REPORT

RESULTS FROM OIL SPILL MODEL SIMULATIONS IN LAKE MICHIGAN

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RPS asa

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Introduction

RPS ASA was contracted by Enbridge Pipeline to simulate hypothetical spills of a light crude oil from a pipeline crossing beneath Lake Michigan near Mackinaw, Michigan (Figure 1). The OILMAP model was used to determine the transport and fate of a short duration release of crude from an assumed catastrophic break of the line at the lake bed within the Straits of Mackinac, the narrow waterway that connects Lake Michigan to Lake Huron. For this study, two scenarios have been simulated using wind and current data from two seasons (summer and winter). Wind conditions used in the simulations were selected to be representative of the corresponding season. The resulting spill trajectories are reflective of the wind data that were chosen to represent typical conditions in the Mackinac area. Simulations using wind data from different sources or from a different time period would result in a different spill trajectory.

Figure 1. Map showing the location of the pipeline segment crossing the Straits and the hypothetical pipeline spill site at its center.

Modeling Approach

ASA's OILMAP spill modeling system was used to analyze the potential for surface and shoreline oiling from the theoretical spills. The OILMAP simulations provide an estimate of the oil's path and weathering under particular selected environmental conditions. For this study two individual pipeline rupture scenarios were simulated to be representative of summer and winter seasons that can be considered likely scenarios based on the wind climate in the area. The spill scenarios are based on pipeline flow rates and operational parameters. The spill volume used was provided by Enbridge.

Results from the modeling are provided as maps of the oil pathways and as time series of oil weathering over the duration of the simulation, expressed as the volume of spilled oil on the water surface, on the shore, evaporated, and entrained in the water column.

Environmental Data

Hydrodynamics

The Straits of Mackinac are an area of complex and unique hydrodynamic characteristics. Individual seiches occur in both Lake Michigan and Lake Huron which generate currents through the Straits. These currents are driven by the difference in water level in each lake with flow traveling from the higher water level side to the lower. Additionally, the water column within the Straits of Mackinac is density stratified during the summer months when surface water is warmed, and exhibit a distinctly different flow pattern than what is observed during the non-stratified winter season. Mean surface currents within the Straits that are directed towards Lake Huron are associated with the density-stratified summer months, along with a deeper return flow towards Lake Michigan (known as bi-directional currents). In the non-stratified winter months the current flow is directed in an easterly direction towards Lake Huron at all depths with a monotonic decrease in speed from the water surface to the bottom (Saylor and Sloss, 1975). Recent research (Anderson and Schwab, 2013) has shown that the reversing flow present within the Straits has a period of approximately 3 days, can reach speeds up to 1 m/s, and has a flow of 80,000 m^3/s.

Although three-dimensional hydrodynamic models that combine both lakes are in development at the Great Lakes Environmental Research Laboratory (GLERL), presently only separate two-dimensional hydrodynamic models are available, one for Lake Michigan and one for Lake Huron. For this study the oil spill modeling was conducted using the currents from only Lake Huron, which were obtained from GLERL Great Lakes Coastal Forecasting System (GLCFS) and extracted for dates which exhibited typical current flows associated with the summer and winter seasons. It must be kept in mind that oil that travels into Lake Michigan is transported only by winds, while oil that moves into Lake Huron is transported by winds and surface currents.

Winds

Wind data used in the simulations was obtained from GLERL Great Lakes Coastal Forecasting System (GLCFS). This dataset defines the wind field at 10 meters above the land/sea surface and is provided at a one-hour interval. A combined wind dataset from Lake Michigan and Lake Huron was utilized for this study. Figure 2 shows the distribution of wind speeds and directions for the summer months. Figure 3 shows the distribution of wind speeds and directions for the winter months.

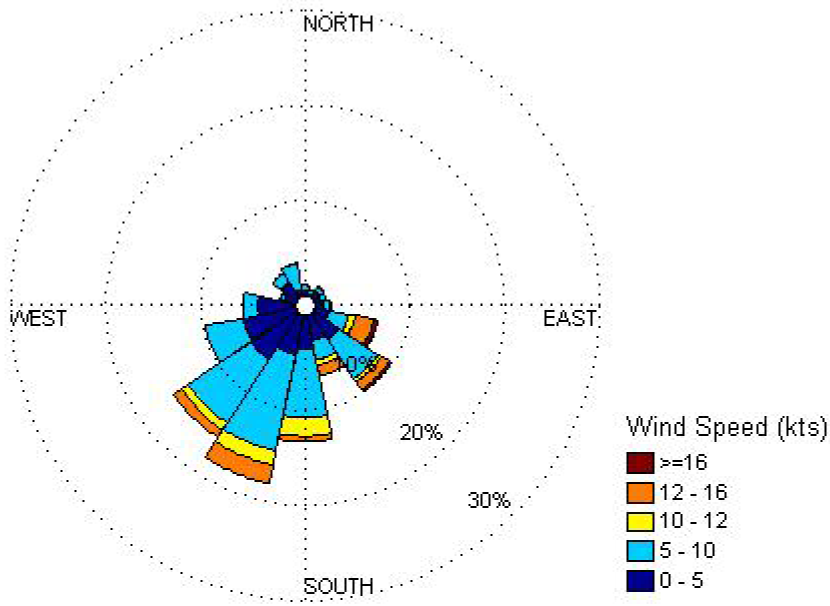


Figure 2. Wind rose diagram showing the distribution of summer wind speed and direction in the region of the spill simulations. Data are from the Great Lakes Coastal Forecasting System (GLCFS).

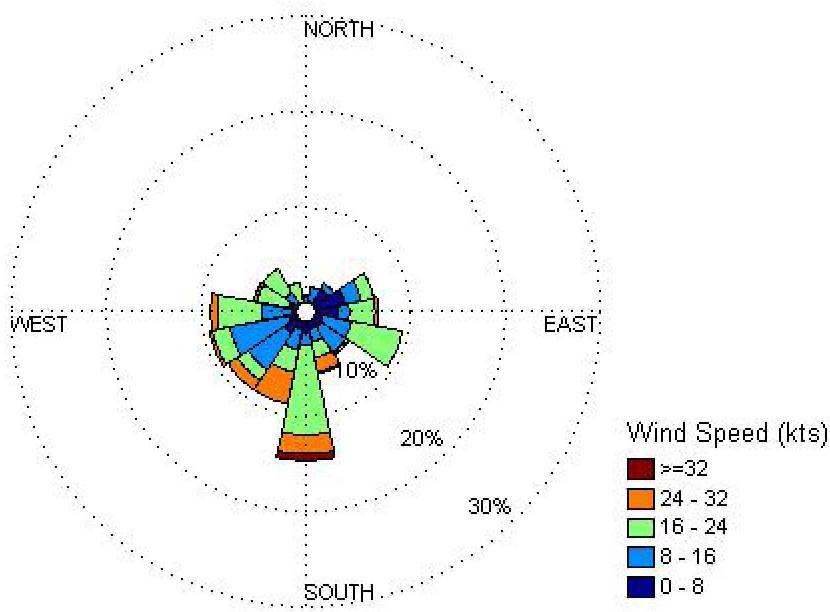


Figure 3. Wind rose diagram showing the distribution of summer wind speed and direction in the region of the spill simulations. Data are from the Great Lakes Coastal Forecasting System (GLCFS).

Oil Properties

Table 1 lists the properties of the light crude oil used in the modeling.

Table 1. Crude oil properties.

Oil Type	API	Density (g/cm^3)	Viscosity (cP)	Maximum Water Content (%)
Light Crude	40.7	0.8217	3.9	30

Spill Scenarios

Two potential subsurface light crude spill scenarios were simulated as summarized in Table 2. The center point of the pipeline was used as the spill site (see Figure 1) and each spill was simulated (tracked) for 5 days. The dates for the simulations were based on the selection of wind data typical for the summer and winter seasons. These scenarios and the resulting spill trajectories are representative of typical conditions, but are just one possible outcome for spills at this location.

Table 2. Summary of Spill Scenarios

Scenario ID	Oil Type	Spill Type	Period	Date of Simulation	Spill Duration	Total Spilled Volume	Simulation Duration
1	Light Crude	Subsurface (Pipeline Leak)	Winter	11/23/2013	0.5 hrs	7,858 bbl	5 days
2	Light Crude	Subsurface (Pipeline Leak)	Summer	7/15/2013	0.5 hrs	7,858 bbl	5 days

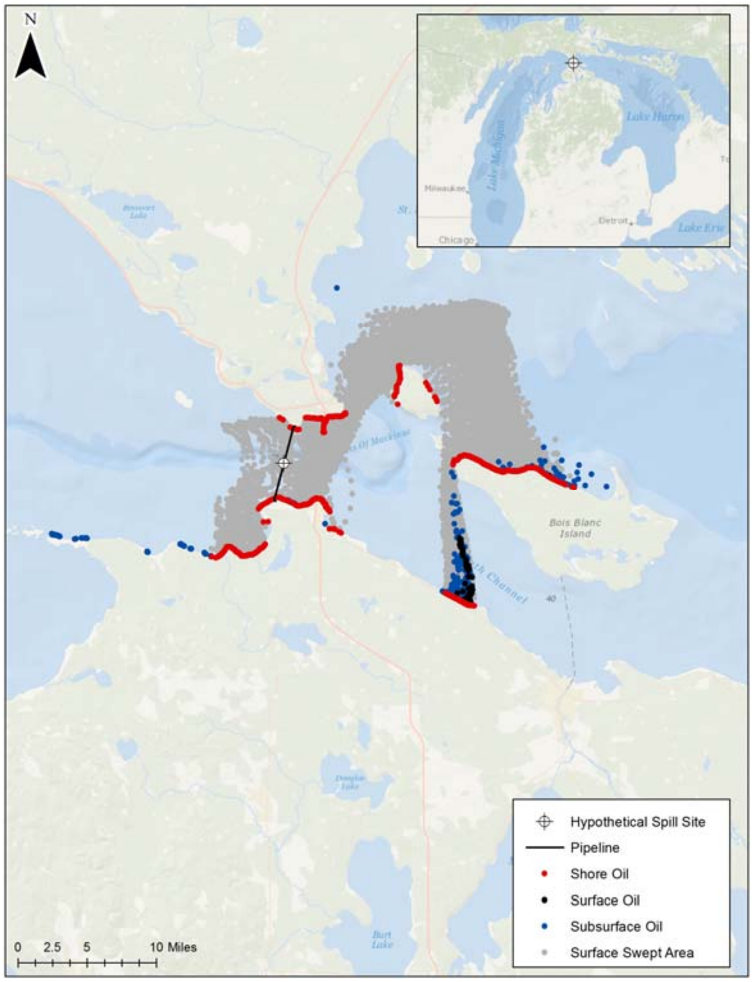
Model Results

Model results from the two scenarios are provided below in Figures 4 and 5. Each figure includes a map showing the trajectory of the oil over the length of the simulation period and a graph showing the fate of the oil over that period. The maps are colored to show oil on the sea surface, entrained into the water column by wave energy and stranded on the shoreline at the end of the 5-day simulation period. The associated graph of the oil mass balance shows the degree of weathering that the oil undergoes during this period. The graph depicts the barrels of oil predicted to be in a sea surface slick (Surface), below the surface as entrained oil droplets (Entrained), stranded on the shoreline (Ashore), and evaporated to the atmosphere (Atmosphere).

As shown by the mass balance graphs in both scenarios, the light crude oil rises to the surface almost instantly and immediately starts to evaporate and become entrained into the water column by waves. The volatile nature of the light crude oil causes rapid evaporation from the surface slick. Wind blowing over the water surface generates waves that force the oil into the water column. Winds during the winter months are typically stronger than summer winds and more oil is entrained into the water column during the winter spill. The lower wind speeds in the summer mean that less oil is entrained by waves leaving more oil on the surface and the possibility for more evaporation.

The trajectory maps in Figures 4 and 5 show that oil does travel into both Lakes Michigan and Huron. However, the majority of the oil is driven to the east into Lake Huron by winds and currents. At the end of the 5 day winter simulation, there is no oil left on the water surface, nearly 52% of the oil has been entrained by waves into the water column, 15% has stranded on the shoreline and 34% has evaporated. At the end of the 5 day summer simulation, 6% of the released oil remains on the water surface, 11% has been entrained into the water column, 33% has stranded on the shoreline, and nearly 51% has evaporated.

Maps in the Appendix show the predicted spill trajectory for the summer and winter seasons at 6, 12, 24 and 48 hours after the spill start.



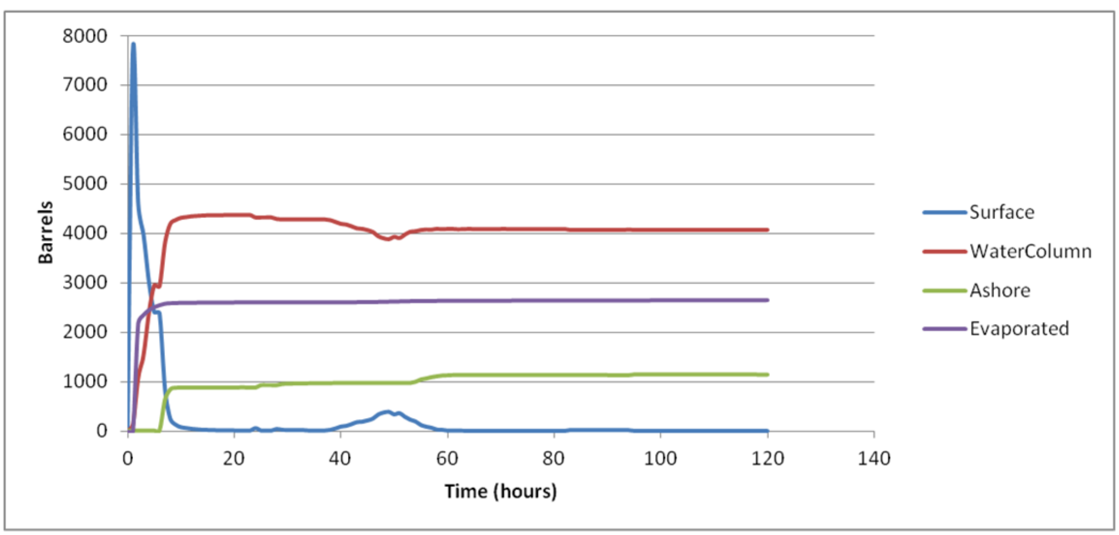
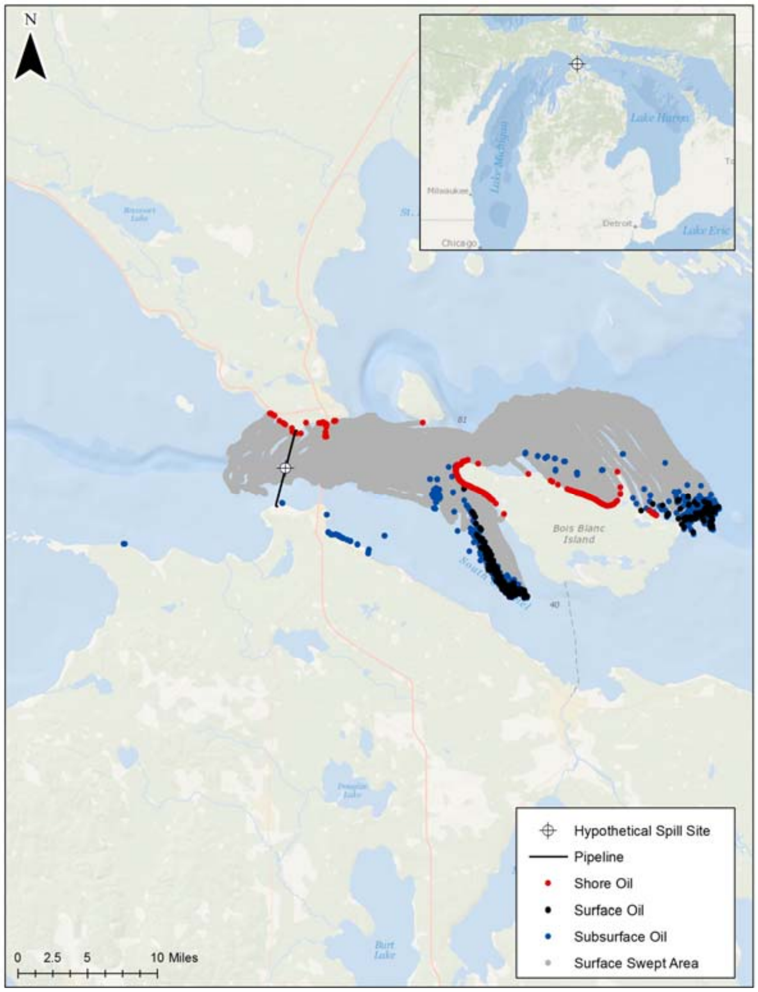


Figure 4. The oil trajectory predicted for a subsurface release of 7,858 bbl of light crude oil in the winter season is shown on the map. The surface, subsurface, and shoreline oil depicted is the model prediction at the end of the 5-day simulation of the spill. The graph shows the oil mass balance over the course of the 5-day period.



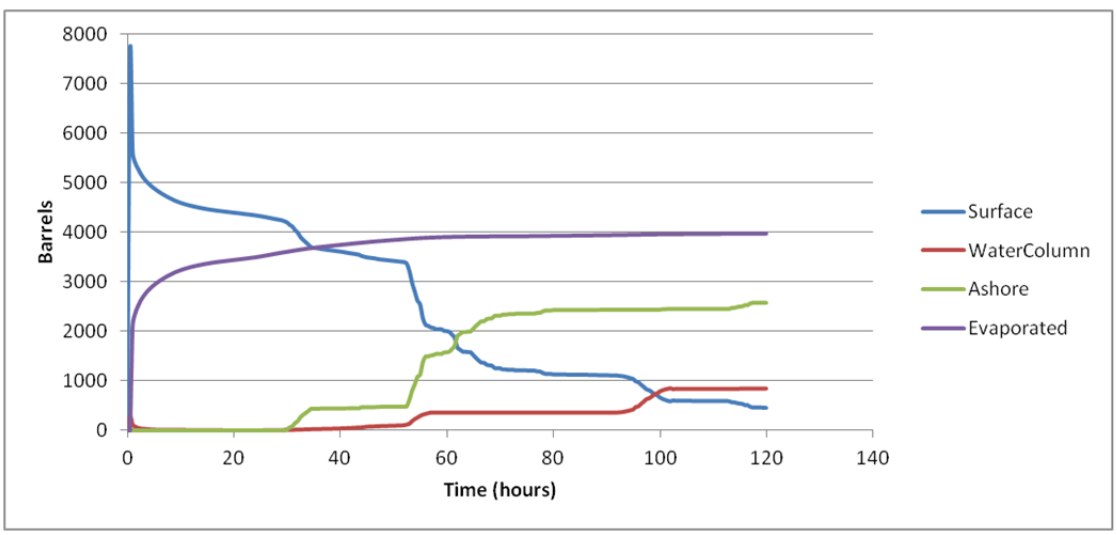


Figure 5. The oil trajectory predicted for a subsurface release of 7,858 bbl of light crude oil in the summer season is shown on the map. The surface, subsurface, and shoreline oil depicted is the model prediction at the end of the 5-day simulation of the spill. The graph shows the oil mass balance over the course of the 5-day period.

References

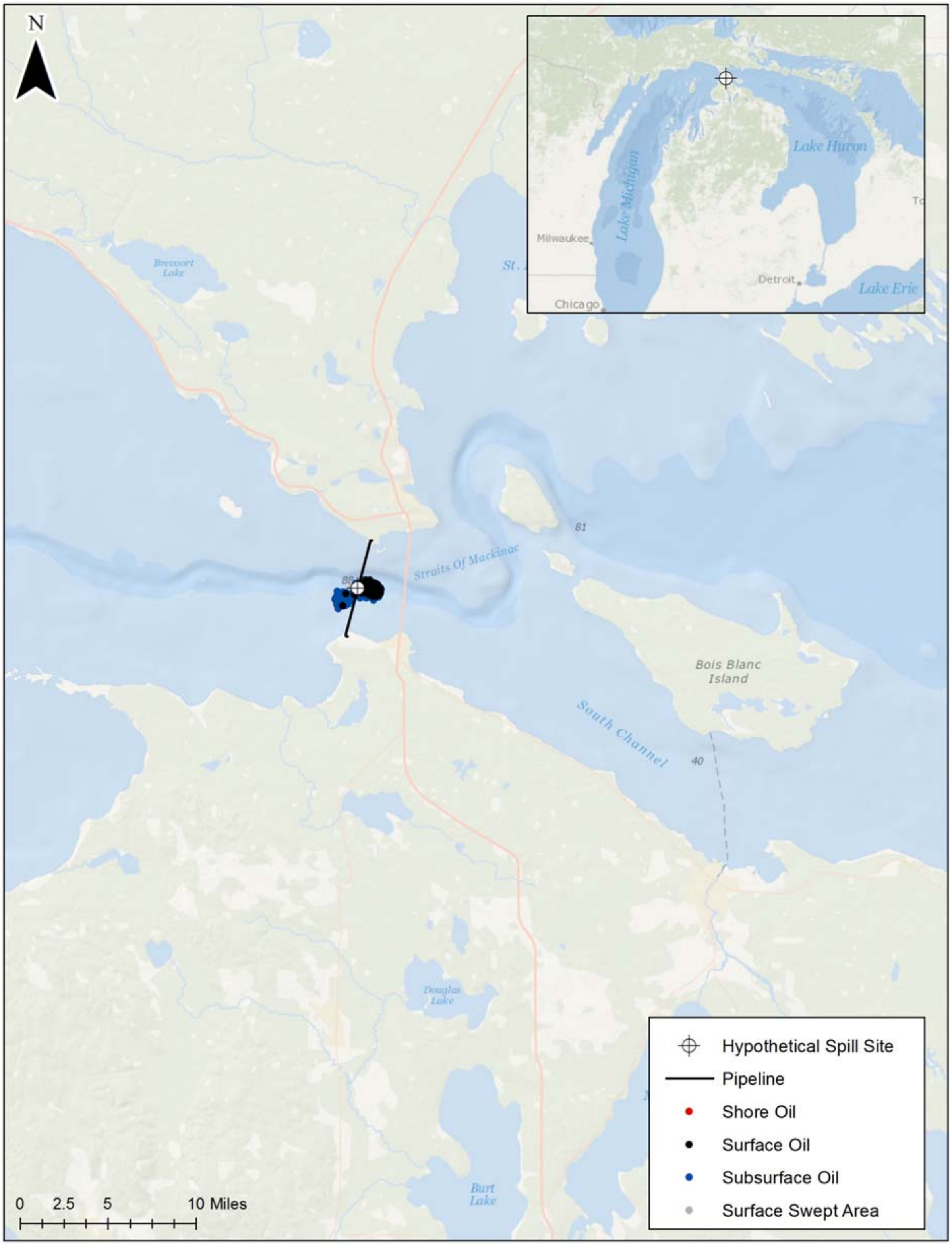
Anderson, E.J. and Schwab, D.J., (2013). Predicting the oscillating bi-directional exchange flow in the Straits of Mackinac. J Great Lakes Res, http://dx.doi.org/10.1016/j.jglr.2013.09.001

Saylor, J.H. and Miller, G, (1991). Current Flow through the Straits of Mackinac. Great Lakes Environmental Research Laboratory (GLERL). http://www.glerl.noaa.gov/pubs/fulltext/1991/19910004.pdf

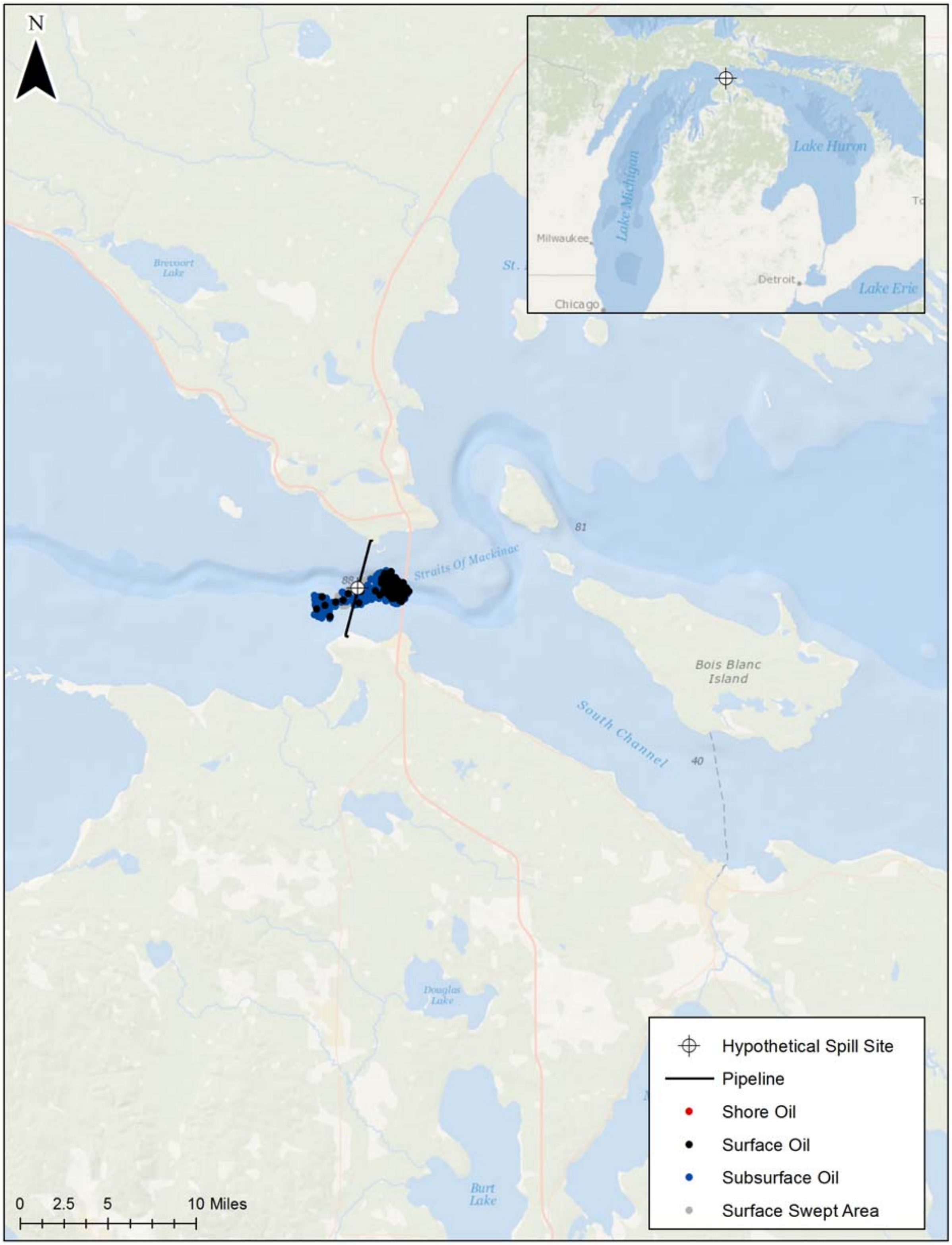
Saylor, J.H. and Sloss, P.W., (1976). Water Volume Transport and Oscillatory Current Flow through the Straits of Mackinac. Great Lakes Environmental Research Laboratory (GLERL). http://www.glerl.noaa.gov/pubs/fulltext/1976/19760003.pdf

Appendix – Maps Showing Spill Trajectories at 6, 12, 24 and 48 Hours

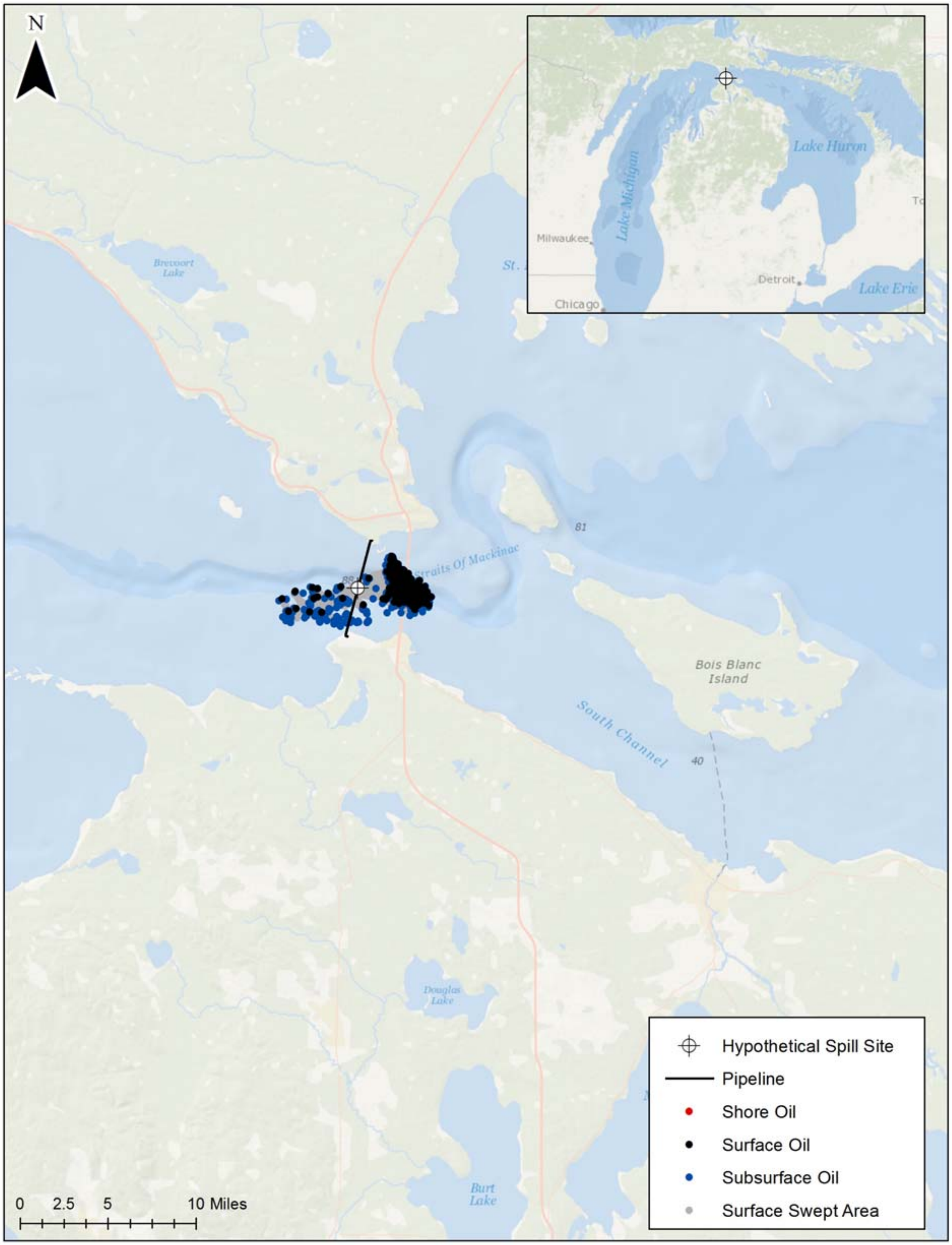
Maps contained in this appendix are snapshots of the predicted oil spill trajectory for summer and winter environmental conditions.



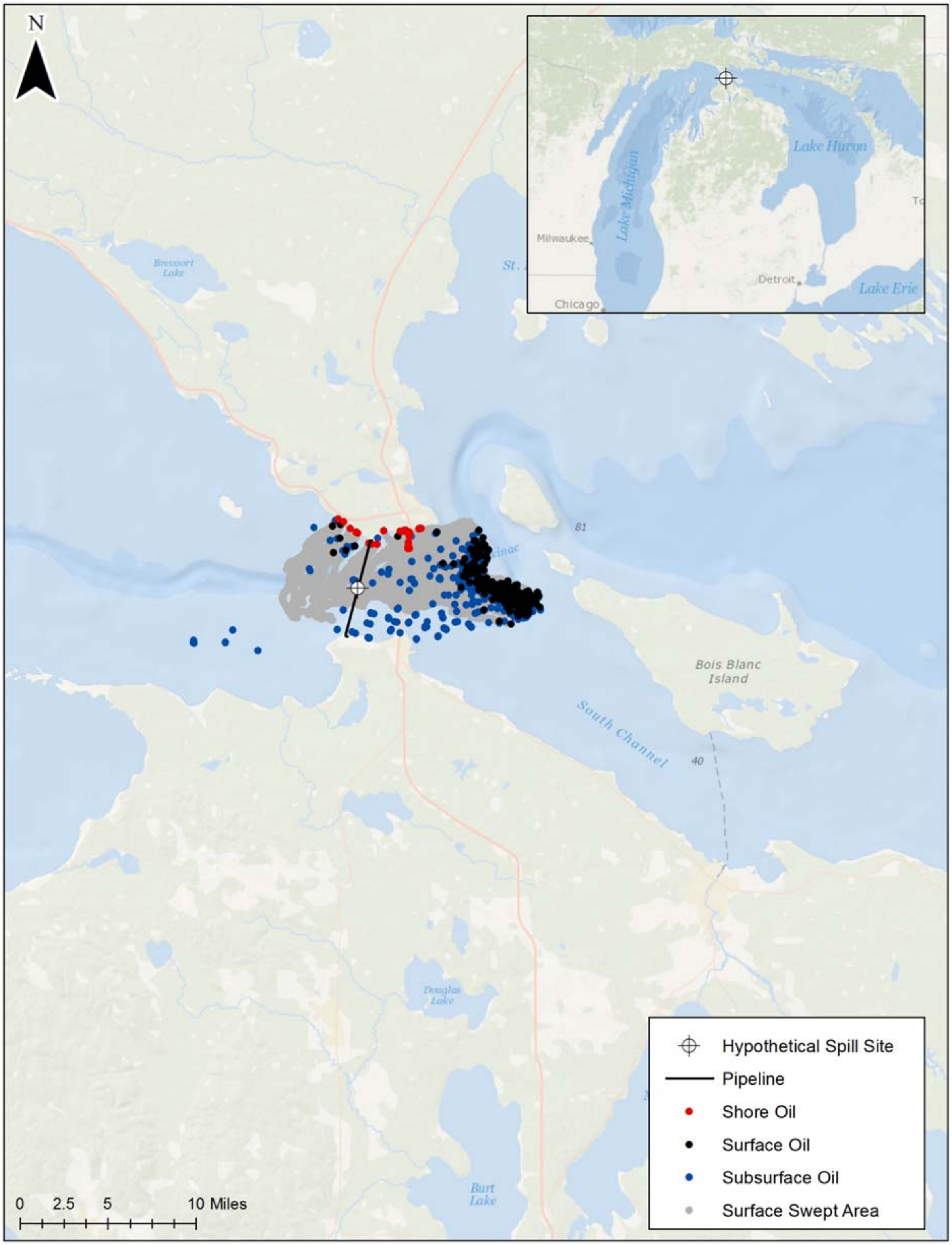
Summer spill trajectory at 6 hours



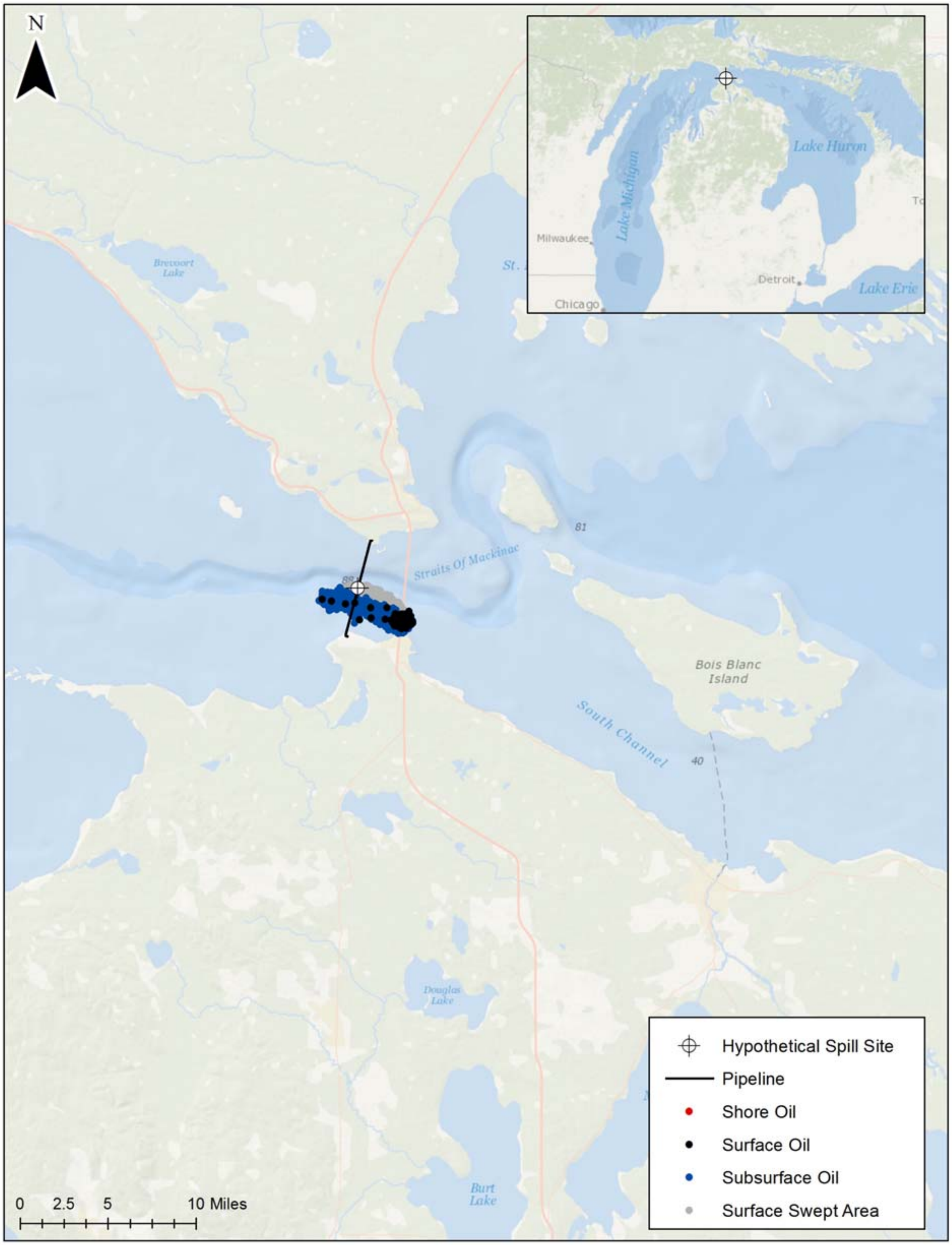
Summer spill trajectory at 12 hours



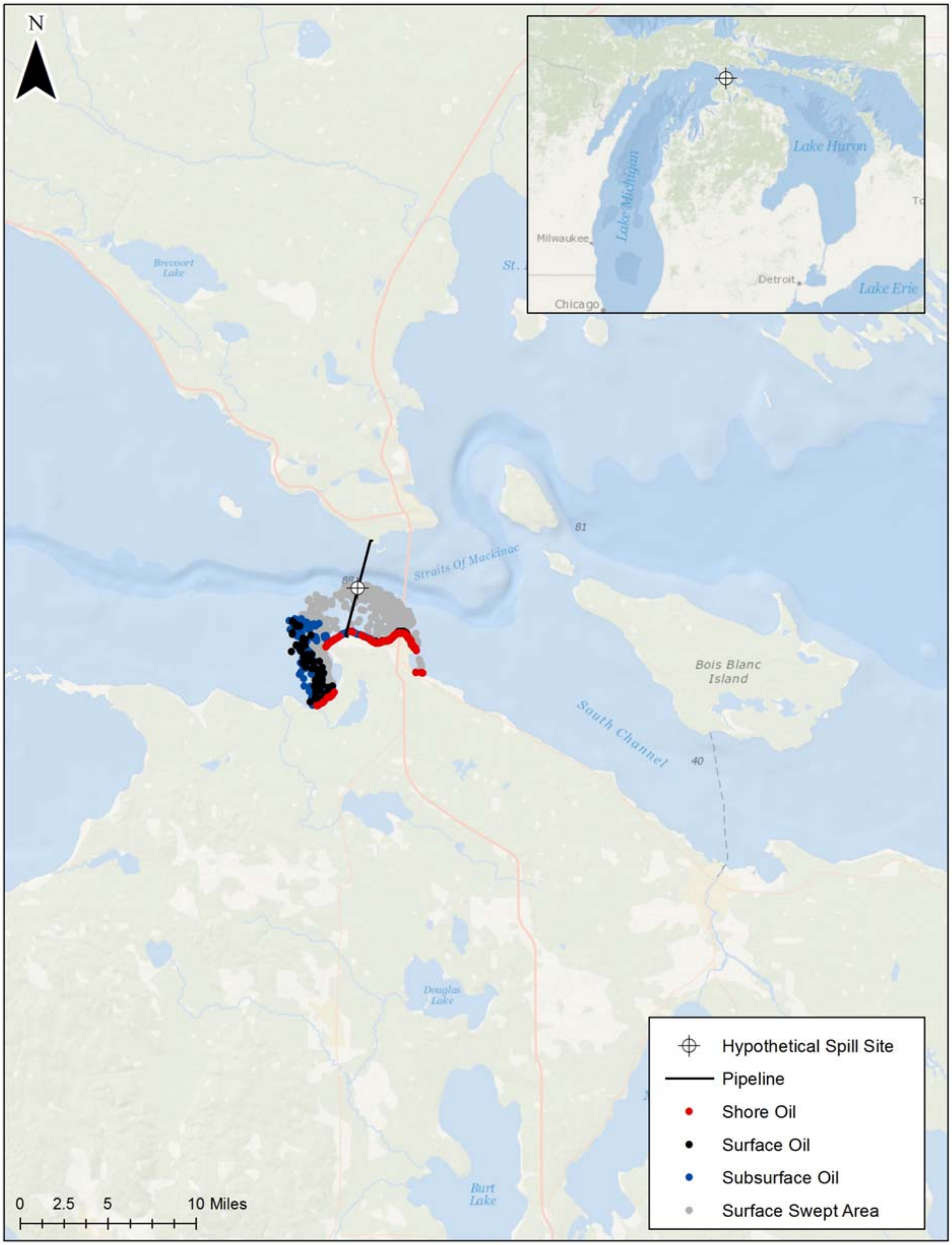
Summer spill trajectory at 24 hours



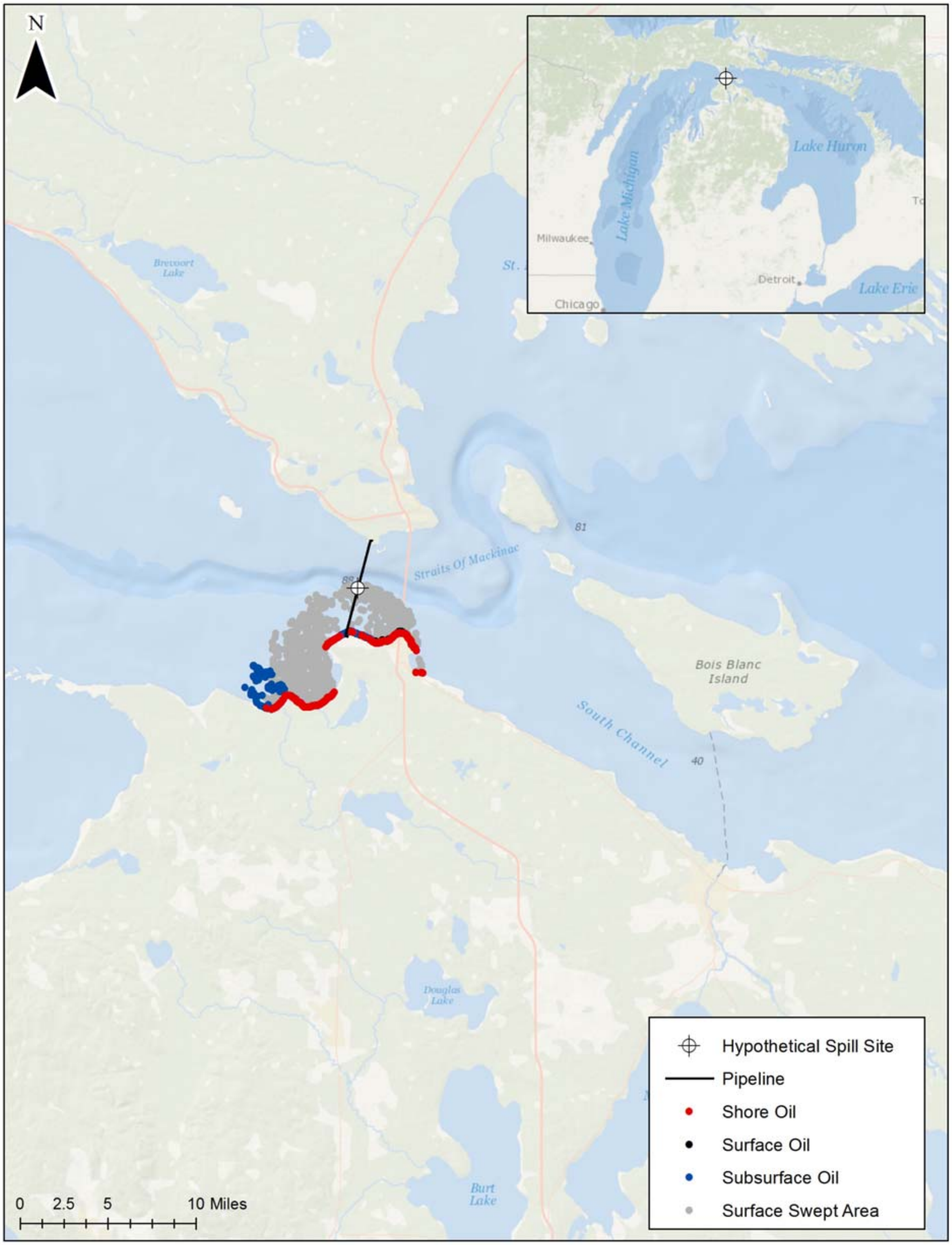
Summer spill trajectory at 48 hours



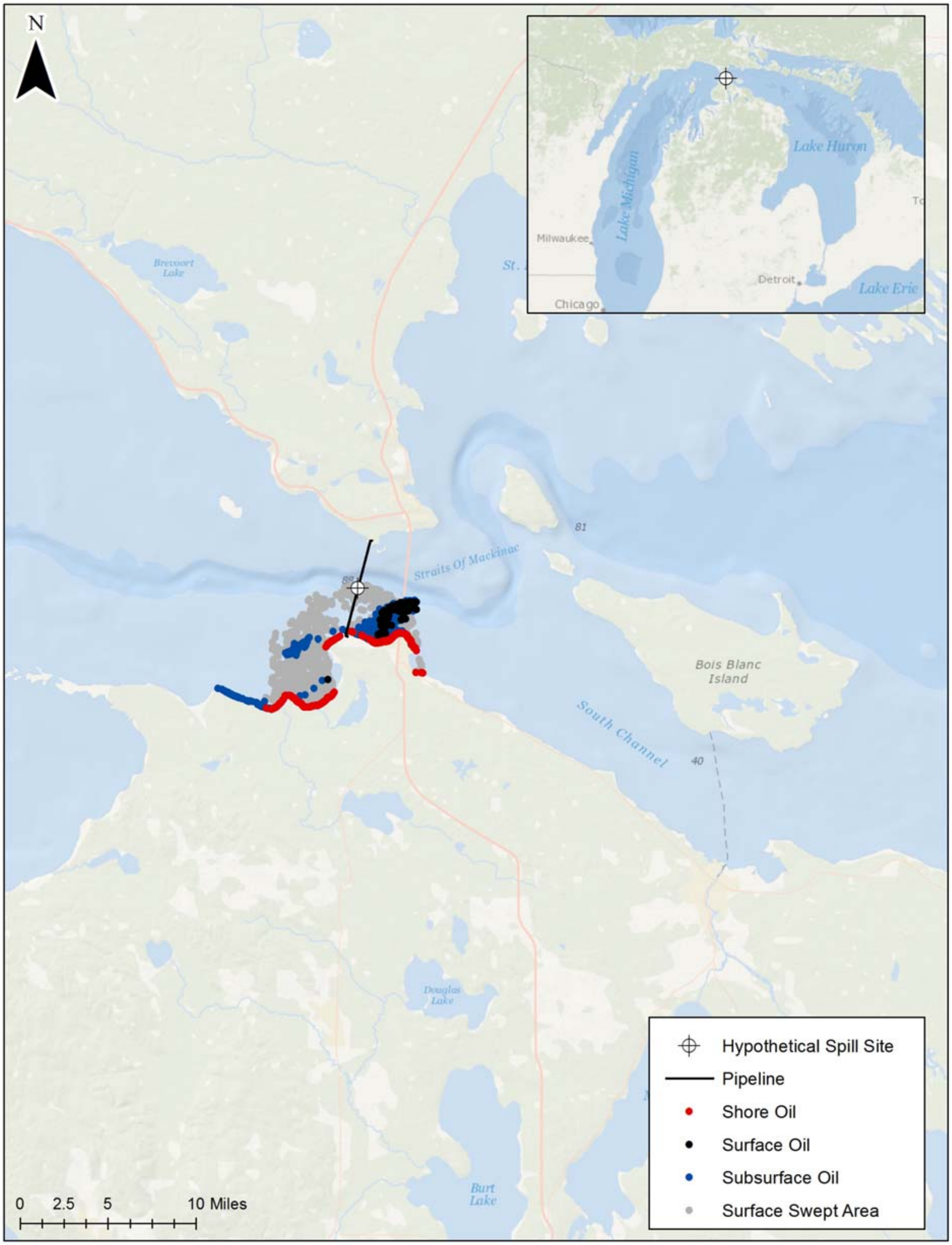
Winter spill trajectory at 6 hours



Winter spill trajectory at 12 hours



Winter spill trajectory at 24 hours



Winter spill trajectory at 48 hours