New York State Great Lakes Wind Energy Feasibility Study: Geophysical and Geohazards Characterization

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NEW YORK STATE | NYSERDA

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Our Mission:

Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

New York State Great Lakes Wind Energy Feasibility Study: Geophysical and Geohazards Characterization

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Prepared by:

Worley Group, Inc. (dba Advisian)

Reading, PA

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Abstract

The Great Lakes Wind Feasibility Study investigates the feasibility of adding wind generated renewable energy projects to the New York State waters of Lake Erie and Lake Ontario. The Study examines myriad issues, including environmental, maritime, economic, and social implications of wind energy areas in these bodies of freshwater and the potential contributions of these projects to the State's renewable energy portfolio and decarbonization goals under the New York State Climate Act.

The study, which was prepared in response to the New York Public Service Commission Order Case 15-E-0302, presents research conducted over an 18-month period. Twelve technical reports were produced in describing the key investigations while the overall feasibility study presents a summary and synthesis of all twelve relevant topics. This technical report offers the data modeling and scientific research collected to support and ascertain Great Lakes Wind feasibility to New York State.

To further inform the study in 2021, NYSERDA conducted four public webinars and a dedicated public feedback session via webinar, to collect verbal and written comments. Continuous communication with stakeholders was available through greatlakeswind@nyserda.ny.gov NYSERDA's dedicated study email address. Additionally, NYSERDA and circulated print advertisements in the counties adjacent to both Lake Erie and Lake Ontario as to collect and incorporate stakeholder input to the various topics covered by the feasibility study.

Keywords

Sediment, substrate, geohazard, Great Lakes Wind, Lake Erie, Lake Ontario

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Acronyms and Abbreviations

ENC	Electronic Navigation Chart
ft	feet
g	acceleration of gravity
GLAHF	Great Lakes Aquatic Habitat Framework
GLSAD	Great Lakes Sediment Archive Database
km	kilometers
LAMP	Lakewide Action and Management Plans
m	meters
mi	miles
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
NYSERDA	New York State Energy Research and Development Authority
PCB	polychlorinated biphenyls
SAV	Submerged Aquatic Vegetation
USGS	United States Geological Survey

Summary

This Geophysical and Geohazards Characterization Study, hereafter referred to as the “study,” was prepared to support The New York State Energy Research and Development Authority’s (NYSERDA’s) Great Lakes Wind Feasibility Study. The current study contains a description of surficial sediments, stratigraphy, subsurface features, and other geohazard considerations in the New York State waters of Lakes Erie and Ontario.

The purpose of this document is to provide NYSERDA and the public with an assessment, based on the best information available, of geohazards associated with siting and developing New York Great Lakes Wind projects. While an evaluation of site-specific conditions is beyond the scope of the study, these findings provide critical information on potential geohazards for consideration in site and route selection, foundation design, and installation methodologies among other aspects of development planning.

S.1 Surficial Sediments

Surficial sediment distribution within Lake Erie and Lake Ontario was estimated from grain-size statistics available from the Great Lakes Sediment Archive Database. Within Lake Erie, dominant surficial soil types include clays, silts, and sands. Inferred surficial sand concentration within the eastern part of Lake Erie approximates the boundary of the East Basin and may be indicative of an area of relatively increased bottom current activity. Within Lake Ontario, dominant surficial soil types include the full range of clays, silts, sands, gravels, and rock. Sand distributions hint at the approximate boundaries of Lake Ontario’s major basins: Niagara, Mississauga, Genesee, Rochester, and Kingston basins, which are separated by ridges.

S.2 Stratigraphy and Depth to Bedrock: Lake Erie

Within Lake Erie, stratigraphically, older sediments that overlie the bedrock appear to be interbedded glacial tills, outwash deposits, glacio-lacustrine deposits, and glacial beach sediments. These glacial sediments range from fine-grained clays to coarse sands and gravels. Pebbles, cobbles, and boulders are also possible within these glacial sediments. Younger sediments are predominantly clays and silts. Coarser sediments within the younger units are concentrated in areas of higher energy.

Seismic data collected over Lake Erie in the late 1960s "show no evidence of structural deformation of bedrock or overlying unconsolidated materials" (Weston Geophysical n.d.). Faulting is not anticipated to be a significant concern for the siting, installation, or operation of Great Lakes wind in the New York waters of Lake Erie.

Within Lake Erie, the sediment thickness over bedrock is almost 116 meters (m; 380 feet [ft]), at the thickest section within the Eastern Basin. However, within New York State waters, the sediment thickness is less than 76.2 m (250 ft), with an average closer to 30.5 m (100 ft). Bedrock is outcropping along most of the shoreline in the eastern portion of the lake, including the New York State shoreline.

S.3 Stratigraphy, Structure, and Depth to Bedrock: Lake Ontario

Lake Ontario Quaternary sediments are described in literature as comprising up to five stratigraphic units. Hutchinson et al. (1993) describe the units as Unit A (oldest) through Unit E (youngest) and differentiate them by their seismic character and position within the section. The majority of Lake Ontario's shallow sediments in New York waters is described as lacustrine clay and silt, with the shoreline areas dominated by fine or medium-textured glacial till and lacustrine sand and gravel.

In general, the structure map of Lake Ontario bedrock shows that the south shoreline exhibits a steeper bedrock surface, whereas the northern shoreline grades more gently. The bedrock is also shallower in the western half of the lake, and deeper in the eastern half. The sediment thickness over bedrock is thickest, approximately 116 m (380 ft), in a narrow section associated with Dundas Valley in the far western portion of Lake Ontario. More representative of the overall lake, New York State waters have sediment thicknesses that are less than 90 m (295 ft), with an average closer to 22.8 m (74.8 ft).

Buried drumlins, just above bedrock, are identified in the eastern and deepest portion of Lake Ontario (Rochester Basin) within Unit A. The drumlins exhibit widths up to 600 m and heights up to 40 m. The drumlins appear as ridge-like features that are oriented northeast-southwest, indicating a glacial flow direction along that same trend. There are no observed direct outcrops of the drumlin deposits exposed at the lakebed, although they do have surface expression. These localized features may present elevated seabed gradients that may influence siting feasibility. They will also exhibit local variability in the subsurface soil column, with a potentially thicker fraction of coarse-grained materials, including sand, gravel, cobbles, etc. where present, which in turn may influence siting and foundation engineering.

There is evidence observed onshore within the Canadian province of South Ontario for faulting of bedrock material. Shear zones are also identified in the deep basement rocks (associated with the Grenvillian orogeny, more than 980 million years ago) of Lake Ontario. Additionally, there is evidence to suggest that the Clarendon-Linden fault system of New York extends into Lake Ontario along the Scotch-Bonnet sill. However, none of these features are identified with any evidence for post-glacial faulting within Lake Ontario. As such, faulting is not anticipated to be a significant concern for the siting, installation, or operation of Great Lakes wind in the New York State waters of Lake Ontario.

S.4 Other Geohazard Considerations

Additional geohazard considerations that may constrain or impact siting of Great Lakes Wind resources within New York state waters of Lake Ontario and Lake Erie include the presence of reef and shoal sites, concentrated areas of vegetated wetlands and aquatic beds, existing soil contamination, and seismicity. Shipwrecks and archaeological artifacts are also present within the lakes and are an additional consideration for siting. A detailed site investigation for selected Great Lakes Wind development area(s) should be conducted to identify if any sensitive habitats (i.e., reef, shoals, vegetated wetlands and aquatic beds) would be impacted by associated bottom disturbing activities.

Given that contaminants are known to be present and resident across the Lakes, it is recommended that a detailed geochemical analysis of the sediments be conducted to evaluate the state of sediment contamination at any potential future sites for Great Lakes Wind development as they become better defined. A review of historical sediment data from the relevant lake should be considered as part of any detailed site evaluation. A more local assessment, focused on the findings of the site-specific geochemical analysis, will address the presence, type, and quantity of contaminant(s), the anticipated disturbing activities, and anticipated resultant amount of disturbance, dilution, transport, and impacts. Mitigating methods may need to be employed to minimize the effect that disturbance of the lakebed sediments may have with regard to contaminants, dependent upon the findings of the local assessment and any applicable regulatory criteria.

Seismicity is considered low to moderate in the area; however, due diligence in considering appropriate seismic design for foundational structures is good engineering practice. Any selected Great Lakes Wind development area(s) should include a seismic design review that includes a site-specific assessment of liquefaction potential and an appropriate level of seismic design to ensure stability and integrity of the planned structure(s), as per standard engineering design practices and guiding codes/standards.

There are a large number of shipwrecks and historically significant archaeological artifacts documented within Lake Ontario, many of which fall within an area proposed to become a National Marine Sanctuary. These features will be an important consideration with regard to siting turbine and subsystem structures within the lake and routing cables for interconnection back to shore.

1 Introduction

For this report—the Geophysical and Geohazards Characterization Study, hereafter referred to as the "study"—Lakes Erie and Ontario were reviewed to provide context for the evaluation of site conditions for the New York State Great Lakes Wind Energy Feasibility Study. In addition to the water depths, currents and waves, and ice conditions within the lakes, the geologic setting is another key element for determining appropriate locations and foundation design options for potentially developing Great Lakes Wind Energy. The geology of Lake Erie and Lake Ontario is primarily defined by the history of glaciation in the region. The distribution of surficial sediments, stratigraphic units of glaciolacustrine sediments and drift deposits, geomorphological features carved into the lacustrine landscape by glaciers, and the variably eroded and exposed bedrock are important considerations for the siting of renewable energy infrastructure within the lakes. The wind turbine substructures and foundation types will be constrained by soil stiffness, the depth of bedrock below the surface, and other features and conditions that may exist at the lakebed and in the subsurface.

2 Surficial Sediments

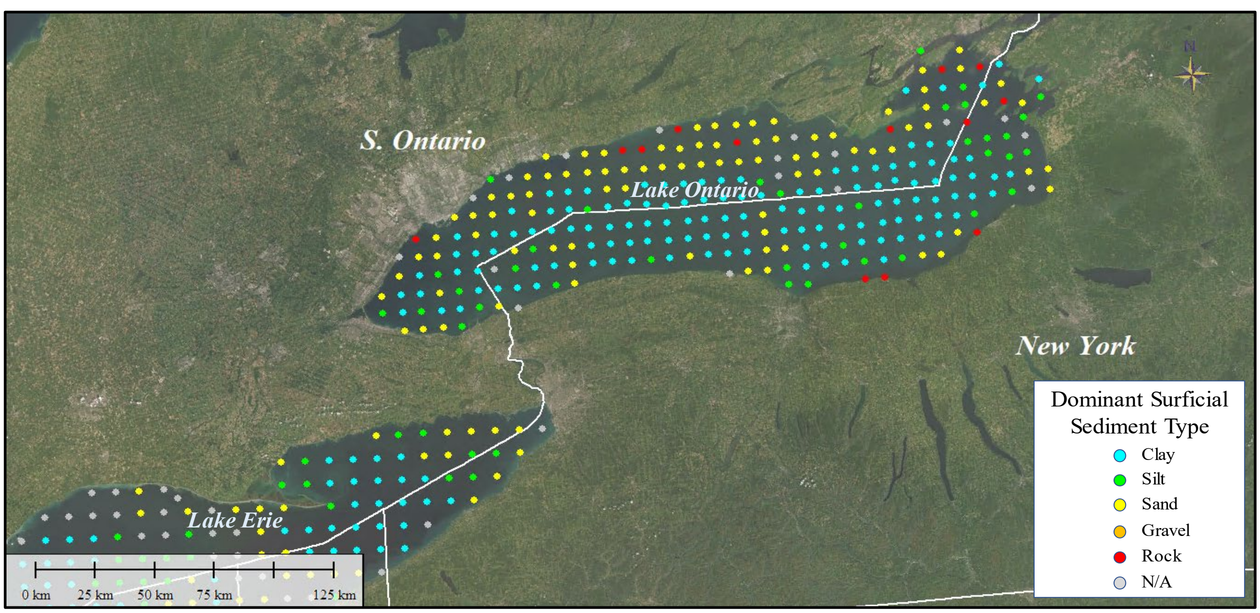
The surficial sediments are an important input for developing appropriate cable design, foundation design, and in consideration of burial requirements, should burial be required. Depending on the sediments, cables may require sheathing or other mitigations to protect from scour or abrasion. Surficial sediments, when supplemented with information from the subsurface, also contribute to the development of geotechnical soil profiles, critical in foundation engineering design and provide insight into trench feasibility and suitable trench design or feasibility of other burial methodologies.

2.1 Surficial Sediment Type Distribution

The Great Lakes Sediment Archive Database (GLSAD) provides data including sediment description, grain-size statistics, and geochemistry for sediment samples collected between 1960–1975 across the Great Lakes (Environment and Climate Change Canada 2021). There are 553 samples within Lake Ontario and Lake Erie, providing consistent coverage across the area of interest (Figure 1). The samples are spaced about 4.7–5.3 miles (mi; 7.5S8.5 kilometers [km]) apart in a grid pattern across Lake Ontario, and about 6 mi (10 km) apart in a grid pattern across Lake Erie. There are 138 GLSAD samples within New York State waters. Most samples were noted as being collected with a Shipek Grab, which generally recovers good quality bottom samples with minimal to no washout.

Figure 1. Distribution of Great Lakes Sediment Archive Database Sediment Samples across Lake Ontario and Lake Erie

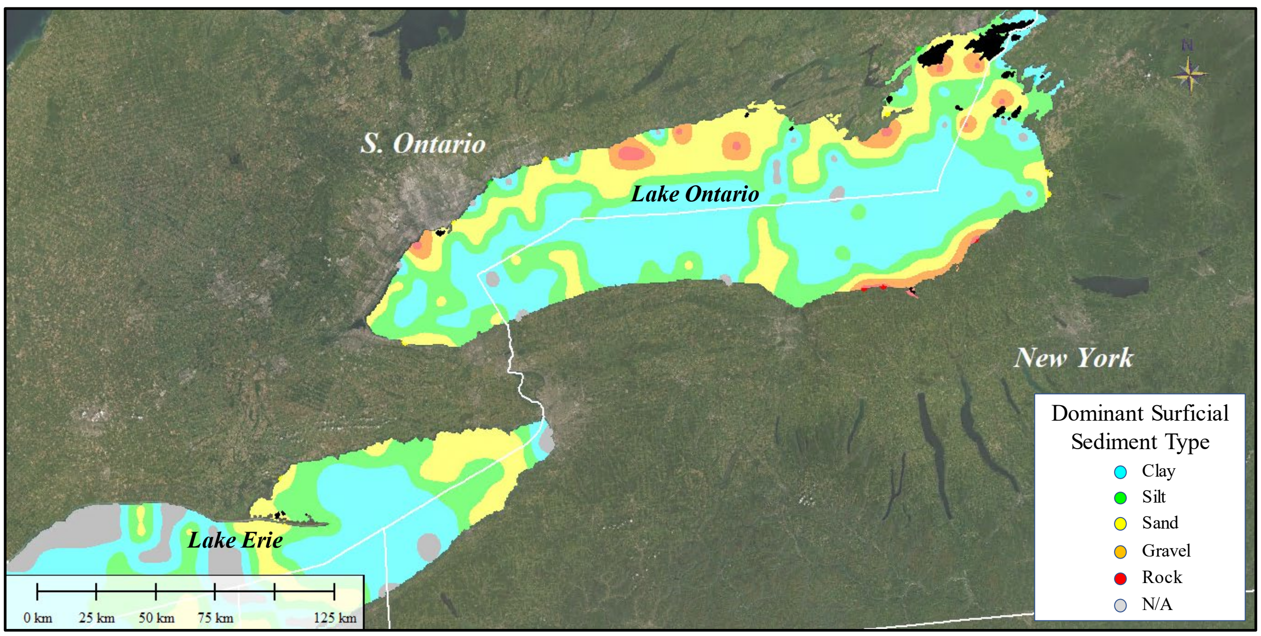
Source: (Environment and Climate Change Canada 2021)



Using the grain-size statistics from GLSAD, a map was created that interpolates between sample sites to characterize the dominant surficial sediment types across the study area (Figure 2). The interpolated sediment distribution assumes a natural gradation from clay (finest) to silt, to sand, to gravel, and to rock (coarsest). A kriging methodology was used for gridding, with numerical values assigned to each soil type, incremented from finest to coarsest, using the reported dominant grain size fraction to identify the primary soil type at each location. Sample sites where no grain size data are reported are coded as "N/A" and are likely places where the grab sampler was unable to capture suitable sample for grain size analysis. Areas of "N/A" might represent areas dominated by gravel, rock, or other substrate that would not be conducive to sampling, although specific conditions and sampling activities at those sites are unconfirmed.

Figure 2. Dominant Surficial Sediment Type Distribution, Derived from Great Lakes Sediment Archive Database Sediment Sample Data

Source: (Environment and Climate Change Canada 2021)



It should be noted that many of the GLSAD sample sites represent mixed sediments (silty sands, sandy clays, etc.). The surficial sediment classification, as presented in Figure 2, focuses on soil types representative of the majority of the sample. As such, the sediment distribution map represents a high-level classification of the dominant surficial sediment constituents across the two lakes. In general, coarser sediments are found along the shoreline, while the central portion of the lakes tends to have finer sediments.

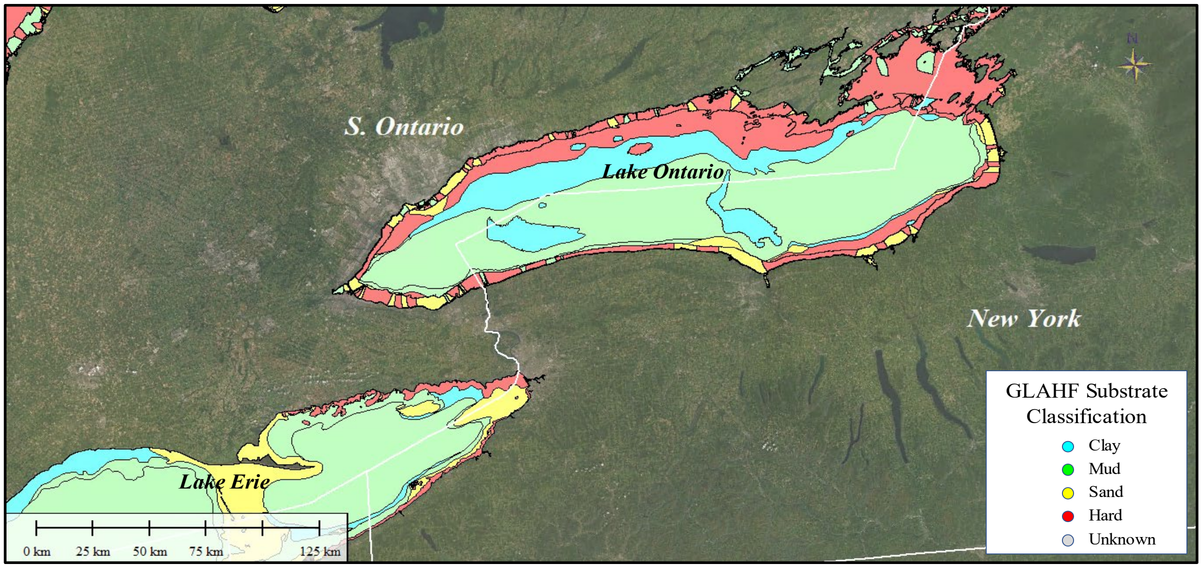
Sand distributions, as defined by the GLSAD-derived dominant surficial sediments, hint at the approximate boundaries of the major basins within the lakes: Niagara, Mississauga, Genesee, Rochester, and Kingston basins separated by ridges in Lake Ontario; East basin in Lake Erie (NOAA 2021). Sands and coarser materials are most likely to be found in areas of higher energy, such as the shoreline and the mouths of rivers; whereas finer grained materials are more likely to settle out in lower energy environments. The distribution of surficial sands and coarser materials not only highlights the basins, but also provides some indication of energy relative to the depositional environment within the lakes.

2.2 Interpretations of Substrate and Quaternary Geology

The derived dominant surficial sediment type distribution can be compared to other published maps that approximate sediment distribution for the lakes. The Great Lakes Aquatic Habitat Framework (GLAHF), for example, published an interpretation of substrate based on digitized, peer-reviewed publications (Figure 3) (Great Lakes Aquatic Habitat Framework 2020). Substrate data is typically intended to aid in assessing habitats and important ecosystems and is not always described in a way that harmonizes with established geotechnical standards. The classification of the GLAHF substrate, for instance, does not appear to consistently refer to standard grain size descriptions, as it includes classes for “mud” which could also be synonymous with clay and/or silt in some classification schemes and “hard” which is not a grain size definition. The GLAHF substrate, therefore, offers only a loose correlation with the GLSAD dominant surficial sediment type distribution.

Figure 3. Substrate for Lake Ontario and Lake Erie

Source: (Great Lakes Aquatic Habitat Framework 2020)

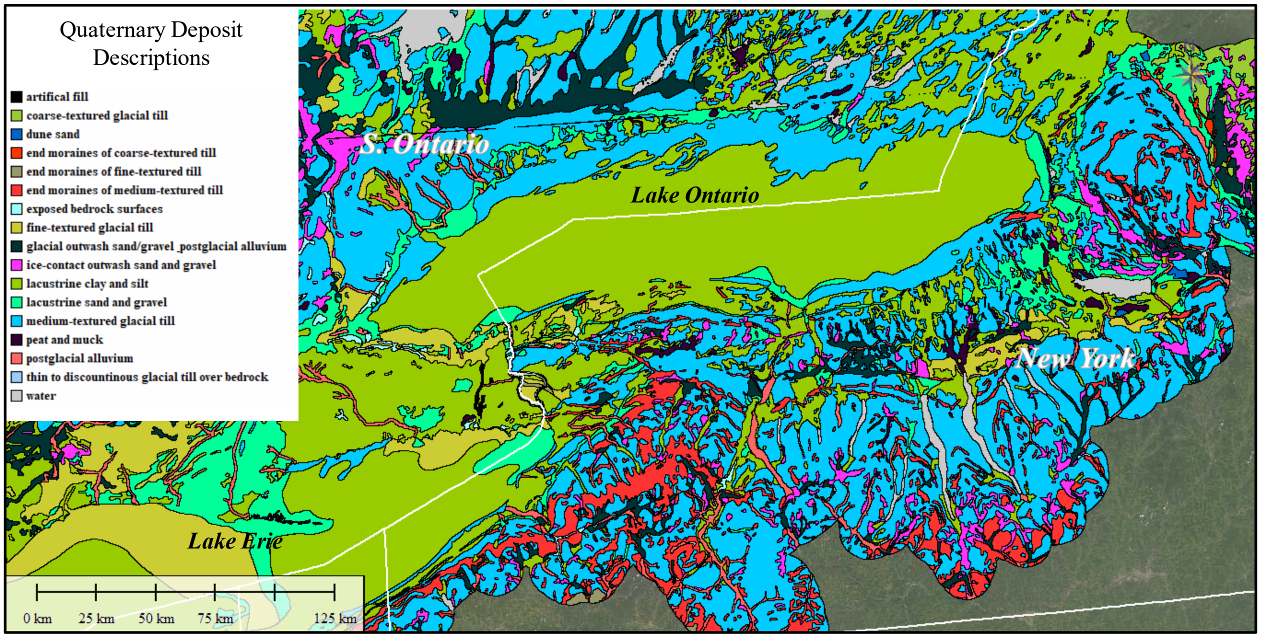


Between the two surficial sediment distributions, GLSAD dominant surficial soil (Figure 2) and GLAHF substrate (Figure 3), a few general similarities exist. For one, they both demonstrate coarser material along the shoreline and a general fining of sediments toward the center of the lakes. There are also some similar trends in the locations and general shapes of broad patches of sediments, approximating the major basin features, although the sediment classifications are not fully consistent.

Another source examined for approximating the surficial sediments across the lakes is the Quaternary geology mapping as published by GLAHF, which consolidates the USGS (U.S. Geological Survey) and the Ontario Ministry of Northern Development and Mines Quaternary datasets (Figure 4) (Great Lakes Aquatic Habitat Framework 2020). The mapped regions of Quaternary deposits are assigned classifications that are a combination of provenance and general grain size descriptors, often grouping sands and gravels, or clays and silts together.

Figure 4. Quaternary Geology, Based on Composited Interpretations

Source: (Great Lakes Aquatic Habitat Framework 2020)



The Quaternary mapping (Figure 4) presents the majority of the lake areas as lacustrine clay and silt, with the shoreline areas dominated by fine or medium-textured glacial till and lacustrine sand and gravel. The Quaternary geology interpretations within Lake Erie's Eastern Basin align fairly well with the GLSAD's estimate of dominant surficial soil distribution trends and reinforces the presence of mixed sediments within the lakes. The shoreline coarsening and basin fining trend is apparent in Lake Ontario: however, the Quaternary geology mapping does not resolve the sediment trends that distinguish the major basins of the lake, as are more clearly observed in both the GLSAD dominant surficial sediments (Figure 2) and GLAHF substrate datasets (Figure 3). In general, the Quaternary geology data set appears to offer lower resolution of surficial sediment distribution patterns within the lakes, particularly for Lake Ontario.

The GLSAD-based surficial sediment distribution (Figure 2) is expected to be a reasonable approximation of surficial conditions to support high-level screening and planning activities for the development of Great Lakes Wind Energy in New York State waters. Typically, normally consolidated finer-grained soils such as clays and silts are preferred for offshore siting and routing of linear infrastructure such as cables where self-embedment is optimized and trenching, lowering, and burial of linear infrastructure is more easily performed. Coarser grained materials at seabed, such as sands, gravels, or exposed rock, limit embedment of cables, and present challenges to trenching, lowering, and burial. Therefore, this initial soil distribution data provides some insights into where the siting of offshore wind energy infrastructure would be relatively better suited from the perspective of self-burial or subsequent trenching, lowering, and burial activities.

It is recommended that dedicated, fit-for-purpose geophysical and geotechnical surveys be conducted over any potential site(s) considered for development of Great Lakes Wind Energy in order to prepare more detailed site characterization. The GLSAD-based dominant surficial sediment distribution map (Figure 2) may be used as an aid to scope appropriate survey programs and for reference in concept site selection.

3 Stratigraphic Units

The stratigraphy within Lake Ontario and Lake Erie are similar, having a fine-grained (i.e., clays and silts) younger sediment package overlying a series of generally coarsening downward, glacial deposits with lateral variability in mixed grain-sizes that represent the glacial history of the region. The sedimentary units overlie bedrock and have variable thickness across the lakes.

3.1 Lake Ontario

Lake Ontario Quaternary sediments are described in literature as comprising up to five stratigraphic units. Hutchinson et al., describe the units as Unit A (oldest) through Unit E (youngest), and differentiate them by their seismic character and position within the section (Hutchinson, Lewis and Hund 1993). A summary table of the stratigraphic units classified by (Hutchinson, Lewis and Hund 1993) is shown in Figure 5.

Figure 5. Summary Table of Interpreted Stratigraphic Units, Seismic Stratigraphy and Lithostratigraphy

Included: Inferred Environment of Deposition, Regional Correlation, and Inferred Age of the Respective Units.

Source: (Hutchinson, Lewis and Hund 1993)

NAME	SEISMIC STRATIGRAPHY		LITHOSTRATIGRAPHY		ENVIRONMENT OF DEPOSITION	REGIONAL CORRELATION	INFERRED AGE (1000 ^{14}C YRS B.P.)
	Seismic Character	Contacts	Lithology	Contacts			
		Sediment water interface, usually sharp and strong		Top of core, watery			
UNIT E	Weakly laminated, ponded in topographic lows, thin on topographic highs		Dark gray, silty clay, generally homogeneous but with occasional black laminae and shell fragments		Present productive lake environment; relatively high energy	Modern Lake Ontario	0, 2
		Conformable, single smooth reflector slightly stronger than surrounding reflectors		Uncertain			
UNIT D	Moderately laminated, partially draped and ponded		Firm dark gray silty clay faintly laminated near the base, homogeneous near the surface		Lake environment transitional between quiet conditions and higher energy, more productive modern conditions	Early Holocene Lake Ontario	4, 6
		Conformable, two distinct, closely spaced reflectors, very consistently strong		<1m long interval of sandy couplets within gray clay couplets			
UNIT C	Well laminated with numerous parallel reflectors, well draped, uniformly thick		Horizontally banded consisting of dark gray-brown and dark gray clay couplets about 1-1.5 cm thick		Quiet water; proglacial to early post glacial lake environment	Lake Iroquois to Early Lake Ontario	8, 10
		Gradational and indistinct		Gradational			
UNIT B	Semi-opaque, massive, some diffractions		Stiff dark gray clay with light gray silt sand blebs and infrequent pebbles		Floating ice margin with debris flows?	Port Huron ice retreat	12
		Discontinuous and fuzzy		Not sampled			?
UNIT A	Hummocky, mounded, large diffractions (eastern half of lake) Massive, very opaque, diffractions (western half of lake)		Coarse to fine gravel of metamorphic, igneous and sedimentary lithologies in a sand-silt matrix		Subglacial, grounded ice occupying entire basin	Port Huron ice or earlier advances	14, 16
		Generally clear, and sharp except under areas of thick drift		Not sampled			
PALEOZOIC BEDROCK							

3.1.1 Units A and B

The oldest unit, Unit A, comprises mixed sediments of pebbles, coarse and fine gravel, silt, and sand, interpreted as a diamict subglacial till. Significant relief in the uppermost boundary of Unit A in the eastern portion of Lake Ontario, presenting as long ridges, has been inferred as drumlins (Hutchinson, Lewis and Hund 1993). More discussion of the drumlins is presented in section 4.1.

Unit B is also interpreted as a till unit, although it generally lacks the coarser gravels and pebbles that are present in Unit A. Unit B is only found in the western portion of Lake Ontario (Hutchinson, Lewis and Hund 1993).

3.1.2 Unit C

Unit C is younger than Units A and B and comprises predominantly clays and silty clays. The unit is interpreted as pro- and peri-glacial lacustrine sediments that drape the underlying tills. Sandier sediments appear near the top of the unit. The consistent lamination within the unit implies a low-energy, undisturbed environment of deposition. Unit C is commonly eroded away in the shallow shoreline areas and is only retained within the basins, yet it remains the unit with greatest coverage across the lake. The top of Unit C is noted by a geophysically-recognizable regional marker horizon, likely associated with the sands (Hutchinson, Lewis and Hund 1993).

3.1.3 Units D and E

Unit D comprises predominantly bedded lacustrine silty clays and clays. The older portion of the unit (near the base) exhibits consistent lamination while the youngest portion of the unit (near the top) is dominated by a massive, homogenous clay. Unit D is interpreted to represent a transitional environment of deposition from the low-energy environment of Unit C to an increased energy, possibly associated with increased circulation within the lake (Hutchinson, Lewis and Hund 1993).

Unit E is the youngest of the defined stratigraphic units within Lake Ontario. The unit is characterized as a silty clay with occasional iron sulfide laminae and pockets of shell fragments. Both Unit D and Unit E are ponded within the lows of the pre-existing topography and are relatively thinner than the older sections. Unit E appears to represent an increased level of energy within the depositional system from that of Unit D. Unit E is the modern depositional unit within Lake Ontario (Hutchinson, Lewis and Hund 1993).

3.2 Lake Erie

Strata within Lake Erie appear to have similar characteristics to those of Lake Ontario. Older sediments that overlie the bedrock appear to be interbedded glacial tills, outwash deposits, glacio-lacustrine deposits, and glacial beach sediments. These glacial sediments range from fine-grained clays to coarse sands and gravels. Pebbles, cobbles, and boulders are also possible within these glacial sediments (McNeilan & Associates, LLC 2017). These Lake Erie glacial sediments appear to be similar to the sediment packages of Units A through C in Lake Ontario.

Younger sediments are predominantly clays and silts, similar to Units D and E of Lake Ontario. Coarser sediments within the younger units are concentrated in areas of higher energy, such as the shallow waters along the coastline or within the incised channels of fluvial pathways into the lake. Finer sediments are ponded in the basin, where the depositional environment is relatively lower energy (McNeilan & Associates, LLC 2017).

Seismic data collected over Lake Erie in the late 1960s "show no evidence of structural deformation of bedrock or overlying unconsolidated materials" (Weston Geophysical). More discussion of deformation and faulting is presented in section 4.2.

3.3 Bedrock

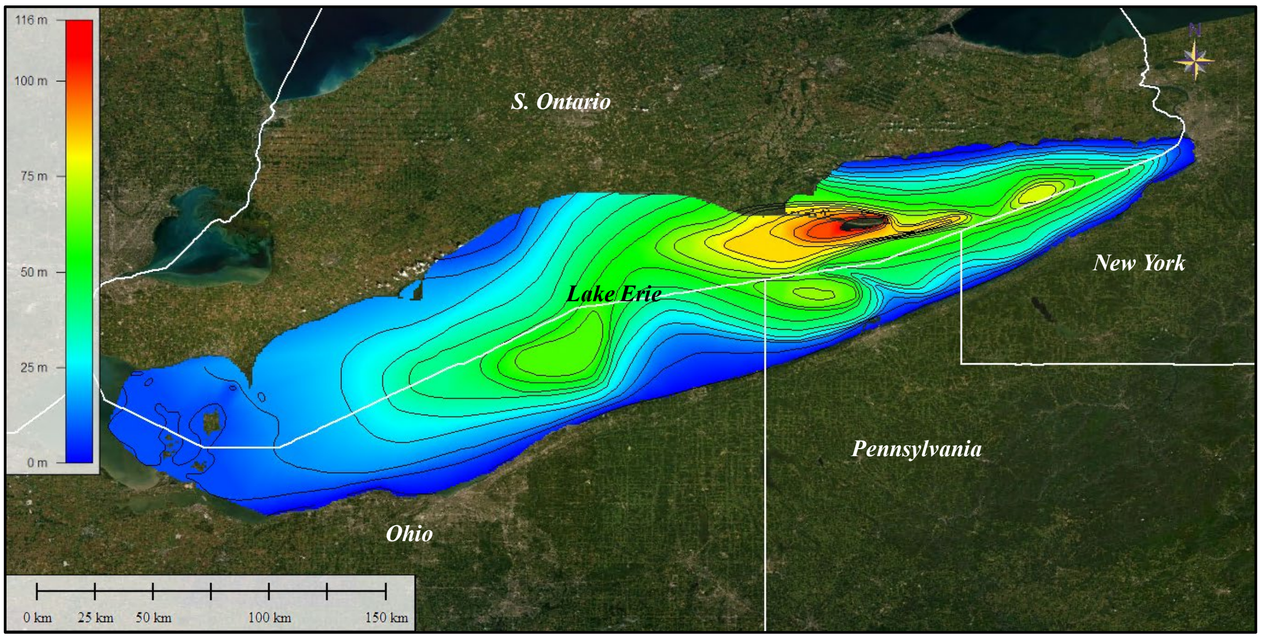
Bedrock conditions within the lakes are a critical element for consideration of siting Great Lakes Wind Energy infrastructure and the type of technology that might be suitable to install across the area. Shallow bedrock may prevent deep piled foundations, for example, from reaching a suitable depth to ensure the necessary holding capacities per the design requirements. The depth to bedrock is also a significant consideration for evaluating burial requirements for cables, including identifying appropriate burial methodologies and their feasibility. Where burial may not be feasible, such as in areas of bedrock exposure, protection or stabilization of the cables may be required to mitigate against abrasion.

3.3.1 Lake Erie Bedrock

Work completed by Morgan, et al., published in 2020 by the Geological Survey of Canada in Open File 8733, included a summary of the Lake Erie sediment thickness above bedrock (Figure 6) (Morgan, Todd and Lewis 2020). Within Lake Erie, the sediment thickness over bedrock is almost 380 feet (ft; 116 meters [m]), at the thickest section within the Eastern Basin. However, within New York State waters, the sediment thickness is less than 250 ft (76.2 m), with an average closer to 100 ft (30.5 m).

Figure 6. Lake Erie Sediment Thickness above Bedrock

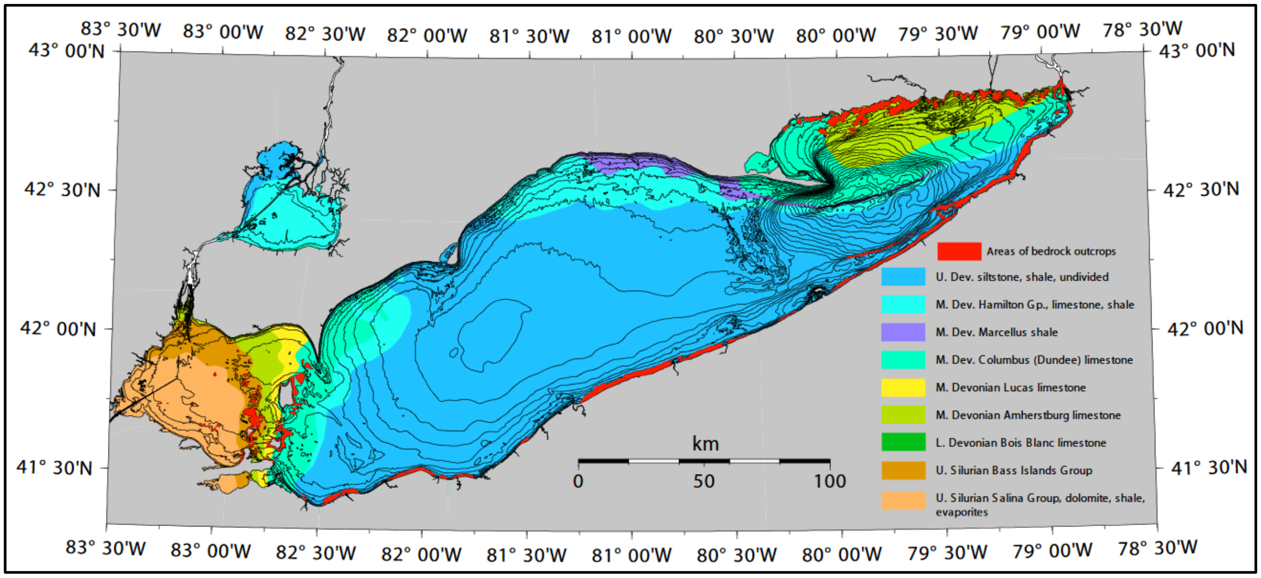
Source: (Morgan, Todd and Lewis 2020)



Within Lake Erie, bedrock is outcropping along most of the shoreline in the eastern portion of the lake, including the New York State shoreline, as noted by the red-colored areas in Figure 7.

Figure 7. Areas of Exposed Bedrock in Lake Erie

Source: (Holcombe, et al. 2005)



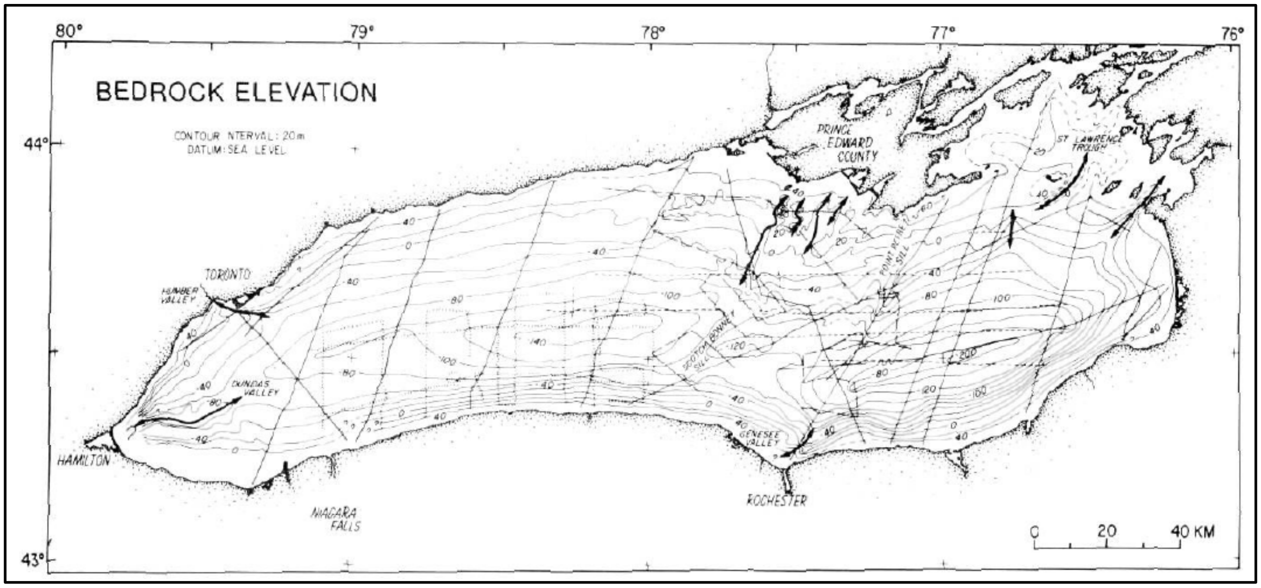
3.3.2 Lake Ontario Bedrock

In general, the structure map of Lake Ontario bedrock (Figure 8) shows that the south shoreline exhibits a steeper bedrock surface, whereas the northern shoreline grades more gently. The bedrock is also shallower in the western half of the lake, and deeper in the eastern half. Bedrock is commonly exposed at the shoreline along Lake Ontario, as various erosional processes yield little to no overlying Quaternary sediments in many places along the lake's margin (NOAA 2021).

For Lake Ontario, a sediment thickness map was developed for this assessment from the available lakebed bathymetry data published by the National Geophysical Data Center (NGDC) and the bedrock structure map published by Hutchinson et al (National Geophysical Data Center 1999) and Figure 8. The elevation details from Figure 8 were georeferenced and manually digitized for this effort.

Figure 8. Bedrock Elevation for Lake Ontario

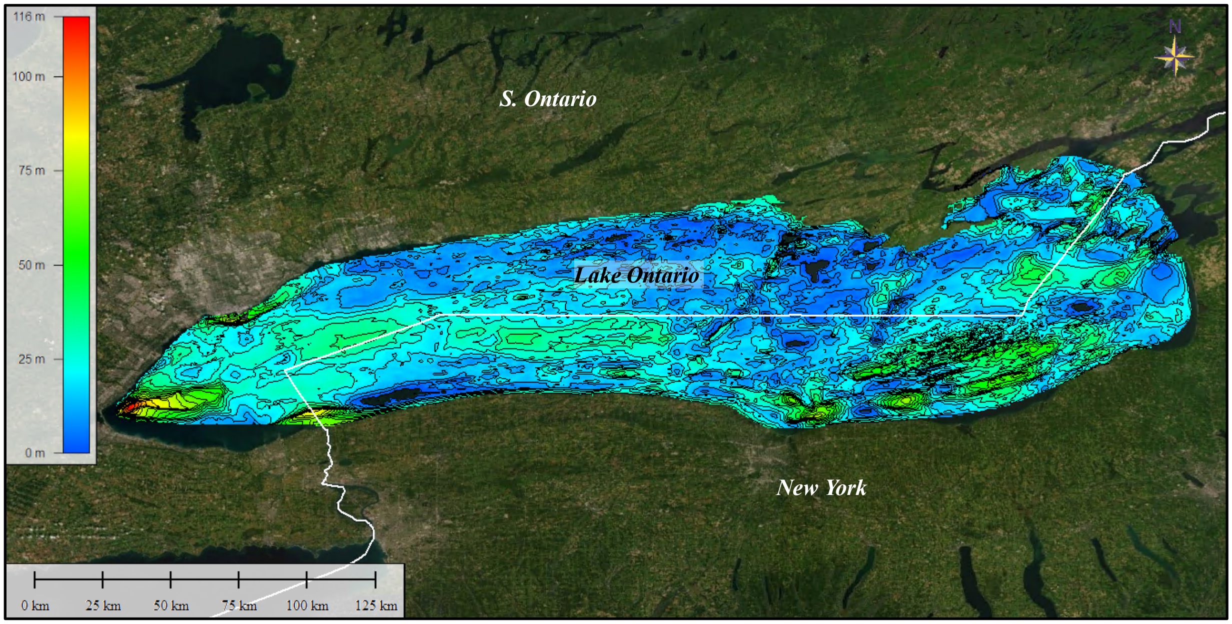
Source: (Hutchinson, Lewis and Hund 1993)



The resulting sediment thickness for Lake Ontario is estimated based on the difference in lakebed elevation and bedrock elevation (Figure 9). The sediment thickness over bedrock is thickest, approximately 380 ft (116 m), in a narrow section in the far western portion of Lake Ontario. This area is associated with Dundas Valley (denoted on Figure 8). More representative of the overall lake, New York State waters have sediment thicknesses that are less than 295 ft (90 m), with an average closer to 74.8 ft (22.8 m).

Figure 9. Lake Ontario Sediment Thickness above Bedrock

Source: (National Geophysical Data Center 1999) and (Hutchinson, Lewis and Hund 1993)



In general, within New York State waters, both lakes exhibit the presence of bedrock within 66 ft (20 m) or less from the surface in places, which would indicate challenges with deep pile driving within those portions of the lakes. More details about the technology limitations are considered in New York State Great Lakes Wind Energy Feasibility Study: Substructure Recommendations (NYSERDA 2022e).

3.4 Nominal Soil Profile Above Bedrock

The soil profile above bedrock appears fairly consistent between Lakes Erie and Ontario, consisting of predominantly soft to stiff clays and silt units overlying a more coarse-grained unit of deposits sitting on top of bedrock. The typical soil model for the stratigraphy section would consist of normally to under consolidated fine-grained deposits with interspersed ribbons of sand where intact (uneroded). Locations where erosion, unconformities, nonconformities, or truncated strata within the soil section could indicate where stiffer, over consolidated soils, based on depth, are present in the section. Lower in the section, in Unit B, more variable, mixed, and predominantly coarser grained deposits will vary in composition and soil properties based on location in the Lakes. Silts and lacustrine samples are typically considered to be sensitive soils and may exhibit dilation, deformation, loss of strength and capacity, liquefaction, and flow when disturbed, such as during installation activities or under seismic or cyclic loads. Site specific analyses of soil borings and distinct design soil parameters are beyond the scope of a general feasibility study, however, the soil composition and units in the Lakes generally look favorable for the siting of offshore wind development infrastructure.

4 Subsurface Features

Subsurface features within Lake Ontario and Lake Erie's Quaternary sediments, specifically drumlins, faults, and shallow gas, are reviewed to evaluate if they may constrain the siting and/or design of Great Lakes Wind Energy infrastructure.

4.1 Drumlins

Drumlins are a landform that resembles an elongated hill, created by the sculpting forces beneath a flowing glacier. They are relict landform deposits of a glacier's prior presence and passing. An example of a drumlin on land is shown in Figure 10.

Figure 10. Example of a Drumlin on Land, Note Fence Posts and Power Line Poles for Scale

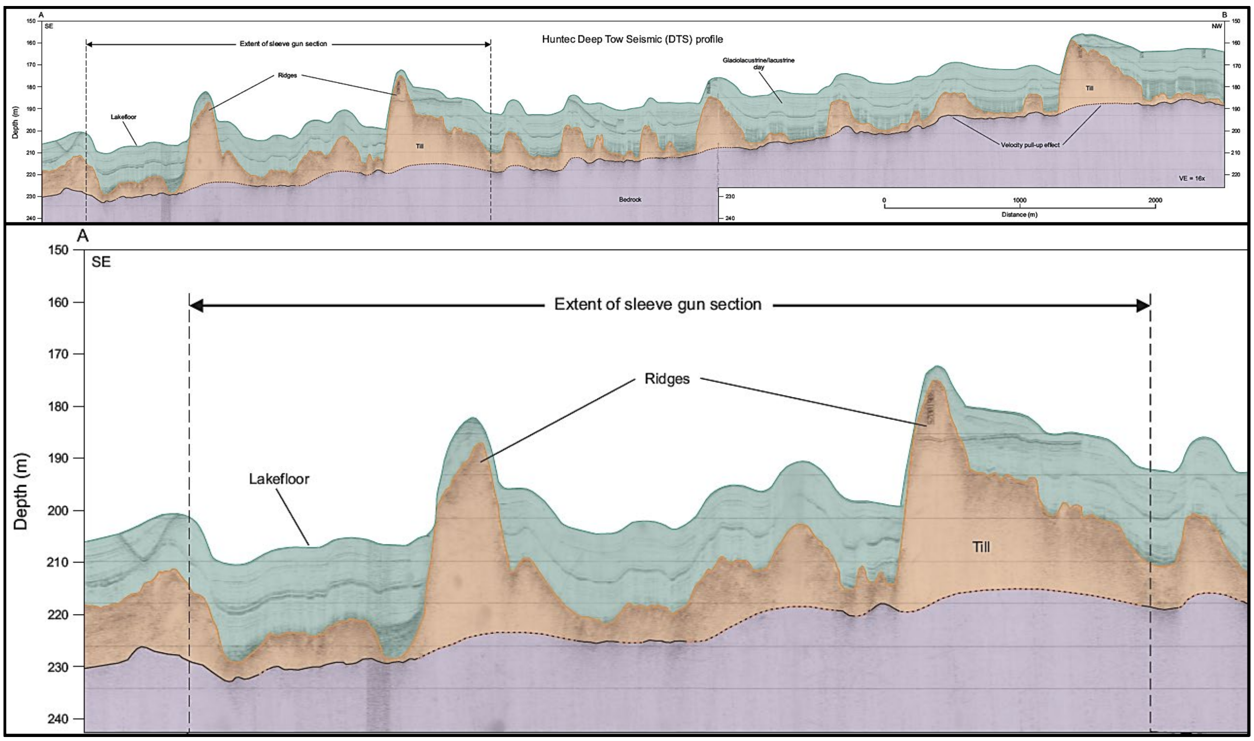
Source: (MH and DE 2016)

Drumlins typically consist of varied glacially derived deposits and may contain sand, silt, clay, gravel, cobbles, and boulders. They are essentially a mélange of glacially eroded material deposited to form the landform.

Buried drumlins, just above bedrock, are identified in the eastern and deepest portion of Lake Ontario (Rochester Basin), within Unit A (Hutchinson, Lewis and Hund 1993), and as shown in the geophysical cross-section in Figure 11.

Figure 11. Huntec Deep Towed Seismic Geophysical Cross Section Profile of Drumlins in the Rochester Basin, Lake Ontario

Source: (Coflin, et al. 2017)

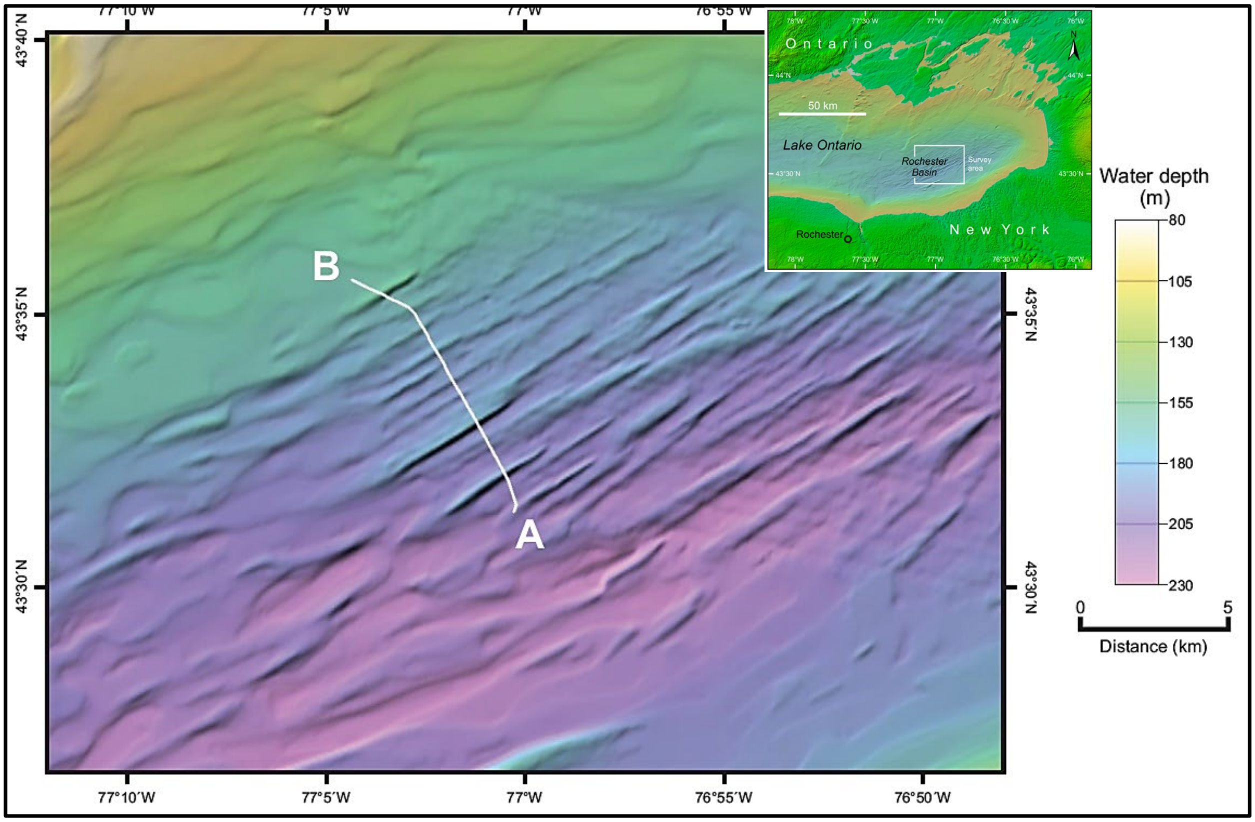


The drumlins exhibit widths up to 600 m (1969 ft) and heights up to 40 m (131 ft). The drumlins are covered by a clay drape that is thinner along the steep ridge flanks and thicker where sediments ponded between the ridges.

The drumlins appear as ridge-like features that are oriented northeast-southwest, indicating a glacial flow direction along that same trend. Although buried, where present, they do have expression and influence on the seabed topography as shown in Figure 12; however, there are no observed direct outcrops of the drumlin deposits exposed at the lakebed (Coflin, et al. 2017).

Figure 12. Bathymetric Surface Rendering Showing Lake Floor Expression of Buried Drumlins in Rochester Basin, Lake Ontario

Source: (Coflin, et al. 2017). Note: Inset image provides location of view within Lake Ontario. The transect A-B is the Huntec deep towed seismic cross-section data shown in Figure 11.



The drumlins contribute to irregular thickness within the till unit, which also contributes to variation in overburden above the drumlin deposits. These variations over relatively short distances will impact siting of Great Lakes Wind Energy facilities. The nature of the till deposits, with mixed grain-sizes and potential for gravels or coarser materials intermixed may introduce additional challenges with foundation selection, site-specific design, and installation. Although the draped and ponded sediments overlying the drumlines cause the surface expression of the drumlins to be more muted than the buried features themselves, there remains geomorphic expression of the drumlins on the lake bottom.

These localized features may present elevated seabed gradients that influence siting feasibility, depending on the technology selected and gradient tolerances. They also will locally have variability in the subsurface soil column where present, with potentially thicker fraction of coarse-grained materials, including sand, gravel, cobbles, etc. where present, which in turn may influence the siting and engineering of wind energy development foundations applicable to the local conditions.

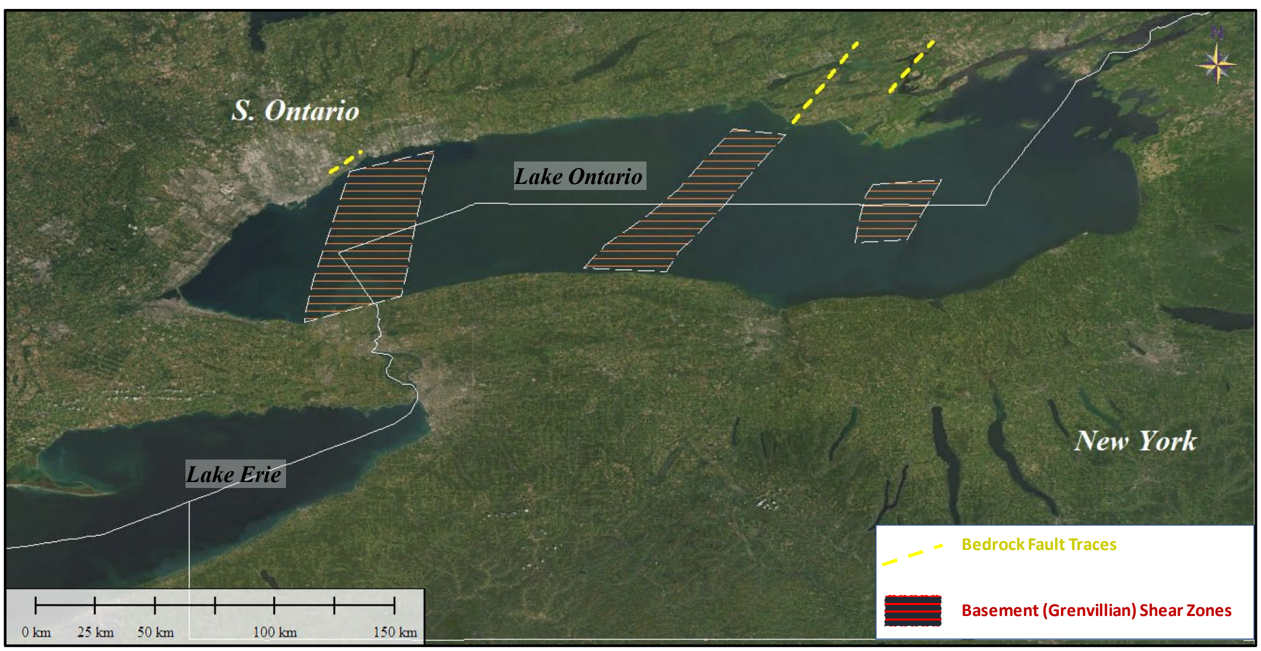
Specific discussion of foundation technology considerations is presented in New York State Great Lakes Wind Energy Feasibility Study: Substructure Recommendations (NYSERDA 2022e). If Great Lakes Wind Energy development proceeds in the portion of Lake Ontario where the drumlins are present, it is recommended that detailed, site-specific geophysical and geotechnical data be acquired and reviewed to ensure feasibility and to support detailed siting, engineering design, and installation planning.

4.2 Faults

With regard to faults, there is evidence observed onshore within the Canadian province of South Ontario for faulting of bedrock material. There are also shear zones identified in the deep basement rocks (associated with the Grenvillian orogeny, more than 980 million years ago) of Lake Ontario (Figure 13), (Hutchinson, Lewis and Hund 1993). However, neither are identified with any evidence for post-glacial faulting within the Lakes.

Figure 13. Basement Shear Zones and Bedrock Fault Traces in Lake Ontario

Source: (Hutchinson, Lewis and Hund 1993)

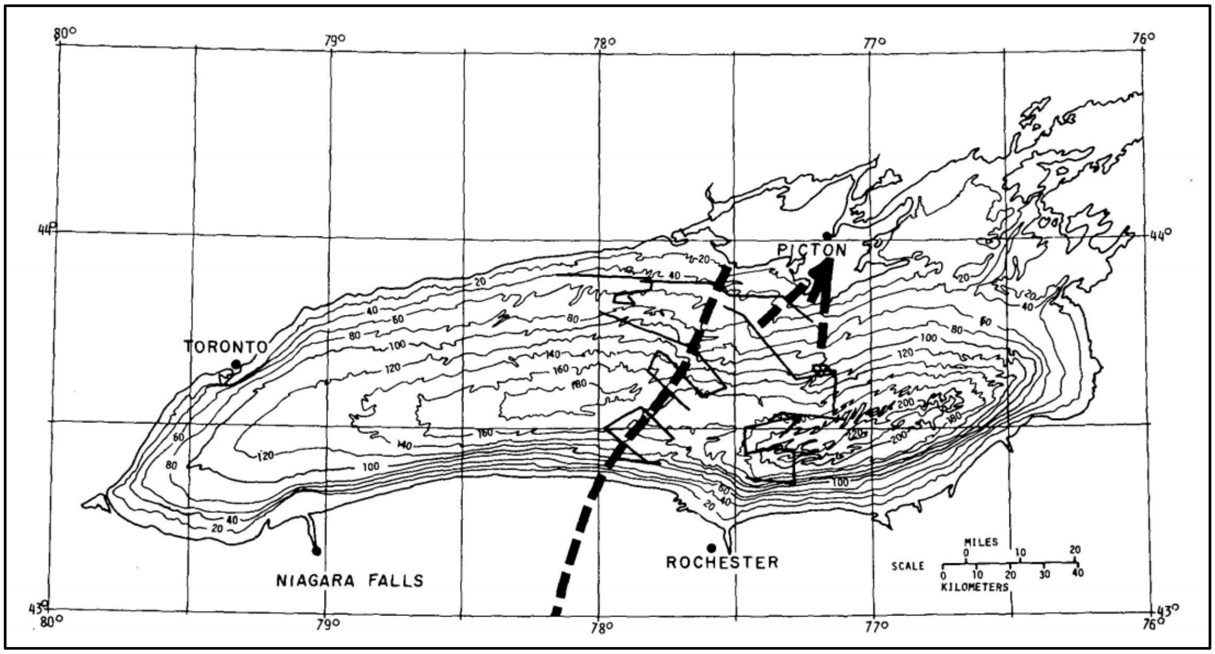


There is also evidence to suggest that the Clarendon-Linden fault system of New York State extends into Lake Ontario along the Scotch-Bonnet sill (Figure 14). As with the features noted in Figure 13, there are "no observable indicators of postglacial Holocene movement within the unconsolidated lacustrine section" (Hutchinson, Pomeroy, et al. 1979). Similarly, no active faulting is noted in the New York State portion of Lake Erie (Weston Geophysical).

Figure 14. Extension of the Clarendon-Linden Fault along the Scotch-Bonnet Sill in Lake Ontario

Illustrated with bathymetry contours and survey track lines.

Source: (Hutchinson, Pomeroy, et al. 1979)



Given that there has been no evidence for post-glacial faulting within Lake Ontario or the New York State portion of Lake Erie, faulting is not anticipated to be a significant concern for the siting, installation, or operation of Great Lakes Wind Energy in the New York State waters of Lake Ontario or Lake Erie. Active faulting could affect the performance and holding capacity of piled foundations. Therefore, although the available information suggests no to minimal faulting, careful review of site-specific geophysical data should be conducted to confirm the absence and/or avoidance of deformed or displaced strata that could indicate active faults to be subsequently avoided by surface and subsurface foundations zones with an appropriate offset. Faults can also sometimes be seismogenic in nature, triggering earthquakes when movement of the fault occurs. More discussion about the region's seismicity is presented in section 5.4.

4.3 Possible Shallow Gas

Within Lake Ontario there are observations of "acoustic scattering and limited penetration" in geophysical seismic data, particularly in the northeast and also near the mouth of the Niagara River, as depicted in Figure 15. These regions are interpreted as areas of possible shallow gas, likely biogenic in nature (Hutchinson, Lewis and Hund 1993). Such accumulations are commonly formed in situ from the decomposition of organic matter. There does not appear to be any evidence of seepage or expulsion of the gas to the surface, based on the lakebed morphology.

Figure 15. Location of Possible Shallow Gas Accumulations in Lake Ontario

Source: (Hutchinson, Lewis and Hund 1993)

The presence of shallow gas is a consideration for foundation siting and design/installation as well as trenching and burial activities. Shallow gas could affect the performance and holding capacity of piled foundations. The gas could also be released from the formation, possibly creating a potentially hazardous situation, particularly if the gas is under increased pressure, and, gas prone zones are typically avoided as much as possible.

Given the information available, careful review of site-specific subsurface geophysical data should be conducted to verify the presence or absence of shallow gas accumulations at any selected development site. In general, avoidance of the shallow gas areas is recommended where activities associated with foundation installation or trenching activities are planned. The site-specific subsurface data should be referenced to ensure an understanding of the nature of any shallow gas features, impact to the planned infrastructure and operational activities, and identification of any necessary mitigations.

5 Other Geohazard Considerations

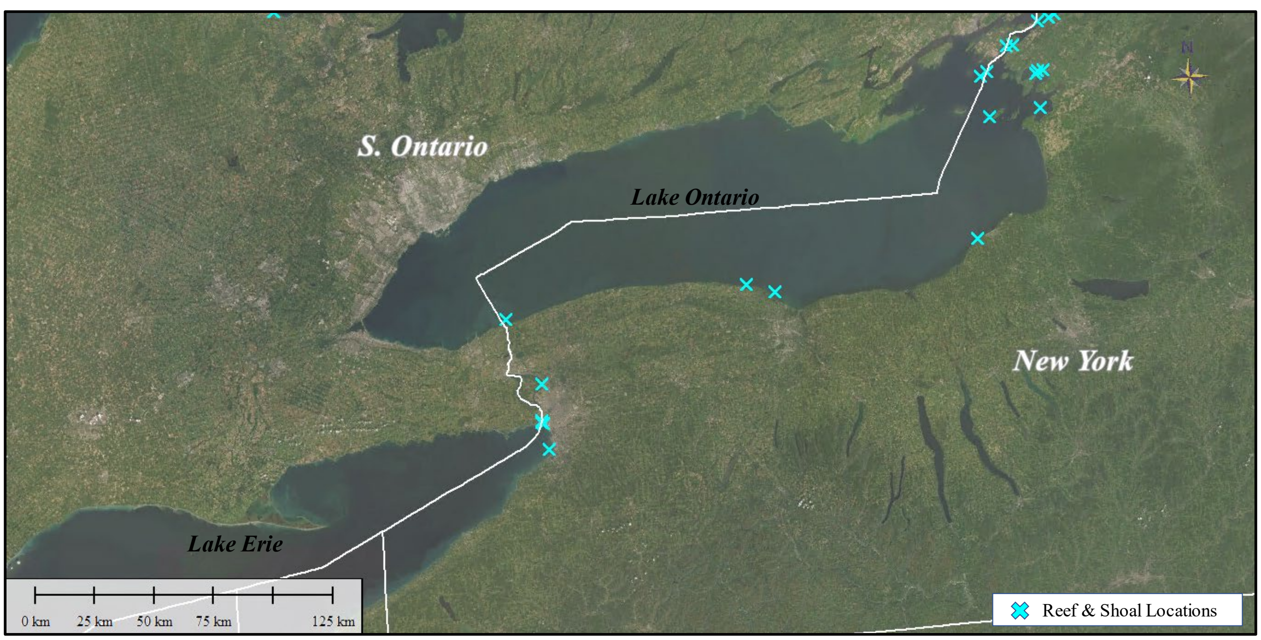
Additional geohazard considerations that may constrain or impact siting of Great Lakes Wind Energy resources within New York State waters of Lake Ontario and Lake Erie include the presence of reef and shoal sites, concentrated areas of vegetated wetlands and aquatic beds, existing soil contamination, and seismicity. Shipwrecks and archaeological artifacts are also present within the lakes and are an additional consideration for siting.

5.1 Reef and Shoal Sites

There are several locations within the New York State waters of Lake Ontario and a few in Lake Erie that are identified as reef and shoal sites (Figure 16). These areas are important habitat and fish spawning locations. Bottom disturbing activities in proximity to these locations may trigger additional regulatory processes, required implementation of protective mitigation measures, or may be subject to a mandated buffer distance from the reef or shoal area. Discussion of the fish communities in Lake Erie and Lake Ontario is presented in New York State Greatlakes Wind Energy Feasibility Study: Relative Risks, Minimization/Mitigation, and Benefits (NYSERDA 2022i).

Figure 16. Locations of Reef and Shoal Sites within Study Area

Source: (Great Lakes Aquatic Habitat Framework 2020)



The GLAHF compiled a listing of known reef and shoal locations from various data sources (Great Lakes Aquatic Habitat Framework 2020). A table of documented sites within New York State waters is provided in Table 1. Note that additional sites may be present and not formally documented in the GLAHF data set and some sites are located across the international border in Canadian waters and therefore not included in the table.

Table 1. Known Reef and Shoal Sites within New York State Waters

Source: (Great Lakes Aquatic Habitat Framework 2020)

Feature Name	Lake	County	Latitude	Longitude
Lewis Shoal	Lake Ontario	Monroe	43.31312	-77.6579
Herrick Shoal	Lake Ontario	Jefferson	44.04153	-76.1981
Johnson Shoal	Lake Ontario	Jefferson	44.05301	-76.1615
Middle Shoal	Lake Ontario	Jefferson	44.05000	-76.1880
Rumsey Shoal	Lake Ontario	Niagara	43.28689	-79.0577
Galloo Shoal	Lake Ontario	Jefferson	43.89645	-76.4642
Lime Barrel Shoal	Lake Ontario	Jefferson	43.91257	-76.1915
Wautoma Shoals	Lake Ontario	Monroe	43.35000	-77.8022
Ford Shoals	Lake Ontario	Oswego	43.44235	-76.5866
Bird Island Reef	Lake Erie	Erie	42.89508	-78.9066
Horseshoe Reef	Lake Erie	Erie	42.88470	-78.9014
Middle Reef	Lake Erie	Erie	42.88634	-78.9109
Seneca Shoal	Lake Erie	Erie	42.78579	-78.8801

A detailed site investigation for selected Great Lakes Wind Energy development area(s) should be conducted to identify if any sensitive habitats would be impacted by associated bottom disturbing activities.

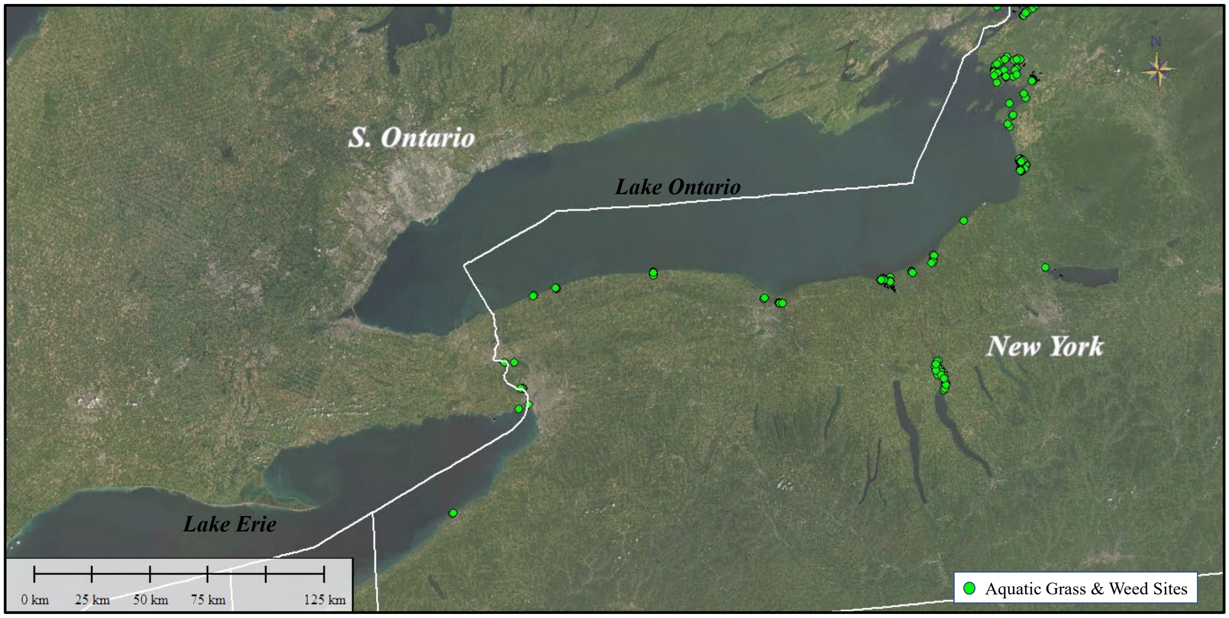
5.2 Vegetated Wetlands and Aquatic Beds

Portions of Lake Ontario and Lake Erie are identified as vegetated wetlands and aquatic beds. A few different sources describe these areas in and around the lakes, including Electronic Navigation Charts (ENCs) and the Submerged Aquatic Vegetation (SAV) Classification Map. These areas within the lakes provide a critical food source and habitat to a number of species within the lakes' ecosystem.

There are several locations along the shoreline of Lake Ontario and a few along Lake Erie, illustrated on Figure 17, that are identified on ENCs as areas with aquatic grasses and weeds (NOAA 2021).

Figure 17. Location of Aquatic Grasses and Weeds, Based on Electronic Navigation Chart Data

Source: (NOAA 2021)



Ongoing research by Michigan Tech Research Institute and Great Lakes Restoration involves using satellite imagery to classify SAV across the Great Lakes (Shuchman, Sayers and Brooks 2013, Brooks, et al. 2015). An example of mapped SAV coverage and classifications is presented in Figure 18.

Figure 18. Satellite-Derived Great Lakes Submerged Aquatic Vegetation Classification Map

Source: (Shuchman, Sayers and Brooks 2013, Brooks, et al. 2015)

Note that additional areas of submerged aquatic vegetation may be present in the lakes and not formally captured in the ENCs or SAV classification map. Further discussion of fish and terrestrial communities and associated habitats in and surrounding Lake Erie and Lake Ontario is presented in New York State Greatlakes Wind Energy Feasibility Study: Relative Risks, Minimization/Mitigation, and Benefits (NYSERDA 2022i).

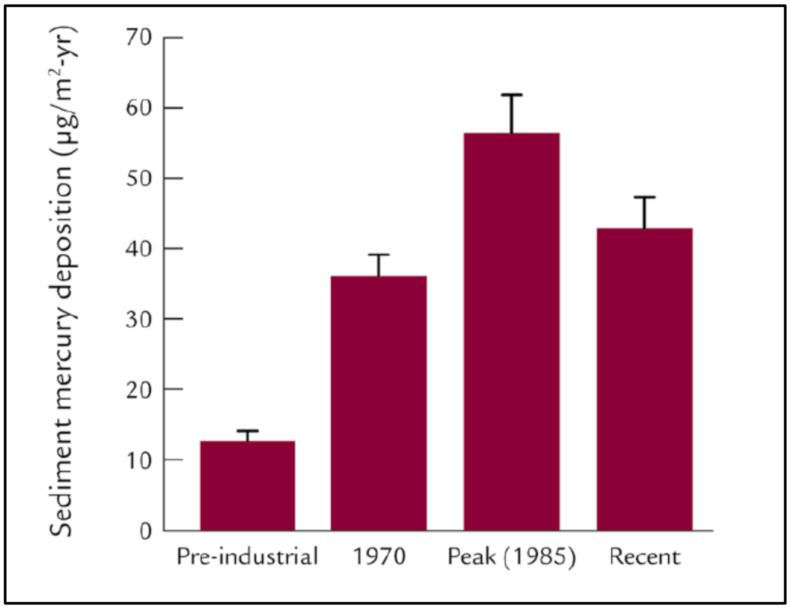
Due to the concentration of this aquatic vegetation in proximity to portions of the lake shore, the shoreline cable crossings and port-side activities would be most likely to have potential impact with these sites. A detailed site investigation for selected Great Lakes Wind Energy development area(s) should be conducted to identify if any SAV or wetlands sites would be impacted by associated bottom disturbing activities. Bottom disturbing activities in proximity to these locations may trigger additional regulatory processes, required implementation of protective mitigation measures, or may be subject to a mandated buffer distance from these areas.

5.3 Existing Sediment Contamination

The Great Lakes have been subjected to various types of anthropogenically sourced contamination, such as mercury accumulations and phosphorous loading, that have a negative impact on the fragile ecosystem of the lakes. Deposition of mercury within the Great Lakes, for example, increased from the pre-industrial period and peaked around 1985 (Figure 19).

Figure 19. Sediment Records of Mercury Accumulation in the Great Lakes

Source: (Evers, et al. 2011)

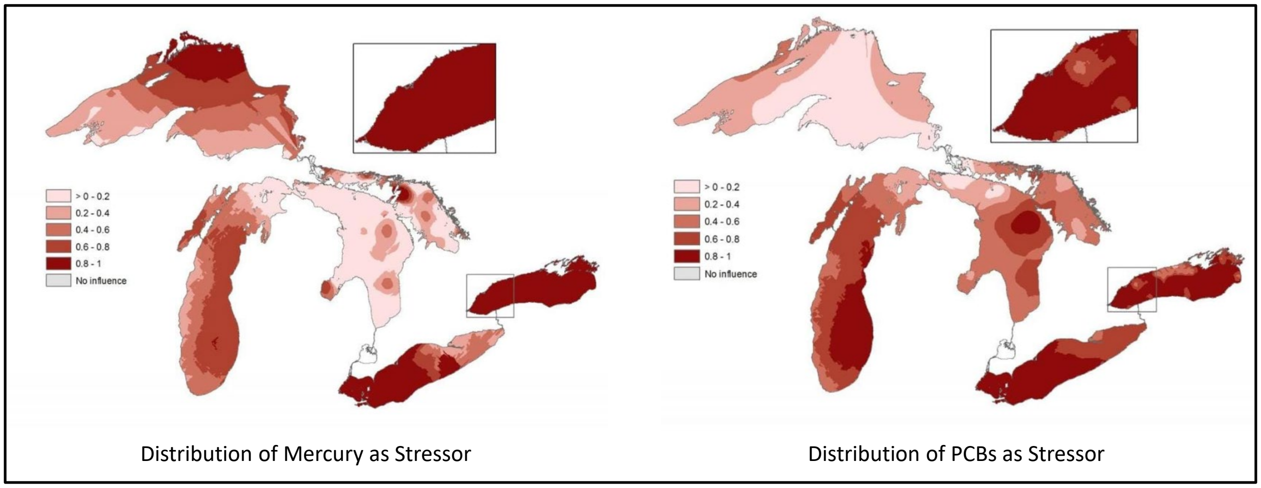


Specific efforts are made to monitor, reduce, and prevent further damage to the lake ecosystems from mercury and other such contaminants through Lakewide Action and Management Plans (LAMPs), established for both Lake Erie and Lake Ontario. Chemical concentrations in Lake Ontario sediments are rated as "Fair" overall and generally showing an "Improving" trend over time. Many of the contaminants in Lake Ontario appear to concentrate in the fine-grained sediments of the deeper parts of the basins (Environment and Climate Change Canada and the U.S. Environmental Protection Agency 2018). Lake Erie is assessed similarly, as "Fair" and "Improving." In terms of distribution, the Lake Erie LAMP indicates there is "decreasing gradient of chemical concentrations in Lake Erie sediment from the Western basin to the Eastern basin, and from south to north in the Central basin" (Environment and Climate Change Canada and the U.S. Environmental Protection Agency 2021).

A portion of contaminants that are introduced into the lakes can settle within the sediments. When the sediments are later disturbed, these contaminants may be re-introduced into the lake's waters and elevate concentrations in the water column and potentially results in new accumulations within the region's wildlife and vegetation. Sediment disturbance is possible during the process of offshore wind development, and the type and amount of possible disturbance varies based on the specific activity. Figure 20 provides a sense of contaminant distribution for mercury and polychlorinated biphenyls (PCBs), and their relative contribution as a stressor within the Great Lakes.

Figure 20. Distribution of Mercury and PCBs in the Great Lakes

Source: Great Lakes Environmental Assessment and Mapping Project, via (Illinois-Indiana Sea Grant 2022)



Given that contaminants are known to be present and resident across the Lakes, the potential for future impacts from contamination is ultimately location dependent, which is beyond the scope of this study. It is therefore recommended that a detailed geochemical analysis of the sediments be conducted to evaluate the state of sediment contamination at any potential future sites for Great Lakes Wind Energy development as they become better defined. A review of historical sediment data from the relevant lake should be considered as part of any detailed site evaluation. A more local assessment, focused on the findings of the site-specific geochemical analysis, will address the presence, type, and quantity of contaminant(s), the anticipated disturbing activities, and anticipated resultant amount of disturbance, dilution, transport, and impacts. Mitigating methods may need to be employed to minimize the effect that disturbance of the lakebed sediments may have with regard to contaminants, dependent upon the findings of the local assessment and any applicable regulatory criteria.

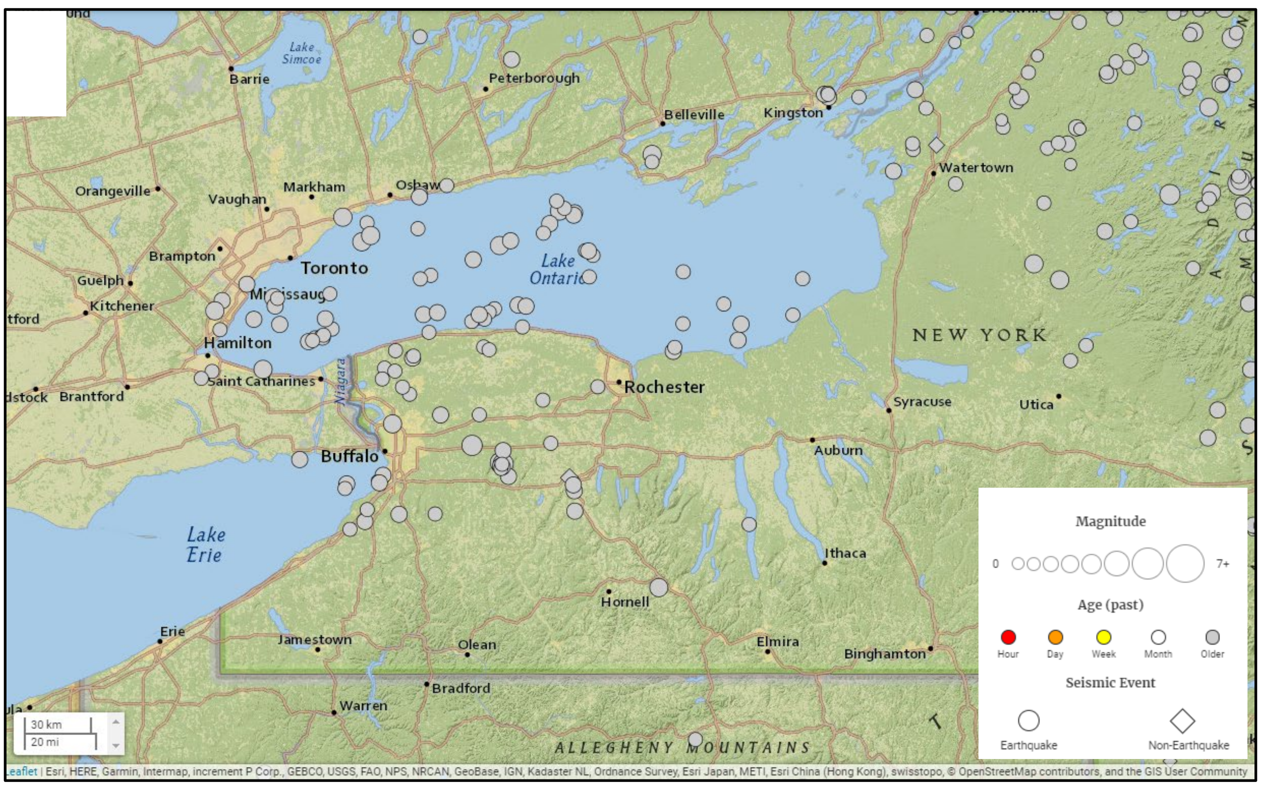
5.4 Seismicity

Evaluating seismicity of an area involves evaluating how frequently earthquakes occur, the magnitude of those earthquake events, and what source mechanisms are characteristic for a particular area. Information about a region's earthquakes are used to calculate seismic hazard, which is referenced by engineers to appropriately design structures able to withstand the expected earthquake response, such as extreme shaking and/or liquefaction.

The USGS publishes earthquake records from 1900 to present. Small to medium-sized earthquakes are documented in the Lake Ontario, Lake Erie, and surrounding New York State area, as illustrated in Figure 21. The largest earthquake event in close proximity to the potential Great Lakes Wind Energy development area occurred on August 12, 1929, with the epicenter located about 5 km (3 mi) south of Corfu, NY, at a depth of 9 km (6 mi). The earthquake was identified as a magnitude 4.7 event (USGS 2021a). The USGS earthquake map is interactive and dynamically updates to capture recent activity. At the time of this report preparation, all events were older than one month.

Figure 21. United States Geological Survey Earthquakes for New York State Region, 1900-Present

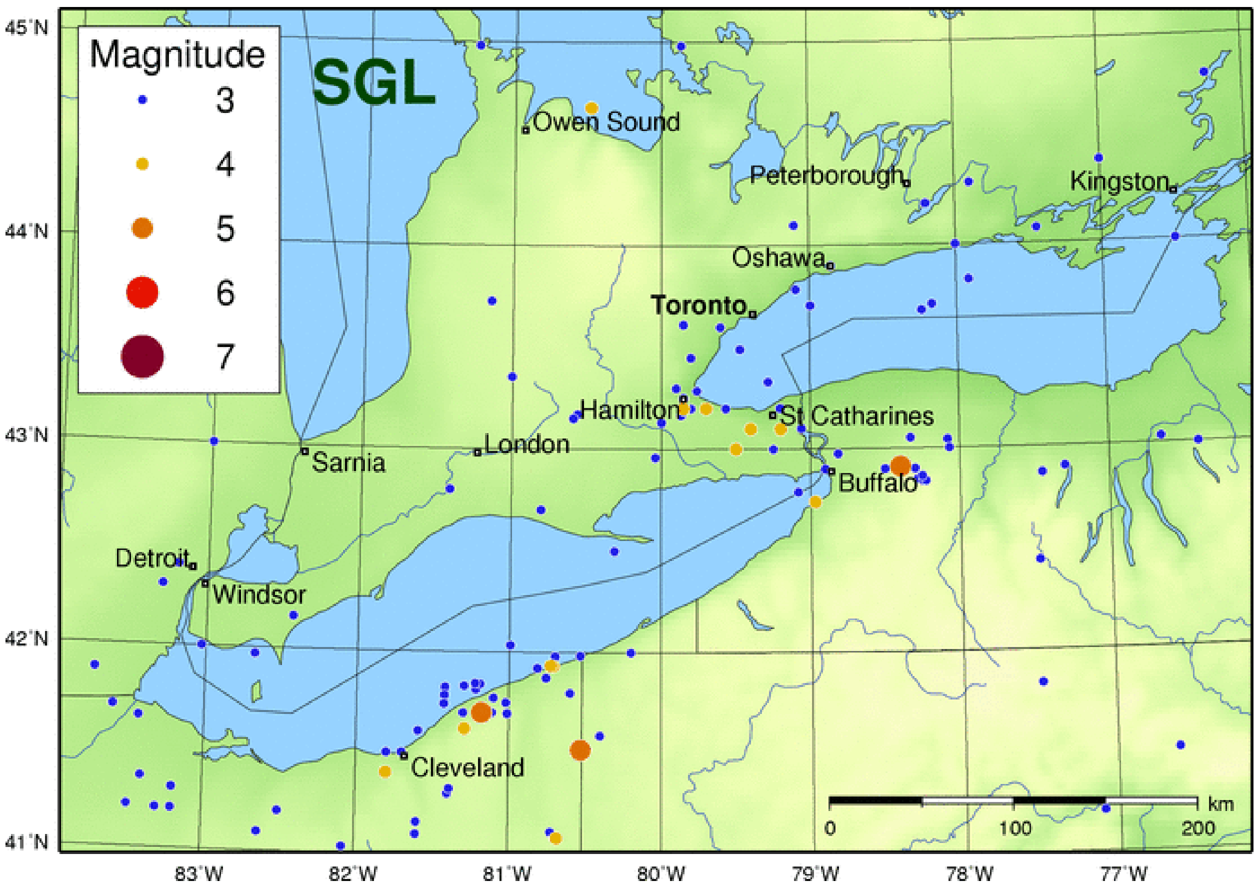
Source: (USGS 2021b)



Lake Ontario and Lake Erie fall within what Canada refers to as the "Southern Great Lakes Seismic Zone" (Government of Canada 2021). The region is known for low-to-moderate seismic activity, typical for its intraplate locale (Figure 22). Hutchinson et al., describe the earthquake events in this region as "generally weak (less than magnitude 3), poorly located, and mostly unconstrained for depth of rupture" (Hutchinson, Lewis and Hund 1993).

Figure 22. Southern Great Lakes Seismic Zone and the Region's Earthquake Activity

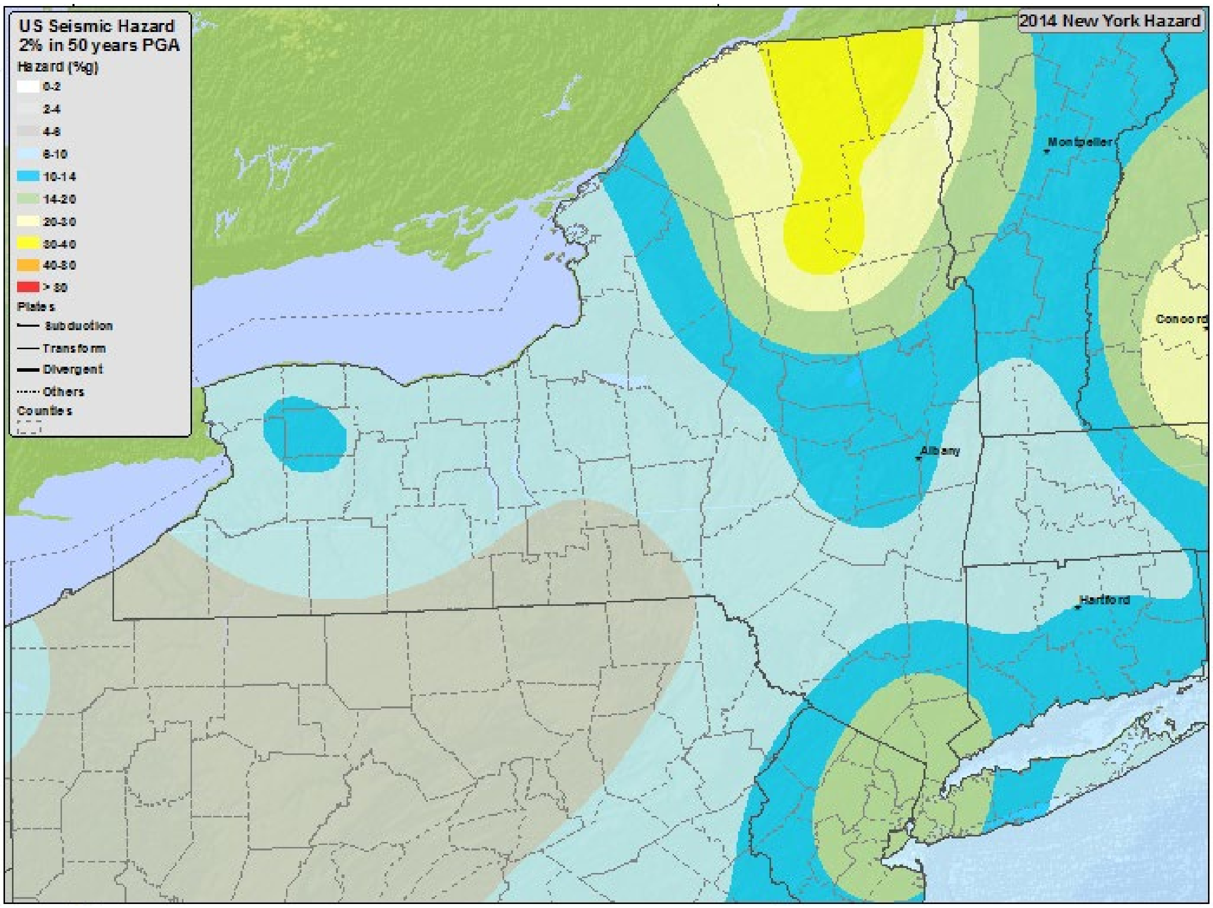
Source: (Government of Canada 2021)



While seismicity is considered low to moderate in the area, due diligence in considering appropriate seismic design for foundational structures is good engineering practice. The USGS's 2014 Seismic Hazard Map for New York State suggests that areas adjacent to Lake Ontario and Lake Erie have a 2% chance of exceeding 0.04-0.1g in 50 years (Figure 23) (USGS 2014). Hazard maps are regularly reviewed and sometimes updated as the region's record and understanding of earthquake activity and modeling within the scientific community evolves; therefore, it is important to ensure that the latest and most complete models are referenced in the design stage.

Figure 23. 2014 Seismic Hazard Map for New York State

Source: (USGS 2014)



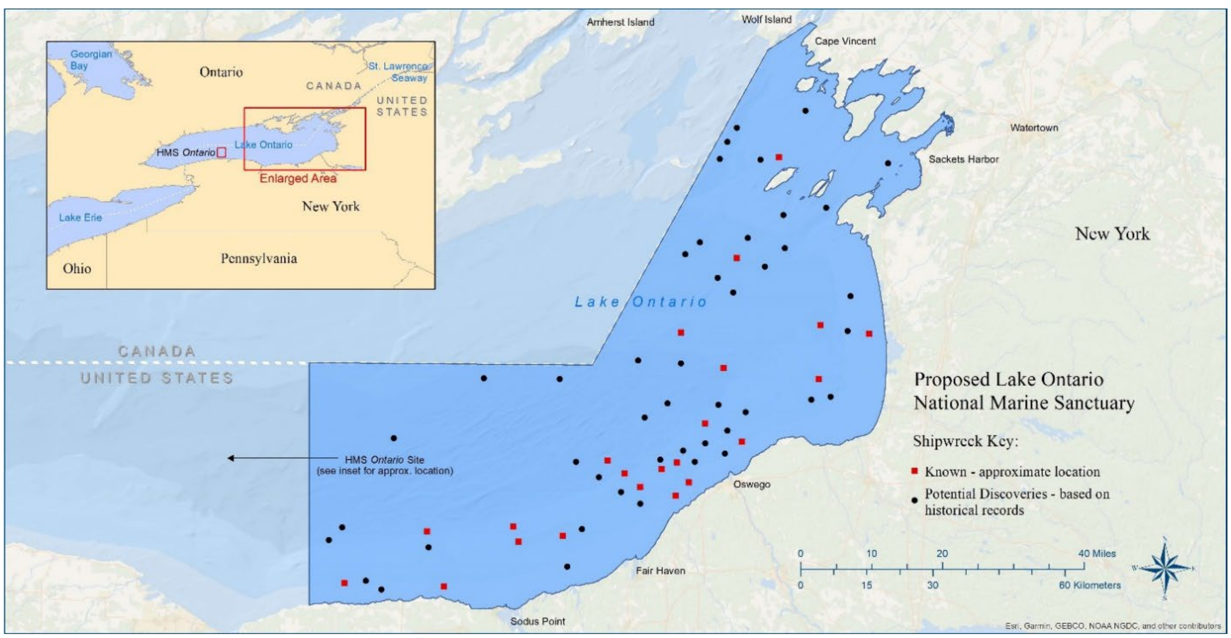
Silts and Lacustrine soils may be “sensitive” which means they may be prone to large strength losses on disruption, such as an earthquake, single, or cyclic loads, resulting in loss of capacity, liquefaction, and flow. Any selected Great Lakes Wind Energy development area should include a seismic design review that includes a site-specific assessment of liquefaction potential and an appropriate level of seismic design to ensure stability and integrity of the planned structure(s), as per standard engineering design practices and guiding codes/standards.

5.5 Shipwrecks and Historically Significant Artifacts

There are a large number of shipwrecks and historically significant archaeological artifacts documented within Lake Ontario, which will be an important consideration with regard to siting turbine and subsystem structures within the lake and routing cables for interconnection back to shore. In April 2019, NOAA (National Oceanic and Atmospheric Administration) proposed to designate roughly 1,724 square mi (2,774 square km) of Lake Ontario's waters and bottomlands as a National Marine Sanctuary (encompassing Jefferson, Wayne, Oswego, and Cayuga counties; Figure 24). This area contains at least 21 known shipwrecks and one military aircraft over a 200-year period of American history. An additional 47 shipwrecks are also believed to be within the designated zone (Office of National Marine Sanctuaries 2021). This Proposed National Marine Sanctuary boundary is still under consideration. Alternatives have been proposed to include the Thousand Islands.

Figure 24. Proposed Lake Ontario National Marine Sanctuary Indicating Known and Potential Wrecks

Source: (NOAA National Marine Sanctuaries 2021)



Further discussion of wrecks and historical sites is presented in New York State Greatlakes Wind Energy Feasibility Study: Relative Risks, Minimization/Mitigation, and Benefits (NYSERDA 2022i).

6 Conclusions

This study reviewed the sediments, bedrock conditions, and potential geohazard-related constraints within New York State waters of Lake Erie and Lake Ontario where Great Lakes Wind Energy development is under consideration. The following are conclusions and recommendations resulting from the study.

6.1 Surficial Sediments

Surficial sediments within the lakes are an important input for siting turbine placement, developing appropriate foundation design, and in consideration of cable routing, design, and possible burial requirements. The GLSAD-based surficial sediment distribution map derived for this study is expected to be a reasonable approximation of surficial conditions to support high-level screening and planning activities for the development of Great Lakes Wind Energy in New York State waters.

It is recommended that dedicated, fit-for-purpose geophysical and geotechnical surveys be conducted over any potential site(s) considered for development of Great Lakes Wind Energy in order to prepare more detailed site characterization. The GLSAD-based dominant surficial sediment distribution map (Figure 2) may be used as an aid to scope appropriate survey programs and for reference in concept site selection.

6.2 Strata within the Lakes

The stratigraphy within Lake Ontario and Lake Erie are similar, having a fine-grained (i.e., clays and silts) younger sediment package overlying a series of generally coarsening downward glacial deposits with lateral variability in mixed grain-sizes. The sedimentary units overlie bedrock and have variable thickness across the lakes. Within Lake Erie, the sediment thickness over bedrock within New York State waters is less than 250 ft (76.2 m), with an average of about 100 ft (30.5 m). For Lake Ontario, the sediment thickness over bedrock in NYS waters is less than 295 ft (90 m), with an average of 74.8 ft (22.8 m).

Bedrock conditions within the lakes are a critical element for consideration of siting Great Lakes Wind Energy infrastructure and the type of technology that might be suitable to install across the area. Relatively shallow bedrock in New York State portions of Lake Erie and Lake Ontario may prevent deep piled foundations; for example, from reaching a suitable depth to ensure the necessary holding capacities per the design requirements.

The depth to bedrock is also a significant consideration for evaluating burial requirements for cables, including identifying appropriate burial methodologies and their feasibility. Where burial may not be feasible, such as in areas of bedrock exposure, protection or stabilization of the cables may be required to mitigate against abrasion.

Site specific analyses of soil borings and distinct design soil parameters are beyond the scope of a general feasibility study; however, the soil composition and units in the Lakes generally appear favorable for the siting of offshore wind development infrastructure.

6.3 Buried Drumlins

Buried drumlins are identified just above bedrock, in the eastern and deepest portion of Lake Ontario, within Rochester Basin. Although buried, where present, they do have expression and influence the seabed topography. These localized features may present elevated seabed gradients that influence siting feasibility, depending on the technology selected and gradient tolerances. There will also be local variability in the subsurface soil column where drumlins are present, with a potentially thicker fraction of coarse-grained materials, including sand, gravel, cobbles, etc., which, in turn, may influence the siting and foundation design.

If Great Lakes Wind Energy development proceeds in the portion of Lake Ontario where the buried drumlins are present, it is recommended that detailed, site-specific geophysical and geotechnical data be acquired and reviewed to ensure feasibility and to support detailed siting, engineering design, and installation planning.

6.4 Faulting

Active faulting could affect the performance and holding capacity of piled foundations. This study finds no evidence for post-glacial faulting within Lake Ontario or the New York State portion of Lake Erie. As such faulting is not anticipated to be a significant concern for the siting, installation, or operation of Great Lakes Wind Energy in the NYS waters of Lake Ontario or Lake Erie. However, careful review of site-specific geophysical data in the vicinity of any planned surface and subsurface foundations zones should be conducted to confirm the absence and/or appropriate avoidance of deformed or displaced strata that could indicate active faults.

6.5 Possible Shallow Gas

Within Lake Ontario, particularly in the northeast and also near the mouth of the Niagara River, there are observations interpreted as possible subsurface accumulations of shallow biogenic gas. The presence of shallow gas is a consideration for foundation siting, foundation design, and installation activities. Careful review of site-specific subsurface geophysical data should be conducted to verify the presence or absence of shallow gas accumulations at any selected development site. In general, avoidance of the shallow gas areas is recommended where activities associated with foundation installation or trenching activities are planned. The site-specific subsurface data should be referenced to ensure an understanding of the nature of any shallow gas features, impact to the planned infrastructure and operational activities, and identification of any necessary mitigations.

6.6 Reef and Shoal Sites

There are several locations within the New York State waters of Lake Ontario and a few in Lake Erie that are identified as reef and shoal sites. These areas are important habitat and fish spawning locations and may be sensitive to bottom disturbing activities. A detailed site investigation for proposed Great Lakes Wind Energy development area(s) should be conducted to identify if any sensitive habitats would be impacted by associated bottom disturbing activities.

6.7 Vegetated Wetlands and Aquatic Beds

Portions of Lake Ontario and Lake Erie are identified as vegetated wetlands and aquatic beds. Due to the concentration of this aquatic vegetation in proximity to portions of the lake shore, the shoreline cable crossings and port-side activities would be most likely to have potential impact with these sites. A detailed site investigation for proposed Great Lakes Wind Energy development area(s) should be conducted to identify if any SAV or wetlands sites would be impacted by associated bottom disturbing activities.

6.8 Sediment Contamination

A portion of heavy metal and chemical contaminants that are introduced into the lakes can settle within the sediments. When the sediments are later disturbed, these contaminants may be re-introduced into the lake's waters and elevate concentrations in the water column and potentially can result in new accumulations within the region's wildlife and vegetation. Sediment disturbance is possible during the process of offshore wind development, and the type and amount of possible disturbance varies based on the specific activity. Given that contaminants are known to be present and resident across the Lakes, the potential for future contamination from disturbed sediments is ultimately location dependent.

It is recommended that a detailed geochemical analysis of the sediments at any proposed Great Lakes Wind Energy development area be conducted to evaluate the baselines for sediment contamination and to develop an appropriate management plan, if necessary. A review of historical sediment data from the relevant lake should be considered as part of any detailed site evaluation. The detailed geochemical analysis of the sediments should address the presence, type, and quantity of contaminant(s), evaluate the anticipated disturbing activities, and anticipate resultant amount of disturbance, dilution, transport, and impacts. Mitigating methods may need to be employed to minimize the effect that disturbance of the lakebed sediments may have with regard to contaminants, dependent upon the findings of the local assessment and any applicable regulatory criteria.

6.9 Seismicity

The region is known for low-to-moderate earthquake activity, typical for its intraplate locale. Although seismicity is considered low-to-moderate in the area, due diligence in considering appropriate seismic design for foundational structures is good engineering practice. The USGS's 2014 Seismic Hazard Map for New York State suggests that areas adjacent to Lake Ontario and Lake Erie have a 2% chance of exceeding 0.04-0.1 g (acceleration of gravity) in 50 years.

Silts and Lacustrine sediments may be prone to large strength losses on disruption, such as an earthquake, single, or cyclic loads, resulting in loss of capacity, liquefaction, and flow. Any proposed Great Lakes Wind Energy development area should include a seismic design review that includes a site-specific assessment of liquefaction potential and an appropriate level of seismic design to ensure stability and integrity of the planned structure, as per standard engineering design practices and guiding codes/standards.

6.10 Shipwrecks and Historical Sites

There are a large number of shipwrecks and historically significant archaeological artifacts documented within Lake Ontario. A National Marine Sanctuary encompassing Jefferson, Wayne, Oswego, and Cayuga counties has been proposed to designate roughly 1,724 square mi (2,774 square km) of Lake Ontario's waters and bottomlands as a protected natural and historical area. Bottom disturbing activities in proximity to shipwrecks and historical sites are typically avoided, and an established buffer distance applied to ensure the site remains undisturbed. The location of these types of historically significant seabed obstructions will be an important consideration with regard to siting turbine and subsystem structures within the lake and for routing cables for interconnection back to shore. The designation of the region as a National Marine Sanctuary, if approved in the future, may introduce regulation that could modify or restrict certain activities, although the designation does not necessarily exclude wind development.

7 References

Brooks, C., A. Grimm, R. Shuchman, M. Sayers, and N. Jessee. 2015. "A satellite-based multi-temporal assessment of the extent of nuisance Cladophora and related submerged aquatic vegetation for the Laurentian Great Lakes." *Remote Sensing of Environment* 157: 58-71 doi:https://doi.org/10.1016/j.rse.2014.04.032

Coflin, K. C., B. Phu, C.F. M. Lewis, and B. J. Todd. 2017. "Seismic study of ridges on the lake floor in Rochester Basin, eastern Lake Ontario, New York: evidence for till composition." Open File 8178, Geological Survey of Canada. doi:10.4095/299647

Environment and Climate Change Canada and the U.S. Environmental Protection Agency. 2021. "Lake Erie Lakewide Action and Management Plan, 2019-2023." Cat. No. En164-60/2021E-PDF.

Environment and Climate Change Canada and the U.S. Environmental Protection Agency. 2018. "Lake Ontario Lakewide Action and Management Plan, 2018-2022." Cat. No. En164-58/2019E-PDF.

Environment and Climate Change Canada. 2021. *Great Lakes Sediment Archive Database (1960-1975).* Accessed February 22, 2021. https://data.ec.gc.ca/data/substances/monitor/great-lakes-water-quality-monitoring-and-aquatic-ecosystem-health-data/great-lakes-sediment-archive-database-1960-1975/?lang=en

Evers, D. C., J. G. Wiener, C. T. Driscoll, D. A. Gay, N. Basu, B. A. Monson, K. F. Lambert, et al. 2011. *Great Lakes Mercury Connections: The Extent and Effects of Mercury Pollution in the Great Lakes Region.* Report BRI 2011-18, Gorham, Maine: Biodiversity Research Institute, 44.

Government of Canada. 2021. *Earthquakes Canada: Earthquake zones in Eastern Canada.* March 06. Accessed July 2021. https://earthquakescanada.nrcan.gc.ca/zones/eastcan-en.php#SGLSZ

Great Lakes Aquatic Habitat Framework. 2020. *Data: an aquatic, geospatial database for the Great Lakes.* Accessed February 22, 2021. https://www.glahf.org/data/

Holcombe, T. L., L. A. Taylor, J. S. Warren, P. A. Vincent, D. F. Reid, and C. E. Herdendorf. 2005. *Lake-Floor Geomorphology of Lake Erie.* Research Publication RP-3, National Environmental Satellite, Data and Information Service, National Geophysical Data Center, World Data Center for Marine Geology and Geophysics, 26.

Hutchinson, D. R., C.F. M. Lewis, and G. E. Hund. 1993. "Regional Stratigraphic Framework of Surficial Sediments and Bedrock Beneath Lake Ontario." *Geographie physique et Quaternaire* 47 (3): 337-352. http://doi.org/10.7202/032962ar

Hutchinson, D. R., P. W. Pomeroy, R. J. Wold, and H. C. Halls. 1979. "A geophysical investigation concerning the continuation of the Clarendon-Linden fault across Lake Ontario." *Geology* 7 (4): 206-210. doi:https://doi.org/10.1130/0091-7613(1979)7<206:AGICTC>2.0.CO;2

Illinois-Indiana Sea Grant. 2022. *Great Lakes Mud.* Accessed 2022. https://www.greatlakesmud.org/pcbs.html; https://www.greatlakesmud.org/heavy-metals.html

McNeilan & Associates, LLC. 2017. "Windfarm Ground Conditions Icebreaker Wind Demonstration Project Lake Erie." McN&A Project No. 16-02, Norfolk, Virginia.

MH, and DE. 2016. *The Gradational Tour: Drumlin.* April 5. Accessed August 2021. https://mdgradationaltour.wordpress.com/2016/04/05/drumlin/

Morgan, N. A., B. J. Todd, and C.F. M. Lewis. 2020. *Interpreted seismic reflection profiles, sediment thickness and bedrock topography in Lake Erie, Ontario, Canada and Michigan, Ohio, Pennsylvania and New York, U.S.A.* Open File 8733, Geological Survey of Canada, 26. https://doi.org/10.4095/326715

National Geophysical Data Center. 1999. "Bathymetry of Lake Ontario." *Data set.* Edited by NOAA. National Geophysical Data Center. https://doi.org/10.7289/V56H4FBH

NOAA. 2021. *Chart Downloader for Electronic Navigational Charts.* Accessed February 22, 2021. https://charts.noaa.gov/ENCs/ENCs.shtml

—. 2021. *Great Lakes Bathymetry.* Accessed February 22, 2021. https://www.ngdc.noaa.gov/mgg/greatlakes/

NOAA National Marine Sanctuaries. n.d. *Proposed Lake Ontario National Marine Sanctuary.* https://sanctuaries.noaa.gov/lake-ontario/

New York State Energy Research and Development Authority (NYSERDA). 2022. "New York State Great Lakes Wind Energy Feasibility Study: Substructure Recommendations," NYSERDA Report Number 22-12e. Prepared by the National Renewable Energy Laboratory, Golden, CO. nyserda.ny.gov/publications

New York State Energy Research and Development Authority (NYSERDA). 2022. "New York State Great Lakes Wind Energy Feasibility Study: Relative Risks, Minimization/Mitigation, and Benefits," NYSERDA Report Number 22-12i. Prepared by, Worley Group, Inc. (dba Advisian), Reading, PA. nyserda.ny.gov/publications

Office of National Marine Sanctuaries. 2021. *Proposed Lake Ontario National Marine Sanctuary Draft Environmental Impact Statement and Draft Management Plan.* Draft Management Plan, Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries.

Office of National Marine Sanctuaries. 2021. *Proposed Lake Ontario National Marine Sanctuary Draft Environmental Impact Statement and Draft Management Plan.* Draft Management Plan, Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries.

Shuchman, R. A., M. J. Sayers, and C. N. Brooks. 2013. "Mapping and monitoring the extent of submerged aquatic vegetation in the Laurentian Great Lakes with multi-scale satellite remote sensing." *Journal of Great Lakes Research* 39: 78-89. doi:https://doi.org/10.1016/j.jglr.2013.05.006

USGS. 2014. *2014 Seismic Hazard Map - New York.* Accessed July 2021. https://www.usgs.gov/media/images/2014-seismic-hazard-map-new-york

—. 2021a. *Earthquake Hazards Program: M 4.7 - 5 km S of Corfu, New York.* Accessed July 2021. https://earthquake.usgs.gov/earthquakes/eventpage/ushis814/executive

—. 2021b. *Earthquake Hazards: Information by Region - New York.* Accessed July 2021. https://www.usgs.gov/natural-hazards/earthquake-hazards/science/information-region-new-york?qt-science_center_objects=0#qt-science_center_objects

Weston Geophysical. n.d. "Lake Erie Bathymetry and Sediments." Document / Page Pulled 8204280427.

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New York State Energy Research and Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov