

# INDEPENDENT RISK ANALYSIS for the Straits Pipelines

**FINAL REPORT**

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## Table of Contents

List of Contributors.....	0
Acknowledgments.....	2
Acronym and Abbreviated Phrase List.....	17
Introduction.....	26
References .....	31
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 .....	32
A.1 Introduction.....	32
A.1.1 Guiding Requirements .....	35
A.2 Input Data and Assumptions .....	37
A.1.2 Basic Information.....	37
A.2.2 Isolation Valves.....	38
A.2.3 Elevation Profile and Critical Locations.....	39
A.2.4 Potential Causes of Failure .....	41
A.2.5 System Detection and Response Time.....	42
A.2.6 Tiers of Failure.....	46
A.3 Analysis Results for Base Case of Rupture and Pin-holes.....	48
A.3.1 Rupture Cases .....	49
A.3.2 Three Inch Pinhole Size Leakage Case.....	50
A.4 Worst Case Discharge Results for Different Tiers of Failure.....	51
A.4.1 Tier 1 .....	51
A.4.2 Tier 2 .....	52
A.4.3 Tier 3 .....	52
A.4.4 Tier 4.....	52
A.4.5 Tier 5 .....	53
A.5 Summary .....	54
A.6 References .....	54

Task B: Analyzing the Likely Environmental Fate and Transport of Oil or Other Products Released from the Straits Pipeline Under a Worst-case Scenario .....	56
B.1 Introduction .....	56
B.2 Approach .....	57
B.2.1 Meteorological and Environmental Data .....	57
B.2.2 Hydrodynamic and Oil Dispersal Modeling .....	58
B.2.3 Oil Dispersal Simulation .....	61
B.2.4 Atmospheric Dispersion Modeling .....	63
B.3.1 Hydrodynamic Modeling Results - Oil Beaching .....	68
B.3.2 Hydrodynamic Modeling Results - Surface Oiling .....	70
B.3.3 Hydrodynamic Modeling Results - Proportional Fate .....	71
B.3.4 Atmospheric Dispersal Analysis - Crude Oil .....	73
B.4 Discussion .....	76
B.4.1 Overall Considerations .....	76
B.4.2 Oil Dispersal Modeling Limitations .....	76
B.4.3 Comparison To Previous Transport Models for Spills in the Straits of Mackinac .....	77
B.5 Summary .....	78
B.6 References .....	79
Task C: Analyzing How Long it Takes to Contain and Clean Up the Worst-case Release .....	81
C.1 Introduction .....	81
C.2 Literature Review .....	81
C.2.1 Overview of Spill Response .....	81
C.2.2 Incident Command System and the Unified Command Structure .....	82
C.2.3 Tactics to Respond to and Clean Up Oil Releases .....	83
C.2.4 Reviews of Documents for the Straits of Mackinac .....	88
C.3 Data Collected .....	91
C.3.1 Fate of Oil in the Worst Case Scenario .....	92
C.3.2 Interview with Mackinac County Emergency Managers .....	95

C.3.3 Interview with the US Coast Guards Sector Sault Sainte Marie.....	96
C.3.4 Interviews with Enbridge representatives .....	97
C.3.5 List of Equipment Identified .....	101
C.3.6 Time to Respond, Deployment, and Staging.....	101
C.3.7 Shoreline Cleanup .....	101
C.4 Methodology .....	102
C.4.1 Containment and Recovery on Water .....	102
C.4.2 Shoreline Cleanup Time Estimate.....	105
C.5 Analysis.....	105
C.5.1 Time to Contain and Recover Oils on Water .....	105
C.5.2 In situ Burning.....	111
C.5.3 Estimated Time to Clean up Oils on Shorelines .....	112
C.6 Conclusion.....	115
C.7 References .....	116
Task D: Analyzing the Short and Long-term Public Health and Safety Impacts .....	118
D.1 Introduction.....	118
D.2 Approach.....	119
D.2.1 Worst-case determination for public health and safety.....	119
D.2.2 Description of populations at risk .....	119
D.2.3 Hospital capacity.....	122
D.2.4 Chemicals of Concern.....	122
D.2.5 Zones of Potential Exposure (ZOPE).....	125
D.2.6 Human Health Risk Assessment (HHRA).....	126
D.2.7 Worst-case Determination for Fire and Explosion Risk .....	131
D.3 Analysis.....	138
D.3.1 Safety Risk and Consequence Analysis .....	138
D.3.2 Fire and Explosion Risk Analysis .....	141
D.3.3 Qualitative Risk Analysis.....	147

D.4 Discussion .....	155
D.4.1 Uncertainty and Limitations of the Models .....	156
D.5 Summary .....	156
D.6 References .....	158
Task E: Analyzing the Short- and Long-term Ecological Impacts .....	165
E.1 Introduction .....	165
E.2 Approach: Conceptual Model for Impacts to Natural Resources .....	166
E.3 Crude Oil and its Contaminants of Concern .....	167
E.3.1 Evaluation of a Worst-case Spill Scenario .....	169
E.3.2 Impacts on Shorelines .....	172
E.3.3 Natural Resources in the Straits of Mackinac .....	176
E.3.4 Overall Ecosystem Impacts .....	211
E.3.5 Summary .....	213
E.4 References .....	215
Task F: Analyzing Potential Measures to Restore the Affected Natural Resources and Mitigate Adverse Impacts Upon Ecological and Cultural Resources .....	223
F.1 Introduction .....	223
F.1.1 Scope of Task F .....	227
F.2 Approach .....	228
F.2.1 Definition of Worst-case Scenario .....	228
F.3 Analysis .....	229
F.3.1 Habitat .....	230
F.3.2 Organisms .....	238
F.3.3 Cultural Resources .....	246
F.3.4 Predicted Costs Associated with the Proposed Restoration Strategies .....	258
F.4 Discussion .....	261
F.5 Summary .....	263
F.6 References .....	263

Task GI: Estimating the Amount of Natural Resource and Other Economic Damages, Public and Private, That Would Result from a Worst-case Release.....	272
GI.1 Introduction.....	272
GI.1.1 General Introduction to the Issue.....	272
GI.1.2 SOW from the State of Michigan .....	272
GI.2 Background.....	273
GI.2.1 Other Studies .....	273
GI.2.2 Assessing Losses .....	275
GI.3 Approach.....	275
GI.3.1 Methods Overview.....	275
GI.3.2 Description of Spill Scenarios Used to Measure Economic Damages from a Worst-case Spill .....	278
GI.4 Analysis and Results.....	279
GI.4.1 Recreational Beach Use Valuation .....	279
GI.4.2 State and Federal Park Day Visits .....	281
GI.4.3 State and National Park Camping.....	283
GI.4.4 Recreational Fishing Valuation .....	285
GI.4.5 Recreational Boating Valuation.....	287
GI.4.6 Commercial Fishing Valuation.....	289
GI.4.7 Impacts to Great Lakes Commercial Shipping.....	292
GI.4.8 Effects on Michigan’s Energy Supply.....	294
GI.4.9 Water Supply Effects.....	297
GI.4.10 Lost Amenity Value to Residential Property.....	303
GI.4.11 Estimates of State-wide Losses to Tourism Activities .....	306
GI.5 Conclusions.....	311
G.I.6 References.....	314
Task H: Estimating the Governmental Costs That Would Be Incurred as a Result of a Worst-case Release .....	319
H.1 Introduction.....	319

H.1.1 Policy Instrument Focus.....	319
H.1.2 The Line 5 Oil Spill “Policy Network”.....	320
H.1.3 Review of Relevant Spills.....	323
H.2 Approach.....	324
H.2.1 Government Costs: Oil Spill Response.....	324
H.2.2 Government Benefits: Gain in State and Federal Tax Revenues.....	327
H.3 Analysis of Government Costs and Benefits .....	328
H.3.1 Costs from the Decline of Visitor Related Tax Expenditures.....	328
H.3.2 Governmental Costs Due to Shoreline Oiling.....	329
H.3.3 Health Costs .....	330
H.3.4 Analysis of Government Response Oversight and Damage Assessment Costs .....	330
H.3.5 Government Loss from Responsible Party Cleanup Cost Deduction .....	334
H.4 Summary .....	335
H.5 References.....	335
Section X: Broader Impacts .....	338
X.1. Introduction.....	338
X.2. Approach.....	339
X.2.1. Background .....	339
X.2.2. Data and Methods .....	342
X.3. Analysis.....	349
X.3.1. Quantitative overview of perceived risk .....	349
X.3.2. Qualitative overview of perceived risk .....	354
X.3.3. Tribal Concerns.....	364
X.4. Discussion .....	374
X.5 Summary .....	377
Summary of Costs.....	382

## Figures

Figure 1. The Straits of Mackinac and Surrounding Area .....	26
Figure A1: Locations of isolation valves north and south of the Straits crossing.. .....	38
Figure A2. Elevation profile of Straits Pipelines.. .....	39
Figure A3. Line 5 Straits crossing profiles with modeled critical locations.....	40
Figure A4: Coating damage found during a pipeline inspection. ....	41
Figure B1. Annual and Average Surface Water Temperatures for the Straits of Mackinac Region .....	58
Figure B2. FVCOM Terrain Following Mesh Application Computational Grid Section .....	59
Figure B3. Comparison of 2016 Hydrodynamic Model Predicted Water Currents to Real-Time Meteorological Buoy Monitoring Data Measured for the Straits of Mackinac .....	60
Figure B4: Satellite Image of the Spill Location Assumed for the Atmospheric Dispersion Calculations Near the Town of Mackinaw City, MI.....	64
Figure B5-A. Ground-level Concentrations ( $\rho_A$ ; $\mu\text{g}/\text{m}^3$ ) of VOCs in the Air Over Mackinaw City, MI for Atmospheric Stability Class F .....	74
Figure B5-B. GIS Overlay Map Depicting VOC Plume from Line 5 Oil Spill During Atmospheric Dispersal Over Mackinac City, MI .....	74
Figure C1. Incident Command Structure .....	83
Figure C2. Open Water Area Covered with Floating Oil and Oiled Shoreline Length in Lake Huron Over Time for the Modeled Dec. 27 Scenario.....	93
Figure C3. Volumes of Oil Floating on the Water and Beached on Shore Over Time for the Modeled Dec. 27 Scenario without taking into account clean up activities .....	94
Figure C4. Fate of Oils on Water (Red) and Shorelines (Green) 3, 12, 24 (Left), 48, 96, 120 (Right) hrs After Oil Release from Center Channel of Straits of Mackinac at 6 am on December 27, 2016 .....	95
Figure C5. Cumulative Recovery Rates Over 72 Hours of Response Time (Enbridge) .....	100
Figure C6. Oil Recovered as a Function of Time in hours From ROC Simulations with No Wind for 8-Hour Operations.....	106
Figure C7. Oil recovered as a Function of Time in hours from ROC Simulations with the Wind Conditions for the Storm (Dec. 27 - 31st 2016).....	107

Figure C8. Recoverable Oil Over the First Five Days of a Spill Using Average Conditions for Each Month .....	109
Figure C9. Oil Recovered as a Function of Wind Speed. ROC Simulations Were Run at Two Temperatures for 8-Hour Operations. With Increasing Wind Speed There is Limited Oil Recovery .....	110
Figure C10. Oil Recovered as a Function of Time From ROC Simulations with No Wind for 8-Hour Operations.....	112
Figure D1: Community Health Assessment Regions (Source: Michigan Department of Health and Human Resources, 2016a) .....	121
Figure D2.. Straits of Mackinac Worst Case Oil Dispersal Predicted During the Summer Season .....	126
Figure D3.. Summary of the Pipeline Analysis Method.....	132
Figure D4.. SEG <sub>x</sub> Estimation Based on the Hazard.....	137
Figure D5. Potential Non-carcinogenic Risk from PAH Exposure Due to the Worst-case Release .....	138
Figure D6. Potential Carcinogenic Risk from PAH Exposure Due to the Worst-case Release .	139
Figure D7.. Liquid Release, LFL Impact Distance, Based on Circular Diameter .....	143
Figure D8. Liquid Gasoline Release, Pool Fire Heat Radiation Impact Distance, Based on Circular Diameter (or Channel Equivalent Diameter) .....	144
Figure D9. Hazard Impact Circles Equivalent to $Ind_{risk}$ Values for Individuals (receptors) at Boundaries of Three Impact Zones.....	145
Figure D10.. Michigan Public Water Supply IntakeLocations.....	150
Figure E1. Conceptual Model for Impacts to Natural Resources from a Line 5 Pipeline Rupture and Subsequent Oil Spill in the Straits of Mackinac .....	168
Figure E2. GIS Mapping of 10-day Oiled Area Scenarios for Mackinac Straits and Lakes Huron and Michigan .....	171
Figure E3. GIS Mapping of 60-day Oiled Area Scenarios for Mackinac Straits and Lakes Huron and Michigan .....	172
Figure E4. Shoreline Habitats Exceeding Thresholds for Socioeconomic Impacts ( $>1 \text{ g/m}^2$ ). Criteria Based Upon NOAA (2013). SEF $>1\text{g/m}^2$ (light grey); EF $>100\text{g/m}^2$ (black).....	173



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.....	176
Figure E6. 10-day Oil Dispersal Scenario of Unique Terrestrial Community Complexes .....	178
Figure E7. Map of Field Data Locations, Color-coded by Dominant Cover Type (from Bourgeau-Chavez et al., 2008).....	182
Figure E8. Submerged Aquatic Vegetation Location and Density Within and Adjacent to Mackinac Straits Derived from MTRI’s Classification Relative to 10-Day Post Oiling Scenario.....	183
Figure E9. Aquatic Food Web of Lake Huron.....	185
Figure E10. Lakes Huron and Michigan Fish Spawning Areas (based on GLAHF and Goodyear Atlas).....	197
Figure F1. Articulating Federal Cultural and Natural Resources Laws in the United States (From King, 2008) .....	225
Figure F2. Public Water Supply Intakes in Michigan.....	235
Figure F3. Known Archaeological Sites on or Near Michigan Beaches in the Straits of Mackinac and Lake Huron Shores.....	248
Figure GI1. Conceptual Illustration of Economic Measures Of The Recreation Losses Due To An Oil Spill.....	277
Figure GI2. Economic Effect of a Change in Commercial Fish Landings Due to a Spill.....	291
Figure GI3. Location of Propane Heated Households .....	295
Figure GI4. Scenario 1 Groundwater Wells Within 200 Feet of Oiled Shorelines and Affected Lake Water Intakes .....	298
Figure GI5. Scenario 2 Groundwater Wells Within 200 Feet of Oiled Shorelines and Affected Lake Water Intakes .....	301
Figure GI6. Scenario 3 Groundwater Wells Within 200 Feet of Oiled Shorelines and Affected Lake Water Intakes .....	301
Figure H1. Geographic Boundaries for Federal Contingency Plans –USCG Sault Sainte Marie Captain of the Port (COTP) Zone and EPA Region 5 Northern Michigan Subarea.....	321

Figure H2. Straits of Mackinac Oil Release Scenario Maps for Counties Directly and Indirectly Affected by Shoreline Contamination .....	325
Figure H3. Logarithmic Curve of Government Response Cost Vs. Spill Volume for Three Historical Spills Applied to The Estimated Worst-case Discharge Volume for a Straits Spill .....	333
Figure H4. Government Response Cost Vs. Oiled Shoreline Length for Three Historical Spills Applied to The Estimated Worst-case Oiled Shoreline Length for a Straits Spill.....	334
Figure X1. Comments by Submission Type .....	346
Figure X2. - Total Support among all Comments Submitted .....	351
Figure X3. - Support among All Comments Excluding Questionable Comments .....	351
Figure X4. Comment by Organizational Affiliation .....	352
Figure X5. Support among Individuals without an Organizational Affiliation .....	354
Figure X6 Ceded Territory under the 1836 Treaty (Newland, et al. 2018) .....	371

## Tables

Table 1. Risk Analysis Project Team Members and Roles.....	28
Table 2. Summary of the Specific Spill Scenarios Case Study Selections for Each Assessment Task.....	30
Table A1: Comparison of assumptions for this and previous estimates of spill volumes at the Straits. ....	34
Table A2. Basic Information of Straits Crossing Pipelines .....	37
Table A3. Line 5 Straits crossing critical locations. ....	40
Table A4: Line 5 threats and associated failure modes. ....	42
Table A5. Correspondence between pipeline threats and analyzed tiers of failure. ....	46
Table A6. Worst case discharge scenarios (west segment). ....	48
Table A7. Worst case discharge scenarios (east segment). ....	48
Table A8. Rupture cases analysis result for Tier 1. ....	50
Table A9. Rupture cases analysis result for Tier 2. ....	50
Table A10. 3-inch hole leakage cases analysis result for Tier 1.....	51
Table A11. 3-inch hole leakage cases analysis result for Tier 2.....	51

Table A12. Straits Pipelines worst case discharge volume in US Oil Barrels for different tiers of failure. ....	54
Table B1. Locations and Geographic Coordinates for Simulated Pipeline Rupture and Crude Oil Release .....	62
Table B2. Parameters for Several Atmospheric Stability Classes .....	67
Table B4. Summary of Monthly Maximum Water Surface Area Oilings (Km <sup>2</sup> ) Predicted for the Straits of Mackinac Region During 2016 Meteorological Conditions .....	71
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) .....	75
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) .....	75
Table B7. Comparison of Modeling Techniques and Capabilities for Current and Previous Assessments of Oil Spill Scenarios in the Straits of Mackinac Region.....	78
Table D1. Vulnerable Populations (Source: U.S. Census Bureau, n.d.).....	122
Table D2. Health Effects of Chemicals of Potential Concern (ATSDR, 2011; NIOSH, 2016). ....	125
Table D3. Simulated PAH Values from Concentrations in 49 Different Crude Oil Spill Samples and the Monte Carlo Simulation .....	129
Table D4. Potential Incremental Lifetime Cancer Risks (ILCR) and HQ Estimated for Straits of Mackinac Populations Exposed to Line 5 Crude Oil PAHs .....	129
Table D5. Summary Statistics of Selected VOCs ( <i>mgm3</i> ) for the Worst-case Crude Oil Spill from Atmospheric Area Source Dispersion at <i>xm</i> = < 1000 <i>m</i> . ....	140
Table D7. Population Risk Indicator for Vapor Cloud Release with Pool Fire.....	147
Table D8. General and Specific Adverse Human Health Effects Associated with Oil-Contaminated Drinking Water Consumption Summary (Adopted From Kponee et al., 2015) .....	148
Table E1. Oil Barrel Distribution Among Habitats Along the Shorelines of Lakes Huron and Michigan from the Four Sampled Worst-case Scenarios, From Section B .....	170
Table E2. 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) .....	175

Note: Light and dark grey represent exceedance for TEC and PEC respectively. ....	175
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) .....	175
Note: Light and dark grey represent exceedance for TEC and PEC respectively. ....	175
Table E4. Michigan’s Natural Communities at Risk Following a Line 5 Pipeline Rupture in the Mackinac Straits (see Figure E6) .....	179
Table E5. Insect Species in Coastal Habitats of Lakes Michigan and Huron Most Vulnerable to Oil Exposure Post Line 5 Pipeline Rupture in the Mackinac Straits .....	188
Table E8. Reptile and Amphibian Species Most Vulnerable to Oil Exposure Post Line 5 Pipeline Rupture Given Their Use of Surrounding and Adjacent Areas in the Mackinac Straits .....	190
Table E6. Fish Species in Lakes Michigan and Huron Most Vulnerable to Oil Exposure Post Line 5 .....	193
Table E9. Mammal Most Vulnerable to Oil Exposure Post Line 5 Pipeline Rupture Given Their Use of Littoral and Coastal Habitats for Foraging, Breeding, and Brooding in the Mackinac Straits .....	210
Table E10. Physiological and Ecological Effects Summary of Petroleum or Individual PAHs on Organisms (see Albers, 2003) .....	212
Table F1. Oil Spill Comparison .....	229
Table F2. Selected Maximum Contaminant Levels from the National Primary Drinking Water Regulations .....	237
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 .....	261
Table G11. Broad Summary of Categories of Loss Assessed and General Approach to Measuring Losses .....	277
Table G12. Shoreline Length and Number Of Counties In Michigan, Wisconsin, And Ontario Affected By Three Candidate Worst-Case Spills .....	279
Table G13. Present Value of Lost Welfare from Reduced Beach Trips (million) .....	280
Table G14. Economic Damages to Recreational Day Trips for Three Worst-case Spill Scenarios .....	283

Table GI5. Economic Damages to Camping Trips for Three Worst-case Spill Scenarios .....	284
Table GI6. Economic Damages to Recreational Fishing Trips for Three Worst-case Spill Scenarios .....	287
Table GI7. Economic Damages to Recreational Boating for Three Worst-case Spill Scenarios	289
Table GI8. Lakes Huron and Michigan Management Units Harvests in the 1836 Treaty-ceded Waters .....	292
Table GI9. Commercial Fish Harvest Economic Damages for Three Worst-case Spill Scenarios .....	292
Table GI10. Michigan Energy Effects (\$ million).....	296
Table GI11. Costs for Groundwater Wells Monitoring .....	299
Table GI12. Costs for Lake Water Intakes .....	301
Table GI13. Total Cost for Water Supply.....	303
Table GI14. Total Welfare Losses to Lakefront Homeowners Under Different Worst-case Scenarios (\$ millions) .....	305
Table GI15. Tourism Visitor Expenditure Profiles.....	310
Table GI16. Estimated Lost Incomes (labor and proprietors) .....	310
Table GI17. Summary of Damages from Simulated Worst-Case Spills (\$ millions).....	312
Table H1. Scenario 1 Direct Economic Loss Estimates to Affected Communities by Out-Of-State Tourists Who Decide Not To Visit Counties Affected by The Oil Spill .....	326
Table H2. Scenario 2 Direct Economic Loss Estimates to Affected Communities by Out-Of-State Tourists Who Decide Not To Visit Counties Affected by The Oil Spill .....	326
Table H3. Scenario 3 Direct Economic Loss Estimates to Affected Communities by Out-Of-State Tourists Who Decide Not To Visit Counties Affected by The Oil Spill .....	326
Table H4. Tax Rates for Sales, Lodging, Transportation Fuels, and Other Factors .....	327
Table H5. Scenario 1 Government Tax Revenues Lost from Declines in Out-Of-State Beach Visitations .....	328
Table H6. Scenario 2 Government Tax Revenues Lost from Declines in Out-Of-State Beach Visitations .....	328
Table H7. Scenario 3 Government Tax Revenues (Not Including Canadian Tax Revenues) Lost from Declines in Out-Of-State Beach Visitations .....	329

Table H8. Government Tax Revenues Gained from Oil Spill Cleanup Responsible Party Funding	
.....	329
Table H9. Tasks G, H and I Three Worst-case Scenario Estimated Shoreline Cleanup Costs	
Based on the 2010 Marshall Spill Costs Per Kilometer Reporting.....	330
Table 3. Summary of total potential liability for a worst-case spill from the Straits pipelines. .	382

**Several appendices to this report are available as a separate document:**

Appendix A-1 Leakage Calculations

Appendix A-2 Historical Data

Appendix B-1 Oil Dispersal and Proportional Oil Fate

Appendix B-2 GIS Processing of FVCOM Modeling Results for Further Analysis

Appendix C-1 Wave and Current Data.

Appendix C-2 Total USCG Inventories

Appendix C-3 USCG Boom Trailer Locations

Appendix C-4 Three-year Average Wind Conditions (2015-2018) for the Straits Region

Appendix D-1 Population Characteristics

Appendix D-2 Safety Risk and Consequence Detailed Methodology

Appendix D-3 Explosion and Fire Hazard Methodology

Appendix GI-1 Economic Calculations

Appendix GI-2 Short-term Impacts on Petroleum Supply from a Line 5 Disruption

Appendix J Response to Comments on the Independent Risk Analysis of Straits Pipelines Draft Report

**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
APE	Area of Potential Effect
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[a]pyrene
bbbl	Oil Barrel (42 U.S. gallons)
BRFS	Behavioral Risk Factor Survey
BRFSS	Behavioral Risk Factor Surveillance System
BSEE	Bureau of Safety and Environmental Enforcement
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
CDI	Chronic Daily Intake
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
CTI	Chironomidae Trophic Index
CXPA	Semi-volatile Aromatic Compounds
CXVO	Volatile Organic Compounds
DARP	Damage Assessment and Restoration Plan
DED	Explosion Duration (in one year)
Dilbit	Diluted Bitumen
DEQ	Department of Environmental Quality (Michigan)
DNR	Department of Natural Resources (Michigan)
DOJ	U.S. Department of Justice
DOT	U.S. Department of Transportation
DR	Dynamic Risk Assessment Systems, Inc.
DWH	Deepwater Horizon
ED	Exposure Duration
EF	Ecological Factor



EIA	U.S. Energy Information Administration
EMS	Emergency Medical Services
EPA	U.S. Environmental Protection Agency
ERSP	Estimated Recovery Systems Potential
ESA	Endangered Species Act
ET	Exposure Time
ETA	Event Tree Analysis
EVOS	Exxon Valdez Oil Spill
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 <sub>2</sub> S	Hydrogen Sulfide
HHRA	Human Health Risk Assessment
HSE	Health and Safety Executive
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
IO	Input-Output Modeling
IR	Inhalation Rate
IRB	Institutional Review Board
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
Line 6B	Enbridge Pipeline 6B located near Marshall, MI
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
MDNRE	Michigan Department of Natural Resources & Environment
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
NAGPRA	Native American Graves Protection and Repatriation Act
NEPA	National Environmental Policy Act of 1970
NGDC	National Geophysical Data Center
NGL	Natural Gas Liquids
NGO	Non-Governmental Organization
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
OTI	Oligochaeta Trophic Index
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 (Michigan)
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
TNT	Trinitrotoluene
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
USFS	U.S. Forest Service
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 serve as a hub for recreation, tourism, commercial shipping, as well as commercial, sport and subsistence fishing (several tribes retain fishing rights in these 1836 treaty-ceded waters).

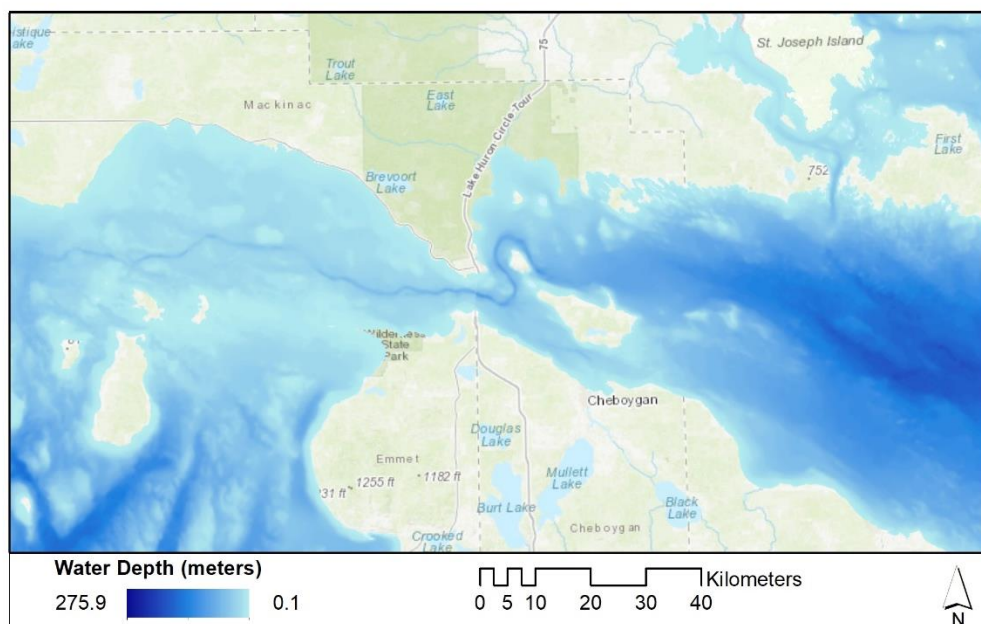


Figure 1. The Straits of Mackinac and Surrounding Area

Source: 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. The 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.

This assessment serves to complement the Alternatives Analysis for the Straits Pipeline commissioned by the State in 2017. The original intent was to have this independent risk analysis 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 selected 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.

As specified in the State of Michigan's Request for Proposals, the Scope of Work (SOW) for this project requires 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. Sub-groups of experts worked on each task defined in the scope of work; these tasks correspond to the chapters in this report. Table 1 summarizes the project teams and the role of each member. The Section Leads for each team, together with PI Guy Meadows and Project Coordinator Amanda Grimm, formed the Project Coordination Team, facilitating the exchange of information and overall analysis development.

The tasks were defined as follows:

- A** 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.
- B** Analyzing the likely environmental fate and transport of oil or other products released from the Straits Pipelines in a worst-case scenario.
- C** Analyzing how long it would take to contain and clean up the worst-case release.
- D** Analyzing the short and long-term public health and safety impacts.
- E** Analyzing the short and long-term ecological impacts.
- F** Analyzing potential measures to restore the affected natural resources and mitigate the ecological impacts.
- G** Estimating the amount of natural resource damages that would result from a worst-case release.
- H** Estimating the governmental costs that would be incurred as a result of a worst-case release.

**I** Estimating all other economic damages, public and private, that would result from a worst-case release.

**X** Broader impacts

Several Tasks include appendices, which provide additional details, calculations, tables, and figures. In particular, Appendix GI2 analyzes the short-term impacts on petroleum supply from a Line 5 disruption. A list of appendices is provided following the Table of Contents in this document.

Table 1. Risk Analysis Project Team Members and Roles

SECTION	TASK	LEAD	SCIENTIST	AUTHOR(S)	OTHER(S)
A	Worst Case	Amanda Grimm (MTU)	Ying Huang (NDSU)	Guy Meadows (MTU)	
				Mir Sadri-Sabet (MTU)	
				Samuel Ariaratnam	
				(Ariaratnam Enterprise, Inc.)	
B	Fate & Transport	Gord Paterson (MTU)	Pengfei Xue (MTU)	Dave Schwab (UofM)	Eric Anderson (NOAA)
				Dave Shonnard (MTU)	Philip Chu (NOAA)
C	Clean-up	Daisuke Minakata (MTU)	Aline Cotel (UofM)	Amlan Mukherjee (MTU)	
				Stephen Techtmann (MTU)	
D	Public Health	Kelly Kamm (MTU)	Richard Olawoyin (OU)	Charles Ide (WMU)	
				Gord Paterson (MTU)	
E	Ecological Impacts	Jill Olin (MTU)	Charles Ide (WMU)	Marla Fisher (WMU)	
				Robert Powell (PASS)	
				Victor Carmona (Detroit Mercy)	
				Kevin Strychar (GVSU)	
				Dave Flaspohler (MTU)	
F	Restoration	Steve Techtmann (MTU)	Avery Demond (UM)	Aline Cotel (UofM)	
				Tim Scarlett (MTU)	
				Jill Olin (MTU)	
G	Nat Res Damage	Latika Gupta (MTU)	Frank Lupi (MSU)	Yongli Zhang (Wayne)	
				Carson Reeling (WMU)	
				Max Melstrom (LUC)	
				Steve Miller (MSU)	
H	Gov Costs	Adam Wellstead (MTU)	John Bratton (LimnoTech)	Dave Shonnard (MTU)	
				Amlan Mukherjee (MTU)	
I	Public & Private Costs	Latika Gupta (MTU)	Frank Lupi (MSU)	Yongli Zhang (Wayne)	
				Carson Reeling (WMU)	
				Max Melstrom (LUC)	
				Steve Miller (MSU)	
J	Final Report	Amanda Grimm (MTU)	Guy Meadows (MTU)	Sarah Green (MTU)	
X	Broader Impacts including Public and Native Community Interests	Roman Sidortsov (MTU)		John Baeten (MTU)	Alice Lippert (Independent Consultant, Retired DOE)
				Chelsea Schelly (MTU)	Joanne Shore (Independent Consultant, Retired AFPM)
				Mark Rouleau (MTU)	

University of Michigan (UM), Michigan State University (MSU), Western Michigan University (WMU), Michigan Technological University (MTU), Oakland University (OU), Grand Valley State University (GVSU), Wayne State University (WSU), North Dakota State University (NDSU), Loyola University Chicago (LUC), Powell and Associates Science Services (PASS), Department of Energy (DoE), American Fuel & Petrochemical Manufacturers (AFPM)

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 the pipeline 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 the line could also impact the Great Lakes at other locations because it runs close to the shorelines and crosses navigable waters and wetlands.

The Straits of Mackinac and the Great Lakes are unique features on Earth. No historical oil spill has occurred in such a vast freshwater system and so we have no case study from which to estimate the impacts of a potential spill in the Straits. Therefore, we draw on several other spill events, coupled with hydrodynamic models and ecological assessments, to project impacts of oil to this region. The July 2010 spill from Enbridge's Line 6B into a tributary of Michigan's Kalamazoo River is geographically the closest large pipeline failure, though the oil did not reach the Great Lakes. However, Line 6B carried diluted bitumen (dilbit), which is much heavier than the products transported in Line 5; so, clean-up procedures and long-term impacts would be quite different. Oil spilled in a river is carried downstream, whereas variable currents in large lakes can carry material across a wide area. Because other large oil spills have occurred in marine systems, most previous studies have focused on the oil impacts in saltwater and marine coastal environments. As a result, our understanding of effective clean-up methods and impacts of oil on large freshwater systems is scant. Freshwater oil spills differ from marine spills in several key respects. Compared to the ocean, spills in the Great Lakes have the potential to contaminate drinking water supplies, to affect wider areas of concentrated populations, and to encounter numerous human structures and activities. Furthermore, predicting oil dispersal patterns in the lakes requires specific modeling of local currents, whereas tides and wave action are of less concern than in marine systems. For this report, we used the best available information, along with well-supported assumptions, to estimate the impacts of a worst-case spill from Line 5.

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)*

While the federal definition of a worst-case scenario dictates the calculation of the volume of oil that could be released, the impacts of such a spill depend on the season in which it occurs and specifically on the weather immediately after a spill event. To accommodate the range of possible impacts from a fixed volume released, oil dispersal was modeled across a full year (2016) of known weather conditions in the Straits (Task B). Task authors then determined which scenario constitutes a worst case for their specific topic. For example, Task C identified a winter spill as the most difficult to respond to safely; Task D found that a large area of floating oil in summer would constitute the greatest health hazard. The extent of oiled shoreline was the most critical feature for Tasks E, F, and G/I, and each considered several scenarios. The scenarios selected for each task are listed in Table 2.

This variation among tasks was intended to allow the assessment to capture the worst-case damages for each and demonstrate the range of plausible impacts across the year. Certainly, no single spill would simultaneously cause all of the impacts described. We chose the spring “Scenario 1” adopted by Tasks G, H and I as representative to estimate the overall liability from a worst-case scenario spill at the Straits.

Table 2. Summary of the Specific Spill Scenarios Case Study Selections for Each Assessment Task

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

This final report has been revised in response to public comments on a draft version of this document released September 19, 2018. A summary of those public comments, and responses from the analysis team, is provided in Appendix J accompanying this document.

## 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.

		WCS			
		Enbridge Maximum Potential Release Volume	FLOW May 2018 Straits Spill Damages Memo	Dynamic Risk Alternatives Analysis (2017)	Michigan Tech-led Independent Assessment (this report)
Assumptions	Flow rate	600K bbl (25.2M gal) per day (Based on commercial capacity + 10%; ~3,975 m <sup>3</sup> /hr) and assumes full design flow rate through one 20" pipeline	Not defined	1,789 m <sup>3</sup> /hr per 20" pipeline (total 3578 m <sup>3</sup> /hr, 540,000 bbl/day), assumes flow is split evenly between east and west lines	614,238 bbl (25.8M gal) per day (max flow rate in Enbridge-provided operational data + 5%; ~4,069 m <sup>3</sup> /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 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 time	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



	<b>Valves</b>	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
	<b>Shutdown time</b>	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 Tiers 4/5 manual closure (1-2 hours)
	<b>Decision time</b>	10 minute decision time after leak detection	Not defined	10 minute decision time after leak detection	10 minute decision time after leak detection
	<b>Drain-down</b>	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
	<b>2-phase flow</b>	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
	<b>WCS volume(s)</b>	6,428 bbl (270K gal) if valves close properly, 19,164 bbl if they do not close in the designed time frame	59,500 bbl (2.5 million gal)	Approx 2,600 bbl (109K gal) for rupture case and 2,900-4,500 bbl (122K-189K gal) for north or south shore 3" leak	Between 4,400 and 58,000 bbl (185K-2.4 million gal)

### 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.**

- a. 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.
- b. The worst case discharge is the largest volume, in barrels, of the following:
  1. 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
  2. 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
  3. 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 (1.07M gal/hr). 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.

Several leak monitoring methods have been put into place for the Straits Pipelines. The information on the pipeline monitoring and leak detection systems provided to the analysis team can be summarized as follows:

- Visual surveillance and reports - Oil or oil odors may be reported by third parties or by Enbridge employees/contractors.
- SCADA - Pipeline conditions (such as pipeline pressure) are monitored from the control room through the Supervisory Control And Data Acquisition ("SCADA") system, which is designed to identify unexpected operational changes, such as pressure drops along the pipeline, that may indicate a leak. Additional sensors monitored through SCADA provide information such as concentrations of explosive vapor, pump seal failures, equipment vibration levels and sump levels, which can be used by the controller to identify potential leaks.

- Computational Pipeline Monitoring Systems (CPM) - Enbridge employs computer-based pipeline monitoring systems that utilize measurements and pipeline data to detect and alarm on anomalies that could indicate possible leaks.
  - The Enbridge primary computational pipeline monitoring system (or Material Balance System, aka “MBS”) continuously monitors changes in the calculated volume of liquids to alert the control room of potential leak conditions. Pump station pressure and flow measurements are used to identify and alarm on pipeline rupture events. Rupture detection - The control center procedures require immediate shutdown of the pipeline upon receipt of a rupture alarm.
  - Automated Pressure Deviation – Pressure is monitored during pipeline shut-in conditions and alarms are generated if a significant pressure drop occurs.
  - Automated Volume Balance - Enbridge employs complementary computer-based pipeline monitoring system that determines a time-averaged volume imbalance using injection and delivery flow meters during running conditions. If the imbalance exceeds a pre-set threshold, it will generate an alarm.
  - Acoustic Inline Inspection - Acoustic inline inspection tools are specially designed to confirm the integrity of the pipeline and for the detection and localization of very small leaks through unique acoustic signatures.

#### A.2.2 Isolation Valves

Each end of the Line 5 Straits crossing has isolation valves on each 20 " pipeline (Primary Valves) and on the 30" pipeline where the 20” lines meet (Secondary Valves, Fig A1).

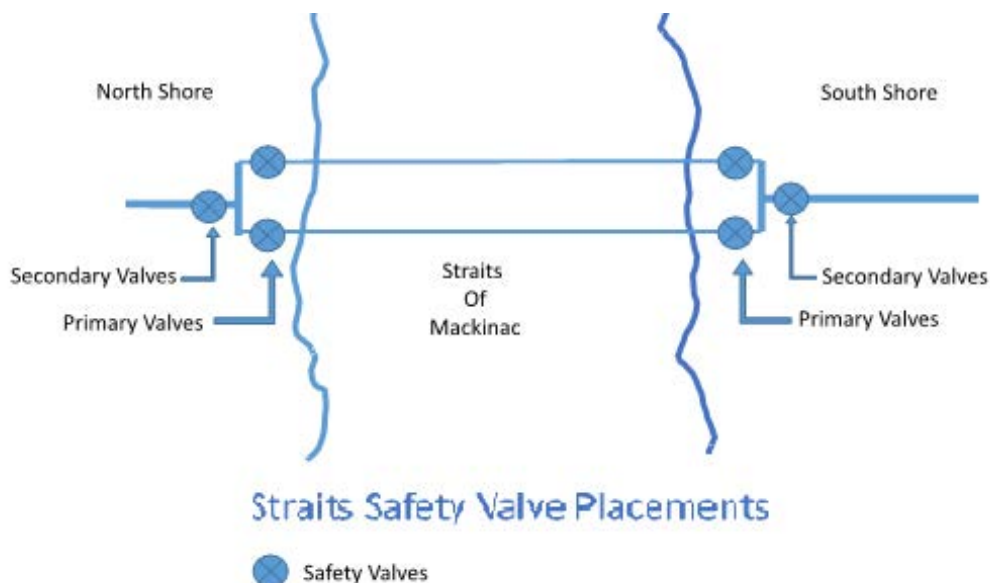


Figure A1:

Locations of isolation valves north and south of the Straits crossing. The primary and secondary valves are less than 300 m apart on the south shore and < 100 m apart on the north shore; both sets of valves are inside the Enbridge properties on either end of the Straits segment.

### A.2.3 Elevation Profile and Critical Locations

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

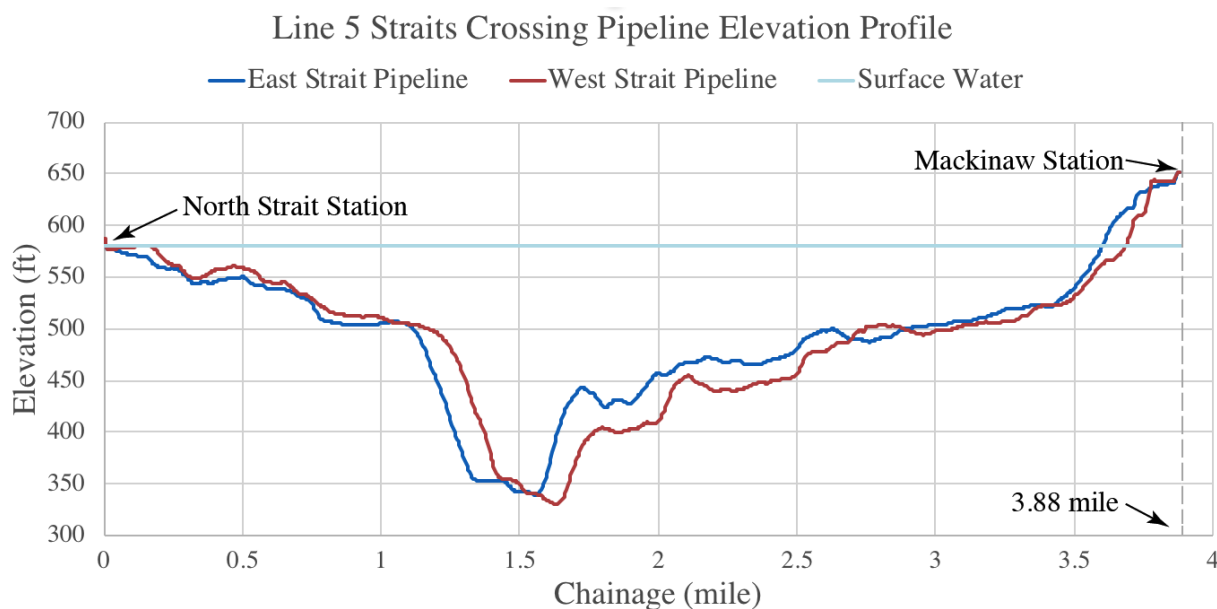


Figure A2. Elevation profile of Straits Pipelines. The pipelines are unburied from approx. the 1 mile to 3 mile marks in this diagram and are buried beneath the lake bottom closer to shore. The primary and secondary valves depicted in Figure A1 are located inside the stations.

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 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 also from the lowest elevation point.

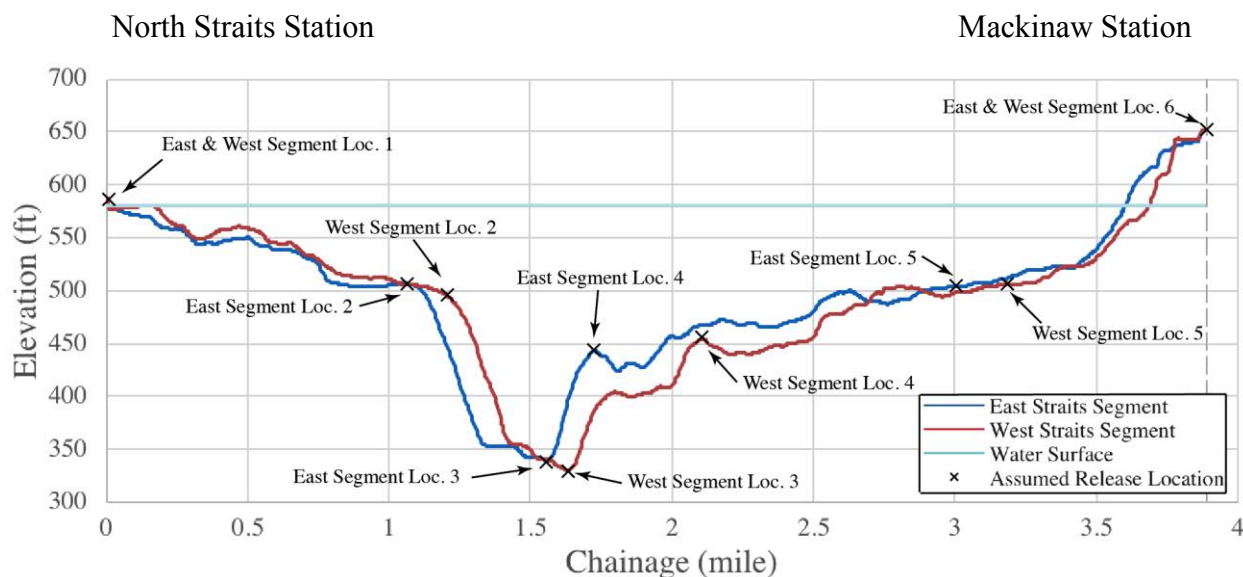


Figure A3. Line 5 Straits crossing profiles with modeled critical locations. Locations 1 and 6 are inside North Straits Station and Mackinaw Station, respectively.

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 external or internal corrosion, defects, fatigue or third-party damage. In 2017, Enbridge provided an interim report of coating damage found during inspections (Figure A4). Coating gaps were confirmed at multiple locations with an inconclusive result reported for one additional location. Coating gaps were sufficiently large that bare pipe metal was 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 differential pressures, i.e., large fluctuations in internal pressure that stress the pipe material over time; incorrect operation, such as 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. Both a pinhole leak and full (guillotine) ruptures of one or both Straits pipelines were evaluated to identify the worst-case release volume. Two pinhole sizes, 0.6 and 3 inches, were evaluated. The large pinhole diameter of 3 inches was chosen based on historical data from European offshore pipelines (CONCAWE 2008 and EGIG 2008; similar records were not available for US pipelines) showing that 95% of small leaks involved a hole with a diameter of 3 inches or less. A scenario based on a 0.6" hole was also analyzed in order to capture both ends of the likely range of pinhole sizes; because the 0.6" pinhole scenario resulted in a lower release volume than the 3" scenario, only the worst pinhole case (a 3 inch hole) was included in the reporting.

Table A4: Line 5 threats and associated failure modes.

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

$$\text{Total Response Time} = \text{Spill/Leak Detection Time} + \text{Decision/Isolation Time} \quad (\text{A-E1})$$



#### A.2.5.1 Spill/Leak Detection Time

According to 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 these values 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 of these systems because the pipeline is used to transport multiple products, in the case of Line 5 including light crude and Natural Gas Liquids (NGL), using the same conduit according to seasonal needs. These detections systems are most accurate for steady-state operations. A pipeline under transient conditions (start-up and shut-down) produces additional background noise which results in less accurate 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 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<sup>3</sup> of natural gas was vented to the atmosphere at TransCanada Station 68 after an emergency shutdown caused by blowing a 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 up to 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. Correspondence between pipeline threats and analyzed tiers of failure.

Threats	Manifestation	Pipes Likely Affected	Tier
<i>Spanning stress</i>	Guillotine rupture	One 20"	Tier 1 Rupture or Pin-hole in one 20" line with immediate response
<i>Cracking (fatigue)</i>	Larger area hole	One 20"	
<i>Corrosion</i>	Pinhole leak	One 20"	
<i>Third-party damage</i>	Any hole size	One 20"	Tier 2 Rupture or Pin-hole in one 20" line with maximum allowable response time
<i>Incorrect Operation (over pressure/hammer shock)</i>	Guillotine rupture	One or both 20"	Tier 3 Rupture in both 20" lines with primary valve failure
<i>Third-party damage</i>	Any hole size to rupture	One or both 20"	Tier 4 Rupture in one 20" line with manual valve closure
			Tier 5 Rupture in both 20" lines with manual valve closure

Five tiers of failure were analyzed based on the failure types in **Error! Reference source not found.**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 total 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 (21,000 gal/hr) 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 (4200 gal/hr) 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
<i>3" pin-hole</i>	W3Loc2	W3Loc3	W3Loc4	W3Loc5
<i>Rupture</i>	WRLoc2	WRLoc3	WRLoc4	WRLoc5

Table A7. Worst case discharge scenarios (east segment).

Hole Size	Location 2	Location 3	Location 4	Location 5
<i>3" pin-hole</i>	E3Loc2	E3Loc3	E3Loc4	E3Loc5
<i>Rupture</i>	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 (A-E2) below:

$$\text{Total Leak Amount} = \text{Leakage before Closing Valve} + \text{Leakage after Valves Closed} \quad (\text{A-E2})$$

The leakage after valve closure is the same for a rupture and 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 (A-E3) below:

$$\text{Leakage after Valves Closed} = \text{Pipeline Cross-section Area} \times \text{Distance from the Lowest Elevation Point} \quad (\text{A-E3})$$

Thus, from Equation (A-E3), 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 (35,700 gal) in Locations 2 and 4 for both pipes. However, for this analysis, to be conservative, a minimum 15% (which is 1,000 bbl/42,000 gal \*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 (A-E2), 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 (A-E4):

$$\text{Rupture Leakage before Closing Valve} = \text{Response Time} \times \text{Flow Rate} \quad (\text{A-E4})$$

Equation (A-E1) in Section A.2.5 shows that the total response time in Equation (A-E4) 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 up to 2 hours. Refer to Section A.5 for more details of detection and isolation time.

Based on Equation (A-E4) 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 (176,400 gal) in a Tier 1 failure and 8,500 bbl (357,000 gal) 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 (A-E5) below:

$$3'' \text{ Hole Leakage before Closing Valve} = \text{Spill/Leak Detecting Time} \times 3'' \text{ Hole Leakage Flow Rate} + \text{Decision/Isolation Time} \times \text{Rupture Leakage Flow Rate} \quad (\text{A-E5})$$

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 (184,800 gal) 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 (361,200 gal).

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 inch 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 (184,800 gal).

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-inch 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 (361,200 gal).

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-inch 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 (348,600 gal). 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 (705,600 gal).

For this Tier 3 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-inch 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 a total of up to 2 hours from the rupture to isolation. During the time before manual shut down, the pipeline is

assumed to continue carrying crude oil at the full flow rate, and all of the crude oil within this time period is discharged. For one 20" pipe, the discharge amount is 25,600 bbl (1,075,200 gal). After manual shutdown, the drawdown volume for location 5 on the west line is 3,400 bbl (142,800 gal) for a total discharge amount of approximately 29,000 bbl (1,218,000 gal).

For this Tier 4 failure to occur:

- All automated detection equipment is assumed to work as designed.
- The time required to make the decision to shut down Line 5 is included in the manual shut down window
- 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 up to 2 hours to complete.
- One 20-inch 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 (680,400 gal).

#### **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 up to 2 hours. During the time before manual shut down, 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 this time period is discharged. The discharge amount is 51,200 barrels (2,150,400 gallons). This is added to the combined post-shutdown drawdown volume of 6,800 bbl (285,600 gal) from both 20" lines at Location 5 for a total release volume of 58,000 bbl (2,436,000 gal).

For this Tier 5 failure to occur:

- All automated detection equipment is assumed to work as designed.
- The time required to make the decision to shut down Line 5 is included in the manual shut down window
- 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 up to 2 hours to complete.
- Both 20 inch underwater pipelines are involved.

Notes:

- 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 (1,360,800 gal).

## 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 Pipelines worst case discharge volume in US Oil Barrels for different tiers of failure.

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

As suggested above, the amount of product spilled is directly related to the time required to shut appropriate valves and isolate the failure from the rest of the pipeline system. An analysis of the impacts of reduced valve closure times on cleanup and shoreline impact has been requested and is address in Appendix J, Response to Comments, of this report.

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# 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<sup>3</sup>/s and thus play essential roles in navigation and shipping in this region, 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 began 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<sup>2</sup>) and the amount (barrels/gallons, 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. Appendix B1 provides copies of those additional figures and tables.

## **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 26<sup>th</sup>, 2016. The first reports of ice for Lakes Huron and Michigan in late 2016 occurred on December 11<sup>th</sup> and 12<sup>th</sup>, 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/>).

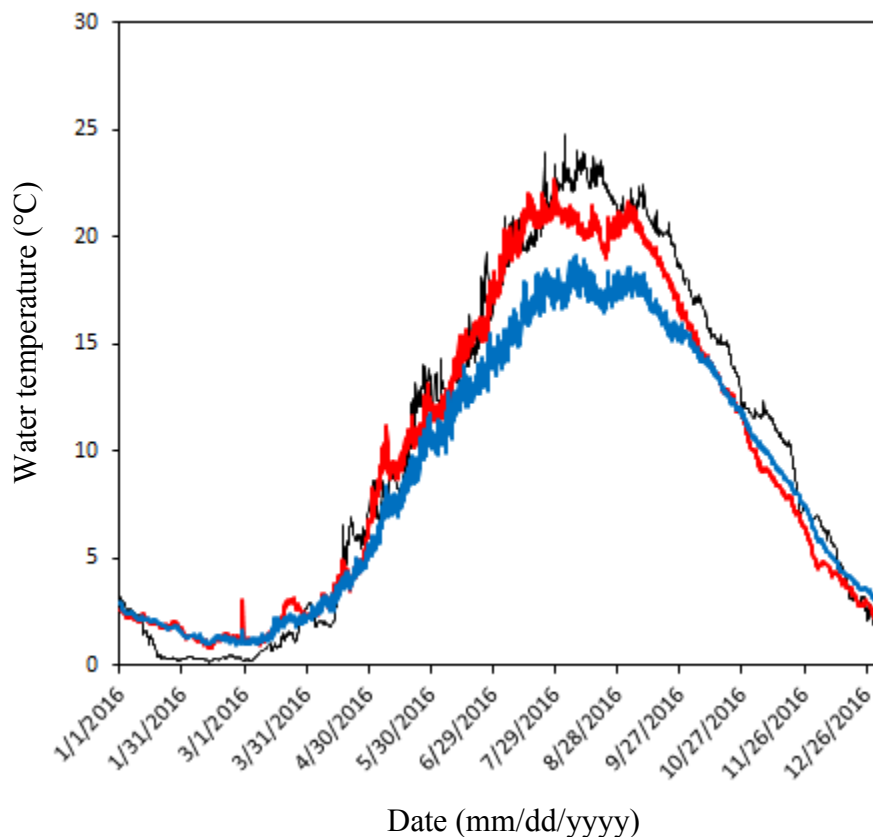


Figure B1. Annual and Average Surface Water Temperatures for the Straits of Mackinac Region

The black line represents average daily surface water temperatures for 2016 with the blue line indicating average daily surface water temperatures from 2008–2015. The red line provides the average daily surface water temperatures for the years 2012, 2013 and 2015 combined.

Source: 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 for predicting water flow and current patterns in the Straits of Mackinac region uses the next-generation Lake Michigan-Huron Operational Forecast System (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.

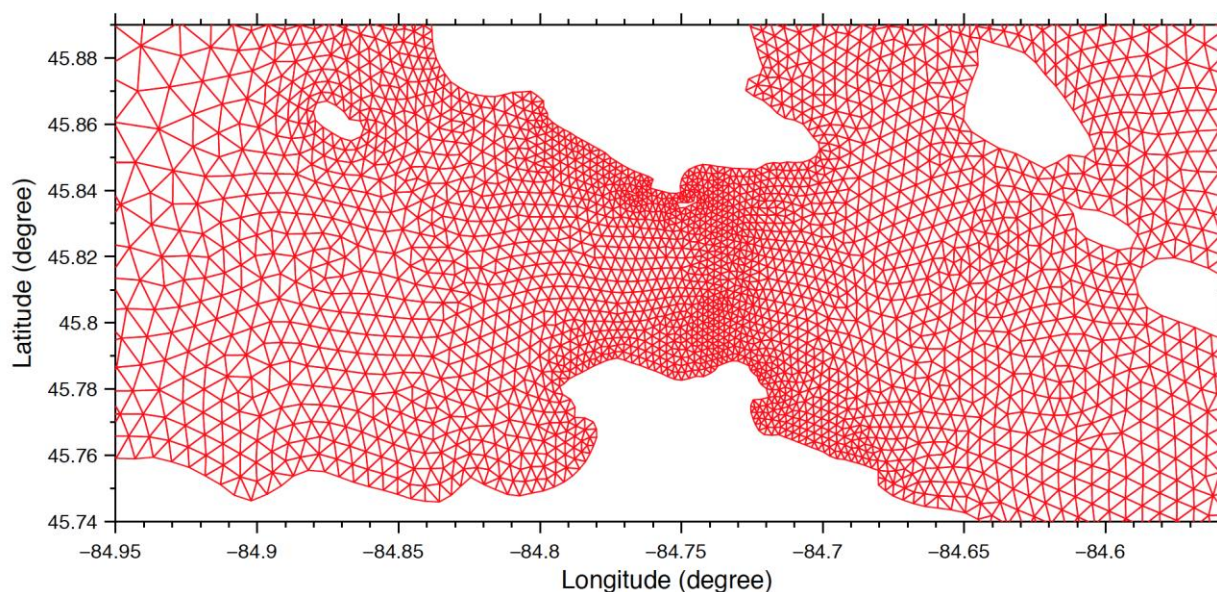


Figure B2. FVCOM Terrain Following Mesh Application Computational Grid Section

Figure B2 contains 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.

Model comparisons 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) assessed the accuracy of model predictions for water currents within the Straits of Mackinac region. 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.

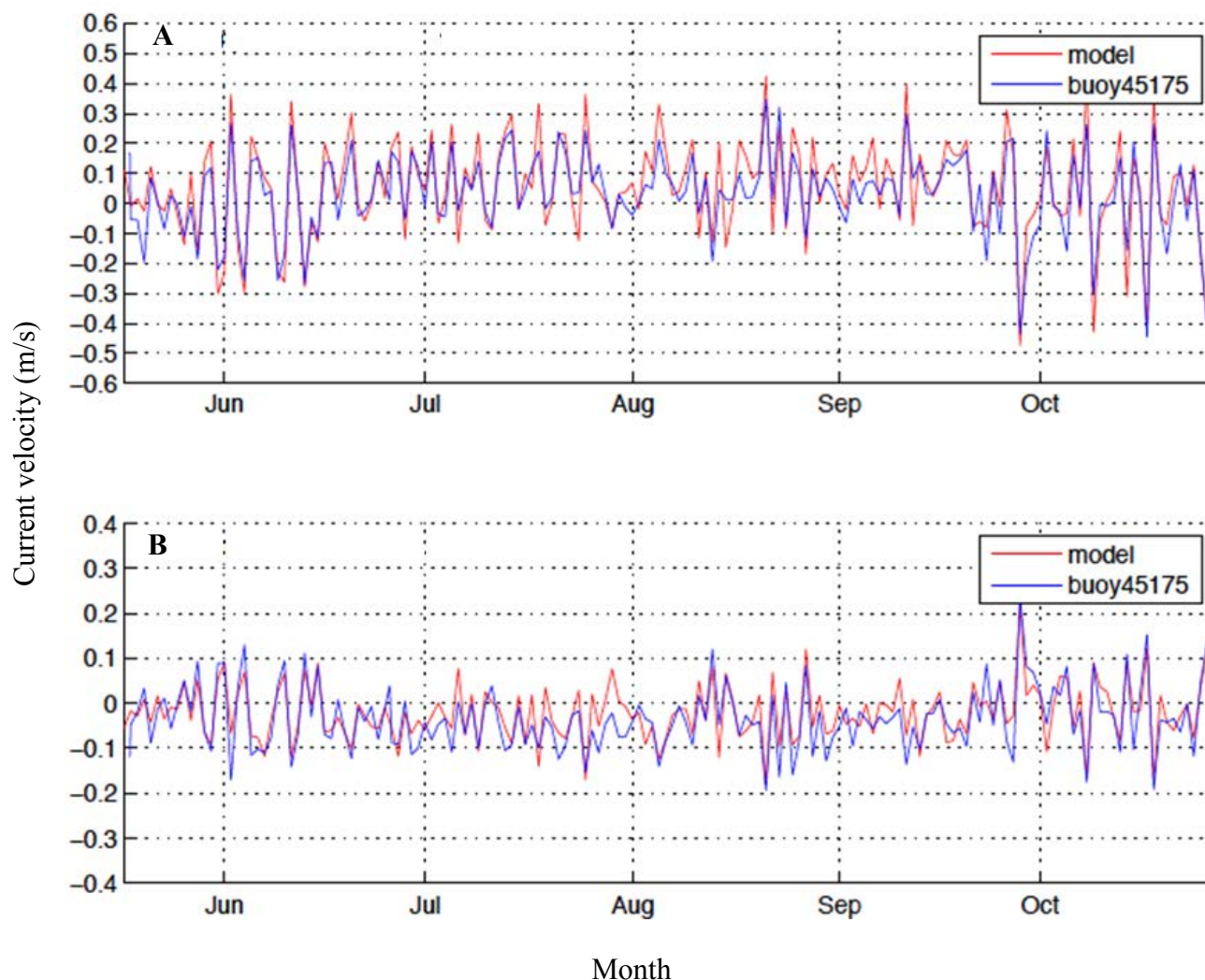


Figure B3. Comparison of 2016 Hydrodynamic Model Predicted Water Currents to Real-Time Meteorological Buoy Monitoring Data Measured for the Straits of Mackinac

Figure B3 is a 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 uses the Lagrangian particle tracking code contained within the FVCOM hydrodynamic model. In the current version of the particle tracking code, the computational scheme is optimized due to improvements in 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<sup>2</sup>/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 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<sup>2</sup>) of Lake Michigan, Lake Huron or Straits of Mackinac surface waters predicted to be at risk of oiling. Of note, FVCOM model predictions of oiled shoreline and lake surface area represent the 1 x 1 km FVCOM grid and, for oiled shoreline, an assumption that grid cells overlapping the shoreline each contain 1 km of shoreline. This gridded approach 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 used to identify the cases with the most extensive shoreline oiling and then converted to geographic information system (GIS) based distance estimates using a high-resolution shoreline layer for use by subsequent Tasks, as described in Appendix B2. 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 the predominant process 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 B-E1 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:

$$\% \text{ Evaporation} = (3.41 + 0.054T) \times \ln(t) \quad (\text{B-E1})$$

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. Evaporation stopped for particles that became beached at any time following release in the oil dispersal simulation.

Wind and ice-cover also affect oil spill trajectory and evaporation and become prominent 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. Three percent 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, collectively referred to as BTEX. The objective of this part of the analysis was to provide a prediction of ground-level concentrations ( $\mu\text{g}/\text{m}^3$ ) 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. Figure B4 provides a satellite map of the affected area 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. 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 to approximate oil spill size to estimate dispersion of emitted VOCs.

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 consists of 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.

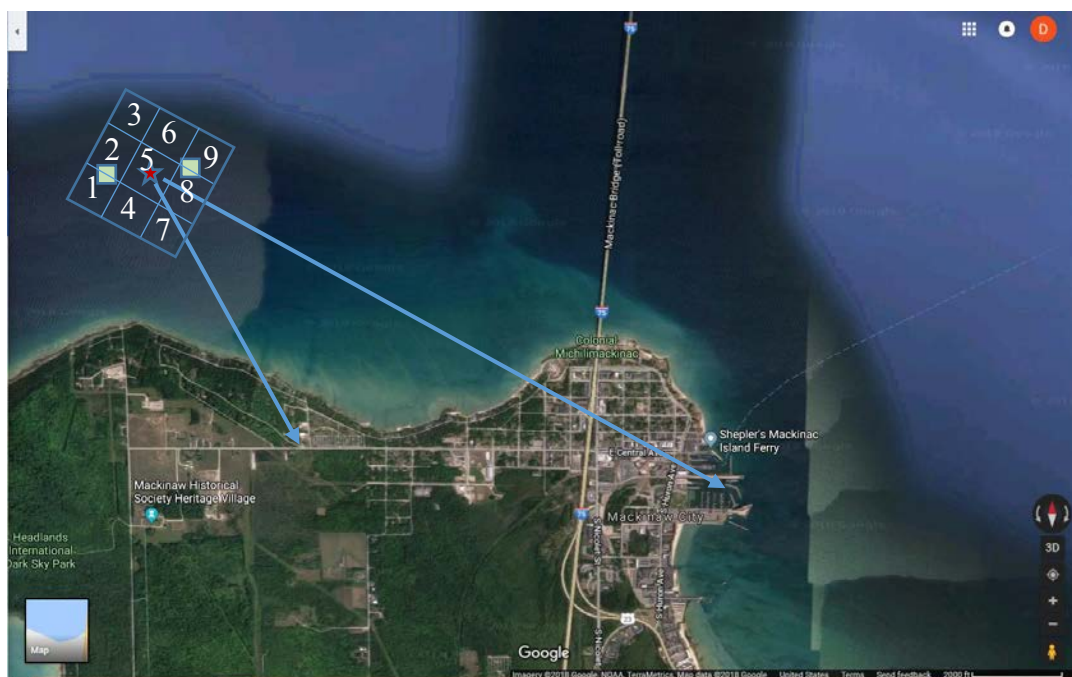


Figure B4: Satellite Image of the Spill Location Assumed for the Atmospheric Dispersion Calculations Near the Town of Mackinaw City, MI

Figure B4 is a 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 (B-E2) below.

$$\rho_{VOC} = \frac{w_A (10^6)}{(\pi v_x \sigma_y \sigma_z)} \left[ \exp\left(-\left(\frac{h^2}{2 \sigma_z^2}\right)\right) \exp\left(-\left(\frac{y^2}{2 \sigma_y^2}\right)\right) \right] \quad (\text{B-E2})$$

Inputs for this modeling approach for predicting the ground level mass concentration of VOCs ( $\rho_{VOC}$ ;  $\mu\text{g}/\text{m}^3$ ) 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 ( $w_A$ ; g VOC/s), and wind speed in units of meters per second ( $v_x$ ; 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 ( $\sigma_y$ ) for VOC dispersion in the cross-wind direction in units of meters ( $y$ ; m) and also the standard deviation ( $\sigma_z$ ) 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 lake surface represents the height of the emission (0 m). This height is assumed because the low specific gravities of the light crude oil products transported in the pipeline will cause them to rise rapidly to the lake surface following a potential pipeline rupture and release. The values of  $\sigma_y$  and  $\sigma_z$  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. Modifications included 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  $x$ ,  $y$ ,  $\sigma_y$  and  $\sigma_z$  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](http://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<sup>3</sup>. The solubility of NGL in water is very low. Therefore, the emission rate (m<sup>3</sup>/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 a crosswind ( $\sigma_y$ ) and vertical directions ( $\sigma_z$ ) for pollutant dispersion among different atmospheric stability classes are provided in equations B-E3 and B-E4 below:

$$\sigma_y = ax^b \quad (\text{B-E3})$$

$$\sigma_z = cx^d + f \quad (\text{B-E4})$$

The values for  $\sigma_y$  (m) and  $\sigma_z$  (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

Atmospheric stability class	All distances ( $x$ )	Downwind distances ( $x \leq 1$ km)			Downwind distances ( $x \geq 1$ 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

\*Note: 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.

## 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 modeled for each month in the Straits of Mackinac are provided in Table B5 below. As described in section B.2.3, these monthly worst cases were identified as the conditions that resulted in a prediction of beached oil in the largest number of 1 x 1 km FVCOM grid cells. A more exact estimate of oiled shoreline length was then calculated based on the summed length of the shoreline segments within the affected grid cells (Appendix B2). Individual figures depicting the worst case shoreline oiling scenarios can be found in Appendix B1. 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 scenario with the widest dispersal, covering 711 1-km<sup>2</sup> grid cells containing 1,021 km (643 miles) of shoreline, was predicted for the worst case in February (release date: 02/26/2016 12:00 pm) with Lake Michigan coastline predicted to represent 822 km (511 miles) of this total oiled shoreline and 199 km (124 miles) of Lake Huron shoreline also receiving oil for this specific simulation. The worst case for June resulted in a smaller impact area (514 grid cells) but the highest total shoreline length (2,006 km/1,247 miles, all in Lake Huron) due in large part to the transport of oil to eastern Lake Huron where the shorelines are complex (see Appendix B1, Figure A-B1-6). 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 348 km (216 miles) 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 (800+ km) were predicted for January–July in comparison to August–December, when maximum oiled shoreline distances were predicted to be  $\leq 650$  km. For example, the

average maximum oiled shoreline distance predicted for January–July was 1106 km (687 miles). This distance compares to an average oiled shoreline distance of approximately 528 km (328 miles) predicted for August–December.

Table B3. Summary of Monthly Maximum Oiled Shoreline Distances (in km) Predicted for the Straits of Mackinac Region During 2016 Meteorological Conditions

Month	Release date and time	Release Location	Dispersal duration (days)	Total grid cells with shoreline oiling	Total oiled shoreline distance (km)	Lake Michigan shoreline (km)	Lake Huron shoreline (km)
Jan.	01/17/16 1800hrs	North	60	558	1146	57	1089
Feb.	02/28/16 1200hrs	Center	60	711	1021	822	199
Mar.	03/01/16 1800hrs	Center	60	704	996	813	183
Apr.	04/24/16 1800hrs	South	60	542	794	794	0
May	05/12/16 1200hrs	Center	60	412	847	< 1	847
Jun.	06/20/16 0000hrs	Center	60	514	2006	0	2006
Jul.	07/13/16 0000hrs	North	60	427	927	0	927
Aug.	08/21/16 0600hrs	South	30	353	650	0	650
Sept.	09/17/16 0000hrs	South	20	321	572	< 1	572
Oct.	10/08/16 0000hrs	South	10	182	348	0	348
Nov.	11/30/16 0000hrs	South	15	314	587	1	586
Dec.	12/27/16 1800hrs	Center	15	225	414	34	380

The dates and times (24 hr clock) of oil release for the specific maximum oiling simulations are also provided in Table B3. Release location indicates the general location of oil release within the submerged section of the Line 5 pipeline within the Straits of Mackinac (see Table B1). 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. Total grid cells represents the number of cells in the 1 x 1 km FVCOM grid predicted by the model to contain beached oil, while shoreline lengths represent the total length of shoreline segments in those grid cells (calculated in a GIS) that could potentially be oiled. Graphical representations of the dispersal simulations included here are provided in Figures B6-B17 provided in Appendix B1 of this report.

### B.3.2 Hydrodynamic Modeling Results - Surface Oiling

A summary of the maximum surface areas of floating oil ( $\text{km}^2$ ) 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 B1. 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 ( $1745 \text{ km}^2$ ) 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  $26 \text{ km}^2$  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 ( $1102 \text{ km}^2$ ) and April ( $1745 \text{ km}^2$ ), a dispersal time of 30 days resulted in the greatest area. In comparison, maximum oiled surface areas for May ( $712 \text{ km}^2$ ), June ( $1033 \text{ km}^2$ ) and July ( $1288 \text{ km}^2$ ) 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 ( $921 \text{ km}^2$ ), February ( $783 \text{ km}^2$ ), and August ( $1317 \text{ km}^2$ ). 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  $1112 \text{ km}^2$  in comparison to an average oiled surface area of  $588 \text{ km}^2$  predicted for September - December.

The dates and times (24 hr clock) of oil release for the specific maximum oiling simulations are also provided in Table B4. 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 B1 of this report.

Table B4. Summary of Monthly Maximum Water Surface Area Oilings (Km<sup>2</sup>) Predicted for the Straits of Mackinac Region During 2016 Meteorological Conditions

Month	Release date and time	Release location	Dispersal time (days)	Total oiled surface area (km <sup>2</sup> )	Lake Michigan surface area (km <sup>2</sup> )	Lake Huron surface area (km <sup>2</sup> )
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 B1 (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  $\mu\text{g}/\text{m}^3$  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  $1.0 \times 10^6$  –  $4.1 \times 10^6$   $\mu\text{g VOC}/\text{m}^3$  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.

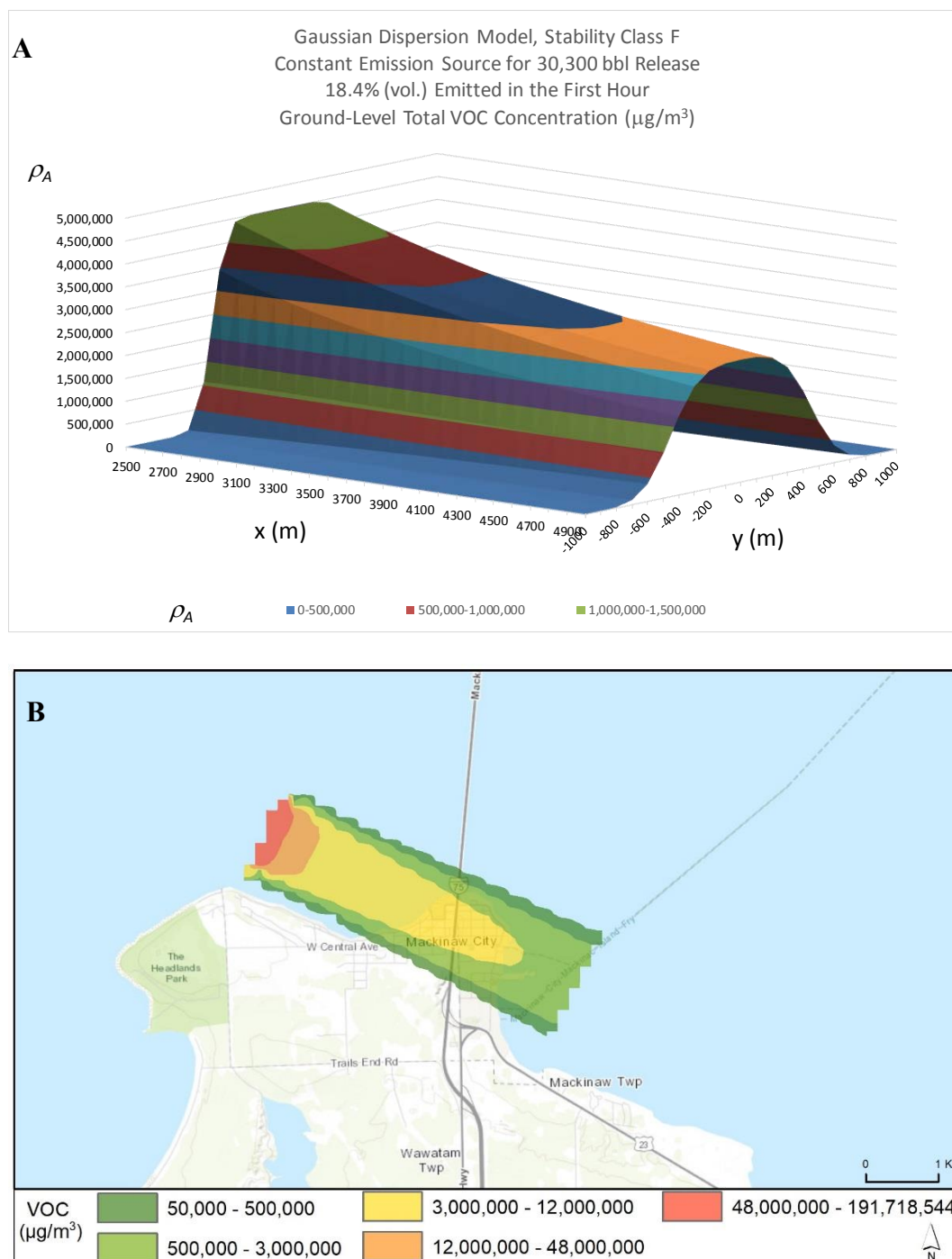


Figure B5-A. Ground-level Concentrations ( $\rho_A$ ;  $\mu\text{g}/\text{m}^3$ ) of VOCs in the Air Over Mackinaw City, MI for Atmospheric Stability Class F (most stable, least dispersion, highest concentrations)

Figure B5-B. GIS Overlay Map Depicting VOC Plume from Line 5 Oil Spill During Atmospheric Dispersal Over Mackinac City, MI (colors represent VOC concentrations within the plume in units of  $\mu\text{g}/\text{m}^3$ )



When the GDM was run for BTEX compounds (benzene, toluene, ethylbenzene, and xylene), similarly shaped plume profiles as for the VOCs shown in Figures B5-A and B5-B 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 ( $2,800 \text{ m} \leq x \leq 4500 \text{ m}$ ,  $-500 \text{ m} \leq y \leq +500 \text{ m}$ )

Crude oil components	Predicted concentration range ( $\mu\text{g}/\text{m}^3$ 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 ( $2,800 \text{ m} \leq x \leq 4500 \text{ m}$ ,  $-500 \text{ m} \leq y \leq +500 \text{ m}$ )

Natural gas liquid components	Predicted concentration range ( $\mu\text{g}/\text{m}^3$ 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 individual components sinking in the water column following release or additional degradation processes beyond evaporation that could change its chemical and physical characteristics. For example, as the more volatile components of the oil evaporate, the physical properties of the remaining oil will change and the remaining oil could potentially be more prone to other weathering processes such as dissolution, degradation, emulsification, and biodegradation. Additionally, when floating, semi submerged, or dispersed oil comes into contact with suspended sediment, the sediment can bind to it causing the oil to sink. These processes were not included in the current study and could potentially exacerbate impacts in cases where a significant amount of oil remains offshore for an extended period. The oil spill model also does not consider resuspension of beached oil. Oil that is resuspended from the beach can be brought onshore repeatedly through the littoral transport mechanism, and potentially increase the extent of impacted shoreline. However, the general 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. These predictions are especially accurate 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 the DHI group. 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 B7 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.

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 contribute to degradation 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.

Table B7. Comparison of Modeling Techniques and Capabilities for 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 (locations)	1 (Center)	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

## 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<sup>2</sup>) 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 worst-case distributions of beached oil for each month that covered between 182 and 711 of the model's 1 km<sup>2</sup> grid cells, representing 348–2006 km (216–1247 miles) of shoreline. The monthly worst cases for maximum surface area of floating oil ranged from 494–1745 km<sup>2</sup> 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. However, no individual scenario generated from the modeling efforts conducted here can be considered to represent the single 'worst-case' condition across each of the task groups that encompass this report.

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.

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# 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, initial surveys are performed, the affected shoreline is divided into segments; teams are then assigned to survey these segments for the extent of oil. Clean up guidelines and endpoints are agreed upon, subsequently, a plan is put into place for cleanup operations and effectiveness of cleanup is monitored throughout the cleanup process. 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 shorelines 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, 2017). 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).

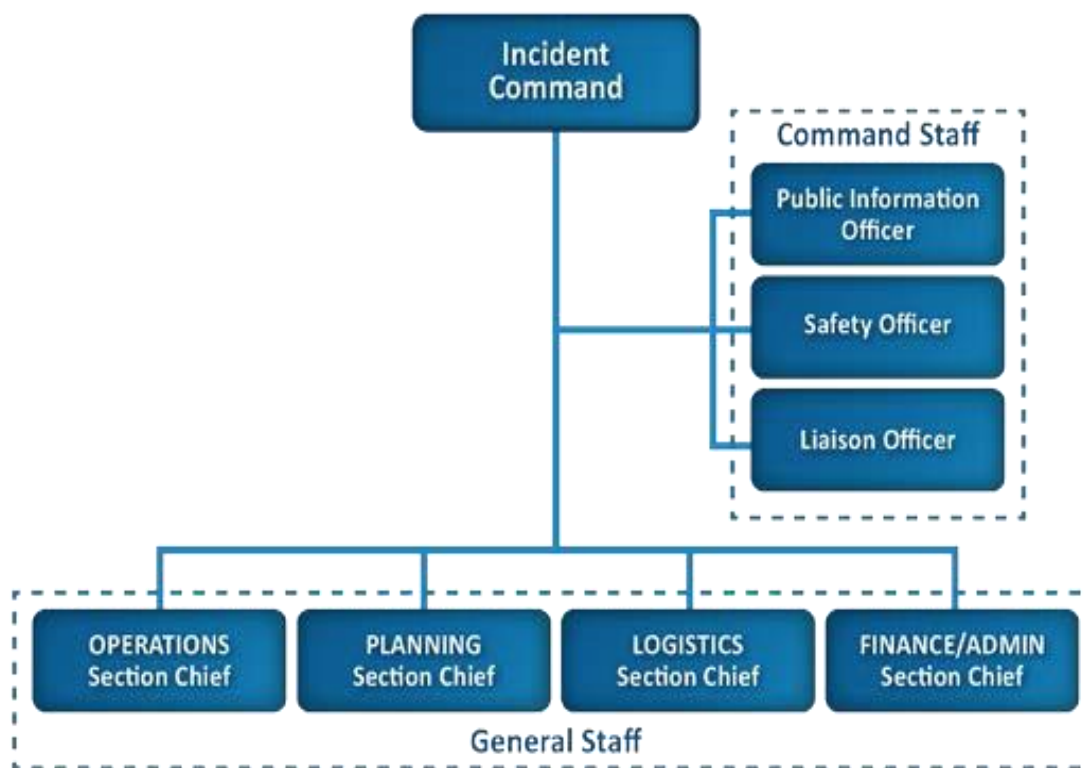


Figure C1. Incident Command Structure (National Response Framework, 2013)

### 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 shorelines. 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, as well as governor's declaration of a State Emergency and other federal agencies (e.g. EPA) approval. 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.

Significant effort has gone into exploring the use of in-situ burning technology to enhance preparedness for pollution incidents on the waters of Northern Michigan. In-situ burning is the intentional burning of floating oil as a method to remove large amounts of oil from the water's surface. The workgroup consisted of Area Committee members, including the U.S. Coast Guard, Environmental Protection Agency, National Oceanic and Atmospheric Administration, Michigan Department of Health and Human Services, U.S. Fish and Wildlife Service, Tribal sovereign nations, Michigan Department of Environmental Quality, and others. To establish a framework for the application of in-situ burning on the Great Lakes, the workgroup reviewed hundreds of pieces of research publications and collaborated with research entities and academia including the Coast Guard Research and Development Center. The workgroup also studied information about ISB use in Alaska to gain best practices for utilization in severe cold weather environments. The group's efforts culminated in a set of guidelines to request approval for use of in-situ burning on the

waters of the Great Lakes in Northern Michigan. In August 2017, U.S. Coast Guard, Sector Sault Sainte Marie, in partnership with member agencies from federal, state, local and tribal stakeholders, held a widely attended environmental workshop in Mackinaw City, Michigan, to determine the feasibility of using in-situ burning as a response tactic in addition to mechanical recovery of an oil spill in the Straits of Mackinac. The Area Committee and Regional Response Team 5 members discussed the risk versus reward of in-situ burning, operational parameters necessary to conduct ISB, and public outreach. This workshop was the first of its kind in Regional Response Team 5 to evaluate the use of an alternative technology on the Great Lakes

#### 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 shorelines 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 shorelines. However, one consequence of the large-scale use of sorbent booms is the creation of large amounts of contaminated wastes, proper handling of such wastes need to be anticipated. However due to the high consequence area of the Straits the large scale use of sorbents may be acceptable to remove oil from the system. 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 shoreline to dislodge the beached oil and then capture the washed oil through booming at the shore. 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 shoreline 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 shoreline substrate is used to get rid of the oil and contaminated material. This process requires that the removal of the shoreline material does not represent substantial harm to the shoreline ecosystem and requires refilling with the comparable material during the restoration processes.

In some cases, some oil is left on shorelines 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 shoreline and the environmental sensitivity index must be taken into account in choosing the best strategy for removal of oil from shorelines. 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 booms (Al-Majed et al., 2012).
Exclusionary booming	Use of boom to exclude oil from a sensitive shoreline.

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
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 shorelines 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 shorelines.
Washing	Water can be used to flush oil from contaminated shorelines. 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 shorelines 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 with clean fill.
Bioremediation	Natural microbes can break down oil to remove it from the environment.

#### C.2.4 Review 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 regarding regulatory criteria and lessons learned from multi-agency pollution response exercises

conducted in the Straits of Mackinac. The documents 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, many of the existing documents are designed to 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 the 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 (Unified Coordination Group) 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 the 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 the 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 the 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. 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 (18 miles) 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 C2 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 C3 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.

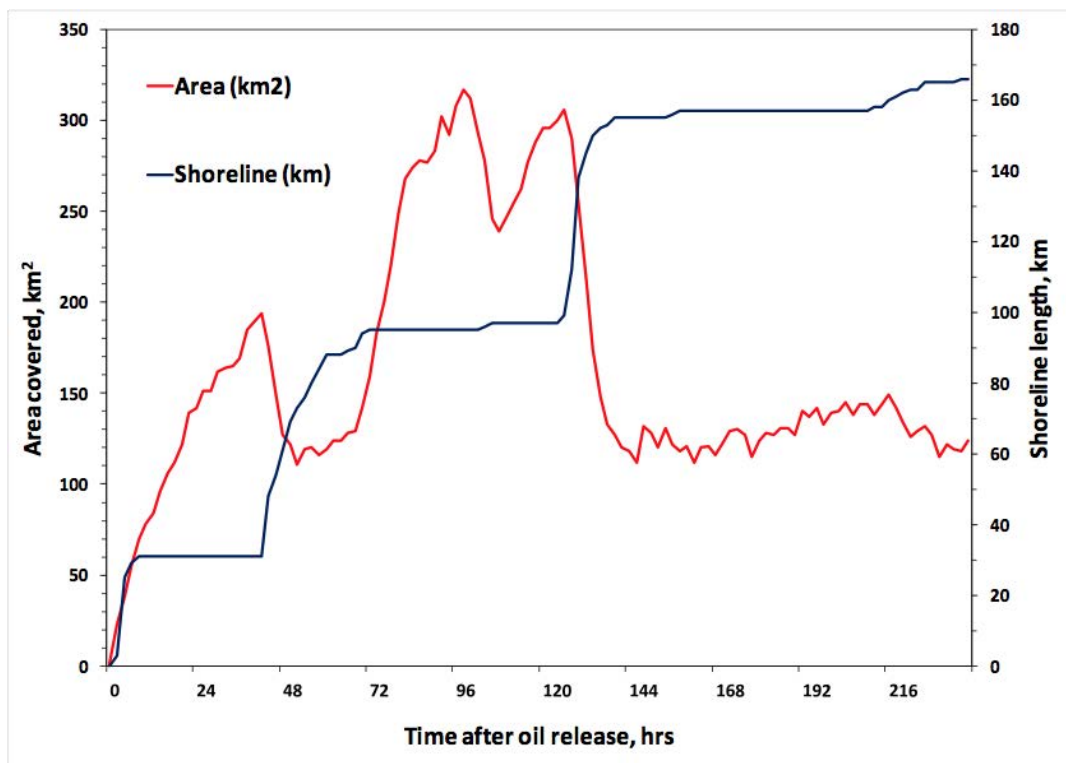


Figure C2. Open Water Area Covered with Floating Oil and Oiled Shoreline Length in Lake Huron Over Time for the Modeled Dec. 27 Scenario

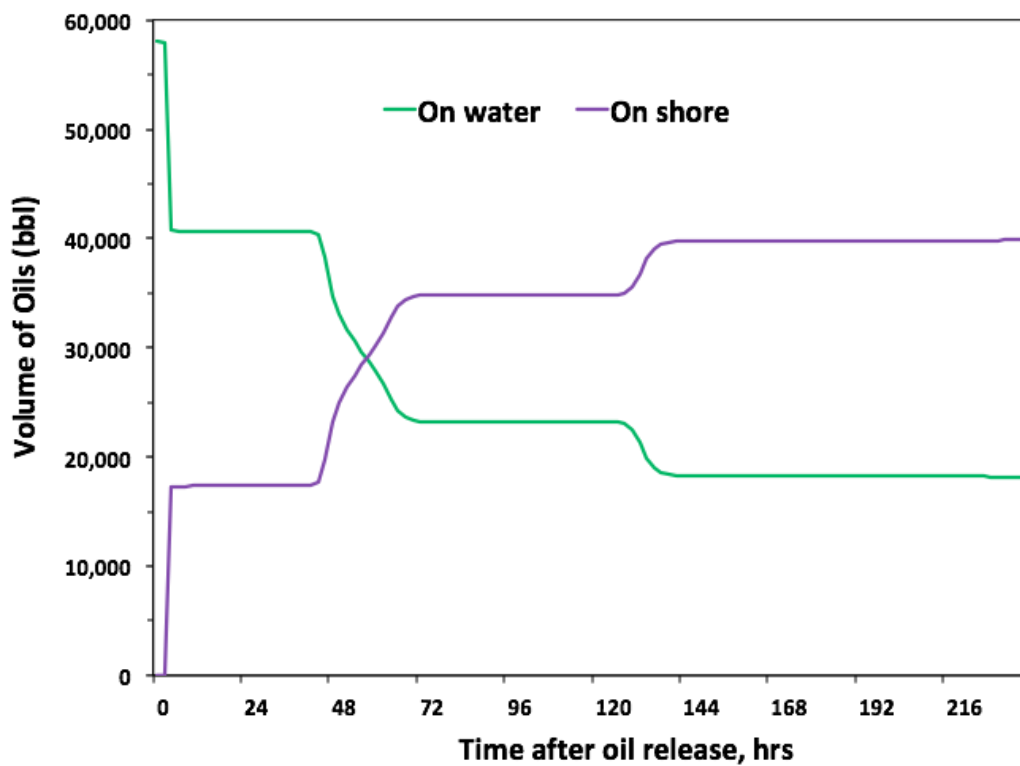


Figure C3. Volumes of Oil Floating on the Water and Beached on Shore Over Time for the Modeled Dec. 27 Scenario without taking into account clean-up activities

Weather conditions 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 C4 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.

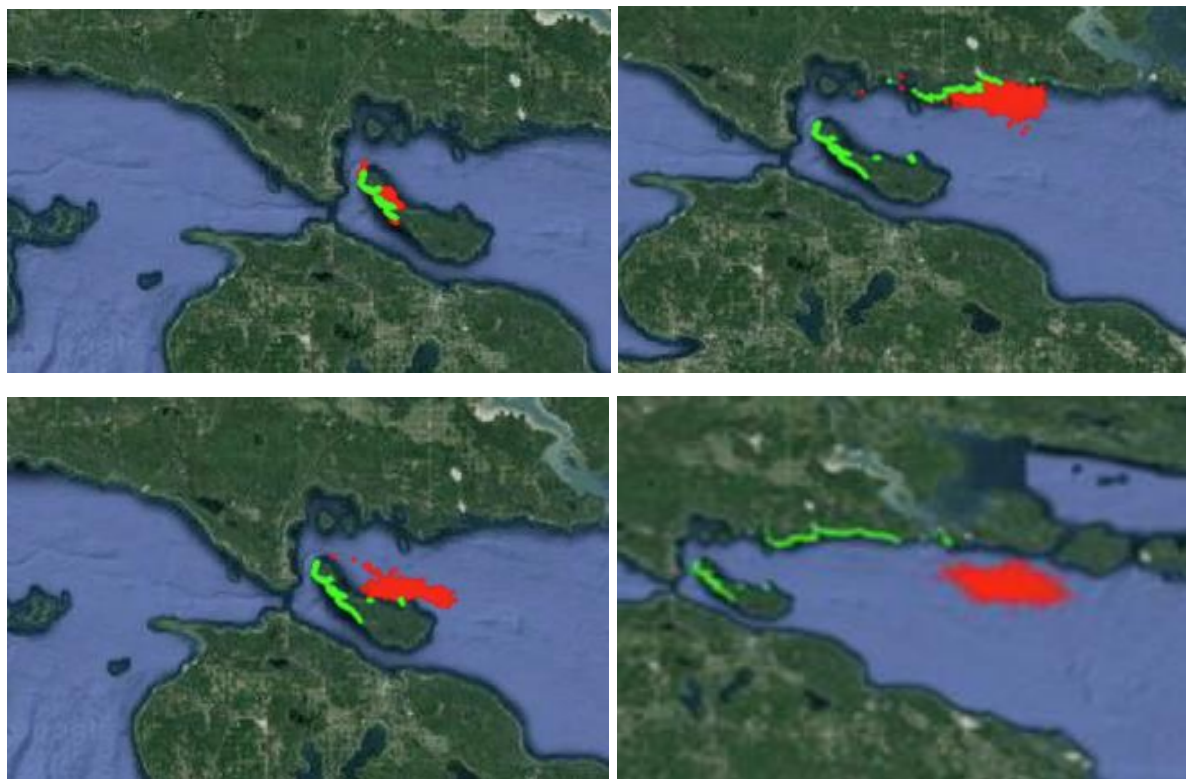




Figure C4. Fate of Oils on Water (Red) and Shorelines (Green) 3, 12, 24 (Left), 48, 96, 120 (Right) hrs After Oil Release from Center Channel of Straits of Mackinac at 6 am on December 27, 2016

### 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 (for more details, see <https://www.atcllc.com/straitscables/>) 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. Once notification occurred, 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. , Equipment from local, state and federal agencies is cataloged in the Michigan Critical Incident Management System (MI CIMS) (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 as described to the team by the emergency managers. 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 a 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 oil has to be at least 2 mm 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 decrease the response time significantly.

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.

#### 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

Timeline	Incremental recovery rate (US gallons per hour)	Notes
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

Source: Provided by Enbridge, based on a combination of badge ratings and effective rates generated by the Genwest ERSP calculator.

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

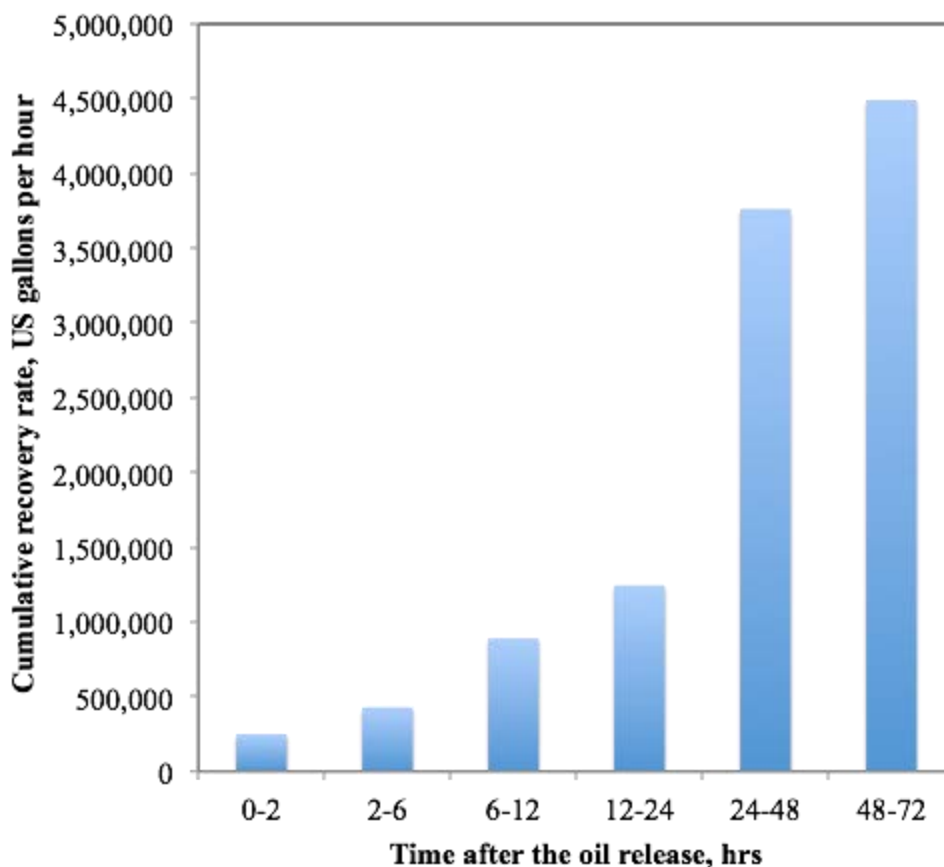


Figure C5. Cumulative Recovery Rates Over 72 Hours of Response Time (Enbridge)

#### 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 MPC 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 quantitatively 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, endpoints for cleanup are determined early in the process, and then a plan is put into place for clean-up operations. Throughout the process, additional monitoring is included to assess which shorelines remain in need of cleaning. The additional monitoring may include determination of baseline environmental and biological conditions. This baseline could be determined from previous surveys of the area or through the identification of baseline control sites.

Throughout the cleanup process, the conditions on the affected shoreline are monitored to ensure removal of oil to baseline conditions and recovery of affected shorelines. The SCAT 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 shorelines is thoroughly documented, endpoints for clean up are agreed upon, 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 equation C-E1 below:

$$58,000 \text{ barrels of oil} \times (100-X)/100 \quad (\text{C-E1})$$

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 in equation C-E2:

$$58,000 \text{ barrels of oil released} \times 0.5 \times 1.8 = 52,200 \text{ barrels} \quad (\text{C-E2})$$

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. Only mechanical recovery and in situ burns were considered as response measures as dispersant application would not be employed in response to an oil spill in the Great Lakes. 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.

A large amount of additional equipment could be mobilized during a response from Enbridge contractors (appendix). 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. The equipment listed in Table C5 represent a conservative estimate of the equipment available.

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	Straits - Enbridge
	2	Cheboygan, MI - Enbridge
	1	Escanaba - Enbridge
Current Buster II	4	Straits – Enbridge
Foilex TDS 150 Skimmer	4	Straits – Enbridge
Lamor Bucket recovery systems	1	Cheboygan, MI – Enbridge
	1	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. 27<sup>th</sup>, 2016 to 7:00 PM on Dec 31<sup>st</sup>. The simulation used an instantaneous or batch release of 52,200 barrels of oil and assumed a 8-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 sulfur; pour point of < -30 °C; vapor pressure of 82.8 kPa; and, a density of 809.1 kg/m<sup>3</sup> (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 no longer visible on the surface (Delvigne and Sweeney, 1988). This “real weather” simulation underscores the limitations of some of this equipment in bad weather.

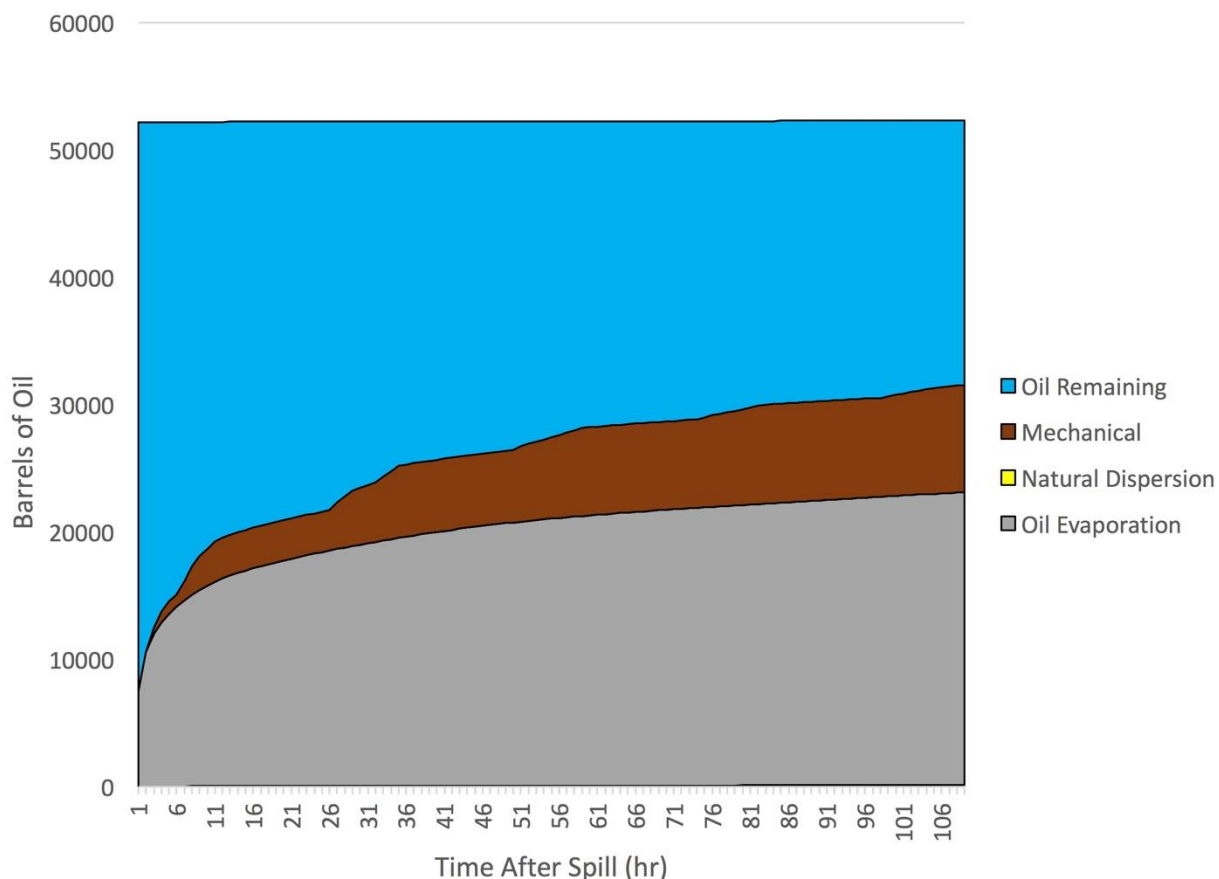


Figure C6. Oil Recovered as a Function of Time in hours From ROC Simulations with No Wind for 8-Hour Operations

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 with skimmers, booms, and current busters is shown in brown.



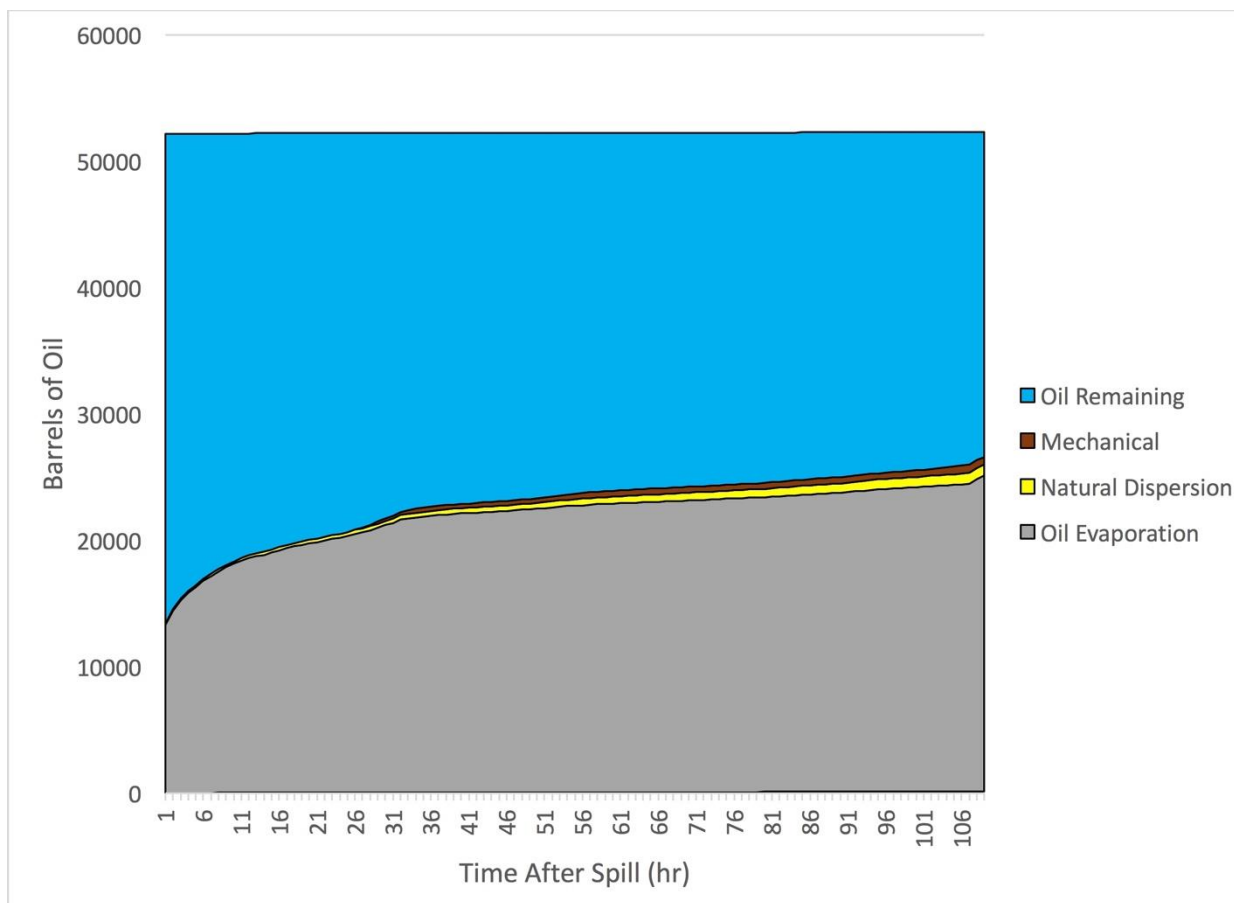


Figure C7. Oil recovered as a Function of Time in hours from ROC Simulations with the Wind Conditions for the Storm (Dec. 27 - 31st 2016)

Oil remaining is shown in blue. Oil that evaporated is shown in grey. Oil that was naturally dispersed is shown in yellow. Oil that was mechanically recovered is shown in brown.

Table C6. Oil Recovery Estimates from ROC Simulations Based on 8-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	23,014.7	24,998.3
Mechanical Recovery	8,390.7	646.9
Natural Dispersion	0	861.3
Remaining on water	20,794.6	25,693.5

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 C3). 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 because 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.

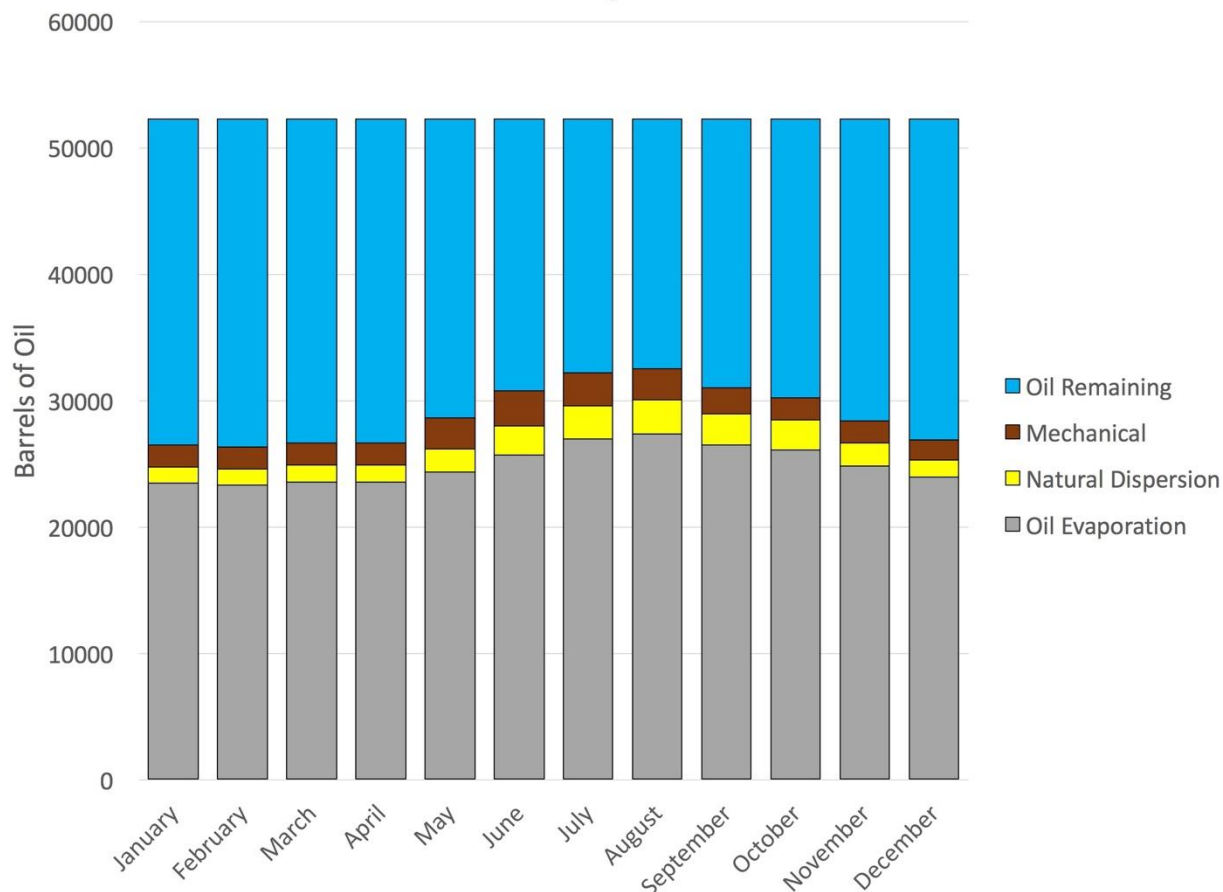


Figure C8. Recoverable Oil Over the First Five Days of a Spill Using Average Conditions for Each Month

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 8-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.

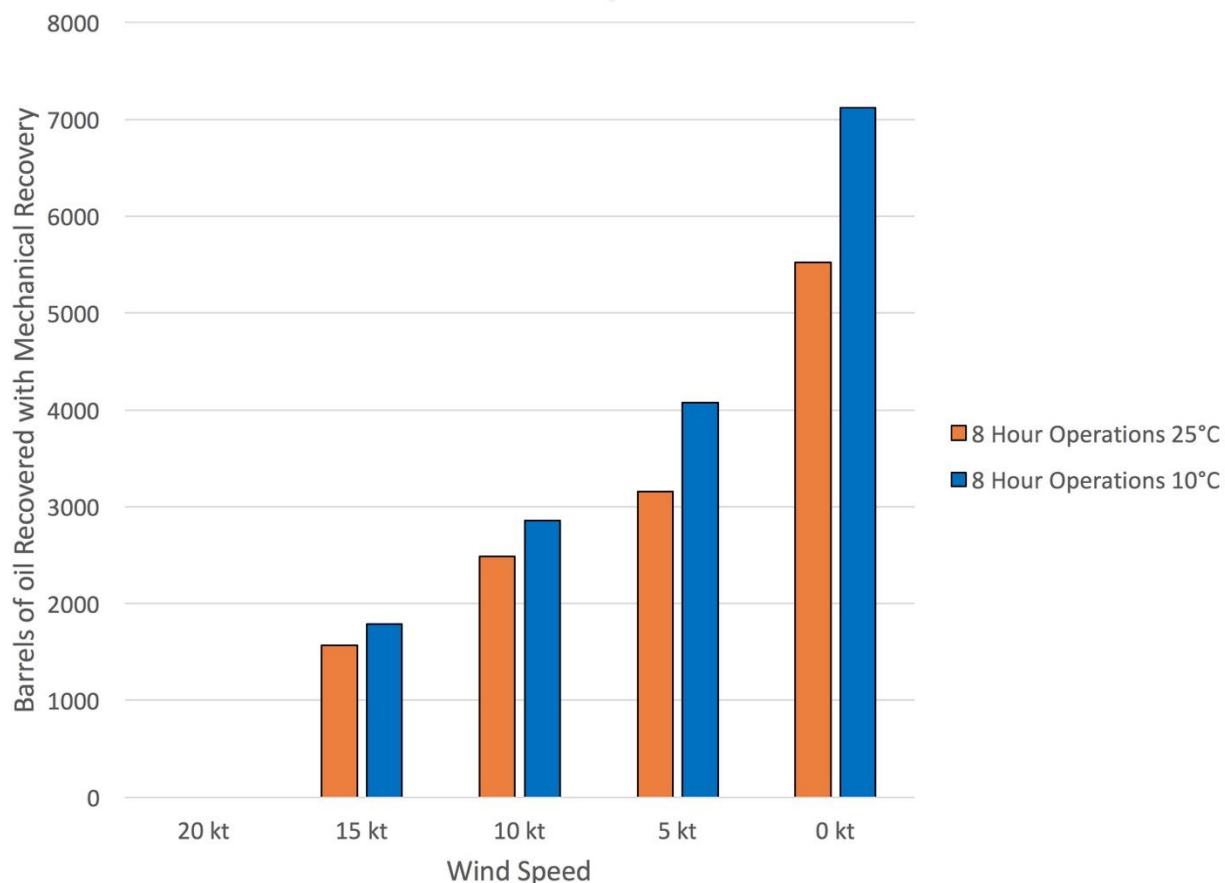


Figure C9. Oil Recovered as a Function of Wind Speed. ROC Simulations Were Run at Two Temperatures for 8-Hour Operations. With Increasing Wind Speed There is Limited Oil Recovery

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 hr 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: 1000 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 3,197.8 bbl (134,307.6 gal) of oil with a burn efficiency of near 90%. It is noted that Enbridge has been considering the purchase of fire booms.

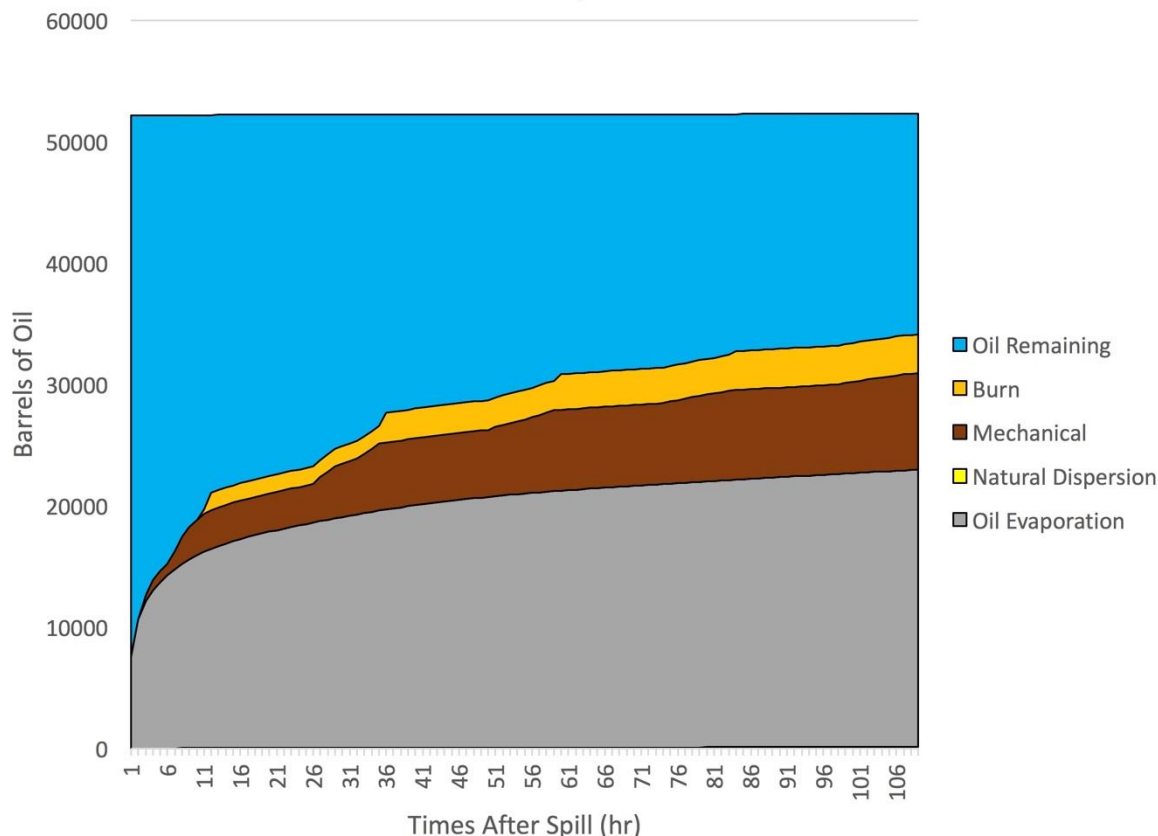


Figure C10. Oil Recovered as a Function of Time From ROC Simulations with No Wind for 8-Hour Operations

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 cleanup, 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.

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 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.

Table C7. Summary of Shoreline Recovery and Clean Up Time from Three Past Oil Releases

	<b>Deepwater Horizon</b>	<b>Marshall, MI</b>	<b>Refugio, CA</b>
Amount of Oil Spilled	4,900,000 bbl (205.8M gallons)  (Lehr et al. 2010)	20,082 bbl (843,444 gal)	2500 bbl (105,000 gal)
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)  <b>(19 months)</b>	July 19, 2011  <b>(12 months)</b>	July 16, 2015 (JIC, 2015a)  <b>(2 months)</b>
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  <b>(48 months)</b>	Fall 2014 (October 2014) (Quist 2017)  <b>(51 months)</b>	March 2, 2017 (Same time when Unified command was disestablished) (Refugio Response Joint Information Center, 2017)  <b>(22 months)</b>
Beach/River Closure Days	May 7, 2010-June 15, 2011 (max for Louisiana) (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016)  <b>(14 months)</b>	June 21, 2012 (USFWS et al., 2015)  <b>(23 months)</b>	July 17, 2015 (JIC, 2015b)  <b>(2 months)</b>
Fishing Closures	September 2010 (all state waters east of the Mississippi) (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016)  <b>(5 Months)</b>	July 28, 2012 (MDHHS 2012)  <b>(24 months)</b>	June 29, 2015 (JIC, 2015a)  <b>(41 days)</b>



## **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 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.

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# 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, between Michigan's Upper and Lower Peninsula. 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 at risk of exposure to Line 5 products and their chemical components following a worst-case spill 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 (H<sub>2</sub>S). 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 spill scenario from the Line 5 pipeline. Risks include 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 following a worst-case spill scenario.

## **D.2 Approach**

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

Oil dispersal simulations conducted for this report predicted that majority of any oil product potentially released from a Line 5 pipeline spill 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 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 km<sup>2</sup> (53 mi<sup>2</sup>) for July across the Straits of Mackinac channel and nearby Lake Michigan and Lake Huron waters. The maximum oiled surface area was used as a surrogate of the increased potential for human health risks associated with the volatile nature of many crude oil constituents due to the positive relationship between surface area and evaporation rate for crude oil products. (Stiver & Mackay, 1984).

Michigan's Straits of Mackinac region is a popular tourist destination. During the summer season the region experiences 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 also increase participation in 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. Cooler air and water temperatures reduce the extent of evaporation and weathering of oil and its constituents (Fingas, 2013; Fingas 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, pregnant women, 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 (US Census Bureau, 2016) indicate these counties have large

elderly populations (21-27% aged 65 years and older), small populations of young children (less than 5% of the population is <5 years of age) and about 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.

The Straits region is home to the Sault Ste. Marie Tribe and Bay Mills Indian Community of the Chippewa Indians and the Little Traverse Bay Bands of Odawa Indians. Further west in the Upper Peninsula, the Hannahville Indian Community is located along the northern shore of Lake Michigan. 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 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 affects 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 (US Census Bureau, 2016). Unemployment is a notable contributor to a region's vulnerability. Mackinac County has an unemployment rate of 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 is available 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 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. Permanent residents of the affected area 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 permanent residents 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).

Exposure to CoPC may exacerbate certain health conditions. 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. In the affected counties, about 1 in 10 adults have asthma. The prevalence of COPD is 8% in the health district that includes Mackinac County (Luce, Mackinac, Alger, and Schoolcraft District) and Northwest Michigan regions, but slightly higher (12%) in District 4 (Figure D1) (Michigan Department of Health and Human Services, 2016b). The self-reported cardiovascular disease figure is about 12% in the affected regions in the Lower Peninsula, but only 7% in the Upper Peninsula region that includes Mackinac County (Michigan Department of Health and Human Services, 2016b).

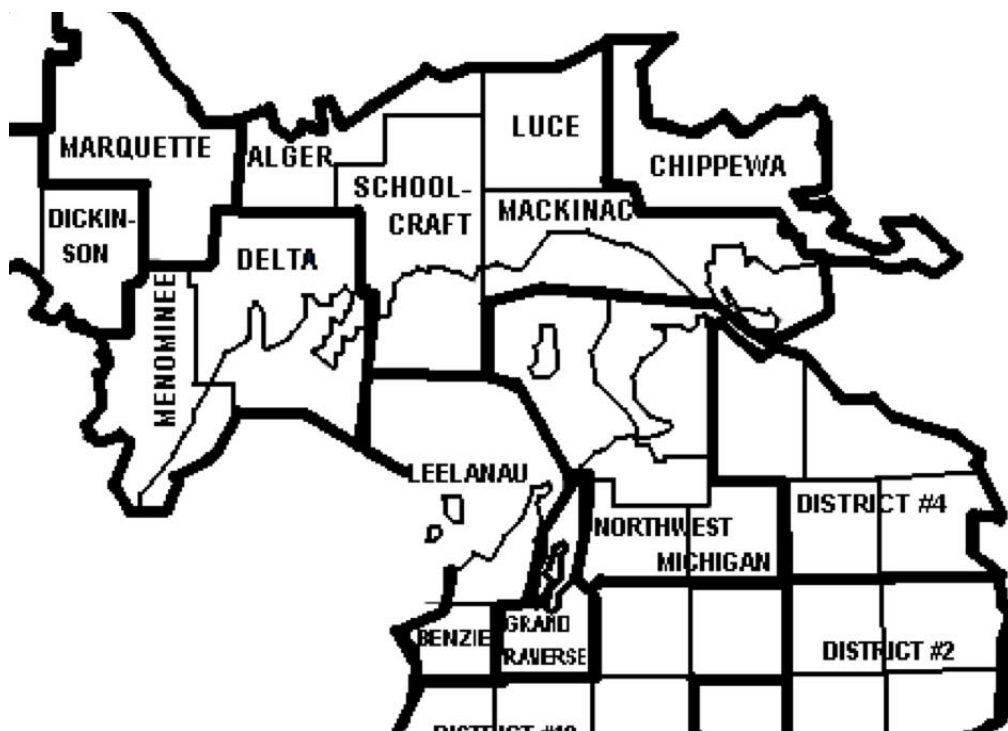


Figure D1: Community Health Assessment Regions (Source: Michigan Department of Health and Human Resources, 2016a)

### 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 (Michigan Department of Health and Human Services, 2016a). 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
<b>Economically disadvantaged</b> (percent below poverty line)	11.80%	18.00%	13.70%
<b>Total minority population</b> (total percent African American, American Indian, Asian, Native Hawaiian, 2+ races, Hispanic or Latino)	9.00%	8.20%	26.70% (16.70% American Indian)
<b>Children</b> (percent below age 5)	4.80%	4.10%	3.80%
<b>Children</b> (percent below age 18)	19.80%	17.10%	16.10%
<b>Elderly</b> (percent over the age of 65)	21.40%	26.00%	27.50%
<b>Disabled</b> (percent under the age of 65)	10.60%	14.80%	12.50%
<b>Uninsured</b> (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 (Olawoyin, et al, 2018).

#### D.2.4.1 Effects of Weathering on Crude Oil

The behavior of crude oil released in the environment is determined 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 the oil is spilled and occur most rapidly immediately following the spill. Most weathering processes are temperature dependent and become negligible as temperatures approach 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 one spill to another. 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 a crucial 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 critical factor during oil spills; crude oil densities commonly range from 0.7 to 0.99 g/cm<sup>3</sup> thus it floats when released into freshwater (1.00 g/cm<sup>3</sup>) environments (National Academies of Sciences, Engineering, and Medicine, 2016).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, dispersion of the unrecoverable oil into the water column increases the available surface area of the oil which enhances natural degradation processes such as biodegradation and dissolution (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 release spilled oil begins to weather, which changes 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. 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 after to a worst-case spill scenario 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 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 generally contains fewer total PAHs relative to heavy crude oil (NOAA, 2010) and fewer of the carcinogenic PAHs (National Research Council of the National Academies, 2003). The PAHs continue to break down during the weathering of the oil (Johnson et al., 2008); studies demonstrate their presence in < 1% of weathered samples (NOAA & Food and Drug Administration, 2010).

The human health effects from exposure to TPH depend on factors such as the types of chemical compounds present in the TPH, duration of exposure, the 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 concern to public health and safety. These TPH compounds pose adverse human and environmental health risks in different ways. The BTEX compounds, for instance, can affect the human central nervous system (CNS). At elevated concentrations and exposure, these compounds can be acutely toxic and lethal. Table D2 provides a summary of the known health effects of the CoPC.

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. As an example, at a particular concentration of benzene in inhaled air, ingested soil or potable water, ingested throughout an individual's lifetime, can result in a  $1 \times 10^{-6}$  (a one in a million) increase in the risk of developing cancer.

#### 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 U.S. 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 spill scenario 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 the Michigan Water Quality Criteria, which for some chemicals is any detectable amount. A concentration of 5 micrograms per liter ( $\mu\text{g/L}$ ) 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 (ATSDR, 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

CoPC	Health Effect, low/short-term exposure	Health Effect, high/long-term exposure	Carcinogenic classification (IARC)
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	

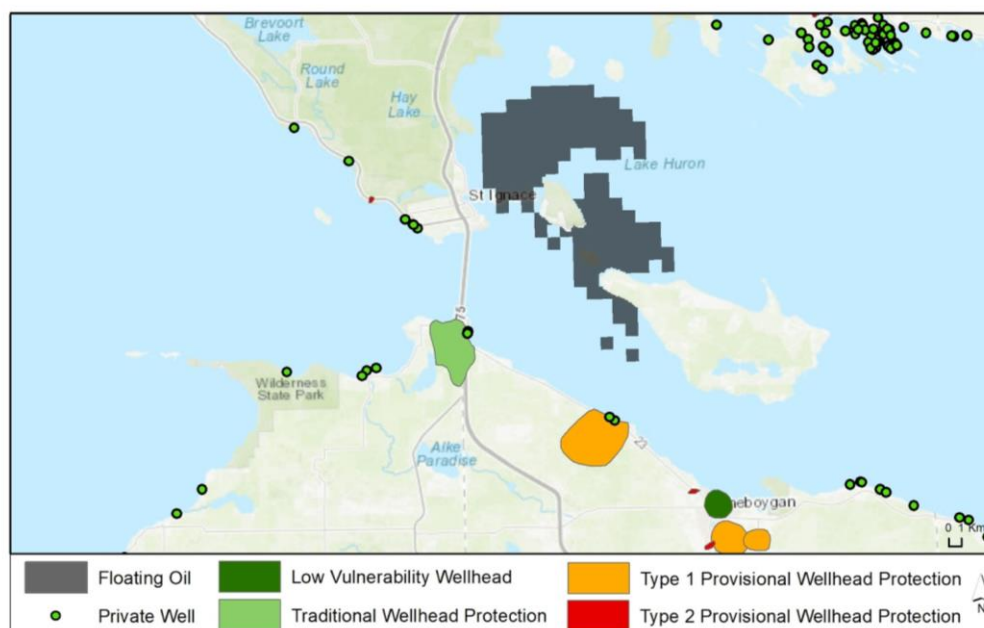


Figure D2.. Straits of Mackinac Worst Case Oil Dispersal Predicted During the Summer Season

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 circles 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 depend 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 exposed individual. The flammability hazard under the worst-case spill scenario has been analyzed separately in section D3.0. 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 populations along the Straits of Mackinac that may be affected by the worst-case spill scenario. 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 a worst-case spill scenario would directly expose permanent residents, seasonal residents and transient residents (both children and adults) through the 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 primary 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 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 US EPA 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. 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 this worst-case spill scenario.

#### 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 individuals. The model assumes that exposure to carcinogenic CoPC will increase the risk of cancer induction in these individuals, which means 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 an individual 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) (Table D3). 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 for each PAH were determined as shown in Table D3.

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

#### *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, 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 used the data obtained from the worst-case spill scenario 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 relevant assumption 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 D3. Simulated PAH Values from Concentrations in 49 Different Crude Oil Spill Samples and the Monte Carlo Simulation

Crude oil	TEQ <sup>a</sup>	49 different crude oils <sup>b</sup>	Monte Carlo Simulation (Cs) <sup>c</sup>	B[a]P 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

<sup>a</sup> Potency equivalence factors (PEFs) for individual PAHs relative to B[a]P (Nisbet and Lagoy, 1992)

<sup>b</sup> Maximum, and mean PAH content in 48 different crude oils (Kerr et al., 1999)

<sup>c</sup> Results generated in this analysis

Table D4. Potential Incremental Lifetime Cancer Risks (ILCR) and HQ Estimated for Straits of Mackinac Populations Exposed to Line 5 Crude Oil PAHs

Population	ADDi ng (c)	ADDi ng (n)	ADD derm (c)	ADD derm (n)	ADDi nh (c)	ADDi nh (n)	ILCRi ng	ILCR derm	ILCRi nh	Total ILCR	HQin g	HQd erm	HQin h	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	3.0
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	3.5
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	2.4
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	0.3
<b>Total ILCR and Total HQ</b>														
	Negligible human risk													
	Adverse non-carcinogenic health effects possible													
	Potential carcinogenic human risk													
	Serious carcinogenic human risk													

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 exposed individuals may face during a possible worst-case spill scenario. The total ILCR 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.,  $1 \times 10^{-6}$ ), it is considered an acceptable or negligible risk, and an upper ILCR of 1 in 10,000 ( $1 \times 10^{-4}$ ) representing serious human risk and values in between considered a potential human risk.

#### D.2.6.6 Volatile Organic Compound

Numerous VOCs 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 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 (cancer or non-cancer) can be evaluated using the deterministic risk assessment method previously discussed.

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. A 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 effects.

The VOCs considered in this analysis for human health effects following a worst-case spill scenario are listed in Table A-D2-4 (Appendix 2), however only the BTEX compounds were analyzed further because of their toxicity and potential effects on humans. Furthermore, 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 volunteers may be exposed to the spilled oil during clean up and mitigation activities, 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, releasing fresh oil 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), and physical exertion.

The cancer risk of 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**

We explored the fire and explosion consequences of the characteristics and quantity of the substance released in a worst-case spill 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 spill scenario,

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 helps guide the prioritization of threats, vulnerabilities, and enhanced risk management practices. For this worst-case spill scenario, the probability of harm/damage/fatality to people and public safety around susceptible areas along the Straits was examined. The adverse effects and impacts 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 spill scenario of products from the Line 5 pipeline along the Strait of Mackinac.

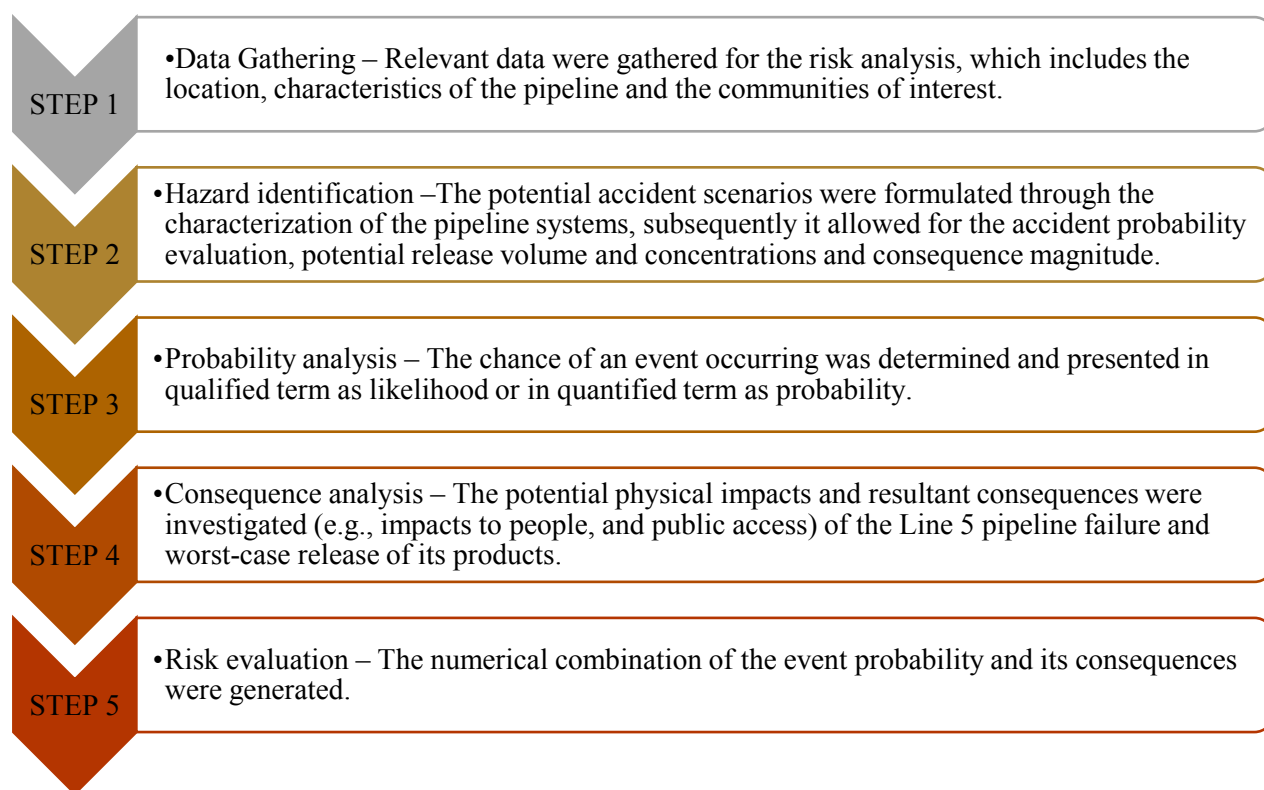


Figure D3.. Summary of the Pipeline Analysis Method

Task D worst-case spill 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 spill scenario locations 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 is 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<sup>L</sup>RA) Methods

Qualitative risk analysis (Q<sup>L</sup>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 spill scenario, the risk estimation can help define the zones of vulnerability. 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 with a numerical value assigned to each of the factors. These risk factors are summed to generate numerical score value for the identified hazard-prone segment length of the pipeline. The segments are then grouped and 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 worst-case spill scenario.

#### D.2.7.2 Quantitative Risk Analysis Methods

Quantitative risk analysis (Q<sup>N</sup>RA) methods estimate numerical event probabilities or frequencies of occurrence, within a timeframe, related with specific, measurable and possible consequences. The Q<sup>N</sup>RA methods present risk in terms of the probability of a quantified outcome. An example is the risk of fatal injury from the worst-case spill scenario that can be presented as the annual probability that one fatality could occur. This numerical probability represents the underlying concept of Individual (*Ind*<sub>Risk</sub>) and Population Risk Analyses (PRA) conducted in this study.

There are two main Q<sup>N</sup>RA methods:

1. Actuarial Q<sup>N</sup>RA 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<sup>N</sup>RA 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. The predictive Q<sup>N</sup>RA method (PQM) is another method but 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 this analysis considers a worst-case spill 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. Details of the methodology are available in Appendix D3.

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

A worst-case spill scenario for the release of flammable gases and/or volatile flammable liquids assumes that 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 spill scenario 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 a 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 the 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 were the wind stability, area topography (rural or urban), and the duration of the release.

#### D.2.7.5 Potential Consequences

The probability of fire, explosion, and potential fatalities was 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 exposed individual and the hazard source.

The potential consequences of the worst-case spill scenario are dependent on the crude oil properties, 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. The impact distance is a point at some distance away from the pipeline where the crude oil flowed/pooled or dispersed to prior to ignition. 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. Fire and explosion modeling was used for the estimation of the effects of the potential release that ignites.

Thermal radiation emitted will be the main 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 the 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 worst-case spill scenario, 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 is 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 spill scenario.

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 near the pipeline would be based on potential exposures to a flash fire, jet fire (for natural gas liquids), pool fire (for crude oil releases) or explosion if there are obstructions along the vapor cloud paths. The hazard impact distance ( $R_0$ ), which is the distance between the hazard source and the individual location from the shoreline,  $R_0$  may influence the individual's exposure," (Figure D4).

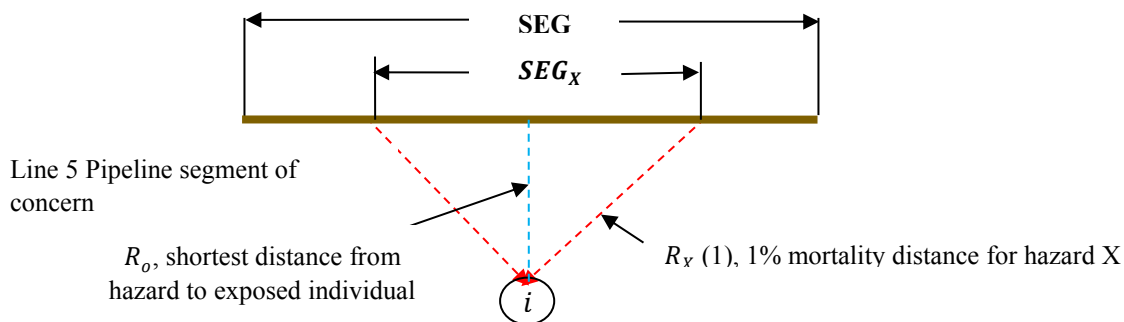


Figure D4..  $SEG_x$  Estimation Based on the Hazard.

For an individual at a specific location away from the hazard source, the IR was estimated for 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 at risk individuals with the possibility of 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 spill scenario. 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 exposed individual does hold true, then adults living permanently around 500 m (0.3 miles) 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  $1 \times 10^{-6}$ , 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.

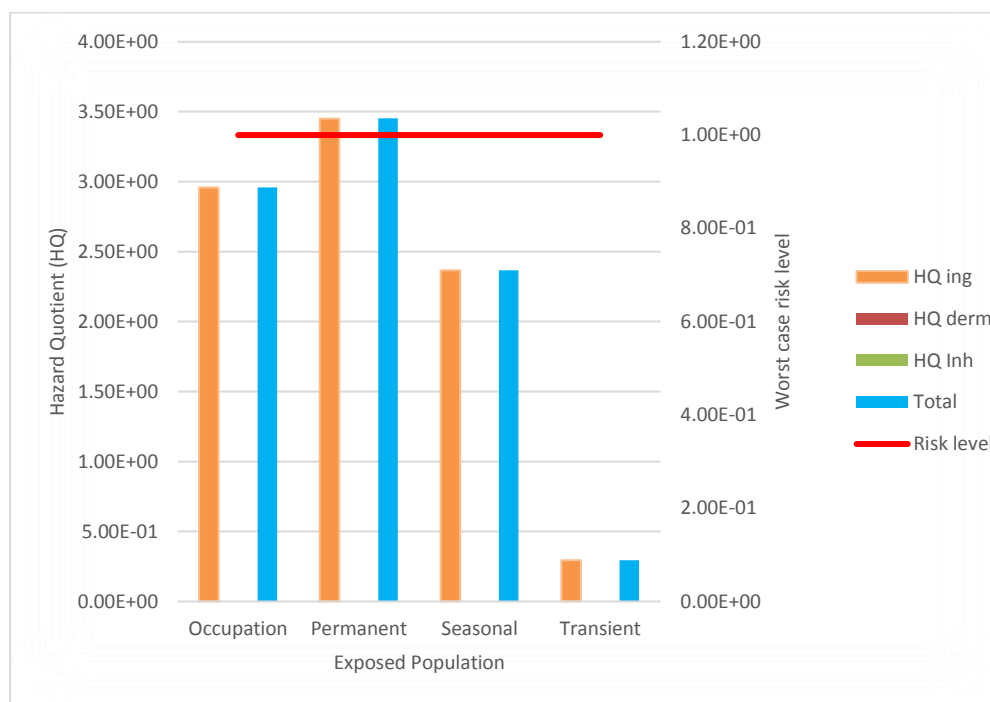


Figure D5. Potential Non-carcinogenic Risk from PAH Exposure Due to the Worst-case Release



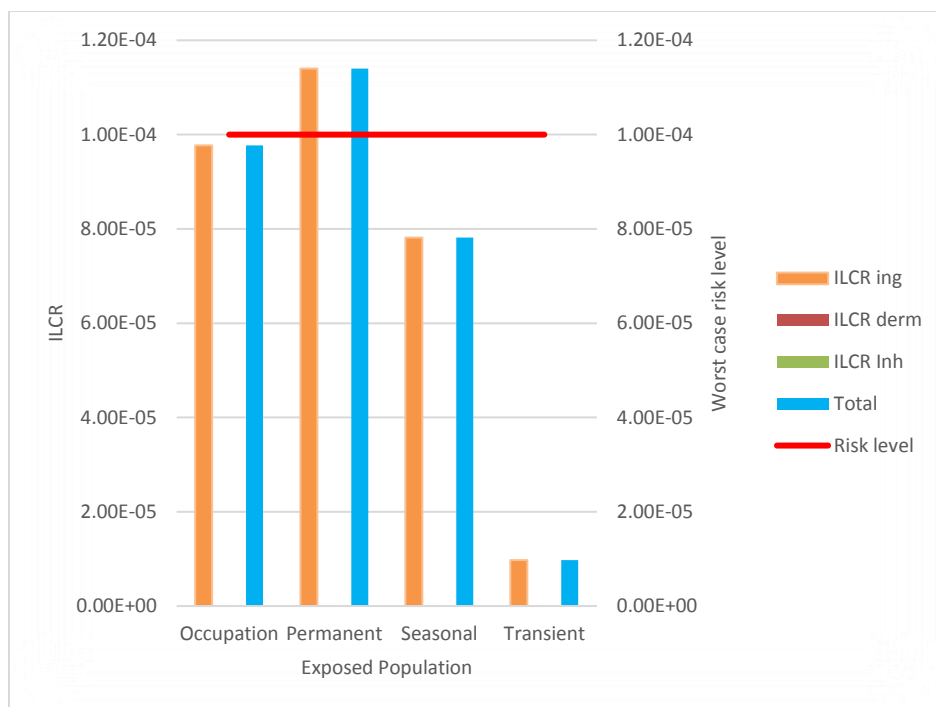


Figure D6. Potential Carcinogenic Risk from PAH Exposure Due to the Worst-case Release

Mackinaw City residents directly exposed to the CoPC immediately following a worst-case spill scenario may experience some health effects. These range 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 ( $9.8 \times 10^{-5}$ ), 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 poses a public concern, and adequate measures should be put in place to properly protect the public in the event of a worst-case spill in the Straits portion of 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 et al., 1999). For example, the Michigan Department of Community Health issued a Do Not Eat fish consumption advisory for the approximately 56-kilometer (35-mile) 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. 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. Following the Deepwater Horizon oil spill over 229,000 km<sup>2</sup> (88,400 mi<sup>2</sup>) of waters in the Gulf of Mexico were eventually 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  $x(m) = < 1000 m$ .

Species	Lifetime <sup>a</sup>	Residential Risk (child in parentheses)					Occupational Risk			
		Ci= UCL1- $\alpha$ mg/m <sup>3</sup>	Ei	CDIi (90%) mg/kg- day	ILCRi	HQi	TLV- TWAii mg/m <sup>3</sup>	CDIi (90%) mg/kg- day	ILCRi	HQi
Benzene	> 5 d		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

<sup>a</sup> Source (Bari & Kindzierski, 2018), d= days.

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).

Species	Lifetime	Ci= UCL1- $\alpha$ mg/m <sup>3</sup>	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

<sup>a</sup> Source (Bari& Kindzierski, 2018), d= days.

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  $2.22 \times 10^{-6}$  for adults,  $7.20 \times 10^{-6}$  for children and  $5.49 \times 10^{-6}$  for workers, which are 2, 7 and 5 times higher (respectively) than the established values in the guidelines of US EPA ( $1 \times 10^{-6}$ ) but lower than the worst-case level of  $1 \times 10^{-4}$ .

### 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 are 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 calculation that the Line 5 pipeline along the Straits of Mackinac worst-case spill scenario will be a rupture, pool fire, flash fire or explosion scenario is 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 are described in Appendix D3.

The highest estimated hazard conditional probability is for rupture pool fire, 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 spill scenario 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 feet (ft) associated with flash fires. The limits of flash fire impacts are defined relative to the LFL boundary of the vapor cloud air mixture.

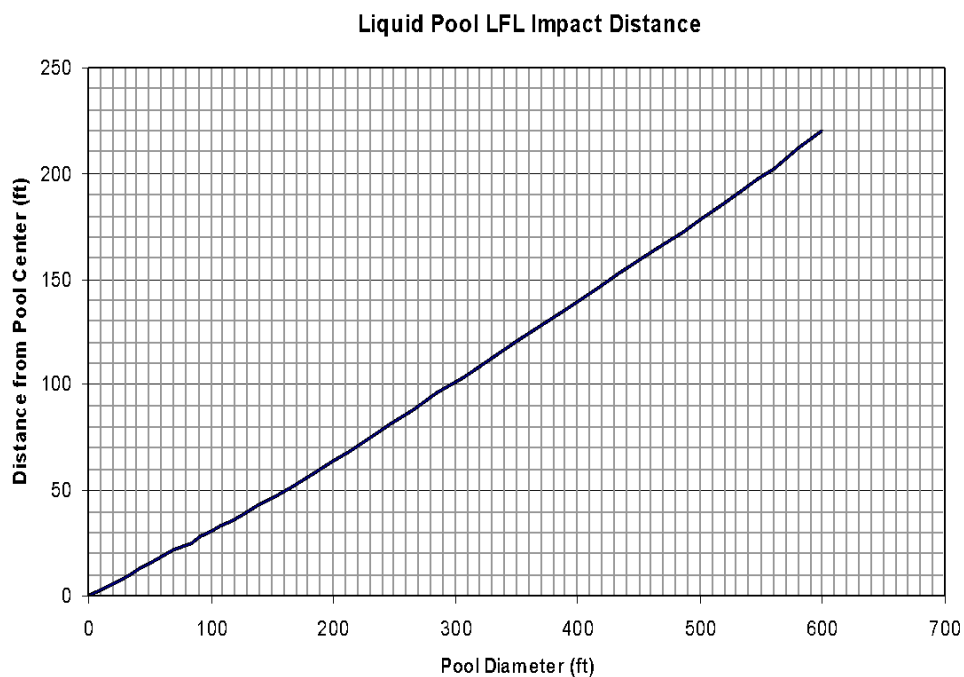


Figure D7.. Liquid Release, LFL Impact Distance, Based on Circular Diameter

#### *D.3.2.3.2 Pool Fires*

This analysis assumed that the pool formation will occur around the pipeline ROW, with circular shape over the pipeline centerline, since the flow would be relatively unrestricted. Figure D7 provides the estimated LFL impact distance from the center of a crude oil pool. Figure D8 is a plot of the heat radiation vs. impact distance in feet from pool center 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.

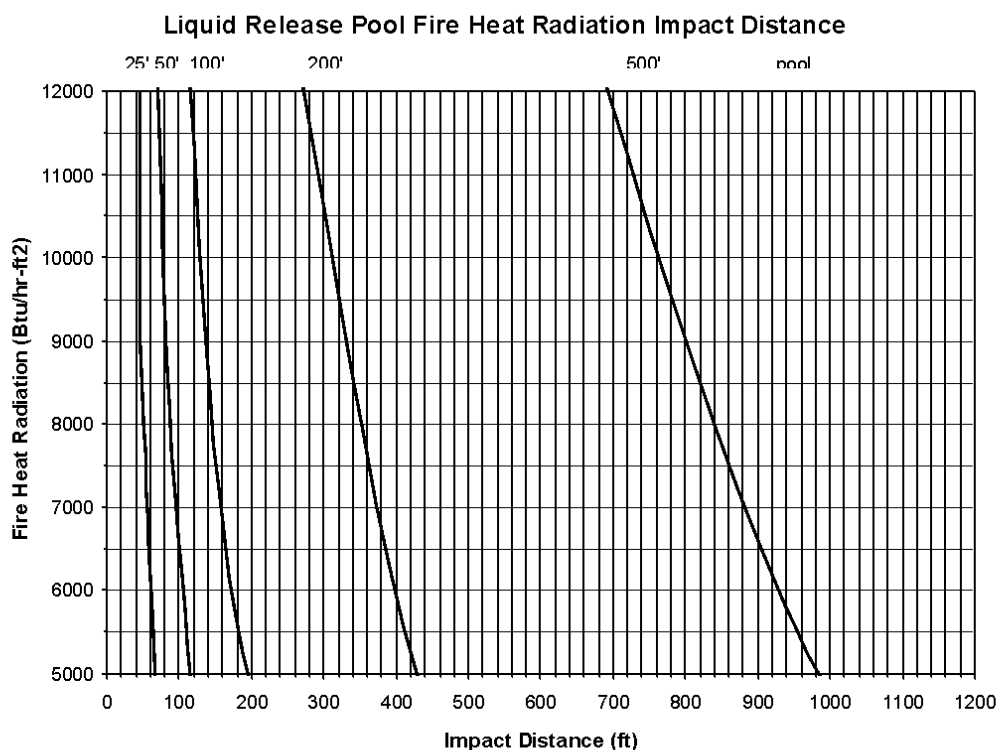


Figure D8. Liquid Gasoline Release, Pool Fire Heat Radiation Impact Distance, Based on Circular Diameter (or Channel Equivalent Diameter)

#### 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<sup>2</sup>).

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 and 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 exposed individuals (receptor), beyond the basic IR estimate. These indicators provide more insight on the level of risk from the worst-case spill scenario considering the areas around the Strait, human population, and other factors. The indicators do not replace the  $Ind_{Risk}$  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.

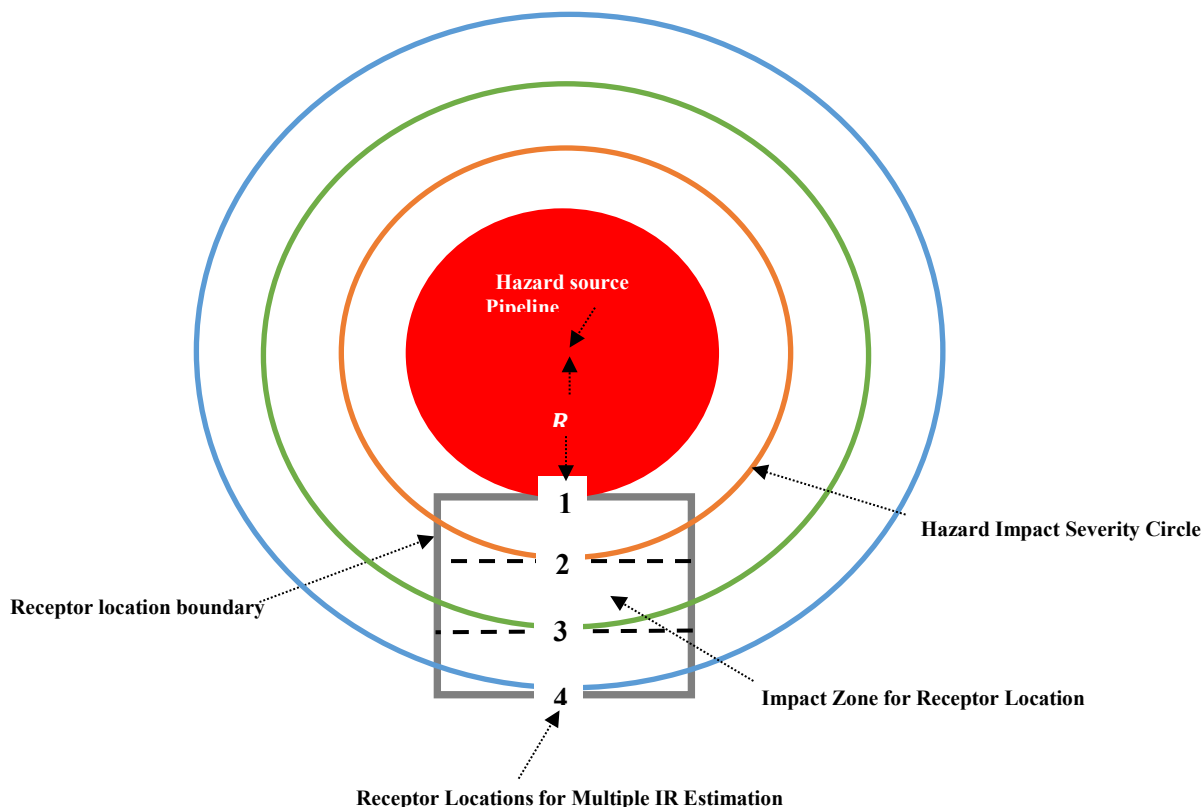


Figure D9. Hazard Impact Circles Equivalent to  $Ind_{risk}$  Values for Individuals (receptors) at Boundaries of Three Impact Zones

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 adjacent boundaries. 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 of 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 represents 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.

Appendix D3 provides the results for this analysis and also further clarification of the methods.

#### D.3.2.6 Population Risk Indicator Calculation

The population risk indicator (PRI) is a risk indicator parameter relative to the population location, estimated by dividing the area of concern into several population zones. The zone 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 worst-case spill 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 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.

For this analysis, at a receptor location depth of 450 ft there are 1000 people assumed 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  $990/3 = 330$  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
	<b>PRI =</b>							350

The PRI calculation considered evenly distributed population across the impact zones due to the worst-case assumptions, however the population areas around Mackinaw 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 face 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 drowning if a 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 and can result in sore, painful blisters on the feet. Workers may contract infectious diseases spread by mosquitoes or ticks (such as 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 human health risk as associated with the subsequent consumption of contaminated potable water derived from these 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. General and Specific Adverse Human Health Effects Associated with Oil-Contaminated Drinking Water Consumption Summary (Adopted From Kponee et al., 2015)

<b>General adverse effect</b>	<b>Specific symptoms</b>
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 US 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 (US EPA, 2009b). 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 spill scenario. For example, the cities of St. Ignace and Mackinac Island have water supply intakes 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 (Figure D2) and at risk of oiling under the worst-case spill scenario. Public notification is mandatory under incidents such as chemical spills that can release contaminants included under the NPDWR into public drinking water sources (Michigan Department of Environmental Quality, 2009). Such violations and situations that have the potential to generate serious adverse human health effects due to short-term exposure require public notification. 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, 2013b). 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 returned to service (US 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 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.

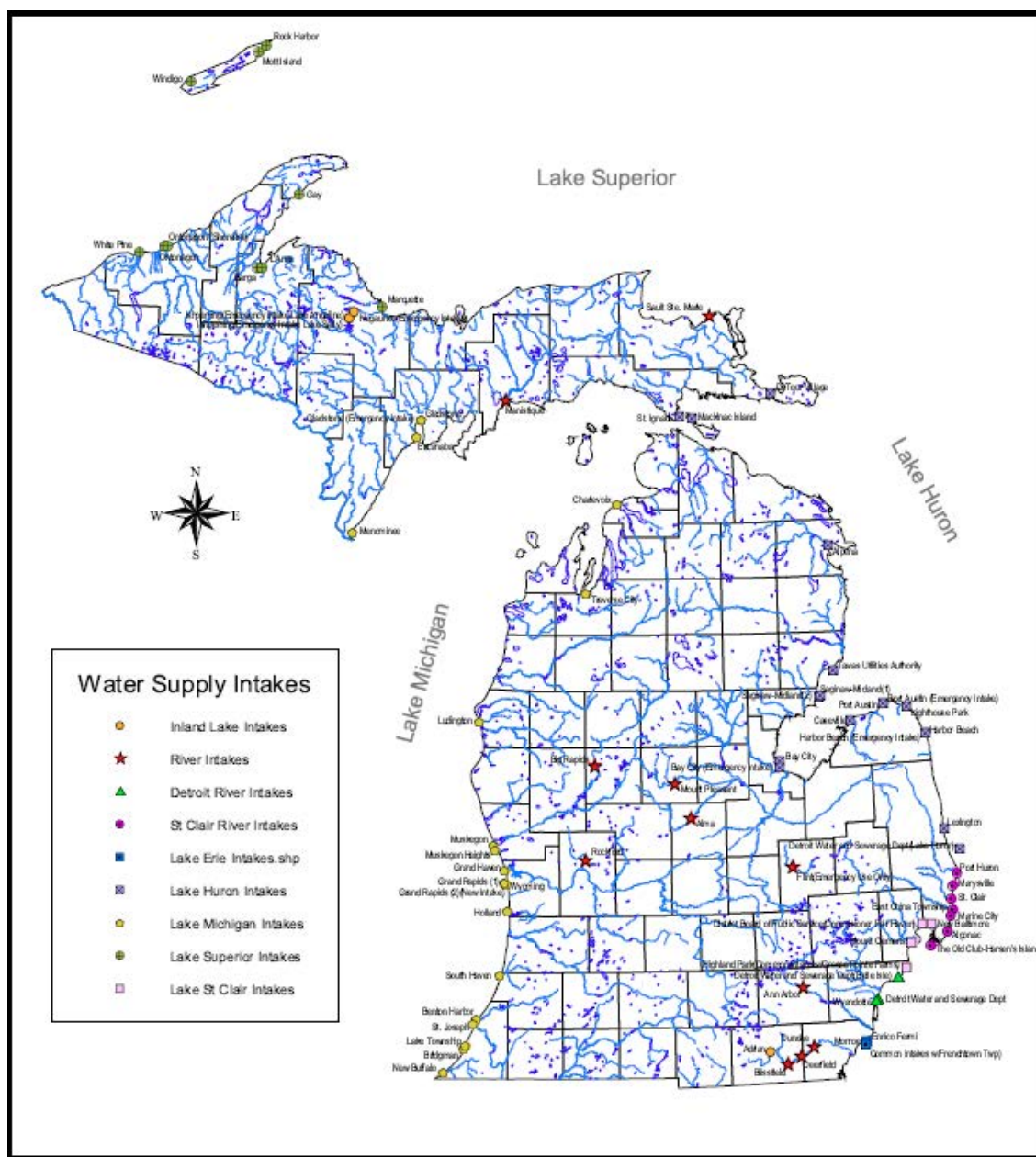


Figure D10.. Michigan Public Water Supply Intake Locations

Source: 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, Emmet and Mackinac counties that have

coastal shorelines within the Straits of Mackinac channel and are at potential risk of oil contamination (Figure 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 2013b). 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.

Following the 2010 Kalamazoo River oil spill, testing of 216 private drinking water wells showed no evidence of petrochemical contamination that would be indicative of the presence of constituents from 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 2013b). No evidence of contamination of private drinking water wells by oil-related organic compounds (i.e., benzene, toluene, ethylbenzene, xylenes) occurred in any of the wells included in the Kalamazoo River drinking water well sampling program. The nature of groundwater flow into the Kalamazoo River mitigated drinking well contamination in the oil-affected region of the river as a potential consequence of the pipeline release. Specifically, the Kalamazoo River is a gaining stream such that 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 in 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 spill 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 how many of these 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 untreated water is consumed.

*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 key 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 vital 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 marine 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 directly impacted Gulf States (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 that affect ecosystems and human health trigger an increase in stress response among the individuals impacted. A study conducted by Gill, Picou & 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 and the BP oil spills, which were the largest and most damaging spills in North America. The researchers compared the social and mental health impacts of these two disasters. Random samples of residents of Cordova, Alaska, and south Alabama were collected five months after each event using standardized indicators of event-related stress 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 after the event (National Commission, 2011). The uncertainty of recovery and economic hardships that follow can affect children and adolescents significantly (Olawoyin et al., 2012). Effects on children and youth are related to the nature of the disaster, their proximity to 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 and 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. Other tribal activities, such as social events, cultural observance gatherings, and tribal fishing and sports may also be disrupted. 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). Furthermore, the involvement of indigenous persons in cleanup activities has 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 last longer among the indigenous people more than other groups in the community and require extended mental health services.

During the BP oil spill, large volumes 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. Consequences of the spill 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 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. The authors also 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**

A spill along the Straits of Mackinac may be consequential to public health and public safety. This analysis concludes that acute inhalation exposure to CoPC may lead to the following short-term health effects in exposed individuals; 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. 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 who will be exposed to the spill initially will not have repeated exposure, especially from the VOCs that disperse relatively quickly.

The daily intakes calculated for each chemical that could 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 Fate and Transport team determined the concentration of the VOCs that may be released from a worst-case spill scenario, 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 upper target 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. For adult residents living within 500 m (0.3 miles) of the shoreline area of Mackinaw City, this might represent increased risks of both carcinogenic and non-carcinogenic health effects due to exposure to 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, the risk values determined in this independent analysis of the worst-case scenario of Line 5 pipeline represent estimates only. Wind speeds in the Mackinac Straits are unpredictable and 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 more difficult, which could also affect the impact of a spill on human health and safety. The estimated human health risk estimates are statistical probability values; actual outcomes may also differ considerably due to the inherent uncertainties involved in dealing with a complex system. 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  $5 \times 10^4$  mg/m<sup>3</sup>. 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 Mackinaw 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 spill scenario. Additionally, there are 306 private drinking water wells located within about 200 feet of the waterline for Cheboygan, Chippewa, Emmet, and Mackinac counties that can potentially be at risk of oil contamination. However, groundwater flow is generally net positive across the Great Lakes constituting 0.1 – 2.7% of water inflow across the basin. Thus, groundwater aquifers proximate to the Straits of Mackinac are at low risk of contamination due to positive groundwater flow into the Straits. However, residents that draw drinking water directly from surface water sources would be at a higher risk of developing health effects from the oil toxins

This study examined the effects of a potential oil spill on community mental health. 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 scenario.

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 generally decline upon removal of individuals to 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 Mackinaw City fall outside of zone 3 which has 0% probability of fatality from flammability and explosive hazards. Hence the public is not expected to be at an increased risk of fire and explosion following a 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 spill scenario would be minimal.

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# 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 result from both the physical properties of the 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 (1) short-chain aliphatic hydrocarbons such as benzene, toluene, ethylbenzene, and xylenes (BTEX) that are very toxic but rapidly degraded and volatilize, and (2) polycyclic aromatic hydrocarbons (PAHs) that are very toxic and can persist in the environment for much longer periods. These chronic adverse 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 worst-case example 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 the trajectory of dispersing oil in benthic, water column and shoreline areas.
- Physiological effects 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., developmental, immunological, 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.

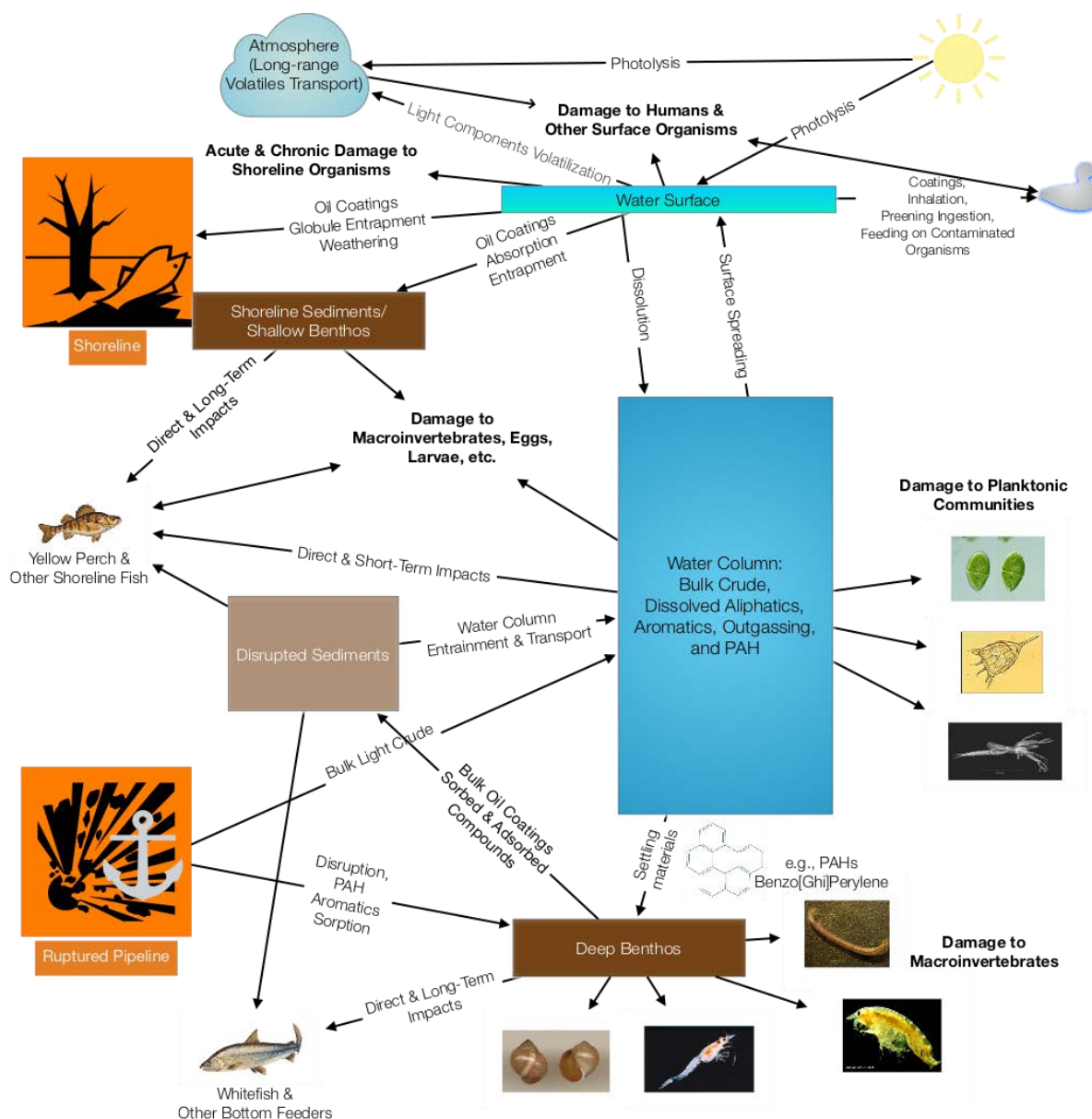


Figure E1. Conceptual Model for Impacts to Natural Resources from a Line 5 Pipeline Rupture and Subsequent Oil Spill in the Straits of Mackinac

Both the BTEX and PAH components of crude oil are highly toxic, and many are carcinogenic to organisms across all life-history stages. The BTEX oil components are short-lived, volatilize quickly at the surface, and don't bind to sediments. These 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  $\geq 3$  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 length 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.* The Michigan Water Quality Standards (Rule 57) states that “Toxic substances shall not be present in the surface waters of the state at levels that are or may become injurious to the public health, safety, or welfare, plant and animal life, or the designated uses of the waters.” However, Rule 57 only provides specific limits for BTEX compounds and does not provide a specific limit for hydrocarbons. Therefore, the level defined by the Alaska Aromatics Freshwater Quality Standard (WQS) was chosen: 15  $\mu\text{g}$  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 for hydrocarbons and is thus appropriate for the Great Lakes. A Straits pipeline spill volume of 58,000 bbl (2.44 M gallons) of light crude oil would have a mass of  $7.9 \times 10^9$  grams (Section A, assuming a density of  $0.86 \text{ g/cm}^3$ ). If that volume 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 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 re-suspend 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.

Table E1. Oil Barrel Distribution Among Habitats Along the Shorelines of Lakes Huron and Michigan from the Four Sampled Worst-case Scenarios, From Section B

Scenario	Shoreline Type	Shoreline Width (m)	Lake Huron			Lake Michigan		
			Shoreline Length (km)	Area (km <sup>2</sup> )	# of Barrels	Shoreline Length (km)	Area (km <sup>2</sup> )	# 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.

*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 is 1 g/m<sup>2</sup>. The threshold for ecological impacts is 100 g/m<sup>2</sup>.



- 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 is 1,610  $\mu\text{g/kg}$  and PEC is 22,800  $\mu\text{g/kg}$ .

To convert shoreline oil 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.

## Impacted Shoreline 10-days

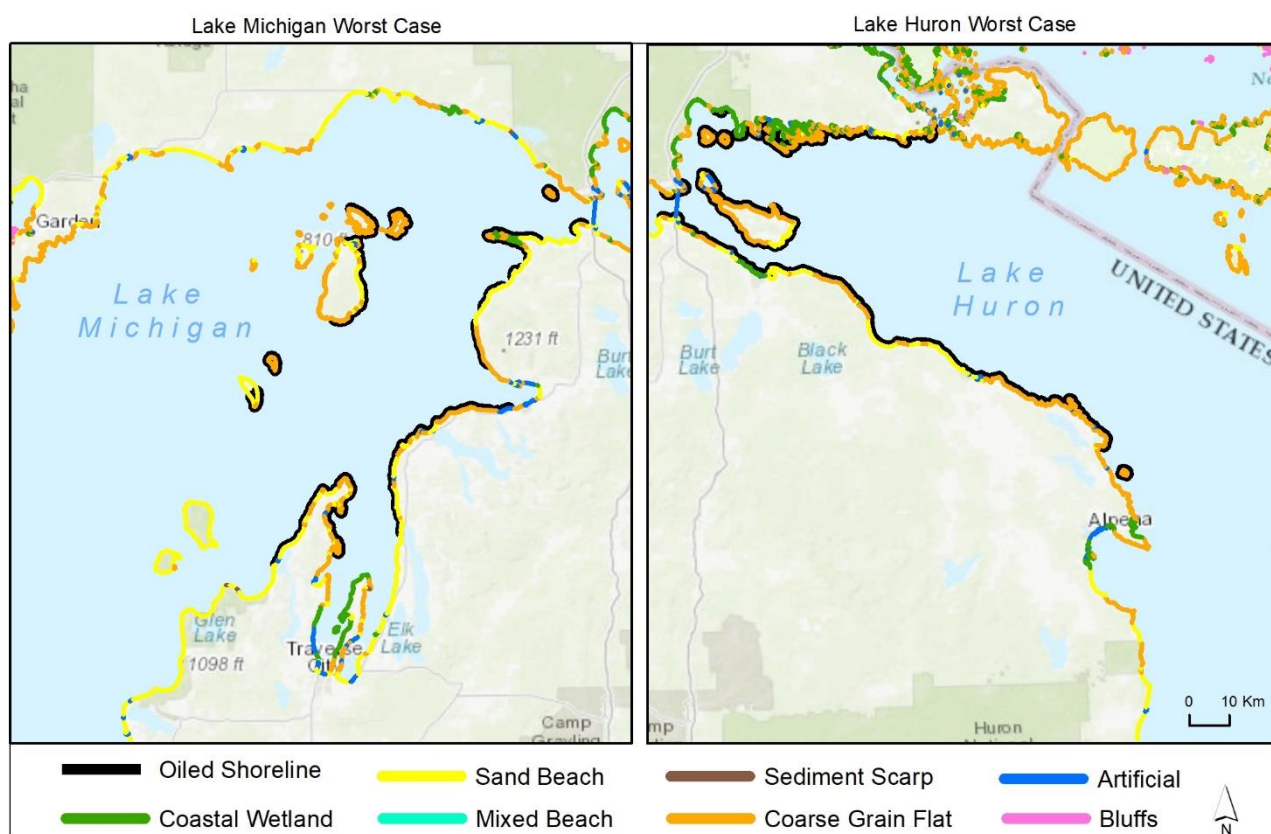


Figure E2. GIS Mapping of 10-day Oiled Area Scenarios for Mackinac Straits and Lakes Huron and Michigan

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.

## Impacted Shoreline 60-days

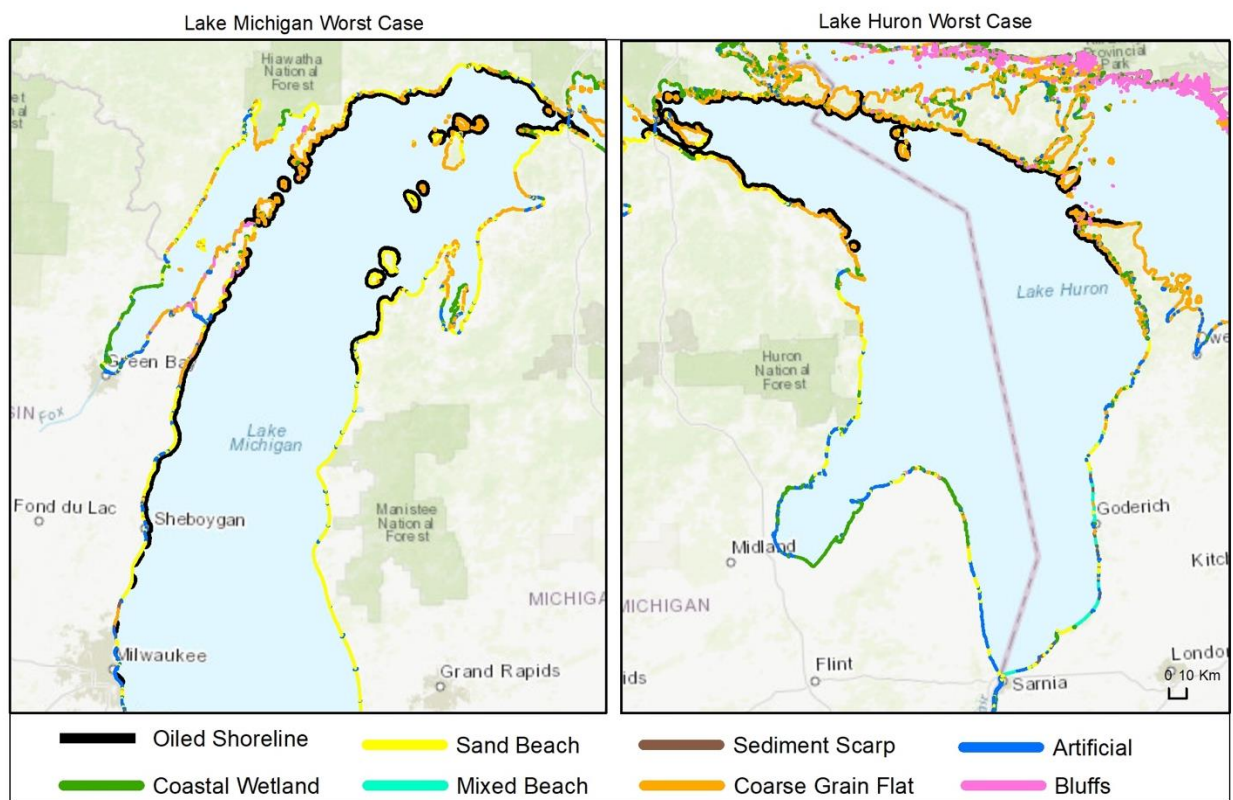


Figure E3. GIS Mapping of 60-day Oiled Area Scenarios for Mackinac Straits and Lakes Huron and Michigan

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 touched by oil. 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 ( $>1\text{ g/m}^2$ ). All shoreline types for both Lake Huron and Lake Michigan, shown as areas colored gray ( $>1\text{ g/m}^2$ ) and black ( $>100\text{ g/m}^2$ ) in Figure E4. Therefore, shoreline cleanups is required for all four scenarios.

### Short Term Effects 10-days

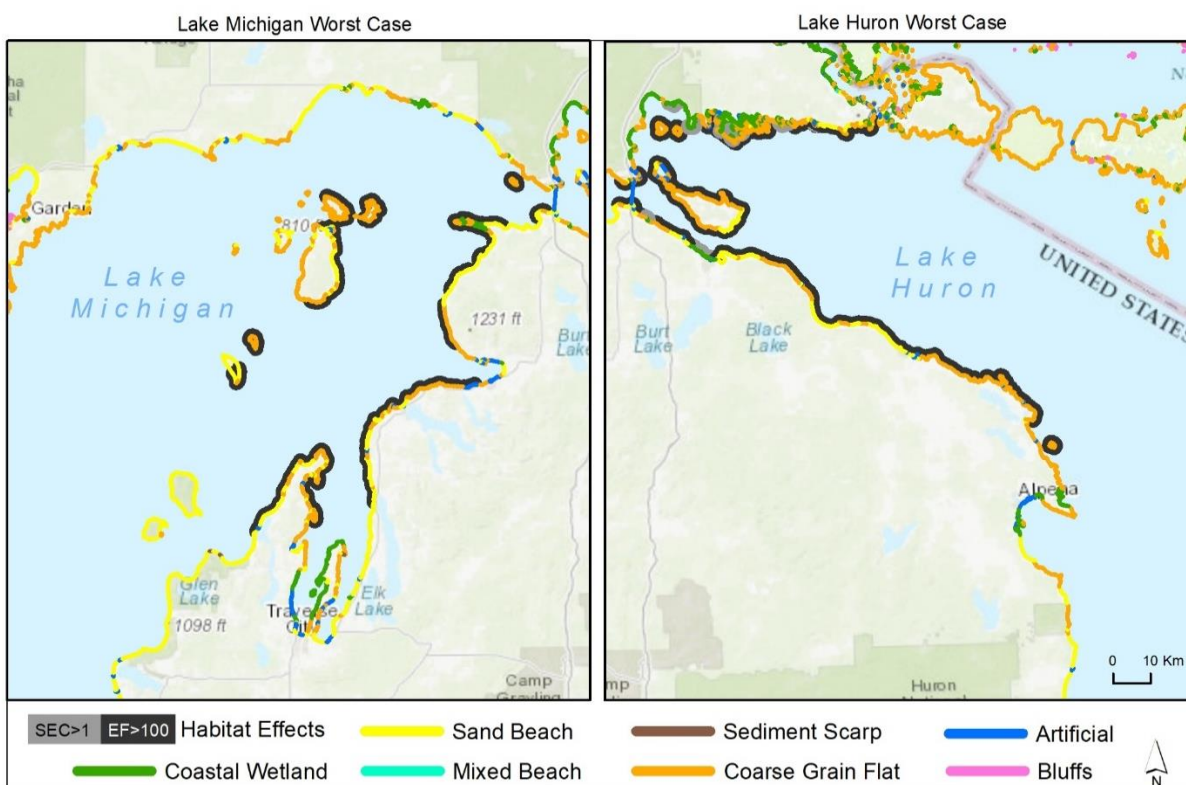


Figure E4. Shoreline Habitats Exceeding Thresholds for Socioeconomic Impacts ( $>1\text{ g/m}^2$ ). Criteria Based Upon NOAA (2013). SEF  $>1\text{ g/m}^2$  (light grey); EF  $>100\text{ g/m}^2$  (black)

#### 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 meet levels that exceed NOAA's threshold for ecological impact ( $>100\text{ g/m}^2$ ). The exception is coastal wetlands in Lake Huron. Oil exposure to this habitat does not exceed the  $100\text{ g/m}^2$  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. 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 are 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).

#### 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 several types of shoreline habitat in both Lake Huron and Lake Michigan. Toxicity to sediment-dwelling organisms would occur 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 E2. 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)

Habitat	Lake Huron				Lake Michigan			
	TEC		PEC		TEC		PEC	
	exceeded		Exceeded		Exceeded		Exceeded	
	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								

Note: Light and dark grey represent exceedance for TEC and PEC respectively.

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)

Habitat	Lake Huron				Lake Michigan			
	TEC		PEC		TEC		PEC	
	Exceeded		Exceeded		Exceeded		Exceeded	
	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								

Note: Light and dark grey represent exceedance for TEC and PEC respectively.



## 8% PAH Short Term Impacts 10-days

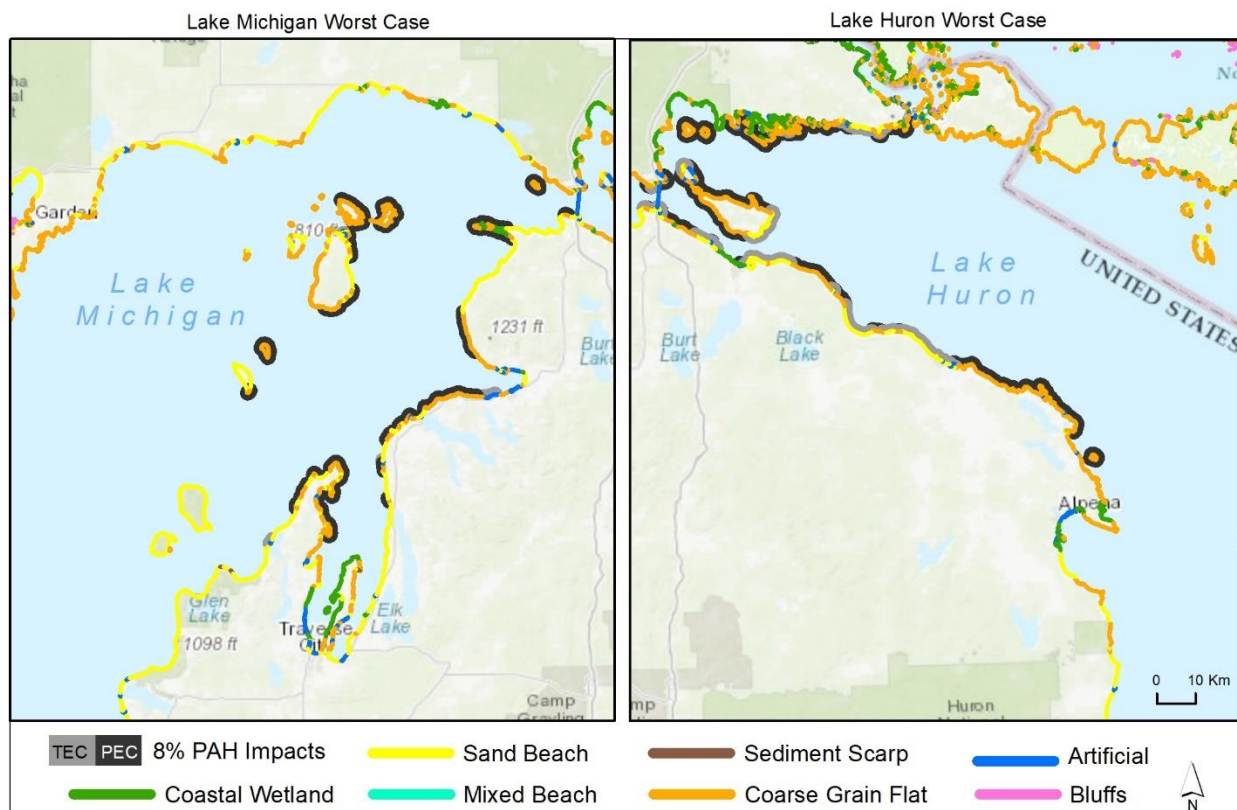


Figure E5. Lakes Huron and Michigan Shoreline Habitats Exceeding Thresholds for Short-term and Long-term Threshold Effect Concentration (TEC) and Probable Effect Concentration (PEC) at 8% PAHs

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 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 natural communities native to Michigan (Kost et al., 2007). A natural community is 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 in the Mackinac Straits and surrounding areas (Table E4). These habitats have been designated critically impaired (S1), imperiled (S2) and rare (S3) by MNFI based on their rarity and vulnerability to disturbance, and include Coastal Fens, Great Lakes Marshes, Open Dunes and Sand/Gravel Beaches (Table E4). 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 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 DEQ Environmental Areas, DNR Ecological Reference Areas, and non-profit coastal reserves. Specifically, 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 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.

## MNFI Biotics Impacted 10-day

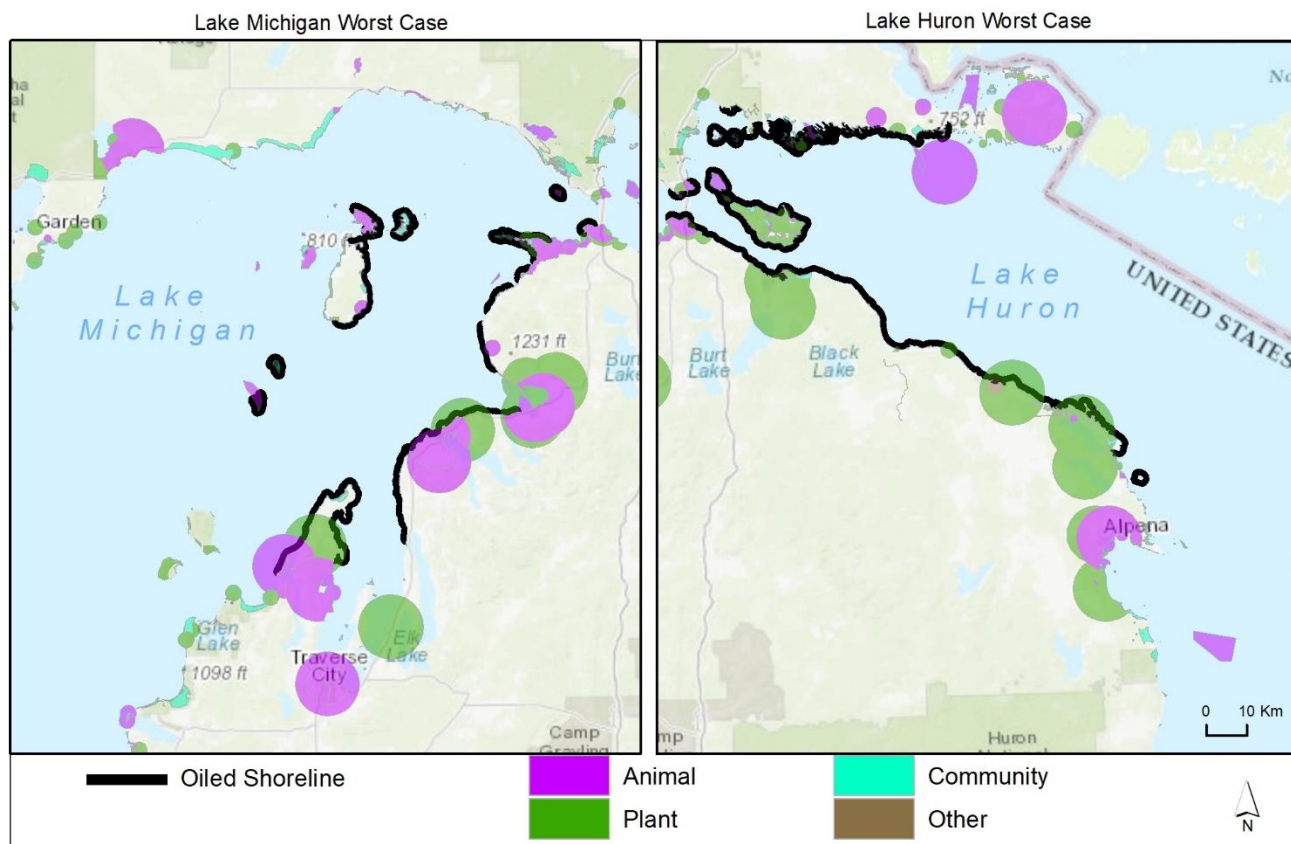


Figure E6. 10-day Oil Dispersal Scenario of Unique Terrestrial Community Complexes

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 Line 5 Pipeline Rupture 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, waterfowl, and songbirds
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

# INDEPENDENT RISK ANALYSIS – PROJECT ID#1801011

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 birds; 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 areas 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. More than 202,343 hectares (500,000 acres) of coastal wetlands are distributed throughout the Great Lakes basin. Seventy percent of the Great Lakes coastal wetlands are located within the United States (~350,000 acres), of which 75-80% (i.e., 275,748 acres) 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 essential 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 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. However, some rare species use these wetland systems such as Black Tern, Least Bittern and Marsh Wren (MI DNR, personal communication).

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 Great Lakes Piping Plover population, 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 Lake Huron tansy and Houghton's goldenrod have similar distributions and are considered Great Lakes Endemic species; the Pitcher's thistle is found throughout the Great Lakes region and thrives on wind-swept open dunes and requires up to eight years to produce seed.
- 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 impacts 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 services in Great Lakes nearshore habitats including juvenile and adult habitat for commercially and recreationally 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.

## Field Site Classes 10-day

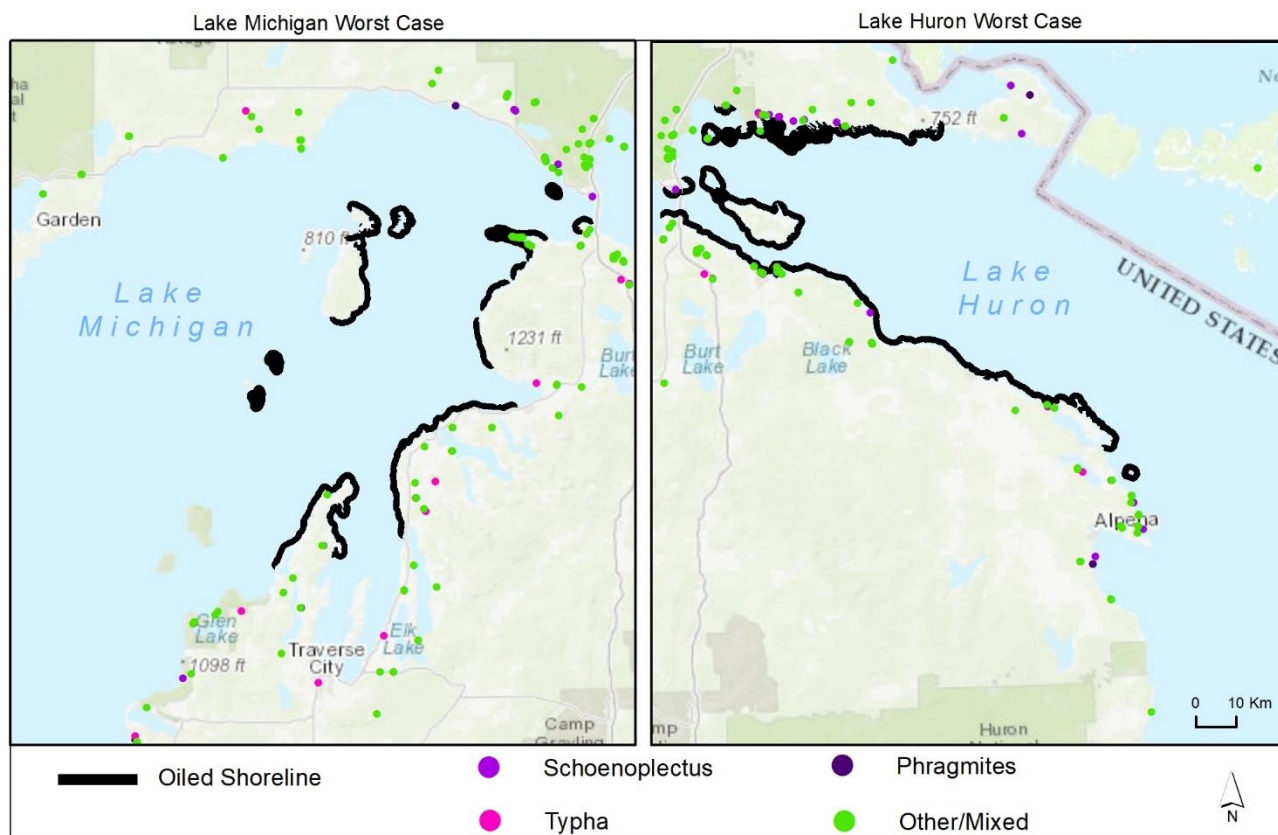


Figure E7. Map of Field Data Locations, Color-coded by Dominant Cover Type (from Bourgeau-Chavez et al., 2008)

*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 of 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.

## Submerged Aquatic Vegetation Impacted 10-day

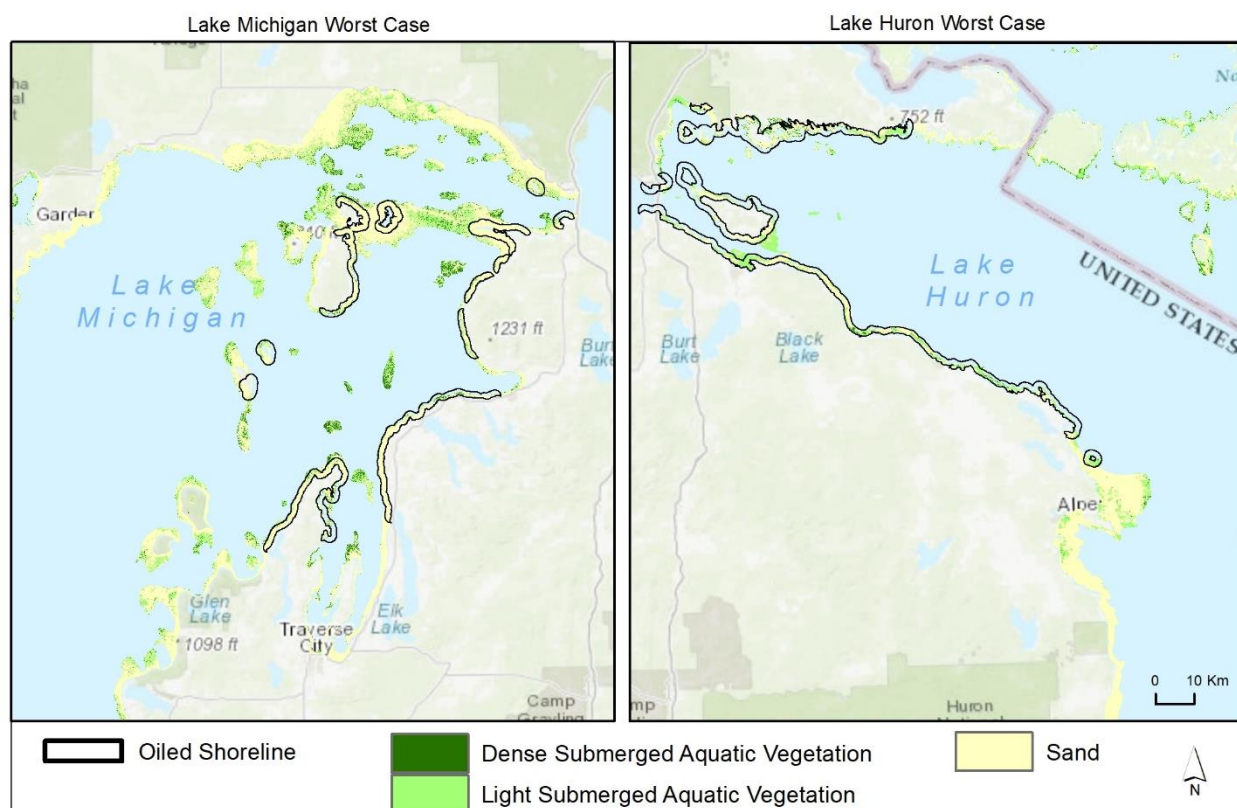


Figure E8. Submerged Aquatic Vegetation Location and Density Within and Adjacent to Mackinac Straits Derived from MTRI's Classification Relative to 10-Day Post Oiling Scenario

Plankton are a major component 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 fresh and weathered South Louisiana crude oil. They 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 observed decreased chlorophyll concentrations and productivity relative to control concentrations within 33 hours. 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) occur over chronic periods of time as some organisms bioaccumulate and increase the toxins in their tissues (Figure E9). This food web response has been observed in salt water; thus, there is a level of uncertainty as to whether annelids and polychaetes are capable of biodegrading oil spilled in freshwater.

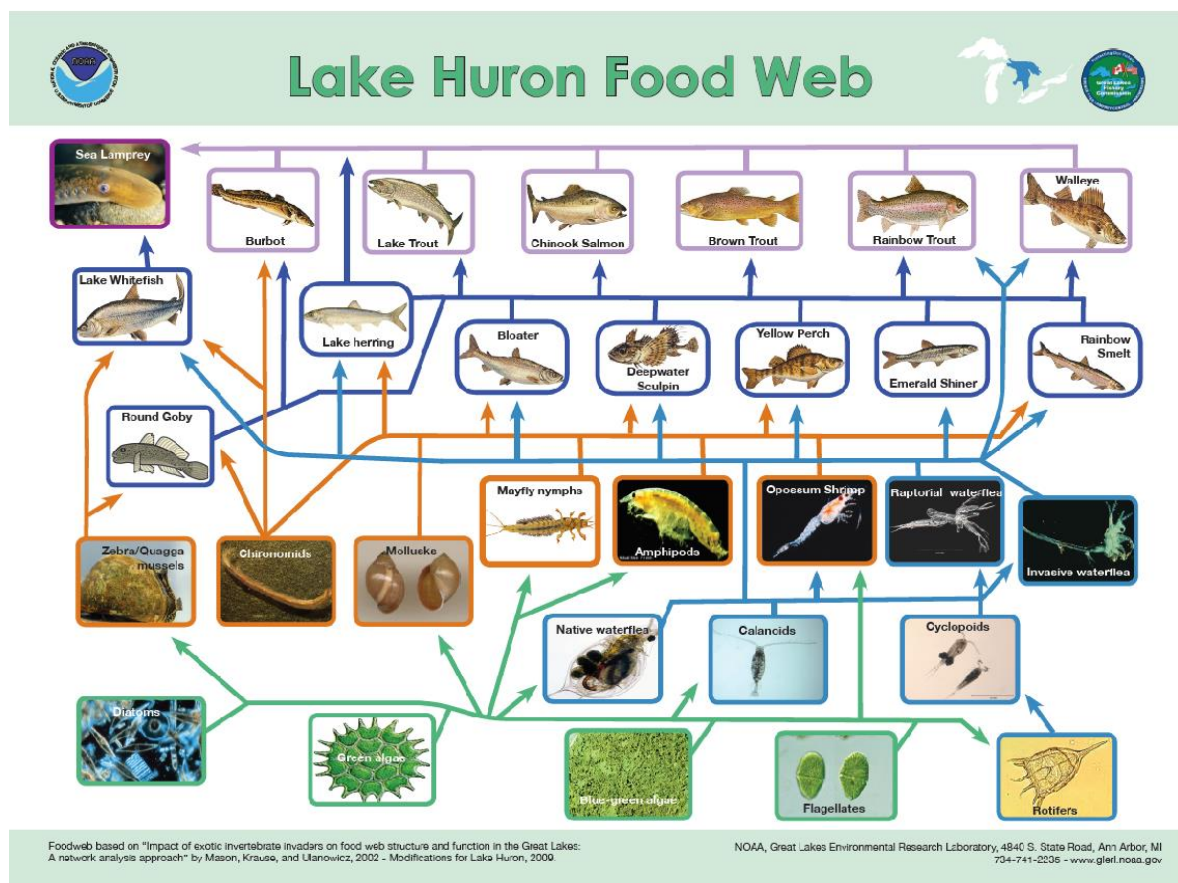


Figure E9. Aquatic Food Web of Lake Huron

Figure E9 depicts 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.

With 125 species of bivalves occurring in the Laurentian Great Lakes (GLERL, 2018), mollusks play a vital role in the ecosystem, including the state-listed endangered Black Sandshell and Eastern Pondmussel, threatened Slippershell, and species of special concern, Elktoe and Rainbow (MNFI, 2018). 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 quagga 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 ( $LC_{50} = 0.8 \mu\text{L/L}$ ) more sensitive than the adults ( $LC_{50} = 550 \mu\text{L/L}$ ). 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 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 could 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 impacts of oil 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) reports that they have 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.

### Insects

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 are 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 Most Vulnerable to Oil Exposure Post Line 5 Pipeline Rupture in the Mackinac Straits

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

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

We assess 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 in Table E6. Of these species, Blanding’s Turtle and the Eastern Massasauga Rattlesnake have a 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 E6). 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 a 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 concerning (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 experience 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 is expected in amphibians and reptiles, but these remain poorly studied.

Table E6. Reptile and Amphibian Species Most Vulnerable to Oil Exposure Post Line 5 Pipeline Rupture Given Their Use of Surrounding and Adjacent Areas in the Mackinac Straits

Name		Conservation Status				Habitat	
Common	Species	IUCN	CITES	US	MI	Lakes	Biome
Blanding's Turtle	<i>Emydoidea blandingii</i>	E	II	UR	SC	both	Wetlands
American Bullfrog	<i>Lithocates catesbeiana</i>	LC	-	-	-	both	Wetlands; Lake
Blue-Spotted Salamander	<i>Ambystoma laterale</i>	LC	-	-	-	both	Woodland Ponds
Brown Snake	<i>Storeria dekayi dekayi</i>	LC	-	-	-	both	Wetlands; Woody
Cope's Gray Treefrog	<i>Hyla chryocelis</i>	LC	-	-	-	both	Wetlands; Ponds
Eastern American Toad	<i>Bufo americanus</i>	LC	-	-	-	both	Wetlands; Woody
Eastern Box Turtle	<i>Terrapene carolina</i>	NT	II	-	SC	Michigan	Forest
Eastern Fox Snake	<i>Pantherophis gloydi</i>	NT	-	-	T	both	Forest
Eastern Garter Snake	<i>Thamnophis sirtalis</i>	LC	-	-	-	both	Forest
Eastern Massasauga Rattlesnake	<i>Sistrurus catenatus catenatus</i>	V	-	T	SC	both	Wetlands; Woody
Eastern Milksnake	<i>Lampropeltis triangulum</i>	LC	-	-	-	both	Streams
Eastern Newt	<i>Notophthalmus viridescens</i>	LC	-	-	-	both	Wetlands
Eastern Red-Backed Salamander	<i>Plethodon cinereus</i>	LC	-	-	-	both	Wetlands
Eastern Snapping Turtle	<i>Chelydra serpentina</i>	LC	-	-	-	both	Ponds
Five-Lined Skink	<i>Plestiodon fasciatus</i>	LC	-	-	-	both	Forest
Four-Toed Salamander	<i>Hemidactylum scutatum</i>	LC	-	-	-	both	Forest
Fowler's Toad	<i>Anaxyrus fowleri</i>	LC	-	-	SC	Michigan	Dunes
Gray Treefrog	<i>Hyla versicolor</i>	LC	-	-	-	both	Wetlands; Ponds

INDEPENDENT RISK ANALYSIS – PROJECT ID#1801011

Green Frog	<i>Lithobates clamitans</i>	LC	-	-	-	both	Wetlands; Ponds
Mink Frog	<i>Lithobates septentrionalis</i>	LC	-	-	-	both	Wetlands; Ponds
Mudpuppy	<i>Necturus maculosus</i>	LC	-	-	SC	both	Wetlands; Ponds
North American Racer	<i>Coluber constrictor</i>	LC	-	-	-	Michigan	Grassland
Northern Leopard Frog	<i>Lithobates pipiens</i>	LC	-	-	-	both	Wetlands; Ponds
Northern Red-Bellied Snake	<i>Storeria occipitomaculata</i>	LC	-	-	-	both	Wetland; Forest
Northern Ribbon Snake	<i>Thamnophis septentrionalis</i>	LC	-	-	-	both	Wetlands
Northern Ring-Necked Snake	<i>Diadophis punctatus</i>	LC	-	-	-	both	Grassland
Northern Water Snake	<i>Nerodia sipedon</i>	LC	-	-	-	both	Wetlands; Lakes
Painted Turtle	<i>Chrysemys picta</i>	LC	-	-	-	both	Wetlands
Pickrel Frog	<i>Lithobates palustris</i>	LC	-	-	SC	both	Wetlands
Red-Eared Slider	<i>Trachemys scripta elegans</i>	LC	-	-	-	both	Wetlands
Smooth Green Snake	<i>Opheodrys vernalis</i>	LC	-	-	-	both	Wetlands
Spiny Softshell	<i>Apalone spinifera</i>	LC	-	-	-	Michigan	Ponds
Spotted Salamander	<i>Ambystoma maculatum</i>	LC	-	-	-	both	Wetlands; Ponds
Spotted Turtle	<i>Clemmys guttata</i>	V	-	-	T	both	Forest
Spring Peeper	<i>Pseudacris crucifer</i>	LC	-	-	-	both	Wetlands
Western Chorus Frog	<i>Pseudacris triseriata</i>	LC	-	-	-	both	Wetlands
Wood Frog	<i>Lithobates sylvatica</i>	LC	-	-	-	both	Ponds
Wood Turtle	<i>Glyptemys insculpta</i>	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 are found in Lake Michigan waters and 36 in Lake Huron waters (Table E7).

A number of these fish species have conservation status in the state of Michigan, two of which are associated with tributaries, the Channel Darter and Pugnose Shiner, and two that prefer cooler open water habitats, the Cisco and Lake Sturgeon (Table E7). Both Cisco and Lake Sturgeon spawn in the Straits area and are threatened species. 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 critical 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 species, including Lake Trout, Lake Whitefish, Round Whitefish, Rainbow Trout, Rainbow Smelt, Lake Herring, Smallmouth Bass, Yellow Perch, Walleye, Carp, Northern Pike, Muskellunge, White Sucker, Channel Darter, Common Shiner, Rock Bass, and Alewife.

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.

#### Exposure to Oil

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 included whitefish and ciscoes, grayling, and char, trout, and salmon. 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 E7).

Table E7. Fish Species in Lakes Michigan and Huron Most Vulnerable to Oil Exposure Post Line 5

Name		Conservation Status				Value		Characteristics						
Common	Species	IUCN	CITES	US	MI	Fisheries	Recreation	Lake	Pelagic	Littoral	River	Season	Habitat	Migratory
Alewife	<i>Alosa pseudoharengus</i>	LC	-	-	-			B		X		Su	Cold shoreline	RB
Black Crappie	<i>Pomoxis nigromaculatus</i>	LC	-	-	-		X	H		X		Sp	Intermediate shoreline	R
Bloater	<i>Coregonus hoyi</i>	V	-	-	-			M	X			Sp	Deep cold	RB
Bluegill	<i>Lepomis macrochirus</i>	LC	-	-	-		X	B		X		Sp	Warm shoreline	R
Brook Trout	<i>Salvelinus fontinalis</i>		-	-	-		X	B	X	X	X	Sp	Cold open water	RB
Brown Trout	<i>Salmo trutta</i>	LC	-	-	-		X	B			X	Sp	Cold open water	R
Bullhead	<i>Ictalurus melas</i>	LC	-	-	-			H	X			Sp	Warm shoreline	RB
Burbot	<i>Lota lota</i>	LC	-	E	-		X	B		X		Sp	Deep cold	RB
Carp	<i>Cyprinus carpio</i>		-	-	-	X	X	B	X	X		Su	Warm shoreline	RB
Channel Catfish	<i>Ictalurus punctatus</i>	LC	-	-	-	X	X	B		X		Sp	Warm shoreline	RB
Channel Darter	<i>Percina copelandi</i>	LC	-	-	E			H			X	Sp	Cold shoreline	RB
Cisco	<i>Coregonus artedii</i>	LC	-	-	T	X	X	B		X		W	Deep cold	RB
Coho Salmon	<i>Oncorhynchus kisutch</i>	-	-	ET	-	X	X	B	X		X	Sp	Cold open water	R
Deepwater Sculpin	<i>Myoxocephalus thompsonii</i>	-	-	-	-			B		X		W	Deep cold	R
Emerald Shiner	<i>Notropis atherinoides</i>	-	-	-	-			B		X		Sp	Cold shoreline	R
Gizzard Shad	<i>Dorosoma cepedianum</i>	LC	-	-	-			B		X		Sp	Cold shoreline	RB

INDEPENDENT RISK ANALYSIS – PROJECT ID#1801011

Name		Conservation Status				Value		Characteristics						
Common	Species	IUCN	CITES	US	MI	Fisheries	Recreation	Lake	Pelagic	Littoral	River	Season	Habitat	Migratory
Chinook Salmon	<i>Oncorhynchus tshawytscha</i>	-	-	ET	-	X	X	B	X			Sp	Cold open water	R
Lake chub	<i>Couesius plumbeus</i>	LC	-	-	-			M			X	Sp	Cold open water	R
Lake Sturgeon	<i>Acipenser fulvescens</i>	LC	II	-	T			B		X		Su	Cold open water	RB
Lake Trout	<i>Salvelinus namaycush</i>	-	-	-	-	X	X	B		X		F	Cold open water	RB
Lake Whitefish	<i>Coregonus clupeaformis</i>	-	-	-	-	X	X	B		X		F	Cold open water	RB
Largemouth Bass	<i>Micropterus salmoides</i>	LC	-	-	-		X	B		X		Sp	Warm shoreline	RB
Longnose Dace	<i>Rhinichthys cataractae</i>	LC	-	-	-			M			X	Sp	Intermediate shoreline	RB
Longnose Sucker	<i>Catostomus catostomus</i>	LC	-	SU	-	X	X	B		X		Sp	Cold open water	RB
Muskellunge	<i>Esox masquinongy</i>	LC	-	-	-		X	B		X	X	Sp	Intermediate shoreline	RB
Northern Pike	<i>Esox lucius</i>	LC	-	-	-		X	B		X		Sp	Intermediate shoreline	RB
Pink Salmon	<i>Oncorhynchus gorbuscha</i>	-	-	-	-		X	M			X	Sp	Cold open water	R
Pugnose Shiner	<i>Notropis anogenus</i>	LC	-	-	E			H			X	Sp	Intermediate shoreline	R
Pumpkinseed	<i>Lepomis gibbosus</i>	LC	-	-	-		X	B		X		Sp	Warm shoreline	RB
Rainbow Smelt	<i>Osmerus mordax</i>	LC	-	-	-	X		B				Sp	Intermediate shoreline	R
Rainbow Trout	<i>Oncorhynchus mykiss</i>	-	-	ET	-		X	B	X	X		Sp	Intermediate shoreline	R



# INDEPENDENT RISK ANALYSIS – PROJECT ID#1801011

Name		Conservation Status				Value				Characteristics				
Common	Species	IUCN	CITES	US	MI	Fisheries	Recreation	Lake	Pelagic	Littoral	River	Season	Habitat	Migratory
Rock Bass	<i>Ambloplites rupestris</i>	LC	-	-	-	X	X	H		X		Sp	Intermediate shoreline	RB
Round Whitefish	<i>Prosopium cylindraceum</i>	-	-	-	-	X		B		X		F	Cold open water	RB
Slimy Sculpin	<i>Cottus cognatus</i>	LC	-	-	-			B		X		W	Deep cold	RB
Smallmouth Bass	<i>Micropterus dolomieu</i>	LC	-	-	-		X	B		X		Sp	Warm shoreline	RB
Spottail Shiner	<i>Notropis hudsonius</i>	LC	-	-	-			B		X		Sp	Cold shoreline	RB
Walleye	<i>Stizostedion vitreum vitreum</i>	LC	-	-	-	X	X	B		X		Sp	Cold shoreline	RB
White Bass	<i>Morone chrysops</i>	LC	-	-	-		X	B		X	X	Sp	Warm shoreline	RB
White Sucker	<i>Catostomus commersoni</i>	LC	-	-	-	X	X	B			X	Sp	Intermediate shoreline	RB
Yellow Perch	<i>Perca flavescens</i>	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.

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’ahue, 2001; Dupuis & Ucan-Marín, 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 result of acute toxicity from many biochemical reactions that disrupt central nervous system functions due to lipid-soluble hydrocarbons 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 40-50% of eggs of Pacific Herring were exposed to oil and that 99% were killed on the oiled shores. This resulted in a reduction of over 40% of the expected total production of from Prince William Sound.

A rupture in Line 5 would impact spawning areas for numerous 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 is 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 has 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, the 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 necessary for movements between habitats and as a potential fitness parameter because of its direct impact on foraging success, predator-prey interactions, and dominance-hierarchy encounters (Kennedy & Farrell, 2006).

## Spawning grounds 10-days

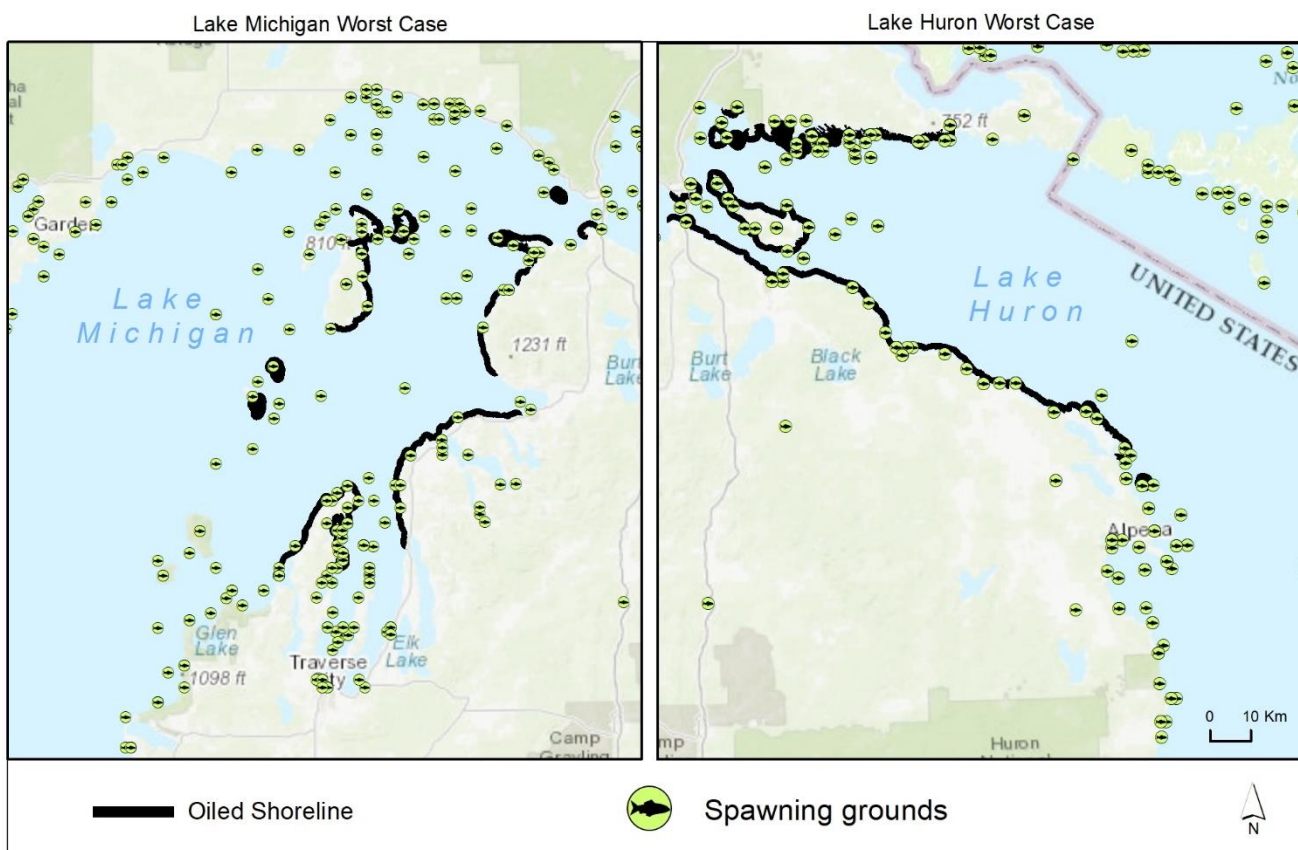


Figure E10. Lakes Huron and Michigan Fish Spawning Areas (based on GLAHF and Goodyear Atlas)

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.

#### 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, a grade of residual fuel oil that may be blended with smaller quantities of distillates to obtain a fuel oil with a specific viscosity (also known as Type 6 heating fuel oil in Canada or No. 6 fuel oil in the United States), revealed a general pattern of increasing incidence and severity of several skeletal and craniofacial deformities (Debruyne 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. Adult perch are also primary prey for walleye, largemouth bass, northern pike and Double-Crested Cormorant (MIDNR, 2005). Yellow Perch spawn in

the spring in spawning grounds near Line 5. Therefore, an increase in mortalities to eggs and larvae is expected after an oil discharge.

*Lake Sturgeon* are listed as Threatened under the Endangered Species Act of the State of Michigan (Part 365 of PA 451, 1994 Michigan Natural Resources and Environmental Protection Act). 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 recreational forage fish. 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.

#### Summary of Oil Impacts to Fish

- 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 near 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 E8

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 E8). 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. Moreover, it was shown that the Black Oystercatchers 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. Collectively these data

imply 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 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), indicative of the long retention times for PAH compounds absorbed upon and into the sediments.

Chronic impacts were 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).

#### Influence of Geography on Bird Use of the Straits

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 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, a 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 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.



INDEPENDENT RISK ANALYSIS – PROJECT ID#1801011

Table E8. Bird Species Most Vulnerable to Oil Exposure Post Line 5 Pipeline Rupture Given Their Use of Surrounding and Adjacent Coastal and Wetland in the Mackinac Straits

Name		Conservation Status					Characteristics					
Common	Species	IUCN	CITES	US	MI	Waders	Waterfowl	Shorebirds	Raptors	Colonial	Habitat	Migratory
American Bittern	<i>Botaurus lentiginosus</i>	LC	-	-	SC	Y	N	N	N	N	Marshes	B
American Black Duck	<i>Anas rubripes</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
American Coot	<i>Fulica americana</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
American Golden Plover	<i>Pluvialis dominica</i>	LC	-	-	-	N	N	Y	N	N	Shoreline	M
American Wigeon	<i>Anas americana</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Bald Eagle	<i>Haliaeetus leucocephalus</i>	LC	II	D	SC	N	N	N	Y	N	Lake	R
Belted Kingfisher	<i>Megaceryle alcyon</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Black Scoter	<i>Melanitta nigra</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Black Tern	<i>Chlidonias niger</i>	LC	-	-	SC	N	N	Y	N	Y	Shoreline	B
Black-Crowned Night Heron	<i>Nycticorax nycticorax</i>	LC	-	-	SC	Y	N	N	N	Y	Marshes	B
Blue-Winged Teal	<i>Anas discors</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Bonaparte's Gull	<i>Larus philadelphia</i>	LC	-	-	-	N	N	Y	N	N	Shoreline	M
Bufflehead	<i>Bucephala albeola</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Canada Goose	<i>Branta canadensis</i>	LC	I	D	-	N	Y	N	N	N	Lake	B
Canvasback	<i>Aythya valisineria</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Caspian Tern	<i>Hydroprogne caspia</i>	LC	-	-	T	N	N	Y	N	Y	Shoreline	B

# INDEPENDENT RISK ANALYSIS – PROJECT ID#1801011

Name		Conservation Status						Characteristics				
Common	Species	IUCN	CITES	US	MI	Waders	Waterfowl	Shorebirds	Raptors	Colonial	Habitat	Migratory
Cattle Egret	<i>Bubulcus ibis</i>	LC	II	-	SC	Y	N	N	N	N	Marshes	B
Common Gallinule	<i>Gallinula chloropus</i>	LC	-	E	T	N	Y	N	N	N	Lake	B
Common Goldeneye	<i>Bucephala clangula</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Common Loon	<i>Gavia immer</i>	LC	-	-	T	N	Y	N	N	N	Lake	B
Common Merganser	<i>Mergus merganser</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Common Tern	<i>Sterna hirundo</i>	LC	-	-	T	N	N	Y	N	Y	Shoreline	B
Double-Crested Cormorant	<i>Phalacrocorax auritus</i>	LC	-	-	-	N	Y	N	N	Y	Lake	B
Dunlin	<i>Calidris alpina</i>	LC	-	-	-	N	N	Y	N	N	Shoreline	M
Forster's Tern	<i>Sterna fosteri</i>	LC	-	-	E	N	N	Y	N	Y	Shoreline	M
Gadwall	<i>Anas strepera</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Great Blue Heron	<i>Ardea herodias</i>	LC	-	-	-	Y	N	N	N	Y	Marshes	B
Great Egret	<i>Casmerodius albus</i>	LC	-	-	-	Y	N	N	N	Y	Marshes	M
Greater Scaup	<i>Aythya marila</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Greater Yellowlegs	<i>Tringa melanaleuca</i>	LC	-	-	-	Y	N	N	N	N	Marshes	M
Green Heron	<i>Butorides striatus</i>	LC	-	-	-	Y	N	N	N	Y	Marshes	B
Green-winged Teal	<i>Anas crecca</i>	LC	-	-	-	N	Y	N	N	N	Marshes	B
Herring Gull	<i>Larus argentatus</i>	LC	-	-	-	N	N	Y	N	Y	Shoreline	B

# INDEPENDENT RISK ANALYSIS – PROJECT ID#1801011

Name		Conservation Status						Characteristics				
Common	Species	IUCN	CITES	US	MI	Waders	Waterfowl	Shorebirds	Raptors	Colonial	Habitat	Migratory
Hooded Merganser	<i>Lophodytes cucullatus</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Horned Grebe	<i>Podiceps auritus</i>	V	-	-	-	N	Y	N	N	N	Lake	R
Killdeer	<i>Charadrius vociferus</i>	LC	-	-	-	N	N	Y	N	N	Shoreline	B
King Rail	<i>Rallus elegans</i>	NT	-	-	E	Y	N	N	N	N	Marshes	B
Least Bittern	<i>Ixobrychus exilis</i>	LC	-	-	T	Y	N	N	N	N	Marshes	B
Least Sandpiper	<i>Calidris minutilla</i>	LC	-	-	-	N	N	Y	N	N	Shoreline	B
Lesser Scaup	<i>Aythya affinis</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Lesser Yellowlegs	<i>Tringa flavipes</i>	LC	-	-	-	Y	N	N	N	N	Marshes	B
Long-Tailed Duck	<i>Clangula hyemalis</i>	V	-	-	-	N	Y	N	N	N	Lake	M
Mallard	<i>Anas platyrhynchos</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Merlin	<i>Falco columbarius</i>	LC	-	-	T	N	N	N	Y	N	Marshes	B
Mute Swan	<i>Cygnus olor</i>	LC	-	-	-	N	Y	N	N	N	Lake	R
Northern Harrier	<i>Circus cyaneus</i>	LC	II	-	SC	N	N	N	Y	N	Dune; Scrub	B
Northern Pintail	<i>Anas acuta</i>	LC	-	-	-	N	Y	N	N	N	Marshes	B
Northern Shoveler	<i>Anas clypeata</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Osprey	<i>Pandion haliaetus</i>	LC	-	-	SC	N	N	N	Y	N	Lake	B
Pectoral Sandpiper	<i>Calidris melanotos</i>	LC	-	-	-	N	N	Y	N	N	Shoreline	M

# INDEPENDENT RISK ANALYSIS – PROJECT ID#1801011

Name		Conservation Status					Characteristics					
Common	Species	IUCN	CITES	US	MI	Waders	Waterfowl	Shorebirds	Raptors	Colonial	Habitat	Migratory
Peregrine Falcon	<i>Falco peregrinus</i>	LC	I	-	E	N	N	N	Y	N	Shoreline	M
Pied-Billed Grebe	<i>Podilymbus podiceps</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Piping Plover	<i>Charadrius melodus</i>	NT	-	ET	E	N	N	Y	N	N	Shoreline	B
Prairie warbler	<i>Setophaga discolor</i>	LC	-	-	E	N	N	N	N	N	Dune; Scrub	B
Red-Breasted Merganser	<i>Mergus serrator</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Redhead	<i>Aythya americana</i>	LC	II	-	-	N	Y	N	N	N	Lake	M
Red-Necked Grebe	<i>Podiceps grisegena</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Ring-Billed Gull	<i>Larus delawarensis</i>	LC	-	-	-	N	N	Y	N	Y	Shoreline	R
Ring-Necked Duck	<i>Aythya collaris</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Ruddy Duck	<i>Oxyura jamaicensis</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Ruddy Turnstone	<i>Arenaria interpres</i>	LC	-	-	-	Y	N	N	N	N	Shoreline	B
Sanderling	<i>Calidris alba</i>	LC	-	-	-	N	N	Y	N	N	Shoreline	M
Sandhill Crane	<i>Grus canadensis</i>	LC	I, II	E	-	Y	N	N	N	N	Marshes	B
Semipalmated Plover	<i>Calidris pusilla</i>	LC	-	-	-	N	N	Y	N	N	Shoreline	M
Snow Goose	<i>Chen caerulescens</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Solitary Sandpiper	<i>Tringa solitaria</i>	LC	-	-	-	N	N	Y	N	N	Shoreline	M
Sora	<i>Porzana carolina</i>	LC	-	-	-	Y	N	N	N	N	Marshes	B

# INDEPENDENT RISK ANALYSIS – PROJECT ID#1801011

Name		Conservation Status					Characteristics					
Common	Species	IUCN	CITES	US	MI	Waders	Waterfowl	Shorebirds	Raptors	Colonial	Habitat	Migratory
Spotted Sandpiper	<i>Actitis macularia</i>	LC	-	-	-	N	N	Y	N	N	Shoreline	B
Surf Scoter	<i>Melanitta perspicillata</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Tundra Swan	<i>Olor columbianus</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Virginia Rail	<i>Rallus limicola</i>	LC	-	-	-	Y	N	N	N	N	Marshes	B
White Pelican	<i>Pelecanus erythrorhynchos</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
White-Winged Scoter	<i>Melanitta deglandi</i>	LC	-	-	-	N	Y	N	N	N	Lake	M
Wilson's Snipe	<i>Capella gallinago</i>	LC	-	-	-	N	Y	N	N	N	Marshes	B
Wood Duck	<i>Aix sponsa</i>	LC	-	-	-	N	Y	N	N	N	Lake	B
Yellow Rail	<i>Coturnicops noveboracensis</i>	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 birds 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 are 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.

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 cumulative monthly counts of 5000+ individuals during peak months 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 frequently found 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.

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). Other important colonial nesting species use areas associated with Mackinac Straits and include Common Tern, Herons and Gulls (see Table E7).

#### Timing of Waterbird Migration

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 piping plover arrives 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 sensitive resources, but they are generally scattered throughout their range with only a few individuals in each location (NOAA, 1994). These species are considered of cultural importance to Native Americans and have economic importance to Michigan because they are harvested for fur.

MNFI's Biotics 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 associate 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 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 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 will 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 Most Vulnerable to Oil Exposure Post Line 5 Pipeline Rupture Given Their Use of Littoral and Coastal Habitats for Foraging, Breeding, and Brooding in the Mackinac Straits

Name		Conservation Status				Habitat				Importance	
Common	Species	IUCN	CITES	US	MI	Forage	Breeding	Brooding	Season	Keystone	Economic
North American Beaver	<i>Castor canadensis</i>	LC	-	-	-	Littoral	Littoral	Littoral	W; Sp	Ecosystem engineers	X
North American River Otter	<i>Lontra canadensis</i>	LC	II	-	-	Littoral	Both	Both	W; Sp	Predators of fish & invertebrates	X
American Mink	<i>Neovison vison</i>	LC	-	-	-	Littoral	Littoral	Littoral	W; Sp	Predators of small mammals	X
Muskrat	<i>Ondatra zibethicus</i>	LC	-	-	-	Littoral	Coastal	Both	W; Sp	Prey of larger predators	X
Raccoon	<i>Procyon lotor</i>	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 ecosystem health because they are unpredictable in time and space, difficult to fully remediate, and pose long-term risks to aquatic and terrestrial habitats and species. As such, oil spills represent acute and chronic risks including widespread animal mortalities, losses of natural communities and their 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 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. Estimates between 324 km (210 miles) (10-day scenario) and 888 km (552 miles) (60-day scenario) of shoreline is at risk in Lake Michigan, and between 449 km (279 miles) (10-day scenario) and 1,075 km (668 miles) (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. Distribution along shoreline areas would also place > 50,000 acres of natural communities including Great Lakes Marsh, Open Dunes and Wooded Dune and Swale Complex areas at greatest risk. Toxicity from short- and long-term exposure to oil can induce physiological responses (see Table E10 for a summary). Also, 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 consequences for species fitness, and population recovery and persistence.

Using NOAA's established thresholds based on oil values ( $\text{g/m}^2$ ), 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 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 E3). Thus adverse impacts to nearshore and shoreline habitats and associated species are predicted following a rupture in Line 5.

Table E10. Physiological and Ecological Effects Summary of Petroleum or Individual PAHs on Organisms (see Albers, 2003)

Effect <sup>a</sup>	Plant or		Reptile or				
	Microbe	Invertebrate	Fish	Amphibian	Bird	Mammal <sup>b</sup>	Benthos
<b>Individual Organisms</b>							
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				
<b>Groups of Organisms<sup>c</sup></b>							
Local population change	x	x	x		x	x	x
Altered Community Structure	x	x	x		x	x	x
Biomass Change	x	x	x				x

<sup>a</sup>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

<sup>b</sup>Includes a sampling of literature involving laboratory and domestic animals

<sup>c</sup>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 the State of Michigan and include shorelines in Wisconsin and Ontario. While these areas may be outside Michigan, our evaluation sought to account for regional 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. Risk of exposure is particularly relevant during the bird nesting and fish spawning seasons, as large amounts of oil are expected across these areas. It is, therefore, possible that the extent of risk on natural resources could be reduced given cleanup activities and time of year of an event.

Secondary resource impacts caused by response efforts such as vegetation removal, wetland disturbance, increased boat and pedestrian traffic, disturbance or destruction of habitat, or potential introduction of invasive species following a rupture in Line 5 may initially increase risk to natural resources. These secondary resource impacts and measure for restoration proposed by Task F were not evaluated as part of our assessment, as our considerations of worst-case scenario include the greatest extent of risk and response activities require consultation with state and federal authorities prior to implementation. However, given the ecological, cultural and economic value of natural resources in the Mackinac Straits and associated areas, these secondary impacts will need to be considered in response efforts.

### **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 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 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 qualitative than quantitative. A total of 47 state- and federally-listed species of conservation status were 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 critical habitat for insects, fish, waterfowl, waterbirds, and mammals. They serve as feeding areas for migrating and nesting shorebirds including Piping Plover and Tern species. 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. Shoreline and wetland amphibians, reptiles, and mammals 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.

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# 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 (NRDA) under the Oil Pollution Act (OPA) is a legal process that requires an evaluation of injuries to natural and cultural resources and their services and determination of the type and extent of restoration needed to address the injuries. Several coordinated steps are used to identify the actions needed to restore injured resources and compensate for lost services. NRDA is performed by a council of trustees who are representatives from agencies that act on behalf of the public. These trustees could be members of federal, state, local, and tribal agencies that have jurisdiction over the injured resources. The OPA charges trustee agencies to identify and implement actions appropriate to restore, replace or acquire the equivalent resources to those injured by the oil spill in order to return those resources to their baseline condition. The NRDA process steps include preassessment, injury assessment, and restoration. During the preassessment phase the goal is to determine what happened and whether there is a need for a full assessment. In the injury assessment phase the harm done by the spill is assessed relative to baseline. Finally, in the restoration phase compensation is made for the injured resources. 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. Moreover, they assume that the baseline has been established. Experience with previous 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 the determination of environmental changes following an oil spill is a complex problem and, furthermore, 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, some scientists believe that the herring, some pods of killer whales, and the pigeon guillemot still have not recovered (Esler, Ballachey, Cushing, Kaler, Bodkin, Monson, Esslinger, & Kloecker, 2018). 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 restoration needed in the event that the worst-case spill from Enbridge's Line 5 in the Straits of Mackinac occurs. Primary restoration would address direct damage of the resources and attempts to restore those resources to baseline. Determining compensatory restoration requires analysis of the services lost due to a spill and may be quite specific to the particular spill scenario and the habitat and organisms impacted by the spill. However, after these specific conditions are known, it may be possible to estimate the return to baseline conditions using equivalency analysis. Equivalency analysis includes both habitat equivalency and resource equivalency (Desvousges, Gard, Michael, & Chance, 2018). In both analyses the goal is to use the amount of habitat or ecological resources lost to scale for the extent of damage and the time to recover those lost habitats and resources. This process allows for determination of the amount of compensatory services needed to account for the services lost and can direct compensatory restoration efforts.

Certainly, cultural resources such as maritime archaeological sites or culturally-sacred sites, once damaged by an oil spill, can be lost in perpetuity; similarly, it is possible that an oil spill may alter 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). 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 also examines costs of restoration, including assessment, cleanup, efforts to restore and monitoring of restoration for cultural and natural resources. We will discuss examples of injuries to resources that may require both primary and compensatory restoration. 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, even though 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 such as 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; threatened and endangered plants or animals, archaeological sites, significant objects, artifacts, documents, and historically important sites, such as battlefields, cemeteries, and shipwrecks. Whereas intangible things like cyclical natural events (culturally-significant weather patterns and related cultural practices), subsistence practices, stories, songs, and dances; social practices, including rituals and religious practices; all have cultural significance.

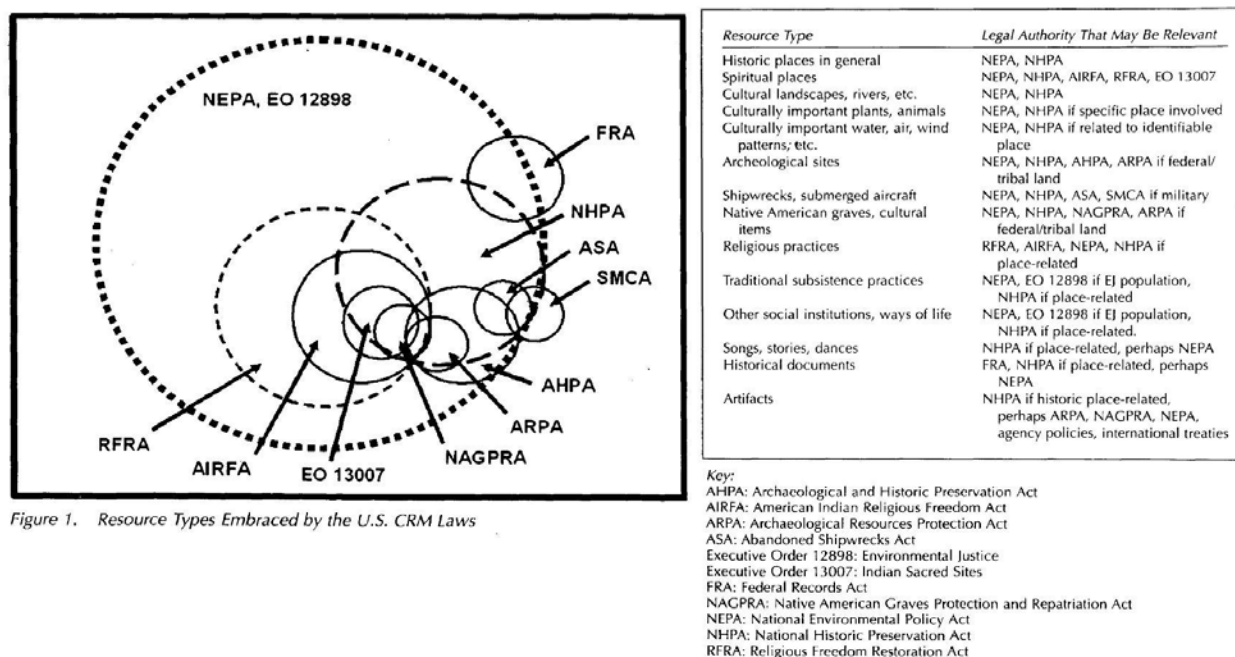


Figure 1. Resource Types Embraced by the U.S. CRM Laws

Figure F1. Articulating Federal 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, policies, and regulatory frameworks 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 are only the major laws and regulations. Many other laws establish critical rules about specific elements of cultural resources (Figure F1).

The Canadian federal government began to create similar laws and regulations 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 regulatory 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 administrators could assess the impacts of government actions 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 may follow cleanup (Task C) or occur simultaneously as many of the primary restoration approaches may be part of the cleanup operation. The boundary between cleanup and primary restoration is mainly legal and the parties responsible for the actions. Cleanup is conducted under the response authorities and restoration is conducted under the NRDA authorities and lead by the trustees. In the case of the Enbridge Line 6B oil discharge near Marshall, MI, the spill occurred in July 2010. 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 the case of the Line 6B spill, cleanup operations and primary restoration were concurrent, but directed by different authorities (response versus NRDA). Industry expectations are that the immediate cleanup of oil spills in open water may collect only about 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 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. In the example of Enbridge Line 6b spill near Marshall, MI again, the initial containment and cleanup effort moved ahead without fully 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 response team undertook emergency containment efforts and initiated subsequent cleanup operations 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.). 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 than it was for the Marshall spill.

### **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 restoration, based on an analysis of costs incurred from previous oil spills. For the Straits, these costs are by necessity estimates because no comparable oil spill has ever occurred in the Great Lakes. These cost figures do not include the provision or development of alternative drinking water sources, or the restoration of cultural resources. Furthermore, the ultimate costs even for 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 an 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 the quality of open water. Task F, therefore, adopted the four worst-case scenarios from Task E, selected as those that gave the largest amount of oiled shoreline for each of the two lakes, Michigan and Huron, at two time-frames, 10 and 60 days after a spill (Table F3). A spill from Line 5 would threaten additional resources, not included in Task E, such as cultural heritage sites or community water sources. An analysis of the costs associated with the restoration of these resources is not provided here because there is insufficient published documentation on those costs from other oil spills. Furthermore, cultural resources, and their values, are necessarily specific to their locales. This omission does not mean that these resources are any less important than shoreline habitat, but rather the lack of data precludes the itemization of their costs for restoration.

Complete restoration for all cultural and natural resources may not be possible. For example, archaeological sites are non-restorable resources, 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.

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 documented 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 Line 5 spill would be more similar to that 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 as that with the Deepwater Horizon. However, the freshwater environment of Michigan is more comparable to that of the Enbridge Line 6B. Thus, the impacted habitats are more similar to those near Enbridge Line 6B than in the Deepwater Horizon marine environment. Hydrodynamic modeling of a spill in the Straits predicts significant impacts on freshwater coarse-grained shorelines, an environment not substantially impacted in either the Deepwater Horizon or the Line 6B spills.

#### **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, such 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). Substantial injury may 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, 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 not to do more damage, the chance exists that cleanup efforts could also lead to damage to the system.

Table F1. Oil Spill Comparison

<b>Oil Spill</b>	<b>Deepwater Horizon (04/20/2010)</b>	<b>Enbridge Line 6B (07/25/ 2010)</b>	<b>Enbridge Line 5 (hypothetical)</b>
<b>Type of oil</b>	Sweet, light, most abundant compounds greater than C <sub>1</sub> -C <sub>5</sub> were BTEX compounds (Reddy et al., 2011)	Diluted bitumen (density = 0.92 g/cm <sup>3</sup> ) (DEQ, 2016)	Sweet, light
<b>Depth of release</b>	1,522 m	Below grade	≤ 90 m
<b>Estimated amount of release</b>	780,000 m <sup>3</sup>	3190 m <sup>3</sup>	9221 m <sup>3</sup>
<b>Location of spill</b>	Gulf of Mexico, 66 km from southeast coast of Louisiana	Marshall, MI	Straits of Mackinac, MI
<b>Amount of shoreline oiled</b>	2,113 km (Nixon et al., 2016)	126 km (39 miles of the Kalamazoo River)	Variable based on spill scenario (Task B)
<b>Types of shoreline impacted</b>	Beaches (50.8%), Marshes (44.9%) Other (4.3%) (Michel et al., 2013)	Primarily wetland and wooded floodplain, emergent marshes, and rare fen	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.3.1.1.2 Approach for Restoration*

Several 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.

#### Physical Removal of Contaminated Material:

*Description of Approach:* Clean up and restoration both include 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 unacceptable damage to the system (Michel and Rutherford, 2014). Manual clean up on a limited scale could address the extent of oiling in these habitats. In addition to manual clean up, monitoring of natural recovery may be an acceptable strategy for restoration as natural processes may restore systems to baseline, depending on the extent of injury.

*Limitations:* Sediment removal can have an adverse impact on environmental conditions in some habitat types. Wetlands are particularly sensitive to injury from sediment removal, thus this method must be employed selectively in those environments.

Bioremediation:

*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 cause more harm than good to the habitat. Monitored natural attenuation could be a pathway for removal of residual oil. 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). Multiple species of microbes are capable of breaking down oil and detoxifying it to carbon dioxide (CO<sub>2</sub>) (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 break down 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. 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, microbial biodegradation of oil can sometimes occur rapidly even under cold conditions (McFarlin, Prince, Perkins, & Leigh, 2014).

Plantings:

*Description of Approach:* During initial clean-up efforts, response workers may remove oiled plants. This vegetation is essential to providing habitat and protection for many of the organisms that live in wetlands (Uzarski, Burton, Cooper, Ingram, & Timmermans, 2005). Plants also control erosion and thus, the level of suspended solids. Therefore, restoration of an injured wetland ecosystem includes the (re)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

Final Report – September 2018

cases where the root systems are still intact and not damaged by oil, it may be possible to cut down only the above-ground vegetation. Both new plantings and pruned plants would need to be monitored to ensure success. 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). 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, restoration efforts targeted removal of invasive 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.).

*Limitations:* Although rapid wetland restoration would be desirable, new vegetation can only be planted during the warmer months. Furthermore, the plantings need to be planned to ensure that native species are used to help restore the wetlands to the conditions prior to the spill. Additionally, care must be taken when employing plantings to not introduce non-native invasive species to preserve the wetland habitat.

#### *F.3.1.1.3 Monitoring*

Key aspects of the wetland will be monitored to evaluate the effectiveness of these strategies, including habitat structure, the progress of vegetation, and use by animals. These will provide a basis for evaluating the success of these restoration projects. The adaptive monitoring approach for restoration was successfully employed in the Gulf of Mexico during the Deepwater Horizon restoration (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016). A similar approach may be applicable in a potential spill in the Straits of Mackinac.

### **F.3.1.2 Intertidal Shoreline and Uplands**

#### *F.3.1.2.1 Description of Injury*

Various 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 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*

##### Replacement of contaminated substrate:

*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

Final Report – September 2018

utilized due to the potential for the heavy machinery to cause additional 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 the material is commonly brought in to supplement lost sand, for example, during winter storms.

#### Bioremediation:

*Description of Approach:* Bioremediation may be an appropriate approach to remove residual oil in locations that have been cleaned either using manual or mechanical means. 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 appropriate to break down the oil. Additionally, it is possible that environmental factors, such as temperature, may limit the microbial community's ability to break down oil.

#### 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). Replacing this vegetation will be essential if any is lost or injured during the spill or cleanup. Similar to the plantings for wetlands, these might be part of the early restoration efforts to mitigate some of the 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:* Planting can only be done in warmer seasons.

#### *F.3.1.2.3 Monitoring*

A similar set of parameters used in monitoring the success of restoration approaches for wetlands could be employed to monitor intertidal and upland settings impacted by the spill. Monitoring would document recovery of habitat structure, vegetation return, and use of the area by animals, including birds and terrestrial wildlife that take advantage of the upland environments.

### 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 oil will cover up to 346 km<sup>2</sup> of water surface. 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. Containment

Final Report – September 2018

and recovery efforts can capture a portion of the oil on the water surface (Task C). 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 5,600 µg/L and 51,000 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, some of these compounds may sorb 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 need to be implemented, and bottled water provided until appropriate treatment, or alternative water supplies could be developed.



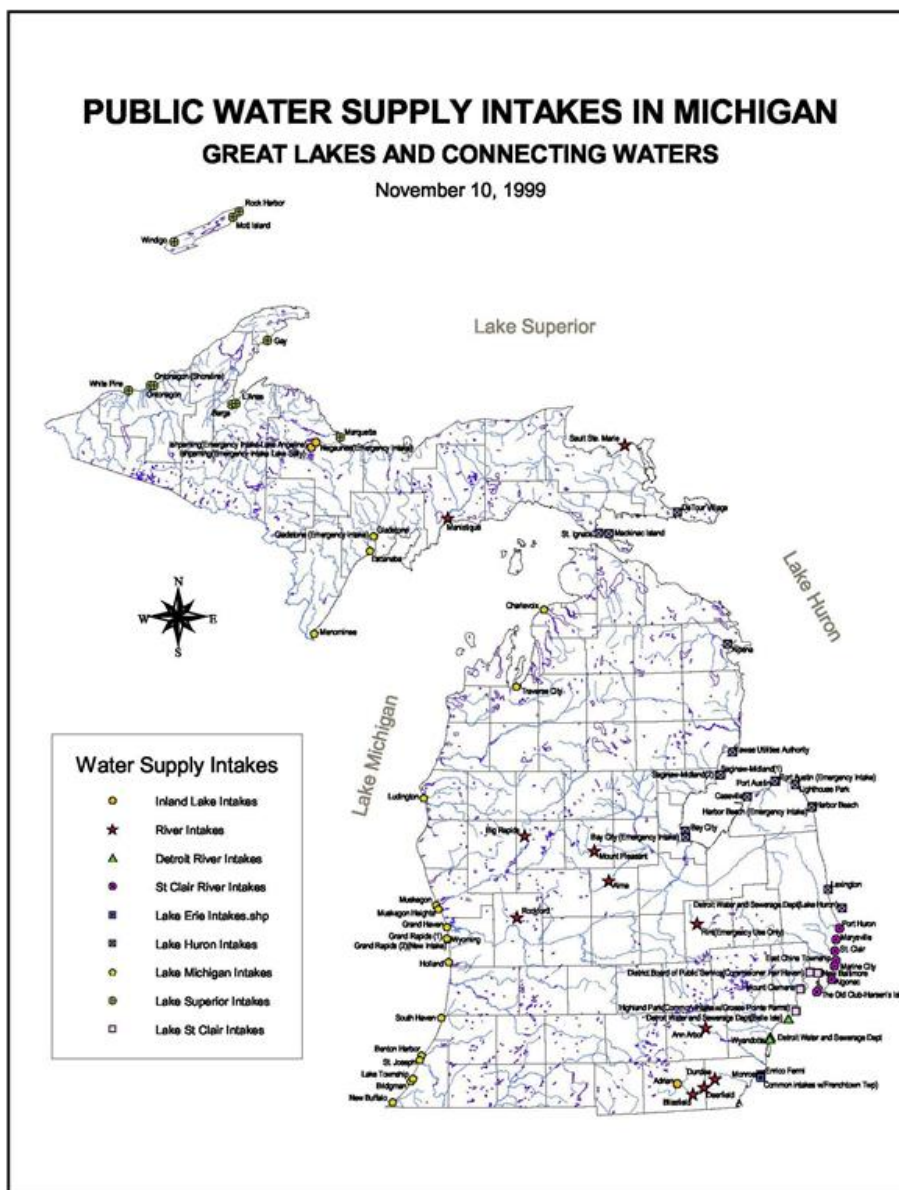


Figure F2. Public Water Supply Intakes in Michigan

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. However, the timeframe for microbial degradation may vary considerably. Wick et al.

Final Report – September 2018

(2000) observed that benzene might be degraded at the oxic-anoxic interface in a lake, with pseudo-first-order rate constant between 1 and 2.5 day<sup>-1</sup>; however, in the hypolimnion, the rate constant was  $\leq 0.04$  day<sup>-1</sup>.

PAH contamination may warrant a more active approach. PAHs can move from the sediments into the lake water. Therefore, one approach for remediation is to remove oil-contaminated sediments by dredging for disposal at an approved location on land. The type of dredge would depend on the depth of the water, 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 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). Studies have shown that treatment using ozonation and sand filtration may be effective as pretreatment steps before the drinking water treatment process (Hong and Xiao, 2013). Alternatively, regulated compounds may be removed as part of the drinking water treatment process. To remove benzene, the EPA has approved granular activated carbon in combination with packed tower aeration. To remove benzo(a)pyrene, the EPA has approved granular activated carbon. Alternatively, new water supplies could be developed. Following the July 2016 spill of oil into the North Saskatchewan River near Maidstone, Saskatchewan, authorities trucked in bottled water, followed by the installation of a temporary pipeline stretching 30 kilometers to draw water from the South Saskatchewan River (Canadian Press, 2016; 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 in the case of an oil spill in the Straits.

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).

#### *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 many highly sensitive habitats as defined by NOAA's environmental sensitivity index. Included in these are 13 unique 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. There are also 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. These critical and sensitive habitats must be targets for protection during the containment and cleanup response, to immediately protect them from oil. In some systems, beached oil can persist for many years. For example, oil has persisted for nearly 30 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 within cobbled beaches. The best way to preserve these habitats is to prevent oil intrusion. If these habitats are oiled, restoration approach could involve three approaches, natural attenuation, manual removal, and/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 time. Manual removal would employ 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 requires great care. Monitoring of restoration of these sensitive habitats must include monitoring the rate of oil removal through either natural attenuation or bioremediation. Monitoring of bioremediation as a restoration approach requires examining the concentration of 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 mammals.

### **F.3.2 Organisms**

#### **F.3.2.1 Aquatic Vegetation**

##### *F.3.2.1.1 Description of Injury*

A spill can have direct and indirect impacts on submerged aquatic vegetation (SAV) and floating aquatic vegetation. Oiling could directly impact vegetation. Cleanup operations may cause additional damage to vegetation. SAV serves 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 limiting 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). Direct contact with an oil slick would be deleterious to floating aquatic vegetation.

##### *F.3.2.1.2 Approach for Restoration*

Backfilling scars: 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 would 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 and other restoration efforts.

Plantings: Plantings will help to restore plant beds to a robust state. 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, various methods exist such as the use of tubes to core the plant and carry

the plant along with the accompanying sediment containing the microbes found in the rhizosphere of these plants.

Enhancement of vegetation beds through nutrient addition: Establishment and growth of aquatic vegetation require nutrients. Nutrient addition at the site of the vegetation beds encourages growth and establishment of the aquatic vegetation. Fertilizer stakes can provide nutrient addition in the vegetation beds, followed by monitoring of available nutrients to ensure sufficient nutrients in the water for plant growth, but not excess nutrients.

Protection of existing vegetation beds through signage: Uninjured, injured, and restored vegetation beds must be protected 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 been 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 to establish but can be initiated in the first growing season post-spill and continued until establishment. Scars must be backfilled 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. Nutrient amendments would be monitored to ensure the level of nutrients present is sufficient to stimulate plant growth while remaining below unhealthy excesses.

### **F.3.2.2 Macroenthos**

#### *F.3.2.2.1 Description of Injury*

The injury assessment is based on restoring ecosystem services. Macroenthos are an essential element in the food chain and building blocks of the ecosystem. The species distribution and abundance can serve as a surrogate to determine water quality and ecosystem health. Task E provides a list of species typically encountered in the Straits area. 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 macroenthos species, any oil in the water or on their body would result in the death of the animal. Macroenthos 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, and protection of existing habitats through signage. Submerged aquatic vegetation restoration is another key 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. Monitoring efforts would target only certain species (but representative of the whole ecosystem).

##### Bioremediation

As described in the previous sections, natural attenuation will be necessary to account for total oil removal.

#### *F.3.2.2.3 Monitoring*

Monitoring would take advantage of a new framework for ecological data in the Great Lakes, the Great Lakes Aquatic Habitat Framework (GLAHF). GLAHF has developed a database specifically to document benthic organisms. The following indices are used: "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). A 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 methods described above to restore the nearshore zone and coastal wetlands can enhance restoration of mussels, clams, and snails. Enhancing and restoring submerged aquatic vegetation is equally essential to help these species recover after a spill. Substrate will also 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 are in the Straits region as well as a few species of conservation concern as described by Task E.

#### *F.3.2.4.2 Approach for Restoration*

Restoration of the nearshore zone and coastal wetlands will follow 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 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 are 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 artedii*), 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 are identified as 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.

Restore or protect habitats on which fish rely for spawning and foraging activities.



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.

Restore lost fish by facilitating additional reproduction and/or reduce mortality of injured species.

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 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 encompass a broad region rather than 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 critical to note that baseline conditions in the Great Lakes have been changing as invasive species and other stressors have

Final Report – September 2018

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*), waterbirds including Common Loons and Grebes, and waterfowl many of which have both high ecological value and also economic value as 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. 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 waterfowl 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 taxon 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.

Restore or protect habitats on which birds rely for nesting, foraging and staging activities.

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 nesting shorebirds including Common Terns and Piping Plovers. Through this approach nesting areas will be 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 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 estimation of bird species presence and abundance will occur at restored habitats in order to monitor the population and distribution of species. There are 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>), , 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>). Additionally, Michigan Feature Inventory (<https://mnfi.anr.msu.edu/data/specialanimals.cfm>) can be used to report on presence or absence of bird species. 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, few species 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 significant numbers at any location and are widely scattered throughout their range (NOAA, 1994). These species are

considered of cultural importance to Native Americans and have economic importance to Michigan because 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.

#### Restore or protect habitats nesting and foraging habitats.

The five mammal species at risk of oil spills, use coastal habitats for breeding and brooding their young. These mammal populations are mobile and can breed and forage in areas unaffected by oil. However, their economic importance to tribal and commercial trappers warrants restoration efforts to restore and maintain populations. Restoration of coastal wetlands will follow 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 and estimation of terrestrial mammal presence and abundance will occur at restored habitats in order to monitor the population and distribution of species.

Monitoring mammal populations in Michigan are challenging as the issuance of a fur bearer license does not provide accurate information for monitoring mammal populations in any specific area. River Otter, is the one exception, in that mandatory registration is required for collection and data regarding distribution may be available. Additionally, MIDNR has a trapper harvest survey which may provide some information about species distribution. These 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 social practices. These resources are protected by and/or managed using a patchwork of legal and regulatory instruments at multiple scales, from international compacts to municipal regulations. The laws and regulations generally recognize the interdependence of natural and cultural systems. Because the State of Michigan commissioned this study, we largely use United States laws and regulations to structure our discussion. As an example, in a disaster response, an incident commander must choose appropriate actions to protect or restore cultural resources in relation to their eligibility for listing on the National Register of Historic Places, which is a requirement under NHPA. Through consultation with SHPO, THPO, and/or Federal Preservation Officers, determinations of eligibility guide appropriate action for each resource

type in different impacted areas. Since a worst-case spill could also include Canadian shoreline, response planning will differ in those locations.

While this discussion broadly refers to communities and stakeholder groups, we note that Native American and First Nations, Métis, and Inuit (FNMI) communities sometimes have enhanced authority in consultations about cultural resources. Regulators and resource managers often consider tribal communities to be “vulnerable risk bearers” and/or “environmental justice communities,” designations that give them additional authority during consultation. Tribes are often sovereign governments with treaty rights and rights established by national and international laws. For these reasons, the authors often highlighted tribal/FNMI interests in this Task; the Broader Impacts section (Task X) also includes a detailed discussion of these issues.

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. The discussion below is necessarily incomplete because this study can only consider the cultural resources that are known to exist within the Straits of Mackinac and Lower Michigan’s northwestern and northeastern coasts. A more accurate prediction of the frequency of use and significance of cultural resources would require development of 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. 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 oiled wetlands or beaches quickly.

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.

Land owners and resource managers make decisions about archaeological sites pursuant to HNSA, NEPA, and other statutes, as well as regulations and policies promulgated thereunder. 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, USFWS, 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.

### Known Archaeological Sites by Type, on Beaches in Straits Area/Lake Huron. Michigan State Historic Preservation Office

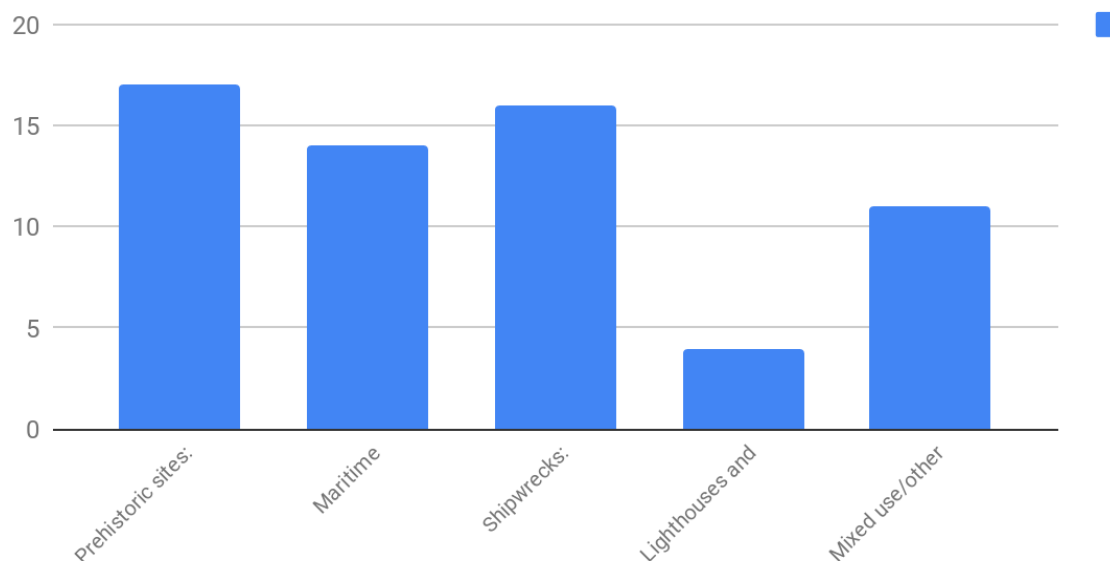


Figure F3. Known Archaeological Sites on or Near Michigan Beaches in the Straits of Mackinac and Lake Huron Shores

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. For sites that could confidently be placed on a beach, coastal wetland, or in the nearshore shallows, we

Final Report – September 2018

sorted them into categories on Table F.2, including prehistoric occupations (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 private landowners hold the vast majority of waterfront property, 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 small number of known sites 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). Since the data in the site files was not collected for that purpose, there is no reason to believe that anyone could use the Michigan SHPO site files to *accurately* estimate the total number of sites that would likely suffer damage per kilometer of beach shoreline in Ontario, Wisconsin, and/or western or northern 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 hydrocarbon contamination would influence radiocarbon dating (Reger et al., 1992). This study was of very limited scope and scale and cannot be widely extrapolated 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. When damage cannot be avoided, archaeologists mitigate these losses through the recovery of remaining scientific and historical data.
- 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 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 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 Lakes Michigan or Huron 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). Several potential damages will effect shipwrecks following an oil spill. Hydrocarbons or other chemicals may directly contaminate a wreck, the sediments in which a water or aircraft is embedded, and might change or disturb the adhering/surrounding microbiome. Wrecks may be physically damaged by anchor drags from responding vessels during oil containment and/or recovery or by subsequent dredge activity (including destabilizing sediments within or around the vessel or changing sedimentation patterns). Vessels may also be damaged



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 (NMS). Thunder Bay NMS knows the accurate location of just under 100 of those wrecks. Hundreds of 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 describe southern Lake Michigan as including “the largest and best-preserved group of U.S. Navy, sunken, historical, 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. The rapidity of these events 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. The evidence of design and change 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 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 blanketed 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

Final Report – September 2018

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 the international admiralty court, including the Law of Salvage and Finds. The United States now regulates underwater heritage according to the Abandoned Shipwreck Act (ASA) 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 states and territories took control of wrecks in their coastal bottomlands. In Michigan, state officials manage wrecks following 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*

A worst-case spill may impact historic buildings, monuments, or landscapes. 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 can possess a significant concentration, linkage, or continuity of land use in space and SHPO or other managers will consider them eligible for the National Register of Historical Places 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 building's 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 the high-water mark or in wetlands, but maritime engineering features are common. The high proportion of docks and piers and such features in the archaeological site inventory illustrate this fact. 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 but located where waves and spray from rough surf may damage them. 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. (This report includes archaeological resources surrounding structures such as lighthouses 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* apply 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, its 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.

Final Report – September 2018

- 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 responders must select these techniques appropriate for each unique situation of a particular spill (Chin, 2010). When possible and appropriate, a professional conservator should guide actions at significant properties or sites and landscapes that are potentially eligible for listing on the National Register of Historic Places.
- 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 stated under NEPA, NHPA, and NAGPRA, among other laws and regulations, 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. 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 could include 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 broader 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 Traditional Cultural Property 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, except the Spider Cave Site and the Burnt Bluffs (Cleland & Peske, 1968; Lemaitre & Decart, 2008). While people painted images on bluffs or ledges above the high-water mark, spray and/or vapor condensation still damage the artwork. In BTEX, both benzene and toluene are 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 restoration following an oil spill is a difficult task, as many factors 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 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 escaped 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.

Final Report – September 2018



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 difficult 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 restoration of the shoreline only. They do not include costs of 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 restoration were approximately \$8.8 billion. A total of 2113 km of shoreline was oiled (Nixon et al., 2016). Therefore, a realistic cost for restoration of shoreline from the Deepwater Horizon is \$4.16 million/km (\$6.70 million/mile). 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 is evident 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 the 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 121.6 km. The costs from the consent decree for 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). The remaining \$58,000,000 was

part of the state settlement for natural resource damages (U.S. Fish and Wildlife, 2015). These costs were mainly for compensatory restoration projects as much of the primary restoration for the Marshall spill occurred during the cleanup phase. Therefore, primary restoration was associated with cleanup costs. Using the \$62 million number, the cost per km of shoreline oiled was estimated to be \$510,000/km (\$820K/mile). 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. The lower cost estimates from the Marshall MI spill are in part due to the types of shoreline impacted, but also because they were mainly for compensatory restoration and did not include the costs for primary restoration. As such, the cost estimates from the Marshall MI spill and the Deepwater Horizon spill provide brackets for the amounts to restore these four different spill scenarios.

It is also essential to note that the hydrodynamic scenarios used for estimating restoration costs do not account for reduced impacts if the containment, recovery, and cleanup operations successfully reduce the volume of oil dispersed and the extent of shoreline impacted. While the 60-day scenarios represent absolute worst-case scenarios, if initial mitigation is effective, the length of oiled shoreline is more likely to correspond to the 10-day scenarios. Therefore, our estimates for primary ecological restoration range from \$165,300,000 to \$1,949,400,000.

To calculate the total costs of a specific scenario across all tasks, it is 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 (619 miles), corresponding to cost estimates for restoration of \$508,000,000 (Marshall cost basis) to \$4,148,000,000 (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. This value falls roughly midway along our \$165,300,000 to \$1,949,400,000 range of estimates, making it useful where a single value is more useful than a range.

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

<b>Primary lake impacted</b>	<b>Days after spill</b>	<b>Total Shoreline oiled (km)</b>	<b>Cost Basis Marshall, MI</b>	<b>Cost Basis Deepwater Horizon</b>
Huron	10	449	\$228,900,000	\$1,869,190,000
Michigan	10	324	\$165,300,000	\$1,949,400,000
Huron	60	1075	\$548,100,000	\$4,477,000,000
Michigan	60	888	\$452,800,000	\$3,698,200,000

## F.4 Discussion

No oil spills of the predicted magnitude have occurred in freshwater environments similar to the Great Lakes, providing a challenge to determining the value of 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 restoration in the event of a rupture in Enbridge Line 5 in the Straits of Mackinac could reach more than \$4.4 billion for the oil spill scenario involving impacts to 1075 km (668 miles) 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, contain abundant 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 cost estimate for ecological restoration is realistic, given the richness and diversity of the areas at risk, but are necessarily uncertain because ultimate costs are very sensitive to the specific location, scale, and scope of an oil spill near the Straits of Mackinac.

Cleanup activities immediately following a rupture in Line 5 may reduce the risk to open water, natural and cultural resources, and would thereby reduce the cost of restoration activities. However, the impact of cleanup measures proposed in Section C was not included; thus, our consideration of worst-case scenario included a greater extent of risk than might ultimately be realized in the case of a timely deployment of clean-up activities. It is also important to note that the valuation and costs determined in this Section account for all shorelines oiled 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. If circumstances allowed for effective mitigation the

extent of oiled shoreline would be more similar to the 10-day scenarios predicted by Task E. Consequently, the upper cost estimate is \$1.9 billion for restoration for a scenario in which containment and recovery operations are successful.

The focus of this section was the restoration to baseline conditions of the natural resources that might be impacted by an oil spill. The information provided here is a summary of strategies that have been applied in ecological restoration following oil spills. The specific strategies to be used would need to be determined as part of the NRDA/DARP process, following an assessment of the injuries and in consultation with all stakeholders. An underlying assumption is that baseline conditions are known. Task E provides information regarding the current status of possibly impacted natural resources. As part of a strategy of preparing for a spill, it would behoove the pertinent authorities to determine what parameters should be monitored and to gather data now that would support the establishment of a baseline.

Our focus was providing a cost for the restoration of shoreline areas; however, additional strategies may be useful in mitigating population losses, such as fishery closures, artificial reef creation and dam removal. According to federal law, the damage to natural resources and ecosystems from oil spills must be assessed, monitored and restored, and the losses incurred between the incident and restoration must be compensated for. The stakeholder governmental agencies use six criteria to focus and maximize the value of restoration efforts toward the recovery of natural resource injuries and service losses, 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, compensatory restoration projects that reflect the geographic area affected by a spill and 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 restoration efforts in past oil spills. There is, therefore, a high likelihood of success of these approaches in the Great Lakes. However, the exact restoration strategies, approaches and timelines are decided upon by the Trustees during the NRDA process. Our analysis suggests that it is essential for habitats to be restored for recovery 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 the Straits of Mackinac, to move toward habitat restoration at early stages of the restoration process. The Straits encompass numerous sensitive habitats which must be adequately protected during the cleanup and spill response phases.

In this section, we have focused on approaches for 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 restoration approaches to be successful, it is essential to have robust baseline data for the resources at risk. Nevertheless, in the case of some resources, it may be very difficult, if not impossible, to bring conditions back to baseline after a spill despite substantial effort.

## F.5 Summary

This section focuses on evaluating restoration techniques and costs for both environmental and cultural resources. Previous oil spills and restoration projects following the Deepwater Horizon and the Line 6B near Marshall, MI, informed the analysis. We reviewed a range of typical techniques for ecological restoration from sediment removal to beach/vegetation cleaning to plantings and 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 \$1,949 million when containment and recovery are taken into account. Cultural resources restoration and litigation costs would increase this estimate.

## F.6 References

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# 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.<sup>1</sup>

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; and
- vi. Loss of tax revenues.<sup>2</sup>

## **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

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<sup>1</sup> 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 activities do not recover immediately after oil is cleaned up because we lack the expertise, data and time to do so – such assessments of non-recreational natural resource damages are time intensive and typically done by ecologists. That said, portions of the damages to habitat and wildlife and restoration are covered by Task E and F.

<sup>2</sup> Loss of tax revenues is covered in Task 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). Another feature of the FLOW report that differs from our report relates to how affected areas are determined. Here we determine affected areas based on the spill simulations based on actual weather events, whereas the FLOW report appears to base spill affected areas on earlier publications of areas with any probability of being oiled (a much larger spatial area than any one spill). An additional significant difference between our report and the flow report is that we base our numbers on economic value measures tied to theoretically desirable concepts of economic value and income changes consistent with economic principles of benefit cost analysis. In many places, such as tourism, the FLOW report measures the effect of spending changes as they ripple through the economy, rather than the lost income due to the spending changes. Given these differences, we would expect the results of our analysis to differ with the FLOW report.

#### 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 that 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 some of the 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.<sup>3</sup> 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 measure such losses appropriately. 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

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<sup>3</sup> A full NRDA under OPA would also assess any compensation to the public required to make up for lost enjoyment of damaged natural resources beyond any affected recreational uses.

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 beach going, 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  $p$  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 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. The shaded area in the right panel of the figure illustrates this decline in value. 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. This distinction between theoretically appropriate measures of economic value and economic measures of spending and total economic activity is relevant for anyone seeking to compare results of tasks G and I to literature on economic spending and economic activities that

might be affected by a spill; these will not be the same because the latter do not measure economic values.

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.

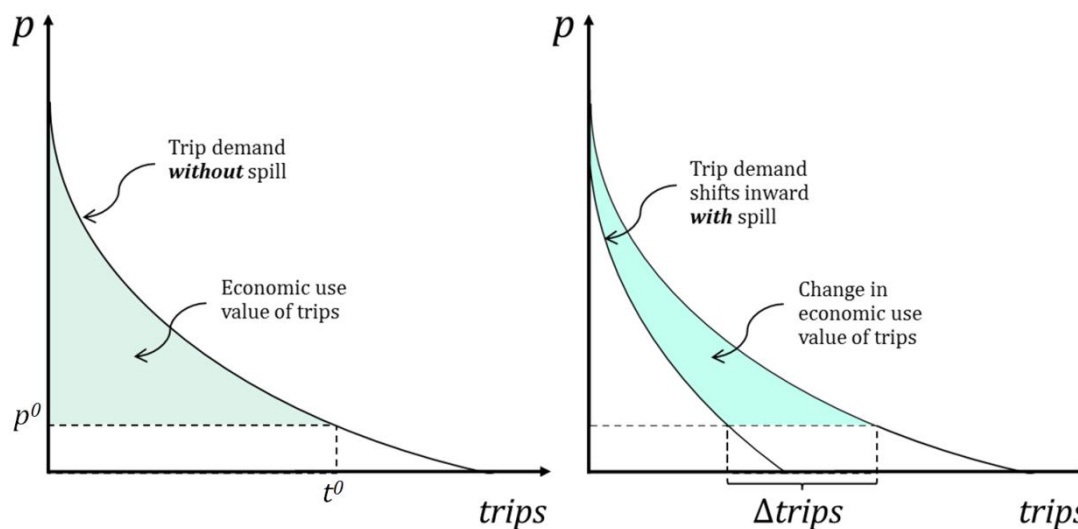


Figure GI1. Conceptual Illustration of Economic Measures Of The Recreation Losses Due To An Oil Spill ( $p$  = trip price)

Table GI1. Broad Summary of Categories of Loss Assessed and 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

Category	Concept	Simplified summary of measurement approach
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 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 <sup>a</sup>	Scenario 2 <sup>b</sup>	Scenario 3 <sup>c</sup>
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
<b>Counties – Total</b>	<b>28</b>	<b>22</b>	<b>10</b>

<sup>a</sup> Derived from center\_mm03\_hr\_1440\_highest1\_2016\_03\_01T18\_0704km.

<sup>b</sup> Derived from south\_mm04\_hr\_1440\_highest1\_2016\_04\_24T18\_0542km.

<sup>c</sup> 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

$$v_l = (v_l^A - v_l^1)b_l \quad (\text{GI-E1})$$

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 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 lost value of a beach on NLH. We calculate the average lost value per beach as the WTP for a closed NLH 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) times 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 NLM 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 <sup>a</sup>	1	2	3
Michigan	\$288.3	\$268.8	\$102.7
Wisconsin	\$110.3	\$87.6	—
<i>Total loss</i>	<i>\$398.6</i>	<i>\$356.4</i>	<i>\$102.7</i>

<sup>a</sup> 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

$$Loss = \Delta t_1 \times WTP + \frac{\Delta t_2 \times WTP}{1+r} \quad (GI-E2)$$

where  $\Delta t$  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 visit parks 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 (the  $r$  in the equation).

We measure WTP using benefit transfer and calculate the change in trips ( $\Delta t$ ) 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

$$\Delta t_1 = -t \times [z_{c1} \mathbf{a}_c \mathbf{B} \mathbf{c} + z_{p1} \mathbf{a}_p \mathbf{B} \mathbf{c}] \quad (GI-E3)$$

$$\Delta t_2 = -t \times [z_{c2} \mathbf{a}_c \mathbf{B} \mathbf{c} + z_{p2} \mathbf{a}_p \mathbf{B} \mathbf{c}] \quad (GI-E4)$$

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 measures 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.<sup>4</sup>

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 approach 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 monthly trip 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 examined a number of other oil spills, which indicate declines in recreation lasting one season. This includes the Ixtoc I oil spill on June 3, 1979, and the Burmah Agate oil spill on November 1, 1979, which decreased tourism activity in Texas in the seasons the spills occurred (Restrepo et al., 1980), and the Amoco Cadiz oil spill on March 16, 1978, which reduced tourism visits by about 11% for one year (Grigalunas et al., 1986). We, therefore, identify  $z$  using the value Tourangeau et al. (2017) reports for recreational boating in the North Gulf, the activity that was impacted in the core DWH oil spill area in the first but not the second season of the spill, and is therefore the scale of impact we expect on park tourism from a spill at the Straits. 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

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<sup>4</sup> Longwoods International (2016) estimates 71 million day trips in Michigan, but these are not specific to outdoor recreation areas.



day per user in 2016 dollars in the U.S. Great Lakes/Northeast region. This WTP value is \$58.73 in 2018 dollars.

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
Reduction in days to periphery in year 2	0	0	0
Value lost per day	58.73	58.73	58.73
<i>Total loss</i>	<i>\$20,335,972</i>	<i>\$18,689,337</i>	<i>\$7,282,605</i>

#### 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 to 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 (GI-E4) above, where now  $\Delta t$  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 (GI-E3) and (GI-E4).

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 camping days occurred at 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.<sup>5</sup> 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 reported in Tourangeau et al. (2017). We identify  $z$  using the value Tourangeau et al. (2017) reports for recreational boating in the North Gulf, the activity that was impacted in the core DWH oil spill area in the first but not the second season of the spill, and is therefore the scale of impact we expect on park tourism from a spill at the Straits. 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 dollars.

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.

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
<i>Total loss</i>	<i>\$2,197,455</i>	<i>\$1,751,760</i>	<i>\$1,042,256</i>

<sup>5</sup> 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>.

#### 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

$$\text{Loss} = (\Delta t_{MI1} + \Delta t_{WI1}) \times \text{WTP} + \frac{(\Delta t_{MI2} + \Delta t_{WI2}) \times \text{WTP}}{1+r} \quad (\text{GI-E5})$$

We develop different models to calculate changes in trips ( $\Delta t$ ) and trip values (WTP). This development is done because we have access to a sample of individual trip data that allows 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 publicly available lake-level trip summaries. We calculate the change in total trips as a function of the location of oiled shoreline in each lake, in terms of a core and periphery. 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

$$\Delta t_{MI1} = -t_{MI} \times [z_{c1} \mathbf{a}_c \mathbf{B} \mathbf{c} + z_{p1} \mathbf{a}_p \mathbf{B} \mathbf{c}] \quad (\text{GI-E6})$$

$$\Delta t_{MI2} = -t_{MI} \times [z_{c2} \mathbf{a}_c \mathbf{B} \mathbf{c} + z_{p2} \mathbf{a}_p \mathbf{B} \mathbf{c}] \quad (\text{GI-E7})$$

where  $t_{MI}$  is the baseline number of fishing trips 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 trips to county  $n$  in month  $m$ ,  $\mathbf{c}$  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 trips by dividing total hours of effort by five. We use the 2015-2017 trip averages, including sport and charter fishing effort in the case of Michigan and sport fishing in Green Bay in the case of Wisconsin.

Tourangeau et al. (2017) report declines in recreational fishing activity after the DWH 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

$$\text{WTP} = (v^A - v^1)f + v^1 \quad (\text{GI-E8})$$

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

$$\begin{aligned} U_{ijt} &= \rho c_{ijt} + \delta_j + \varepsilon_{ijt} \\ &= \omega_{ijt} + \varepsilon_{ijt} \end{aligned} \quad (\text{GI-E9})$$

is the utility function. Utility for angler  $i$  is a function of travel cost  $c_{ijt}$  to alternative  $j$  in year  $t$ , fishing quality  $\delta_j$ , and an error term  $\varepsilon_{ijt}$  that includes idiosyncratic factors that affect the demand for a fishing alternative.  $\omega_{ijt}$  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 reported in Klatt (2014). The average per-trip WTP to access the lost fishing site(s)  $s$  is

$$v_s = \sum_{i=1}^N \frac{\omega_{ijt}}{N} \cdot \frac{N}{N_s} \quad (\text{GI-E10})$$

where  $N_s$  is the number of sample trips taken to the affected sites before the spill. We use the model to calculate WTP 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, which is an upper bound on losses per trip because the model does not include an option to stop taking trips (Haab and McConnell, 2002).

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  $\Delta t$ . 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.

Final Report – September 2018

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
<i>Total loss</i>	<i>\$6,207,993</i>	<i>\$2,001,949</i>	<i>\$401,099</i>

#### 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 non-motorized 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 non-motorized boating days is

$$\text{Loss} = (\Delta t_{MI1} + \Delta t_{WI1}) \times \text{WTP} + \frac{(\Delta t_{MI2} + \Delta t_{WI2}) \times \text{WTP}}{1+r} \quad (\text{GI-E11})$$

where  $\Delta t$  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 ( $\Delta t$ ) 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

$$\Delta t_{MI1} = -t_{MI} \times [z_{c1} \mathbf{a}_c \mathbf{B} \mathbf{c} + z_{p1} \mathbf{a}_p \mathbf{B} \mathbf{c}] \quad (\text{GI-E12a})$$

$$\Delta t_{MI2} = -t_{MI} \times [z_{c2} \mathbf{a}_c \mathbf{B} \mathbf{c} + z_{p2} \mathbf{a}_p \mathbf{B} \mathbf{c}] \quad (\text{GI-E12b})$$

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 non-motorized 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 non-motorized 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 DWH 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 non-motorized 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 dollars.

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  $\Delta t$ . 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 NLH and NLM. 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
Non-motorized 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
<i>Grand total</i>	<i>\$32,543,417</i>	<i>\$16,223,220</i>	<i>\$3,725,396</i>

#### 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 no significant premium across the market as a whole.<sup>6</sup> We therefore, focus on losses to commercial fishers.

We define total loss to commercial fishing as

$$Loss = \sum_i^S \Delta h_{i1} \cdot P_i + \frac{1}{1+r} \sum_i^S \Delta h_{i2} \cdot P_i \quad (GI-E13)$$

where  $\Delta h_i$  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  $P \times (h_{i0} - h_{i1}) = P \times \Delta h_i$ .

We calculate the change in commercial harvest for species  $i$  in year 1 as

$$\Delta h_{i1} = -[z_{c1} \mathbf{a}_c \mathbf{B}_i \mathbf{c} + z_{p1} \mathbf{a}_p \mathbf{B}_i \mathbf{c}] \quad (GI-E14)$$

and in year 2 as

$$\Delta h_{i2} = -[z_{c2} \mathbf{a}_c \mathbf{B}_i \mathbf{c} + z_{p2} \mathbf{a}_p \mathbf{B}_i \mathbf{c}] \quad (GI-E15)$$

where  $\mathbf{a}$  is a  $1 \times 2$  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  $m$ ,  $\mathbf{c}$  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 NLM and NLH: 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.

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<sup>6</sup> 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>.



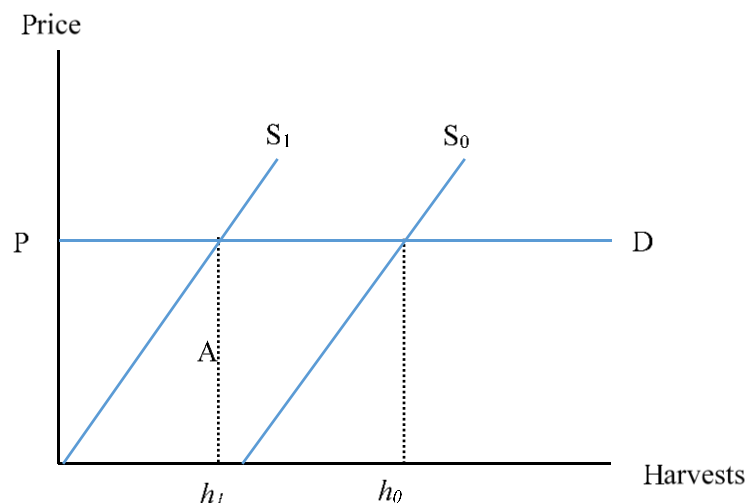


Figure GI2. Economic Effect of a Change in Commercial Fish Landings Due to a Spill

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. This database shows Michigan's Great Lakes fishery had landings valued at \$8 million in 2016, with Lake Michigan and Lake Huron contributing \$1 million and \$4.8 million, respectively. 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 that 90% of the average monthly harvest is lost in the core area in the months after the spill in the first year,  $z_{c1} = 0.9$ , and in the following year,  $z_{c2} = 0.9$ , and that 11% of the average monthly harvest is lost in the periphery,  $z_{p1} = 0.11$ , in the months after the spill in the first year, and that no harvest is lost in the periphery in the second year,  $z_{p2} = 0$ . These losses are based on the reduction in pelagic fish harvests in Louisiana (for the core) and Florida (for the periphery) from 2009 to 2010, after the DWH oil spill (Carroll et al., 2016). Reopening of Gulf areas occurred within four months of the spill (in August), with all areas reopening within one year of the spill; we assume the harvest loss extends into the second year because there is evidence pelagic fishery harvests did not recover

from the DWH oil spill until 2011 (Carroll et al., 2016), though we note that many other fishery types in the Gulf suffered lower losses (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 \$4 million.

Table GI8. Lakes Huron and Michigan Management Units Harvests in the 1836 Treaty-ceded Waters

Species	Harvest in pounds (2014)		Price per pound (2016)
	Lake Michigan	Lake Huron	
Lake whitefish	1,253,780	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. Commercial Fish Harvest Economic Damages for Three Worst-case Spill Scenarios

Scenario	1	2	3
Reduction in lake whitefish harvest in year 1	893,957	893,957	893,957
Reduction in lake trout harvest in year 1	448,475	318,628	184,661
Reduction in walleye harvest in year 1	16,475	4,559	13,930
Reduction in yellow perch harvest in year 1	4,963	2,895	2,675
Reduction in chinook salmon harvest in year 1	39,004	4,875	38,896
Reduction in lake whitefish harvest in year 2	893,957	727,339	166,617
Reduction in lake trout harvest in year 2	54,814	36,734	18,080
Reduction in walleye harvest in year 2	16,475	2,900	13,575
Reduction in yellow perch harvest in year 2	4,963	2,607	2,356
Reduction in chinook salmon harvest in year 2	39,004	123	38,881
<i>Total loss</i>	\$4,036,621	\$3,399,249	\$2,406,112

#### 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

Final Report – September 2018

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 the 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. Depending on water flows and weather conditions, 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. Vessel operators could partially mitigate the costs of such a short-term stoppage 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 ( $2.8 \times 5$ ) 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:

$$y = \sum_{i=1}^5 2.8 \cdot i = 42 \quad (\text{GI-E16})$$

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).

Additionally, 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 into gas, diesel, jet fuel, and other refined products, including PBF Energy (Toledo), BP (Toledo), Marathon (Detroit). 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.<sup>7</sup> 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.

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<sup>7</sup> A detailed description of energy markets linked to Line 5 supplies and a more complete qualitative description of the potential energy market dynamics following a Line 5 supply disruption is presented in Appendix GI-2.

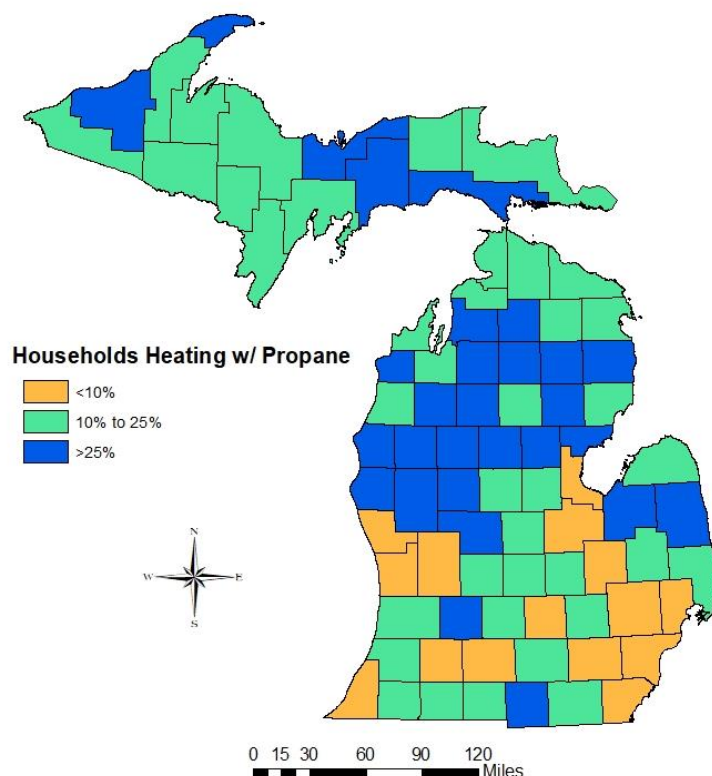


Figure GI3. Location of Propane Heated Households

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,  $\Delta P$ , times the baseline quantity of propane demanded,  $Q$ :

$$\Delta P \times Q, \quad (\text{GI-E17})$$

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,

Final Report – September 2018

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:

$$\text{Lost Producer Surplus for Northern Michigan crude} = \Delta P \times Q \quad (\text{GI-E18})$$

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 quantity and price change 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 quantity and price change 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	_____
<i>Total Loss</i>	52.8	8.2	120

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 many 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. An oil spill may impact groundwater 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 of impacts on private wells. 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

$$A = 346 * N * 13 \quad (\text{GI-E19})$$

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. Municipal water suppliers using lake water in counties would be 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,

$$\begin{aligned} \text{costs} = & \text{population served by lake water} \times \\ & \text{alternative water supply costs (\$ per day per capita)} \times \\ & \text{alternative water supply time (days)} \end{aligned} \quad (\text{GI-E20})$$

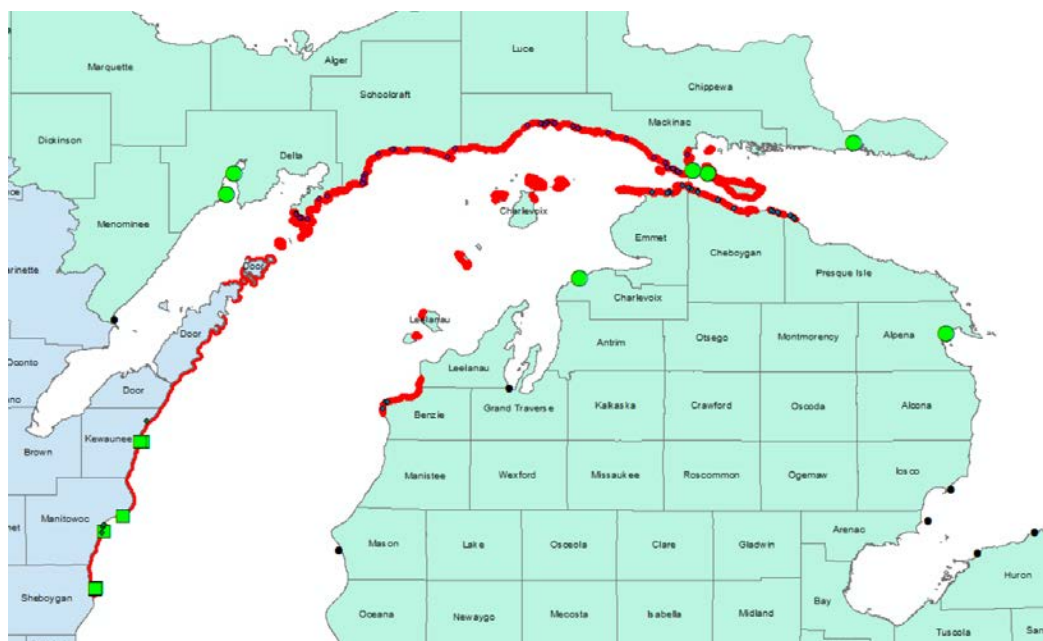


Figure GI4. Scenario 1 Groundwater Wells Within 200 Feet of Oiled US Shorelines and Affected Lake Water Intakes

In Figure GI4, red lines depict soiled 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 (CXPB)	\$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	98
Scenario 2	290	0	290
Scenario 3	310	0	310
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 the 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 evaporated or beached based on results from Tasks A and B. The limitation of transportation for bottled water supply to the Mackinac Island could be of concern if ferries are shut down during the oil spill event. However, according to practices in other oil spills, it is highly likely that the Coast Guard

will allow critical vessel traffic through the spill area for water (food or other supply) and other emergency concerns. For example, during the Texas oil spill Coast Guard officials did allow cruise ships to travel through the incident area to minimize inconvenience to the thousands of passengers aboard and limit economic impacts from the spill (Bacon, 2014).

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.

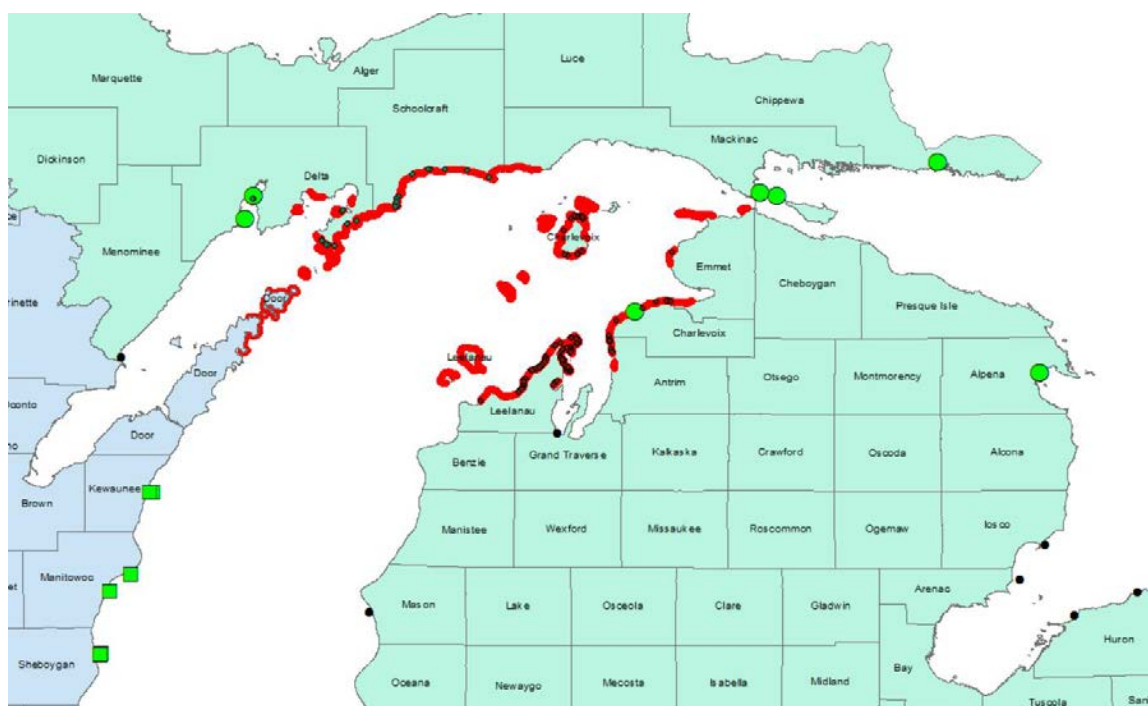


Figure GI5. Scenario 2 Groundwater Wells Within 200 Feet of Oiled US Shorelines and Affected Lake Water Intakes

In figure GI5, 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.

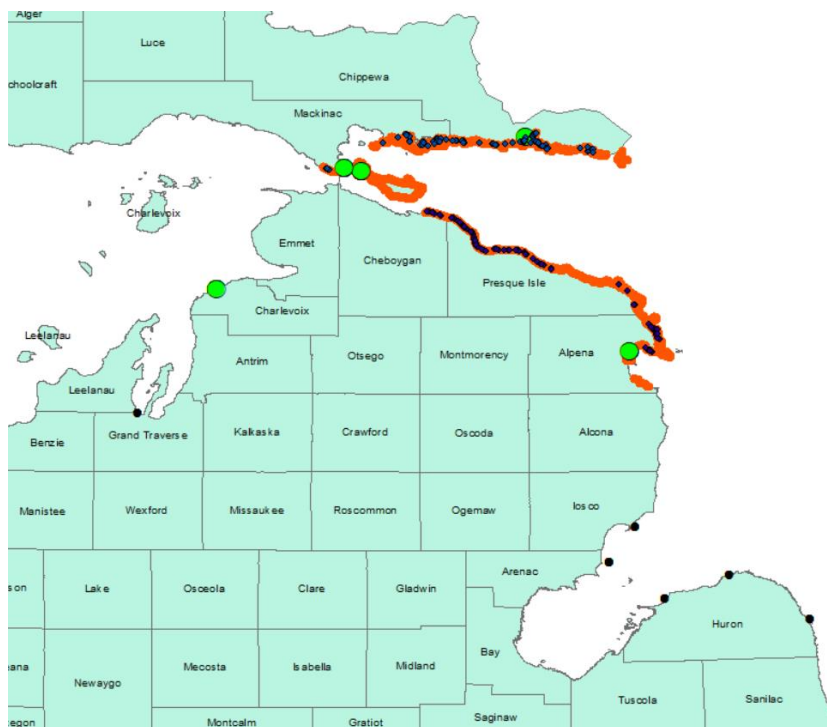


Figure GI6. Scenario 3 Groundwater Wells Within 200 Feet of Oiled US Shorelines and Affected Lake Water Intakes

In figure GI6, 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.

celgnace.

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		
<b>Total Events</b>	<b>13</b>		

## INDEPENDENT RISK ANALYSIS – PROJECT ID#1801011

<b>Costs for Testing</b>			
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		
<b>Total Costs for One Test</b>	<b>\$346</b>		
<b>Number of Water Supply Tested</b>	<b>Michigan</b>	<b>Wisconsin</b>	<b>Total</b>
Scenario 1	2	7	9
Scenario 2	3	0	3
Scenario 3	4	0	4
<b>Costs for Water Quality Testing/Monitoring</b>	<b>Michigan</b>	<b>Wisconsin</b>	<b>Total</b>
Scenario 1	\$8,996	\$31,486	\$40,482
Scenario 2	\$13,494	\$0	\$13,494
Scenario 3	\$17,992	\$0	\$17,992
<b>Costs for Alternative Water Supply</b>	<b>Michigan</b>	<b>Wisconsin</b>	<b>Total</b>
Daily Cost for Alternative Water Supply (Bottled Water), \$/day-customer	\$9.55	\$9.55	
<b>Scenario 1</b>			
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	
<b>Total Costs</b>	<b>\$1,930,437</b>	<b>\$1,184,200</b>	<b>\$3,114,637</b>
<b>Scenario 2</b>			
Affected Water Intake	Charlevoix	None	
Population Served	3124	0	3124
Time for alternative water supply, days	2	0	
<b>Total Costs</b>	<b>\$59,668</b>	<b>\$0</b>	<b>\$59,668</b>

Final Report – September 2018

<b>Scenario 3</b>			
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	
<i>Total Costs</i>	<i>\$2,229,925</i>	<i>\$0</i>	<i>\$2,229,925</i>
<b><i>Total Cost for Surface Water Intakes</i></b>	<b><i>Michigan</i></b>	<b><i>Wisconsin</i></b>	<b><i>Total</i></b>
<i>Scenario 1</i>	\$1,939,433	\$1,215,686	\$3,155,119
<i>Scenario 2</i>	\$73,162	\$0	\$73,162
<i>Scenario 3</i>	\$2,247,917	\$0	\$2,247,917

Table GI13. Total Cost for Water Supply

<b>Total Cost for Water Supply (Groundwater Wells and Surface Water Intakes)</b>	<b>Michigan</b>	<b>Wisconsin</b>	<b>Total</b>
<i>Scenario 1</i>	\$2,357,747	\$1,238,176	\$3,595,923
<i>Scenario 2</i>	\$1,377,582	\$0	\$1,377,582
<i>Scenario 3</i>	\$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.<sup>8</sup>

<sup>8</sup> 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

In our context, the event that degrades environmental quality would be a worst-case oil spill from the Line 5 pipeline. Lakefront property value reductions 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 example, finds that coastal home values recovered a few months after the spill (Siegel et al. 2013; Winkler and Gordon 2013).

We can express the price of a home 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

$$P_i = \sum_{t=0}^{600} \frac{B_i}{(1+r)^t} = B_i \frac{(1+r)^{600}-1}{r(1+r)^{600}} = B_i A_{r,600} \quad (\text{GI-E21})$$

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 (GI-E21) 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

$$B_i^1 - B_i^0 = [P_i^1 - P_i^0]/A_{r,600} = \Delta P_i/A_{r,600}, \quad (\text{GI-E22})$$

where  $\Delta P_i = P_i^1 - P_i^0$ . Assuming remediation takes  $m$  months, the present value of a change in total welfare across all homes is

$$\sum_i \frac{\Delta P_i}{A_{r,600}} \cdot A_{r,m}. \quad (\text{GI-E23})$$

Note that the welfare measure in (GI-E23) may underestimate the true measure. Prior work in the economics literature (e.g., McCluskey and Rauser 2003) finds that for some types of environmental harms property values may not fully return to their pre-event values after remediation due to “stigma” effects, i.e., individuals place a lower value on property upon realizing the possibility of environmental damage, although we are not aware of any literature that demonstrates long term property stigma effects on property values due to oil spills. The welfare measure in (GI-E23) 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 (GI-E23).

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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.

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 (\$ millions)

Scenario <sup>a</sup>	State	Annual interest rate =	Lost amenity value to coastal property <sup>b</sup>		
			2.5%	5%	7%
1	Michigan		\$1.52	\$2.33	\$3.04
	Wisconsin		\$4.83	\$7.37	\$9.62
	<i>Total</i>		<i>\$6.35</i>	<i>\$9.70</i>	<i>\$12.66</i>
2	Michigan		\$4.70	\$7.17	\$9.36
	Wisconsin		\$1.34	\$2.04	\$2.67
	<i>Total</i>		<i>\$6.03</i>	<i>\$9.21</i>	<i>\$12.03</i>
3	Michigan		\$6.09	\$9.30	\$12.14
	Wisconsin				
	<i>Total</i>		<i>\$6.09</i>	<i>\$9.30</i>	<i>\$12.14</i>

<sup>a</sup> 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

<sup>b</sup> Total figures may not add due to rounding.

The State of Wisconsin provided statewide parcel-level tax assessment data, which includes homes’ estimated fair-market value. We restrict our analysis to properties within one mile of shoreline predicted to be oiled in each scenario. This is reasonable as the amenity value of having coastal property (e.g., due to scenic vistas) is derived from immediate proximity to the beach; when other research has shown that spills affect property values, it is generally in areas along coastlines or in very close proximity to the shore. Indeed, most prior work only measures effects of oil spills on waterfront properties (e.g., Epley 2012; Simons et al. 2001; Winkler and Gordon 2013), while others find small effects on properties up to 1.5 miles from shore (Hellman and Walsh 2017). 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. Using GIS, we identify 9,500–12,300 affected properties across Michigan and Wisconsin, depending on the scenario. The total estimated market value of these properties before a spill is \$2.6–2.8 billion, though this is the total value, not the change in value due to the spill.

Few peer-reviewed studies examine the effect of oil spills on coastal property values. Simons et al. (2001) examine the effect of a freshwater 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, although they do not report the duration of this negative effect. Epley (2013), Siegel et al. (2013), and Winkler and Gordon (2013) all examine the effect of the DWH spill on coastal property values. These studies collectively find that the spill decreased sales prices by 1–16 percent, with effects lasting 3.5–5 months after the initial spill. Given our focus on a worst-case outcome, we assume the change in price ( $\Delta P_i$  in (GI-E23)) is  $\Delta P_i = 0.16P_i^0$  and (ii) the duration of spill effects on property values ( $m$  in (GI-E23)) is 5 months.

We calculate the welfare measure in (GI-E23) for affected properties in Wisconsin and Michigan separately. For Wisconsin properties, we reduce the annualized benefit for each affected property by 16 percent, then sum the results across all properties. For Michigan properties, we calculate the average annualized benefit from owning a home in a coastal census block using (GI-E21), then multiply this average benefit by 0.16 times the number of homes in the census block to calculate the total census block-level losses from the spill. We then add the total losses across all census blocks to calculate the total losses to Michigan coastal properties. Table GI14 reports the present value of welfare losses to lakefront property owners from a worst-case spill for a range of values for  $r$ . The choice of  $r$  is arbitrary; annual rates used in real estate valuation typically range from 7–10 percent, although other values can be used. Aggregate lost value from the simulated spills totals \$6.0 million–\$12.6 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. We detail our approach in an appendix to this section of the report, and provide a summary of the approach in the following section.

##### **GI.4.11.1 Approach**

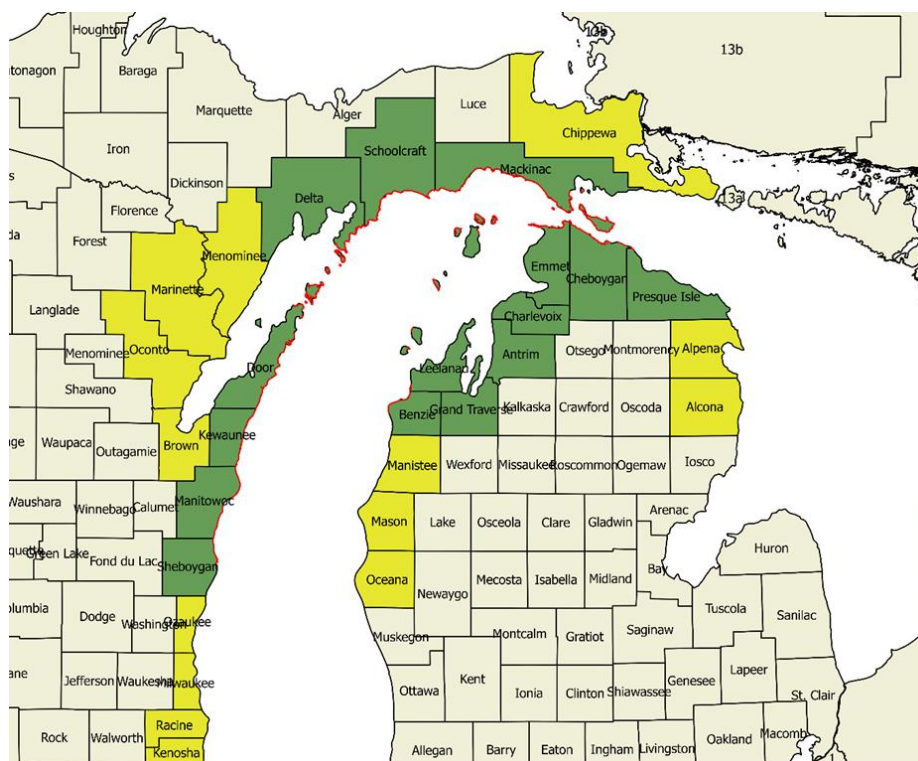
Impacted communities across the U.S. states Michigan and Wisconsin and the Canadian Province of Ontario are expected to see a decrease in tourism activity from both in-state and out-of-state visitors. Three simulations were undertaken, representing the worst-case scenarios based on the miles of shoreline 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 of detail for Michigan and Wisconsin. The collected statistics include annual estimates of counts of visitors and total expenditures. Michigan tourism counts and expenditures were derived from Longwoods International's report "Michigan 2016 Visitor Research" (Longwoods International 2016). The report uses county-level estimates to delineate county-shares of state visitors and expenditures, which for Michigan were provided by the 2014 Tourism

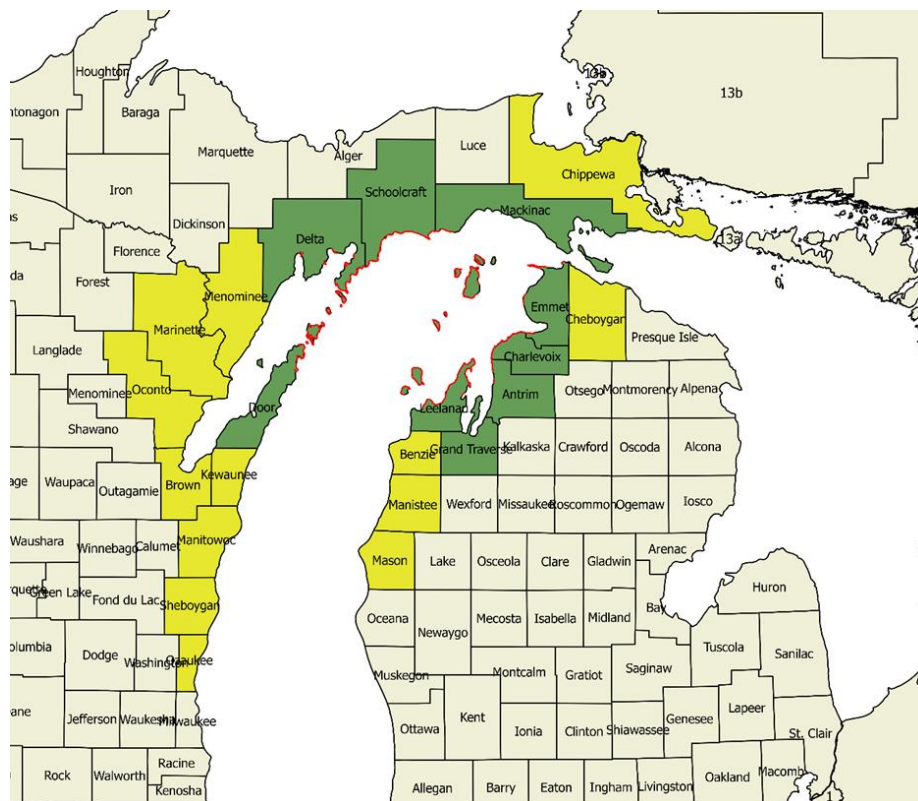


Economics estimates (Tourism Economics 2014). ) and for Wisconsin are collected from the Wisconsin Department of Tourism 2017 (Wisconsin Department of Tourism 2017).

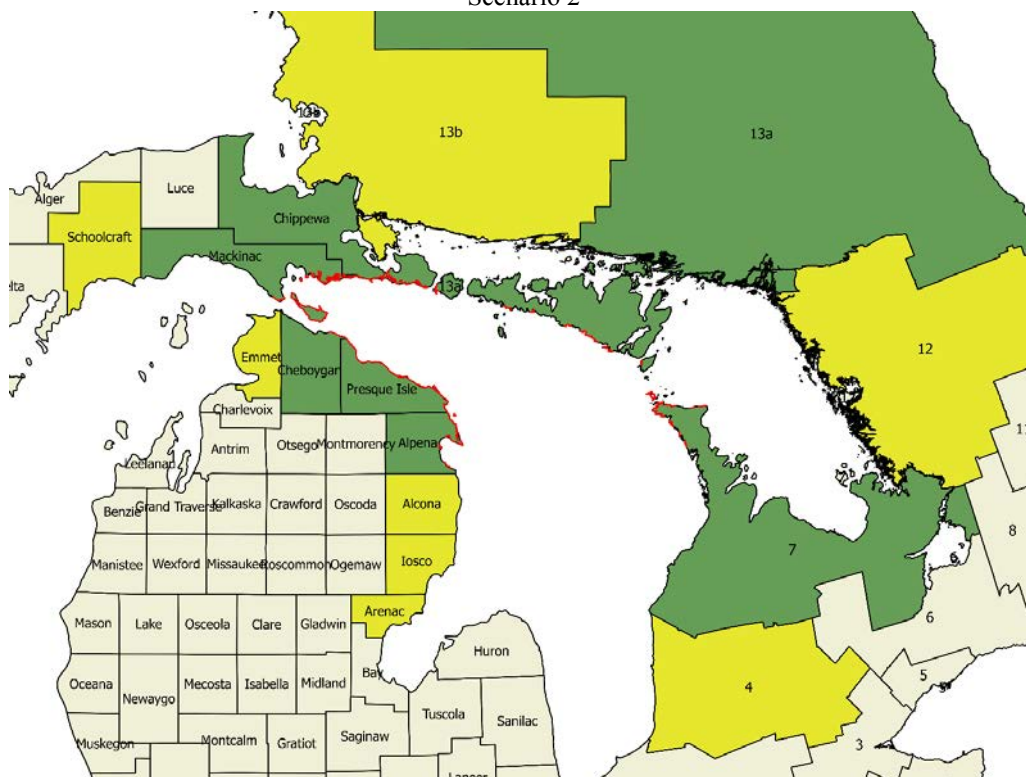
For the three simulations, counties were assigned as a core-impacted region, a periphery region or as not being impacted, based on the modeled distribution of beach surface deposits from a Line 5 release (Figure GI7). Core (green) areas are expected to have oiled areas. These areas are likely to have 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

Final Report – September 2018

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 the DWH spill outcomes along similarly specified core and periphery areas. In the DWH spill, core counties experienced about a 45 percent decrease in shoreline visits the year of the spill, while periphery counties experienced about a 22 percent decline (Tourangeau et al. 2017). We apply these DWH shoreline visitation losses to tourism. The core area will also experience a 10 percent reduction in the following year for the total duration of 18 months, based on shoreline visitation losses in DWH. Annual tourism activities are broken out by month, based on the share of annual Mackinac Bridge crossings to account for the months of impacts.

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. Michigan and Wisconsin expenditure breakouts by category of purchases follow estimated tourism expenditure profiles for Michigan (Longwoods International 2016), and break out expenditures by type of purchases (lodging, food establishments, retail, etc.) as shown in Table GI15. This profile is also used for Wisconsin.

The estimate of state tourism expenditure impacts is then calculated as:

$$T_{exp} = (\sum_{n=1}^N exp_n \cdot T_n) \cdot (\sum_{k=1}^K ss_k), \quad (GI-E24)$$

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 GI15. Tourism Visitor Expenditure Profiles

Michigan and Wisconsin	
Lodging	37%
Restaurant Food & Beverage	25%
Retail Purchases	14%
Recreation/Sightseeing/Entertainment	12%
Transportation at Destination	11%

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 the 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 represent a combined loss of income in both Michigan and Wisconsin (greater breakout is available in Appendix GI1). 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.

Table GI16. Estimated Lost Incomes (labor and proprietors)

Michigan & Wisconsin	Out of State Only		All Tourism	
	GDP by State	GDP-Indirect B-tax	GDP by State	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 will 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 (Scenario 1, Figure GI7) would cause the largest measured damages (\$1.37 billion in total estimated damages).

Table GI17. 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 - non-motorized	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
<b>Recreational damages (subtotal)</b>		<b>459.8</b>	<b>395.1</b>	<b>115.1</b>
Lost amenity value to coastal property	Yes	6.4	6.0	6.1
Commercial fishing	No	4.0	3.4	2.4
Commercial shipping	No	43	43	43
Michigan energy supply effects	No	181	181	181
Water supply effects	Yes	3.6	1.4	3.6
<b>Other damages (subtotal)</b>		<b>238.0</b>	<b>234.8</b>	<b>236.1</b>
Lost incomes for tourism and recreation-related businesses	Yes	679.7	427.2	105.4
<b>Unmeasured Damages</b>				
Human health costs		ND	ND	ND
Value-added commercial fish products		ND	ND	ND
Subsistence fisheries		ND	ND	ND
Miscellaneous cultural activities		ND	ND	ND
Compensatory habitat costs		ND	ND	ND
<b>Total economic damages</b>		<b>1,377.5</b>	<b>1,057.1</b>	<b>456.6</b>

ND: Cannot be determined

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. In many spills, the compensatory habitat restoration activities designed to compensate for non-recreational natural resource damages have been more than double the recreational losses. Similarly, in DWH, a study that measured the economic value of use and non-use natural resource damages (Bishop et al. 2017) found them to be an order of magnitude higher than the use values alone (English et al. 2018). Thus, the lack of numbers for compensatory habitat projects is a potentially significant caveat to the economic damage estimates.
- Potential human health impacts were not assigned monetary values, although as mentioned in section D, there are potential human health impacts.
- Our review of the literature on environmental harms does provide some examples of non-oil spill harms where damages last beyond their remediation due to stigma effects. Since studies of oil spills do not show long term property or recreational losses post-cleanup, we do not estimate any long term stigma effects. However, based on previous spills, we do allow for damages in areas that may be perceived to be harmed even if no oil appears on the shore (our periphery damage areas).
- 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 crucial role in propane markets. However, inventory data is only available for the Midwest region. Moreover, 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.

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Final Report – September 2018



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# 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. A top-down “policy instrument” approach is applied to account for the ubiquitous presence of government agencies responsible for managing both the immediate and long-term consequences of such a disaster. 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 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 statutes, 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.

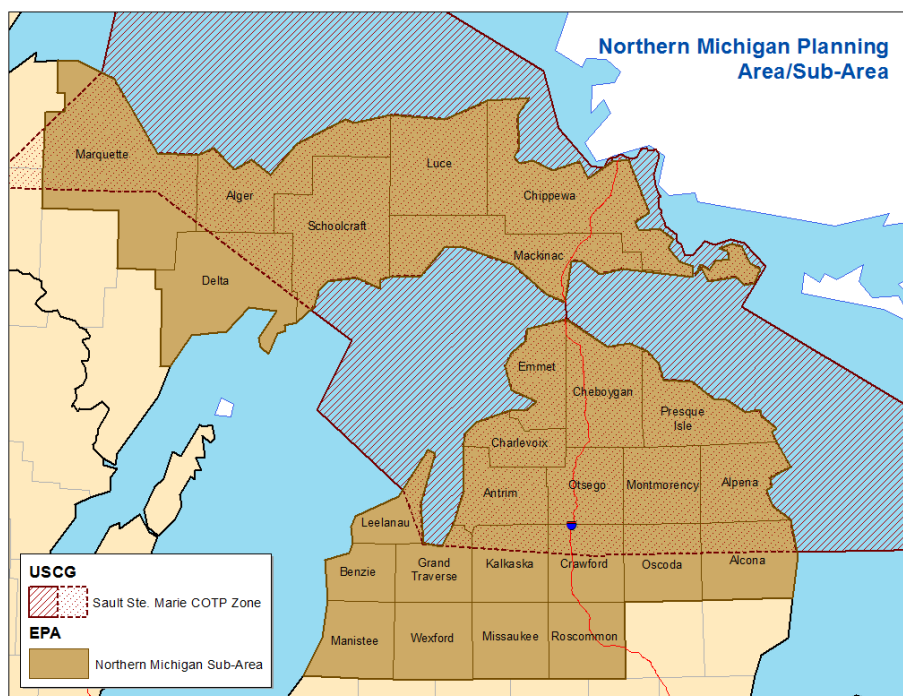


Figure H1. Geographic Boundaries for Federal Contingency Plans –USCG Sault Sainte Marie Captain of the Port (COTP) Zone and EPA Region 5 Northern Michigan Subarea

Source: 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

Final Report – September 2018

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:

Federal Government

Coast Guard

EPA

Federal Emergency Management Agency

Fish and Wildlife Service

Michigan State Government

Michigan Department of Environmental Quality

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

Indian Bands

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 the payment of a \$61 million fine, 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, dollars per 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 reduced visits by out-of-state tourists 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

Final Report – September 2018

destination are shown in Table H1 for Scenario 1. Similarly, estimates for Scenarios 2 and 3 are displayed in Tables H2 and H3.

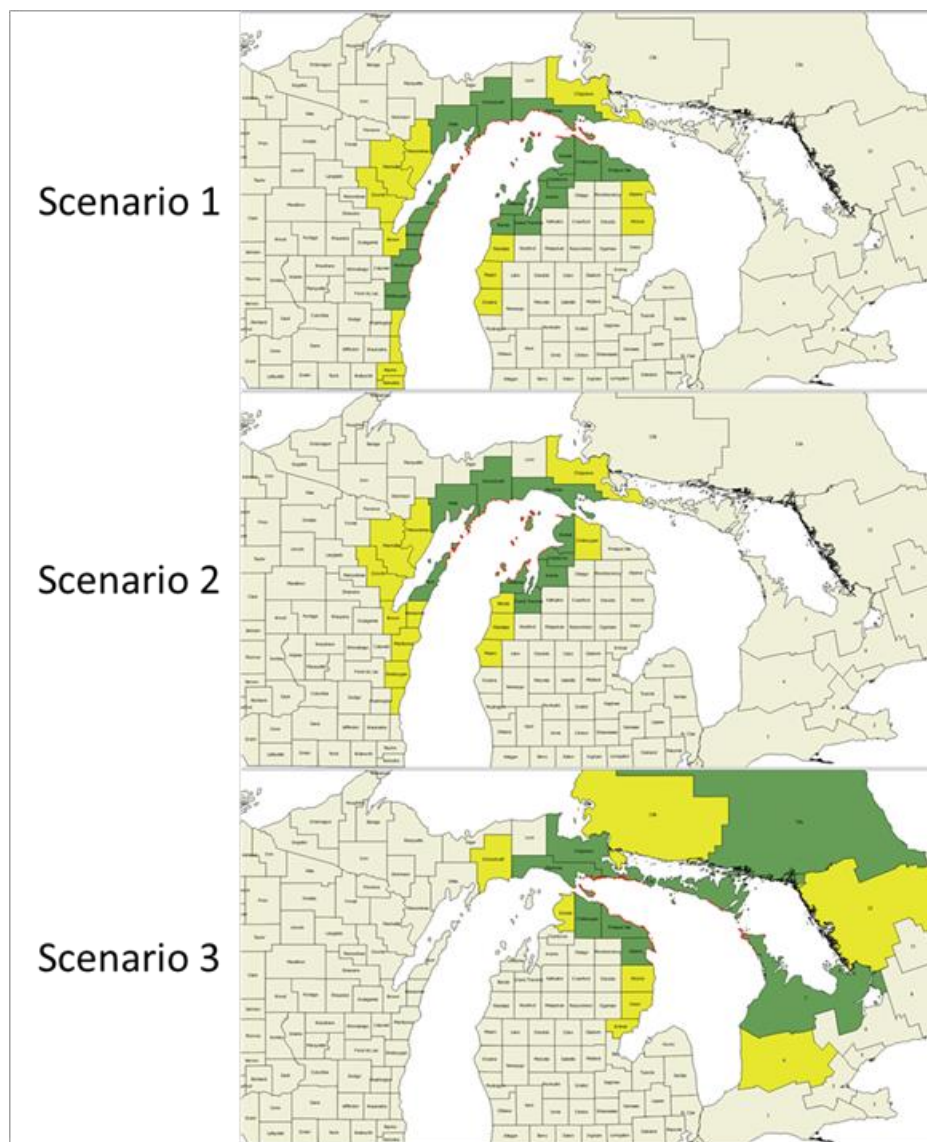


Figure H2. Straits of Mackinac Oil Release Scenario Maps for Counties Directly and Indirectly Affected by Shoreline Contamination

Table H1. Scenario 1 Direct Economic Loss Estimates to Affected Communities by Out-Of-State Tourists Who Decide Not To Visit Counties Affected by The Oil Spill

<b>Economic Activity Lost</b>	<b>Michigan</b>	<b>Wisconsin</b>
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
<b>Total</b>	\$496,164,969	

Table H2. Scenario 2 Direct Economic Loss Estimates to Affected Communities by Out-Of-State Tourists Who Decide Not To Visit Counties Affected by The Oil Spill

<b>Economic Activity Lost</b>	<b>Michigan</b>	<b>Wisconsin</b>
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
<b>Total</b>	\$309,874,217	

Table H3. Scenario 3 Direct Economic Loss Estimates to Affected Communities by Out-Of-State Tourists Who Decide Not To Visit Counties Affected by The Oil Spill

<b>Economic Activity Lost</b>	<b>Michigan</b>	<b>Wisconsin</b>
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
<b>Total</b>	\$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](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, Transportation Fuels, and Other Factors

<b>Tax Type</b>	<b>Michigan</b>	<b>Wisconsin</b>	<b>Federal</b>
<b>Lodging<sup>1</sup> (%)</b>	6	5	NA
<b>Sales (%)</b>	6	5.5 <sup>2</sup>	NA
<b>Transportation</b>			
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
<b>Income (%) <sup>3</sup></b>	4.25	6.27	22

<sup>1</sup> 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>.

<sup>2</sup> The most common rate among affected counties in WI.

<https://www.revenue.wi.gov/Pages/FAQS/pes-taxrates.aspx>

<sup>3</sup> 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

	<b>Michigan</b>	<b>Wisconsin</b>	<b>Federal</b>
<b>Sales Taxes Lost</b>			
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
<b>Fuel Taxes lost</b>			
Transportation at Destination	\$2,667,801	\$3,696,195	\$3,273,255
<b>Lodging Taxes Lost</b>	\$4,086,559	NA	NA
<b>Income Taxes Lost</b>	\$7,769,838	\$19,646,747	\$109,156,293
<b>Total Lost Revenues</b>	\$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

	<b>Michigan</b>	<b>Wisconsin</b>	<b>Federal</b>
<b>Sales Taxes Lost</b>			
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
<b>Fuel Taxes lost</b>			
Transportation at Destination	\$2,358,669	\$1,748,612	\$2,044,274
<b>Lodging Taxes Lost</b>	\$3,613,028	NA	NA
<b>Income Taxes Lost</b>	\$6,869,508	\$9,294,569	\$68,172,328
<b>Total Lost Revenues</b>	\$21,461,763	\$18,290,409	\$70,216,602

Table H7. Scenario 3 Government Tax Revenues (Not Including Canadian Tax Revenues) Lost from Declines in Out-Of-State Beach Visitations

	<b>Michigan</b>	<b>Wisconsin</b>	<b>Federal</b>
<b>Sales Taxes Lost</b>			
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
<b>Fuel Taxes lost</b>			
Transportation at Destination	\$1,022,388	\$0	\$462,210
<b>Lodging Taxes Lost</b>	\$1,566,103	NA	NA
<b>Income Taxes Lost</b>	\$2,977,656	\$0	\$15,413,749
<b>Total Lost Revenues</b>	<b>\$9,302,814</b>	<b>\$0</b>	<b>\$15,875,959</b>

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 for 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 Responsible Party Funding

	<b>Michigan</b>	<b>Wisconsin</b>	<b>Federal</b>
<b>Income Taxes Gained</b>	\$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 (493-619 miles) 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. Tasks G, H and I Three Worst-case Scenario Estimated Shoreline Cleanup Costs Based on the 2010 Marshall Spill Costs Per Kilometer Reporting

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. The economic impact of a worst-case spill on drinking water intakes is considered as part of Tasks G/I.

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 2,006 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.

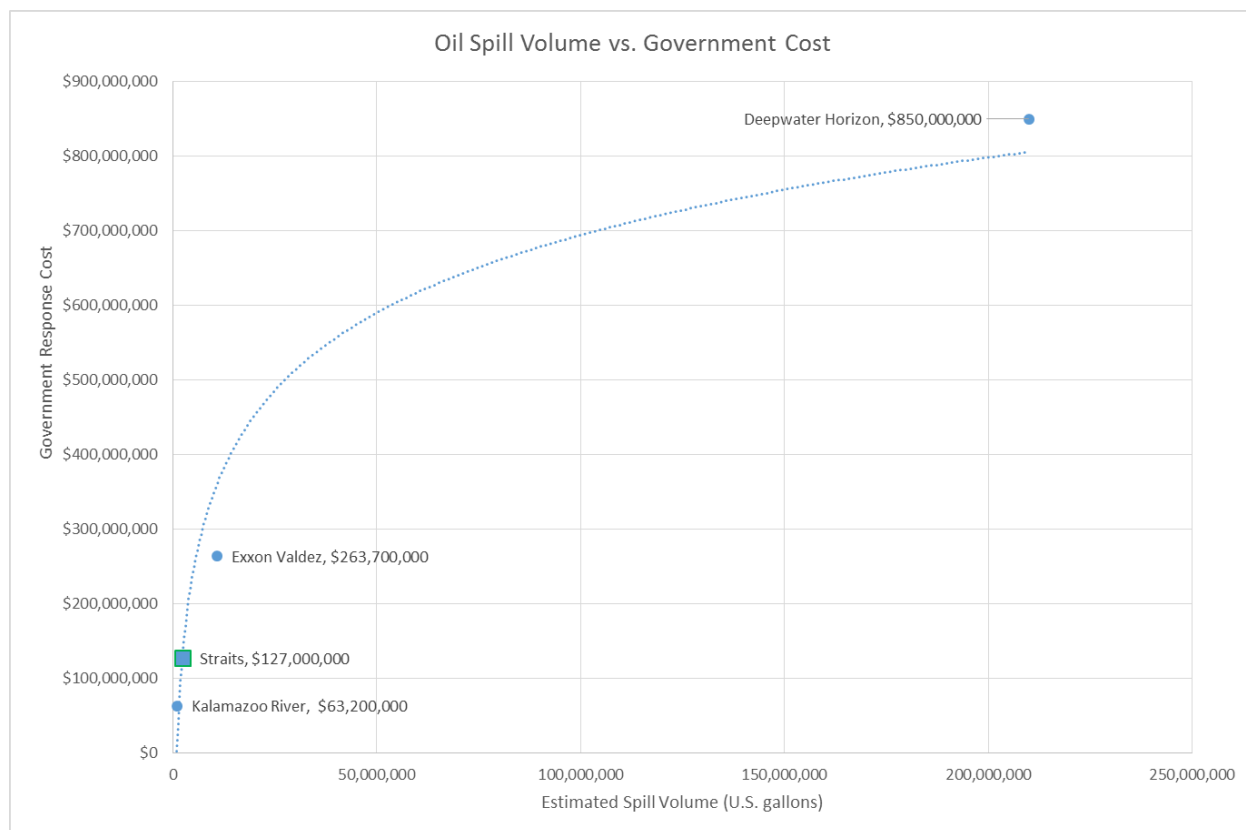


Figure H3. Logarithmic Curve of Government Response Cost Vs. Spill Volume for Three Historical Spills Applied to The Estimated Worst-case Discharge Volume for a Straits Spill

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 the incorporation of global values from mostly marine spills with limited shoreline impacts into these compilations.

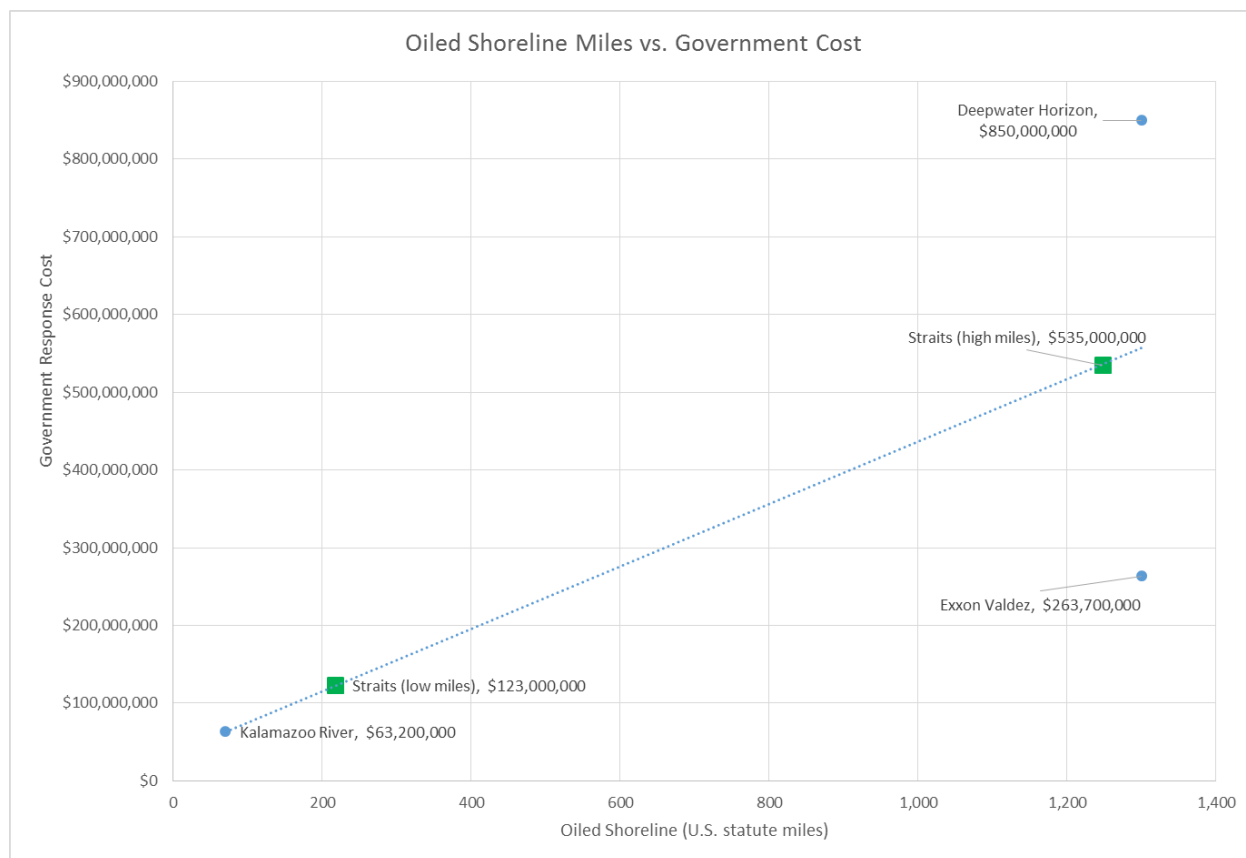


Figure H4. Government Response Cost Vs. Oiled Shoreline Length for Three Historical Spills Applied to The Estimated Worst-case Oiled Shoreline Length for a Straits Spill

### 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 Summary

The aim of Task H was to estimate the costs of a worst-case spill to federal, state, local, and tribal governments, including responding to the spill, conducting damage assessments, overseeing cleanup and restoration, negotiating settlements, and changes in tax revenues. Total governmental costs for response and oversight, which would be reimbursable by the responsible party, could range from \$123M to \$535M based on extrapolations from historical spills, with acute response/cleanup (days to weeks) focused on floating oil and longer-term activities (months to years) focused on shoreline oiling. Lost tax revenues due to reduced tourism revenues are estimated at \$175M and corporate income tax revenue loss from the application of cleanup cost tax deductions are estimated at \$263M for a total of \$338M in (non-reimbursable) lost tax revenues. Increases in tax revenues due to new income taxes from workers hired for the cleanup were estimated at up to \$131M. Public drinking water-related governmental costs were not estimated but are considered as part of Tasks G/I.

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## Section X: Broader Impacts

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### **X.1. Introduction**

In order to provide a balanced assessment of the Straits Pipelines, 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 aforementioned groups. For the purposes of 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 can 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. Yet, 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

Final Report – September 2018



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 are able to engage a wide range of stakeholders who are mostly 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” is 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 an adverse future 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 (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 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 is 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 Vancley, 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.

SLO is actively pursued by industries 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. In relation to the Straits Pipelines, the first area of concern requires acknowledgement 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.

A 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 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 Dynamic Risk (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 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 in order to properly interpret our results. 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 and 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 totaling 1,136 submissions 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 874 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 but were unable to obtain any additional information about CEAM. After performing further research, we found a petition in support of the Straits Pipelines that was identical to the comments submitted by CEAM on the website that belongs to Consumer Energy Alliance (Consumer Energy Alliance 2017). According to the website, Consumer Energy Alliance has a Midwest chapter making Consumer Energy Alliance Midwest (CEAM) a likely source of the comments (Consumer Energy Alliance 2017). After analyzing these submissions, we deemed 2,010 comments as questionable (albeit to a different degree) 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 totaling 1,136 submissions 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 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). These comments were submitted in the following ways: (i) 33,932 comments (or 75.47%) were submitted by their authors directly through the Michigan Petroleum Pipelines website; (ii) 10,835 comments (or 24.10%) were submitted as postcards both online and via mail; (iii) 353 comments (or 0.8%) were mail submissions primarily in the form of a written letter, and (iv) 4 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 were then sent to our research team for analysis.



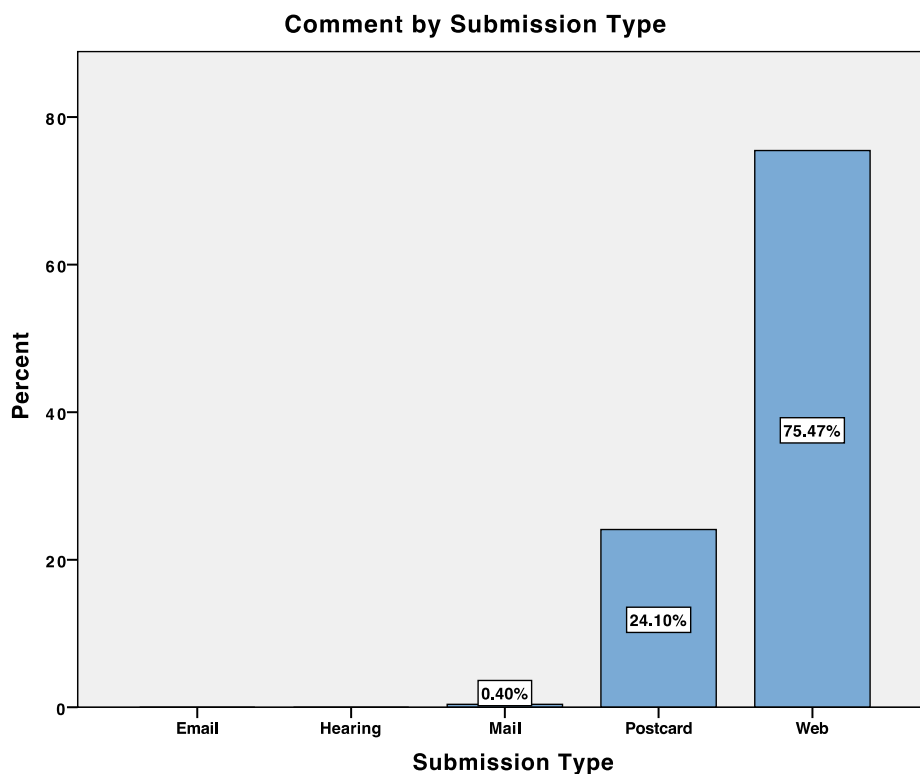


Figure X1. Comments on the Dynamic Risk Alternatives Analysis by Submission Type

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 Pipelines. CEAM submitted 874 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, Clean-up 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 Pipelines. 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.3.2.3.

#### X.2.3.5. 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 an 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).

Further details emerge when examining the distribution 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 (874 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. 1,136 comments (or 2.5%) were determined to have significant 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.

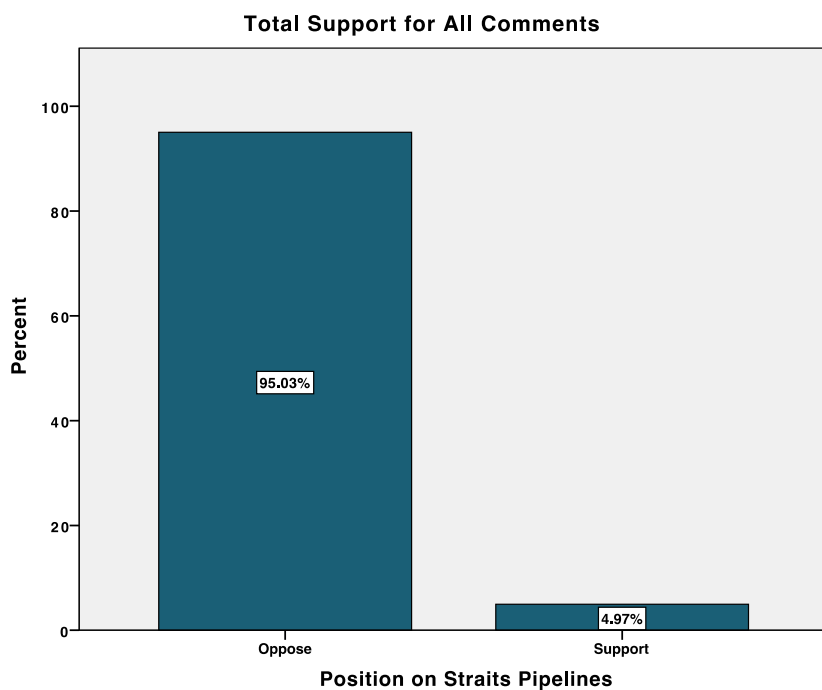


Figure X2. - Total Support among all Comments Submitted

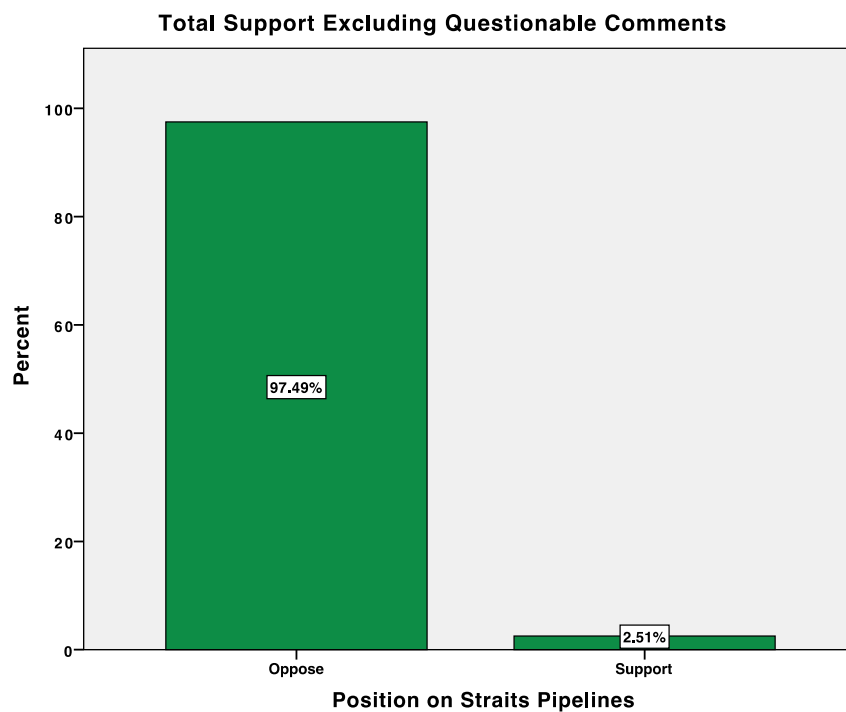


Figure X3. - Support among All Comments Excluding Questionable Comments

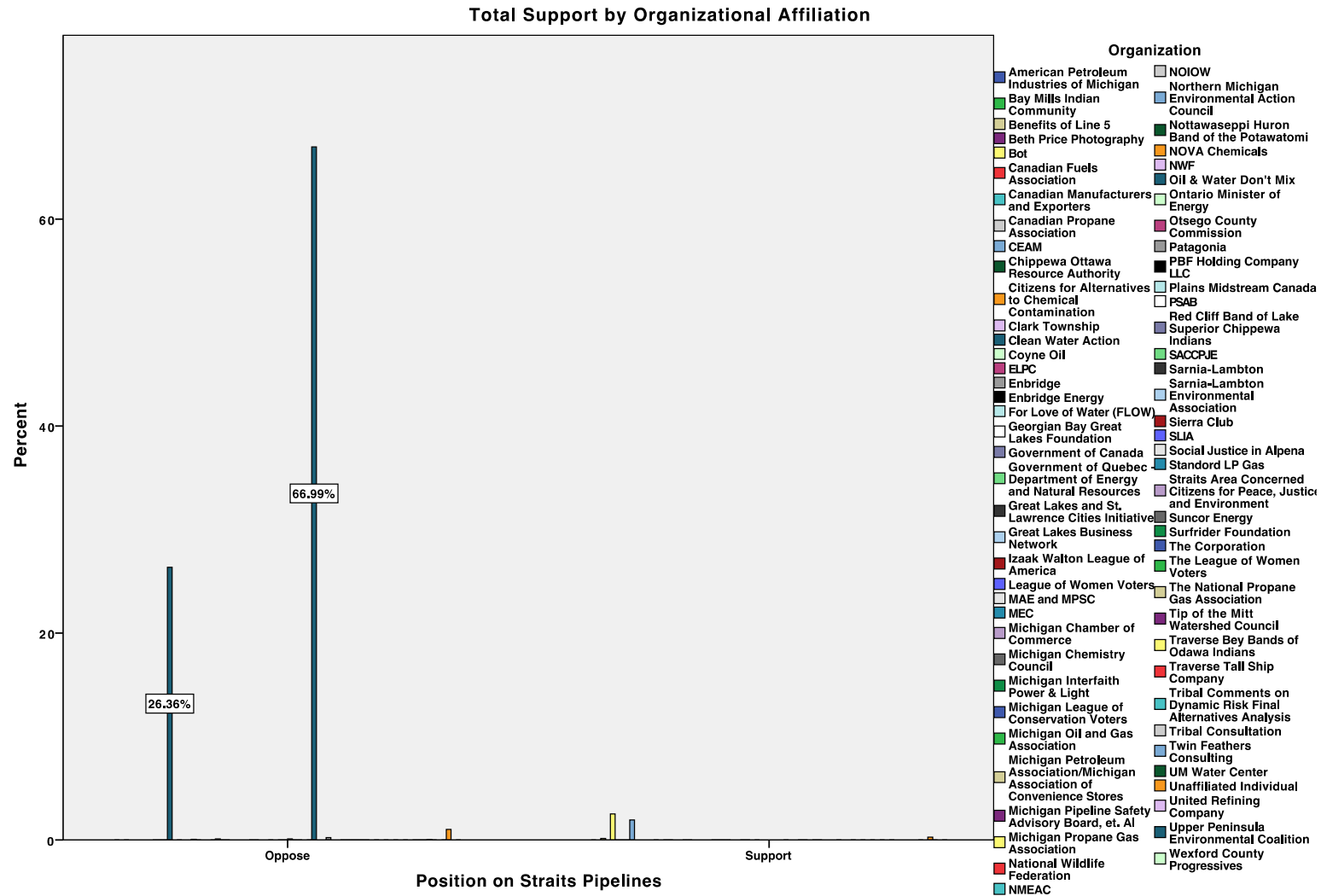


Figure X4. Comment by Organizational Affiliation

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 who 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 1,136 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.

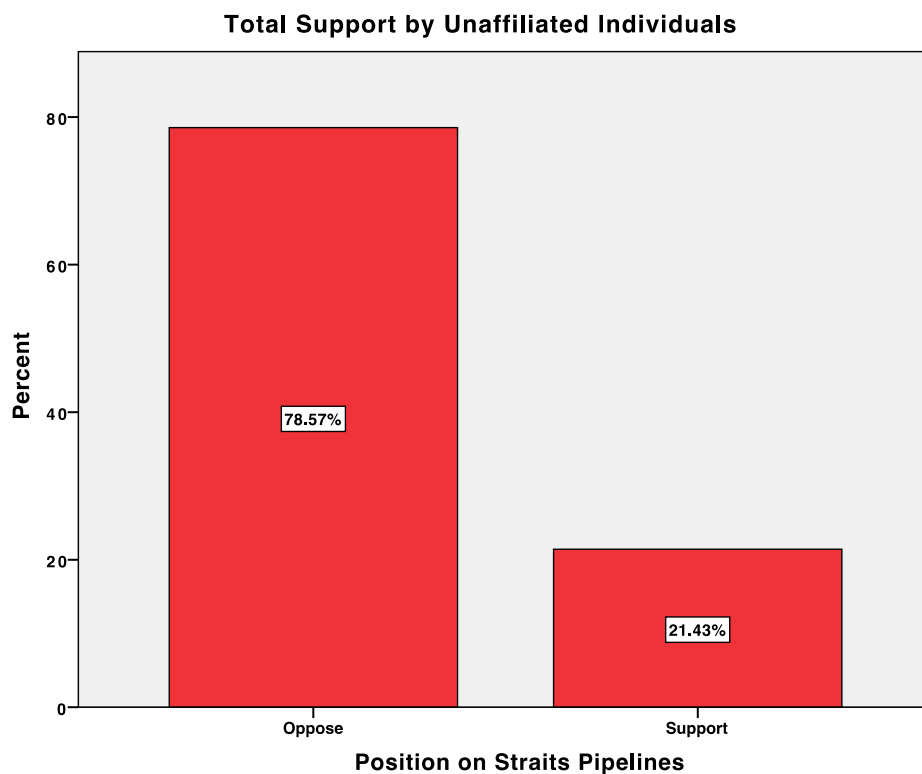


Figure X5. Support among Individuals without an Organizational Affiliation

### 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 pursuant to a combined axial and open-coding method, as specified in the Approach subsection. In order 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.

<b>Prevalence</b>	<b>Number of Statements Per Subcategory</b>
Low	1-3
Moderate	4-10
High	11-20
Very High	Over 21

*X.3.2.1.1 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 such a 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.3.2.1.2 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 note 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.3.2.1.3. 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.3.2.1.4. 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.3.2.1.5. 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 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 from a worst case scenario citing studies (e.g. by the Brookings Institute) and reasonable comparisons (the cost of the 1990 Exxon Valdez oil spill). Yet even the most abstract estimates are not without merit, as 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.3.2.1.6. Additional risk considerations*

As we note 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. We see such an interruption of service in the short term a valid concern, as confirmed by the analysis in Appendix GI. Upper Peninsula residents have one of the highest propane consumption rates in the nation. The adverse consequences of a sudden interruption of propane supply are not a matter of irrational fears. As stated in Appendix GI-2, pipeline work in Wisconsin during the winter of 2013-2014 resulted in localized propane shortages and record high prices in Michigan as providers struggled to find alternative supply and transportation options.

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 can 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.3.2.2. 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 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. “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?” – stated one respondent. 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 shutdown, 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, 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.3.2.3. 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 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 an evidence of a rare event that proves Enbridge’s great safety record. Analysis of public comment data that is attentive to SLO and the potential 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. It is difficult to quantify the legitimacy of the state, but public comments already indicate that trust in the state and perceptions of state legitimacy are being challenged by this process; loss of state legitimacy is hard to quantify in economic terms but absolutely 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 absolutely 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.3.3. Tribal Concerns

#### X.3.3.1. 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.3.3.2. 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 pointed also 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.3.3.3. Clean-up timeline

Concerns over the clean-up 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 clean-up 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 a clean-up of a winter spill would be physically impossible (Little Traverse Bay Band of Odawa Indians 2015).

Tribes also point to past clean-up 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 clean-up efforts.

Enbridge’s past responses to oil spills are frequently referenced by the tribes as evidence to question the legitimacy of any adequate clean-up scenario that Enbridge would undertake if a leak was detected within the Straits of Mackinac.

#### X.3.3.4. 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.3.3.5. 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. Natural resources are utilized by Tribal communities 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 another resource 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, martin, 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.3.3.6. Restoration

Because Tribal Nations saw most impacts as irreversible, restoration appears to be a moot point. This is particularly true in relation to Traditional Cultural Properties such as sacred sites.

#### X.3.3.7. 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.3.3.8. Government and public costs

Additional costs associated with a petroleum release that would be assumed by the public were also articulated by Tribal Nations. Among these were 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 recreationalists inspired to visit ‘Pure Michigan’
- Damage to fishing docks, boats and equipment

#### X.3.3.9. 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, 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 clean-up time and costs, and many other factors. Although the extent and nature of legal claims is 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 to 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 X6 (Newland, *et al.* 2018).





Figure X6 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 a 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.3.3.10. 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 from 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 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 understand of capacity for addressing impacts to drinking water among all the discrete communities that would be impacted. It also requires understanding of the long-term impacts on non-human species that have economic, cultural, and ecological value that are 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 attempt to manage risk.

Although the analysis in this section is largely qualitative, this does not mean that some if not all of the results cannot be quantified. Such quantitative analysis will require corroborating evidence obtained through additional data collection methods that we were unable to utilize due to the time constraints of this study. More importantly, the lack of exact percentages and dollar figures in the qualitative part of our analysis should not be interpreted as a lack of serious risks.

#### *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 was 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 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 Pipelines represented less than 5% of the total comments. When the 2,010 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 5 month frame indicates that the public is attempting to engage in the Straits Pipelines 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*

The opportunity to comment on the Alternatives Analysis was taken by many commenters 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 a petroleum release. 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 a cleaner environment), 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 Pipelines generally and do not engage in assessment of relative balance of cost and benefits associated with continued operation. Opponents, on the other hand, express their views in a more 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 Pipelines 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.

SLO revocation may signal a conflict between a community and an industrial actor or community members and industrial and government actors. It is not uncommon for such conflicts to turn violent, resulting in destabilization of a community (Wilson 2016). Given the constraints of this study, we were unable to extend our analysis to potential effects of SLO revocation. However, this issue is of critical importance and should be given due attention.

#### *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 Pipelines, 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 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 Pipelines, 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. Tribal Nations are particularly concerned about a petroleum release and, therefore, are unanimously opposed to continued operation of the Straits Pipelines. Tribal members are particularly vulnerable to such an event because their cultural identity, heritage, and subsistence activities are inextricably linked to the quality of Great Lakes’ water. Because of the Tribal Nations’ legal rights to fish, hunt, and gather, extensive and expensive litigation against Enbridge and, potentially the State of Michigan is part of a worst case scenario. In addition, 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 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 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 tasked 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 Pipelines.



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## Summary of Costs

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 (2.44 million gallons) 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 3 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 3. Summary of total potential liability for a worst-case spill from the Straits pipelines.

<b>Liability</b>	<b>Task</b>	<b>Estimate (millions)</b>
<b>Cleanup costs</b>	F, H	\$500
<b>Recreational damages</b>	G/I	\$460
<b>Lost income for tourism and recreation businesses</b>	G/I	\$680
<b>Other damages</b>	G/I	\$238
<b>Total</b>		\$1,878

This cost estimate was made as comprehensive as possible, but confident estimates for several categories of cost could not be produced within the scope of this short-term project. These include the cost of repairing the pipeline itself, the costs of irreversible damage to resources for which valuation estimates are not available, human health impacts, value-added commercial fish products, subsistence fisheries, and compensatory habitat costs. 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.