Environmental Sensitivity to Oil Exposure in the Great Lakes Waters:

A Multimodal Approach.

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1. INTRODUCTION

1.1 Context

The Great Lakes' economies and social development in both USA and Canada have significantly benefited from centuries of movement of commodities and in particular of natural resources. Among them, oil is a commodity receiving increasing attention because of growing needs for export but also because of the concerns associated with the impacts of oil products when spilled in the environment. Assessing the balance between costs and benefits of oil transportation has recently triggered a number analyses conducted at the national level aiming at increasing safety (ex: national risk assessment for ship source oil spills in Canada, WSP 2014). Recent scientific reviews (Lee et al. 2015; Fitzpatrick, F.A. et al. 2015) on oil fate and behaviour when spilled in aquatic systems have highlighted the need for further research on freshwater environments. Such research would particularly be beneficial in support of planning and responding in case of oil spills in areas where multiple modes of transports exist.

This study builds on a previous risk assessment of ship source oil spills in Canadian waters (WSP 2014), which includes the Great Lakes but only considered oil volumes and movements occurring in Canadian waters. One of the conclusion of this study was the need to integrate data from both USA and Canada in order to appropriately assess sensitivity to oil exposure and risk of spills.

1.2 Objectives

The objective of this study is to complete a sensitivity analysis to oil exposure in the Great Lakes based on a spatial, multimodal approach that includes oil transported via marine, rail and pipeline transport modes. This analysis provides a visual tool to compare the contribution of the sensitivity of various sources of oil transported in the Great Lakes basin. The analysis was conducted using the most recent oil volumes transported in the Great Lakes basin, but the developed approach could be further applied to include oil volumes transported as the results of future projects. The results of this analysis can therefore be used to define areas sensitive to oil exposure now, and could be adjusted if volumes were to change in the future. Such results could be applied as a first step towards the identification of areas requiring a more detailed risk assessment and where response plans could be developed/expanded as a priority.

1.3 Study Area

The study area includes the 5 Laurentian Great Lakes as well as the St Lawrence River, up to the limit where freshwater meets salt waters, close to Quebec City.

1.4 Study Limitations

The following limitations should be considered when assessment the accuracy and validity of the results:

- The study area is narrowed to Great Lakes basin and the activities occurring at the proximity of the Great Lakes shores. The results do not include rivers (other than the St. Lawrence River) and tributaries.
- Pollution sources from vessels are limited to ships carrying Automatic Identification Systems (AIS), which includes barges carrying oil as cargo, vessels above 400 GT and oil tankers above 150 GT). Smaller vessels, although carrying oil as fuel, are not included in the vessel tracking maps.
- Oil is categorised as crude oil (for pipeline and rail); fuel oil or heating oil, gasoline and other oil products (for marine shipping). Other petroleum products such as coke and asphalt, although moved in large quantities, were not included in this study.
- This study is based on publicly available data obtained from various federal departments and agencies. For oil movement, data from the last recent years were analyzed and combined to produce heat maps for each transport mode. Future projects (ex: pipelines) and changes in shipping activities will modify the results of this study as they are related to current oil volumes and movements.
- No responses (either mechanical recovery of oil or alternative response techniques such as dispersants) to spills are considered in this sensitivity analysis. The results from the study assume the absence of a response and will provide a “worst case” scenario for each zone.
- The sensitivity index was developed using data on physical, biological and social features that would generally be affected by oil if spilled in the environment. Further analyses could be conducted to select specific features affected by the exposure of specific oil types. This analysis is a first attempt to collect data from both USA and Canada and provide a large-scale estimate of oil exposure sensitivity.
- This analysis is not a risk assessment because it does not consider the

probability of spills from each transport mode. Although spills probabilities for marine shipping exist, similar data for pipeline and rail was not available. In addition, this analysis does not consider the trajectory, behaviour and weathering of oil if spilled. Such information would be required to accurately define the risk of oil spills at a smaller spatial (and temporal) scale.

2. METHODOLOGY

2.1 Scope

The methodology herein aims at providing a framework to evaluate the sensitivity of the Great Lakes water to oil exposure from marine, pipeline and rail transport mode.

2.2 General Approach

The sensitivity to oil exposure was defined as the product between 2 estimates: the oil volumes from each transport mode and the environmental sensitivity index (ESI). This approach involves the following key elements:

- Oil data was used to generate heat maps, considering marine shipping (water based sources) and terrestrial activities (pipeline and rail), based on most recent years of data.
- The environmental sensitivity index (ESI) was calculated following methods developed in the national oil spills risk assessment in Canada (WSP 2014, Marty and Potter 2014), which includes the portion of the Great Lakes situated in Canada. This index combines data on physical, biological and human environments.
- The overall sensitivity to oil exposure is determined for each transport mode (pipelines, rail and marine) by connecting spatial layers in a Geographic Information System (GIS) metadata. This approach produces maps to assess the spatial distribution of the sensitivity.

2.3 Data Collection

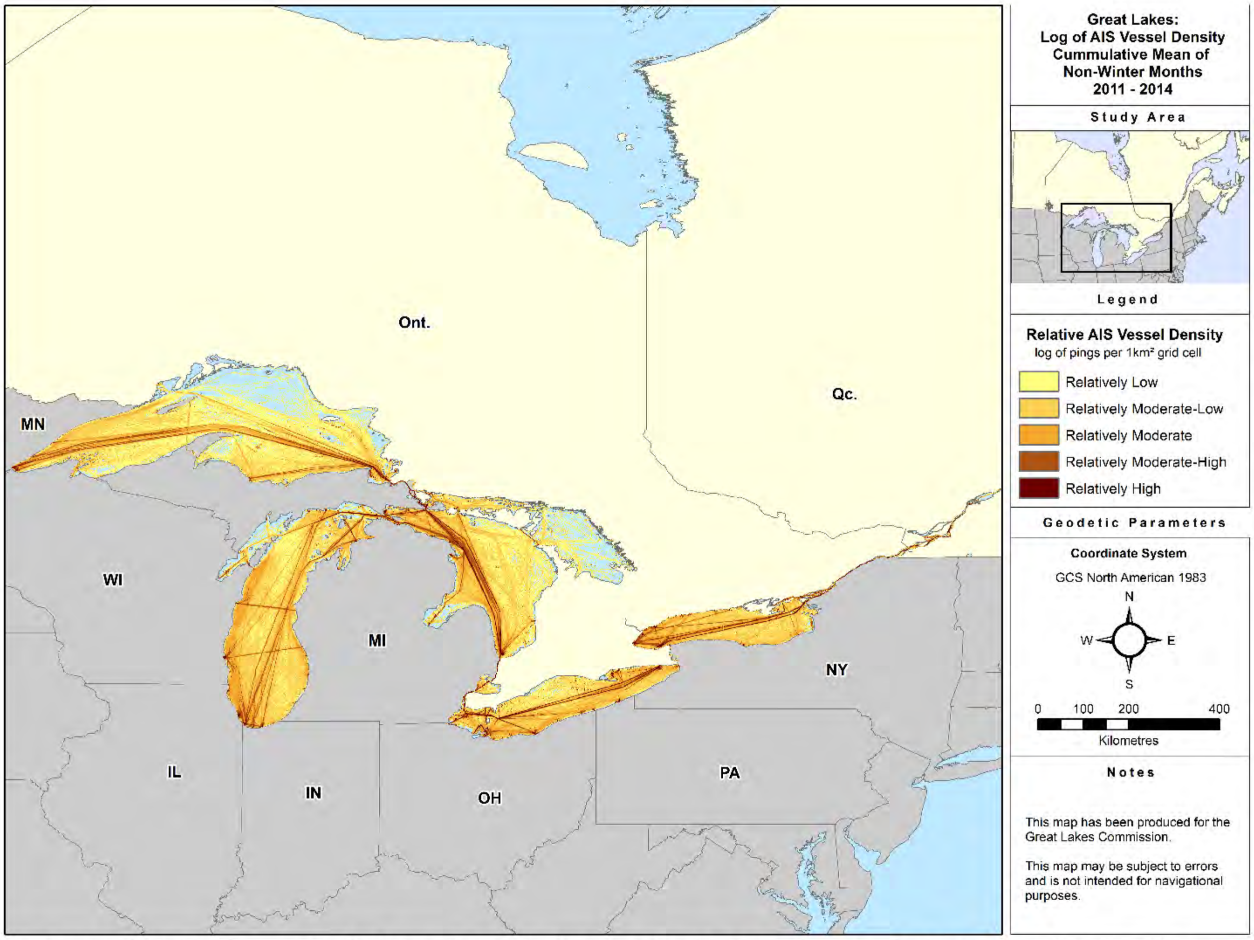
Different datasets are required to project oil volumes in Great Lakes waters and calculate the environmental index. Specific details on the data assembled and how they were manipulated for this study are provided in the following sections.

2.3.1 Vessel Traffic

To identify areas within the Great Lakes that have relatively high amounts of vessel traffic density, we used Automatic Identification System (AIS) data from 2011 to 2014 collected by the US Coastguard and compiled by the National Oceanic and Atmospheric Administration (NOAA) & the Bureau of Ocean Energy Management (BOEM), which provide records of geographic point data of vessel location, filtered to one minute per month. AIS is required for all ships above 300 tonnes, according to international regulation (IMO). The data was then integrated into a GIS framework using a 1 km^2 grid of the Great Lakes, which was then used in conjunction with a spatial join count to identify the amount of AIS points per grid cell per month.

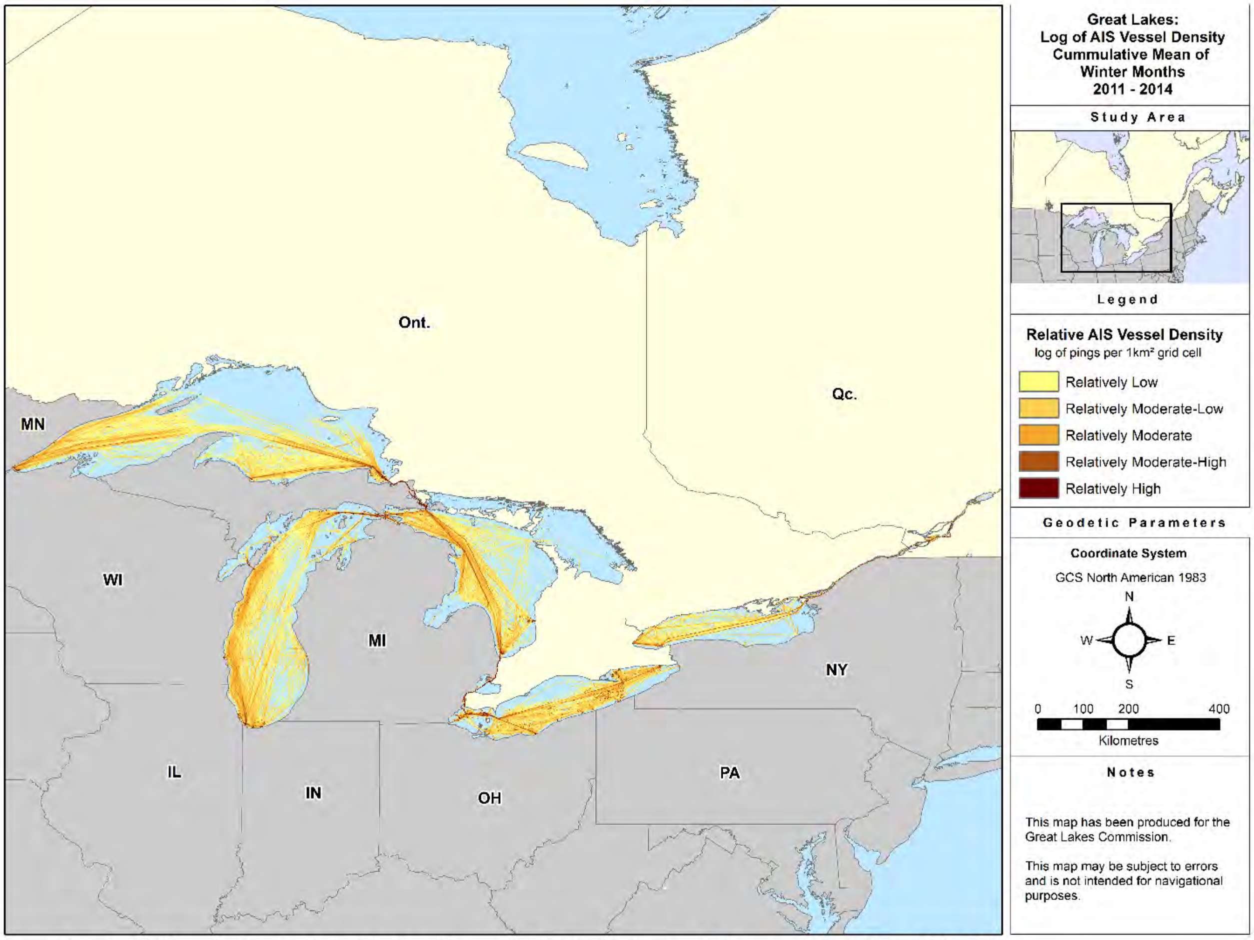
Statistical analyses were conducted to test for inter-annual variations and to detect seasonal patterns. The results from these analyses showed that we can use mean values for all years (no significant variation between years) but also that significant variation occurs seasonally. Therefore, summer and winter maps were considered to more accurately capture traffic variation and therefore potential variation in exposure.

Figures 1 and 2, below illustrate the mean traffic densities in summer and winter, with a logarithmic transformation. Most of marine shipping traffic occurs when the seaway is open, with concentrated traffic observed in the seaway itself.



Average AIS Vessel traffic density (log) for the non-winter months (April, May, June, July, August, September, October, November) from 2011 - 2014.

Fig. 1: Summer marine shipping density in the Great Lakes, based on AIS data. Data shown in log transformed scale to facilitate visualization.



Average AIS Vessel traffic density (log) for the winter months (December, January, February and March) from 2011 - 2014.

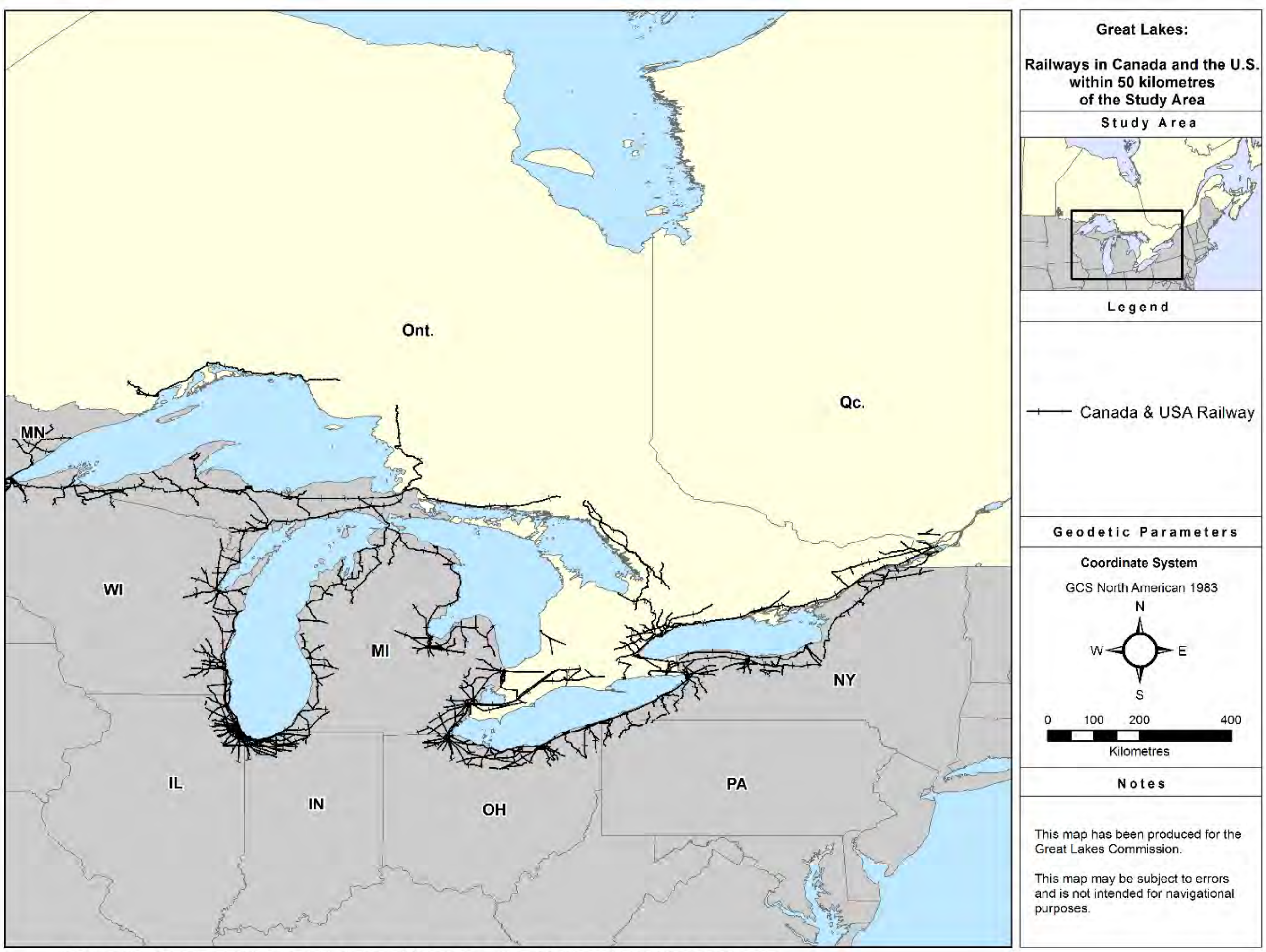
Fig. 2: Winter marine shipping density in the Great Lakes, based on AIS data. Data shown in log transformed scale to facilitate visualization.

The AIS data was then combined with navigable waterways (shipping lanes) spatial data collected from the U.S. Army Corps of Engineers (USACE), locations of refineries in North America collected from Natural Resources Canada (NRCAN), and commodity data on gasoline, fuel oil, and other petroleum products from 2011 – 14 from the St. Lawrence Seaway Management Corporation (SLSMC). The commodity data is based on actual opening and closing dates of navigation, where the average opening date of navigation is late March, and the closing date of navigation is late December.

2.3.2 Railway Data

The railway spatial data were collected from NRCAN for Canada (National Railway Network), and from the Bureau of Transportation Statistics for the United States (North American Transportation Atlas Data). Commodity data on crude oil transported by rail was also collected from 2011-14 for the two countries. The commodity data from Canada was collected from the National Energy Board (NEB), and for the United States it was collected from the U.S. Department of Energy (EIA).

The two features were in the same vector spatial format (lines), and were merged together, and rail nodes that were within 50-kilometres of the study area were selected for further manipulation (figure 3).



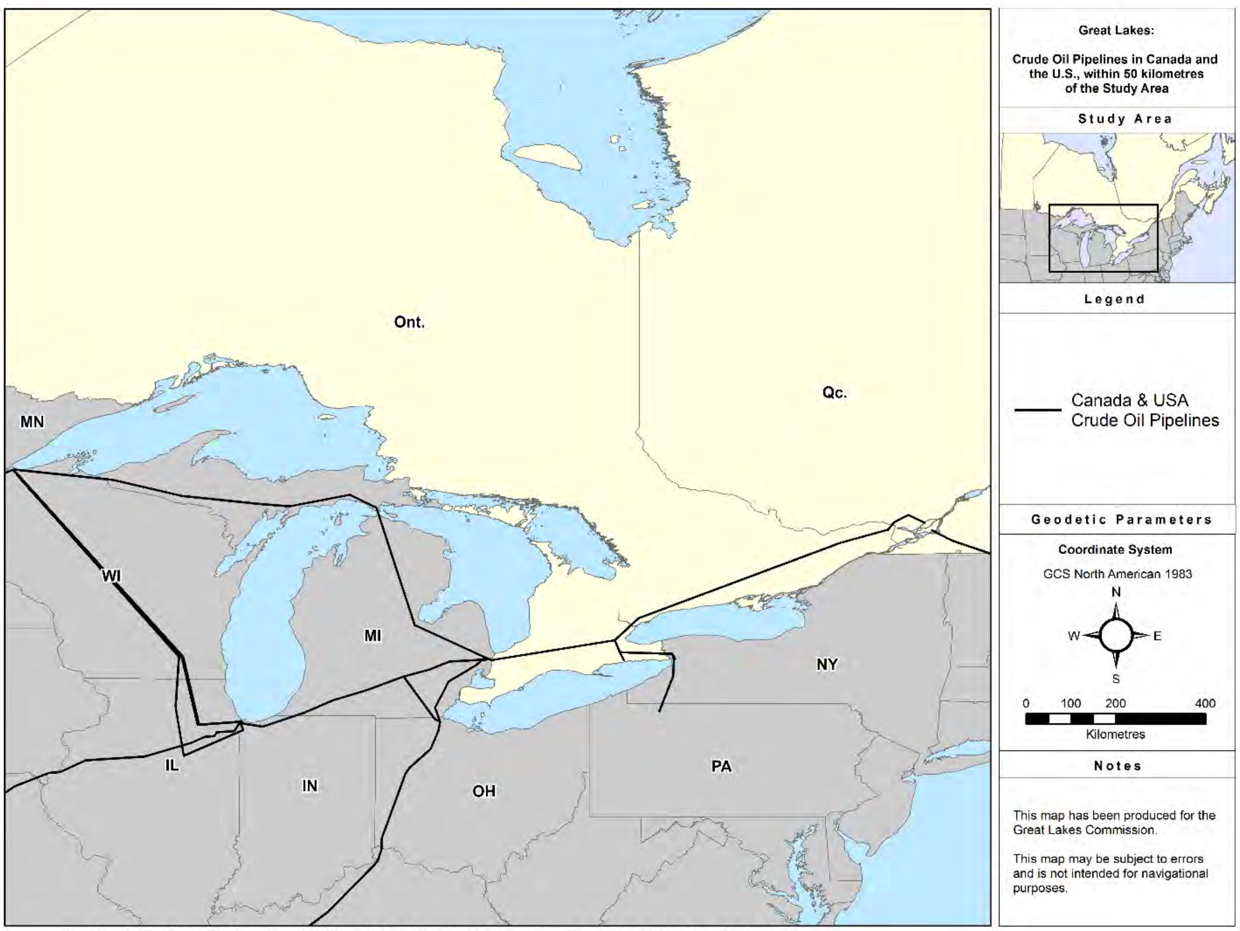
Railway in Canada and the United States of America, within 50 kilometres of the study area.

Fig. 3: Rail in Canada and the U.S. within 50-kilometres of the study area.

2.3.3 Pipeline Data

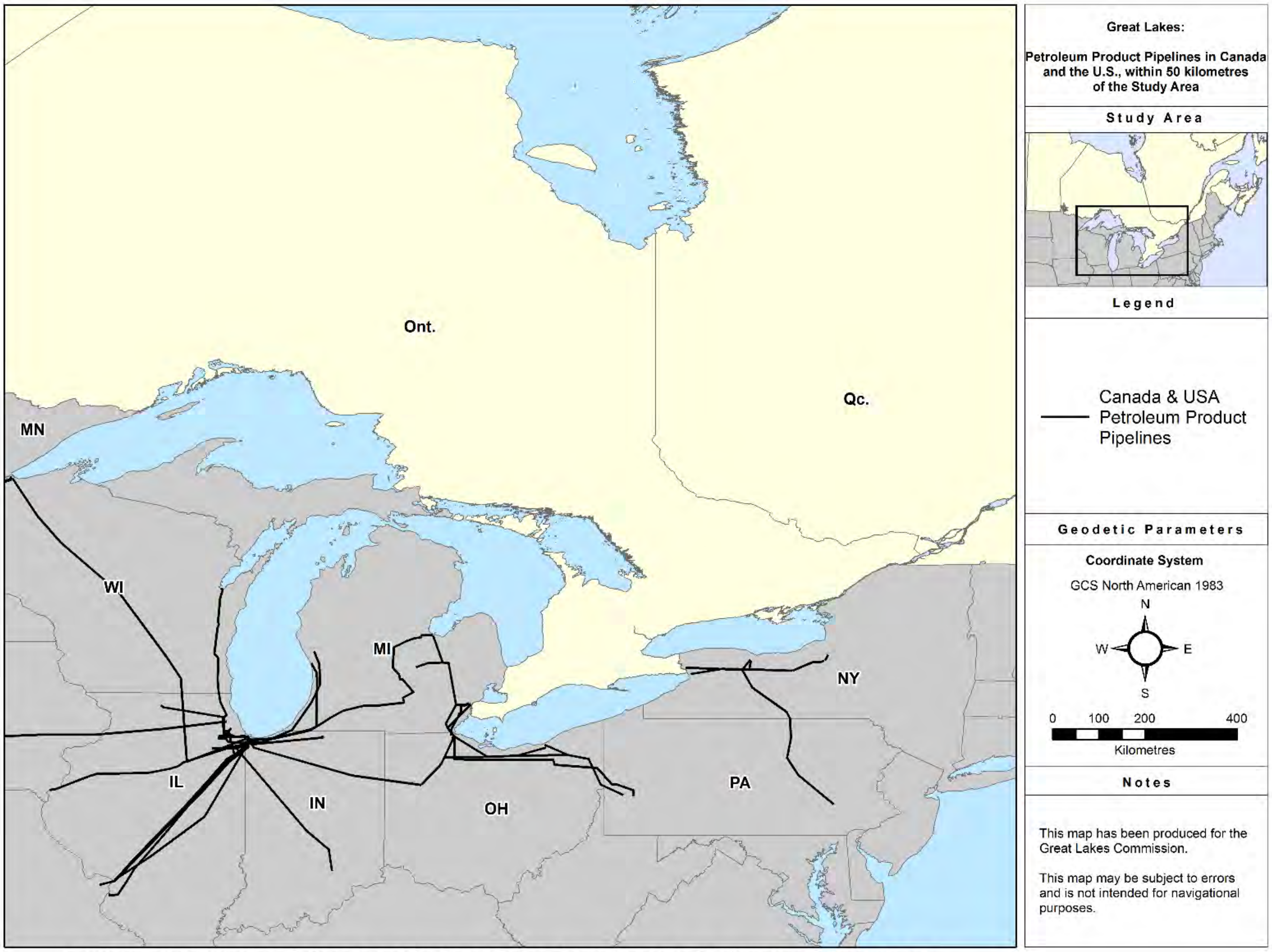
The pipeline spatial data was collected from the EIA as two separate vector features for crude oil pipelines and petroleum product pipelines. Commodity data on crude oil, liquefied petroleum products & refined petroleum products Statistics Canada and from the EIA for Canada and the USA respectively.

The crude oil pipeline and petroleum pipeline nodes that were within 50-kilometres of the study area were selected for further manipulation (figures 4, and 5).



Crude oil pipelines in Canada and the United States of America, within 50 kilometres of the study area.

Fig. 4: Crude Oil product pipeline nodes within 50-kilometres of the study area.



Petroleum product pipelines in Canada and the United States of America, within 50 kilometres of the study area.

Fig. 5: Petroleum product pipeline nodes within 50-kilometres of the study area.

2.3.4 Vessel Density & Sensitivity

To calculate the vessel density, we applied a spatial buffer of 5-kilometres to the navigable waterways data, this layer was given a value of 1. A 25-kilometre spatial buffer was applied to the refineries, and given a value of 5, the two layers were then combined to create a shipping lane and refineries layer. This was then multiplied by the log of non-winter vessel traffic data, to act as a proxy for shipping density of the commodities we are interested in for the scope of this project (figure 6). To calculate the relative sensitivities by each oil type, the relative navigable waters density was used as the base, considering the 4-year mean (2011-14) of oil commodity types (gasoline, fuel oil, and other petroleum products) as the modifiers.

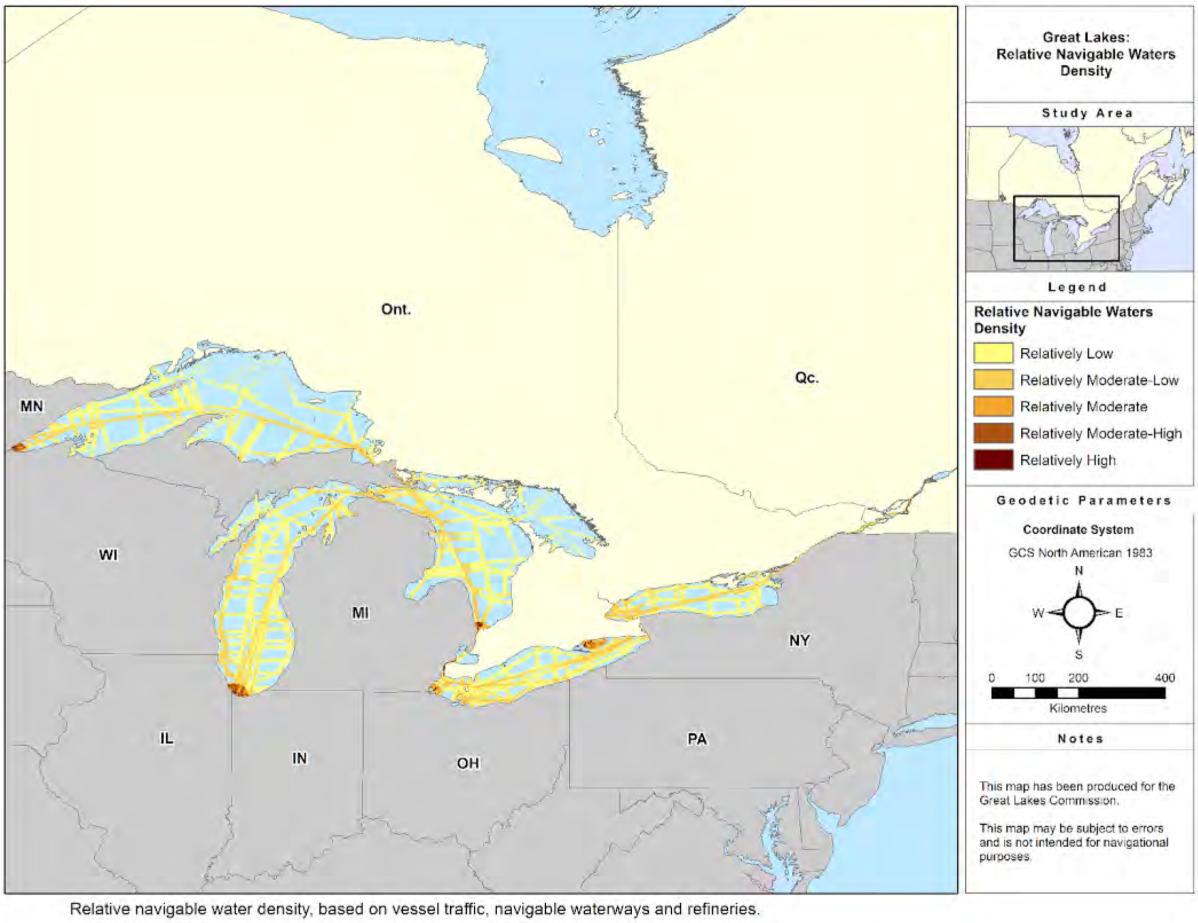
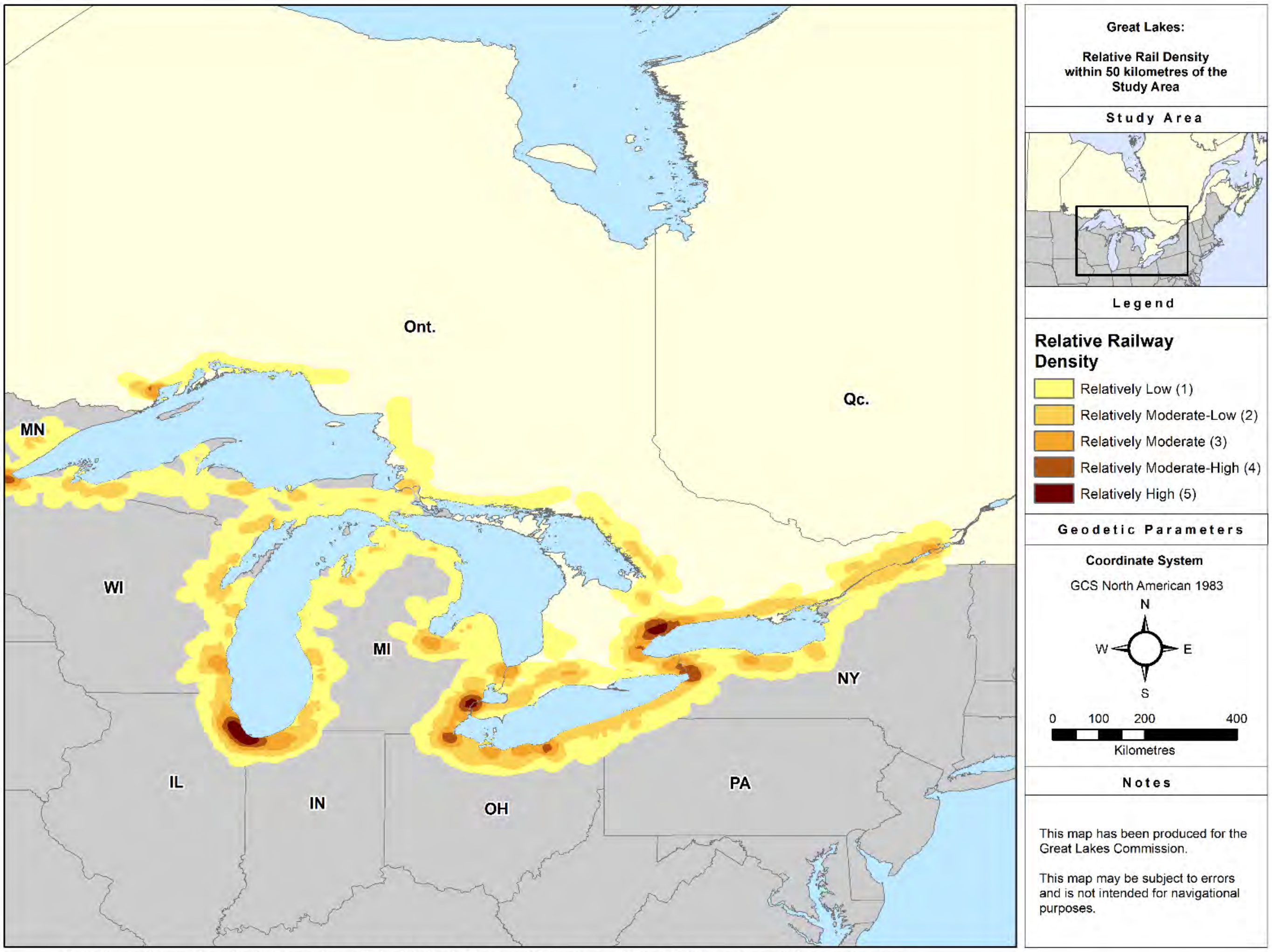


Fig. 6: Relative navigable water density in the Great Lakes, based on AIS vessel density, navigable waterways (shipping lanes) and proximity to refineries.

2.3.5 Pipeline and Rail Density &Sensitivity

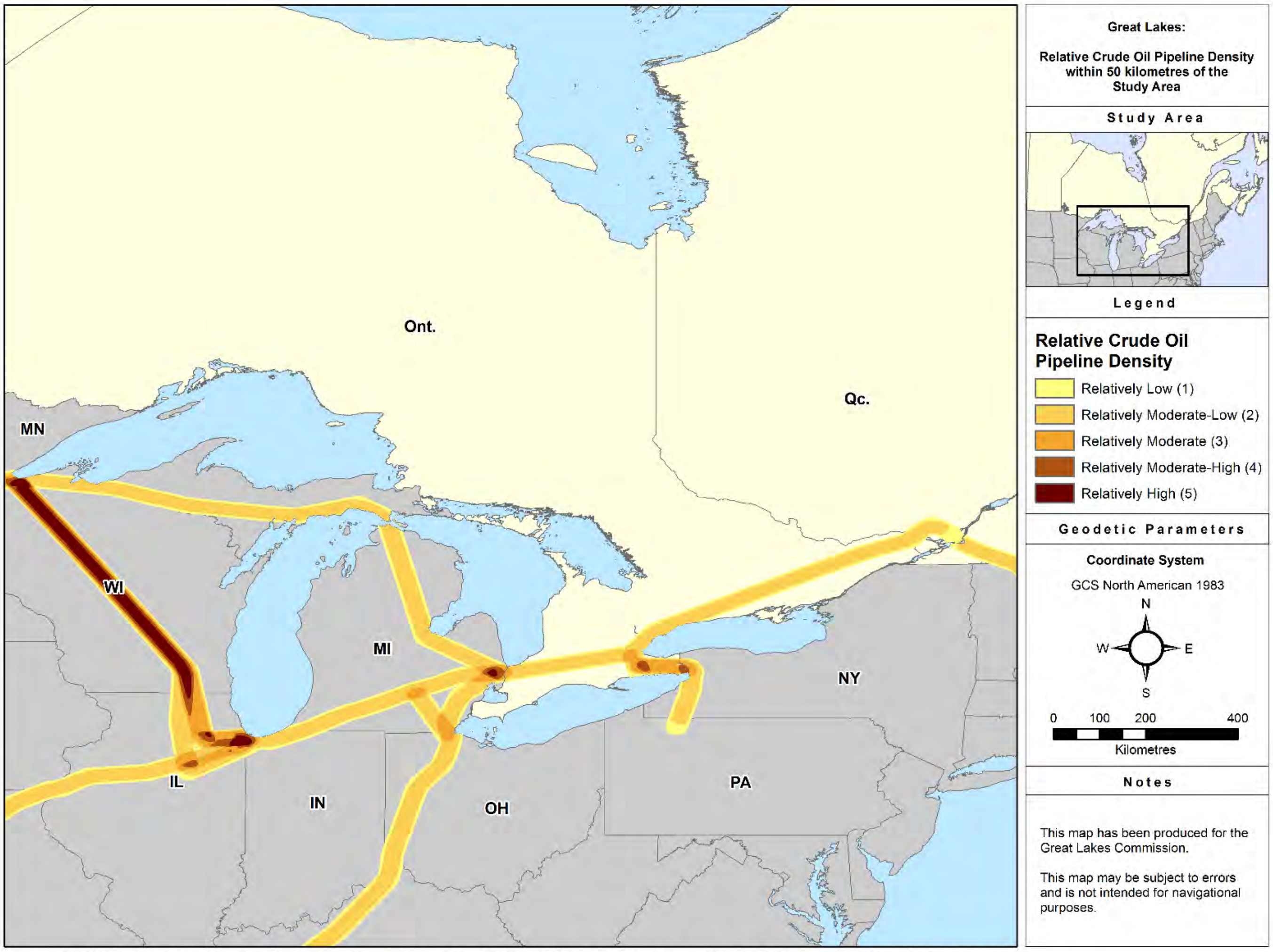
To calculate the relative sensitivities for pipeline and rail, a line density estimation was used to calculate the relatively magnitude per area (similar to the KDE method, which will be further discussed in a later section) within a GIS. The estimation was applied to each feature (crude oil pipeline, petroleum product pipeline, and rail) using no weighting and a search distance of 50-kilometres (25-kilometres on each side of the line).

The relative magnitude scores were then re-classified into 5-categories from relatively low (1) to relatively high (5) using Jenks Natural Breaks classification, this was then clipped to land only, to ensure no overlap with water (refer to figures 7, 8, and 9).



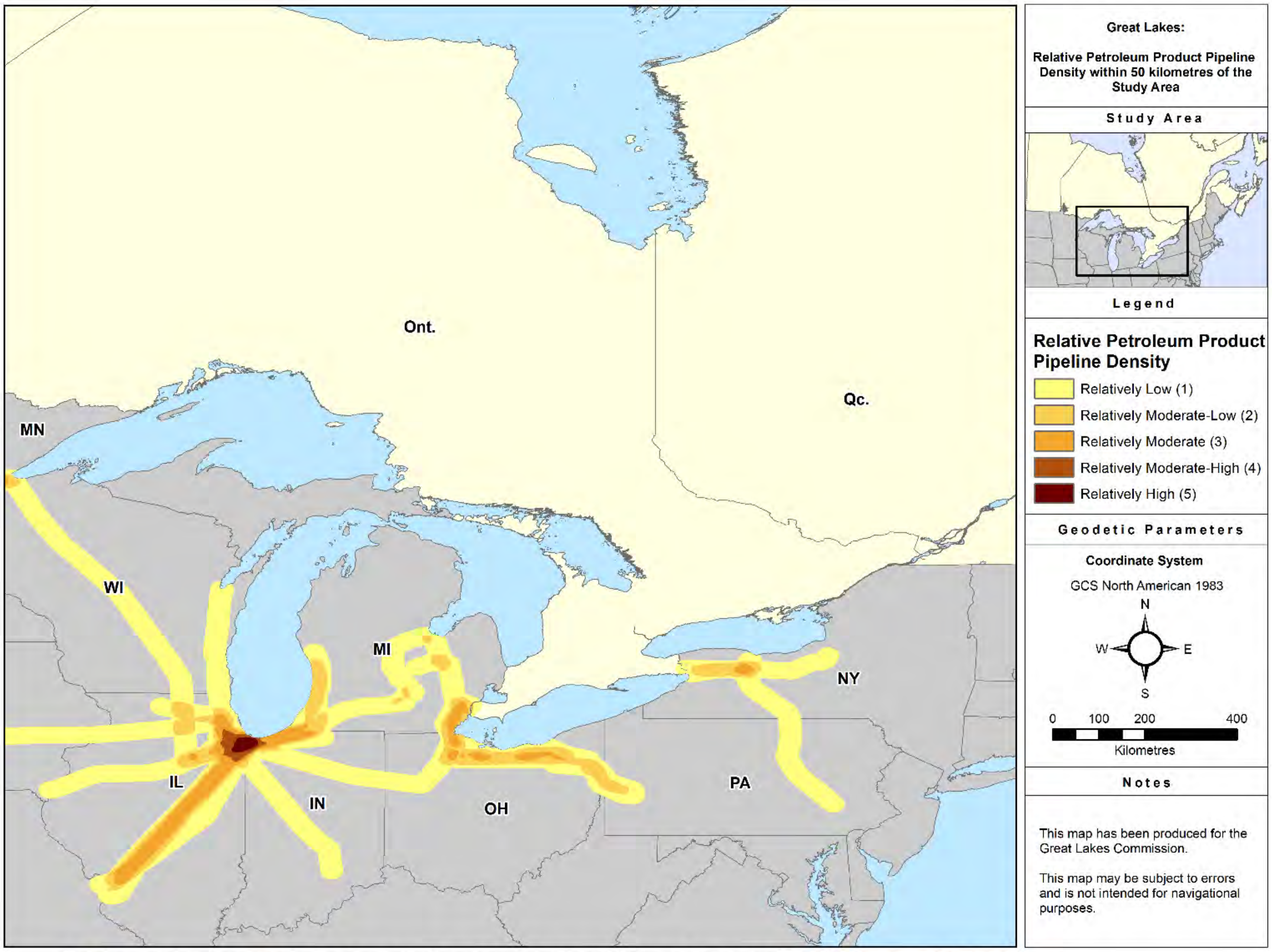
Relative railway density in Canada and the United States of America, within 50 kilometres of the study area.

Fig. 7: Relative rail density, calculated using the line density function within a GIS.



Relative crude oil pipeline density in Canada and the United States of America, within 50 kilometres of the study area.

Fig. 8: Relative crude oil pipeline density, calculated using the line density function within a GIS.



Relative petroleum product pipeline density in Canada and the United States of America, within 50 kilometres of the study area.

Fig. 9: Relative petroleum product pipeline density, calculated using the line density function within a GIS.

In order to calculate the relative sensitivities of each mode of transport and commodity, commodity data were extracted from each mode of transport per 4 sections that interacted with our study area. They included Ontario and Quebec in Canada, PADD 1 and PADD 2 in the United States (figure 10). Mean values for each mode of transport and type of commodity from 2011 – 2014 were calculated. The mean values of each commodity were applied to the grid cells that resided within each section, along with a section indicator (which acts as a Boolean turning the grid cell on or off).

In order to project terrestrial data into waters, a proximity calculation was applied to weight grid cells that were within 5 or 10-kilometres of the density layer. Grid cells that were within 5-kilometres were given a distance modifier value of 1, while the grid cells that were within 10-kilometres were given a distance modifier value of 0.5.

Then the relative densities within 10-kilometres of pipeline and rail were applied to the grid cells to calculate the transportation mode by water density (i.e. if there was an area where a density value of 5 was, those grid cells would have a density value of 5).

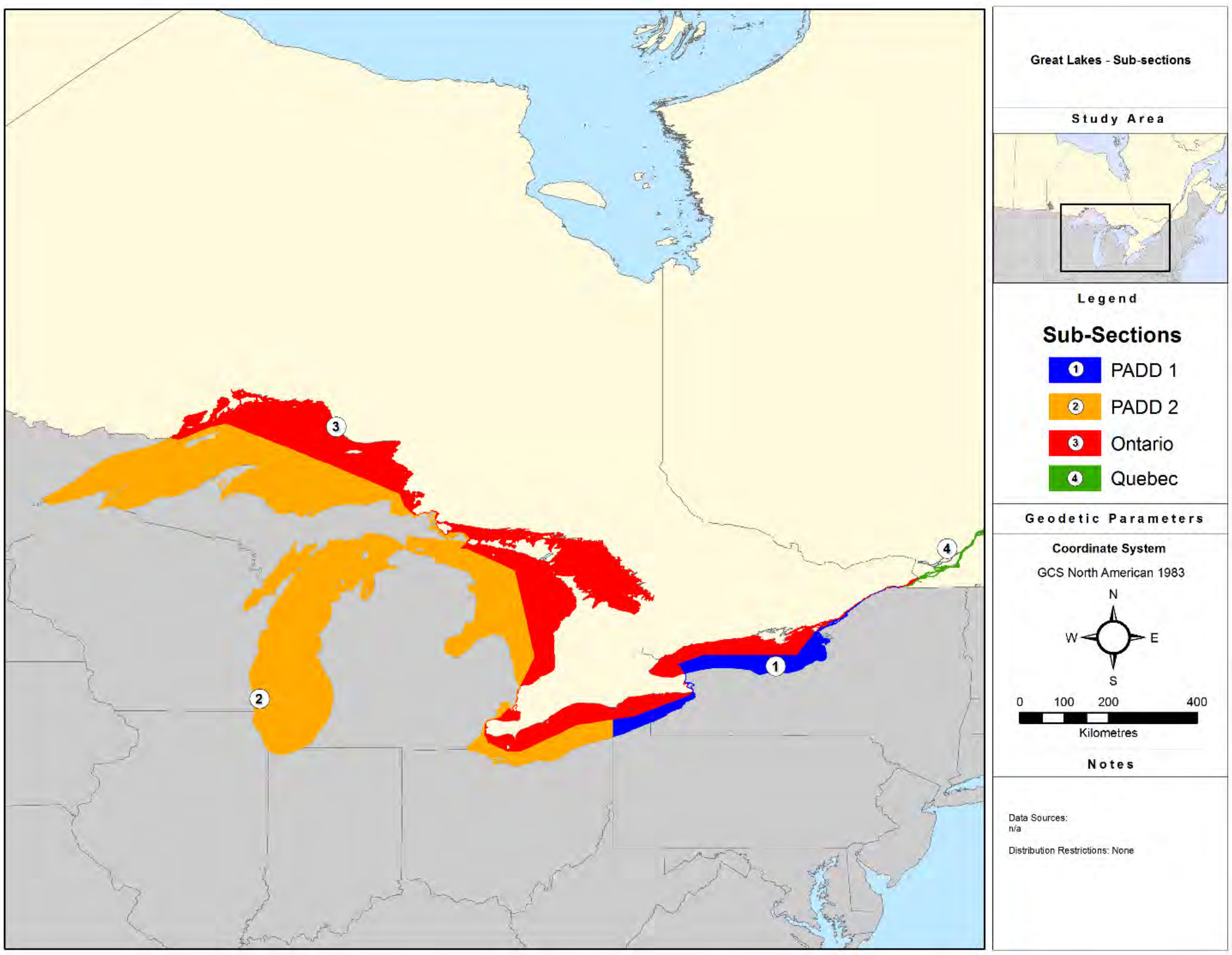


Fig. 10: The four sections in the Great Lakes, the commodity data was split up into (PADD 1, PADD 2, Ontario, and Quebec).

The distance modifier for each mode of terrestrial transportation was multiplied by the relative density of each terrestrial mode of transportation, to get the overall relative density per mode of terrestrial transportation (i.e. Overall Relative Transportation Mode Density (ORTMD) = Distanced Modifier x Relative Grid Cell Density).

The overall relative densities of each mode of transportation were then multiplied by the commodity values per section to get the relative sensitivities for crude oil moved by rail, crude oil moved by crude oil pipelines, liquefied petroleum products moved by petroleum pipelines, and refined petroleum products moved by petroleum product pipelines. (e.g. Relative Transportation Sensitivity = District Indicator x ORTMD x Mean Volume Transported per District per Transportation Mode).

2.4.1 Environmental Data

The environmental data assembled for this project has mostly been provided by federal, provincial/ States (US and Canada) authorities and used to qualify environmental sensitivity. To integrate this sensitivity with the oil layers, the following components of the physical, biological and human environments were considered.

Physical environment

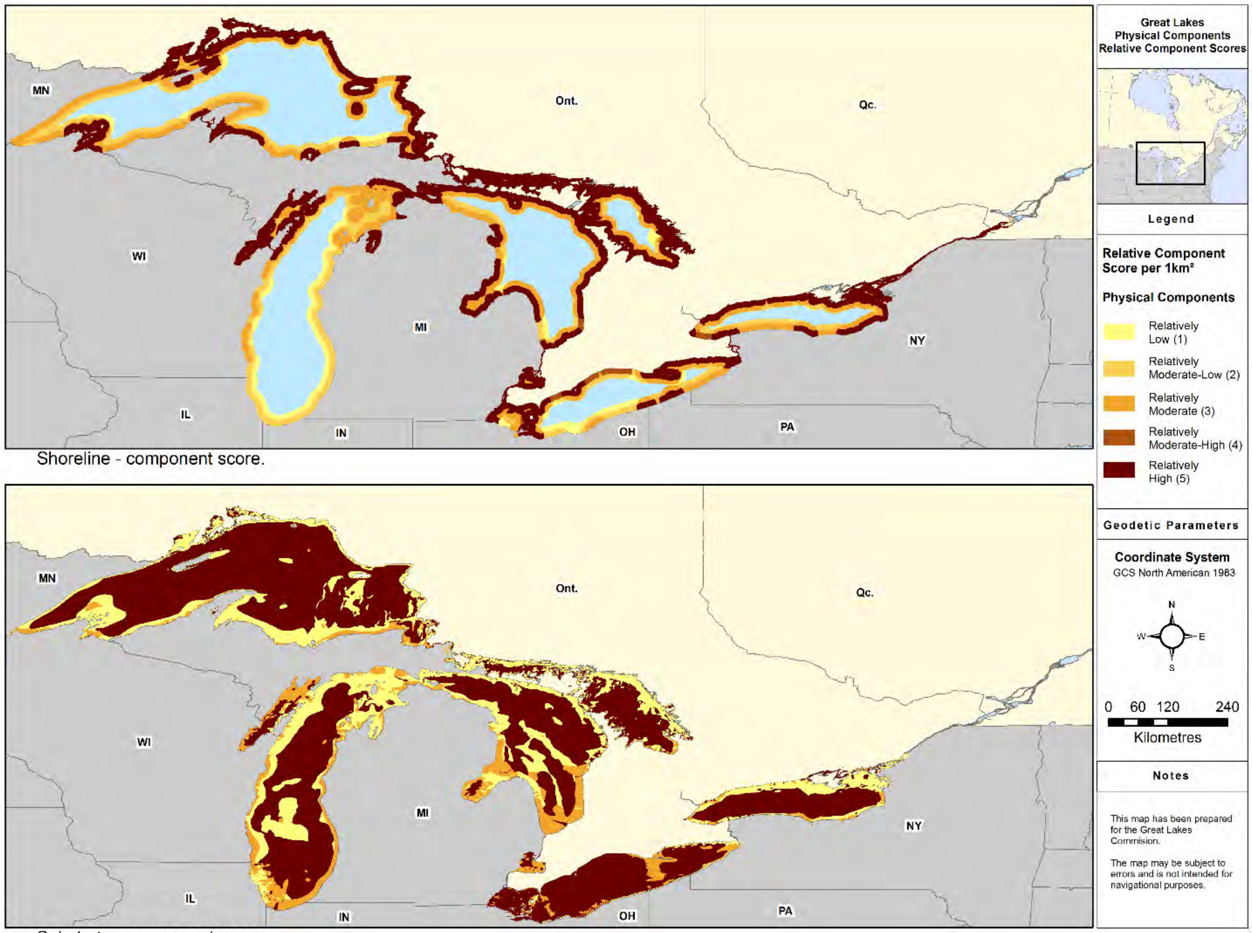
Two sets of data were used and combined to describe the physical environment. Spatial data on the substrate characteristics and shoreline classifications were combined.

Substrate

A substrate classification was used to define the physical sensitivity to oil exposure. Originally collected to inform oil spill response plans, data from NOAA and ECCC were available and combined to produce Great Lakes substrate map. The existing classification (up to 12 classes) was processed to produce a gradient of values from 1 to 5, according to substrate granulometry (from fine to coarse).

Shoreline

As oil may reach nearshore environments first (if spilled from a terrestrial source), shoreline values were given values ranking from 1 (low) to 10 (high) based on the substrate classification developed by NOAA (NOAA, 2002). A spatial buffer of 5 and 10 km with 1 and 0.5 distance modifiers were applied to each, and a natural break function was used to reclassify the data into 5 categories from low to high.



Substrate - component score.

Fig. 11: Top: Shoreline component score based on NOAA and ECCC shoreline classification. Bottom: Substrate component score.

Biological environment

Two sets of data layers were combined to describe the biological environment. Spatial point features on fish data available for all Great Lakes were combined with areas at status (protected areas and important habitats).

Fish Nursery/Spawning Areas

The spawning and nursery areas of Great Lakes fishes' data (Goodyear et al. 1982) is georeferenced database integrating about 66 fish species data by geographic location. The kernel density estimation (KDE) function was applied to identify geographic areas where a species relative abundance is situated (Fieberg, 2007; Nelson et al. 2008; Kenchington et al. 2014).

The KDE technique was applied to each of the fish species types, using no weighting (*i.e.* all fish species were considered equal) and potential distribution within a 20-kilometres radius. Using Jenks Natural Breaks, which aims to minimize variance between classes and maximize variance from class to class (Jenks, 1967), each of species data was classified using a 5-level scale (Szlafsztein et al. 2007), from relatively low (1) to relatively high (5). All the re-classified data was spatially summed, re-classified again into the 5-level scale using Jenks Natural Breaks and re-sampled into the 1km^2 grid cells for consistency purposes.

Protected Areas & Important Habitats (PAIHs)

Several data sources were combined from Federal and Provincial/states sources in USA and Canada to describe important habitats and protected areas. Such data is important to complement species data as species data may be inconsistent spatially due to sampling bias and species movements. Important bird areas (IBAs), protected areas (parks, conservations lands, ecological reserves, environmental systems, wilderness areas, recreational areas, etc.), critical habitats and Ramsar wetlands were the datasets used for calculating the PAIHs components. Each dataset was processed into the 1km^2 study grid, using multiple spatial buffers and grid cells were given a value of 0.5 if the dataset was within a distance of 10-kilometres or a value of 1 if it was within a distance of 5-kilometres. The features were then spatially summed and re-classified into the 5-level scale using Jenks Natural Breaks to get the final PAIHs component map.

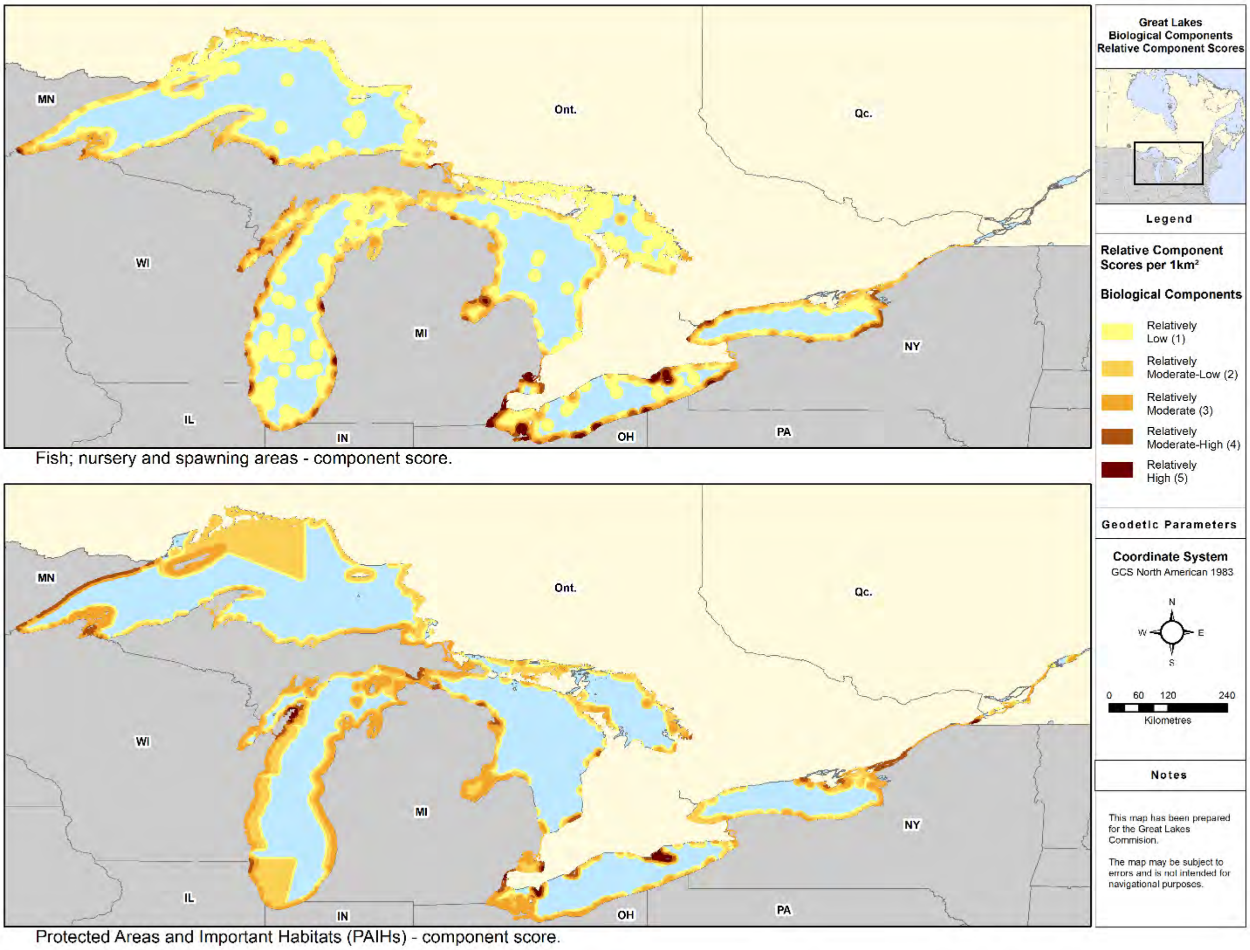


Fig. 12: Top: Fish species and habitat distribution, modified from Goodyear, C. S., T. A. Edsall, D. M. Ormsby Dempsey, G. D. Moss, and P. E. Polanski. 1982. Atlas of the spawning and nursery areas of Great Lakes fishes. 14 vols. U. S. Fish and Wildlife Service, Washington, DC. FWS/OBS-82/52. Bottom: Protected areas and important habitats areas. Bottom: Protected Areas and Important habitat relative component score based on several data sources.

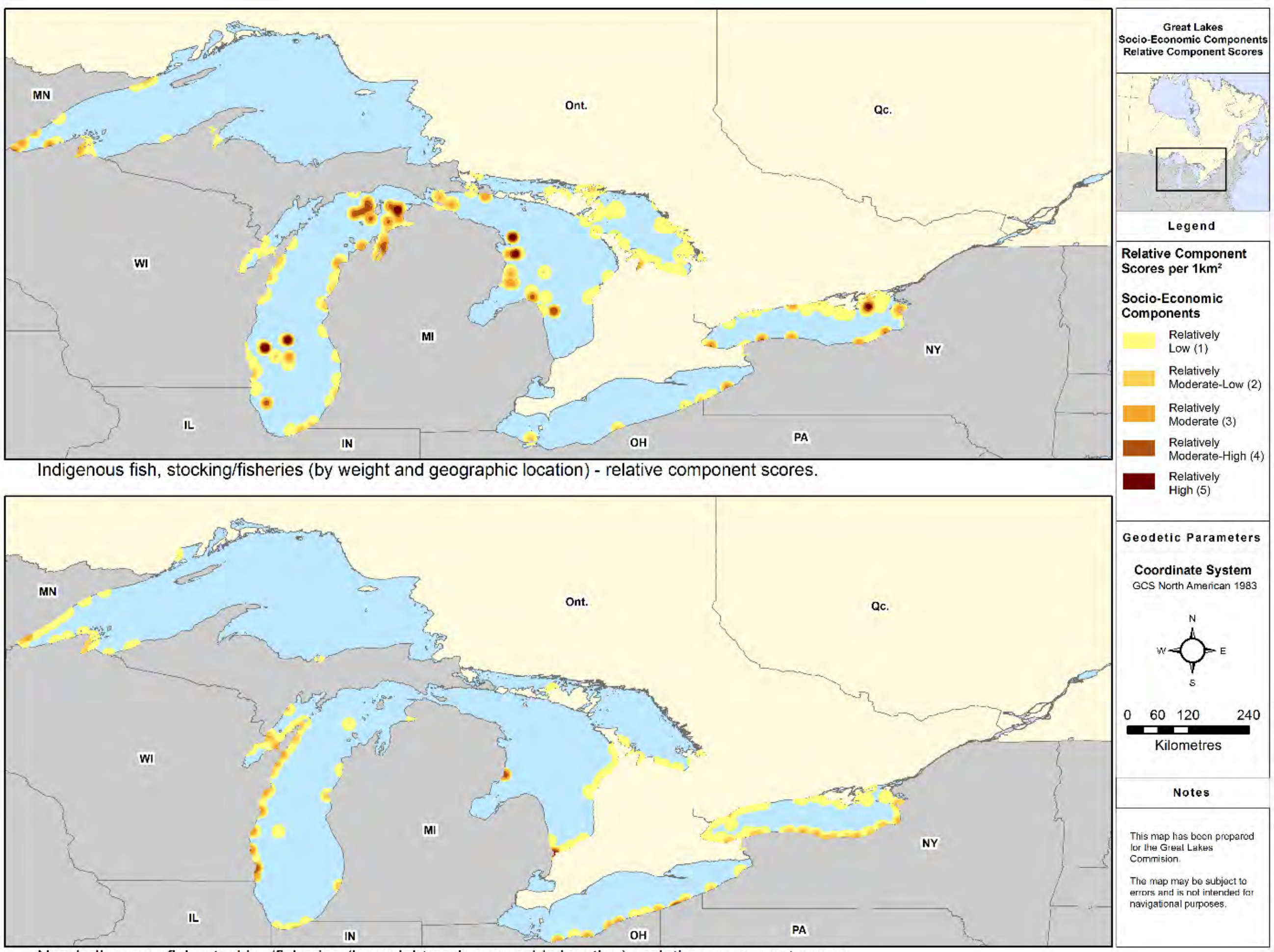
Socio-economic environment

Three types of data were combined to characterize the human or socio-economic environments: Fisheries data, ports locations and population densities. Freshwater intakes data was not found at the scale of the Great Lakes and human population may have captured some uses in freshwaters.

Fisheries/Stocking

Fisheries data was collected from the Great Lakes Fisheries Commission (GLFC) database, as longitude and latitude data from 2006 - 2015 as a comma-separated values file (CSV), converted into geospatial point data as separated by indigenous and non-indigenous species. Some of the points were excluded from the analysis (no latitude/longitude coordinates, or site location name) fish weight were associated with the points, which formed the basis of the analysis.

In order to estimate relative intensity, we applied a non-parametric kernel density estimation (KDE) function within a GIS, which takes into account the geographic location of a point along with its weight (Silverman, 1986; Sveegard et al. 2011; Erisman et al. 2012). Observations for a coordinate were expended to a 25-kilometre radius. As for the other data layers, a Jenks Natural Breaks was applied to classify the data in a 5-level scale to classify the data from relatively low (1) to relatively high (5), applied and re-sampled into the 1km^2 grid cells for consistency purposes to get separate indigenous and non-indigenous fisheries/stocking intensity maps. Both layers were then combined using a spatial sum, and re-classified again into 5-classes using Jenks Natural Breaks to get the final fisheries/stocking intensity (component) map.



Indigenous fish, stocking/fisheries (by weight and geographic location) - relative component scores.

Non-indigenous fish, stocking/fisheries (by weight and geographic location) - relative component scores.

Fig. 13: Fisheries stocking relative density (component score) for indigenous and non-indigenous fish in the Great Lakes.

Ports data

The data used for ports was collected by the NTAD showing geographic locations as geospatial point data. Similar to methods used for PAIHs, multiple spatial buffers were created based on the distance the port is in relation to the 1km^2 study grid. Grid cells were given a value of 2.5 if they were within a distance of 20-kilometres or a value of 5 if they were within a distance of 10-kilometres to a port.

Population Density

Population data was compiled from US (2010) and Canadian (2011) censuses. Tracts within 50-kilometres influenced the overall calculation. Population density per tract was calculated, Jenks Natural Breaks was applied to classify the data into the 5-level scale. A distance modifier (similar method applied to ports) was applied here, where the grid cells that were within 20-kilometres of the tracts were given a distance modifier value of 0.5 and within 10-kilometres a value of 1. This was then multiplied with the relative population density values to get the relative population density component map.

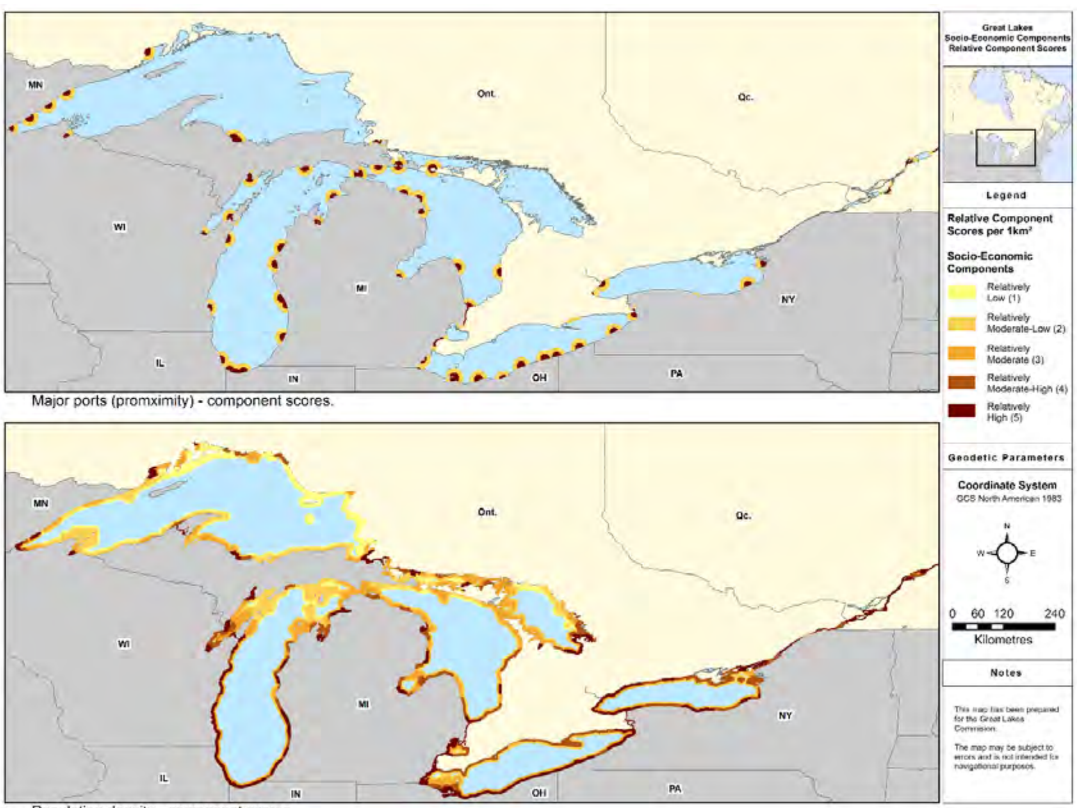


Fig. 14: Component scores for ports in the Great Lakes and the relative population densities in proximity to the Great Lakes.

3. Results

3.1 Environmental Sensitivity Index (ESI)

This section outlines the index developed to assess the environmental sensitivity to oil spills in the different environments. Its purpose is to quantify the relative risk associated with oil spills in different geographical regions, to convert the estimates of oil spill frequencies into indicators of environmental risk.

The following sub-sections describe the approach used and detail each of the indicators that compose the Environmental Sensitivity Index (ESI).

3.2 Approach

Based on existing literature (Office of Response and Restoration, 2013; DNV, 2011; Cohen, 2010; NOAA, 2002), a relative index, called the Environmental Sensitivity Index (ESI), was selected to evaluate the sensitivity of each zone. The ESI incorporates three indicators:

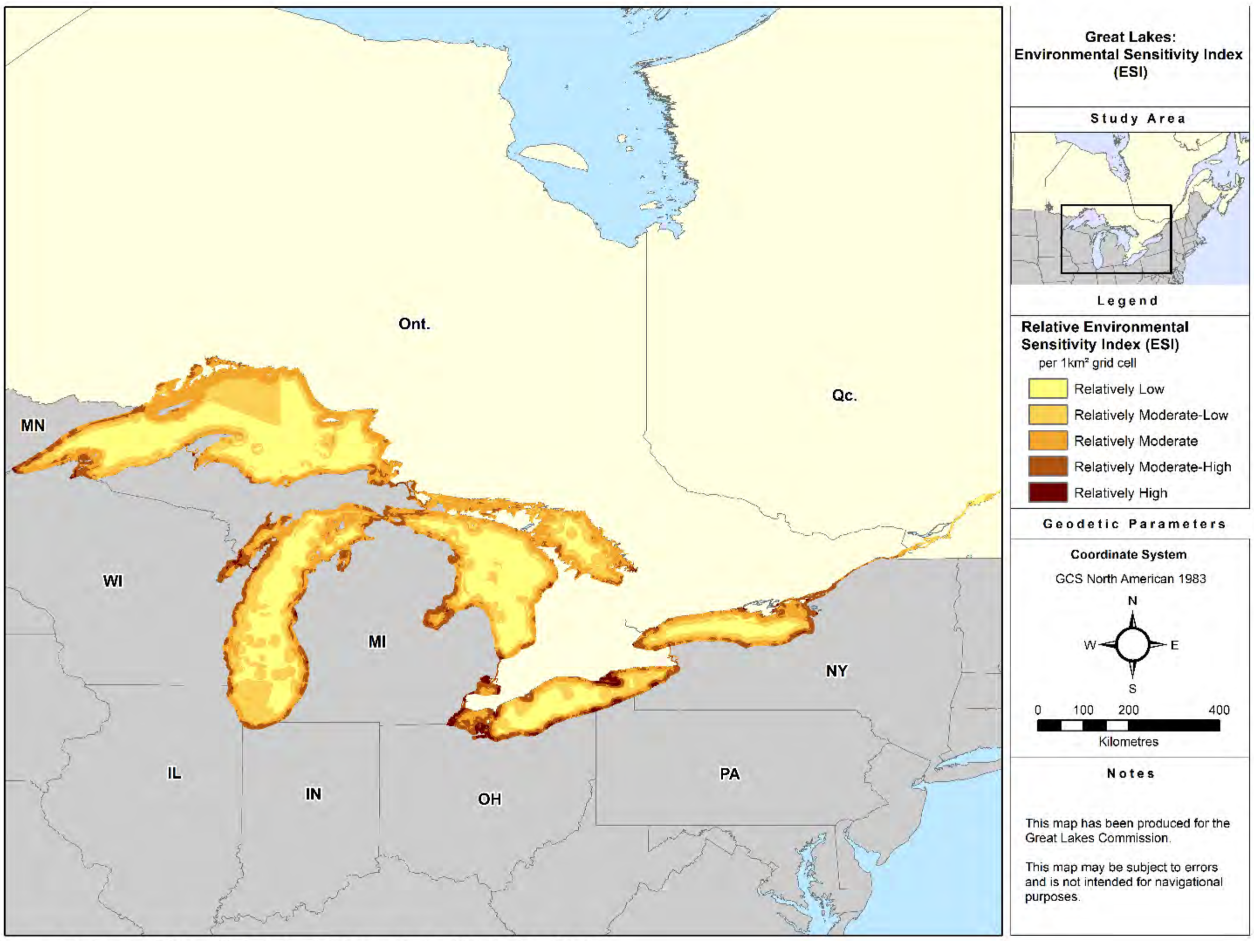
- The Physical Sensitivity Indicator (PSI), that is the degree of difficulty involved in the coastal clean-up operations.
- The Biological Sensitivity Indicator (BSI), the sensitivity level of natural resources that are affected by an oil spill.
- The Socio-Economic Indicator (SEI), the direct commercial losses caused by a spill, in addition to an evaluation of the damage caused to social resources.

The relative weight of each indicator is based on a review of costs breakdown of worldwide oil tanker spills from 1992 to 1997 (DNV, 2001). This breakdown is consistent with the weights used by Cohen (2010).

$$ESI = 0.3(PSI) + 0.5(BSI) + 0.2(SEI)$$

Although this method allows for a relatively good quantification of environmental sensitivity, it has some limits:

- The indicators (PSI, BSI and SEI) are each expressed as average values representing a given grid cell. They characterise the general sensitivity for each of the zones. These indicators are considered as global (large scale) indicators.
- The overall calculation is dependent on the data used for each indicator. For this project, a limited number of layers were used and further analyses and studies would be beneficial to refine sensitivities, in both nearshore and offshore zones of the Great Lakes.
- The ESI calculation has been originally developed for the marine environment and the weights applied in this study for each parameter would benefit from further consultations to evaluate their application in freshwaters.



Environmental Sensitivity Index (ESI), per 1km² grid in the Great Lakes.

Fig. 15: Environmental Sensitivity Indicator for the Great Lakes, indicating areas where sensitivity is highest. Calculation is weighted as; 0.3(PSI) + 0.5(BSI) + 0.2(SEI).

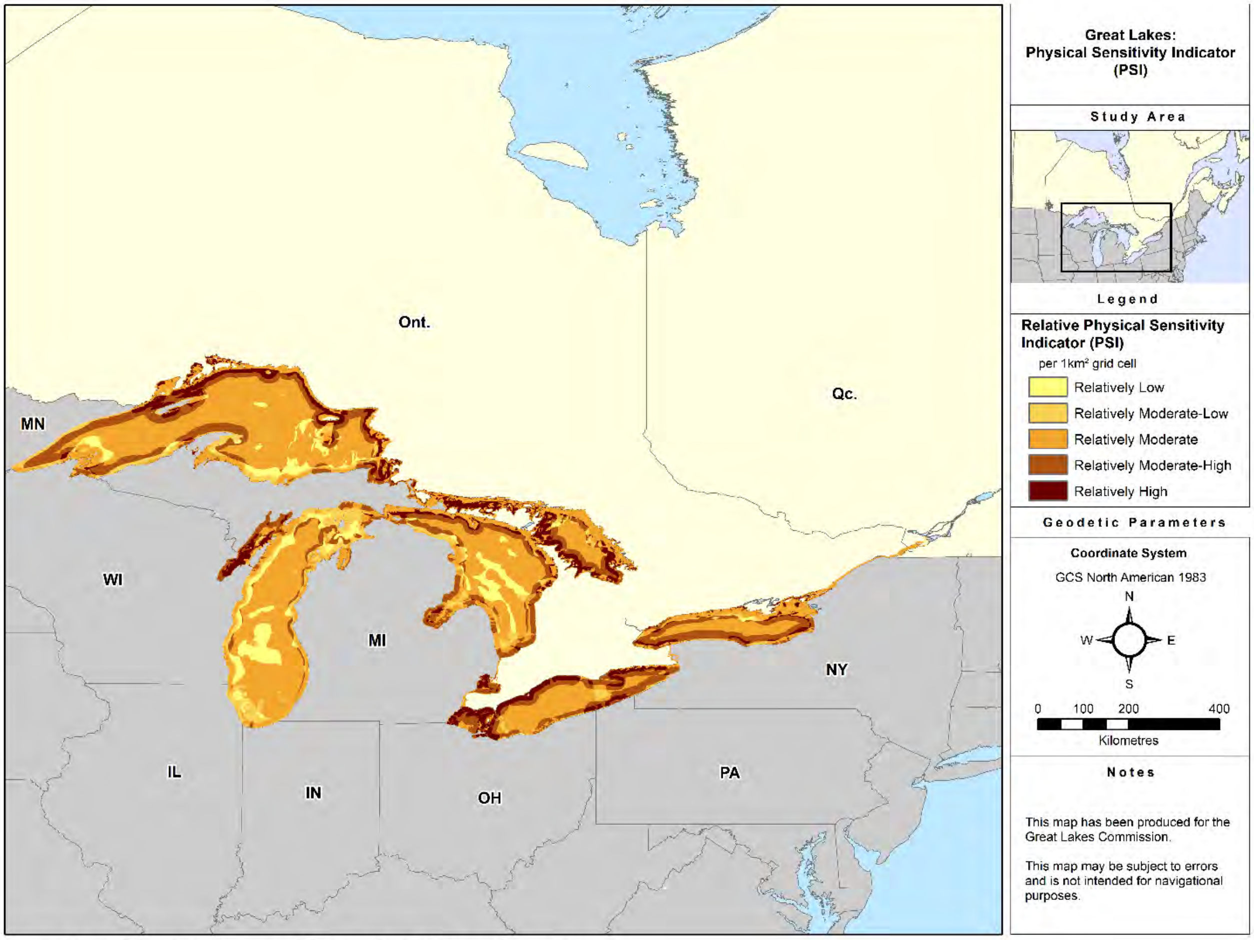
The environmental sensitivity (ESI) calculated for this project is mapped in Fig. 15 and shows that nearshore areas have typically a higher sensitivity than offshore areas. This results is consistent with the fact that nearshore areas tends to have a more divers habitats, and generally supports more divers function for the ecosystem as a whole. The ESI are also higher in the nearshore zone due to higher values in the socio-economic indicator, as most socio economic features are associated to the shores.

It is important to note that the difference between nearshore and offshore ESI values could also stem from the less abundant data available in the offshore zone. Further analysis and potential further data collection would be needed to make sure that similar spatial coverage exists for each lake. Nonetheless, at least for the Canadian waters, the ESI values reported in this report are consistent with those reported in the WSP (2014) risk assessment, which included ESI calculations based on a much larger number of spatial layers. The limitation for the present study was to find similar data for both Canadian and US waters.

The following section provides a description of the methodology and findings for each of the 3 indicators part of the ESI calculation.

3.2.1 Physical Sensitivity Indicator (PSI)

The existing shoreline classification developed by NOAA and ECCC for spill response plans allows for the attribution of a rank according to a scale related to substrate sensitivity to natural oil persistence and ease of clean-up. Since most coastal regions include diverse shoreline types, the physical sensitivity indicator (PSI) in a given area was calculated as a function of the ranks for each shoreline type.



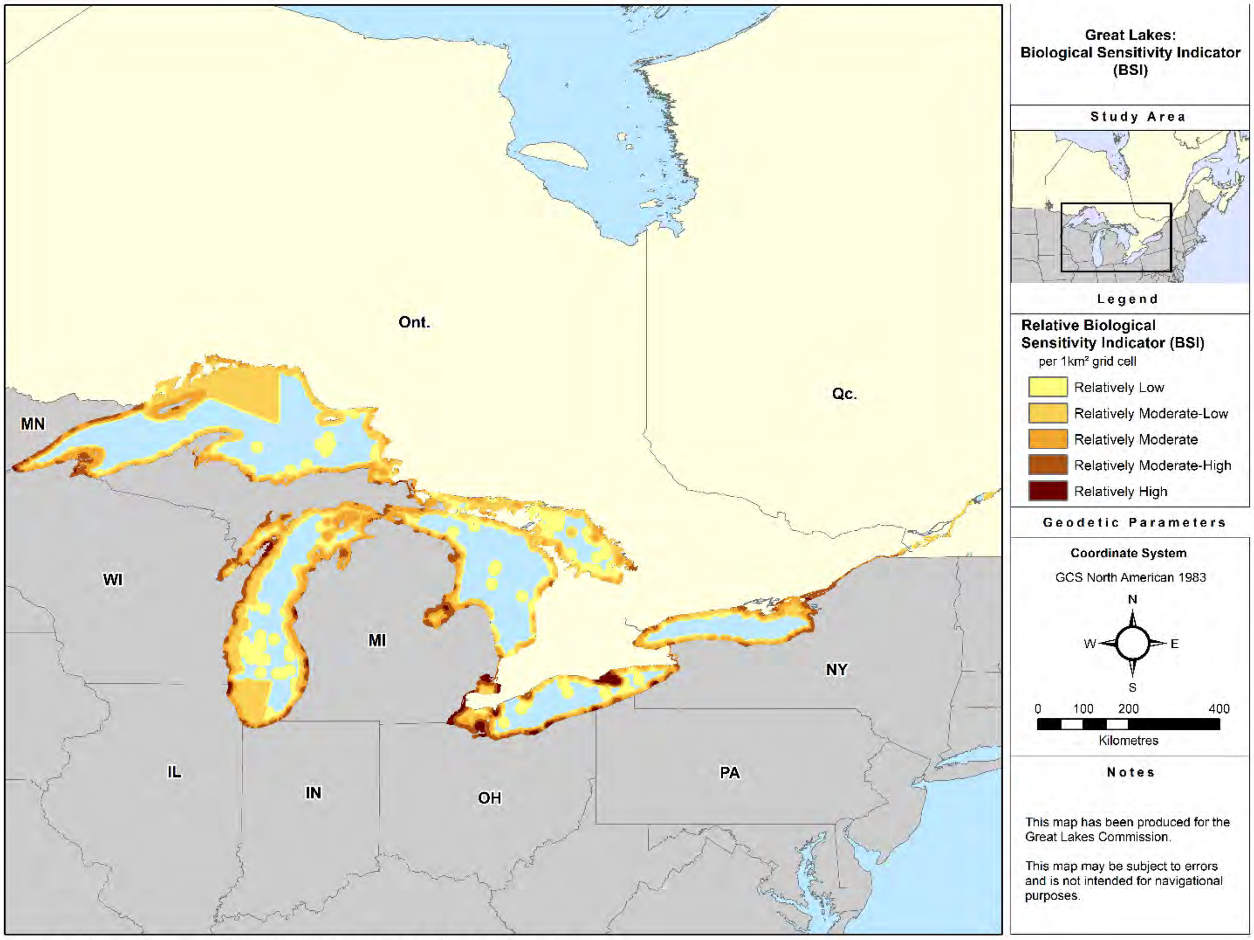
Physical Sensitivity Indicator (PSI), per 1km² grid in the Great Lakes.

Fig. 16: Physical indicator (as substrate type) in the Great Lakes (combined ECCC and NOAA data).

The results on the physical sensitivity are mapped on Fig. 16 and are showing the wide range in the type of substrate found in the Great Lakes (from fine sand to boulders). Among the layers compiled for this project, the substrate data is the most compatible between US and Canada as both data sets were developed in coordination for the same application (assessing clean-up during oil spills response).

3.2.2 Biological Sensitivity Indicator (BSI)

The distribution of biological resources in Great Lakes waters is highly variable and the data generally does not provide fair representation of biological features in offshore zones compared to nearshore zones. Although nearshore environments are typically more productive compared to offshore zones, the low sensitivity observed in offshore areas for the Great Lakes is partially related to the lack of data in this zone.



Biological Sensitivity Indicator (BSI), per 1km² grid in the Great Lakes.

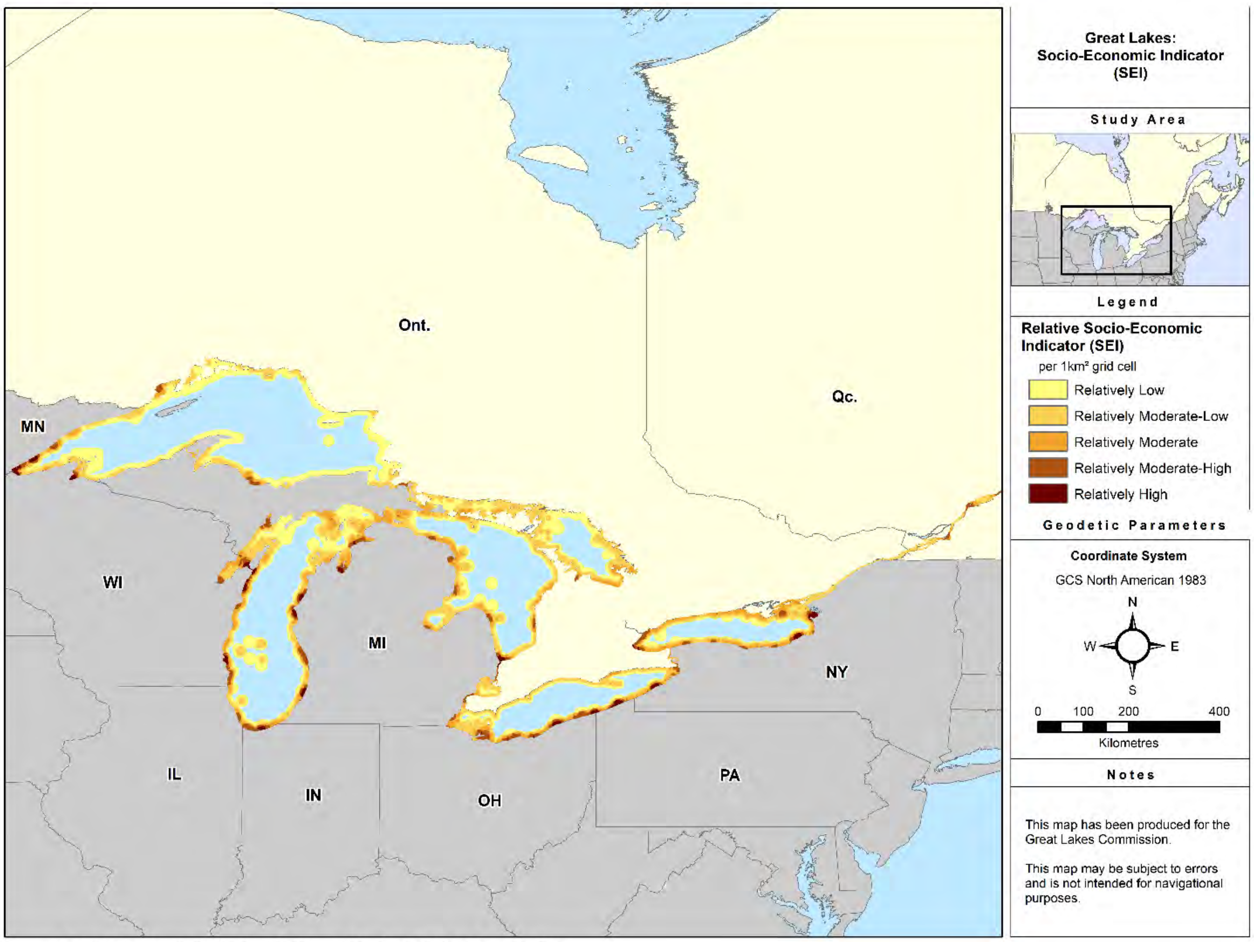
Fig. 17: Biological indicator for the Great Lakes, based on fish species counts and protected/ important habitats areas.

The Fig. 17 provides a visualization of the biological features compiled for this report. There was an attempt to represent both species data (fish data) and habitat (as protected and important habitat). Species data tends to be more variable spatially, likely because of the difficulty to obtain consistent data applicable at the scale of the Great Lakes.

It is important to note that species data processed for this project only included fish species. Other data on species density or biomass (ex: benthic species) or on production (ex: primary production) may be useful to produce a more complete picture of biological features in the Great Lakes. As for most data layers, the challenge is to obtain data applicable at the scale of the Great Lakes.

3.2.3 Socio-Economic Indicator (SEI)

The socio-economic indicator was calculated on three features and the results are mapped in Figure 18. On this map, most of the high sensitivity values were reported in areas where commercial fisheries and high population densities were found. Therefore, the lower Great Lakes were generally associated with a higher socio-economic value.



Socio-Economic Indicator (SEI), per 1km² grid in the Great Lakes.

Fig. 18: Socio-economic indicator, based on commercial fishery estimates, ports location and human population.

As for the other indicators, the number of layers required to assess the socio-economic value of an area as large as the Great Lakes is well underestimated in this report. Other data, such tourism, industry/agriculture activities, cultural/historical sites and water intakes would be important contributors to this indicator as they are likely to be impacted if oil was spilled in the Great Lakes.

In addition of increasing the number of layers to more accurately depict the socio-economic values of the Great Lakes, an assessment of the relative contributions of each layers in the calculation of the indicator would be valuable. The current calculation is based on equal weight for each data layer, although depending on the area, the importance of human population may be considered higher than other variables. Although achieving consensus on the relative contribution of different data sources may be particularly challenging, developing such indicator could benefit from consultations of various stakeholders conducted at a regional scale.

3.3 Environmental sensitivities to specific transportation mode

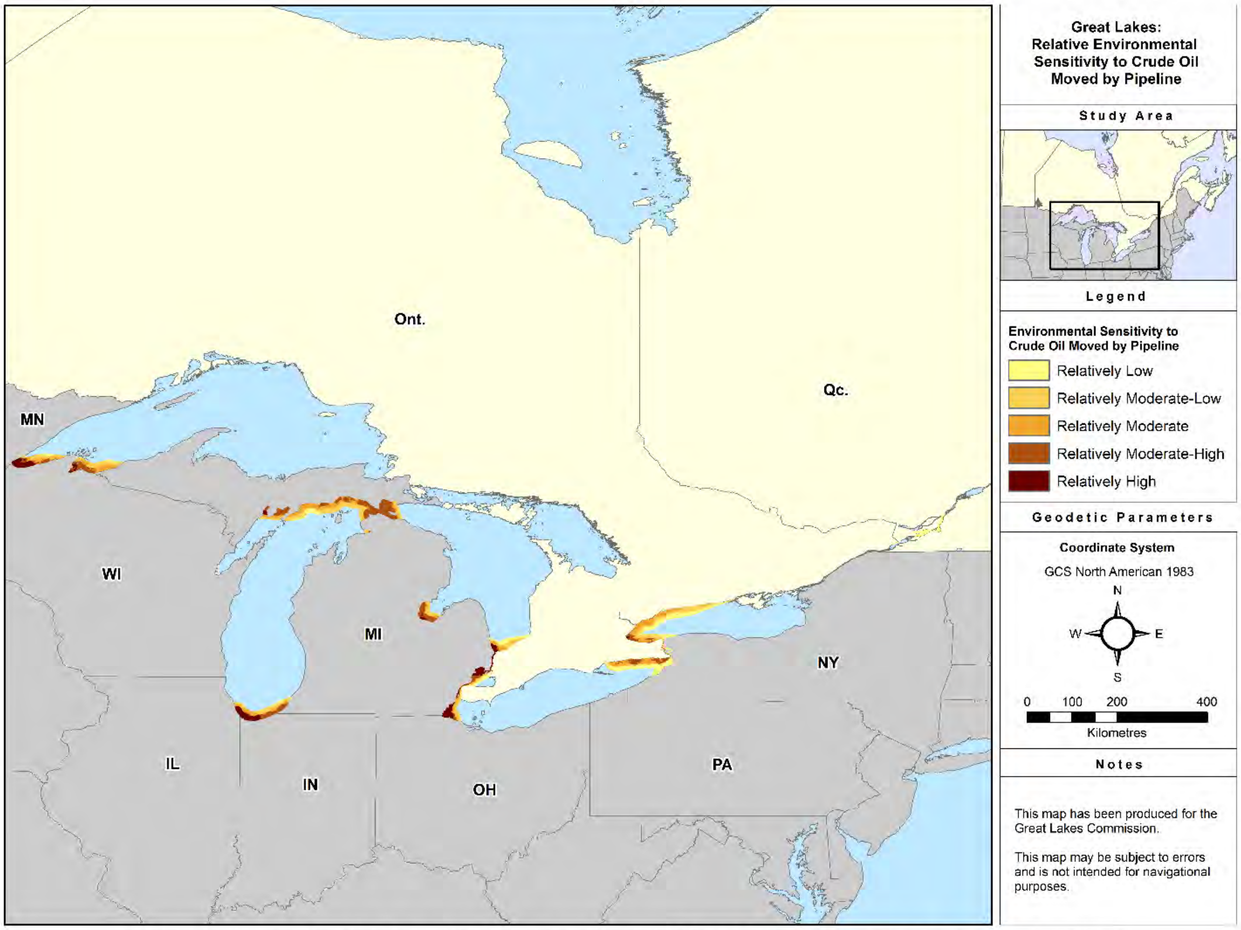
The following section provides the results on the environmental sensitivities to the 3 potential sources of exposure considered in this report: pipelines, rail and marine shipping. For each, and when appropriate, the type of oil was considered.

For these overall results are the integration of ESI values, location of transportation mode (densities) and volume of commodity associated.

3.3.1 Oil associated with pipelines

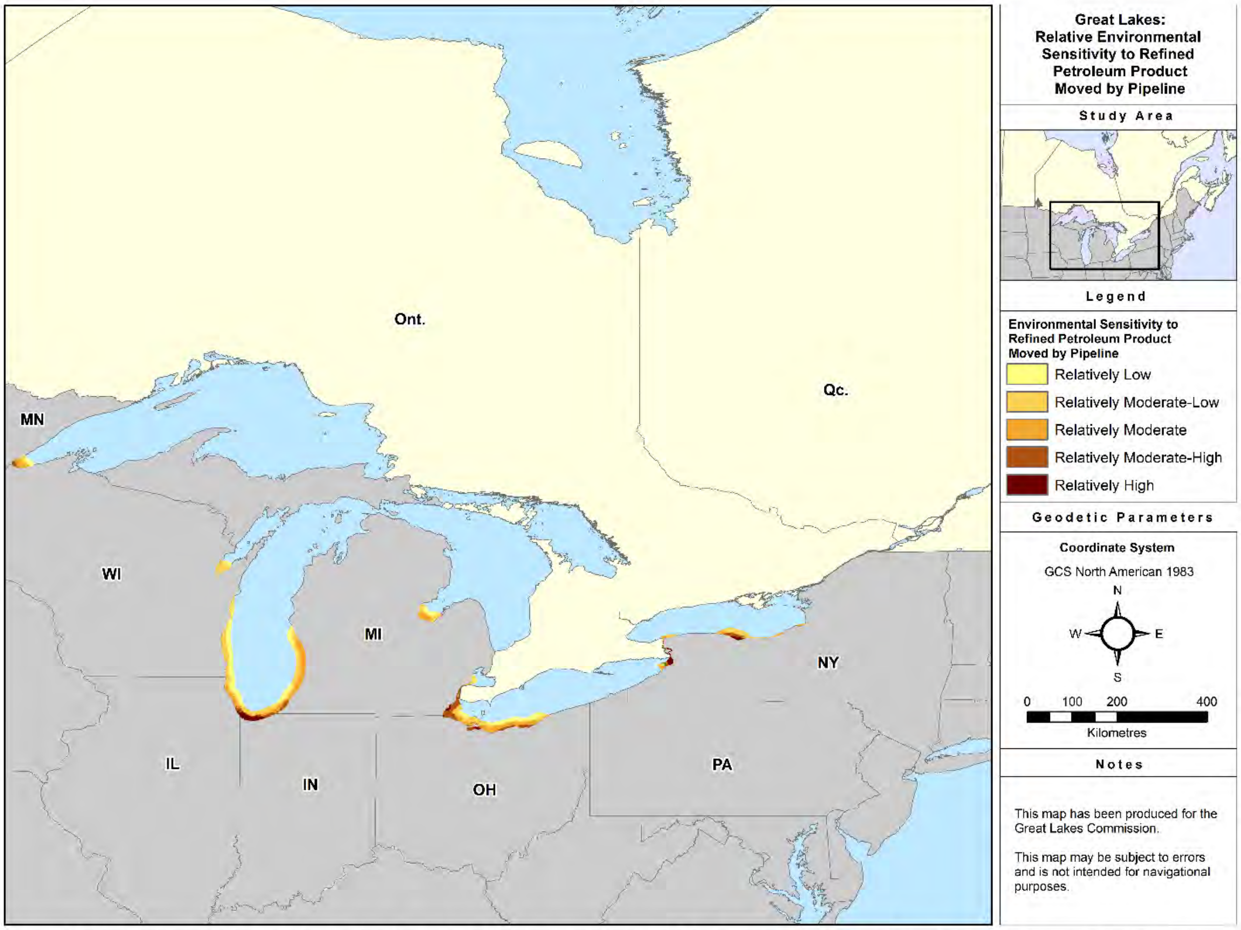
The following maps are showing the results obtained for crude (Fig. 19), refined products (Fig. 20) and Liquefied products (LNG) (Fig. 21). The results are showing that the high sensitivity areas are mostly located in the southern portion of Lake Michigan, Lake Erie as well as in the south-West portion of Lake Superior. Among the 3 types of petroleum products moved by pipelines, crude oil and refined products contribute the most to the environmental sensitivity. The lower sensitivity to LNG is due to the lower volumes of that commodity. As discussed later in this document, it is also important to note that LNG will be associated to a lower impact if spilled in the environment, compared to crude and refined oil products. Therefore, although having an idea of LNG movement is useful to assess over petroleum products movements, considering the type of product is necessary for future risk analysis.

These results are based on the current volumes moved by pipelines but the approach used in this report allows for considering future projects and increased volumes.



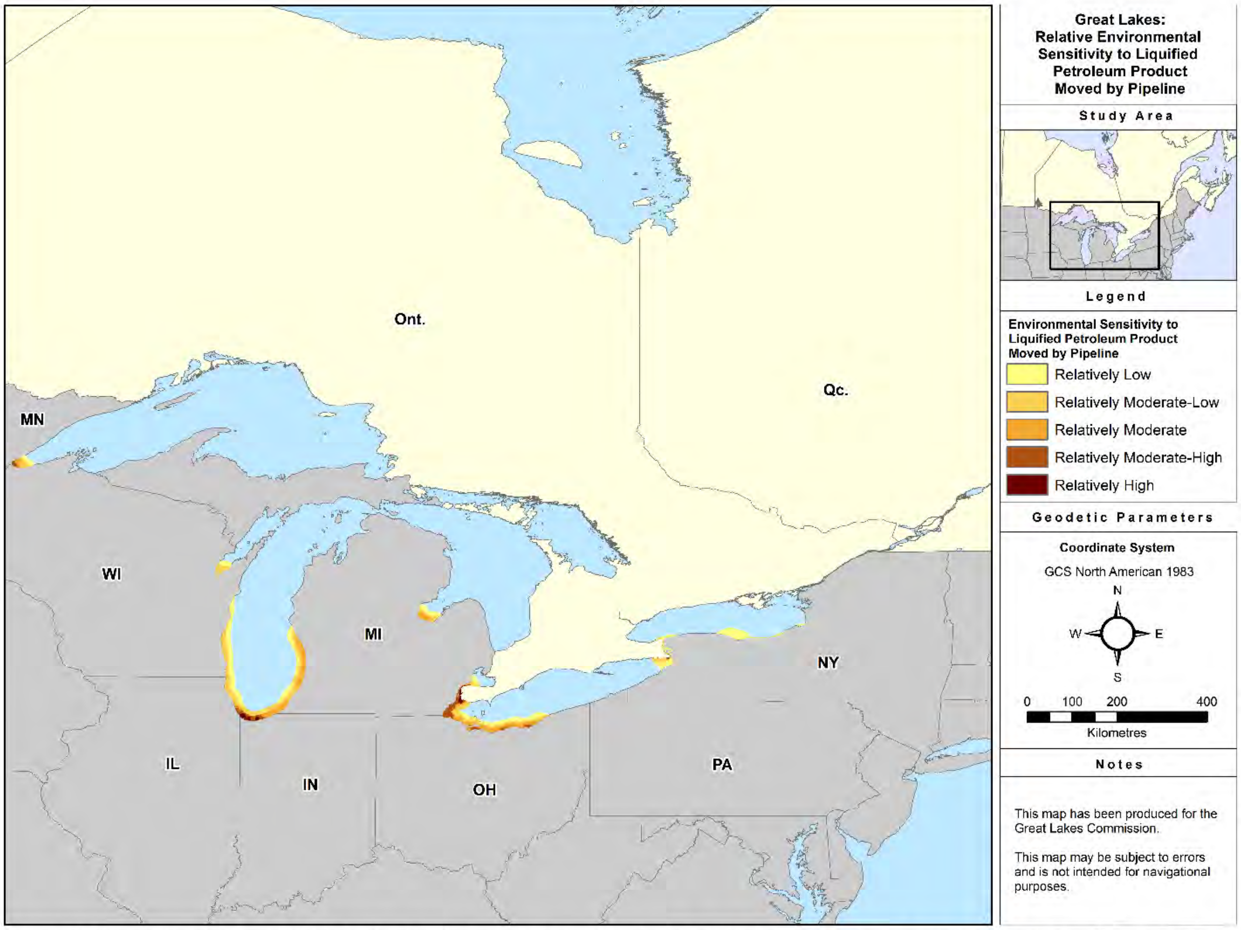
Relative environmental sensitivity to crude oil product moved by pipeline (crude oil pipeline sensitivity x environmental sensitivity)

Fig. 19: Environmental sensitivity to crude oil products moved by pipelines around the Great Lakes.



Relative environmental sensitivity to refined petroleum product moved by pipeline (refined petroleum pipeline sensitivity x environmental sensitivity)

Fig. 20: Environmental sensitivity to refined oil products moved by pipelines around the Great Lakes.



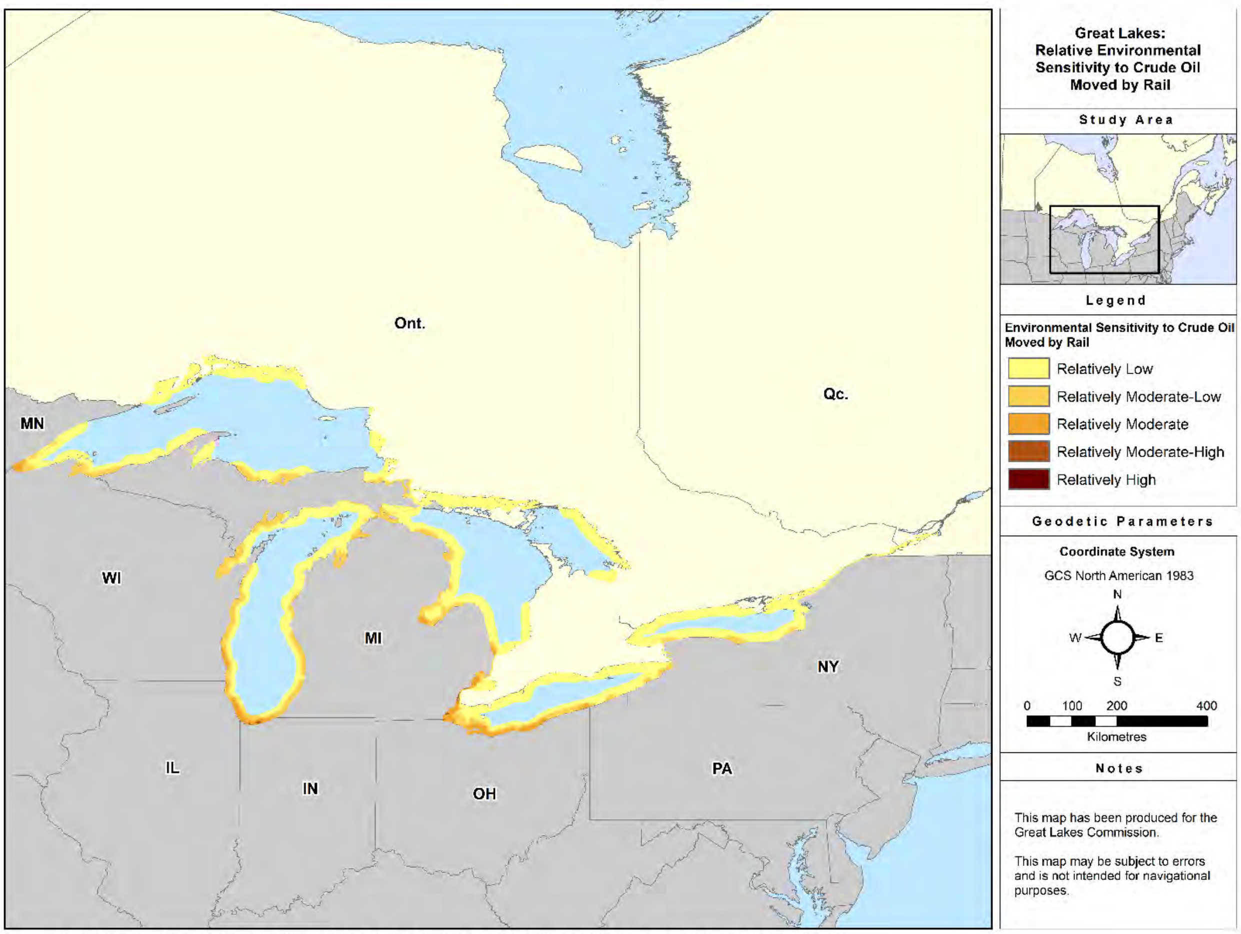
Relative environmental sensitivity to liquified petroleum product moved by pipeline (liquified petroleum pipeline sensitivity x environmental sensitivity)

Fig. 21: Environmental sensitivity to liquefied petroleum products moved by pipelines in the Great Lakes.

3.3.2 Oil associated with rail

Only crude oil is currently be moved by rail in the Great Lakes basin. The environmental sensitivity to crude oil moved by rail ranges from relatively low to moderate. These lower values compared to pipelines are explained by the lower volumes transported by rail.

There are limitations comparing sensitivities obtained for pipelines and rails because of differences in the mode of transportation. Further analysis would be needed to assess the likely volume spilled between transportation modes. In the case of rail, the spill volume will be a function of the number of cars involved in the incident and this number would need to be generated based on an analysis of spill probabilities associated to rail.



Relative environmental sensitivity to crude oil moved by rail (rail sensitivity x environmental sensitivity)

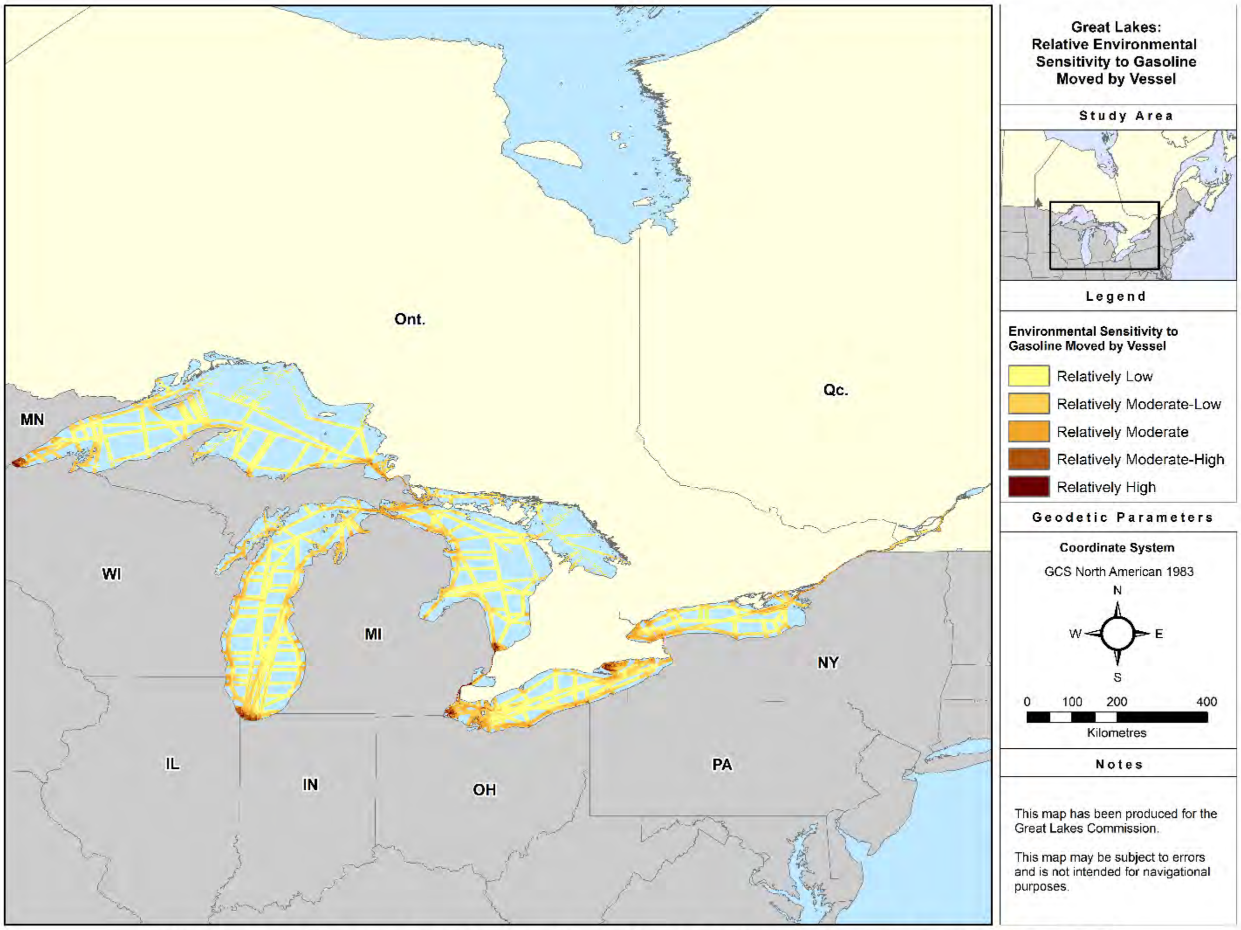
Fig. 22: Environmental sensitivity to crude oil products moved by rail in the Great Lakes.

3.3.2 Oil associated with marine shipping

The following maps provide the results of the environmental sensitivity to gasoline (Fig. 23), fuel oil (Fig. 24) and other petroleum products (Fig. 25). There is currently no crude oil moved within the Great Lakes. The results are showing that fuel oil is contributing the most to the environmental sensitivity to oil exposure related to marine shipping. Compared to other types of oil, fuel oil is likely moved more frequently within a lake, to refuel communities relying on this commodity for heat purposes.

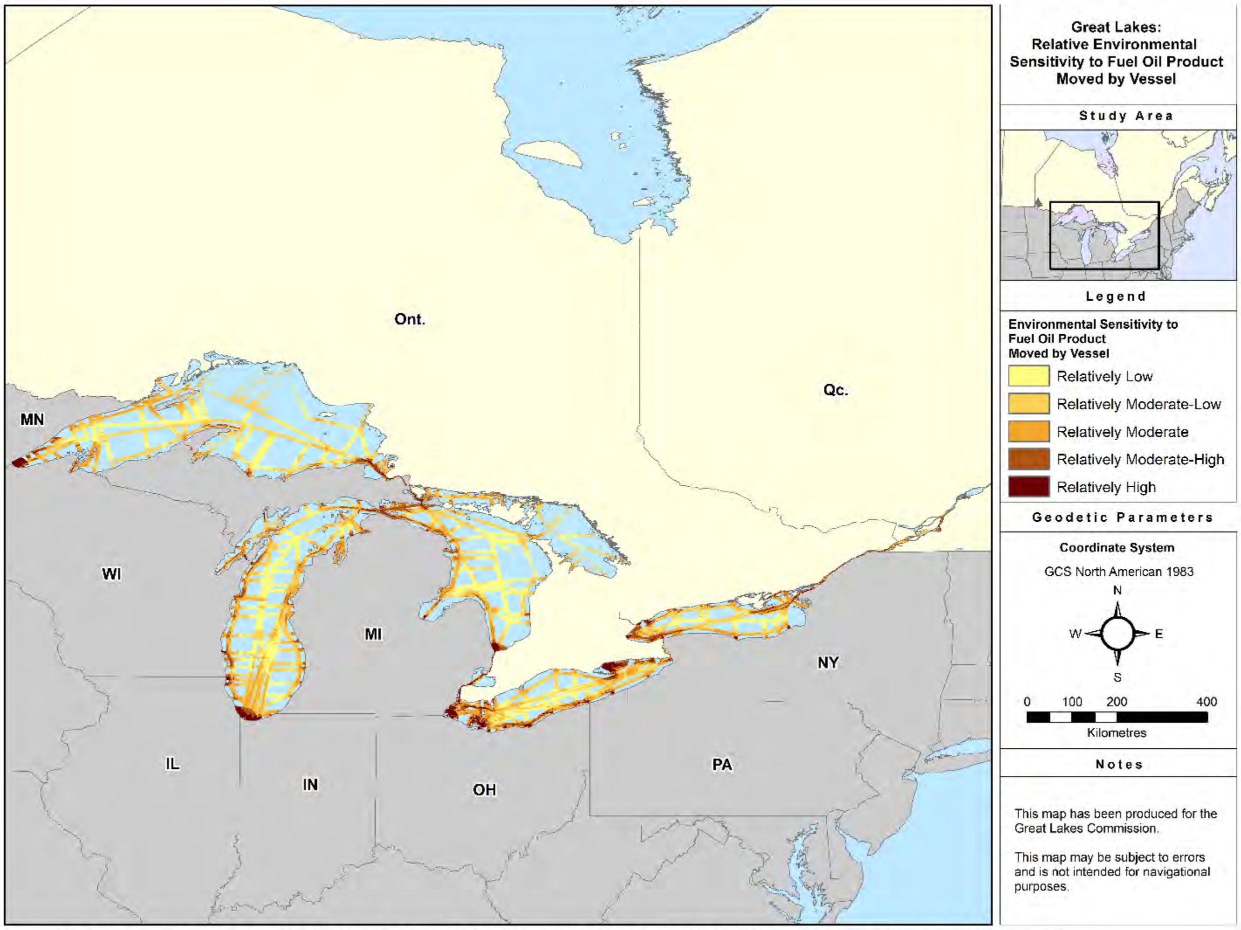
Further analysis would be needed to consider the properties of oil and its effects when spilled in the environment. Gasoline (mostly diesel) will dissipate quickly at the surface of the water if spilled compared to other heavier oil types and will also evaporate rapidly due to its low density. In contrast, fuel oil will likely remain for a longer time at the water surface and will therefore have a higher probability to reach shores and be associated to a higher environmental impact. The other oil products considered in this analysis includes asphalt products, which will sink if spilled in water and will therefore have an impact on benthic and nearshore zones.

In addition of considering the oil properties to infer behaviour, further analysis is needed to assess specific impacts (vulnerabilities) and characterize toxicity (chronic and acute). Light products, although with a lower residence time at the surface of the water, are typically associated with an acute toxicity whereas heavier oils will remain longer in the environment and will likely have more chronic effects on the biota. In this report, environmental features were assembled together in one metric and further detailed work would be needed to better characterize the exposure, the sensitivity and the recovery (or resilience) to oil. This more detailed work would be needed to better select (or weigh) the features to be considered to update the environmental sensitivity index.



Relative environmental sensitivity to gasoline moved by vessel (gasoline product vessel sensitivity x environmental sensitivity)

Fig. 23: Environmental sensitivity to gasoline moved by marine shipping in the Great Lakes.



Relative environmental sensitivity to fuel oil product moved by vessel (fuel oil product vessel sensitivity x environmental sensitivity)

Fig. 24: Environmental sensitivity to fuel oil moved by marine shipping in the Great Lakes.

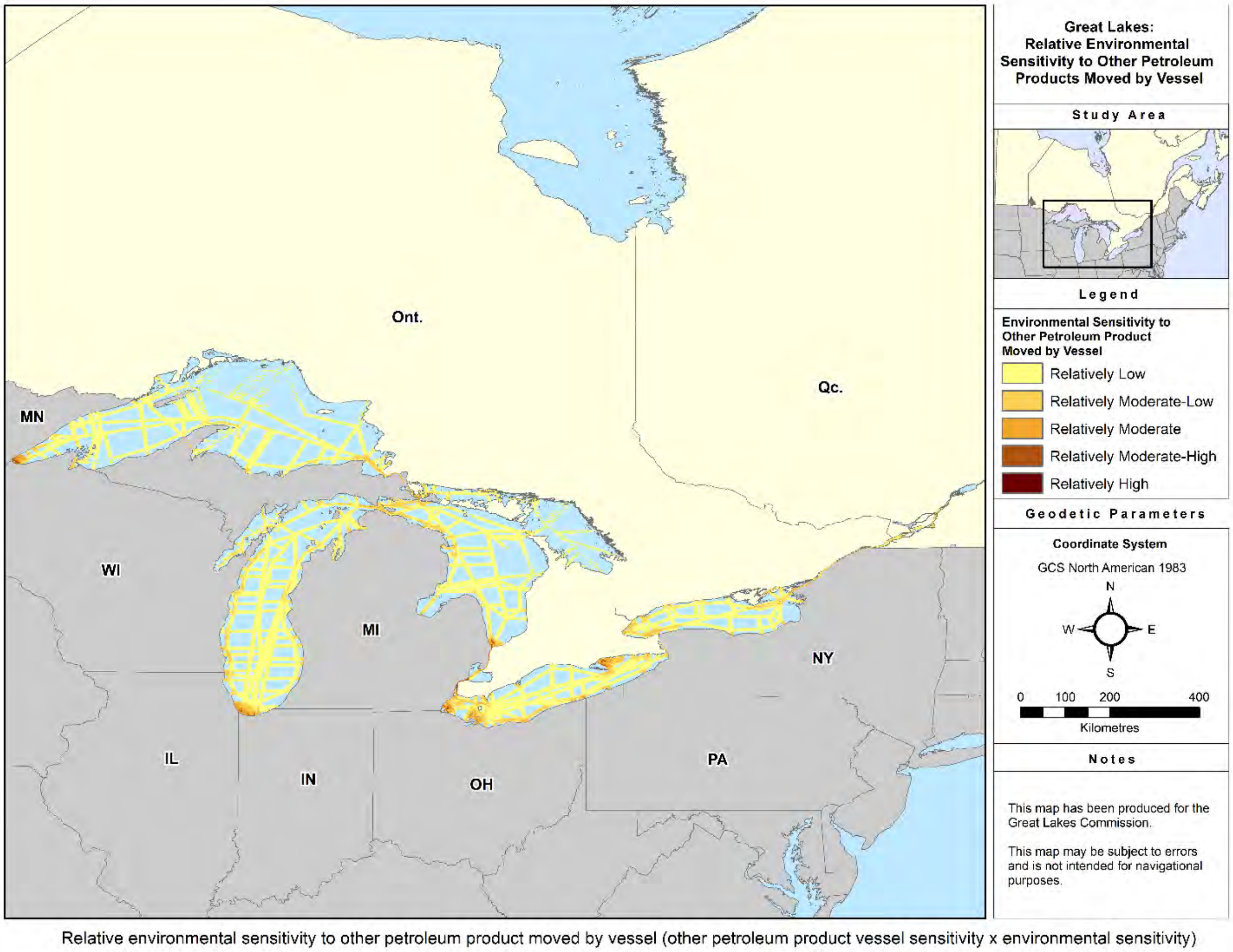


Fig. 25: Environmental sensitivity to other petroleum products moved by marine shipping in the Great Lakes.

4. Conclusions

This report provides a first picture on the volumes of oil moved via 3 modes of transportation in the Great Lakes basin. For each transportation mode, several oil types were considered and for each oil type, environmental features were overlaid to produce an estimate of the sensitivity to specific oil type and transportation mode. In short, these results helps with two questions: 1- where and how much oil products are moving in the Great Lakes and close to the shores of the Great Lakes? And, 2- are the areas associated with high volumes of oil close to environmentally sensitive areas in the Great Lakes waters?

The results from this study differ from those produced by a risk assessment which will require modelling the dispersion of oil in time and space at a given spill location. The trajectory output may then be connected to an environmental database and depending on exposure, will activate specific features impacted by oil. This impact or consequence metric is then connected to a probability metric to provide an estimate of risk.

The analysis presented in this report contributes to a better understanding of the locations that could benefit from a more detailed risk assessment. For each oil types and transportation mode, it is possible to localize the areas where there is an overlap between oil transportation and environmental sensitivity. Using the mapping approach developed in this report, high sensitivity areas can be identified and selected for probability assessment and further oil trajectory analyses.

Where and how much oil is moved in the Great Lakes area?

The results from this report are showing that most of the oil moved on water or close to water in the Great Lakes is moved by pipelines, followed by rail and then by marine shipping. The table below shows the overall volumes of main oil products for each transportation modes.

Table 1: Mean volumes of oil products moved in the Great Lakes basin for pipeline, rail and marine shipping – in thousands of barrels (10^3 bbl).

Mean of oil volumes moved by mode of terrestrial transportation (2011 - 14) (10^3 bbl)							
	Terrestrial				Marine Shipping		
Region	Crude oil by pipeline	Refined petroleum product by pipeline	Liquified petroleum product by pipeline	Crude oil product by rail	Gasoline	Fuel oil	Other petroleum products
Ontario	308,877	0	433,030	17,353			
Quebec	104,005	0	86,785				
PADD 1	12,126	1,049,501	37,157	73,273			
PADD 2	583,634	336,598	274,317	162,027			
Totals	**1,008,642**	**1,386,099**	**831,289**	**252,653**	**4,575**	**9,093**	**2,778**

In relation to spills and planning for prevention, it is important to consider all types of transportation. Although this report did not consider probabilities of spills of each mode of transport, it is likely that a spill from a pipeline is likely to be associated with higher volumes than a spill by rail (likely involving a few cars). These results supports the idea that prevention of spills from pipeline should be a priority given the high volumes of both crude and refined oil. As indicated earlier, these numbers are current volumes (2011-2014) and should be revised with projected projects such as the Eastern pipeline expansion.

What are the areas sensitive to oil exposure in the Great Lakes waters?

Overall, the results presented in this report are showing that all 3 modes of transport are affecting similar areas of the Great Lakes, namely, the lower lakes where most of the traffic and human activities are occurring.

It is challenging to merge all the results obtained for each transport modes into one single map due to differences in product types and also due to the assumptions for each sensitivity calculations. To be more accurate, the analysis would benefit from including probabilities of spills (per oil type) to have better understanding on the volume spilled per transport mode.

Appendix: Data sources

Protected Areas & Important Habitats

1. Important Bird Areas

1a. Canadian data

Bird Studies Canada. Important Bird Areas of Canada Database, 2015. Port Rowan, Ontario: Bird Studies Canada. Retrieved 2 February 2017 from http://www.ibacanada.org

1b. USA data

Audubon. Important Bird Areas of the United States of America, 2016. Retrieved 4 November 2016 from http://www.audubon.org/important-bird-areas

2. Protected Areas (Parks, Conservation Lands, Ecological Reserves, Environmental Systems, Private Land, Wilderness Areas, Recreation Areas, etc.)

2a. Canadian data

Natural Resources Canada. Atlas of Canada 1,000,000 National Frameworks Data, Protected Areas-Protected Areas, 2008. Retrieved 4 February 2017 from http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/08e80876-a3a6-5aba-9c94-4ff82337cc64.html

2b. USA data

U.S. Geological Survey, Gap Analysis Program (GAP). Protected Areas Database of the United States (PAD-US), version 1.4 Combined Feature Class, 2016. Retrieved 4 November 2016 from https://gapanalysis.usgs.gov/padus/data/download/

3. Critical Habitats

3a. Canadian data

Fisheries and Oceans Canada. Critical Habitat of Species at Risk, 2015. Retrieved 4 February 2017 from https://gcgeo.gc.ca/geonetwork/metadata/eng/db177a8c-5d7d-49eb-8290-31e6a45d786c

3b. USA data

U.S. Fish & Wildlife Service. FWS Critical Habitat for Threatened and Endangered Species Dataset, 2016. Retrieved 4 February 2017 from https://catalog.data.gov/dataset/fws-critical-habitat-for-threatened-and-endangered-species-datasetf6b00

4. Ramsar Wetlands

IUCN and UNEP-WCMC. The World Database on Protected Areas (WDPA), 2014. Cambridge, UK: UNEP-WCMC. Retrived 4 Feburary 2017 from http://biodiversitya-z.org/content/ramsar-sites-wetlands-of-international-importance

Other biological

1. Nursery & Spawning areas

Goodyear, C. S., T. A. Edsall, D. M. Ormsby Dempsey, G. D. Moss, and P. E. Polanski. 1982. Atlas of the spawning and nursery areas of Great Lakes fishes. 14 vols. U. S. Fish and Wildlife Service, Washington, DC. FWS/OBS-82/52.

Infrastructure

1. Pipelines

1a. Canada & USA data (overlap)

U.S. Energy Information Administration. Crude Oil Pipelines, 2016. Retrieved 4 February 2017 from https://www.eia.gov/maps/layer_info-m.php

U.S. Energy Information Administration. Petroleum Product Pipelines, 2016. Retrieved 4 February 2017 from https://www.eia.gov/maps/layer_info-m.php

2. Rail

2a. Canadian data

Natural Resources Canada**.** GeoBase - National Railway Network (NRWN), 2008. Retrieved 4 February 2017 from: http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/41049aec-b400-a1c1-0b85-9282973d752d.html

2b. USA data

Bureau of Transportation Statistics. North American Transportation Atlas Data (NORTAD). North America: United States Department of Transportation, 2014. Retrieved 4 February 2017 from: https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_atlas_database/2014/polyline

3. Vessel data (2011 – 2014)

Bureau of Ocean Energy Management (BOEM), and National Oceanic and Atmospheric Administration (NOAA). AIS data made available from MarineCadastre.gov, 2017. Retrieved 4 January 2017 from: https://www.marinecadastre.gov/ais

4. Refineries in North America

Natural Resources Canada (NRCAN). Refineries - North American Cooperation on Energy Information. Retrieved 4 January 2017 from: http://open.canada.ca/data/en/dataset/57e7bc4c-680b-4640-9fa1-ded7ce186fab

5. Great Lakes Shipping Lanes

U.S. Army Corps. of Engineers. USACE Waterway Network, 2012. Great Lakes Maritime Research Institute. Toledo, Ohio, USA. Retrieved 4 January 2016 from: http://www.navigationdatacenter.us/data/datanwn.htm

Commodity data

1. Canada Pipeline

Statistics Canada. Summary of pipeline movements – monthly (cubic metres), 2016. Retrieved 4 January 2017 from: http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=1330003&tabMode=dataTable&srchLan=-1&p1=-1&p2=9

2. Canada Rail

National Energy Board (NEB). Canadian Crude Oil Exports by Rail – monthly, 2016. Retrieved 4 January 2017 from: https://www.neb-one.gc.ca/nrg/sttstc/crdlndptrlmprdct/stt/cndncrdlxprtsrl-eng.html

National Energy Board (NEB). Canadian Crude Oil Exports – By Export Transportation System Summary, 2015. Retrieved 4 January 2017 from: https://www.neb-one.gc.ca/nrg/sttstc/crdlndptrlmprdct/stt/cndncrdlxprttrnsprttnsstm5yr/cndncrdlxprttrnsprttnsstm5yr-eng.html

3. USA Pipeline

U.S. Department of Energy (EIA). Movements by Pipeline between PAD Districts, 2017. Retrieved 4 January 2017 from: https://www.eia.gov/dnav/pet/pet_move_pipe_dc_R20-R10_mbbl_m.htm

4. USA Rail

U.S. Department of Energy (EIA). Movements of Crude Oil and Selected Products by Rail between PAD Districts, 2017. Retrieved 4 January 2017 from: https://www.eia.gov/dnav/pet/PET_MOVE_RAIL_A_EPC0_RAIL_MBBL_M.htm

5. Great Lakes Shipping

The St. Lawrence Seaway Management Corporation. 2014 Traffic Report, 2015. Retrieved 4 January 2017 from: http://www.greatlakes-seaway.com/en/pdf/traffic_report_2014_en.pdf

The St. Lawrence Seaway Management Corporation. 2013 Traffic Report, 2014. Retrieved 4 January 2017 from: http://www.greatlakes-seaway.com/en/pdf/traffic_report_2013_en.pdf

The St. Lawrence Seaway Management Corporation. 2012 Traffic Report, 2013. Retrieved 4 January 2017 from: http://www.greatlakes-seaway.com/en/pdf/traffic_report_2012_en.pdf

The St. Lawrence Seaway Management Corporation. 2011 Traffic Report, 2012. Retrieved 4 January 2017 from: http://www.greatlakes-seaway.com/en/pdf/traffic_report_2011_en.pdf

Physical

1. Substrate

Great Lakes Aquatic Habitat Framework (GLAHF). Substrate, 2012. Retrieved 4 January 2017 from: http://glahf.org/data/

2. Shoreline

Great Lakes Aquatic Habitat Framework (GLAHF), NOAA, and Environment and Climate Change Canada (ECCC). Harmonized Shoreline Classifications, 2012. Retrieved 4 January 2017 from: http://glahf.org/data/

3. Ice Concentration

Great Lakes Aquatic Habitat Framework (GLAHF), and NOAA Great Lakes Environmental Research Laboratory. Annual Ice Cover Duration, 2014. Retrieved 4 January from: http://glahf.org/data/

Socio-Economic

1. Population

- Canada

Statistics Canada. Population and Dwelling Count Highlight Tables, 2011 Census, 2012. Retrieved 4 January 2017 from: http://www12.statcan.gc.ca/census-recensement/2011/dp-pd/hlt-fst/pd-pl/Table-Tableau.cfm?LANG=Eng&T=301&S=3&O=D

- USA

U.S. Census Bureau. Population Density by Census Tract, 2010. Retrieved 4 January 2017 from: https://www.census.gov/geo/maps-data/data/tiger-data.html

2. Fisheries stocking

GLFC 2006-2015 database. http://www.glfc.org/fishstocking/

3. Ports

Bureau of Transportation (NTAD). https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_atlas_database/index.html

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NOAA, 2002. Environmental Sensitivity Index Guidelines, Version 3.0. NOAA Technical Memorandum NOS OR&R 11, Hazardous Materials Response Division, Office of Response and Restoration, NOAA Ocean Service.

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