did not learn about the rupture/explosion until 40 minutes after it had happened (Robertson & Riley, 2014). It appears that the communications system, cameras, leak detection system, automated pressure relief, alarm server, pipeline field devices found in valve or compression stations, and satellite terminals or signal transmission may have been compromised during the incident.

A 2014 memo from the Industrial Control Systems team at SANS, a large provider of cybersecurity training, focused on the BTC incident as a case study (Lee et al., 2014). They note that malicious compromising of remote facility communications or equipment is “not a novel concept”, and that security professionals often use such tactics for sanctioned penetration testing. Mittal et al. point out that in 2014, “hackers launched an all-out assault on 50 oil and gas companies in Europe using well-researched phishing campaigns and advanced versions of Trojan horse attacks”, and that in 2016, “energy was the industry second most prone to cyber-attacks, with nearly three-quarters of US oil and gas companies experiencing at least one cyber incident”.

There is also the possibility of routine equipment failure. The assumption that remote valve control, an active containment measure, could fail is in line with the EPA RMP approach to worst-case scenario planning but is also based on several historical incidents confirming its plausibility via several mechanisms. For example, on June 21, 2017, natural gas condensate leaked at Engie’s Gjoa offshore platform and one emergency valve failed to close as designed while another failed to open as designed. The valves were later found to be corroded; regular testing had revealed problems, but they had not been addressed. On June 30, 2000, 133,000 m^3 of natural gas was vented to the atmosphere at TransCanada Station 68 after an emergency shutdown caused by a blown fuse. The valves did not operate as designed in the event of a failure because the system had not been programmed correctly. Finally, in an incident at the Louisiana Offshore Oil Port, a valve failed to close because of excessive wear on a stripped stem nut, but the SCADA system showed the valve to be closed.

In a scenario where valves cannot close automatically or remotely as designed, the isolation valves would need to be closed manually. For our largest volume/lowest probability scenario (Tier 5), we assumed a manual valve closure time of 2 hours based on a written exchange between Enbridge and the State of Michigan. In response to the question from the Michigan Petroleum Pipeline Task Force, “Assuming a leak takes place at the Straits pipelines, and any automatic or remote shut-off systems fail, approximately how long would it take Enbridge workers or contractors to manually close the pipeline on both ends of the Straits?”, Enbridge responded as follows:

Enbridge has back-up power generators installed at the valve locations, which makes the scenario posed in the question extremely unlikely to occur. However, in the event that valves could not be controlled at the Straits, other valves would be remotely closed on Line

5, upstream and downstream of the Straits. In addition, our practice is to dispatch staff to site to control any manual valves in the area, which would include closing the valves at the Straits. Such actions would take between 15 minutes to 2 hours depending on the time of day and location of existing personnel. (Shamla 2015, emphasis added):

This length of time seems appropriate given that, although there are Enbridge personnel based locally in the Straits area, in a worst case scenario with severe weather conditions, travel could be difficult and the Mackinac Bridge could be closed, significantly increasing the typical response time. Furthermore, we requested that Enbridge estimate the time that would be required to manually close the valves at the north side of the Straits only, thus interrupting the flow toward the underwater portions of Line 5. This time has been estimated by Enbridge to be approximately 1 hour. Therefore, we have also estimated the volume that would be released in a scenario where the northern end of the Straits pipelines is closed after one hour.

A.2.6 Tiers of Failure

As previously defined in Table A4, several failure types were considered based upon plausible threats. In Table A5 below, these threats are now grouped into five Tiers of failure in order of severity in creating plausible worst case scenarios.

Table A5. Primary Threats Induced Pipeline Manifestation

<table>
<tr><td>Threats</td><td>Manifestation</td><td>Pipes Likely Affected</td><td>Tier</td></tr>
<tr><td>Spanning stress</td><td>Guillotine rupture</td><td>One 20"</td><td rowspan="4">Tier 1 Rupture or Pin-hole in one 20" line with immediate response

Tier 2 Rupture or Pin-hole in one 20" line with maximum allowable response time</td></tr>
<tr><td>Cracking (fatigue)</td><td>Larger area hole</td><td>One 20"</td></tr>
<tr><td>Corrosion</td><td>Pinhole leak</td><td>One 20"</td></tr>
<tr><td>Third-party damage</td><td>Any hole size</td><td>One 20"</td></tr>
<tr><td>Incorrect Operation (over pressure/hammer shock)</td><td>Guillotine rupture</td><td>One or both 20"</td><td rowspan="2">Tier 3 Rupture in both 20" lines with primary valve failure

Tier 4 Rupture in one 20" line with manual valve closure

Tier 5 Rupture in both 20" lines with manual valve closure</td></tr>
<tr><td>Third-party damage</td><td>Any hole size to rupture</td><td>One or both 20"</td></tr>
</table>

Five tiers of failure were analyzed based on the failure types in Table A5.

Tier 1 – Pipeline failure is identified right away, and the decision to shut down is made immediately. All equipment including electronic devices, valves, computer monitoring system, etc. is working as expected. Only one failure has occurred on one of the 20" pipelines (rupture or pinhole leakage). Such a failure could be caused by corrosion, fatigue cracking, deformation or geo-hazards, facility and equipment damage, incorrect operation or sabotage. In this situation, the responding time is 3.5 minutes.

Tier 2 – The pipeline failure is identified right away; however, the full 10-minute decision time allowed under Enbridge protocols is utilized before valve shutdown is initiated. All equipment including electronic devices, valves, computer monitoring system, etc. is working as expected. Only one failure has occurred on one of the pipelines (rupture or pinhole leakage). As in Tier 1, this could be the result of corrosion, fatigue cracking, deformation or geo-hazards, facility and equipment, incorrect operation or sabotage. In this situation, the responding time is 3.5 minutes plus 10 minutes for a total response time of 13.5 minutes.

Tier 3 – The pipeline failure is identified right away; release volumes corresponding to both an immediate shutdown (as in Tier 1) and a 10-minute shutdown delay (as in Tier 2) are estimated. All equipment is working as expected. Both the West Strait Segment and the East Strait Segment are ruptured, and there is a failure of the primary valves. This scenario could result from facility and equipment damage inducing dual ruptures, accidental mechanical damage / third-party damage, an incorrect operation that induces dual ruptures, or sabotage resulting in dual ruptures. In this situation, the responding time is either 3.5 minutes (immediate shutdown) or 13.5 minutes (10-minute shutdown delay).

Tiers 4 and 5 – Remote electric valve closure fails, and valves have to be shut down manually. In this tier, a rupture failure at one pipe is assumed for Tier 4 and ruptures of both pipes are assumed for Tier 5. In this situation, the responding time is two hours.

Plausibility Considerations – As noted above, to reach a Tier 4 or Tier 5 failure, multiple independent events must occur. In such a case, it is obvious that significantly less oil could be injected into the environment should reasonable actions be taken in the proper order. For that reason, we have also provided estimates of the range of spill volumes that could be realized that fall between Tier 3 and Tiers 4 and 5.

A scenario where a leak goes undetected or ignored, as described above in subsection A.2.5.1, is not explicitly included among the tiers of failure described above. The scenario is excluded because it is difficult to identify a specific evidence-based maximum detection time to assume in the event of such a failure and because the team determined that any reasonable detection time would result in a lower release volume than the release volume included in the Tier 5 scenario. Therefore, an undetected or ignored leak would not represent the maximum plausible worst-case scenario. For a rupture, it is reasonable to expect that one of the overlapping leak detection methods in place (rupture detection system, controller monitoring via SCADA, CPM, third-party & employee reporting) would detect such a large spill within the two-hour window assumed for manual valve closure. In the case of a pinhole leak, using the flow rate assumed for this analysis, a leak of 500 bbl/h is the largest flow rate, based on Enbridge-provided information that might go undetected by their CPM system. For such a leak to exceed our Tier 5 scenario volume, it would have to continue undetected for 116 hours, or approximately 5 days. Even assuming ice cover, the assessment team felt that it would not be plausible for such a leak to continue for longer than that with no visual observation of surface oil. Similarly, a 100 bbl/h leak would create a less obvious surface sheen, but it would take over 24 days to exceed our Tier 5 volume, which the team also considered implausible.

Finally, it is theoretically possible that a release scenario could occur at the exact time that the product being transported in Line 5 is transitioning between light crude oil and natural gas liquids. If this were to happen, depressurization of the NGL could cause it to expand dramatically in volume, pushing more crude oil out of the pipeline than would otherwise be expected. The formation of a leak/rupture at the same time as a product transition is very unlikely, but this possibility is one reason for the conservative assumption of minimum oil release discussed in Section A.3.1.

A.3 Analysis Results for Base Case of Rupture and Pin-holes

To calculate the maximum plausible spill for each tier of failure, the discharge volumes for pipeline rupture and pinhole failure cases are analyzed for each of the locations in Figure A4/Table A3. Tables A6 and A7 summarize the 12 cases analyzed for each 20″ pipeline, for a total of 24 analysis cases. All of the base cases analyzed in Tables A6 and A7 assume one failure (rupture or pinhole in one 20 pipe).

Table A6. Worst Case Discharge Scenarios (West Segment)

Hole Size	Location 2	Location 3	Location 4	Location 5
3" pin-hole	W3Loc2	W3Loc3	W3Loc4	W3Loc5
Rupture	WRLoc2	WRLoc3	WRLoc4	WRLoc5

Table A7. Worst Case Discharge Scenarios (East Segment)

Hole Size	Location 2	Location 3	Location 4	Location 5
3" pin-hole	E3Loc2	E3Loc3	E3Loc4	E3Loc5
Rupture	ERLoc2	ERLoc3	ERLoc4	ERLoc5

In the case of rupture or pinhole leakage in one 20" pipe, the maximum possible leak amount can be calculated by Equation (2) below:

$$\text{Total Leak Amount} = \text{Leakage before Closing Valve} + \text{Leakage after Valves Closed} \tag{2}$$

The leakage after valve closure is the same for a rupture and that of a pinhole leak. Full drain-down to the maximum possible extent is required for both; they differ only in drainage rate. However, leakage after closure does vary depending on the position of the leak within the elevation profile of the pipeline because the densities of all products transported by Line 5 are lower than the density of water. As a result, only the product remaining between the rupture/pin-hole location and the lowest elevation location along the Straits crossing would be released after the valves are completely closed. Thus, for either a rupture or a pinhole leakage, the leakage after the valves closed can be calculated using the same equation, as in Equation (3) below:

$$\begin{aligned}&\text{Leakage after Valves Closed} = \text{Pipeline Cross-section Area} \times \\ &\text{Distance from the Lowest Elevation Point}\end{aligned} \tag{3}$$

Thus, from Equation (3), it can be seen that the locations of the rupture/pin-hole dominate the amounts of leakage after valve closed. Detail calculations of the leakage after valves closed for the base case of rupture/pin-hole is given in Appendix A-1. In Appendix A-1, it is worth noting that if the pipeline rupture or leakage occurred at Locations 3 (the lowest elevation on each line), the water would keep most of the oil inside the pipe instead of releasing to the environment after valve closure. Thus, theoretically, at Locations 3, the oil release will be only the amount before valve closure, and after valve closure, there will be very little oil released to the water due to the specific gravity difference between oil and water. Also, at Locations 2 and 4, after valves closure, due to the short distance between lowest elevation to these locations, the oil release is also expected to be very small, less than 850 bbl in Locations 2 and 4 for both pipes. However, for this analysis, to be conservative, a minimum 15% (which is 1,000 bbl *in Tables A8-A11) of oil released post-shutdown has been assumed throughout all locations. This was done both to be conservative and to account for the possibility that a product transition between crude oil and NGL could be occurring at the time of the incident, as described in Section A.2.6. More details of calculations, please refer to Appendix A-1.

The leakage before closing valve in Equation (2), due to different detection times for a rupture vs. a pinhole, the detection time used to calculate the leakage before closing the valves for ruptures and, different pinhole sizes will be different, resulting in different leakage volumes before the valves are closed. Details for the total spill volumes for different cases are presented in the sections below.

A.3.1 Rupture Cases

For rupture cases, the leak amount before closing the valve can be calculated as Equation (4):

$$\text{Rupture Leakage before Closing Valve} = \text{Response Time} \times \text{Flow Rate} \tag{4}$$

Equation (1) in Section A.2.5 shows that the total response time in Equation (4) has two parts: spill/leak detection time and decision/isolation time. In a case of rupture, the spill/leak detection time is immediate. However, the decision and isolation time varies with different circumstances, which will result in different total response time for various tiers of study as shown in Table A5. In detail, for Tier 1, the decision time is assumed to be immediate, the isolation time is the 3.5 minutes of pump and valve closure time, resulting in a total response time of 3.5 minutes. For Tier 2 and Tier 3, the decision is assumed to be made within the 10 minutes allowable window, and the isolation time is the 3.5 minutes of pump and valve closure time, leading to a total response time of 13.5 minutes. For Tiers 4 and 5, the valves are assumed to be closed manually with a total response time of 2 hours. Refer to Section A.5 for more details of detection and isolation time.

Based on Equation (4) and considering all the 16 cases listed in Tables A6 and A7, the crude oil discharge amounts for Tier 1 and Tier 2 in East and West Segments are listed in Tables A8 and A9. Estimated discharges are rounded to the nearest hundred barrels to reflect the accrued uncertainty. From Figure A3 and Table A3, it can be seen that Locations 1 (ERLoc1 and WRLoc1) and Locations 6 (ERLoc6 and WRLoc6) are above water at the shore (stations), which is above water and out of the scope of this study, so potential spill volumes were not estimated for these locations. For the four locations underwater (Locations 2 to Locations 5), **Error! Reference source not found.**A8 and **Error! Reference source not found.** A9 show that spills from Location 5 on either line (ERLoc5 and WRLoc5) would result in very similar release volumes, which are the identified worst-case locations for both tiers, with a plausible maximum crude oil discharge of 4,200 bbl in a Tier 1 failure and 8,500 bbl in a Tier 2 failure.

Detailed calculations of the leakage before valve closure for the base case of rupture to derive Table A8 and Table A9 are provided as an example in Appendix A-1.

Table A8. Rupture Cases Analysis Result for Tier 1

Rupture Case Name East	Total Leak Amount (Barrels)	Rupture Case Name West	Total Leak Amount (Barrels)
ERLoc2 (Under Water)	2500*	WRLoc2 (Under Water)	2500*
ERLoc3 (Under Water)	2500*	WRLoc3(Under Water)	2500*
ERLoc4 (Under Water)	2500*	WRLoc4 (Under Water)	2500*
ERLoc5 (Under Water)	4100	WRLoc5 (Under Water)	4200

** Conservative assumption of minimum 15% leakage post-shutdown applies.*

Table A9. Rupture Cases Analysis Result for Tier 2

Rupture Case Name East	Total Leak Amount (Barrels)	Rupture Case Name West	Total Leak Amount (Barrels)
ERLoc2	6800*	WRLoc2	6800*
ERLoc3	6800*	WRLoc3	6800*
ERLoc4	6800*	WRLoc4	6800*
ERLoc5	8300	WRLoc5	8500

* *Conservative assumption of minimum 15% leakage post-shutdown applies.*

A.3.2 Three-Inch Pinhole Size Leakage Case

The analysis procedure for 3″ pinhole leakage follows the same approach described in Section A.3.1 for rupture cases. However, a 3″ pinhole would affect the leakage flow rate and spill/leak detection time. Thus, the leakage of a 3″ pinhole before the valve closure is different than in rupture cases and it can be calculated as Equation (5) below:

$$\text{3" Hole Leakage before Closing Valve} = \text{Spill/Leak Detecting Time} \times \text{3" Hole Leakage Flow Rate} + \text{Decision/Isolation Time} \times \text{Rupture Leakage Flow Rate} \tag{5}$$

The analysis results for the 3” pinhole case related to Tier 1 and Tier 2 are listed in Tables A10 and A11. As for the rupture cases, Locations 1 and 6 are listed for comparison, and only the results from the four locations underwater (Locations 2 to Locations 5) are considered for the worst case analysis. Table A10 and A11 show similar results for the 3” pinhole cases compared with the rupture cases. Location 5 is again identified as the worst case discharge location for both tiers, with a total leakage of 4,400 bbl from the west line producing the largest volume for a Tier 1 failure (with the decision to shut down made immediately). For Tier 2 (where the decision to shut down is made after 10 minutes), a Location 5 leak on either line results in the same estimated release volume of 8,600 bbl.

Table A10 3-Inch Hole Leakage Cases Analysis Result for Tier 1

Pinhole Case Name East	Total Leak Amount (Barrels)	Pinhole Case Name West	Total Leak Amount (Barrels)
E3Loc2	2500*	W3Loc2	2500*
E3Loc3	2500*	W3Loc3	2500*
E3Loc4	2500*	W3Loc4	2500*
E3Loc5	4300	W3Loc5	4400

* *Conservative assumption of minimum 15% leakage post-shutdown applies.*

Table A11. 3-Inch Hole Leakage Cases Analysis Result for Tier 2

Pinhole Case Name East	Total Leak Amount (Barrels)	Pinhole Case Name West	Total Leak Amount (Barrels)
E3Loc2	6800*	W3Loc2	6800*
E3Loc3	6800*	W3Loc3	6800*
E3Loc4	6800*	W3Loc4	6800*
E3Loc5	8600	W3Loc5	8600

** Conservative assumption of minimum 15% leakage post-shutdown applies.*

A.4 Worst Case Discharge Results for Different Tiers of Failure

A.4.1 Tier 1

Comparing Tables A8 and A10, it can be seen that in this tier, the worst discharge underwater occurs when a 3" pinhole leak occurs in the west line at Location 5 (W3Loc5) near Mackinaw Station with shutdown occurring in 3.5 minutes, which would result in the largest discharge amount for this tier, 4,400 bbl.

For this Tier 1 failure to occur:

- All automated detection equipment is assumed to work as designed
- The decision to shut down Line 5 was made immediately upon detection
- All automated valve closures are assumed to have worked as designed
- One 20” underwater pipeline was involved.

A.4.2 Tier 2

Comparing Tables A9 and A11, it can be seen that in this tier, the worst discharge underwater occurs when a 3" pinhole leak occurs at Location 5 (either W3Loc 5 or E3Loc5 near Mackinaw Station), with shutdown occurring in 13.5 minutes, which would result in the largest discharge amount of 8,600 bbl.

For this Tier 2 failure to occur:

- All automated detection equipment is assumed to work as designed
- The decision to shut down Line 5 was not made until 10 minutes after detection
- All automated valve closures are assumed to have worked as designed
- One 20” underwater pipeline was involved.

A.4.3 Tier 3

In Tier 3, both segments are ruptured at approximately the same location. The rupture discharge amounts of the West and East Segments for Location 5 are added together (ERLoc5 plus WRLoc5). If this occurs using the response time assumed for Tier 1, (3.5 minutes), based on Table A8, the estimated release is 8,300 bbl. If this occurs using the response time assumed for Tier 2 (13.5 minutes), based on Table A9, the response time is 13.5 minutes, resulting in a total discharge amount of 16,800 bbl.

For this Tier 3, worst-case failure to occur:

- All automated detection equipment is assumed to work as designed
- The decision to shut down Line 5 was made at 10 minutes after detection
- The automated valve closures for the primary valves have failed
- All other automated valves are assumed to have worked as designed
- Both 20” underwater pipelines were involved.

A.4.4 Tier 4

In Tier 4, the rupture location associated with the largest release volume is at Location 5 near Mackinaw Station, and the manual shut down time is assumed to be 2 hours. During the 2 hours, the pipeline is assumed to continue carrying crude oil at the full flow rate, and all of the crude oil within this 2-hour period is discharged. For one 20" pipe, the discharge amount is 25,600 bbl. After manual shutdown, the drawdown volume for location 5 on the west line is 3,400 bbl for a total discharge amount of approximately 29,000 bbl.

For this Tier 4 failure to occur:

- All automated detection equipment is assumed NOT to work as designed
- The decision to shut down Line 5 was made at 10 minutes after detection
- The automated valve closures for the primary valves have failed
- The automated valve closures for all valves have failed
- Pumps do not stop operating until manually shut down
- All valves and pumps must be manually shut down, requiring 2 hours to complete
- One 20” underwater pipeline was involved.

Note:

1) If the pumps do not remain in full operation during this assumed 2-hour manual shut down time, the volume released for this tier of failure would be significantly reduced.
2) If a reduced time of only 1 hour to manually close only the immediate primary or secondary valves on the north side of the Straits is considered, thus interrupting the flow toward the underwater portions of Line 5, the released volume is reduced to 16,200 bbl.

A.4.5 Tier 5

In Tier 5, the rupture is also assumed to be at Location 5 (both ERLoc5 and WRLoc5) near Mackinaw Station, and the manual shutdown time is assumed to be 2 hours. During this 2 hours, both pipelines are still carrying crude oil at the full assumed flow rate, which is 25,600 bbl./h, and all of the crude oil within 2-hour period is discharged. The discharge amount is 51,200 barrels. This is added to the combined post-shutdown drawdown volume of 6,800 bbl from both 20" lines at Location 5 for a total release volume of 58,000 bbl.

For this Tier 5 failure to occur:

- All automated detection equipment is assumed NOT to work as designed
- The decision to shut down Line 5 was made at 10 minutes after detection
- The automated valve closures for the primary valves have failed
- The automated valve closures for all valves have failed
- Pumps do not stop operating until manually shut down
- All valves and pumps must be manually shut, requiring 2 hours to complete
- Both 20” underwater pipelines are involved.

Note:

1) If the pumps do not remain in full operation during this assumed 2-hour manual shut down time, the volume released for this tier of failure would be significantly reduced.
2) If a reduced time of 1 hour is required to manually close only the immediate primary or secondary valves on only the north side of the Straits, thus interrupting the flow toward the underwater portions of Line 5, the released volume is reduced to 32,400 bbl.

A.5 Summary

The summary of the worst case discharge volumes (rounded to the nearest 100 barrels) for the defined five tiers of failure are presented in Table A12 below. These estimated volumes would apply to spills of either light crude or NGL.

Table A12. Straits Crossing Pipeline Worst Case Discharge Volume in US Oil Barrels for Different Tiers of Failure

Tier 1 (barrels)	Tier 2 (barrels)	Tier 3 (barrels)	Tier 4 (barrels)	Tier 5 (barrels)
4,400	8,600	17,000	16,200 to 29,000	32,400 to 58,000

A.6 References

American Gas Association (2011). AGA White Paper: Automatic Shut-off Valves (ASV) and Remote Control Valves (RSV) on Natural Gas Transmission Pipelines. Washington, DC: American Gas Association. Retrieved from https://www.aga.org/sites/default/files/asv-rcv_white_paper_final_short_version_3-30-11_0.pdf

Dancy, J. R., & Dancy, V. A. (2016). Terrorism and Oil & Gas Pipeline Infrastructure: Vulnerability and Potential Liability for Cybersecurity Attacks. *ONE J*, *2*, 579.

Dynamic Risk Assessment Systems, Inc. (2017). Alternatives Analysis for the Straits Pipelines – Final Report. Document number SOM-2017-01-RPT-001. Retrieved from https://mipetroleumpipelines.com/document/alternatives-analysis-straits-pipeline-final-report

Kane, R. J. (2017). Defining a Worst-Case Release Scenario for the Enbridge Crude Oil Pipelines Crossing the Straits of Mackinac – Line 5. Retrieved from https://mipetroleumpipelines.com/sites/mipetroleumpipelines.com/files/Risk%20%26%20Worst-Case%20Analysis%20Comments%20RJKane%2020170802%20.pdf

Lee, R. M., M. J. Assante, and T. Conway. (2014) ICS Defense Use Case (DUC) Dec. 20, 2014. Retrieved from https://ics.sans.org/media/Media-report-of-the-BTC-pipeline-Cyber-Attack.pdf May 29, 2018.

Mittal, A., Slaughter, A., and P. Zonneveld. (2017). Protecting the connected barrels: Cybersecurity for upstream oil and gas.

Robertson, J. and M. Riley. (2014). Mysterious ’08 Turkey Pipeline Blast Opened New Cyberwar. Available at https://www.bloomberg.com/news/articles/2014-12-10/mysterious-08-turkey-pipeline-blast-opened-new-cyberwar

PHMSA (Pipeline and Hazardous Materials Safety Administration) (2016). Failure Investigation Report: Plains Pipeline, LP, Line 901 Crude Oil Release, May 19, 2015, Santa Barbara County, California. Retrieved from https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/PHMSA_Failure_Investigation_Report_Plains_Pipeline_LP_Line_901_Public_0.pdf

Shamla, B. (February 27, 2015). Responses to follow-up questions from the Michigan Petroleum Pipeline Task Force. [Memorandum].Edina, MN: Enbridge Energy. Retrieved from https://www.michigan.gov/documents/deq/Appendix_B.6_493994_7.pdf

Shaw, D., Phillips, M., Baker, R., Munoz, E., Rehman, H., Gibson, C., & Mayernik, C. (2012). Leak detection study–DTPH56-11-D-000001. *US Department of Transportation, Pipeline and Hazardous Materials Safety Administration, Final Report*, (12-173).

Sulaima, M. F., Abdullah, F., Bukhari, W. M., Ali, F. A., Nasir, M. N. M., & Yahya, A. B. (2014). Oil and Gas Offshore Pipeline Leak Detection System: A Feasibility Study. *Applied Mechanics & Materials*, *699*.

USEPA (2009). Risk management program guidance for offsite consequence analysis. Retrieved from https://www.epa.gov/rmp/rmp-guidance-offsite-consequence-analysis.

Task B: Analyzing the likely environmental fate and transport of oil or other products released from the Straits Pipeline under a worst-case scenario

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B.1 Introduction

Michigan Technological University (Michigan Tech) and its subcontractors were retained to conduct an independent risk analysis of a worst-case oil spill scenario associated with the underwater Line 5 crude oil and natural gas pipeline operated by Enbridge Inc. Line 5 transits the Straits of Mackinac region connecting the waters of Lakes Michigan and Huron between the State of Michigan's upper and lower peninsulas.

The fate and transport of crude oil products released into bodies of fresh- or saltwater are highly dependent on environmental conditions that include water and air temperatures, wind conditions, water currents, ice cover and also the physical and chemical properties of the released material.

Water currents in the Straits of Mackinac can reach up to 1 m/s and can also reverse direction every 2-3 days flowing either easterly into Lake Huron or westerly towards Lake Michigan (Saylor and Sloss, 1976). Flow volumes through the Straits can reach 80,000 m^3 /s and thus play an important role in navigation and shipping in this region, in the transport of nutrients, sediments and contaminants between Lakes Michigan and Huron, and also the ecology and biodiversity of this region. Further, seasonality within this area of the Great Lakes basin can result in substantially variable meteorological conditions across the winter, spring, summer, and fall with additional considerations for ice-cover being required to assess the fate and transport of an oil spill this region.

A total of 4380 oil dispersal simulations were conducted to estimate the fate and transport of crude oil released from northern, mid-channel, or southern locations within the span of the Line 5 pipeline that transits the Straits of Mackinac. Individual simulations were initiated at 6-hour intervals with oil being allowed to disperse for a maximum of 60 days. From each of these scenarios, dispersal maps were developed to depict the maximum extent of shoreline oiling (km) and also the maximum extent of surface area oiling (km^2) and the amount (barrels, kg) of oil beached at shoreline locations. Oil fate was also evaluated concerning the proportions of the worst case release oil volume that becomes beached, evaporates or remains on the water surface during a maximum 60 day dispersal period.

Combinations of figures including dispersal maps, oil fate over time (beached, evaporated, afloat) and summary tables from the oil spill simulations were produced and made available to the other project Chapter teams for their use in selecting ‘worst case' transport scenarios. These figures and tables are included as Appendix B in this report.

B.2 Approach

B.2.1 Meteorological and Environmental Data

Fate and transport of released oil depend primarily on ambient atmospheric and marine environmental conditions. To assess the full range of environmental conditions that could impact the transport and fate of an oil spill in the Straits, the year 2016 was selected to provide a representative sample of conditions. Meteorological data for the year were readily available, as well as *in situ* measurements of water currents and atmospheric conditions in the Straits from a weather, wave, and current monitoring buoy deployed during that period by Michigan Tech. Meteorological data including hourly wind speed and direction, air temperature, dew point and cloud cover during 2016 were obtained from the National Oceanic and Atmospheric Administration's (NOAA) operational High-Resolution Rapid Refresh (HRRR), a data-assimilated atmospheric model based on the Weather Research and Forecasting (WRF) model. These conditions were used to drive the hydrodynamic model described in section B.2.2 of this report. Lake conditions (currents, water temperature, ice, and water levels) for the Straits of Mackinac were simulated using the NOAA Lake Michigan-Huron Operational Forecast System (LMHOFS), based on the FVCOM oceanographic model.

Water temperatures in 2016 were representative of typical conditions in the Straits, though average-lake temperatures were slightly above long-term average data collected from 2008 - 2015 (0.5-3°C; Figure B1). In comparison, 2016 water temperatures in the Straits region were consistent with average data for recent years including 2012, 2013 and 2015 (Figure B1).

The 2016 ice season in the Straits of Mackinac extended from January to late April with the last ice reported for Lake Huron on April 26th, 2016. The first reports of ice for Lakes Huron and Michigan in late 2016 were reported on December 11th and 12th, 2016, respectively. This extent of ice cover is typical coverage for the region of interest. However, the overall lake-extent of ice in 2016 was lower than the long-term average for both Michigan and Huron. Information for Great Lakes ice cover is available through NOAA's Great Lakes Environmental Research Laboratory (GLERL) website (https://www.glerl.noaa.gov/data/ice/).

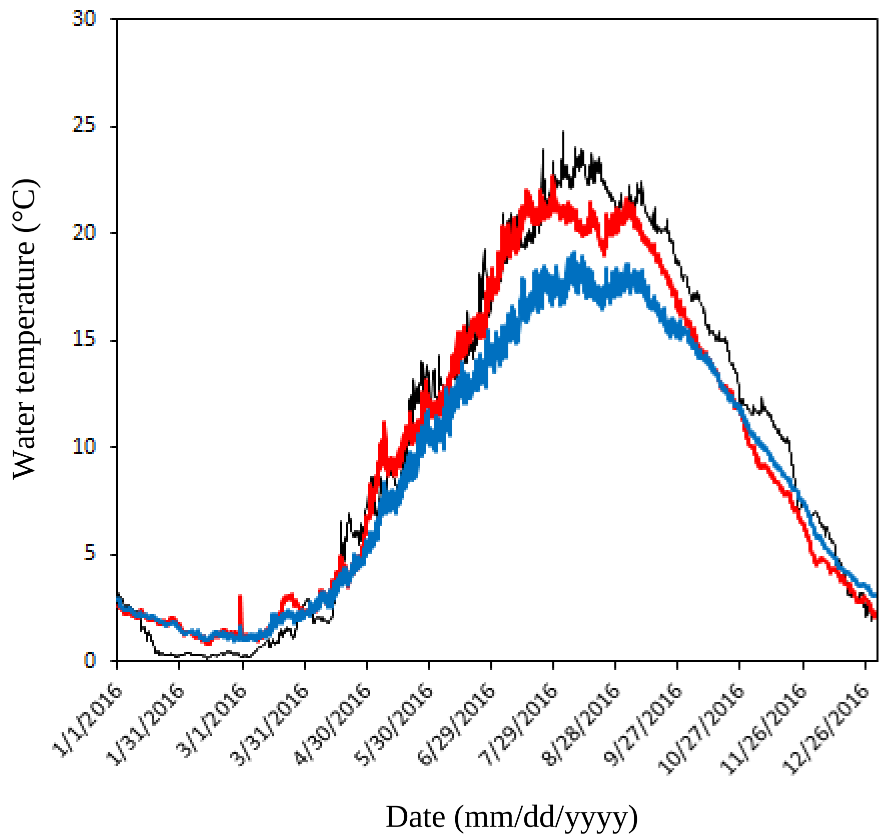

Figure B1: Annual and average surface water temperatures for the Straits of Mackinac region. Average daily surface water temperature for 2016 is represented by the black line with average daily surface water temperatures from 2008 - 2015 represented by the blue line. Average daily surface water temperatures for the years 2012, 2013 and 2015 are represented by the red line Data retrieved from the NOAA/GLERL Great Lakes Coastal Forecasting Systems (Nowcast; http://data.glos.us/glcfs/).

B.2.2 Hydrodynamic and oil dispersal modeling

The computational modeling framework used to predict water flow and current patterns in the Straits of Mackinac region is based on the next-generation LMHOFS, developed by the NOAA/GLERL. The LMHOFS hydrodynamic model is described by Anderson and Schwab (2013, 2017) which itself is a derived version of the Finite Volume Community Ocean Model (FVCOM; Chen et al., 2006). FVCOM is a free-surface, hydrostatic, primitive-equation hydrodynamic model that solves the continuity, momentum, and energy equations in three-dimensions on an unstructured, sigma-coordinate (terrain-following) mesh. FVCOM has been successfully validated and applied in multiple coastal ocean settings in addition to within the Great Lakes and associated connecting channels, including the Straits of Mackinac, and prior assessment to evaluate oil dispersal in Lakes Michigan and Huron and associated waters of the Straits of Mackinac connecting channel (Schwab 2014, 2016). Bathymetric and coastline data used for model development were obtained from NOAA's National Geophysical Data Center (NGDC) and interpolated to an unstructured computational mesh covering the entirety of Lakes Michigan and Huron and simulated on Michigan Tech's supercomputing cluster. The horizontal grid resolution of the mesh ranges from 100 m in the Straits of Mackinac to 2.5 km for the centers of Lakes Michigan and Huron. A section of the computational grid for the Straits region is shown in Figure B2. Vertical resolution (lake depth) was structured through 20 uniformly distributed sigma layers. Model conditions were initialized from the NOAA LMHOFS model on January 1, 2016. Model simulations were carried out for 2016 using the gridded (3-km) hourly atmospheric forcing conditions as described in B.2.1.

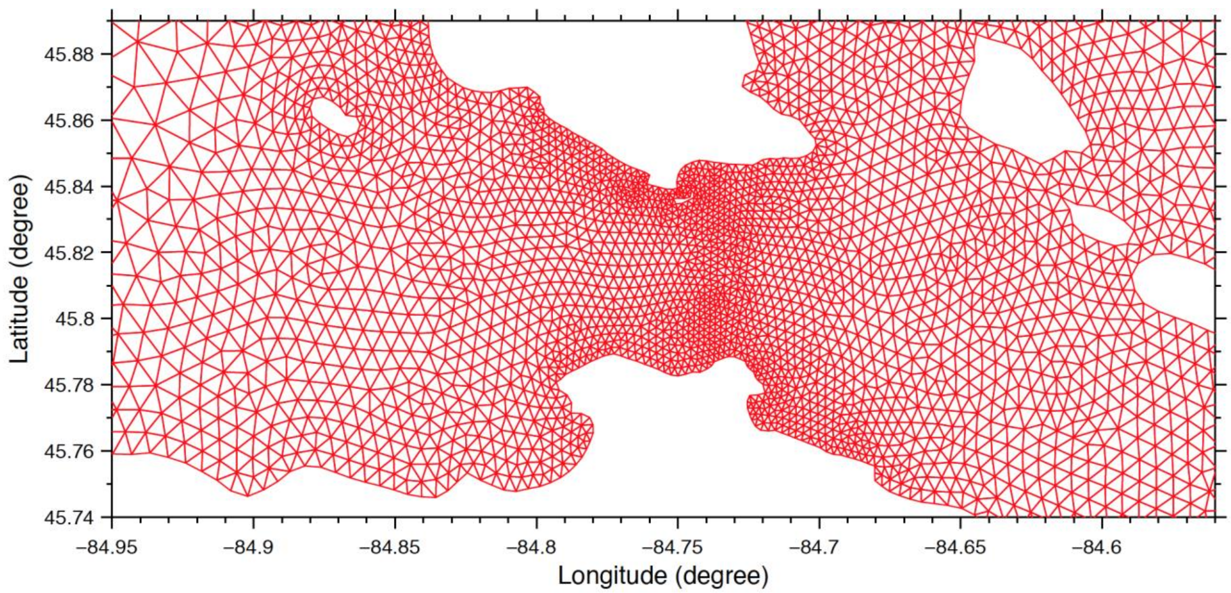

Figure B2: A section of the computational grid describing the terrain following mesh applied by FVCOM for the bathymetry of the Straits of Mackinac Region adjacent Lake Michigan and Lake Huron bottom surfaces.

To assess the accuracy of model predictions for water currents within the Straits of Mackinac region, model output was directly compared against real-time monitoring data retrieved from Michigan Tech's Mackinac Straits West meteorological buoy (45715; http://glbuoys.glos.us/45175/) for the 2016 open water monitoring season (Figure B3). During the open water season (April - November), this buoy is deployed (45° 49.5156N; 84° 46.3302W) and maintained to the west of the Mackinac Bridge in surface waters on the north side of the shipping channel directly to the west of the Line 5 location in the Straits of Mackinac. Lake conditions including, but not limited to, air and water temperatures, wind speed and direction, wave height, period and direction, and current speed and direction at multiple vertical locations are monitored from the lake surface to approximately 18 m depth at 10-minute intervals.

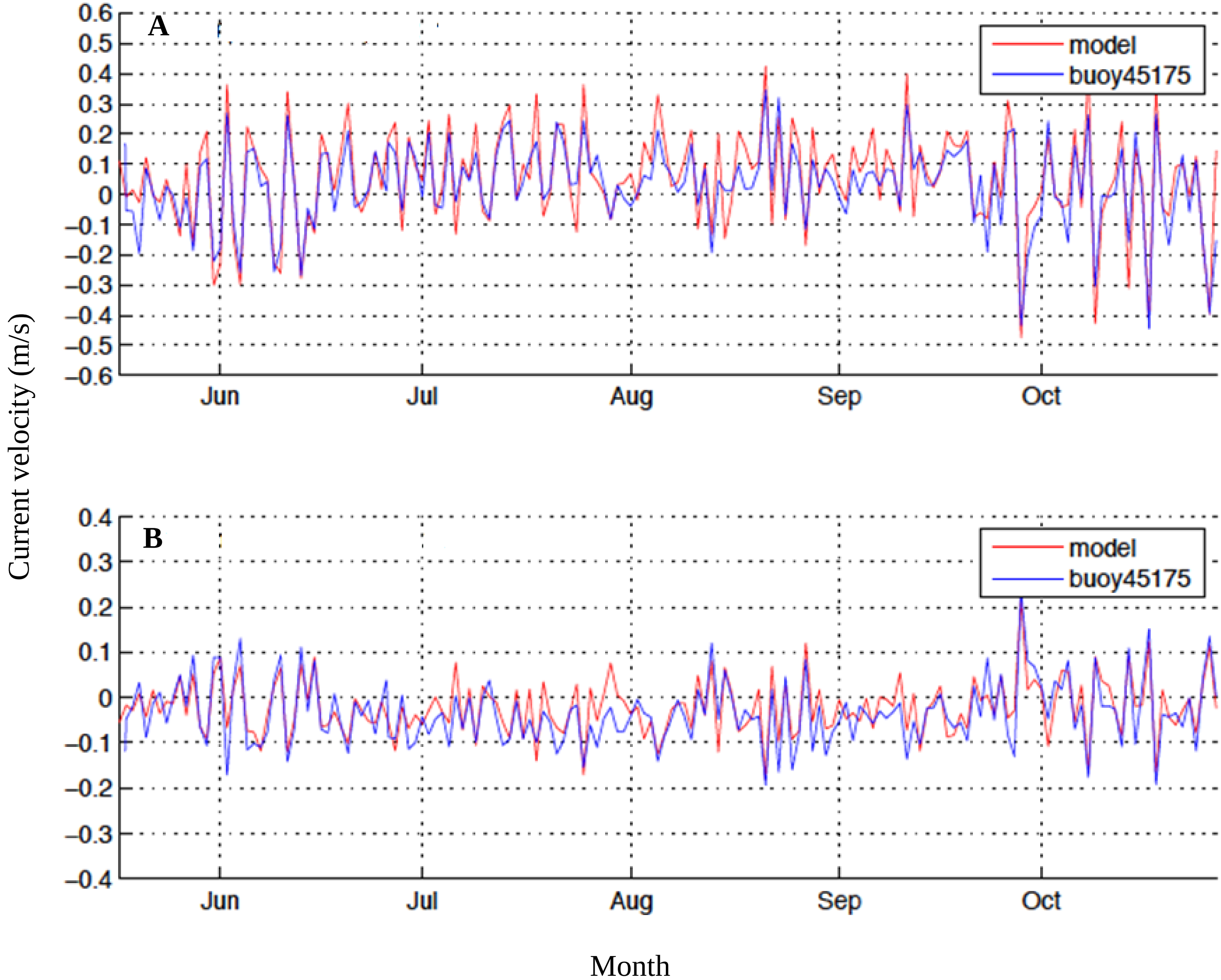

Figure B3: Comparison of hydrodynamic model predicted water currents (red) to real-time meteorological buoy monitoring data (blue) measured for the Straits of Mackinac during the 2016 open water season. Panels represent water currents predicted (model) and observed (buoy) at a depth of 2 m and for currents flowing in the A) eastern and B) western directions within the Straits region. Comparisons of modeled and observed currents at the buoy location were similar at other depths.

B.2.3 Oil dispersal simulation

In this assessment, the dispersal of oil was simulated using a cloud of individual tracer particles that move with the combined effect of the water currents predicted by the hydrodynamic model and a small fraction of the surface wind. The computer code that simulates the movement of individual particles is based on the Lagrangian particle tracking code contained within the FVCOM hydrodynamic model. In the current version of the particle tracking code, the computational scheme has been optimized by improving the algorithm for identifying the mesh element containing a specific particle location. The particle tracking method used in this approach is identical to that applied by Schwab 2014 and very similar to that employed in NOAA's Generalized NOAA Oil Modeling Environment dispersal model framework (GNOME; https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/response-tools/gnome.html) but has been optimized to conduct a larger number of simulations based on a single hydrodynamic model run. A random walk process was used to simulate subgrid-scale turbulent variability in the velocity field. A horizontal diffusion coefficient of 10 m^2/sec was used in the current assessment as recommended for the default GNOME setting.

For each simulation, the oil discharge was represented by 10,000 unique tracer particles that were released from at least one of the three locations identified as potential rupture locations in Task A (Table B1). For the North and South locations, half of the particles were released from the West Pipeline and the other half from the East Pipeline. For the Center location, all 10,000 particles were released at a point midway between the West Pipeline and East Pipeline. Particles were released on the water surface owing to specific gravities of the light synthetic and light crude products that are less than that of water and will result in these products quickly rising through the water column and floating on the water surface above the pipeline following a potential rupture. Oil dispersal simulations conducted using a greater number of individual particles (20,000) did not result in statistically different predictions regarding the total extent (km) of shoreline susceptible to oiling (i.e., 'beached' oil), or the maximum extent (km^2) of Lake Michigan, Lake Huron or Straits of Mackinac surface waters predicted to be at risk of oiling. It should be noted that the FVCOM model predictions of oiled shoreline and lake surface area are based on the 1 x 1 km FVCOM grid and an assumption that grid cells overlapping the shoreline each contain 1 km of shoreline. This underestimates oiled shoreline length due to the sinuosity of the Lakes Michigan and Huron shorelines and the presence of islands, so the model results were converted to geographic information system (GIS) based distance estimates using a high-resolution shoreline layer for use by subsequent Tasks. The volume of oil released during a pipeline rupture represents the 58,000 barrels identified in Tier 5 of the Task A worst-case scenario. Thus, at the time of initial release, an individual particle represents 5.8 barrels of oil where one barrel contains 42 gallons (US) or 159 liters of oil. Releases corresponding to Tiers 1 – 4 can be similarly scaled based upon the estimated volume corresponding to each tier of failure.

Table B1. Locations and geographic coordinates for simulated pipeline rupture and crude oil release.

Pipeline rupture location	West Pipeline		East Pipeline	
	Lat. (°N)	Long. (°W)	Lat. (°N)	Long (°W)
North	45.82832	-84.7616	45.82653	-84.7554
Center	45.81873	-84.7652	45.81903	-84.7600
South	45.79697	-84.7736	45.79770	-84.7662

Evaporation or weathering of oil is one of the most important processes affecting its fate during a spill. The rate of oil evaporation is heavily dependent on the composition of the product and also specific environmental conditions including water temperature. The logarithmic function described in equation 1 below by Fingas (2013 and 2015) for Alberta Sweet Mixed Blend was included into the oil dispersal calculations to account for evaporation within the dispersal model framework for this assessment:

$$\% \text{ Evaporation} = (3.41 + 0.054T) \times \ln(t) \qquad (1)$$

In this function, T represents water temperature (°C), and ln(t) represents the natural logarithm of time in minutes with time being the duration in minutes of particle travel from the time of initial release until the particle becomes beached on the shoreline. Alberta Sweet Mixed Blend is highly similar in composition to the light crude oil products transported through the Line 5 pipeline. Evaporation rates were calculated for each particle as determined by the unique temperature profiles experienced by each particle during dispersal. For particles that become beached at any time following release, no further evaporation was considered in the oil dispersal simulation.

Wind and ice-cover represent important considerations for potential effects on oil spill trajectory and evaporation and become increasingly important for predicting oil dispersal in the Straits of Mackinac region during the winter season. For wind, a 3% windage factor was included within the model. This is a typical value for windage used in offshore oil trajectory analysis (GNOME). The oil spill model's predictive framework was also updated in this assessment to include ice-cover conditions and potential effects on oil dispersal and evaporation. For periods when an individual particle was subject to ice-cover conditions >

80%, wind effects on particle (oil) dispersal were reduced to zero. During periods when ice-cover was < 20%, wind effects were increased to 3% with a linear increase in wind effects included for intermediate ice-cover between 20 – 80%. Evaporation rates were scaled similarly for periods of the year when ice-cover can affect oil evaporation.

B.2.4 Atmospheric Dispersion Modeling

A pipeline rupture that could result in the release of light crude oil product from the Line 5 pipeline into the waters of the Straits of Mackinac would not only affect the aquatic and coastal wildlife but would release volatile organic compounds (VOCs) originating from the pipeline crude oil product into the air, exposing and affecting local populations. Some of these compounds are known to have both non-carcinogenic and carcinogenic effects, particularly VOCs such as benzene, toluene, ethylbenzene, and xylene isomers that are collectively referred to as BTEX. The objective of this part of the analysis was to provide a prediction of ground-level concentrations ($\mu g/m^3$) of total VOCs as well as BTEX compounds directly downwind from a potential release from Line 5 west of the Mackinac Bridge and northwest of the town of Mackinaw City, MI., with its population of nearly 1,000 residents. The main objective was to model atmospheric dispersion as accurately as possible under the time and resource constraints of this project. Another objective was to provide air concentrations to Task D researchers for health risk assessments. Model assumptions and parameters were intentionally used in this dispersion modeling such that air concentrations were generated on the high end of the expected range, consistent with a worst-case scenario. These assumptions and parameters include dispersion occurring in a stable atmosphere, an emission source area that is likely to be smaller than expected and the closest to Mackinaw City, the use of a network of point sources to approximate emissions from an area source, and others to be described below. The ground-level concentrations of total VOCs and BTEX compounds downwind of a worst-case release location were provided to the health risk assessment researchers in Task D for incorporation into their analyses.

The coordinates of three possible worst-case release locations are shown in Table B2 as identified by Task A in this assessment. For the atmospheric dispersion modeling, we selected the coordinates for the South pipeline location due to its greater proximity to the Mackinaw City population center relative to the northern and central locations. A satellite map of the location is provided in Figure B4 with the spill locations indicated with two light green squares and with the source location for dispersion calculation indicated with a red star just offshore where the twin pipelines enter the shoreline from the north. If a spill occurred at this location, the city limits of Mackinaw City would be only a few 100s of meters from the source of the oil release. This case was used to represent a worst-case scenario from the standpoint of local Mackinaw City population exposure to airborne VOCs.

Furthermore, regarding modeling assumptions, the source of VOC emissions from a hypothetical worst-case oil spill would form an area source rather than a point source. The size of such an area source would be dependent on local flow characteristics of the water in the Straits as well as on wind direction and speed. To approximate oil spill size for the purpose of estimating dispersion of emitted VOCs, it was assumed that after one hour of worst-case release, half of the crude oil worst case volume would be released with an oil layer thickness of 10 mm and a square oil spill source region of about 1000 m on a side. We recognize that these assumptions are idealizations of an actual situation, but are they required to make progress on estimating dispersion of airborne VOCs. Furthermore, this square-shaped emission source region is divided into nine equal area sections with a point source located at the center of each section, as shown in Figure B3. Each of these nine-point sources emits at a rate that is 1/9 of the estimated total emission rate for the oil spill, to be discussed below.

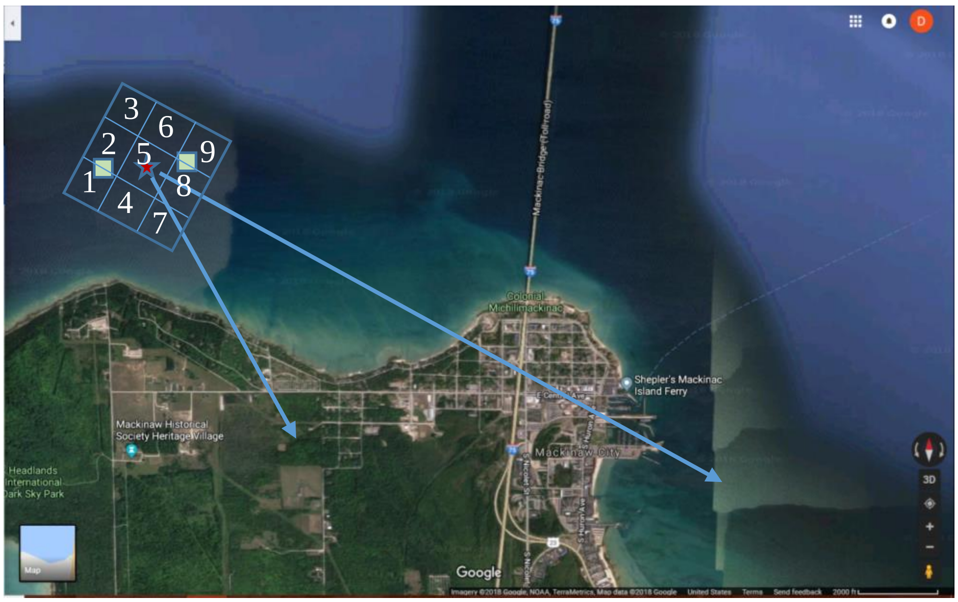

Figure B4: Satellite image of the spill location assumed for the atmospheric dispersion calculations near the town of Mackinaw City, MI. Coordinates of South worst-case spill location: West pipeline 45.79697°N, -84.7736°W; East pipeline 45.7977°N, -84.7662°W. Source location for dispersion calculation; arrows represent potential wind directions affecting Mackinaw City and shoreline homes within the city limits. Blue square approximates the oil spill size after one hour.

B 2.4.1. Atmospheric modeling methods

The Gaussian dispersion model (GDM) approach was used in this analysis. It approximates the actual dispersion resulting from the turbulent transport of non-reactive chemical species in the atmosphere. The predictions are approximate because the model assumes a constant wind speed that does not vary with height and also assumes constant dispersion characteristics in the atmosphere that do not vary with height above the surface. The GDM predicts the time-averaged concentration of VOCs with the understanding that significant local fluctuations in VOC concentration are expected but are smoothed over a suitable averaging dispersal period. Other atmospheric dispersal models such as NOAA's Areal

Locations of Hazardous Atmospheres (ALOHA; https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/response-tools/aloha.html) can improve on the GDM approach by incorporating variable wind speed with height and allowing dispersion to vary in all coordinate directions. However, we feel that the uncertainty in modeling the emission rate at the source (i.e., pipeline rupture location) dominates the prediction of downwind air concentrations rather than the accuracy in modeling the dispersion of chemical constituents at greater heights in the local atmosphere where they pose a lesser risk for human exposure.

The specific GDM mathematical formula used to predict ground-level concentrations of emitted VOCs in the air is provided in equation (2) below.

$$\rho_{VOC} = \frac{w_A\,(10^6)}{(\pi\, v_x\, \sigma_y\, \sigma_z)} \left[exp\left(-\left(\frac{h^2}{2\,\sigma_z^2}\right)\right) exp\left(-\left(\frac{y^2}{2\,\sigma_y^2}\right)\right)\right] \tag{2}$$

Inputs for this modeling approach for predicting the ground level mass concentration of VOCs (ρVOC; µg/m3) in units of micrograms per cubic meter of air include the emission rate of VOCs from the spilled oil in units of grams of VOC per second (ωA; g VOC/s), and wind speed in units of meters per second (vx; m/s). For a worst-case analysis, a constant wind speed of 1.5 m/s (5.4 km/h) was assumed. Additional inputs for the GDM approach include the standard deviation (σy) for VOC dispersion in the cross-wind direction in units of meters (y; m) and also the standard deviation (σz) for dispersion in the vertical direction (z; m). Lastly, the height of the emission source in meters (h; m) is also required. For the hypothetical underwater release of crude oil from the submerged Line 5 pipeline, the height of the emission source was represented by the lake surface (0 m). This height is assumed due to the low specific gravities of the light crude oil products transported in the pipeline that will result in their rapid rise to the lake surface following a potential pipeline rupture and release. The values of σy and σz are functions of downwind distance from the source, x, and also of the specific atmospheric stability conditions outlined below.

The GDM assumes a point source for the VOC emissions, and so to use this equation to estimate VOC concentrations downwind from an area source, some modifications are needed. This is accomplished by applying the GDM to each of the nine point sources in the square area emission source region shown in Figure B3. For any location of interest in Mackinaw City, the ground-level VOC concentration in the air will be the sum of the contributions by each of the nine model results. Furthermore, for any location, the values of x, y, σ_y and σ_z will differ slightly for each of the nine GDMs because of the relatively small distances among each of the nine point sources from the center of the entire area source region. The summed concentration results were smoothed using a simple three-point averaging formula to get the predicted smoothed concentration profiles, shown below. Finally, to model a worst-case dispersion scenario, an atmospheric stability class of F was assigned for GDM simulations. Stability classes are used to describe the extent to which atmospheric turbulence can help to increase the mixing of unpolluted air into the pollution plume and help effectively reduce the concentration(s) of the contaminant(s) in the plume. Stability classes rank from A - F with class A representing the most unstable (turbulent) conditions through to class F which represents the most stable conditions that are least likely to reduce contaminant concentrations in a dispersal plume. Thus, for this assessment, class F represents stable nocturnal conditions that can potentially lead to the highest ground-level concentrations thus representing a worst case condition for health risks.

B 2.4.2 Emission rates

For this atmospheric dispersion analysis, the release of the worst case spill volume was assumed to occur over a two-hour period at the location indicated in Figure B3. The oil spill area will expand over time during this release period as will the emissions of VOCs from the exposed oil surface. The expected emission rate of VOCs from the oil spill will rise early in the two hour release period, reach a maximum, and then decline as the release of oil slows down and ceases and as the volatilization of VOCs declines. This process is complicated and difficult though not impossible to model with sufficient computational resources. However, for this risk assessment, it is assumed that a sufficiently accurate method to model VOC emission rate to estimate the maximum extent of VOC emission from a spill volume is to assume that the worst case volume is released instantaneously. Similar to the hydrodynamic modeling approach, atmospheric dispersal used the (Fingas 2013, 2015) evaporation equation described in equation 1 to predict VOC evaporation from the crude oil spill volume.

Over a one-hour period, the evaporation equation predicts an average emission rate over the first hour of the spill of 212 kg VOCs per second. In addition to predicting total VOC emission rate, estimates for the emissions of BTEX compounds were calculated by multiplying to total VOC emission rate above by the volume fraction of each of the BTEX compounds in a representative crude oil product transported by the Line 5 pipeline (Shell Synthetic Light - SSX; www.crudemonitor.ca). As noted for predicting evaporation of oil during dispersal across the water surface by the hydrodynamic, the Fingas (2013, 2015) evaporation model was developed for Alberta Sweet Mixed Blend crude oil which is highly similar in composition to the light crude oil products such as Shell Synthetic Light transported through the Line 5 pipeline. Five year average contents for BTEX in the SSX product are 0.14% (by volume) for benzene, 0.42% for toluene, 0.17% for ethylbenzene, and 0.57% for xylenes.

For the analysis of dispersion from a pipeline release of natural gas liquid (NGL) product, disclosed information indicates that propane is the majority (55 - 80% by vol.) component of the NGL mixture with a density of 500 -550 kg/m^3. The solubility of NGL in water is very low. Therefore, the emission rate (m^3/s) of the product at the surface will very closely match that from the pipeline at the bottom of the Straits save for the short delay for the released vapors to rise through the water column to the surface. A release rate of half of the worst case volume per hour was assumed consistent with the crude oil emission rate scenarios described above. Also, benzene and toluene concentrations described for the NGL products are up to 1% of the mixture.

The formulas describing the calculations for the standard deviations associated with crosswind (σ_y) and vertical directions (σ_z) for pollutant dispersion among different atmospheric stability classes are provided in equations 3 and 4 below:

$$\sigma_y = ax^b \tag{3}$$

$$\sigma_z = cx^d + f \tag{4}$$

The values for σ_y (m) and σ_z (m) vary with distance downwind from the initial source (*x, km*) according to the values described for the parameters *a*,*b*,*c*,*d* and *f* among the different atmospheric stability classes are provided in Table B2. For this work, only stability class F was considered for the worst case scenario.

Table B2. Parameters for Several Atmospheric Stability Classes. Class A is the most unstable (maximum dispersion) representing strong vertical mixing during sunny days, while class F is the most stable (minimum dispersion) representing nighttime periods.

. Atmospheric stability class	All distances (*x*)	Downwind distances (*x*) ≤ 1 km			Downwind distances (*x*) ≥ 1 km		
	Equation parameters						
	a	*c*	*d*	*f*	*c*	*d*	*f*
A	213	440.8	1.941	9.27	459.7	2.094	-9.6
B	156	106.6	1.149	3.3	108.2	1.098	2
C	104	61	0.911	0	61	0.911	0
D	68	33.2	0.725	-1.7	44.5	0.516	-13
E	50.5	22.8	0.678	-1.3	55.4	0.305	-4
F	34	14.35	0.74	-0.35	62.6	0.18	-48.6

B.3 Analysis

B.3.1 Hydrodynamic Modeling Results - Oil Beaching

A summary of the maximum oiled shoreline distances (km) as associated with the theoretical worst-case release of oil in the Straits of Mackinac are provided in Table B5 below. Individual figures depicting the worst case shoreline oiling scenarios can be found in Appendix B. In general, Lake Huron shorelines are predicted to be at the greatest risk of oiling for these monthly worst cases. For June, July, August, and October, model predictions indicated that released oil for the worst case in that month became beached along Lake Huron shorelines only. Lake Michigan shorelines were predicted to be most susceptible to oiling in the worst cases during February, March, and April. The single greatest distance of oiled shoreline of 711 km was predicted for the worst case in February (release date: 02/26/2016 12:00 pm) with Lake Michigan coastline predicted to represent 567 km of this total oiled shoreline and 144 km of Lake Huron shoreline also receiving oil for this specific simulation. Generally, the worst case oiled shoreline distances were associated with a pipeline rupture and release location within the central or southern sections of Line 5 transiting the Straits of Mackinac. For example, worst case shoreline oiling distances resulting from a rupture and release of crude oil at the northern location within the Straits of Mackinac section of the Line 5 pipeline were only predicted for January and July release scenarios. For all other months of the year, maximum oiled shoreline distances were associated with crude oil releases from central and southern locations of Line 5 within the Straits of Mackinac.

Oiled shoreline distances and oiled surface area for each spill were calculated at intermediate time intervals of 1, 2, 3, 6, 10, 15, 20, 30 and 60 days after the spill. Table B3 presents a summary of the worst case for each month. For January–July, the largest oiled shoreline distances were associated with the maximum calculated dispersal time of 60 days (Table B3). In contrast, the length of oiled shoreline reached a maximum and stabilized at 30 and 20 days for the August and September worst-case scenarios, respectively. For the meteorological, wind, and current conditions typical of the Straits of Mackinac in October, the hydrodynamic model predicted a maximum oiled shoreline distance of 182 km following only a ten-day dispersal time. For November and December, the maximum oiled shoreline length was reached after 15 days dispersal time. In general, longer maximum oiled shoreline distances (> 400 km) were predicted for January–July in comparison to August – December, when maximum oiled shoreline distances were predicted to be ≤ 353 km. For example, the average maximum oiled shoreline distance predicted for January - July was 553 km. This compares to an average oiled shoreline distance of approximately 279 km predicted for August - December.

Table B3. Summary of monthly maximum oiled shoreline distances (km) predicted for the Straits of Mackinac region during 2016 meteorological conditions. The dates and times (24 hr clock) of oil release for the specific maximum oiling simulations are also provided. Release location indicates the general location of oil release within the submerged section of the Line 5 pipeline within the Straits of Mackinac. Dispersal duration indicates the time in days required to reach the maximum length of oiled shoreline as predicted by FVCOM hydrodynamic model simulations for the meteorological, water current, and ice-cover conditions present in the Straits of Mackinac region for the simulation month. Graphical representations of the dispersal simulations included here are provided in Figures B6-B17 provided in Appendix B of this report.

Month	Release date and time	Release Location	Dispersal duration (days)	Total oiled shoreline distance (km)	Lake Michigan shoreline (km)	Lake Huron shoreline (km)
January	01/17/2016 1800hrs	North	60	558	38	520
February	02/28/2016 1200hrs	Center	60	711	567	144
March	03/01/2016 1800hrs	Center	60	704	558	146
April	04/24/2016 1800hrs	South	60	542	542	0
May	05/12/2016 1200hrs	Center	60	412	5	407
June	06/20/2016 0000hrs	Center	60	514	0	514
July	07/13/2016 0000hrs	North	60	427	0	427
August	08/21/2016 0600hrs	South	30	353	0	353
September	09/17/2016 0000hrs	South	20	321	1	320
October	10/08/2016 0000hrs	South	10	182	0	182
November	11/30/2016 0000hrs	South	15	314	3	311
December	12/27/2016 1800hrs	Center	15	225	37	188

B.3.2 Hydrodynamic Modeling Results - Surface Oiling

A summary of the maximum surface areas of floating oil (km^2) associated with the theoretical worst-case release of oil in the Straits of Mackinac is provided in Table B4 below. Individual figures depicting the worst-case oiled surface area scenarios can be found in Appendix B. Similar to the results for oiled shoreline distances, the majority of oil dispersal simulations predict that in the monthly worst cases, oil dispersed from the Line 5 pipeline spreads mainly to Lake Huron surface waters. For example, the greatest extent of surface area oiling predicted for worst cases in January, May, June, July, August, September, November, and December encompass the surface waters of Lake Huron. However, for the other four months of the year, worst case predictions indicate that Lake Michigan surface waters are at risk of oiling. Furthermore, the single greatest extent of the oiled surface area (1745 km^2) was predicted to occur solely on Lake Michigan surface waters during the worst case in April (release date: 04/24/2016 12:00 pm). For this simulation, oil was released from the north location identified by Task A. However, there was no specific pattern of surface area oiling as related to the potential location of a pipeline rupture with the monthly worst case surface area oilings generally being equally distributed among the north, central, and south pipeline release locations. Lake Michigan waters were predicted to be most at risk of oiling during February, March, April, and October with only 26 km^2 of Lake Huron surface water predicted to be at risk of oiling during the worst case in February. In March, April, and October the maximum oiled surface areas were isolated solely to Lake Michigan waters.

For all of the simulations, maximum oiled surface areas were predicted to occur during or within 30 days of oil release (Table B6). For example, for the worst-case surface area oilings for March (1102 km^2) and April (1745 km^2), a dispersal time of 30 days resulted in the greatest area. In comparison, maximum oiled surface areas for May (712 km^2), June (1033 km^2) and July (1288 km^2) were predicted to occur following 20 days dispersal time. This compares to a dispersal time of 15 days for maximum surface area oiling to occur during January (921 km^2), February (783 km^2), and August (1317 km^2). For the last four months of the year, only six days of dispersal were required for oil to reach the maximum coverage across Lake Michigan and/or Lake Huron waters proximate to the Straits of Mackinac. Similar to the pattern observed for oiled shorelines, maximum oiled surface areas during January - July were much higher relative to those for September - December. Specifically, the maximum oiled surface areas for January - August averaged 1112 km^2 in comparison to an average oiled surface area of 588 km^2 predicted for September - December.

Table B4. Summary of monthly maximum water surface area oilings (km^2) predicted for the Straits of Mackinac region during 2016 meteorological conditions. The dates and times (24 hr clock) of oil release for the specific maximum oiling simulations are also provided. Release location indicates the general location of oil release within the submerged section of the Line 5 pipeline within the Straits of Mackinac. Dispersal time indicates the time in days during which FVCOM hydrodynamic model simulations predicted the maximum extent of surface area oiling for the meteorological, water current and ice-cover conditions present in the Straits of Mackinac region for the simulation month. Graphical representations of the dispersal simulations included here are provided in Figures B18-B29 provided in Appendix B of this report.

Month	Release date and time	Release location	Dispersal time (days)	Total oiled surface area (km^2)	Lake Michigan surface area (km^2)	Lake Huron surface area (km^2)
January	01/18/2016 1800hrs	North	15	921	1	920
February	02/28/2016 0000hrs	Center	15	783	757	26
March	03/15/2016 1800hrs	South	30	1102	1102	0
April	04/24/2016 1200hrs	North	30	1745	1745	0
May	05/12/2016 1800hrs	North	20	712	0	712
June	06/20/2016 0000hrs	Center	20	1033	0	1033
July	07/14/2016 0000hrs	Center	20	1288	0	1288
August	08/21/2016 0600hrs	South	15	1317	0	1317
September	09/17/2016 0000hrs	South	6	563	0	563
October	10/26/2016 0000hrs	Center	6	494	494	0
November	11/29/2016 1800hrs	Center	6	572	0	572
December	12/13/2016 1800hrs	North	6	723	0	723

B.3.3 Hydrodynamic Modeling Results - Proportional Fate

Comparison figures describing the temporal fate of the released oil during the 60 day duration of the monthly worst cases in terms of the proportions (%) of the released volume that become beached on shorelines, remain afloat on the water surface, and the amounts lost to evaporation are provided in Appendix B (Figures B30-B41). For the January simulation, a total of approximately 5% of the release volume is lost to evaporation over a 60 day dispersal period with a negligible amount of the oil remaining on the water surface by 60 days. Beaching of oil occurs within the first 24 hours of release with oil continuing to become beached after 60 days at which time approximately 96% of the released oil volume has been deposited along coastal shorelines. In the February oil dispersal simulation, a slightly greater proportion (8%) of the release volume is evaporated over 60 days relative to January. Approximately 90% of the released oil becomes dispersed across the water surface within the first 48 hours beginning to become beached after this time. However, after 720 hours of dispersal (30 days), approximately 85% of the released oil has now become beached along the shorelines increasing to approximately 90% after 60 days of dispersal time. For the March dispersal simulation, total evaporation is reduced to approximately 5% after 60 days. This low extent of evaporation for January - March is consistent with the greater extent of ice-cover and low water temperatures for the Straits of Mackinac region during the mid-late winter season. Similar to the January dispersal, approximately 95% of the released oil has been beached by 60 days with little to no material remaining afloat on either the Lake Michigan or Lake Huron water surface.

With the onset of warmer air and water temperatures and reduced ice-cover, the total amount of oil evaporation predicted for an April dispersal scenario approaches 32% by the end of 60 days dispersal. Relative to the negligible amounts of oil remaining on the surface after 60 days for the January - March simulations, approximately 3% of the worst case release volume is predicted to remain afloat after 60 days dispersal in April with 60% of the initial volume being beached after this dispersal time. The May dispersal simulation predicted rapid beaching of oil within the first 6 hours and approximately 60% of the oil being beached after 240 hours (10 days) dispersal. By 60 days, < 1% of the release volume was predicted to remain afloat for the May simulation. Oil released in June was predicted to be reduced in volume by approximately 32% due to evaporation after 60 days. Oil released in June was also quickly beached after 6 hours of dispersal with the maximum extent of oil beaching occurring by approximately 840 hrs (34 days) after release. No oil released in June was predicted to remain afloat after 60 days dispersal. The July dispersal simulation was highly similar to that predicted for oil released in June with all beaching of all being complete after 840 hours and no oil predicted to remain afloat after 60 days dispersal. The highest overall loss of oil volume to evaporation was predicted for oil released in August with approximately 40% of the worst case volume predicted to be evaporated after 60 days. Nearly all beaching of oil was predicted to occur by 480 hours (20 days) dispersal with 60% of the release volume being beached by this time with none of the worst case volume remaining afloat after this time.

For the September simulation, 33% of the oil was evaporated in the first 48 hours with no oil remaining on the water surface after ten days. The remaining volume of released oil was predicted to become rapidly beached with 67% predicted to be deposited on shorelines after 240 hours (10 days). The fate of oil released for the October worst case simulation was defined by evaporation and beaching within the first approximately 180 hours (7.5 days) of dispersal. By this time, approximately 33% of the oil volume was predicted to evaporate with the remaining 67% predicted to become beached along coastal shorelines. No oil was predicted to remain on the water surface after ten days of dispersal during the October worst case scenario. By November, the extent of oil lost to evaporation was predicted to be reduced to 26% of the total volume with any floating oil becoming beached after 360 hours (15 days) dispersal. Of the total worst-case release volume, 76% was predicted to become beached by 15 days dispersal. The fate of oil during the December worst case simulation was similar to that predicted for the November scenario with all beaching of oil occurring within 15 days of release and approximately 75% of the released oil being beached. No oil was predicted to remain afloat after this time, and approximately 25% of the initial worst-case release volume was predicted to be lost to evaporation in December. For all scenarios, the total proportion of oil lost to evaporation occurred rapidly within the first 24 - 48 hours of dispersal with little further loss of oil volume to evaporation predicted over the remaining simulation time.

B 3.4 Atmospheric Dispersal Analysis - Crude Oil

The surface (3-D) plot to follow shows a perspective on the plume VOC concentrations from 2500 m to 5000 m downwind (x-direction) from the center section of the square area emission source (section 5) and from -1000 m to 1000 m in the crosswind direction (*y*-direction; Fig. B5 A). The *x*-direction (expressed in meters, m) is aligned with the wind direction, and the *y*-direction (m) is considered the cross-wind direction. These *x* and *y* distances will encompass the Mackinaw City downtown area and outlying onshore and offshore areas. The y = 0 line on the surface plots is location directly downwind from the center of the area emission source (oil spill). The vertical axis on each figure is the concentration of VOCs at ground-level in units of $\mu g/m^3$ of air. The surface plot shows concentration in different colored ranges as noted in the legend. The surface plots for concentrations at ground-level will be presented for the most stable atmosphere (class F) because this is a worst-case scenario yielding the highest concentrations in the risk assessment. From the GDM predictions, significant populations within the Mackinaw City would experience VOC inhalation exposures at concentrations of between near 1.0×10^6 – 4.1×10^6 µg VOC/m^3 air over an area of approximately 2 km x 1 km. Figure B5 B shows a contour plot of the VOC plume from just downwind from the area source region to past Mackinaw City. Much higher VOC concentrations are predicted to be present over water before the plume reaching the city which may present a risk to any boaters or recreationists on the water at the time of release. The likelihood of potential exposure over water at night time consistent with stability class F is lower than during the day, however.

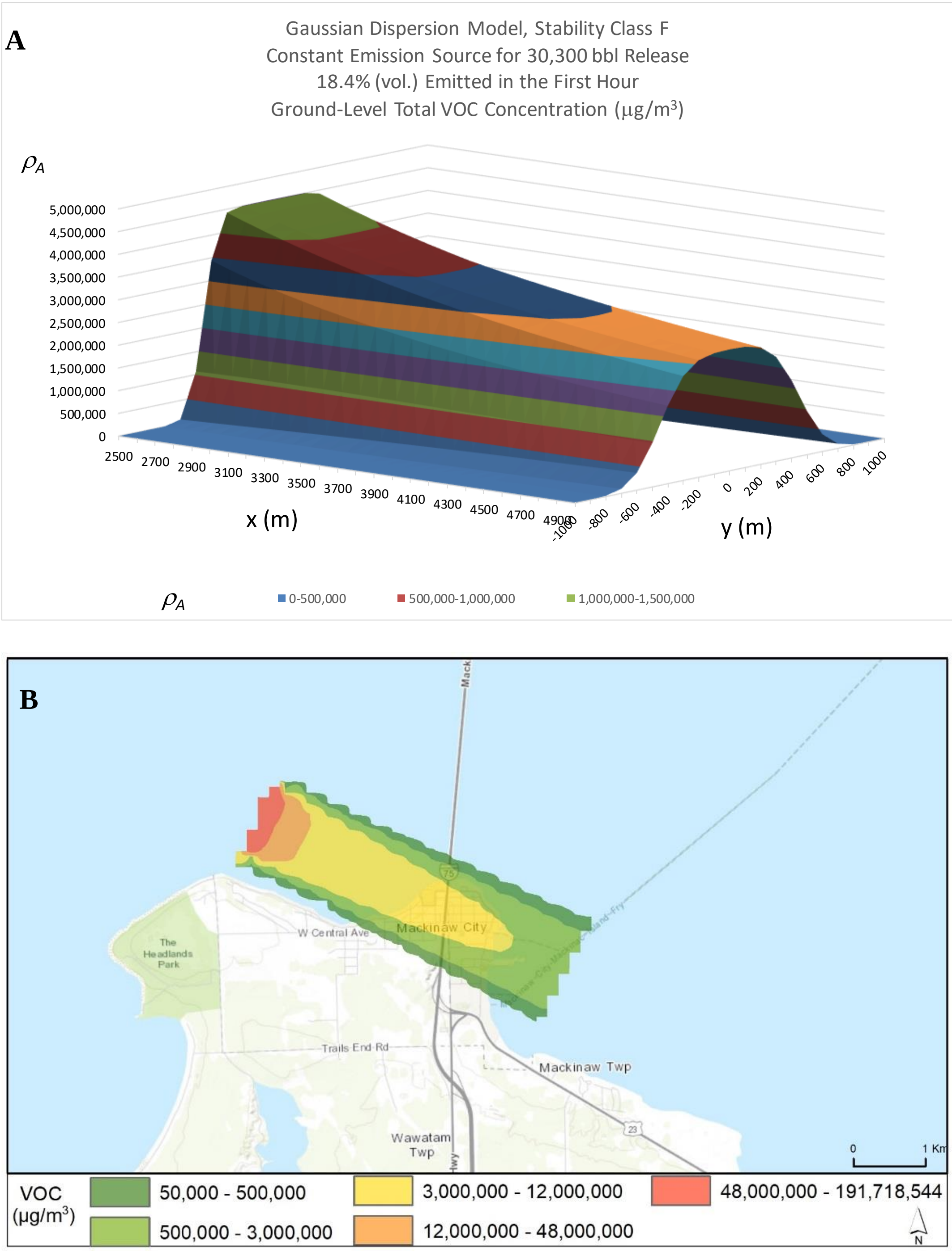

Figure B5. A) Ground-level concentrations (ρ_A; µg/m^3) of VOCs in the air over Mackinaw City, MI for atmospheric stability class F (most stable, least dispersion, highest concentrations). B) GIS overlay map is depicting VOC plume from Line 5 oil spill during atmospheric dispersal over Mackinac City. Colors represent VOC concentrations within the plume in units of µg/m^3.

When the GDM was run for BTEX compounds (benzene, toluene, ethylbenzene, and xylene), similarly shaped plume profiles as for the VOCs shown in Figure B5 were predicted, except that the concentrations were much lower based on the volume fractions of each compound in the crude oil mixture. A summary of key predictions from the GDM is presented in Table B5 for VOCs and BTEX compounds.

Table B5. Crude oil component concentrations predicted by the area source GDM over Mackinaw City (2,800 m ≤ x ≤ 4500 m, -500 m ≤ y ≤ +500 m).

Crude oil components	Predicted concentration range (µg/m^3 air)
Total Volatile Organic Carbons	$1.0 \times 10^6 – 4.1 \times 10^6$
Benzene	$1.4 \times 10^3 – 5.8 \times 10^3$
Toluene	$4.2 \times 10^3 – 1.7 \times 10^4$
Ethylbenzene	$1.7 \times 10^3 – 7.0 \times 10^3$
Xylene(s)	$5.7 \times 10^3 – 2.4 \times 10^4$

Key GDM results in Table B6 for dispersion of VOCs from a release of NGL from the Straits pipelines show higher total VOC, toluene, and benzene concentrations compared to that of Sweet Alberta Crude from Table B5.

Table B6. NGL VOC, Toluene, and Benzene Concentrations Predicted by the Area Source GDM over Mackinaw City (2,800 m ≤ x ≤ 4500 m, -500 m ≤ y ≤ +500 m).

Natural gas liquid components	Predicted concentration range (µg/m^3 air)
Total Volatile Organic Carbons	$3.2 \times 10^6 – 1.3 \times 10^7$
Toluene	$3.2 \times 10^4 – 1.3 \times 10^5$
Benzene	$3.2 \times 10^4 – 1.7 \times 10^5$

B.4 Discussion

B.4.1 Overall Considerations

It should be clear from the above description of the multitude of spill scenario simulations that were created by the Task B team that there is no single scenario for fate and transport that can be unequivocally identified as the 'worst case.' After considerable discussion with leaders of the other task teams, we decided on three possible metrics by which to measure the impact of a particular scenario, namely length of oiled shoreline, area of oiled open water, and volume of beached oil and demonstrated the month to month variation of these metrics. That way, each task team could choose a scenario or scenarios which would best suit their particular area of interest. Even though some of the worst cases occurred in winter months, there were some areas, like impact on shoreline recreations that might be high only in the summer. So in the following task report sections, you will see that several different 'worst case' scenarios are used to investigate potential types of damage, remediation, and restoration.

B.4.2 Oil Dispersal Modeling Limitations

The oil dispersal simulations conducted in this study did not make considerations for any processes that could contribute to crude oil or any of its components to sink in the water column following release. The chemical and physical characteristics of the crude oil products transported through the Line 5 pipeline dictate that the majority of these products or their constituents would remain afloat until becoming beached along the shoreline or evaporate over time during dispersal.

In this study, the predicted air concentrations at ground-level for Mackinaw City, MI were generated using GDM. The GDM is an acceptable model to use for predicting air concentrations of non-reacting molecules and is expected to yield an accuracy within a factor of 2 compared to observations. This is especially true under favorable atmospheric conditions of constant wind speed and direction, wind speed above 1 m/s, and long averaging time for air concentrations (Robertson and Barry, 1989). Model assumptions and dispersion parameters were purposefully adopted to predict concentrations of VOCs at the upper end of the expected range. For example, emission source area was estimated to be relatively small compared to the most likely expectations. This conservative strategy is often used in health risk assessments to generate risks at the high end of expectations, such that if no significant risk to the public is found, the analysis will be overly-protective of the public's health.

B.4.3 Comparison to previous transport models for spills in the Straits of Mackinac

Schwab (2016) presented a statistical analysis of the results of 840 spill scenarios from a Line 5 release in the center of the Line 5 crossing. The results of the cases were used to develop statistical distribution maps for offshore impact area, impacted shoreline area, the shortest time it would take to reach a specific section of shoreline, and several time series plots related to these parameters. This study used the same FVCOM modeling framework for hydrodynamics as the present study, but with a more limited set of spill scenarios and spill behavior.

As part of the 2017 Dynamic Risk Line 5 Alternatives Analysis sponsored by the State of Michigan, an oil spill simulation study was conducted by DHI. The trajectory and fate study was included mainly to compare the relative risk of various Line 5 replacement alternatives. This study used a similar approach to Schwab (2016) and the current study. They used a proprietary hydrodynamic modeling system (MIKE/OS) to simulate currents in the Straits. The MIKE/OS model also includes a particle-based oil spill trajectory model. Table B6 below compares some of the characteristics of the Schwab model, the Dynamic Risk Line 5 Alternatives Analysis Report (2017) modeling efforts, and the current study.

Table B6. The comparison of modeling techniques and capabilities for the current and previous assessments of oil spill scenarios in the Straits of Mackinac region.

	Model/report		
	Schwab (2016)	Dynamic Risk (2017)	Current Study
Hydrodynamic & spill trajectory modeling system	FVCOM	MIKE/OS	FVCOM
Maximum spill volume (barrels)	25,000	9,800	58,000
Number of weather scenarios simulated	860	120	1460
Number of release points	1 (central)	3 (Center, North, South)	3 (Center, North, South)
Wind and current effects simulated?	N	Y	Y
Ice condition included?	N	Y	Y
Temperature-dependent evaporation?	N	Y	Y

Horizontal diffusion (oil dispersal) method	Random walk	Fay spreading	Random walk
Oil emulsification modeled?	N	Y	N

One of the biggest differences between the studies is the number of weather condition scenarios included. Because currents in the Straits can change considerably from day to day, and even hour to hour, the transport and fate of an oil spill will depend strongly on exactly when the spill occurs and the subsequent weather conditions. The current study includes simulations of a release starting at each six-hour interval for a full year, including winter conditions when ice may be a factor. The goal of the Dynamic Risk simulations was to examine some *representative* outcomes of a spill to compare alternatives, while the goal of the present study is to find cases with the *worst* outcome. Thus, examining the impact of a spill under 1460 different sets of weather conditions is more likely to identify extreme cases than using just 120 cases or even 860 cases in non-winter conditions.

The other main difference between the studies is how oil weathering is treated. In all three studies, the primary processes affecting the weathering of floating oil (evaporation and dispersion) are included, although the Schwab study does not include the temperature dependence of evaporation. The present study does not include emulsification or sinking. In most cases, a large percentage of the oil volume evaporates or is beached within a few days. Emulsification and sinking tend to be more important when oil remains offshore for an extended period. In the cases considered here involving light crude oil, only a small percentage of the initial release volume would be affected by emulsification or sinking.

B.5 Summary

This report used hydrodynamic and atmospheric dispersion modeling approaches to investigate the transport and fate of petroleum products resulting from a worst-case discharge of petroleum products from Line 5 oil in the Straits of Mackinac. Specific meteorological conditions during and after discharge from the pipeline are the main factor determining transport and fate. To account for the variety of conditions that can occur in the Straits, oil dispersal simulations were conducted over a one-year period to include the meteorological, water current and ice cover conditions that are representative of the daily, monthly and seasonal conditions from January – December. Oil dispersal simulations were conducted to estimate the maximum extents of shoreline oiling (km) and surface area (km^2) oiling that could occur during periods up to 60 days post-oil release in the absence of clean-up and remediation efforts. Dispersal simulations released oil at six-hour intervals during the period January 1 through December 31 from northern, mid-channel and southern pipeline locations, resulting in 4380 unique spill scenarios.

The locations and volume of oil release from the pipeline were those as defined earlier in Task A of the risk assessment report. The hydrodynamic model predicted maximum oiled shoreline distances for each month ranging from 182 - 711 km. The monthly worst cases for maximum oiled surface areas ranged from 494 - 1745 km^2 with Lake Huron surface waters frequently being at greater risk of oiling relative to Lake Michigan waters. The monthly worst-case scenarios identified here constitute a robust set of cases to be considered for each of the subsequent tasks. Task A's will be shown; there is no one 'worst case' that provides the highest risk for every task.

Atmospheric dispersal modeling predicted that population centers including Mackinaw City would be at increased risk of exposure to concentrations of oil constituents such as benzene and other volatile organic carbon compounds that would be released from an oil spill in the Straits of Mackinac region. The severity of that risk is presented in Task D of this report.

B.6 References

Anderson, EJ., Schwab, DJ. (2013). Predicting the oscillating bi-directional exchange flow in the Straits of Mackinac. Journal of Great Lakes Research, 39(4), 663-671 pp.

Anderson, EJ., Schwab, DJ. (2017). Meteorological influence on summertime baroclinic exchange in the Straits of Mackinac. Journal of Geophysical Research-Oceans, 122(3), 2171-2182 pp.

Chen, C., Beardsley, R.C., Cowles, G. (2006). An unstructured grid, finite-volume coastal ocean model (FVCOM) system. Oceanography 19, 78–89pp.

Dynamic Risk Assessment Systems, Inc. (2017). Alternatives Analysis for the Straits Pipelines – Final Report. Document number SOM-2017-01-RPT-001. Retrieved from https://mipetroleumpipelines.com/document/alternatives-analysis-straits-pipeline-final-report

Fingas, M.F. (2013). Modeling Oil and Petroleum Evaporation. J. Petroleum Science Research, 2:3, 104-115pp.

Fingas, M. (2015). Handbook of Oil Spill Science and Technology (ed M. Fingas), John Wiley & Sons, Inc., Hoboken, NJ. doi: DOI: 10.1002/9781118989982

Robertson, E., Barry, P.J. (1989), The validity of a Gaussian plume model when applied to elevated releases at a site on the Canadian shield, Atmospheric Environment, 23(12), 351-362 pp.

Saylor, JH., Sloss, PW. (1976). Water volume transport and oscillatory current flow through the Straits of Mackinac. Journal of Physical Oceanography, 6(2), 229-237.

Schwab, DJ. (2014). Straits of Mackinac Contaminant Release Scenarios: Flow Visualization and Tracer Simulations. U-M Water Center Research Report, 7pp. Available from http://graham.umich.edu/water/news/mackinac-straits-contaminant-scenarios

Schwab, DJ. (2016). Statistical analysis of Straits of Mackinac Line 5: Worst case spill scenarios, 23 pp. http://graham.umich.edu/water/project/mackinac-oil-spill

Task C: Analyzing how long it takes to contain and clean up the worst-case release.

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C.1. Introduction

Task C provides a synthesis of relevant private and public response plans and resources for responding to a worst-case release of oils as defined for this section (longest shoreline oiled in the shortest amount of time). This section's task includes the identification and assessment of all federal, state, local, and private (i.e., Enbridge) emergency resources that are available for oil spill response in the Straits. The response plan is based on an assessment of the time to deployment of equipment and resources, the interactions between relevant stakeholders in a worst-case scenario for an oil spill, recent emergency response exercises conducted in the Straits, and interviews with relevant authorities and response personnel.

This task is divided into three sections. The first section provides a review of the literature on response plans to oil spills, including but not limited to the description of tactics for spill response and documentation available from agencies and Enbridge related to spill response. The second section identifies the datasets that have been collected for the resources and deployment times that will support the assessment. Interviews with relevant stakeholders such as the United States Coast Guard (USCG), the Mackinac County emergency management office, and Enbridge have also been summarized here. The third section describes the methodology that is used to estimate the time for containment and recovery for the different scenarios defined in the previous section.

C.2. Literature Review

A number of documents were reviewed to assess the plans currently in place to coordinate cleanup and response efforts in the Straits. This literature review section includes: (1) Overall logistics of the spill response and cleanup including the response procedure, containment, recovery, and shoreline cleanup procedures; (2) Organizational structure of a typical incident command system and unified command structure; and (3) Tactical response to clean up oil releases; and (4) Review of the documents for the Straits of Mackinac.

C.2.1 Overview of Spill Response

Coordinated oil spill response can be broken into distinct phases in which different tactics and strategies will prevail. These phases cover a variety of time ranges, some of which can last for hours while others may extend for months or years. This section seeks to summarize the phases of oil spill response. The initial response to the spill includes mobilizing people and equipment to respond rapidly to the site of the spill. This initial response creates a proper chain of command and often involves the Incident Command System (ICS) and, depending on the size of the spill and those affected, a Unified Command Structure. The initial response involves emergency shutdown, initiating actions to contact the appropriate authorities, and initiating the ICS. The next phase of response involves containment efforts, where attempts are made to prevent the spread of oil in the water or on shore. This phase is important to limit the impacts of the oil spill to a defined location and to allow for efficient recovery of released oil. Recovery often happens simultaneously with containment. Recovery operations seek to remove as much oil as possible from the contaminated area using various methods described later in the report. This step is essential in limiting the spread of the spill and begins the process of cleanup. On-water spills containment and recovery are the preferred methods of cleanup, as oil is more efficiently recovered from water than from sediment or shoreline. Therefore, the containment and recovery are the initial stages of cleanup and have much more defined timeframe.

As oil is beached, the tactics and the approaches for recovery are altered. Shoreline cleanup often takes much more time and is very methodical in the approach. In previous spills, the Shoreline Cleanup Assessment Technique (SCAT) has been applied to evaluate and monitor the cleanup of shoreline (Santaner et al., 2011). In the SCAT methodology, the affected shoreline is divided into segments; these segments are monitored for the extent of oil. Subsequently, a plan is put into place for cleanup operations. Throughout the process, additional monitoring is included to assess which shorelines are still in need of cleaning. This approach can often take the form of multiple phases. These phases typically include phase I. an initial or reactive phase where surveys and immediate cleanup priorities are determined. During this phase, the priority is mostly removal of bulk oil from shorelines. In phase II, the extent of oiling on beaches is thoroughly documented and overall treatment objectives defined. Phase III includes the undertaking of the operational part of shoreline cleanup. Teams are dispatched to treat individual shoreline segments. Additionally, treatment and natural recovery processes are monitored. In phase IV, end-points are agreed upon by all parties and documented. Additional locations for long-term monitoring are identified to ensure natural attenuation and other processes are sufficiently removing residual oil. These phases of spill response can range from hours for the initial response, to days and weeks for containment and recovery, to weeks, months, or years for shoreline cleanup, depending on the specifics of the spill.

C.2.2 Incident Command System and the Unified Command Structure

Most spill response will follow the ICS, which provides an organizational structure for a coordinated response to an incident. ICS is a management system (Figure C1) designed to integrate facilities, equipment, personnel, procedures, and communications within a common organizational structure (National Response Framework, 2013). Typically, the incident response includes activities to facilitate in five areas, such as command, operations, planning, logistics, and finance/administration (Figure C1). As part of this structure, an incident commander or an on-scene coordinator will be identified. As the Straits of Mackinac are a coastal system, the Sault Ste. Marie USCG Captain of the Port would be the predetermined Federal On-Scene Coordinator (FOSC). These plans describe the role of each of the different agencies identified to have a role in the response and their role in coordinating with the responsible party for a spill (Northern Michigan Area Contingency Plan, 2015). Figure C2 represents an overview of the joint field office (JFO), the primary federal incident management field structure, which has primary responsibility for response and recovery by coordinating federal, state, tribal and local governments, and the private-sector. The coordination occurs following the principles of Unified Area Command (UAC).

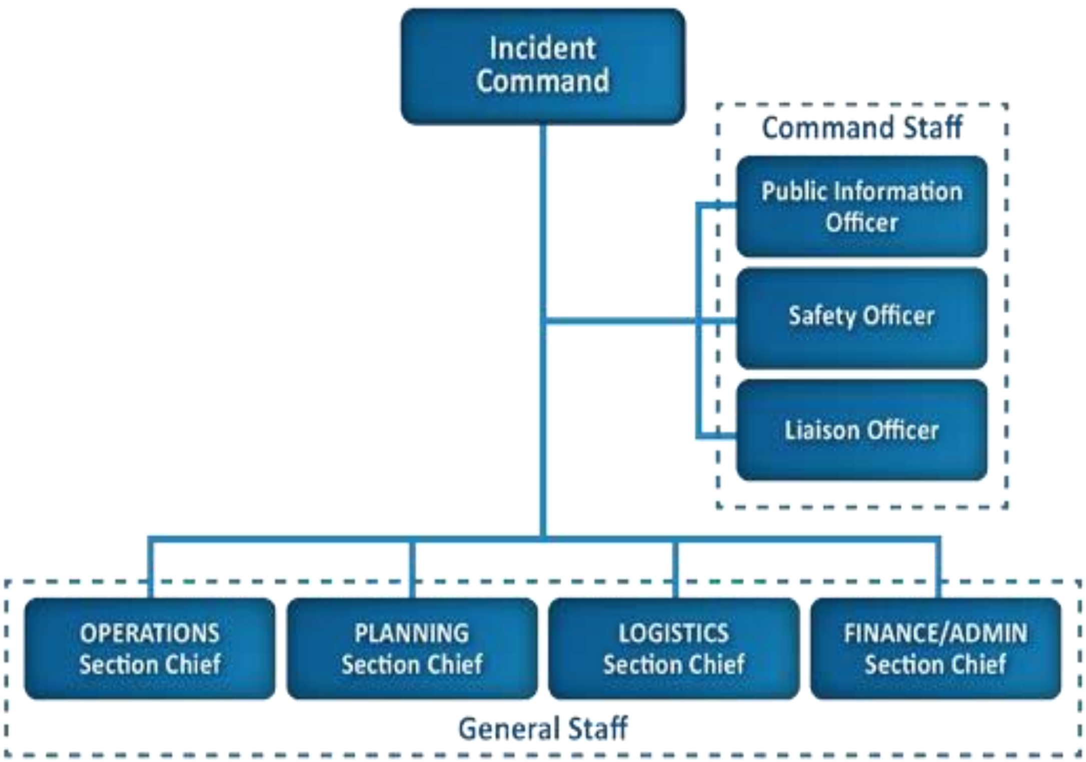

Figure C1: Incident Command Structure (National Response Framework, 2013)

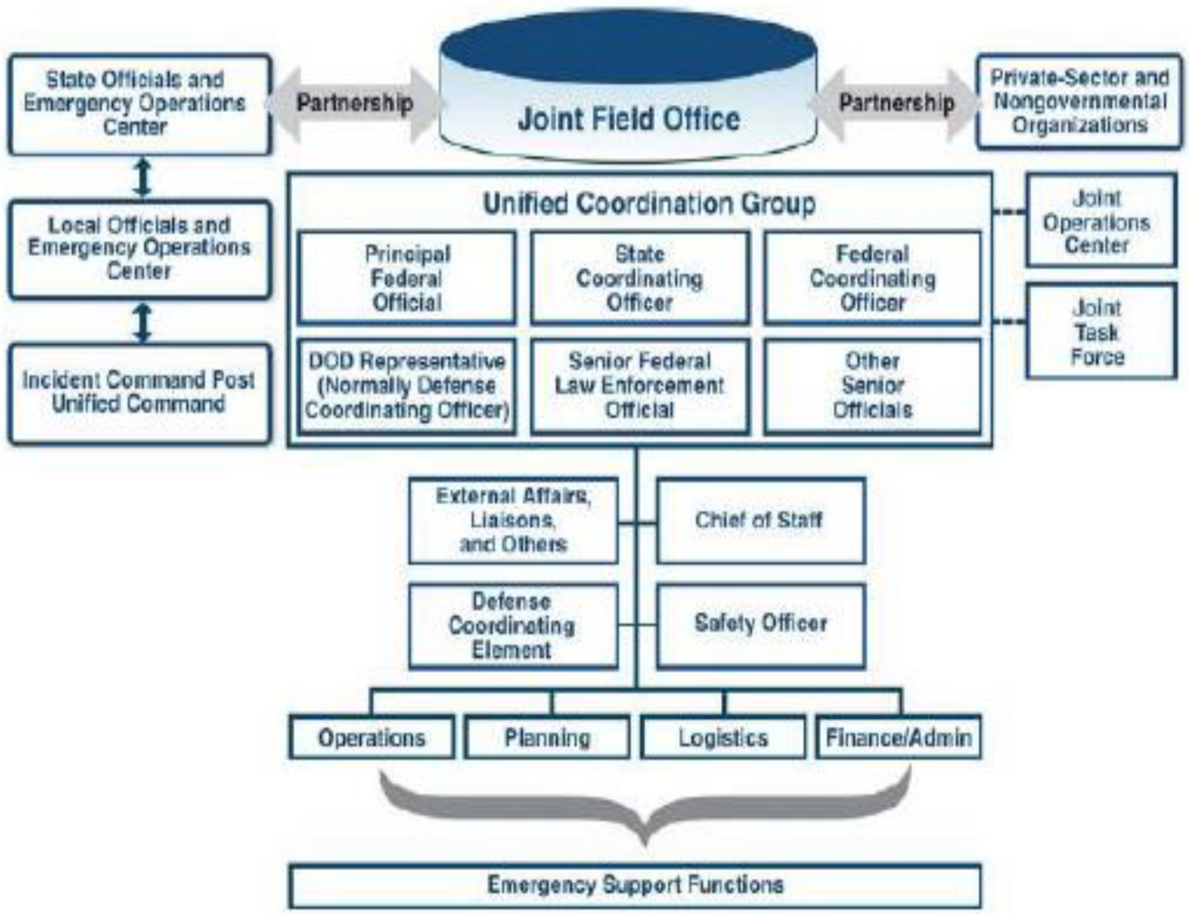

Figure C2: Command structure in the Joint Field Office (JFO) (Northern Michigan Area Contingency Plan, 2015)

The JFO is led by the Unified Coordination Group (UCG) that is comprised of federal officials, State Coordinating Officer, Federal Coordinating Officer, Defense Coordinating Officer, Senior Federal Law Enforcement Official, and other senior officials (Northern Michigan Area Contingency Plan, 2015).

C.2.3 Tactics to Respond to and Clean Up Oil Releases

Efforts to clean up oil spills have employed a range of response strategies in the past ranging from physical to biological removal of oil (US EPA, 2013). Oil responses can be broken down into two different categories based on the location of oil to include on water and shoreline oil. The response strategies to a spill in inland waters often are different than a spill response to an open water oil spill. Here the team summarizes many of the tactics and technologies proposed to be used in response to a spill in the Straits of Mackinac. An overarching goal in oil spill cleanup is to limit the amount of oil that is beached. Methods for recovery and removal of oil are more efficient when recovering oil directly from the water rather than from beaches. In all spill response situations, the response can take multiple phases starting with containment and recovery followed by remediation. Each of the distinct phases has a set of technologies that are designed to be best suited for the phase and setting.

C.2.3.1 On water oil response strategies

Most examples of offshore oil spills have happened in the marine environment. Many of the tactics are shared between a spill in the ocean and the Great Lakes. In open water, the response has included physical, chemical, and biological response to oil. The goal of physical responses to oil is to contain the spread of oil and physically remove the oil from the system. A common approach employed in physical removal is the use of booms and skimmers to corral the oil and remove the oil into storage containers for controlled disposal.

C.2.3.1.1 Open water containment

Booms are floating structures that are designed to control the spread of an oil slick. These can be used to protect sensitive habitats from oiling. In other instances, booms can be used to collect oil in one location for removal using skimmers. Sections of booms can be towed by a vessel at slow speeds to capture oil in a boom. A specialized removal system called Current Busters can be used to actively collect oil using boats at higher speeds (~3 kts) than those towing typical booms. These current busters can be towed behind a vessel to collect oil. This oil then is contained within a temporary collection area in the current buster. This oil can then be recovered using skimmers. The operating limits of these current busters are based on the speed of towing, the temporary storage, and the sea states (e.g., current, wave height, wind speed, salinity). Reports from the manufacturer state that the throughput efficiency was high in calm seas. In chop up to 1 ft., the efficiency dropped but was still 80% when towed at slower speeds (NOFI, 2018).

There is a possibility that an oil spill would occur in the Straits during times when ice cover is present. Containment of oil spilled under ice takes a unique set of tactics. As ice can often slow the spread of oil, a common containment strategy for under-ice containment is to cut ice slots through the ice to allow the oil to accumulate inside of these trenches. Skimmers can then be used to recover the oil that is collected in these trenches. There is a system that performs both ice breaking and oil skimming within the system.

C.2.3.1.2 Open water recovery and removal

Recovery of oil is often performed using skimmers. Skimmers are used to separate water from oil and recover the oil in the storage containers. A number of skimmer types exist. Weir skimmers are a common type of skimmer that runs water over a lip or weir to separate the oil on the surface from the water and recover the oil. These skimmers can be applied to recover oil from inside of a boom collection area or in temporary storage within a current buster.

In situ burning has also been used for removal of oil from the water surface in open water response cases. Oil is corralled into an enclosure with fire-resistant booms. The oil is then set on fire. In situ burning is a well-established practice and is considered to be a relatively cost-effective method (NRC, 2015). During the Deepwater Horizon, controlled burns were used to remove approximately 220,000 to 310,000 barrels of oils from the system demonstrating their efficiency for rapid removal of large amounts of oil (Alan et al., 2011). This response strategy requires approval from the FOSC to be used in the Great Lakes. A number of factors must be considered before approval for an in situ burning, including the potential for an impact on air quality in the region. In general, in situ burning is a more efficient oil removal from open water than physical removal. The efficiency depends on the types of oil (i.e., light crude, heavy oils) and weather conditions.

Under ice-covered conditions on the open water, in situ burning may be effective and is considered as a practical strategy in the Straits regions. As mentioned above, ice can be used to contain oil and then instead of skimmers, in situ burning can take place pending EPA approval with respect to air quality concerns. The USCG have been testing this strategy in the region and are confident that this would be effective on-water oil removal assuming the weather and water conditions are adequate.

These strategies are designed to recover as much oil as possible on the water quickly before the oil reaches shore. However, it is likely that some oil will reach shore. The response strategies involved in responding to and cleaning up beached oil are distinct from open water response and recovery.

C.2.3.2 Inland oil response strategies

Containment of oil and protection of shoreline are essential in responding to oil in nearshore and onshore environments. A number of the technologies involved in open water cleanup can also be used in responding to oil onshore (US EPA, 2013).

C.2.3.2.1 Near-shore containment

Containment of oil near-shore could take the form of deploying booms around sensitive areas to prevent oil from reaching the shore and diverting the oil to collection regions. While many of these techniques have been developed for response to inland oil spills on streams and rivers, there is potential to use this in near-shore settings in the Straits.

Oil sorbent booms may also be used as a means for containment and clean up. These booms contain a sorbent material that is designed to collect the oil and limit its spread. Oil sorbent booms can be applied in nearshore settings to capture oil as it approaches shore or to collect oil from beaches that have already been oiled. Once the oil has reached the shore, the use of sorbent material can be helpful in removing it from the beaches. However, one limitation of the large-scale use of sorbent booms is the creation of large amounts of contaminated wastes. Another limitation of oil sorbent booms is that while they are most effective at the removal of fresh oil, their efficiency of absorption decreases as weathering occurs to the oil, potentially limiting their removal ability.

C.2.3.2.2 Near-shore recovery and removal

Recovery of oil in the near-shore environment can use shallow water skimmers to recover oil that has been collected in near-shore booms. These skimmers have the ability to separate the oil from the water in shallow environments and efficiently remove the oil from the water and oil mixture. Skimmers cannot remove beached oil. Therefore, the approach to deal with beached oil is to wash the beach to dislodge the beached oil and then capture the washed oil through booming at the beach edge. This dislodged oil can then be recovered using shallow water skimmers. Washing can take many forms in terms of the temperature and the pressure of the water used for washing. The substrate of the beach and the extent of oiling must be considered when deciding on which type of washing method to use. Washing requires unified command approval before application. In situ burns can also be applied on land where there are large quantities of oil on some combustible substrate such as vegetation. The use of in situ burns can be used when other options for oil removal have been ruled out. In many instances, mechanical removal of the beach substrate is used to get rid of the oil and contaminated material. This process requires that the removal of the beach material does not represent substantial harm to the shoreline ecosystem and requires refilling with comparable material during the restoration processes.

In some cases, some oil is left on beaches after attempts have been made to remove the oil when the locations of the cleanup efforts or additional removal efforts would result in significant damage to the shoreline ecosystem. In these cases, bioremediation may be applied. Bioremediation leverages the natural ability of microbes to break down oil and use the components of oil as a food source (Atlas, 1991). Oil biodegradation often happens naturally and can be employed to clean up residual oil. In some cases, nutrients are limiting and thus need to be applied to stimulate the biological community to break down the oil (Venosa and Zhu, 2003). The process of bioremediation often requires longer time frames (e.g., months) than other cleanup strategies (days to weeks) and is routinely monitored to ensure appropriate removal of the oil.

The substrate of the beach and the environmental sensitivity index must be taken into account in choosing the best strategy for removal of oil from beaches. NOAA has created general guidelines for the predicted behavior and suggested response strategies based on the type of beach or shoreline impacted by the oil (Department of Commerce, 2013). Tables C1 and C2 summarize the strategies used for oil containment and recovery as well as shoreline cleanup with important limitations/considerations for their use.

Table C1: Equipment used for oil containment and recovery on water.

Strategy	Description and limitations
Booming for collection or deflection	Boom is deployed on the water toward the approaching current to divert oil in a controlled way to recover oil. Boom can also be used to divert oil away from the sensitive shoreline areas. Boom is used at currents greater than 1 knot (Fingas, 2012). High winds and high waves restrict the use of boom (Al-Majed et al., 2012).
Exclusionary booming	Use of boom to exclude oil from a sensitive shoreline. Current should not exceed 0.75 knots and breaking waves should not exceed 0.5 feet (US EPA, 2013)
Current buster	A system designed to be towed behind a vessel for capture and storage of oil as part of containment strategy.
In situ burning	A method for efficient removal of oil from water surfaces by corralling oil and then igniting the oil. Approval and environmental assessment are required.
Skimming	A method for recovery of oil after it has been collected through booming or current buster technology.

Table C2: Equipment used for oil containment and recovery on shorelines.

Strategy	Description and limitation
Booming	Use of booms to protect sensitive shoreline and prevent resuspension of oil that is beached.
Oil sorbent boom	Oil sorbent materials can be used to recover fresh oil from beaches and absorb oil before it can re-enter the water after washing of shoreline.
In situ burning	Oiled vegetation and other materials can be burnt to remove oil from contaminated environments.
Skimming	Shallow water skimmers can be used to recover oil that has collected near shore as well as oil that has been washed off of contaminated beaches.
Washing	Water can be used to flush oil from contaminated beaches. The pressure and temperature used must be taken into account when deciding on flushing. Approval is required.
Vacuuming	Oil that has pooled can be vacuumed off beaches to recover oil.
Mechanical removal	In some cases, oil is mechanically removed from beaches using heavy equipment meant to recover oil and then replace the removed material will clean fill.
Bioremediation	Natural microbes can break down oil to remove it from the environment.

C.2.4 Reviews of Documents for the Straits of Mackinac

Several documents define the specific operations for responding to a spill in the Straits of Mackinac. This section outlines the capabilities and limitations of existing spill response plans and resources, which have been assessed by evaluating the following plans in terms of regulatory criteria and lessons learned from multi-agency pollution response exercises conducted in the Straits of Mackinac. The documents that will be reviewed include: Area Contingency Plan (ACP); Relevant Spill Prevention, Control and Counter (SPCC) Measures Plans; and Enbridge-specific response plans.

A number of documents govern oil spill response in the Straits. These documents range from Enbridge-specific documentation such as the Great Lakes Region Integrated Contingency Plan to regional and national documents as well as joint contingency plans between the US and Canada. As part of this effort, we examined the current response plans. These response plans outline the goals and operational structure for the response to a spill. While there are a number of response tactics outlined in these reports, it is essential to consider that spill response, and cleanup would involve a large number of agents including federal, state, and local governments and agencies, along with the responsible party and their oil spill removal organizations. In a response involving so many agencies, the organizational structure is almost as important as the machinery and technology used to limit the spread and enhance the removal of oil. Therefore, much of the existing documents are designed to clearly delineate the agencies involved in an oil spill response and the organizational structure that governs the spill response.

Herein the team reviews key points from three major documents that govern the response to oil in the Straits. The documents include: (1) National Incident Management Handbook covering a broad perspective on the incident response; (2) Northern Michigan Area Contingency Plan providing a more specific survey of the response for an incident in Northern Michigan; and (3) Enbridge’s Integrated Contingency Plan, specifically designed by Enbridge, detailing their response strategy for oil spills in the Great Lakes Region.

C.2.4.1 Summary of National Incident Management Handbook

In case of emergencies and disaster, the federal government reaches out to state and tribal governments in accordance with National Incident Management System (NIMS) and National Response Framework (NRF), as per Homeland Presidential Directive 5. Federal Emergency Management Agency (FEMA) coordinates the delivery of federal disaster relief to state and local governments. This action is based on four core components namely, preparedness, communication and information management, resource management and command and management. Apart from these, the actions are based on a few key principles such as common terminology, modular organization, and management by objective, reliance on an Incident Action Plan (IAP), chain of command and unity of command, manageable span of control.

The prevailing handbook aids FEMA personnel to use the NIMS command and management component for disaster management field operations. The handbook specifies the common responsibilities of federal disaster response personnel and describes the minimum information to be provided by the respective agency to personnel. It also stresses the importance of unified command and creation of UCG as the disaster relief team would involve multiple agencies from different geographical and functional jurisdictions.

Under a FEMA Stafford Act, UCG consists of a Federal and a State Coordinating Officer along with senior officials from other entities. The composition of a UCG will depend upon the location of the incident, type of the incident, jurisdictions involved, authorities involved and others. It is very important to initiate the UCG on the disaster at hand through an initial UCG meeting checklist. Additionally, the handbook presents the role and responsibilities of various officials in a UCG. Also, information on funding and hiring through flowcharts are presented in the handbook. Finally, the handbook specifies different planning processes that could be adopted by USCG personnel in case of an emergency.

C.2.4.2 Summary of Northern Michigan Area Contingency Plan

This Northern Michigan ACP is a 55-page document that summarizes the strategy for a coordinated federal, state and local response to incidents that take place in the Northern Michigan region. The incidents considered in this document includes a discharge or substantial threat of discharge of oil, a release of a hazardous substance or a fire from a vessel, offshore facility, or onshore facility operating within the boundaries of the coastal and inland areas.

For the cleanup, USCG is responsible for the coastal zone defined to mean all United States waters subject to the tide; United States waters of the Great Lakes; specified ports and harbors on inland rivers; and the waters of the Exclusive Economic Zone. For the cleanup, U.S. EPA is responsible for the inland zone defined to mean the environment inland of the coastal zone excluding the Great Lakes and specified ports and harbors on inland rivers. The National Response System (NRS) was developed to coordinate all government agencies with responsibility for environmental protection for the immediate and effective cleanup of oil or hazardous substance discharges. A Spill of National Significance (SONS) is defined as a spill which greatly exceeds the response capability at the local and regional levels and which, due to its size, location and actual or potential adverse impact on the environment is so complex, it requires extraordinary coordination of federal, state, local and private resources to contain and clean up.

For the response structure, a captain of the Port, Sault Ste. Marie, MI is the pre-designated FOSCs for oil and hazardous materials incidents in the Straits of Mackinac coastal zone and will integrate within the command structure of the local officials, providing federal resources and funding mechanism to support the removal activities. The responsible party is responsible for all cleanup activities. U.S. EPA Region 5 is the pre-designated FOSCs for oil and hazardous materials incidents in the Northern Michigan Sub-Area. EPA FOSCs are available to respond to chemical and oil incidents and can provide additional contractor services for cleanup.

For the cleanup assessment protocol, 40 CFR 300.320 (General Pattern of Response) indicates that 'removal shall be considered complete when so determined by the FOSC in consultation with the Governor(s) of the affected state(s)'. When FOSC considers removal complete, removal funding from the Oil Spill Liability Trust Fund (OSLTF) ends. In situ burns depend on the case by case basis on the Great Lakes via consultation involving the FOSC, responsible party, and applicable state and federal agencies, and trustees.

C.2.4.3 Summary of Enbridge Integrated Contingency Plan and Tactical Response Plan

The Enbridge ICP is an integral document that outlines the response measures and details the processes that would occur in the event of an incident. This plan contains a core set of information common to ICPs across the Enbridge system as well as multiple appendices that are specific to the area of interest. The core section of the ICP covers the methodology laid out by Enbridge for an efficient spill response as well as a description of the ICS that would be employed in the event of an incident. The ICS system lays out the key roles and responsibilities of each person involved in the response and coordinated system to ensure appropriate reporting and organized system for response. This document also lays out the different methodologies that would be employed depending on the type of response.

C.2.4.4 Programmatic Agreements Among Agencies

Currently, there is a programmatic agreement among five parties namely, the FEMA, the Michigan State Historic Preservation Office, the Michigan State Police Emergency Management, Homeland Security Division and Participating Tribes. The goal of this agreement is to support the citizens and first responders for building, sustaining and improving the capability to prepare for, protect against, respond to, recover from and mitigate all hazards.

In case of an emergency FEMA extends its support to States, Commonwealths, and communities pursuant to the Homeland Security Act of 2002, Pub. L. No. 107-296 (2002), Robert T. Stafford Disaster Relief and Emergency Assistance Act, Pub. L. No. 93-288 (1974), the National Flood Insurance Act of 1968, Pub. L. No. 90-448 (1968), the National Flood Insurance Reform Act of 1994, Pub. L. No. 103-325 (1994), the Post-Katrina Emergency Management Reform Act of 2006, Pub. L. No. 109-295 (2006), Executive Order 13407 (2006), and such other acts, executive orders, implementing regulations, or Congressionally authorized programs as are enacted from time to time.

Particularly, for the state of Michigan, FEMA has consulted with the Michigan State Historic Preservation Office (SHPO) pursuant to Section 106 of the National Historic Preservation Act (NHPA), Pub. L. No. 89-665 (1966) and the regulations implementing Section 106 of the NHPA (Section 106) at 36 CFR Part 800. This is done to implement its programs for eligible National Register of Historic Places pursuant to 36 CFR Part 60 (historic properties). Additionally, FEMA has identified and differentiated tribes based on the residency status for sites of religious and cultural significance on or off tribal lands in Michigan. The document also lists the tribes that already have a Tribal Historic Preservation Officer (THPO) and pending invitations.

The agreement also lists various stipulation such as confirmation with Section 106, Programmatic Agreements for communication facilities and others for this agreement. Additionally, roles of FEMA, State and Tribal Historic Preservation Offices, Recipient (s), Tribal Consultation, Public Participation have been clearly stated for identification and evaluation of properties with historical, religious, and cultural significance along with their time frames and communications.

FEMA will first determine the scope of the project under consideration based on the written request made. Then, conformance of the project with the allowances will be checked by FEMA and consideration of a project under Section 106 will depend upon its conformity. Additional expedited reviews will be conducted for this purpose. Based on this, FEMA may either declare "no historic properties affected" in case of lack of conformity or can move ahead to resolve the issue. The recipient is allowed to notify FEMA for changes in the approved scope of work, in case of unexpected discoveries, unidentified properties or unexpected effects and assist FEMA during the workflow. If any historical remains are found in private land, then they belong to a private owner.

Finally, during the implementation of the agreement, there is scope for amendments, dispute resolution, severability and termination in case of contradicting or violating any applicable existing law or regulation.

C.3. Data Collected

In this section, the worst case is first defined based on modeling outputs provided by Task B that simulated the fate of oil for atmospheric forcing conditions that occurred over the year of 2016. It is not practical to estimate the time to contain and recover the oil released in hundreds of different scenarios. However, weather conditions and other external factors can affect the time required to contain, recover and clean up a potential spill. Thus, representative scenarios resulting from averaged monthly weather conditions and historical environmental conditions will be considered, attempting to highlight the impact of various weather conditions on the timeline of the cleanup. This section also includes outcomes from interviews with three entities that would be involved in the cleanup operations: (1) Mackinac County emergency managers; (2) the USCG; and (3) the Enbridge corporation. Finally, the last section summarizes the available equipment that can be considered for the containment and recovery of oil on water and shore-based cleanup operations based on the extensive literature reviews conducted as described in the previous section.

C.3.1 Fate of Oil in the Worst Case Scenario

Task B predicted the transport and fate of oil based on two key inputs: the atmospheric forcings that represent weather conditions for all of 2016; and, the worst-case discharge volume identified in Task A. The metrics extracted from this modeling included: (1) the extent of lake surface area (i.e., Lake Michigan and Lake Huron) covered with floating oil; (2) the percentage of oil volume beached at different time points after the spill begins; and (3) the total length of shoreline oiled. For this section, the worst case scenario for the cleanup was considered to be the case when *the longest distance of shoreline was oiled within the shortest amount of time*. This criterion was applied because rapid beaching of a large fraction of the spill will limit the damage mitigation that can be provided by on-the-water-recovery efforts or burning. Based on this criterion, the oil release scenario originating from the center of the Straits of Mackinac (Location 3 in Figure A3) at 6 am on December 27, 2016, was chosen as the case study for this task. The Task B team estimated that 29 km of Lake Huron shoreline would be oiled after six hours - the most shoreline oiled at six hours out of the 4,380 unique simulations generated for Task B. Figure C3 shows the water surface area covered with floating oil and the length of oiled shoreline as a function of time after the oil release for the first ten days of the modeled December 27 spill. Similarly, Figure C4 shows the changes in the volumes of floating and beached oil over time.

While some of the analyses for this Task C estimate how long it would take to recover and clean up oil based on this specific event with corresponding weather conditions, a similar event could happen on any date during a different year. The oil recovery and cleanup time estimate and analysis in this (Task C) are shown as an example of a worst-case event during part of the year 2016. This scenario where a large amount of shoreline is oiled in a relatively short amount of time poses considerable problems as cleanup of shoreline typically requires more time than on water cleanup.

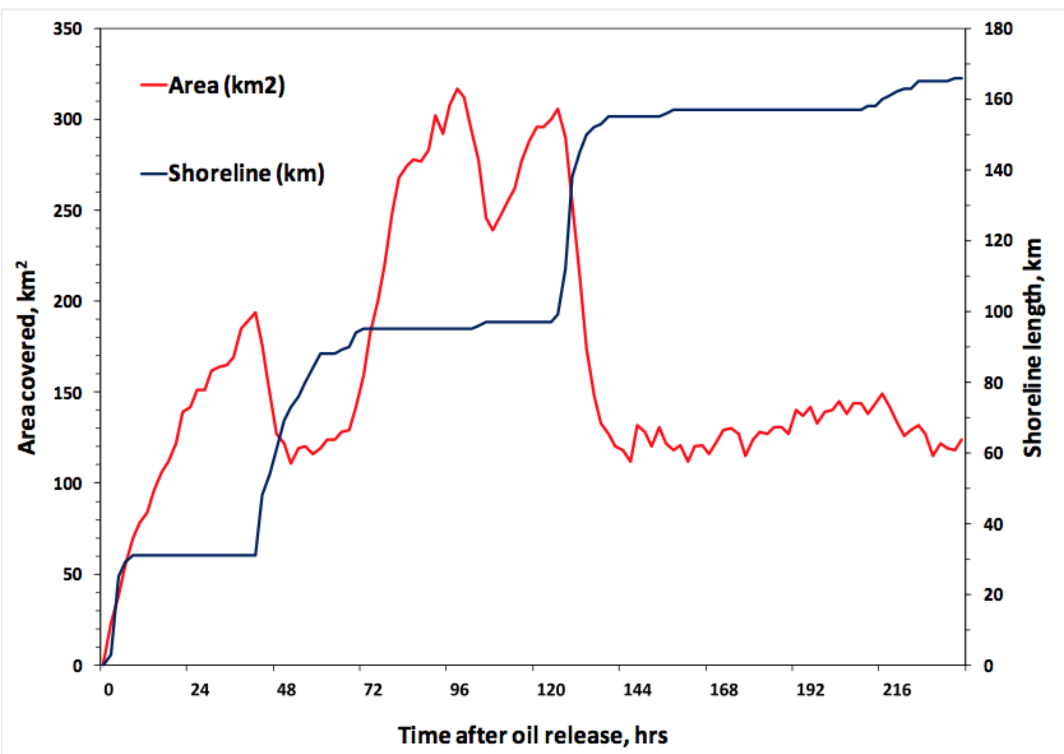

Figure C3: Open water area covered with floating oil and oiled shoreline length in Lake Huron over time for the modeled Dec. 27 scenario.

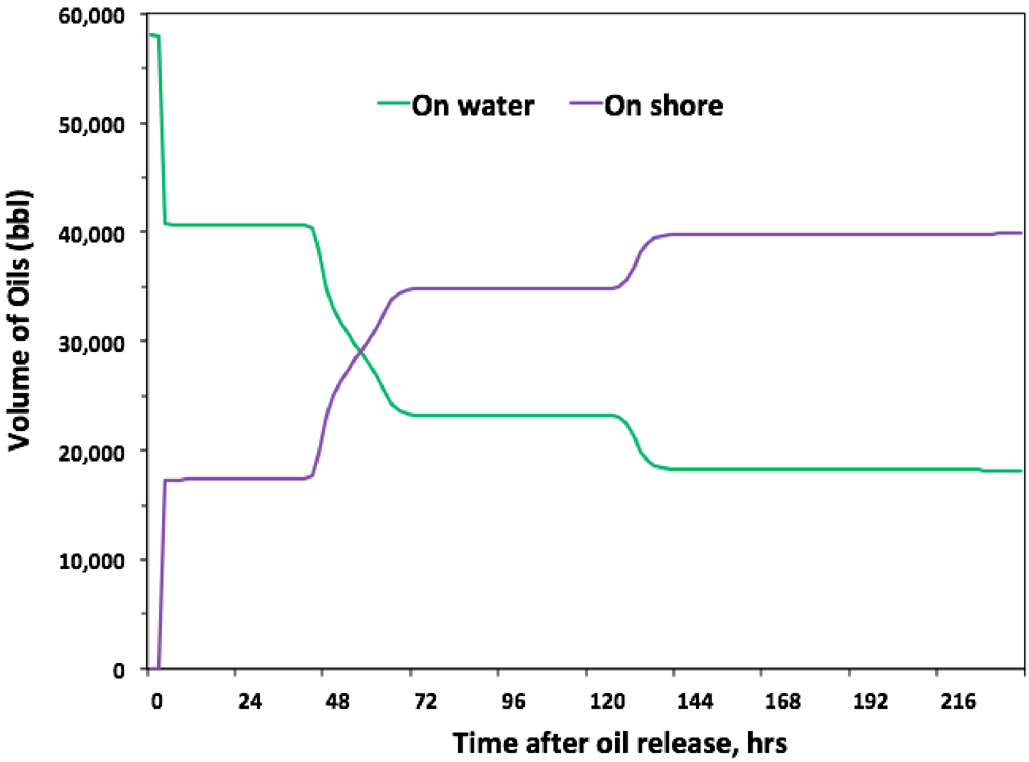

Figure C4: Volumes of oil floating on the water and beached on shore over time for the modeled Dec. 27 scenario.

Weather conditions do affect the containment and cleanup of oil on water and shorelines. Some weather conditions affecting containment, recovery and cleanup activities include: (1) ice coverage; (2) wave heights; (3) wind speed; and, (4) current speeds. The water on December 27, 2016, for the worst case was not covered with ice. Weather conditions in the year of 2016 are available in previous Task B, and Appendix C1 provides the wave and current data on December 27, 2016, as well as ice cover maps.

Figure C5 represents the simulated fate of oil particles on water and shorelines by Task B for the worst case scenario defined above. Because of the direction of currents on this specific date, oil particles were transported towards the Lake Huron side. Within the first few hours, oil particles reached the shoreline on the west side of Mackinac Island and Bois Blanc Island. Oil particles continued to spread to the shorelines along HW 134 in Port Dolomite, heading further east along the shoreline. The percentages of floating and beached remaining oil are 62% and 38% at 3 hrs, 61% and 39% at 12 hrs, 61% and 39.1% at 24 hrs, 45.8% and 54.2% at 48 hrs, 15.7% and 84.3% at 96 hrs, and 15.7% and 84.4% at 120 hrs, respectively.

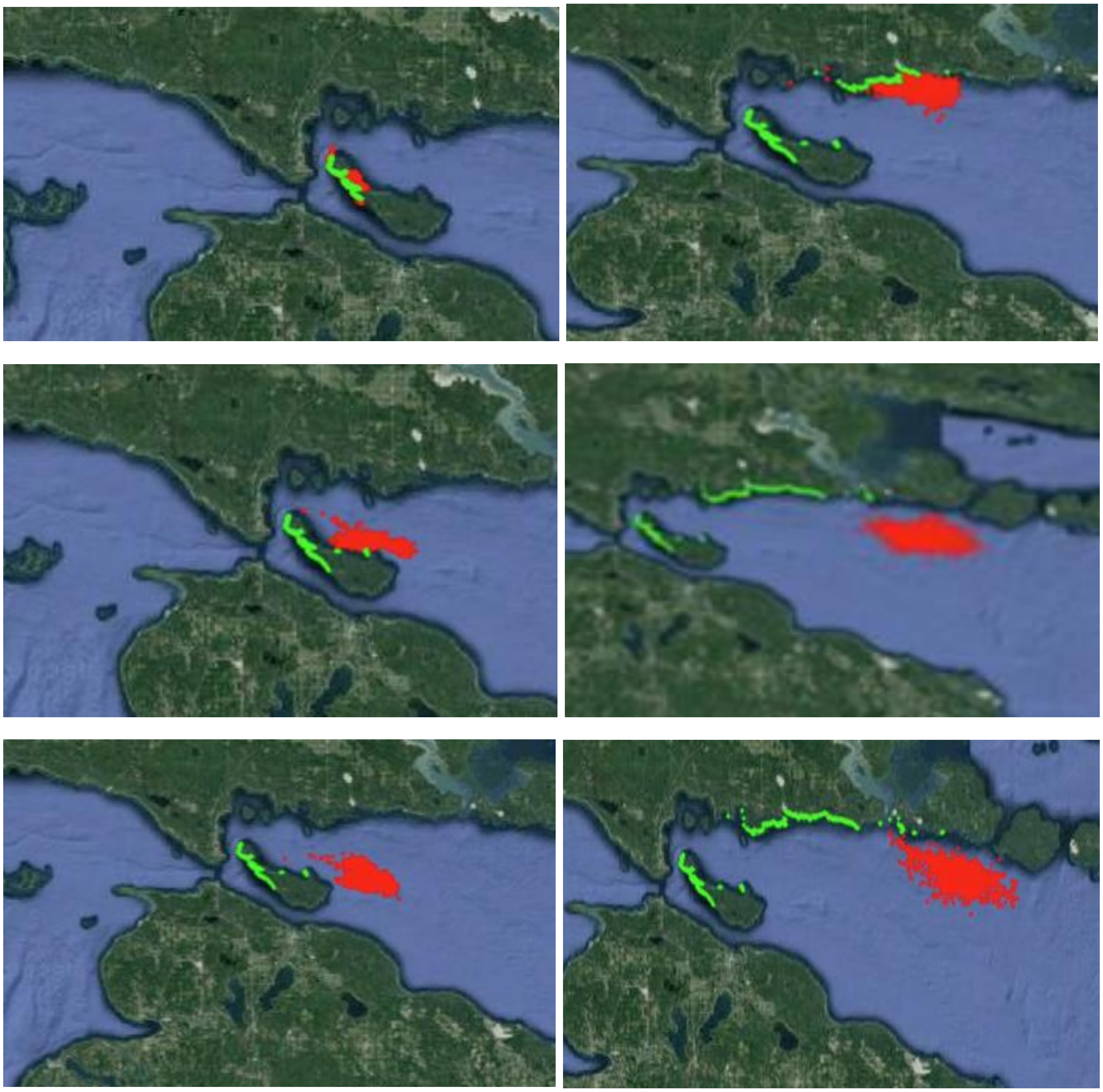

Figure C5: Fate of oils on water (red) and on shorelines (green) 3, 12, 24 (left), 48, 96, 120 (right) hrs after the oil release from the center channel of the Straits of Mackinac at 6 am on December 27, 2016.

C.3.2 Interview with Mackinac County Emergency Managers

The team met with Mike Kasper (main emergency coordinator) and Bryce Tracy (911 coordinator and hazmat technician) on May 15, 2018. They are both involved in response and training for local agencies in Mackinac County. The meeting began by discussing the recent American Transmission Company (ATC) incident in order to help this team understand the typical procedure for responding to an emergency in the Straits area. Overall, the response to the ATC incident went well, local OSROs and other entities offered skimmers and booms.

Mike and Bryce, as local emergency managers, have built a coalition in the Straits area with industry, other governmental agencies, private owners, etc., also including Canadian partners so that equipment is readily available in the event of an incident in the county.

With respect to the ATC incident, a maritime contingency plan was put in place. The Mackinac County staff recalled that there was great information flow. Notification occurred within minutes, and a physical unified command was set up within 2 hours. They stated that this would be the same if Canada had been involved. In the event of a spill in the Straits area, a similar procedure would be used. Regarding getting equipment on site, closure of the Mackinac Bridge could occur due to inclement weather, but the emergency use of the bridge could still be approved, and a local airstrip (a space shuttle backup landing strip) could also be used if equipment needed to be airlifted to the area by the National Guard.

Equipment from local, state and federal agencies is cataloged in the MICEMS database (updated every year), this does not track equipment from private industry, but local managers have a very good idea of the availability of such equipment. Mackinac county does not own booms and skimmers. Therefore, communication and relationships built during emergency training exercises are key to the effectiveness of emergency responses in the Straits area.

A typical incident structure has the following elements. Within a few hours, a local command center is established, entities involved can be the fire department, emergency medical services (EMS), and/or law enforcement; then it transitions to federal oversight within 24 hours with a unified command structure (which typically involves staff with stronger technical training). Law enforcement units and EMS receive awareness training only. The fire department has operational response training. The priorities are identified as: (1) human health; (2) incident stabilization, i.e. confinement versus containment; (3) property and ecological damages; and (4) air monitoring which falls within the EPA Region 5 responsibilities.

All access points are identified in the Enbridge's tactical response plan (TRP) as well as all the streams and booms deployment information. The unified command determines access to private property and there is live video capability for communication between cleanup sites and unified command.

The team discussed the impact of ice presence in the event of a worst-case scenario spill. Ice can trap oil and help containment and recovery. Channels within the ice have to be created with icebreakers to collect the oil. Oil has to be thick enough if in situ burning is to be used. Otherwise, oil can be skimmed once collected in the channels. In situ burning has gained support. Approval from EPA region 5 has to be obtained before any burning can take place, and can take up to nine hours to be received. During broken ice conditions, smaller loops of booms can be used and in situ burning utilized. Shoreline (water depth about one foot) skimming and wetlands cleanup has been practiced during training exercises.

C.3.3 Interview with the US Coast Guards Sector Sault Sainte Marie

Our meeting with the USCG Sector Sault Sainte Marie on May 15, 2018, started with a Powerpoint presentation highlighting the typical procedure followed in case of an incident, i.e., how an incident report is generated with a call to the National Response Center, how the typical partners are notified, etc. Partners include the Department of Environmental Quality (DEQ), the Department of Natural Resources (DNR), the Environmental Protection Agency (EPA), NOAA and relevant local managers. Incident reports are available to the public or industry in a redacted format. The State of Michigan is divided into two sectors: Sector Sault Sainte Marie for the northern part of the state (North of Alpena) and the Detroit office for the southern section. The Straits of Mackinac fall under the protection of the USCG Sector Sault Sainte Marie.

A response team leaves within an hour after notification. The USCG provides supervision but not clean up. They are authorized to hire cleanup contractors; they currently have about 20 contracts in their area. Most contractors are trained in the ICS. The response teams are regional and defined in a similar fashion as the EPA regions. The USCG station owns a response trailer with 400 feet of booms with an extra 7000 feet of booms in the Sector Sault Sainte Marie area. In addition, 30,000 feet of booms can be depended on from Canada (see detailed list of equipment in Appendix C2).

If an incident warrants it, the national strike force can be called upon, the closest for Sector Sault Sainte Marie is located in Fort Dix, NJ. They have additional equipment that and can be deployed within a 2-hour window. They have specialized training beyond the regional team training. Part of the team's discussion focused on the issue of spill cleanup during ice conditions on the lakes. The USCG shared that ice can help in the event of a spill during icy conditions. In this circumstance, the ice has to be at least 2 mm oil thick and the wind less than 20 knots. The ice helps to contain the oil in addition to fire booms, and the oil can then be ignited. For burning to be used, the state has to declare a situation of emergency. The USCG and local emergency manager have been working on streamlining this process, as large time delays can render the in situ burning process unworkable. Since 2012 and 2013, the USCG has been refining their technique of oil cleanup in icy conditions. Exercises have been taking place with local managers and the USCG research and development center. Ice on piers makes it hard to load equipment (located in Escanaba and Cheboygan). Furthermore, ice-capable tugs are necessary.

An exercise in 2011 saw mobilization from MPC and T & T (i.e., Enbridge's OSROs in the Straits area). As a result, they have stored equipment locally to significantly decrease the response time.

Currently, eight current busters are present in the area and based on experience during the exercises, they perform adequately, similarly with bucket skimmers. Modifications have been made to some of the equipment, for example, cages around skimmers to prevent debris from clogging the openings and steam in the hoses to avoid freezing. In addition to equipment owned by Enbridge, its OSROs, and the USCG, each local tribe has some equipment, as well as response trailers. The team did not feel it necessary to obtain the details of their equipment, as it is minimal and would be used in addition to extensive equipment from Enbridge and its contractors on a very local scale.

The meeting concluded with a presentation on the Refugio Oil Spill in California as an example of a typical oil cleanup response in a coastal environment. Details can be found on the website of NOAA's Damage Assessment, Remediation, and Restoration Program (NOAA, 2015).

C.3.4 Interviews with Enbridge representatives

The team visited Enbridge's facility at the Straits of Mackinac pumping station on the south side of the Straits on June 5, 2018. The objective of this visit was to assess their state of preparedness and verify the resources available to respond to a potential cleanup scenario. The meeting included Enbridge operations and emergency response managers, exercise and training support, pipeline maintenance and equipment management experts, risk managers, and contractors who would be responding along with Enbridge in the event of a spill.

Broadly the preparedness is a function of the recovery capacity of the deployable equipment and the organizational and human resources that will be necessary to mount an effective response. The discussion identified the following as the primary components of Enbridge's response plan: equipment resources available on site and deployable immediately in the case of a spill, and an incident management plan including various documents and guidelines.

C.3.4.1 Equipment and recovery rate provided by Enbridge

At the facility in Mackinac City, oil containment and recovery equipment are available for immediate use at both sides of the bridge. According to Enbridge, the locally available equipment listed above covers 100% of their anticipated open water oil containment and recovery needs and 50% of shoreline protection needs. Upon an oil release incident, Enbridge would deploy resources from locations where employees and equipment are located and also utilize two OSROs as part of any response in this area.

The recovery rates shown in Table C3 reflect additive recovery capacities per the timelines indicated and the incremental amounts of equipment arriving in the area of the Straits of Mackinac during a response. These rates were provided to the team by Enbridge and represent a combination of values. First, they include recovery rates for the Current Busters and Lamor Bucket Recovery (LBR) systems, which were calculated using the Genwest Estimated Recovery Systems Potential (ERSP) calculator (BSEE and Genwest systems 2015). The ERSP calculator accounts for limitations such as the throughput efficiency and recovery efficiency to estimate an effective recovery rate. The rates in Table C3 also include the sum of the badge ratings of Enbridge- and OSRO-owned skimmers, which have not yet been converted to an effective recovery capacity that accounts for limiting factors such as daylight, weather, sea state, and emulsified oil in the recovered material and are therefore not equivalent to the ERSP-calculated rates. For consistency, therefore, we calculated our own effective recovery rate timeline based on available equipment using the Genwest Response Options Calculator, as detailed in Section C3.5.

Table C4 represents the estimated recovery rates of the two kinds of current busters and the LBR system during the 24-hour period after the oil release incident, provided by Enbridge based on the ERSP calculator. The additive recovery rates shown in Table C3 include the recovery rates of the three types of equipment in Table C4. Figure C5 shows the cumulative recovery rates over 72 hours of response time. It is noted that Enbridge focuses on the first 72 hours of response, as requested by the team when they met with Enbridge representatives on June 5, 2018. However, Enbridge would continue to mobilize and deploy equipment after 72 hours.

Table C3: Incremental recovery rates over 72 hours of response time provided by Enbridge, based on a combination of badge ratings and effective rates generated by the Genwest ERSP calculator.

Timeline	Incremental recovery rate (US gallons per hour)	Note
0-2 hrs	248,376	Enbridge local resources with some OSRO involvement
2-6 hrs	178,555	Enbridge resources in the state of Michigan and growing OSRO involvement
6-12 hrs	461,813	OSRO resources are cascading into the deployment area
12-24 hrs	353,458	More OSRO resources applied
24-48 hrs	2,520,231	The peak of OSRO involvement
48-72 hrs	729,388	OSRO resources continue to arrive

Table C4: Recovery rates of current busters and Lamor bucket recovery (LBR) system, estimated based on the Estimated Recovery Systems Potentials Calculator (BSEE and Genwest systems, 2015)

Timeline	Recovery rate by Current Buster II (US gallons per hour)	Recovery rate by Current Buster IV (US gallons per hour)	LBR system (US gallons per hour)
0-24 hrs	1,551	3,248	6,531

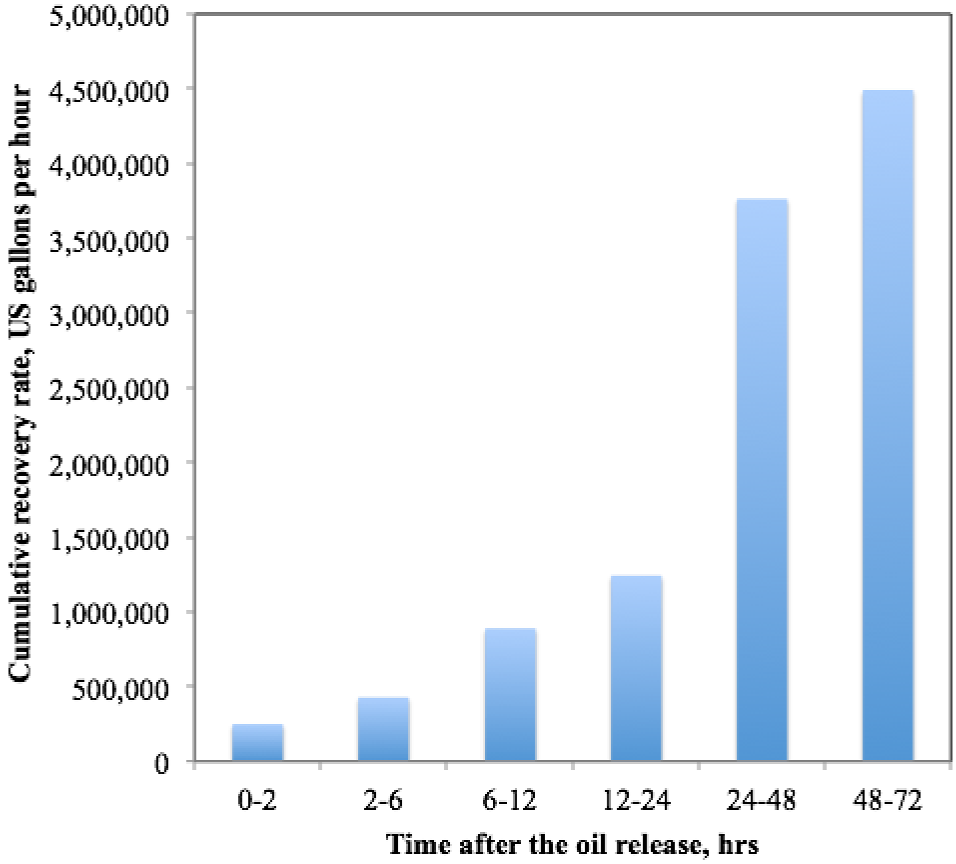

Figure C5: Cumulative recovery rates over 72 hours of response time (Enbridge)

C.3.4.2 Incident Control Management System

The success of spill response lies in not only the available equipment and the location from where they are to be deployed, but also the organizational and human resources available to Enbridge. An Incident Control Management System (ICMS) has been developed by Enbridge to ensure the close communication and coordination between all responding parties (USCG, Enbridge, contractors, etc.) in the event of a spill. It has been developed to deliver a layered response with a goal to recover as much of the spilled oil from the open waters and to minimize long-term shoreline damage.

The ICMS includes various guidelines that will provide direction in the event of a spill including an ICP, a TRP, a listing of tactical control points, inland spill response guide, and an incident management handbook. These documents contain privileged information not available for public use. Organizationally, Enbridge aims to maintain and develops close relationships with contractors as well as federal, state, local and tribal agencies. Training exercises are also a critical component of the response plan.

C.3.5 List of Equipment Identified

The team conducted extensive reviews of available documents. Based on this and the interviews with each entity described in the previous subsections, a large list of equipment was created. The information was gathered from the 2017 Tactical Response Plan Straits of Mackinac (version 3.0) and the 2017/2018 ICP for the Great Lakes region from Enbridge. Included are equipment owned by Enbridge and its contractors, T&T and MTC in the Detroit area. A separate list of equipment owned by the USCG Sector Sault Ste Marie is provided in Appendix C2 and the trailer locations in Appendix C3.

C.3.6 Time to Respond, Deployment, and Staging

Equipment used to contain and recover oil on water needs to be deployed from its storage locations. Enbridge equipment storage sites are located on both the North and South sides of the Straits of Mackinac. The equipment is stored in trailers. When an incident occurs, within minutes all entities including Enbridge, Mackinac county emergency office, USCG Sector Sault Ste Marie and other state offices are supposed to be notified. According to Enbridge, upon an incident notification, the trailers would be mobilized to the shore immediately, and efforts to contain and recover floating oil would begin using current busters and skimmers. According to the Mackinac County Emergency Management office, it takes approximately two hours to deploy this equipment on the water from storage. Booms are also stored in the trailers; these will be staged near the sensitive shorelines defined by the Enbridge Tactical Response Plan (TRP). In general, deployment and staging of booms takes 4-6 hours according to the Enbridge TRP and the interviewees. It should be noted that availability of personnel is another important factor affecting the response time, but this factor is difficult to assess in a quantitative manner based on the information made available to the team.

C.3.7 Shoreline Cleanup

Several metrics define cleanup and are generally determined by the FOSC. Shoreline cleanup is often based on a framework known as SCAT. In this approach, the affected shoreline is divided into segments. These segments are monitored for the extent of oil, and then a plan is put into place for clean-up operations. Throughout the process, additional monitoring is included in order to assess which shorelines remain in need of cleaning. This approach can often take the form of multiple phases. During Phase I, the initial or reactive phase, surveys and immediate cleanup priorities are determined. During this phase, the priority is mostly removal of bulk oil from shorelines. In Phase II, the extent of oiling on beaches is thoroughly documented and overall treatment objectives defined. In Phase III, the operational part of shoreline cleanup is undertaken, and teams are dispatched to treat individual shoreline segments. In addition, treatment and natural recovery processes are monitored. In Phase IV, endpoints are agreed upon by all parties and documented. Additional locations for long-term monitoring are identified to ensure that natural attenuation and other processes sufficiently remove residual oil.

C.4 Methodology

In this section, the overall methodology for estimating the time required to recover floating oil and to clean oil from shorelines is described. Quantitative estimates of oil recovery and cleanup times are highly dependent on the particular scenarios surrounding the spill. Therefore, these estimates carry with them several assumptions and have limitations. The approach for estimating cleanup times and the assumptions and limitations of these estimates will also be described in this section.

C.4.1 Containment and Recovery on Water

Task B used particle-based modeling to simulate the fate of the worst case release identified by Task A as a Tier 5 failure (10,000 oil particles representing 58,000 barrels). According to Task B's simulation, then, each oil particle represented 5.8 barrels of light crude oil. The percentages of the oil volume (accounting for weathering) that were beached on the shore (X%) at different time points after the beginning of the spill were simulated by Task B. Thus, it is possible to estimate how much oil has not yet been beached (including both floating and evaporated material) using the equation below:

$$58{,}000 \text{ barrels of oil} \times (100\text{-}X)/100 \qquad \text{(C.1)}$$

This same procedure can be applied to differing quantities of oil associated with Tiers 1-4 defined as part of Task A. Once the oil is released, it begins to weather, which makes some of the oil not recoverable through mechanical means. According to 33 CFR Appendix C to Part 154, the oil available for on-water recovery can be estimated as 50% of the initial release volume for light crude (Group 2) oil spills in the Great Lakes, with an approximate emulsification factor of 1.8 (Tables 2 and 3 of that document). Thus, the volume of recoverable oil can be estimated for planning containment and recovery as follows:

$$58{,}000 \text{ barrels of oil released} \times 0.5 \times 1.8 = 52{,}200 \text{ barrels} \qquad \text{(C.2)}$$

The following items are available for use in a recovery effort and located at the Straits or within easy driving distance:

- 4 × Current Buster II, two on each side of Mackinac Bridge [90 barrels/hr (3,780 gallons/hr) of capacity for each unit to capture oil on water];
- 4 × Current Buster IV, one in St. Ignace, two in Cheboygan and one in Escanaba [200 barrels/hr (8,400 gallons/hr) of capacity for each unit to capture oil on water];
- 4 × Foilex skimmer, two on each side of the Mackinac Bridge (model TDS 150) [185 barrels/hr (7,770 gallons/hr) of capacity to pump out to storage];
- Boom [four trailers on each side of the Straits; and
- 2 × LBR system: one in Cheboygan and one in Escanaba – ice pack conditions, adverse conditions.

This inventory and location information is publically available in the redacted version of the Straits of Mackinac TRP Version 3.0 (2017). The recovery rates given are the badge rates (manufacturer-supplied capacities), and so they are higher than the Enbridge-provided effective rates for current busters and LBR systems shown in Table C4.

The team used the list described above as the initially available response equipment to estimate the time for containment and recovery of floating oil (see also Table C5 below). The team used the Response Options Calculator (ROC) to estimate the time it would take to contain and recover oil on water. The ROC is "a publicly available oil spill planning and response model that simulates oil weathering, spreading, and recovery by advanced skimming systems, treatment by dispersant application, and removal by in situ burning" (Dale, 2011). The ROC was developed by combining and updating the algorithms from NOAA's Automated Data Inquiry for Oil Spills (ADIOS) and Spill Tools programs with joint efforts by the Department of Interior, Shell Oil, and the American Petroleum Institute with input from NOAA, USCG, and other industry partners. The ROC also includes new algorithms for oil slick spreading. ROC can take into account the weather conditions including water temperature and wind speed. Many of the limitations for important spill response equipment are built into the ROC simulator allowing for consideration of the impact of weather on spill response.

For mechanical recovery, various response measures can be input into the simulator. ROC simulations were run to simulate an oil spill response in the Straits of Mackinac. The following equipment (Table C5) was used in the simulations with the nameplate parameters used. These nameplate parameters were adjusted with an assumed throughput efficiency of 20%, which is a common adjustment factor used in calculating Effective Daily Recovery Rates (33 CFR Appendix C to Part 154). The ROC software also accounts for the offload time and transit time for each equipment to be deployed on site based on the worst case scenario, equipment specification given by the manufactures, and geological information in the Straits of Mackinac. Thus, the team decided to use this robust software to simulate the time required to contain and recover floating oil.

There is a large amount of additional equipment that could be mobilized during a response from Enbridge contractors. The USCG and Tribes also maintain response equipment in Northern Michigan. It is also possible for other OSROs to lend their equipment for use in the Straits region in the event of a spill. However, both because the fast currents in the Straits make the early hours of response (and therefore the immediately available equipment) the most critical and due to the limited resources available to the team, the initial containment and recovery timeline estimate was performed based on the equipment listed in Table C5.

Table C5: Equipment and their numbers used for the simulation of time to contain and recover oils on water using the ROC.

Equipment	Number	Location and owner
Current Buster IV	1 2 1	Straits - Enbridge Cheboygan, MI - Enbridge Escanaba - Enbridge
Current Buster II	4	Straits – Enbridge
Foilex TDS 150 Skimmer	4	Straits – Enbridge
Lamor Bucket recovery systems	1 1	Cheboygan, MI – Enbridge Escanaba, MI – Enbridge
Medium Drum Skimmer	2	Straits - MPC
Medium Brush Skimmer	1	Straits – MPC
Medium Weir Skimmer	1	Straits - T&T

The ROC simulation scenario was run for five days. Initial simulations were run from 6:00 AM on Dec. 27th, 2016 to 7:00 PM on Dec 31st. The simulation used an instantaneous or batch release of 52,200 barrels of oil and assumed a 24-hour operation period for containment and recovery operations. The water temperature was set as the average water temperature over the five days of the simulation recorded by the nearby Spectacle Reef station (see Figure A-C5-1 in Appendix C4), which was 1.64 °C. Two initial simulations were run: (1) a good weather scenario with no wind and (2) a scenario with the actual wind speeds recorded by the Spectacle Reef station for that time period. In both simulations, the equipment was deployed two hours after the spill began (if the weather conditions allowed deployment). The oil characteristics used in this simulation were those programmed into ROC for U.S. HIGH SWEET – CLEARBROOK because of the similarity of that crude's characteristics to those of Line 5. This is a light sweet crude oil and is one of the products transported in the Straits of Mackinac. Briefly, the characteristics of HIGH SWEET oils include: 0.14 wt% of total sulphur; pour point of < -30 °C; vapor pressure of 82.8 kPa; and, a density of 809.1 kg/m^3 (Enbridge, 2017).

The critical assumptions used in the simulation by the ROC include:

- No influence of tides, land, ice, or debris upon the simulation of oils on water;
- Constant water temperature assumed during simulation based on seawater. Hence, the evaporation estimates are higher than those produced by Task B.
- Constant swath width of a skimmer for a given response system during the simulation;
- Constant location of an oil slick during a simulation time; and
- No account of oil loss due to coming ashore.

A full description of the ROC's capability can be found in Dale (2011).

C.4.2 Shoreline Cleanup Time Estimate

Estimation of the time to clean up shoreline is very difficult, as it depends on the specific conditions surrounding the spill scenarios. Factors such as the amount of oil on a shoreline, the type of shoreline that is oiled, and other factors all impact the cleanup operations and the time to clean up a shoreline. Estimates of time to clean up shoreline were based on the comparison of three previous spills that cover a range of oil releases spanning three orders of magnitude. These spills were: (1) Deepwater Horizon on April 20, 2010; (2) Marshall, MI, on July 26, 2010; and (3) Refugio, CA, on May 19, 2015. None of these spills represent a perfect analog for a potential spill in the Straits of Mackinac region. Therefore, these estimates of time to clean up the shoreline represent coarse estimates and must be considered carefully.

C.5 Analysis

C.5.1 Time to Contain and Recover Oils on Water

The ROC simulations provided insights into the efficiency of the available equipment to remove oil spilled on water and the impact of weather on the recovery of oil. A good weather scenario was simulated in which there was no wind. In the good weather scenario, 16,991.2 barrels of oil were recovered after five days with the available equipment; however, taking evaporation into account, 12,963.3 barrels remain on the water. The effectiveness of recovery operations, even in good weather, decreases with the thickness of the oil slick, which is why the amount of oil recovered per hour decreases later in the simulation. Therefore, as the spill progresses and the thickness of the oil decreases, the effectiveness of recovery decreases. This decrease in effectiveness is important to note because at some point in time during the recovery phase of the spill response, the equipment will no longer be able to sufficiently recover the oil and efforts would shift to collecting the oil as it nears the shoreline.

In addition to the good weather scenario, a simulation was run using the actual environmental conditions experienced during the Dec 27th scenario. In this case, the wave and wind conditions were such that much of the equipment could not operate or would be working at reduced operational efficiencies. Therefore, the amount of oil recovered under these conditions is much less (1,036.8 barrels). The simulations show that under the increased wind conditions, natural dispersion increased, removing 895.5 barrels. Natural dispersion is the process whereby wave action results in the formation of small oil droplets that are then dispersed through the water column and removed from the oil spill (Delvigne and Sweeney, 1988). This "real weather" simulation underscores the limitations of some of this equipment in bad weather.

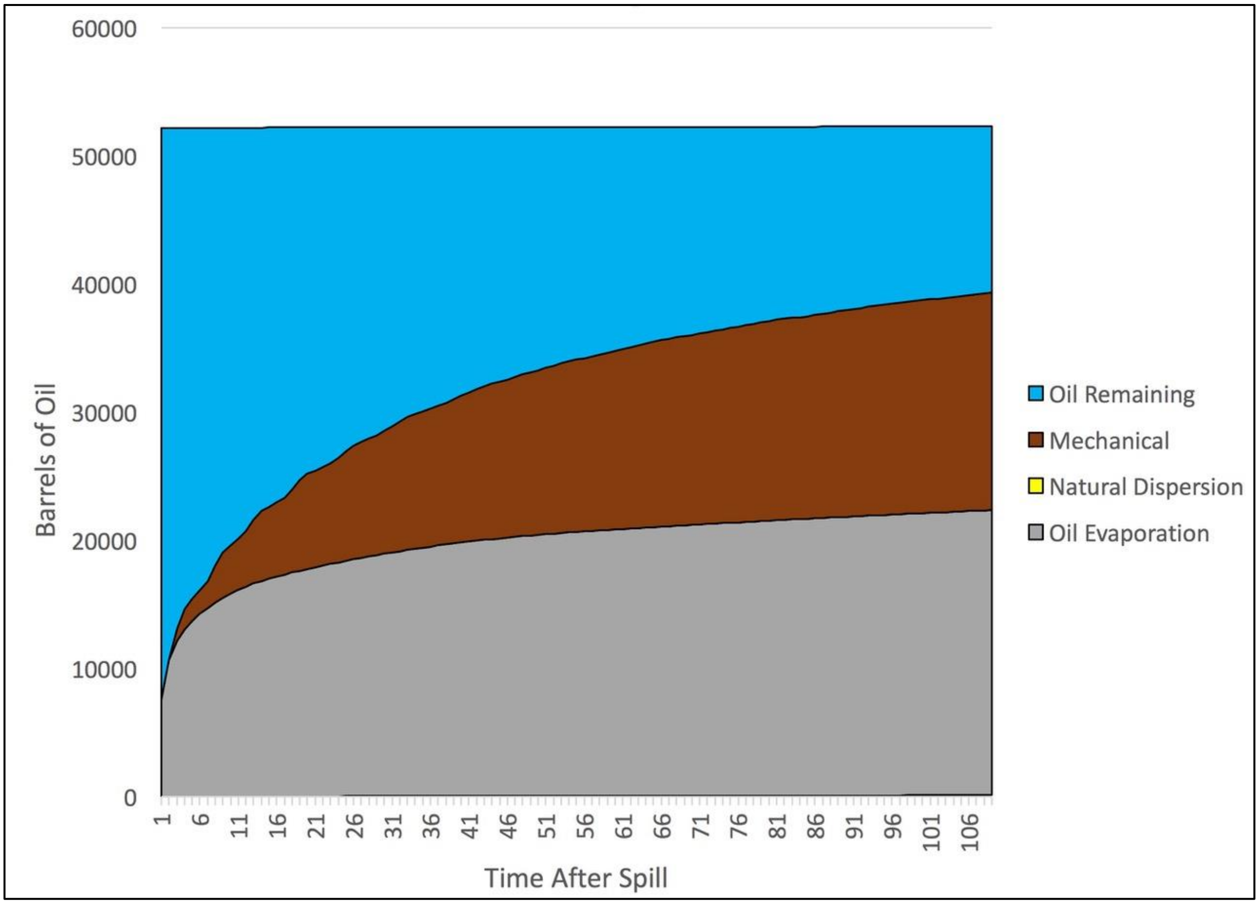

Figure C6: Oil recovered as a function of time from ROC simulations with no wind for 24-hour operations. Oil remaining is shown in blue. Oil that evaporated is shown in grey. Oil that was naturally dispersed in shown in yellow. Oil that was mechanically recovered with skimmers, booms, and current busters is shown in brown.

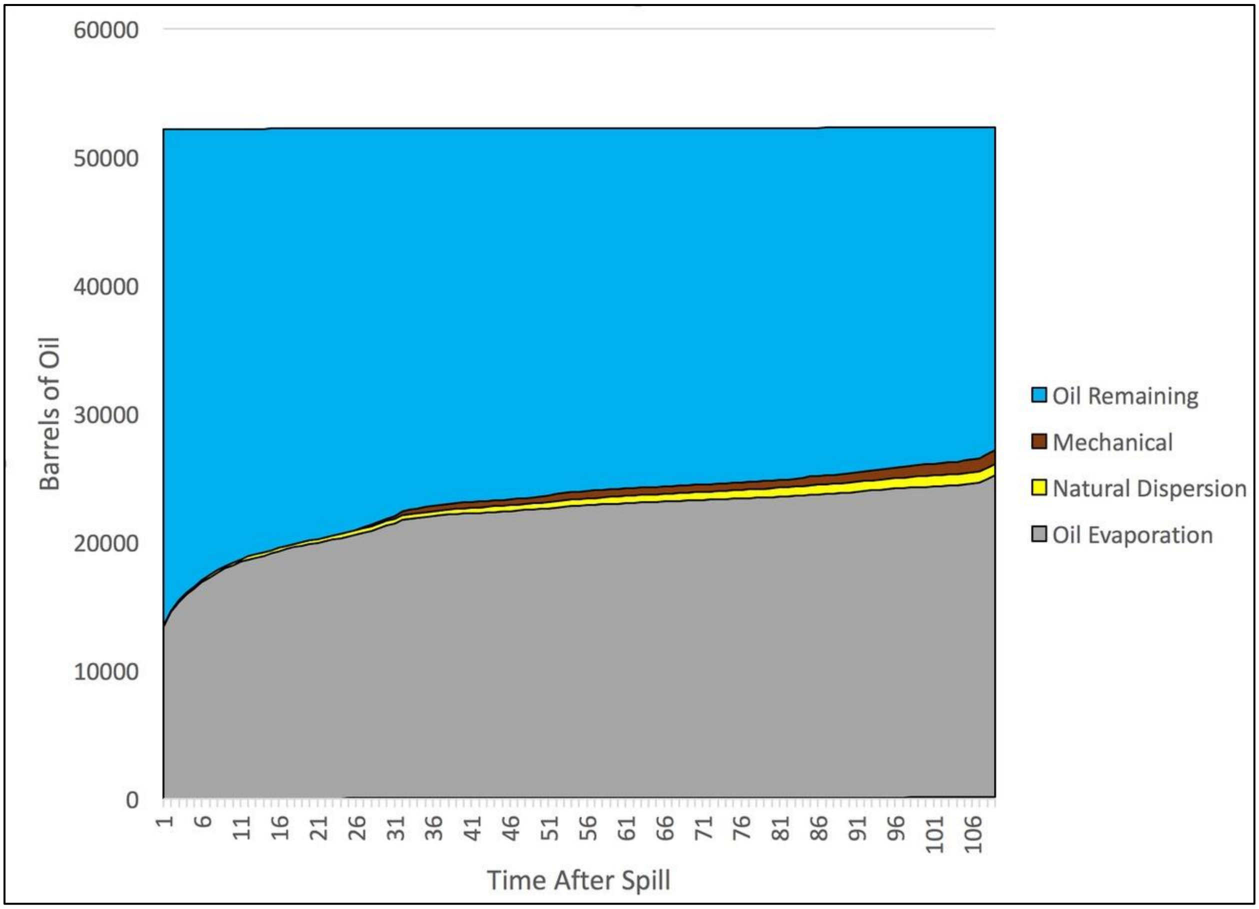

Figure C7: Oil recovered as a function of time from ROC simulations with the wind conditions for the storm (Dec. 27 - 31st 2016). Oil remaining is shown in blue. Oil that evaporated is shown in grey. Oil that was naturally dispersed in shown in yellow. Oil that was mechanically recovered is shown in brown.

Table C6: Oil recovery estimates from ROC simulations based on 24-hour work day with and without the wind conditions from Dec. 27th, 2016.

Category	Volume of oil with no wind (bbl)	Volume of oil with wind (bbl)
Evaporation	22,245.550	25,102.110
Mechanical Recovery	16,991.220	1,036.880
Natural Dispersion	0	895.55
Remaining on water	12,963.330	25,165.660

Based on these simulations, much of the loss in recovery is due to limitations on the ability of equipment to function in the weather conditions experienced at the Straits. Hydrodynamic modeling suggests that within the first five days of the spill, 34,822 barrels of oil are on the shorelines (Figure C4). The ROC simulation does not take into account oil that is being beached. Therefore, much of the remaining oil on water may be beached by the end of the five days. While there would still be substantial oil remaining on the water after five days, in both the good and bad weather scenarios, the amount of oil would be less due to beaching. This would result in the thickness of the remaining slick being much lower.

The simulations presented above represent good and bad weather scenarios. The bad weather scenario represents a worst-case scenario, where the spill happens during a strong storm with weather conditions that do not allow for the efficient functioning of equipment. While this case study assumes the weather conditions that occurred on specific dates in December, these wind and wave conditions could occur at any point during the year, and thus this represents a generalizable worst case. To better understand the average conditions in the Straits of Mackinac, weather data were retrieved for the last three years from the Spectacle Reef Light Station (east of the Straits of Mackinac) and White Shoal Light Station (west of the Straits of Mackinac). Simulations were run using these average wind and water temperature conditions for each month to gain insights into the average performance of the equipment (Figure C8).

These simulations indicate that mechanical recoveries would be greatest during the summer months where weather conditions allow for more efficient operation of the equipment. Also, the volume of oil lost to evaporation is higher during the summer months due to higher temperatures. These simulations also suggest that the storm on December 27th does represent a worst-case scenario, as average mechanical oil recoveries during winter months are greater than was predicted based on those storm conditions. It is also notable that average conditions in the Straits result in diminished recoveries compared to our initial good weather, “no wind” scenario.

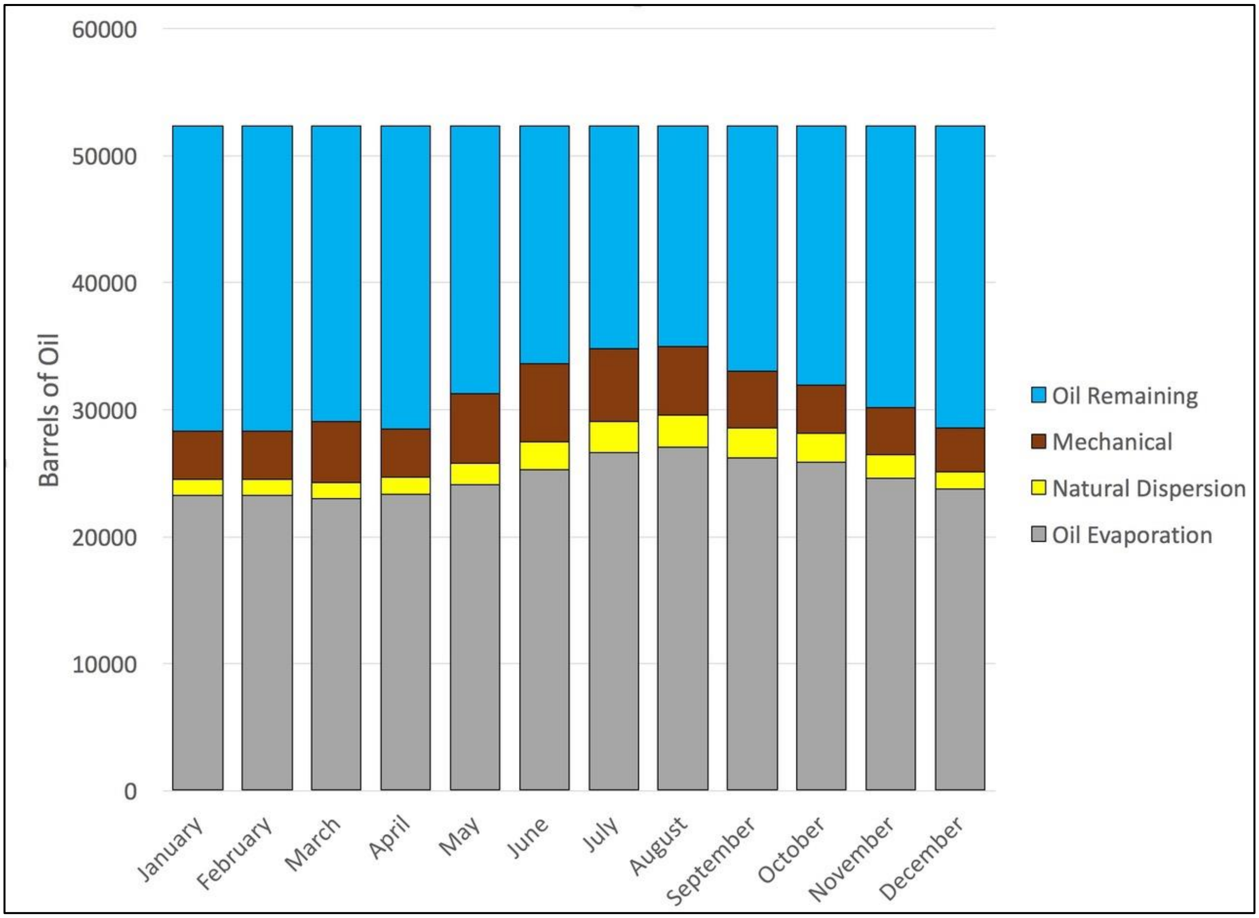

Figure C8: Recoverable oil over the first five days of a spill using average conditions for each month. Data for the Spectacle Reef stations was used to generate average water temperature and wind speeds for each month. ROC simulations were run under these environmental conditions for 24-hour operations. Oil remaining is shown in blue. Oil that evaporated is shown in grey. Oil that was naturally dispersed is shown in yellow. Oil that was mechanically recovered is shown in brown.

To more fully appreciate the impact of weather on equipment recovery conditions, the efficiency of oil recovery was simulated under various conditions. Simulations were performed using two temperatures 25°C and 10°C, over a range of wind conditions (0, 5, 10, 15, and 20 knots) (Figure C9). These conditions represent the range of wind conditions that are experienced in the Straits of Mackinac over the course of the year. While it appears that temperature impacts the ability to recover oil, the primary constraints on oil recover are wind and by proxy wave conditions. Appendix C4 is a detailed analysis of the wind conditions experienced in the Straits. This analysis indicates that in every month there are conditions under which recovery of oil would not be possible due to wind and wave conditions.

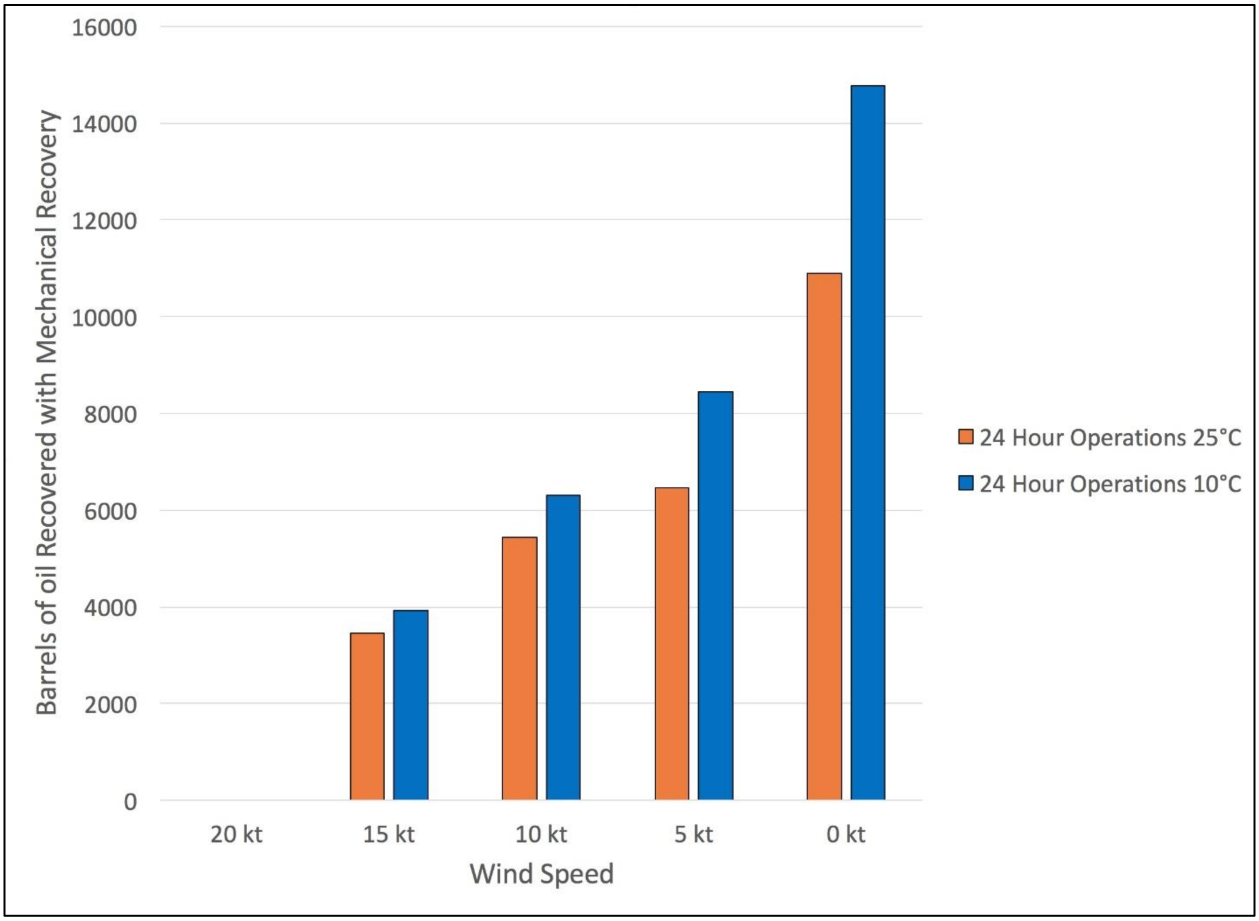

Figure C9: Oil recovered as a function of wind speed. ROC simulations were run at two temperatures for 24-hour operations. With increasing wind speed there is limited oil recovery.

While these simulations factor into the amount of time for the response gear to transit from the site of collection to an offloading site, the simulations only allow for a single set distance. However, as the hydrodynamic models of the oil spill indicate, the oil slick is continually moving and spreading. Therefore, the distance to the center of the slick in relation to the collection and storage equipment is constantly changing, and the time required to move the gear to the offload locations must also be dynamically changing. These changes have the potential to increase the overall time required for clean up as the spill migrates out of the Straits into open water locations.

In all of these simulations, there is residual oil on the water at the end of the five-day modeling period. As the spill response continues, the oil becomes increasingly difficult to recover as the oil slick continues to thin out. During a spill in the Straits, the on water recovery equipment would gather oil and then offload the oil into storage barges. As the oil moves out of the Straits, the response equipment would follow, as shown for the fate of oil up to 120 hrs in Figure C5. During oil spill response planning, a number of staging locations have been identified throughout the Straits region as part of Enbridge's TRP. Oil spill trajectory models would be used to predict the movement of oil and determine which of these locations would be used to stage the equipment for the next operational cycle. This movement of equipment to follow the moving oil slick has the potential to increase the response time as the oil slick moves and thins out.

Operations would continue to recover the oil past the five days simulated here. These operations would follow the same approaches as the oil moves around. As the slick expands, it may be more difficult to cover the area over which the slick is present. However, it is also essential to note that as the spill response continues, there is a building response of recovery equipment that would allow more area to be covered. At some point in time, the on-water recovery operations would become less effective due to the amount of oil remaining on water. At this point, efforts would be focused on dealing with the oil that has reached shorelines.

C.5.2 In situ Burning

In response to an oil spill response in the Straits of Mackinac, in situ burning is *not* off the table. Discussions of the in situ burning options have been ongoing between the State and USCG. Thus, the team included an in situ burning example in the baseline simulation (i.e., December 27th weather with no wind, as shown in Figure C6). ROC has a built-in option for in situ burning. The in situ burning for this specific case follows: 500 feet of fire boom were used. The in situ burns would begin six hours after the spill and continue during the five-day simulation. ROC predicted seven burns could occur during the five-day response. This would remove 3,054.9 bbl of oil with a burn efficiency of near 90%. It is noted that Enbridge has been considering the purchase of fire booms.

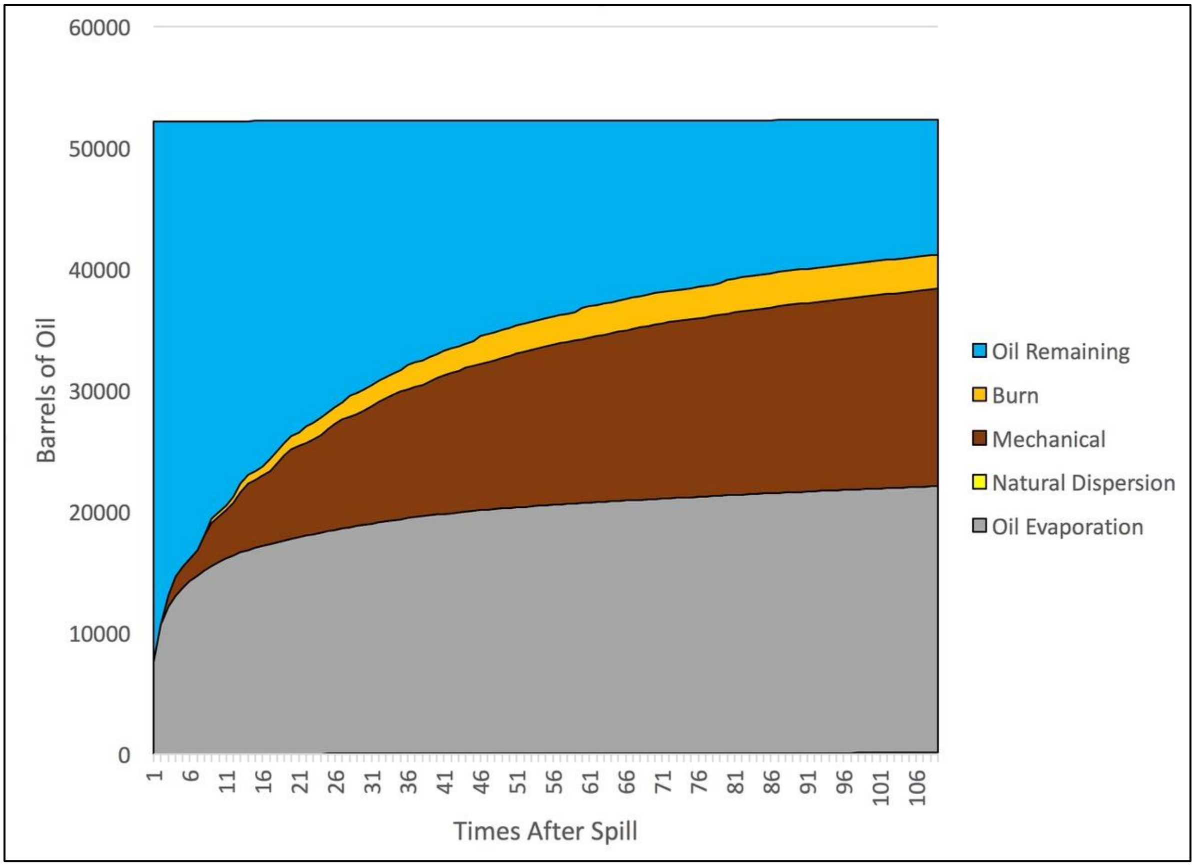

Figure C10: Oil recovered as a function of time from ROC simulations with no wind for 24-hour operations. Oil remaining is shown in blue. Oil that evaporated is shown in grey. Oil that was naturally dispersed is shown in yellow. Oil that was removed by in situ burning is shown in orange. Oil that was mechanically recovered with skimmers, booms, and current busters is shown in brown.

C.5.3 Estimated Time to Clean up Oils on Shorelines

In analyzing past spills, there are a number of points during the cleanup process at which the shorelines could be considered sufficiently cleaned. Ultimately, the decision for when cleanup is complete is made by the FOSC. The team has analyzed three spills that cover a range of oil releases spanning three orders of magnitude. The amount of shoreline oiled in the spills ranges from 70 to 1,101 miles. SCAT operations are broken into multiple phases. In the last phase of the SCAT process, the active part of cleanup is over, and monitoring operations are employed to determine whether submerged oil is resuspended. During the shoreline clean up, a number of milestones can be met where the affected regions are reopened. These milestones could be the end of phase III of the SCAT process, where operations move more toward monitoring than active cleanup. Another milestone in the cleanup of shorelines may be the reopening of beaches after closures are lifted, or when the closure of fisheries is lifted. Clean up could also be deemed finished when federal involvement in the processes has ceased due to the transfer of authority to state and local agencies or disestablishment of the unified command. The most conservative estimates may define the end of cleanup operations as when the responsible party no longer has obligations for cleanup. It is important to note that whatever is considered the endpoint of the shoreline cleanup process, access to and use of the affected shorelines for recreational purposes are mostly restored on a much shorter time frame than when cleanup is deemed complete. Additionally, in the process of clean up, much of the restoration is ongoing, and ecosystem services are being restored to the affected areas. Often the final stages of cleanup are focused on very few segments of shoreline, and most of the other segments have been deemed requiring no further intervention and are deemed clean. It is at this phase in the spill response that cleanup and restoration efforts overlap in order to remove residual oil and return the impacted shoreline to pre-spill conditions.

Table C7: Summary of shoreline recovery and clean up time from three past oil releases

	Deepwater Horizon	Marshall, MI	Refugio, CA
Amount of Oil Spilled	4,900,000 bbl (Lehr et al. 2010)	20,082 bbl	2500 bbl
Oiled Shoreline	1101.7 miles (Michel et al., 2013)	70 miles	24 miles
Date of spill	April 20, 2010	July 26, 2010	May 19, 2015
Greater than 90% cleanup was achieved	November 2011 – moved to shoreline completion plan (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016) **(19 months)**	July 19, 2011 **(12 months)**	July 16, 2015 (JIC, 2015a) **(2 months)**
Date when RP involvement ended	15 April 2014 (last 2.74 miles of shoreline moved to the middle response phase) (Sparks, 2014)– still monitored but not active clean up **(48 months)**	Fall 2014 (October 2014) (Quist 2017) **(51 months)**	March 2, 2017 (Same time when Unified command was disestablished) (Refugio Response Joint Information Center, 2017) (**22 months)**
Beach/River Closure Days	May 7, 2010 to June 15, 2011 (max for Louisiana) (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016) **(14 months)**	June 21, 2012 (USFWS et al., 2015) **(23 months)**	July 17, 2015 (JIC, 2015b) **(2 months)**
Fishing Closures	September 2010 (all state waters east of the Mississippi) (**5 Months)** (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016)	July 28, 2012 (MDHHS 2012) **(24 months)**	June 29, 2015 (JIC, 2015a) **(41 days)**

Shoreline operations would begin as soon as possible after the spill when the SCAT process would be initiated. During this SCAT process, assessment and deployment of resources would occur to clean the beaches. While cleanup operations would proceed as rapidly as possible, if the spill were to occur in winter, weather may delay some of these operations as conditions for deployment of some shoreline clean up tactics may be prevented.

Based on comparisons with these other spills, there is great variability in the time required for a spill to be cleaned up. This variability is due to a number of factors, including the extent of oiled shoreline, the amount of oil that makes it to the shoreline, and the type of oil, among others. This variability makes it difficult to predict an exact date when a spill would be cleaned. The estimated worst-case spill in the Straits of Mackinac would be well below the volume released in the Deepwater Horizon oil spill and more than the amount of oil that was released in the 2010 Marshall, MI spill. The type of oil that is being transported through Line 5 is a light crude oil, which is similar to the type of oil that was released in the Deepwater Horizon spill. The oil spilled in the Marshall, MI spill was a heavier diluted bitumen (dilbit) oil, which made cleanup efforts more difficult and required dredging for cleanup. Additionally, there is a great diversity of shoreline types in the Straits of Mackinac region, which would require not only a coordinated cleanup effort, but effort specifically tailored to particular shoreline types, similar to the Deepwater Horizon spill. Finally, the extent of shoreline predicted to be oiled would be much greater than the Marshall, MI spill, but well below the amount of shoreline oiled in the Deepwater Horizon oil spill. These differences place the cleanup operations for a spill in the Straits somewhere between the Marshall MI spill and the Deepwater Horizon spill. Therefore, we estimate that active shoreline cleanup would continue for anywhere from 12 to 24 months, with the responsible party's involvement lasting for a longer time during the monitoring phases.

C.6 Conclusion

The response to an oil spill requires multiple phases and coordinated efforts of a large number of people and equipment. While the fate of oil is highly dependent on environmental conditions, such as current, temperature, wave height, and wind, the availability of equipment and personnel also changes dynamically as additional personnel and local/state/regional/national/international entities get involved in the cleanup activity. Task C reviewed resources available to the team to understand the organizational response plan and practices and attempted to estimate the approximate time required to contain and recover floating and beached oil. While the list of equipment used for the estimate was limited to what is stored onsite close to the Straits by Enbridge and a few local contractors, the calculations highlighted the significant differences in the time required for containment/recovery of floating oil depending on weather conditions. The estimate was based on the weather conditions that occurred in 2016, and the worst case was defined based on the simulated fate of oils provided by Task B. Finally, the results can be extrapolated to other weather conditions and different fate scenarios.

Once the oil is beached, shoreline cleanup operations take over. From comparison to other spills, the shoreline operations could take much longer depending on the extent and severity of shoreline oiling. These operations follow a standardized approach that allows for efficient deployment of people and equipment to clean up the shoreline. The process of shoreline clean up could proceed for months to years depending on the exact scenarios surrounding the spill. During the process, segments of shoreline would be deemed clean and returned to use. It is, therefore, possible that shoreline cleanup operations for a potential spill in the Straits of Mackinac could continue for months to up to two years following the spill.

C.7 References

Al-Majed, A. A., Adebayo, A. R., & Hossain, M. E. (2012). A sustainable approach to controlling oil spills. *Journal of environmental management*, *113*, 213-227

Allen, A.A., Jaeger, D., Mabile, N.J., Costanzo, D. (2011, March) The Use of Controlled Burning during the Gulf of Mexico Deepwater Horizon MC-252 Oil Spill Response. International Oil Spill Conference Proceedings: No. 1, pp. abs194.

Atlas, R. M. (1991). Microbial hydrocarbon degradation—bioremediation of oil spills. *Journal of Chemical Technology and Biotechnology*, *52*(2), 149-156.

CFR (2018) Title 33: CFR Appendix C to Part 154, Guidelines for Determining and Evaluating Required Response Resources for Facility Response Plans.

Dale, D. (2011) Response Options Calculator (ROC) Users Guide. GenWest Systems, Inc.

Deepwater Horizon Natural Resource Damage Assessment Trustees (2016) Deepwater Horizon oil spill: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement.

Delvigne, G. A. L., Sweeney, C. (1988). Natural dispersion of oil. Oil and Chemical Pollution, 4(4), 281-310.

Enbridge (2017) Crude Characteristics No.28. by Enbridge Pipelines Inc. Enbridge Energy Partners, L.P.

Fingas, M. (2012). *The basics of oil spill cleanup*. CRC Press

https://darrp.noaa.gov/oil-spills/refugio-beach-oil-spill accessed on Jun 29, 2018.

Joint Information Center. (2015a) Spill Cleanup Operation Reaches 98 Percent, Four-County Beach Survey Results. Refugio Response Join Information Center.

Joint Information Center. (2015b) Refugio State Beach slated to reopen July 17. Refugio Response Join Information Center.

Lehr, B., Bristol, S., Possolo, A. (2010) Oil budget calculator. Deepwater Horizon. The Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team.

Michel, J., Owens, E.H., Zengel, S., Graham, A., Nixon, Z., Allard, T., Holton, W., Reimer, P.D., Lamarche, A., White, M., Rutherford, N., Childs, C., Mauseth, G., Challenger, G., Taylor, E. (2013) Extent and Degree of Shoreline Oiling: *Deepwater Horizon* Oil Spill, Gulf of Mexico, USA. PLoS ONE 8(6): e65087.

NOAA (2015) Damage Assessment, Remediation, and Restoration Program.

NOFI (2018) http://www.nofi.no/en/oilspill/nofi-current-buster-teknologi accessed on July 11, 2018.

Northern Michigan Area Contingency Plan, August 2015.

NRC (2015) Spills of Diluted Bitumen from Pipelines: A Comparative Study of Environmental Fate, Effects, and Response. National Academies Press.

Refugio Response Joint Information Center (2017). Unified Command for Refugio Beach oil spill response operations disestablished. http://refugioresponse.com/go/doc/7258/2522638/index.html accessed on July 10, 2018

Santner, R., Stong, B., Cocklan-Vendl, M., Michel, J., Owens, E. H., & Taylor, E. (2011, March). The Deepwater Horizon MC252-Macondo shoreline cleanup assessment technique (SCAT) program. In *International Oil Spill Conference Proceedings (IOSC)* (Vol. 2011, No. 1, p. abs270). American Petroleum Institute.

Sparks, M.T. (2014) U.S. Department of Homeland Security and United States Coast Guard, Memorandum, FOSC Update on deepwater horizon response.

U.S. EPA. (2013) Inland Response Tactics Manual.

U.S. Fish and Wildlife Service (USFWS), Nottawaseppi Huron Band of the Potawatomi Tribe, and Match-E-Be-Nash-She-Wish Band of the Pottawatomi Indians. (2015) Final damage assessment and restoration plan/environmental assessment for the July 25-26, 2010 Enbridge Line 6B oil discharges near Marshall, MI.

Venosa, A. D., Zhu, X. (2003). Biodegradation of crude oil contaminating marine shorelines and freshwater wetlands. *Spill Science & Technology Bulletin*, *8*(2), 163-178.

Task D: Analyzing the short and long-term public health and safety impacts

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D.1 Introduction

The Enbridge Line 5 pipeline transports light crude oil products in addition to natural gas liquids (NGL) under the Straits of Mackinac waterway that connects Lakes Michigan and Huron and is located between the State of Michigan's Upper and Lower Peninsula regions. A potential pipeline rupture and release in this area could threaten public health and safety due to exposure to these materials and their components through released material inhalation, ingestion, and dermal exposure. Additional concerns include fire and explosion risk associated with oil product flammability. This report provides an assessment of the possible health and safety risks posed to populations that could be exposed to Line 5 products and their chemical components following a potential pipeline rupture and subsequent worst-case release scenario.

Oil spills and associated cleanup activities represent a range of health hazards to exposed individuals, communities and populations. Unrefined petrochemical products such as crude oils contain a range of chemical constituents that can increase the risks of adverse effects to human health and public safety following exposure. These chemicals include, but are not limited to; volatile organic compounds (VOCs) such as the known carcinogens benzene, toluene, ethylbenzene, and xylenes, collectively abbreviated as BTEX; polycyclic aromatic hydrocarbons (PAHs), heavy metals such as nickel and vanadium, and hydrogen sulfide (H2S). The primary objective of this effort was to identify and understand the potential risks to public health and safety that might be experienced by populations that are at risk of exposure under a worst-case release scenario from the Line 5 pipeline. This includes the potential short-term (acute) and long-term (chronic) effects associated with the chemical components of released oil which cleanup workers, volunteers, healthcare professionals and the general public may be exposed to through various exposure pathways during and possibly following a pipeline rupture and release.

D.2 Approach

D.2.1 Worst-case determination for public health and safety

Oil dispersal simulations conducted for this independent risk analysis report, predicted that majority of any oil product potentially released from a Line 5 pipeline rupture will have left the Straits of Mackinac channel within the first approximately 24 hours following release and the majority of evaporation will occur early after the release (Task B - fate & transport graphs of evaporation rate, Appendix B-1). The small volume of VOCs released more than 24 hours after the worst-case release or released far from the shoreline will likely not result in human exposures at levels high enough to cause harm to human health. Subsequently, oil dispersal simulations that demonstrated the greatest extent of surface area oiling within the Straits of Mackinac region during the first 12 hours of release during July was used to estimate the worst-case public health and safety risks as associated with the potential rupture of the Line 5 pipeline. The specific release scenario predicted a maximum oiled surface area of 138 km2 for July across the Straits of Mackinac channel and nearby Lake Michigan and Lake Huron waters. The maximum oiled surface area was determined as a surrogate of the increased potential for human health risks as associated with the volatile nature of many crude oil constituents and the positive relationship between surface area and evaporation rate for crude oil products. (Stiver & Mackay, 1984).

Michigan's Straits of Mackinac region represents an important tourist destination during the summer season experiencing a significant increase in seasonal residents and workers in addition to local, state, national and international tourists that visit the area's state parks, beaches and island resorts. Increased water temperature during the summer months will also permit/facilitate recreational water sports activities that could increase the extent of direct human contact and exposure to oil through dermal absorption. Further, greater summer water temperatures foster more rapid evaporation of the volatile components in spilled oil potentially increasing the risk of inhalation exposure relative to cooler spring, fall and winter air and water temperatures that reduce the extent of evaporation and weathering of oil and its constituents (Fingas, 2013; 2015)

D.2.2 Description of populations at risk

The population that would be exposed to the contaminants of potential concern (CoPC) under the various scenarios studied are considered to be at-risk. Certain groups in the population are particularly more vulnerable to the potential hazards of a worst-case release, and thus are more susceptible to the associated health impacts. According to the American Journal of Managed Care (2006), vulnerable populations typically include economically disadvantaged, racial and ethnic minorities, uninsured, children (and fetuses), elderly, and disabled persons.

The region surrounding the Straits of Mackinac includes three counties: Emmet and Cheboygan Counties in the Lower Peninsula, and Mackinac County in the Upper Peninsula. U.S. Census Bureau estimates (American Community Survey, 2016) indicate these counties have large elderly populations (21-27% aged 65 years and older), a relatively small population of young children (less than 5% of the population is <5 years of age), and 10-15% of the population less than 65 years old is disabled (Table D1 and Appendix D1). Less than 10% of the populations of Emmet and Cheboygan Counties are minorities. The total minority population in Mackinac County is more than 25% with the majority of these individuals identifying as American Indian.

Mackinac County and the surrounding regions are home to the Sault Ste. Marie Tribe and Bay Mills Indian Community of the Chippewa Indians. The entire area of concern for the worst-case scenario is inside the approximately 13.8 million acres in the northern Lower Peninsula and eastern Upper Peninsula of Chippewa Tribal lands that were ceded to the U.S. government in the 1836 Treaty of Washington. Tribal members have maintained their rights to fish and hunt in ceded territories, and commercial fishing is also allowed under the rules and regulations of the 2000 Great Lakes Consent Decree (LTBB, 2013). In the Little Traverse Bay Band of Odawa Indians (LTBB) report (2013), approximately 62% of LTBB whitefish harvest came from trap nets sets in the WFM04 Lake Michigan management unit located on the west side of the Mackinac Straits (LTBB, 2013). Therefore, the economy and food security of these American Indian populations could be severely impacted by an oil release that affected fisheries and wildlife.

In each of the three counties, more than 1 in 10 individuals live below the poverty line, with nearly 1 in 5 living below the poverty line in Cheboygan County. About 10% of the population does not have health insurance (American Community Survey, 2016). Unemployment is a major contributor to a region’s vulnerability. Mackinac County has an unemployment rate at nearly 20%; unemployment rates in Emmet and Cheboygan Counties are lower, 15% and 8%, respectively (Michigan Department of Technology, Management and Budget, Local Area Unemployment Statistics, & Bureau of Labor Market Information and Strategic Initiatives, 2018). Detailed labor force data can be viewed in Appendix D1. Furthermore, Mackinac Island, Mackinaw City, and St. Ignace have a significant shift in employment from May to October as summer seasonal businesses open. Seasonal workers increase the labor force as well as the resident population during this period.

One method of classifying at-risk populations is by their exposure level. Individuals with the highest level of potential exposure are the oil spill cleanup workers who are exposed to high concentrations of oil products and may be exposed via dermal, inhalation, and accidental ingestion routes. These workers are also potentially exposed to chemicals and materials used in the cleanup process that may be harmful to human health (D’Andrea & Reddy, 2013). The next highest level of exposure include persons exposed to the oil products from restoration work or local cleanup efforts. These may include volunteers or paid employees. These individuals are potentially exposed through inhalation and dermal exposures, but the concentration and/or frequency of contact is likely to be lower than the previously described group. However, these persons, especially volunteers, may not utilize appropriate personal protective equipment to reduce exposure. For example, volunteers cleaning wildlife may wear gloves to prevent dermal exposure but not masks to reduce inhalation exposures. The next level of exposed individuals are the permanent residents of the affected area. These individuals may be exposed via inhalation during the acute phase of the scenario and may have dermal and accidental ingestion exposures if oil products remain in the affected area long term. While these individuals may have longer-term exposures, the concentrations they would be exposed to are far less than persons directly involved in cleanup activities. The groups with the lowest level of exposure are short-term residents, seasonal workers, and tourists. These individuals would likely be exposed via inhalation during the acute phase of the scenario, but would not be exposed long term, and advisories would be in place to reduce the risk of dermal and accidental ingestion of oil products (such as beach closures).

The Mackinac Straits area does not have a large permanent resident population (Appendix D1), but it is a particularly popular tourist spot, and many households in the surrounding counties are identified as seasonal by the U.S. Census Bureau. Visitor data is complex to analyze, as it is comprised of several industries. While there is no visitor data specific to Emmet, Cheboygan, and Mackinac Counties, there are studies of the impact of tourism on the local economy. According to a Tourism Economic study (2016), visitor spending contributed $89.91 million, $363.39 million, and $219.98 million to the economies of Cheboygan, Emmet, and Mackinac counties respectively (Michigan Economic Development Corporation, 2016).

Certain health conditions may be exacerbated by exposure to CoPC. Individuals with chronic respiratory conditions, such as asthma and chronic obstructive pulmonary disease (COPD) may be more sensitive to the effects of exposure to VOCs.

Data from the Michigan Behavioral Risk Factor Survey (BFRS) are available at the regional level; however, due to small sample populations in the affected region, the estimates are aggregated from 2014-2016 and are available at the county level. Estimates for Mackinac County are combined with Luce, Schoolcraft, and Alger Counties (LMAS). Data from the northern Lower Peninsula are available as District 4 and Northwest Michigan (Figure D1). About 1 in 10 adults in the three regions reported they currently had asthma, similar to the overall Michigan prevalence. The prevalence of COPD was about 8% in LMAS and Northwest Michigan regions, but slightly higher (12%) in District 4. The self-reported cardiovascular disease figure was about 12% in the regions in the Lower Peninsula, but only 7% in the Upper Peninsula LMAS region.

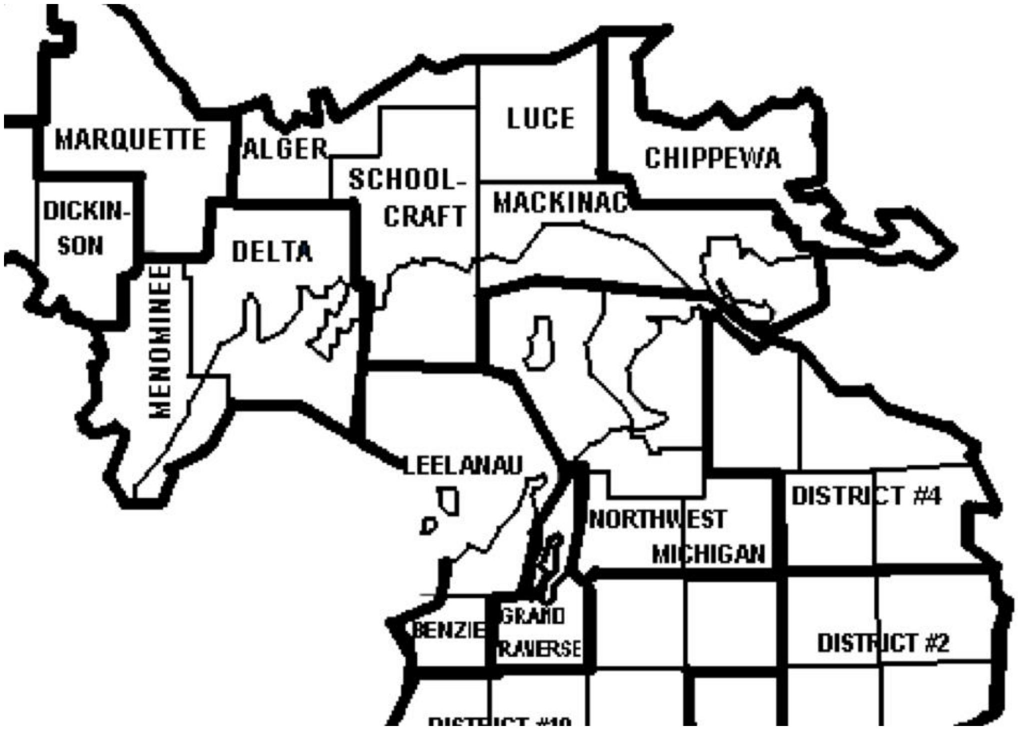

Figure D1: Community Health Assessment Regions (Source: Michigan BRFSS, 2014-2016)

D.2.3 Hospital capacity

Hospital access is limited within the tri-county region (Emmet, Cheboygan, and Mackinac Counties). Four hospitals serve the area; St. Ignace (15 bed), Charlevoix (25 bed), Petoskey (202 bed), and Sault Ste. Marie (82 bed) and all maintain 24-hour emergency departments (MDHHS, 2016). The St. Ignace hospital is located directly in the affected region on the northern side of the Mackinac Bridge. Petoskey is the next closest hospital located 36 miles southwest of Mackinaw City in the Lower Peninsula. Sault Ste. Marie is the closest larger hospital in the Upper Peninsula, 51 miles north of St. Ignace. All four hospitals have federal designations (Critical Access or Sole Community hospitals) that provide financial support to ensure the viability of rural hospitals. The nearest trauma centers to the affected area are Marquette (162 miles from St. Ignace) and Traverse City (118 miles from Mackinaw City); both are Level 2 trauma centers and Burn Surge Facilities (Moore et al., 2014; Detro-Fisher, 2013). Mackinac Island maintains a small medical clinic with 24-hour emergency care but has limited resources. Medical evacuations from Mackinac Island are conducted by boat or air ambulance.

Table D1. Vulnerable Populations (Source: U.S. Census Bureau, n.d.)

Population Group	Emmet County	Cheboygan County	Mackinac County
Economically disadvantaged (percent below poverty line)	11.80%	18.00%	13.70%
Total minority population (Σ percent African American, American Indian, Asian, Native Hawaiian, 2+ races, Hispanic or Latino)	9.00%	8.20%	26.70% (16.70% American Indian)
Children (percent below age 5)	4.80%	4.10%	3.80%
Children (percent below age 18)	19.80%	17.10%	16.10%
Elderly (percent over the age of 65)	21.40%	26.00%	27.50%
Disabled (percent under the age of 65)	10.60%	14.80%	12.50%
Uninsured (percent under the age of 65)	8.10%	9.80%	12.30%

D.2.4 Chemicals of Concern

Total Petroleum Hydrocarbons (TPH) is a term used to describe a broad family of several hundred chemical compounds that originate from crude oil (chemical mixture). By categorizing TPH in groups of petroleum hydrocarbons (called petroleum hydrocarbon fractions; each fraction contains many individual compounds) that act identically in environmental media (air, soil or water), the chemical effects can be modeled.

Hydrocarbon compounds in the vapor phase are very mobile and break down quickly in air. These VOCs, such as benzene, are of concern because they can be present at significant concentrations in light oils. However, due to airborne dispersion and degradation and the limited proportions of VOCs in bulk oil (< 5%), the human health risks are limited and short-term, unless obstructions such as buildings or houses within the zone of contamination limit compound diffusion. Soil or water contamination by TPH pose the most potential for human health risk if the chemicals migrate into shallows aquifer used for drinking water or recreational activities.

The Line 5 pipeline carries light crude oil. Hence the TPH will float on water and form thin surface films. Individual compounds will then separate from the original crude oil mixture with volatile elements evaporating into the air almost immediately after the oil arrives on the surface of the water. When spilled oil becomes beached on shorelines, TPH can migrate through to the soil layer and potentially into groundwater. Other compounds will bind to soil particles and reside in the soil for extended periods, while others can be broken down by soil microorganisms.

D.2.4.1 Effects of Weathering on Crude Oil

The behavior of a crude oil released in the environment is affected by its chemical composition and physical properties including density, viscosity, flash point, and adhesion. Oil spilled into the environment undergoes a series of physical and chemical changes known as weathering (Fingas, 2012). Weathering processes occur at different rates but begin as soon as oil is spilled and occur most rapidly immediately following. Most weathering processes are temperature dependent and will to zero as temperatures reach freezing. Both weathering processes and the rates at which they occur depend more on the type of oil than on environmental conditions and therefore vary from spill to spill. Overall, the chemical and physical composition of crude oils greatly influences how these compounds behave in the environment. According to the Transportation Research Board and National Research Council (2003), the most significant weathering process is evaporation because it accounts for the greatest loss of material. Evaporation is an important process for most oil spills. The rate of evaporation depends primarily on the composition of the oil product, and secondarily on environmental conditions, such as temperature and waves (Schwab, 2016). Density is also an important factor during oil spills with crude oil densities commonly ranging from 0.7 to 0.99 g/cm3 thus tending to float if released into freshwater (1.00 g/cm3) environments (National Academies of Sciences, Engineering, and Medicine 2016). Therefore, evaporative losses of light components can increase the density of the remaining oil. Additionally, vaporization and emulsification have been found to be extremely sensitive to initial oil viscosity and composition (Mishra & Kumar, 2015).

When oil is spilled into an aquatic environment, it is important to disperse the unrecoverable oil into the water column. Dispersion increases the available surface area of the oil which enhances natural processes such as biodegradation and dissolution that play a significant role in degrading the oil (Prince, 2010). Oil can be naturally dispersed by turbulent currents caused by weather events, such as storms, as was observed following the Exxon Valdez oil spill (Wolfe et al., 1994). Immediately after a spill, the spilled oil begins to weather at an increasing rate, changing its chemical and physical properties. First, the viscosity of the oil increases as it weathers, which decreases the ability of the oil to form small droplets. Additionally, as oil weathers, lighter components (alkanes, aromatics) are removed, while other heavier components, such as asphaltenes become more concentrated (Oudot et al., 1998).

D.2.4.2 Health Effects of Chemicals of Concern

The CoPC that may contaminate the air, soil and/or groundwater due to the release of Line 5 products include the following:

- Total Petroleum Hydrocarbons: Gasoline-range TPH
- Petroleum-Related Volatile Organic Compounds (VOCs): These include Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX). Benzene is listed as one of the most toxic compounds on the list of carcinogens on the EPA’s drinking water standards.

- Other Gases: Pentane, Hexane, Hydrogen Sulfide
- Polycyclic Aromatic Hydrocarbons: 16 US EPA Priority PAHs

Though all crude oils contain PAHs, light crude oil mostly contains fewer total PAHs relative to heavy crude oil (NOAA, 2010) and also fewer of the carcinogenic PAHs (NRC, 2003). The PAHs continue to break down during weathering of the oil (Johnson et al., 2008) with studies demonstrating their presence in < 1% of weathered samples (US FDA, 2010).

The potential human health effects from exposure to TPH are dependent on factors including the types of chemical compounds present in the TPH, duration of exposure, frequency of exposure, and the amount or dose of the chemicals. The toxicities of most TPHs are still unknown; however, certain compounds such as PAHs, volatile and semi-volatile organic compounds (VOCs such as BTEX), and flammable and combustible fractions of TPH are of interest to public health and safety. These TPH compounds pose adverse human and environmental health risks in different ways. The BTEX compounds, for instance, can potentially affect the human central nervous system (CNS). At elevated concentrations and exposure, these compounds can be acutely toxic and lethal. A summary of the potential health effects of the CoPC is described in Table D2.

Human health-based standards for organic compounds are usually established to achieve certain risk-based levels based on long-term (lifetime) exposure to the CoPC. An example would be, at a particular concentration of benzene in inhaled air, ingested soil or potable water, ingested throughout a receptor's lifetime, has the potential to result in a 1 x 10-6 (a one in a million) increase in cancer development from the exposure.

D.2.4.3 Polycyclic Aromatic Hydrocarbons (PAHs)
Polycyclic aromatic hydrocarbons are a group of organic compounds containing two or more conjugated aromatic rings. The US Environmental Protection Agency (US. EPA) listed 16 PAHs as priority pollutants, 7 of which are carcinogenic. These PAHs have been determined to pose a risk to the public through inhalation, ingestion and dermal absorption.

D.2.5 Zones of Potential Exposure (ZOPE)

As the spilled oil washes ashore around the areas identified in Figure D2, the areas of potential contamination of the soil beneath the weathered oil on the shoreline may contain any of the non-gaseous CoPC. The areas of concern in a worst-case scenario spill are the shorelines of Emmet, Cheboygan, and Mackinac Counties. The proportion of shoreline affected depends on the scenario modeled.

The ZOPE for groundwater contamination are defined as areas of groundwater that contain CoPC above Oregon Water Quality Criteria, which for some chemicals is any detectable amount. A concentration of 5 micrograms per liter (µg/L) for VOCs was used as a reasonable cutoff for defining the area of contamination in groundwater, which is similar to commonly reported laboratory method reporting levels.

Table D2. Health effects of chemicals of potential concern (ASTDR, 2011; NIOSH, 2016).

CoPC	Health Effect, low/short-term exposure	Health Effect, high/long-term exposure	Carcinogenic classification (IARC)
Benzene	Drowsiness, dizziness, rapid heart rate, headaches, tremor, confusion, vomiting or irritation of the stomach (ingestion), redness/sores (dermal)	Excessive bleeding, anemia, unconsciousness, coma, death	Known human carcinogen
Toluene	Headache, dizziness, drowsiness, confusion, weakness, nausea, loss of appetite, memory loss	Unconsciousness, coordination difficulties, permanent cognitive impairment, vision/hearing loss, developmental delays (fetus), death	Not classified
Ethylbenzene	Eye, throat, skin irritation	Dizziness, hearing loss, kidney damage	Possible human carcinogen
Xylenes	Skin, eye, nose, throat irritation, difficulty breathing, impaired lung function, memory loss, headache, loss of coordination, stomach discomfort, confusion	Hearing loss, loss of muscle coordination, death	Not classified
Hexane	Muscle weakness, numbness in extremities	Peripheral neuropathy	None
Hydrogen Sulfide	Eye, nose, throat irritation, difficulty breathing (especially in asthmatics), headaches, poor memory, tiredness, balance problems	Respiratory distress, respiratory arrest, unconsciousness, poor memory/attention span, poor motor function	None
PAHs	Throat irritation, difficulty breathing	Reduced lung function,	Some PAHs are known human carcinogens
Sulfur dioxide	Increased asthma symptoms, breathing difficulties, nose and throat irritation	Emphysema, bronchitis, exacerbate heart disease, lung function changes, life-threatening	None
Carbon monoxide	Headache, dizziness, weakness, vomiting, chest pain, confusion	Unconsciousness, angina, death	
Carbon dioxide	Headache, dizziness, restlessness, difficulty breathing, sweating, increased heart rate	Coma, asphyxia, convulsions	

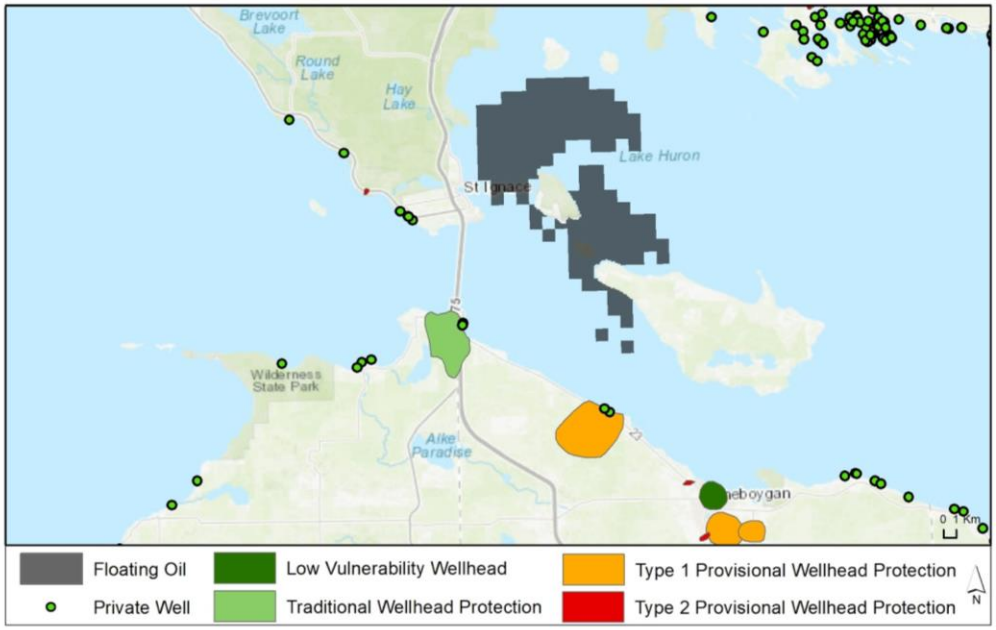

Figure D2: Worst case oil dispersal predicted for the Straits of Mackinac during the summer season. Floating oil is indicated by the black and grey areas dispersed across the water surface. Green, yellow and red colored shapes identify drinking water wellhead protection areas with the green symbols () along the shorelines indicating private drinking water wells located within 200 feet of the Straits of Mackinac shoreline.

D.2.6 Human health risk assessment (HHRA)

The imminent hazards from human exposures to petroleum products (crude oil and/or NGL)) include the damaging properties of the products including toxicity and flammability. The toxic effects on human health are dependent on the concentration and dose of the chemicals, while the flammability hazard can result in radiant heat emission, explosion, and fire, which are dangerous to human health depending on the lower flammability limits of the chemical vapors and the location of the receptor. The flammability hazard under the worst-case scenario has been analyzed separately in section 3.0. In this section, the potential human health impacts from toxic exposure to released substances from the Line 5 pipeline was evaluated. Detailed methodology for human health risk assessment is available in Appendix D2.

D.2.6.1 Deterministic Human Health Risk Assessment (HHRA)

A conventional deterministic risk assessment was used to estimate the potential carcinogenic and non-carcinogenic risks from worst-case inhalation, ingestion and dermal contact exposures to CoPC, in the air, water and soil for susceptible population along the Straits of Mackinac that may be affected by the worst-case oil release. An HHRA (US

EPA, 2009a) was conducted to identify CoPC and/or derived emissions sources that may pose the worst-case health risks.

D.2.6.2 Multi-pathway Exposure Modeling

Human health risk assessment calculations assumed that permanent residents, seasonal residents and transient residents (both children and adults) will be directly exposed to soil, air and water.

The route of entry into the human body can be through three main exposure pathways a) inhalation of contaminated particles and dissolved chemical present in the air; b) ingestion from contaminated water, food or soil; c) and dermal absorption due to contact with contaminated materials.

Inhalation was assumed as the major exposure pathway for the VOCs, while ingestion, inhalation and dermal absorption were examined for PAHs. The majority of volatile TPH identified in crude oil rapidly enter the human bloodstream when inhaled. The rate of dermal absorption of TPH through the skin is very slow and less of a concern than inhalation and ingestion risks. Most TPH exit the body through exhalation and excretion mechanisms.

A time-weighted average dose was linked to the exposure simulation concentrations and was used for the exposure analysis for the inhalable volatile compounds. The assessment of the chronic and acute inhalation exposure risks considered the dose-response criteria of the USEPA and the carcinogenic and non-carcinogenic risks for all risk-posing CoPC were estimated for the different population groups. In this analysis, four VOCs (benzene, toluene, ethylbenzene, xylenes) and 16 PAHs with known toxicity values were considered in this analysis. These represent the CoPC that pose the greatest risks to public health and safety due to a crude oil or NGL release of the volume represented by the worst-case in this analysis.

D.2.6.3 Carcinogenic Risk Assessment

Risk of adverse effects due to accidental ingestion of contaminated soils or water (surface water or during swimming related activities), inhalation of toxic compounds from vapors from released products and absorption of chemicals through the human skin, were calculated by combining the intake (dose) with an appropriate reference dose or slope factor.

D.2.6.3.1 Incremental lifetime cancer risk (ILCR)

The additional cancer risks in exposed adults and children were evaluated by applying the incremental lifetime cancer risk (ILCR) model. This model assumes that exposure to carcinogenic CoPC will increase the risk of cancer induction in exposed receptors. This means that there is no safe or threshold dosage for known carcinogenic substances, such as benzo(a)pyrene or benzene. The model result gives a worst-case likelihood that a receptor will develop cancer from exposure to the CoPC over a lifetime (US EPA, 2004). The total risks are assumed to be additive from multiple CoPC and exposure routes; this is described further under risk characterization.

D.2.6.3.2 Toxicity equivalency factors (TEQ)

The concentrations of the 16 priority PAHs have been analyzed in 48 crude oils from around the world in (Kerr et al.,1999; Pampanin & Sydnes, 2013). The results of the analyses are summarized in Table D3, which shows wide PAH concentration variation in crude oil from different locations.

PAH concentrations were not available for the Line 5 products. Therefore, a randomization approach was used in addition to the data reported by Pampanin and Sydnes (2013) to estimate the most likely values for PAHs in Line 5 light crude products. The expected values of the random variable were determined as shown in Table D3.

The toxicity equivalency factor (TEQ) method was used to evaluate the eco-toxicological risk. The total carcinogenic risk from multiple PAH compounds was estimated by converting the carcinogenic potency of each individual PAH relative to Benzo[alpha]pyrene B[a]P, which is the most potent carcinogenic PAH.

Table D3. Simulated PAH values from concentrations in 49 different crude oil spill samples and the Monte Carlo simulation

Crude oil	TEQ [a]	49 different crude oils [b]		Monte Carlo Simulation (Cs) [c]	BaP eq mg/kg TEQ
PAH Compound		Maximum mg/kg oil	Mean mg/kg oil	mg/kg oil	
Naphthalene	0.001	3700	427	2946.5	2.9
Acenaphthene	0.001	58	11.1	43.9	0.04
Acenaphthylene	0.001	11 [38]	0	5.0	0.005
Fluorene	0.001	380	70.34	333.5	0.3
Anthracene	0.01	17	4.3	7.6	0.08
Phenanthrene	0.001	400	146	349.4	0.3
Fluoranthene	0.001	15	1.98	13.4	0.01
Pyrene	0.001	20	9.2	14.7	0.01
Benzo[g,h,j]perylene	0.001	1.7	0.08	1.3	0.001
Benzo[a]anthracene	0.1	16	2.88	12.2	1.2
Chrysene	0.01	120	30.36	42.1	0.4
Benzo[b]fluoranthene	0.1	14	4.08	11.2	1.1
Benzo[k]fluoranthene	0.1	1.3	0.07	0.9	0.09
Benzo[a]pyrene	1	7.7	1.5	1.6	1.6
Dibenz[a,h]anthracene	1	7.7	1.25	5.7	5.7
Indeno[1,2,3-cd] pyrene	0. 1	1.7	0.08	0.2	0.02
Total PAHs				3789.21	13.8
		Total Carcinogenic PAHs		73.9	10.0

[a] Potency equivalence factors (PEFs) for individual PAHs relative to B[a]P (Nisbet and Lagoy 1992)
[b] Maximum, and mean PAH content in 48 different crude oils Kerr et al., 1999
[c] Results generated in this analysis

D.2.6.4 Non-carcinogenic Risk Assessment

The hazard quotient (HQ) is the ratio of exposure to the estimated daily exposure level at which no adverse health effects are likely to occur. This model measures the risk of non-carcinogenic adverse health effects. As with carcinogenic risk assessment, the HQ is determined separately for ingestion, dermal, and inhalation exposure routes. When the total HQ for the various CoPC is greater than 1, then adverse health effects are possible due to exposure.

D.2.6.5 Risk Characterization of Potential Human Health Effects of PAHs

The risk characterization process involved using the data obtained from the worst-case oil spill analysis and related exposure parameters to evaluate human health risks. Several assumptions were made in the model calculation, and the Monte Carlo model was applied to evaluate the concentration distribution and exposure risk of the population. The most important of the assumptions is the use of PAH concentration values obtained from the review of 49 different studies/cases, to establish the average concentrations of the compounds in the Line 5 products.

Table D4. Potential incremental lifetime cancer risks (ILCR) and HQ estimated for Straits of Mackinac populations exposed to Line 5 crude oil PAHs

Population	ADDing (c)	ADDing (n)	ADDderm (c)	ADDderm (n)	ADDinh (c)	ADDinh (n)	ILCRing	ILCRderm	ILCRinh	Total ILCR	HQing	HQderm	HQinh	Total HQ
Occupational	1.3E-05	1.2E-02	6.3E-10	5.6E-07	6.3E-10	5.6E-07	9.8E-05	1.6E-08	2.4E-09	9.8E-05	3.0E+00	1.4E-04	1.4E-04	3.0E+00
Permanent Resident	1.6E-05	1.4E-02	7.4E-10	6.5E-07	7.3E-10	6.5E-07	1.1E-04	1.8E-08	2.9E-09	1.1E-04	3.5E+00	1.6E-04	1.6E-04	3.5E+00
Seasonal Resident	1.1E-05	9.5E-03	5.0E-10	1.6E-08	5.0E-10	4.4E-07	7.8E-05	1.3E-08	2.0E-09	7.8E-05	2.4E+00	1.1E-04	1.1E-04	2.4E+00
Transient Resident	1.3E-06	1.2E-03	6.3E-11	5.6E-08	6.3E-11	5.6E-08	9.8E-06	1.6E-09	2.4E-10	9.8E-06	3.0E-01	1.4E-05	1.4E-05	3.0E-01

Totals from all three exposure pathways (ingestion, dermal, inhalation) were computed to estimate the total cancer risk and total hazard index for each contaminant. Totals for each pathway for all contaminants were also computed and summed to estimate the ILCR. The total ILCR to an individual over a lifetime is accumulative across dermal, ingestion, and inhalation exposures. The risk range values for the ILCR are presented in Table D4.

The risk values for each of the CoPC were calculated, and the total risk value provided the estimates of the total health risks that receptors may face during a possible worst-case event along the Line 5 pipeline in the Straits of Mackinac. This represents the cumulative health risks for all toxic PAHs in the Line 5 product. If the ILCR of the CoPC is less than 1 in 1,000,000 (i.e., 1 x 10-6), it is considered an acceptable or negligible risk, and an upper ILCR of 1 in 10,000 (1 x 10-4) representing serious human risk and values in between considered a potential human risk.

D.2.6.6 Volatile Organic Compound

There are numerous VOCs that are hazardous air pollutants and pose a wide range of direct adverse human health effects (Colman Lerner et al., 2012). BTEX compounds have been classified as toxic air pollutants (Jian et al., 2013; Olawoyin et al., 2014). The US EPA and International Agency for Research on Cancer (IARC) also recognize there is adequate scientific evidence to establish a positive relationship between exposure to benzene and potential cancer development in humans.

Exposures to VOC compound mixtures have been related to toxicological effects on human health ranging from depression of the CNS, lymphatic, hematopoietic, hepatic, birth defects, pulmonary edema, leukemia, acute granular tracheitis, laryngitis, bronchitis and the impairment of the circulatory systems (Table D2) (ATSDR, 2007; Smith et al., 2010; Lupo et al., 2011; Vlaanderen et al., 2011; Alghamdi et al., 2014; McKenzie et al., 2014; Chen et al., 2016). The potential human health residential risks from VOCs exposure (carcinogenic or non-carcinogenic) can be evaluated using the deterministic risk assessment method previously discussed.

In this independent risk analysis, the consequent health risks to the public (cleanup workers, residents, and visitors along the Straits, with potential for exposure) from VOCs emission were assessed in two ways: health risk evaluation including non-cancer and cancer risks (US EPA method) and occupational VOCs were evaluated using the exposure risk assessment (American Conference of Governmental Industrial Hygienists, ACGIH method) for workers.

D.2.6.6.1 Estimation of VOC concentration using the Land's Method

The Land's method was used to calculate the concentrations of VOCs for resident and worker exposures (Land, 1975; Gilbert, 1987).

D.2.6.6.2 Cancer and non-cancer risk exposure assessment using the US EPA method

The non-cancer and cancer risk assessments of exposure to VOCs through inhalation were evaluated based on the US EPA method (US EPA, 2009a). The non-cancer risk was assessed by comparing the daily ambient concentrations with their respective chronic non-cancer inhalation reference levels. The adverse effects contributions from the individual VOCs were also evaluated. The non-cancer risk indicator, usually expressed by the HQ, refers to all other adverse health risks, excluding cancer. For a given airborne toxic chemical, exposure below the reference level ($HQ < 1$) is unlikely to be related to adverse health effects. When the non-carcinogenic risk $HQ > 1$, long-term exposure can potentially result to non-carcinogenic health diseases.

The VOCs from the Line 5 pipeline considered in this analysis for human health effects, following a worst-case release, however only the BTEX compounds were analyzed further because of their toxicity and potential effects on humans. In addition, the lifetime cancer risk associated with individual compounds was calculated, where data was available.

D.2.6.6.3 Assessment of occupational exposure using the ACGIH method

Cleanup workers and others may be exposed to the spilled oil and the oil may persist longer based on the prevailing microclimates. Factors that may determine the extent and effect of shoreline oiling include; the lake tides and wave energy, type of substrate, shoreline slope and type and shoreline sensitivity. The weathered oil may form a thin sheen on the lake, and during cleanup activities, the sheen may be disturbed, and fresh oil would then be released with associated chemical constituents. Other factors that may increase the risk for cleanup workers include; high temperature and humidity, direct sun exposure (with no shade) or extreme heat conditions in the summer months, limited air movement (no breeze or wind), physical exertion (generates heat), possibly from the use of personal protective clothing and equipment during cleanup activities.

The cancer risk of the cleanup workers exposed to emitted VOCs during the oil spill response was evaluated using the ACGIH method. The ACGIH provides threshold limit values (TLV) based on short-term exposure limit and time-weighted average standards. The TLVs are based on a time-weighted average (TLV-TWA), which represents the worker's exposure time that cannot be exceeded during an 8-hour workday and 40-hour workweek.

D.2.7 Worst-case Determination for Fire and Explosion Risk

Pipelines used for transporting hazardous materials such as crude oil or NGL have potential risk factors that may result in an accident. These factors include the type and volatility of the transported materials, high operating pressures, potential impacts, external force on the pipeline, operating locations, and proximity to public assets, among other factors. The potential risk from a pipeline is the combination of the probability of the pipeline failure (i.e., the likelihood of any failure to the pipeline) and the severity (magnitude) of the consequences/impacts afterward define the potential risk from the pipeline.

We explored the consequences of the characteristics and quantity of the substance released in a worst-case scenario. The consequences of failures were estimated based on available information and experimental evidence. These data were analyzed and integrated into the risk analysis for the quantitative estimation of public risks within specified distances of the Line 5 pipeline failure. In the event of a potential worst-case scenario of the Line 5 pipeline failure, the separation distance between the release locations and public assets was evaluated and results reported in this section.

Risk analysis methods comprise of threats/vulnerability identification and the ensuing consequences, and the evaluation of the possible impacts to provide valuable information for decision-making. Risk estimation and evaluation integrates the probability that an event will occur with an approximation of the expected impacts/consequences as a risk measure. This integration provides guidance for the prioritization of threats, vulnerabilities and for enhanced risk management practices. For the worst-case analysis of potential pipeline failure along the

Straits of Mackinac, the probability of harm/damage/fatality to people and public safety around susceptible areas along the Straits was examined. The adverse effects and impacts of the Line 5 pipeline failure can include fatal and non-fatal injuries due to exposure to thermal radiant energy from flash or pool fires, explosion blast pressures or airborne toxic chemical concentrations above safe thresholds, resulting to inhalation risks.

The steps in Figure D3 summarize the pipeline risk analysis conducted for the worst-case release of products from the Line 5 pipeline along the Strait of Mackinac.

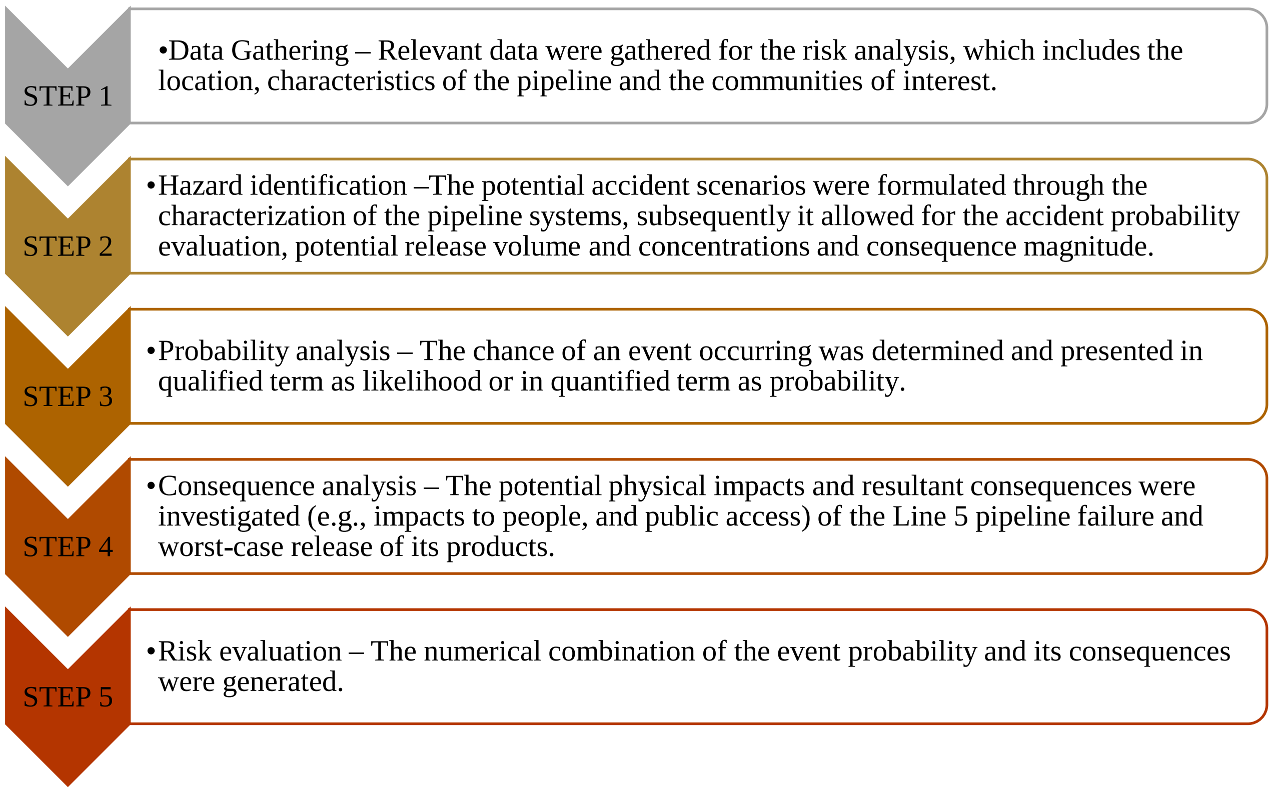

Figure D3: Summary of the pipeline analysis method.

Task D worst-case scenario analysis assumptions include:

A. No mitigation factors are considered.
B. Meteorological conditions: Atmospheric stability class F (stable atmosphere) and uniform wind speed 1.5 meters per second (3.4 miles per hour). Ambient air temperature is assumed to be 25 °C.
C. Topography: According to US EPA (40 CFR 68.22(e)), the topography can be classified as rural or urban.
   i. Urban areas are defined as areas with as many obstacles in the immediate area, where obstacles include buildings or trees.

ii. Rural areas mean there are no buildings in the immediate area, and the terrain is generally flat and unobstructed.

The areas surrounding the worst-case locations for a potential spill in the Strait of Mackinac are considered rural in this analysis; however, there is a gradational shift from rural to urban classification along the shoreline.

D. Total quantity in the pipeline is spilled (58,000 barrels) and forms a pool which spreads instantaneously to a depth of one centimeter (0.033 foot or 0.39 inch). The spill takes place onto a flat, non-absorbing surface.
E. The release rate to air is estimated as the rate of evaporation from the pool.
F. The release results in a vapor cloud, containing the total quantity of the substance released from the pipeline.
G. Ignition sources are uniformly distributed (the ignition probability not dependent on release directions);
H. The vapor cloud detonates using a TNT-equivalent method (assumes a 10-percent yield factor).
I. An endpoint for a vapor cloud explosion as an overpressure of 1 pound per square inch (psi) is assumed.
J. The effect in a defined impact zone is constant.

Risk analysis methods are classified into qualitative and quantitative risk analysis methods. Detailed methodology is available in Appendix D3.

D.2.7.1 Qualitative Risk Analysis ($Q^L RA$) Methods

Qualitative risk analysis ($Q^L RA$) methods focus only on relative impacts or describe the probability and consequences in relative terms, such as high, medium and low. In the analysis of the worst-case release of crude oil from Line 5 pipeline, the risk estimation can help define the zones of vulnerability zone, if the proximity to public assets and resources (including human presence) are outside the vulnerability zone, then there would no further analysis required (Bass Trigon Software, 2002). Qualitative risk analysis methods integrate probability and consequences by using mathematical scoring techniques to produce a relative risk (RR) ranking of the different hazards from the pipeline. These methods outline the risk factors, and a numerical value is assigned to each of the factors. These risk factors are summed up to generate numerical score value for the identified hazard-prone segment length of the pipeline. The segments are then grouped/ ranked based on the RR of the pipeline rupture. The ranking which considers the probability and consequences of the hazard represents the total risk of the pipeline failure.

D.2.7.2 Quantitative Risk Analysis Methods

Quantitative risk analysis ($Q^N RA$) methods estimate numerical event probabilities or frequencies of occurrence, within a timeframe, related with specific, measurable and possible consequences. The $Q^N RA$ methods present risk in terms of the probability of a quantified outcome. An example will be the risk of fatal injury from the Line 5 pipeline accident can be presented as the annual probability that one fatality could occur. This, therefore, is the principle/underlying idea of the Individual Risk (Ind_{Risk}) and Population Risk Analysis (PRA) conducted in this study.

There are two main Q^NRA methods:

1. Actuarial Q^NRA methods (AQM): The probability of future events is estimated based on the historical data and available information on the incidence of comparable events.

2. Synthesis Q^NRA methods (SQM): The probability of an event is estimated from the probabilities of contributing events (causal factors) using applicable mathematical approximations.

The SQM is most appropriate for a catastrophic event since these events are usually rare in contrast to the AQM where events would be expected to be relatively frequent within a uniform population. Another method that can be used is the predictive Q^NRA method (PQM), this is mostly applicable when the actual physical conditions and situations relative to the pipeline are known (such as the regions of weaknesses, the presence of corrosion, wear and tear, etc.). Risk analysis is unable to provide predictions for future events; it is most suitable for estimating the chance of specified events.

The methodology adopted for the analysis in this study considers a worst-case release scenario, hence a combination of the AQM and SQM which considered historical data of different events that can potentially contribute to the critical outcome (risk of fatality) from a flammable or explosive product release from the Line 5 pipeline. Details of the methodology are available in Appendix D3.

D.2.7.3 Estimation of Distance to Overpressure Endpoint for Flammable Substances

It is assumed that for a worst-case scenario involving releases of flammable gases and/or volatile flammable liquids, the total quantity of the flammable substance would develop into a vapor cloud within the upper and lower flammability limits (UFL/LFL) and the cloud ignites. A conservative assumption for the worst-case consideration assumes that 10% of the flammable vapor cloud partakes in the explosion. The distance (endpoint) to an overpressure level of 1 psi is estimated to come from the explosion of the vapor cloud. This endpoint is the threshold for potentially serious injuries to the public due to property damages resulting from a vapor cloud explosion. An overpressure of 1 psi could lead to the partial demolition of residential buildings, with credible potentials to cause serious injuries to people, restrict access to public utility services due to damages to infrastructure and smashing of glass windows. These may result in fatalities, skin lacerations from flying glass, and other falling debris from damaged structural materials.

D.2.7.4 Worst-Case Analysis for Toxic Liquids

The worst-case analyses for toxic liquids at ambient conditions, or toxic gases liquefied by refrigeration, can be conducted through the 3 step approach:

Step 1: Determine the worst-case scenario. Identify the toxic liquid and quantity released. Atmospheric dispersion models of NGL were modeled and reported in Task B of this report.

Step 2: Determine the release rate. Estimate the volatilization rate for the toxic liquid and the duration of the release.

Step 3: Determine distance to the endpoint. The worst-case consequence distance was estimated based on the quantity released, release rate and toxic endpoint. The distance to the required overpressure endpoint of 1 psi for a vapor cloud explosion of the flammable substance was estimated. Also considered are the wind stability, area topography (rural or urban), and the duration of the release.

D.2.7.5 Pipeline Failures Potential Consequences

The probability of fire, explosion, and potential fatalities were determined by considering the conditional probabilities of different succeeding events that may lead to fatal injury of an exposed individual. The conditional probabilities are dependent on the pipeline characteristics, the distance between the receptor (exposed individual) and the hazard source.

The potential consequences of the Line 5 pipeline failure are dependent on the crude oil properties being transported, the mechanism of pipeline failure, operating pressure, and accident location. The main hazards from the Line 5 pipeline are chemical *toxicity and flammability*. Natural gas and petroleum liquid products are flammable and can potentially lead to fire or explosions under appropriate conditions.

Within the impact zones and distances, toxic inhalation, fires, and explosions can cause direct and secondary adverse effects to the public and their safety. The impact distance is the distance between the hazard source and the evaluation location. This is a point at some distance away from the pipeline where the crude oil flowed/pooled and migrated before igniting. There are three release basic scenarios defined for the worst-case analysis with public health consequences. These scenarios represent the release mode (rupture) and the ensuing ignition.

The dispersion modeling equations estimated the airborne concentrations of vapor from the release, and fire and explosion modeling was used for the estimation of the effects of the potential release that ignites.

Thermal radiation emitted will be the major potential hazard from jet or pool fire. If the exposure to people exceeds a certain threshold for a given exposure period, the people are at risk of serious injury or fatality. The heat flux intensity varies depending on the fire size (flame dimensions, speed, and other variables), which decreases as the distance from the fire increases. Consequently, fire exposure risk decreases with distance away from the hazard.

D.2.7.6 Hazard Categories
This analysis considers three distinct types of release hazards as "Worst-Case Basis Scenarios." Rupture flash fire; rupture jet (or pool) fire; and rupture explosion.

Flash fires occur as rapid propagation of a flame front which moves through the flammable vapor cloud with no destructive pressure increase.

In the event of a flash fire, people indoors have a certain degree of protection, provided the fire remains outside. If an explosion occurs, the risk of injury or fatality is based on the direct effects of the shockwave or blast overpressure, together with the hazard of falling debris and structural. Therefore, depending on the hazard that the public would be exposed to, based on the Line 5 pipeline worst-case release, the risk from indoor exposure may be greater than outdoor exposure.

A hazardous explosion is defined as a confined vapor cloud ignition for which the blast overpressure is intense enough to result in significant damages to people, property and environmental assets; this explosion is known as detonation. If there is minimal blast overpressure, the ignition can be described as deflagration or flash fire.

The harmful impacts of an explosion come predominantly from pressure increases at a point from a blast or shockwave, as it travels through the air. The blast overpressure decreases with increasing distance away from explosion epicenter. Exposed people within the detonation, deflagration or flash fire zone may be susceptible to serious injuries or fatality. The risk of non-fatal and fatal injury is dependent on the intensity and duration of exposure to thermal radiation or blast overpressure.

D.2.7.7 Pipeline Risk Estimate Calculations
The methodology is described in detail in Appendix D3. Briefly, a standard analytical structure for exploring the potential consequences of an initiating event was used to describe the related possible events from a worst-case event.

In the event of a catastrophic failure of Line 5, the pipeline products may be released which could result in the dispersion of gas or liquid vapors (unignited), or a flash fire or an explosion that could cause harm to people nearby within the vulnerability zone, defined by injurious intensity levels of the physical effects. These adverse impact levels vary depending on the various locations and distances from the pipeline accident to public resources.

D.2.7.8 Calculating the Individual Risk (Ind_{Risk})
The Ind_{Risk} for an individual in the Straits of Mackinac, in close proximity to the pipeline would be based on potential exposures to a flash fire, jet fire (for natural gas liquids) or pool fire for crude oil releases), or explosion if there are obstructions along the vapor cloud paths. The individual exposure may be influenced by the *hazard impact distance* $^{R}{}_{o}$, also referred to as "impact radius", and "hazard footprint length" which is the distance between the hazard source and the individual receptor location from the shoreline (Figure D4).

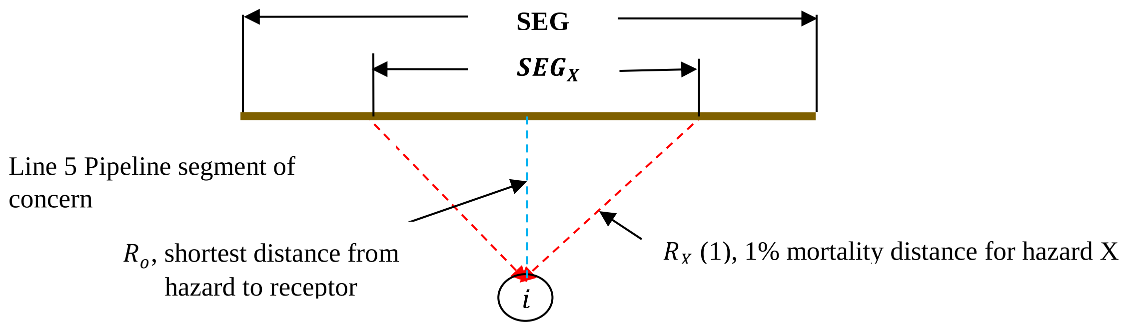

Figure D4: SEG_x estimation based on the hazard.

For an individual at a specific location away from the hazard source, and IR is estimated or each hazard. Following the determination of the IR for each of the hazards identified, the total individual risk (TIR) for all hazard types was determined.

Further details of the methodology are found in Appendix D3.

D.2.7.9 Hazard Impact Distance
The applicable hazard consequence modeling was used to estimate the hazard impact distances, or the length of the pipe within the segment of concern from which a product release can potentially lead to a flash fire, jet/pool fire, or explosion. The consequences or impacts of which could affect the receptors with the possibility for a fatality at a level of at least one percent (1%) mortality. The 1% mortality level is a conservative and reasonable estimate of the boundary of adverse effects and serious damages. Further details of the methodology are found in Appendix D3.

D.2.7.10 Maximum and Average Mortality and Fatality Probability
Mortality is fatality probability expressed as a percentage; 100% mortality equals a probability of 1.0, this is dependent on the hazard impact distance. The overpressure data represents mortality probabilities for indoor exposure, and it will be conservative when applied for outdoor exposure since the risk is greater indoors for explosion scenarios.

Within the zone surrounding the LFL, flash fires are assumed to have 100% mortality. This assumption is based on a worst-case event. However, the survivability in the LFL bounded zone depends mainly on; a) the concentration profile of the vapor cloud mixture, b) the exact pattern of the flame front and mode of ignition, c) the location of persons proximate to the flame front as the flame burns through the cloud, and d) other factors unique to each specific situation. There have been fires in which the mortality was less than 100%. Appendix D3 provides further information about mortality from fire heat radiation.

D.3 Analysis

D.3.1 Safety Risk and Consequence Analysis

Figures D5 and D6 illustrate the potential risk levels for carcinogenic and non-carcinogenic effects. From the results, there will be human health impact from a worst-case pipeline product release, under the scenarios considered in this analysis. However, the level of risk to cleanup workers and all categories of seasonal residents are low, compared to the potential risks to permanent residents. If the assumptions for the concentration of the chemical compounds and the receptor does hold true, then people (adults) living permanently around 500 m from the shoreline around Mackinaw City are susceptible to both carcinogenic and non-carcinogenic risks. The ILCR level for permanent residents around this defined radius could be up to 114 times higher than the acceptable/negligible human health risk level of 1 x 10-6, but these levels are still lower than the worst-case risk level of 1 in 10,000 people. The increase in the risk level around this radius is due to the combined effects of chemicals and the potential for a longer exposure period, while the HQ level is 3.5 times higher than the risk threshold for non-carcinogenic effects.

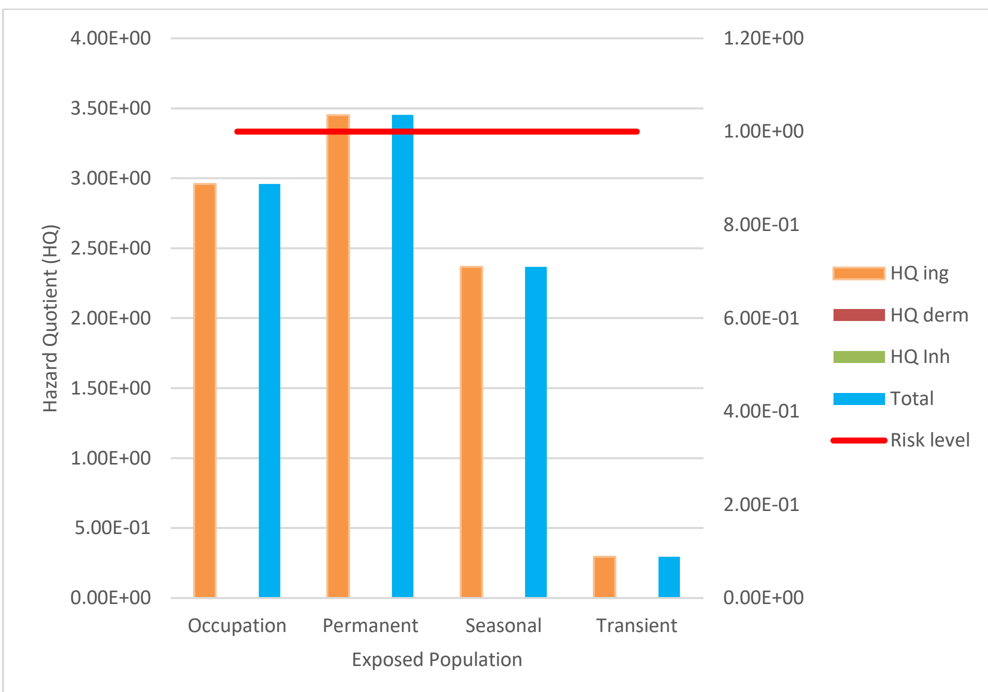

Figure D5: Potential non-carcinogenic risk from PAH exposure due to the worst-case release.

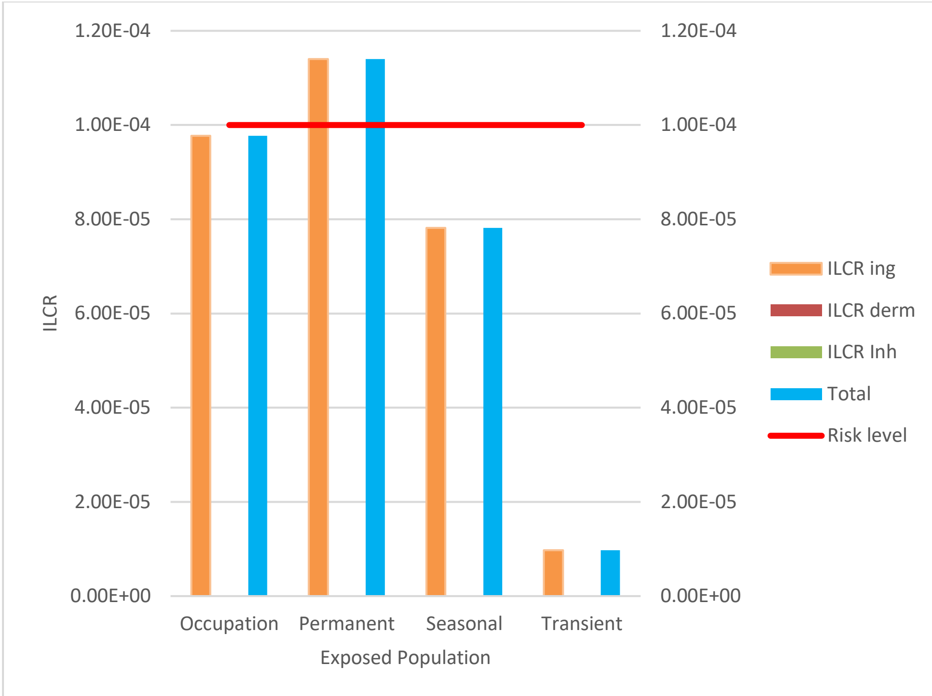

Figure D6: Potential carcinogenic risk from PAH exposure due to the worst-case release.

It is expected that people directly exposed to the CoPC, immediately following a worst-case release in Mackinaw City, may experience varying degrees of health complications, from circulatory system complications to central nervous system issues, depending on the dose and duration of individual exposure. The cleanup workers and seasonal residents were shown in the analysis to have very low HQ; therefore, these groups may not have any significant health effects (chronic or acute). Nevertheless, the ILCR values for these groups, especially the cleanup workers (9.8E-05), showed that there is potential for health risks to occupational residents which may include the development of cancer if exposure is prolonged. The value suggests that at least one in 10,000 workers may develop one form of cancer due to the exposure. This level of risk for permanent residents and workers pose a public concern, and adequate measures should be put in place to properly protect the public in the event of a worst-case accident along the line 5 pipeline.

D.3.1.1 PAHs and Seafood Safety

The consumption of crude oil contaminated fish poses primary risks to humans due to the direct consumption of oil. Chemical constituents of crude oil that potentially pose the greatest risk to humans from the consumption of contaminated fish and seafood include PAH compounds such as the 16 priority PAH compounds. These compounds are generally hydrophobic and thus do not dissolve in water and tend to accumulate in the fatty tissues of exposed organisms. However, relative to compounds such as polychlorinated biphenyls (PCBs) which are highly hydrophobic and not present in crude oil, PAH compounds generally do not exhibit the phenomenon of food web biomagnification such that their concentrations in biota do not generally increase as associated with the increasing food web trophic status.

Following oil spills including the Exxon Valdez (1989), M/V Braer (1993), Deepwater Horizon (2010) and Kalamazoo River (2010) events, fisheries closures or fisheries exclusion zones were established to protect human health and safety due to the potential risks associated with the consumption of oil-contaminated fish and seafood (Moller, Dicks, Whittle & Girin 1999). For example, the Michigan Department of Community Health issued a Do Not Eat fish consumption advisory for the approximately 56-kilometer section of the Kalamazoo River impacted by the Line 6B spill. The consumption ban remained in place from the time of the spill (July 2010) until June 2012 when the advisory was lifted following testing that did not demonstrate contamination of fish by oil-related chemicals that would pose an increased risk to human consumers. Fisheries closures in the Gulf of Mexico following the Deepwater Horizon eventually resulted in over 229,000 km2 being closed to fisheries activities (NOAA Fisheries, Southeast Regional Office, 2010a). However, testing of fish and seafood collected during the July - November 2010 period following the Deepwater Horizon oil spill did not demonstrate any significant PAH contamination of fish and seafood (NOAA Fisheries, Southeast Regional Office, 2010b). Additionally, no demonstrable degradation of the sensory characteristics (e.g., taste, smell, texture) of fish and seafood were evident for Gulf of Mexico fish and seafood products potentially affected by the Deepwater Horizon spill.

D.3.1.2 Analysis Results for VOCs and Potential Human Health Effects
Daily average exposures to benzene (mg/kg/day) were calculated for children and adults (Table D5 and D6).

Table D5. Summary statistics of selected VOCs ($\frac{mg}{m^3}$) for the worst-case crude oil spill from atmospheric area source dispersion at $x(m) =< 1000\ m$. [a] Source (Bari, Md. A., Kindzierski W.B., 2018), d= days.

Species	Lifetime [a]	Ci= UCL1-α mgm3	Ei	Residential Risk (child in parentheses)			Occupational Risk			
				CDIi (90%) mgKg-day	ILCRi	HQi	TLV-TWAii mgm3	CDIi (90%) mgKg-day	ILCRi	HQi
Benzene	> 5 d	15.6	1.37	0.35	1.93E-02 **(9.01E-02)**	0.04	0.94	0.02	1.17E-03	0.00
Toluene	> 2 d	118	1.17	2.65		0.00	119	2.68		0.00
Ethylbenzene	> 1 d	121	1.23	2.72		0.01	266	5.99		0.02
m,p-Xylene	< 1 d			2.47						
o-Xylene	<1 d	110	1.16			0.01	266	5.99		0.03
TVOC				8.20 **(38.3)**		0.06 **(0.28)**		14.68		0.05

Table D6. Summary statistics of selected VOCs ($\frac{mg}{m^3}$) for the worst-case crude oil spill from atmospheric area source dispersion at $x(m) = 1000 - 5000\ m$ (Affecting areas around Mackinaw City). [a] Source (Bari, Md. A., Kindzierski W.B., 2018), d= days.

Species	Lifetime [a]	Ci= UCL1-α mgm3	Ei	Residential Risk (child in parentheses)			Occupational Risk			
				CDIi (90%) mgKg-day	ILCRi	HQi	TLV-TWAii mgm3	CDIi (90%) mgKg-day	ILCRi	HQi
Benzene	> 5 d	15.6	1.37	0.011	2.22E-06 **(7.20E-06)**	0.00	0.94	0.0083	5.49E-06	0.00
TVOC				0.013 **(1.05)**		0.01 **(0.15)**		0.0096		0.01

The average daily intake would be higher for children at all distances. The individual non-cancer risk quotients (HQ) for benzene were <1 for individual BTEX compounds and also for the total HQ, thereby indicating that long-term exposure to benzene would not represent significant health risk in the area. The expected cancer risks (ILCR values) from the calculation for adults and children were in the order of $2.22 * 10^{-6}$ for adults, $7.20 * 10^{-6}$ for children and $5.49 * 10^{-6}$ for workers, which are 2, 7 and 5 times higher (respectively) than the established values in the guidelines of US EPA ($1 * 10^{-6}$) but lower than the worst-case level of $1 * 10^{-4}$.

D.3.2 Fire and Explosion Risk Analysis

D.3.2.1 Conditional Probability of Individual Exposure

An individual along the Strait of Mackinac can be affected only if present at or around the impact location, at the time of the worst-case incident. The exposure probability is estimated for an individual area for the average individual for regular residents and season residents/tourists separately. The methods for this calculation is described in Appendix D3. This calculation suggests that seasonal residents have a higher probability of individual exposure because they are outdoors for a greater period of the day.

D.3.2.2 Numerical Analysis of Line 5 Worst Case Product Release

The conditional probability that the Line 5 pipeline along the Straits of Mackinac worst-case release will be a rupture, pool fire, flash fire or explosion scenario are calculated (presented in Appendix D3). These results show that for rupture pool fire, 20% of the time the pipeline release will be from a full diameter rupture, and 3% of the time it would ignite. Once ignited, 95% of the time it would result in a fire rather than an explosion, and that 95% of the time the fire would be a pool fire. These assumptions are also true for flash fires, except that the flash fire hazard conditional probability would only allow for a flash fire 5% of the time for a crude oil case. Finally, for the explosion scenario, 20% of the time the pipeline release will be from a full diameter rupture, and there is a 3% probability of the vapor cloud igniting and 5% of the time, the fire will ignite and lead to an explosion. The heat radiation intensity levels at close distances would result in 100% mortality. In this case, the mortality is 100%. Calculations for estimating the mortality for lower heat radiation levels is described in Appendix D3.

The hazard conditional probability for rupture pool fire is estimated as the highest, followed by the hazard conditional probability from explosion hazards for seasonal residents (Appendix D3). Total individual risks for seasonal residents in zone 1 is 19 times greater than the benchmark value. The total individual risks in all zones are greater by double-digit except for the total individual risks to permanent residents in zone 2, which is nine times greater risk than baseline.

D.3.2.3 Worst-Case Consequences Estimation

The impact estimation from uncontained flammable liquid vapor dispersion in the air after a worst-case accidental release would involve; flash fires; crude oil liquid pool fires; and unconfined vapor cloud explosions. The release consequences were modeled using the air dispersion, flash fire, pool fire, and explosion outputs.

The air dispersion modeling provided estimated boundaries for the LFL vapor cloud from the worst-case pipeline rupture. The zone confined by the LFL is the zone where a flash fire, pool fire or explosion may occur, which are dependent on prevailing conditions present at the zone during or after the potential. The estimated IR considered that the hazard source could be displaced away from the right of way (ROW) by the overwater flow of crude oil and overland flow along the shorelines. Ignition could result in a fire or explosion developing from the initial location or the new location away from the release point at the pipeline. Depending on the topography near the ruptured pipe, between the pipeline and the receptor location, the crude oil release could form a pool near the pipeline release point positioned along the centerline of the pipeline, or it may form a flowing liquid pool that migrates away from the initial release point.

D.3.2.3.1 Flash fires

Figure D7 shows the pool diameter in ft associated with flash fires. The limits of flash fire impacts are defined relative to the LFL boundary of the vapor cloud air mixture.

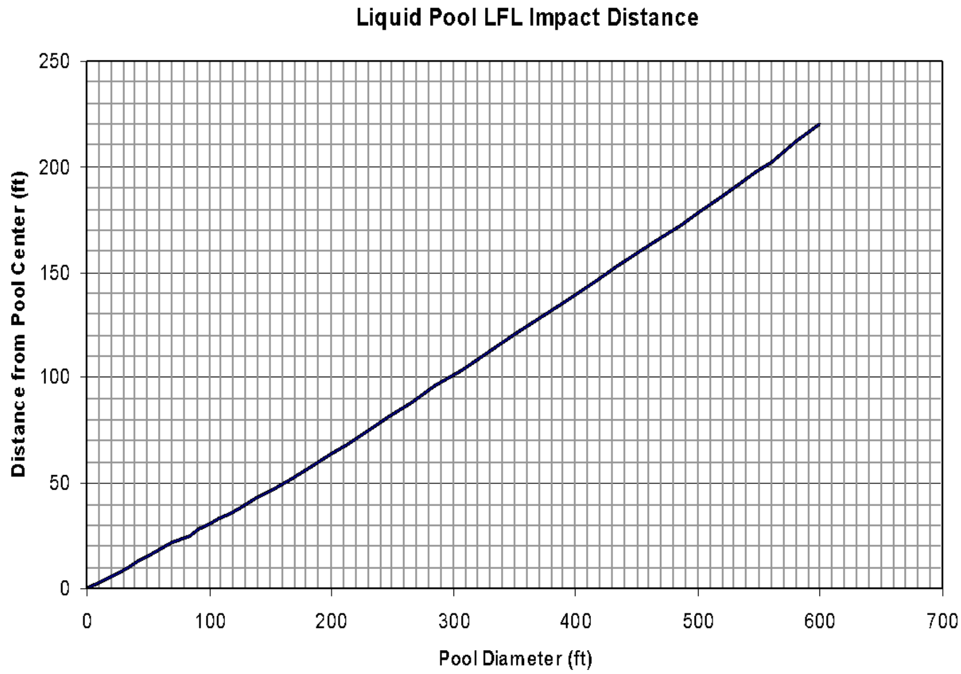

Figure D7: Liquid release, LFL impact distance, based on circular diameter.

D.3.2.3.2 Pool fires

The analysis was based on the assumption that the pool formation will occur around the pipeline ROW, with circular shape over the pipeline centerline, since the flow would be relatively unrestricted. The estimated LFL impact distance from the center of a crude oil pool is presented in Figure D7. The heat radiation vs. impact distance in ft from pool center is presented in Figure D8, for pool diameters of 25, 50, 100, 200 and 500 ft.

Figure D8 show the impact distances for pool fires relative to $\frac{Btu}{hr-ft^2}$ heat radiation intensity. The impact distance varies with the pool diameter. For a rupture pipeline, the modeling under the scenarios considered shows an impact distance of 70 ft or less for heat radiation levels between 5,000 and 12,000 $\frac{Btu}{hr-ft^2}$ for a 25' diameter pool, and the impact distance is between 700 -1000 ft for radiation intensity between 5,000 and 12,000 $\frac{Btu}{hr-ft^2}$ for a 500 ft diameter pool fire.

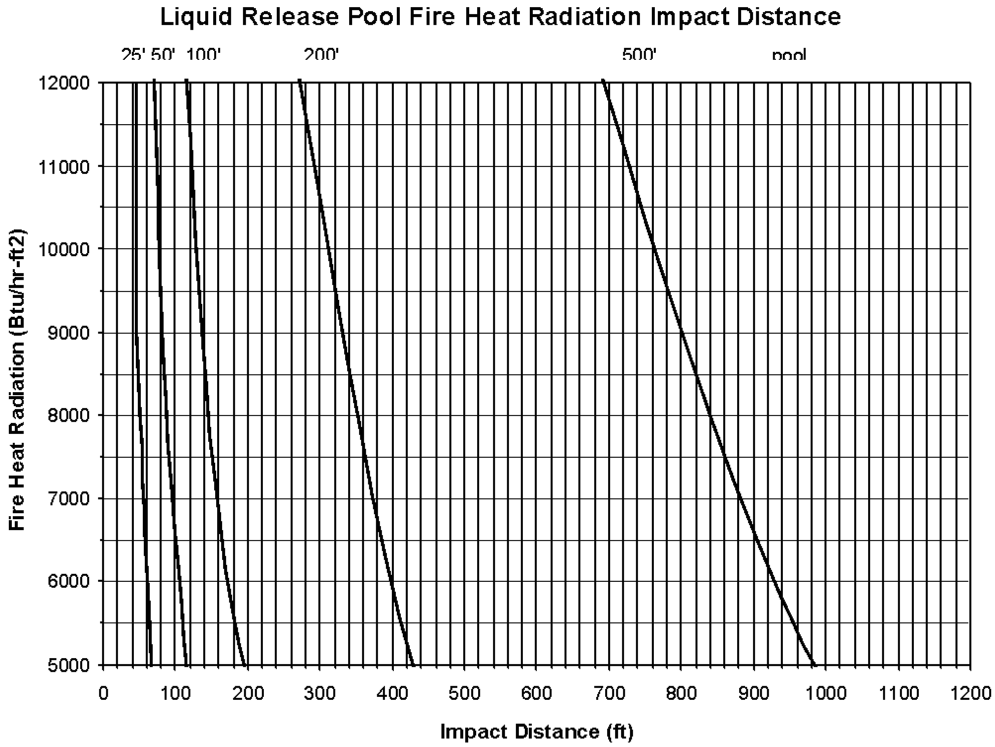

Figure D8. Liquid gasoline release, pool fire heat radiation impact distance, based on circular diameter (or channel equivalent diameter).

D.3.2.3.3 Vapor cloud explosions

For the uncongested location scenario, the modeling presented no potential of getting to the lower blast overpressure of 1 psi for a 1% mortality, based on the 20" pipe size and pressure considered in the analysis. Therefore, the results suggest that there will be no vapor cloud explosion with overpressure yielding potential fatalities in the uncongested areas. However, considering confinement, congestion, or partial congestion, the individual risk for explosion hazard was determined to be the highest. Hexane was used as the surrogate compound in modeling for the light crude oil vapor dispersion and ignited releases. Figure D8 presents the estimated pool fire impact distance from the pool center in terms of heat radiation in units of Btu/(hr-ft^2). Flammable vapors have the potential to ignite as unconfined vapor cloud explosion (UVCE), although these situations are uncommon (Lees, 1996).

D.3.2.4 Population Risk Considerations

Other measures of potential consequences/impacts in addition to the IR were considered in this analysis, based on the population susceptibility to risk in the potentially affected areas (area of concern). Two calculated risk indicators were applied, the TIR indicator and the population risk indicators. These parameters define the indicator measures used for risk characterization relative to the receptors, beyond the basic IR estimate. Which provides more insight on the level of risk from the worst-case pipeline accident considering the areas around the Strait, human population, and other factors. The indicators were not intended to replace the IndRisk estimates and the comparison with the standard risk value of 1.0E - 06, they are used to supplement the risk characterization which includes population data.

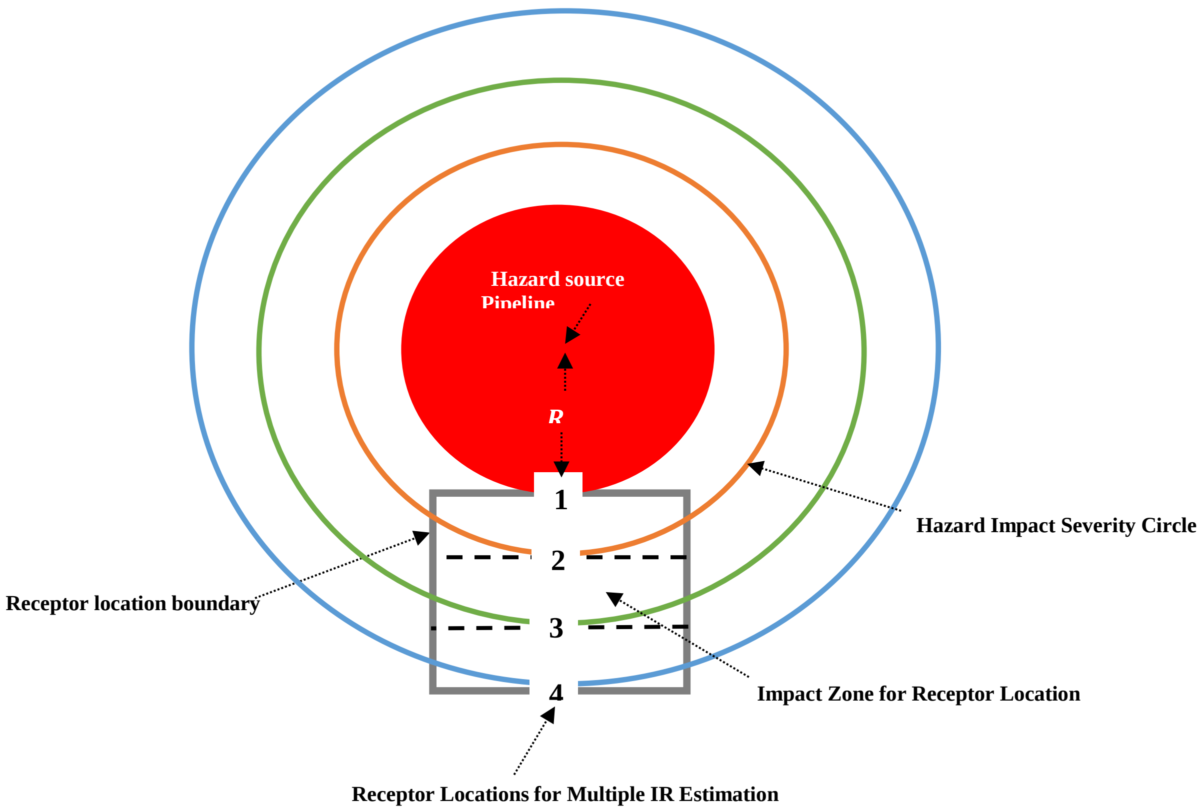

Figure D9. Hazard impact circles equivalent to Ind_{Risk} values for receptors at boundaries of three impact zones.

In Figure D9 the zones and hazard impact circles are illustrated, the radii of which define the impacts on the zone boundaries. The hazard impact was evaluated at each impact distance (R_o, R_1, R_2, R_3, R_4 and so on for all analyzed zones). The distance from the pipeline hazard source to the front boundary of the first zone is R_o. The other impact distances are the distances to the front and rear boundaries of the respective zones according to the boundaries they have contacts with. In the illustration (Figure D9) only three zones are shown; however, the analysis considered multiple zones, depending on the direction of impact.

For each of the three hazard impacts (rupture pool fire, rupture flash fire, and rupture explosion), the IR value or the impact was evaluated at each of the distances. The average IR representing the hazard impact within a zone was determined as the average at the front and rear boundary of the zone.

D.3.2.5 Total Individual Risk Indicator Ratio
The total individual indicator ($TInd_{Risk}$) is the total Ind_{Risk} averages across the depth of the area of concern to the Ind_{Risk} at the receptor center line. The $TInd_{Risk}$ Indicator Ratio is defined as the ratio of the Average $TInd_{Risk}$.to the front receptor line $TInd_{Risk}$. This measure indicates how quickly the TIR decreases across the area, hence it represents an indirect measure of the risk level to the people in those areas. The smaller the value, the less risk to the population for a given property line $TInd_{Risk}$. The risk to the population around a specific receptor location line is minimized or lesser if $TInd_{Risk}$. indicator ratio value is small.

The results for this analysis and further clarification of methods are presented in Appendix D3.

D.3.2.6. Population Risk Indicator Calculation
The population risk indicator (PRI) is a population location risk indicator parameter, estimated by dividing the area of concern into a number of population zones. This begins from the receptor line closest to the ruptured pipeline and moving away from the receptor line toward the opposite side of the area, zone boundaries are then defined at appropriate intervals, with the zone boundaries parallel to the property line. The average impact was determined by estimating the potentially affected population for each zone, and the total affected population of the area was calculated.

The impact of the scenario is computed for the zones defined in Appendix D3, Table A-D3-4. The corresponding potential mortality values for each of the hazard scenarios were then determined.

For the worst case scenario PRI calculation, a uniform average outdoor population of 99% of the total receptor location population was assumed to be distributed evenly across the zones.

Assuming for this analysis, at receptor location depth of 450 ft and there are 1000 people in the area. The assumed outdoor population event is 99% of the site population or 990 persons. Each of the zone population for the 3 zones would be $\Omega = 990/3 = 330$ persons per zone.

Table D7 was prepared only for potential pool fires population impacts since it is the most dominant hazard for the pipeline risk. The result obtained from the PRI calculation is a conservative indicator that measures the location aggregate population at risk for a potential worst-case pipeline incident in the area. It is an indicator and not an estimate of risk.

Table D7. Population Risk Indicator for Vapor Cloud Release with Pool Fire

Zone	Distance from Pipeline (ft)		Zone Boundary Mortalities (Rjf) (%)		Avg PRjfF Mortality (Rjf) (%)		Zone Population (Ω)	People at risk per zone (n)
	Begin	End	Begin	End				
1	1500	3500	100	55	77.5	0.775	330	256
2	3500	6860	55	1	28	0.28	330	92
3	6860	12000	1	0	0.5	0.005	330	2
	PRI =							350

The PRI calculation considered evenly distributed population across the impact zones due to the worst-case assumptions, however the population areas around Mackinac city fall outside of zone 3 with 0% mortality at the end of the zone boundary.

D.3.3 Qualitative Risk Analysis

D.3.3.1 Additional hazards to cleanup workers

Cleanup workers are exposed to additional hazards beyond exposure to the CoPC. These hazards include heat exposure such as heat rash, heat exhaustion, heat stroke, and sunburn. Climate factors (such as high temperature, high humidity, or low wind), working in the direct sun, physical exertion, and wearing personal protective equipment (PPE, including respirators) increase these hazards. Workers are at risk of eye injuries from dust, particulates, oil droplets, or chemicals. Oil-slick surfaces and debris covered with water or oil may increase the risk for slips, trips, and falls. Workers may be at risk of possibly drowning if the fall is into the water. There is a risk of accidents and collision when using heavy equipment, boats, and vehicles during the cleanup work, as well as noise pollution from this equipment. Immersion foot symptoms (tingling and/or itching sensation, red, dry, and painful feeling, swelling, cold and blotchy skin, numbness, and a prickly or heavy feeling in the foot) may occur to cleanup workers if their feet are wet for long periods of time. This can result in sore, painful blisters on the feet. Workers may contract infectious diseases spread by mosquitoes or ticks (West Nile Virus, Lyme's disease). Personal protective equipment such as clothing, shoes, and tools may become contaminated when in contact with poisonous plants such as Poison Ivy, Poison Oak or Poison Sumac transferring contaminants to workers.

During the cleanup of the Deepwater Horizon spill, an additional source of exposure for workers to compounds such as the BTEX group included exhaust from the gasoline and diesel engines used in the vessels associated with cleanup activities (Kirrane et al., 2007). Critically, industrial hygiene monitoring of the offshore cleanup workers for the Deepwater Horizon spill indicated that much of their benzene exposure was potentially attributable to their proximity to the engines used to propel the cleanup vessels or other equipment (i.e., gas-powered pumps) present on the vessels (Kirrane et al., 2007).

D.3.3.2 Drinking Water Contamination

The potential contamination of surface and groundwater resources by spilled oil represents a health risk to human receptors as associated with the subsequent consumption of contaminated potable water derived from these primary drinking water sources. Human health risks associated with the consumption of drinking water contaminated by crude oil and/or petroleum-based products include, but is not limited to, the symptoms listed in Table D8.

Table D8. Summary of general and specific adverse human health effects associated with the consumption of oil-contaminated drinking water (Adopted from Kponee et al., 2015).

General adverse effect	**Specific symptoms**
Irritation	Eye
	Throat
	Skin
	Rash
	Rhinorrhea (Runny nose)
	Cough
Gastrointestinal	Stomach pain
	Diarrhea
Neurologic	Headache
	Sleepiness
	Dizziness
Hematologic	Anemia
Other	General pain

For this report, three potential sources of exposure to oil products as associated with the consumption of drinking water are represented by: 1) Municipal drinking water intakes; 2) private drinking water wells; and, 3) submerged private water intake cribs. Under the Safe Drinking Water Act, the EPA has identified biological and chemical hazards that pose risks to public health if present above legally enforceable regulatory standards in public drinking water systems. These National Primary Drinking Water Regulations (NPDWR) include microorganisms, disinfectants, disinfectant byproducts, inorganic and organic chemicals, and radioactive materials (EPA, 2009). Oil-related organic chemical compounds such as BTEX and specific PAH compounds are included within these mandated regulatory standards.

D.3.3.2.1 Municipal drinking water intakes

There are 12 municipal drinking water intakes located in the Michigan boundaries of the Straits of Mackinac, Lake Huron and Lake Michigan waters (Figure D10). Among these, submerged water intakes for the communities of St. Ignace, Mackinac Island, and Mackinac Island are located in areas of the Straits of Mackinac and adjacent Lake Huron waters and are most proximate to the Line 5 pipeline location under the worst case scenario. For example, water supply intakes for the cities of St. Ignace and Mackinac Island are located within 10 miles of the Line 5 pipeline. Further, the shoreline and surface water regions in these locations were predicted to be susceptible to oiling within 24 hours of the oil spill dispersal simulations completed for this assessment (Fig. D2) and at risk of oiling under the worst-case scenario. Public notification is mandatory under incidents such as chemical spills that can release contaminants included under the NPDWR into public drinking water sources (MDEQ, 2009). This notification is required for violations and situations that have significant potential to have serious adverse effects on human health as a result of short-term exposure. For example, following the Line 6B oil spill into the Kalamazoo River on July 26, 2010, the Calhoun County Health Department issued a precautionary bottled water advisory July 29, 2010, despite the absence of evidence indicating any potential oil contamination of groundwater resources (Michigan Department of Community Health, 2013). Similarly, after the release of approximately 1200 barrels of crude oil into the Yellowstone River near Glendive Montana in January 2015, a water consumption advisory was issued for residents served by the Glendive Montana Water Treatment Plant with bottled water provided for affected users until March 2015 when the treatment plant was returned into service (EPA Region 8 2015).

In the event of a worst-case spill scenario in the Straits of Mackinac, oil dispersal modeling predicts that the municipal water intake for DeTour Village would be susceptible to oil contamination in approximately 5% of dispersal simulations. Additional water intakes located further from potential Line 5 rupture locations such as those for the cities of Alpena, Charlevoix, Traverse City, Menominee, Escanaba are provided in Figure D10. For these intakes, however, the probabilities of oil presence in waters proximate to municipal intake locations are predicted to be < 5% of modeled dispersal conditions.

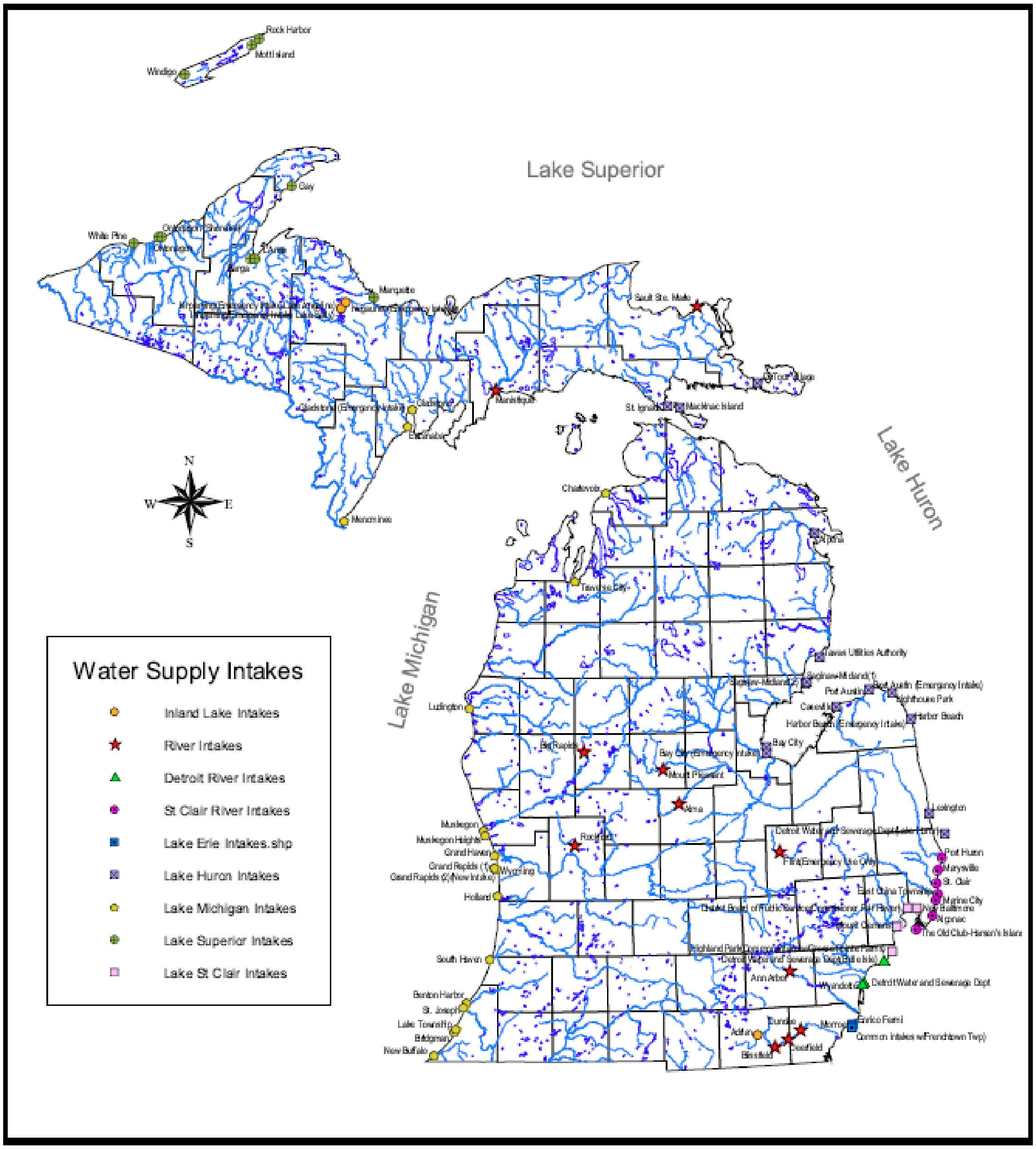

Figure D10: Location of public water supply intakes for the State of Michigan. Figure provided by the United States Geological Survey's Michigan Water Science Center and available at https://mi.water.usgs.gov/pdf/watersupplyintakes.pdf

D.3.3.2.2 Private drinking water wells

Under a worst-case Line 5 oil release in the Straits of Mackinac, there are approximately 306 private drinking water wells located within approximately 200 feet of the waterline for Cheboygan, Chippewa, Emmett and Mackinac counties that have coastal shorelines within the Straits of Mackinac channel and are at potential risk of oil contamination (Fig D2). Following the release of diluted bitumen crude oil into the Kalamazoo River due to the rupture of Enbridge's Line 6B pipeline, a drinking water well sampling program was designed and executed for private wells located within 200 feet of the high-water mark established by a July 2010 flood event (Michigan Department of Community Health 2013). For at-risk private drinking water wells associated with the Kalamazoo Line 6B spill, chemicals monitored included those having mandated maximum contaminant levels under the Safe Drinking Water Act in addition to non-mandated petroleum related chemicals. This testing demonstrated minimal evidence of immediate contamination or any longer-term oil-related contamination among tested private wells.

As a result of the 2010 Kalamazoo River oil spill, a total of 216 private drinking water wells were tested for evidence of petrochemical contamination that would be indicative of the presence of constituents of the diluted bitumen crude oil product released from the ruptured pipeline. This testing program demonstrated evidence of oil-related contamination in only two of the sampled wells with elevated concentrations of the inorganic contaminants nickel and iron identified in the two locations. These concentrations of nickel and iron detected by the sampling program in the affected wells, however, were not considered to pose adverse risks to human health (Michigan Department of Community Health 2013). No evidence of contamination of private drinking water wells by oil-related organic compounds (i.e., benzene, toluene, ethylbenzene, xylenes) was determined in any of the wells included in the Kalamazoo River drinking water well sampling program. The general absence of drinking water well contamination as associated with the crude oil product spilled during the Kalamazoo River event was associated with the nature of groundwater flow in the region of the Kalamazoo River affected by the oil spill. Specifically, the Kalamazoo River has been characterized as a gaining stream such the groundwater flow is positive into the river thus groundwater used for drinking water is unlikely to be impacted by released oil. Similarly, groundwater flow is generally net positive into the Great Lakes contributing 0.1 - 2.7% of net inflow across the basin (Neff & Nicholas, 2005). Thus, the risks of crude oil contamination in private drinking water wells located in the areas of the Straits of Mackinac at risk of oiling from a Line 5 pipeline rupture and release are considered to be low. Despite this, in the event of an oil spill in the Straits of Mackinac region, it is recommended that a drinking water sampling program be established to monitor for evidence of contamination by the released oil and its constituents in private drinking water wells that could be at risk of contamination. Such a program would include testing as soon as possible following the initial spill and at annual intervals over a period of time subsequently following the event.

D.3.3.2.3 Submerged private water intake cribs

Submerged private water intake cribs associated with seasonal cottages and camps are also anticipated to be present within remote coastal areas of Lake Huron and

Michigan that do not have access to municipal water provision or where remote access sufficiently prohibits private well construction. The State of Michigan does not maintain records of such generally unapproved water intake installations, but these also represent potential sources of human exposure to oil-contaminated water under a worst-case scenario. Such intake cribs commonly draw raw lake water that remains untreated for use in primarily grey (washing and bathing) and black (wastewater) water type applications. It is also unknown as to the number of such private intake cribs that have primary (filtration) or secondary (chlorination and/or UV disinfection) levels of treatment to provide potable drinking water once drawn from the raw source. Such intake sources could pose a high risk for exposure to oil-contaminated water, especially if left untreated prior to use for consumption.

D.3.3.3. Fisheries

Sport and commercial fisheries represent the predominant fisheries activities in Michigan waters of the Straits of Mackinac region, however, tribal and subsistence fishing also constitutes important components of this industry. Commercial fisheries landings reported for the State of Michigan in 2016 totaled over 6 million pounds of fish with a commercial value of $8.2 million (NOAA Office of Science and Technology, National Marine Fisheries Service 2016). Of the species included in these landings, Lake Trout and Lake Whitefish represent the primary landed fish and represent over 78% of the total catch in 2016 (NOAA Office of Science and Technology, National Marine Fisheries Service 2016). These two species also represent important cultural, economic and subsistence resources in the 1836 tribal ceded waters within the Straits of Mackinac Region. People who rely on subsistence fisheries are more susceptible to exposure to contaminated Great Lakes fish because they may rely on fish as a primary protein source and in some places are less aware of fish consumption advisories and closures (George, Kjolhede & Korfmacher, 2010).

D.3.3.4. Effects of Stress and Mental Health Related to the Oil Spill

A large oil spill into the Great Lakes has the potential to affect guiding sport fishers, marina workers, other boat or tourism-related occupations. Fishermen are directly affected by large oil spills in bodies of water that contaminate fish swimming in the oil-polluted water. Fishermen and tourists can also inhale the fine particulate matter and volatile compounds from oil spills. Temporary closure of the waterways may affect the tourism activities in the area, which may lead to psychological stress affecting some of the marina workers, and other tourism-related occupational workers. For example, the BP Deepwater Horizon oil spill directly affected commercial fishers and indirectly affected residents of the greater New Orleans metropolitan area. The BP oil spill released an estimated 4.1 million barrels of oil into the Gulf of Mexico over a three-month period (Allan et al., 2012). As a result, the seafood industry and recreational fishing for residents in south Louisiana were in jeopardy, along with the other Gulf States that were directly impacted (Lee & Blanchard, 2012).

A worst-case oil spill will not only affect tourists and workers in the tourism industry, but the residents may also be affected. Mental health issues are a significant concern after disasters such as a potential oil spill at the Straits of Mackinac. During the first three months after the initial explosion from the Deepwater Horizon spill, the Department of Psychiatry of Louisiana State University conducted interviews with focus groups of residents living in the most heavily affected areas to better understand the types of resources, interventions, and services that would be most helpful in supporting residents and their families. The individuals interviewed reported symptoms including suspiciousness and mistrust, the beginning of dissension in communities, uncertainty about the future, anger, anxiety, symptoms of anxiety, and acute stress with symptoms of posttraumatic stress disorder (Osofsky et al., 2011).

Oil spills which affect ecosystems and human health indicate an increase in stress response among the individuals impacted. A study conducted by Gill & Ritchie (2012) suggest that the vulnerability of children and families, and communities, to the psychological, social, economic, and ecological consequences of disasters can extend beyond the first year of the disaster. The study focused on the Exxon Valdez oil spill and the BP oil spill, which were the largest and most damaging spills in North America. The researchers compared the social and mental health impacts of these two major disasters. Random samples of residents of Cordova, Alaska, and south Alabama were collected five months after each event. A standardized indicator of event-related stress was used for both samples. The analysis revealed similarly high levels of initial psychological stress for survivors of both disasters. The strongest predictors of stress were family health concerns, commercial ties to renewable resources, and concern about economic future, economic loss, and exposure to the oil. Oil spills are different from other types of disasters in that communities dependent on natural resources for their social and economic livelihood may remain in an extended period of recovery, and the environmental effects are often not realized until many years in the future (National Commission, 2011). The uncertainty of recovery and economic hardships that follow can affect children and adolescents significantly. Effects on children and youth are related to the nature of the disaster, the proximity of the event, the degree of exposure of the child or family, demographic factors such as the age, gender, and minority status of the child and family, and qualities of the recovery environment, including medical, social, economic, community, and spiritual support (Osofsky et al., 2011).

A key group that may experience mental health effects is the tribal community. The indigenous people have a special cultural connection to the lakes, and they may be directly affected by the oil spill, with the presence of oil sheens on the lake. Indigenous communities have significant ties to the local territories; therefore, they support the communities with resource and economic development, land management and health care delivery services. Traditional companionship and cultural healing practices including rituals, which are essential to the wellness and health of the indigenous people (Kirmayer et al., 2003), may be affected if the spilled oil contaminates the heritage sites. Compared to non-indigenous residents, a research study reported that indigenous people are more likely to exhibit clinical symptoms of depression which may extend beyond the first year of the oil spill (Palinkas et al., 1992). In addition to cultural appreciation of the lake resources and experience of the direct impacts of the oil spill disaster causing social disruption in the community affecting tribal activities (such as social events, cultural observance gatherings, tribal fishing and sports etc.), the involvement of indigenous persons in cleanup activities has also been shown to exacerbate mental stress leading to depression among the tribal groups, especially among women. Food and water safety issues in the communities affected may cause chronic stress disorders, including; paranoia, anxiety, anger, insecurity and lack of trust in the government. The outcome of these effects could adversely affect the quality of relationships in the community between families, friend, and neighbors. Therefore, it can potentially result in disruption of their way of life, more conflicts, less interest in traditional activities and ultimately, erosion of cultural values (Miraglia, 2002).

Additionally, the indigenous residents may develop post-traumatic health outcomes relative to the spill event, cleanup, and recovery activities. Following the Exxon Valdez disaster, the indigenous people in the spill area reported several post-traumatic conditions, including the feeling of intrusion and privacy violations in their communities by cleanup teams, researchers, news media, etc. (Miraglia, 2002). Restrictions of access to cultural heritage sites, resource allocation, and equitable compensation issues may involve legal proceedings, and these could potentially lead to post-traumatic chronic stress disorders (Slett et al., 2016), which may be long-lasting among the indigenous people more than other groups in the community and require extended mental health services.

During the BP oil spill, large amounts of crude oil and dispersants were released into the Gulf of Mexico, resulting in damage to the environment and disruptions in the way of life for many communities. Osofsky et al. (2016) conducted a study that examined the effects of the stress from the BP disaster on child and adolescent mental health. Overall, there were a number of consequences that may have increased the stress of area residents, including direct exposure to toxins from oil and dispersants, harm to wildlife, damage to the environment, and disruption of the economy. Therefore, children and families may have experienced significant concerns about their lives, such as loss of work, loss of family businesses, eating local seafood, and loss of normal activities. Data were collected both before and after the Gulf oil spill, and two theoretical possibilities were examined to understand the mental health effects in children following this disaster. First, stress related to the oil spill may predict mental health symptoms, such as post-traumatic stress disorder (PTSD) symptoms, among youth. Second, there may also be important cumulative effects such that high pre-existing PTSD symptoms (before the spill) may interact to predict post-oil spill PTSD symptoms. Overall, youth with increased exposure to high oil spill stress had the highest post-oil spill symptoms of PTSD. In addition, they explored whether child age, gender, and minority status affected the link between stress related to the oil spill and post-disaster PTSD symptoms. It was concluded that children might be at increased risk following the oil spill. For example, younger children may be less able to process the oil spill event and cope with the disaster based on the family's level of stress. Gender and minority status were predicted to be the main effect predictors (Osofsky et al. 2016), but not that the demographic variables would change the main effects of oil spill stress on symptoms.

D.4 Discussion

The U.S. and Canada both rely heavily on the Great Lakes for fishing, recreation and tourism, agriculture, and shipping. A spill along the Straits of Mackinac may be consequential to public health and public safety. Therefore, this analysis concludes that acute inhalation exposure to CoPC may lead to the following short-term health effects in exposed receptors; minor discomfort, irritability, mild irritation of the eyes, nose and/or throat, mild cough, and symptoms consistent with CNS control such as; mild headache, light headedness, minor vertigo, dizziness, and/or nausea. In addition, mild, temporary, localized skin irritation could occur if the spilled oil contacts the human skin surface. These short-term health effects will discontinue once the source and possibility of exposure are reduced or completely removed. For instance, if there is an oil spill, most of the people that will be exposed to the spill initially, may not have repeated exposure especially from the VOCs that disperse relatively quickly.

The daily intakes calculated for each chemical that can potentially contaminate environmental media (soil, water, and air) provided the basis for developing a human health risk model. The model examined the excess lifetime cancer risks, and HQ from ingestion, dermal, and inhalation exposure to 16 priority PAHs and four hazardous VOC compounds were determined. The concentrations of the PAHs were determined based on 784 trials generated by the Monte Carlo simulation. The concentration of the VOCs that may be released from a worst-case Line 5 pipeline rupture were determined by the Fate and Transport team, then by using the Land's method, the upper confidence level at 95% of the concentrations were determined. Based on the concentrations of the CoPC, risk models were developed to characterize associated risks to public health and safety around the Strait of Mackinac. None of the individual VOC contaminants exceeded the target upper limit of cancer risk (), except close to the release point. However, the release point is located at a distance away from the public.

Benzene and other BTEX compounds slightly exceeded the lower chronic and acute health risk screening criteria of U.S. regulatory agencies cancer benchmark, where cancer occurrence increases by one for every one million exposed individuals compared to the general population that would not be exposed. It was determined that adult residents living around 500m from the shoreline of Mackinac City might have increased risk of both carcinogenic and non-carcinogenic risks from hazardous PAHs. The effect would be mostly chronic due to the assumed duration of exposure. The HQ is the ratio of the determined concentration relative to the reference dose for each compound evaluated, with non-carcinogenic adverse health effects, which was then compared to the benchmark the acceptable target value of 1. The HQ from PAH contamination could be more than three times higher than the HQ benchmark of 1. Overall, though the risk to public health was predicted to be relatively low based on the model assumptions; however, the permanent residents would be affected more than the workers and seasonal residents.

D.4.1 Uncertainty and Limitations of the Models

Several factors affect the risks related to worst-case pipeline failures. Usually, there are data gaps in the information on all the factors making the information required for the analysis incomplete. To fill these gaps, default values from established procedures are used based on numerous assumptions necessary to generate model input requirements. This procedure can potentially affect the overall accuracy of the estimated pipeline and population risks. Consequently, it must be well recognized, that the risk values determined in this independent analysis of the worst-case scenario of Line 5 pipeline are, indeed, estimates. Wind speeds in the Mackinac Straits can often be unpredictable but would have significant effects on the distribution and impact of an oil spill. If the spill occurred in the winter months, ice and strong currents could make clean up significantly more difficult, which could also affect the impact of a spill. The estimated probabilities of failure and associated human health risk estimates are statistical probability values which may be close to actual real-world values but may also differ considerably due to the inherent uncertainties involved in dealing with a complex system such as a pipeline through several terrains. Regardless of the uncertainty challenges, the scientific methods used for the analyses are of high confidence, and they are reasonable within the context of public health and safety risk assessment.

D.5 Summary

The results of this study demonstrate that concentrations of CoPC including VOCs in the immediate vicinity of a Line 5 pipeline release will initially be very high ranging up to 5 x 10^4 mg/m^3. However, as these VOCs and other chemical constituents in spilled crude oil or NGL products become dispersed downwind, the concentrations of these individual chemicals will decrease at distances further isolated from the initial release point including local population centers such as Mackinac City. Subsequently, such reductions in the concentrations of CoPCs due to downwind dispersal are predicted to minimize the risks to public health and safety as associated with CoPC toxicity and flammability hazards resulting from a worst-case release event and anything else covered in the main text.

Among the groups at risk identified in this study, seasonal residents were predicted to be at higher levels of risk from CoPC hazards relative to the permanent residents in the area. Although the risk of developing adverse health effects for seasonal residents is generally low, the potential for increased risk in this sub-group was associated with higher potentials for exposure as associated with participation in recreational activities such as swimming and watersports that could increase contact and exposure to spilled pipeline products. Additionally, seasonal residents are more likely to occupy dwellings closer to oil-contaminated shorelines that can increase the potential for individual exposures to CoPC through inhalation and dermal contact. As per observations in other oil spill events such as Deepwater Horizon, cleanup workers and potentially volunteers associated with remediation efforts could face increased risks under above assumption of increased and prolonged contact and exposure to spilled oil products.

The oil dispersal simulation showed that public water supply sources are within ten miles of the Line 5 pipeline for the cities of St. Ignace and Mackinac Island which are susceptible to oiling within 24 hours of the oil spill under the worst-case scenario. Additionally, there are 306 private drinking water wells located within about 200 feet of the waterline for Cheboygan, Chippewa, Emmett, and Mackinac counties that can potentially be at risk of oil contamination. However, the Great Lakes contribute between 0.1 - 2.7% of net (positive) inflow across the basin. It was concluded that the drinking water aquifers in the Straits of Mackinac positively flow into the river. Hence the risk from an oil spill in underground drinking water to residents of the area is significantly low. Residents that draw drinking water directly from surface water sources would be at a higher risk of developing health effects from the oil toxins

The effect of the potential oil spill on community mental health was examined. The possibility of being directly exposed to toxic chemicals from the oil spill and other indirect effects such as; ecosystem disruption and pollution, wildlife health effects, environment degradation, and socio-economic disruption can have significant mental health effects on the residents of the affected areas along the Strait of Mackinac. People in the area may experience mental stress due to the intrusion of their privacy during cleanup and recovery activities. Food and usable water safety may lead to aggravated mental stress levels. The risk of chronic stress disorder and PTSD is higher for women, children and the indigenous people in the communities. It is more likely for the indigenous people in the tribal communities to experience depression following the spill accidents than other groups in the population. Occupational workers and tourists may feel some psychological pain due to loss of money and recreational opportunities either from income or vacation planning. The outcome of these mental health effects could adversely affect the quality of life and relationships in the community. Therefore mental health services may be required for an extended period following the worst-case spill accident.

Modeling efforts predicted that none of the individual CoPC constituents in crude oil would exceed the upper target limits for increased cancer risks. However, the predicted concentrations may result in increased short-term non-cancer adverse health effects including general malaise, respiratory symptoms such as; shortness of breath especially in previously compromised individuals, irritation of eyes, throat, skin rashes, headache and nausea. These symptoms would be reduced upon removal of individuals from CoPC exposure or due to the removal of the CoPC source (e.g., cleanup activities). Furthermore, results from the modeling of the flammability and explosive hazards showed minimal risks to the residents closest to the potential worst-case release point. The analysis showed that the areas around Mackinac city fall outside of zone 3 which has 0% probability of fatality. Hence the public is not expected to be at an increased risk of fire and explosion, as a consequence of the worst-case release.

The results of this study predict that increases in the short- and long-term risks to public health and safety due to worst-case crude oil or NGL release from the Line 5 pipeline are relatively low with no potential fatalities and chronic adverse health effects expected. However, this conclusion is only valid for the assumed conditions and data available for the analysis and as included in this report. Following validated regulatory methods and guidelines and based on existing investigations of adverse human health effects associated with oil spill events, the results of this study conclude that the public health and safety consequences following a worst-case Line 5 pipeline rupture and release would be minimal.

D.6 References

Abdel-Shafy, H. I., & Mansour, M. S. (2016). A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. *Egyptian Journal of Petroleum*,*25*(1), 107-123. doi:10.1016/j.ejpe.2015.03.011

Agency for Toxic Substances and Disease Registry (ATSDR). (2005). Public Health Assessment Guidance Manual. Appendix G: Calculating Exposure Doses. Retrieved on February 12, 2018, from https://www.atsdr.cdc.gov/hac/phamanual/appg.html

Agency for Toxic Substances and Disease Registry (ATSDR). (2013). What Health Effects Are Associated With PAH Exposure? Retrieved March 04, 2018, from https://www.atsdr.cdc.gov/csem/csem.asp?csem=13&po=11

Agency for Toxic Substances and Disease Registry (ATSDR). (2017). ATSDR's Substance Priority List. Retrieved March 6, 2018, from https://www.atsdr.cdc.gov/spl/index.html

Agency for Toxic Substances and Disease Registry (ATSDR). (2011). Toxicologic Profiles for Benzene, Toluene, Ethylbenzene, Xylenes, Hexane, Hydrogen Sulfide, PAHs, and Sulfur Dioxide. Retrieved July 9, 2018, from https://www.atsdr.cdc.gov/index.html

Agency for Toxic Substances and Disease Registry (ATSDR). 2007. Toxicological Profile for Benzene. Atlanta, GA: United States Agency for Toxic Substances and Disease Registry Division of Toxicology and Environmental Medicine/Applied Toxicology Branch; 2007.

Alexander, J., & Wallace, B. (2012). Sunken Hazard: Aging oil pipelines beneath the Straits of Mackinac, an ever-present threat to the Great Lakes. Retrieved on February 12, 2018, from https://www.nwf.org/-/media/PDFs/Regional/Great-Lakes/NWF_SunkenHazard.ashx?la=en&hash=B68511CA659D760CC128E2EF31010FD444844AAF

Alghamdi, M.A., Khoder, M., Abdelmaksoud, A.S., Harrison, R.M., Hussein, T., Lihavainen, H., Al-Jeelani, H., Goknil, M.H., Shabbaj, I.I., Almehmadi, F.M., Hyv€arinen, A.P., Ha€meri, K., 2014. Seasonal and diurnal variations of BTEX and their potential for ozone formation in the urban background atmosphere of the coastal city Jeddah, Saudi Arabia. Air Qual. Atmos. Health 7, 467-480.

Allan, S. E., Smith, B. W., & Anderson, K. A. (2012). Impact of the deepwater horizon oil spill on bioavailable polycyclic aromatic hydrocarbons in gulf of Mexico coastal waters. *Environmental Science & Technology, 46*(4), 2033.

American Journal of Managed Care. (2006). Vulnerable Populations: Who Are They? Retrieved March 15, 2018, from http://www.ajmc.com/journals/supplement/2006/2006-11-vol12-n13suppl/nov06-2390ps348-s352?p=2

Arata, C. M., Picou, J. S., Johnson, G. D., & McNally, T. S. (2000). Coping with technological disaster: An application of the conservation of resources model to the Exxon Valdez oil spill. Journal of Traumatic Stress, 13(1), 23-39. 10.1023/A:1007764729337

Bass Trigon Software, (2002).

Bruno, K., Collentine, C., Hayes, D., Murphy, J., Blackburn, P., Pearson, A., Swift, A., Laduke, W., Ward, E., & Whiting, C. (2016). Enbridge Over Troubled Water: The Enbridge GXL System's Threat to the Great Lakes. Retrieved on February 12, 2018, from https://content.sierraclub.org/.../1224_EnbridgeOverTroubledWater_10_low.pdf

California Department of Education (CDE). 2007. Guidance Protocol for School Site Pipeline Risk Analysis Volume 2 – Background Technical Information and Appendices. School Facilities Planning Division, Sacramento. https://www.cde.ca.gov/ls/fa/sf/documents/v2protocoldis5.doc (accessed 02 May 2018)

Carls, M. G., Rice, S. D., & Hose, J. E. (1999). Sensitivity of fish embryos to weathered crude oil: Part I. low-level exposure during incubation causes malformations, genetic damage, and mortality in larval pacific herring (clupea pallasi). *Environmental Toxicology and Chemistry, 18*(3), 481-493. 10.1002/etc.5620180317

Center for Chemical Process Safety (CCPS), *Guidelines for Chemical Process Quantitative Risk Analysis*, American Institute of Chemical Engineers, New York, New York, 1989.

Center for Chemical Process Safety (CCPS), *Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVES*, American Institute of Chemical Engineers, New York, 1994.

Center for Chemical Process Safety (CCPS), *Guidelines for Evaluating Process Plant Buildings for External Explosions and Fires*, American Institute of Chemical Engineers, New York, New York, 1996.

Centers for Disease Control and Preventio., (2018), Emergency Preparedness and Response, Facts About Benzene. National Center for Emerging and Zoonotic Infectious Diseases (NCEZID). Retrieved on May 17, 2018, from https://emergency.cdc.gov/agent/benzene/basics/facts.asp

Centers for Disease Control and Prevention. 2007. NHANES 2005–2006. Available: http://www.cdc.gov/nchs/ nhanes/nhanes2005-2006/nhanes05_06.htm [accessed 02 July 2018].

Chen, W.-H., Chen, Z.-B., Yuan, C.-S., Hung, C.-H., Ning, S.-K., 2016. Investigating the differences between receptor and dispersion modeling for concentration pre- diction and health risk assessment of volatile organic compounds from petro- chemical industrial complexes. J. Environ. Manag. 166, 440-449.

Colman Lerner, J.E., Sanchez, E.Y., Sambeth, J.E., Porta, A.A., 2012. Characterization and health risk assessment of VOCs in occupational environments in Buenos Aires, Argentina. Atmos. Environ. 55, 440-447.

Cope, M. R., Slack, T., Blanchard, T. C., & Lee, M. R. (2013). Does time heal all wounds? community attachment, natural resource employment, and health impacts in the wake of the BP deepwater horizon disaster. Social Science Research, 42(3), 872-881. 10.1016/j.ssresearch.2012.12.011

D'Andrea MA, Reddy GK, FACRO Health effects of benzene exposure among children following a flaring incident at the British Petroleum refinery in Texas City. Pediatr Hematol Oncol. 2014;31:1–10. doi: 10.3109/08880018.2013.831511.

Department of Justice. (2016). United States, Enbridge Reach $177 Million Settlement After 2010 Oil Spills in Michigan and Illinois. Retrieved on March 1, 2018, from https://www.justice.gov/opa/pr/united-states-enbridge-reach-177-million-settlement-after-2010-oil-spills-michigan-and

Detroit-Fisher, D. Michigan Regional Trauma Resources, Region 7. Michigan Department of Community Health, Lansing MI. October 2013.

Dynamic Risk Assessment Systems. (2017). *Alternatives Analysis for the Straits Pipeline* (United States, The State of Michigan). Retrieved March 28, 2018, from https://mipetroleumpipelines.com/document/alternatives-analysis-straits-pipeline

Enbridge. (n.d.). Enbridge's Line 5: Essential to Michigan's Energy Picture. Retrieved on March 20, 2018, from https://www.enbridge.com/~/media/Enb/Documents/Projects/line5/Line_5_Economic_Benefits.pdf?la=en

EPA (2004). General RMP Guidance - Chapter 4: Offsite Consequence Analysis. Retrieved on March 13, 2018, from https://www.epa.gov/rmp/general-rmp-guidance-chapter-4-offsite-consequence-analysis

EPA. (2005). Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. Retrieved on February 12, 2018, from https://epa-prgs.ornl.gov/radionuclides/2005_HHRAP.pdf

EPA. (2009). Risk Management Program Guidance for Offsite Consequence Analysis. Retrieved on March 1, 2018, from https://www.epa.gov/sites/production/files/2013-11/documents/oca-chps.pdf

EPA. (2009). National Primary Drinking Water Regulations. EPA 816-F-09-004, 7pp.

EPA. (2010). EPA Response to Enbridge Spill in Michigan: Water Data. Retrieved on March 1, 2018, from https://archive.epa.gov/region5/enbridgespill/data/web/html/datawater.html

EPA. (2011). BP Oil Spill Response Air Monitoring: National Air Toxics Workshop National Air Toxics Workshop. Retrieved March 04, 2018, from https://www3.epa.gov/ttnamti1/files/ambient/airtox/2011workshop/day2DaveShelowBPOilSpill.pdf

EPA, Region 8. (2015). Bridger Pipeline Release. Retrieved on July 4, 2018, from https://www.epa.gov/region8/bridger-pipeline-release.

EPA. (2016). IRIS Chemical Search. Retrieved on March 10, 2018, from https://cfpub.epa.gov/ncea/iris/search/

EPA. (2017a). Great Lakes Facts and Figures. Retrieved on March 1, 2018, from https://www.epa.gov/greatlakes/great-lakes-facts-and-figures

EPA. (2017b). Volatile Organic Compounds' Impact on Indoor Air Quality. Retrieved March 04, 2018, from https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality#main-content

EPA. (n.d.). EPA Response to Enbridge Spill in Michigan. Retrieved on February 12, 2018, from https://www.epa.gov/enbridge-spill-michigan

FEMA, DOT, and EPA, *Handbook of Chemical Hazards Analysis Procedures*, US Environmental Protection Agency, US Department of Transportation, and the Federal Emergency Management Agency, 1989.

Fingas, M. (2012). Review of The Properties and Behaviour of Diluted Bitumens. Retrieved on March 10, 2018, from https://www.researchgate.net/profile/Merv_Fingas/publication/282580648_Review_of_The_Properties_and_Behaviour_of_Diluted_Bitumens/links/56131df508aec7900afb1481/Review-of-The-Properties-and-Behaviour-of-Diluted-Bitumens.pdf

Gas Research Institute, *A Model for Sizing High Consequence Areas Associated with Natural Gas Pipelines*, GRI-001 0189, October 2000.

Gerarde HW [1960]. Toxicology and biochemistry of aromatic hydrocarbons. New York, NY: Elsevier Publishing Company.

Gerstein, M., & Oosting, J. (2017). Enbridge: Pipeline had coating gaps for years. Retrieved on February 12, 2018, from http://www.detroitnews.com/story/news/politics/2017/10/27/enbridge/107065856/

George, V.; Kjolhede, A,; Korfmacher, K. 2010. Subsistence consumption of locally caught fish in Rochester, New York: 2009 Rapid Assessment Report. University of Rochester Medical Health Center, Environmental Health Sciences Center, Community Outreach and Education Core. 26 pp.

Gilbert, R.O. (1987). Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold, New York

Gill, D. A., Picou, J. S., & Ritchie, L. A. (2012). The Exxon Valdez and BP oil spills: A comparison of initial social and psychological impacts. American Behavioral Scientist, 56(1), 3-23. 10.1177/0002764211408585

Gohlke JM, Doke D, Tipre M, Leader M, Fitzgerald T. A review of seafood safety after the deepwater horizon blowout. Environ Health Perspect. 2011; 119:1062–1069

Groysman, A. (2017). *Corrosion problems and solutions in oil refining and petrochemical industry*. Cham: Springer International Publishing. Retrieved on March 1, 2018, from https://link-springer-com.huaryu.kl.oakland.edu/book/10.1007%2F978-3-319-45256-2

Heintz, R. A., Short, J. W., & Rice, S. D. (1999). sensitivity of fish embryos to weathered crude oil: Part ii. increased mortality of pink salmon (oncorhynchus gorbuscha) embryos incubating downstream from weathered Exxon Valdez crude oil. *Environmental Toxicology and Chemistry, 18*(3), 494. 10.1897/1551-5028(1999)018<0494:SOFETW>2.3.CO;2

Hellou J, Warren WG, Mercer G. (1995). Organochlorines in Pleuronectidae: comparison between three tissues of three species inhabiting the Northwest Atlantic. Arch Environ Contam Toxicol 29(3):302–308.

Heron MP, Hoyert DL, Murphy SL, Xu JQ, Kochanek KD, Tejada-Vera B. 2009. Deaths: Final Data for 2006. Natl Vital Stat Rep 57(14):1–134.

Intrinsik Environmental Sciences Inc. (2014). Human Health Risk Assessment of Pipeline Spill Scenarios Technical Report for the Trans Mountain Pipeline ULC Trans Mountain Expansion Project. Retrieved on March 1, 2018, from https://docs2.neb-one.gc.ca/ll-eng/llisapi.dll?func=ll&objId=2480640&objaction=download&viewType=1

Järup, L. (2003). Hazards of heavy metal contamination. British Medical Bulletin, 68(1), 167-182. 10.1093/bmb/ldg032

Jernelöv, A. (2010). The threats from oil spills: Now, then, and in the future. *Ambio, 39*(5-6), 353-366. 10.1007/s13280-010-0085-5

Jian, L.; Zhong, M.S.; Liang, J.; Yao, J.J.; Xia, T.X.; Fan, Y.L.; Li, J.D.; Tang, Z.Q. Application and benefit evaluation of tiered health risk assessment approach on site contaminated by benzene. Huan Jing Ke Xue 2013, 34, 1034–1043.

Jokuty, P. (*2001*). PROPERTIES OF CRUDE OIL AND OIL PRODUCTS (NOT JUST ANOTHER PRETTY DATABASE). International Oil Spill Conference Proceedings. 2001(2), *p. 975-981*. http://ioscproceedings.org/doi/abs/10.7901/2169-3358-2001-2-975

Johnson, LL, Arkoosh, MR, Bravo, CF, Collier, TK, Krahn, MM, Meador, JP., The Effects of Polycyclic Aromatic Hydrocarbons in Fish from Puget Sound, Washington. In The Toxicology of Fishes Eds RT. Di Giulio and DE. Hinton. CRC Press 2008, Pages 877–923.

Jung, J., Kim, M., Yim, U. H., Ha, S. Y., Shim, W. J., Chae, Y. S., . . . Kwon, J. (2015). Differential toxicokinetics determines the sensitivity of two marine embryonic fish exposed to Iranian heavy crude oil. Environmental Science & Technology, *49*(22), 13639.

Kerr JM, Melton HR, McMillen SJ, Magaw RI, Naughton G, Little GN (1999) Polyaromatic hydrocarbon content in crude oils around the world. Conference paper from the 1999 SPE/EPA Exploration and production environmental conference held in Austin, Texas, USA, 28 February-3 March.

Kingston P. 1999. Recovery of the marine environment following the Braer spill, Shetland. In: Proceedings of the 1999 Oil Spill Conference. Washington, DC: American Petroleum Institute, 103–109.

Kirmayer, L., Simpson, C., and Cargo, M. 2003. Healing traditions: Culture, community and mental health promotion with Canadian Aboriginal peoples. Aust Psychiatry. 11: S15–S23. doi: 10.1046/j.1038-5282.2003.02010.x

Kirrane, E., Loomis, D., Egeghy, P., Nylander-French, L. (2007). Personal exposure to benzene from fuel emissions among commercial fishers: Comparison of two-stroke, four-stroke and diesel engines. Journal of Exposure Science and Environmental Epidemiology, 17, 151–158

Kponee, KZ, Chiger, A., Kakulu, II., Vorhess, D., Heiger-Bernays, W. (2015). Petroleum contaminated water and health symptoms: A cross sectional pilot study in a rural Nigerian community. Environmental Health, 14: 86-94.

Lah, K. (2011). Polycyclic Aromatic Hydrocarbons - Toxipedia. Retrieved March 04, 2018, from http://www.toxipedia.org/display/toxipedia/Polycyclic+Aromatic+Hydrocarbons

Land, C.E. (1975). Tables of confidence limits for linear functions of the normal mean and variance. Selected Tables in Mathematical Statistics Vol III p 385-419.

Law RJ, Kelly C, Baker K, Jones J, McIntosh AD, Moffat CF. 2002. Toxic equivalency factors for PAH and their applicability in shellfish pollution monitoring studies. J Environ Monitor 4(3):383–388.

Lee, M. R., & Blanchard, T. C. (2012). Community attachment and negative affective states in the context of the BP deepwater horizon disaster. American Behavioral Scientist, 56(1), 24-47. 10.1177/0002764211409384

Lees, Frank P., *Loss Prevention in the Process Industries*, Second Edition, 1996.

Little Traverse Bay Bands of Ottawa Indians. (2013). *2012/2013 Annual Harvest Report (Rep.)*. Retrieved March 16, 2018, from Ottawa Natural Resources Department website: http://www.ltbbodawa-nsn.gov/NRD/2014/2013 Annual Harvest Report.pdf

Lupo PJ, Symanski E, Waller DK, Chan W, Langlois PH, Canfield MA, Mitchell LE. Maternal exposure to ambient levels of benzene and neural tube defects among offspring: Texas, 1999–2004. Environ Health Perspect. 2011; 119:397–402. doi: 10.1289/ehp.1002212

Mahurpawar, M. (2015). Effects of Heavy Metals on Human Health. *International Journal of Research - Granthaalayah*. Retrieved March 4, 2018, from http://granthaalayah.com/Articles/Vol3Iss9SE/152_IJRG15_S09_152.pdf

McGee, A. (2015, March). Potential Health Effects from Exposure to VOC Emissions. Retrieved March 04, 2018, from http://www.toxipedia.org/display/FOC/Potential+Health+Effects+from+Exposure+to+VOC+Emissions

McKenzie LM, Guo R, Witter RZ, Savitz DA, Newman LS, Adgate JL (2014): Birth outcomes and maternal residential proximity to natural gas development in rural Colorado. Environ Health Perspect Apr; 122(4):412-7. doi: 10.1289/ehp.1306722

Meador JP, Stein JE, Reichert WL, Varanasi U. 1995. Bioaccumulation of polycyclic aromatic hydrocarbons by marine organisms. Rev Environ Contam 143:79–165.

Michigan Department of Community Health. (2012). Kalamazoo River/Enbridge Spill: Evaluation of people's risk for health effects from contact with the submerged oil in the sediment of the Kalamazoo River. Retrieved on March 1, 2018, from http://www.michigan.gov/documents/mdch/Enbridge_Sediment__BLUE_FINAL_5-23-2012_387874_7.pdf

Michigan Department of Community Health. (2013). Public Assessment: Kalamazoo River/Enbridge Spill: Evaluation of Air Contamination. Retrieved on March 1, 2018, from https://www.michigan.gov/documents/mdch/Enbridge_Air_PHA_FINAL_RELEASE_9-30-2015_501495_7.pdf

Michigan Department of Community Health. (2013). Kalamazoo River/Enbridge spill: evaluation of crude oil release to Talmadge Creek and Kalamazoo River on residential drinking water wells on nearby communities (Calhoun and Kalamazoo Counties, Michigan). Public Health Assessment Final Release. 90 pp.

Michigan Department of Environmental Quality. (2009). Safe Drinking Water Act: Drinking Water and Municipal Assistance Division Supplying Water to the Public. 325 pp.

Michigan Department of Health and Human Services. (2016). 2016 Michigan Certificate of Need Annual Survey; Number of Licensed Beds in Hospitals by County. Retrieved July 7, 2018, from https://www.michigan.gov/documents/mdhhs/Report_011_-_Licensed_Beds_in_Hospitals_by_County_600991_7.pdf

Michigan DTMB, Local Area Unemployment Statistics (LAUS), & Bureau of Labor Market Information and Strategic Initiatives. (2018). County Labor Force. Retrieved March 15, 2018, from http://milmi.org/datasearch/county-labor-force.aspx

Michigan Economic Development Corporation. (2016). 2016 Michigan Tourism Economic Impact - By County. Retrieved March 16, 2018, from https://medc.app.box.com/s/yso7vz641n3xcmldw99hrx2319u0h0xs

Michigan Petroleum Pipelines. (2017). Need for Transparency Underscored by Revelation Enbridge Knew of Coating Damage Despite March Statements. Retrieved on February 12, 2018, from https://mipetroleumpipelines.com/document/october-27-2017

Miraglia, R.A. 2002. The cultural and behavioral impact of the Exxon Valdez Oil Spill on the native peoples of Prince William Sound, Alaska. Spill Sci. Technol. Bull. 7(1): 75–87. doi: 10.1016/ S1353-2561(02)00054-3

Mishra, A. K., & Kumar, G. S. (2015). Weathering of oil spill: Modeling and analysis. *Aquatic Procedia, 4*, 435-442. 10.1016/j.aqpro.2015.02.058

Moller, TH., Dicks, B., Whittle, KJ., Girin, M. (1999). Fishing and harvesting bans in oil spill response. International Oil Spill Conference Proceedings, March 1999, 1: 693-699.

Moore, C. Regional Trauma Resources, Region 8. Michigan Department of Community Health, Lansing, MI. March 2014.

Murad, A. Health Indicators and Risk Estimates by Community Health Assessment Regions and Local Health Departments, Selected Tables, 2014-2016, Michigan Behavioral Risk Factor Surveillance System. Bureau of Epidemiology and Population Health, Michigan Department of Health and Human Services; December 12, 2017.

National Academies of Sciences, Engineering, and Medicine. (2016). Spills of Diluted Bitumen from Pipelines: A Comparative Study of Environmental Fate, Effects, and Response. Retrieved on March 9, 2018, from https://www.nap.edu/catalog/21834/spills-of-diluted-bitumen-from-pipelines-a-comparative-study-of

National Commission. (2011). Deep Water: The Gulf Oil Disaster and the Future Of Offshore Drilling - Report to the President. Retrieved on March 14, 2018, from https://www.gpo.gov/fdsys/pkg/GPO-OILCOMMISSION/content-detail.html

National Park Service U.S. Department of the Interior. (2009). 20 Years Later ...Exxon Valdez Oil Spill. Retrieved on March 12, 2018, from https://www.nps.gov/kefj/learn/nature/upload/kefj_evos_1989-2009_qa.pdf

National Research Council [1986]. Emergency and continuous exposure guidance levels for selected airborne contaminants. Vol. 6. Benzene and ethylene oxide. Washington, DC: National Academy Press, Committee on Toxicology, Board on Toxicology and Environmental Health Hazards, Commission on Life Sciences, National Research Council, pp. 7-33.

National Research Council of the National Academies. Oil in the Sea III: Inputs, Fates and Effects, National Academies Press, Washington DC, 2003.

National Transportation Safety Board, Pipeline. (2010). Rupture and Oil Spill Accident Caused by Organizational Failures and Weak Regulations. Retrieved on March 13, 2018, from https://www.ntsb.gov/news/press-releases/Pages/PR20120710.aspx

Neff, BP., Nicholas, JR. 2005. Uncertainty in the Great Lakes water balance. United States Geological Survey, Investigations Report 2004-5100, Reston, VA. 42 pp.

NOAA. (2015). Great Lakes eco-region. Retrieved on March 1, 2018, from http://www.noaa.gov/resource-collections/great-lakes-eco-region

NIOSH. (2016). Pocket guide to chemicals hazards. Retrieved July 9, 2018, from https://www.cdc.gov/niosh/npg/

Nisbet, C. and LaGoy, P. (1992) Toxic Equivalency Factors (TEFs) for Polycyclic Aromatic Hydrocarbons (PAHs). Regulatory Toxicology and Pharmacology, 16, 290-300.

NOAA/FDA (National Oceanic and Atmospheric Administration/ Food and Drug Administration). 2010. Protocol for Interpretation and Use of Sensory Testing and Analytical Chemistry Results for Re-opening Oil-impacted Areas Closed to Seafood Harvesting. Available: sero.nmfs.noaa.gov/sf/deepwater_horizon/attachment%201%20(3).doc [accessed 02 July 2018].

NOAA Fisheries, Southeast Regional Office. (2010a). Deepwater Horizon/BP Oil Spill: Size and Percent Coverage of Fishing Area Closures Due to BP Oil Spill. Retrieved on June 29, 2018, from http://sero.nmfs.noaa.gov/deepwater_horizon/size_percent_closure/index.html

NOAA Fisheries, Southeast Regional Office. 2010b. Deepwater Horizon/BP Oil Spill: Re-opening Decisions, Test Results, and Post Re-opening Surveillance Data. Retrieved on June 29, 2018, from http://sero.nmfs.noaa.gov/deepwater_horizon/previous_reopening/index.html

NOAA Office of Science and Technology, National Marine Fisheries Service. 2016. Commercial Fisheries Statistics, Great Lakes Commercial Fishery Landings. Retrieved on June 29, 2018, from https://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/other-specialized-programs/great-lakes-landings/index.

NOAA. (2017). How does oil impact marine life? Retrieved on March 26, 2018, from https://oceanservice.noaa.gov/facts/oilimpacts.html

NOAA. (2018). How Oil Harms Animals and Plants in Marine Environments. Retrieved on March 12, 2018, from https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/how-oil-harms-animals-and-plants-marine-environments.html

Olawoyin RO, Oyewole SA, McGlothlin CW, Heiderich B, Abegunde SO, Nieto AV, Okareh OT, (2014). Characteristic Fingerprints of Polycyclic Aromatic Hydrocarbons & Total

Petroleum Hydrocarbons Pollution in Petrochemical Areas, Int'l J.Environ. Pollut. Solutions, 2 (1)1-19

Osofsky, H. J., Osofsky, J. D., & Hansel, T. C. (2011). Deepwater Horizon oil spill: Mental health effects on residents in heavily affected areas. Disaster Medicine and Public Health Preparedness, 5(4), 280-286. 10.1001/dmp.2011.85

Osofsky, J. D., Osofsky, H. J., Weems, C. F., Hansel, T. C., & King, L. S. (2016). Effects of stress related to the gulf oil spill on child and adolescent mental health. *Journal of Pediatric Psychology, 41*(1), 65-72. 10.1093/jpepsy/jsu085

Oudot, J., Merlin, F. X., & Pinvidic, P. (1998). Weathering rates of oil components in a bioremediation experiment in estuarine sediments. *Marine Environmental Research, 45*(2), 113-125. 10.1016/S0141-1136(97)00024-X

Palinkas, L.A., Russell, J., Downs, M.A., and Petterson, J.S. 1992. Ethnic differences in stress, coping, and depressive symptoms after the Exxon Valdez oil spill. J. Nerv. Ment. Dis. 180(5): 287–295. doi: 10.1097/00005053-199205000-00002

Pampanin DM, Sydnes MO (2013). Polycyclic aromatic hydrocarbons a constituent of petroleum: presence and influence in the aquatic environment. In: Kutcherov V (ed) Hydrocarbon. InTech, ISBN: 978-953-51-0927-3. doi:10.5772/48176

Pastakia, C. M., & Jensen, A. (1998). The rapid impact assessment matrix (Riam) For eia. *Environmental Impact Assessment Review, 18*(5), 461-482. doi:10.1016/s0195-9255(98)00018-3

Piatt, J. F., Lensink, C. J., Butler, W., Kendziorek, M., & Nysewander, D. R. (1990). Immediate impact of the 'Exxon Valdez' oil spill on marine birds. The Auk, 107(2), 387-397.

Prince, R. C. (2010). Bioremediation of marine Oil Spills. (pp. 2617-2630). Berlin, Heidelberg: Springer Berlin Heidelberg.10.1007/978-3-540-77587-4_194

Sault Ste. Marie Tribe of Chippewa Indians. (2018, February). History & Culture: 1836 Treaty Ceded Territory. Retrieved March 16, 2018, from https://www.saulttribe.com/history-a-culture/1836-treaty-ceded-territory

Schleifstein, M. (2016). BP oil spill cost fishing industry at least $94.7 million in 2010. Retrieved on March 1, 2018, from http://www.nola.com/environment/index.ssf/2016/06/bp_spill_cost_gulf_fishing_ind.html

Schwab, D. (2014). Statistical Analysis of Straits of Mackinac Line 5: Worst Case Spill Scenarios. Retrieved on March 1, 2018, from http://graham.umich.edu/media/pubs/Mackinac-Line-5-Worst-Case-Spill-Scenarios.pdf

Silliman, B. R., Johan van de Koppel, McCoy, M. W., Diller, J., Kasozi, G. N., Earl, K., Zimmerman, A. R. (2012). Degradation and resilience in Louisiana salt marshes after the

BP-Deepwater Horizon oil spill. *Proceedings of the National Academy of Sciences of the United States of America, 109*(28), 11234-11239. 10.1073/pnas.1204922109

Slett, M., Pillsworth, L., and Eykelbosh, A.J. 2016. Community impacts of fuel spills: A case study from BC's Central Coast. Vancouver, BC: National Collaborating Centre for Environmental Health.

Smith MT. Advances in understanding benzene health effects and susceptibility. Ann Rev Public Health. 2010; 31:133–148. doi: 10.1146/annurev.publhealth.012809.103646

Thomas RE, Brodersen C, Carls MG, Babcock M, Rice SD. 1999. Lack of physiological responses to hydrocarbon accumulation by Mytilus trossulus after 3-4 years chronic exposure to spilled Exxon Valdez crude oil in Prince William Sound. Comp Biochem Physiol C Pharmacol Toxicol Endocrinol 122(1):153–163.

Transportation Research Board and National Research Council. (2003). *Oil in the Sea III: Inputs, Fates, and Effects*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10388.

Troisi, G., Barton, S., & Bexton, S. (2016). Impacts of oil spills on seabirds: Unsustainable impacts of non-renewable energy. International Journal of Hydrogen Energy, 41(37), 16549-16555. 10.1016/j.ijhydene.2016.04.011

United States Census Bureau. (n.d.). QuickFacts: Michigan. Retrieved March 15, 2018, from https://www.census.gov/quickfacts/MI

US EPA (U.S. Environmental Protection Agency). 2009a. Risk and Technology Review (RTR). Risk Assessment Methodologies: For Review by the EPA's Science Advisory Board. EPA-452/R-09-006. June 2009.

U.S. EPA (U.S. Environmental Protection Agency). 2009b. The National Listing of Fish Advisories: Release of 2008 Data. Available: http://water.epa.gov/scitech/swguidance/fishshellfish/fishadvisories/ [accessed 14 June 2010].

US EPA (U.S. Environmental Protection Agency). Exposure factors handbook: 2011 edition, office of research and development. Washington, DC: National Center for Environ- mental Assessment; 2011c [EPA/600/R-090/052F, September].

US EPA (U.S. Environmental Protection Agency). (2005). Fact Sheet Attachment A 2005 Remediation General Permit Fact Sheet Excerpts. Retrieved May 18, 2018, from https://www3.epa.gov/region1/npdes/remediation/RGP2010_FactSheet_AttachmentA.pdf

U.S. EPA. 1991. Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals). Publication 9285.7-01B. Office of Emergency and Remedial Response, Washington, DC. NTIS PB92-963333.

US EPA (U.S. Environmental Protection Agency). 1992. Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised). EPA-454/R-92-024. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

US EPA (U.S. Environmental Protection Agency). 1996. Soil Screening Guidance: User's Guide. Second Edition. Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. Publication 9355.4-23.

US EPA. (2004). US Environmental Protection Agency. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment); OSRT. Innovation; U.S. Environmental Protection Agency: Washington, DC, USA,

U.S. Fish and Wildlife Service. (2010). Effects of Oil on Wildlife and Habitat. Retrieved on March 12, 2018, from https://www.fws.gov/home/dhoilspill/pdfs/DHJICFWSOilImpactsWildlifeFactSheet.pdf

United States Food and Drug Administration and National Oceanographic and Atmospheric Administration, Protocol for Interpretation and Use of Sensory Testing and Analytical Chemistry Results for Re-Opening Oil-Impacted Areas Closed to Seafood Harvesting, July 2010.

Vlaanderen J, Lan Q, Kromhout H, Rothman N, Vermeulen R. Occupational benzene exposure and the risk of lymphoma subtypes: a meta-analysis of cohort studies incorporating three study quality dimensions. Environ Health Perspect. 2011; 119:159–167. doi: 10.1289/ehp.1002318

Wolfe, D. A., Hameedi, M. J., Galt, J. A., Watabayashi, G., Short, J., O'Claire, C., & Sale, D. (1994). The fate of the oil spilled from the Exxon Valdez. *Environmental Science & Technology, 28*(13), 560A.

Wang, Z.; Hollebone, B. P.; Fingas, M.; Fieldhouse, B.; Sigouin, L.; Landriault, M.; Smith, P.; Noonan, J.; Thouin, G. (2003). *Characteristics of Spilled Oils, Fuels, and Petroleum Products: 1. Composition and Properties of Selected Oils*. Retrieved on March 1, 2018, from https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1000AE6.TXT

World Health Organization. (2017). Arsenic Factsheet. Retrieved March 04, 2018, from http://www.who.int/mediacentre/factsheets/fs372/en/

Yender R, Michel J, Lord C. 2002. Managing Seafood Safety after an Oil Spill. Seattle, WA: Hazardous Materials Response Division, Office of Response and Restoration, National Oceanic and Atmospheric Administration.

YoungeDyke, D. (2017). Line 5 Oil Pipeline System Spanning Michigan Has Had 29 Known Spills, Nearly Doubling the Number Previously Believed to Have Occurred. Retrieved on February 12, 2018, from https://www.nwf.org/en/Latest-News/Press-Releases/2017/4-24-17-Line-5-Oil-Pipeline-System-Spanning-Michigan-Has-Had-29-Known-Spills

Task E: Analyzing the short and long-term ecological impacts

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E.1 Introduction

The waters and shoreline areas of Lake Michigan and Lake Huron including areas surrounding and adjacent to the Straits of Mackinac contain abundant natural resources, including fish, wildlife, beaches, coastal sand dunes, coastal wetlands, marshes, limestone cobble shorelines, and aquatic and terrestrial plants, many of which are of considerable ecological and economic value. These areas include stretches of diverse and undisturbed Great Lakes shorelines that provide habitat for many plant and animal species.

Oil spills in aquatic environments cause adverse physical, physiological, and ecological effects to natural resources. Impacts resulting from both the physical properties of oil and the toxicities of its constituent compounds. Physical impacts occur because oil is hydrophobic and lipophilic and coats surfaces on aquatic habitats, beaches, feathers, fur, skin, and plants.

Mortality of various organisms has been documented after many large oil spills (e.g., Flint, Fowler, & Rockwell, 1999; Goldsworthy, Gales, Giese, & Brothers, 2000; Munilla et al., 2011). Mortality that occurred in the early days and weeks following these events is known as the acute phase. In addition to direct mortality from external oiling, oil spills affect plants and animals indirectly through degradation of habitat, alterations in food web structure, and contamination by toxic compounds. These toxic compounds include short-chain aliphatic hydrocarbons and benzene, toluene, ethylbenzene, and xylenes (BTEX) that are very toxic but will be rapidly degraded and volatilized and polycyclic aromatic hydrocarbons (PAHs) that are very toxic and can persist in the environment for much longer periods. These adverse chronic effects can extend for months, years, or decades, sometimes exceeding the magnitude of acute mortalities (Iverson & Esler, 2010; Monson, Doak, Ballachey, & Bodkin, 2011). The extent of acute and chronic health effects from an oil spill depends on the spill location and magnitude, the composition of the oil, and the nature of the local environment, which determines the impacts on organisms and ecosystems.

Health effects can include impaired reproduction, compromised immunity, altered feeding behavior, decreased growth, and delayed development. Also, the effects of oil exposure on the ecology and behavior of organisms can lead to losses across the food web that reduce food availability for other species and reduce the extent of habitat available for reproduction.

Degradation of preferred habitats and foraging resources sometimes reduces populations of keystone species, leading to ecosystem-wide impacts. For example, oil-related declines in bottom-dwelling (benthic) organisms can lead to declines in survival and reproduction among small fish that are the main food source for larger fish and waterbirds such as common loons.

Section E provides an overview of natural resources within Lakes Michigan and Huron and the areas near the Mackinac Straits. We provide an evaluation of the physiological and ecological risks to organisms within the potential zone of oil exposure for four sample scenarios provided by Section B. Because no similar event has ever occurred in the Great Lakes, the magnitude of impacts to natural resources was assessed by comparison to several surrogate oil spill events and toxicity studies from the literature. The oil spills include the 2010 Enbridge spill into the Kalamazoo River, the 2010 Deepwater Horizon oil spill, and the 1989 Exxon Valdez oil spill.

This document consists of:

- A conceptual model for ecological impacts with a description of the ecological resources in Lake Michigan, Straits of Mackinac, and Lake Huron to serve as a baseline for evaluation.
- An evaluation of worst-case oil spill scenarios, concerning the properties of oil in aquatic environments that could be caused by a rupture in the Line 5 pipeline situated in the Straits of Mackinac.
- A summary of how spilled oil impacts the critical habitats, species, and ecosystem services of Lake Michigan, Straits of Mackinac and Lake Huron in the short and long-term.

E.2 Approach: Conceptual Model for Impacts to Natural Resources

The scenarios produced by Section B characterize the spread of surface oil within the Mackinac Straits and surrounding areas and predict the amounts of oil that could eventually reach specific areas of shoreline. These spill scenarios also predict how much light oil evaporates (volatilizes) into the atmosphere as the slick spreads. Section E characterizes how the oil could impact natural resources following four sample worst-case spills (see Figure E1).

Because light crude oil is less dense than the overlying water, the bulk of the oil would rise towards the surface where it would spread like an oil slick along the surface of the water. However, some components would dissolve in the water and would stick to sediments or suspended particles, which may eventually settle to the bottom (Figure E1). Of primary concern is oil that reaches shorelines, where it can remain for a long time.

Organisms that cannot escape the oil in the water column or on the surface are at risk. Planktonic communities in the water column, and near the shore and shoreline organisms, for example, plants next to and in the water at the shore, and eggs and larvae of fish, amphibians, and insects will die from being coated by oil. These impacts can propagate through the food web resulting in loss of biological productivity in the oil-impacted areas.

Thus, potential acute and chronic impacts of a Line 5 pipeline oil spill include, but are not limited to, the following:

- Mortality resulting from oil coating and other routes of exposure to organisms that cannot avoid or move away from of the trajectory of dispersing oil in benthic, water column and shoreline areas.
- Physiological effects are resulting from exposure to oil components, including PAHs, that cause disruption of endocrine and metabolic processes through absorption, and ingestion of oiled sediment particles.
- Ecological effects to the lake bottom, open water, and beach communities including population and diversity loss, and loss of reproductive potential resulting from a reduction in available nesting, staging, spawning, and rearing habitats.
- Both physiological and ecological effects may create long-term negative impacts in Great Lakes food webs that result in diminished prey populations followed by reduced numbers of large predators.

E.3 Crude Oil and its Contaminants of Concern

This section provides an overview of the characteristics of the oil that could be released from the Line 5 pipeline. We describe the constituents of oil that would cause the greatest adverse effects on Great Lakes habitats and their associated communities.

Crude oil is a solution of hydrocarbon compounds with different chemical, physical, and toxic properties. These compounds can interact in different ways with air, water and soils, and their associated organisms. Interactions can range from no impacts to health impacts such as smothering by oil coating, acute chemical toxicity, chronic toxicity, mutagenesis (permanent changes in DNA), carcinogenesis (induction of cancer), and metabolic disruptions (e.g., lead to developmental, immune, or neurological problems). Disrupted habitats and adverse impacts on individual organisms propagate through the ecosystem, which can suffer short and long-term effects.

Crude oil is made up of thousands of hydrocarbon compounds with different molecular weights, densities, and chemical structures. Some of these compounds associate with sediment particles and others tend to rise to the surface. Some will dissolve in the water column. Of those that reach the surface, some will volatilize, and others will spread on the surface. Crude oils contain aromatic hydrocarbons, which have structures containing one or more aromatic rings. The compounds containing only one aromatic ring are the most abundant and are referred to collectively as BTEX, an acronym based on the chemical names of benzene, toluene, ethylbenzene, and xylene. Those with more than one ring are commonly referred to as PAHs (polycyclic aromatic hydrocarbons) and include such compounds as naphthalene and phenanthrene.

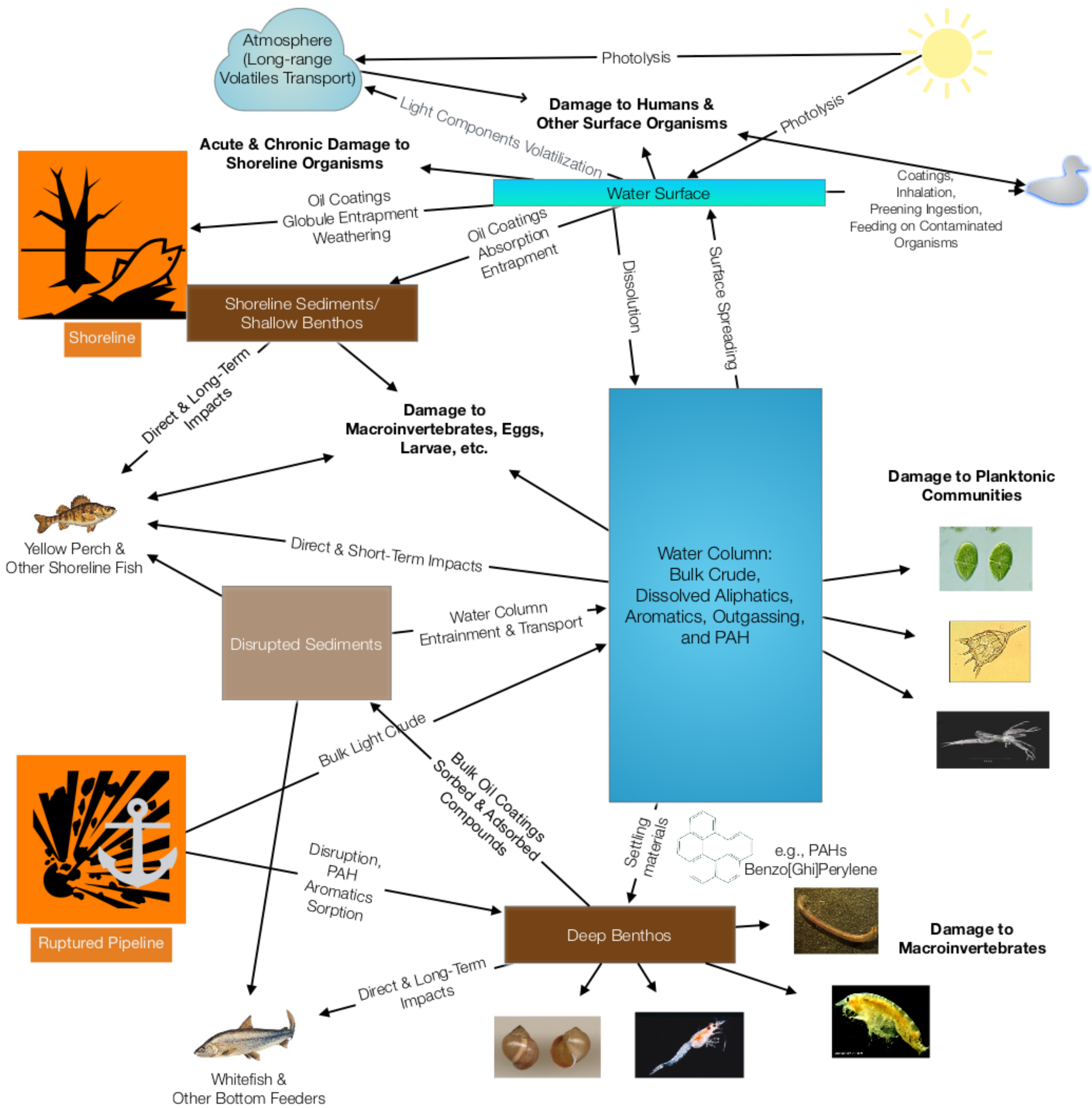

Figure E1. A conceptual model for impacts to natural resources from a Line 5 pipeline rupture and subsequent oil spill in the Straits of Mackinac.

Both the BTEX and PAH components of crude oil are highly toxic, and many are carcinogenic to organisms across all life-history stages. Organisms include benthic invertebrates, phytoplankton, zooplankton, fish, birds, reptiles, amphibians, and mammals. The BTEX oil components are short-lived, volatilize quickly at the surface, and don't bind to sediments. The BTEX components generally remain in the environment for about six to ten days following a spill. They do not bioaccumulate appreciably (Neff, 2002), and thus, pose short-term risks relative to PAHs.

PAHs, in contrast, bind readily to sediment and bioaccumulate. They can persist for decades or more in the environment (Meador, Stein, Reichert, & Varanasi, 1995). In general, the toxicity of PAHs increases with molecular weight. PAHs with ≥3 aromatic rings are less volatile than smaller compounds, remain longer in the environment, and have longer-lasting, sub-lethal health effects on organisms.

Polycyclic aromatic hydrocarbons are the particular focus because they persist in the environment, bioaccumulate in tissues, and are toxic to phytoplankton and zooplankton, bivalves, and the juvenile/larval life stages of most species that form the base of the Great Lakes food web.

E.3.1 Evaluation of a Worst-Case Spill Scenario

The degree and duration of exposure to oil or its components would affect the magnitude of any physiological or ecological response and is highly dependent on the pattern of oiling in the environment. Specifically, oil could be in the water, in the sediments, and along the shoreline, and different types of shoreline would have different responses.

Scenarios. In evaluating risks to natural resources in and surrounding the Mackinac Straits, we considered scenarios that represented the maximum amount of shoreline (km) oiled in each of Lakes Michigan and Huron. Evaluations for ten days and 60 days of oil dispersal from a rupture in the Line 5 pipeline were based on hydrodynamic modeling scenarios provided by Task B. The 10-day time was chosen because Task B showed that ~95% of the oil was landed within 10-days following a rupture in the Line 5 pipeline. The 10-day timeframe provides a baseline for evaluating short-term impacts, and the 60-day timeframe is used for long-term. Within these time frames, Task B considered environmental factors that can weather oil and reduce the overall number of barrels with the passage of time.

Water. Water impairments are defined by Alaska Aromatics Freshwater Quality Standard (WQS), which is 15µg of total aqueous hydrocarbons per liter of water (Alaska Department of Environmental Conservation, Division of Water, 2015). The Alaskan WQS is the most stringent state standard and is thus appropriate for the Great Lakes. A Straits pipeline spill volume of 58,000 BBL (9.2M liters) of light crude oil would have a mass of 7.9 x10^9 grams (Section A, assuming a density of 0.86 g/cm^3). If that volume were evenly diluted to the Alaskan WQS level up to 13 trillion gallons of water surrounding the pipeline break would be impaired.

Sediments. During an initial pipeline breach (Figure E1), oil would be rapidly dispersed into the water, which is denser than oil, causing bulk movement (advection) of the oil in every direction, including the benthic (lake bottom) sediments beneath the break (Figure E1). Since the pipeline slightly elevated above the bottom of the Straits, oil could disrupt and resuspend some of the upper, loosely packed lake bottom sediments. Some oil components, such as PAHs, would bind (sorb) to the lake bottom sediments and suspended particles. The extent of oil impacts to deep water sediments cannot be evaluated because it is too dependent on the precise progression of the pipeline breach.

Sediment impacts in nearshore zones are included within the shoreline analysis.

Shoreline. The most quantitative accounting of damage from oil spills in aquatic environments is based on an assessment of damage to shorelines. Many factors determine the extent of damage incurred, including the type of oil, the mass of oil per unit area of shoreline, and the degree of penetration of the oil into the shoreline. The type of shoreline is also relevant; oil impacts depend on the local habitats, biodiversity, and geology, shoreline width, and related features. The following metrics were used to evaluate the toxicity and sensitivity threshold of natural resources within the zone of exposure.

- For total oil: NOAA (2013) defines two thresholds for oil contamination. The oil contamination threshold for socioeconomic impacts is1 g/m^2. The threshold for ecological impacts is 100 g/m^2.
- For PAH contamination of sediments: Two levels are defined for PAH effects (MacDonald, 2000). The Threshold Effects Concentration values (TEC) is the level at which health impacts on organisms are detectable. The Probable Effects Concentration values (PEC) is the level at which health impacts frequently occur (PEC). Here the consensus-based values from Ingersol et al. (2001) were used; the TEC is1,610 µg/kg and PEC is 22,800 µg/kg.

To convert the shoreline oil surface area coverage values into mass (g) values, we estimated the oil penetration into the various types of shoreline materials using values measured from studies on the Exxon Valdez oil spill for various degrees of oiling then converted volume to mass using dry density values for the various materials.

Table E1. Barrels of oil distributed among habitats along the shorelines of Lakes Huron and Michigan from the four sampled worst-case scenarios, from Section B.

			Lake Huron			Lake Michigan		
Scenario	Shoreline Type	Shoreline Width (m)	Shoreline Length (km)	Area (km^2)	# of Barrels	Shoreline Length (km)	Area (km^2)	# of Barrels
10-day	Artificial	0.5	26	13	1392	14	7	72
	Coarse Grain Flat Coast	1	288	288	28660	181	181	18041
	Coastal Wetland/ Riparian Zone	20	47	940	421	21	422	16877
	Sand Beach	5	88	440	14956	108	541	3738
60-day	Artificial	0.5	33	17	4241	80	40	2959
	Coarse Grain Flat Coast	1	693	693	32748	392	392	16404
	Coastal Wetland/ Riparian Zone	20	184	3678	2907	44	880	1574
	N/A -- Mixed Beach	2	1	2	8	25	12	331
	Rocky Cliffs/ Bluffs	0.5	52	26	373	344	1720	21544
	Sand Beach	5	112	559	5518	3	6	299

Shoreline classifications for the Mackinac Straits and Lakes Huron and Michigan were compiled from NOAA's Environmental Sensitivity Index and Environment Canada's Environmental Sensitivity Atlas (sourced from GLAHF, 2018). Shoreline types are classified as Artificial, Coarse Grain Flat Coast, Mixed Beach, Coastal Wetland/Riparian Zone, Rocky Cliffs/Bluff and Sand Beach habitats (Figure E2, E3). The distribution of oil according to shoreline type is shown in Table E1 for each of the four sample scenarios.

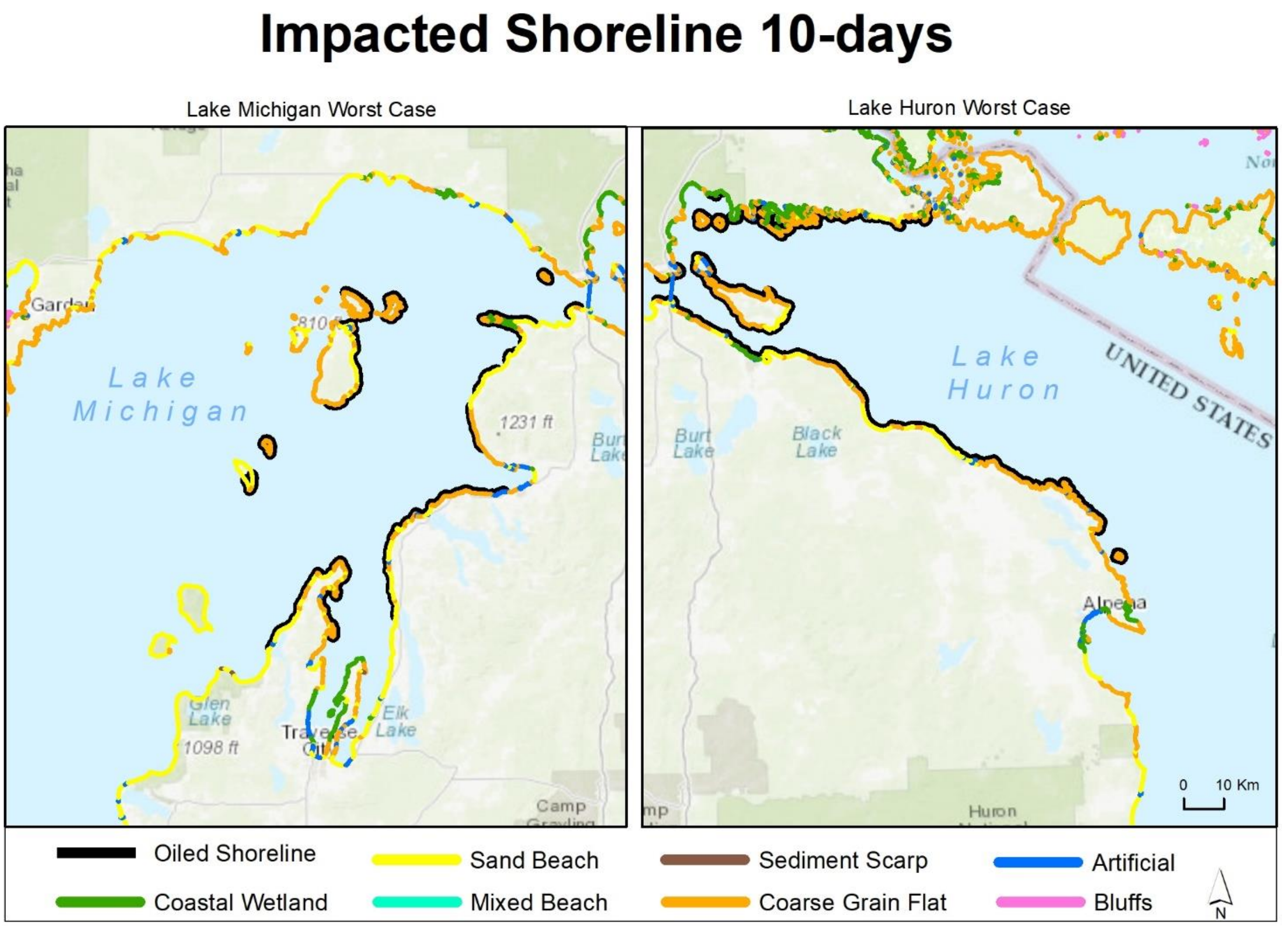

Figure E2. Oiled areas in Mackinac Straits and Lakes Huron and Michigan following the 10-day scenarios based on GIS mapping. The plots of shorelines oiled represent independent worst-case scenarios for each Lake. They are not predicted to occur at the same time. Habitats are identified from shoreline classifications of NOAA's Environmental Sensitivity Index and Environment Canada's Environmental Sensitivity Atlas. See Table E1 for oil distribution information.

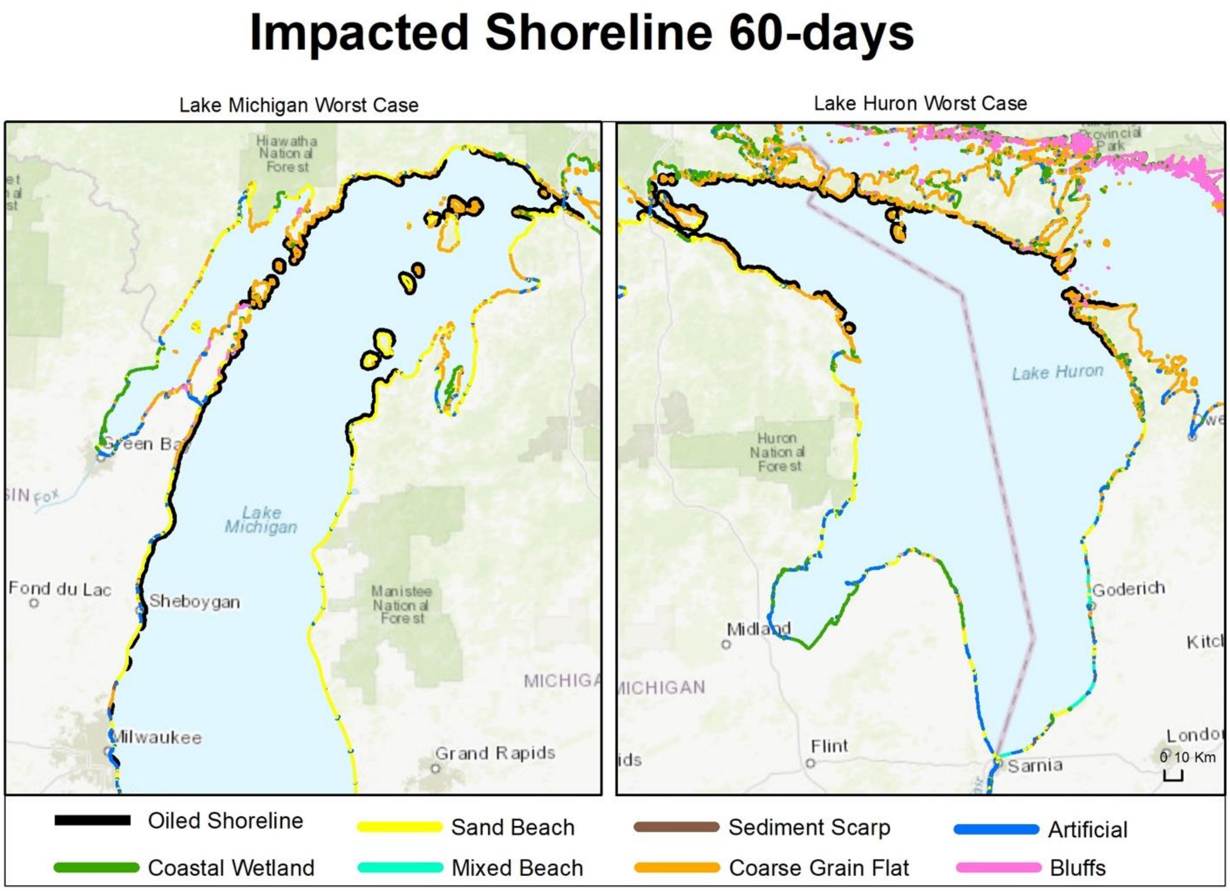

Figure E3. Oiled areas in Mackinac Straits and Lakes Huron and Michigan following the 60-day scenario, based on GIS mapping. The plots of shorelines oiled represent independent worst-case scenarios for each Lake. They are not predicted to occur at the same time. Habitats are identified from shoreline classifications of NOAA's Environmental Sensitivity Index and Environment Canada's Environmental Sensitivity Atlas. See Table E1 for oil distribution information.

E.3.2 Impacts on Shorelines

Considering the number of barrels released from a Line 5 rupture and the distribution along shoreline environments in Lakes Michigan and Huron our findings indicated that both lakes exceeded the NOAA threshold for socioeconomic impacts (SEF) and ecological impacts (EF) for all shorelines. Many shoreline sediments could exceed toxic thresholds for PAHs, depending on the amount of PAHs in the released oil.

E.3.2.1 Threshold for Socioeconomic Impacts

In both the 10-day and 60-day scenarios, all shoreline exposed to oil would exceed NOAA's socioeconomic impact threshold criteria for triggering shoreline cleanup ($>1 g/m^2$). This includes all shoreline types for both Lake Huron and Lake Michigan, shown as areas colored gray (>1g/m2) and black (>100 g/m2) in Figure E4. Therefore, shoreline cleanups would be required for all four scenarios.

E.3.2.2 Threshold for Ecological Impacts

In the short-term (10-day) scenarios, nearly all of the oiled shorelines in Lake Huron and Lake Michigan would be exposed to levels that exceed NOAA's threshold for ecological impact (>100 g/m^2). The exception is coastal wetlands in Lake Huron. Oil exposure to this habitat does not exceed the 100 g/m^2 threshold criteria after ten days. In the longer 60-day scenarios, all shoreline contacted by oil in both Lake Huron and Lake Michigan would exceed levels resulting in ecological impacts.

E.3.2.3 Thresholds for PAH Toxicity

The consensus-based sediment quality guidelines TEC and PEC were used to predict the toxicity of PAHs in oil-contaminated sediments.

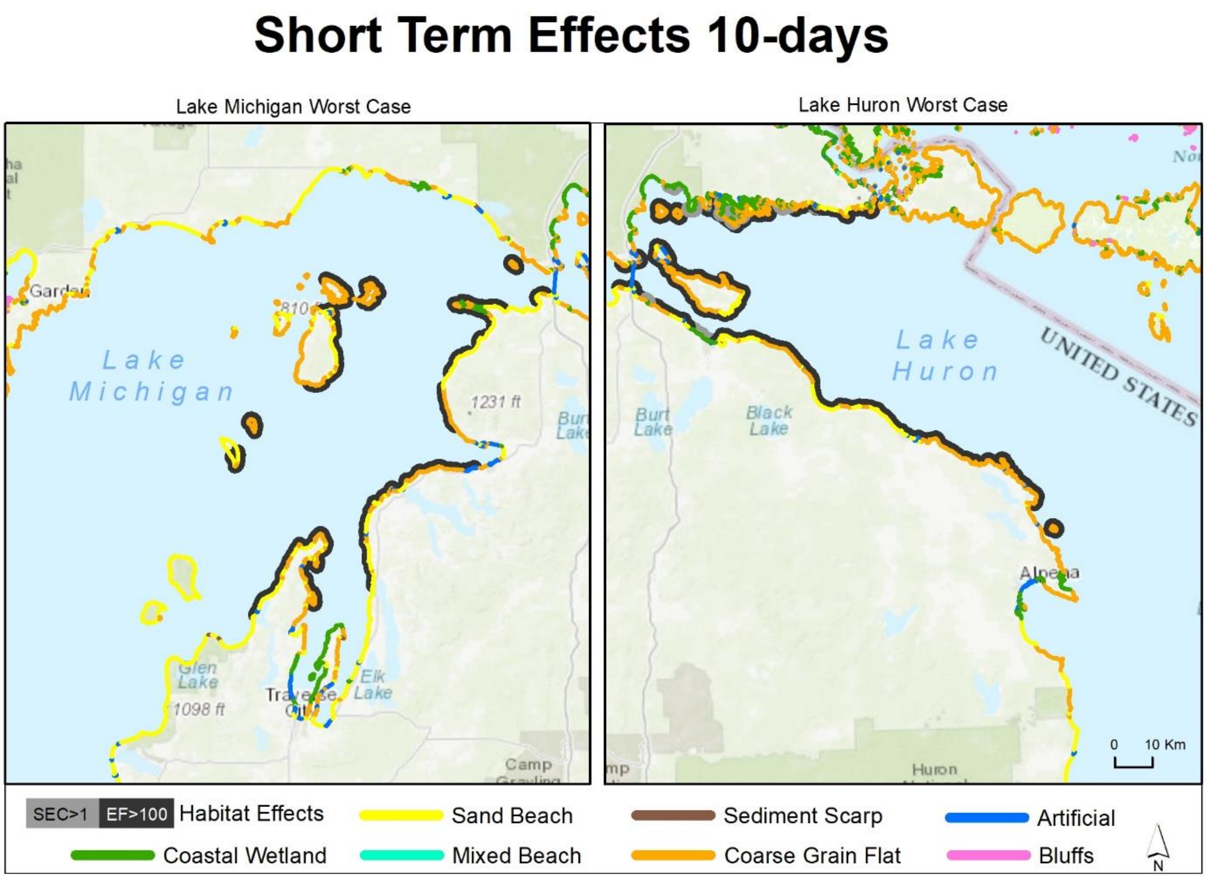

Figure E4. Shoreline habitats exceeding thresholds for socioeconomic impacts (>1 g/m^2). Criteria based upon NOAA (2013). SEF >1g/m^2 (light grey); EF >100g/m^2 (black).

The PAH content of the Line 5 products was estimated from typical values of light crude oil. The ranges of PAH in light crude oil are highly variable, ranging from 10 to 35 weight % (Dupuis and Ucan-Marin, 2015). Here more conservative estimates of 2% and 8% PAH were chosen.

E.3.2.4 Threshold and Probable Effect Concentration at 2% PAHs

For oil with 2% PAHs, toxicity to sediment-dwelling organisms among the shoreline habitats was below the PEC for all locations. On about 25% of the shoreline types, the concentration fell above the TEC, though below the PEC (Table E2). Since the TEC is the PAH concentration at which impacts upon organisms become detectable, some toxic effects would be expected at these sites. For example, at 2% total PAH, Lake Huron habitats, artificial and Coarse Grain Flat Coast and Lake Michigan habitats, Coarse Grain Flat Coast, exceeded the TEC at both time intervals (Table ET2). None of the shorelines in either Lake exceeded the NOAA PEC for either period using the 2% PAH value.

E.3.2.5 Threshold and Probable Effect Concentration at 8% PAHs

For oil with 8% PAHs nearly all shoreline types exceeded the TEC at both 10- and 60-day intervals (Table E3). Specifically, Artificial and Coarse Grain Flat Coast in both Lakes meet the threshold at each time interval, while Sand Beach meets the threshold in Lake Huron for both time intervals and Coastal Wetlands/Riparian Zones in Lake Michigan meet the threshold at ten days (see Figure E5). At 8% PAHs, the PEC threshold was exceeded for shoreline habitats for both Lake Huron and Lake Michigan. Toxicity to sediment-dwelling organisms would be present in these shoreline habitats, specifically coastal wetlands in Lake Michigan, artificial habitats along Lake Huron and coarse grain flat coast habitats in Lake Huron and Lake Michigan. These results indicate a high probability for damage to sediment-dwelling organisms for all four of these shoreline types.

Table ET2. For oil containing 2% PAHS, Lakes Huron and Michigan shoreline habitats exceeding thresholds for short-term and long-term Threshold Effect Concentration (TEC) and Probable Effect Concentration (PEC). Light and dark grey represent exceedance for TEC and PEC respectively.

	Lake Huron				Lake Michigan			
	TEC exceeded		PEC Exceeded		TEC Exceeded		PEC Exceeded	
Habitat	10-day	60-day	10-day	60-day	10-day	60-day	10-day	60-day
Coastal Wetland								
Artificial								
Coarse Grain Flat Coast								
Sand Beach								
Rocky Cliffs/Bluffs								
Sediment Scarp								

Table E3. For oil containing 8% PAHs, Lakes Huron and Michigan shoreline habitats exceeding thresholds for short-term and long-term Threshold Effect Concentration (TEC) and Probable Effect Concentration (PEC). Light and dark grey represent exceedance for TEC and PEC respectively.

	Lake Huron				Lake Michigan			
	TEC Exceeded		PEC Exceeded		TEC Exceeded		PEC Exceeded	
Habitat	10-day	60-day	10-day	60-day	10-day	60-day	10-day	60-day
Coastal Wetland								
Artificial								
Coarse Grain Flat Coast								
Sand Beach								
Rocky Cliffs/Bluffs								
Sediment Scarp								

8% PAH Short Term Impacts 10-days

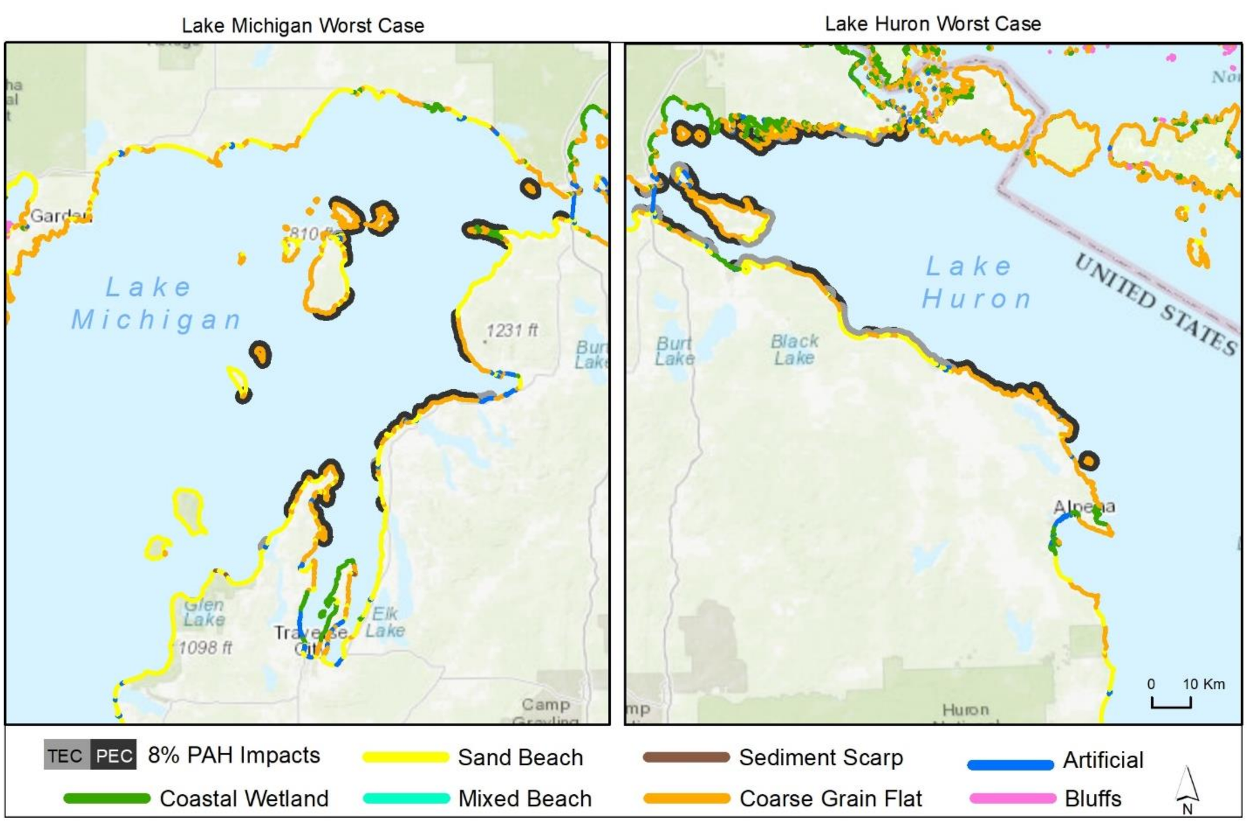

Figure E5. Lakes Huron and Michigan shoreline habitats exceeding thresholds for short-term and long-term Threshold Effect Concentration (TEC) and Probable Effect Concentration (PEC) at 8% PAHs. Light and black represent exceedance for TEC and PEC respectively.

E.3.3 Natural Resources in the Straits of Mackinac

Quantifying the effects of oil spills on organismal populations is challenging, due to a frequent lack of baseline data on toxicity, population sizes, habitat use, and foraging strategies of species residing in affected areas (see Henkel et al., 2012). These processes are often not well understood for organisms breeding and foraging in terrestrial and freshwater ecosystems affected by oil. The following section provides an overview of the baseline biodiversity, mammals, birds, reptiles, amphibians, fish, invertebrates, and vegetation, at risk following a rupture in the Line 5 pipeline.

Information was sourced from multiple publicly available state, federal and non-governmental data sources, including, NOAA's Environmental Sensitivity Index (ESI), U.S. Fish and Wildlife Critical Habitat Designation, Michigan's Natural Features Inventory (MNFI), Michigan Department of Natural Resources (DNR), Michigan's Department of Environmental Quality (DEQ), Great Lakes Aquatic Habitat Framework (GLAHF), Audubon Society Important Bird Areas (IBA), eBird Database and Journal of North American Herpetology. We provide a general review of the potential ecological and physiological effects of oil exposure by applying these concepts to the habitats and organisms in the Zone of Exposure in Lakes Michigan and Huron and areas surrounding and adjacent to the Straits of Mackinac following a worst-case scenario rupture of the Straits Line 5 pipeline.

E.3.3.1 Habitats

The MNFI natural community classification recognizes 76 rare and natural communities native to Michigan (Kost et al., 2007). A natural community is defined as an assemblage of interacting plants, animals, and other organisms that repeatedly occurs across the landscape under similar environmental conditions (Albert, Cohen, Kost, & Slaughter, 2008). Of the 76 communities, MNFI identified, 12 of these unique terrestrial community complexes are found in the Mackinac Straits and surrounding areas (Table E4). These habitats have been designated critical by MNFI based on their rarity and vulnerability to disturbance, and include Coastal Fens, Great Lakes Marshes, Open Dunes and Sand/Gravel Beaches. These unique habitats are home to a vast range of organisms, and the majority of these habitats and associated species communities are at risk of oil impact as they are either entirely or partially located in shoreline areas where the oil will make landfall. Specifically, Great Lakes Marsh, Open Dunes and Wooded Dune and Swale Complex are at greatest risk due to their proximity to shoreline areas and acreage (Table E4).

In addition to the rare and natural communities in areas surrounding and adjacent to the Mackinac Straits, there are several aquatic and terrestrial areas of conservation and preservation status. Based on USGS's Protected Areas Inventory, specific areas are protected due to their biodiversity. In the Mackinac Straits, the conservation areas at greatest risk of oiling following rupture of the Line 5 pipeline include Mackinac State

Park, Cheboygan State Park, Hiawatha National Forest, and Michigan Islands National Wildlife Refuge. Other at-risk conservation areas include critical and barrier dunes, Dingman Marsh and French Farm Flooding State Wildlife Area, High Island Natural Area, Beaver Island State Wildlife Research Area, Seiner's Point Natural Area, and Sault Ste. Marie State Forest Area. Areas of conservation status that are not directly adjacent to Mackinac Straits, but are located within the radius of the oil spill include Thompson's Harbor State Park, Thunder Bay National Marine Sanctuary Underwater Preserve, Sleeping Bear Dunes National Lakeshore and Old Mission State Park. Additionally, there are some areas designated as conservation easements within the predicted spill radius.

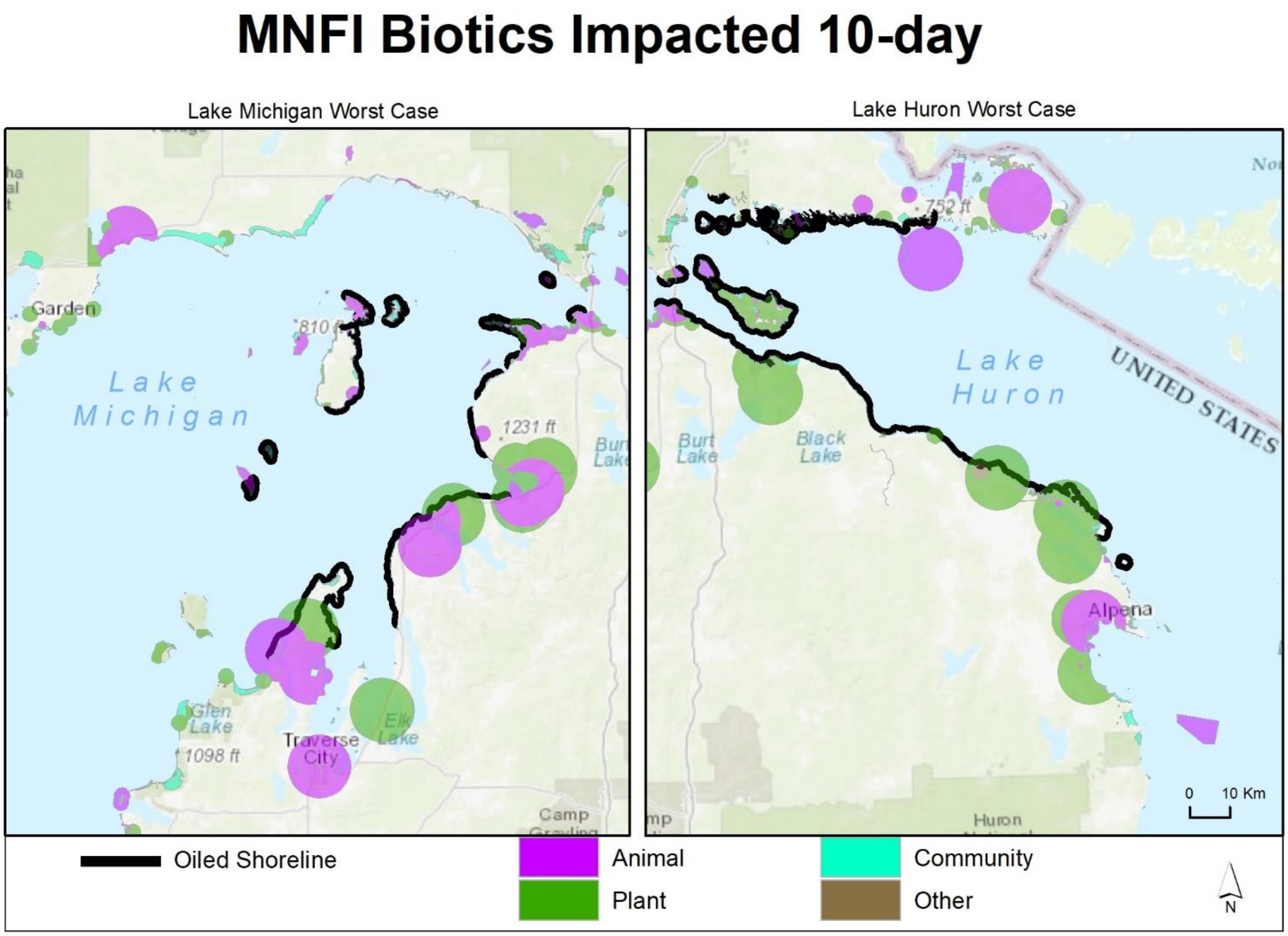

Figure E6. Distribution of unique terrestrial community complexes (highlighted in green) identified by MNFI's biotic database at risk in the Mackinac Straits and surrounding areas relative to the 10-day oil dispersal scenario (see Table E4 for descriptions of habitats).

Table E4. Michigan's natural communities at risk following a rupture in the Line 5 pipeline in the Mackinac Straits (see Figure E6). The Table describes the habitat, the approximate acreage at risk of exposure, the state rank of importance, location by county and importance to ecological resources located in coastal habitats of Lakes Michigan and Huron that are most vulnerable to oil exposure following rupture of the Line 5 pipeline in the Mackinac Straits.

Classification	Description	Acreage	State Rank	Prevalent County	Importance
Alvar	grass- and sedge-dominated community	1715	S1	Chippewa	Beaver; Eastern Massasauga Rattlesnake; Houghton's Goldenrod
Coastal Boreal Forest	conifer or conifer-hardwood forest type occurring on moist to dry sites	3082	S3	Alpena; Presque Isle; Cheboygan; Emmet; Mackinac, Chippewa; Schoolcraft, Delta	Critical feeding, roosting, and perching habitat for migrating shorebirds and waterfowl
Coastal Fen	sedge- and rush-dominated wetland that occurs on calcareous substrates	381	S2	Alpena; Presque Isle; Mackinac; Emmet; Charlevoix	Houghton's Goldenrod; Wading and Raptor bird species
Great Lakes Barrens	coniferous savanna community of scattered and clumped trees, and an often dense, low or creeping shrub layer	182	S2	Mason	Pitcher's Thistle
Great Lakes Marsh	herbaceous wetland community occurring statewide along the shoreline of the Great Lakes and their major connecting rivers	7262	S3	Menominee; Delta; Schoolcraft; Mackinac; Chippewa; Manistee; Leelanau; Emmet; Cheboygan; Presque Isle; Alpena; Arenac; Bay	Important habitat for insects, fish, waterfowl, water birds, and mammals
Interdunal Wetlands	rush-, sedge-, and shrub-dominated wetland situated in depressions within open dunes or between beach ridges	276	S2	Menominee; Delta; Schoolcraft; Mackinac; Chippewa; Manistee; Leelanau; Emmet; Cheboygan; Presque Isle; Alpena; Arenac; Bay; Charlevoix; Benzie; Alcona; Iosco	Important feeding areas for migrating shorebirds and waterfowl; Houghton's Goldenrod

Limestone Bedrock Lakeshore	sparsely vegetated natural community dominated by lichens, mosses, and herbaceous vegetation	447	S2	Delta; Mackinac; Chippewa	Provides stopover and feeding corridors for migratory; Houghton's Goldenrod
Limestone Cobble Shore	cobble shore with sparse vegetation	529	S3	Delta; Mackinac; Chippewa	Rich in aquatic invertebrates including midges, stoneflies, and mayflies, prey for birds and fishes; Houghton's Goldenrod; Lake Huron Tansy
Open Dunes	grass- and shrub-dominated multi-seral community located on wind-deposited sand formations near the shorelines	6393	S3	Manistee; Benzie; Leelanau; Grand Traverse; Charlevoix; Emmet; Cheboygan; Mackinac	Important habitat and feeding areas for migrating and nesting shorebirds including Piping Plover and Tern spp.; Houghton's Goldenrod; Pitcher's Thistle
Rich Conifer Swamp	groundwater-influenced, minerotrophic, forested wetland dominated by northern white-cedar	1211	S3	Gogebic; Iron; Dickinson; Menominee; Delta; Schoolcraft; Mackinac; Chippewa; Cheboygan; Presque Isle; Alpena; Alcona; Iosco; Arenac; Emmet; Charlevoix; Antrim; Grand Traverse; Leelanau; Benzie; Manistee	Provide critical habitat for terrestrial mammals and bird species.
Sand and Gravel Beach	high levels of disturbance, typically quite open, with sand and gravel sediments and little or no vegetation	47	S3	Gogebic; Iron; Dickinson; Menominee; Delta; Schoolcraft; Mackinac; Chippewa; Cheboygan; Presque Isle; Alpena; Alcona; Iosco; Arenac; Emmet; Charlevoix; Antrim; Grand Traverse; Leelanau; Benzie; Manistee	Sand beaches are favorite feeding grounds for shorebirds including the Piping Plover. Gravel beaches, especially on islands, are used by nesting gulls, terns, cormorants, and other waterbirds.
Wooded Dune and Swale Complex	large complex of parallel wetland swales and upland beach ridges (dunes) found in coastal embayments and on large sand spits along the shorelines	39643	S3	Leelanau; Emmet; Delta; Schoolcraft; Mackinac	Foraging area for raptors and shorebirds.

S1: Critically imperiled in the state because of extreme rarity (often five or fewer occurrences) or because of factor(s) such as very steep declines making habitat vulnerable to extirpation; *S2*: Imperiled in the state because of rarity due to very restricted range, very few occurrences (often 20 or fewer), steep declines, or other factors making it very vulnerable to extirpation from the state; *S3*: Vulnerable in the state due to a restricted range, relatively few occurrences (often 80 or fewer), recent and widespread declines, or other factors making it vulnerable to extirpation.

Coastal Wetlands and Dunes

Great Lakes coastal wetlands are defined as an area of wetland directly influenced by the waters of one of the Great Lakes or its connecting channels. Great Lakes coastal wetlands are found throughout the basin, along shorelines, in the mouths of tributaries, and along connecting channels. There are more than 202,342.8 hectares (500,000 acres) of coastal wetlands across the Great Lakes basin. Seventy percent of the Great Lakes coastal wetlands are located within the United States, of which 73% are in the state of Michigan (Bourgeau-Chavez et al., 2008). Wetlands support many beneficial ecological functions, as well as economic and cultural values. They play an important role in the Great Lakes ecosystem, providing habitat for many plant and animal species, hydrologic retention, nutrient cycling, shoreline protection, and sediment trapping.

The dominant wetland habitat in the Mackinac Straits is classified as other/mixed (Figure E7). This classification includes all peatland, shrub, and forested wetland, as well as mixed emergent and wet-meadow wetlands. Also, at risk are areas identified as wetland monocultures, dominated by species such as *Typha*, *Phragmites*, and *Schoenoplectus* (Figure E7). These monocultures are common to disturbed areas and are less important to wildlife.

The Great Lakes basin contains the largest freshwater dune complex in the world with ~111,288.6 hectares (275,000 acres) of dune formations located in Michigan alone. Coastal dune areas are ecologically unique and support a diversity of plants and wildlife. Habitat for many diverse plants and animals, including rare or endangered species (MNFI, 2018), such as:

- The Piping Plover, which nests along the dunes' gravel and sand beaches, is federally listed as endangered.
- Lake Huron Tansy, Houghton's Goldenrod, and Pitcher's thistle plant are listed as threatened; the Pitcher's thistle thrives only on wind-swept open dunes, requires up to eight years to produce seed, and is found nowhere else in the world.
- One of Michigan's rarest insects, the Lake Huron locust, thrives in sparsely vegetated dune systems and relies on the dunes' natural processes.

E.3.3.2 Plants and Plankton

A Straits of Mackinac Line 5 oil spill impact shoreline, littoral, floating and submerged aquatic vegetation and phytoplankton, which form the base of the food web.

Submerged Aquatic Vegetation

Submerged Aquatic Vegetation (SAV) provides several ecosystem important services in Great Lakes nearshore habitats including juvenile and adult habitat for commercially and recreationally important fishes, foraging habitat for waterfowl, and nutrient retention (Angradi, Pearson, Bolgrien, Bellinger, & Starry, 2013). The SAV in the Great Lakes is predominantly *Cladophora*, with localized areas of vascular plants, other filamentous algae, and diatoms.

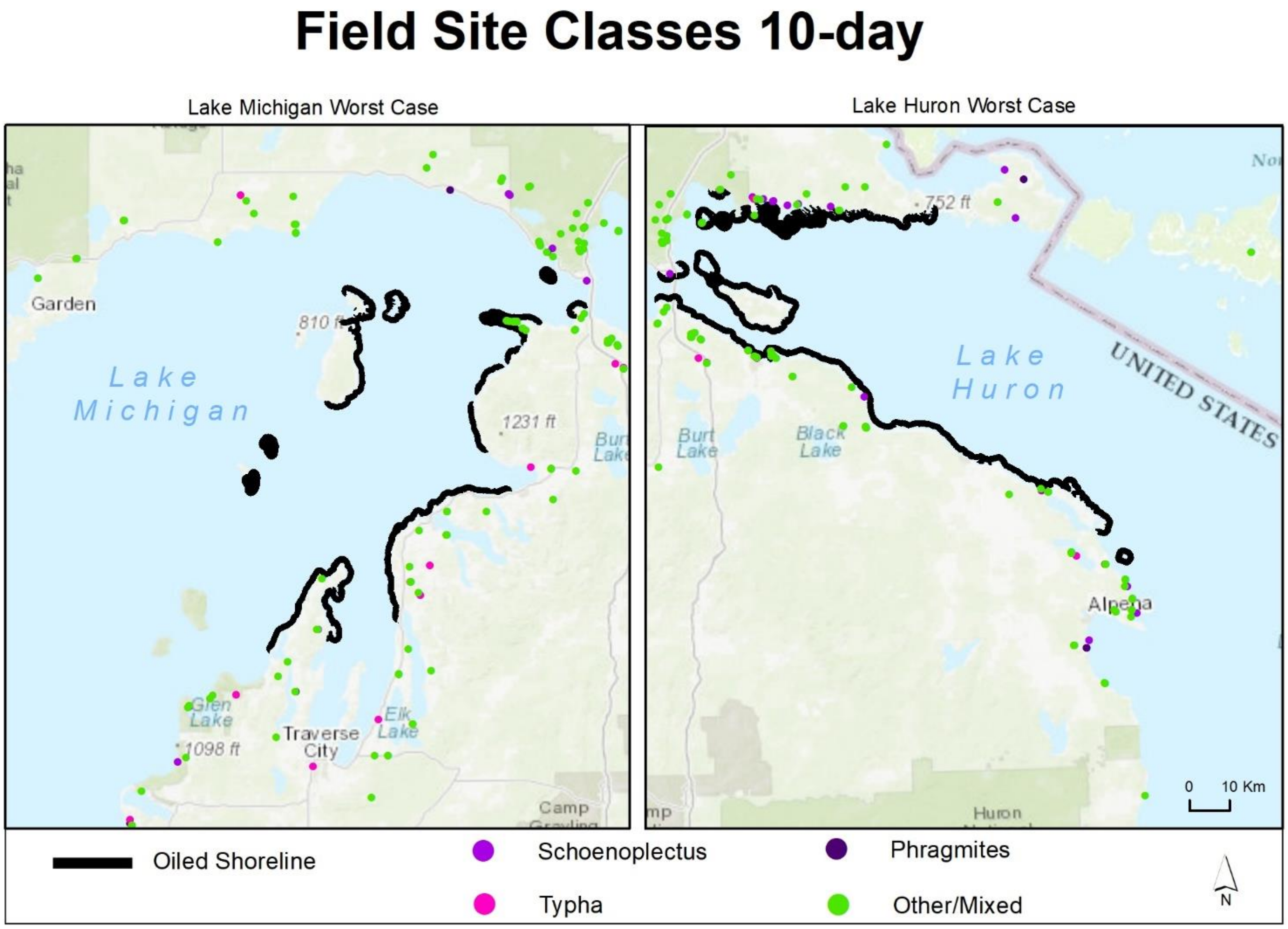

Figure E7. Map of field data locations, color-coded by dominant cover type (from Bourgeau-Chavez et al., 2008)

Cladophora is a native, filamentous, green alga that grows attached to solid substrate. SAV in Mackinac Straits is comprised of large areas of relatively low density (Figure E8), interspersed with dense patches. These dense patches of concentrated growth have been identified in the north end of Lake Michigan, specifically west of the Straits in Grays Reef Passage near Simmons Island, Beaver Island, and on Dahlia Shoal (Figure E8). Low-density SAV beds have been mapped along shoreline areas of South Channel and in Hammond Bay in Lake Huron (Figure E8). Low-density SAV beds located in areas within the Straits are at highest risk from oil following a rupture in Line 5 pipeline (Figure E8).

Physical smothering of plant tissue reducing photosynthesis, application of oil to soils, and repeated, heavy exposure is detrimental to plant productivity (Judy, Graham, Lin, Hou, & Mendelssohn). The effects of oil on submerged vegetation (such as *Cladophora* and other subtidal, freshwater species), however, remain untested. Moreover, in the Great Lakes, SAV species are seasonal and field studies to understand disappearance are difficult to design without controlled, manipulative experimentation. There is no published data available on toxicity and population-level impacts of oil exposure on SAV. One study on the impact of oiled sediment exposure on the seagrass species, *Ruppia maritima*, found no differences in growth but decreases in reproductive output and root morphology, with an associated decrease in sediment cohesion following oiling (Martin, Hollis, & Turner, 2015) resulting in lost productivity.

Plankton

Plankton are major components of the water column and include both photosynthesizing phytoplankton (producers) and zooplankton (consumers).

Oil has repeatedly been found to affect phytoplankton through both laboratory and field studies (Ozhan, Parsons, & Bargu, 2014), with evidence of death and lost productivity. Bender et al. (1977) exposed the phytoplankton community off the coast of Virginia to

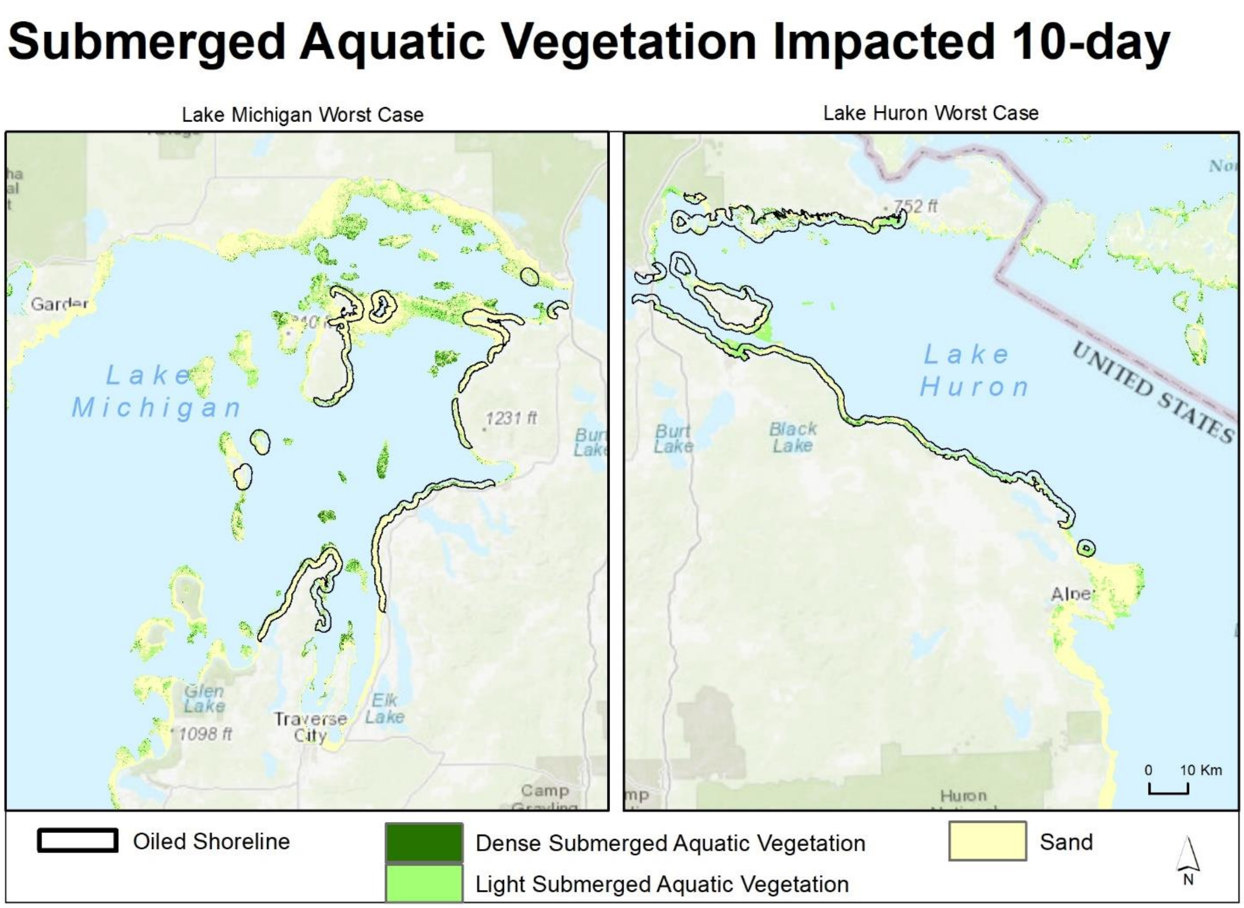

Figure E8. Location and density of submerged aquatic vegetation within and adjacent to Mackinac Straits derived from MTRI's classification relative to oiling following the 10-day scenario.

fresh and weathered South Louisiana crude oil. The observed a decrease in phytoplankton productivity and density relative to controls within the first day of addition in both treatments. Recovery time differed among treatments but occurred within about one week. Glide and Pinckney (2012) exposed a phytoplankton community from South Carolina, to both Macondo and a Texas crude oil. They bserved decreased chlorophyll concentrations and productivity relative to control concentrations within 33 h. Thus, both studies indicated decreases in phytoplankton over a short period of oil exposure. It is difficult to generalize on individual species and community sensitivities to oil and its components, particularly for Great Lakes assemblages. For example, diatom densities decreased in some studies and were resistant in others (Parsons, Morrison, Rabalais, & Turner, 2015). While initial decreases in community biomass would be likely, potential for recovery is expected to be relatively rapid, given reproduction and growth rates.

Zooplankton plays a vital role as a food source for a variety of higher trophic level organisms (e.g., fish, birds). They also cycle nutrients through the food web by converting lower trophic level plant resources (e.g., photosynthesizing phytoplankton) into food for higher trophic levels. Zooplankton may be exposed to oil products floating on the surface (Cormack, 1999), to oil droplets formed within the water column (Almeda, Wambaugh, Wang, Hyatt, Liu, & Buskey. 2013), and to hydrocarbon byproducts resulting from the dissolution of spilled oil (Bellas, Saco-Álvarez, Nieto, Bayona, Albaigés, & Beiras, 2013). Zooplankton can absorb or ingest oil and toxic components, such as PAHs, can be passed on to fish or birds that eat them.

E.3.3.3 Invertebrates

Invertebrate species play key roles in both terrestrial and aquatic food webs because they serve as food for birds, fish, and other species. Invertebrates occupy shoreline, wetland, coastal dunes, littoral (near shore) and deep-water habitats. Given their vast distribution in habitats, in and adjacent to the Straits area, and their importance to the food web, their susceptibility to oil has consequences for all parts of the ecosystem, albeit very little is known regarding oil spill impacts on this broad category of organisms.

Aquatic Invertebrates

Oil adheres to sediments and floating particles that can be carried to the bottom of both deep-water and shoreline environments. Sediment-dwelling invertebrate species such as Mollusks, Crustaceans, and Annelids that contact oiled particles or surfaces would be vulnerable to being smothered by oil or to other acute or chronic effects. Depending upon the oil constituents and concentration of PAHs, spilled oil can persist for decades in the sediments, directly affecting the benthic invertebrates. As a result, significant food web issues (i.e., a lack of food for each higher trophic level and/or increased toxicity as organisms store toxins in fatty issues) occur over chronic periods of time as some organisms' bioaccumulate and increase the toxins in their tissues (Figure E9).

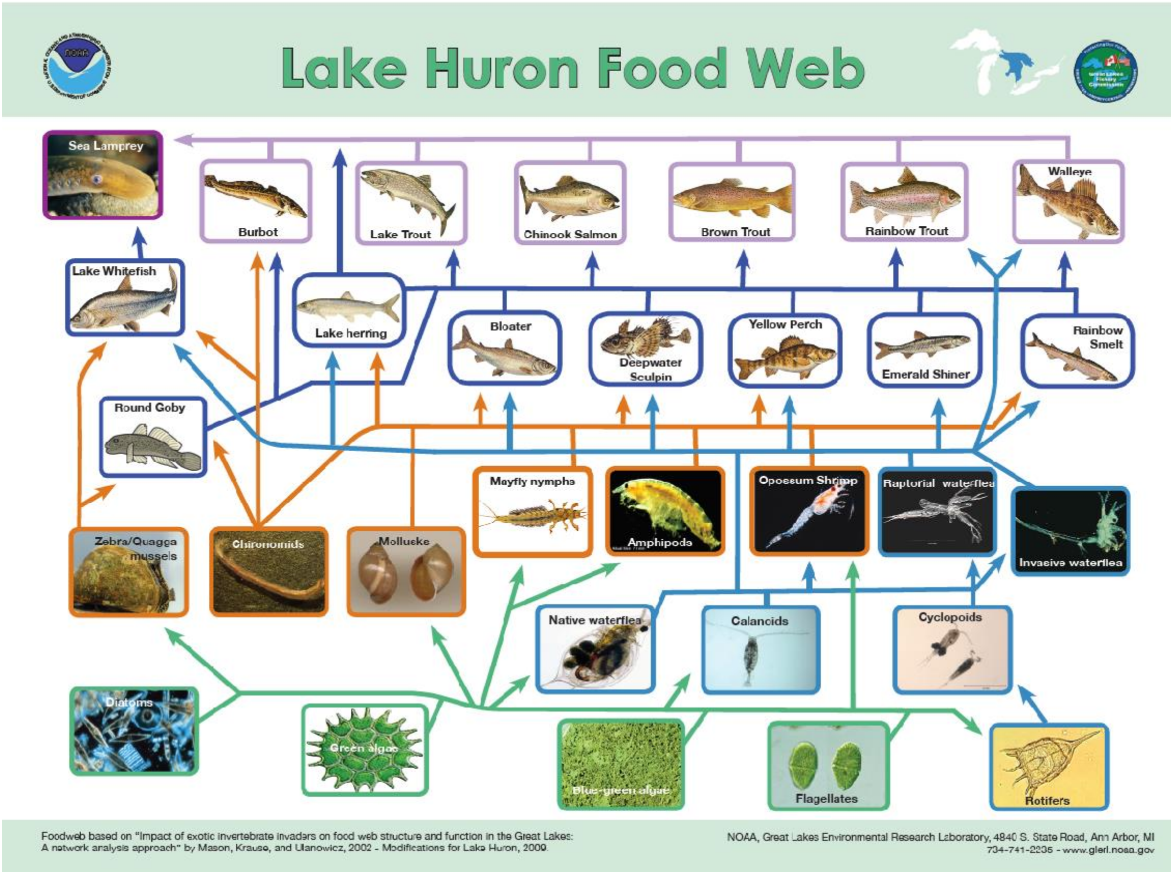

Figure E9. Aquatic food web of Lake Huron depicting the importance of food web connections between aquatic invertebrates and higher trophic level fishes (NOAA, 2009). Piscivorous birds such as loons, mergansers, eagles, and osprey would add another trophic level above the fish.

Mollusks

With 125 species of bivalves occurring in the Laurentian Great Lakes (GLERL, 2018), mollusks play a vital role in the ecosystem. These organisms create habitat beds providing shelter and food for many higher-level organisms and help prevent coastal erosion (Beck et al., 2009). Bivalves are especially susceptible to oil because they ingest contaminated particles through filter feeding.

In some ecosystems, mussels are the keystone species because of their high capacity to reproduce producing food for other organisms. Dreissenids, for example, zebra and brown mussels, have become so dominant that in many locations they cover a large part of the bottom of many lakes, including Lakes Michigan and Huron. Mollusks also have very strong filtering capacities which are beneficial in a 'healthy' ecosystem, but an oil-polluted environment poses problems due to their ability to trap toxins for weeks, months, years, and even decades (Carls & Harris, 2005). Sundt et al. (2011) report that accumulated toxins in mussel populations can be higher than their surrounding environment. Ingested toxins like PAH's are retained on their gills and absorbed and deposited in fatty tissues limiting feeding and growth rates (Culbertson, Valiela, Olsen, & Reddy, 2008), reducing or eliminating immunity (Hannam, Bamber, Galloway, Moody, & Jones, 2010), and weakening their ability to use byssal threads for attachment (Lindén, 1977). Banni et al. (2010) suggest that oil exposure causes DNA damage to occur within the first 48 hours and continued prolonged exposure beyond 72 hours is much more severe causing greater physiological damage. Thomas et al. (1999), however, suggests that some mussels are capable of withstanding acute responses to oil, but chronic exposures result in serious negative survival consequences (i.e., death). Culbertson et al. (2008) report that chronic oil spill exposure not only has severe negative consequences on mussels (and the benthos) over time but that exposure will affect food webs, such that species who feed on the mussels will either be poisoned or alternatively, as the mussels die, so does their food source.

Gastropods [e.g., freshwater limpets (Ancylidae), pond snails (Physidae, Lymnaeidae)] reside in the benthos inhabiting nearshore intertidal and/or estuarine ecosystems, some have both benthic and planktonic life stages feeding on dead plant/animal matter, algae, or preying on other animals (Blackburn, Mazzacano, Fallon & Black, 2014). Two species of terrestrial snails identified by MNFI's biotics data have a conservation status of special concern in Michigan, the Spike-Lip Crater and the Eastern Flat-Whorl. Both species occupy wetland and coastal habitats and would be vulnerable to spilled oil.

Crustaceans [e.g., Amphipods (e.g., Diporeia), Isopods, Mysidacea (opossum shrimp), Decapods, Anostaca (fairy shrimp), Cladocera, Copepods, and Ostracods (seed shrimp)] (GLERL, 2018). Many crustaceans in the Great Lakes and specifically Lake Michigan (e.g., *Diporeia*) span the shallow estuaries to the deep-water environments.

Crustaceans are a key component in many deep-water benthic habitats (e.g., *Diporeia* was once dominant but has markedly declined in abundance). They typically scavenge dead and decaying matter and become food for higher trophic levels such as benthic fishes (Cave & Strychar, 2014). Crustaceans play a significant role in food webs, as prey for other invertebrates, fish, birds, and even mammals (Pauly, Christensen Dalsgaard, Froese, & Torres, 1998; Rasmuson, 2012). Oil spill events cause long-term harm to this group of organism, and have resulted in drastic die-offs lasting six or more years (Sanders et al., 1980; Elmgren, Hansson, Larsson, Sundelin & Boehm, 1983; Jewett & Dean, 1997).

Recolonization by crustaceans is very slow, sometimes taking over a decade to reach pre-spill levels (Dauvin, 1989). Surviving females may produce abnormal larvae (Elmgren, Hansson, Larsson, Sundelin & Boehm, 1983). Molisani et al. (2013) reported that amphipod populations are especially sensitive to pollution, possibly due to low dispersal rates, limited mobility, and the lack of a planktonic life stage. In laboratory studies, acute 48-hour toxicity trials showed that their larvae were nearly 700 times (LC_{50}= 0.8 µl/L) more sensitive than the adults (LC_{50}= 550 µl/L). In Lakes Michigan and Huron, *Diporeia* populations have crashed since 2002 (Burlakova et al., 2018); their demise may be a delayed response to cumulative pollution and/or disease in the Great Lakes drainage basin, weakening their immune systems while reducing/retarding their feeding and reproductive potential (Cave & Strychar, 2014). Dauvin (1989, 1998) reports that the loss of such a group (e.g., *Diporeia*) has detrimental long-term consequences that usually go unnoticed until crashes are observed in higher trophic levels.

Annelids [Hirundinea (leaches), Polychaetes (e.g., Manayunkia sp.), Oligochaetes, Nematoda (roundworms), Nematomorpha (horsehair worms), Nemertea (ribbon worms), Platyhelminthes (flatworms)] (GLERL, 2018). These are some of the most common and abundant organisms in coastal and estuarine ecosystems. Their response to oil spills is very different compared to crustaceans. Some species of Annelids are immediately and negatively affected by oil exposure while others actually show short-term benefits (Peterson et al., 1996).

Driscoll and McElroy (1997) report that some annelids can contribute to the biodegradation of spilled oil, as was observed during the Exxon Valdez oil spill in Prince William Sound (Alaska). Laubier (1980) similarly reported that some polychaetes can tolerate very high levels of PAHs and have been observed actively feeding while other organisms are dying. Because of the lack of research on the topic of oil and impact on annelids, it is difficult to know which of these groups would biodegrade oil.

Ciliophora (ciliates), Rhizopoda (amoebae), Porifera (sponges), Coelenterates (Hydra), Rotifera (rotifers), Tardigrada (water bears), Entoprocta, Ectoprocta (Bryozoans) (GLERL, 2018). Protozoans as a group are highly diverse ranging from plant-like (i.e., the ability to photosynthesize), animal-like (i.e., absorbing nutrients from their surroundings or consuming other organisms), mixotrophic, and even parasitic. As a group, some are mobile while others are sessile. GLERL (2018) report that they have recently been recognized as a "critical link" in the microbial food web. The effects of oil pollution on these groups are both acute and chronic, severe and wide-ranging. When death is not immediate, growth rates, reproduction, and feeding are significantly reduced.

Oil can cause immediate death of these organisms, or it may severely retard growth rates, reproduction, and feeding. Species that survive experience chronic (decades-long) difficulty with recruitment, colonization, and larval development, and in some instances, altered behavior (Blackburn, Mazzacano, Fallon & Black, 2014). Since several of these species contribute to the building blocks of many food webs and food chains, the direct impacts of oil pollution on their existence has detrimental effects on higher trophic levels (e.g., fish, birds), further altering the community and ecosystem.

<u>Insects</u>

Similar to benthic invertebrates, terrestrial insects in wetland and shoreline habitats are essential to maintaining healthy breeding mammal and bird populations. Despite their importance to food webs, insects are often overlooked in environmental oiling scenarios. The larvae of aquatic insects and their immature forms can be present in the benthos, the plankton community, the shallow sediments along the shoreline, and on shoreline vegetation. Insects at every stage of development serve as valuable, high-quality food resources for higher trophic levels.

Michigan is home to thousands of species of terrestrial and aquatic insects, including numerous insect families in the orders (Aquatic Insects of Michigan, http://aquaticinsects.org/index.html):

- Coleoptera
- Diptera
- Ephemeroptera
- Heteroptera
- Hymenoptera
- Lepidoptera
- Megaloptera
- Neuroptera
- Odonata
- Orthoptera
- Plecoptera
- Trichoptera

Several species with conservation status have been documented along the coastlines of the Straits and the waters of northern Lakes Michigan and Huron (Table E5).

Table E5. Insect species in coastal habitats of Lakes Michigan and Huron that are most vulnerable to oil exposure following rupture of the Line 5 pipeline in the Mackinac Straits.

Name		**Conservation Status**				**Habitat**
Common	**Species**	**IUCN**	**CITES**	**US**	**MI**	**Requirements**
Hungerford's Crawling Water Beetle	*Brychius hungerfordi*	-	-	E	E	Streams
Hine's Emerald Dragonfly	*Somatochlora hineana*	NT	-	E	E	Wetlands
Incurvate Emerald Dragonfly	*Somatochlora incurvata*	LC	-	LT	SC	Wetlands
Lake Huron Locust	*Trimerotropis huroniana*	-	-	-	T	Sand Dunes
Aweme borer	*Papaipema aweme*	-	-	-	SC	Wetlands

These aquatic insects either spend part of their life cycles in the water column, the sediments at depth or along the shoreline, or are adapted for carrying out certain life requirements in the aquatic environment, such as hunting food.

It is our assessment that any larvae, pupae, or adult insects directly exposed during the initial release, or the first few days following a light crude oil release, will likely be killed immediately or within a few days of exposure. Those on the fringes of the release or re-inhabiting the benthos, shorelines, or reeds, following the initial impacts, will then be subjected to sub-lethal yet chronic impacts due to ingestion and absorption of residual oil phases, such as slowly dissolving, desorbing, and weathering PAHs. The impacts that ingestion of these insect life stages will have on the other trophic levels are not fully elucidated, but it is certain that the effects will be negative.

E.3.3.4 Reptiles and Amphibians

A total of 55 species of reptiles and amphibians are resident in the state of Michigan (Michigan Herp Atlas, 2018). Of that total, there are 38 species of reptiles and amphibians in the counties adjacent to and surrounding the Mackinac Straits (Phillips, 2016), and these species are listed in Table E8. Of these species, Blanding's Turtle and the Eastern Massasauga Rattlesnake have state, federal, and international conservation status (MNFI, 2018). These species also happen to be associated with wetland habitats surrounding and adjacent to the Mackinac Straits (MNFI, 2018). Other species of conservation concern in Michigan include the Eastern Box Turtle, Fowler's Toad, Mudpuppy, Pickerel Frog, Spotted Turtle and Wood Turtle (Table E8). However, only the Fowler's Toad has been observed in habitats (i.e., dunes) that are within the zone of exposure.

The Michigan reptiles and amphibians most vulnerable to a Line 5 pipeline rupture and subsequent oil spill would be those associated with wetland and dune habitats (Michigan Herp Atlas, 2018; Michigan DNR, 2018). These include Blanding's Turtle, Cope's Gray Treefrog, Eastern American Toad, Eastern Massasauga Rattlesnake, Eastern Red-Backed Salamander, Fowler's Toad, Gray Treefrog, Painted Turtle, Pickerel Frog and Spotted Salamander (Table E9). For the amphibians, uptake through the skin is particularly important (Smith et al., 2007), especially in the presence of ultraviolet light, which may increase PAH toxicity (Malcolm & Shore, 2003).

Relatively few field studies of toxicity link physiological consequences with amphibian and reptile exposure to PAHs. Aside from coping with reduced habitat quality, individuals may be faced with increased intra- and interspecific competition in new habitats. For example, a West African black turtle species (*Pelusios niger*) that changed its habitat use following an oil spill in the Niger Delta experienced increased competition with a congener (*Pelusios castaneus*) already resident in the new habitat (Luiselli, Akani, & Politano, 2006). Similar ecological and physiological effects identified for fishes and birds may be expected in amphibians and reptiles, but these remain poorly studied.

Table E8. Reptile and Amphibian species in the State of Michigan that are most vulnerable to oil exposure following rupture of the Line 5 pipeline in the Mackinac Straits given their use of areas adjacent to and surrounding the Mackinac Straits.

Name		Conservation Status				Habitat	
Common	**Species**	**IUCN**	**CITES**	**US**	**MI**	**Lakes**	**Biome**
Blanding's Turtle	*Emydoidea blandingii*	E	II	UR	SC	both	Wetlands
American Bullfrog	*Lithocates catesbeiana*	LC	-	-	-	both	Wetlands; Lake
Blue-Spotted Salamander	*Ambystoma laterale*	LC	-	-	-	both	Woodland Ponds
Brown Snake	*Storeria dekayi dekayi*	LC	-	-	-	both	Wetlands; Woody
Cope's Gray Treefrog	*Hyla chryocelis*	LC	-	-	-	both	Wetlands; Ponds
Eastern American Toad	*Bufo americanus*	LC	-	-	-	both	Wetlands; Woody
Eastern Box Turtle	*Terrapene carolina*	NT	II	-	SC	Michigan	Forest
Eastern Fox Snake	*Pantherophis gloydi*	NT	-	-	T	both	Forest
Eastern Garter Snake	*Thamnophis sirtalis*	LC	-	-	-	both	Forest
Eastern Massasauga Rattlesnake	*Sistrurus catenatus catenatus*	V	-	T	SC	both	Wetlands; Woody
Eastern Milksnake	*Lampropeltis triangulum*	LC	-	-	-	both	Streams
Eastern Newt	*Notophthalmus viridescens*	LC	-	-	-	both	Wetlands
Eastern Red-Backed Salamander	*Plethodon cinereus*	LC	-	-	-	both	Wetlands
Eastern Snapping Turtle	*Chelydra serpentina*	LC	-	-	-	both	Ponds
Five-Lined Skink	*Plestiodon fasciatus*	LC	-	-	-	both	Forest
Four-Toed Salamander	*Hemidactylium scutatum*	LC	-	-	-	both	Forest
Fowler's Toad	*Anaxyrus fowleri*	LC	-	-	SC	Michigan	Dunes
Gray Treefrog	*Hyla versicolor*	LC	-	-	-	both	Wetlands; Ponds

Green Frog	*Lithobates clamitans*	LC	-	-	-	both	Wetlands; Ponds
Mink Frog	*Lithobates septentrionalis*	LC	-	-	-	both	Wetlands; Ponds
Mudpuppy	*Necturus maculosus*	LC	-	-	SC	both	Wetlands; Ponds
North American Racer	*Coluber constrictor*	LC	-	-	-	Michigan	Grassland
Northern Leopard Frog	*Lithobates pipiens*	LC	-	-	-	both	Wetlands; Ponds
Northern Red-Bellied Snake	*Storeria occipitomaculata*	LC	-	-	-	both	Wetland; Forest
Northern Ribbon Snake	*Thamnophis septentrionalis*	LC	-	-	-	both	Wetlands
Northern Ring-Necked Snake	*Diadophis punctatus*	LC	-	-	-	both	Grassland
Northern Water Snake	*Nerodia sipedon*	LC	-	-	-	both	Wetlands; Lakes
Painted Turtle	*Chrysemys picta*	LC	-	-	-	both	Wetlands
Pickerel Frog	*Lithobates palustris*	LC	-	-	SC	both	Wetlands
Red-Eared Slider	*Trachemys scripta elegans*	LC	-	-	-	both	Wetlands
Smooth Green Snake	*Opheodrys vernalis*	LC	-	-	-	both	Wetlands
Spiny Softshell	*Apalone spinifera*	LC	-	-	-	Michigan	Ponds
Spotted Salamander	*Ambystoma maculatum*	LC	-	-	-	both	Wetlands; Ponds
Spotted Turtle	*Clemmys guttata*	V	-	-	T	both	Forest
Spring Peeper	*Pseudacris crucifer*	LC	-	-	-	both	Wetlands
Western Chorus Frog	*Pseudacris triseriata*	LC	-	-	-	both	Wetlands
Wood Frog	*Lithobates sylvatica*	LC	-	-	-	both	Ponds
Wood Turtle	*Glyptemys insculpta*	V	II	-	SC	both	Streams

Note: Conservation Status Listings: IUCN designations: LC – Least Concern, V – Vulnerable, NT – Near Threatened; CITES designations: I – Appendix I, II – Appendix II; US designations: D – Delisted, T – Threatened, E – Endangered; MI designations: SC – Special Concern, T – Threatened, E – Endangered. No designations (-).

E.3.3.5 Fish

The waters of Lakes Michigan, Huron, and their associated tributaries are home to a large diversity of ecologically, commercially, and recreationally important fish species. Using the NOAA ESI, MNFI biotic data, and GLAHF spawning index, 40 fish species have been identified in areas adjacent to and surrounding the Mackinac Straits, 35 of which can be found in Lake Michigan waters and 36 in Lake Huron waters (Table E6).

A number of these fish species have conservation status. Those species with status under Endangered Species Act (ESA) include Burbot, Coho, Chinook, Rainbow Trout and the Long-Nose Sucker (Table E6). An additional four species have conservation status in the state of Michigan, two of which are generally associated with tributaries, the Channel Darter and Pugnose Shiner, and two that prefer cooler open water habitats, the Cisco and Lake Sturgeon. Both Cisco and Lake Sturgeon spawn in the Straits area. The Michigan DNR has identified spawning locations for Lake Sturgeon in river tributaries of both Lakes, including the Cheboygan, Carp, Milleconquins, Manistique, and Manistee Rivers; all areas that are vulnerable to an oil spill. It is important to note that many of the fish species in the Lakes are species that migrate up rivers to spawn and include trout and salmonids. Important fish spawning habitat in the Straits have been identified for other species, including Alewife, Rainbow Smelt, and Walleye (Table E6).

Given that oil from a Line 5 rupture will contaminate the sediments on the bottom of the lakes, and the shorelines, fish that are more benthic (bottom dwellers) and fish in the near-shore littoral zone will have higher exposure and have more adverse health impacts than fish found offshore in the water column. Eggs and larvae, the most sensitive fish life stages, will suffer the highest mortalities and longer-term population level decreases resulting from a reduction in survival.

<u>Exposure to Oil</u>

Historically, two main types of fish assemblages existed across the Great Lakes. In the deeper and less productive open waters, the fish assemblage mainly consisted of salmonids and coregonids (Collingsworth et al., 2017; Table E6) and includes whitefish and ciscoes, grayling, and char, trout, and salmons. In shallow and more productive embayment area, such as Green Bay and Saginaw Bay the fish assemblage consisted mainly of percids, cyprinids, and centrarchids (Collingsworth et al., 2017; Table E6).

Early-life stages of fish are particularly sensitive to oil exposure and suffer the highest mortality and health impacts. Eggs and larvae are the most sensitive fish stages to be affected by exposure to oil, since they drift passively in water and cannot move away from oil while adult fish can swim away. Eggs and larvae are also often in locations that have the most severe exposures, such as near the water surface and on the bottom of the lake in shallow nearshore areas (Barron & Ka'aihue, 2001; Dupuis & Ucan-Marin, 2015). Thus, eggs and larvae located near oiled shorelines would suffer high mortalities.

If fish eggs or larvae are present when oil is spilled and contact the oil before the BTEX fraction evaporates (24 hours to 6 days), they would be subject to rapid BTEX-induced narcosis. Narcosis is the end result of acute toxicity from many biochemical reactions that cause disruption of central nervous system functions due to lipid-soluble hydrocarbons

Table E6. Fish species in Lakes Michigan and Huron that are most vulnerable to oil exposure following rupture of the Line 5 pipeline in the Mackinac Straits.

Name		**Conservation Status**				**Commercial Value**			**Characteristics**						
Common	**Species**	**IUCN**	**CITES**	**US**	**MI**	**Fisheries**	**Aquaculture**	**Recreation**	**Lake**	**Pelagic**	**Littoral**	**River**	**Season**	**Habitat**	**Migratory**
Alewife	*Alosa pseudoharengus*	LC	-	-	-	X			B		X		Su	Cold shoreline	RB
Black Crappie	*Pomoxis nigromaculatus*	LC	-	-	-			X	H		X		Sp	Intermediate shoreline	R
Bloater	*Coregonus hoyi*	V	-	-	-				M	X			Sp	Deep cold	RB
Bluegill	*Lepomis macrochirus*	LC	-	-	-			X	B		X		Sp	Warm shoreline	R
Brook Trout	*Salvelinus fontinalis*		-	-	-			X	B	X	X	X	Sp	Cold open water	RB
Brown Trout	*Salmo trutta*	LC	-	-	-		X	X	B			X	Sp	Cold open water	R
Bullhead	*Ictalurus melas*	LC	-	-	-				H	X			Sp	Warm shoreline	RB
Burbot	*Lota lota*	LC	-	E	-			X	B		X		Sp	Deep cold	RB
Carp	*Cyprinus carpio*		-	-	-	X		X	B	X	X		Su	Warm shoreline	RB
Channel Catfish	*Ictalurus punctatus*	LC	-	-	-	X		X	B		X		Sp	Warm shoreline	RB
Channel Darter	*Percina copelandi*	LC	-	-	E				H			X	Sp	Cold shoreline	RB
Cisco	*Coregonus artedi*	LC	-	-	T	X		X	B		X		W	Deep cold	RB
Coho Salmon	*Oncorhynchus kisutch*	-	-	ET	-	X	X	X	B	X		X	Sp	Cold open water	R

Deepwater Sculpin	*Myoxocephalus thompsonii*	-	-	-	-			B		X		W	Deep cold	R
Emerald Shiner	*Notropis atherinoides*	-	-	-	-			B		X		Sp	Cold shoreline	R
Gizzard Shad	*Dorosoma cepedianum*	LC	-	-	-			B		X		Sp	Cold shoreline	RB
Chinook Salmon	*Oncorhynchus tshawytscha*	-	-	ET	-	X	X	B	X			Sp	Cold open water	R
Lake chub	*Couesius plumbeus*	LC	-	-	-			M			X	Sp	Cold open water	R
Lake Sturgeon	*Acipenser fulvescens*	LC	II	-	T			B		X		Su	Cold open water	RB
Lake Trout	*Salvelinus namaycush*	-	-	-	-	X	X	B		X		F	Cold open water	RB
Lake Whitefish	*Coregonus clupeaformis*	-	-	-	-	X	X	B		X		F	Cold open water	RB
Largemouth Bass	*Micropterus salmoides*	LC	-	-	-		X	B		X		Sp	Warm shoreline	RB
Longnose Dace	*Rhinichthys cataractae*	LC	-	-	-			M			X	Sp	Intermediate shoreline	RB
Longnose Sucker	*Catostomus catostomus*	LC	-	SU	-	X	X	B		X		Sp	Cold open water	RB
Muskellunge	*Esox masquinongy*	LC	-	-	-		X	B		X	X	Sp	Intermediate shoreline	RB
Northern Pike	*Esox lucius*	LC	-	-	-		X	B		X		Sp	Intermediate shoreline	RB
Pink Salmon	*Oncorhynchus gorbuscha*	-	-	-	-	X	X	M			X	Sp	Cold open water	R
Pugnose Shiner	*Notropis anogenus*	LC	-	-	E			H			X	Sp	Intermediate shoreline	R
Pumpkinseed	*Lepomis gibbosus*	LC	-	-	-		X	B		X		Sp	Warm shoreline	RB

Rainbow Smelt	*Osmerus mordax*	LC	-	-	-	X			B				Sp	Intermediate shoreline	R
Rainbow Trout	*Oncorhynchus mykiss*	-	-	ET	-		X	X	B	X	X		Sp	Intermediate shoreline	R
Rock Bass	*Ambloplites rupestris*	LC	-	-	-	X		X	H		X		Sp	Intermediate shoreline	RB
Round Whitefish	*Prosopium cylindraceum*	-	-	-	-	X			B		X		F	Cold open water	RB
Slimy Sculpin	*Cottus cognatus*	LC	-	-	-				B		X		W	Deep cold	RB
Smallmouth Bass	*Micropterus dolomieui*	LC	-	-	-			X	B		X		Sp	Warm shoreline	RB
Spottail Shiner	*Notropis hudsonius*	LC	-	-	-				B		X		Sp	Cold shoreline	RB
Walleye	*Stizostedion vitreum vitreum*	LC	-	-	-	X		X	B		X		Sp	Cold shoreline	RB
White Bass	*Morone chrysops*	LC	-	-	-			X	B		X	X	Sp	Warm shoreline	RB
White Sucker	*Catostomus commersoni*	LC	-	-	-	X		X	B			X	Sp	Intermediate shoreline	RB
Yellow Perch	*Perca flavescens*	LC	-	-	-	X		X	B		X		Sp	Intermediate shoreline	RB

Note: Conservation Status Listings: IUCN designations: LC – Least Concern, V – Vulnerable, NT – Near Threatened; CITES designations: I – Appendix I, II – Appendix II; US designations: D – Delisted, T – Threatened, E – Endangered; MI designations: SC – Special Concern, T – Threatened, E – Endangered. No designations (-). Migratory Status Listings: R – Resident, B – Breeding, M – Migratory Route.

getting into cell membranes and nervous tissue (Peterson et al., 2003). Eggs and larvae in contact with the oil slick on the lake surfaces are also at risk of becoming coated in oil. Oiling smothers and kills through obstruction of gas- and ion-exchange surfaces, ingestion of toxicants, or the loss of the epithelial mucus that protects fish from infections (Fodrie et al., 2014). For example, after the Exxon Valdez oil spill Brown et al. (1996) estimated that in the 1989 year class of Pacific Herring 40-50% of eggs were exposed to oil and 99% were killed on the oiled shores, resulting in reduction of over 40% of the expected total production of from Prince William Sound.

A rupture in Line 5 would impact spawning areas for a number of fish species, exposing early and adult life-stages to risk (Figure E10; Goodyear, Edsall, Dempsey, Moss, & Polanski, 1982). Reductions in growth, survivorship and sub-lethal impacts including cardiotoxicity, genotoxic damage, and cranial malformations similar to that observed in fish after the Exxon Valdez oil spill and in fish from other oil spills are expected.

Of the many components of oil, PAHs are considered the most toxic and cause adverse impacts over the duration of exposure. Physiological effects from exposure to PAHs as well as indirect and delayed effects that may affect populations have been shown to occur with exposure to PAHs. A wide range of fish species have been shown to be adversely affected by PAHs from oil. For example, adult fish have experienced changes in heart and respiratory rates, gill structural damage, enlarged liver, reduced growth, fin erosion, corticosteroid stress response, immunosuppression, impaired reproduction, increased external and decreased internal parasite burdens, behavioral responses, and a variety of biochemical, blood, and cellular changes (Carls, Rice & Hose, 1999; Albers, 2003; Fodrie et al., 2014; Incardona, Collier & Scholz, 2004; Incardona et al., 2005). These physiological changes from exposure to PAHs in oil are evident in fish in many oil spills, including from light crude oil (Conan, 1982; Law & Hellou, 1999).

Because PAHs can persist in subsurface sediments and physically protected reservoirs, PAHs can be biologically available for many years (Short et al., 2003). Thus, impacts from an oil spill to the physiology of fishes can persist for long periods, well after cleanup activities have ceased

Adult populations of fish decreased after eggs were exposed to oil. In a collection survey of 21 species of juveniles and adults one year after the Exxon Valdez oil spill, presence of oil was a significant predictor of reduced fish density in mid-intertidal areas (Barber, McDonald, Erickson, & Vallarino, 1995). It was concluded from Heintz et al. (2000) that local fish populations whose natal habitats are contaminated with PAHs at low parts per billion (ppb) levels can be expected to experience mortality during exposure, or reduced survivorship afterward. Longer term survivors will show reduced reproductive output at maturity (Heintz et al., 2000). Juvenile Pacific Herring exposed to water-soluble fractions of North Slope crude oil showed reduced swimming ability and reduced ability to recover after exhaustive exercise (Kennedy & Farrell, 2006). Locomotor capability is important for movements between habitats and is generally cited as a potential fitness parameter because of its direct impact on foraging success, predator-prey interactions, and dominance-hierarchy encounters (Kennedy & Farrell, 2006).

Because fish swim away from oil, oil-contaminated sediments may also alter adult fish habitat choices. Oil in anoxic sediments can be long-lasting (Teal & Horwath, 1984). Fish avoided the area containing heavy oil-contaminated sediments in the Burra Haaf (Shetland) after the Braer oil spill, and there was concern that a once-rich fishing ground for small deep water (demersal) trawlers and seine netters would be subsequently nonproductive (Goodlad, 1996). Fish eggs and larvae populations that are physically smothered by oil will be exposed to lethal doses and have high mortalities. Drifting eggs and larvae near fish spawning grounds that come in contact with the oil sheen are also at risk. The worst-case scenarios show fish spawning sites in Lake Michigan and Lake Huron that will be impacted by oil.

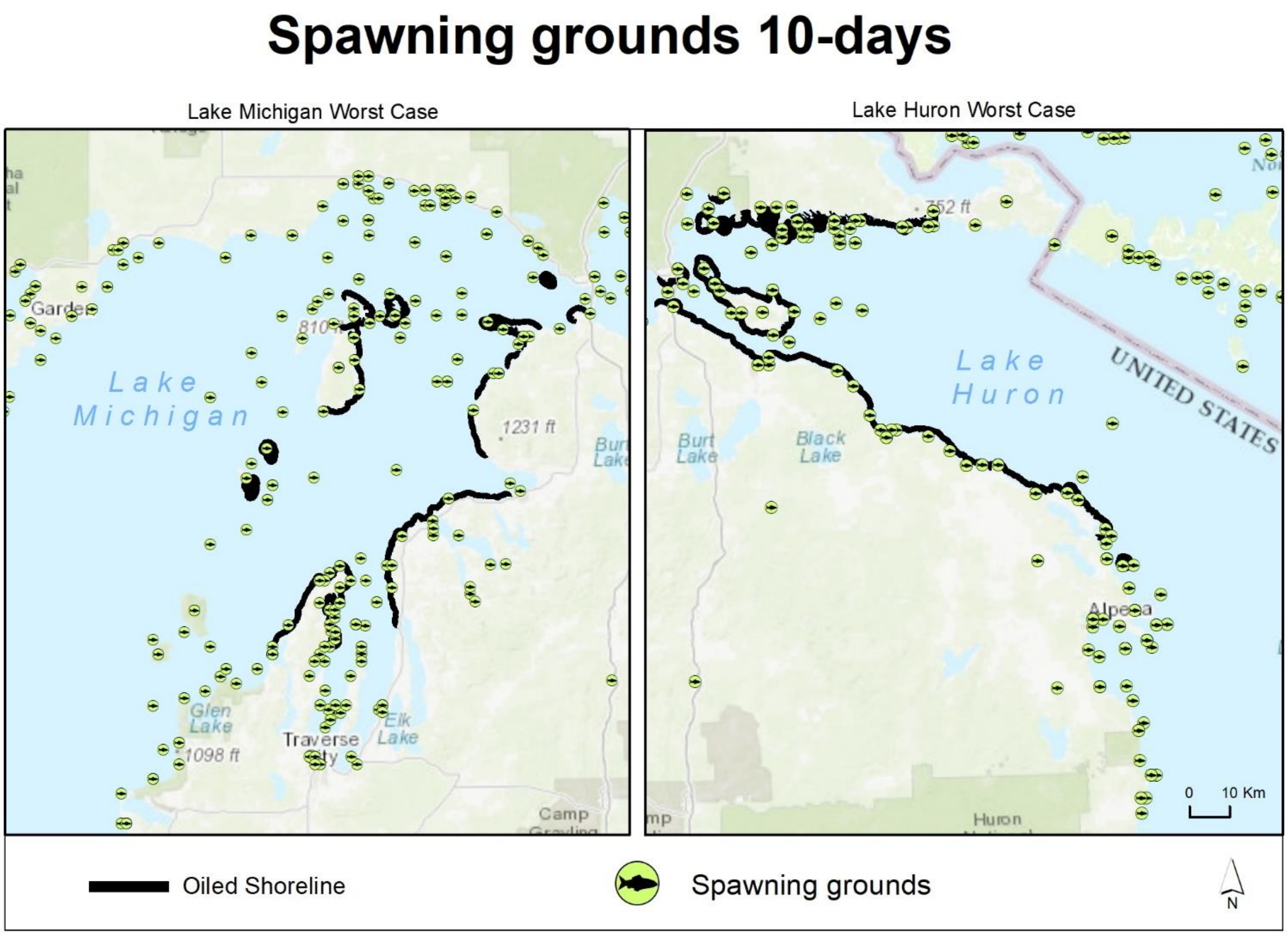

Figure E10. Spawning areas of fishes in Lakes Huron and Michigan based on GLAHF and Goodyear Atlas.

Vulnerability of Select Fish Species of Importance

Lake Whitefish are bottom-dwelling fish that feed on a wide variety of bottom-living invertebrates and small fishes. This commercially important fish would accumulate PAHs from contaminated sediments and remain contaminated as long as PAHs persist in the sediments, which can be long after water column PAH levels return to background levels. Because of a reduction in numbers of their preferred prey, *Diporeia*, the diets of whitefish have also shifted to include zebra and quagga mussels, which are expected to bioconcentrate PAHs. Lake Whitefish lay eggs under the ice when they move inshore from deeper waters to spawn in Nov-Dec. Predators of Lake Whitefish include Lake Trout, Northern Pike, Burbot, and Walleye. Lake Whitefish from Wabamun Lake (Alberta, Canada) exposed to bunker C oil revealed a general pattern of increasing incidence and severity of several skeletal and craniofacial deformities (Debruyn et al., 2007). The combination of sub-lethal PAH health impacts, oiling of spawning grounds, declines of *Diporeia* and reduced ice cover projected for the Great Lakes may result in an elevated risk for Lake Whitefish.

Lake Trout are mainly benthic feeders, and the adult diet includes forage fishes such as Chubs, Ciscos, Sticklebacks, Alewife, Smelt, Sculpins and macroinvertebrates. In the mid-1980s, two Lake Trout refuge areas were established in regions where the most productive spawning habitats occurred in Lake Michigan (LAMP, 2008); the Northern refuge area is adjacent to Line 5. Two Lake Trout refuge areas are also located in Lake Huron; the Northern refuge area is also close to Line 5. Exposure to oil and PAH contamination of Lake Trout is, therefore, of elevated concern since Lake Trout in the refuge areas may be impacted by increased egg mortalities and adults may be impacted by sub-lethal PAH exposures.

Yellow Perch are estimated to have comprised approximately 85% of the sport fish caught in Michigan prior to 1977. Yellow Perch are generalists, eating minnows, aquatic insects, quagga mussels and round goby. Walleye, Largemouth Bass, Northern Pike and Double-Crested Cormorant, once on the endangered species list but now a common residential bird in the Great Lakes region, feed on adult perch as primary prey (MDNR, 2005). Yellow Perch spawn in the spring in spawning grounds near Line 5. Therefore an increase in mortalities to eggs and larvae would be expected after an oil discharge.

Lake Sturgeon, are listed as endangered or threatened, and stocking is considered essential to restoring population levels (Tillett et al., 2016). Lake Sturgeon are nearshore fish that feed along lake bottoms, eating a variety of small animals including snails, crustaceans, aquatic insects, mussels, and small fish. Sturgeon may be at risk to impacts from exposure to oil because they live in close association with sediments and have a relatively greater lipid content than other fishes so could sequester relatively more PAHs.

Cisco, also known by the common name lake herring, is a member of the Salmonidae family. Cisco, although once abundant, is a threatened fish in the Great Lakes. It is a pelagic, cold-water fish, an important forage fish, and is also caught by anglers. Lake Huron, Grand Traverse Bay, and St. Mary's River are top locations for big cisco (MI Sea Grant, 2018). Cisco feed primarily on microscopic zooplankton, but bottom-dwelling invertebrates and aquatic insect larvae are also part of their diet. Cisco typically move into shallow waters to spawn, in late November to mid-December and then move back to deeper waters.

<u>Summary of Oil Impacts to Fish</u>

- Significant mortality to eggs and larvae by oiling and also delayed population impacts of sub-lethal doses compromising health, growth, and reproduction. Many fish spawn in close proximity to Line 5 and their spawning grounds will be impacted depending on the season of an oil spill (see Table E6). For example, Lake Whitefish and Lake Trout spawn in the late fall; Sturgeon and Alewife spawn in summer; and Smallmouth Bass, Walleye, Yellow Perch and Rainbow Smelt spawn in spring.
- Sub-lethal impacts to eggs and larvae from exposure to PAHs may cause DNA damage, altered gene expression levels, cardiac damage, morphological abnormalities and impaired reproduction.
- Long-term impacts to populations due to the persistence of oil and biological exposures closely associated with shallow and benthic sediments. Fish will be more at risk for impacts to growth and survivorship if they are feed in sediments as adults, and if their spawning grounds are exposed to oil as eggs and larvae.
- Indirect effects of trophic cascades and interactions, which transmit impacts well beyond the acute-phase mortality

E.3.3.6 Birds

The coastal and open-water areas adjacent to and surrounding Mackinac Straits provide food and nesting habitats to resident and migratory species, including shorebirds, colonial nesters, and waders. This area serves as a key migratory pathway for many waterfowl and raptor species moving through and over-wintering in the Straits of Mackinac. Table E7 lists 76 species of birds that have been observed in shoreline, marsh and lake habitats in Lakes Michigan and Huron and the Mackinac Straits. The ecology of these species makes them vulnerable to oil exposure through habitat use and diet.

Twenty-two of these species have state, federal, and/or international conservation status including species such as Bald Eagle, Peregrine Falcon, Cattle Egret and Piping Plover (Table E7; MNFI, 2018). In addition to species of conservation concern, there are a number of bird species that would be especially vulnerable to an oil spill given their ecology and potential to be in contact from oil on shorelines and in wetland vegetation. These species are waders, waterfowl, and colonial and shoreline nesters (Table E7). Toward this point, MNFI identified Great Blue Heron Rookeries within the Straits.

The National Audubon Society has designated Important Bird Areas within the state of Michigan. These areas have both global, and state significance for bird species and include designations of 4 million acres in Michigan (National Audubon Society, 2018). Five state-level areas are in or close to the Mackinac Straits, including Mackinac Straits Hawk Watch, Sand Products and Epoufette Island Shoal, Beaver Islands Colonial Waterbirds, Mackinac Straits to St. Martin's Bay, Helmet Shoal and Saddlebag Island (National Audubon Society, 2018; Dynamic Risk, 2017).

Oil Toxicity to Birds

Birds are especially vulnerable to the toxic effects of oil, through short-term acute exposure of feathers leading to death from hypothermia, smothering, drowning, or ingestion of toxins during preening. Oil effects arise from chronic toxic exposure from ingesting contaminated prey, during foraging around persistent sedimentary pools of oil, and through disruption of vital social functions in socially organized species, such as caregiving or reproduction (Peterson et al., 2003). Some soaring migratory birds such as Bald Eagles and Turkey Vultures are chiefly scavengers, so could come into contact with oil through feeding on dying or dead waterbirds, beached fish, and other contaminated dead organisms.

Persistent exposure to oil via contaminated sediments, such as feeding on prey that live in contaminated sediments, has been shown to cause adverse health impacts. Studies of the black oystercatcher (*Haematopus bachmani*) demonstrated population-level impacts from chronic exposure to toxins through ingestion of oil. In the summer of 1989, after the Exxon Valdez oil spill, pairs of black oystercatchers with foraging territories on heavily oiled shores showed reduced incidence of breeding and smaller eggs than those that bred elsewhere (Peterson et al., 2003). Chick mortality was enhanced in proportion to the degree of shoreline oiling in both 1989 and 1990. In addition, it was shown that the black oyster-catchers consumed oiled mussels and that parents gathering prey on oiled shores in 1991 and 1992 fed chicks more, but chicks grew less than those un-oiled shores. Fledging late or at small size has negative implications for chick survivorship. This implies energetic or developmental costs and reproductive impairment from ingestion of toxics three years after the oil spill (Peterson et al., 2003).

Balseiro et al. (2005) found that of 2,465 birds found dead after the "Prestige" oil spill off the coast of Spain, 65% were immature birds, with the percent immature as high as 79% for Razorbills (*Alca torda*) and 74% for Common Murres (*Uria aalge*). They hypothesized that young, less experienced birds were less able to endure the multiple stresses associated with oil exposure.

The association between foraging on littoral benthic invertebrates and chronic exposure to residual toxins from the oil is also illustrated by Pigeon Guillemots (*Cepphus columba*), seabirds that restrict their foraging to the near-shore environment. Pigeon Guillemots suffered acute mortality during the Exxon Valdez spill (Peterson et al., 2003). In 1999, ten years after the oil spill, chicks, which eat fish, showed no evidence of ongoing exposure to toxins. However, the adults, which include shallow-water benthic invertebrates in their diets, had elevated CYP1A in their livers (Peterson et al., 2003). This is indicative of the long retention times for PAH compounds absorbed upon and into the sediments.

Chronic impacts were also seen in Harlequin Ducks (*Histrionicus histrionicus*), which prey on intertidal benthic invertebrates, after the Exxon Valdez oil spill. Radio tracking of adult females revealed higher mortality rates while overwintering on heavily oiled Knight and Green Island shores (22%) in 1995–96 through 1997–98 compared to unoiled Montague Island (16%). The ducks showed induction of the CYP1A biomarker in 1998, indicating ongoing exposure to oil and health impacts nine years after the spill (Peterson et al., 2003).

<u>Influence of Geography on Bird Use of the Straits</u>

The Straits of Mackinac are continentally important for waterbird migration, with tens to hundreds of thousands of individuals passing through the area each spring and fall. These include the orders *Anseriformes* [waterfowl], *Podicipediformes* [grebes], *Gaviiformes* [loons], and *Suliformes* [cormorants]). Waterbirds, including waterfowl game species, provide a number of ecosystem services that directly or indirectly benefit humans. These include provisioning (e.g., meat, feathers, eggs), cultural services for western and indigenous societies, and as predators, herbivores, and vectors of seeds and nutrients (Green & Elmberg, 2014). Many of these migrating birds rest and feed in large numbers in the Straits near the Mackinac Bridge and the Line 5 pipeline area. The Mackinac Straits lie on two natural nexi for migrating birds. In the spring and fall, waterbirds, including loons, grebes, cormorants, and waterfowl, generally move along a north-south path that favors routes passing over water. Access to water during migration provides resting sites, refuge from predators, and opportunities to forage. Northbound waterbirds that travel up from lower portions of Lakes Michigan and Huron are naturally concentrated by the narrowing geography of the two lakes as they near the Straits. Similarly, landbirds moving north in the spring favor overland routes that provide cover, foraging opportunities, and thermals that aid the soaring birds (e.g., Bald Eagle). They are concentrated by the tapering shape of the northern Lower Peninsula.

Species commonly seen in this area (some of which are seasonally very abundant) include more than 25 species of waterfowl, common loons, grebes, and cormorants, many of which have both high ecological value and also great economic value as important game species. In addition, over 50,000 raptors, including Bald and Golden Eagles migrate over the Straits region each year, hunting and scavenging during their passage. Because the Mackinac Straits act as a migratory concentration point for a diversity of birds, any release of oil in this area has the potential to impact populations of birds breeding across large portions of North America (U.S. and Canada) and wintering in the southern Atlantic Ocean and Gulf of Mexico. In addition to spring and fall migrating birds, summer breeding birds include some federally endangered species such as the Piping Plover and other species with special value and protected status (Bald Eagles). Birds represent some of the most vulnerable organisms to long-term impacts of oil spills.

Table E7. Bird species in the State of Michigan that are most vulnerable to oil exposure following rupture of the Line 5 pipeline in the Mackinac Straits, given their use of coastal and wetland areas adjacent to and surrounding the Mackinac Straits.

Name		**Conservation Status**				**Characteristics**						
Common	**Species**	**IUCN**	**CITES**	**US**	**MI**	**Waders**	**Waterfowl**	**Shorebirds**	**Raptors**	**Colonial**	**Habitat**	**Migratory**
American Bittern	*Botaurus lentiginosus*	LC	-	-	SC	Y	N	N	N	N	Marshes	B
American Black Duck	*Anas rubripes*	LC	-	-	-	N	Y	N	N	N	Lake	B
American Coot	*Fulica americana*	LC	-	-	-	N	Y	N	N	N	Lake	B
American Golden Plover	*Pluvialis dominica*	LC	-	-	-	N	N	Y	N	N	Shoreline	M
American Wigeon	*Anas americana*	LC	-	-	-	N	Y	N	N	N	Lake	B
Bald Eagle	*Haliaeetus leucocephalus*	LC	II	D	SC	N	N	N	Y	N	Lake	R
Belted Kingfisher	*Megaceryle alcyon*	LC	-	-	-	N	Y	N	N	N	Lake	B
Black Scoter	*Melanitta nigra*	LC	-	-	-	N	Y	N	N	N	Lake	M
Black Tern	*Chlidonias niger*	LC	-	-	SC	N	N	Y	N	Y	Shoreline	B
Black-Crowned Night Heron	*Nycticorax nycticorax*	LC	-	-	SC	Y	N	N	N	Y	Marshes	B
Blue-Winged Teal	*Anas discors*	LC	-	-	-	N	Y	N	N	N	Lake	B
Bonaparte's Gull	*Larus philadelphia*	LC	-	-	-	N	N	Y	N	N	Shoreline	M
Bufflehead	*Bucephala albeola*	LC	-	-	-	N	Y	N	N	N	Lake	M
Canada Goose	*Branta canadensis*	LC	I	D	-	N	Y	N	N	N	Lake	B
Canvasback	*Aythya valisineria*	LC	-	-	-	N	Y	N	N	N	Lake	M
Caspain Tern	*Hydroprogne caspia*	LC	-	-	T	N	N	Y	N	Y	Shoreline	B
Cattle Egret	*Bubulcus ibis*	LC	II	-	SC	Y	N	N	N	N	Marshes	B
Common Gallinule	*Gallinula chloropus*	LC	-	E	T	N	Y	N	N	N	Lake	B

Common Goldeneye	*Bucephala clangula*	LC	-	-	-	N	Y	N	N	N	Lake	B
Common Loon	*Gavia immer*	LC	-	-	T	N	Y	N	N	N	Lake	B
Common Merganser	*Mergus merganser*	LC	-	-	-	N	Y	N	N	N	Lake	B
Common Tern	*Sterna hirundo*	LC	-	-	T	N	N	Y	N	Y	Shoreline	B
Double-Crested Cormorant	*Phalacrocorax auritus*	LC	-	-	-	N	Y	N	N	Y	Lake	B
Dunlin	*Calidris alpina*	LC	-	-	-	N	N	Y	N	N	Shoreline	M
Forster's Tern	*Sterna fosteri*	LC	-	-	E	N	N	Y	N	Y	Shoreline	M
Gadwall	*Anas strepera*	LC	-	-	-	N	Y	N	N	N	Lake	B
Great Blue Heron	*Ardea herodias*	LC	-	-	-	Y	N	N	N	Y	Marshes	B
Great Egret	*Casmerodius albus*	LC	-	-	-	Y	N	N	N	Y	Marshes	M
Greater Scaup	*Aythya marila*	LC	-	-	-	N	Y	N	N	N	Lake	M
Greater Yellowlegs	*Tringa melanaleuca*	LC	-	-	-	Y	N	N	N	N	Marshes	M
Green Heron	*Butorides striatus*	LC	-	-	-	Y	N	N	N	Y	Marshes	B
Green-winged Teal	*Anas crecca*	LC	-	-	-	N	Y	N	N	N	Marshes	B
Herring Gull	*Larus argentatus*	LC	-	-	-	N	N	Y	N	Y	Shoreline	B
Hooded Merganser	*Lophodytes cucullatus*	LC	-	-	-	N	Y	N	N	N	Lake	B
Horned Grebe	*Podiceps auritus*	V	-	-	-	N	Y	N	N	N	Lake	R
Killdeer	*Charadrius vociferus*	LC	-	-	-	N	N	Y	N	N	Shoreline	B
King Rail	*Rallus elegans*	NT	-	-	E	Y	N	N	N	N	Marshes	B
Least Bittern	*Ixobrychus exilis*	LC	-	-	T	Y	N	N	N	N	Marshes	B
Least Sandpiper	*Calidris minutulla*	LC	-	-	-	N	N	Y	N	N	Shoreline	B
Lesser Scaup	*Aythya affinis*	LC	-	-	-	N	Y	N	N	N	Lake	M
Lesser Yellowlegs	*Tringa flavipes*	LC	-	-	-	Y	N	N	N	N	Marshes	B

Long-Tailed Duck	*Clangula hyemalis*	V	-	-	-	N	Y	N	N	N	Lake	M
Mallard	*Anas platyrhynchos*	LC	-	-	-	N	Y	N	N	N	Lake	B
Merlin	*Falco columbarius*	LC	-	-	T	N	N	N	Y	N	Marshes	B
Mute Swan	*Cygnus olor*	LC	-	-	-	N	Y	N	N	N	Lake	R
Northern Harrier	*Circus cyaneus*	LC	II	-	SC	N	N	N	Y	N	Dune; Scrub	B
Northern Pintail	*Anas acuta*	LC	-	-	-	N	Y	N	N	N	Marshes	B
Northern Shoveler	*Anas clypeata*	LC	-	-	-	N	Y	N	N	N	Lake	M
Osprey	*Pandion haliaetus*	LC	-	-	SC	N	N	N	Y	N	Lake	B
Pectoral Sandpiper	*Calidris melanotos*	LC	-	-	-	N	N	Y	N	N	Shoreline	M
Peregrine Falcon	*Falco peregrinus*	LC	I	-	E	N	N	N	Y	N	Shoreline	M
Pied-Billed Grebe	*Podilymbus podiceps*	LC	-	-	-	N	Y	N	N	N	Lake	B
Piping Plover	*Charadrius melodus*	NT	-	ET	E	N	N	Y	N	N	Shoreline	B
Prairie warbler	*Setophaga discolor*	LC	-	-	E	N	N	N	N	N	Dune; Scrub	B
Red-Breasted Merganser	*Mergus serrator*	LC	-	-	-	N	Y	N	N	N	Lake	B
Redhead	*Aythya americana*	LC	II	-	-	N	Y	N	N	N	Lake	M
Red-Necked Grebe	*Podiceps grisegena*	LC	-	-	-	N	Y	N	N	N	Lake	M
Ring-Billed Gull	*Larus delawarensis*	LC	-	-	-	N	N	Y	N	Y	Shoreline	R
Ring-Necked Duck	*Aythya collaris*	LC	-	-	-	N	Y	N	N	N	Lake	B
Ruddy Duck	*Oxyura jamaicensis*	LC	-	-	-	N	Y	N	N	N	Lake	M
Ruddy Turnstone	*Arenaria interpres*	LC	-	-	-	Y	N	N	N	N	Shoreline	B
Sanderling	*Calidris alba*	LC	-	-	-	N	N	Y	N	N	Shoreline	M
Sandhill Crane	*Grus canadensis*	LC	I, II	E	-	Y	N	N	N	N	Marshes	B
Semipalmated Plover	*Calidris pusilla*	LC	-	-	-	N	N	Y	N	N	Shoreline	M

Snow Goose	*Chen caerulescens*	LC	-	-	-	N	Y	N	N	N	Lake	M
Solitary Sandpiper	*Tringa solitaria*	LC	-	-	-	N	N	Y	N	N	Shoreline	M
Sora	*Porzana carolina*	LC	-	-	-	Y	N	N	N	N	Marshes	B
Spotted Sandpiper	*Actitis macularia*	LC	-	-	-	N	N	Y	N	N	Shoreline	B
Surf Scoter	*Melanitta perspicillata*	LC	-	-	-	N	Y	N	N	N	Lake	M
Tundra Swan	*Olor columbianus*	LC	-	-	-	N	Y	N	N	N	Lake	M
Virginia Rail	*Rallus limicola*	LC	-	-	-	Y	N	N	N	N	Marshes	B
White Pelican	*Pelecanus erythrorhynchos*	LC	-	-	-	N	Y	N	N	N	Lake	M
White-Winged Scoter	*Melanitta deglandi*	LC	-	-	-	N	Y	N	N	N	Lake	M
Wilson's Snipe	*Capella gallinago*	LC	-	-	-	N	Y	N	N	N	Marshes	B
Wood Duck	*Aix sponsa*	LC	-	-	-	N	Y	N	N	N	Lake	B
Yellow Rail	*Coturnicops noveboracensis*	LC	-	-	T	Y	N	N	N	N	Marshes	B

Note: Conservation Status Listings: IUCN designations: LC – Least Concern, V – Vulnerable, NT – Near Threatened; CITES designations: I – Appendix I, II – Appendix II; US designations: D – Delisted, T – Threatened, E – Endangered; MI designations: SC – Special Concern, T – Threatened, E – Endangered. No designations (-). Migratory Status Listings: R – Resident, B – Breeding, M – Migratory Route. Sources of Information include, NOAA's ESI and MNFI's biotic datasets.

Vulnerability of Select Bird Species of Importance

Although the Mackinac Straits represents a relatively narrow passage between Lakes Michigan and Huron, it is wide enough to prevent a complete visual count of waterbirds passing through it.

For the Mackinac Straits area, we summarize data from eBird, a quality-checked citizen science dataset housed at the Cornell Laboratory of Ornithology. The numbers provide useful relative abundance estimates and give a rough estimate of the numbers and timing of bird use of the Straits. Because most waterbirds migrate both during the day and night, and visual counts are only able to estimate day movements, these numbers should be viewed as conservative compared to the actual number of birds passing through the Straits area. Below, we summarize only the most abundant species with several dozen other bird species (waterbirds and non-waterbirds) reported from the Straits area using this same dataset.

The Piping Plover, in particular, is listed as endangered under the ESA and by the State of Michigan, and the U.S. Fish and Wildlife Service (USFWS) has identified critical habitat for the Great Lakes breeding population. Of 14 Michigan counties identified as containing critical habitat, 11 (Emmet, Charlevoix, Cheboygan, Presque Isle, Benzie, Leelanau, Schoolcraft, Mackinac, Mason, Iosco, Muskegon) are within the shoreline that is predicted to be impacted by an oil spill (USFWS, 2018). Moreover, the Piping Plover nests and feeds at the shore, strand line, and wetlands along the Great Lakes so would almost certainly be among the shorebirds to be at risk of an oil spill, especially during the breeding season (1 May and 15 August).

Bird migration is inherently dynamic as birds arrive and depart, rest, feed, court, and otherwise go about their migratory and pre- and post-breeding habits. During migration and overwintering, some waterbirds pass through the Straits in a few minutes, while others remain for weeks or months. Direct and indirect bird exposure to oil will, therefore, be a function of 1) the quantity of oil released, 2) the duration/persistence of oil present at or near the water surface and in the food web, 3) the season of oil release, and 4) the physical and biological behavior of oil and birds in the area.

Among waterfowl (order Anseriformes), Redhead (*Aythya americana*) is by far the greatest user of the Straits in late fall and winter with cumulatively in the last five years. Long-tailed Duck (*Clangula hyemalis*) was the next most common waterfowl with counts of 1,000 to nearly 3,000 during peak (see below) spring and fall months. Red-breasted Merganser (*Mergus serrator*) was the third most commonly reported duck and was found frequently in the low hundreds of individuals, with April-May and October-November peaks in abundance. In order of decreasing abundance, the following waterfowl can also be considered common spring and fall migrants (some breeding in the area): Canada Goose (*Branta canadensis),* White-winged Scoter (*Melanitta fusca*), Common Merganser

(*Mergus merganser*), Mallard (*Anas platyrhynchos*), Common Goldeneye (*Bucephala clangula*), Bufflehead (*Bucephala albeola*) and Greater Scaup (*Aythya marila*).

The most abundant non-Anseriform waterbirds included Ring-billed Gull (*Larus delawarensis*), Double-crested Cormorant (*Phalacrocorax auritus*), Herring Gull (*Larus argentatus*), Common Loon (*Gavia immer)*, and Red-necked Grebe (*Podiceps grisegena*). Estimates of the numbers of these five species during peak months in spring and fall ranged from the low hundreds to over a thousand.

<u>Timing of Waterbird Migration</u>

For most waterbirds, April-May in the spring and September-November in the fall represent the peak use periods of the Straits. This use varies somewhat with species and weather patterns (e.g., winter ice), but it is clear that a significant oil spill during any of these five months would represent the worst case scenario in terms of maximum exposure to migratory species. For resident and breeding species, the periods of greatest vulnerability would differ. For example, the breeding piping plover arrives on its breeding territories in the counties adjoining the Straits in the first week of May and does not leave until August, so that the approximately three month period of May, June, and July would be the most sensitive time frame for this shoreline foraging and beach breeding species.

E.3.3.7 Mammals

The state of Michigan is home to nearly 60 species of mammals (Michigan DNR, 2018). These range from small species, such as White-Footed Mouse and Southern Flying Squirrel, to large species that include Moose, Bobcat, and Bear (Michigan DNR, 2018). The mammals most likely to be impacted by oil spills along the shore of Lakes Huron and Michigan are Raccoon, Muskrat, North American River Otter, North American Beaver, and Mink (Table E9). These species are considered sensitive resources, but they are generally are widely scattered throughout their range with only a few individuals in each location (NOAA, 1994). These species are considered of economic importance to Michigan because they are harvested for fur.

MNFI's biotic data identified the Northern Long-Eared Bat as a species of state and federal conservation status that may be vulnerable to oil following a rupture in Line 5 pipeline because they are associated with coastal habitats. Additional conservation status species identified by MNFI's data include Gray Wolf, Moose, Woodland Vole and Little Brown Bat. However, these species are associated with forested rather than coastal or wetland areas and are unlikely to be exposed to oil.

Impacts from chronic exposure to oil were also seen in the sea otter recovery rate after the Exxon Valdez oil spill. The recovery rate was less than predicted (4% versus 10%) and was attributed to a higher mortality for animals born after the spill (Bowyer et al., 2003). Persistent exposure seven to nine years after the spill was verified by examining contaminated sediments and induction of a detoxification enzyme and biomarker of exposure in sea otter prey (clams, mussels, crabs). Abundance in these prey species was not different between the contaminated and control site, so prey availability was not considered the reason for the increased mortality of the sea otters (Bowyer et al., 2003). In contrast, piscivorous river otters showed little evidence of chronic oil exposure even along heavily oiled shorelines, implying that foraging in sediments entails greater risk (Bowyer et al., 2003).

For mammals, secondary poisoning (e.g., by ingesting contaminated prey items) is thought to be more common than poisoning from the original source (e.g., oil in the sediment). Inhalation as a route of exposure may be more relevant to animals spending time in or near the contaminated sediment or water (e.g., rodents), especially immediately after an oil release when the lighter oil components are evaporating. Lactational or placental transfer of toxins is a potential route of maternal transfer in mammals, whereas developmental exposure to toxins occurs during egg formation in other groups (Smith et al., 2007).

Some mammal species are less capable of abandoning preferred habitats, particularly those with small home ranges, high site fidelity, or reliance on specific nesting habitats. In these cases, behavior or ecological interactions may be altered. In Alaska, river otters (*Lontra canadensis*), whose coastal habitat was heavily oiled following the Exxon Valdez oil spill, selected different habitat characteristics and maintained larger home ranges in oiled habitats for more than 1 year following the oil spill (Bowyer, Testa, & Faro, 1995).

Table E9. Mammal species in the State of Michigan that are most vulnerable to oil exposure following rupture of the Line 5 pipeline in the Mackinac Straits because they use of littoral and coastal habitats for foraging, breeding, and brooding.

Name		**Conservation Status**				**Habitat**				**Importance**	
Common	**Species**	**IUCN**	**CITES**	**US**	**MI**	**Forage**	**Breeding**	**Brooding**	**Season**	**Keystone**	**Economic**
North American Beaver	*Castor canadensis*	LC	-	-	-	Littoral	Littoral	Littoral	W; Sp	Ecosystem engineers	X
North American River Otter	*Lontra canadensis*	LC	II	-	-	Littoral	Both	Both	W; Sp	Predators of fish & invertebrates	X
American Mink	*Neovison vison*	LC	-	-	-	Littoral	Littoral	Littoral	W; Sp	Predators of small mammals	X
Muskrat	*Ondatra zibethicus*	LC	-	-	-	Littoral	Coastal	Both	W; Sp	Prey of larger predators	X
Raccoon	*Procyon lotor*	LC	-	-	-	Littoral	Coastal	Coastal	W; Sp	Predators of fish & invertebrates	X

Note: Conservation Status Listings: IUCN designations: LC – Least Concern, V – Vulnerable, NT – Near Threatened; CITES designations: I – Appendix I, II – Appendix II; US designations: D – Delisted, T – Threatened, E – Endangered; MI designations: SC – Special Concern, T – Threatened, E – Endangered. No designations (-).

E.3.4 Overall Ecosystem Impacts

Oil spills represent a threat to aquatic ecosystem health because they are unpredictable in time and space, difficult to fully remediate, and pose long-term risks to aquatic habitats and species. As such, oil spills represent acute and chronic risks including widespread animal mortalities, losses of ecosystem services in addition to longer lasting effects such as alteration of animal behaviors and food web structure and potentially long-term contamination of ecosystem resources (Silliman et al., 2002). The Great Lakes have remained relatively immune to oil spills in comparison to marine ecosystems, and this proves challenging for evaluating the potential risks and injuries that could occur during a large spill in this ecosystem.

Acute effects associated with the unintentional releases of oil products into aquatic ecosystems are generally associated with the lethality of direct oiling. Crude oil contains over 2,000 individual compounds including chemicals such as the BTEX group that is soluble in water and can cause short-term acute effects and also PAHs that can persist for long periods in aquatic sediments and soils and represent a chronic hazard. It is estimated that between 324 km (10-day scenario) and 888 km (60-day scenario) of shoreline is at risk in Lake Michigan, and between 449 km (10-day scenario) and 1075 km (60-day scenario) are at risk in Lake Huron, are at risk of oiling following a rupture in Line 5 pipeline (see Table E1; Figures E2, E3). This distribution of oil along shoreline and nearshore areas would place species that use littoral, beach and wetland habitats at risk. Toxicity from short- and long-term exposure to oil can induce a number of physiological responses (see Table E10 for a summary). In addition, many species are vulnerable to habitat and trophic-level alterations arising from damage to habitat structure and prey communities (Velando, Munilla, & Leyenda, 2005). Therefore, both the physiological and ecological effects of oil on organisms can have important consequences for species fitness, and population recovery and persistence.

Using NOAA's established thresholds based on oil values (g/m^2), both lakes exceeded the threshold that would prompt a socioeconomic and ecological impact response. Further evaluation examined the established threshold levels for effects, TEC (a lower effect level at which no or minimal effects are predicted) and PEC (an upper effect concentration level at which adverse effects are highly probable or will frequently be seen). For oil containing 2% PAH nearly all shoreline types impacted would exceed the TEC threshold in at least one scenario examined (Table E2). For oil containing the higher level of 8% PAH, several types of shorelines would also exceed the PEC threshold (Table ET3). Thus adverse impacts to nearshore and shoreline habitats and associated species are predicted following a rupture in Line 5.

Table E10 Summary of physiological and ecological effects of petroleum or individual PAHs on organisms (see Albers, 2003).

Effect[a]	Plant or Microbe	Invertebrate	Fish	Reptile or Amphibian	Bird	Mammal[b]	Benthos
Individual Organisms							
Death	x	x	x	x	x	x	x
Impaired reproduction	x	x	x	x	x	x	x
Reduced growth and development	x	x	x	x	x		x
Altered rate of photosynthesis	x						
Altered DNA	x	x	x	x	x	x	
Malformations			x		x		
Tumors or lesions		x	x	x		x	
Cancer			x	x		x	
Impaired immune system			x		x	x	
Altered endocrine system			x		x		
Altered behavior		x	x	x	x	x	
Blood disorders		x	x	x	x	x	
Liver and Kidney disorders			x		x	x	
Hypothermia					x	x	
Inflammation of epithelial tissue				x	x	x	
Altered respiration or heart rate		x	x	x			
Gill hyperplasia			x				
Fin erosion			x				
Groups of Organisms[c]							
Local population change	x	x	x		x	x	x
Altered Community Structure	x	x	x		x	x	x
Biomass Change	x	x	x				x

[a]Some effects have been observed in the wild and in the laboratory, whereas others have only been induced in laboratory experiments or are in population changes estimated from measures of reproduction and survival

[b]Includes a sampling of literature involving laboratory and domestic animals

[c]Populations of microalgae, microbes, soil invertebrates and parasitic invertebrates can increase or decrease in the presence of petroleum, whereas populations of other plants, invertebrates and vertebrates decrease

Adverse impacts from a Line 5 rupture will have trophic level and food web consequences stemming from mortalities that occur after the oil spill. Invertebrate species play major roles in the food web. The oil spill will increase mortality of the benthic and pelagic communities, the base of the food web, which could result in a decrease in fish and wildlife populations that depend on them as a food source. Currently, prey-fish densities are decreasing in Lakes Michigan, and Huron and these decreases are correlated with a trend of decreasing zooplankton and benthic macroinvertebrates, not including the invasive dreissenid mussels (Bunnell et al., 2013). Increased mortality to these benthic organisms from an oil spill may thus further reduce prey-fish populations and effect piscivorous fish that are of commercial and recreational value.

Clean-up activities conducted by Coast Guard and Enbridge immediately following a rupture in Line 5 may reduce the extent of shoreline oiling and risk to natural resources, thereby reducing the risk of habitats and organisms to exposure. However, any measure for cleanup proposed by Section C was not included in our evaluation, as our considerations of worst-case scenario include the greatest extent of risk. Similarly, high levels of uncertainty regarding the response time, time of year (e.g., ice cover), and equipment function precluded inclusion. It is also important to note that the amount of shoreline predicted from the worst-case models was chosen based on total shoreline distance in Lakes Michigan and Huron. Some of the shoreline habitat considered in our evaluation is outside the borders of Michigan State and include shorelines in Wisconsin and Ontario. While these areas may be outside the scope of Michigan State, our evaluation sought to be comprehensive, as well as account for species that are transient or migratory. The exposure of vertebrates, including fish, birds, and mammals to oil depends on the time of year and preferred habitats for foraging, nesting or brooding. Species that use nearshore and shoreline habitats are at most risk of exposure. This is particularly relevant during the bird nesting and fish spawning seasons, as large amounts of oil are expected to be distributed across these areas.

It is, therefore, possible that the extent of risk on natural resources could be reduced given clean-up activities and time of year of an event.

E.3.5 Summary

The Great Lakes have faced a range of anthropogenic stressors, and for native mammals, birds, fishes, reptiles, amphibians, micro-organisms, and plants an oil spill would generally increase this stress, especially in nearshore habitats where spilled oil tends to accumulate following dispersal. In this section, we focused on characterizing the habitats and species at risk of adverse impacts from oil. We took the approach of describing the adverse physiological and ecological effects that have been observed in previous spills such as the Exxon Valdez and Deepwater Horizon.

Despite substantial effort, information regarding species abundance and distribution in Lakes Michigan and Huron and surrounding areas were difficult to quantify. Aside from benthic invertebrate species, most other species considered at risk of oil exposure are migratory and not always in the Straits area, making our characterization of risk more qualitatively as opposed to quantitative. A total of 47 state- and federally-listed species of conservation status have been identified in the areas surrounding Mackinac Straits. Additionally, ~60,000 acres of rare and unique habitats are at risk (Table E4). Open dunes, wooded dune and swale, and marsh dominate these shoreline habitats. These areas are important habitat for insects, fish, waterfowl, waterbirds, and mammals. They serve as feeding areas for migrating and nesting shorebirds including Piping Plover and Tern spp. Fish species of ecological and economic importance are at risk for reductions in population due to oiling of spawning grounds and nursery habitats. Adult fish that are living and feeding in oil contaminated sediments are also at risk; these include Lake Whitefish, an economically valuable species. Bird species are especially vulnerable to mortality and chronic health effects from oil exposure due to their use of open water, coastal and wetland areas adjacent to and surrounding the Mackinac straits during spring and fall bird migration. Amphibians, reptiles, and mammals that use shoreline and wetlands habitats are at risk of exposure due to their use of near shore and coastal habitats for foraging, breeding and brooding. Finally, declines in abundance of primary producers and primary consumers resulting from an oil spill would mean that consumers higher up in the food chain may need to shift to finding alternative food sources, affecting ecosystem dynamics in oiled areas. Given this diversity and richness, an event like an oil spill may represent a point of no return for species loss and extirpation.

E.4 References

Alaska Department of Environmental Conservation. (2015). Listing methodology for determining water quality impairments from petroleum hydrocarbons, oils and grease. Division of Water.

Albers, P. (2003). Petroleum and Individual Polycyclic Aromatic hydrocarbons. Handbook Sciences; National Academies Press. Ecotoxicology, Second Edition. H David J. Hoffman, Barnett A. Rattner, G. Allen Burton, Jr., John Cairns, Jr. Eds. p 341-372.

Albert, D.A., Cohen, J.G., Kost M.A., & Slaughter, B.S. (2008) Cartography by H.D. Enander. Distribution Maps of Michigan's Natural Communities. 174pp.

Allan, J.D., McIntyre, P.B., Smith, S.D.P., Halpern, B.S., Boyer, G.L., Buchsbaum, A., Burton, G.A., …Steinman, A.D. (2013). Joint analysis of stressors and ecosystem services to enhance restoration effectiveness. *Proceedings of the National Academy of Sciences, 110*, 372-377.

Almeda, R., Wambaugh, Z., Wang, Z., Hyatt, C., Liu, Z., & Buskey, E.J. (2013). Interactions between zooplankton and crude oil: toxic effects and bioaccumulation of polycyclic aromatic hydrocarbons. *PloS ONE,* 8, e67212.

Angradi, T., Pearson, M., Bolgrien, D., Bellinger, B., & Starry, M. (2013). Predicting submerged aquatic vegetation occurrence (SAV) in a Great Lakes estuary. Presented at Society of Wetland Scientists, Duluth, MN.

Aquatic Insects of Michigan, http://aquaticinsects.org/index.html

Balseiro, A., Espi, A., Marquez, I., Perez, V., Ferreras, M.C., Garcia Marin, J., & Prieto, J.M. (2005). Pathological features in marine birds affected by the Prestige's oil spill in the north of Spain. *Journal of Wildlife Diseases, 41*, 371-378.

Banni, M., Negri, A., Dagnino, A., Jebali, J., Ameur, S., & Boussetta, H. (2010). Acute effects of benzo[a]pyrene on digestive gland enzymatic biomarkers and DNA damage on mussel *Mytilus galloprovincialis*. *Ecotoxicology and Environmental Safety, 73*, 842-848.

Barber, W.E., McDonald, L.L., Erickson, W.P., & Vallarino, M. (1995). Effect of the Exxon Valdez oil spill on intertidal fish: a field study. *Transactions of the American Fisheries Society, 124*, 461-476.

Barron, M.G., & Ka'aihue L. (2001). Potential for photo-enhanced toxicity of spilled oil in Prince William Sound and Gulf of Alaska waters. *Marine Pollution Bulletin,* 43, 86-92.

Beck, M.W., Brumbaugh, R.D., Airoldi, L., Carranza, A., Coen, L.D., Crawford, C., … Zhang, G. (2009). Shellfish Reefs at Risk: A Global Analysis of Problems and Solutions. 52 pp. Arlington, VA: The Nature Conservancy.

Bellas, J., Saco-Álvarez, L., Nieto, Ó., Bayona, J.M., Albaigés, J., & Beiras, R. (2013). Evaluation of artificially-weathered standard fuel oil toxicity by marine invertebrate embryo-genesis bioassays. *Chemosphere,* 90, 1103–1108.

Bender, M.E., Shearls, E.A., & Ayres, R.P. (1977). Ecological effects of experimental oil spills on eastern coastal plain estuarine ecosystems. *Proceedings of the International Oil Spill Conference, 1977,* 505-509.

Blackburn M., Mazzacano, C.A.S., Fallon, C., & Black, S.H. (2014). Oil in our oceans. A review of the impacts of oil spills on marine invertebrates. Portland, OR. The Xerces Society for Invertebrate Conservation. 152 pp.

Bourgeau-Chavez, L.L., Lopez, R.D., Trebitz, A., Hollenhorst, T., Host, G.E., Huberty, B., Gauthier, R.L., & Hummer, J. (2008). Landscape-Based Indicators. Great Lakes Coastal Wetlands Monitoring Plan, eds:T.M. Burton, J.C. Brazner, J.J.H. Ciborowksi, G.P. Grabas, J. Schneider, & D.G. Uzarski. Great Lakes Coastal Wetland Consortium, Great Lakes Commission.

Bowyer, R.T., Blundell, G.M., Ben-David, M., Jewett, S.C., Dean, T.A., & Duffy, L.K. (2003). Effects of the Exxon Valdez Oil Spill on River Otters: Injury and Recovery of a Sentinel Species *Wildlife Monographs, 153,* 1-53.

Bowyer, R.T., Testa, W.J., & Faro, J.B. (1995). Habitat selection and home ranges of river otters in a marine environment: Effect of the *Exxon Valdez* oil spill. *Journal of Mammalogy, 76,* 1-11.

Brown, E.D., Baker, T.T., Hose, J.E., Kocan, R.M., Marty, G.D., McGurk, M.D., Norcross, B.L. & Short, J. (1996). Injury to the early life history stages of Pacific herring in Prince William Sound after the Exxon Valdez oil spill. *American Fisheries Society Symposium, 18*, 448-462.

Bunnell, D.B., Barbiero, R.P., Ludsin, S.A., Madenjian, C.P., Warren, G.J., Dolan, D.M., Brenden, T.O.,…Weidel, B.C. (2013). Changing ecosystem dynamics in the Laurentian Great Lakes: Bottom- up and top- down regulation. *BioScience* 64, 26-39.

Burlakova, L.E., Barbiero, R.P., Karatayev, A.Y., Daniel, S.E., Hinchey, E.K., & Warren, G.J. (2018). The benthic community of the Laurentian Great Lakes: Analysis of spatial gradients and temporal trends from 1998 to 2014. Journal of Great Lakes Research, https://doi.org/10.1016/j.jglr.2018.04.008

Carls, M.G., & Harris, P.M. (2005). Exxon Valdez Oil Spill Restoration Project Final Report: Monitoring of Oiled Beds in Prince William Sound and the Gulf of Alaska. Juneau, AK: National Marine Fisheries Service, Alaska Region. 140 pp.

Carls, M.G., Rice, S.D., & Hose, J.E. (1999). Sensitivity of fish embryos to weathered crude oil: Part I. Low-level exposure during incubation causes malformations, genetic damage, and mortality in larval Pacific Herring (*Clupea pallasi*). *Environmental Toxicology and Chemistry, 18,* 481-493.

Cave C.S., & Strychar K.B. (2014). Decline of *Diporeia* in Lake Michigan: Was disease associated with invasive species the primary factor? *International Journal of Biology, 7,* 93-99.

Collingsworth, P.D., Bunnell, D.B., Murray, M.W., Kao, Y, Feiner, ZS., Claramunt, R. M., Lofgren, B.M., Book, T.O., & Ludsin, S.A. (2017). Climate change as a long-term stressor for the fisheries of the Laurentian Great Lakes. *Reviews in Fish Biology and Fisheries*, *27*, 363-391.

Conan, G. (1982). The long-term effects of the Amoco Cadiz oil spill. *Philosophical Transactions of the Royal Society of London B Biological Sciences, 297*, 323-333.

Cormack, D. (1999). Response to marine oil pollution – review and assessment (Vol. 2). Dordecht: Springer-Kluwer Academic.

Culbertson, J.B., Valiela, I., Olsen, Y.S., & Reddy, C.M. (2008). Effect of field exposure to 38-year-old residual petroleum hydrocarbons on growth, condition index, and filtration rate of the ribbed mussel, *Geukensia demissa*. *Environmental Pollution, 154,* 312-319.

Dauvin, J.C. (1989). Life cycle, dynamics and productivity of Crustacea-Amphipoda from the western English Channel. *Journal of Experimental Marine Biology and Ecology, 128,* 31-56.

Dauvin, J.C. (1998). The fine sand *Abra alba* community of the bay of Morlaix twenty years after the Amoco Cadiz oil spill. *Marine Pollution Bulletin, 36*, 669-676.

Debruyn, A.M., Wernick, B.G., Stefura, C., McDonald, B.G., Rudolph, B.L., Patterson, L., & Chapman, P.M. (2007). In situ experimental assessment of Lake Whitefish development following a freshwater oil spill. *Environmental Science and Technology, 15*, 5983-6989

Driscoll, S.B.K., & McElroy, A.E. (1997). Elimination of sediment-associated benzo[a]pyrene and its metabolites by polychaete worms exposed to 3-methylcholanthrene. *Aquatic Toxicology, 39*, 77-91.

Dupuis, A., & Ucan-Marin, F. (2015). A literature review on the aquatic toxicology of petroleum oil: An overview of oil properties and effects to aquatic biota. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/007. vi + 52 p.

Dynamic Risk Alternatives analysis for the Straits Pipeline. (2017). Final Report. Dynamic Risk Assessment Systems.

Elmgren, R., Hansson, S., Larsson, U., Sundelin, B. & Boehm, P.D. (1983). The Tsesis oil spill: Acute and long-term impact on the benthos. *Marine Biology, 73*, 51-65.

Etkin, D.S., McCay, D.F., Michel, J. (2007). Review of the state-of-the-art on modeling interactions between spilled oil and shorelines for the development of algorithms for oil spill risk analysis modeling. MMS OCS Study 2007-063. Environmental Research Consulting, Cortland Manor, New York. MMS Contract 0106PO39962. 157 pp.

Fingas, M.F., Brown, C.E., & Gamble, R.L. (1996). The visibility and detectability of oil slicks and oil discharges on water. Arctic and Marine Oil Spill Program (AMOP) Technical Seminar Vol. 22 pp 865-886.

Flint, P.L., Fowler, A.C., & Rockwell, R.F. (1999). Modeling bird mortality associated with the *M/V Citrus* oil spill off St. Paul Island, Alaska. *Ecological Modelling 117*, 261-267.

Fodrie, F.J., Able, K.W., Galvez, F., Heck, K.L., Jensen, O.P., Lopez-Duarte, P.C., Martin, C.W., Turner, R.E., Whitehead, A. (2014). Integrating organismal and population responses of estuarine fishes in Macondo spill research. *Bioscience*, *64*, 778–788.

GLERL. 2018. Benthos of the Great Lakes. Available at: https://www.glerl.noaa.gov/seagrant/GLWL/Benthos/Benthos.html#Group

Gilde, K. & Pinckney, J.L. (2012). Sublethal effects of crude oil on the community structure of estuarine phytoplankton. *Estuaries and coasts*, 35, 853-861.

Goldsworthy, S.D., Gales, R.P., Giese, M., & Brothers, N. (2000). Effects of the *Iron Baron* oil spill on little penguins (*Eudyptula minor*). I. Estimates of mortality. *Wildlife Research*, *27*, 559-571.

Goodlad, J. (1996). Effects of the Braer oil spill on the Shetland seafood industry. *Science of the Total Environment*, *186*, 127-133.

Goodyear, C.S., Edsall, T.A., Dempsey, D.M.O., Moss, G.D., & Polanski, P.E. (1982). Atlas of the spawning and nursery areas of Great Lakes fishes. 14 vols. U. S. Fish and Wildlife Service, Washington, DC. FWS/OBS-82/52.

Great Lakes Aquatic Habitat Framework. (2018). Data Available at https://www.glahf.org/.

Green, A.J., & Elmberg, J. (2014). Ecosystem services provided by waterbirds. *Biological Reviews, 89*, 105-122.

Hannam, M.L., Bamber, S.D., Galloway, T.S., Moody, J.A., & Jones, M.B. (2010). Effects of the model PAH phenanthrene on immune function and oxidative stress in the haemolymph of the temperate scallop *Pecten maximus*. *Chemosphere, 78*, 779-784.

Heintz, R.A., Rice, S.D., Wertheimer, A.C., Bradshaw, R.F., Thrower, F.P., Joyce, J.E., & Short, J.W. (2000). Delayed effects on growth and marine survival of Pink Salmon *Oncorhynchus gorbuscha* after exposure to crude oil during embryonic development. *Marine Ecology Progress Series*, *208*, 205-216.

Henkel, J.R., Sigel, B.J., & Taylor, C.M. (2012). Large-scale impacts of the *Deepwater Horizon* oil spill: Can local disturbance affect distant ecosystems through migratory shorebirds? *Bioscience*, *62*, 676–685.

Incardona, J.P., Carls, M.G., Teraoka, H., Sloan, C.A., Collier, T.K., & Scholz, N.L. (2005). Aryl hydrocarbon receptor-independent toxicity of weathered crude oil during fish development. *Environmental Health Perspectives*, *113*, 1755-1762.

Incardona, J.P., Collier T.K., & Scholz, N.L. (2004). Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. *Toxicology and Applied Pharmacology*, *196*, 191-205.

Ingersoll, C. G., MacDonald, D. D., Wang, N., Crane, J. L., Field, L. J., Haverland, P. S., ... & Smorong, D. E. (2001). Predictions of sediment toxicity using consensus-based freshwater sediment quality guidelines. *Archives of Environmental Contamination and Toxicology*, *41*(1), 8-21.

Iverson, S.A., & Esler, D. (2010). Harlequin duck population injury and recovery dynamics following the 1989 *Exxon Valdez* oil spill. *Ecological Applications, 20*, 1993-2006.

Jewett, S.C, & Dean, T.A. (1997). The effects of the Exxon Valdez Oil Spill on Eelgrass Communities in Prince William Sound, Alaska, 1990–95. Alaska Department of Fish and Game, Habitat and Restoration Division, Restoration Project Final Report 95106. Anchorage: Alaska Department of Fish and Game. 291 pp.

Judy, C.R., Graham, S.A., Lin, Q., Hou, A., Mendelssohn, I.A. (2014) Impacts of Macondo oil from Deepwater Horizon spill on the growth response of the common reed *Phragmites australis*: a mesocosm study. *Marine Pollution Bulletin 79*, 69-76.

Kennedy, C.J., & Farrell, A.P. (2006). Effects of exposure to the water-soluble fraction of crude oil on the swimming performance and the metabolic and ionic recovery post-exercise in Pacific herring (*Clupea pallasi*). *Environmental Toxicology and Chemistry, 25*, 2715-2724.

Kost, M.A., Albert, D.A., Cohen, J.G., Slaughter, B.S., Schillo, R.K., Weber, C.R. & Chapman, K.A. (2007). Natural Communities of Michigan: Classification and Description. Report for the Michigan Dept. of Natural Resources, Wildlife Division and Forest, Mineral and Fire Mgmt. Division. 314pp.

Lake Michigan Lakewide Management Plan. (2008). http://www.epa.gov/glnpo/michigan.html

Laubier, L. (1980). The Amoco Cadiz oil spill: An ecological impact study. *Ambio, 9*, 268-276.

Law, R.J., & Hellou, J. (1999). Contamination of fish and shellfish following oil spill incidents. *Environmental Geoscience, 6*, 90-98.

Lindén, O. (1977). Sub-lethal effects of oil on mollusk species from the Baltic Sea. *Water, Air, and Soil Pollution, 8*, 305-313.

Luiselli, L., Akani, G.C., & Politano, E. (2006). Effects of habitat alteration caused by petrochemical activities and oil spills on the habitat use and interspecific relationships among four species of Afrotropical freshwater turtles. *Biodiversity and Conservation, 15*, 3751-3767.

MacDonald, D.R. (2000). Development and evaluation of consensus-based sediment quality guidelines for freshwater systems. *Archives of Environmental Contamination and Toxicology, 39*, 20-31.

Malcolm, H.M., & Shore, R.F. (2003). Effects of PAHs on terrestrial and freshwater birds, mammals, and amphibians. in Douben PE, ed. PAHs: An Ecotoxicological Perspective. Wiley. 225–242 pp.

Martin, C.W., Hollis, L.O., Turner, R.E. (2015). Effects of oil-contaminated sediments on submerged vegetation: an experimental assessment of *Ruppia maritima*. *PLoS ONE, 10*, e0138797.

Meador, J.P., Stein, J.E., Reichert, W.L., & Varanasi, U. (1995). Bioaccumulation of polycyclic aromatic hydrocarbons by marine organisms. *Reviews in Environmental Contamination and Toxicology, 143*, 79-165.

Michigan Department of Natural Resources. (2005). Double-crested Cormorants in Michigan: A review of history, status, and issues related to their increased population. Report No. 2.

Michigan Herp Atlas. (2018). Available from: https://www.miherpatlas.org/

Michigan SeaGrant. (2018) http://www.miseagrant.umich.edu.

Michigan Tech Research Institute. Great Lakes Coastal Wetland Mapping (online) http://www.mtri.org/coastal_wetland_mapping.html

Molisani, M.M., Costa, R.N., Cunha, P., de Rezende, C.E., Ferreira, M.I.P. & de Assis Esteves, F. (2013). Acute toxicity bioassay with the amphipod, *Grandidierella bonnieroides* after exposure to sediments from an urban estuary (Macaé River Estuary, RJ, Brazil). *Bulletin of Environmental Contamination and Toxicology, 90*, 79-84.

Monson, D.H., Doak, D.F., Ballachey, B.E., & Bodkin, J.L. (2011). Could residual oil from the *Exxon Valdez* spill create a long-term population "sink" for sea otters in Alaska? *Ecological Applications*, *21*, 2917-2932.

Munilla, I., Arcos, J.M., Oro, D., Alvarez, D., Leyenda, P.M., & Velando, A. (2011). Mass mortality of seabirds in the aftermath of the *Prestige* oil spill. *Ecosphere,* 2, 1-14.

National Audubon Society (2018). Important Bird Areas. https://www.audubon.org/important-bird-areas.

National Oceanic and Atmospheric Administration. (1994). Environmental Sensitivity Index (ESI). https://response.restoration.noaa.gov/maps-and-spatial-data/environmental-sensitivity-index-esi-maps.html.

National Oceanic and Atmospheric Administration. (2009). Lake Huron Food Web. Impact of exotic invertebrate invaders on food web structure and function in the Great Lakes: A network analysis approach" by Mason, Krause, and Ulanowicz, 2002 - Modifications for Lake Huron.

National Oceanic and Atmospheric Administration. (2013). Screening Level Risk Assessment Package - Bunker Hill. National Oceanic and Atmospheric Administration, 37 pp., retrieved from: https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/protect/ppw/pdfs/argo.pdf

Neff, J.M. (2002). Bioaccumulation in Marine Organisms. Effects of contaminants from oil well produced water. Elsevier New York.

Ozhan, K., Parsons, M.L., & Bargu, S. (2014). How were phytoplankton affected by the Deepwater Horizon oil spill? *BioScience*, 64, 829-836.

Parsons, M., Morrison, W., Rabalais, N.N., Turner, R.E. (2015). Phytoplankton and the Macondo oil spill: A comparison of the 2010 phytoplankton assemblage to baseline conditions on the Louisiana Shelf. Environmental Pollution, 207, 152-160.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., & Torres, F. (1998). Fishing down marine food webs. *Science, 279*, 860-863.

Peterson, C.H., Kennicutt, M.C., Green, R.H., Montagna, P., Harper, D.E., Powell, E.N., & Roscigno, P.F. (1996). Ecological consequences of environmental perturbations associated with offshore hydrocarbon production: A perspective on long-term exposures in the Gulf of Mexico. *Canadian Journal of Fisheries and Aquatic Sciences, 53,* 2637-2654.

Peterson, C.H., Rice, S.D., Short, J.W., Esler, D., Bodkin, J.L., Ballachey, B.E., & Irons, D.B. (2003). Long-term ecosystem response to the Exxon Valdez oil spill. *Science, 302*, 2082-2086.

Peterson, C.H., Rice, S.D., Short, J.W., Esler, D., Bodkinm J.L., Ballachey, B.E., & Irons, D.W. (2003). Long-term ecosystem response to the *Exxon Valdez* oil spill. *Science, 302*, 2082-2086.

Phillips, J.G. (2016). Update geographic distributions of Michigan Herpetofauna: A synthesis of old and new species. *The Journal of North American Herpetology, 1,* 45-69.

Poggiale, J.C., & Dauvin, J.C. (2001). Long-term dynamics of three benthic *Ampelisca* (Crustacea-Amphipoda) populations from the Bay of Morlaix (western English Channel) related to their disappearance after the Amoco Cadiz oil spill. *Marine Ecology Progress Series, 214*, 201-209.

Rasmuson, L.K. (2012). The biology, ecology and fishery of the Dungeness crab, Cancer magister. *Advances in Marine Biology, 65,* 95-148.

Sanders, H.L., Grassle, J.F., Hampson, G.R., Morse, L.S., Garner-Price, S., & Jones, C.C. (1980). Anatomy of an oil spill: long-term effects from the grounding of the barge Florida in West Falmouth, Massachusetts. *Journal of Marine Research, 38,* 265-380.

Seuront, L. (2011). Hydrocarbon contamination decreases mating success in a marine planktonic copepod. *PLoS ONE*, 6, e26283.

Short, J.W., Rice, S.D., Heintz, R.A., Carls, M.G., & Moles, A. Long-term effects of crude oil on developing fish: Lessons from the Exxon Valdez oil spill. *Energy Sources, 25*, 509-517.

Sillimana, B.R., van de Koppel, J., McCoya, M.W., Dillera, J., Kasozid, G.N., Earla, K., Adams, P.N., & Zimmerman, A.R. (2012). Degradation and resilience in Louisiana salt marshes after the BP–Deepwater Horizon oil spill. *Proceedings of the National Academy of Sciences, 109,* 11234-11239.

Smith, P.N., Cobb, G., Godard-Codding, C., Hoff, D., McMurry, S., Rainwater, T., & Reynolds, K. (2007). Contaminant exposure in terrestrial vertebrates. *Environmental Pollution, 150*, 41-64.

Sundt, R.C., Pampanin, D.M., Grung, M., Baršienė, J., & Ruus, A. (2011). PAH body burden and biomarker responses in mussels (Mytilus edulis) exposed to water from a North Sea oil field: Laboratory and field assessments. *Marine Pollution Bulletin, 62,* 1498-1505.

Teal, J.M., & Howarth, R.W. (1984) Oil spill studies: a review of ecological effects. *Environmental Management, 8,* 27-44.

Thomas, R.E., Harris, P.M., & Rice, S.D. (1999). Survival in air of *Mytilus trossulus* following long term exposure to spilled Exxon Valdez crude oil in Prince William Sound. *Comparative Biochemistry and Physiology Part C: Toxicology and Endocrinology, 122*, 147-152.

Tillet, D.E., Buckler, J.A., Nicks, D.K., Candrl, J.S., Claunch, R.A., Gale, R.W., Puglis, H.J., Little, E.E., Linbo, T.L., & Baker, M. (2016). Sensitivity of Lake Sturgeon (*Acipenser fulvescens*) early life stages to 2,3,7,8-tetrachlorodibenzo-*P*-dioxin and 3,3′,4,4′,5-pentachlorobiphenyl. *Environmental Toxicology and Chemistry, 36,* 988-998.

United States Fish and Wildlife Service. (2018). Piping Plover critical habitat. https://www.fws.gov/midwest/endangered/pipingplover/counties.html

Velando, A., Munilla, I., & Leyenda, P.M. (2005). Short-term indirect effects of the *Prestige* oil spill on European shags: Changes in availability of prey. *Marine Ecology Progress Series, 302*, 263-274.

Task F: Analyzing potential measures to restore the affected natural resources and mitigate adverse impacts upon ecological and cultural resources

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F.1 Introduction

Natural Resource Damage Assessment/Damage Assessment and Restoration Plan (NRDA/DARP) under the Oil Pollution Act (OPA) requires an evaluation of injuries to natural and cultural resources and their services and using the results of such an evaluation to determine the type and extent of restoration needed to address the injuries. OPA charges trustee agencies to identify and implement actions appropriate to restore, replace or acquire the equivalent to those injured by the oil spill to return those resources to their baseline condition. Restoration takes two forms: primary restoration, defined as any action that helps return injured resources and services to baseline, or the condition that would have existed had the incident not occurred, and compensatory restoration, defined as any action taken to reimburse the public for interim losses during the period between the oil spill and the return to the baseline condition. These definitions assume that the baseline can, in fact, be restored. However, experience with some oil spills such as Deepwater Horizon (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) and Exxon Valdez (U.S. National Oceanic and Atmospheric Association, 2014) demonstrate that even after many years, restoring the baseline is not necessarily achievable after a spill. This outcome leads to the question as to whether, in certain situations, natural and cultural resources are altered or lost in perpetuity. For example, twenty-five years after the Exxon Valdez spill, scientists believe that the herring, some pods of killer whales, and the pigeon guillemot still have not recovered. An estimated 0.25% of oil from the original spill is still on the shoreline, and dissolved polycyclic aromatic hydrocarbons (PAHs) continue to impact pink salmon embryo development (Michel, Esler, & Nixon, 2016). Monitoring of historic shipwrecks since the Deepwater Horizon spill has shown that contamination significantly accelerated irreversible corrosion and decay (Hamdan, Salerno, Reed, Joye, & Damour, 2018).

This section of the report focuses on *primary restoration* in the event of the worst case spill from Enbridge's Line 5 in the Straits of Mackinac occurs. *Compensatory restoration*, by its nature of reimbursing the public for losses during the period between the incident and the restoration of baseline, cannot be determined until the losses have been inventoried and full recovery has occurred. Furthermore, it is impossible to determine *a priori* which resources can never be fully restored to baseline. Certainly, cultural resources such as maritime archaeological sites or culturally-sacred sites, once damaged by an oil spill, can be lost in perpetuity; similarly, natural resources such as the underwater sinkholes in Lake Huron, habitats for ancient microbial life, known to occur in just a few other places on earth (Biddanda et al., 2011) may also be irrevocably altered. Microbial life provides a key example of how damages to cultural and natural resources are often linked and at times irreversible (Hamdan et al., 2018). This report examines costs of primary restoration, including assessment, cleanup, and monitoring of cultural and natural resources. We will discuss injuries to examples of resources that may require both primary and compensatory restoration, but the latter costs cannot be included. According to the pertinent legal processes under OPA, trustee agencies would have to develop a Damage Assessment and Restoration Plan (DARP) based on a careful assessment of the ecological and cultural injuries following the spill in order to determine appropriate compensatory restoration.

The regulatory framework for cultural resources may be different from that for ecological resources, despite the fact that legal and regulatory contexts generally refer to "environment" in a very broad sense that includes natural, cultural, and historical elements. The term cultural resources often refers to historical and culturally-significant places like buildings, monuments, or sites. However, cultural resources incorporate a much wider range of tangible and intangible things. Tangible resources can include significant landscapes, bodies of water, or other natural features; important plants or animals, archaeological sites, important objects, artifacts, documents, and particularly important types of sites, such as battlefields, cemeteries, and shipwrecks. Whereas intangible things like cyclical natural events (culturally-important weather patterns and related cultural practices), subsistence practices, stories, songs, and dances; social practices, including rituals and religious practices; all have cultural significance.

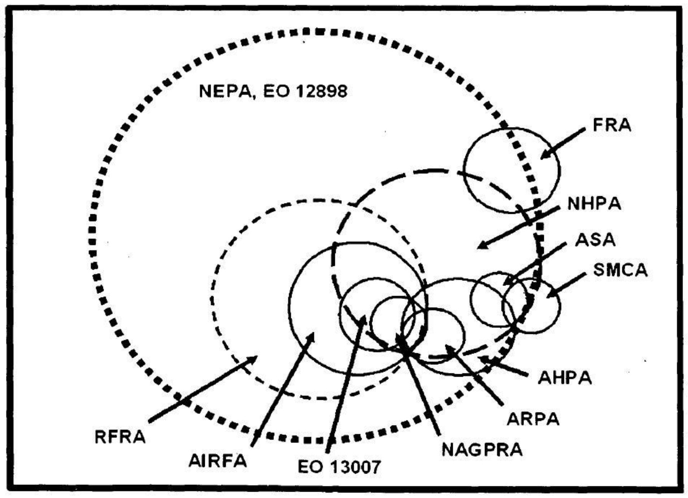

Figure 1. Resource Types Embraced by the U.S. CRM Laws

Resource Type	*Legal Authority That May Be Relevant*
Historic places in general	NEPA, NHPA
Spiritual places	NEPA, NHPA, AIRFA, RFRA, EO 13007
Cultural landscapes, rivers, etc.	NEPA, NHPA
Culturally important plants, animals	NEPA, NHPA if specific place involved
Culturally important water, air, wind patterns, etc.	NEPA, NHPA if related to identifiable place
Archeological sites	NEPA, NHPA, AHPA, ARPA if federal/tribal land
Shipwrecks, submerged aircraft	NEPA, NHPA, ASA, SMCA if military
Native American graves, cultural items	NEPA, NHPA, NAGPRA, ARPA if federal/tribal land
Religious practices	RFRA, AIRFA, NEPA, NHPA if place-related
Traditional subsistence practices	NEPA, EO 12898 if EJ population, NHPA if place-related
Other social institutions, ways of life	NEPA, EO 12898 if EJ population, NHPA if place-related.
Songs, stories, dances	NHPA if place-related, perhaps NEPA
Historical documents	FRA, NHPA if place-related, perhaps NEPA
Artifacts	NHPA if historic place-related, perhaps ARPA, NAGPRA, NEPA, agency policies, international treaties

Key:
AHPA: Archaeological and Historic Preservation Act
AIRFA: American Indian Religious Freedom Act
ARPA: Archaeological Resources Protection Act
ASA: Abandoned Shipwrecks Act
Executive Order 12898: Environmental Justice
Executive Order 13007: Indian Sacred Sites
FRA: Federal Records Act
NAGPRA: Native American Graves Protection and Repatriation Act
NEPA: National Environmental Policy Act
NHPA: National Historic Preservation Act
RFRA: Religious Freedom Restoration Act

Figure F1: Articulating Cultural and Natural Resources Laws in the United States (From King, 2008).

In the U.S. and Canada, cultural resources preservation and management follows from a patchwork of laws and policies that include international, national, regional, state, and Native American/First Nation tribal contexts (King, 2008; Noble, 2010; Pokytylo & Mason, 2010). These laws govern actions by government agencies and those private individuals or corporations with undertakings funded through or permitted by those agencies. In the U.S., the National Historic Preservation Act of 1966 (NHPA) and the National Environmental Policy Act of 1970 (NEPA) exert the most influence over remediation and restoration efforts during an environmental disaster. These acts are the most important only, as many other laws and policies establish critical rules about specific elements of cultural resources (Figure F1).

The Canadian federal government began to create similar laws and policies in 1973, leading to the Canadian Environmental Assessment Act of 1992 (CEAA), which was replaced and updated in 2012. Rules associated with this act apply only to crown lands, however, and under the Constitution Act 1867-1982, provincial laws govern planning and heritage matters throughout Canada. The regulatory patchwork is therefore equally complex in Ontario, where primary acts involving natural and cultural heritage are the Ontario Planning Act, the Ontario Environmental Assessment Act, The Environmental Protection Act, and the Ontario Heritage Act. As with laws in the U.S., both these laws and the policy frameworks derived from them include requirements for public consultation with special attention to First Nations, Métis, and Inuit communities (FNMI) (Letourneau, 2017; Williamson, Robertson & Hughes, 2017).

CEAA, NHPA, and NEPA each created broad frameworks by which actions of federal governments could be assessed for their impacts on the environments, public health, and cultural resources of the nation and mandated public involvement in the decision-making processes (King, 2008; Kirchhoff, Gardner, & Tsuji, 2013). Academic and policy experts have engaged in a robust and vigorous discussion on the implementation of practices within these legal frameworks (Brody, Di Bianca & Krysa, 2012; Candor, 1996; Jenni, Merkhofer, & Williams, 1995). In the context of this report, we note that significant tensions exist between different models of "stakeholder" participation in established professional management practice, as discussed further in Chapter X. The old methods of informing public groups about issues and taking public comment at meetings are evolving toward more "collaborative management" arrangements in the administration of environmental and cultural resources (Reed, 2008; McKay & Johnston, 2018; Harvey, Clarke, & Carvalho, 2001).

Primary restoration follows cleanup (Task C). Similar strategies may be employed in both: the boundary between cleanup and primary restoration is perhaps one of a timeline. In the case of the Enbridge Line 6B oil discharge near Marshall, MI, the spill occurred in July 2010 (U.S. Fish and Wildlife Service, Nottawaseppi Huron Band of the Potawatomi Tribe, & Match-E-Be-Nash-She-Wish Band of the Potawatomi Tribe, 2015). Immediate cleanup measures included installing containment booms and the use of skimmers, vacuum trucks, and removal of heavily oiled sediment and vegetation. The excavation of heavily contaminated sediment continued during the winter. In the summer of 2011, Enbridge was directed by the U.S. EPA to address the more than 220 areas in the river that were still showing evidence of contamination. Work shifted to more targeted excavation and dredging, removing contaminated sediment aimed at "sheen management," and bringing in clean soil of a similar type to backfill and restore the river banks and replanting native vegetation. Efforts to reduce the impact of the contamination continued through Fall 2014. In this incident, the activities during the first year may be classified as cleanup, whereas those of the subsequent years may be classified as primary restoration. Industry expectations are that the immediate cleanup of oil spills in open water may collect only upwards of 15% of the oil spilled (Nikiforuk, 2016). The remainder may be collected through dredging or shoreline cleanup, or be dispersed or degraded during the primary restoration period. But the end point of primary restoration may be challenging to pinpoint. As of 2014, (25 years after the Exxon Valdez spill in 1989), between 16,000 and 21,000 gallons still remained on beaches, breaking down at a rate of less than 4% per year (Short et al., 2007). Thus, an operational definition of the end point of restoration will need to be defined as part of the DARP.

The inclusion of cultural resources further complicates the prediction of restoration cost. Considering again the example of Enbridge Line 6b spill near Marshall, MI, the response team's initial containment, and cleanup effort moved ahead without considering cultural resources in its actions. The spill occurred during a flooding event on or about July 25, 2010. The response began the day following the discovery of the spill, and by August 10th, the site report mentions the identification of no-go exclusion zones established through communication with State Historic Preservation Office (SHPO) and archaeologists (U.S. EPA, 2010). On August 31st, the EPA's Federal On-Scene Coordinator ordered Enbridge to cease cleanup and restoration until it could comply with NHPA. The EPA notified stakeholder groups and communities, along with Michigan SHPO and appropriate Tribal Historic Preservation Office (THPO) in early September. The spills occurred in July; however, Enbridge did not start meaningful consultation with other cultural resources stakeholders until October and November. This timeline meant that the emergency containment efforts and the initiation of subsequent cleanup operations were undertaken without consultation or detailed consideration of cultural resources. The plans for cultural resources were approved another month later on October 22nd, 2010, essentially three months after the spill event.

In the case of the Line 6B spill, the Area of Potential Effect (APE) included only a few cultural resources. A worst-case spill in the Straits of Mackinac could be much more impactful, in terms of the number of sites, the site types, and the administrative oversight of those sites (private land, state or municipal parklands, national or provincial forest resources, marine sanctuaries, etc.). In addition, the three tribal governments local to the Marshall, MI, spill elected not to comment on the reports, plans, or actions of Enbridge or U.S. EPA during September and October. In the case of a spill in the Straits of Mackinac, it is unlikely that all local Native American/FNMI tribal governments and other stakeholder groups will opt out of involvement during the consultation required under NEPA, NHPA, and/or CEAA. The NRDA/DARP must incorporate community involvement in the restoration process since the impacts of the oil spill may be felt for years (if not decades), may be sequestered in remote locations, or may have impacts observed only by those most familiar with the specifics of the location. The level of tribal and other stakeholder and interest group participation in deliberations about Line 5 to date already demonstrates a strong commitment to involvement in the process of risk analysis and the design of response and restoration plans. In the event of a spill in the Straits of Mackinac, the consultation process will be much longer, costlier, and more involved in order to reach an acceptable resolution.

F.1.1 Scope of Task F

This task seeks to identify the type and extent of primary restoration needed to return the environment to baseline from the anticipated damage from the worst-case spill. The environment is broadly defined and includes natural and cultural resources in various areas including open water, wetlands, intertidal areas and uplands, both the physical habitat and the organisms residing therein, and the cultural resources, including maritime structures, archeological sites and other culturally significant sites. This task also addresses the potential costs associated with the anticipated primary restoration, based on an analysis of costs incurred from previous oil spills. For the Straits, these costs are necessarily estimates because no comparable oil spill has ever occurred in the Great Lakes. These cost figures do not include compensatory restoration of natural resources, the provision or development of alternative drinking water sources, or the compensatory restoration of cultural resources, among other costs. Furthermore, it should be noted that the ultimate costs even for primary natural resource restoration can be difficult to quantify at the outset: the consent decree for Deepwater Horizon (U.S. Department of Justice, 2016) includes substantial funds for unknown injuries and adaptive management in the aftermath of the spill.

F.2. Approach

F.2.1 Definition of Worst-case Scenario

One objective of this task is to give a ballpark estimate of the cost of primary restoration, in the case of a worst-case oil spill. A brief examination of the costs for the Deepwater Horizon oil spill and the Line 6B oil spill near Marshall, MI, suggested that most of the restoration costs were associated with oil removal from the shoreline and the restoration of those habitats, rather than with the restoration of water quality of open water. Task F, therefore, adopted the four worst-case scenarios from Task E, which were chosen as those that gave the most oiled shoreline for each of the two lakes, Michigan and Huron, at each of two-time windows, 10 and 60 days after a spill (Table F3). A potential spill from Line 5 may threaten additional resources, however, such as cultural heritage sites or community water sources. An analysis of the costs associated with the restoration of these resources is not provided herein. This omission is due to a lack of information, as the costs associated with such restoration are not systematically published and available as part of the documentation available from other oil spills. This omission should not be interpreted to mean that these resources are any less important than shoreline habitat, but rather the lack of systematic data precludes the itemization of their costs for restoration. Similarly, the focus here is on primary restoration and that costs associated with compensatory restoration are not included here. The goal of compensatory restoration is to reimburse the public for the ecosystem losses during the period between the incident, and the restoration of baseline and that timeline cannot be simulated.

It should also be noted that it may not be possible for all cultural and natural resources to be restored. For example, archaeological sites are a non-restorable resource, since they are an irreplaceable record of people living at a distinct place and time. While NRDA activities related to archaeological resources can identify and quantify contamination and physical damage to sites, the sites generally cannot be restored. Damage assessment surveys focus on the mitigation of damage through data recovery as the spill response shifts into cleanup and restoration. This approach allows researchers to capture as much of the remaining scientific and historical information as possible. The costs of these surveys are assumed to be included in each ecological restoration project discussed below. Furthermore, place-based cultural heritage, such as communal ricing traditions, use of sacred sites, or family fishing, *may* not be restored. If a community has long traditions using a particular wetland location for fishing, hunting migratory waterfowl, and ritual or religious activities, loss of the use of that place for decades effectively severs generations of the community's youth from their heritage. This loss of cultural heritage was clear in the case of the Exxon Valdez oil spill (Dyer, 1993; also Section X in this report). The injury assessment of the NRDA must account for primary and compensatory restoration in a manner that it demonstrates an appreciation for ecological and cultural, both tangible and intangible, resources.

F.3 Analysis

This analysis relies heavily on information from the Deepwater Horizon and Enbridge Line 6B oil spills because relatively complete cost data is available for both. Table F1 gives an overview of those spills compared to a hypothetical spill in the Straits of Mackinac. As this table shows, the type of oil in a hypothetical Line 5 spill may be more similar to that in the case of the Deepwater Horizon than that in Line 6B. The oil would be released at depth in the lake, but not at as great a depth occurred with the Deepwater Horizon. However, the freshwater environment of Michigan is more similar to that of the Enbridge Line 6B. Thus, the impacted habitats may have greater similarities with those in the case of Enbridge Line 6B that with Deepwater Horizon; yet, it could be claimed that the natural resources damaged in the case of Deepwater Horizon were of greater significance than those in the case of Line 6B spill in Marshall MI. Hydrodynamic modeling of a spill in the Straits predicts significant impacts on coarse-grained shorelines, which were not substantially impacted in either the Deepwater Horizon or the Line 6B spills. Given the uniqueness of the Great Lakes, we argue that its natural resources also have a value greater than those impacted in the Line 6B spill.

Table F1. Oil Spill Comparison

Oil Spill	**Deepwater Horizon (04/20/2010)**	**Enbridge Line 6B (07/25/ 2010)**	**Enbridge Line 5 (hypothetical)**
Type of oil	Sweet, light, most abundant compounds greater than C_1-C_5 were BTEX compounds (Reddy et al., 2011)	Diluted bitumen (density = 0.92 g/cm^3) (DEQ, 2016)	Sweet, light
Depth of release	1,522 m	Below grade	≤ 90 m
Estimated amount of release	780,000 m^3	3190 m^3	9221 m^3
Location of spill	Gulf of Mexico, 66 km from southeast coast of Louisiana	Marshall, MI	Straits of Mackinac, MI
Amount of shoreline oiled	2,113 km (Nixon et al., 2016)	126 km (39 miles of the Kalamazoo River)	Variable based on spill scenario (Task B)
Types of Shoreline Impacted	Beaches (50.8%), Marshes (44.9%) Other (4.3%) (Michel et al., 2013)	Primarily wetland	Coarse-grained (44.1 - 64.5%) Sand Beach (10.4 - 38.7%) Wetland (5 - 17.1%) (Estimates based on scenarios from Table F.3)

F.3.1 Habitat

F.3.1.1 Wetlands

F.3.1.1.1 Description of injury

Coastal wetlands support an immense degree of biodiversity in the Great Lakes. Up to one-third of the primary productivity is based in the coastal wetlands, which thereby provide major support to the Great Lakes food web (Brazner, Sierszen, Keough, & Tanner, 2000). These sites are essential to several categories of ecosystem services (provisioning services, as nesting grounds; regulating services such as erosion and flood control; and supporting services such as nutrient cycling). Previous spills have resulted in substantial injury to wetland ecosystems (Nixon et al., 2016). It is therefore expected that substantial injury would occur to coastal wetlands in the case of a worst-case spill in the Straits of Mackinac. This injury would consist in oiling of the physical environment along with vegetation and organisms in the habitat. Based on the experience with the Deepwater Horizon, it is expected that there may be acute effects where the biota may not recover. Where the vegetation has died, and the root system is lost, the possibility exists for greater erosion of the shoreline. While it is assumed that cleanup efforts would be careful to not do more damage, the chance exists that cleanup efforts could also lead to damage to the system.

F.3.1.1.2 Approach for restoration

<u>Sediment Removal:</u>

Description of Approach: A number of approaches for restoration of wetland habitats have been employed in previous spills (Zhao et al., 2016). These approaches have sought to restore the physical conditions in the habitat as well as to enhance its capacity for ecosystem services. Restoration generally involves removal of oil using sorbents and the removal of contaminated sediments using manual or mechanical means (where possible) and the deposition of clean sediment of a similar nature. In some wetlands, the physical removal of sediments would result in greater damage to the system (Michel and Rutherford, 2014). In these habitats, the extent of oiling may be addressed through manual cleanup efforts on a limited scale.

Limitations: Sediment removal can have a dramatic impact on the environmental conditions of the location. In the case of wetlands, large-scale sediment removal may not be the method of choice primarily due to the damage that could be done as a result of this approach.

<u>Bioremediation:</u>

Description of Approach*:* Despite efforts to remove the oil using manual methods, there still may be residual oil. Furthermore, extensive manual removal may be deemed to potentially cause more harm than good to the habitat. This residual oil may be eliminated through monitored natural attenuation. In previous spills, monitored natural attenuation and biostimulation have been applied to further cleanup and restore the damages to wetlands (Atlas & Hazen, 2011; Atlas et al., 2015). A number of microbes are capable of breaking down oil and detoxifying it to carbon dioxide (CO_2) (Hazen, Prince, & Mahmoudi, 2016). These microbes are primarily bacteria and are present in many ecosystems. In monitored natural attenuation, these oil-degrading microbes are relied upon to break down the residual oil and remove it from the system. A biodegradation study on sediment from the Kalamazoo River demonstrated that natural attenuation could breakdown roughly 25% of the residual oil mass (FSOC Desk Report, 2016).

Factors such as nutrient availability and temperature may limit the rate of biodegradation. If natural removal of the oil is prohibitively slow, biostimulation can be used to increase the degradation rate. Fertilizers, such as nitrogen and phosphorous which are often limiting for oil biodegradation, are added to the system to increase the rate and extent of oil removal.

Limitations: One of the major limitations of bioremediation is that it requires time for it to be effective. Bioremediation can take weeks to months to years to remove substantial amounts of oil (Mahmoudi et al., 2013). The removal may be incomplete, and the system needs to be routinely monitored to ensure that the oil continues to degrade (National Research Council, 2013). Stimulation may or may not be a possibility. For example, microbial activity during winter is often slow because of the cold temperatures. However, examples do exist of microbial oil biodegradation that occurs under very cold conditions at very fast rates (McFarlin, Prince, Perkins, & Leigh, 2014).

<u>Plantings:</u>

Description of Approach: Oiled plants may be removed during initial cleanup operations. This vegetation is essential to providing important habitat and protection for many of the organisms that live in wetlands (Uzarski, Burton, Cooper, Ingram, & Timmermans, 2005). In addition, plants also control erosion and thus, the level of suspended solids. Therefore, restoration of an injured wetland ecosystem includes the planting of native plant species. Some plants such as blue joint grass, sedges, and some rushes are common in many Great Lakes wetlands and could be candidates for plantings (MNFI, 2018). In cases where the root systems are still intact and not damaged by oil, it may be possible to cut down only the part above ground. In both cases, new plantings and pruned plants, the vegetation would need to be monitored to ensure its growth. Marsh restoration was a target of early restoration steps taken in the aftermath of the Deepwater Horizon oil spill because of its importance as a habitat and in erosion control, (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016).

Limitations: Although marsh restoration may be desirable early on in the restoration, planting new vegetation may only be undertaken during the warmer months. Furthermore, the plantings need to planned to ensure that native species are used to help restore the wetlands to the conditions prior to the spill. In some cases, wetlands have been impacted by invasive species (Trebiz and Taylor, 2007). Restorations that involve replanting of impacted wetlands could help to enhance the wetlands through the removal of invasive plants and replacing with native species. In the restoration of the Marshall, MI spill, a number of invasive species were targeted for removal and replacement with native species (U.S. Fish and Wildlife Service, 2015). Consultation with tribal elders with access to traditional ecological knowledge may be useful in making an informed choice (U.S. Fish and Wildlife Service, n.d.).

F.3.1.1.3 Monitoring

To evaluate the effectiveness of these strategies, key aspects of the wetland will be monitored including habitat structure, the progress of vegetation, and use by animals. These will provide a basis for evaluating the success of these restoration projects. An adaptive monitoring approach for restoration is suggested, as was used in the Gulf of Mexico during the Deepwater Horizon restoration (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016).

F.3.1.2. Intertidal Shoreline and Uplands

F.3.1.2.1 Description of injury

A number different intertidal habitats are present in the Straits of Mackinac and the greater Lake Michigan and Lake Huron area, including coarse-grained flat coastline, sand beaches, and sediment scarps. These important habitats would need to be restored in the event of a spill. An oil spill would result in oil contamination on these shorelines, which would impact their use for native organisms as well as for recreational uses.

F.3.1.2.2 Approach for restoration

<u>Replacement of contaminated substrate:</u>

Description of approach: Oiled covered geologic material could be removed from the shoreline using heavy earth moving equipment and then replaced with geologic material of a similar nature (Michel et al., 2013). Depending on the location, this may have a limited impact on the ecosystem and may be a rapid way for the restoration of contaminated areas. In more sensitive habitats, mechanical removal would not be utilized due to the potential for the heavy machinery to cause more damage. In these cases, manual cleaning may be a valid approach.

Limitations: This approach is quite invasive and requires the sourcing of material that is suitable for replacement of the contaminated material. Material replacement may be possible in some locations, particularly sandy beaches, where material is commonly brought in to supplement sand lost, for example, during winter storms.

Bioremediation:

Description of Approach: Bioremediation may be an appropriate approach in locations that have been cleaned either using manual or mechanical approaches, but residual oil remains. Bioremediation could take the form of natural attenuation, or biostimulation may be applied to ensure rapid removal of residual oil in these contaminated habitats.

Limitations: Natural attenuation requires that conditions are sufficient to break down the oil. Additionally, it is possible that microbial community is limited by factors that cannot be engineered, such as temperature.

Plantings:

Description of approach: Many of the potentially impacted intertidal and upland habitats have beach grasses that serve necessary functions as habitat and protection from erosion (Maun and Krajnyk, 1989). If this vegetation is lost or injured during the spill or cleanup, it is essential to replace that vegetation. Similar to the plantings for wetlands, these might be part of the early restoration efforts to mitigate some of the potential indirect effects of a spill such as increased erosion. In the case of plantings, native beach plants and grasses will be planted in the injured areas as well as other places along the beach to enhance the beach system and enable enhanced habitat restoration.

Limitations: Plantings can only be undertaken in warmer weather. Additionally, it is essential that care is taken to ensure that native species are used in plantings to restore injured environments in the intertidal upland settings.

F.3.1.2.3 Monitoring

A similar set of parameters used to the monitoring approaches used in monitoring the success of restoration approaches for wetlands could be employed to monitor intertidal and upland settings impacted by the spill. Monitoring of success could involve monitoring habitat structure, vegetation return, and animal use, including birds and terrestrial wildlife that take advantage of some of the upland settings.

F.3.1.3 Open water

F.3.1.3.1 Description of injury

Based on the hydrodynamic modeling, by Task B, it is anticipated that a maximum of 346 km^2 of water surface will be covered by oil. However, the water velocity is not uniform throughout the water column: if there is strong counter-current wind, the maximum velocity may occur at 2-3 meters below the surface (Derecki and Quinn, 1988). Thus, the area covered at the surface may not represent the maximum horizontal area of the spill. Some percentage of the oil on the surface may be collected through containment and the application of sorbents. During the primary restoration, the consideration is the removal of oil that is left behind after initial cleanup. The standards to which the water needs to be cleaned are defined by State of Michigan's Part 4 Rules Water Quality Standards (of Part 31, Water Resources Protection Act 451 of 1994), or by other applicable standards. R 323.1050 which states that the surface waters of the state may not have oil films in "unnatural quantities." The primary regulated constituents in oil are benzene, toluene, ethylbenzene, and xylene (BTEX) and PAHs. R 323 1057 states that levels of toxic substances in the surface waters of the state shall not exceed the human health values for toluene of 5600 μg/L and 51000 μg/L for drinking source water and nondrinking water, respectively, and for benzene, 12 μg/L and 310 μg/L, for drinking source water and nondrinking source water, respectively (Table FT2). During surface oil spills, the BTEX compounds, which have relatively high vapor pressures, may volatilize. However, in subsurface spills, these compounds may solubilize in the water column to an appreciable extent. In the case of the Deepwater Horizon spill, BTEX compounds were measured at concentrations up to 78 μg/L (Reddy et al., 2011). PAHs have considerably lower vapor pressures and are widely viewed as environmentally persistent (Doyle, Muckian, Hickey, & Clipson, 2008). Furthermore, the presence of PAHs in the Great Lakes has been a concern for decades, in part due to the lakes' long hydrologic retention times and great depths (Huang & Batterman, 2014). These compounds may sorb to the organic matter present in the lake, reducing their availability for biodegradation (Riding et al., 2013). Since the potential release is at the lake bottom, these compounds may be sorbed directly to the organic matter in the sediment. Alternatively, as they are transported upwards in the water column as part of the oil plume, they may sorb to organic matter present therein. Then, they may settle back to the lake sediments as part of "lake snow" (Grossart and Simon, 1993).

Figure F2 shows the location of intakes for public water supply intakes in Michigan for the Great Lakes and connecting waters. Table F2 gives the maximum permissible drinking water concentrations for some of the contaminants present in oil. If the concentrations of contaminants in lake water exceed permissible levels, affected communities would have to close their water intakes. Severe conservation measures would be implemented and bottled water would need to be provided until appropriate treatment, or alternative water supplies could be developed.

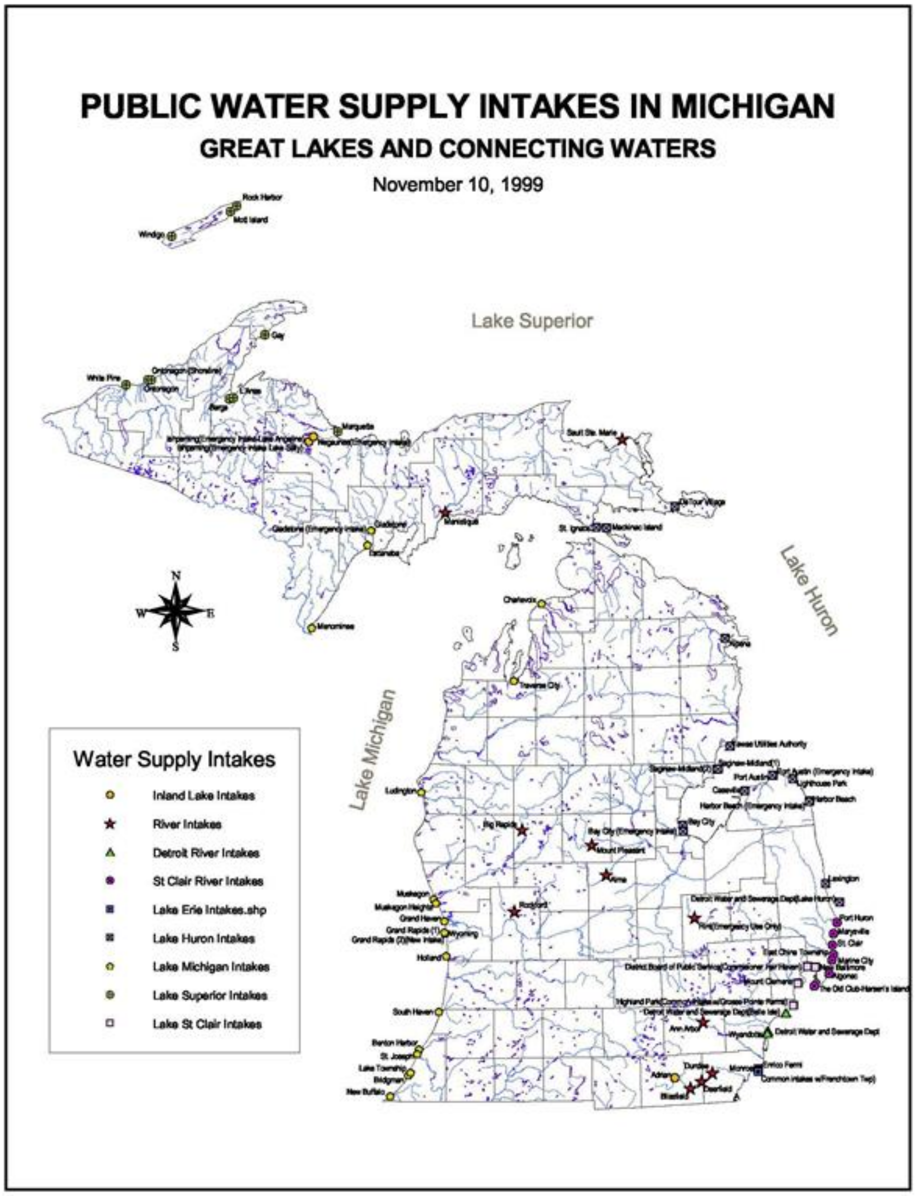

Figure F2: Public Water Supply Intakes in Michigan
Source: US Geological Survey, 1999.

F.3.1.3.2 Approaches for restoration

Description of approach: Dissolved compounds, such as BTEX, would be removed through natural processes such as abiotic weathering and microbial degradation (Harriman et al. 2017, Ward et al. 2018). In this situation, the monitoring of BTEX concentrations in the lake water without active intervention may be a valid approach. But, it must be noted that the timeframe for microbial degradation may vary considerably. Wick et al. (2000) observed that benzene may be degraded at the oxic-anoxic interface in a lake, with pseudo-first-order rate constant between 1 and 2.5 day^{-1}; however, in the hypolimnion, the rate constant was $\leq 0.04\ day^{-1}$.

In the case of PAHs, a more active approach may be warranted. PAHs can move from the sediments into the lake water. Therefore, one approach for remediation is to remove oil-contaminated sediments by dredging; the contaminated sediments would be disposed of at an approved location on land. The type of dredge would depend on the depth of the water where the oil is located, with trailing suction hopper dredgers having the capability of dredging up to 155 m in depth (International Association of Dredging Companies, 2014), so it would have the capability to dredge the sediments of the Straits of Mackinac as its maximum depth is 295 ft (90 m). The benefits of dredging of the location of the spill site would have to be balanced with the known risks of suspending sediments contaminated with other persistent pollutants such as mercury, which is also of concern in the Great Lakes (U.S. Environmental Protection Agency, 2004).

Communities whose raw water source have been contaminated by oil spills have responded with different approaches. In addition to transient water contamination, long-term impacts on drinking water may occur if the sediments near a drinking water intake are contaminated. In January 2015, 40,000 gallons of oil spilled beneath the Yellowstone River, six miles upstream of Glendive Montana. The population relied on bottled water, while filters were added to the city treatment plant (Associated Press, 2015). Treatment using ozonation and sand filtration as pretreatment steps before the drinking water treatment process could be evaluated for its suitability (Hong and Xiao, 2013). To remove compounds such as benzene in drinking water treatment, the EPA has approved granular activated carbon in combination with packed tower aeration (n.d. a). To remove benzo(a)pyrene, the EPA has approved granular activated carbon (n.d. b). Alternatively, new water supplies could be developed. Following the July 2016 spill of oil into the North Saskatchewan River near Maidstone, Saskatchewan, accommodations were made to supply water for close to 70,000 people (Canadian Press, 2016). The area was placed under severe water conservation measures and bottled water was trucked in. A temporary pipeline stretching 30 kilometers to draw water from the South Saskatchewan River was put into place (Krugel, 2016). In both cases, the short-term solution was the trucking in of bottled water. The longer-term solution in the first example was treatment; in the second, an alternative surface water source. Neither of these communities turned to groundwater, which would be an option in some locations. Consultations with appropriate drinking water professionals would be needed to determine whether treatment or an alternative drinking water source, surface or groundwater, would be the best long-term option for the affected communities.

Table F2. Selected Maximum Contaminant Levels from the National Primary Drinking Water Regulations

Contaminant	MCLG (mg/L)	MCL (mg/L)
Benzene	zero	0.005
Benzo(a)pyrene (PAHs)	zero	0.0002
Ethylbenzene	0.7	0.7
Toluene	1	1
Xylenes (total)	10	10

MCLG=Maximum Contaminant Level Goal. MCL=Maximum Contaminant Level. Source: U.S. EPA (2018).

Limitations: While the impact of the spill may be felt throughout the food web, previous work has shown that the base of the food web can often be sensitive indicators of oil contamination and the presence of oil (Smith et al., 2015). Microbes respond rapidly to environmental change and can be used as a monitoring tool for removal of oil and restoration of a system. In the marine environment, oil-degrading microbes similar to those employed in bioremediation of on-shore locations can grow substantially in open water in response to an oil spill (King, Kostka, Hazen, & Sobecky, 2015). These changes in the composition of microbial community can be useful for monitoring the presence of trace amounts of oil and also for understanding when the base of the system has returned to baseline conditions. In addition, the microbes that respond to oil often have the ability to break down the oil components and thus may participate in natural attenuation of the oil in the system (Hazen et al., 2010). Yet, one of the major limitations to the use of microbes as indicators of contamination and the restoration state of the system is that there is still limited information on the natural diversity of microbes in the Straits of Mackinac region. Thus, in order to use microbial community composition as a tool for environmental restoration, additional background information is required regarding the composition of the microbial community and how it shifts in response to oil.

F.3.1.3.3 Monitoring

Monitoring of the natural microbial communities as a tool for determining restoration state is a relatively new approach. Key indicator microbial organisms will be determined, and their abundance and distribution monitored at set locations in the open water to ensure that the microbial community composition has returned to pre-spill conditions.

F.3.1.4 Critical/Sensitive Habitat

F.3.1.4.1 Description of injury

Within the Straits region, there are a number of highly sensitive habits as defined by NOAA's environmental sensitivity index. Included in these are 13 unique terrestrial communities in the Straits of Mackinac (Kost et al., 2007). These habitats include coastal fens, Great Lakes marshes, open dunes, and gravel/cobbled shorelines. Many of these are in proximity to the shoreline and are at risk for oiling from a potential spill. These habitats are home to a variety of organisms that are at risk of oiling. In addition to these unique communities, there are a number of areas of conservation in the Straits of Mackinac region.

F.3.1.4.2 Approach for restoration

Great care needs to be taken in restoring these areas, as efforts to clean up may cause additional damage. It is therefore important that these critical and sensitive habitats be targets for protection during the containment and cleanup response, to protect them from oil in the first place. In some systems, if oil is beached, it has the potential to persist for many years. Oil has persisted for many years in fine-grained sand and gravel beaches in the Prince William Sound following the Exxon Valdez spill (Nixon & Michel, 2018). This persistent submerged oil is often found in cobbled beaches. Therefore, protection is often the best way of preserving these habitats. If these habitats are oiled, restoration approach could involve three approaches, natural attenuation, manual removal, or bioremediation (Boufadel et al., 2015). As described previously natural attenuation is allowing natural processes to break down the oil. While requiring little effort, this process can take a long period of time depending on the environmental conditions. Manual removal would involve the use of heavy machinery or washing by hand to remove the contaminated material. Bioremediation takes advantage of natural microbial communities to break down residual and submerged oil. In some cases, microbial activity can occur slowly based on environmental constraints including nutrient limitation or oxygen availability. In bioremediation, nutrients in the form of fertilizer can be added to a location to stimulate the natural microbial activity and increase the rate of oil breakdown.

F.3.1.4.3 Monitoring

Due to the sensitivity of these habitats, restoration must be done with great care. Monitoring of restoration of these sensitive habitats must include monitoring the rate of oil removal through either natural attenuation or bioremediation. If bioremediation is chosen as a restoration approach, monitoring must include examining the concentration or oil, but also the impacts of the approach including routine toxicology testing (Prince and Atlas, 2018). Monitoring must also include assessments of the effectiveness of these restoration approaches in enhancing the habitat for other organisms including vegetation and shoreline birds and mammal populations.

F.3.2. Organisms

F.3.2.1. Aquatic Vegetation

F.3.2.1.1 Description of injury

A potential spill can have direct and indirect impacts on submerged aquatic vegetation (SAV) and floating aquatic vegetation. This vegetation could be directly impacted by oiling during the spill. Additional vegetation injury is possible during cleanup operations that may remove contaminated vegetation or injure existing vegetation. SAV serves as an important role in aquatic ecosystems as an integral habitat for underwater species such as fish and invertebrates as well as contributing to stabilizing sediments and limit nutrient release due to sediment resuspension (Angradi *et al.* 2013). In the Straits of Mackinac, SAV primarily consists of a native filamentous algae *Cladophora* along with some vascular plants and other filamentous algae (Schuchman *et al.* 2013). Floating aquatic vegetation is at great risk due to the direct contact with a slick.

F.3.2.1.2 Approach for restoration

<u>Backfilling scars:</u> The injured and removed aquatic vegetation may leave scars on the lake bed that must be filled as a part of initial restoration operations. Attempts will be made to fill in scars of plants removed from SAV beds with similar clean sediments to return the site to the original grade. Backfilling these scars would prevent further degradation of SAV beds and allow for recolonization by neighboring plants as well other restoration efforts to proceed.

<u>Plantings:</u> Plantings will help to restore plant beds to a robust. These plantings could be done by broadcasting of seed or through directly planting whole plants. Care must be taken to ensure the success of plantings of whole plants. If transplanting from existing beds, a number of methods exist such as the use of tubes to core the plant and carry the plant as well as the sediment containing the microbes found in the rhizosphere of these plants that may help the transplanted plants to establish themselves in the beds.

<u>Enhancement of vegetation beds through nutrient addition:</u> Establishment and growth of aquatic vegetation requires nutrients. While there may be nutrients present in the water of the lake, studies have shown that nutrient addition at the site of the vegetation beds, would be useful in encouraging growth and establishment of the aquatic vegetation. Nutrient addition can be done through the addition of fertilizer stakes in the vegetation beds and monitoring of available nutrients such that there are sufficient nutrients in the water for plant growth, but not excess nutrients.

<u>Protection of existing vegetation beds through signage:</u> It is important to protect uninjured, injured, and restored vegetation beds from further damage. Protecting existing vegetation beds can be done through the deployment of buoys and other

signage. In some cases, it may be important to implement restrictions that would limit scarring of other vegetation.

Limitations: These techniques have employed in other restoration efforts, so there is a high likelihood of success for the restoration of aquatic vegetation. These approaches could be used as an early restoration approach to begin to enhance other restoration efforts. Plantings take time for establishment but can be performed in the first growing season post-spill and continued until establishment. Furthermore, it is important to backfill scars with sediment that has similar properties to the ambient sediment to ensure the establishment of the plants and no further disturbance to the system.

F.3.2.1.3 Monitoring

Monitoring for the success of the restoration would involve tracking plant density and establishment of transplanted plants. Additional monitoring would be needed if approaches were taken to stimulate establishment through nutrient amendment or wave mitigation. For nutrient amendments, it would be essential that appropriate amounts of nutrients are added to the stimulate plant growth but not excessive amounts.

F.3.2.2. Macrobenthos

F.3.2.2.1 Description of injury

The injury assessment is based on restoring ecosystem services. Macrobenthos are an essential element in the food chain, building blocks of the ecosystem. The species distribution and abundance can serve as a surrogate to determine water quality and ecosystem health. A list of species typically encountered in the straits area is provided by Task E. We will assume that all the species typically encountered would be injured in the case of a worst-case scenario spill in the Straits. Because of the breathing mechanism of most macrobenthos species, any oil in the water or on their body would result in the death of the animal. Macrobenthos are found in the bottom layer of the water column and in the shallow water zone close to shore. Since the pipeline is located either close to the bottom or on the lake bottom, it is possible that some of the oil released might cover part of the substrate near the pipeline, therefore destroying macrobenthos habitat. Assuming that the density of the oil released is lighter than water, shore will be the most significant habitat impacted. However as described in Task E’s section, oil can adhere to sand or silt particles, and sink to the bottom of the water column. Based on Task C’s cleanup evaluation, some portion of the shoreline along the Straits will most likely be adversely affected during a worst-case scenario spill.

F.3.2.2.2 Approach for restoration

Habitat restoration

Macro-invertebrates live in a range of habitats including bottom substrates, wetlands, intertidal shorelines, etc. The restoration of these habitats is described above and will be leveraged to restore/protect these organisms; restoration methods include planting, nutrient addition, protection of existing habitats thru signage. Submerged aquatic vegetation restoration is another important element of the recovery of macrobenthos and is also described above.

Sediment removal

If the shore is composed of sand, the contaminated sand can be removed by heavy equipment and transported to an agreed upon containment area. Clean sand can be brought in to replace the sand that was removed.

Limitations: During that process, most animals would be removed with the sand. If there are no reintroduction efforts, the shoreline will need to be monitored to make sure that the population is recovering on its own. Only certain species (but representative of the whole ecosystem) will be monitored.

Bioremediation

As described in the previous sections, natural attenuation will be necessary to account for total oil removal.

F.3.2.2.3 Monitoring

A new framework for ecological data in the Great Lakes will be used to help with our monitoring efforts, GLAHF (Great Lakes Aquatic Habitat Framework). GLAHF had a database specifically related to benthic organisms. The indices that GLAF uses are the following: "Oligochaeta Trophic Index (OTI), Chironomidae Trophic Index (CTI), Shannon index of diversity, Simpson index of diversity, Pielou evenness index, taxa richness, Oligochaetae abundance, Chironomidae abundance, Bivalves abundance, Diporeia abundance, Dressenidae abundance, proportion of Oligochaeta, ratio of Oligochaetae / Chironomidae" (glahf.org). Sampling of macrobenthos organisms will take place on an agreed upon schedule to monitor the population and distribution of species in the various restored habitats.

F.3.2.3 Mussels, clams, snails

F.3.2.3.1 Description of injury

Mussels, clams, and snails are found in the bottom of the water column, nearshore zone and coastal wetlands, which will be greatly affected in a spill event as described above. These animals provide ecosystem services to other animals higher in the food chain and even help protect against coastal erosion. The habitats that would be impacted in an oil spill are critical for the life cycle of these animals and for those who depend on the shelter created by the bivalves and mollusks in the Great Lakes.

F.3.2.3.2 Approach for restoration

The nearshore zone and coastal wetlands will be restored following the methods described above. Enhancing and restoring submerged aquatic vegetation is equally essential to help these species recover after a spill. In addition, substrate will be brought in to create new habitats for these organisms, similar to creating oyster beds in the restoration of the Deepwater Horizon spill (Deepwater Horizon 2016, Chapter 5 Appendix B).

F.3.2.3.3 Monitoring

Sampling of mussels, clams, and snails will take place on an agreed upon schedule to monitor the population and distribution of species in the various restored habitats. The GLAHF framework mentioned above has a bivalve index that can be compared to results found in the monitoring efforts after a spill.

F.3.2.4 Reptiles and Amphibians

F.3.2.4.1 Description of injury

Reptiles, turtles, and amphibians are found in the nearshore zone, specifically dune habitats, and coastal wetlands, which will be greatly affected in a spill event as described above. These habitats are critical for the life cycle of these animals. Sand beaches are used by turtles for nesting and are therefore a critical habitat of the survival of the species. The Straits area is of primary importance for these animals as more than half of the reptile and amphibian species in Michigan can be found in the Straits region as well as a few endangered species as described by Task E.

F.3.2.4.2 Approach for restoration

The nearshore zone and coastal wetlands will be restored following the methods described above. Sediment removal and replacement will take place in sand environments typically used by these animals. Signage will be set up to deter contact with the human population.

Enhancing and restoring submerged aquatic vegetation is equally essential to help these species recover after a spill. The methods described above will be implemented to help the recovery of reptiles and amphibians.

F.3.2.4.3 Monitoring

Observation and collection of reptiles, turtles, and amphibians will take place to monitor the population and distribution of species in the various restored habitats. The Michigan DNR has a monitoring system (https://www.miherpatlas.org/) in place to collect abundance and distribution of reptiles, turtles, and amphibians across the entire State of Michigan. This database will be used as a starting point in the monitoring efforts taking place after a spill.

F.3.2.5 Fish

F.3.2.5.1 Description of injury

The waters of Lakes Michigan, Huron, and their associated tributaries are home to a large diversity of ecologically, and both commercially and recreationally, important fish species. Based on NOAA's ESI mid-1990s, MNFI's biotic data, and GLAHF's spawning index, 40 species of fish have been identified in areas surrounding and adjacent to the Mackinac Straits for at least a portion of their lives (see description and list in Table ET6). This includes four species of conservation status in Michigan—Cisco (*Coregonus artedi*), Lake Sturgeon (*Acipenser fulvescens*), Pugnose Shiner (*Notropis anogenus*) and Channel Darter (*Percina copelandi*). Oil from a rupture in Line 5 will contaminate the water column, benthic sediments, and shoreline in both Lake Michigan and Lake Huron. There are a number of fish species in the Straits area that have great commercial and recreational value to tribal and tourism interest in Michigan but also have life-history characteristics that make them vulnerable to an oil spill (27 of 40 species; Table ET6), for example, Lake Trout (*Salvelinus namaycush*) and Lake Whitefish (*Coregonus clupeaformis*). Lake Trout and Lake Whitefish spawn in nearshore cobble and offshore rocky reef habitats (Goodyear, 1982), some of which have been identified as important spawning locations adjacent to the Mackinac Straits. Adult life stages of these species in addition to others (see Table ET6) may be uniquely buffered against oil pollution due to their mobility and ability to move away from the oil. Eggs and larvae are the most sensitive fish life stages, and therefore at risk to experience the greatest rates of direct mortality. Loss of eggs and larvae will affect population-level processes. These direct impacts coupled with expected losses to nearshore spawning habitats and prey resources such as benthic invertebrates will increase the risk to fish populations.

F.3.2.5.2 Approach for restoration

For injuries to fishes resulting from worst-case scenarios of a Line 5 rupture, restoration goals are as follows:

- Restore or protect habitats spawning and foraging habitats.
- Restore lost fish by facilitating additional reproduction and/or reduce mortality of injured species.

<u>Restore or protect habitats on which fish rely for spawning and foraging activities.</u>

Littoral intertidal habitats including areas adjacent to coastal wetlands, cobble shorelines, and SAV beds will be restored following the methods described above. Through this approach maintenance of known spawning habitats will allow for reproduction and population persistence for littoral spawners. However, oil is predicted to enter some tributaries and be in the water column, posing a risk to riverine and deep-water fish species. Restoration activities such as the creation of artificial reefs to serve as spawning habitats and removal of dams to allow for fish passage into upper river reaches should be considered.

Many fish species forage on benthic macrofauna (e.g., Oligochaeta, Chironomidae, Bivalves, Diporeia, Dressenidae) (Bunnell et al., 2015), and restoration strategies proposed above will aid in maintaining and restoring these critical resources for fishes.

<u>Restore lost fish by facilitating additional reproduction and/or reduce mortality of injured species.</u>

Reduction in human-fish interactions with fishery closures or voluntary/incentivized harvest reductions would help mitigate the loss of individuals following oiling. Following fishery closures in 2010 in response to the Deepwater Horizon oil spill, Fodrie and Heck (2011) recorded order-of-magnitude higher juvenile abundances of Spotted Seatrout (*Cynoscion nebulosus*), as well as elevated catch rates of species throughout their survey region suggesting a positive effect of fishery closures on fish populations following an oil spill. Alternative strategies such as the implementation of strategies to reduce post-release mortality in the recreational fishery could be considered to maintain breeding age individuals (Sitar et al., 2017).

F.3.2.5.3 Monitoring

Given the importance of fishes to commercial and tribal fisheries and recreational anglers in Lakes Michigan and Huron, monitoring fish populations and their response to any restoration efforts will largely be from a broad perspective rather than at localized restored habitat areas. Annual harvests reported by commercial, tribal and recreational fisheries will likely be the main source of population monitoring data. The USGS conducts a bottom trawl survey for purposes of managing the fisheries of Lake Michigan (https://www.glsc.usgs.gov/deepwater-ecosystems/deepwater-ecosystems-prey-fish-assessment/lake-michigan-benthic-prey-fish). In addition to monitoring population-level responses to restoration, monitoring contaminant levels in fish tissues will inform on the response of lakes to oil in the ecosystem and provide information pertinent for human consumption guidelines. The Environmental Protection Agency (EPA) established a long-term contaminant monitoring program in the 1970s and has been collecting top predator fishes such as Lake Trout and Walleye and evaluating emerging chemical trends (https://www.epa.gov/great-lakes-monitoring/great-lakes-fish-monitoring-and-surveillance). These long-term data sets will provide a baseline for evaluating the recovery of fish populations. It is important to note that baseline conditions in the Great Lakes have been changing as invasive species and other stressors have impacted the system. Therefore monitoring of spill restoration must take into the account influences of other stressors and attempt to provide more robust habitat for recovery of injured populations.

F.3.2.6. Birds

F. 3.2.6.1 Description of injury

Over 70 species of birds occur in waters and wetlands of Lakes Michigan and Huron, and the areas surrounding and adjacent to the Mackinac Straits for at least a portion of their lives (see description and list in Table ET7). The Mackinac Straits, in particular serve as a migratory pathway for a range of species, including raptors such as Bald Eagle (*Haliaeetus leucocephalus*), and waterbirds such as Common Loons, Grebes, and Cormorants, many of which have both high ecological value and also great economic value as important game species (MNFI, 2018). In addition to migrating birds, shoreline nesters include the federally-endangered Piping Plover (*Charadrius melodus*) and other species with special value and protected status (19 species of conservation status), such as Peregrine Falcon (*Falco peregrinus*) are common to this area (MNFI, 2018).

Birds, including those inhabiting and migrating through the Mackinac Straits area, play vital roles in ecosystems, serving as both predators and prey in a large number of food webs. In addition to their role in Great Lakes ecosystems and their resonance with the public, birds make significant direct economic contributions to the region. For example, both consumptive (i.e., migratory bird hunting) and non-consumptive (i.e., bird watching) activities generate billions of dollars annually in economic activity (Nicholas & Jaworski, 1979)). In addition to direct mortality through external oiling, oil spills can affect bird populations through degradation of habitat; reduced prey populations; alterations in food web structure; and contamination of resources by toxic compounds, including polycyclic aromatic hydrocarbons (Bergeon-Burns, Olin, Woltmann, Stouffer & Taylor, 2014). Due to the ecological and economic value of bird species in the Mackinac Straits, restoration alternatives for this taxa following a rupture in Line 5, will need to address the diversity of species injured in areas and habitats where efforts would provide the greatest benefits within their geographic ranges.

F. 3.2.6.2 Approach for restoration

For injuries to birds resulting from worst-case scenarios of a Line 5 rupture, restoration goals are as follows:

- Restore or protect habitats on which birds rely for nesting, foraging and staging activities.
- Restore lost birds by facilitating additional reproduction and/or reduce mortality of injured bird species.

<u>Restore or protect habitats on which birds rely for nesting, foraging and staging activities.</u>

Intertidal habitats including sandy beach and coastal wetlands will be restored following the methods described above. Sediment removal and replacement will take place in sand environments typically used by these nesting shorebirds. Through this approach creation of nesting areas will available for a range of bird species. Restoration activities aimed at enhancing foraging capacity and prey populations could include the creation of foraging areas such as ephemeral pools on beach habitat that would benefit the federally-endangered Piping Plover and restoring SAV beds (outlined in the section above) for waterfowl species.

Restore lost birds by facilitating additional reproduction and/or reduce mortality of injured bird species.

Reduction in human-bird interactions with alternatives of seasonal waterfowl closures or beach closures during shorebird nesting seasons would help mitigate the loss of individuals following oiling. Signage could be used to reduce wildlife-human interactions, particularly during bird nesting seasons and provide the general public with educational materials regarding wildlife in the areas.

F.3.2.6.3 Monitoring

Observation and collection of bird species will take place to monitor the population and distribution of species in the various restored habitats. There are a number of monitoring systems in place to collect the number and distribution of birds in Michigan. These monitoring systems include the Great Lakes Colonial Waterbird Survey (https://reeis.usda.gov/web/crisprojectpages/0205154-waterbird-monitoring-population-demographics-and-conservation-of-colonial-waterbirds-and-the-piping-plover-in-the-us-great-lakes.html), National Audubon Society Important Bird Areas in Michigan (https://www.audubon.org/important-bird-areas/state/michigan), Michigan Feature Inventory (https://mnfi.anr.msu.edu/data/specialanimals.cfm) and U.S. Fish and Wildlife Service that monitor state and federally endangered and threatened species (https://www.fws.gov/midwest/endangered/pipingplover/index.html). These monitoring and data collection programs will be used to represent baseline population demographics for post-spill comparisons and metrics.

F.3.2.7 Terrestrial mammals

F.3.2.7.1 Description of injury

Of the nearly 60 mammal species in Michigan, there are few species that are likely to be impacted by oil along the shore of Lakes Huron and Michigan. These include raccoon (*Procyon lotor*), muskrat (*Ondatra zibethicus*), North American river otter (*Lontra canadensis*), North American beaver (*Castor canadensis*), and mink (*Neovison vison*). In general, these species are considered sensitive resources, but often they do not occur in appreciable concentrations at any location, and are widely scattered throughout their range (NOAA, 1994). These species are considered of economic importance to Michigan, as they are harvested for fur.

F.3.2.7.2 Approach for restoration

For injuries to terrestrial mammals resulting from worst-case scenarios of a Line 5 rupture, restoration goals are as follows:

- Restore or protect habitats nesting and foraging habitats.

<u>Restore or protect habitats nesting and foraging habitats.</u>

The five mammal species at risk of oil spills, use coastal habitats for breeding and brooding their young. These mammal populations are mobile and have the capacity to breed and forge in areas unaffected by oil. However, their economic importance to tribal and commercial trappers warrants restoration efforts to restore and maintain populations. Coastal wetlands will be restored following the methods described above.

These species forage in littoral habitats, feeding on invertebrates and fishes in some cases. Restoration activities aimed at enhancing foraging capacity and prey populations, such as restoration of intertidal and SAV habitat and benthic macrofauna populations, would benefit the recovery of these populations.

F.3.2.7.3 Monitoring

Observation of terrestrial mammal populations will take place various restored habitats. The Michigan DNR monitors mammal populations (https://www.michigan.gov/dnr/0,4570,7-350-79136_79608---,00.html) through the issuance of trapping permits among other wildlife management programs. MI DNR data will be used as a starting point in the monitoring efforts taking place after a spill.

F.3.3 Cultural Resources

Cultural resources include a wide range of tangible places and things as well as intangible beliefs and social practices. As discussed above, these resources are protected by and/or managed using a patchwork of legal and policy instruments at multiple scales, from international compacts to municipal regulations. The laws and policies generally recognize the interdependent natural and cultural systems. Because this study was commissioned by the State of Michigan, we largely use United States policy to structure our discussion. As an example, most cultural resources are evaluated in relation to their eligibility for listing on the National Register of Historic Places, which is a requirement under NHPA. Determinations of eligibility and inventories of sites and properties are made by SHPO, THPO, and/or Federal Preservation Officers. Since a worst-case spill could also include Canadian shoreline, response planning may differ in some locations.

While this discussion refers to communities and stakeholder groups, it is important to note that Native American and FNMI communities sometimes have greater legal status in consultations about cultural resources. A detailed discussion of this appears in the Broader Impacts section of this report, but tribal communities are considered “vulnerable risk bearers” and/or “environmental justice communities.” In addition, tribes are often sovereign governments with treaty rights and rights established by national and international laws. For these reasons, tribal/FNMI interests are often highlighted in this Task.

To complete this study, we reviewed information in the State of Michigan’s State Historic Preservation Office, compiling information on archaeological sites, National Register-listed historic properties and districts, and those cultural resources of particular interest to SHPO staff for which we could get geospatial information, including shipwrecks, archaeological sites, and lighthouses. These resources are discussed in each section below, but this survey should not be understood as equally representative of all cultural resources within a given kilometer of shoreline. Our focus in that study was on the known cultural resources within the Straits of Mackinac and Michigan’s northwestern and northeastern coasts. A more accurate prediction of the frequency and significance of cultural resources would require developing predictive models for a very large area of the Lake Huron and Michigan coastlines, based upon human use of different resource types and ecological zones at different points in human history.

We discuss four categories of cultural resources, sorted according to administrative or practical categories: archaeological sites; shipwrecks; buildings, monuments, and landscapes; and sacred sites/culturally-significant places. These categories are arbitrary and overlap since for example, a shipwreck is an archaeological site, and a cemetery is also a sacred site, but the divisions are useful because of administrative categorization.

F.3.3.1 Archaeological Sites: Terrestrial, Inundated-Terrestrial, and Maritime (other than shipwrecks)

F.3.3.1.1 Description of Injury

Archaeological sites are a non-renewable resource that would be damaged by an oil spill. The sites form an irreplaceable record of scientific and historical data from more than 12,000 years of human occupation of the Great Lakes. The State of Michigan has invested millions of dollars in protecting, studying, and developing some of the major archaeological and historical sites, such as at Fort Mackinac, Colonial Michilimackinac, and Mackinac Island, and other historical and cultural sites like the mission at St. Ignace, Fayette State Park. The oil can damage artifacts and spoil some types of scientific and historical data, but more importantly, sites can be damaged by the containment and cleanup effort when oiled sediments are removed by digging or dredging. For example, heavy equipment must cross terrain to access wetland or oiled beaches quickly. In addition, because an emergency-response crew’s exposure of sites draws public attention to them, damage due to the subsequent increase in looting and collecting can occur.

Archaeological sites are managed by laws and policies in HNPA, NEPA, and other laws, depending upon where they sit, on public or privately-owned lands. Within the potential spill area are a wide range of land ownership types, from federally managed lands in the United States and Canada (USFS, NPS, USF&W, Parks Canada), to State or Provincial Parks or land holdings, Tribal/First Nations lands, municipal or county lands, public land trust lands (not for profit NGO), landholding companies, and privately-held property.

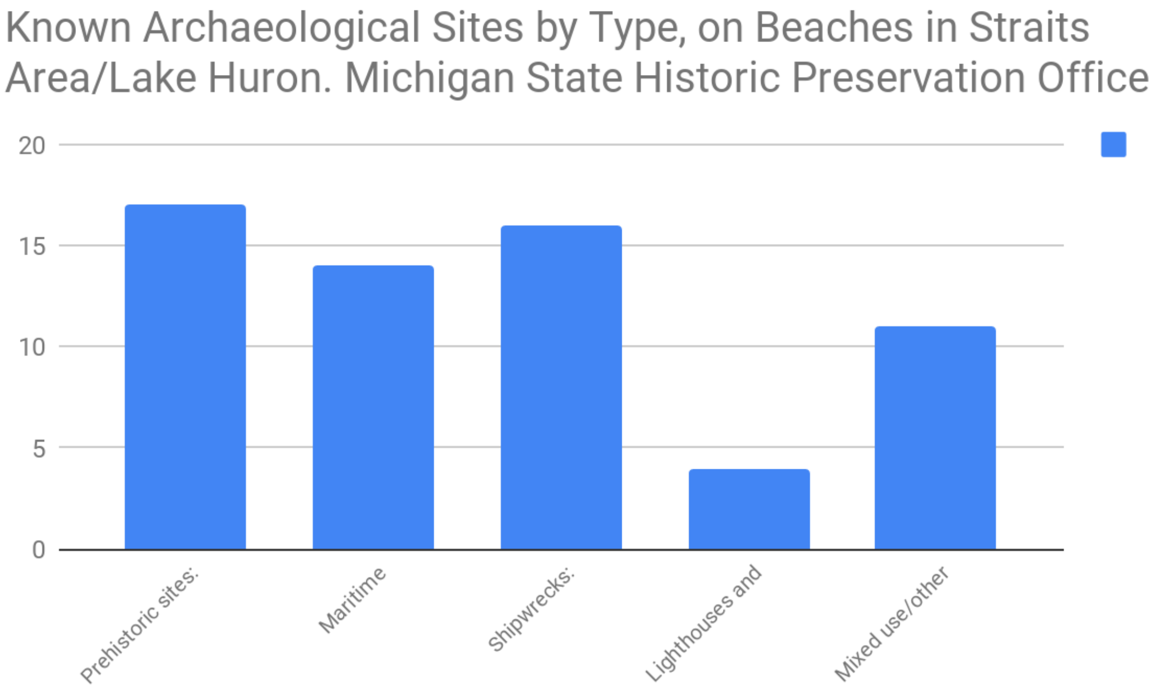

Figure F.2. Known archaeological sites on or very near Michigan beaches in the Straits of Mackinac and Lake Huron shores. Samples selected from about 300 sites in townships with maritime shores.

The research team completed a survey of archaeological resources in the State of Michigan's State Historic Preservation Office site files to understand potential injuries of a spill on cultural resources. We narrowed our focus to sites on or near the beaches of the Straits of Mackinac and the coast of Lake Huron by using township and watershed designations. That search yielded about 275 sites. Those sites were then sorted. For sites that could confidently be placed on a beach, coastal wetland, or in the nearshore shallows, we sorted them into categories on Table 3.X, including prehistoric occupation (from small lithic scatter to major village); maritime infrastructure (including piers, docks, lifesaving complexes, cribbing, landings);

shipwrecks; lighthouses and complexes; and other historic/mixed period (missions, forts, fisheries, logging, etc.).

The sites uncovered in this search were divided nearly equally between pre-contact Native American sites, maritime infrastructure, and shipwrecks, with all other site types making another quarter of the total. These numbers are not very useful, however, since they only show the number of sites known. This number is a derivative of the numbers of surveys conducted and the locations of those surveys. Because there is such intense public interest in shipwrecks, these have been subject to intensive survey and study by avocational and professional scholars alike. Shipwrecks also tend to be in the bottomlands, under the control of the state.

Archaeologists have less systematic information about terrestrial archaeological sites along the coastline and very little about sites in coastal wetlands. When land is managed by federal agencies (like the US National Park Service, Parks Canada, or the United States Forest Service) or state/provincial agencies (such as MDNRE or State/Provincial Parks), those agencies might have good inventories of sites on the land bordering on the lake. Since the vast majority of waterfront property is privately owned, however, little formal survey has been completed overall.

As an example, there were only 17 prehistoric sites identified on beaches in the survey of records in the SHPO site files, ranging from small lithic scatters associated with ephemeral resource extraction activities to substantial villages or ritual sites. This contrasts with historical atlases that show that almost every major river had an ancient, protohistoric, or historic-era Native American occupation at some time (c.f. Tanner, 1987, particularly maps 6, 9, 13, 20, 21, 23, 24, 25, 27, 29, and 33). There is no reason to believe that the Michigan SHPO site files can be used to estimate the total number of sites that would be impacted per kilometer of shoreline of beaches in Ontario, Wisconsin, or even western Michigan.

The EVOS follow up survey documented that vandalism and looting of archaeological sites increased after sites were identified and exposed during cleanup and restoration. One EVOS-related study found no detrimental effect when the authors tested ten samples of organic material to see if radiocarbon dating would be influenced by hydrocarbon contamination (Reger et al., 1992). This study was of very limited scope and scale and cannot be extrapolated to widely to other spill events. Pipeline spills release many compounds for which we have little basis to measure their effect on residue analyses, materials characterization, site preservation, or data recovery in archeological situations (Evans and Firth, 2016).

F.3.3.1.2 Goals of restoration

For injuries to archaeological sites resulting from worst-case scenarios of a Line 5 rupture, restoration goals are as follows:

- Because the scientific and historical information contained in archaeological sites cannot be restored, effort must be made to avoid damage during containment, cleanup, and restoration. This will also be mitigated by the recovery of scientific and historical data when damage is unavoidable.
- Monitor long-term effects of the spill and for damage due to looting following exposure and increased public awareness of sites

F.3.3.1.3 Approach for restoration

- For archaeological sites, NEPA and NHPA-mandated mitigation studies are assumed to be built-in as part of any remediation and restoration projects that involve removing or encapsulating sediments on sites.
- NEPA and NHPA-mandated consultation with stakeholders also part of this process.
- In addition, a post-spill trust fund should sponsor an annual survey of terrestrial archaeological resources within the impact zone, on the model of that done following Deepwater Horizon and EVOS.

F.3.3.1.4 Monitoring

- Both the EVOS and Deepwater Horizon spills provide models for how the trust funds can be used to sponsor annual monitoring programs for cultural resources. The trust can provide operating budgets to regional partners and resource management agencies to monitor sites.

F.3.3.2 Shipwrecks

F.3.3.2.1 Description of injury

Shipwrecks include any watercraft (or aircraft or associated artifacts) which sank in Lake Michigan or Ontario and have become fixed to the bottomland, ranging from dugout canoes to steel bulk carriers and WWII fighter planes. Shipwrecks can be irreparably damaged due to an oil spill, causing damage to the cultural resource, loss of sustainable economic income (sport divers and eco- and heritage tourism), and loss to the natural environment (reef formation and habitat). The damage can be the result of direct contamination by hydrocarbons or other chemicals that damage the microbiome adhering to the wreck and the sediment in which it is embedded; physically damaged by responding vessel anchor drags during oil recovery, or dredge activity (including destabilizing sediments within or around the vessel or changing sedimentation patterns); and through vandalism or looting during and after cleanup efforts. The overall effect of oil spills on archaeological resources, in general, is not well understood and is discussed more below.

The Great Lakes contain thousands of shipwrecks, with 6,000 being a common estimate of the total number in all the lakes. There are 37 known wrecks within the area of the Straits of Mackinac that are known to the State of Michigan. By contrast, about 200 ships are known to have sunk in the area of the nearby 4,300-square mile Thunder Bay National Marine Sanctuary. Thunder Bay NMS knows the accurate location of just under 100 of those wrecks. Hundreds more wrecks dot the bottom of Lakes Huron and Michigan, including in the nearshore shallows, littoral zone, and beaches (National Ocean Service, 2017; Halsey, 2007; O'Shea, 2002, 2004). As an example of the diversity of these resources, the United States Navy's Naval History and Heritage Command describes southern Lake Michigan as including "the largest and best-preserved group of U.S. Navy, sunken, historic, aircraft in the world" (Naval History and Heritage Command, 2018). Shipwrecks are an important part of the cultural heritage because they have several compelling beneficial uses: (1) They are akin to archaeological time capsules, usually formed in an instant of disaster. This makes them valuable sources of historical and scientific information about "floating communities" in the human past, including associations with work, recreation, and travel. (2) Ships can be formally engineered vessels (a.k.a. "academic design") or informally designed using artisanal practices (a.k.a. "vernacular design"), as well as documenting their life-history of modification during use. This makes ships important to the history of technology and engineering. (3)Shipwrecks are part of the communal memory of the maritime landscape, and stakeholders and members of public groups often consider them graves or essentially sacred sites. (4) Some wrecks have military association and significance as memorials or war graves. (5) Wrecks often form the basis of artificial reefs and are often elements within environmental remediation or habitat improvement projects. Finally (6), wrecks attract sport divers and eco-tourists and are therefore a valuable asset for natural and cultural heritage tourism (Hulse, 1979; Vrana & Halsey, 1992; Kaoru & Hoagland, 1994; Halsey, 1990).

Hamdan et al. (2018) recently reported that after the Deepwater Horizon oil spill, deep water wrecks were contaminated directly by spilled oil and also by "marine snow" accumulations-- hydrocarbons and other chemicals adhered to suspended particles of inorganic minerals and organic matter floating in the water column (see section F.3.1.3). Bacteria and plankton then colonized these adhered particles, producing exopolymeric substances on the particles' surfaces, which then precipitated as snow and blanked wrecks and the sediments encasing them. The effects of this process are still damaging shipwrecks nine years after this spill. Hamdan et al. reported that the oil and MOSSFA-impaired wrecks had less microbiome diversity and that the physical sediments encasing wrecks had altered color, porosity, and geochemistry. Other research by this team has demonstrated that post-spill changes in a shipwreck's surface biofilm can dramatically increase rates of active corrosion after the population of oil-consuming microbes increases proportionally to other organisms in the microbiome (Salerno, Little, Lee, & Hamdan, 2018). The relationship between microbiome and corrosion rates has been a concern for maritime archaeologists looking at steel and wooden vessels and in engineering efforts to establish and maintain artificial reefs (Blanchette, 2000; Church et al., 2007; Cullimore & Johnston, 2008; Gjelstrup Bjordal, 2012). At this time we cannot model the formation of lake snow from a Line 5 discharge and therefore cannot predict what (if any) effect this might have on decay rates of cultural resources in the Great Lakes.

Restoration costs for shipwreck sites are particularly difficult to estimate because of the special legal status of this resource. Shipwrecks are a special type of cultural resource because their use and management are governed by legal practice rooted in international admiralty court, including the Law of Salvage and Finds. Underwater heritage in the United States is now governed under the Abandoned Shipwreck Act of 1987, but other laws may apply, particularly the Sunken Military Craft Act of 2004. Those wrecks within National Marine Sanctuaries, such as Thunder Bay NMS, will also be protected by the National Marine Sanctuaries Act of 1972 and the Archaeological Resources Protection Act of 1979 (ARPA). Following from the ASA, each of the United States and its territories took control of wrecks in their coastal bottomlands. In Michigan, wrecks are governed by laws in Part 761 of the Aboriginal Records and Antiquities part of the Natural Resources and Environmental Protection Act of 1994, among other laws. The legal authority to manage shipwrecks in Wisconsin derives from amendments to the 1969 Wisconsin Field Archaeology Act, reinforced by the federal ASA. Canada has no equivalent to the ASA. The Canada Shipping Act put shipwrecks under the administration of the Ministry of Transport, except for those in Marine Protected Areas (Runyan, 1990).

F.3.3.2.2 Goals of restoration

For injuries to shipwrecks resulting from worst-case scenarios of a Line 5 rupture, restoration goals are as follows:

- Prevent damage by quickly defining sensitive zones for the containment and cleanup crews where they should avoid anchoring, dredging, or other activities.
- Monitor shipwrecks and other submerged cultural resources for contamination and damage.
- Document scientific and historical information exposed due to damage during containment and cleanup efforts, during illegal looting following cleanup activities, and/or due to burial with contaminated sediments.

F.3.3.2 3 Approach for restoration

- Fund an annual survey of maritime resources within the impact zone, on the model of that done following Deepwater Horizon.

F.3.3.2.4 Monitoring

- Both the EVOS and Deepwater Horizon spills provide models for how the trust funds can be used to sponsor annual monitoring programs for cultural resources.

The trust can provide operating budgets to regional partners and resource management agencies to monitor sites.

F.3.3.3. Historic Buildings, Monuments, and Landscapes: buildings, lighthouses, harbors, wharves, and other engineered features of the maritime landscape.

F.3.3.3.1 Description of injury

Historic buildings, monuments, or landscapes may be impacted by a worst-case spill. Buildings can include residential, commercial, or industrial properties, as well as engineered maritime structures such as harbors, docks, weirs, or breakwaters. Monuments may include historical markers, sculptures, plaques, natural features like reefs and bluffs, or other structures or features that serve commemorative functions. Cultural or historical landscapes are larger structures, understood as assemblages of vegetation, buildings and structures, roads and waterways, and natural features that people have used, shaped, or modified over time. Landscapes possess a significant concentration, linkage, or continuity of land use in space and can be considered eligible if they exhibit integrity and significance. Most of the landscapes that would be injured by a spill are usefully considered Maritime Cultural Landscapes (MCL) (Ford, 2017; Ford, 2011, Wyatt, 2015; Wyatt & Dietrich-Smith, 2018). These landscapes are aptly defined by James Delgado, who added to the words of Christer Westerdahl (Delgado, 2018:23):

MCLs can be characterized as the sum of "human utilization of maritime space by boat, settlement, fishing, hunting, shipping and its attendant subcultures" comprising the "whole network of sailing routes, old as well as new, with ports and harbors along the coast, and its related constructions and remains of human activities, underwater as well as terrestrial." It includes not only this cultural history of the physical environment but also how this place is perceived, at a deeper level, by humans who have lived and worked there over time. MCLs offer a lens through which the totality of this human/ environment relationship can be viewed. As the history of a place is a tapestry woven over time, the study and characterization of MCLs provides an opportunity to recognize, understand, and appreciate the threads each culture who called this place "home" contributed to what we observe today.

Studies of cultural resources have historically focused on individual elements within a landscape, such as fishery buildings, lighthouses, maritime life-saving stations, boatyards and docks, warehouses, and so on (Williams 1998). This landscape focus has shifted both academic thought and management practice toward larger-scale thinking about these cultural resources.

Injuries to these resources could vary in a worst-case spill. For structures, contamination of the physical fabric of a monument or building is a threat, if such contamination will degrade the material of which it is constructed. BTEX and PAH and the process of cleaning it will cause damage to surfaces, to paints, coatings, patinas, or other finishes. Of greater concern would be the removal of contaminated building fabric, such as siding, foundations, or window treatments, since these can negatively impact a buildings historical integrity. Equally concerning is the removal of topsoil or sediments through dredging or excavation, which can remove the associated sites and features that link the individual elements within a landscape and provide scientific and historical context for a structure.

Buildings and structures are not common below high water mark or in wetlands, but maritime engineering features are common. This is illustrated by the high proportion of docks and piers and such features in the archaeological site inventory. There are some exceptions, however, and as an example, there are 20 lighthouses in the Straits area and more than 80 in northern lakes Michigan and Huron (not including harbor lights and other navigation aids, beacons, and markers). Lighthouses are important historic structures of the maritime landscape and as such are excellent examples of injuries to historic properties and monuments. Lighthouses can be above the high water mark or located where they are easily contaminated by waves and/or spray from the surf. While some still operate as official navigation aids, many historic lighthouses are operated as heritage sites because they are monuments to ships lost near their locations. Lighthouses become important monuments in community identity and engineering history, so many have been documented by the Historic American Engineering Record/Historic American Building Survey (HAER/HABS). Lighthouses also provide an economic benefit by drawing heritage tourists. Most of these lighthouses are built of stone or brick, with some are metal and wood. Like most engineered maritime infrastructure, these are not likely to be structurally compromised by an oil spill. The primary injury will be the required cleaning and restoration of these lighthouses so that they are safe for inhabitants or visitors, remain unblemished, and can continue to be preserved for future generations. (The archaeological resources surrounding structures such as lighthouses are assumed to be included in section 3.3.1.) Depending upon the building's significance and intended use, the restoration costs can vary considerably (see Goals below).

F.3.3.3.2 Goals of restoration

Under the NHPA, the Secretary of the Interior established professional standards on the preservation of the nation's historic properties. The Secretary of the Interior's *Standards for the Treatment of Historic Properties* are intended to be applied to a wide variety of resource types, including buildings, sites, structures, objects, and districts. Versions of these standards were published in 1978, then revised in 1983, 1995, and 2017 (Grimmer, 2017). The Standards address four treatments: preservation, rehabilitation, restoration, and reconstruction. These are defined here to prevent confusion with the more general use of the term "restoration" in this report. Projects choose among these strategies based upon the building's or monument's condition, it's intended use, and other factors (Grimmer, 2017:2-3):

Preservation is defined as the act or process of applying measures necessary to sustain the existing form, integrity, and materials of a historic property. Work, including preliminary measures to protect and stabilize the property, generally focuses upon the ongoing maintenance and repair of historical materials and features rather than extensive replacement and new construction. The Standards for Preservation require retention of the greatest amount of historic fabric along with the building's historic form.

Rehabilitation is defined as the act or process of making possible a compatible use for a property through repair, alterations, and additions while preserving those portions or features which convey its historical, cultural, or architectural values. The Rehabilitation Standards acknowledge the need to alter or add to a historic building to meet continuing or new uses while retaining the building's historic character.

Restoration is defined as the act or process of accurately depicting the form, features, and character of a property as it appeared at a particular period of time by means of the removal of features from other periods in its history and reconstruction of missing features from the restoration period. The limited and sensitive upgrading of mechanical, electrical, and plumbing systems and other code-required work to make properties functional is appropriate within a restoration project. The Restoration Standards allow for the depiction of a building at a particular time in its history by preserving materials, features, finishes, and spaces from its period of significance and removing those from other periods.

Reconstruction is defined as the act or process of depicting, by means of new construction, the form, features, and detailing of a non-surviving site, landscape, building, structure, or object for the purpose of replicating its appearance at a specific period of time and in its historic location. The Reconstruction Standards establish a limited framework for recreating a vanished or non-surviving building with new materials, primarily for interpretive purposes.

For injuries to buildings, monuments, or landscapes resulting from worst-case scenarios of a Line 5 rupture, restoration goals are as follows:

- Restoration or preservation of contaminated historic buildings according to the least-intrusive remediation strategy that can return them as closely as possible to their pre-spill condition and uses.
- Restoration of landscapes that restore the human use of places while minimizing disruptions of current and historical uses.

F.3.3.3.3 Approach for restoration

- If possible, choose initial cleaning methods that have the minimal negative impact on the fabric of the historic building or monument. Possible methods include steam cleaning and dry ice dusting, but these must be selected for the unique situation of a particular spill (Chin, 2010). When possible and appropriate, a professional conservator should guide actions at significant properties.

- The National Park Service has many publications that can help guide restoration choices for historic sites, monuments, and landscapes. The SHPO and THPO officials can also provide guidance: https://www.nps.gov/nr/publications/index.htm
- NEPA and NHPA are harmonized to allow for the consideration of both ecological and historical/cultural concerns in landscape restoration (c.f. U.S. Council on Environmental Quality and Advisory Commission on Historic Preservation, 2013; Chawla, Balbach, & Hartman 2013).

F.3.3.3.4 Monitoring

- Both the EVOS and Deepwater Horizon spills provide models for how the trust funds can be used to sponsor annual monitoring programs for cultural resources.

F.3.3.4 Sacred Sites and Culturally-Significant Places: including ritual sites, cemeteries, pictograph/petroglyph sites, and other Traditional Cultural Properties.

F.3.3.4.1 Description of Injury

Native American and First Nations peoples have expressed their concerns about a worst-case spill from Line 5, as detailed in Chapter X. As structured under NEPA, NHPA, and NAGPRA, among other laws and policies, tribal and FNMI governments would expect consultation as part of a response and restoration process. Injuries to tribal nations and communities can include economic, public health, and natural resources damage described in other tasks of this report, but they will also experience injury to places with religious, cosmological, or other social importance. Places with significant cultural values may be deemed eligible for listing on the National Register of Historic Places and listed as Traditional Cultural Properties (Parker and King 1998). It is also important to note that the legal expectation of consultation does not extend only to those federally-recognized tribes in Michigan, but also to those tribal communities with historical ties to the area stemming from movements and resettlements during the wars in the region between 1641 and 1870. This means that a cemetery impacted by oil might require consultations with officials representing various bands or communities among the Mississauga Ojibwa, Ottawa, Menominee, Potawatomi, or other Ojibwa peoples, along with other groups that might including the Tionontati, Huron, and Sauk, among others.

The islands of the Straits of Mackinac are sacred places to Anishinaabeg peoples, with many National Register-eligible sites related to historical uses, cosmology, and faith traditions. These places are much more inclusive than tribal fisheries and tribal communications on the issue, detailed in Chapter X, identify concerns about use of sites related to gathering medicinal plants, harvesting culturally-significant food crops or resources (such as pottery clay), protecting known and unknown cemeteries on the shoreline, ceremonial and other gathering places. Individual tribal governments (generally THPO officers or other officials) maintain inventories of sites. Sometimes this information is shared with federal or state agencies for collaborative land management programs. Both the tribal and federal agencies protect the confidentiality of this information. We, therefore, did not request access to those datasets for our study, but communications with various tribal officials made clear that they knew their TCP rights, the locations of cemeteries and significant sites, and would vigorously protect them in the event of a spill.

As one example of places considered significant, rock art sites dot Ontario's coasts, including significant islands like Manitoulin Island, Ontario, and the waterfront landscape of Georgian Bay and Lake Huron. These sites generally have cultural significance, with specialized place-based cultural and ecological knowledge. Noted among these are the Killarney Bay and Collins Inlet sites. Such marked sites are much less commonly known in Lake Michigan, with the exception of Spider Cave Site and the Burnt Bluffs (Cleland & Peske, 1968; Lemaitre & Decart, 2008). While art was often painted on bluffs or ledges above the high-water mark, the images can still be damaged by spray or condensation. In BTEX, both benzene and toluene are established as powerful solvents. While there are no published studies of the effects of BTEX on the organic pigments in petroglyphs, in a worst-case scenario of a spill filling Georgian Bay, it is highly probable that the contaminants would cause irreversible damage to exposed art panels. This damage would have a direct effect upon people's ability to use these sites during the intergenerational transmission of cultural knowledge, as documented at the Burnt Bluffs location in Fayette State Park. (c.f. Ruuska & Armitage, 2015).

F.3.3.4.2 Goals of Restoration

For injuries to sacred sites and places of cultural significance resulting from worst-case scenarios of a Line 5 rupture, restoration goals are as follows:

- Establish collaborative restoration in a culturally-sensitive and appropriate manner, which attempts to harmonize traditional knowledge and management systems with scientific practice, including things like Traditional Ecological Knowledge into decision making.
- Support tribal communities as they monitor for any long-term effects of contamination on restored ecosystems, food resources, and their potential impact on cultural practices.

F.3.3.4.2 Approach for restoration

- Fund the organization of response teams that include tribal collaborators and distributed system to enable the gathering of Traditional Ecological Knowledge and cultural information about the injured shoreline, on the model of that done following EVOS and Deepwater Horizon. Adopt current best practices in Community-Based Monitoring that provide meaningful feedback to the restoration management process. (McKay and Johnston, 2018; Noble & Birk, 2011; Harvey, Clarke, & Carvalho, 2001).

F.3.3.4.3 Monitoring

- Both the EVOS and Deepwater Horizon spills provide models for how the trust funds can be used to sponsor annual monitoring programs for cultural resources. Many current projects are available as models. The trust can provide operating budgets to tribal and regional partners and resource management agencies to coordinate their efforts, create citizen science programs, and empower local peoples to remain active in monitoring ecological health and cultural well-being of their communities.

F.3.4 Predicted costs associated with the proposed restoration strategies

F.3.4.1 Framework for cost evaluation

The prediction of costs for primary restoration following an oil spill is a difficult task, as there are many factors that can impact such costs, including the quantity of shoreline impacted, the types and accessibility of shoreline habitats, the time of year of the spill, and the density of cultural resources. Therefore, any estimate of primary restoration costs entails making a large number of assumptions and carries with it a high level of uncertainty. Here we have sought to estimate costs based on a comparison to other spills. In this Task, we have used the Deepwater Horizon and the Marshall MI spills (Table FT1) as a basis, due to the amount of information available regarding restoration and the associated costs. Neither of these spills are perfect analogs for a potential spill in the Straits of Mackinac. The Deepwater Horizon spill was substantially larger spill than what is predicted here, where the oil was released into a comparatively warmer marine environment. Much of the habitat impacted in the Deepwater Horizon was unique and ecologically important, similar to the circumstances in the Straits of Mackinac. There are few freshwater analogs to a spill in the Straits of Mackinac. The Line 6B spill in Marshall, MI occurred in a freshwater setting spilling an estimated 20,000 barrels of oil (U.S. Fish and Wildlife Service, Nottawaseppi Huron Band of the Potawatomi Tribe, & Match-E-Be-Nash-She-Wish Band of the Potawatomi Tribe, 2015). However, the extent of shoreline oiling was considerably less than that estimated for a Straits of Mackinac spill, since the spill was somewhat confined to a river channel and was not released at depth in a large lake.

These factors, among others, must be taken into account when trying to make cost comparisons between previous spills and a potential spill in the Straits. Since an *a priori* itemization of exact costs is virtually impossible and any adjustment factors would be subjective, we have opted to identify a range of costs for restoration based on a comparison to these two spills. Our approach identifies the cost to restore one km of shoreline based on these previous spills and use hydrodynamic model predictions developed in previous tasks for the determination of the extent of shoreline oiling for a predicted spill in the Straits of Mackinac region. These estimates address primary restoration of the shoreline only. They do not include costs of compensatory ecological restoration, restoration of cultural resources, or funds to address alternative drinking water supplies.

F.3.4.2 Costs to restore previous spills

F.3.4.2.1. Deepwater Horizon

To evaluate the cost of restoring the various habitats that would be affected by an oil spill in the Straits of Mackinac, the team reviewed the available information on the Deepwater Horizon oil spill. The costs for restoration of the Deepwater Horizon spill were found in the settlement for natural resource damages (U.S. Department of Justice, 2016). These costs were used to calculate the cost of restoration per km oiled. According to this settlement, the costs associated with primary restoration were approximately $6.46 billion. A total of 2113 km was of shoreline was oiled (Nixon et al., 2016). Therefore, a realistic cost for restoration of shoreline from the Deepwater Horizon is $3.06 million/km. These costs represent a coarse metric for determination of restoration costs.

The costs associated with restoration of different types of habitat can vary greatly, with some types of shoreline being more expensive to restore than others. This variability in costs can be seen in the categorization of early restoration projects for the Deepwater Horizon listed in the DARP documents (Chapter 5 Appendix B). These early restoration efforts included many types of activities from the creation of oyster beds to cleanup of wetlands to building boat ramps, etc. Even within one type of shoreline, the per kilometer shoreline costs vary tremendously based on accessibility of the site and other factors. Based on previous projects, wetlands are typically more expensive to restore than sandy beaches. Real-world experience from Deepwater Horizon underscores some of the limitations determining potential costs of a theoretical spill. Therefore, this analysis used the coarse per kilometer estimate for the total restoration.

F.3.4.2.2. Marshall MI

To estimate costs per km of shoreline oiled for the Marshall, MI spill, we took the total length of river oiled at 60.8 km. With two banks per km of shoreline, the total amount of shoreline oiled would be 112.6 km. The cost of restoration was $62,000,000. This number is based on the $4,000,000 that was requested by the NRDA trustees as part of the Damage Assessment and Restoration Plan (U.S. Fish and Wildlife Service, Nottawaseppi Huron Band of the Potawatomi Tribe, & Match-E-Be-Nash-She-Wish Band of the Potawatomi Tribe, 2015) in addition to the $58,000,000 that was part of the state settlement for natural resource damages (U.S. Fish and Wildlife, 2015). Therefore, the cost per km of shoreline oiled was estimated to be $510,000/km. This figure is close to that estimated by Richardson and Brugnone (2018) using a similar approach.

F.3.4.3. Cost determined per km of shoreline oiled

We have chosen to work with models for shoreline oiling determined by Task E, which were the hydrodynamic simulations that predicted the greatest amount of shoreline oiling at ten days and 60 days. Each simulation represents a different spill scenario. Thus we calculated costs for four different potential spills in the Straits region. The following simulations were used for determination of amount of shoreline oiled: (1) The longest shoreline oiled in Lake Huron after 10 days, (2) the longest shoreline oiled in Lake Huron after 60 days, (3) the longest shoreline oiled in Lake Michigan after 10 days, and (4) the longest shoreline oiled in Lake Michigan after 60 days. Based on these estimates, we used the cost to restore one km of shoreline based off of the Deepwater Horizon and Marshall, MI spills. The Marshall, MI estimate represents a lower cost scenario, and the Deepwater Horizon represents a higher cost scenario. As such, these costs provide brackets for the amounts to restore these four different spill scenarios. It is also essential to note that the hydrodynamic scenarios that were used for the estimation of primary restoration costs do not take into account the containment, recovery, and cleanup operations. These operations have the potential to decrease the amount of shoreline that is oiled. While the 60-day scenarios represent absolute worst-case scenarios, it is more likely to see the amount of oiled shoreline from the 10-day scenarios. Therefore, our estimates for primary ecological restoration range from $165,300,000 to $1,372,600,000.

For the purpose of calculating the total costs of a specific scenario across all tasks, it is also useful to apply the same approach used above to the most economically costly of the three scenarios on which Tasks G, H and I are focused. This most costly scenario is referred to in those sections as “Scenario 1”, and is based on the current and weather conditions that occurred on March 1, 2016. The total shoreline oiled for that scenario 60 days post-spill, again representing unmitigated conditions, is 996 km, corresponding to cost estimates for restoration of $508,000,000 (Marshall cost basis) to $3,047,000,000 (Deepwater Horizon cost basis) using the cost determination per km approach just described. Because Task H focuses on Marshall as an analogous spill, in part because it occurred in Michigan and so the government response structure and associated costs may be more similar, they carry forward the estimate of approximately $500 million as the total cost of cleanup on which to base government cost estimates. As made clear above, the total estimated cleanup cost is sensitive to several assumptions, but this value also falls roughly midway along our $165,300,000 to $1,372,600,000 range of estimates, making it useful where a single value is needed rather than a wide range of estimates.

Table F3. Cost estimates for primary shoreline restoration based on the per kilometer costs for the Marshall, MI spill and the Deepwater Horizon Spill for four spill scenarios.

Primary lake impacted	Days after spill	Total Shoreline oiled (km)	Cost Basis Marshall, MI	Cost Basis Deepwater Horizon
Huron	10	449	$228,900,000	$1,372,600,000
Michigan	10	324	$165,300,000	$991,100,000
Huron	60	1075	$548,100,000	$3,286,300,000
Michigan	60	888	$452,800,000	$2,714,600,000

F.4. Discussion

No oil spills of the predicted magnitude have occurred in the Great Lakes relative to marine environments which have provided a challenge for valuing resources and therefore the cost to restore and mitigate injury to those resources. In the process of establishing a cost framework, we took an approach of providing a range in cost estimates as there are a number of factors that we did not or could not consider in the cost estimate. Our cost framework considered only the worst-case scenarios of the extent of shoreline oiled provided by Section B. Estimates of natural and cultural resource restoration in the event of a rupture in Enbridge Line 5 at or near its crossing at the Straits of Mackinac could reach more than $3.2 billion for the oil spill scenario that impacts 1075 km of Lake Huron shoreline. The waters and shoreline areas of Lakes Michigan and Huron as well as the areas surrounding and adjacent to the Straits of Mackinac, where oil is predicted to contact, are abundant with natural and cultural resources that are of vast cultural, ecological and economic value, including, archeological sites, shipwrecks, fish, wildlife, wetlands, coastal sand dunes, and a variety of aquatic and terrestrial plants. This estimate is realistic, given the richness and diversity of the areas at risk, but with high levels of uncertainty regarding the location, scale, and scope of an oil spill near the Straits of Mackinac, and the potential for a worst-case scenario involving a rupture that affects a wider geographical range, or that involves a greater amount of oil released. The higher cost estimates are based on numbers associated with restoration of the Deepwater Horizon oil spill and the longest shoreline oiling for scenarios that do not take into account cleanup.

Cleanup activities immediately following a rupture in Line 5 may reduce the extent of shoreline oiling and risk to open water, natural and cultural resources, thereby reducing the cost of restoration activities. However, any measure for cleanup proposed by Section C was not included, as our considerations of worst-case scenario include the greatest extent of risk. Similarly, high levels of uncertainty regarding the response time, time of year (e.g., ice cover), and equipment function precluded inclusion. It is also important to note that the valuation and costs determined in this Section account for all shoreline oilings in Lakes Michigan and Huron. Some of these areas are outside the borders of the State of Michigan and include shorelines in Wisconsin and Ontario. While restoring a spill in the Straits of Mackinac may be complex like the Deepwater Horizon, containment and recovery efforts may help to lessen the amount of oiled shoreline. It is, therefore, possible that the extent of shoreline oiling would be more similar to the

10-day scenarios predicted by Task E. Therefore, $1.3 billion may be a more likely cost estimate for restoration of a worst case in scenarios where containment and recovery operations occur.

Our focus was providing a cost for restoring shoreline areas; however, additional strategies that were proposed to mitigate population losses, such as fishery closures, artificial reefs creation and dam removal— alternatives to provide spawning habitat for fishes, were not specifically included in our estimates, as they require agency consultation. Natural Resource Damage Assessment under OPA is the legal process that federal agencies use to evaluate the impacts of oil spills on natural and cultural resources. The damages to natural resources and ecosystems from oil spills must be assessed, monitored, and restored, and their related injuries must be compensated, according to federal law. The agencies use six criteria focus and maximize the value of restoration efforts toward recovery of natural resource injuries and service losses that occurred as a result of an oil spill, including relation to natural resource injuries and service losses, avoidance of additional adverse impacts, project costs, likelihood of success, service benefits and public health and safety. Within these criteria, restoration projects and project locations that reflect the geographic area affected by a spill and which address the diversity of resource injuries that resulted from it are preferred.

Many of the proposed approaches for restoration have been used as part of restoring past oil spills. There is, therefore, a high likelihood of success of these approaches as applied in the Great Lakes. However, the exact restoration strategies and approaches are to be decided upon by the Trustees during the NRDA process. Our analysis suggests that it is essential for habitats to be restored for recovery and restoration of the injured ecological resources. During the Deepwater Horizon restoration, a number of projects were identified and initiated while the damage assessment was ongoing (http://www.gulfspillrestoration.noaa.gov/restoration/early-restoration). A similar approach may be useful in rapidly responding to a spill and moving toward the restoration of habitat at early stages of the restoration process. As there are a number of sensitive habitats in the Straits of Mackinac and many of the habits would require substantial investment to restore, it is essential to adequately protect these habitats during the cleanup and spill response phases to prevent injury to these habitats.

In this section, we have focused on approaches for primary restoration, where the goal is to restore the resources to the pre-spill baseline conditions. Achieving the pre-spill baseline is a foundational aspect of oil spill restoration. However, for primary restoration approaches to be successful, it is essential to have robust baseline data for the resources at risk. Detailed information about the natural and cultural resources in the Straits of Mackinac is essential for determining baseline conditions and monitoring of the success of restoration following an oil spill. In some cases, despite substantial effort, it may be very difficult for primary restoration to bring conditions back to baseline after a spill.

F.5 Summary

This section focuses on evaluating restoration techniques and costs for both environmental and cultural resources. The analysis was informed by previous spills and restoration projects following the Deepwater Horizon and the Line 6B near Marshall, MI, oil spills. We reviewed a range of typical techniques for ecological restoration from sediment removal to beach/vegetation cleaning to bioremediation. Regarding cultural resources, a compensatory approach is taken as a return to baseline conditions is difficult. Because of the unique and complex environment of the Great Lakes and the Straits area, we propose a bracket for our cost estimates regarding ecological restoration. A likely cost range could be 165 million to 1,372 million when containment and recovery are taken into account. Cultural resources restoration, compensatory restoration, and litigation costs would increase this estimate.

F.6 References

Angradi, T. R., Pearson, M. S., Bolgrien, D. W., Bellinger, B. J., Starry, M. A., & Reschke, C. (2013). Predicting submerged aquatic vegetation cover and occurrence in a Lake Superior estuary. Journal of Great Lakes Research, 39(4), 536-546.

Associated Press. (2015). Drinking water trucked into Montana city after oil spill. Accessed at http://www.cbc.ca/news/world/drinking-water-trucked-into-montana-city-after-oil-spill-1.2919086.

Atlas, R. M., & Hazen, T. C. (2011). Oil biodegradation and bioremediation: a tale of the two worst spills in U.S. history. *Environmental Science & Technology, 45*(16), 6709-6715.

Atlas, R. M., Stoeckel, D. M., Faith, S. A., Minard-Smith, A., Thorn, J. R., & Benotti, M. J. (2015). Oil biodegradation and oil-degrading microbial populations in marsh sediments impacted by oil from the Deepwater Horizon well blowout. *Environmental Science & Technology*, *49*(14), 8356-8366.

Bergeon-Burns, C. M., Olin, J. A., Woltmann, S, Stouffer, P.C., & Taylor, S. 2014. Effects of oil on terrestrial vertebrates: Predicting impacts of the Macondo blowout. *BioScience, 64*(9), 820–828.

Biddanda, B. A., Nold, S. C., Dick, G. J., Kendall, S. T., Vail, J. H., Ruberg, S. A. & Green, C. M. (2011). Rock, water, microbes: Underwater sinkholes in Lake Huron are habitats for ancient microbial life. *Nature Education Knowledge, 2*(12), 9.

Blanchette, R.A. (2000). A review of microbial deterioration found in archaeological wood from different environments. *International Biodeterioration & Biodegradation, 46,* 189–204.

Boufadel, M. C., Geng, X., Michel, J., & Nixon, Z. (2015). *Priorities, Methods, and Costs for Restoration of Lingering Subsurface Oil from the Exxon Valdez Oil Spill in Prince William Sound, Alaska.* Retrieved from http://www.arlis.org/docs/vol1/EVOS/2015/RP15150121.pdf.

Brazner, J. C., Sierszen, M. E., Keough, J. R., & Tanner, D. K. (2000). Assessing the ecological importance of coastal wetlands in a large lake context. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen*, *27*(4), 1950-1961.

Brody, T.M., Di Bianca, P., & Krysa, J. (2012). Analysis of inland crude oil spill threats, vulnerabilities, and emergency response in the Midwest United States. *Risk Analysis 32*(10), 1741-1749.

Bunnell, D. B., Davis, B. M., Chriscinske, M. A., Keeler, K. M., & Mychek-Londer, J. G. (2015). Diet shifts by planktivorous and benthivorous fishes in northern Lake Michigan in response to ecosystem changes. *Journal of Great Lakes Research*, *41*, 161-171.

Canadian Press. (2016). Saskatchewan oil spill: drinking water could be unsafe for months, government warns. Accessed at https://www.huffingtonpost.ca/2016/07/25/saskatchewan-oil-spill_n_11181258.html.

Candor, R. (1996). Rethinking risk management in the federal government. *The Annals of the American Academy of Political and Social Science*, *545*, 135-143.

Chawla, M.K., Balbach, H.E., & Hartman, E.J. (2013). Two for the Price of One: Integration of NEPA and NHPA Procedures. Washington, D.C.: U.S. Army Corps of Engineers, Engineer Development and Research Center, Department of Defense Legacy Resource Management Program. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a608631.pdf.

Church, R., Warren, D., Cullimore, R., Johnston, R. L., Schroeder, W., Patterson, W., Shirley, T., Kilgour, M., Morris, N., & Moore, J. (2007). Archaeological and biological analysis of World War II shipwrecks in the Gulf of Mexico: artificial reef effect in deep water. OCS Study MMS, 2007-015. New Orleans, LA: U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. Retrieved from https://www.boem.gov/ESPIS/4/4239.pdf.

Cullimore, D.R., & Johnston, L. A. (2008). Microbiology of concretions, sediments and mechanisms influencing the preservation of submerged archaeological artifacts. *International Journal of Historical Archaeology, 12*, 120–132.

Deepwater Horizon Natural Resource Damage Assessment Trustees. (2016). *Deepwater Horizon oil spill: Final programmatic damage assessment and restoration plan and final programmatic environmental impact statement.* Retrieved from http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan.

Derecki, J.A., & Quinn, F. H. (1988). Comparison of vertical velocity measurements in the Great Lakes connecting channels with theoretical profiles. *Hydraulic Engineering, Proc. of the 1988 National Conference HY Div/ASCE*, Colorado Springs, CO, August 8-12, 1988.

Doyle, E., Muckian, L., Hickey, A. M., & Clipson, N. (2008). Microbial PAH degradation. *Advances in Applied Microbiology*, *65*, 27-67.

Dyer, C. (1993). Tradition loss as secondary disaster: long-term cultural impacts of the Exxon Valdez oil spill. *Sociological Spectrum*, *13*(1), 65-88.

Evans, A., & Firth, X. (2016). Anthropogenic impacts of development-led archaeology in an offshore context. In M.E. Keith (Ed.), *Site formation processes of submerged shipwrecks*, (pp. 133-156). Miami, FL: University Press of Florida.

Financial Stability Oversight Council (FSOC). (2016). FSOC Desk Report for the Enbridge Line 6B Oil Spill Marshall, Michigan (2016, April). Retrieved from https://www.epa.gov/sites/production/files/2016-04/documents/enbridge-fosc-report-20160407-241pp.pdf

Fodrie F. J., & Heck, K. L., Jr. (2011). Response of coastal fishes to the Gulf of Mexico oil disaster. *PLoS ONE*, *6*(7), e21609.

Ford, B. (2017). *The Shore is a Bridge: the Maritime Cultural Landscape of Lake Ontario*. Texas A&M University Press, College Station, TX.

Gjelstrup Björdal, C. (2012). Microbial degradation of waterlogged archaeological wood. *Journal Cultural Heritage*, *13*, S118–S122.

Grossart, H.-P., & Simon, M. (1993). Limnetic macroscopic organic aggregates (lake snow): Occurrence, characteristics and microbial dynamics in Lake Constance. *Limnology and Oceanography*, *38*, 532-546.

Halsey, J. R. (1990). *Beneath the Inland Seas: Michigan's Underwater Archaeological Heritage*. Lansing: Michigan Department of State.

Halsey, J. R. (2007). "Wrecked, Abandoned, and Forgotten?: Public Interpretation of Beached Shipwrecks in the Great Lakes", in J. H. Jameson Jr. and D. A. Scott-Ireton (Eds.), *Out of the Blue: Public Interpretation of Maritime Cultural Resources* (pp. 158-170). New York: Springer Science+Business Media.

Hamdan, L. J., Salerno, J. L., Reed, A., Joye, S., & Damour, M. (2018). The impact of the Deepwater Horizon blowout on historic shipwreck-associated sediment microbiomes in the northern Gulf of Mexico. *Scientific Reports, 8,* DOI:10.1038/s41598-018-27350-z.

Harriman, B. H., Zito, P., Podgorski, D. C., Tarr, M. A., & Suflita, J. M. (2017). Impact of photooxidation and biodegradation on the fate of oil spilled during the Deepwater Horizon incident: advanced stages of weathering. *Environmental Science & Technology*, *51*(13), 7412-7421.

Harvey, N., Clarke, B. D., Carvalho, P. (2001). The role of the Australian Coastcare program in community-based coastal management: a case study from South Australia. *Ocean & Coastal Management* 44(3–4), 161-181

Hazen, T. C., Prince, R. C., & Mahmoudi, N. (2016). Marine oil biodegradation. *Environmental Science & Technology, 50*(5), 2121-2129.

Hazen, T.C., Dubinsky, E.A., DeSantis, T.Z., Andersen, G.L., Piceno, Y.M., Singh, N., …& Stringfellow, W.T. (2010). Deep-sea oil plume enriches indigenous oil-degrading bacteria. *Science, 330*(6001), 204-208.

Hong, P. K. A., & Xiao T. (2013). Treatment of oil spill water by ozonation and sand filtration. *Chemosphere, 91*, 641-647.

Huang, L., & Batterman, S. A. (2014). Multimedia model for polycyclic aromatic hydrocarbons (PAHs) and Nitro-PAHs in Lake Michigan. *Environmental Science and Technology*, *48*, 1317-13825.

Huang, L., Chernyak, S. M,. & Batterman, S. A. (2014). PAHs, nitro-PAHS, hopanes and steranes in lake trout from Lake Michigan. *Environmental Toxicology and Chemistry, 33*, 1792-1801.

Hulse, C. A. (1979). An Archaeological Perspective on the Value of Great Lakes Shipwrecks. *Underwater Parks: Symposium Proceedings 57-59*. Michigan State University Cooperative Extension Service Bulletin E-1350. East Lansing: Michigan State University.

International Association of Dredging Companies. (2014). Facts about trailing suction hopper dredgers. *Facts About, No. 1*. Retrieved from https://www.iadc-dredging.com/ul/cms/fck-uploaded/documents/PDF%20Facts%20About/facts-about-trailing-suction-hopper-dredgers.pdf.

Jenni, K.E., Merkhofer, M. W., & Williams, C. (1995). The rise and fall of a risk-based priority system: lessons from DOE's environmental restoration priority system. *Risk Analysis 15*(3), 409.

Kaoru, Y. and Hoagland, P. (1994). The Value of Historic Shipwrecks. *Coastal Management* 22(2):195.

King, G. M., Kostka, J. E., Hazen, T. C., & Sobecky, P. A. (2015). Microbial responses to the Deepwater Horizon oil spill: from coastal wetlands to the deep sea. *Annual Review of Marine Science, 7,* 377-401.

King, T. F. (2008). *Cultural resource laws and practice*. New York, N.Y.: AltaMira Press.

Kirchhoff, D., Gardner, H.L., & Tsuji, L. J. (2013). The Canadian Environmental Assessment Act, 2012 and associated policy: Implications for aboriginal peoples. *The International Indigenous Policy Journal, 4*(3), 1-14.

Kost, M. A., Albert, D. A., Cohen, J. G., Slaughter, B. S., Schillo, R. K., Weber, C. R., & Chapman, K. A. (2007). *Natural Communities of Michigan: Classification and Description*. Accessed at https://mnfi.anr.msu.edu/reports/2007-21_Natural_Communites_of_Michigan_Classification_and_Description.pdf.

Krugel, L. (2016). Drinking water top priority after oil spill into river: Brad Wall. Accessed at https://globalnews.ca/news/2850686/giant-hose-awaits-pumps-to-move-vital-water-into-prince-albert-sask/.

Létourneau, M. R. (2017). Under the old stones of Kingston, Ontario: the City of Kingston archaeological master planning process. In S. Baugher, D. Appler, & W. Moss (Eds.), *Urban archaeology, municipal government and local planning: Preserving heritage within the Commonwealth of Nations and the United States* (pp. 91-114). Cham, Switzerland: Springer International Publishing.

Mahmoudi, N., Porter, T. M., Zimmerman, A. R., Fulthorpe, R. R., Kasozi, G. N., Silliman, B. R., & Slater, G. F. (2013). Rapid degradation of Deepwater Horizon spilled oil by indigenous microbial communities in Louisiana saltmarsh sediments. *Environmental science & technology*, *47*(23), 13303-13312.

Maun, M. A., & Krajnyk, I. (1989). Stabilization of Great Lakes sand dunes: effect of planting time, mulches and fertilizer on seedling establishment. *Journal of Coastal Research*, *5*, 791-800.

McKay, A. J., Johnson, C. J. (2017). Identifying Effective and Sustainable Measures for Community-Based Environmental Monitoring. *Environmental Management* 60(3), 484-495

McFarlin, K. M., Prince, R. C., Perkins, R., & Leigh, M. B. (2014). Biodegradation of dispersed oil in arctic seawater at -1°C. *PloS ONE*, 9(1), e84297.

Michel, J., & Rutherford, N. (2014). Impacts, recovery rates, and treatment options for spilled oil in marshes. *Marine Pollution Bulletin, 82*(1-2), 19-25.

Michel, J., Esler, D., & Nixon, Z. (2016). *Studies on Exxon Valdez lingering oil: Review and update on recent findings-February 2016*. Retrieved from http://evostc.state.ak.us/Universal/Documents/Publications/04-05-16_March_2016_LO_Update.pdf.

Michel, J., Owens, E. H., Zengel, S., Graham, A., Nixon, Z., Allard, T., Holton, W., Reimer, P. D., Lamarche, A., White, M., Rutherford, N., Childs, C., Mauseth, G., Challenger, G., & Taylor, E. (2013). Extent and degree of shoreline oiling: Deepwater Horizon oil spill, Gulf of Mexico, USA. *PloS ONE, 8*(6), e65087.

Michigan Department of Environmental Quality. (2016). Enbridge Energy, Limited Partnership, Line 6B Pipeline Release, Marshall, Michigan, Case No.: 15-1411-CE, Conceptual Site Model, January 2016. Accessed from https://www.michigan.gov/deq/0,4561,7-135-3313_56784-248127--,00.html

Michigan Department of Environmental Quality. (2018). Michigan Water Quality Standards, Part 4 Rules. https://www.michigan.gov/documents/deq/wrd-rules-part4_521508_7.pdf, accessed May 17, 2018.

Michigan Natural Features Inventory (MNFI). (2018). Biotic-Diversity GIS Database. Michigan State University Extension. https://mnfi.anr.msu.edu/ accessed May 1, 2018.

Michigan Natural Features Inventory. (2018) Great Lakes Marshes. Michigan State University Extension. https://mnfi.anr.msu.edu/communities/community.cfm?id=10671 accessed July 8, 2018.

NOAA. 1994. Environmental Sensitivity Index (ESI) Maps. Office of Response and Restoration.https://response.restoration.noaa.gov/maps-and-spatial-data/environmental-sensitivity-index-esi-maps.html. Accessed May 1, 2018, for Lakes Michigan and Huron.

National Research Council. 2013. *An ecosystem services approach to assessing the impacts of the Deepwater Horizon oil spill in the Gulf of Mexico*. Washington, DC: The National Academies Press.

Nicholas, C.R., & Jaworski, E. (1979) Economic value of fish, wildlife, and recreation in Michigan's coastal wetlands. *Coastal Zone Management Journal*, *5:3*, 181-194.

Nikiforuk, A. (2016). Why we pretend to clean up oil spills. *Hakai Magazine.* Retrieved from https://www.smithsonianmag.com/science-nature/oil-spill-cleanup-illusion-180959783/

Nixon, Z., & Michel, J. (2018). A review of distribution and quantity of lingering subsurface oil from the Exxon Valdez Oil Spill. *Deep Sea Research Part II: Topical Studies in Oceanography, 147,* 20-26.

Nixon, Z., Zengel, S., Baker, M., Steinhoff, M., Fricano, G., Rouhani, S., & Michel, J. (2016). Shoreline oiling from the Deepwater Horizon oil spill. *Marine Pollution Bulletin, 107*(1), 170-178.

Noble, B.F. (2010). *Introduction to environmental impact assessment: A guide to principles and practice.* Oxford, UK: Oxford University Press.

Noble, B. and Birk, J. (2011). Comfort monitoring? Environmental assessment follow-up under community–industry negotiated environmental agreements. *Environmental Impact Assessment Review* 31(1):17-24.

O'Shea, J. M. 2002. Mapping Lake Huron's Au Sable Shoreline and Near Shore Shipwrecks. University of Michigan, Museum of Anthropology. Report on file, Michigan State Historic Preservation Office, Lansing, MI.

O'Shea, J. M. 2004. *Ships and Shipwrecks of the Au Sable Shores Region of Western Lake Huron*. Memoirs of the Museum of Anthropology, Book 39. Ann Arbor: University Museum University of Michigan.

Pokytylo, D., & Mason, A. R. (2010). Archaeological heritage resource protection in Canada: The legislative basis. In P.M. Messinger and G. S. Smith (Eds.), *Cultural heritage management: A global perspective* (pp. 48-69). Gainesville, FL: University Press of Florida.

Prince, R. C., & Atlas, R. M. (2018). Bioremediation of marine oil spills. Consequences of Microbial Interactions with Hydrocarbons, Oils, and Lipids: Biodegradation and Bioremediation, 1-25.

Reddy, C. M., Arey, J. S., Seewald, J. S., Sylva, S. P., Lemkau, K. L., Nelson, R. K., … & Camilli, R. (2011). Composition and fate of gas and oil released to the water column during the Deepwater Horizon oil spill. Proceedings of the National Academy of Sciences Jul 2011, DOI: 10.1073/pnas.1101242108.

Reed, M. S. (2008). Stakeholder participation for environmental management: A literature review. Biological Conservation 141(10):2417-2431.

Reger, D. R., McMahan, J. D., and Holmes, C. E.. (1992). *Effect of Crude Oil Contamination on Some Archaeological Sites in the Gulf of Alaska, 1991 Investigations*. Alaska Office of History and Archaeology Report no. 30. Division of Parks and Outdoor Recreation, Department of Natural Resources, State of Alaska.

Richardson, R. B., & Brugnone, N. (2018). Oil spill economics: Estimates of the economic damages of an oil spill in the Straits of Mackinac, Michigan. Accessed at http://flowforwater.org/wp-content/uploads/2018/05/FLOW_Report_Line-5_Final-release.pdf

Riding, M. J., Doick, K. J., Martin, F. L., Jones, K. C., & Semple, K. T. (2013). Chemical measures of bioavailability of PAHs in soil: Fundamentals to application. *Journal of Hazardous Materials*, *261*, 687-700.

Runyan, T.J. (1990). Shipwreck legislation and the preservation of submerged artifacts. *Case Western Reserve Journal of International Law*, *22*(1), 32-41.

Salerno J.L., Little, B., Lee, J., & Hamdan, L. J. (2018) Exposure to crude oil and chemical dispersant may impact marine microbial biofilm composition and steel corrosion. *Frontiers in Marine Science*, *5*, 196.

Short, J. W., Irvine, G. V., Mann, D. H., Maselko, J. M., Pella, J. J., Lindeberg, M. R., Payne, J. R., Driskell, W. B., & Rice, S. D. (2007). Slightly weathered Exxon Valdez oil persists in Gulf of Alaska beach sediments after 16 years. *Environmental Science and Technology*, *41*, 1245-1250.

Shuchman, R. A., Sayers, M. J., & Brooks, C. N. (2013). Mapping and monitoring the extent of submerged aquatic vegetation in the Laurentian Great Lakes with multi-scale satellite remote sensing. Journal of Great Lakes Research, 39, 78-89.

Sitar S. P., Brenden, T. O., He, J. X., & Johnson, J. A. (2017). Recreational postrelease mortality of Lake Trout in Lakes Superior and Huron. *North American Journal of Fisheries Management*. *37*, 789-808.

Smith, M. B., Rocha, A. M., Smillie, C. S., Olesen, S. W., Paradis, C., Wu, L., ... & Hazen, T. C. (2015). Natural bacterial communities serve as quantitative geochemical biosensors. *MBio*, *6*(3), e00326-15.

Tanner, H. H. (1987). *Atlas of Great Lakes Indian History*. Norman: University of Oklahoma Press.

Trebitz, A. S., & Taylor, D. L. (2007). Exotic and invasive aquatic plants in Great Lakes coastal wetlands: distribution and relation to watershed land use and plant richness and cover. *Journal of Great Lakes Research*, *33*(4), 705-721.

U.S. Council on Environmental Quality and U.S. Advisory Council on Historic Preservation. (2013). NEPA and NHPA: A Handbook for Integrating NEPA and Section 106. Accessed at https://ceq.doe.gov/docs/ceq-publications/NEPA_NHPA_Section_106_Handbook_Mar2013.pdf.

U.S. Department of Justice. (2016). *Consent decree among defendant BP Exploration & Production Inc. ("BPXP"), The United States of America, and the States of Alabama, Florida, Louisiana, Mississippi, and Texas*. Retrieved from https://www.justice.gov/enrd/file/838066/download.

U.S. Environmental Protection Agency. (2018). National Primary Drinking Water Regulations. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#Organic. Accessed May 17, 2018.

U.S. Environmental Protection Agency. (2004). Results of the Lake Michigan mass balance study: mercury data report. *EPA 905 R-01-012*, Chicago, IL: Great Lakes National Program Office.

U.S. Environmental Protection Agency. (2010). Pollution/Situation Report Kalamazoo River/Enbridge Spill - Removal POLREP-SITREP. SITREP #16 Kalamazoo River/Enbridge Spill Z5JS Marshall, MI. Accessed at https://archive.epa.gov/region5/enbridgespill/pdfs/web/pdf/20100810_sitrep16.pdf.

U.S. Environmental Protection Agency. (n.d.a). How will benzo-a-pyrene be removed from my drinking water? Accessed at https://safewater.zendesk.com/hc/en-us/articles/212077707-7-How-will-benzo-a-pyrene-be-removed-from-my-drinking-water-

U.S. Environmental Protection Agency. (n.d.b). How will benzene be removed from my drinking water? Accessed at https://safewater.zendesk.com/hc/en-us/articles/211403538-7-How-will-benzene-be-removed-from-my-drinking-water-

U.S. Fish and Wildlife Service (2015, June 8) *Enbridge Must Restore Environment Injured by 2010 Kalamazoo River Oil Spill* Retrieved from https://www.fws.gov/midwest/news/785.html

U.S. Fish and Wildlife Service, Nottawaseppi Huron Band of the Potawatomi Tribe, & Match-E-Be-Nash-She-Wish Band of the Powatomi Tribe. (2015). Final damage assessment and restoration plan/environmental assessment for the July 25-26, 2010 Enbridge Line 6B oil discharges near Marshall, MI. Retrieved from https://www.fws.gov/midwest/es/ec/nrda/MichiganEnbridge/pdf/FinalDARP_EA_EnbridgeOct2015.pdf.

U.S. Fish and Wildlife Service. (n.d.). Traditional Ecological Knowledge for Application by Service Scientists. Accessed at www.fws.gov/nativeamerican/pdf/tek-fact-sheet.pdf.

U.S. National Ocean Service, National Oceanic and Atmospheric Administration. (2017). *About Thunder Bay National Marine Sanctuary*. Updated July 31, 2017. Retrieved from https://thunderbay.noaa.gov/about/welcome.html

U.S. National Oceanic and Atmospheric Association. (2014). *Detecting changes in a changing world: 25 years after the Exxon Valdez oil spill.* Retrieved from https://response.restoration.noaa.gov/oil-and-chemical-spills/significant-incidents/exxon-valdez-oil-spill/detecting-changes-changing-worl).

U.S. Naval History and Heritage Command, United States Navy. (2018). The Navy's Historic Aircraft Wrecks in Lake Michigan. Published online on February 26th, 2018. Retrieved from https://www.history.navy.mil/research/underwater-archaeology/sites-and-projects/aircraft-wrecksites/aircraft-wrecks-in-lake-michigan.html

US Geological Survey. (1999). Public Water Supply Intakes in Michigan. Accessed at https://mi.water.usgs.gov/pdf/watersupplyintakes.pdf.

Uzarski, D. G., Burton, T. M., Cooper, M. J., Ingram, J. W., & Timmermans, S. T. (2005). Fish habitat use within and across wetland classes in coastal wetlands of the five Great Lakes: development of a fish-based index of biotic integrity. *Journal of Great Lakes Research, 31*, 171-187.

Vrana, K. J. and Halsey, J. R. (1992). Shipwreck allocation and management in Michigan: A review of theory and practice. *Historical Archaeology* 26(4):81-96.

Ward, Collin P., Charles M. Sharpless, David L. Valentine, Deborah P. French-McCay, Christoph Aeppli, Helen K. White, Ryan P. Rodgers, Kelsey M. Gosselin, Robert K. Nelson, and Christopher M. Reddy. (2018) Partial photochemical oxidation was a dominant fate of Deepwater Horizon surface oil. *Environmental science & technology* 52, no. 4 : 1797-1805.

Wick, L.Y., McNeill, K., Rojo, M., Medilanski, E., & Gschwend, P. M., (2000). Fate of benzene in a stratified lake receiving contaminated groundwater discharges from a Superfund site. *Environmental Science and Technology*, *34*, 4354-4362.

Williamson, R. F., Robertson, D. A., & Hughes, S. (2017). Archaeological Resource Management in Toronto: Planning, preservation, and interpretation. In S. Baugher, D. Appler, & W. Moss (Eds.), *Urban archaeology, municipal government and local planning: Preserving heritage within the Commonwealth of Nations and the United States* (pp. 91-114). Cham, Switzerland: Springer International Publishing.

Wyatt, B. (ed.) (2015). *Volume 1: Presentation Papers, Proceedings of the Maritime Cultural Landscape Symposium, October 14-15, 2015, University of Wisconsin-Madison.* Washington D.C.: The National Center for Preservation Technology and Training National Park Service, U.S. Department of the Interior.

Zhao, Q., Bai, J., Huang, L., Gu, B., Lu, Q., & Gao, Z. (2016). A review of methodologies and success indicators for coastal wetland restoration. *Ecological Indicators*, *60*, 442-452.

Task GI: Estimating the amount of natural resource and other economic damages, public and private, that would result from a worst-case release

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GI.1 Introduction

GI.1.1 General introduction to the issue

We estimate the dollar value of natural resource damages by calculating the monetary cost of injuries to natural resources that would result from a worst-case release. Damages to natural resources are evaluated by identifying the functions or "services" provided by the resources, determining the baseline level of the services provided by the injured resources, and quantifying the reduction in service levels as a result of the contamination. We use several methods to quantify damages, including market-based and non-market resource valuation and economic impact analysis.

GI.1.2 SOW from the State of Michigan

The 1953 Easement "makes Enbridge liable for all damages or losses to public or private property" (Risk Analysis Final RFP 2017). This report analyzes the natural resource and economic damages of a worst-case scenario as commissioned by the State of Michigan. The State defined our Scope of Work in two sections:

1. Estimating the natural resource damage amount that would result from a worst-case release.[1]

This analysis would include, but is not limited to:

i. Available information regarding the baseline ecological, natural resource and economic conditions in the areas potentially affected by a worst-case release;

ii. The economic value of the natural resources destroyed or impaired;

iii. The economic value of the public uses and ecological services provided by the affected resources that would be lost until a final cleanup and restoration is complete; and

iv. The economic value of any residual damages to natural resources that could not be cleaned up or restored.

2. Estimating all other economic damages, public and private, that would result from a worst-case release.

This analysis would include but is not limited to, identifying and estimating the scope and magnitude of damages not otherwise accounted for in (1), above, to:

i. Subsistence, sport, and commercial fishing and hunting;

ii. Commercial navigation;

iii. Recreational boating;

iv. Tourism and recreation-related businesses in the Great Lakes region;

v. Property values in areas affected by the release

vi. Loss of tax revenues[2]

GI.2 Background

GI.2.1 Other Studies

GI.2.1.1 FLOW assessment

The group For Love of Water (FLOW) commissioned a report on potential economic damages of a Line 5 oil spill (“the FLOW report”, Richardson and Brugnone, 2018). That report sought to quantify many of the same effects as our assessment. The FLOW report finds that natural resource damages of a spill amount to about $700 million and tourism

[1] We use the baseline information to assess a change, for example, a change in value of natural resources. Our natural resource damage amount only measures lost recreational use of natural resources. We do not include any permanent residual damages, although in our scenarios some act ivies do not recover immediately after oil is cleaned up. Damage to habitat and wildlife and restoration is covered by Task E and F.

[2] Loss of Tax revenues is covered in Section H.

impacts to the economy are nearly $5 billion. The FLOW report, like this assessment, makes assumptions about the economic activities affected by a spill as well as the spatial extent of areas affected and the estimated effect in each area. While the categories examined in the FLOW report are generally the same as those examined here, there are frequently different assumptions about the extent and duration of impacts. Different assumptions on these critical dimensions of loss will lead to different loss assessments. For instance, the FLOW report determines natural resource damages by apportioning the NRDA settlement for the Kalamazoo River to the miles of river affected and then applying this damage per mile to spill scenarios for Line 5. For tourism and property value impacts, the FLOW report assumes impacts will last up to five years. Evidence of tourism and property value impacts from past oil spills shows that impacts may last for substantially less than five years. In particular, the recreation assessment for the Deepwater Horizon (DWH) oil spill, the most extensive measurement of recreational trip losses ever conducted for an oil spill, found that shoreline visitation had recovered in most areas after one year and recovered in all areas after two years (Tourangeau et al. 2017).

GI.2.1.2 Others

The Groundwork Center for Resilient Communities report argues that Michigan and Midwest refineries could operate with no economic disruption without Line 5 because other pipelines supply Michigan's needs. Refineries that serve Michigan have upgraded equipment in recent years to primarily handle heavy crude oil, whereas Line 5 transports light crude oil. It discusses solutions to secure propane for Upper Peninsula and northern Michigan residents. The report highlights concerns that the impact of a spill would extend beyond the Straits, potentially compromising Michigan's "Pure Michigan" brand and perceptions of Mackinac Island and the Mackinac Bridge, if oil reached associated beaches.

The LP Environment US report assumes that the cleanup time is four months for a spring or summer spill and that bulk oil remains in the Straits area. The winter spill considers a cleanup time of nine months with bulk oil migrating out of the Straits area. While the study includes NRDA, neither scenario covers effects on recreational activities or commercial activities.

GI.2.2 Assessing Losses

An oil spill may cause both public and private losses. Under public trust doctrines and the Oil Pollution Act, the party responsible for the spill can be held accountable for the losses to public natural resources under a process called Natural Resource Damage Assessment (NRDA). Public losses would include impacts to wildlife and habitat as well as any losses to recreational use of natural resources. Typically, private losses, such as lost business profits, lost wages, and injuries to private property, are not a part of the public claim under NRDA but are considered a part of a private claim determined separately by courts.

To measure public losses, economists can, in principle, measure the lost economic value of public uses and the wildlife and habitat harmed by a spill using survey-based techniques such as contingent valuation. For example, surveys were conducted to measure lost economic values due to the Exxon Valdez spill (Carson et al. 2003) and the DWH spill (Bishop et al. 2017). Credibly measuring spill injuries in this manner is non-trivial, costly, and beyond the scope of our assessment timeline. Alternatively, it is common in NRDAs to use economic valuation to assess losses to the public's recreational uses of natural resources, and to use habitat-scaling techniques for injuries to wildlife and habitat. In essence, habitat scaling approaches adjust the size of projects that restore and enhance wildlife and habitat to ensure they are large enough to offset and compensate for injuries due to the spill. We assume here that habitat scaling approaches would be used to assess damages to habitat and wildlife in the event of a Line 5 spill, and do not attempt to measure these injuries using economics.

Our assessment of natural resource damages estimates economic losses for injuries to recreational uses of natural resources. We specifically assess losses for the following recreational activities: public beach use, sport fishing, boating, and public park use. Our charge also directs us to assess a variety of private losses, which would not normally be a part of an NRDA claim, including losses for commercial fishing, commercial navigation, private property values, and impacts on tourism and recreation-related businesses. We have also included estimated losses for potential effects on drinking water supply, propane and gasoline supply, and incomes of employees in tourism and recreation-related businesses.

GI.3. Approach

GI.3.1 Methods Overview

We seek to measure losses in economic values due to the spill. Economists have a well-established body of theory and practice that establishes how to appropriately measure such losses. While there may be competing public ideas about what economic losses might be, our assessment follows the standards set in economics. Economics classifies these losses into two broad categories: losses to consumers and losses to producers. Consumers include people that engage in natural resource-based recreation such as fishing or beachgoing, people that engage in other forms of tourism that would be affected by a spill, and consumers of products whose supply could be affected by a spill (e.g., users of propane gas). Producers would include commercial fisheries, navigation, refineries, and businesses engaged in support of recreation and tourism. For producers, economics measures a loss in economic value by the loss in profits that occur, where profits represent the difference between revenues and costs. Producer profits could be affected by a spill through a loss in revenues or changes in costs. In the terminology of economics, profits represent a "surplus" value that measures the difference between total revenues and costs.

For consumers, economists also measure changes in economic value with a "consumer surplus" measure that quantifies the difference between total willingness to pay for a good or service and the actual amount paid. The left panel of Figure GI1 illustrates the economic measure of value for a consumer that takes trips to a natural resource. The panel plots a demand curve for trips that shows the relationship between the price of trips and the number of trips that are taken. At some price that is high enough, the consumer would no longer take any trips, but as the price decreases the desired number of trips increases (hence the demand curve slopes downward). At any point on the demand curve, the curve shows the maximum total willingness to pay for an additional trip. The shaded area of the left figure (roughly shaped like a triangle) illustrates the surplus value a consumer receives from taking trips—the difference between the total willingness to pay and the amount paid. The right panel of Figure GI1 illustrates how an oil spill can decrease the demand for trips (by shifting the demand curve to the left). When the curve shifts inward, the consumer's trips decrease, and the economic value the consumer receives from their trips drops accordingly. This decline in value is illustrated by the shaded area in the right panel of the figure. It is this change in consumer surplus in the event of a spill that we seek to measure – we will call this surplus the willingness to pay to avoid the spill or WTP.

The appropriate measure of economic damage due to a spill is measured by the losses in the economic surplus values to producers and consumers, as described above. In addition to being theoretically preferred, these surplus measures are specified for benefit-cost analysis per federal guidelines (OMB 2003) and natural resource damage assessments of oil spills (see, for example, Chapman and Hanneman 2001 or English et al., 2018). It is important to note that because the appropriate economic approach to measuring lost values from a spill is based on lost surplus values, i.e., values that net out costs, the measures would not be the same as other figures that may be publicly available. For example, data on all the spending associated with recreation tells us something about recreators' costs, but it does not directly tell us about the surplus value of recreation. For this reason, one cannot add spending or economic "impact" numbers to economic surplus numbers. However, some of this spending will affect incomes of producers and their employees, and those changes in income are relevant to measuring private losses due to a spill.

Table GI1 provides a summary of the categories of economic losses that we assess. The second column identifies the economic concept being measured, and the final column provides a simplified summary of how the concept is measured in our assessment. Complete measurement details for each category are provided in the sections that follow.

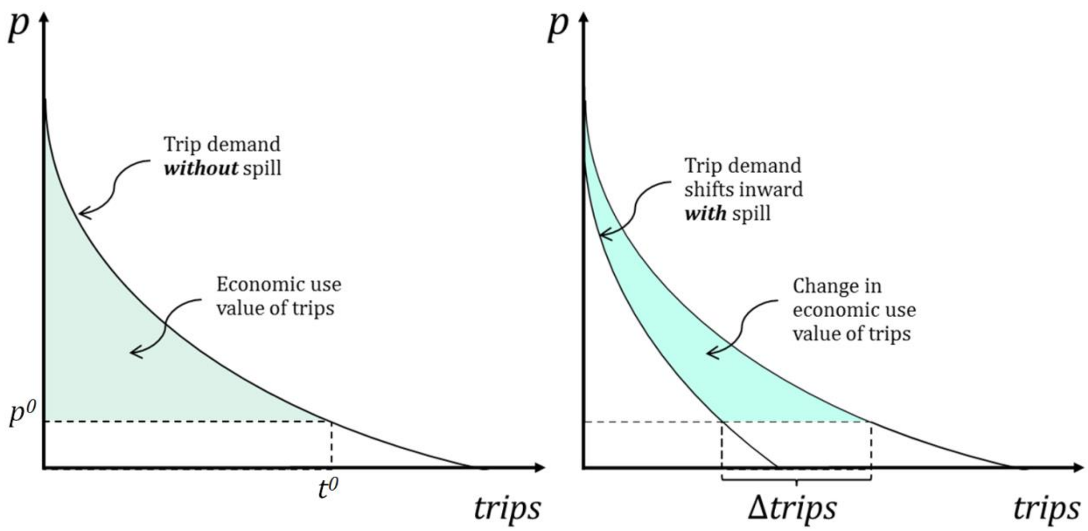


Figure GI1: Conceptual illustration of economic measures of the recreation losses due to an oil spill

Table GI1: A broad summary of the categories of loss assessed and the general approach to measuring losses

Category	Concept	Simplified summary of measurement approach
Recreational losses	Lost consumer surplus for trips (WTP)	WTP times reduction in trips by activity, region and season
Higher propane prices	Lost consumer surplus for propane	Price change times quantity of propane
Commercial fishing	Lost producer surplus for fishing	Price times change in harvest
Commercial navigation	Lost producer surplus for shipping	Cost increase: days waiting time cost per day
Property value	Lost value of services of housing	Flow of housing services times decline from the spill
Water uses	Increased costs of testing and substitute supplies	Well testing costs for groundwater and cost of supply replacement for municipal intakes
Tourism and recreation-related businesses	Lost incomes	Lost visits times spending per visitor is run through a model of the regional economy to estimate lost incomes

GI.3.2 Description of spill scenarios used to measure economic damages from a worst-case spill

We measure the economic damages from a worst-case spill using the predicted extent of shoreline oiling from a spill at the Straits, scaling this extent using information about damages from the DWH oil spill, and inputting the extent data into models of economic activity. We divide the extent into two areas: the "core" and "periphery." The core area receives shoreline oiling. The periphery area is adjacent to the core and extends from an oiled county as far as the oiled county's distance to the Straits so that the last periphery county is approximately double the spill's greatest distance from the Straits. Damages are greater in the core than in the periphery. This pattern is consistent with the spatial extent of losses after the DWH accident, which featured zones of higher and lower losses. Economic losses from this accident were measured based on changes in people's behavior, and losses occurred due to reduced recreation in periphery areas where oil never washed ashore.

We measure the economic damages from three possible Line 5 oil spill scenarios. The risk analysis team identified these scenarios as among the set with the longest amount of shoreline oiling. We number these scenarios 1–3. Scenario 1 affects shoreline on Lake Huron and Lake Michigan, with the core extending to Benzie County (MI) and Cheboygan County (MI) on Lake Michigan and Presque Isle County on Lake Huron. Scenario 2 affects areas in Lake Michigan, with the core extending to Leelanau County and Menominee County (both in MI). Scenario 3 affects areas in Lake Huron only, with the core extending to Alpena County (MI) and Bruce County (ON). Table GI1 presents summaries of these scenarios. In each case, we use an April 1 spill date because a spring spill—which occurs just prior to the summer tourism season—will have the greatest effect on resource use.

Table GI2. Shoreline length and number of counties in Michigan, Wisconsin, and Ontario affected by three candidate worst-case spills.

	Scenario 1[a]	**Scenario 2[b]**	**Scenario 3[c]**
Simulated spill date	April 1, 2016	April 1, 2016	April 1, 2016
Shoreline oiled (km)	704	542	412
Core counties – L. Michigan	13	9	1
Core counties – L. Huron	2	0	6
Periphery counties – L. Michigan	11	11	2
Periphery counties – L. Huron	2	2	6
Counties – Total	***28***	***22***	***10***

[a] Derived from center_mm03_hr_1440_highest1_2016_03_01T18_0704km.
[b] Derived from south_mm04_hr_1440_highest1_2016_04_24T18_0542km.
[c] Derived from center_mm05_hr_1440_highest01_2016_05_12T12_0412km.

GI.4 Analysis and results

GI.4.1 Recreational beach use valuation

A worst-case oil spill from the Enbridge Line 5 pipeline in the Straits of Mackinac may beach oil across several economically-important Michigan beaches. A major consequence of oil beaching is avoided beach trips. This section describes how we calculate the value of lost trips to publicly-accessible beaches.

The lost value from avoided beach trips equals the maximum a visitor is willing to pay to visit the beach per trip times the decrease in beach trips over the course of the season. We use benefit transfer (Rosenberger and Loomis 2003) to estimate these values. Note that an oil spill in the Straits may affect beaches in Michigan's Upper and Lower Peninsulas, Wisconsin, and Ontario. We have detailed beach visitation data for Lower Peninsula Beaches only. We start by describing how we calculate the value of these beaches. We then describe our strategy for estimating the value of beaches in the other regions.

Cheng (2016) estimates the average WTP to avoid the closure of a single beach in several regions throughout the state of Michigan, including the area we predict will be affected by a worst-case oil spill. She finds that average WTP to avoid a single beach closure in NLM and NLH is \$24.74/trip and \$24.76, respectively. WTP to avoid closure of all publicly-accessible beaches along Lakes Michigan and Huron over a season is \$57.32 and \$41.95, respectively. A worst-case oil spill is not predicted to result in the closure of all beaches on either lake, but it is expected to close more than a single beach. We, therefore, interpolate the lost value per trip. Let the proportion of beaches oiled along lake *l* be denoted b_l. Likewise, let the WTP to avoid a single beach closure be v_l^1 and the WTP to avoid closure of all beaches be v_l^A. The interpolated WTP to avoid closure of the oiled beaches along lake *l* is then

$$v_l = (v_l^A - v_l^1)b_l, \tag{1}$$

Next, we estimate the change in the number of beach trips. This change is the baseline number of trips less the expected decrease in trips in the period following the spill. Cheng (2016) estimates the number of trips taken to each beach by residents of Michigan's Lower Peninsula. We scale this figure up by 40% to account for out-of-state visitors. The change in beach visits after a spill will likely vary between the core and periphery. This change is due to "stigma effects," in which visits decline to un-oiled beaches near the spill (i.e., the periphery). For example, Tourangeau et al. (2017) find that beach visits to the Florida Peninsula declined by nearly 23% immediately after the *Deepwater Horizon* (DWH) spill, even though beaches in the region were not oiled. Hence, we assume beach visits decline by 53% for core counties in the first beach visit season after the spill (Memorial Day through Sept. 30) and 10% for core counties in the second beach visit season after the spill. We assume visits decline to periphery counties by 23% in the first beach visit season only. These figures are consistent with the decrease in beach use estimated by Tourangeau et al. (2017) following the DWH spill.

We assume the lost value of an Upper Peninsula beach equals the average value loss of a beach on northern Lake Huron. We calculate the average lost value per beach as the WTP for a closed north Huron beach ($24.76; Cheng 2016) times the number of lost visits for beaches in Alpena, Cheboygan, and Presque Isle Counties (equal to the estimated number of visits from Cheng (2016). We multiply this value by the decline in beach visits—either 53% or 23%, depending on whether the county is in the core or periphery) divided by the number of beaches in these counties. Finally, we multiply this value by the number of beaches in each UP county.

We use an analogous procedure to calculate the lost value for Wisconsin beaches, except that we assume these beaches are equivalent to an average northern Lake Michigan beach. We do not have any data on visitation or beach location for Ontario; hence, we assume the value of lost visits is zero for Canadian beaches.

Table GI3 summarizes our results for Michigan and Wisconsin beaches. The simulated spills are expected to cause $103 million to $399 million in losses in present value terms (assuming a discount rate of 2.5%) to beach users in the two seasons following the spill.

Table GI3. Present Value of Lost Welfare from Reduced Beach Trips (million)

Scenario[a]	1	2	3
Michigan	$288.3	$268.8	$102.7
Wisconsin	$110.3	$87.6	———
Total loss	*$398.6*	*$356.4*	*$102.7*

[a] 1 = center_mm03_hr1440_highest01_2016_03_01T18_0704km
2 = south_mm04_hr1440_highest01_2016_04_24T18_0542km
3 = center_mm05_hr1440_highest01_2016_05_12T12_0412km

GI.4.2 State and Federal Park Day Visits

This section describes the calculation of loss to day trips to state and federal parks near Lake Huron and Lake Michigan. Travelers visit these parks for hiking, sightseeing, touring and picnicking. We calculate day trips from state and federal visitor statistics after excluding percentages measuring fishing, boating, and beach trips. Not all travelers visit these parks because of the proximity to a lake. However, many of the most popular parks in Michigan are located along the shores of the Great Lakes, which suggests that day visitors highly value water-based amenities.

We define total loss to day trips as

$$Loss = \Delta t_1 \times \text{WTP} + \frac{\Delta t_2 \times \text{WTP}}{1+r} \tag{2}$$

where Δt is the change in the number of outdoor and touring day trips due to a spill in Michigan counties with shoreline on the Great Lakes. WTP is the maximum willingness to pay per day to enjoy the outdoors in the region affected by the spill. The subscripts 1,2 indicate whether the value occurs in year 1 or year 2. We discount the year two values by a discount rate r.

We measure WTP using benefits transfer and calculate the change in trips (Δt) using a model described below. We measure the baseline number of day trips from visitor statistics for parks in counties that border the Great Lakes. We define these counties as the tourist region that a spill could affect. The trip model measures the change in total days as a function of the location of core and periphery areas.

We model the change in day trips in Michigan as

$$\Delta t_1 = -t \times \left[z_{c1}\mathbf{a}_c\mathbf{Bc} + z_{p1}\mathbf{a}_p\mathbf{Bc}\right] \qquad (3)$$

$$\Delta t_2 = -t \times \left[z_{c2}\mathbf{a}_c\mathbf{Bc} + z_{p2}\mathbf{a}_p\mathbf{Bc}\right] \qquad (4)$$

where t is the baseline number of days in a year, $\mathbf{a}$ is a $1{\times}n$ matrix of affected counties, $\mathbf{B}$ is a $n{\times}m$ matrix of the share of days in county n in month m, $\mathbf{c}$ is a $m{\times}1$ matrix of affected months, and z is the percent reduction in days at an affected county-month pair. Day trips to the counties affected by the oil spill are not likely to cease entirely, so $z < 1$. The impact of the spill is largest in core counties, smaller in periphery counties and absent in other counties. The subscripts c,p indicate whether a term measure impacts in a core or periphery county.

We calculate the baseline number of day trips by summing annual visits to all state parks, state recreation areas, Mackinac state historic parks, national parks and national forests in Michigan. We did not acquire the data for Wisconsin parks in time for this report. These data do not include day trips to private recreation areas, county parks or municipal parks. The DNR provided state park and recreation area monthly day use visits. Mackinac State Historic Parks (MSHP) provided annual visits to the Mackinac historic parks. We collected data on national park visits from the National Park Service's Visitor Use Statistics Program website – specifically, those categorized as "recreation visits." We collected national forest visit data from the U.S. Forest Service's National Visitor Use Monitoring Program web-based reports, including "day use developed site visits" and "general forest area visits." We used the 2015-2017 annual average for the state and National Park areas, the 2017 value for Mackinac historic parks, and the 2012 value (the latest available) for national forests. We assigned each park, recreation area and national forest to a county; if unit boundaries included more than one county, we used the county that included most of the unit area. For national forests with two physical subunits—Hiawatha and Huron-Manistee—we assigned each subunit to a county and assumed half of the visits went to each subunit. The statewide total is 29.6 million day trips, including specifically 11.1 million trips to parks in Lake Michigan counties and 1.3 million trips to parks in Lake Huron counties. [3]

To adjust for double-counts, we reduce these amounts, first, by 15% to account for people visiting multiple parks in a single trip (Phil Porter, pers. comm.), and second, by 35% for beach users (20%), recreational anglers (15%) and recreational boaters (10%), which are measured in separate models. The beach, angler, and boater fractions approximate observed swimming, fishing, and boating activities in Michigan national forests, which are the only areas that report activity participation rates. This yields a benchmark of 11,128,968 day trips. We calculate the county shares from the observed number of days trips to each county with a state or federal park.

We calculate the month shares using the Michigan state park data, which are disaggregated by month. We assume parks for months with missing values had zero visits. We calculate the number of bookings across all parks for each month, separately for lodging and camping. Dividing the sum of monthly visits across parks by total visits generates the month shares.

Tourangeau et al. (2017) report that recreation in the Gulf declined 0% to 45.5%, depending on the area, month and type of activity, after the DWH oil spill. Tourangeau et al. (2017) do not report declines for activities other than fishing, beach use or boating. We, therefore, identify z using the smallest value Tourangeau et al. (2017) report, in the first and second years of the spill, for a conservative estimate of the spill effect. Specifically, we use z_{c1} = 0.284, z_{c2} = 0, z_{p1} = 0 and z_{p2} = 0.

We use benefit transfer to measure the value of recreational day trips. Rosenberger et al. (2017) conduct a meta-analysis of recreational use values, and estimate recreation is worth $55.93 per day per user in 2016$ in the U.S. Great Lakes/Northeast region. This WTP value is $58.73 in 2018$.

Table GI4 shows the economic damages for recreational day trips for three spill scenarios. We assume that park demand fully recovers after the end of the summer season, in August of the first year after the spill. The greatest losses arise in scenario 1 when the oil spill reaches shoreline in Lake Huron and Lake Michigan. The economic damages to park day trips in this scenario are $20.3 million.

Table GI4. Economic damages to recreational day trips for three worst-case spill scenarios

Scenario	1	2	3
Days in Michigan	11,128,968	11,128,968	11,128,968
Days in Wisconsin		Not measured	
Reduction in days to core in year 1	346,283	318,244	124,009
Reduction in days to core in year 2	0	0	0
Reduction in days to periphery in year 1	0	0	0

[3] Longwoods International (2016) estimates 71 million day trips in Michigan, but these are not specific to outdoor recreation areas.

Reduction in days to periphery in year 2	0	0	0
Value lost per day	58.73	58.73	58.73
Total loss	*$20,335,972*	*$18,689,337*	*$7,282,605*

GI.4.3 State and National Park Camping

We calculate the loss to state and federal park campers for the same reason we calculate the loss of day visitors. It is likely that many campers stay overnight at parks in coastal counties because of the proximity of the lakes. Concerns about water conditions will deter some of these camping trips. We calculate camping days from state and federal statistics of overnight stays, which include developed camping, undeveloped camping, and lodging at state and federal parks.

We define total loss to camping days as in equation (4) above, where now Δt is the change in the number of camping days due to a spill in counties with shoreline on the Great Lakes, and WTP is the maximum willingness to pay per day to camp. We model the change in camping days in Michigan as in equations 3 and 4.

We calculate the baseline number of camping days as the sum of annual visitor nights to all state parks, state recreation areas, national parks and national forests in Michigan. We did not acquire the data for Wisconsin parks in time for this report. The Michigan data do not include camping at private recreation areas. The DNR provided state park and recreation area monthly booking nights; we assume the average party size is three per booking. We collected National Park overnight stay counts from the National Park Service's Visitor Use Statistics Program website. We used data on average annual overnight stays from 2015-2017 for the state and national parks. We collected data on national forest visits from the U.S. Forest Service's National Visitor Use Monitoring Program web-based reports, specifically those categorized as "overnight use developed site visits." We assigned each park, recreation area and national forest to a county; if unit boundaries included more than one county, we used the county that included most of the unit area. For national forests with two physical subunits—Hiawatha and Huron-Manistee—we assigned each subunit to a county and assumed half of the visits went to each subunit. To adjust for double-counts, we reduce these amounts by 35% for beach users (20%), recreational anglers (15%) and recreational boaters (10%), which are measured in other sections. The beach, angler, and boater fractions approximate observed swimming, fishing and boating activities in Michigan national forests, which are the only areas that report such numbers.[4] This calculation yields a benchmark of 1,228,888 camping days. We calculate the county shares from the observed number of camping days in each county with a state or national park

As in the previous section, we calculate the month shares using the Michigan state park data and measure z using the measured reductions in recreational activity following the DWH spill

[4] This information comes from the USFS National Visitor Use Monitoring Program. The program reports with activity participation rates are available at https://apps.fs.usda.gov/nvum/results/A09007.aspx/FY2012.

reported in Tourangeau et al. (2017). We identify z using the smallest value Tourangeau et al. (2017) report, in the first and second years of the spill, for a conservative estimate of the spill effect. Specifically, we use $z_{c1} = 0.284$, $z_{c2} = 0$, $z_{p1} = 0$ and $z_{p2} = 0$.

We use benefit transfer to measure the value of camping days. Rosenberger et al. (2017) conduct a meta-analysis of recreational use values and estimate a day of developed camping is worth \$23.57 per user in 2016\$ in the U.S. Great Lakes/Northeast region. This WTP value is \$24.75 in 2018\$.

Table GI5 shows the economic damages for camping trips for five spill scenarios. We assume that the demand for park camping fully recovers after the end of the summer season, in August of the first year after the spill. The greatest losses arise in scenario 1 when the oil spill affects a wide area across Lake Huron and Lake Michigan. The economic damages to park camping in this scenario are \$2.2 million.

GI.4.4 Recreational fishing valuation

We calculate the lost value of recreational fishing that would occur in the event of a spill. Recreational fishing includes for-hire charter fishing and non-charter, sport-fishing in Lake Huron and Lake Michigan.

The formula for calculating loss is

$$\text{Loss} = (\Delta t_{MI1} + \Delta t_{WI1}) \times \text{WTP} + \frac{(\Delta t_{MI2}+\Delta t_{WI2})\times\text{WTP}}{1+r} \quad (5)$$

Table GI5. Economic damages to camping trips for three worst-case spill scenarios

Scenario	1	2	3
Days in Michigan	1,228,888	1,228,888	1,228,888
Days in Wisconsin		Not measured	
Reduction in days to core in year 1	88,791	70,782	42,114
Reduction in days to core in year 2	0	0	0
Reduction in days to periphery in year 1	0	0	0
Reduction in days to periphery in year 2	0	0	0
Value lost per day	24.75	24.75	24.75
Total loss	*\$2,197,455*	*\$1,751,760*	*\$1,042,256*

We develop different models to calculate changes in trips (Δt) and trip values (WTP). This development is done because we have access to a sample of individual trip data that allow us to measure WTP using a standard economic valuation method, but we cannot use this data to measure the effect of a spill on total trips. Instead, we establish the baseline number of trips from publically available lake-level trip summaries. We calculate the change in total trips as a function of the location of oiled shoreline in each lake. The following paragraphs describe these methods in more detail.

For the sake of brevity, consider the effects of a spill on fishing trips in Michigan only. We define the change in fishing trips in Michigan in year 1 and year 2 as

$$\Delta t_{MI1} = -t_{MI} \times [z_{c1}\mathbf{a}_c\mathbf{Bc} + z_{p1}\mathbf{a}_p\mathbf{Bc}] \quad (6)$$

$$\Delta t_{MI2} = -t_{MI} \times [z_{c2}\mathbf{a}_c\mathbf{Bc} + z_{p2}\mathbf{a}_p\mathbf{Bc}] \quad (7)$$

where t_{MI} is the baseline number of fishing trips in a year, **a** is a $1 \times n$ matrix of affected counties, **B** is a $n \times m$ matrix of the share of trips to county n in month m, **c** is a $m \times 1$ matrix of affected months, and z is the percent reduction in trips to an affected county-month pair. An analogous expression gives the change in Wisconsin trips. Trips to the counties affected by the oil spill are not likely to cease entirely, so $z < 1$. We divide affected counties into core and periphery counties. The impact of the spill is largest in core counties, smaller in periphery counties and absent in remaining counties. The subscripts c,p indicate whether a term measures impacts in a core or periphery county.

We measure the baseline number of trips to each lake using creel data. The baseline number of annual trips to the Great Lakes in Michigan is 1,279,344, and the baseline number of trips in Wisconsin is 532,319. Both the Michigan and Wisconsin Departments of Natural Resources (DNR) use creel surveys to measure and track recreational fishing effort. We convert the Wisconsin data, which is denominated in hours, to a measure trips by dividing total hours of effort by five. We use the 2015-2017 trip averages, including recreational and charter fishing effort in the case of Michigan and fishing in Green Bay in the case of Wisconsin.

Tourangeau et al. (2017) report declines in recreational fishing activity after the Deepwater Horizon oil spill. We use these estimates to identify z. Specifically, we use $z_{c1} = 0.328$, $z_{c2} = 0.0$, $z_{p1} = 0.0$ and $z_{p2} = 0$.

The WTP amounts vary by the extent of the spill. A spill that oils more shoreline and damages more fishing sites causes the WTP per trip to increase because anglers have fewer substitute sites to fish elsewhere. We measure WTP as

$$\mathrm{WTP} = (v^A - v^1)f + v^1 \quad (8)$$

where the willingness to pay to lose a single site is v^1, the willingness to pay to avoid the loss of all fishing sites in Lakes Huron and Michigan is v^A, and f is the number of core and periphery counties divided by the number of shoreline (on Lakes Huron or Michigan) counties in Michigan. We calculate v^1 and v^A from a per-trip valuation model based on random utility maximization (RUM) methods. The model defines individual well-being, or utility, as a function of the attributes of each alternative, where

$$\begin{aligned} U_{ijt} &= \rho c_{ijt} + \delta_j + \varepsilon_{ijt} \\ &= \omega_{ijt} + \varepsilon_{ijt} \end{aligned} \quad (9)$$

is the utility function. Utility for angler i is a function of travel cost c_{ijt} to alternative j in year t, fishing quality δ_j, and an error term ε_{ijt} that includes idiosyncratic factors that affect the demand for a fishing alternative. ω_{ijt} is the observable portion of utility. The probability an angler visits any particular site can be estimated by specifying a distribution for the error. The model parameters are then calculated using maximum likelihood estimation. See Melstrom and Lupi (2013) for a published version of this model. We parameterize the RUM model using the data collected from a monthly survey of licensed Michigan anglers that are reported in Klatt (2014). The average per-trip WTP to access the lost fishing site(s) s is

$$v_s = \sum_{i=1}^{N} \frac{\omega_{ijt}}{N} \cdot \frac{N}{N_s} \tag{10}$$

where N_s is the number of sample trips taken to the affected sites before the spill. We use the model to calculate WTPs for fishing sites in Cheboygan, Emmet, and Mackinac counties, which have the greatest probability of being affected by a spill at the Straits. After adjusting for inflation, the average WTP (v^1) for the individual Lake Huron and Lake Michigan sites is \$39.42. The WTP to avoid losing all Lake Huron and Lake Michigan fishing sites (v_M^A) is \$129.34.

We calculate the damages from a spill scenario by inputting indicators for core and periphery counties, and the duration of the spill cleanup, into the model that calculates Δt. We assume that fishing demand fully recovers after the end of the summer season, in August of the first year of the spill. Table GI6 presents the loss amounts. The greatest losses arise in scenario 1 when the oil spill reaches into Lake Huron and Lake Michigan. The total economic damages to recreational fishing in this scenario are \$6.2 million.

Table GI6. Economic damages to recreational fishing trips for three worst-case spill scenarios

Scenario	1	2	3
Trips in Michigan	1,279,344	1,279,344	1,279,344
Trips in Wisconsin	532,319	532,319	532,319
Reduction in trips to core in year 1	61,155	23,724	6,593
Reduction in trips to core in year 2	0	0	0
Reduction in trips to periphery in year 1	0	0	0
Reduction in trips to periphery in year 2	0	0	0
Interpolated value lost per trip	101.51	84.38	60.83
Total loss	*\$6,207,993*	*\$2,001,949*	*\$401,099*

GI.4.5 Recreational boating valuation

We calculate the lost value of recreational boating in the event of a spill. This lost value includes motorized and nonmotorized boating, exclusive of boats primarily intended for fishing, in Lake Huron and Lake Michigan.

The formula for calculating loss for either motorized boating days or nonmotorized boating days is

$$\text{Loss} = (\Delta t_{MI1} + \Delta t_{WI1}) \times \text{WTP} + \frac{(\Delta t_{MI2} + \Delta t_{WI2}) \times \text{WTP}}{1+r} \tag{11}$$

where Δt is the change in the number of boating days due to a spill and WTP is the maximum willingness to pay per day to go boating in an affected area absent the spill. The subscripts *MI*, *WI* indicate whether the change occurs in Michigan or Wisconsin, and the subscripts 1,2 indicate whether the value occurs in year 1 or year 2. The year 2 values are discounted at the rate r.

We measure WTP using benefit transfer and calculate the change in days (Δt) using a model. We measure the baseline number of boating days from lake-level summaries. The boating days model measures the change in total days as a function of the location of oiled shoreline. The following paragraphs describe these methods in more detail.

For the sake of brevity, consider the effects of a spill on Michigan only. We define the change in boating days in year 1 and year 2 as

$$\Delta t_{MI1} = -t_{MI} \times \left[z_{c1} \mathbf{a}_c \mathbf{B} \mathbf{c} + z_{p1} \mathbf{a}_p \mathbf{B} \mathbf{c} \right] \tag{12a}$$

$$\Delta t_{MI2} = -t_{MI} \times \left[z_{c2} \mathbf{a}_c \mathbf{B} \mathbf{c} + z_{p2} \mathbf{a}_p \mathbf{B} \mathbf{c} \right] \tag{12b}$$

where t_{MI} is the baseline number of days in a year, $\mathbf{a}$ is a $1 \times n$ matrix of affected counties, $\mathbf{B}$ is a $n \times m$ matrix of the share of days in county n in month m, $\mathbf{c}$ is a $m \times 1$ matrix of affected months, and z is the percent reduction in days at an affected county-month pair. An analogous expression gives the change in Wisconsin boating user days. Days in the counties affected by the oil spill are not likely to cease entirely, so $z < 1$. We divide affected counties into core and periphery counties. The impact of the spill is largest in core counties, smaller in periphery counties and absent in remaining counties. The subscripts *c*,*p* indicate whether a term measures impacts in a core or periphery county.

We calculate the baseline number of boating user days using data on total boating days in Michigan and Wisconsin, the number of registered boats, the number of users per boat, and an assumption about the spatial distribution of boating activity in the Great Lakes. The 2008 Great Lakes Recreational Boating Report (U.S. Army Corps of Engineers, 2008) publishes the most recent information about the number of Great Lakes recreational boating user days in Michigan and Wisconsin. The data for this report come from the 2003-2004 National Recreation Marine Research Center's National Boater Panel. The report estimates 5,853,000 and 2,828,000 boating days in Michigan and Wisconsin, respectively, in 2003. The boating report has not been updated with more recent boating day data, so we adjust the 2003 boating day data based on changes in registered boat records, which are available for more recent years. Specifically, we change the 2003 amounts by -16.7% for Michigan and +0.1% for Wisconsin. The shares of motorized and nonmotorized boating days also come from the 2008 Great Lakes Recreational Boating Report (U.S. Army Corps of Engineers, 2008). This report disaggregates the number of watercraft by type, and we subtract the imputed share of days using aluminum fishing boats from the imputed share of motorized boating days to avoid double counting the value of recreational fishing.

We calculate the average number of users per boat from published summaries of the 2012 National Recreational Boating Survey data (U.S. Coast Guard, 2017); the day-weighted mean number of persons aboard per boating day in the motorized category is 2.9, and the day-weighted mean in the nonmotorized category is 2.3.

We calculate the county and month shares using a mix of data and reasonable assumptions. We summed the number of public harbor and private marina slips in potentially affected counties and then distributed the remaining number of known slips (reported in U.S. Army Corps of Engineers (2008)) evenly among the other counties. We assumed the share of boating user days across counties is equivalent to the distribution of these slips. Next, we assumed the boating season occurs April through September, with equal parts in each month.

We again use the Tourangeau et al. (2017) report to measure z. Tourangeau et al. (2017) find that recreational boating trips in the Gulf declined 28.4% in the north Gulf in the first few months after the Deepwater Horizon oil spill, with no substantial reductions noted elsewhere in the Gulf. We therefore set $z_{c1} = 0.284$, $z_{c2} = 0$, $z_{p1} = 0$ and $z_{p2} = 0$.

We use benefit transfer to measure the value of a recreational boating day. Rosenberger et al. (2017) conduct a meta-analysis of recreational use values and estimate nonmotorized boating is worth $96.88 per day per user in 2016$ in the U.S. Great Lakes/Northeast region. Motorized boating is worth $46.33 per day per user in 2016$ in the same region. These WTP values are $101.72 and $48.65, respectively, in 2018$.

We calculate the damages from a spill scenario by using indicators for core and periphery counties, and the duration of the spill cleanup, into the model that calculates Δt. We assume that recreational boat use fully recovers after the end of the summer season, in August of the first year of the spill. Table GI7 presents the loss amounts. The greatest losses arise in scenario 1 when the oil spill affects shoreline in large parts of northern Lake Huron and northern Lake Michigan. The economic damages to recreational boating in this scenario are $32.5 million.

Table GI7. Economic damages to recreational boating for three worst-case spill scenarios

Scenario	1	2	3
Days in Michigan	8,921,767	8,921,767	8,921,767
Days in Wisconsin	3,545,471	3,545,471	3,545,471
Motorized boating			
Reduction in days to core in year 1	532,754	267,658	63,552
Reduction in days to core in year 2	0	0	0
Reduction in days to periphery in year 1	0	0	0
Reduction in days to periphery in year 2	0	0	0
Value lost per day	48.65	48.65	48.65
Total loss	$25,916,641	$13,020,630	$3,091,599
Nonmotorized boating			

Reduction in days to core in year 1	65,145	31,483	6,231
Reduction in days to core in year 2	0	0	0
Reduction in days to periphery in year 1	0	0	0
Reduction in days to periphery in year 2	0	0	0
Value lost per day	101.72	101.72	101.72
Total loss	$6,626,776	$3,202,591	$633,797
Grand total	*$32,543,417*	*$16,223,220*	*$3,725,396*

GI.4.6 Commercial fishing valuation

An oil spill will affect commercial fishing through the closure of fishing grounds to contain and remove oil, and to protect consumers if fish are contaminated. The loss to commercial fishing includes the value of commercial and tribal fishers' lost harvests. We calculate these losses using harvest statistics reported for commercial fishing management areas in northern Lakes Huron and Michigan. It is also possible that the loss to commercial fishing includes some value to fish consumers who place a premium on Great Lakes fish products over non-Great Lakes fish products. However, there is limited evidence to indicate a price premium for Great Lakes fish, including lake whitefish, which is the most valuable commercial fish. Historically a premium may have existed (Frick, 1965), but more recently the price for Great Lakes fish has not responded to changes in harvest, which suggests that there is no significant premium.[5] We, therefore, focus on losses to commercial fishers.

We define total loss to commercial fishing as

$$Loss = \sum_i^S \Delta h_{i1} \cdot \mathrm{P}_i + \frac{1}{1+r} \sum_i^S \Delta h_{i2} \cdot \mathrm{P}_i \qquad (13)$$

where Δh_i is the change in the harvest of species i, measured in pounds, and P_i is the price per pound of species i. The subscripts 1,2 indicate whether the harvest occurs in year 1 or year 2. We discount the year 2 values at the rate r. This basic formula is based on the model of a commercial fish market shown in Figure GI2. In this model, the price is fixed and fish demand is perfectly elastic due to the availability of perfect (or near-perfect) substitutes. An oil spill will cause the supply curve to shift backward. The loss from this change is marked as the area A. This area is measured as $\mathrm{P}\times(h_{i0} - h_{i1}) = \mathrm{P}\times\Delta h_i$.

We calculate the change in commercial harvest for species i in year 1 as

$$\Delta h_{i1} = -\left[z_{c1}\mathbf{a}_c\mathbf{B}_i\mathbf{c} + z_{p1}\mathbf{a}_p\mathbf{B}_i\mathbf{c}\right] \qquad (14)$$

and in year 2 as

$$\Delta h_{i2} = -\left[z_{c2}\mathbf{a}_c\mathbf{B}_i\mathbf{c} + z_{p2}\mathbf{a}_p\mathbf{B}_i\,\mathbf{c}\right] \qquad (15)$$

[5] From fact sheet Michigan Commercial Fisheries Marketing and Product Development, available at http://www.miseagrant.umich.edu/files/2013/01/07-701-fs-whitefish-marketing.pdf.

where **a** is a 1×2 matrix that indicates whether management units in NLH and NLM are part of the core, $\mathbf{B}_i$ is a $2\times m$ matrix of the harvest that occurs in NLH or NLM in month m, **c** is a $m\times 1$ matrix of affected months, and z is the percent reduction in harvest. We distinguish between NLH and NLM being a core or periphery area. The impact of the spill is largest in the core, smaller in the periphery and absent in other parts of the lakes. The subscripts c,p indicate whether a term measures impacts in the core or periphery.

The baseline harvest is drawn from the following fisheries management areas in northern Lake Michigan and northern Lake Huron: WFM-00 through WFM-06 and WFH-01 through WFH-06 for lake whitefish, and MM-1 through MM-5 and MH-1 for lake trout, walleye, yellow perch and Chinook salmon. Lake whitefish harvest includes state-licensed commercial and tribal harvests. Lake trout, walleye, yellow perch and Chinook salmon are harvested only by tribal fishers. Commercial and tribal harvest of other species is minimal. The month shares are drawn from those used in the model of recreational fishing.

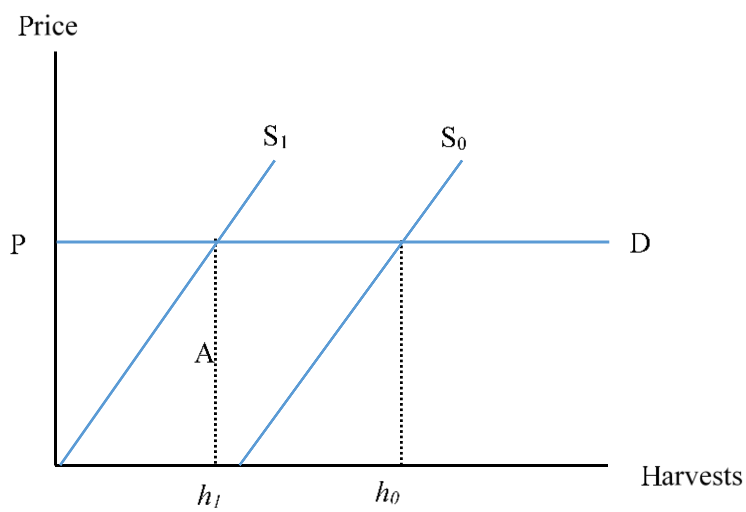


Figure GI2. The economic effect of a change in commercial fish landings due to a spill

The 2015 report of the 2000 Consent Decree (Michigan Department of Natural Resources, 2016) provides management area harvest data. This report provides information about the commercial and tribal harvest in management units that fall within the 1836 Treaty-Ceded waters of the Great Lakes. We rely on this report because the region that is most likely affected by a worst-case spill lies in the 1836 Treaty-Ceded waters. We summed these data across management areas to measure total harvest in each lake for each species. We report harvest statistics in Table GI8.

Prices come from National Marine Fisheries Service (NMFS) records (National Marine Fisheries Service). The NMFS maintains a database of Great Lakes commercial fishery landings and revenues. We calculate the price for each species by dividing species revenues in Michigan by the harvest (in pounds). We report these prices in Table GI8.

We calculate z by evaluating the distribution of a spill in NLH and NLM. We assign NLH or NLM to the core if the spill enters one or the other, and to the periphery, if no oil or a negligible amount of oil passes into NLH or NLM. We assume two-thirds of the core area closes to fishing, $z_{c1} = 0.667$, and one-third of the periphery, $z_{p1} = 0.333$, until August after the spill, and that no areas close to fishing, $z_{c2} = 0$ and $z_{p2} = 0$, in subsequent months. This closure assumption is similar to commercial fishing closures after the Deepwater Horizon oil spill; reopening of Gulf areas occurred within four months of the spill (in August), with all areas reopening within one year of the spill (Carroll et al., 2016).

Table GI9 shows the economic damages for three spill scenarios. The duration of the closure is four months (beginning in August). We also assume that the discount rate is $r = 0.025$. The greatest losses arise in scenario 1, where the oil spill affects large areas in northern Lakes Huron and Michigan. The economic damages to commercial harvests in this scenario are $1.6 million.

Table GI8. Harvests in 2014 from Lake Huron and Lake Michigan management units in the 1836 treaty-ceded waters.

Species	Harvest in pounds		Price per pound
	Lake Michigan	Lake Huron	
Lake whitefish	12,537,80	287,213	1.82
Lake trout	518,081	254,996	0.78
Walleye	4,999	23,401	2.66
Yellow perch	4,494	4,062	2.69
Chinook salmon	212	67,022	1.63

Table GI9. Economic damages to damages to commercial fish harvests for three worst-case spill scenarios

Scenario	1	2	3
Reduction in lake whitefish harvest in year 1	662,521	539,039	123,482
Reduction in lake trout harvest in year 1	332,370	277,472	220,833
Reduction in walleye harvest in year 1	12,210	7,172	11,134
Reduction in yellow perch harvest in year 1	3,678	2,804	2,711

Reduction in chinook salmon harvest in year 1	28,906	14,477	28,860
Reduction in lake whitefish harvest in year 2	0	0	0
Reduction in lake trout harvest in year 2	0	0	0
Reduction in walleye harvest in year 2	0	0	0
Reduction in yellow perch harvest in year 2	0	0	0
Reduction in chinook salmon harvest in year 2	0	0	0
Total loss	*$1,632,254*	*$1,310,083*	*$504,985*

GI.4.7 Impacts to Great Lakes Commercial Shipping

The Great Lakes is home to substantial waterborne commerce and is a key component of North America's economic health. The Great Lakes and the St. Lawrence Seaway has been estimated to contribute about $35 billion in annual revenues, including the operations of port facilities and shipping activities, and the generation of goods and commodity production facilitated by inland waterway shipping (Martin Associates 2011). It is also estimated to contribute 227,000 jobs. Through the St. Lawrence Seaway, production in the Great Lakes all the way to Louisiana has access to international shipping along the North American Eastern Seaboard. A Line 5 release would have an impact on shipping going through the Straits of Mackinac, with potential economic consequences.

While it is beyond the scope of this study to estimate the full breadth of potential economic impact of a Line 5 release from delayed shipments or forced alternative routes, we can estimate the expected impact on shipping costs of cargo vessels held up in the Great Lakes. In this assessment, we estimate the lost productivity of lake freighters and tugs temporarily obstructed by a Line 5 release in the Straits of Mackinac.

This high-level assessment assumes the operating costs of a Great Lakes freighter is $1 million per day of operation. This operating cost corresponds with average total voyage costs of Great Lakes freighters from about $778,000 to over $1.55 million (Martin Associates 2017) and average typical cross-Straits shipping times of 32 hours between Green Bay and Detroit. This cost includes fuel costs, pilotage, and others that may not be incurred while anchored. It does not distinguish operating costs of freighters and tugs. It also does not take into account the costs of delays on the shipper, nor the receiver of the commodities shipped. Rather it assumes operating costs are incurred while anchored because of Coast Guard closure of the Straits, assuming the closure will last five days. The assessment assumes an April event, during which the Straits have an average daily traffic of 2.8 passages of commercial shipping vessels. Shipments more than five days out are expected to be deferred at port to avoid the lost operating costs of being anchored in the lakes.

In testimony to the Pipeline Task Force, the Coast Guard asserts that a Line 5 break or leak would prompt closure of boating activity if a sheen were visible on the surface of the water. Using simulations of hourly surface flows, it was determined that an impassable sheen would be present in the Straits from between five to ten days, depending on water flows and weather conditions. The costs of such a short-term stoppage could be mitigated by vessel operators by leaving vessels dormant in port or through other mitigating actions that minimize operations costs. However, those within a five-day window may not have the option of mitigating actions. Rather, they will likely be compelled to anchor outside the impacted region in wait. The cost of that wait time is the basis of this estimate.

Given an average passage of 2.8 ships per day and expected stoppage of five days, on the day of the release, 2.8 vessels will be moored for five days. An additional 2.8 vessels arriving on the second day of stoppage will be moored for four days. By the fifth date, 14 (2.8*5) vessels will be in waiting for passage through the Straits. The sixth-day passage will likely result in bottleneck delays in vessels along the Straits as well as at the Soo Locks, but these costs are not considered.

The progressive build-up of moored vessels will result in 42 shipping days lost, as:

$$y = \sum_{i=1}^{5} 2.8 \cdot i = 42 \quad (16)$$

Assuming daily operational costs of $1 million, implies a financial cost of $42 million for shipping companies. This cost represents a loss in shipping productivity, but the burden of such costs cannot easily be assigned and depends on the terms agreed upon by the shipping entities.

GI.4.8 Effects on Michigan's Energy Supply

Line 5 is a 646-mile pipeline carrying light crude from Superior, WI to Sarnia, Ontario. It enters MI near Ironwood, moving up to 540,000 bpd of light crude oil, synthetic crude oil, and NGLs, including propane, to and through the state. Line 5 transports primarily light crude oil and NGL. Propane, one component of NGL, is one of the products transported on Line 5, serving Wisconsin and Michigan. 2600 bpd of NGLs are delivered to Rapid River, where propane is extracted and delivered to customers in the Upper Peninsula and Northern Michigan. 65% of propane demand in the Upper Peninsula and 55% of overall Michigan propane needs are met by Line 5 (as of June 2016). In Michigan, NGLs are used to heat homes; produce consumer goods such as clothing and medical equipment; and manufacture tires for the auto industry (Enbridge Line 5 Operational Reliability Plan 2018; Line 5 and Other Pipelines in Michigan 2018).

In addition, 14,000 bpd of light sweet crude oil enters Line 5 and is transported to regional refineries, including the Marathon refinery in Detroit. 30% of light crude stays in the region to fuel area refineries. Some light crude and NGLs are refined in Sarnia and returned in the form of propane or other byproducts. Line 5 serves as a conduit for refineries that process crude oil: PBF Energy (Toledo), BP (Toledo), Marathon (Detroit) into gas, diesel, jet fuel, and other refined products. Line 5 also provides transportation of Northern Michigan crude to the market (Enbridge Line 5 Operational Reliability Plan 2018; Line 5 and Other Pipelines in Michigan 2018).

A shutdown of Line 5 due to a spill at the Straits will impact Michigan propane consumers through higher prices. The American Community Survey (US Census Bureau) provides data on the number of households that use propane. About 18% of households use propane as a primary heat source in the Upper Peninsula (UP) of Michigan (22,050 households in 2016), and 65% of that supply comes from Line 5 (See Figure GI3). Average annual usage is 1,141 gallons per household. This average propane usage amounts to about 25 million gallons a year. Rapid River can produce up to 30 million gallons a year (Dynamic Risk 2017), more than enough to meet the demand for the UP.

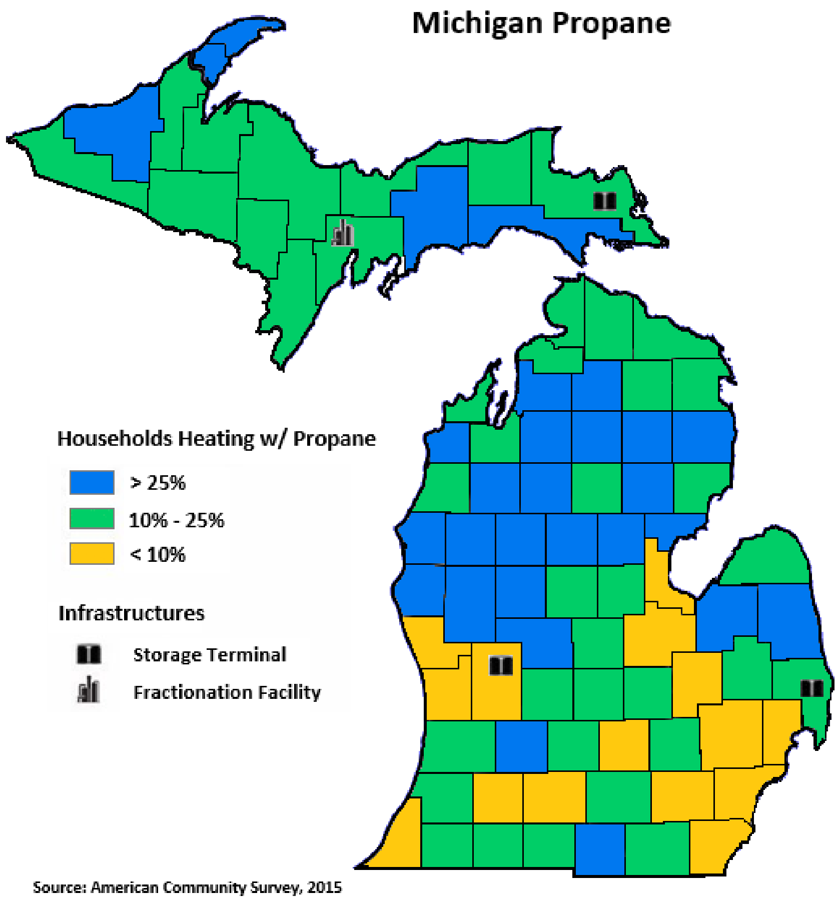


Figure GI3: Location of Propane Heated Households

The loss in consumer surplus due to a rise in propane prices as a result of damage to Line 5 can be measured as the change in price, ΔP, times the baseline quantity of propane demanded, Q:

$$\Delta P \times Q, \tag{17}$$

which is an approximation of the change in surplus that becomes exact for a small change in P. We take the total number of households dependent on propane as a heating source (22,050 in the UP; 296,979 in the LP: MAE 2018), then multiply that by average consumption (1141 gallons) and the estimated change in price.

While there are nearly 300,000 propane users in the Lower Peninsula (LP) of Michigan, the Upper Peninsula (UP) users are likely to face more immediate and serious disruptions to propane supply. Alternatives like rail transportation, truck transportation, and building a new pipeline to the UP all come with higher prices and with their own sets of challenges. Dynamic Risk (2017) estimated that the increase in price would range from 10 cents to 35 cents per gallon for UP customers if Line 5 were taken offline. We use the upper bound as this is likely to be completely borne by UP residents and does not include the cost of unreliable supply. For this reason, we expect the loss in producer surplus to be negligible, as 100% of the increase in price is likely to be borne by consumers in the UP; consumers are likely to be price takers. Therefore, lost consumer surplus for propane consumers in the UP is estimated to be approximately $ 8.8 million. For LP customers, the cost is likely to be approximately $0.13 per gallon (Dynamic Risk 2017), giving a lost consumer surplus of $44 million. Lost producer surplus for the LP producers is hard to estimate as a variety of providers serve the LP. Moreover, specific (and proprietary) company data would be required for further analysis of losses in producer surplus in both UP and LP (MEA 2018).

Crude oil extracted in the LP is sent through the Markwest Michigan Pipeline to an interconnection with Line 5 in Lewiston, MI. The crude is then sent via Line 5 to a terminal in Marysville for processing. Taking Line 5 offline means Michigan crude would need to be transported from Lewiston to Marysville via alternative means—likely truck transport, since Lewiston has no rail service. The need for alternative transportation measures will reduce producer surplus for Michigan oil producers, approximated as:

$$\textit{Lost Producer Surplus for Northern Michigan crude} = \Delta P \times Q. \qquad (18)$$

Dynamic Risk (2017) estimates truck transportation would increase costs to Michigan, crude oil producers by $2.40 per barrel. In 2016, 3,426,902 barrels of crude oil was sent to refineries via the Markwest Michigan Pipeline (MEA 2018). This amounts to approximately $8.2 million per year in lost producer surplus. Producers in Northern LP are likely to be price takers, and therefore, will bear most of the costs (Dynamic Risk 2017).

In regards to the disruption of supply to refineries, Dynamic Risk (2017) estimates that the price per gallon of gasoline and diesel for Michigan consumers would rise by $0.02. Michigan consumers are expected to consume approximately 6 billion gallons of gasoline and diesel in 2018 (MEA 2018). This amounts to a lost consumer surplus of $120 million/year.

Table GI10: Michigan Energy Effects ($ million)

	Propane	**Northern Michigan Crude Oil**	**Gasoline**
Lost Consumer Surplus	52.8	———	120
Lost Producer Surplus	———	8.2	———

While Dynamic Risk (2017) estimates that refineries in Detroit and Toledo would face increased costs of about $0.76/bbl, we are unable to estimate lost producer surplus since figures for supplies to refineries in Detroit and Toledo from Line 5 are not available at this time (MEA 2018).

GI.4.9 Water Supply Effects

Oil spills release a number of contaminants to water, resulting in damage to water quality. This release of contaminants is a particular concern for drinking water quality if oil spills occur in freshwater systems like the Great Lakes. The Great Lakes is the source water for a number of of municipal water facilities, serving a considerable population in the Great Lakes area. As such, it is necessary to include the costs associated with water quality damage from an oil spill in the Great Lakes. These include costs for alternative drinking water supplies and costs for water quality testing and monitoring. This section will evaluate the costs associated with damage to the drinking water supply from a worst-case oil spill.

First, we estimate the cost of a worst-case oil spill to groundwater users. In the event of an oil spill, groundwater may be impacted at near lakeshore sites (within 200 feet of shore) along the Great Lakes (Michigan Department of Community Health 2013). However, the gradient would be strong and would push oil directly back to the lakes. Hence, there is a very low probability that private wells will be impacted. In the event of an oil spill, groundwater wells would be monitored for volatile organic compounds (CXVO), semi-volatile aromatic compounds (CXPA), and metals (beryllium, iron, mercury, molybdenum, nickel, titanium, vanadium), based on the recommendation of MDEQ and the water quality assessment of Kalamazoo River Spill. Wells within 200 feet of oiled shorelines should be tested. The testing schedule is determined based on the water quality assessment of Kalamazoo River Spill (Michigan Department of Community Health 2013). Specifically, during the initial response to the spill (3 months), well water would be tested every other week or until there are two testing events with no detections of oil-related chemicals. Following the period of initial response, monthly sampling would occur for three months, and then the wells would be sampled quarterly over the cleanup period.

According to the MDEQ Testing Fee Schedule (MDEQ State Drinking Water Lab 2016), the overall cost for CXVO, CXPA, and metals testing would be $346/sample. The cleanup time could vary dramatically from 41 days to 51 months (Consent Decree, 2017; Refugio Response

Joint Information Center, 2015). Here, we take the medium cleanup time, 18 months. Assuming the cleanup time is 18 months, there would be thirteen tests performed for each well. With N total wells, the costs for water testing would be

$$A = 346 * N * 13 \tag{19}$$

Figures GI4-GI6 show the number of groundwater wells qualified for testing. The detailed cost is calculated in Table GI11.

Next, we calculate the damage to surface water users. There are a number of municipal water suppliers using lake water in counties affected by the oil spill. In the event of an oil spill, lake water quality in those affected areas is likely to be compromised. The worst scenario would be that water intakes would be shut down and residents would have to use an alternative drinking water supply (e.g., bottled water) as in other water crisis events. Therefore, for the worst-case scenario,

$$\begin{aligned} &costs = population\ served\ by\ lake\ water\ \times \\ &alternative\ water\ supply\ costs\ (\$\ per\ day\ per\ capita) \times \\ &alternative\ water\ supply\ time\ (days) \end{aligned} \tag{20}$$

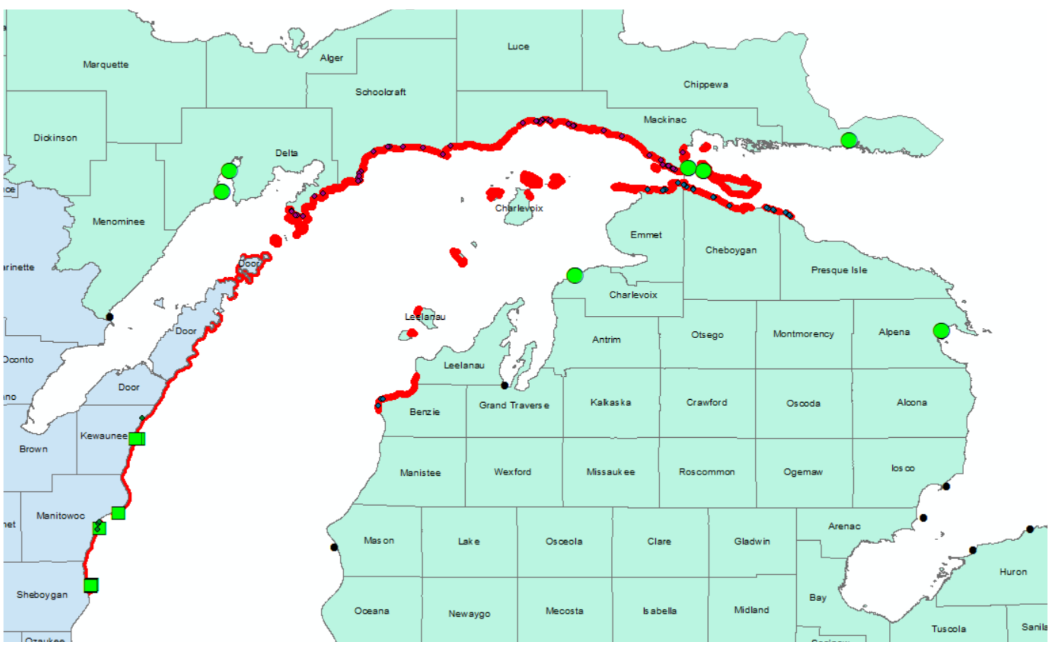


Figure GI4: Groundwater wells within 200 feet of oiled shorelines and affected lake water intakes in Scenario 1; Red lines, oiled shorelines; black dots, groundwater well within 200 feet of oiled shorelines; green marks, lake water intakes; Number of wells in: Northern Lower Peninsula = 30; Upper Peninsula= 63; Wisconsin= 5; Affected lake water intakes: Mackinac Island, and St Ignace, City of Green Bay, Cheboygan, and Manitowoc.

Table GI11: Costs for Groundwater Wells Monitoring

Events of Testing			
Initial Response (3 months), Every Other Week	6		
Following three months (3 months), Every Month	3		
During the rest of the cleanup period (total 18 months), Every Three Month	4		
Total Events	13		
Costs for Testing			
Volatile Organic Compounds by GC/MS (CXVO)	$100		
Aromatic Compounds by GC/MS (CXPA)	$110		
Metals			
Beryllium	$18		
Iron	$28		
Mercury	$18		
Molybdenum	$18		
Nickel	$18		
Titanium	$18		
Vanadium	$18		
Total Costs for One Test	$346		
Number of Wells Tested	Michigan	Wisconsin	Total
Scenario 1	93	5	
Scenario 2	290	0	
Scenario 3	310	0	
Costs for Water Wells Testing	Michigan	Wisconsin	Total
Scenario 1	$418,314	$22,490	$440,804
Scenario 2	$1,304,420	$-	$1,304,420
Scenario 3	$1,394,380	$-	$1,394,380

The data for the population served by lake water in contaminated areas are obtained from each water utility. The alternative water supply cost is estimated based on the cost of bottled water supplied during the Flint water crisis ($2.6/case) and average daily water use for drinking, cooking, and hygiene (28 gallons/day-capita) (Mlive Michigan, 2018; Water Footprint Calculator, 2017). The alternative water supply time varies at different water intakes. Mackinac Island and St. Ignace are very close to the location of oil spill, and water intakes in these two areas would be heavily impacted. Therefore, the alternative water supply time for these two water intakes is assumed to be 60 days, which is the time when most oil is beached or evaporated based on results from Tasks A and B. For Alpena, Charlevoix, and Cheboygan, Team B's simulations find more than 95% of oil particles will have already been beached by the time oil reaches water intake areas. Hence, there is a low probability that the drinking water quality would be comprised for these areas. However, the water supply may be closed, or water advisories may be given for a few days. The shutdown (advisory) time is assumed to be two days based on the practice of water closure during algal blooms (The Blade, 2014). For Manitowoc and the city of Green Bay, we assume that there is no necessity for alternative water supply for two reasons. First, more than 95% of oil particles will have already been beached by the time oil reaches to the water intake areas (similar to water intakes in Alpena, Charlevoix, and Cheboygan). Second, these two water utilities have emergency and standby ground water wells for alternative water supply (Green Bay Wisconsin, 2003; Manitowoc Wisconsin, 2003).

The costs for water quality testing and monitoring would also be included (same as the calculation of costs for groundwater wells). Figures GI4-GI6 show water intakes affected by the oil spill in scenarios 1, 2, and 3, respectively. The detailed damages from the effects of a worst-case spill on lake water users are calculated in Table GI12.

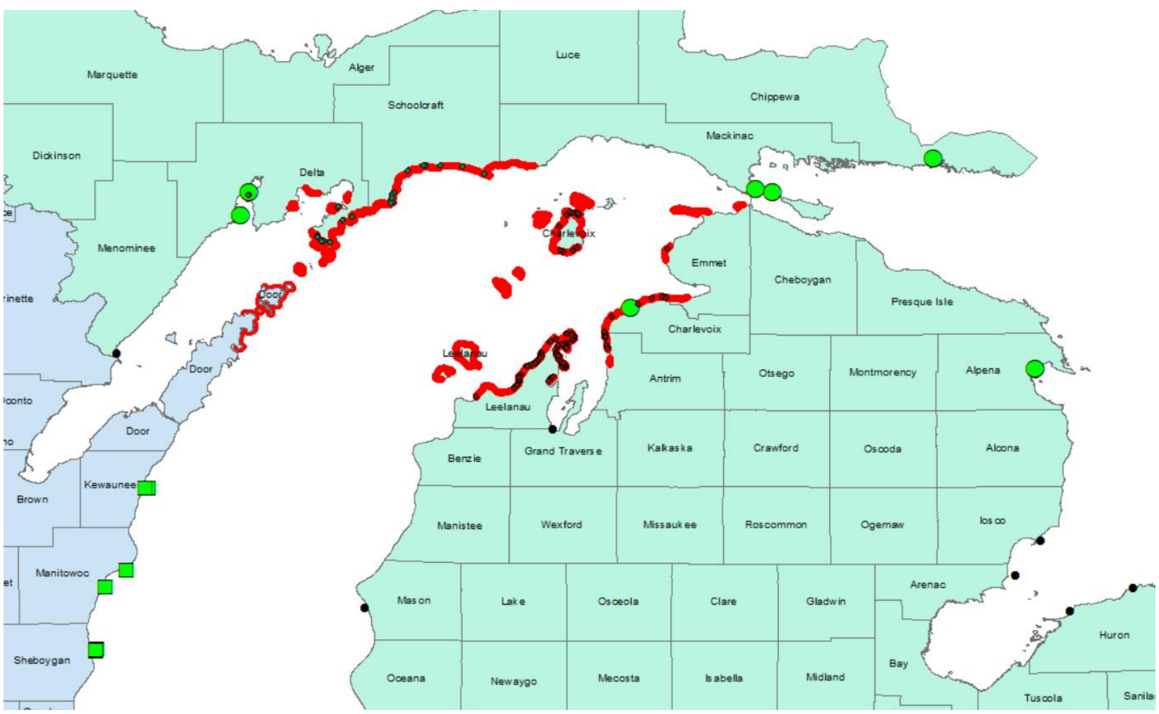


Figure GI5: Groundwater wells within 200 feet of oiled shorelines and affected lake water intakes in Scenario 2 (April); Red lines, oiled shorelines; black dots, groundwater well within 200 feet of oiled shorelines; green marks, lake water intakes; Number of wells in: Northern Lower Peninsula = 260; Upper Peninsula= 30; Wisconsin= 0; Affected lake water intake: Charlevoix.

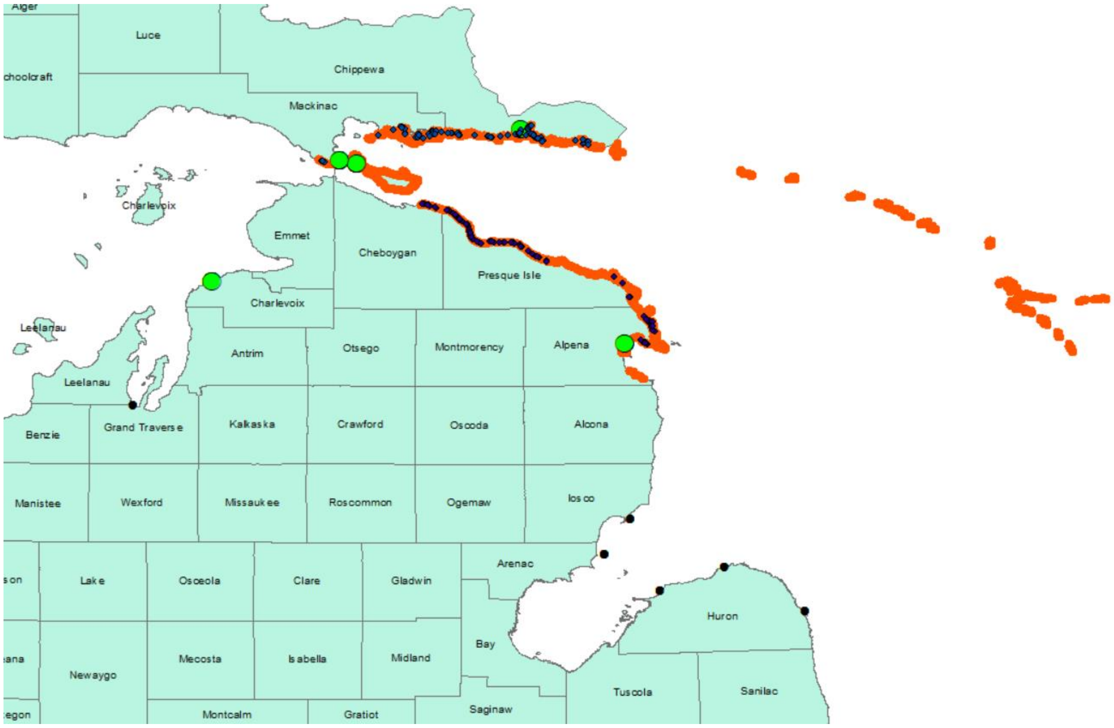


Figure GI6: Groundwater wells within 200 feet of oiled shorelines and affected lake water intakes in Scenario 3 (May); Red lines, oiled shorelines; black dots, groundwater well within 200 feet of oiled shorelines; green marks, lake water intakes; Number of wells in: Northern Lower Peninsula = 122; Upper Peninsula= 188; Wisconsin= 0; Affected lake water intake: Alpena, Mackinac Island, St Ignace.

Table GI12: Costs for Lake Water Intakes

Events of Testing			
Initial Response (3 months), Every Other Week	6		
Following three months (3 months), Every Month	3		
During the rest of the cleanup period (total 18 months), Every Three Months	4		
Total Events	**13**		
Costs for Testing			
Volatile Organic Compounds by GC/MS (CXVO)	$100		
Aromatic Compounds by GC/MS (CXPA)	$110		
Metals			
Beryllium	$18		
Iron	$28		
Mercury	$18		
Molybdenum	$18		
Nickel	$18		

Titanium	$18		
Vanadium	$18		
Total Costs for One Test	**$346**		
Number of Water Supply Tested	**Michigan**	**Wisconsin**	**Total**
Scenario 1	2	7	9
Scenario 2	3	0	3
Scenario 3	4	0	4
Costs for Water Quality Testing/Monitoring	**Michigan**	**Wisconsin**	**Total**
Scenario 1	$8,996	$31,486	$40,482
Scenario 2	$13,494	$0	$13,494
Scenario 3	$17,992	$0	$17,992
Costs for Alternative Water Supply	**Michigan**	**Wisconsin**	**Total**
Daily Cost for Alternative Water Supply (Bottled Water), $/day-customer	$9.55	$9.55	
Scenario 1			
Affected Water Intake	Mackinac Island, St Ignace	City of Green Bay, Cheboygan, Manitowoc, and Manitowoc	
Population Served	3369	243241	246610
Time for alternative water supply, days	60	0 or 2	
Total Costs	**$1,930,437**	**$1,184,200**	**$3,114,637**
Scenario 2			
Affected Water Intake	Charlevoix	None	
Population Served	3124	0	3124
Time for alternative water supply, days	2	0	
Total Costs	**$59,668**	**$0**	**$59,668**
Scenario 3			
Affected Water Intake	Alpena, Mackinac Island, St Ignace	None	
Population Served in Mackinac Island and St Ignace	3369	0	3369
Time for alternative water supply for Mackinac Island and St Ignace, days	60	0	
Population Served in Alpena	15680	0	
Time for alternative water supply for Alpena, days	2	0	
Total Costs	*$2,229,925*	*$0*	*$2,229,925*

Total Cost for Surface Water Intakes	***Michigan***	***Wisconsin***	***Total***
Scenario 1	$1,939,433	$1,215,686	$3,155,119
Scenario 2	$73,162	$0	$73,162
Scenario 3	$2,247,917	$0	$2,247,917

Table GI13: Total cost for water supply

Total Cost for Water Supply (Groundwater Wells and Surface Water Intakes)	**Michigan**	**Wisconsin**	**Total**
Scenario 1	$2,357,747	$1,238,176	$3,595,923
Scenario 2	$1,377,582	$0	$1,377,582
Scenario 3	$3,642,297	$0	$3,642,297

GI.4.10 Lost Amenity Value to Residential Property

A worst-case oil spill from the Enbridge Line 5 pipeline in the Straits of Mackinac may beach oil across several counties in Michigan and Wisconsin. A major consequence of oil beaching is lost amenity values to homeowners with lakefront property. This section describes how we calculate this lost value.

We can express the price of a house as a function of the property's characteristics (e.g., square footage, lot size, number of bedrooms, etc.), which may include environmental amenities like beach access and scenic vistas. Let P_i^0 be the value of house *i* given some baseline level of environmental amenities. Suppose next that some event degrades the environmental amenities at home *i*. The sale price of the home after the event is then P_i^1. Rosen (1974) shows that the welfare loss to property *i*'s owners from the oil spill is $P_i^1 - P_i^0$, or the difference in the sale price of the property before and after the event.[6]

In our context, the event that degrades environmental quality would be a worst-case oil spill from the Line 5 pipeline. Reductions in the value of lakefront property may arise due to reduced beach access, reduced quality of scenic vistas, and odors associated with the oil. This degradation in environmental quality would be temporary such that environmental quality is restored to its original level upon remediation; prior work analyzing the *DWH* spill, for

[6] The result that the welfare lost from a change in environmental amenity values equals the sale price differential depends on several assumptions. In particular, the event must be "localized" in that it does not affect the entire housing market in question. This assumption likely holds in the case of a worst-case spill, since the value of houses in the same region as those affected by oiling—but that do not have beach access or the same scenic vistas—are not likely to be affected by a spill. Furthermore, moving costs must be zero. We can adjust our welfare measure for non-zero moving costs by subtracting these costs from the price differential $P_i^1 - P_i^0$. Doing so requires an estimate of moving costs. In the absence of this information, the welfare measures we derive here will be a conservative estimate of welfare loss from a change in environmental quality.

example, finds that coastal home values recovered approximately six weeks after the spill (Winkler and Gordon 2013).

The price of a home can be expressed as the present value of an annuity, or a stream of benefits earned over a fixed period of time. We assume the life of a home is 50 years or 600 months, and hence the value of a home can be written

$$P_i = \sum_{t=0}^{600} \frac{B_i}{(1+r)^t} = B_i \frac{(1+r)^{600}-1}{r(1+r)^{600}} = B_i A_{r,600} \quad (21)$$

where r is the monthly capitalization rate (essentially, a discount rate), B_i is the monthly benefits derived from home i, and $A_{r,N}$ is an annuity factor for an investment lasting N periods at rate r. Note from (1) that we can calculate the monthly benefits from home i as $B_i = P_i/A_{r,600}$. Hence, we can write the change in monthly benefits associated with a change in environmental amenities from an oil spill as

$$B_i^1 - B_i^0 = [P_i^1 - P_i^0]/A_{r,600} = \Delta P_i/A_{r,600}, \quad (22)$$

where $\Delta P_i = P_i^1 - P_i^0$. Assuming remediation takes 1.5 months, the present value of a change in total welfare across all homes is

$$\sum_i \frac{\Delta P_i}{A_{r,600}} \cdot A_{r,1.5}. \quad (23)$$

Note that the welfare measure in (3) may underestimate the true measure. Prior work in the economics literature (e.g., McCluskey and Rausser 2003) finds that property values may not fully return to their pre-spill values after remediation due to "stigma" effects—i.e., individuals place a lower value on property upon realizing the possibility of environmental damage. The welfare measure in (3) also abstracts from features of real estate markets that may affect the final sales price of a home (e.g., moving costs or decisions about whether or not to list a home for sale during an event [Guignet 2014]). These features could mean that the true value of welfare loss from an oil spill is larger or smaller than (3).

Researchers in Task B simulated several possible "worst-case" oil spill scenarios. We use GIS to identify the spatial extent of each spill. We use the spills with the longest simulated shoreline oiled for our analysis since these scenarios are associated with the greatest overall level of damages across all environmental and resource outcomes. The specific scenarios analyzed are shown in Table GI14.

Table GI14. Total Welfare Losses to Lakefront Homeowners under Different Worst-Case Scenarios

			Lost amenity value to coastal property		
Scenario[a]	State	Annual interest rate =	2.5%	5%	7%
1	Michigan		$315,445	$483,440	$632,697
	Wisconsin		$999,343	$1,531,560	$2,004,411
	Total		*$1,314,788*	*$2,015,000*	*$2,637,107*
2	Michigan		$971,846	$1,489,419	$1,949,260
	Wisconsin		$277,099	$424,673	$555,786
	Total		*$1,248,946*	*$1,914,093*	*$2,505,046*
3	Michigan		$1,260,823	$1,932,295	$2,528,869
	Wisconsin		———	———	———
	Total		*$1,260,823*	*$1,932,295*	*$2,528,869*

[a] 1 = center_mm03_hr1440_highest01_2016_03_01T18_0704km
2 = south_mm04_hr1440_highest01_2016_04_24T18_0542km
3 = center_mm05_hr1440_highest01_2016_05_12T12_0412km

The State of Wisconsin provided statewide parcel-level tax assessment data, which includes homes' estimated fair-market value. Unfortunately, parcel-level housing value data is not readily available for many counties in Michigan, especially for the counties that would be affected by a worst-case spill. We, therefore, collected US Census data describing (i) the number of housing units in each census block that are within one mile of shoreline contaminated by a spill in each scenario and (ii) the average value of housing units in each census block group. We treat census blocks as the unit of analysis.

Simons et al. (2001) examine the effect of an oil spill on waterfront residential properties' sale prices in Maryland. The authors find the oil spill reduced the value of homes sold during the spill by 11 percent. We, therefore, calculate the quantity ΔP_i in (3) as $\Delta P_i = 0.11P_i^0$.

We calculate the welfare measure in (3) using a range of different values for *r* to provide bounds on the welfare loss to lakefront property owners from a worst-case spill. The choice of capitalization rate *r* is arbitrary; annual rates used in real estate valuation typically range from 7–10 percent, although other values can be used. Table GI14 summarizes these losses. Aggregate lost value from the simulated spills totals $1.2 million–$2.6 million, depending on *r* and the scenario.

GI.4.11. Estimates of State-wide Losses to Tourism Activities

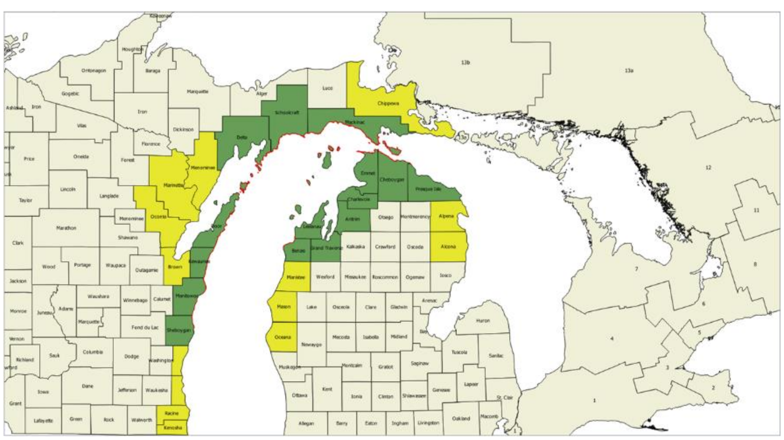
This section posits a macro-level assessment of a worst-case outcome on state tourism. This top-down assessment encapsulates many, but not all, of the effects detailed here. The approach applied here is detailed in the appendix of this report, but reported in summary here.

GI.4.11.1 Approach

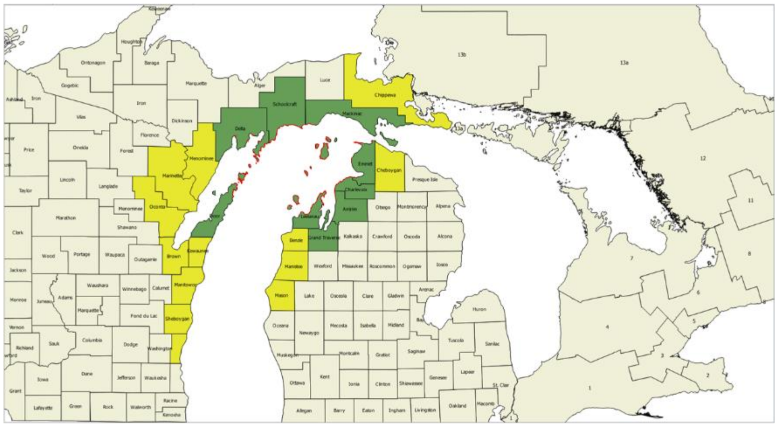
Impacted communities across the U.S. states Michigan and Wisconsin and the Canadian Province of Ontario are expected to see a decrease in tourism activity from both in-state and out-of-state visitors. Three simulations were undertaken, representing the worst-case scenarios based on the miles of shoreline receiving oil deposits. Expected losses in tourism activities in the impacted region are modeled for both total tourism activities and for out-of-state visitors, where the latter represents the loss in dollars flowing into the state.

Estimates are based on state tourism statistics, down to the county level in detail for Michigan and Wisconsin. The collected statistics include annual estimates of counts of visitors and total expenditures. These state-level statistics are based on out-of-state visitation, and therefore are consistent with our basis for estimating the economic impacts. Michigan tourism counts and expenditures were derived from Longwoods International's report "Michigan 2016 Visitor Research" (Longwoods International 2016). County-level estimates for Michigan were provided by the 2014 Tourism Economics estimates (Tourism Economics 2014). The Wisconsin tourism statistics are collected from the Wisconsin Department of Tourism 2017 Wisconsin Economic Impact Research (Wisconsin Department of Tourism 2017 and are reported at the county level.

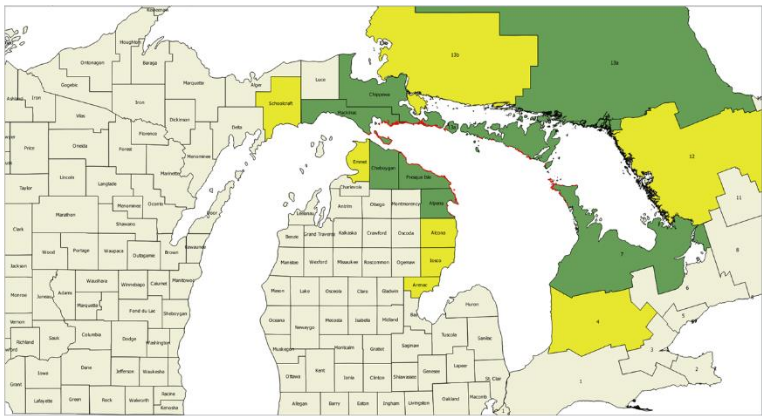
For the three simulations, counties were assigned as a core-impacted region, a periphery region or as not being not impacted, based on the modeled distribution of beach surface deposits from a Line 5 release (Figure GI7). Core (Green) areas are expected to have actual damage to recreational uses. These areas are likely to have regulatory restrictions on beach and other usage around the impacted beaches. Periphery counties (Yellow) are denoted by proximity to core areas. The Red dots along the Lake Michigan and Lake Huron shoreline represent modeled oil deposits along the beach.



Scenario 1



Scenario 2



Scenario 3

Figure GI7: Impacted Regions; Green shade denotes core-impacted regions; Yellow shade denotes periphery-impacted regions; Red denotes oil deposits

Core areas are expected to have impacts up to 18 months following a worst-case release, while periphery areas are expected to have a lesser degree of impact during the year of the release. Modeled tourism responses reflect observation of core and periphery area shoreline recreation impacts following the DWH spill, showing a 45 and 22 percent decline in tourism in the core and periphery areas, respectively, in the year of the release (Tourangeau et al. 2017). The core area will also experience a 10 percent reduction in the following year for the total duration of 18 months. To account for the months of impacts, annual tourism activities are broken out by month, based on the share of annual Mackinac Bridge crossings by month.

All simulations assume an April 1 release date and assume the impact duration is 18 months. Hence, the first year impacts span April through December or about 86 percent of the annual tourism visits to the area. Impacts continue for 18 months post-spill, or through September and affect 79 percent of the baseline tourism activities in the second year. Annual tourism counts and estimated expenditures are provided by the Michigan Economic Development Corporation and the Wisconsin Department of Tourism. The Michigan estimates are accompanied by estimated breakouts of expenditures by type of purchases (lodging, food establishments, retail, etc.) as shown in Table GI14. This profile is also used for Wisconsin.

The estimate of state tourism expenditure impacts are then calculated as:

$$T_{exp} = \left(\sum_{n=1}^{N} exp_n \cdot T_n\right) \cdot \left(\sum_{k=1}^{K} ss_k\right), \tag{24}$$

where T_{exp} is total state tourism spending impacted, exp_n is annual out-of-state tourism expenditures for county n, T_n is the county assignment as a core, or peripheral, ss_k is monthly share (capture) of annual state tourism and is summed over succeeding months up to 18 months post release.

Table GI14: Tourism Visitor Expenditure Profiles

	Michigan and Wisconsin	Ontario
Lodging	37%	17%
Restaurant Food & Beverage	25%	34%
Retail Purchases	14%	12%
Recreation/Sightseeing/Entertainment	12%	5%
Transportation at Destination	11%	33%

Expenditures by category are then transformed to contributions to the annual gross domestic product by state using ratios provided by the Bureau of Economic Analysis. Gross domestic product by state measures the total income generated in a region, including labor income, payments to proprietors' and business owners. It also includes "taxes on production and imports less subsidies." These public payments need to be netted out to gauge the impact on incomes. National statistics indicate that taxes on production and imports less subsidies make up about 6.6 percent of gross domestic product. We apply this to derive final estimates on expected income losses.

Estimated losses in income from lost tourism are presented in Table GI16 for the three scenarios and represents a combined loss of income in both Michigan and Wisconsin (greater breakout is available in the Appendix). Estimates are made that only account for the loss of out-of-state visitors (first column) and for combined in- and out-of-state visitors, where the latter is more aligned to the expected claims of income lost due to a worst-case release.

GI15: Estimated Lost Incomes (labor and proprietors')

Michigan & Wisconsin	Out of State Only GDP by State	Out of State Only GDP-Indirect B-tax	All Tourism GDP by State	All Tourism GDP-Indirect B-tax
Scenario 1	$239,960,470	$224,123,079	$727,756,712	$679,724,769
Scenario 2	$159,927,471	$149,372,258	$457,364,076	$427,178,047
Scenario 3	$39,454,634	$36,850,628	$112,833,224	$105,386,231

The range of expected impacts varies significantly depending on the extent of beach deposits experienced. This extent depends on the climatic conditions at the time of the release. Lost income would be greatest if the oil released migrates west, as these counties are exposed to more tourism activities than their eastern counterparts are.

GI.5 Conclusions

We developed spill scenarios to evaluate the economic damages associated with a worst-case Line 5 spill. We combined the simulated spills from tasks A and B with the economic effects observed from other spills to create our spill scenarios for economic damages because there has not been a large-scale spill in the Great Lakes. In our worst-case scenarios, the spill is assumed to occur in early April and affect the tourism season of June through August and beyond. Three spills with particularly extensive shoreline oiling were examined because they differ in the areas oiled depending on weather and lake water currents. For key recreation activities, we developed spill impact scenarios by transferring estimated percentage reductions by recreation activities and by time periods and zones using losses measured in the DWH spill. Our loss scenarios featured a core impact area (where oil washes ashore) and periphery areas (adjacent to the core) with lower losses, again consistent with the measured effects in DWH, and we scaled the spatial extent according to spill areas from the worst case simulations. Consistent with evidence from other spills, our approach assumes that recreation for most activities recovers within one year (two for beach uses) and that there are no long-term residual injuries to recreational uses of the affected natural resources beyond these periods. These time periods account for cleanup time in affected areas akin to the time in the DWH spill as well as the time it takes for public perceptions of impacts to recover. In the spirit of a worst-case spill, we assume that all oil washes ashore or dissipates and that there is no reduction in spill extent or timing due to the recovery of oil on the water. Similarly, for impacts to navigation, we use the spill simulations to determine the length of time shipping would be blocked and thus incur a cost for waiting. For drinking water supplies, the spill scenarios also impact municipal water intakes that would be closed and groundwater wells that might require testing. Property values are affected in areas where oil washes ashore and recover over time. For tourism and recreation-related businesses and their employees, we estimate lost incomes associated with tourism losses with impact percentages akin to those for beach uses as our worst case.

Among these three spill simulations, we focused on, the spill where oil spreads westward along the northern Lower Peninsula shore of Lake Michigan and reaches Wisconsin caused the largest measured damages. That spill caused $1.37 billion in total estimated damages.

Table GI18 Summary of damages from simulated worst-case spills ($ millions)

Activity	**Includes Wisconsin**	**Scenario 1 damages**	**Scenario 2 damages**	**Scenario 3 damages**
Recreational fishing	Yes	6.2	2.0	0.4
Recreational boating - motorized	Yes	25.9	13.0	3.1
Recreational boating - nonmotorized	Yes	6.6	3.2	0.6
Park day visits	No	20.3	18.7	7.3
Park camping days	No	2.2	1.8	1.0
Recreational beach use	Yes	398.6	356.4	102.7
Recreational damages (subtotal)		459.8	395.1	115.1
Lost amenity value to coastal property	Yes	1.3	1.2	1.3
Commercial fishing	No	1.6	1.3	0.5
Commercial shipping	No	43	43	43
Michigan Energy Supply Effects	No	181	181	181
Water supply effects	Yes	3.6	1.4	3.6
Other damages (subtotal)		230.5	227.9	229.4
Lost incomes for tourism and recreation-related businesses	Yes	679.7	427.2	105.4
Total economic damages		***1,370.0***	***1050.2***	***449.9***

Our analysis is subject to several caveats and limitations, including the following:

- Our estimated spill impact scenarios use the spill simulations without recovery of oil while it is on the water so that any recovery would reduce impacts. Similarly, any protection activities such as booms that would protect water intakes or key beaches would also likely reduce impacts.

- Our estimates do not include dollar values—such as use and non-use values—lost due to injuries to habitat and wildlife that are not manifested through recreational uses. Valuing non-recreational damages to habitat and wildlife resources is challenging even with adequate time and resources. Moreover, we lack adequate comparable studies to transfer economic values for injuries to habitat and wildlife likely to be affected in the Great Lakes. However, the cost of restoring these resources was assessed as a part of report section F. If the restoration of habitat and wildlife services from section F does not compensate for the lost services during the injury period, the standard approach in NRDA would be to assess these losses via habitat-scaling approaches such as habitat equivalency analysis, which is beyond the scope of our assessment and outside the expertise of economists.
- Potential human health impacts were not assigned monetary values, although as mentioned in section D, there are potential human health impacts.
- Regarding recreational hunting, we do not expect a worst-case spill to have a major economic effect on habitat for sport-hunting species. Waterfowl hunting does take place along the Great Lakes coastline during the fall. However, Frawley (2017) estimates that in 2014 there were only about 18,500 duck hunters in all of northern Michigan (UP and NLP) and even fewer goose hunters. Moreover, Austin et al. (2007) estimate that only 5 percent of waterfowl hunting trips are on the Great Lakes, and there are many substitute sites available in the event of a worst-case spill. Hence, losses to recreational hunting from a worst-case spill are likely to be relatively low compared the other recreation activities we assessed.
- Potential impacts on other water uses, such as agricultural and industrial water use, were not assigned monetary values. Agricultural irrigation often uses groundwater, which has a very low probability of contamination. Furthermore, for industrial water use, without knowing exact chemicals, their concentrations in the water, and specific requirement of water quality for particular industries, it is not feasible to estimate the impact to industrial water use.
- We lack data to estimate losses for many categories for Canada, even though spill simulations suggest impacts there. For example, our estimates include approximate lost beach visits to Michigan and Wisconsin beaches and lost tourism-related incomes in Michigan and Wisconsin, but not for Ontario due to a lack of data.
- Several factors affect propane prices: spot prices, inventories, and weather. Propane prices in Michigan tend to be correlated with the overall benchmark prices (for example, Mont Belvieu, TX and Conway, KS) for propane in the United States. Inventories, especially at the regional level, play a very important role in propane markets. However, inventory data is only available for the Midwest region. In addition, if the Great Lakes have a high probability of below-normal temperatures, then heating season stretches further, resulting in above average heating fuel demand in an area with high propane market share (such as the UP). These factors are not included in our estimates for propane prices due to lack of data availability at retail and/or county level. Any new construction of infrastructure to serve the Rapid River facility has not been included either.
- In case of damage to Line 5, alternative infrastructure will need to be built (for example, for loading and offloading) to transport Northern Michigan crude oil and new construction to

serve the Detroit and Toledo refineries, including new terminals and new storage facilities, the cost for which hasn’t been included in this report.

G.I.6 References

Alward, Greg, Doug Olson, and Scott Lindall. 1998. "Using a double-constrained gravity model to derive regional purchase coefficients." Regional Science Association International Meeting, Sante Fe, New Mexico.

Austin, J.C., S. Anderson, P.N. Courant, and R.E. Litan. 2007. "America's North Coast: A Benefit-Cost Analysis of a Program to Protect and Restore the Great Lakes." Washington, D.C.: Brookings Institution.

Bishop et al. 2017. Putting a value on injuries to natural assets: The BP oil spill. Science 356(6335):253-254

The Blade. Toledo's Water Crisis. Accessed 07/12/2018. Available at http://www.toledoblade.com/watercrisis.

Cabrera, VE, R Hagevoort, D Solís, R Kirksey, and JA Diemer. 2008. "Economic Impact of Milk Production in the State of New Mexico1." Journal of dairy science 91 (5):2144-2150.

Carroll, Michael, Brad Gentner, Sherry Larkin, Kate Quikley, Nicole Perlot, Lisa Dehner and Andrea Kroetz. 2016 An analysis of the impacts of the Deepwater Horizon oil spill on the Gulf of Mexico seafood industry. US Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region.

Carson, R., R. Mitchell, M. Hanemann, R. Kopp, S. Presser and P. Ruud. 2003. Contingent Valuation and Lost Passive Use: Damages from the Exxon Valdez Oil Spill. Environmental and Resource Economics 25: 257–286.

Chapman, D. J., & Hanemann, W. M. (2001). Environmental damages in court: The American Trader case. In A. Heyes (Ed.). The law and economics of the environment (pp. 319-367). Cheltenham, UK: Edward Elgar.

Cheng, L. 2016. "Measuring the Value and Economic Impacts of Changes in Water Quality at Great Lakes Beaches in Michigan." Ph.D. Dissertation, Michigan State University, East Lansing.

Coughlin, Cletus C, and Thomas B Mandelbaum. 1991. "A consumer's guide to regional economic multipliers." Federal Reserve Bank of St. Louis Review 73 (January/February 1991).

Dynamic Risk. 2017. "Alternatives Analysis for the Straits Pipeline", Dynamic Risk Assessment Systems, Inc., Prepared for the State of Michigan.

Enbridge. 2018. "Enbridge Line 5 Operational Reliability Plan", accessed June 28, 2018, https://www.enbridge.com/Projects-and-Infrastructure/Public-Awareness/Line-5-Michigan/Safeguarding-the-Great-Lakes/Operations-and-maintenance.aspx

Enbridge. 2018. "Enbridge in Michigan: Line 5 and Other Pipelines – Fueling Michigan's Economic Engine."

English, E., R. von Haefen, J. Herriges, C. Leggett, F. Lupi, K. McConnell, M. Welsh, A. Domanski and N. Meade, In Press. Estimating the value of lost recreation days from the Deepwater Horizon oil spill, Journal of Environmental Economics and Management.

Frawley, B. 2017. 2014 Waterfowl Harvest Survey, Michigan Department of Natural Resources, Wildlife Division Report No. 3647, October 2017.

Frick, Harold. 1965. Economic aspects of the Great Lakes fish of Ontario. Fisheries Research Board of Canada. Bulletin No. 149.

Green Bay, Wisconsin. 2003. Source Water Assessment for Green Bay Water Utility.

Green Leigh, N, and E Blakely. 2013. Planning local economic development: theory and practice. Thousand Oaks: Sage Publications Inc.

Grigalunas, Thomas A., Robert C. Anderson, Gardner M. Brown Jr, Richard Congar, Norman F. Meade, and Philip E. Sorensen. 1986. Estimating the cost of oil spills: Lessons from the Amoco Cadiz incident. Marine Resource Economics 2(3), 1986: 239-262.

Groundwork Center for Resilient Communities. 2018. "Canadian Profits, Michigan Risk Line 5 threatens Michigan's economy and environment, brings little in return."

Guignet, D. 2014. "To Sell or Not To Sell: The Impacts of Pollution on Home Transactions." National Center for Environmental Economics Working Paper #14-01.

Jensen, Rodney C. 1990. "Construction and use of regional input-output models: progress and prospects." International Regional Science Review 13 (1-2):9-25.

Klatt, Jessica K. Linked participation-site choice models of recreational fishing. Michigan State University, M.S. thesis, 2014.

Longwoods International. 2016. Michigan 2016 Visitor Research. Lansing, MI: Michigan Economic Development Corporation. Available online at <https://medc.app.box.com/s/gr02ei0mj39r243k2ni6gy9btyrau28z>.

LP Environment US. 2014. "Questions and Requests for Information to Enbridge regarding the Straits Pipelines"

Mackinac Bridge Authority. 2018. "Monthly Traffic Statistics." Michigan Department of Transportation, accessed June 20, 2018. http://www.mackinacbridge.org/fares-traffic/monthly-traffic-statistics/.

Manitowoc Wisconsin. 2003. Source Water Assessment for Manitowoc Public Utilities.

Martin Associates. 2011. The Economic Impact of the Great Lakes-St Lawrence Seaway System. Lancaster, PA: Martin Associates.

McCluskey, J.J. and G.C. Rausser. 2003. "Stigmatized Asset Value: Is it Temporary or Long-Term?" Review of Economics and Statistics 85(2):276–285.

MDEQ State Drinking Water Lab 2016, Testing Fee Schedule. Available from: http://www.michigan.gov/deqlab.

Michigan Agency for Energy. 2018. “Line 5 Market Impacts/Alternatives”.Energy Security Section

Michigan Department of Community Health. 2013. Public Health Assessment - Kalamazoo River/Enbridge Spill: Evaluation of Crude Oil Release to Talmadge Creek and Kalamazoo River on Residential Drinking Water Wells in Nearby Communities.

Michigan Department of Environmental Quality (MDEQ). 2010. “Michigan Beaches.” Available: http://www.deq.state.mi.us/beach/Default.aspx [accessed June 13, 2018].

Melstrom, Richard T., and Frank Lupi. 2013. Valuing recreational fishing in the Great Lakes. North American Journal of Fisheries Management, 33(6), 1184-1193.

Michigan Department of Natural Resources. 2015 Annual Report on Implementation of the 2000 Consent Decree for 1836 Treaty-Ceded Waters of the Great Lakes. May 2016. Web. Accessed 5.10.2018. Available at <https://www.michigan.gov/documents/dnr/ 2015CD-ImplementationReport_525202_7.pdf>.

Michigan Petroleum Pipelines. 2017. “Risk Analysis Final RFP”.

Miernyk, William H. 1976. "Comments on recent developments in regional input-output analysis." International Regional Science Review 1 (2):47-55.

Mlive Michigan, State spending on bottled water in Flint averaging $22,000 a day. Web. Accessed 07/12/2018. Available at: https://www.mlive.com/news/flint/index.ssf/2018/03/states_average_monthly_bottled.html

National Marine Fisheries Service. Commercial Fisheries Statistics – Great Lakes Commercial Fishery Landings. Web. Accessed 5.10.2018. Available at < https://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/other-specialized-programs/great-lakes-landings/index>.

NOAA. 1978. The Amoco Cadiz oil spill: A preliminary scientific report. A National Oceanic and Atmospheric Administration and Environmental Protection Agency special report, Washington DC, USA

OMB Circular A-4, Regulatory Analysis (09/17/2003)

https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/circulars/A4/a-4.pdf

Ontario Ministry of Tourism, Culture and Sport. 2018. "Regional Tourism Profiles." Queen's Printer for Ontario, accessed June 20, 2018. http://www.mtc.gov.on.ca/en/research/rtp/rtp.shtml.

Richardson, Harry W. 1972. "Input-output and regional economics.", John Wiley and Sons Inc.

Richardson, R. and N. Brugnone. 2018. Oil Spill Economics: Estimates of the Economic Damages of an Oil Spill in the Straits of Mackinac in Michigan, Report to For the Love of Water.

Rosen, S. 1974. “Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition.” Journal of Political Economy 82(1):34–55.

Rosenberger, R.S. and J.B. Loomis. 2003. “Benefit Transfer.” In Champ, P.A., K.J. Boyle, and T.C. Brown (Eds.) *A Primer on Nonmarket Valuation*. Kluwer: Dordrecht, pp. 445–482.

Rosenberger, Randall S., Eric M. White, Jeffrey D. Kline and Clair Cvitanovich. 2017. Recreation economic values for estimating outdoor recreation economic benefits from the National Forest system. General Technical Report PNW-GTR-957.

Simons, R.A., K. Winson-Geideman, and B.A. Mikelbank. 2001. “The Effects of an Oil Pipeline Rupture on Single-Family House Prices.” The Appraisal Journal, October: 410–418.

Stevens, Benjamin H, George I Treyz, David J Ehrlich, and James R Bower. 1983. "A new technique for the construction of non-survey regional input-output models." International Regional Science Review 8 (3):271-286.

Tourangeau, R., E. English, K.E. McConnell, D. Chapman, I. Flores Cervantes, E. Horsch, N. Meade, A. Domanski, and M. Welsh. 2017. "The Gulf Recreation Study: Assessing Lost Recreational Trips from the 2010 Gulf Oil Spill." Journal of Survey Statistics and Methodology 5:281-309

Tourism Economics. 2014. The Economic Impact of Travel in Michigan: Tourism Satellite Account, Calendar Year 2014. Lansing, MI: Michigan Economic Development Corporation.

U.S. Coast Guard. 2012 National Recreational Boating Survey. Web. Accessed 4.26.2018. Available at <http://www.uscgboating.org/library/recreational-boating-servey/ 2012survey%20report.pdf>. U.S. Army Corps of Engineers. Great Lakes Recreational Boating – Main Report. Report prepared by Detroit District of the Army Corps of Engineers. December 2008. Web. Accessed 4.26.2018. Available at <http://www.lre.usace.army.mil/Portals/69/docs/PPPM/PlanningandStudies/ JohnGlenn/boating.pdf>.

U.S. Coast Guard. 2016 Recreational Boating Statistics. Commandant publication P16754.30. May 2017. Web. Accessed 4.26.2018. Available at <https:// www.uscgboating.org/library/accident-statistics/Recreational-Boating-Statistics-2016.pdf>.

US Census Bureau, 2018, “American Community Survey”

VanHulle, Lindsay. 2018. "Does state make $8.33 for every $1 spent on Pure Michigan campaign?". The Center for Michigan, accessed June 20, 2018. https://www.bridgemi.com/special-report/does-state-make-833-every-1-spent-pure-michigan-campaign.

Winkler, D.T. and B.L. Gordon. 2013. “The Effect of the BP Oil Spill on Volume and Selling Prices of Oceanfront Condominiums.” Land Economics 89(4):614–631.

Wisconsin Department of Tourism. 2017. "Economic Impact." accessed April 25, 2018. http://industry.travelwisconsin.com/research/economic-impact.

Water Footprint Calculator, Indoor Water Use at Home. Accessed 07/12/2018. Available at https://www.watercalculator.org/water-use/indoor-water-use-at-home/.

Task H: Estimating the governmental costs that would be incurred as a result of a worst-case release

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H.1 Introduction

This report estimates all government-related costs associated with a worst-case scenario for an oil spill from Line 5 located in the Straits of Mackinac. It would be more fitting to title this report "the costs of government implementation." To account for the ubiquitous presence of government agencies responsible for managing both the immediate and long-term consequences of such a disaster, a top-down "policy instrument" approach is applied. Government costs represent the outcome of implementation efforts. It is therefore instructive to begin by considering what types of tools (outputs) government agencies will implement. By capturing the breadth of government activities, a comprehensive estimate of related costs can be assessed, but also a breakdown of the major types of policies will be provided. In the case of an oil spill of this nature, federal, state, provincial, municipal, First Nation, and Tribal governments and their respective agencies will coordinate their responses to an oil spill, each employing different policy mixes. In some cases, individual agencies may employ multiple policy tools. It is our task to identify these policy instruments and then estimate the costs of implementation.

H.1.1 Policy Instrument Focus

Implementation is the transformation, undertaken by government agencies, of a policy output to a policy outcome that will bring about a policy impact (such as responding to an oil spill) (Knill and Tosun, 2012). A starting point is to first consider different types of underlying policy tools that guide government documents. There are many taxonomies, but generally, policy instruments are informational, regulatory, and economic in nature. Howlett (2011) also distinguishes between substantive and procedural implementation instruments. Substantive instruments directly affect the production, distribution, and consumption of goods and services, whereas procedural instruments are more indirect and instead affect the behavior of actors involved in the implementation process. It is the latter that is often overlooked.

Substantive nodal (informational) instruments could include, for example, a media and advertising campaign providing residents with information about the environmental and health consequences of an oil spill. A focus group of affected residents would be a procedural instrument.

Instruments are used by governments to direct or steer targets through direct enforcement. These include all legal instruments such as statues, delegated legislation between governments, and treaties. They can include independent regulatory commissions and advisory councils. While the costs of these instruments are sunk (i.e., they would occur with or without a spill), they can and do trigger other policy instruments, most notably economic-related instruments.

Treasure (or financial-based) instruments are used to encourage societal actors to undertake some type of activity desired by governments through the provision of financial incentives or to discourage activities through financial penalties. One of the most significant costs involved in a worst-case scenario would be the cleanup effort immediately after the spill. The state would hold Enbridge responsible for contracting out cleanup activities to private companies, and may also mobilize contractors directly, as was done for the Enbridge Line 6b spill in Marshall, MI. This action of contracting out oil cleanup in recent disasters is in contrast to the cleanup of the 1989 Exxon spill, which was directly undertaken by the United States Coast Guard (USCG) and would be considered an **organizational** (or direct provisions) tool. In this case study, a health department providing bottled water would be an example of an organizational tool.

H.1.2 The Line 5 Oil Spill "Policy Network"

When issues arise, affected organizations will respond according to their capacities and legally mandated roles, which is reflected in the policy instruments that are employed (e.g. Oil Spill Liability Trust Fund (OSLTF), Comprehensive Environmental Response, Compensation, and Liability Act, and the Robert T. Stafford Disaster Relief and Emergency Assistance Act).

Central is the Governmental Response Plan. Specifically for this case study, the Northern Michigan Area Contingency Plan summarizes the strategy for a coordinated federal, state and local response to a discharge or substantial threat of discharge of oil that may take place in the Northern Michigan region (Figure H1). While the costs associated with these activities are likely to be reimbursed by Enbridge, there may derivative costs associated with them that will be incurred by governmental agencies.

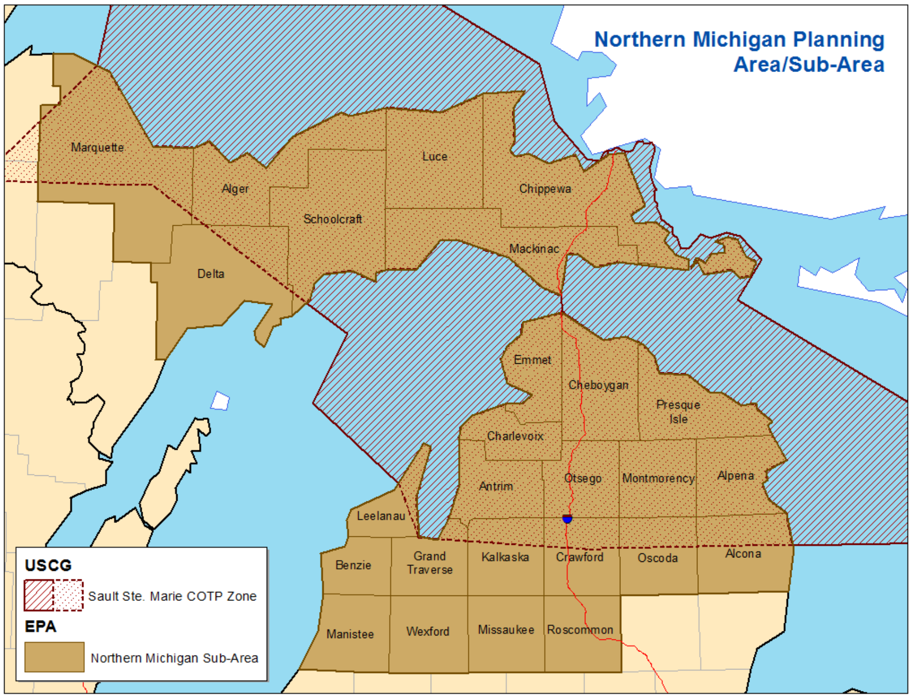

Figure H1: Geographic boundaries for federal contingency plans –USCG Sault Sainte Marie COTP Zone and EPA Region 5 Northern Michigan Subarea. Reproduced from USCG 2015.

The cleanup responsibilities of the specific agencies are as follows:

- The United States Coast Guard (USCG) is responsible for the coastal zone, defined to mean the United States waters of the Great Lakes; specified ports and harbors on inland rivers; and the waters of the Exclusive Economic Zone. A captain of the Port, Sault Ste. Marie, MI is the pre-designated responder for oil and hazardous materials incidents in the Straits of Mackinac coastal zone and will integrate within the command structure of the local officials, providing federal resources and funding mechanism to support the removal activities.

- The U.S. Environmental Protection Agency is responsible for the inland zone, defined to mean the environment inland of the coastal zone excluding the Great Lakes and specified ports and harbors on inland rivers. U.S. EPA Region 5 is the pre-designated responder for oil and hazardous materials incidents in the Northern Michigan Sub-Area. They are available to respond to chemical and oil incidents and can provide additional contractor services for cleanup.

A National Response System (NRS) is in place to coordinate all government agencies with responsibility for environmental protection for the immediate and effective cleanup of oil or hazardous substance discharges. For the cleanup assessment protocol, 40 CFR 300.320

(General Pattern of Response) indicates that removal shall be considered complete when so determined by the agency responders in consultation with the Governor(s) of the affected state(s). These expenses will be paid for by the OSLTF). All costs incurred by the OSLTF will be recovered from Enbridge.

From the Area Contingency Plan (USCG 2015), the following governmental organizations and agencies are identified as central to an oil spill disaster:

<u>Federal Government</u>

Coast Guard

EPA

Federal Emergency Management Agency

Fish and Wildlife Service

<u>Michigan State Government</u>

Michigan Department of Environmental Quality (DEQ's Office of the Great Lakes)

Michigan Public Service Commission

Department of Natural Resources

Michigan Department of Transportation

Michigan State Police, Emergency Management and Homeland Security Division.

Michigan Petroleum Pipeline Taskforce

<u>Indian Bands</u>

Bay Mills Indian Community

Chippewa Ottawa Resource Authority

Grand Traverse Band of Ottawa and Chippewa Indians

Keweenaw Bay Indian Community

Little Traverse Bay Bands of Odawa Indians

Nottawaseppi Huron Band of the Odawa Indians

Saginaw Chippewa Indian Tribe

Sault Ste. Marie Tribe of Chippewa Indians

Little River Band of Ottawa Indians

In addition, there are other agencies that fall outside of the Northern Michigan planning areas, such as the Ontario Ministry of Environment or the Wisconsin Department of Natural Resources.

H.1.3 Review of Relevant Spills

In a memo released by LP Environment USA (2014), the estimated cleanup cost of a worst-case discharge of 8583 barrels would be in the range of $450 million to $1 billion, requiring 4 to 9 months based on seasonal conditions and up to 5-years in long-term remedial and post-cleanup monitoring. This estimate did not include the costs associated with: right-of-way access and property damage claims, legal fees and settlements, fines and penalties, document control and retention by regulators, and pipeline repair costs. Approximately 50% of the estimated cost was attributed to bulk oil recovery, and the rest cumulatively comprised short and long-term environmental cleanup costs, costs to state and federal regulators and various miscellaneous costs related to wildlife, air and water treatment. The underlying methodology used to estimate the costs was not described in the memo.

In a recent study, Richardson and Brugnone (2018) attempted to estimate the economic damages of a rupture of Line 5 in the Straits of Mackinac using a hypothetical worst case discharge of approximately 59,500 barrels of crude oil. The highlights of the economic costs estimated in their study are as follows:

- Natural resource damages and restoration from an oil spill: $697.5 million.
- The present value of economic damages to the tourism sector: $4.8 billion.
- The present value of economic impacts to the commercial fishing sector: $61.0 million
- Economic damages to municipal water systems and wastewater treatment facilities greater than $233 million.
- The present value of economic damages to coastal properties greater than $485 million.

These estimates are categorized differently than the memo presented by LP Environment US (2014) and for a significantly higher worst case discharge volume. They sum to approximately $1.481 billion.

The $/barrel values from these two studies are approximately $116,509 per barrel (LP Environment) and $24,895 per barrel (Richardson and Brugnone, 2018), respectively In comparison, the Enbridge Line 6b spill in the Kalamazoo River on July 26th, 2010 released a total of 20,082 barrels, of which 18,245 barrels were recovered through a cleanup effort that cost Enbridge $1.2 billion. This $1.2 billion cost did not include $61 million fine payment, the $110 million spent on spill prevention safeguards for 2,000 miles of its pipeline system in the Great Lakes region, or the reimbursement of $5.4 million to the government for cleanup costs incurred. These costs translate to approximately $68,589 per barrel released. This cost falls between the estimates from the two reports above.

Needless to say, \$/barrel spilled is not a meaningful metric for comparison, as the severity of the conditions under which the spill occurs, the location of the spill and the response times and preparedness can make a significant difference in the final cleanup costs and environmental damage mitigation. For instance, in the Kalamazoo River spill, the oil flowed for 17 hours before a shut-off occurred. Enbridge's current preparedness and tactical plan suggests no more than 13 minutes before a shut-off occurs. These differences in response time can significantly reduce the impact of the spill.

There is currently a significant gap in knowledge of how the governmental costs are to be estimated. While Richardson and Brugnone (2018) provide a thorough report outlining the expected costs, there is limited discussion of the data sources used and the estimation methods followed. As a result, it is difficult to replicate their study.

H.2 Approach

H.2.1 Government Costs: Oil Spill Response

H.2.1.1 Government Costs: Loss of Local, State and Federal Tax Revenues
Although government costs related to the direct response to an oil spill of Line 5 would be fully reimbursable by the responsible party or parties, other costs to government entities will likely be realized from the broader negative effects on the local and regional economies of the affected areas. Any negative effects on the economy due to an oil spill would have the real effect of reducing tax revenues coming into governments at the federal, state, and local levels. In the analysis presented here, we consider only the effects of <u>reduced visits</u> by <u>out-of-state tourists</u> and the resulting decline in direct economic activity to those affected businesses. Indirect economic effects, so-called multiplier effects, are not accounted for. The impacts of in-state visitors were considered to be minor, assuming that any planned visits to counties affected by an oil spill would simply redirect to other Michigan or Wisconsin locations, yielding minimal net economic losses.

To estimate the magnitude of this reduction in tax receipts, we used the key results from the Task I investigation of the regional economic impacts of a worst-case oil spill from Line 5 in the Straits of Mackinac. More information on Task I estimates of lost economic activity in Michigan can be found in Section GI of this report. Briefly, the economic loss estimates are based on three scenarios in which modeled current and weather patterns move the released oil in different directions, resulting in shoreline contamination affecting different counties in Michigan, Wisconsin, and Ontario. In this analysis, we only consider the loss of tax revenues to the states of MI and WI as well as to the federal government and do not include the province of Ontario in Canada. A map of the three scenarios is shown in Figure H2, which is reproduced from Section GI of this report. Dark green regions represent the areas directly impacted by shoreline oiling. The yellow shaded regions represent counties that are tangentially impacted.

A summary of net declines in direct economic activity in lodging, restaurant food and beverage, retail purchases, recreation/sightseeing/entertainment, and transportation at destination are shown in Table H1 for Scenario 1. Similarly, estimates for Scenarios 2 and 3 are displayed in Tables H2 and H3.

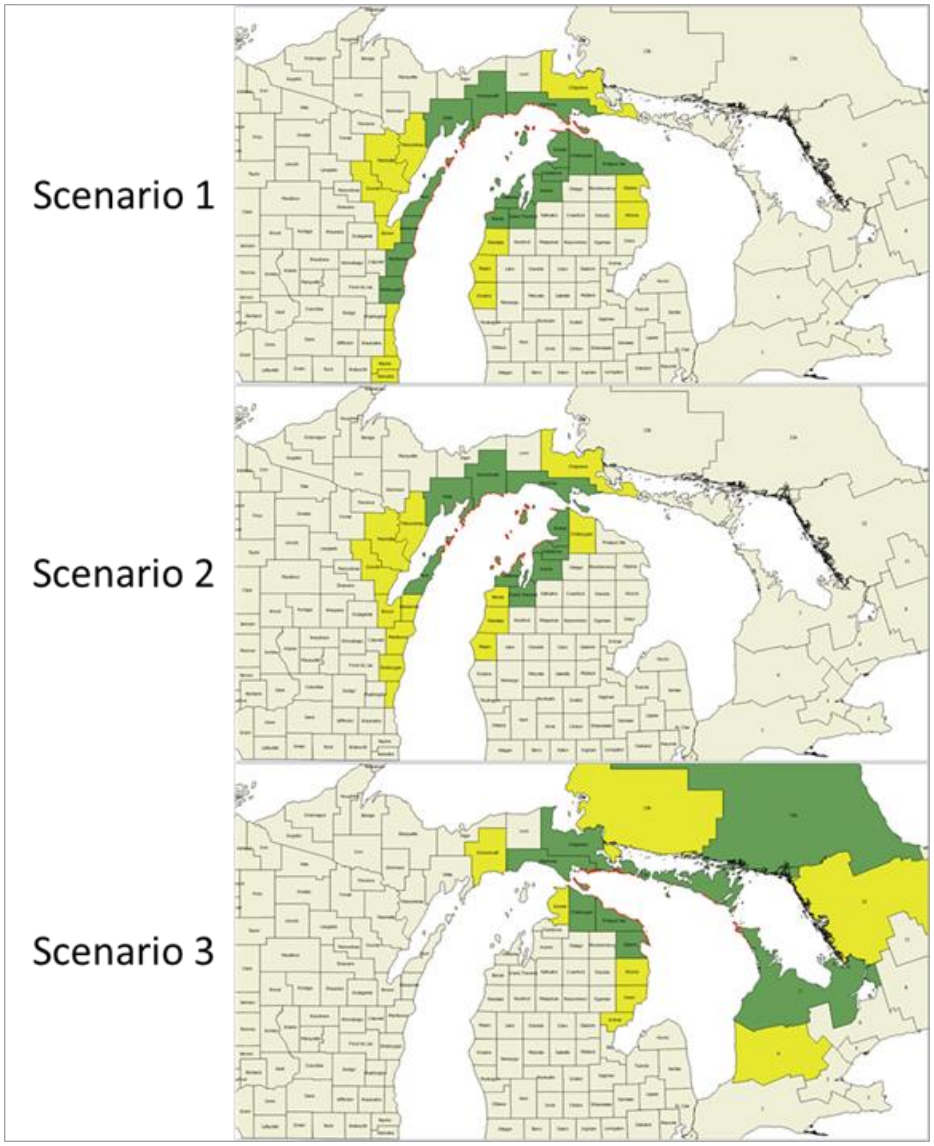

Figure H2: Scenario maps for counties directly and indirectly affected by shoreline contamination by oil released in the Straits of Mackinac.

Table H1. Scenario 1 estimates of direct economic losses to affected communities by out-of-state tourists who decide not to visit counties affected by the oil spill.

Economic Activity Lost	Michigan	Wisconsin
Lodging	$68,109,311	$116,736,462
Restaurant Food & Beverage	$46,601,108	$79,872,316
Retail Purchases	$26,287,804	$45,056,178
Recreation/Sightseeing/Entertainment	$21,508,203	$36,864,146
Transportation at Destination (Fuels)	$20,313,303	$34,816,138
Sub-Total	$182,819,729	$313,345,240
Total	$496,164,969	

Table H2. Scenario 2 estimates of direct economic losses to affected communities by out-of-state tourists who decide not to visit counties affected by the oil spill.

Economic Activity Lost	Michigan	Wisconsin
Lodging	$60,217,138	$55,226,198
Restaurant Food & Beverage	$41,201,200	$37,786,346
Retail Purchases	$23,241,702	$21,315,375
Recreation/Sightseeing/Entertainment	$19,015,938	$17,439,852
Transportation at Destination (Fuels)	$17,959,497	$16,470,971
Sub-Total	$161,635,475	$148,238,742
Total		$309,874,217

Table H3. Scenario 3 estimates of direct economic losses to affected communities by out-of-state tourists who decide not to visit counties affected by the oil spill.

Economic Activity Lost	Michigan	Wisconsin
Lodging	$26,101,713	$0
Restaurant Food & Beverage	$17,859,067	$0
Retail Purchases	$10,074,346	$0
Recreation/Sightseeing/Entertainment	$8,242,646	$0

Transportation at Destination (Fuels)	$7,784,722	$0
Sub-Total	$70,062,494	0
Total		$70,062,494

The taxes on sales and lodging not collected by the States of Michigan and Wisconsin from the lost economic activities in Table H1 are calculated using the tax rates shown in Table H4. In Michigan, taxes on lodging include both sales tax as well as a separate lodging tax, whereas, in Wisconsin, only a sales tax is levied on hotel/motel stays of under a month. Lost state and federal tax revenues from transportation fuels not sold due to an oil spill were estimated using the factors listed in Table H4 and assuming an average fuel price of $3.099/gallon, which represents the current average gasoline retail price for all grades of gasoline form data compiled by the U.S. Energy Information Administration (https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_r20_w.htm). In addition, loss of income taxes for Michigan, Wisconsin, and the federal government are also included in this assessment.

Table H4. Tax rates for sales, lodging, and transportation fuels and other factors.

Tax Type	**Michigan**	**Wisconsin**	**Federal**
Lodging[1] (%)	6	5	NA
Sales (%)	6	5.5[2]	NA
Transportation			
Fuel ($/gallon)	0.259		
Sales ($/gallon)	0.139		
Environmental ($/gallon)	0.009		
Excise Tax ($/gallon)		0.309	
Petroleum Cleanup ($/gallon)		0.02	
Highway Fuel ($/gallon)			0.154
Transit Fuel ($/gallon)			0.029
Underground Tank ($/gallon)			0.001
Income (%) [3]	4.25	6.27	22

[1] WI, only lodging tax is levied on hotel/motel stays. MI, both sales and lodging taxes apply. http://www.ncsl.org/research/fiscal-policy/state-lodging-taxes.aspx,

[2] The most common rate among affected counties in WI.
https://www.revenue.wi.gov/Pages/FAQS/pcs-taxrates.aspx
[3] Rates apply for most common tax filing category of married filing jointly assuming national average household adjusted gross income (AGI) of $117,795.

H.2.2 Government Benefits: Gain in State and Federal Tax Revenues

In addition to the net economic losses presented in section H2.2.1 above, it is expected that the expenses paid by responsible parties for responding to and cleaning up an oil spill will increase household incomes in the United States above the level before the oil spill. In this analysis, and as a simplification, we assume that the vast majority of workers responsible for carrying out the oil spill cleanup are citizens of the state of Michigan. Furthermore, consistent with Table H2, it is assumed that the additional incomes received for oil spill cleanup will increase household incomes of those with the average household AGI of $117,795. The income tax rates, shown in Table H2, apply to this increment of household income increase. This is a simplification of the anticipated outcome where in reality workers from all income levels will participate in the cleanup, but this assumption is consistent with the estimate for income tax losses from section H2.2. Finally, for this calculation, it is assumed that total oil-spill cleanup costs will be $500,000,000 paid by responsible parties (see Section F.3.4.3).

H.3 Analysis of Government Costs and Benefits

H.3.1 Costs from the Decline of Visitor Related Tax Expenditures

Direct costs to the states of Michigan and Wisconsin and the federal government from declines in visitations are shown in Tables H5-H7 for Scenarios 1-3. The costs appearing in this table were calculated using values appearing in Tables H1 and H2 above. The largest losses are from income taxes not collected, but all sales taxes when included together are also significant relative to income taxes. Although still large, transportation fuel taxes and lodging taxes are less significant in comparison.

Table H5. Scenario 1 government tax revenues lost from declines in out-of-state beach visitations.

	Michigan	Wisconsin	Federal
Sales Taxes Lost			
Lodging	$4,086,559	$6,420,505	NA
Restaurant Food & Beverage	$2,796,066	$4,392,977	NA
Retail Purchases	$1,577,268	$2,478,090	NA
Recreation/Sightseeing/Entertainment	$1,290,492	$2,027,528	NA

Fuel Taxes lost			
Transportation at Destination	$2,667,801	$3,696,195	$3,273,255
Lodging Taxes Lost	$4,086,559	NA	NA
Income Taxes Lost	$7,769,838	$19,646,747	$109,156,293
Total Lost Revenues	$24,274,583	$38,662,042	$112,429,548

Table H6. Scenario 2 government tax revenues lost from declines in out-of-state beach visitations.

	Michigan	**Wisconsin**	**Federal**
Sales Taxes Lost			
Lodging	$3,613,028	$3,037,441	NA
Restaurant Food & Beverage	$2,472,072	$2,078,249	NA
Retail Purchases	$1,394,502	$1,172,346	NA
Recreation/Sightseeing/Entertainment	$1,140,956	$959,192	NA
Fuel Taxes lost			
Transportation at Destination	$2,358,669	$1,748,612	$2,044,274
Lodging Taxes Lost	$3,613,028	NA	NA
Income Taxes Lost	$6,869,508	$9,294,569	$68,172,328
Total Lost Revenues	$21,461,763	$18,290,409	$70,216,602

Table H7. Scenario 3 government tax revenues lost from declines in out-of-state beach visitations. Scenario does not include lost Canadian tax revenues.

	Michigan	**Wisconsin**	**Federal**
Sales Taxes Lost			
Lodging	$1,566,103	$0	NA
Restaurant Food & Beverage	$1,071,544	$0	NA

Retail Purchases	$604,461	$0	NA
Recreation/Sightseeing/Entertainment	$494,559	$0	NA
Fuel Taxes lost			
Transportation at Destination	$1,022,388	$0	$462,210
Lodging Taxes Lost	$1,566,103	NA	NA
Income Taxes Lost	$2,977,656	$0	$15,413,749
Total Lost Revenues	$9,302,814	$0	$15,875,959

Increases in government tax receipts are presented in Table H8 based on the assumed total oil spill response and cleanup cost paid by the responsible parties of $500,000,000. The greatest benefit is expected to the federal government with an increase of $110,000,000. These tax benefits are directly linked to the assumed payment by the responsible parties and will change in proportion to the actual response and cleanup costs. At the assumed oil spill response and cleanup cost paid by the responsible parties of $500,000,000, net government costs may be greater or less than benefits depending on the scenario.

Table H8. Government tax revenues gained from oil spill cleanup funded by responsible parties.

	Michigan	**Wisconsin**	**Federal**
Income Taxes Gained	$21,250,000	NA	$110,000,000

H.3.2 Governmental Costs Due to Shoreline Oiling

In any worst-case Straits scenario, there would be a need for extensive shoreline cleanup. For the specific simulated scenarios focused on for Tasks G, H and I, the length of shoreline impacted by a worst-case scenario is estimated to vary between approximately 794 and 996 km depending on wind and current conditions. In the case of a spill, Enbridge will be responsible for the costs associated with the shoreline impact. However, these costs must be estimated and made available to governmental agencies, both to determine Enbridge's total potential liability and because governmental costs – whether reimbursable or not – will be a derivative of this cost. Based on the 2010 spill in Marshall, MI, the estimated cost of shoreline cleanup is approximately $510,000 per km of impacted shoreline, as discussed in Section F3.4.2.2. These cost estimates are highly sensitive to context and the spill scenario and the conditions in which the cleanup is being conducted. Extrapolations of the total cost of the three scenarios that Tasks G and I focus on for their economic analyses are presented in Table

H9. To estimate the impact of the shoreline cleanup on government costs, the Scenario 1 estimate was rounded to $500 million.

Table H9. Estimated shoreline cleanup costs for the three worst-case scenarios focused on by Tasks G, H and I based on the costs per kilometer reported for the 2010 Marshall spill.

Scenario	Days post-spill	km of shoreline oiled	Cost based on Marshall
1	60	996	$508,000,000
2	60	794	$405,000,000
3	60	847	$423,000,000

H.3.3 Health Costs

Local health departments would issue a water advisory. The advisory would include households with wells within 200 feet of the ordinary high water mark (OHWM). The positive charge of groundwater flow into the lakes should not result in any contamination of wells. Following the 2010 Kalamazoo River spill, wells within 200 feet of the OHWM were tested, and no evidence suggested that drinking water wells were contaminated as a result of the spill (MDCH 2012). The St. Ignace and Mackinac Island municipal water utilities draw their water from the lake and would have to consider water advisories and monitoring.

Another cost is the potential accommodation and/or evacuation of people stranded on Mackinac Island due to the prohibition of boating activity during the cleanup phase. Accommodation and food may need to be provided for several days. Air evacuation may need to be provided to those with medical conditions needing treatment.

H.3.4 Analysis of Government Response Oversight and Damage Assessment Costs

Federal, state, and tribal government response and restoration costs can be estimated directly by approximating total personnel hours and travel costs, or indirectly by comparison with other spills by spill volume or length of shoreline oiled. Given the inherent uncertainty in estimating government level of effort and response duration, the calculations below relied primarily on comparison approaches. That said, Fiscal Year 2018 federal per diem rates for most counties around the Straits are $167, with an adjustment up to $178 in July and August, which could be used to estimate subsistence costs for on-site personnel and contractors. Round trip flights from Washington, DC for non-local federal staff to Traverse City, MI are typically approx. $350, and typical rental car rates are $320 per week, plus approx. $50 per week in gas. The full salary cost of government personnel and contractors would likely include overtime and possibly hazardous duty pay, and staffing costs required might increase over time as extra contractors would become necessary to replace government staff who had to return to their regular offices to cover non-emergency responsibilities. For comparison, the rate of total government spending per day during the height of the Kalamazoo River spill response (early August 2010) was estimated at $470,000 per day (USEPA, 2016).

A release volume of 58,000 barrels or 2,436,000 gallons was used to convert government costs incurred from other spills to an equivalent for a Straits spill. This release volume, along with a model-derived oiled shoreline range of 348 to 2,007 km represents the worst scenario modeled for all 12 months, including the three scenarios that Tasks G and I selected to focus on (see prior tasks). Conversion factors from other spills used both linear and non-linear conversion factors, as described below. For comparison with this shoreline kilometers range, the earlier value used in the alternatives assessment by Dynamic Risk, Inc. used 1,000 miles (1,609 km), and the result of prior modeling by University of Michigan and NOAA (National Oceanic and Atmospheric Administration) researchers yielded a value of 700 miles (1,127 km); the range used for these calculations brackets those values.

Both the Deepwater Horizon and Exxon Valdez spills impacted about 1,300 miles (2,092 km) of shore (BP, 2016; ARLIS, 2017). The Kalamazoo River spill was different; approximately 35 miles (56 km) of river (70 miles/113 km of shore, not including islands) were impacted there, although the high density of that oil (dilbit) substantially increased the cleanup costs to over $1 billion due to sinking of oil after volatilization of light components (USEPA, 2016). Deepwater Horizon cleanup (not oversight, fines, or restoration) cost over $14B (BP, 2016); Exxon Valdez cost $2.5B (about $4.5B adjusted for inflation) for cleanup alone (ARLIS, 2017). The Deepwater Horizon Natural Resource Damages Assessment (NRDA; just the study, not the damages themselves), which was not included in the calculations of government costs below due to its unique complexity, cost $1.3 billion (BP, 2016). The Kalamazoo River spill resulted in a $5.4 million payment for "unreimbursed costs incurred by the government in the cleanup" (DOJ, 2016). Enbridge had already reimbursed the government for $57.8 million in cleanup response costs from the spill, so the total was $63.2 million.

Exxon Valdez government costs were $125.2 million (not adjusted for inflation) according to https://www.gao.gov/products/RCED-90-91FS . The Government Accountability Office (GAO) noted that: (1) nine agencies incurred cleanup, damage assessment, and other costs totaling $125.2 million through September 30, 1989; (2) four of those agencies accounted for 94 percent of total costs incurred, and the Department of Defense accounted for the largest portion, $62.8 million; (3) eight of nine agencies sought reimbursement either from the Coast Guard-administered 311(k) fund or through direct reimbursement agreements with the company; (4) since November 15, 1989, agencies have recovered $80.8 million of total oil spill costs; (5) the agencies have not yet recovered $21.6 million of the unreimbursed $44.4 million, because charges were inadequately documented, exceeded formal cleanup agreements, or were not approved in advance by the USCG; (6) the Departments of Health and Human Services and the Interior will not recover $1 million in costs, since the USCG did not approve the expenses in advance; and (7) agencies estimated that cleanup would require another $9.2 million between October 1989 and February 1990.

The Oil Spill Liability Trust Fund (https://www.epa.gov/oil-spills-prevention-and-preparedness-regulations/oil-spill-liability-trust-fund) can cover unreimbursed costs if the responsible party is unknown, unwilling, or unable to pay as follows. The Fund can provide up to $1 billion for any one oil pollution incident, including up to $500 million for the initiation of natural resource damage assessments and claims in connection with any single incident. The main uses of Fund expenditures are:

- State access for removal actions;
- Payments to federal, state, and Indian tribe trustees to carry out natural resource damage assessments and restorations;
- Payment of claims for uncompensated removal costs and damages; and
- Research and development and other specific appropriations.

Using the three spill data points mentioned above (adjusting Exxon Valdez for inflation) yields the plots provided in Figures H3 and H4, based on a spill volume conversion in the first case and shoreline miles oiled conversion in the second. Note that the trend line used to estimate the conversion formula in the first case (volume) was logarithmic, and that the second trend line was linear, given that costs associated with shoreline cleanup do not flatten out at higher values as occurs with offshore cleanup, especially where dispersants and burning were used for offshore areas during Deepwater Horizon. This highlights the fact that none of the comparison spills are direct analogs of a theoretical Straits spill, but they still have comparative value. Exxon Valdez and Deepwater Horizon shoreline lengths were comparable, but oversight costs were quite different due to cleanup technologies used and logistical constraints, as the graph shows, so the high-end value for the Straits is bracketed but not well-constrained by that method.

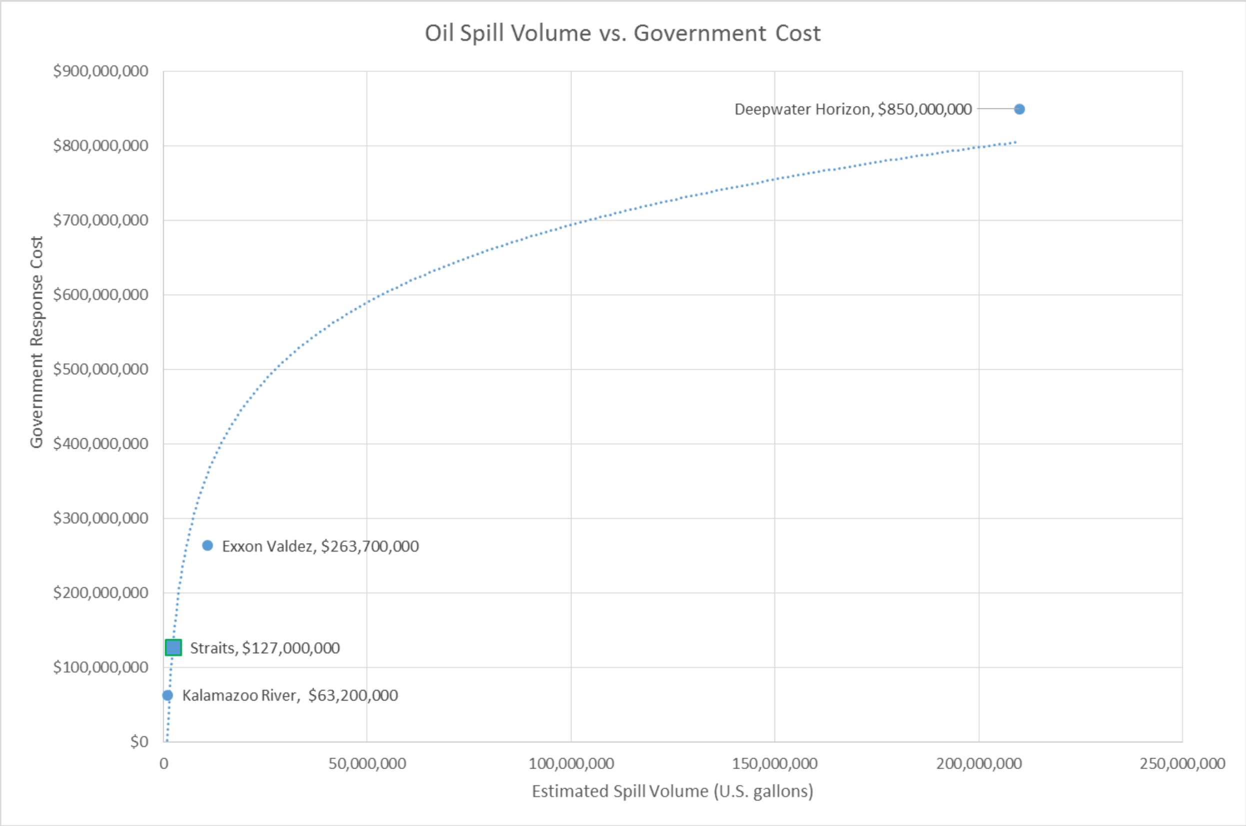

Figure H3: Logarithmic curve fit to government response cost vs. spill volume for three historical spills, then applied to the estimated worst-case discharge volume for a Straits spill.

Using the comparative plotting method yields government cost values of approximately $127 million for a Straits spill based on volume or a range of $123 to $535 million based on length of oiled shoreline. The curve fits through only three points are not statistically robust, but are still useful for general comparisons. Other approaches such as calculating total spill response costs using the methods of Etkin (1999) or Kontovas et al. (2010), and applying a fractional value of 4% for the government cost component (approximate Deepwater Horizon percentage, including NRDA costs), yield values that are unrealistically low ($17.6 million for Etkin and $593 thousand for Kontovas et al.). The low values are likely the result of incorporation of global values from mostly marine spills with limited shoreline impacts into these compilations.

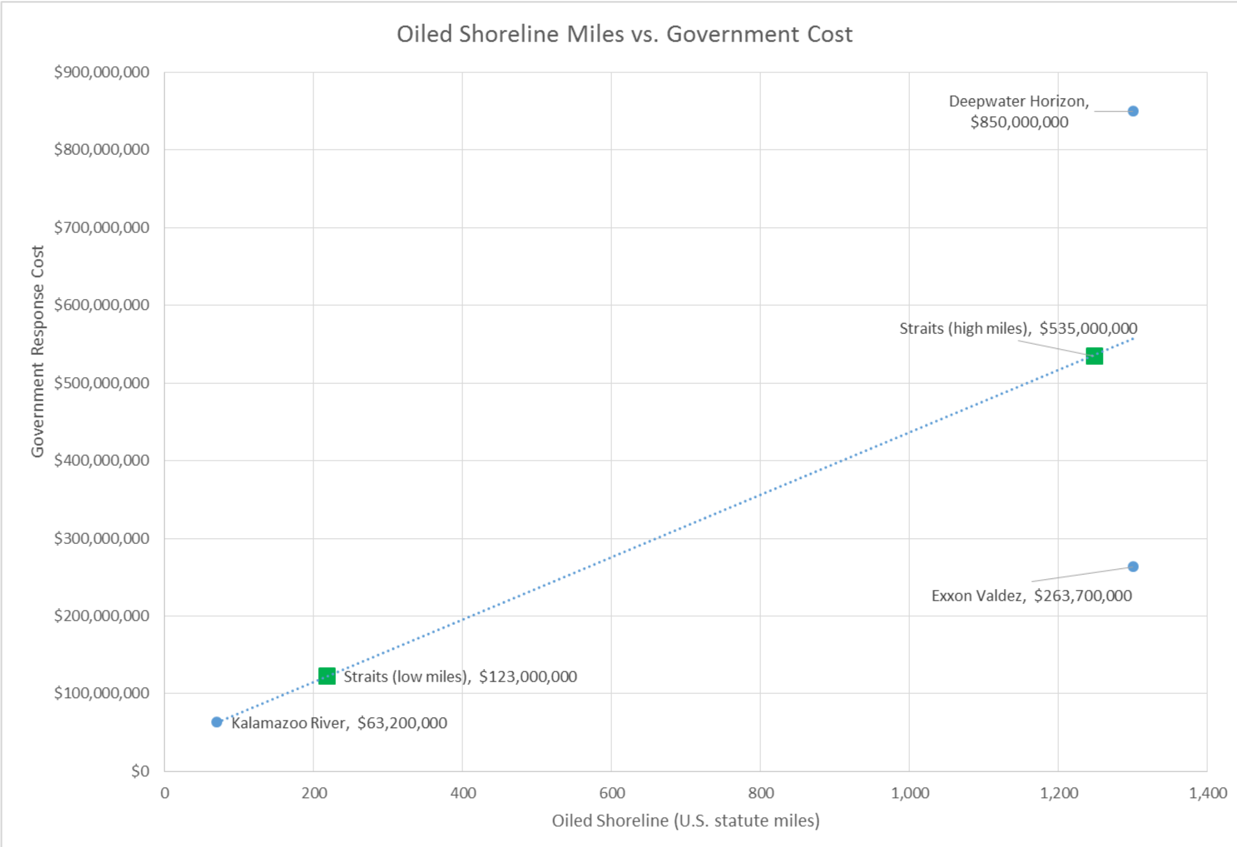

Figure H4: Line fit to government response cost vs. length of oiled shoreline for three historical spills, then applied to the range of estimated worst-case oiled shoreline lengths for a Straits spill.

H.3.5 Government Loss from Responsible Party Cleanup Cost Deduction

An additional cost, which can be estimated from the cleanup costs (but not fines) incurred by the responsible party, would be the lost government tax revenue from the application of the cleanup cost deduction and government reimbursement as a business expense. The total cost of cleanup and other liabilities is typically 2.5 times the cost of cleanup alone, according to Kontovas et al. (2010), so the corporate income tax revenue loss based on the assumed cleanup cost of $500M used earlier would be 21% of $1.25B, or $262.5M.

H.4 References

ARLIS (Alaska Resources Library & Information Services), 2017. Exxon Valdez Oil Spill: FAQs, Links, and Unique Resources at ARLIS. http://www.arlis.org/docs/vol2/a/EVOS_FAQs.pdf

BP, 2016. Gulf of Mexico Environmental and Economic Progress (fact sheet), 2 p. https://www.bp.com/content/dam/bp-country/en_us/PDF/BP%20Gulf%20environment%20and%20economic.pdf

Christopherson, S. and Dave, K., 2014. A new era of crude oil transport: risks and impacts in the Great Lakes Basin.

DOJ (Department of Justice), 2016. United States, Enbridge Reach $177 Million Settlement After 2010 Oil Spills in Michigan and Illinois. https://www.justice.gov/opa/pr/united-states-enbridge-reach-177-million-settlement-after-2010-oil-spills-michigan-and

Enbridge, 2018. Enbridge's 2017 economic impact on Michigan (fact sheet), 4 p. http://enbridgeenergy.com/~/media/Enb/Documents/Factsheets/ProvinceStateEconomicBenefits/2017MIEcoBen.pdf?la=en

Etkin, D.S., 1999, March. Estimating cleanup costs for oil spills. *In* International Oil Spill Conference (Vol. 1999, No. 1, p. 35-39). American Petroleum Institute.

Hasle, Peter, Hans Jørgen Limborg, and Klaus T. Nielsen. "Working Environment Interventions – Bridging the Gap between Policy Instruments and Practice." Safety Science 68 (October 2014): 73–80. https://doi.org/10.1016/j.ssci.2014.02.014.

Hood, C., 1986. The tools of government. Chatham. NJ: Chatham House.

Hood, C.C. and Margetts, H.Z., 2007. The tools of government in the digital age. Palgrave Macmillan.

Howlett, M., 1991. Policy instruments, policy styles, and policy implementation. Policy Studies Journal, 19(2), pp.1-21.

Howlett, M., J. Kim, and P. Weaver. 2006. Assessing Instrument Mixes through Program- and Agency-Level Data: Methodological Issues in Contemporary Implementation Research."Review of Policy Research 23, no. 1: 129–51.

Knill, C. and Tosun, J., 2012. Public policy: A new introduction. Palgrave Macmillan.

Kontovas, C.A., Psaraftis, H.N. and Ventikos, N.P., 2010. An empirical analysis of IOPCF oil spill cost data. Marine pollution bulletin, 60(9):1455-1466.

LP Environment US. (2014). Questions and Requests for Information to Enbridge regarding the Straits Pipelines Contingency Planning and Spill Response: Question 4b & 4c [Memorandum]. Retrieved from https://www.michigan.gov/documents/ag/E4_Straits_2014_Cleanup_Cost_Summary_524140_7.pdf

MDCH (Michigan Department of Community Health). (2012). Public Health Assessment – Initial/Public Comment Release. Kalamazoo River/Enbridge Spill: Evaluation of crude oil release to Talmadge Creek and Kalamazoo River on residential drinking water wells in nearby communities (Calhoun and Kalamazoo Counties, Michigan). Retrieved from https://www.michigan.gov/documents/mdch/Enbridge_drinking_water_public_comment_5-17-2012_385935_7.pdf

Nissinen, Ari, Eva Heiskanen, Adriaan Perrels, Elina Berghäll, Virpi Liesimaa, and Maija Mattinen. "Combinations of Policy Instruments to Decrease the Climate Impacts of Housing, Passenger Transport and Food in Finland." Journal of Cleaner Production. Accessed September 19, 2014. https://doi.org/10.1016/j.jclepro.2014.08.095.

Park, SangHoon, and CheongHoon Baek. "Fiscal Instruments for Sustainable Maintenance of Apartment Housing in Korea." Renewable and Sustainable Energy Reviews 16, no. 7 (September 2012): 4432–44. https://doi.org/10.1016/j.rser.2012.05.012.

Richardson, Robert and Nathan Brugnone. 2018. Oil Spill Economics: Estimates of the Economic Damages of an Oil Spill in the Straits of Mackinac in Michigan. Report Prepared for Prepared for FLOW (For Love of Water), Traverse City, Michigan. http://flowforwater.org/wp-content/uploads/2018/05/FLOW_Report_Line-5_Final-release-1.pdf

University of Michigan, Michigan Sea Grant. (2008). Michigan Jobs, Economic Vitality, and the Great Lakes, unpublished paper.

US Coast Guard. (2015). Northern Michigan Area Contingency Plan (ACP). Retrieved from https://www.watershedcouncil.org/uploads/7/2/5/1/7251350/acp-northernmi-epauscg-aug2015.pdf

USEPA, 2016. FOSC Desk Report for the Enbridge Line 6b Oil Spill, Marshall, Michigan. 241 p. https://www.epa.gov/sites/production/files/2016-04/documents/enbridge-fosc-report-20160407-241pp.pdf

White, Linda A, Susan Prentice, and Michal Perlman. "The Evidence Base for Early Childhood Education and Care Programme Investment: What We Know, What We Don't Know." Evidence & Policy: A Journal of Research, Debate and Practice 11, no. 4 (November 27, 2015): 529–46. https://doi.org/10.1332/174426415X14210818992588.

Task X: Broader impacts

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X.1 Introduction

To provide a balanced assessment of the Straits Pipeline, Team X pursued two overarching objectives. First, the team aimed to provide a qualitative overview of risks arising out of a potential oil and petroleum product release from the Straits Pipelines ("petroleum release"). Second, the team engaged with concerns over a potential petroleum release expressed by local communities, civil society groups, indigenous communities, government actors, and the public at large.

The qualitative overview of risks involved analyses of the perceived risks, their severity, and their tolerability by the groups above. For our analysis, we have adopted the view of risk as an uncertain adverse event or occurrence. Therefore, we treat the petroleum release as a hazard (i.e., risk agent) and the impacts of the release—damage to wildlife, for example—as risks. The team relied on public comments submitted in response to the 2017 Alternatives Analysis for the Straits Pipelines conducted by Dynamic Risk (DR). Our analysis of the public comments suggests that the respondents treated the alternatives analysis as a referendum on risks associated with the Straits Pipelines. Our analysis also showed that we could learn not only about the types of risks perceived by potentially affected parties but also about their perceived severity. In that regard, we found statements about risk severity by some potentially impacted parties, property owners for example, particularly instructive. Perhaps the most valuable takeaway from our analysis has been insights regarding tolerability of risks posed by the Straits Pipelines and, therefore, acceptance of potential decisions regarding the pipelines' future. These findings helped us to identify and articulate significant Social License to Operate (SLO) implications, which will add to a worst-case scenario in the event of a petroleum release.

Risk analyses of the magnitude and importance of the project at hand often generate public discourse aimed at critiquing and, at times, dismissing the validity of the analyses. The discourse usually takes the form of a "lay people vs. experts" debate, which often results in suspicion and mistrust on the public side and alienation and resentment on the expert side. We aim to abate this unnecessary standoff to the extent possible by responding to the concerns of the aforementioned people and entities in a comprehensive, systematic, and scientific manner.

We would like to express our gratitude to the MDEQ staff for providing well-organized electronic copies and hard originals of comments submitted in response to DR's draft and final reports. We are particularly thankful to Nate Zimmer, the MDEQ's Chief of Staff, and MDEQ's student interns for their assistance on this matter. We also would like to express our gratitude to representatives of Michigan's Tribal Nations who responded to our data inquiries. Finally, we would like to thank the Mackinac County Emergency Management Department staff and USCG Sector Sault Sainte Marie personnel for their time and the data that they provided.

X.2 Approach

X.2.1 Background

X.2.1.1 Perceived Risk Analysis

In our analysis, we identify risk as the "potential effects that hazards (or risk agents) would likely cause on specific targets (i.e., built environment, ecosystems, and/or humans)" (IRGC, 2005). To clarify the understanding of risk as "effect," we narrow this definition to mean an uncertain adverse consequence. By defining risk as an uncertain adverse consequence, we can engage a wide range of stakeholders who are most familiar with the adverse effects of an activity (or risk agent) but not necessarily with the activity itself. This view of risk differentiates hazardous activity (e.g., oil transport through the Great Lakes via pipeline) and hazard (e.g., oil spill) from the potential adverse effects of the activity (e.g., drinking water contamination) and provides the opportunity for deeper insight in our risk analysis. This approach provides the opportunity for coastal homeowners, indigenous communities, and various targeted stakeholders who are unlikely to be aware of the intricacies of the oil pipeline business to have their concerns heard. These stakeholders are more likely to be familiar with some adverse consequences because these consequences could have an immediate impact on the stakeholders' livelihoods.

This disregard and bias toward certain "targets" are most prevalent in risk assessments involving oil and gas activities. Risk studies usually tend to favor what is regarded as "objective risk" over what is known as "subjective or perceived risk." Hence, essential to a conceptual understanding of risk is recognizing the difference between objective risk and subjective (or perceived) risk. The implications of this divide are vast, as they extend to the question of who makes decisions about risk, including the rules for determining it. A 1983 Risk Assessment report by the Royal Society described objective risk as the prerogative of "the experts," while subjective or perceived risk was classified as the product of lay-people's anticipation of an adverse event. It is also the objective view of risk as "the probability of a future adverse event multiplied by its magnitude" that dominates the risk and safety literature (Adams, 1995, p. 69). This disregard of the "perceived risk" of "risk targets" fails to recognize significant variables in the analysis.

Crawford-Brown (Adams, 1995)(1999, p. 12) notes that although risk assessment can be done according to an objective standard, risk management must have a subjective element, as managers are people, not machines. Following this notion of the necessity of coexisting objective and subjective risks, we introduce an approach to risk analysis that assigns a value to the adverse consequences perceived by laypeople or "targets." Rosa et al. (2014) add that once an event or occurrence is deemed to be of human value, it ceases to be an objective notion. Risk analysis starts with the identification of the risk. How risk is perceived often guides risk identification, which ultimately determines how risk is assessed and managed. Thus, the purpose and significant value of our analysis are to identify the risks perceived by those who are most vulnerable to the uncertain adverse consequences of the Straits Pipelines operation.

In analyzing these perceived risks and the reasons and origins of the perceptions, we rely on three of the main theories of risk perception: the cultural theory, the Rational Action Paradigm (RAP) theory, and the psychometric theory. The cultural theory is based on a broader understating of perceived risk, as it connects cultural biases to risk-taking or risk avoidance (Wildavsky & Dake, 1990). The RAP theory brings in the basic principle of rational action that is premised on the notion that "human beings are capable of acting in a strategic fashion by linking decisions with outcomes" (Renn, et al., 2001, p. 4). The psychometric theory centers on cognitive factors that influence a person's perception of risk. People's perception of risk is dominated by both the dread risk factor and the unknown risk factor (Slovic, 1987).

Through the lens of the cultural, RAP, and psychometric theories, we were able to gain better understanding of the perceived risks. In addition, perceived risk gives our analysis a much-needed social context. Thus, our approach draws upon the concept of risk governance that places risk analysis in the context of collective decision-making (Sidortsov, 2014). Collective decision-making incorporates diverse actors, such as civil society groups and indigenous communities, and enables them to openly question and sometimes overrule risk experts on non-scientific, ethical, political, and legal grounds. The interdependence of the objective and "socio-cultural" (or subjective) risks, as well as inclusive target (or stakeholder) participation, lies at the foundation of the basic conditions for every risk-related decision. The focus and emphasis on the "subjective" provides for holistic and inclusive identification of the societal, economic, and environmental benefits and risks as felt by those who face the immediate impact. Evaluating risk through the assessment of perceived risk captures the societal values and norms for making judgments about tolerability and acceptability of the risks, and helps in accounting for the social uncertainties that accompany scientific and technical uncertainties.

X.2.1.2 Social License to Operate (SLO)

It is not uncommon for corporate and government decision-makers to dismiss citizens' concerns over risks posed by industrial projects and activities on the grounds that the concerns are driven by irrational fears and self-serving political motives. Analyzing perceived risk, including the reasons and rationale behind it, provides the opportunity to determine if this is, in fact, the case. Therefore, this analysis enables one to evaluate the grounds upon which the impacted parties accept or reject a project or activity and assess its social license to operate (SLO).

SLO is a term used to describe the implicit or explicit relationship between a community and the industrial and/or public actors that manage natural resources. The term is used by a variety of industrial sectors, government policy-makers and civil society alike to explore the dynamics of public perception and the hindrances to and opportunities for achieving public acceptance of natural resource utilization. SLO is generally regarded as being synonymous with community approval, but given the dynamic nature of relationships, community approval fails to capture the full spectrum of public perceptions and the interactions that shape these perceptions (Parsons and Moffat, 2014). SLO helps to capture the expectations that a community has for an industry or industry's operation; from that starting point, it is most productive to view social license, not as a linear relationship that directly binds our two main actor groups, but as a continuum, spectrum or even web of relationships (Dare, Schirmer, and Vanclay, 2014; Edwards and Lacey, 2014; Parsons, Lacey, and Moffat, 2014). SLO is intimately tied to the responsibilities of resource managers and across actors in industry and governing agencies. This is especially important when management is being done on behalf of the public or in contexts where resource use or the impacts related to resource management intersect with economic development in other industrial sectors, common-pool resources such as clean air and water, cultural resources, health, and other contributors to economic development and quality of life.

Industries actively pursue SLO as they operate in particular communities. Communities can be defined as "a social unit of any size that shares common values, or that is situated in a given geographical area" (James et al., 2012, pg. 14). Communities can also be described by stakeholders (James et al., 2012). A stakeholder is defined as "a person with an interest or concern in something" and can be comprised of one or more of the following: shareholders, owners, residents, Indigenous peoples, government or nongovernmental agents, and employees (Merriam-Webster, 2016). Communities are often viewed as people that fall in a certain geographic region. Even when they are grouped by descriptors, however, communities are comprised of many individuals with a variety of perspectives and values that shape how they view industrial operations that take place in their region. Communities have several different relationships with industry; they provide a physical location, are stakeholders in the local environment, comprise a workforce, consume a product, are partners in projects, benefit from or supply infrastructure, pay taxes and are the group of individuals who will have resources extracted from or brought to their community (James et al., 2012).

If the community has a good relationship with industry and/or the public entities tasked with ensuring the safety of industrial activity, then that community may offer a high-level social license. If the community does not approve of the operations of the industry, they withdraw SLO, which can have major ramifications for project feasibility and perceived organizational legitimacy. Industries recognize the value of social license for transforming how industries and communities communicate, and some forecast that social license could become a part of the government licensing process (Lacey, Parsons, and Moffat, 2012; Parsons, Lacey, and Moffat, 2014). When SLO is not achieved or is withdrawn, industrial activities and the public entities that operate to ensure their safety can face social disapproval and active opposition, challenging possibilities for development and continuity of activities.

In this report, SLO is used as an anchor concept to advance two substantial areas of concern based on the analysis of public comment data being provided to the state. Regarding the Straits Pipeline, the first area of concern requires acknowledgment that social license involves a relationship between two sets of actors. There are actors that hold social license (industrial actors and the public actors charged with ensuring the safety of industrial activity) and there are actors that grant social license (community members and/or stakeholders); those to whom social license is granted or from whom social license is withheld cannot simultaneously be the grantors of that social license. Thus, when analyzing the public comment data, it is essential to parse the data in terms of the position of the actors as either those who receive social license or those who give social license. It is clear from the DR comments that perceptions of and tolerance of the risks involved in this project are acceptable to those who directly benefit from the industrial activity, but those actors cannot grant social license to the industrial activity; the community members and stakeholders who are able to give social license have a different perception of the risks of the project and are not willing to accept them, and therefore do not grant social license to this project.

The second key point is that SLO can be given to both industrial actors and the public actors charged with ensuring the safety of industrial activity. Communities and stakeholders, as represented in the comments made by those who do not stand to receive direct economic benefit from the project, are not currently granting social license to either the industrial actors or the public actors charged with ensuring the safety of the project. The withdrawal or withholding of SLO from the public entities representing the state may represent the worst possible case scenario in this project. Given that social license is already lacking or tenuous at best, any violation of the safety of communities could be grounds for community withdrawal of social license granted to agents of the state charged with ensuring the safety of industrial activity. Without SLO, the state’s ability to legitimately govern may be hampered significantly.

Based on our analysis, it is clear that public perception of the project can be best understood using the concept of recreancy, or “the failure of institutional actors to carry out their responsibilities with the degree of vigor necessary to merit the society trust they enjoy” (Freudenburg, 1993 909). Without public trust, without social license, any event, even a minor one, would contribute to a loss of state legitimacy via a withdrawal of social license from the public actors tasked with managing the risks that industrial activity poses for communities.

X.2.2 Data and Methods

X.2.2.1 Data Sources

The primary objective outlined in the Scope of Work (SOW) for this section of the report was to provide a comprehensive overview of perceived risk among the communities likely to be impacted in the "worst-case scenario." Drawing upon insights from the field of risk management (Boutilier 2012), it is possible to divide these communities into two categories: *stakeholders* who believe their fate is directly tied to the Straits Pipelines (or a possible "worst-case scenario") and *non-stakeholders* who are either unaware of their relationship with the Straits Pipelines or have no direct relationship. Given the short timeframe to complete our work and the hypothetical nature of a possible "worst-case scenario," it was most effective, efficient, and analytically meaningful to limit our investigation of perceived risk solely to the Straits Pipelines stakeholders while excluding all non-stakeholders from our analysis. This focus on stakeholders was also necessitated by our secondary objective, which was to assess existing risk tolerability and acceptability concerns.

For the reasons outlined above, we interpret these concerns as falling into the SLO category. SLO has been traditionally limited to stakeholder analysis in current risk management literature (Gehman, Lesfrud and Fast 2017). Given our stakeholder emphasis, we chose to analyze public comment data on the DR draft and final Alternatives Analysis reports (2017) because this was the largest and most easily accessible data source available documenting the attitudes these actors currently hold toward the Straits Pipelines.

The abundance and quality of the public comment data allowed us to alter our original approach and streamline our original data collection. To supplement the public comment data, we conducted semi-structured interviews during meetings with the Mackinac County's Emergency Managers and U.S. Coast Guard (USCG) Sector Sault Ste. Marie personnel on May 15, 2018. In addition, we collected original data from representatives of tribal communities as specified below. Although we chose not to utilize all of the data collection methods and sources identified in the SOW, we nonetheless conducted our research pursuant to the approval and guidance received from Michigan Technological University's Institutional Review Board.

X.2.2.2 Public Comments

Public comment data for the DR draft and final reports were generated as part of two 30-day commenting periods that began on July 6, 2017, and November 20, 2017, respectively. However, some respondents submitted their comments shortly before and after the commenting periods. Comments were solicited specifically on the DR reports. However, rather than limiting comments to the DR reports, most respondents also expressed their views on risks associated with the Straits Pipelines, including the DR reports' version of a "worst-case scenario." Such behavior is to be expected given that public commenting periods are viewed in the risk literature as a rare opportunity for members of the general public to insert themselves more directly into the governance process (Moffat, Lacey, et al. 2016). With that in mind, a preliminary review of the DR analysis public comment data confirmed that most commenters were essentially using this forum to hold an unofficial referendum on the Straits Pipelines. As a consequence, we analyzed the resulting public comment data to identify relevant stakeholder communities and to detail their perceptions of the SLO of the Straits Pipelines. Any alternative data collection approach commonly used in risk studies (surveys for example) would have required significant resources, while other forms of publicly engaged data collection would have required the time necessary to conduct multiple stakeholder focus groups in distant locations while yielding dramatically reduced data points for analysis (Yates and Horvath 2013).

Although the public comment data were deemed the most appropriate source of data for our purposes, there are three issues with these data and its analysis that must be acknowledged to interpret our results properly. First, these data are only representative of those who participated in the public commenting process and not the general public as a whole. That means it is reasonable to infer from these data to those who commented on the alternatives analysis but not any other group of interest, such as voters or residents of the State of Michigan. We believe this is an acceptable data limitation because our analysis goal was to assess risk perceptions among the Straits Pipelines stakeholders rather than all actors who could possibly be impacted by a "worst-case scenario." Actors who took the time to provide a comment on the DR reports qualify as stakeholders because the act of providing a comment is a clear indication that said actor perceives their fate to be interdependent with the Straits Pipelines. This is akin to a revealed preference in economic analysis, which is considered more stable and reliable than a stated preference obtained from a survey (Wardman 1988). Thus, it is reasonable to say that the public comment data from the DR analysis are highly representative of at least the most active or vocal members of the Straits Pipelines stakeholder population. Analyzing this population rather than the general public also makes the most sense from a risk analysis perspective because it is these actors who will play the dominant role in determining whether to revoke or grant SLO if a "worst-case scenario" were to materialize (Moffat, Zhang 2014).

The second limitation of analyzing the Alternatives Analysis public comment data is that these data were generated based on a very particular and specified purpose, while the comments themselves and the analysis conducted here are both more general and differently directed. Commenters were specifically asked to discuss the DR reports and were not prompted to say anything about the Straits Pipelines or DR's "worst-case scenario." Methodologically speaking, this is problematic because it leaves open the possibility that the subject of inquiry for our analysis will fail to arise in the data at all. This turned out not to be the case because, as mentioned above, many Line 5 stakeholders used the public comment forum as a means to gain some influence over the governance process. This makes the data available for analysis from these public comments equivalent to data generated from an open-ended interview or survey question, which is known to produce a more genuine (or less artificial) response than prompting individuals to express attitudes toward a subject that may be unfamiliar or unimportant to them (Dillman, Smyth and Christian 2008). Furthermore, the fact that commenters voluntarily supplied unsolicited views on the Straits Pipelines indicates that their views are strongly held with a high degree of veracity, at least among the most active and vocal stakeholders likely to have the greatest impact on SLO in a "worst-case scenario." It is certainly possible that some commenters withheld views on the Straits Pipelines because they were not specifically asked to comment on this topic, but we consider this to be a minor limitation in the data since our inferences are restricted to the most active and vocal stakeholders exclusively. With this caveat in mind, we believe the Alternatives Analysis public comment data are sufficient to highlight the magnitude of a possible SLO revocation threat during a "worst-case scenario" and to outline factors that could potentially catalyze such an event.

The third limitation of the public comment dataset is the difficulty of data verification. In the course of our preliminary analysis, we flagged a significant number of digitally submitted comments on the basis of their authors' authenticity. There were four distinct subsets of such comments that had identical content, unusual formatting, rapid submission time, submission errors, unlikely names that included profanities, and other anomalies. To determine if these comments were in fact submitted by real people, we identified and contacted a subset of 25 individuals. These individuals were contacted by phone. Four individuals confirmed their identity. None of these individuals explicitly said that they made the public comment and one individual stated that they did not make the comment and would not have made the comment. The remaining three individuals said that they supported pipelines and seemed to indicate that a comment could have been made on their behalf based on a group affiliation. They were not able to cite a specific petition or comment period in which they had participated and would have made their comments. We were unable to determine the exact origin of the comments and the source from which the identities were obtained. However, we suspect that a mailing database or a voter registry was utilized.

In addition to the four datasets, a series of 884 comments were submitted by an organization self-identified as CEAM. Each page of the PDF file contained identical comments, closely matching the text of the aforementioned questionable comments and featuring the same format of names and addresses. We searched the Michigan Department of Licensing and Regulatory Affairs' (LARA) corporation database, as well as other online public databases but were unable to obtain any additional information about CEAM. After analyzing these submissions, we deemed 2,020 comments as questionable on the basis of their authenticity. All of these comments were in support of the Straits Pipelines. We did not find any questionable comments opposing the Straits Pipelines. The comments with authenticity concerns were not excluded from the quantitative analysis but were flagged as such. The four aforementioned sets of questionable comments were excluded from the qualitative analysis, but the comments submitted on behalf of CEAM were not.

X.2.2.3 Quantitative Overview of Perceived Risk
With the above analytical limitations in mind, we now describe the data used in the analysis for this section of the report. The Alternatives Analysis public comment data were obtained from the State of Michigan Attorney General's office in early March 2018. These public comments were originally sent directly to the MDEQ in hard-copy or e-mail form, transcribed during public hearings, or posted online to the Michigan Petroleum Pipelines website during the available 30-day public commenting periods that began on July 6, 2017, and November 20, 2017. A total of 44,966 individual comments were received (see Figure X1). Of these, 43,728 comments (or 97.2%) were submitted online, 10,835 (or 1.9%) were submitted as postcards, 353 comments (or 0.8%) were mail submissions primarily in the form of a written letter, and four comments (less than 0.02%) were obtained during public hearings. Individuals working for the Michigan Attorney General's Office aggregated all of these public comments into a single Excel spreadsheet that included (when available) the original text of the comment, the name and/or contact information of the person responsible for the comment, the comment's submission date and type, the organizational affiliation of the person submitting the comment, and any attachment or supplementary materials supporting the comment itself. This digital file of aggregated comments along with hard copies of all the original comments was then sent to our research team for analysis.

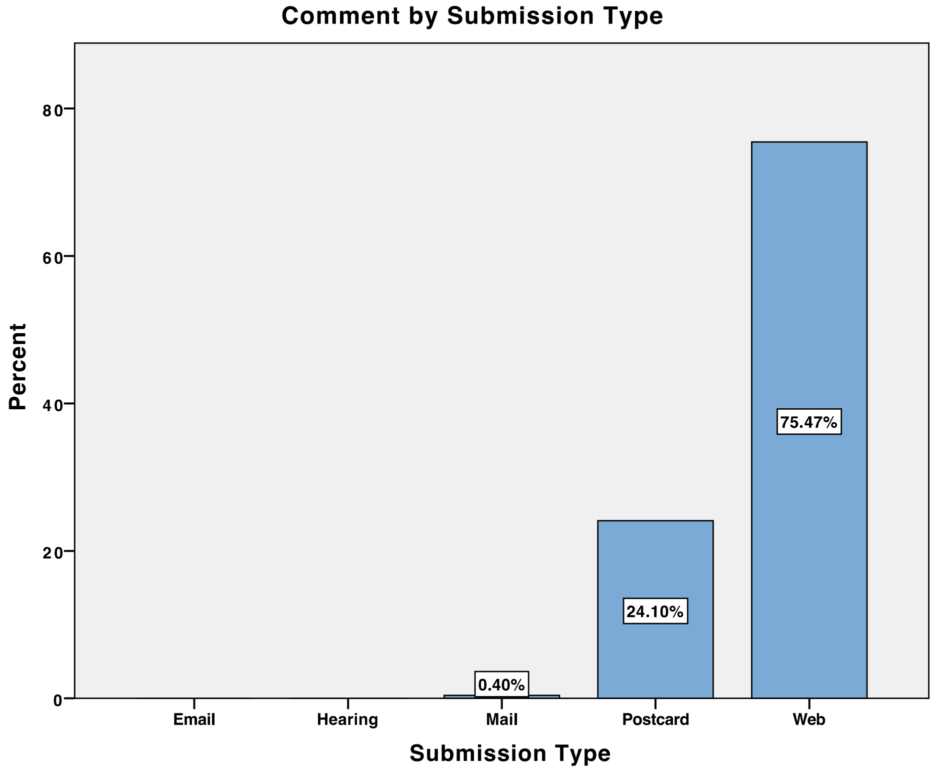

Figure X1: Comments by Submission Type

Some of these comments were submitted directly to the public comment website, while others were submitted as linked attachments via that same website. The differentiation between posted comments and attached documents required that these two forms of comments be analyzed separately, as one form (online posts) were copied verbatim for textual analysis while the second form (document attachments) were opened for individual thematic analysis prior to aggregation of themes via formative coding and analysis.

Organized groups submitted other comments as postcards. For example, Clean Water Action submitted 10,680 postcards and Patagonia submitted 109 postcards signed by individuals opposed to the Straits Pipeline. These postcards were not included in the text content analysis. CEAM submitted 884 form letters in a PDF file. An additional 1,136 comments submitted by unaffiliated individuals are marked as problematic in terms of their authenticity.

X.2.2.4 Qualitative Overview of Perceived Risk

Our preliminary analysis of the comments showed that the vast majority of individual respondents and some institutional respondents chose to extend the scope of their responses beyond the DR reports. More specifically, these respondents commented on the risks associated with the operation of the pipeline, the benefits it brings to them, their communities, and the state of Michigan. In addition, the respondents frequently weighted the perceived risks against the perceived benefits as a way to express their support or opposition for the pipeline.

For detailed analysis, we selected 603 comments that contained substantive statements regarding the risks and benefits posed by the Straits Pipelines, 518 of which were submitted by individuals and 85 by organizations and entities. The responses submitted by individuals included those of “lone individuals” (having no apparent organizational affiliation) and those of individuals who joined group petitions. Because our focus here was on obtaining a qualitative picture of risk, our analysis concentrated on the content of the responses and not on the number of respondents commenting on a particular point or issue. This approach also allowed us to avoid drawing quantitative conclusions based on the analysis of a biased sample of Michigan’s population consisting of individuals whose identities we were not always able to confirm. Thus, for the purposes of this qualitative analysis, we focused on the responses in the form of uniquely worded points of view and statements irrespective of the number of respondents. Accordingly, for the qualitative analysis, we treated thousands of identical comments submitted under the banners of Oil & Water Don't Mix, CEAM, Clean Water Action, and others as one comment.

The comments submitted by individuals tended to focus on the perceived risks and the tolerance thereof, whereas the comments submitted by organizations and entities tended to critique the reports. Our preliminary analysis also showed that despite this difference, the responses by both groups provide their takes on the SLO. Thus, we framed our inquiry into responses submitted by individuals pursuant to the following research question: “In what ways and to what extent do risks perceived by the individual respondents and their willingness to tolerate them affect SLO in the context of the Straits Pipelines?” We framed our inquiry into responses submitted by organizations and entities pursuant to the following research question: “In what ways and to what extent do responses to the DR reports by entities and organizations affect SLO in the context of the Straits Pipelines?”

To answer these questions, we employed complementary and corroborative discourse and content analyses to evaluate and assess the data (Babbie 1999). We drew upon Grounded Theory, an inductive methodological approach to qualitative research that grounds the conceptualizations and patterns in data. Grounded Theory relies on a constant comparative analytical process that involves the following steps: (i) comparing the relevant data to each conceptual category; (ii) incorporating the categories and their properties; (iii) identifying the limits of the emerging pattern; and (iv) refining the emerging concept (Strauss 1987).

Although we maintained the same overarching Grounded Theory methodology for all parts of our qualitative analysis, because of the differences in the content of responses submitted by individuals and organizations, we applied divergent approaches to these data analyses. For responses submitted by affiliated and unaffiliated individuals, we performed several rounds of analysis in NVivo software using a combined axial and open code approach. We coded the data contained in 518 comments submitted by individual respondents in the context of risk identification using the categories from the SOW: Worst Case Scenario, Fate & Transport, Cleanup Timeline, Public Health, Ecological Impacts, Restoration, Natural Resource Damage, and Governmental & Public Costs. We also coded the data in the context of risk tolerance and acceptance by using an open code approach, ultimately arriving to the following categories: Additional Risks, Conditions for Managing Risks, Managing Risk Successes, Managing Risk Difficulties, Lack of Offsetting Benefits, Presence of Offsetting Benefits, Risk-Benefit Analysis by Proponents, and Risk-Benefit Analysis by Opponents.

To gain a better understanding of the patterns behind these categories, we conducted open coding within each category, resulting in several subcategories. We describe these subcategories in the Results subsection below. In the course of our analysis, we reached a preliminary conclusion that trust in Enbridge, the oil and gas industry, and the State government was a major factor behind respondents' acceptance of risks posed by the Straits Pipeline. For this reason, we performed content analysis of the data using keywords to identify references to the Kalamazoo River spill and affiliation with the oil and gas industry among individual respondents.

For responses submitted by organizations and entities online in the form of a document, the attachment was analyzed separately by examining the substantive content of each document to extract and aggregate emergent themes. The data included 185 individual attachments, many of which contained duplicate submissions from organizations (for example, one attachment included 20 postcards scanned into pdf and submitted by Clean Water Action, while another attachment included 16 comments from students in Traverse City). After elimination of duplicate and non-substantive attachments (such as multiple submissions of the same postcard provided by an organized entity), 60 substantive comments were included in the analysis. These data were not analyzed quantitatively, as they are not representative of a larger population and thus do not lend themselves to quantitative analysis. The themes that emerged, however, raise significant considerations for any potential quantification of a "worst-case scenario." The results of this analysis are described below in section X.3.4.

X.2.2.5 Tribal Concerns

The State of Michigan is home to twelve federally recognized sovereign Tribal Nations:

- Bay Mills Indian Community
- Grand Traverse Bay Ottawa and Chippewa Indians
- Hannahville Potawatomi Indian Community
- Keweenaw Bay Indian Community
- Lac Vieux Desert Band of Lake Superior Chippewa Indians
- Little River Band of Ottawa Indians

- Little Traverse Bay Band of Odawa Indians
- Match-E-Be-Nash-She-Wish Band of Pottawatomi Indians Gun Lake Tribe
- Nottawaseppi Huron Band of Potawatomi
- Pokagon Band of Potawatomi
- Saginaw Chippewa Tribe
- Sault Ste. Marie Tribe of Chippewa Indians.

We deem the concerns of these Tribal Nations related to the Straits Pipelines of great importance for the following reasons. First, Tribal communities are highly vulnerable risk bearers in the state of Michigan. Lake Michigan is not only a historically, economically, socially, and culturally significant site for Tribal communities, where natural resources such as fish and wild rice are harvested, but Lake Michigan is also considered fundamental to Tribal identity. Second, as sovereign nations, Tribal communities have legal rights that extend beyond those of the general public. The 1836 Treaty of Washington guaranteed Tribes the right to "access traditional fishing areas and catch fish" within the treaty-ceded waters of Lake Huron, Superior, and Michigan, including the Straits of Mackinac (Chippewa Ottawa Resource Authority (CORA) 2015). Third, the cultural heritage and traditional ecological knowledge of Tribal communities, for example, intergenerational communication of traditional ecological knowledge, is not usually captured by modern scientific or economic measures. The financial and cultural costs assumed by Tribal communities from a worst-case petroleum release would be immeasurable and are not factored into typical response and restoration plans.

To understand Tribal concerns the regarding the "worst case scenario" in the event of a petroleum release from the Straits Pipelines, we conducted a discourse analysis of correspondence between Michigan's Tribal communities and the Michigan Petroleum Pipeline Task Force. Similar to the qualitative analysis described above, these data were coded pursuant to eight categories derived from the structure of the SOW. We chose to analyze Tribal comments in a similar manner as comments submitted by individual respondents because the Tribal Nations offered a particularly distinct (from other organizations and entities) take on DR's reports.

In addition, we sent letters to the aforementioned Tribal Nations asking for their inputs within the scope of Section X SOW. In these letters, we sought feedback from Tribal leaders regarding how they would define a worst-case event and how a worst-case oil spill would affect their community, their environment, and their lifeways. These letters were sent to Tribal leaders through posted mail and email. This correspondence resulted in a dialogue with representatives of the Bay Mills Indian Community, Keweenaw Bay Indian Community, the Little River Band of Ottawa Indians, and the Little Traverse Bay Band of

Odawa Indians. Additionally, the Section X team gave presentations at Keweenaw Bay Indian Community and the United Tribes of Michigan meetings in May 2018.

X.3 Analysis

X.3.1 Quantitative Overview of Perceived Risk

Using the full aggregated data, it was possible to gain some broad insights into the risk perceived by the respondents in connection with the Straits Pipelines. For example, we saw that attitudes toward the Straits Pipelines were relatively negative (see Figure X2). Ninety-five percent of the submitted comments were opposed to the Straits Pipelines or were more concerned about a possible "worst-case scenario" than the potential benefits of the pipelines, with just under 5% in support or more focused on the benefits. Support drops even further to just 2.5% when excluding questionable comments (see Figure X3).

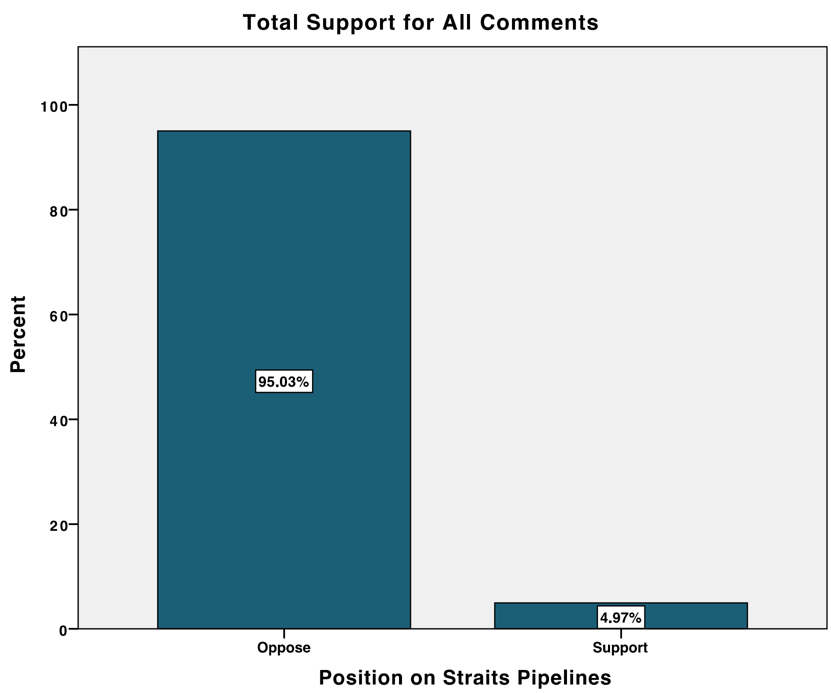

Figure X2: Total Support among all Comments Submitted

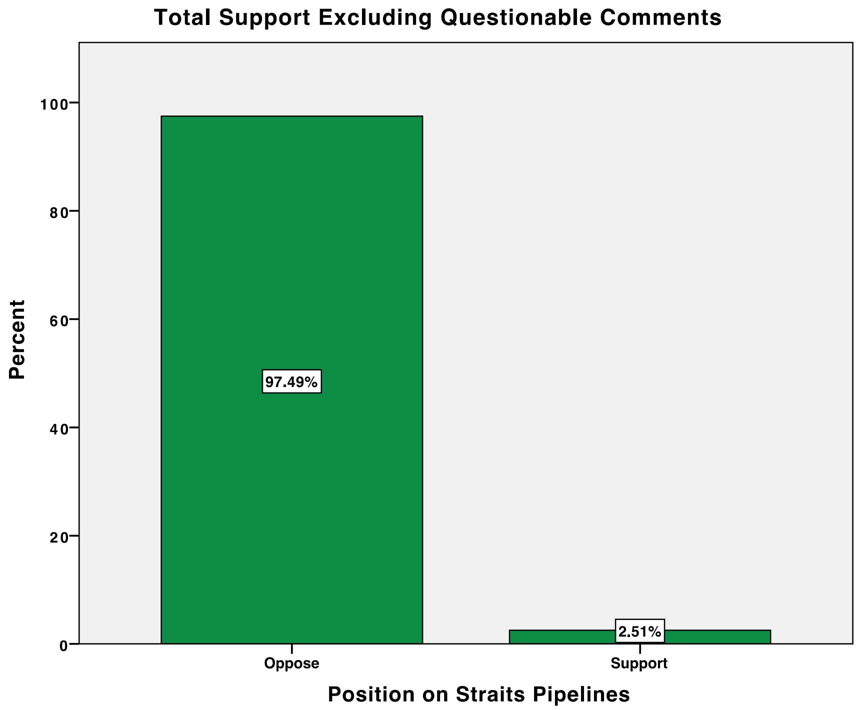

Figure X3: Support among All Comments Excluding Questionable Comments

Further details emerge when examining the distribution of who was responsible for submitting these comments (see Figure X4). For example, we saw that lone individuals with no organizational affiliation submitted 592 comments (or 0.01%) while 44,372 comments (or 98.7%) were submitted on behalf of the following stakeholder organizations: Oil & Water Don't Mix (30,110 comments or 67%), Clean Water Action (11,849 comments or 26.4%), CEAM (884 comments or 1.9%), Patagonia (109 comments or 0.2%), Benefits of Line 5 (69 comments or 0.2%), Great Lakes Business Network (53 comments or roughly 0.1%), No Oil in Our Waters (46 comments or 0.1%), and For the Love of Water (34 comments or roughly 0.1%). Roughly 100 additional organizations submitted just a single comment or two. 1,134 comments (or 2.5%) were determined to have authenticity concerns. Finally, individuals affiliated with the following institutions submitted the remaining 85 comments: Tribal associations (18 comments), members of the petroleum industry (14 comments), local and regional governing bodies (10 comments), and other organizations with no obvious discernible affiliation pertinent to the Straits Pipelines (43 comments). This breakdown of commenter type is evidence of high organizational influence underpinning the SLO of the Straits Pipelines; in this case, organizations throughout the state actively engage with informing SLO.

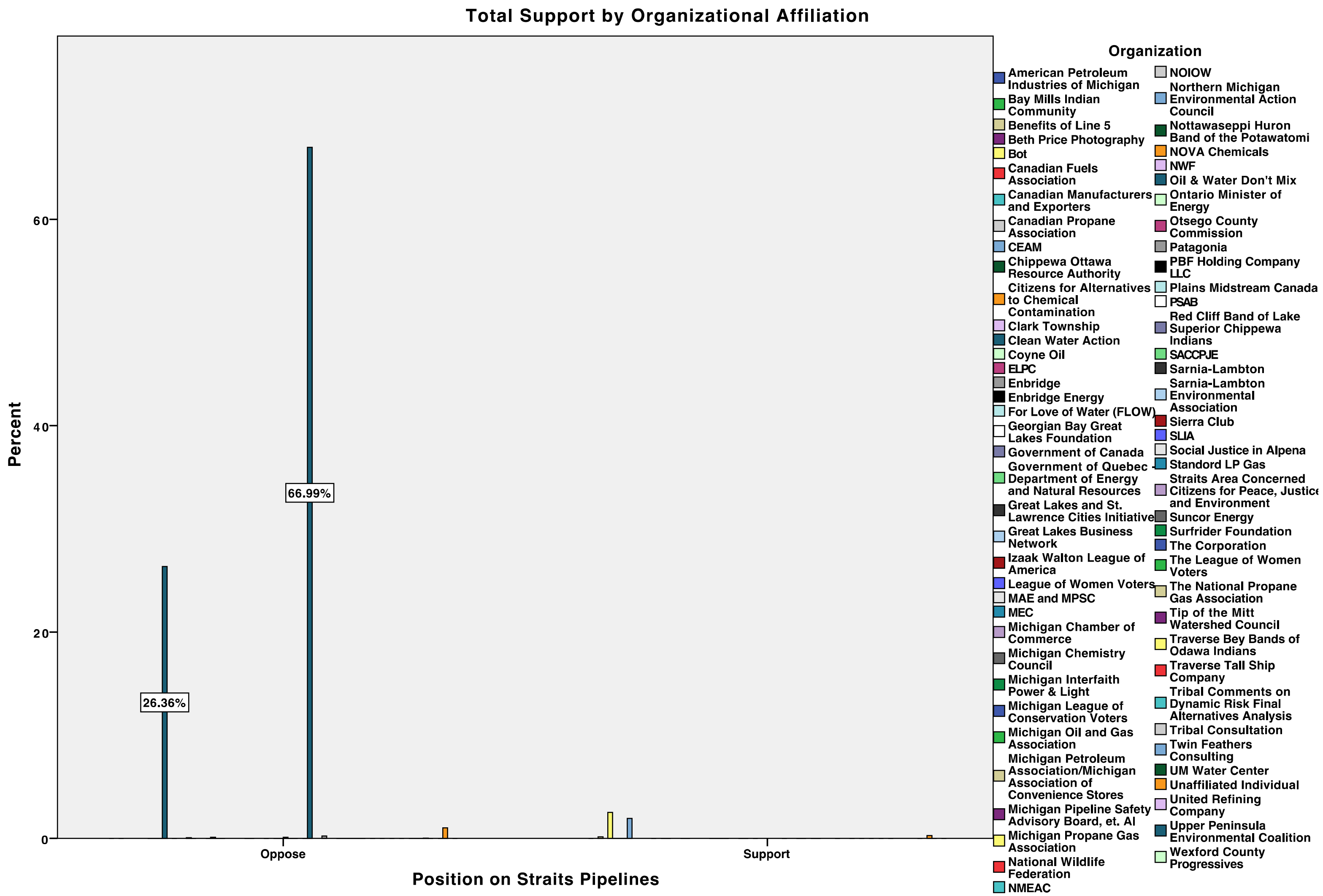

Figure X4: Comment by Organizational Affiliation

The fact that comments submitted by an organization on behalf of individuals greatly overwhelmed purely individual comments by a margin of nearly 100 to 1 tells us that the groundwork is already in place to both activate and institutionally support efforts to invoke SLO in the "worst-case scenario." Using the mission statements of the organizations party to these comments, it is possible to further disaggregate into proponent and oppositional groups. Organizations that submitted more than just a single comment who fell into the proponent group category include CEAM (874 comments) and Benefits of Line 5 (69 comments). The proponent group also includes 30 organizations who submitted just a single comment, such as the American Petroleum Industries of Michigan, the Ontario Ministry of Energy, the Michigan Oil and Gas Association, and all other organizations with a clear connection to the fossil fuels industry. Organizations that submitted more than a single comment who fell into the opposition group category include: Oil & Water Don't Mix (30,110 comments), Clean Water Action (11,849 comments), Patagonia (109 comments), the Great Lakes Business Network (53 comments), No Oil in Our Waters (46 comments), and For the Love of Water (34 comments). There were an additional 34 organizations who submitted just one or two comments which would also be considered opponents. Of the comments submitted solely on behalf of organizations, 42,254 comments (or 97.7%) came from opposition groups, with only 974 comments coming from proponents (excluding questionable 1,134 comments in support of the Straits Pipelines).

When examining the comments of unaffiliated individuals while excluding questionable comments and comments submitted on behalf of an organization or otherwise institutionally affiliated (see Figure X5), a different breakdown in SLO emerges. To analyze these comments, we first reviewed all 592 individual comments and coded each as either "for" or "against" the Line 5 Pipeline based upon whether the comment focused primarily on the positive benefits of Line 5 or its potential for environmental or social harm (a neutral category was also used in the rare case in which the comment lacked a clear attitudinal position). Using this coding scheme, we saw that 78.57% of the comments came from individuals opposed to Line 5 while 21.43% came from proponents.

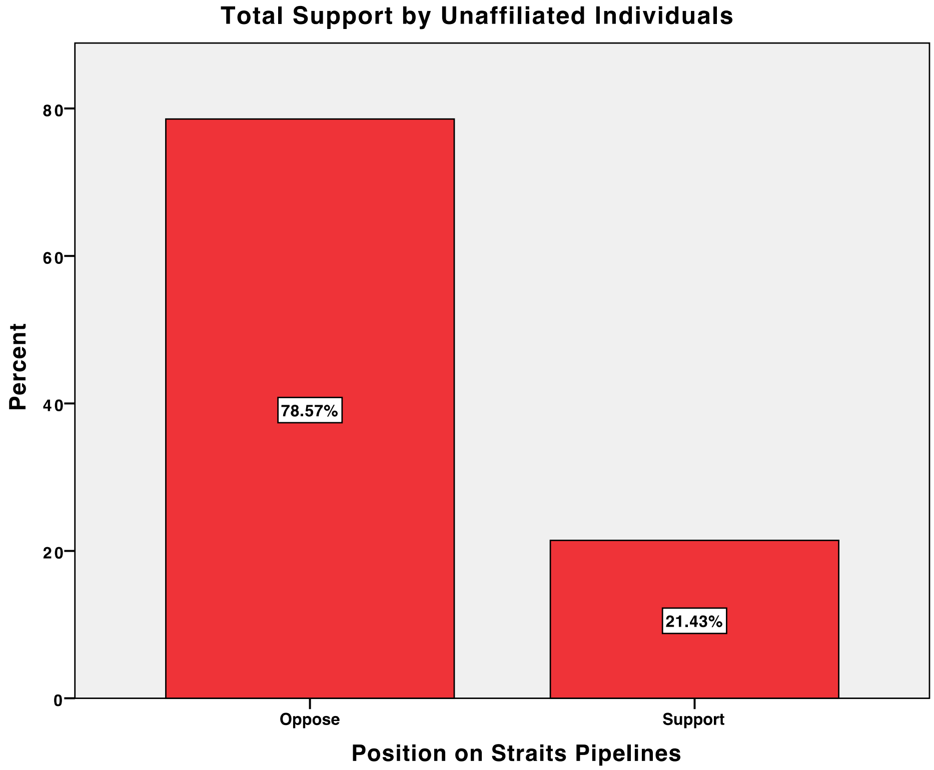

Figure X5. Support among Individuals without an Organizational Affiliation

X.3.2 Qualitative Overview of Perceived Risk

X.3.2.1 Risk Identification by Individual Respondents

As noted above, responses by individual commenters in the form of uniquely worded points of view and statements were made the unit of this analysis. We analyzed these responses using a combined axial and open-coding method, as specified in the Approach subsection. To avoid confusing the results of our quantitative and qualitative analyses that rely on divergent units, we employ a scale showing the prevalence of views, issues, and attitudes in connection with perceived risks from the Straits Pipelines depicted in Table X1.

Table X2. Statement prevalence scale.

Prevalence	Number of Statements Per Subcategory
Low	1-3
Moderate	4-10
High	11-20
Very High	Over 21

X.3.2.2 Worst-Case Scenario

Respondents viewed a worst-case scenario resulting from a release of a product transported through the Straits Pipelines in a binary manner. The respondents who supported the pipeline did not consider a worst-case release a possibility. Correspondingly, their comments did not contain any references describing environmental, economic, and public health impacts of a release. Thus, for these respondents, there is no worst-case scenario because there is no pipeline failure resulting in a product release.

The respondents who opposed the Straits Pipelines and offered their take on a worst case scenario did so in unequivocally grave terms. “Ruin,” “catastrophic,” “one of the biggest man-made disasters in history,” “a serious threat to our lives and our health,” “a disaster waiting to happen,” “monumental, catastrophic damage,” and “annihilation of the most precious place on [E]arth” were among such terms. Descriptions of a worst-case scenario are very prevalent in this category.

Respondents offered comparisons to other hydrocarbon spills, including the 2009 Deep Water Horizon spill in the Gulf of Mexico and the 2010 Enbridge Kalamazoo River oil spill. A high number of statements describe potential sources of failure, the most prevalent being an anchor strike, followed by vandalism and terrorism. A combination of several factors contributing to a pipeline failure, such as the age and general fatigue of the pipeline, received moderate attention. Respondents saw a worst-case spill extend from Northern Michigan to Lake Michigan and Lake Huron to the entire Great Lakes region. A moderate number of statements conclude that Enbridge is taking chances operating the Straits Pipelines, or as one respondent wrote: “The 1 in 60 chance of a failure in Line 5 is meaningless information by itself. It compares to playing Russian roulette with a 60-shot revolver and one bullet.”

X.3.2.3 Fate and Transport and Cleanup Timeline

Perhaps due to the difficult technical nature of fate and transport analysis, the statements for this category are limited to the geographic extent of a potential petroleum release. As we noted above, respondents saw contamination from a potential release affecting the area extending from Northern Michigan to the entire Great Lakes region. A few respondents referred to the 2016 study by Dr. David Schwab as the basis for their views.

Respondents’ views regarding a timeline for a worst case cleanup resemble a mix of misconceptions and legitimate concerns. A moderate number of statements point to a lack of appropriate equipment, lax legal and regulatory framework, and impossibility of cleanup operations during winter as significant barriers to an effective response to a petroleum release. Although these factors can complicate cleanup activities, a shortage of particular equipment for particular weather conditions, for example, they are unlikely to pose insurmountable barriers to an oil spill response.

However, a higher, albeit still a moderate number of responses, cite legitimate concerns regarding the speed and effectiveness of cleanup activities in the event of a petroleum release from the Straits Pipelines. Lack of expertise in oil spill response in fresh water, intricate shoreline configuration, vegetation, access, and icy winter weather conditions, as well as a history of delayed responses to spill events, are among such concerns.

X.3.2.4 Public Health, Ecological Impacts, and Restoration
A low number of statements refer to specific public health impacts such as health implications related to exposure to toxic substances, including carcinogens and mental health issues due to loss of jobs, declining property values, and so on. However, a very high number of statements note the critical importance of clean drinking water for public health.

Statements in the Ecological Impacts category tend to represent general concerns for the Great Lakes ecosystems. In particular, a few statements mention potential damage to fish and bird (including migratory bird) species, as well as the habitats that they occupy. A few statements note the ecological sensitivity of the Great Lakes region.

A low number of statements in the Restoration category center on the irreversibility of damage in the event of a petroleum release and awesome difficulties of restoring affected human and natural systems. A few statements refer to the 2009 Deep Water Horizon spill in the Gulf of Mexico and the 2010 Enbridge Kalamazoo River oil spill as evidence of such difficulties.

X.3.2.5 Natural Resource Damage
Concerns over the integrity of 21% of the world's fresh water supply dominate the statements regarding natural resource damage (EPA 2018). Respondents emphasized the value of fresh water in light of its growing scarcity in many parts of the world. A respondent wrote: "We are fortunate to be near so much of it in a time when much of the world is grappling with scarcity and extreme pollution." Respondents also linked the importance to the health of Michigan's economy, environment, and communities. In addition, a low to moderate number of statements highlight the risk posed to Great Lakes fisheries, beaches, and watersheds, and the overall natural beauty of Michigan.

X.3.2.6 Government and Public Costs
The greatest number of statements coded pursuant to the SOW categories elaborate on the governmental, public, and private costs of a worst-case spill. Within this category, the least prevalent statements are regarding high cleanup costs, costs associated with the loss of drinking water, "brain drain" due to potential economic and environmental impacts, and loss of tax revenue. In addition, a few respondents feared negative impacts on livelihoods of "millions of people," community services, commercial shipping, as well as job losses. A moderate number of statements express concern about government and public cost allocation. The responders noted that these costs would be borne by Michigan's taxpayers and businesses. A moderate number of statements also focus on the loss of private and government revenue due to disruption of commercial and recreational boating, plummeting property values, costs associated with the overall decline of Michigan's economy in the event of the spill, and losses incurred by local businesses.

A high number of statements estimate costs associated with a worst-case scenario. Some respondents offered rather abstract estimates, "costing billions" and "priceless" for example. Others were more precise in their assessment of costs associated with a worst-case scenario citing studies (e.g., by the Brookings Institute) and reasonable comparisons to the cost of the 1990 Exxon Valdez oil spill. Yet even the most abstract estimates are not without merit, as the valuation of damages is inherently subjective.

A high number of statements reflect on the costs of a tarnished Pure Michigan brand, which the state and the tourism industry have been cultivating for over a decade. Some tied the brand to potential losses to the tourism industry, whereas others emphasized the costs associated with the damage to the state's image. "One spill anywhere in the Great Lakes, especially in the Straits of Mackinac, and 'Pure Michigan' becomes 'Putrid Michigan' in the eyes of tourists." "Pure Michigan, but for how long?" These sharply worded statements capture the essence of the sentiment expressed by both groups.

Unsurprisingly, a very high number of statements elaborate on the costs associated with potential losses to the tourism industry. The general concern about the fate of tourism in Michigan is captured in the following statement: "I've been in the tourist industry for 32 years and I can tell you for a fact that once potential visitors to the Michigan shores hear the words 'oil spill' and 'Michigan,' they will instantly look elsewhere to vacation." Many statements show deep and first-hand understanding of this sector of Michigan's economy, explaining the ripple effect that a petroleum release might have on local stores, restaurants, and other businesses.

X.3.2.7 Additional Risk Considerations

As we noted above, our preliminary analysis showed that the scope of risks perceived by respondents extends well beyond the SOW categories. This prompted us to create a separate category, the contents of which we describe below.

A few statements assert that a petroleum release from the Straits Pipelines will be what one respondent described as "the final nail in [t]he [c]offin,", significantly adding to the pollution from other sources. In addition, a few statements raise concerns over a sudden interruption of pipeline service, and transportation of propane in particular, due to an accident. This concern reframes one of the main benefits of the Straits Pipelines to Michigan's Upper Peninsula – delivery of propane to the Rapid River processing facility as one of the risks posed by overreliance on a single means of propane transportation.

A moderate number of statements note the climate change implications associated with continuing use of liquid fossil fuels, some of which are delivered to the market via pipelines. Many respondents framed this concern as a lack of offsetting benefits of the Straits Pipelines, as we discuss in more detail below. A few respondents noted that further investment in the Straits Pipelines raises the risk of stranded assets due to the transition to renewable energy sources. A few statements note respondents' concerns over the suitability of the Straits Pipelines for transportation of oil sand-based petroleum products, which is not currently relevant due to the State of Michigan's 2015 ban on transportation of heavy petroleum products through Line 5.

A high number of statements express lack of trust in the oil and gas industry and Enbridge in particular. Combined with comments of 49 individuals who indicated their lack of trust in the company after the 2010 Kalamazoo River spill (discussed in more detail below), it is reasonable to foresee the sentiment over lack of trust in Enbridge and the oil and gas industry growing and taking more confrontational forms.

A high number of statements indicate that the risks posed by Enbridge's Line 5 are not limited to the Straits of Mackinac. A few respondents noted that a worst-case scenario could happen virtually anywhere along the pipeline's route in Michigan, as it crosses many wetlands, streams, and watersheds connected to the Great Lakes on its way from Wisconsin to Canada. Several respondents identified particularly sensitive spots: the Inland Waterway along with Mullet Lake and the Indian River; upper Black River and Cheboygan River; Burt Lake; and Lake Michigan and its tributaries along U.S. Highway 2 in the Upper Peninsula. The latter location emerged as the worst case location during our meetings with USCG personnel and Mackinac County emergency managers. When asked (independently) about their opinions about a worst-case scenario, the USCG personnel, and emergency managers did not describe particular circumstances or conditions of a petroleum release from the Straits Pipelines. Instead, both pointed to the stretch of the pipeline along U.S. Highway 2 near Lake Michigan's northern shore as their worst-case scenario. The emergency managers cited a combination of less robust technology – pipeline wall thickness and monitoring equipment, as well as higher vulnerability to an errant strike. The USCG personnel cited potential access problems for containment and cleanup equipment, as well as difficult terrain and environment for cleanup activities.

Concerns over Michigan's reputation, image, and heritage and the collective identity of Michigan citizens appear in a high number of statements. One respondent wrote that a petroleum release in the Straits will be "the death knell for the credibility of our state administration and our national reputation", whereas another noted that such an event will exacerbate the negative reputation effect of "the Flint water disaster." A few respondents stated that the bad memory of a spill and negative emotions associated with it would last well beyond the end of cleanup activities. Other responders linked the Great Lakes to the identity of every Michigander.

A very high number of statements identify future generations as risk targets. Many respondents felt responsible for preserving Michigan's natural resources for their children and grandchildren, and some felt outright shame about endangering their future. Some saw the continuing operation of the Straits Pipelines as a gamble with the livelihoods of future generations. A number of elementary school students submitted comments through their teacher. One student asserted her right to weigh in on her future as follows: "Finally, I know I am just a kid, but everyone, even kids, should have a chance to speak, and that is why I think we should shut down Line 5."

State government's credibility emerged as the most prevalent additional risk concern. A very high number of statements indicate disappearing trust in the state government handling the Straits Pipelines issue. Many statements have strong recreancy undertones (we discuss this concept in more detail below) while calling on the State of Michigan to exercise its duty as a public trustee. Some respondents questioned the motivation behind decisions made by key state officials and demanded more transparency. A few respondents called for a multi-state coalition to decide the future of the Straits Pipelines, and a few cited legal grounds for prioritizing the Great Lakes over other considerations. The high prevalence of these types of statements combined with the heightened rhetoric significantly adds to a worst-case scenario.

X.3.3 Qualitative Overview of Risk Tolerance by Individual Respondents

In the course of our analysis, we discovered that respondents based their tolerance and ultimately acceptance of risks associated with the Straits Pipelines on the following factors: (i) Enbridge's ability to manage risks; and (ii) presence or absence of benefits from the Straits Pipelines. Drawing upon these preliminary findings and our analysis of perceived risks, we identified statements where supporters and opponents weighted perceived risks against perceived benefits.

Pipeline proponents pointed to the company's investments in the Straits Pipelines and the overall safety of pipelines compared to other means of transporting oil and petroleum products (low prevalence). One respondent used the 2010 Kalamazoo River spill as an example to show that Enbridge acted in a responsible manner managing the consequences of the spill. A high number of statements cite recent hydro test as evidence of the pipeline's safety and the safe operational record of the Straits Pipelines over the course of its lifetime. "Enbridge has been safely delivering energy through the Straits for 64 years without incident" – this statement exemplifies the sentiment expressed by the proponents regarding Enbridge's operational record in the Straits. The highest number of statements in this category refers to Enbridge's maintenance, preparedness, and training activities as means of managing the risk of a petroleum release. Respondents commented on the ongoing safety drills, preventive maintenance, use of advanced equipment, safety protocols exceeding government standards, employee and contractor training, availability of containment and cleanup equipment and oil spill response personnel, and constant monitoring. One respondent attributed the high level of preparedness to the constant public attention to the Straits Pipelines: "This is one of the most watched, tested, inspected, etc. pipes because it's so controversial."

Pipeline opponents argued along the same lines but drew diametrically opposing conclusions to support their points about Enbridge's problems managing risks associated with the Straits Pipelines. A moderate number of statements deem oil pipelines ultimately unsafe by pointing to a few recent accidents, including the 2010 Kalamazoo River spill and the 2015 Refugio oil spill. A high number of statements refer to Enbridge's poor record of maintaining the Straits Pipelines. Respondents were particularly alarmed by the absence of a number of support anchors that are required to be placed not less than every 75 feet under the terms of the easement. Whereas the proponents saw 64 years' worth of accident-free pipeline operation as evidence of reliability, the opponents were alarmed by the pipeline's age. In contrast with pipeline proponents, the opponents shifted the focus of Enbridge's safety record from the Straits to Line 5 and the company's operations in general. A very high number of statements refer to Enbridge's oil spill and leak history, and the 2010 Kalamazoo River and 1999 Crystal Falls NGL spills in particular, to raise concerns about the company's ability to operate the Straits Pipelines safely. These past accidents also raised concern among many respondents regarding Enbridge leadership's commitment to safety. A high number of statements question the leadership's ability and motivation. As one respondent put it: "Enbridge has shown time and again, that they put profits over the health of people and safety of our environment."

Some respondents took a more conciliatory approach and offered their conditions for risk acceptance. A moderate number of statements suggest rerouting, mandatory insurance or bond, referendum, and/or replacement as conditions for continuing operation of the Straits Pipelines. The most prevalent statements resemble engineering solutions, such as double- and triple-walling, a tunnel, or suspending the pipeline under the Mackinac Bridge.

The proponents noted a wide array of benefits while articulating support for continuing operation of the Straits Pipelines. A few respondents mentioned environmental benefits such as the comparatively safe and efficient method of transporting oil and petroleum products. A low number of statements point to the financial support that Enbridge has been providing to Michigan communities. A moderate number of statements note the jobs that Enbridge provides within the company and the jobs it supports within the oil and gas industry. Several respondents highlighted the importance of the Straits Pipelines as a critical part of Michigan's energy infrastructure, albeit without providing many further details. A moderate number of statements emphasize the tax revenue that Enbridge contributes to the state, the importance of the Straits Pipelines for transporting instate-produced oil, and the low oil and petroleum product prices that are allegedly due to the Straits Pipelines. A moderate number of statements also note the benefits to Canada and its economy and general contributions to Michigan's economy. A high number of statements refer to the Straits Pipelines as indispensable for moving energy through the State of Michigan, including supplying the Upper Peninsula with propane. Some respondents pointed to dramatic increases in propane costs should Line 5 be decommissioned. "Being a resident of the UP, I can't begin to think how much our home heating would cost if it weren't for Enbridge" – wrote one of the supporters.

A few pipeline opponents pointed out the vulnerability of the benefits that the Straits Pipelines provide in case of a sudden interruption of service. A moderate number of comments state that the propane supply benefits are grossly exaggerated and the Upper Peninsula's needs could be met via alternative options, including a smaller dedicated pipeline. Many respondents (high prevalence) saw very little benefits for the State of Michigan compared to the profits received by Enbridge and benefits for the Canadian economy. As one respondent wrote: "Only a small percentage of the oil and gas that goes through the pipeline ends up in Michigan." "Enbridge and its products moving through Line 5 make only a small contribution to Michigan's economy" – wrote another respondent. The overwhelmingly largest number of statements question the very reason for the Strait Pipelines existence transporting oil. Many respondents saw fossil fuels becoming obsolete in light of climate change and the proliferation of renewable energy technologies. One respondent stated, “Do we need this pipeline at all? How else can we meet our energy needs and protect the health of our communities and our earth?” Another respondent interpreted decommissioning as an opportune moment: “But I happen to think it's a perfect opportunity to put in perspective the need to cut back fossil fuel dependence and to bear some of the immediate costs, in terms of adjustments to our ‘way of life’ and to begin to offset the effects of climate change in our lifetimes rather than pass the whole muddle off to future generations.” Some respondents referred to scientific reports and papers to support their views.

The biggest difference in reasoning between the support and opposition came in the way that the two sides weighted risks against the benefits of the Straits Pipelines. The proponents were far less likely to engage in such analysis than the opponents, with the relevant statements of the latter group exceeding those of the former group nearly five-fold. A low number of statements identified low-cost energy (attributable to the Straits Pipelines) as the deciding factor in their analysis. Several respondents (moderate prevalence) decided that greater safety concerns associated with transporting oil and petroleum products by truck and rail outweighed safety concerns over the Straits Pipelines. A moderate number of statements imply absolute safety of the Straits Pipelines, thus not recognizing any risks to weigh. The greatest number of statements (moderate prevalence) insist on the necessity of Straits Pipelines and if they are shut down, on the necessity of another pipeline to transport petroleum products in Michigan. “Our economy needs line 5” – wrote one respondent. “If Line 5 is shut down a new pipeline with a different route will be built in order to meet the demands for energy in Michigan” – wrote another.

In contrast, there is plentiful evidence of the opponents articulating both risks and benefits and comparing them. A few respondents noted that the benefits to Michigan, and not from the entire pipeline system, should be compared with the risks that Michigan has to bear. Several opponents decided that the risks outweighed the benefits after analyzing DR’s reports. A moderate number of statements indicate that people are willing to make sacrifices such as paying more for gasoline and propane in order to avoid a potential petroleum release from the Straits Pipelines. A very high number of statements indicate that the risks posed by the Straits Pipelines generally outweigh the benefits. Water appears to be the main factor here, as respondents cited it as a vital resource. “There is no alternative to clean, fresh water with life-giving nutrients. None. Water is Life” – stated one respondent. A lower number of statements (however high overall) focus on insufficient benefits that the Straits Pipelines generate, including too few jobs, overstated benefits of propane supply, and questionable social value of fossil fuels.

Yet the most instructive part of the opponents’ analysis is the consideration given to the allocation of risks and benefits among risk producers and risk bearers. In this analysis, the respondents not only elaborated on and compared the risks and benefits, but they also did so in the context of economic sectors, specific actors, and geographic locations. A moderate number of statements indicate that the lack of acceptance can be attributed to the perceived unfair allocation of benefits—to Enbridge and its shareholders—and risks—to people, including Michigan citizens. Many respondents (high prevalence) were driven by the perception of Canada receiving the vast majority of benefits while Michigan is left shouldering the risks. A moderate number of statements focus on insufficient benefits that Michigan receives from the pipeline operation. According to one respondent, "This pipeline is not strategically essential to the welfare of Michigan's citizens." Another respondent stated that "Most Michigan residents receive no benefit from it, but all of us will suffer when it ruptures." A very high number of statements describe risks that the Straits Pipelines pose to the State Michigan as outweighing the benefits that the pipeline brings. In particular, a moderate number of statements name risks to the Pure Michigan brand, the state's natural resources, water, and Michigan's economy. Several respondents specifically commented on the unfairness of the risk allocation burden.

X.3.4 Qualitative Overview of Risk Tolerance by Institutional Respondents

The analysis of the comments affiliated with an organization examined not only the substance of the text and the emergent themes but also the relationship between the organizational position of the commenter and the substance of their comment. The analysis clearly demonstrates that the only commenters who provided comments in support of the analysis or the existence of the Straits Pipelines are those who directly benefit economically from continued operations (including national and international industry organizations and representatives of localities in Canada). These comments are generally supportive of the continuance of the Straits Pipelines but do not provide any substantive comments on the Alternatives Analysis itself. All other comments, from a wide array of actors and individuals, critique the Alternatives Analysis in detailed substantive ways and/or raise substantive concerns about the risks posed by the continued operation of the Straits Pipelines.

The analysis also reveals several concerns related to SLO and the largest cost potentially associated with such a scenario, which appears to be a loss of institutional legitimacy through recreancy. The analysis also reveals flaws in study design hindering the potential of accurately estimating potential risks associated with a "worst-case scenario."

Perceptions of risk associated with natural resource utilization are anchored to existing knowledge and particularly to existing knowledge of past events. In this case, a very relevant past event from the perspective of the commenters is the previous oil spill in the Kalamazoo River. Constituents throughout the state of Michigan describe previous incidents such as the Kalamazoo River oil spill as well as the violations of public trust related to contracting and conflicts of interests as examples that, beyond the specific aspects of this project, the state is failing to manage the perceived risks of the project in a way that warrants public trust. For example, analysis of all 603 comments on references to the Kalamazoo spill illustrates that 49 people comment explicitly about the erosion of public trust after the spill and only two people saw the spill as evidence of a rare event that proves Enbridge's great safety record. Analysis of public comment data that is attentive to SLO and the potentially catastrophic costs associated with recreancy suggest that prior to the Kalamazoo River spill, operators may have had SLO, despite some concerns from civil society. However, the spill negatively influenced SLO, not only in relation to Line 6b on which the Kalamazoo River spill occurred but for all operations in Michigan, especially in sensitive areas.

The state's ability to act as a public trustee is contingent on its ability to effectively manage the risks associated with industrial activity, which requires attentiveness to public trust and SLO. However, given the risks associated with transport, the state may be facing a state of recreancy. Therefore, "the worst case" would involve both the loss of SLO for pipelines and facilities operated by pipeline operators in the state as well as damaging the ability of the state to legitimately act on behalf of the public. According to public comments, any spill is the worst-case scenario because clean water is the most important resource of the state and it is the responsibility of the state to protect it, and according to public understandings of the state, any spill is the worst-case scenario because the legitimacy of the state is in jeopardy. There is no way to quantify the legitimacy of the state, but public comments already indicate that this process is challenging trust in the state and perceptions of state legitimacy; loss of state legitimacy is hard to quantify in economic terms but essential for social functioning.

The analysis of public comment data indicates an awareness of shortcomings in the Alternatives Analysis that suggest a lack of perceived legitimacy of the report. For example, issues related to propane supply are used to support claims regarding the necessity of the Straits Pipelines, yet these issues can be countered by existing empirical data within the report itself. The report is generally challenged as problematic, and the state's commissioning of the report is seen as damaging to both SLO and state legitimacy more generally. For example, one commenter wrote: "The Draft Report nowhere explained why the alternatives should be defined and evaluated according to the commercial needs of Enbridge as opposed to the needs of the people, businesses, and governments within the State of Michigan." Another wrote that by accepting this Alternatives Analysis as legitimate, "the State has violated this public trust duty to the citizens of Michigan." A final example is the claim that: "If, as Michigan Attorney General Bill Schuette states, the pipeline would not be permitted if it were built today, then it stands to reason that continued operation of Line 5 does not uphold the State's responsibility to protect the public trust."

Analysis of these comments also reveals an attentiveness to study design that lends itself to critiquing the existing studies (Alternatives Analysis), the current study report, and the ability of the state to effectively promote SLO by examining and managing all associated risks. One of the largest complications to arise is the lack of temporal specification regarding the timeline for the assurances or the examination of risk. In quantifying the potential risk of the existing infrastructure, it is necessary to evaluate future scenarios regarding economic valuation and economic development. For example, in one resolution provided by a Tribal nation, it is mentioned that the Tribe has received a $610,000 grant to redevelop a commercial and subsistence fishing access point immediately west of the Straits. In order to quantify the worst-case scenario in terms of economic impact, it would be necessary to include the future value of these kinds of current investments. As another example of this, one of the public comments mentions that, in the future, the economic value of clean water may surpass the economic value of what is currently being transported through the Straits infrastructure. In order to quantify the worst-case scenario, it would be necessary to include in the analysis future projections regarding the value of the existing water source. This issue may be best communicated via a direct comment submitted by an individual Michigan resident: “There is a significant shortcoming in the scoping of the draft Alternatives Analysis. It has the wrong time perspective. The State must make a long-term choice, but the report evaluates the alternatives on today’s circumstances - not 5, 10, 30 or 50 years from now- yet the infrastructure associated with each alternative will last at least 30 to 50 years.” This comment also holds for the current study, which cannot accurately quantify impacts without considering future economic values and potential future impacts.

X.3.5 Tribal Concerns

X.3.5.1 Worst Case Scenario

A sentiment shared by Tribal Nations was that any spill of oil within the Straits of Mackinac would be a worst-case scenario. Tribal Nations believe that any spill of oil would cause immeasurable and irreplaceable damage to Lake Michigan, an impact that would profoundly affect their cultural heritage and ancestral connection to the Great Lakes. Tribal communities defined a worst-case scenario as any leak of oil that would enter Lake Michigan, no matter how small. For instance, the Little Traverse Bay Band of Odawa Indians argued that “a spill of any petroleum products, heavy or otherwise, transported through Line 5 through the Straits of Mackinac would cause vast irreparable damage to the Treaty fishery (Little Traverse Bay Band of Odawa Indians 2015).”

X.3.5.2 Fate and Transport

Tribal communities argued that the physical location of the pipeline running across the Straits of Mackinac was situated in the worst possible location for an oil spill to occur in the Great Lakes. If oil was released from the Straits Pipelines, Tribal Nations such as Sault Ste. Marie Tribe believe that the material could be transported great distances and in a relatively short time period, cautioning that within three hours of a leak, “oil would spread for miles into Lake Michigan and Lake Huron (Sault Ste. Marie Tribe of Chippewa Indians 2015).”

The Keweenaw Bay Indian Community also pointed to the powerful currents prevalent within the Straits of Mackinac as having the potential to transport leaked oil swiftly from a ruptured pipe, causing challenges for the eventual containment of the spilled oil (Keweenaw Bay Indian Community 2015).

Concern regarding the physical integrity of the Straits Pipelines was also apparent throughout this correspondence. Amongst these concerns were the Little Traverse Bay Band of Odawa Indians, who believed the pipeline to be of “various ages and dubious integrity (Little Traverse Bay Band of Odawa Indians 2015).” The Bay Mills Indian community expressed a similar sentiment, stating that “Line 5 was designed to function for a 50-year period, which has already expired, and it is already subject to small ruptures, which have been documented as occurring along the upland portion of the Line (Bay Mills Indian Community 2015)."

Furthermore, these correspondences articulated the belief that if the pipeline continued to operate, a catastrophic spill was imminent, voiced by The Bay Mills Indian Community as "continued operation of Line 5 will ultimately result in a rupture of the pipeline, causing catastrophic damage to the waters of northern Lake Michigan and Huron and the people who depend on them for their economic livelihood, their quality of life, their cultural and esthetic well-being and their very existence (Bay Mills Indian Community 2015)."

X.3.5.3 Cleanup Timeline

Concerns over the cleanup timeline of an oil spill were also raised by Tribal Nations, specifically related to the remote location of the Straits of Mackinac and the shared uncertainty surrounding Enbridge's oil leak detection technology and the parent company's seemingly unfavorable existing record of oil spill response. The Sault Ste. Marie Tribe argued that it would take at least "three hours for Enbridge to dispatch cleanup crews to the Straits in the event of a spill (Sault Ste. Marie Tribe of Chippewa Indians 2015)." Furthermore, the environmental conditions that occur along the Straits of Mackinac, such as high winds and ice-covered waters, were noted as points of concern, with the Little Traverse Bay Band of Odawa Indians arguing that cleanup of a winter spill would be physically impossible (Little Traverse Bay Band of Odawa Indians 2015).

Tribes also point to past cleanup responses from Enbridge, including an instance in Crystal Falls, MI in 1999 and a 2010 spill in Marshall, MI (Kalamazoo River), as examples of clear failures from the company at effective post-spill cleanup. The Sault Ste. Marie Tribe additionally argued that Enbridge failed to disclose the contents of the spill that occurred in Marshall, MI, which they believe further disrupted cleanup efforts.

The tribes frequently reference Enbridge's past responses to oil spills as evidence to question the legitimacy of any adequate cleanup scenario that Enbridge would undertake if a leak were detected within the Straits of Mackinac.

X.3.5.4 Public Health

A worst-case scenario at the Straits of Mackinac has the potential to shut down water intakes for numerous Tribal communities that depend on Lake Michigan for water. Impacts to public health voiced by Tribal communities included estimates of oil spilled from Enbridge-owned pipelines from 1999-2010, which resulted in forced evacuations of nearby towns (Sault Ste. Marie Tribe of Chippewa Indians 2015). Additionally, Tribal Nations voiced concern regarding the public health impacts related to the associated "multiple chemicals and cancer-causing hydrocarbons added to crude oil to enable it to flow through pipelines that release toxic fumes when spilled (Keweenaw Bay Indian Community 2015)."

X.3.5.5 Ecological Impacts

The ecological impacts resulting from a worst-case oil leak scenario received significant attention by Tribal communities. The immediate landscape of the Straits of Mackinac is an ecologically important region, which Tribal communities note is home to a wide range of important flora and fauna, much of which are regarded as especially "sensitive and vulnerable" (Little Traverse Bay Band of Odawa Indians 2015) Other concerns pointed to endangered species and ecotones, such as "Houghton's goldenrod and Alvar limestone communities."

A worst-case scenario at the Straits of Mackinac would impact the lifeways of Tribal communities, both today and into the future. Tribal communities depend on the natural resources found within the Lake Michigan ecosystem, and an oil spill at the Straits of Mackinac would disrupt the Tribes' ability to utilize these resources. Tribal communities utilize natural resources for both subsistence and commercial purposes, as well as for cultural uses, such as the gathering of medicinal plants. Among these resources, the Lake Michigan fisheries are a predominant resource utilized by Tribal communities, through both subsistence and commercial harvesting, as well as the tourism revenue brought into Tribal communities from the broader fishing industry that is attracted to Lake Michigan.

Tribal Nations depend on myriad other resources found within the Lake Michigan ecosystem. During conversations with Tribal representatives from the Bay Mills Indian Community, culturally significant crops, such as cranberries, cattails, willow, cedar, marsh marigold, wild rice, black ash, mushrooms, and other species of flora found within coastal wetlands were highlighted as traditional food or medicinal resources historically and currently utilized by Tribal members. These species are part of the Bay Mills traditional food sources and cultural identity. Traditional food sources provide both nourishment and medicine to Tribal communities but also are used as a way to articulate cultural traditions to future generations.

In addition to the Great Lakes fisheries, Tribal Nations also utilize many other species of fauna, which would be impacted by a worst-case scenario. These include freshwater resources like mussels and clams, along with frogs and turtles which are harvested for subsistence purposes. Waterfowl and waterfowl eggs are resources that would likely be affected by a worst-case scenario, as both the nesting grounds and the birds themselves might be subjected to oiling. Fur-bearing species, such as muskrats, are also a resource valued by Tribal communities that would be affected by any oil emitted from a rupture of the Straits Pipelines.

Ecological impacts from a worst-case oil spill scenario would affect a wide range of biomes, habitats and individual species. The following list contains ecological areas identified as of particular concern to Tribal communities from representatives of the Bay Mills Indian Community. This list is not all-encompassing, but provides an overview of the myriad resources that Tribal communities depend on:

- The quality and quantity of fresh water found within the Great Lakes and adjacent drainages

- Great Lakes Fisheries, spawning reefs, and shoals
- Impacts to air quality
- Coastal wetlands, including marshes, fens, bogs, estuaries, dunes, and prairies
- Fur-bearing species, such as muskrat, beaver, marten, mink, and otter
- Freshwater animals, including frogs, turtles, mussels, and clams
- Waterfowl and waterfowl nesting areas
- Subsistence gathering crops, such as wild rice, cattails, mushrooms, cranberries, marsh marigold, and berries
- Medicinal plants, such as willow, cedar, and black ash
- Clay deposits used for potting

X.3.5.6 Restoration

Because Tribal Nations saw most impacts as irreversible, restoration appears to be a moot point. The Tribal community viewpoint is particularly true regarding Traditional Cultural Properties such as sacred sites.

X.3.5.7 Natural Resource Damage

Tribal Nations consider the Straits of Mackinac to contain some of the most productive fishing, spawning, and shoaling areas within Lake Michigan, utilized for both subsistence as well as commercial purposes (Chippewa Ottawa Resource Authority (CORA) 2015). A worst-case oil spill scenario has the potential to impact this economic, natural, and culturally significant resource immediately and into the future. Likewise, the preservation of the ecosystem in which these fisheries exist is of equal concern to Tribal Nations, such as the Grand Traverse Bay Band of Ottawa and Chippewa Indians, who cite their “traditional cultural heritage” that “places a high priority on the preservation and responsible use of its natural resources in the 1836 Treaty-ceded territory, including Treaty-reserved fishing rights dependent upon preservation of Great Lakes’ water quality (Grand Traverse Bay Band of Ottawa and Chippewa Indians 2015).”

Furthermore, Tribal Nations point to both the short term and long term impacts an oil spill would have on fisheries, including the viability of spawning success for both salmon and trout. The Sault Ste. Marie tribe refer to studies conducted by the U.S. Fish and Wildlife Service, citing that trout and salmon are species that are “highly sensitive to oil toxins.” Oil toxins can “kill fish eggs” and “oil toxins that linger in sediment and aquatic vegetation long after a spill is ‘cleaned-up’ can harm aquatic ecosystems for decades after a spill occurs (Sault Ste. Marie Tribe of Chippewa Indians 2015).”

X.3.5.8 Government and Public Costs

Tribal Nations also articulated additional costs associated with a petroleum release that would be assumed by the public. Among these was the loss of revenue generated from the *Pure Michigan* campaign, which has influenced tourism to the state of Michigan. For instance, the Keweenaw Bay Indian Community argues that "in addition to devastating impacts to local livelihoods and ecosystems, northern Michigan's vital tourism economy would be crippled and the Pure Michigan campaign, a multi-million dollar investment, would be compromised (Keweenaw Bay Indian Community 2015)."

A worst-case scenario would also damage existing infrastructure, such as commercial fishing docks, which the tribes see as costs they would be forced to assume. For instance, the Sault Ste. Marie Tribe of Chippewa Indians points to an existing $610,000 grant they recently received from the Great Lakes Fishery Trust, coupled with staff time and financial resources expended to "redevelop a commercial and subsistence fishing access point at Epoufette Bay" which they believe would be severely impacted by any oil spill (Sault Ste. Marie Tribe of Chippewa Indians 2015).

Tribal representatives described the economic impacts of a worst-case scenario as either devastating or catastrophic. Some of these concerns surrounded short-term economic losses, which representatives believed would directly impact the viability of tribal commercial fisheries, along with the repair of boats, docks, and shoreline equipment. Other short-term losses voiced by tribal representatives surrounded the impact a worst-case scenario would have on the tourism industry. Questions such as, will tourists visit an area that recently experienced an oil spill? Since the 'pureness' of Lake Michigan is a major draw for tourists, the spoiling of the waters by an oil leak has the potential to affect this state slogan.

Tribal communities would also suffer short- and long-term economic impacts from a worst-case oil spill at the Straits of Mackinac. Great Lakes tourism is a major economic driver for Michigan communities, including Tribal nations. Recreational tourism would likely be negatively impacted from a worst-case oil spill scenario. Some of the most notable economic impacts that Tribal Communities might expect include:

- The cost of fresh, clean water, both currently and in the future
- Tourism revenue generated from casinos, the fishing industry, and outdoor recreationists inspired to visit 'Pure Michigan'
- Damage to fishing docks, boats, and equipment

X.3.5.9 Additional Risks – Cultural Heritage and Threat of Litigation

A spill event would have a significant cultural impact on Tribal communities. The Lakes and the associated resources are a foundational part of the identity of Tribal Nations. A worst-case scenario has the potential to sever these cultural lifeways. While the ecological resources are important by themselves, a concern voiced by Tribal Nations is how these traditional food sources foster intergenerational relationships between Tribal elders and

Tribal youth. If a worst-case scenario was to occur at the Straits of Mackinac, the ability to foster these important connections might be jeopardized forever. Native American food pathways include the identification of culturally significant plants as well as the practice of harvesting, cooking and consuming, traditions and knowledge that have been passed down from generation to generation.

Tribal communities believe in the Seventh Generation principle, that is, every decision we make today should take into consideration how that decision might affect communities seven generations from now. A worst-case scenario occurring at the Straits of Mackinac would impact the immediate generation of Tribal communities, but also those seven generations from now.

The shores of Lake Michigan also contain a high number of traditional cultural properties, cemeteries, and sacred sites, which Tribal communities continue to use today. If damaged from a worst-case scenario, the cultural value of these sites would be lost. If damaged, these sites would be lost to all generations, past, present, and future.

The following list contains examples of some of the potential impacts a worst-case scenario could have on the cultural lifeways of Tribal communities:

- Disruption of traditional cultural practices, such as hunting and gathering
- Traditional lifeways are jeopardized or permanently lost
- Sacred sites and traditional cultural properties are damaged
- Cemeteries located along the shoreline could be damaged and exposed during reclamation efforts
- Cultural traditions and Tribal connections to a space could be lost, such as at Mackinaw Island, where members of the Lake Superior Band of Chippewa Indians gather annually for ceremonies
- Transgenerational ties articulated through visiting traditional cultural properties and engaging with hunting and gathering activities would be seriously damaged

A petroleum release would not only cause significant damage to Tribal Nations, but it would also highly likely result in litigation against Enbridge and, potentially, the State of Michigan. The extent and nature of legal claims by Tribal Nations will depend on the amount of the released product, the geography and the size of the impacted area, the cleanup time and costs, and many other factors. Although the extent and nature of legal claims are difficult to predict, based on our analysis we see lawsuits the event of a spill a near certainty. Therefore, this near certain threat of litigation must be taken into account in determining a worst-case scenario.

We arrived at this conclusion because of the following three reasons. First, although the extent of rights of Tribal Nations to hunt, fish, and gather in the Great Lakes region differs from tribe to tribe, most of these rights have been long-recognized and enforced under the Great Lakes Submerged Lands Act (GLSLA), the 1836 Treaty of Washington, the 2000 Great Lakes Consent Decree, the 2007 Inland Consent Decree and other international, federal, and state law. The position of the Bay Mills Indian Community, the Sault Ste. Marie Tribe of Chippewa Indians, the Grand Traverse Band of Ottawa and Chippewa Indians, the Little River Band of Ottawa Indians, and the Little Traverse Bay Bands of Odawa Indians appears to be particularly strong due to the court decision in *United States v. State of Mich.*, 471 F. Supp. 192 (W.D. Mich. 1979). There, the court affirmed the tribes' commercial and subsistence fishing rights in perpetuity in the parts of Lakes Michigan, Huron and Superior ceded under the 1836 Treaty as depicted in Figure X7 (Newland et al., 2018).

Figure X7: Ceded Territory under the 1836 Treaty (Newland et al., 2018)

Second, Tribal Nations have plentiful capacity to litigate these claims. Most employ superb lawyers and environmental scientists with whom we met. Because of the unanimous and vocal opposition of Tribal Nations of the Straits Pipelines, we expect a high degree of coordination and resource sharing in the event of legal action. In addition, Tribal Nations are likely to receive federal assistance with the financial aspect of litigation.

Third, as our analysis shows, some if not all Tribal Nations are willing and ready to engage in legal battle. Warren C. Swartz, Tribal President of the Keweenaw Bay Indian Community, provided the following litigation outlook in the event of a petroleum release:

> *We will participate in the spill response and the responsible party will pay for our response costs. Will participate in the natural resource damages assessment and the responsible party will pay for it. And we will conduct the restoration of damages to natural resources in full measure and the responsible party will pay for it. And we will bring claims for compensation for these damages and the lost use of our treaty protected trust resources under prevailing federal law. Should Enbridge reach the point of financial collapse, and we believe they will, we will seek funds from the same organization (Oil Spill Liability Trust Fund) that received the fines Enbridge paid for its negligence associated with the Kalamazoo oil spill. Our claims will be both comprehensive and extensive. And for this reason we will not reveal all of the individual items at risk in the in the event of a major oil spill from Line 5 except to say that they are very substantial (Keweenaw Bay Indian Community 2018).*

As we note throughout this section, Tribal Nations view certain resources as irreplaceable and their loss as ruin and a worst-case scenario. Although this makes it difficult to apply conventional damage valuation procedures, we fully anticipate the value of lost tribal resources to be quantified above such procedures due to their subsistence, ceremonial, cultural, and spiritual importance. Tribal representatives informed us that they “will explore all legal avenues for relief” including those under recent court decisions, *United States v. Washington*, 853 F 3d 946 (March 2, 2017), aff’d by 138 S Ct 1832 (June 11, 2017) for example (B. Newland, personal communication, 2018). Therefore, it is reasonable to conclude that legal claims against Enbridge and, potentially, the State of Michigan will be significant in scope, scale, and size making a worst case scenario even worse.

X.3.5.10 Qualitative Overview of Risk Tolerance by Tribal Nations

A discourse analysis of the data collected from Tribal Nations showed a unified opposition to continuing easement for the Straits Pipelines. Tribal leaders urged the State immediately decommission the pipeline and to begin funding research into alternative energy sources. The data found within correspondence between Tribal Nations and the State of Michigan provided information about how Tribal communities would be affected by the continued use of the Straits Pipelines, including potential damage to the Tribal fishing industry along with the economic impacts of a declining Lake Michigan tourist industry. In addition, Tribal Nations point to the historical context in which the pipeline was initially permitted as being outdated and something that would never be permitted in today's regulatory environment (Sault Ste. Marie Tribe of Chippewa Indians 2015). However, this correspondence was not as forthcoming regarding how the pipeline might affect Tribal lifeways. This is likely due to the narrow framing of the state, which does not provide space for considering unquantifiable concerns. To get a better understanding of how a worst-case scenario might impact Tribal communities, we consulted with Tribal leaders, seeking input regarding how a worst-case scenario might impact their communities, their lifeways, and their environment. In this correspondence, we hoped to capture Tribal concerns that might have been overlooked in the estimates of the broad costs associated with a worst-case scenario. Among these were concerns related to such things as traditional cultural properties, burials, culturally significant food sources, and the broad spiritual connection with the Great Lakes. Other concerns revealed the limitations of any current attempt to understand potential impacts, even in economic terms, as the medium and long-term impacts of a potential "worst-case scenario" on affected mammals, plant species, and ecosystems is yet unknown.

During trips to the Keweenaw Bay Indian Community and to Petoskey, MI for the United Tribes of Michigan meeting in May of 2018, we were able to present our role in the Independent Risk Analysis to Tribal communities and consult with Tribal leaders regarding how a worst-case scenario might impact their communities, environment, and lifeways. These in-person meetings gave us the opportunity to answer questions that Tribal leaders had about the project and to facilitate future meetings. In addition to these in-person meetings, we also corresponded with Tribal representatives on conference calls and through email. Tribal staff members from the Bay Mills Indian Community, including their Tribal Historian and Environmental Specialist, provided detailed information regarding how a worst-case scenario would impact specific natural and cultural resources utilized by the Tribe, as well as how an oil spill could impact their community's lifeways.

Tribes unequivocally opposed the pipeline, calling for its immediate decommissioning as a means to begin addressing climate change caused by the burning of fossil fuels. As argued by Warren C. Swartz, Tribal President of the Keweenaw Bay Indian Community, "Michigan should strive to revolutionize alternatives in order to reduce oil consumption and transportation such as investments in cleaner vehicle technology and become a leader like it was a century ago in the production of internal combustion engines" (Keweenaw Bay Indian Community 2015). A similar sentiment was voiced by the Chippewa Ottawa Resource Authority (CORA), stressing that all governments "should anticipate and encourage reductions in the use of fossil fuels" and that by decommissioning Line 5, Michigan would be leading in both the "reduction of oil consumption" and in the "development of alternative energy sources" (Chippewa Ottawa Resource Authority (CORA) 2015).

Tribal concerns also focused on Enbridge's record of managing its pipelines, with the leak that occurred at Talmadge Creek in 2010, which eventually contaminated the Kalamazoo River, used a primary example. The Bay Mills Indian Community uses this incident as evidence showing Enbridge's inability to either monitor or maintain pipelines (Bay Mills

> Indian Community 2015). The Sault Ste. Marie Tribe of Chippewa Indians provided a laundry list of incidents that occurred at Enbridge owned properties between 1999 and 2010, describing the company's pipeline system as having a record that conveys "no credibility to their promise of safety and response" (Sault Ste. Marie Tribe of Chippewa Indians 2015). Furthermore, the potential risk seen in the continued operation of Line 5 was situated in a possible breach of trust between State regulators and the Tribes. This point was addressed by CORA in regards to the GLSLA, which CORA understands as a document of public trust guaranteeing the "perpetual duty of the state to secure to its people the prevention of pollution, impairment or destruction of natural resources, and rights of navigation, fishing, hunting, and use of its lands and waters for other public purposes" (Chippewa Ottawa Resource Authority (CORA) 2015). The continued operation of Line 5 is seen as a breach of this public trust.

X.4 Discussion

Analysis of public comment data provided to the team reveals that members of the stakeholder communities who commented on the Alternatives Analysis were both able to systematically critique that report based on its scientific deficiencies as well as able to provide more general, holistic, and substantive comments regarding public perceptions of risks associated with continued operation of the Straits Pipelines. Using SLO to anchor the analysis demonstrates that those who are able to grant SLO are generally critical of the risks associated with the Straits Pipelines. Overwhelmingly, support for both the Alternatives Analysis and the continued operation of the Straits Pipelines came from entities who may be holders of SLO in association with the industrial sector (industry actors and public entities that benefit from the industrial activities) but not from those who are able to grant SLO. There does not appear to be a strong SLO in this case. Previous events, including the Kalamazoo River spill and the Alternatives Analysis itself, both have had damaging effects on SLO and perceptions of the state as a legitimate grantor of public trust and safety. The impacts associated with loss of public trust in the state as a legitimate manager of the risks posed by industrial activity may represent the highest cost worst-case scenario associated with any potential spill.

The analysis also revealed several substantive considerations specifically related to public perceptions of risks that must be considered in order to effectively evaluate risks. Most of those who provided public comments view clean water as the state's most valuable asset, both economically as well as culturally. The cultural value of this asset is impossible to quantify yet is of overwhelming concern to commenters. Impacts to this water cannot be quantified without much deeper understanding of capacity for addressing impacts to drinking water among all the discrete communities that would be impacted. It also requires an understanding of the long-term impacts on non-human species that have an economic, cultural, and ecological value that is not yet well understood. Furthermore, the temporal mismatch between long-term planning for economic development and ecologically and culturally sustainable communities and the short-term focus of the state's engagement with issues of risk is highly problematic for both accurate assessments of risk and the granting of legitimacy to the state's process in an attempt to manage risk.

X.4.1 Quantitative Analysis

The quantitative analysis assessed public comment data for the DR draft and final reports. Comments were made by and represented individual, organizational, and group opinions. The following methods were used by the public to submit comments: posting directly to the Michigan Petroleum Pipelines website, attaching (documents) comments to a post on the Michigan Petroleum Pipelines website, emailing the State of Michigan or PSAB with a comment, sending mail or postcards compiled by the Michigan Department of Environmental Quality. The digital and physical comments were combined, in an abbreviated form, into a single spreadsheet. The comments were read and categorized. The data was then cleaned to remove duplicate comments and postings unrelated to the pipeline assessment. These data processing steps of aggregation and cleaning were required for an accurate quantitative analysis. After a review of the range of submissions, the data were categorized into the following groups: identifying information provided by the public used in data verification, the method of submission, was it an organization or individual comment, did the comment support the continued use of the pipeline, should the comment be analyzed qualitatively, and any notes about the submission.

Although this analysis cannot be used to generalize conclusions about the public's opinion, there are several insights into the perceived risk that have been uncovered from the public comments. These findings show that there is a significant and organized opposition to the Straits Pipelines. Individuals and organizations in support of the Straits Pipeline represented less than 5% of the total comments. When the 2,020 questionable comments are removed, the percentage of comments supporting the pipeline drops to less than 3%. The presence of organizational support in the face of minimal counter resistance suggests a heightened risk of SLO revocation, which would certainly increase dramatically during a "worst-case scenario" or even a lesser triggering event.

The high number of public comments during this selected five month frame indicates that the public is attempting to engage in the Straits Pipeline decision-making process. This provides both an opportunity and a challenge for industry and state agency's SLO. The limitation of this analysis is that it fails to contextualize temporal changes to SLO, cannot measure perceptions of individuals who did not comment, and does not depict the public's "worst-case scenario". At the same time, the quantitative analysis works synergistically with the other pipeline assessment methods.

X.4.2 Qualitative Analysis

Many commenters took the opportunity to comment on the Alternatives Analysis as an opportunity to provide comments on their perceptions of the risks associated with the Straits Pipelines and their willingness to tolerate such risks, or, in other words, to express support or opposition to the continued operation of the Straits Pipelines. Opponents describe the worst case as catastrophic devastation, suggesting that any spill would result to catastrophic effects, not only potentially for ecosystems and economic activity but also for the culture and image of the state of Michigan. On the other hand, proponents do not identify any possible “worst-case scenario,” as there appears to be the belief that there is no possibility of a failure resulting in spillage. Across both supporters and opponents of the continued operation of the Straits Pipelines, there are a rather small number of references to specific ecological impacts or impacts to public health, and very little is said about the potential costs or difficulties associated with restoration. For example, it is well documented that restoration after catastrophic events is also capable of creating catastrophic damage, economically, ecologically, socially, and culturally; however, public comments cannot be the source for providing this claim, because commenters do not raise this significant issue themselves.

Comments regarding natural resource damages are dominated by concerns regarding risk to water, but these comments are not limited to economic and ecological risks. Commenters also focus on the intangible value of water for the social and cultural identity of the state, and question why that should be put at risk for an economic benefit for those outside the state (Canadian companies and municipalities and national industry actors who do not reside in Michigan and thus would not feel the impacts themselves).

Many commenters associate clean water with the identity of the state (understandably, given the identity of the state as Pure Michigan). Many associate potential risks with the private and public costs that would result from a loss of tourism, including the cascading effects on: boating, brain drain (from loss of highly educated, motivated, successful Michigan residents seeking cleaner environments), community services, local businesses, the state’s image and reputation, job losses, livelihoods, loss of property values, tax and tourism.

In terms of risk tolerance and acceptance, there appears to be a bifurcation in the submitted comments. Proponents, as identified based on comment substance, support the Straits Pipeline generally and do not engage in assessment of the relative balance of cost and benefits associated with continued operation. Opponents, on the other hand, act in a much reasonable way and provide a holistic and comprehensive assessment of perceived risks. This includes both the indirect impacts of a spill (on future tax revenues, for example) and the inability of any current assessment to fully account for future values of clean water, for example, the future value of current economic investments meant to increase the value of fishing economies or other economic resources that would be impacted by a spill. These perceptions of risk are guided by a combination of cultural, psychometric, and RAP factors and tend to provide identification of a broad set of risks, assessment of the relative likelihood of that risk, and evaluation of the relative weight of risks and benefits associated with that identified risk. In contrast, those writing in support of continued operations of the Straits Pipeline tend to focus only on direct economic benefits being received by the commenter (particularly in the case of comments submitted by those with an organizational affiliation), and those comments do not engage in considering the relative likelihood or severity of any identified risks. For the proponents, generally, there is simply no worst case scenario because a petroleum release will not happen. The far more reasonable approach by the opponents provides them with a case for SLO revocation.

X.4.3 Tribal Concerns

Michigan's Tribal Nations share a collective concern over the existence and continued use of Enbridge's Line 5 pipeline. Lake Michigan is part of the identity of these Tribal communities. The belief that "*Water is Life*" speaks to the sacredness that the freshwater within the Great Lakes holds for Tribal communities. This sacred connection is articulated by Frank Ettawageshik, a Tribal elder of the Little Traverse Bay Band of Odawa Indians:

> *The single most important defining element of the place we live, what make this place unique in the entire world, is the Great Lakes and the waters that recharge these lakes from the springs, creeks, streams and rivers that make up this vast watershed. We speak for and honor the waters as the life-blood of our Mother Earth as an integral part of our traditional spirituality. As Native Nations, we utilize these waters to define our boundaries, transport ourselves and trade goods, fish, for our food and commerce, and enjoy their value for recreation and a strong economy (Berry 2015).*

X.5 Summary

Analysis of public comments made in response to the draft and final Alternatives Analysis reports reveals the difficulty of assessing public perceptions through public comment periods, as many comments were found to have authenticity concerns and others did not respond to the Alternatives Analysis itself. However, the comments often revealed broader assessments of the risks associated with the continued operation of the Straits Pipeline, which lends itself to the aims of this team. The team's objective was to systematically analyze these comments to assess perceived risks in order to inform the larger assessment.

Public comments demonstrate the importance of maintaining clean lake waters for the economic and cultural value they provide for all residents of Michigan, including Tribal community members. The provisioning of lake water ecosystems are viewed as essential for businesses, tourism, and cultural identity in the state. Potential impacts to water quality are viewed as the largest perceived risk of continued operation of the Straits Pipeline, but the impacts are perceived as expanding beyond clean water to impact the potential to maintain a robust economy and flourishing communities throughout the state. The public comments also demonstrate the inability of any current analysis to fully capture these impacts, as the analysis is occurring without calculations of future costs, benefits, values, and impacts (such as the future value of clean water).

In an analysis of public comments, only organizations that benefit economically from continued operation express support (and most do not comment on the Alternatives Analysis itself, but rather offer a generic expression of support). Turning to the concept of a social license to operate (SLO) provides context for interpreting this and other findings in this report. SLO is pursued by industrial actors and is often associated with those responsible for ensuring the safety of industrial activity. However, industrial actors cannot themselves grant SLO, which must come from the community stakeholders potentially impacted by the industrial activity. In the case of this analysis, SLO appears to be lacking, as most comments focus on the relative risks outweighing benefits, which are viewed as disproportionately distributed to actors who do not themselves bear any of the associated risks.

In being asked to consider the “worst-case scenario” in the continued operation of the Straits, it is essential to recognize the potential effects that withdrawal of SLO would have for both the industry and the state of Michigan. When public actors are tasked with ensuring the safety of public constituents, they face the risk of recreancy or the loss of public trust when public servants tasks with managing risk are incapable of doing so and thus fail in their assigned responsibility. Without SLO, the state also faces loss of legitimacy, which is arguably impossible to quantify but essential. This analysis suggests that withdrawal of SLO is based on lack of public trust in the process of evaluating the safety of industry activity associated with continued operation of the aging infrastructure of the Straits Pipeline.

X.6 References

Adams, J. (1995). *Risk.* Routlege.

Aven, T., & Renn, O. (2012). On the Risk Management and Risk Governance of Petroleum Operations in the Barents Sea Area. *Risk Analysis, 32*(9), 1561-1575.

Babbie, E. 1999. *The basics of social research.* Belmont: Wadsworth Publications.

Bay Mills Indian Community. 2015. "Resolution No. 15-3-16-B: Support for Decommission of Enbridge Line 5 Oil Pipeline Under the Straits of Mackinac."

Berry, Desmond. 2015. "Memorandum to the Michigan Petroleum Pipeline Task Force."

Boutilier, Robert. 2012. *A Stakeholder Approach to Issues Management.* New York, NY: Business Expert Press, LLC.

Chippewa Ottawa Resource Authority (CORA). 2015. "Tribal/State Consultation with Michigan Petroleum Pipeline Task Force."

Crawford-Brown, D. (1999). *Risk-Based Environmental Decisions: Methods and Culture.* Kluwer.

Dare, M., Schirmer, J., Vanclay, F. (2014). Community engagement and social licence to operate. *Impact Assessment and Project Appraisal, Volume 32*(Issue 3), Pages 188-197.

Dillman, Don A., Jolene D. Smyth, and Leah Melani Christian. 2008. *Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method.* New York, NY: John Wiley & Sons.

Edwards, P., and Justine Lacey. (2014). Can’t climb the trees anymore: social license to operate, bioenergy and whole stump removal in Sweden. *Social Epistemology: A Journal of Knowledge, Culture and Policy, 28.3-4: 239-257*.

EPA. 2018. *Great Lakes Facts and Figures.* June 30. https://www.epa.gov/greatlakes/great-lakes-facts-and-figures.

Freudenburg, W. R. (1993). Risk and recreancy: Weber, the division of labor, and the rationality of risk perceptions. Social Forces, 71(4), 909-932.

Gehman, Joel, Lianne M Lesfrud, and Stewart Fast. 2017. "Social license to operate: Legitimacy by another name?" *Canadian Public Administration* 60 (2): 293-317.

Grand Traverse Bay Band of Ottawa and Chippewa Indians. 2015. "Tribal Council Resolution No. 15-33.2602."

IRGC. (2005). *Risk Governance: Towards and Integrative Approach.* IRGC.

James, P., et al. (2012). *Sustainable Communities, Sustainable Development*.

Keweenaw Bay Indian Community. 2015. "Re: Recommendations to the Michigan Petroleum Pipeline Task Force."

Keweenaw Bay Indian Community. 2018. "Re: Response to John Baeten."

Lacey, J., Richard Parsons, and Kieren Moffat. (2012). Exploring the concept of a Social Licence to Operate in the Australian minerals industry: Results from interviews with industry representatives. *CSIRO, EP125553*.

Little Traverse Bay Band of Odawa Indians. 2015. "Tribal Resolution #030515-01: Decommission and Safe Removal of Pipeline Running Under the Straits of Mackinac."

Merriam-Webster. (2016). "stakeholder." In Morrison, J. (2014). *The Social License: How to keep your organization legitimate*: Springer.

Moffat, Kieren, and Airong Zhang. 2014. "The paths to social licence to operate: An integrative model explaining community acceptance of mining." *Resource Policy* 39: 61-70.

Moffat, Kieren, Justine Lacey, Airong Zhang, and Sina Leipold. 2016. "The social license to operate: a critical review." *Forestry* 89: 477-488.

Parsons, R., and Kieren Moffat. (2014). Constructing the meaning of social licence. *Social Epistemology, 28.3-4: 340-363*.

Parsons, R., Justine Lacey, and Kieren Moffat. (2014). Maintaining legitimacy of a contested practice: how the minerals industry understands its 'social licence to operate'. *Resources Policy, 41: 83-90*.

Renn, et al. (2001). *The Rational Actor Paradigm in Risk Theories: Analysis and Critique, Working Paper, Social Contexts and Responses to Risk.* University of Kent. Retrieved from http://www.kent.ac.uk/scarr/events/finalpapers/renn.pdf

Rosa, et al. (2014). *The Risk Society Revisited: Social Theory of Risk Governance.* Philadelphia: Temple University Press.

Sault Ste. Marie Tribe of Chippewa Indians. 2015. "Enbridge Line 5 Oil Pipeline at the Straits of Mackinac: A postion paper by the Sault Ste. Marie of Chippewa Indians."

Sault Ste. Marie Tribe of Chippewa Indians. 2015. "Resolution No. 2015-45: Resolution in Support of Decommissioning of the Enbridge Line 5 Oil Pipeline at the Straits of Mackinac."

Sidortsov, R. (2014). Reinventing rules for environmental risk governance in the energy sector. *Energy Research and Social Science, 1*(1), 171-182.

Slovic, P. (1987). Perception of Risk. *Science, 236*(4799), 280-285.

Strauss, Anselm. 1987. *Qualitative Analysis for Social Scientists.* Cambridge: Cambridge University Press.

Wardman, Mark. 1988. "A Comparison of Revealed Preference and Stated Preference Models of Travel Behavior." *Journal of Transport Economics and Policy* 22 (1): 71-91.

Wildavsky, A., & Dake, K. (1990). Theories of Risk Perception: Who Fears What and Why? *Daedalus, 119*(4), 44-60.

Yates, Brian F., and Chelsea L. Horvath. 2013. "Social License to Operate: How to Get It, and How to Keep It." *Pacific Energy Summit.* NA: Asia Pacific Foundation of Canada. 1-23.

Summary of Costs and Next Steps

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Summary of Costs and Next Steps

One objective of this Independent Risk Analysis was to estimate the total potential liability from a worst-case scenario spill. The 1953 Easement "makes Enbridge liable for all damages or losses to public or private property" (Risk Analysis Final RFP 2017). To sum all damages across tasks based on the scope of work for this assessment, it is necessary to assume a single scenario. Of the three scenarios used as case studies by the Tasks G/I and Task H teams, their "Scenario 1", based on an unmitigated release of 58,000 bbl caused by a double rupture of the Straits Pipelines at the bottom of the shipping channel during the current and weather conditions experienced on March 1, 2016, resulted in the highest damages and is summarized here.

The total cost, broken down into broad categories, is presented in Table X below. Enbridge's liability would include the reimbursable government costs estimated by Task H, which are a component of the $500 million in estimated total cleanup costs. Further details, including ranges for many of these values, are available in Tasks F, G/I, and H, as noted. Task H also estimated non-reimbursable costs to government, including an approx. $42 million net loss in Michigan/Wisconsin state tax revenues, a $2 million net loss in federal income tax revenues, and $263 million in lost corporate income tax revenue due to a tax deduction of cleanup costs, which are not included in the total liability estimate.

Table 2. Summary of total potential liability for a worst-case spill from the Straits pipelines.

Liability	Task	Estimate (millions)
Cleanup costs	F, H	$500
Recreational damages	G/I	$460
Lost income for tourism and recreation businesses	G/I	$678
Other damages	G/I	$230
Total		$1,868

This cost estimate was made as comprehensive as possible but does not include the cost of repairing the pipeline itself or the costs of irreversible damage to resources for which valuation estimates are not available. Comparison to other estimates of the costs of a Straits Pipeline spill should be made with caution, taking into account differences in assumptions and varying included costs.

The public release of this report will be followed by a 30-day public comment period. During this comment period, the analysis team will prepare and present a public information presentation summarizing the draft analysis. This presentation is currently scheduled for August 13, 2018, in Gaylord, MI. The team will then consider and respond to comments on the draft report, making any appropriate revisions to the analysis, and deliver a final version of the Independent Risk Analysis to the State by September 15, 2018. The revisions made to the final report may result in changes to the numbers summarized above as well as throughout the report.

State of Michigan. (2016). Request for Information and Proposals: Independent Risk Analysis for the Straits Pipelines. Available at https://mipetroleumpipelines.com/resources-reports.