ANALYSIS OF FUTURE OFFSHORE WIND FARM DEVELOPMENT IN ONTARIO

Prepared for
Ontario Power Authority

By
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Wind energy consultant for the world

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DISCLAIMER

DEFINITIONS AND SYMBOLS

agl	above ground level
GIS	geographical information system
GWh	gigawatt-hour
HVDC	high-voltage direct current
IBA	Important Bird Area
km	kilometre
kWh	kilowatt-hour
LIO	Land Information of Ontario
m	metre
m/s	metres per second
MNR	Ontario Ministry of Natural Resources
MW	megawatt
OPA	Ontario Power Authority
O&M	operations and maintenance
WTG	wind turbine generator

EXECUTIVE SUMMARY

Helimax Energy Inc. ("Hélimax") has identified and performed a technical assessment and ranking of 64 offshore sites (totalling nearly 35 000 MW) in the Ontario's Great Lakes offshore region which are considered to have favourable potential for wind project development. All selected sites are in water depths of between 5 m and 30 m, have average annual wind speeds of at least 8.0 m/s and have a sufficient available water sheet to accommodate at least 100 MW of wind power.

Each of the sites was selected using the best available GIS and wind resource information combined with a high-level constraints analysis. Important physical constraints (e.g. shipping lanes, underwater cables, etc.) and environmental constraints (e.g. wetlands, conservation reserves, protected areas, etc.) were considered undevelopable and subtracted from the study area. Once areas with adequate water sheet to support large wind projects were identified, mesoscale maps from the Ontario Wind Resource Atlas were used to estimate the wind resource and the ensuing net energy yields and capacity factors. Lastly, each of the sites was comparatively ranked using a procedure taking into consideration four technical parameters – wind speed, development complexity, social and environmental factors and presence of infrastructure – in an effort to establish the most propitious sites.

While the study does provide an overview of the development potential in the study area, it is important to note that a number of critical factors were not evaluated or were examined in only a preliminary (non site-specific) manner. Such factors include most notably seabed properties and icing conditions of the Great Lakes, as well as non-technical aspects such as visual impact, social acceptability and economic viability.

The study found that the majority of the most promising sites are located in Lake Huron (including Georgian Bay) (27) and Lake Erie (25). Nine sites were identified in Lake Ontario and 3 in Lake Superior.

Hélimax then performed preliminary energy yield calculations of the selected sites based on a generic 5-MW turbine and an assumed installable capacity density of 5.8 MW/km^2. The calculated net capacity factors for all sites range from 34.7% to 40.8%. Furthermore, the present study provides a discussion of the capital and operation and maintenance (O&M) costs as well as a generic schedule of project activities of a generic offshore wind farm to be installed in the Great Lakes.

Lastly, it should be emphasized that the sites it has selected do not necessarily correspond to the projects currently being developed. This report by no means seeks to disparage any sites currently under development which are not part of the 64 sites selected. There are wind power projects that can be feasibly developed beyond the sites that are identified in the present study.

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1 INTRODUCTION

In the fall of 2005, the Ontario Power Authority (OPA) mandated Helimax Energy Inc. (Hélimax) to evaluate the potential for wind power development in the province of Ontario. In the context of that study, Hélimax estimated the offshore wind potential in the Great Lakes, notably with respect to exploitable surface area. Based on certain assumptions, Hélimax evaluated that potential to be over 46,000 MW of installable capacity of wind energy.

Following that study, the OPA commissioned Hélimax to identify the best locations for future wind power projects in the province. In that analysis, Hélimax defined 60 suitable locations for wind projects, geographically dispersed throughout the province below the 50^{th} parallel. The sites retained offered a potential total of nearly 8200 MW of capacity. However, the analysis did not consider offshore areas, as the Ontario Ministry of Natural Resources (MNR) had imposed a moratorium on offshore wind project development.

In March 2008, subsequent to the MNR's lifting of the said moratorium, Hélimax was commissioned by the OPA to extend its study to offshore areas, specifically the Great Lakes.

This report aims to achieve a number of objectives, namely:

- Project or anticipate the locations of future large-scale offshore wind development within those parts of the Great Lakes within Ontario's jurisdiction (Lake Ontario, Lake Erie, Lake Huron including Georgian Bay and Lake Superior);[1]
- Rank the sites based on their viability assuming equal electrical grid integration conditions at all sites;
- Calculate the installable capacity (in MW) that each site could potentially accommodate and calculate an approximate energy yield (in GWh) that each of the projected wind farms could generate;
- Provide preliminary estimates for construction, operation and maintenance costs of developing a generic offshore wind farm in Ontario's Great Lakes;
- Provide a generic schedule for the development of an offshore wind power project from initial project conception to project commissioning;

The sites identified in this study were chosen based on a number of specific criteria. It is recognized that there are other sites suitable for offshore wind power development that do not meet the specific criteria used in this study.

[1] As agreed to with the OPA, the offshore potential of Lake St. Clair was not considered in this analysis.

2 METHODOLOGY

Selecting a viable site for a wind project is a multi-faceted, multi-disciplinary process. In an effort to determine the geographic profile of future offshore wind power development in Ontario's Great Lakes, Hélimax has developed a logical methodology based on a series of criteria or principles which are generally used to identify prime wind farm sites.

These criteria – the basis for the selection and evaluation of sites – fall into two categories: constraints and factors. The differentiation between the two is important: constraints are used to zone out or discard areas considered unsuitable for wind development, while factors serve to qualify and rank the remaining potential sites. Some criteria, such as bathymetry, can be considered both a constraint and a factor.

Hélimax's approach first consisted of combining wind speed data from the Ontario Wind Resource Atlas with a constraints analysis (notably land use and bathymetry). By superimposing the results of this constraints analysis on the wind speed maps, it is possible to understand the geographical distribution of the resource and quantify the constrained potential[2] within the province's Great Lakes. The retained sites were then ranked based on a number of site-specific factors and a weighting mechanism designed to reflect the relative importance of one factor versus another in project siting.

Generally speaking, Hélimax considers the availability of data for this analysis to be adequate. However, certain assumptions had to be made in order to complete this study. Primarily, Hélimax assumed that:

- The supplied GIS data are correct and adequate for the purpose of this study.
- The mesoscale map consulted portrays a realistic overview of the wind resource.
- No constraints present on US soil or in US waters will inhibit wind farm development in the region under study.

The sections below describe in greater detail the methodology used by Hélimax in this mandate to determine and rank future offshore wind farm locations in Ontario's Great Lakes.

[2] Hélimax defines constrained potential as the offshore wind energy potential excluding that which lies in specified exclusion zones and associated buffers.

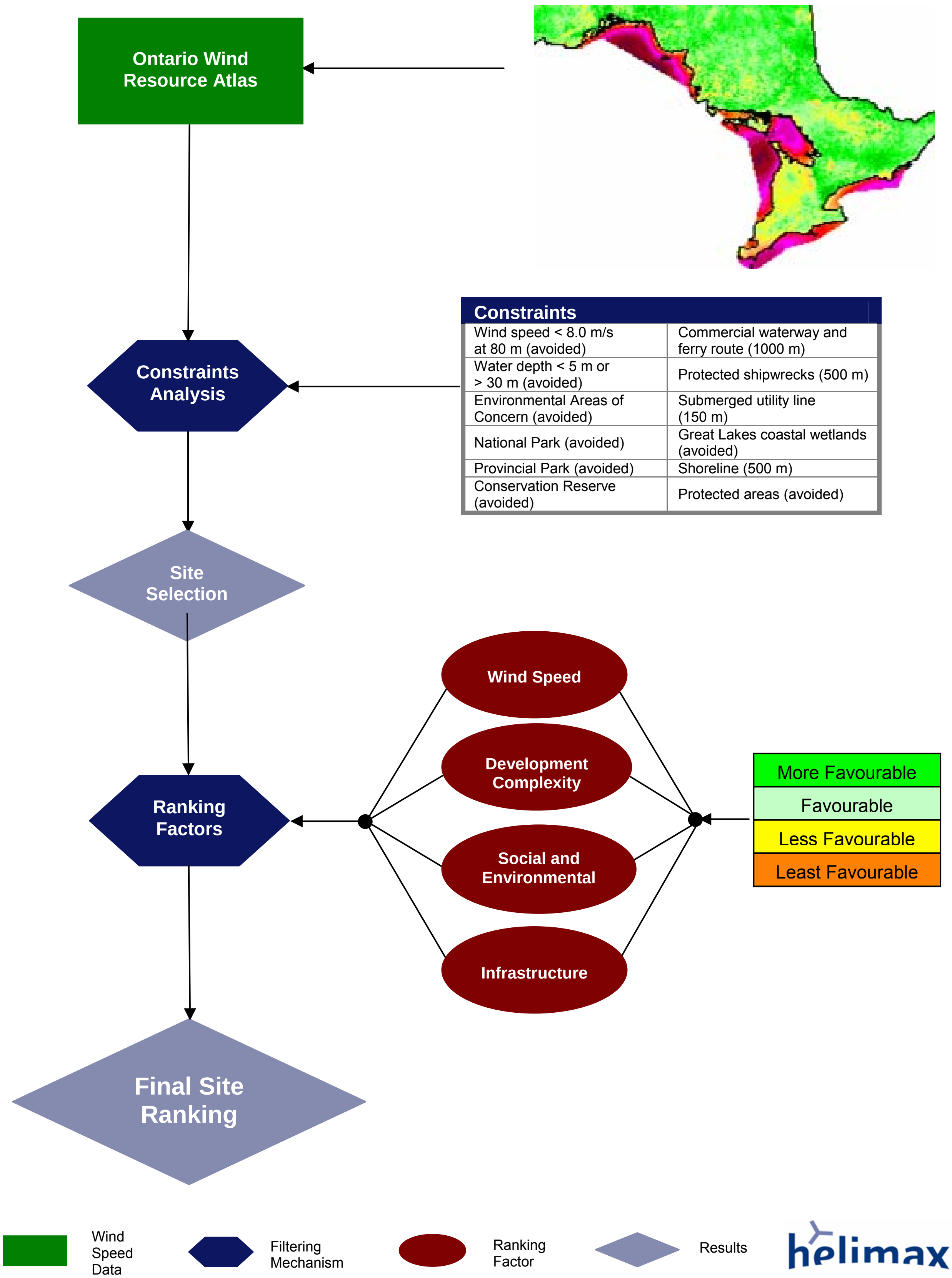

Figure 2-1: Hélimax's Site Selection and Ranking Methodology

2.1 Ontario Wind Resource Atlas

The starting point for the analysis was the wind resource extracted from the Ontario Wind Resource Atlas[3] which details the long-term annual average wind speed throughout the entire province. For this study wind speed data at a horizontal resolution of 100 m at 80 m agl were used. This data set was supplied by the Ontario Ministry of Natural Resources (MNR).

It should be noted, however, that on-site meteorological measurements are required to perform a truly judicious assessment of the local wind resource and ensuing energy yields of a given site. In the absence of such data, Hélimax used the above-mentioned mesoscale wind resource maps as the basis for wind speed estimates and energy yield calculations. However, whereas the accuracy of mean wind speeds derived from *onshore* mesomaps is generally assumed to be ±7%, the precision of such maps for offshore applications is not well known.

Evidently, lower on-site wind speeds will translate into lower energy yields which in turn will detract from the economic viability of the site. If all other technical variables are considered equal, a 10% increase in average wind speed will generally translate into an increase in average energy yield of between 12% and 17%. Figure 2-2 below shows the relative increase in energy yield vs. the relative increase in average wind speed for four mean wind speed categories. It is important to note that as the base average increases, the relative increase in energy yield is less pronounced. This is an important point to consider when comparing near-shore and far-shore sites with strong wind resources.

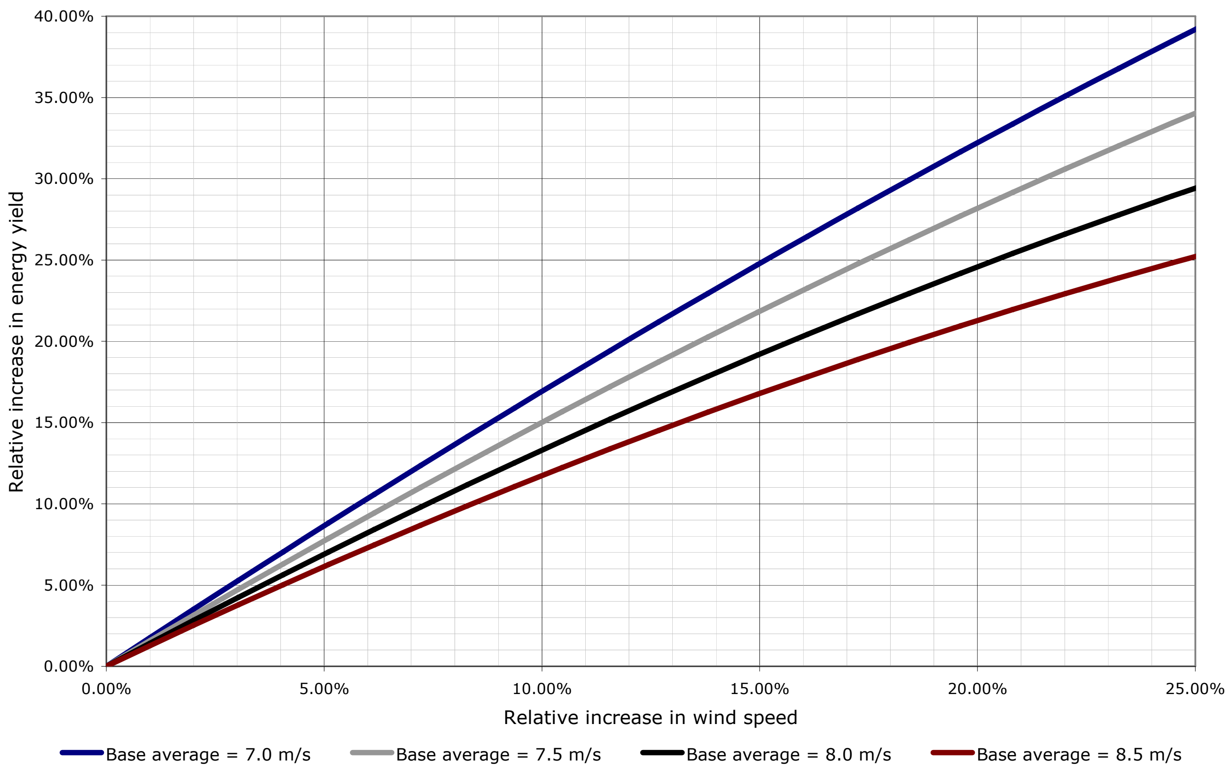

Figure 2-2: Increase in Energy Yield as a Function of Increase in Wind Speed

[3] www.ontariowindatlas.ca

2.2 Constraints Analysis

As stated above, constraints are used to zone out or discard areas considered unsuitable for wind development. Constraints are Boolean (absolute) in nature and are thus attributed values of either 1 or 0. For example, a National Park is considered unsuitable for wind energy development and is assigned a null value and excluded from all further analysis. Areas that are considered developable are assigned a value of 1 and are included in the analysis. Certain types of constraints have buffer zones associated with them.

As there is presently a lack of regulation on setback distances or exclusion zones for most features (waterways, environmentally sensitive areas, etc.) in relation to offshore wind farm development, generic buffer zone sizes were based on Hélimax's professional experience and judgment. Exact buffer zones, however, can only be determined by the relevant authority in the context of site-specific circumstances. Table 2-1 below provides the features considered in this analysis and their associated buffer zones.

Table 2-1: Features and Buffer Distances

Feature	Action Taken (buffer zones in m)
Commercial waterway and ferry route	1000
Protected shipwreck	500
Submerged utility line	150
Shoreline	500
Great Lakes coastal wetland	Avoided, no buffer zone
Conservation reserve	Avoided, no buffer zone
Environmental Area of Concern	Avoided, no buffer zone
National/Provincial Park	Avoided, no buffer zone
Protected area	Avoided, no buffer zone
Water depth < 5 m or > 30 m	Avoided, no buffer zone
Wind speed < 8.0 m/s	Avoided, no buffer zone

2.2.1 Bathymetry

A maximum depth of 30 m was used to screen preliminary sites. This threshold is in line with most offshore projects that will be in operation in the near future, and is considered justified by the inherent risk involved in offshore wind energy. Logically, shallower and more accessible sites will be the first to be developed, though deeper waters may be exploited later as accumulated experience (particularly in Europe) and technological advances allow.

A number of wind parks in the UK and in Germany are planned and consented in depths of 30 m and up, but none of these have yet completed construction or, in most cases, finalized their foundation types. The recently commissioned Barrow project in the UK and the Q7 project in the Netherlands boast foundation depths up to 23 m and 24 m, respectively; however, these projects have not been operational long enough to evaluate the cost-effectiveness and adequacy of such installations. The Beatrice project off the coast of Scotland was constructed in water depths of approximately 45 m.

Lastly, a minimum water depth of 5 m was also used in the screening process. This figure was established as a function of the requirements of the types of barges used to install offshore turbines.

2.2.2 Physical Constraints

Features such as submerged utility lines, shipping lanes and protected shipwrecks are considered physical constraints. The buffer zones defined in Table 2-1 are generally considered appropriate during the site selection process. It should be noted that should the development or study of any of the sites identified herein be pursued further, these buffers may have to be adjusted to account for site-specific conditions.

2.2.3 Environmental Constraints

Parks, coastal wetlands, conservation reserves, protected areas and environmental areas of concern are considered constraints and as such are avoided. Indeed, government officials and MNR base mapping metadata files confirm that development restrictions should be applied to these areas. Environmental constraints used in this assessment are presented in Table 2-1. It should be noted that though areas classified as environmental constraints were avoided, no buffer zones were applied, as these zones are extremely site specific and warrant a much more detailed local investigation.

2.2.4 Constraints Not Considered

Constraints not considered in this analysis include, amongst others, those which could not be readily quantified or mapped, e.g. subjective issues such as social acceptability.

Social acceptability is a significant source of uncertainty, and development of some promising areas might face local opposition due to concerns about effects of turbines on personal enjoyment and recreation (e.g., viewscapes, aesthetic issues and noise), concerns about property values and effects on avifauna. Though difficult to accurately quantify or anticipate, this study did attempt to address this issue in part by including a social and environmental factor (see Section 2.4.3).

Certain physical constraints were also not taken into account. Seabed properties, such as the nature of the soil, have a direct bearing on the type and cost of substructures. For example, the presence of large boulders or rock introduces additional challenges to the driving of monopiles foundation into the ocean floor. However, this parameter is difficult to evaluate without site-specific data, and has therefore not been examined in the context of this study.

The ice loads on foundations are a significant concern for future offshore wind farm development in the Great Lakes. Presently, it seems that no other offshore project in the world faces comparable ice conditions to those of the Great Lakes, namely harsh winters, enclosed areas (lakes) and relatively weak currents. Further, the thickness of the ice on Lake Erie can exceed 70 cm over many kilometres of water sheet. As it was beyond the scope of the present mandate, this parameter was not taken into consideration.

2.2.5 Data Sources

The GIS (Geographical Information System) data were principally acquired from the Land Information of Ontario (LIO) of the MNR. Other information was obtained from the Great Lakes Information Network[4] or publicly available databases. The data layers used for the constraints analysis and the weighting factors (see Section 2.4) and their respective sources are presented in Table 2-2 below.

[4] http://glin.net/

Table 2-2: Sources of Files Used for Constraints and Ranking Factors[5]

Feature	Data Source
Great Lakes coastal wetlands	Institute for Fisheries Research of Environment Canada
Shorelines	Great Lakes Geographic Information System; National Oceanic and Atmospheric Administration
Environmental Areas of Concern	Great Lakes Information Network (GLIN)
Water depths	Great Lakes Information Network (GLIN)
Important Bird Areas	BirdLife International
Radiocommunication systems	Industry Canada
Protected shipwrecks	Ontario Ministry of Culture; various Internet sources
Airports	Ontario Ministry of Natural Resources
Conservation Reserves	Ontario Ministry of Natural Resources
National Parks	Ontario Ministry of Natural Resources
Provincial Parks	Ontario Ministry of Natural Resources
Submerged utility lines	Ontario Ministry of Natural Resources
Wind speeds	Ontario Ministry of Natural Resources
Commercial waterways and ferry routes	Ontario Ministry of Natural Resources; various Internet sources
Protected areas	Ontario Ministry of Natural Resources (Aquatic Conservation Blueprint layer)
Population density	Statistics Canada

2.3 Site Selection

Once all constraints were identified, a post-constraints-analysis map of the province's Great Lakes was created; this map would become the basis of the site selection process. Project locations were selected by combing over the post-constraints map and selecting areas that could reasonably accommodate a significant quantity of wind energy. This step was done manually in order not to overlook any promising sites. Areas of highly fragmented wind resource or areas considered unable to accommodate at least 100 MW were discarded from the analysis. As per the OPA's instructions and as mentioned before, no consideration was given to the sites' proximity to the electrical grid.

Sites were chosen to reflect a sensible and rational site selection process. Site visits were not conducted to validate their potential.

2.4 Ranking Factors

Once all the sites were selected, a simple multi-criteria analysis was applied to rank the retained wind project locations. The following sections discuss the rationale behind the weighting of the factors and the site ranking process.

In contrast to constraints, factors are criteria that qualify a site's suitability and can be used to quantitatively compare one site's suitability versus another's. A factor may enhance or detract from the suitability of a site. Factors incorporated into this study were those generally known to influence developers' selection of offshore sites and were jointly determined by the OPA and Hélimax. Each site is categorized according to quantifiable factors – listed in Table 2-3 – using the best available GIS and wind resource information.

[5] Hélimax makes no guarantee with respect to the accuracy of the data used for identifying or quantifying the constraints and ranking factors.

Table 2-3: Factors Used in Site Ranking Process

Factor	Description	Relative Weighting
Wind Speed	Only wind speeds greater than 8.0 m/s were considered.	1
Development Complexity	Distance to landfall and water depth. Sites nearer to shore and in shallower (but over 5 m) waters are of greater interest.	2
Social and Environmental	Population density, proximity to large urban areas, distance from shore (visual impact), Important Bird Areas	3
Infrastructure	Airports, radiocommunication systems	4

It should be noted that it was not in the scope of the present mandate to assess a certain number of factors which might influence final site selection or turbine micro-siting. In practice, a detailed site evaluation process should take into account all factors affecting site development and as such should include a geotechnical survey; flora, fauna and fish surveys; a detailed noise impact assessment; a detailed wind resource study; an in-depth economic study and site visits by specialized engineers to assess relevant site characteristics.

Each factor is ranked and weighted according to its relative importance in wind project site selection, with wind speed being the most important factor (see Table 2-3). Factors considered most important or critical for wind project siting are more heavily weighted. For example, a higher weight is given to wind speed as opposed to social and environmental factors, as assigning the same weight or importance to each of these factors would severely distort the ranking of the project locations. Weights are chosen by Hélimax based on its professional experience and expertise.

Each site was then, for each of the four factors, attributed one of the following designations:

- Least favourable;
- Less favourable;
- Favourable; or
- More favourable.

The quantitative values corresponding to each class are defined only after the range of values for that factor is known. For example, as the minimum wind speed considered in the study is 8.0 m/s, mean wind speeds falling just above this threshold are naturally classed as *least favourable,* while the highest wind speeds observed are classed as *more favourable*.

It is extremely important to recognize the difference between factors and constraints in this case and to realize that factors are weighted relative to each other. A factor graded *least favourable* does not imply that it is unsuitable for development or will not be developed, but rather that in a comparative sense relative to the other existing options, it is the *least favourable*.

2.4.1 Wind Speed

Only areas exhibiting mean annual wind speeds greater than 8.0 m/s after zoning out constraints were considered in this analysis. The 8.0 m/s threshold was chosen for this study as a conservative but reasonable lower limit for the development of offshore wind power projects in Ontario's Great Lakes.

Wind speeds were graded into four classes (see Table 2-4) according to their relative frequency of occurrence.

Table 2-4: Definition of Classes Used for Ranking – Wind Speed

	Least Favourable	Less Favourable	Favourable	More Favourable
Wind Speed [m/s]	8.0 – 8.15	8.15 – 8.35	8.35 – 8.55	8.55 +

2.4.2 Development Complexity

Development complexity is an important factor for the construction of a large-scale offshore wind energy project. To account for the development complexity factor, the water depth and the distance to landfall were evaluated. Thus, each site was classed based on its mean water depth (with sites in shallower water being considered *more favourable*) and on its distance to landfall (with sites located closer to shore being considered *more favourable*) (see Table 2-5).

The exact point of interconnection must be decided by the local utility using a multitude of criteria. It is outside the scope of this study to assess the availability or capacity of the transmission grid. Hélimax therefore used the distance to landfall for site comparison (with respect to grid access) and relative ranking. The distance to landfall is defined as the shortest straight-line distance between the centroid of each selected site and the nearest mainland point (as opposed to islands). This is a reasonable assumption as sites nearer the coast should have more favourable grid access. Mainland was chosen for the point of landfall as it is assumed that islands would not have adequate transmission access.[6]

Table 2-5: Definition of Classes Used for Ranking – Development Complexity

	Least Favourable	Less Favourable	Favourable	More Favourable
Mean Water Depth [m]	20 – 30	18 – 20	15 – 18	5 – 15
Distance to Landfall (mainland) [km]	14+	7 – 14	4 – 7	0.5 – 4

2.4.3 Social and Environmental Factors

Wind farm development involves many environmental and social issues that are extremely subjective and varied. These issues range from local opposition to wind development on the grounds of visual impact or impact on flora and fauna to communities endorsing local projects for financial or environmental reasons. In an attempt to implicitly address this issue, population density and distance to shore are used as a quantitative indicator. Generally, social issues tend to diminish when fewer people live in the vicinity of a project. As a result, all other factors being equal, a site with a low population density would generally be more attractive to a potential developer.

The visual characteristics of the Great Lakes, or lakescape, are important resources for many reasons. They are crucial elements for Ontarians' sense of identity and culture. They also have economic value in that they attract visitors and contribute to an attractive quality of life for communities established along the shores. To address visual issues, it was decided to consider three threshold distances defined as a function of the relative heights WTGs would represent in comparison with the features of coastal landscapes and lakescapes. Within a 1-km perimeter, turbines will appear to be prominent in the landscape, i.e. they will seem to have the same height as the foreground or greater. Between 1 km and 3 km, turbines will appear to be less prominent, i.e. in relative harmony with the midground. Between 3 km and 9 km, turbines will seem to blend in with the background. At distances exceeding 9 km, the turbines, representing less than 1° of vertical arc, will be insignificant.

[6] The exceptions in this category are Manitoulin Island, Wolfe Island, Amherst Island, Parry Island and Phillip Edward Island, which are considered to have a transmission capacity comparable to that of the mainland.

For the visual impact factor, the distance to shore is defined as the mean distance between each point (spaced at 200-m intervals) within the site and the nearest shore point (including islands). This assumption is conservative as it supposes that every island is inhabited.

Population densities (residents per km^2) were identified throughout the province.[7] Areas with lower population densities were considered *more favourable* for offshore wind farm development. The classes defined in Table 2-6 below were established after a review of the selected sites and corresponding population densities. It should be noted that this factor was considered from a "social" point of view, since, conversely, utilities generally prefer to have power generation close to population centres.

The third social/environmental factor was Important Bird Areas (IBAs). IBAs are not regulated areas but rather serve as guidelines indicating zones which hold significant numbers of globally threatened, restricted-range or biome-restricted species, or have exceptionally large numbers of migratory or congregatory species. Though the IBA database provides information on the sensitivity of a site, a designated IBA zone should not necessarily be considered as a constraint per se (unless it overlaps with a provincial park, for example). A site partially or completely within an IBA is considered least favourable compared to a site outside of those areas.

Table 2-6: Definition of Classes Used for Ranking – Social and Environmental

	Least Favourable	Less Favourable	Favourable	More Favourable
Visual Impact [km from shore]	0 – 1	1 – 3	3 – 9	9+
Population Density [residents/km^2]	45+	20 – 45	5 – 20	0 – 5
IBA	Inside	-	-	Outside

2.4.4 Infrastructure

The proximity of large infrastructure can have an influence on the selection of wind project sites or on the micro-siting of wind turbines. In order to quantify this constraint for the purposes of this assessment, Hélimax used the distances from two types of infrastructure: airports and major radiocommunication systems.

Airport facilities may be considered a significant constraint to offshore wind development. However, the size of the corresponding exclusion zone to be established is influenced by numerous factors such as the size of the airport, orientation of the airstrip, etc. These issues are site-specific and, in the context of this study, a specific buffer zone cannot be set. Therefore, distance from the nearest airport was used as a factor to weigh the potential impact of an airport on the development of an offshore wind farm.

Additionally, it is recognized that development of wind projects can affect certain radiocommunication systems. As stated in the Radio Advisory Board of Canada and the Canadian Wind Energy Association guideline[8] on this issue, Hélimax considers that wind turbines may cause interference with significant radiocommunication systems[9] located within a 10-km radius.

Table 2-7 below defines the classes used by Hélimax to quantify the infrastructure ranking factor.

[7] Based on Statistics Canada's 2006 Census
[8] Technical Information On The Assessment of the Potential Impact Of Wind Turbines On Radio Communication, Radar And Seismoacoustic Systems, April 2007
[9] Major radiocommunication systems considered by Hélimax are radionavigational aids, air and vessel traffic control radar systems and weather radar.

Table 2-7: Definition of Classes Used for Ranking – Infrastructure

	Least Favourable	Less Favourable	Favourable	More Favourable
Airports [km]	0 – 2	2 – 4	4 – 6	6+
Radiocommunication Systems [km]	0 – 10.0	-	-	10+

3 SITE SELECTION RESULTS

This section presents the results of the site selection and ranking process. In all, 64 sites were selected and ranked throughout the study area. Each selected site was ranked according to the factors discussed in Section 2. The most favourable sites are located in areas of good wind speeds, low construction complexity, low social and environmental impact and low infrastructure impact. It should be noted that this ranking process is independent of site size or surface area, thus the best (most favourable) sites are not necessarily those which offer the largest potential installed capacity.

Table 3-1 below illustrates how each site faired for each of the four factors; the colour coding used is consistent with that illustrated in Section 2.4. For example, the best site is ranked as Site 1. This site is classed as m*ore favourable* for the wind speed factor meaning that it boasts average annual wind speeds of greater than 8.55 m/s (Table 2-4); it has a *more favourable* development complexity factor; it has been classed as *favourable* for the social and environmental factor, and, lastly, it has been classed as *less favourable* with respect to infrastructure.

The fact that some sites fair better than others for a given factor but are ultimately ranked lower reflects the weight attributed to each factor. For example, Site 3 and Site 4 are colour-classed the same for the first 3 factors (wind speed, development complexity and social/environmental), while Site 4 was classed better (*more favourable*) for the infrastructure factor than Site 3 (*less favourabl*e). However, Site 3 was attributed the higher overall ranking thanks to its superior wind speed and the weight associated with this most important factor.

Maps presenting the locations of all 64 sites can be found in the Appendix.

Table 3-1: Final Site Ranking

Site ID	Wind Speed	Development Complexity	Social and Environ.	Infra-structure	Final Ranking
1					1
2					2
3					3
4					4
5					5
6					6
7					7
8					8
9					9
10					10
11					11
12					12
13					13
14					14
15					15
16					16
17					17
18					18
19					19
20					20
21					21
22					22
23					23
24					24
25					25
26					26

Site ID	Wind Speed	Development Complexity	Social and Environ.	Infra-structure	Final Ranking
27					27
28					28
29					29
30					30
31					31
32					32
33					33
34					34
35					35
36					36
37					37
38					38
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58					58
59					59
60					60
61					61
62					62
63					63
64					64

4 INSTALLABLE CAPACITY AND ENERGY YIELD CALCULATION

Once the sites were selected, calculations were undertaken to first assess the installable megawatt capacity and then to estimate the energy yield production of each site. The following section presents the methodology used to obtain those figures.

4.1 Installable Capacity

4.1.1 Selection of Turbine

This study assumed the use of a generic 5-MW turbine with a hub height of 90 m and a rotor diameter of 120 m, the specifications of which are based on large-scale turbines currently available and present market trends and are not meant to reflect any particular manufacturer.

4.1.2 Calculation of Megawatt Capacity

Using the above-mentioned 5-MW turbine (with a 120-m rotor diameter), Hélimax assumed for this study an inter-turbine spacing of 9 rotor diameters in one direction (1080 m) and 6 rotor diameters (720 m) in the perpendicular direction. This gives an installable capacity of 5.8 MW/km^2 of available water sheet after constraints and associated buffers.

This inter-turbine spacing is considered adequate and is consistent with current offshore industry practices (in light of currently operating offshore developments, the largest of which is the 80-turbine (160 MW) Horns Rev wind park in Denmark). A denser configuration would result in higher wake losses and potentially increased turbine fatigue, which could have an impact on turbine service life. A more compact layout would also reduce the open water surface, which could have an impact on navigation and commercial and recreational fishing. Conversely, greater spacing between turbines would lead to higher cabling costs and possibly a more prominent visual impact.

Installable megawatt capacity calculations were rounded up to give the approximate number of turbines that could reasonably be accommodated by the available water sheet. For example, a site with an available water sheet of 17.6 km^2 would offer 102.08 MW of installable capacity (assuming 5.8 MW/km^2). Using a 5 MW turbine would correspond to 20.42 turbines (102.08 MW / 5 MW = 20.42). However, as the number of turbines must be an integer, this value would be rounded down to 20 turbines, translating into a revised installable capacity of 100 MW rather than 102.08 MW.

All sites are considered to have a potential installed capacity of between 100 MW and 800 MW.[10] Some sites which are quite large were capped at 800 MW even though they could theoretically accommodate more capacity. This was done to try to realistically reflect the capacity of the area. These larger sites could potentially be divided into a number of smaller sites, but would most likely not total more than 800 MW. Figure 4-1 below shows the distribution of the installable capacity of the selected sites.

[10] Potential installed capacity is calculated by multiplying the MW capacity density (see Section 2.4.2) by the number of square kilometres of usable (non-constrained) water surface.

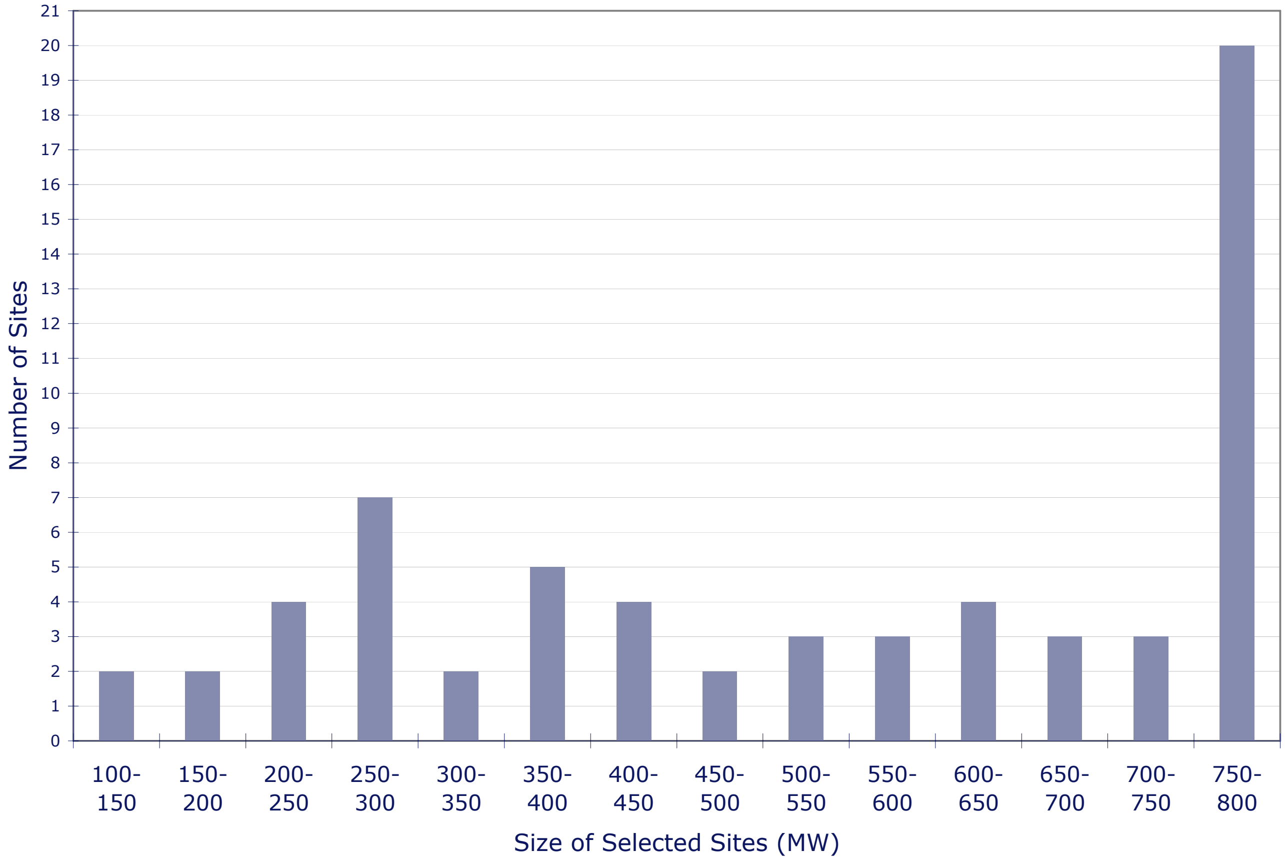


Figure 4-1: Distribution of MW Capacity of Selected Sites (assuming a 5-MW turbine)

4.2 Energy Yield Calculation

4.2.1 Energy Yield Calculation Methodology

A generic power curve (for a 5-MW turbine and at standard air density) suitable for an Ontarian context has been applied in combination with the average wind distribution (mean wind speed at 80 m agl and Weibull k parameters[11]) for each site in order to calculate gross energy yields. It is assumed that the performance of future wind turbines will be comparable to that of today's commercial turbines. Mean wind speeds were obtained from the Ontario Wind Resource Atlas and the k parameter was assumed to be 2 for all sites.

[11] The Weibull statistical distribution is the best representation of the frequency distribution of observed wind speeds. The k parameter helps define the shape of the distribution. The Weibull distribution can degenerate into two special distributions depending on the value of the shape parameter. For k = 1, the distribution reduces to that of an exponential distribution, and for k = 2, the distribution becomes the Rayleigh distribution.

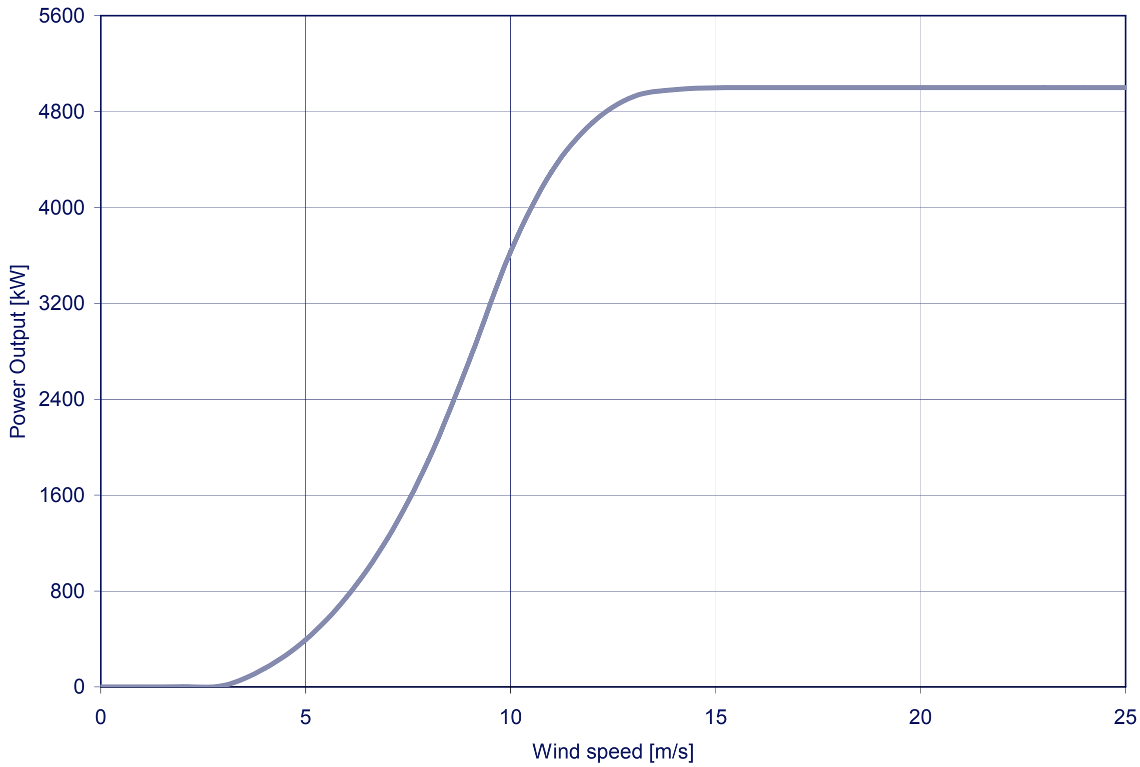


Figure 4-2: Generic 5-MW Turbine[12]

Net energy yields were then calculated using the following equation:

$$E_{Net} = E_{Gross} \times \eta_{af}$$

where:

E_{Net}:	net wind farm energy yield
E_{Gross}:	gross wind farm energy yield
η_{af}:	overall loss adjustment factor, corresponding to the cumulative value of various individual loss factors

The loss adjustment factor takes into account both wake effect between turbines and other losses. Wake effect refers to the effect one turbine has on the turbine(s) located in its wake (downwind) due to the disturbance of air flow passing through its rotor. Other losses include those related to wind turbine and grid availability, electrical losses and aerodynamic losses.

For the sites selected, wake losses have been estimated to be in the order of 8% and the “other losses” factor to be 12%, giving a loss adjustment factor of 0.8096. A breakdown of each loss composing the “other losses” factor is not given as these have been estimated on a province-wide basis. Values for individual sites would have to be evaluated on a site-by-site basis.

[12] This generic turbine does not reflect any turbine manufacturer or type.

4.2.2 Energy Yield Results

Table 4-1 below presents the calculated energy yield estimates and associated net capacity factors for each of the sites. It should be noted that the site ranking results are not exclusively contingent on wind speeds but rather reflect the ensemble of factors and weighting procedure defined in Section 2.4, which explains why some sites ranked higher relative to others but have lower capacity factors.

The calculated net capacity factors for each site (the net average annual output divided by the maximum output at rated capacity) range from 34.7% to 40.8%. Figure 4-3 below shows the relationship between average mean wind speed and net capacity factor. The average net capacity factor for all sites is approximately 37%.

These values are given for prospecting and ranking purposes only and should not be used for financial calculations. The development of sites should follow a more detailed procedure based on further investigation of the sites (comprehensive resource analysis including on-site wind monitoring towers, project layout, etc.).

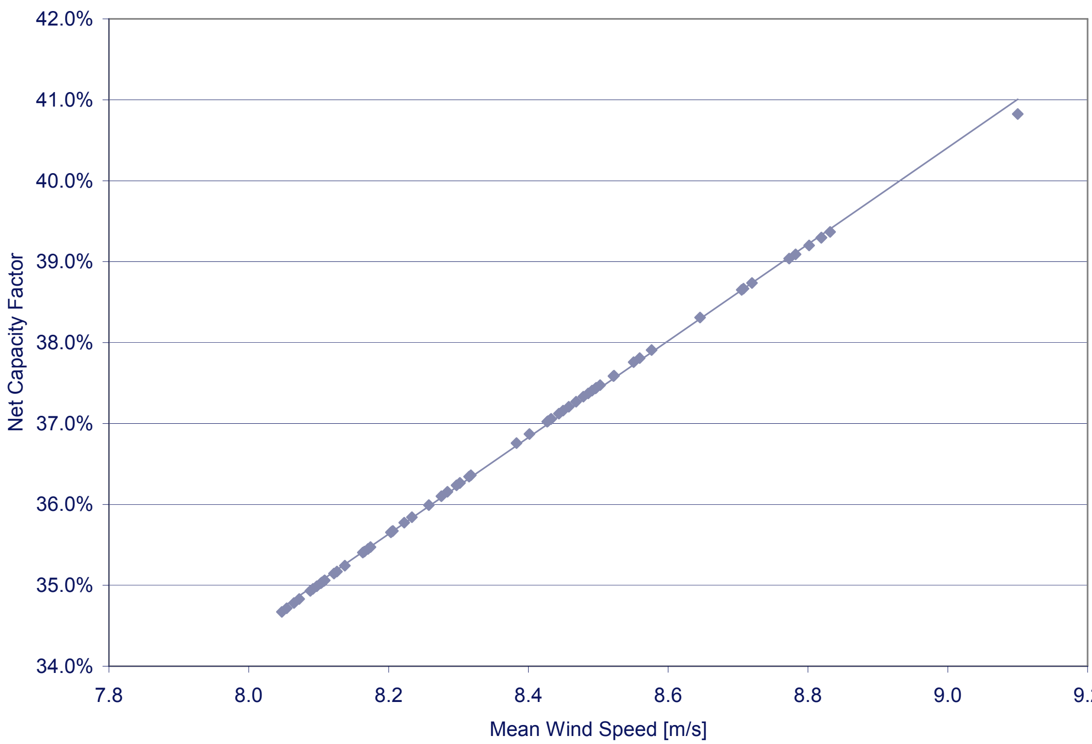


Figure 4-3: Capacity Factor as a Function of Wind Speed

Table 4-1: Energy Yield Results

Site ID and Ranking	Potential Installable Capacity [MW]	Net Energy Yield [GWh/year]	Net Capacity Factor [%]
1	410	1414	39.4
2	405	1315	37.1
3	730	2418	37.8
4	800	2754	39.3
5	765	2567	38.3
6	545	1774	37.2
7	600	1948	37.1
8	800	2646	37.8
9	465	1524	37.4
10	355	1214	39.0
11	315	984	35.7
12	250	791	36.1
13	295	963	37.3
14	530	1825	39.3
15	465	1575	38.7
16	765	2519	37.6
17	240	780	37.1
18	800	2548	36.4
19	695	2273	37.3
20	565	1917	38.7
21	785	2696	39.2
22	520	1651	36.2
23	560	1803	36.8
24	255	777	34.8
25	800	2486	35.5
26	800	2623	37.4
27	360	1128	35.8
28	800	2624	37.4
29	315	1001	36.3
30	635	2002	36.0
31	700	2171	35.4
32	625	1953	35.7
33	800	2500	35.7
34	710	2338	37.6
35	230	731	36.3
36	170	557	37.4
37	800	2512	35.8
38	800	2465	35.2
39	800	2594	37.0
40	445	1478	37.9
41	610	2182	40.8
42	800	2709	38.7
43	800	2739	39.1
44	740	2400	37.0
45	355	1102	35.4

Site ID and Ranking	Potential Installable Capacity [MW]	Net Energy Yield [GWh/year]	Net Capacity Factor [%]
46	110	355	36.9
47	260	797	35.0
48	380	1164	35.0
49	280	869	35.4
50	800	2626	37.5
51	700	2282	37.2
52	360	1093	34.7
53	800	2534	36.2
54	800	2547	36.3
55	225	690	35.0
56	260	791	34.7
57	180	549	34.8
58	150	461	35.1
59	275	847	35.1
60	290	895	35.2
61	800	2448	34.9
62	800	2457	35.1
63	615	1887	35.0
64	405	1244	35.1
Total	**34 500**	**111 503**	**Avg.: 36.7**

5 CAPITAL, OPERATION AND MAINTENANCE COSTS

This section provides a discussion of the capital and operation and maintenance (O&M) costs of a generic offshore wind farm to be installed in the Great Lakes.

5.1 Overview of Offshore Costs

The capital and O&M costs of offshore wind farms are significantly higher than onshore projects, mainly due to higher installation and construction costs, foundation costs, turbine costs and more difficult access conditions. By most estimates, the capital costs of offshore wind are between 30% and 70% greater than those of onshore projects (when including interconnection costs).

In the absence of any operational offshore wind farms in North America, real case examples must be taken from European projects. Figure 5-1 presents the capital costs of 11 offshore wind farms installed between 2001 and 2007 in Northern Europe; the capital costs generally range between $2 million and $3.6 million per megawatt installed. It is worth noting that these prices generally do not include the cost to interconnect the project to the transmission grid. While most capital costs were largely comparable, those of one project, the Beatrice / Moray Firth wind farm, were much higher than the average, partially due to the site's extreme water depth and the preparatory work that has been completed for future expansion phases.

While European projects provide an approximate indication of the scale of investment which might be expected for offshore development in the Great Lakes, certain adjustments will be required to account for market and environmental differences. In particular, the costs of offshore wind in Ontario will deviate from those in Europe due to differences in the transmission network, access to large port facilities, ice accumulation and movement on the Great Lakes, position on the learning curve, turbine supply, and offshore engineering experience.

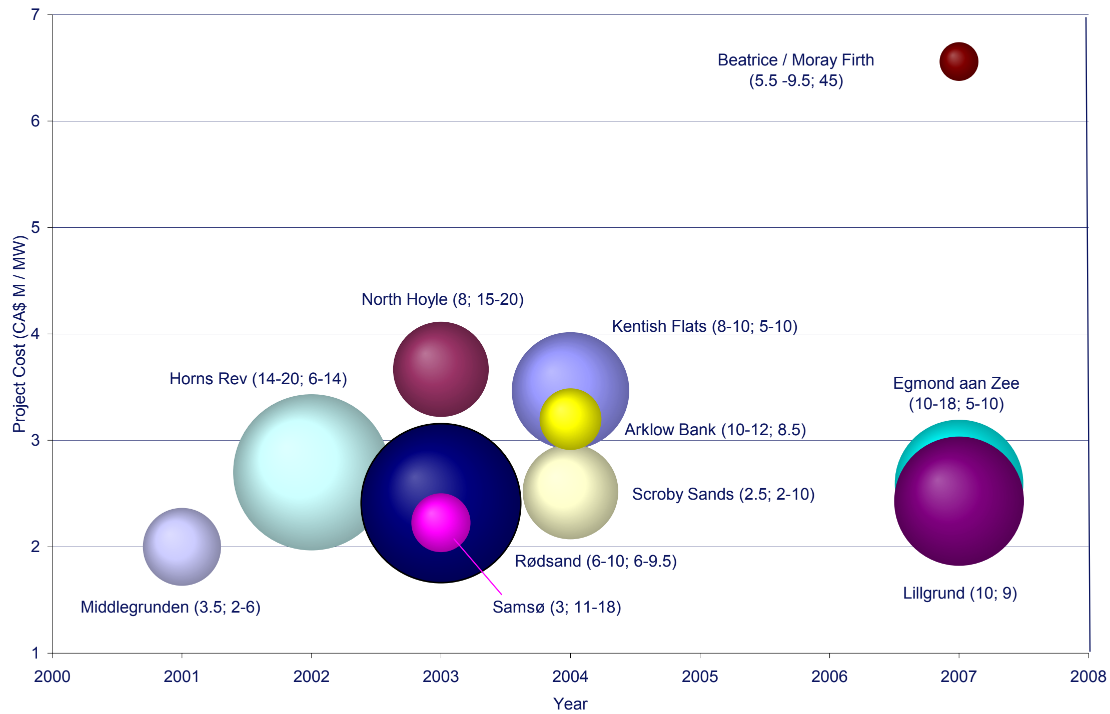


Figure 5-1: Offshore Project Costs – Case Studies[13,14]

For comparative purposes, breakdowns of the principle components of the capital costs of on- and offshore wind farms are provided in Figure 5-2 and Figure 5-3, respectively. While exact ratios from one project to another will vary as a function of site-specific characteristics, the graphs illustrate the differences in the risk profiles of on- and offshore projects. For example, although offshore turbines are more costly, their relative percentage of the total capital costs is significantly less, while civil works and interconnection represent a greater proportion of the total capital costs of an offshore wind farm.

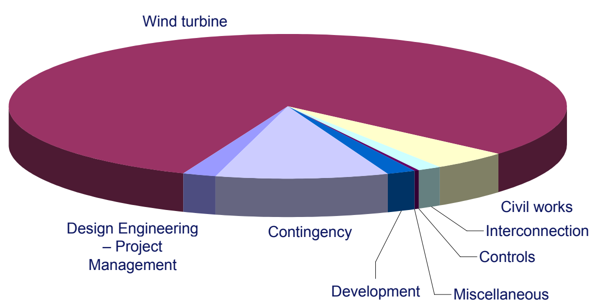


Figure 5-2: Breakdown of Onshore Capital Cost

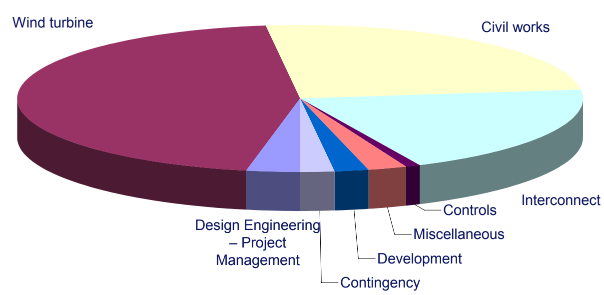


Figure 5-3: Breakdown of Offshore Capital Cost

[13] Data taken from Offshore Centre Denmark, "Offshore Wind Farms", http://www.offshorecenter.dk/offshorewindfarms.asp, accessed 10 April 2008. Assumes a conversion rate of CA$1.50 to € 1.
[14] The values indicated after each wind farm name indicate the distance from shore (in kilometres) and the water depth at the site (in metres), respectively. The size of the circle represents the installed capacity of the project.

5.2 Capital Cost Estimate

5.2.1 Factors Affecting the Capital Cost of Offshore Wind Farms

5.2.1.1 Wind Turbine Generators

Offshore wind turbines are typically more costly than onshore turbines, as they require additional protection against the saline environment, and must be designed to be more robust so as to require fewer interventions during their operation. In addition, given the lower supply and demand for offshore turbines, the manufacturing economics of scale have yet to be achieved, which further adds to the cost premium. However, both economies of scale and movement along the learning curve are expected to lead to a decrease in the costs of offshore wind turbines over the next decade.

Seeing as though the Great Lakes are fresh water lakes, the salt spray protection which is mandatory for turbines installed in European waters would be unnecessary in the Ontario offshore context. However, it is not currently known whether turbine manufacturers would consider selling offshore turbines without salt spray protection, as it might jeopardize their certification. It is therefore possible that offshore project proponents in Ontario might not benefit from a price reduction despite not needing this feature.

5.2.1.2 Civil Work

Due to the high costs of foundations, the civil work component forms a greater percentage of the total capital costs of an offshore wind farm.

Offshore foundations are not new technology; in fact, piled foundations have been used throughout the world as support structures for offshore oil and gas platforms and established practices and guidelines exist for their design. However, as the foundation of an offshore wind turbine is subject to greater live than dead load, the same practices used in the gas and oil industry cannot be directly transferred to wind power engineering without rigorous testing and optimization. Offshore wind turbine foundations must be appropriately designed to withstand the overturning moment caused by wind on the turbine in combination with the horizontal loading from the hydrodynamic forces.

In addition to their fresh water nature mentioned above, the Great Lakes differ from marine environments of northern Europe particularly with respect to ice formation, ice movement and lack of tides. In particular, it is expected that due to the accumulation and movement of ice on the Lakes, foundation designs will have to be adapted accordingly.

5.2.1.3 Interconnection

Currently, the design of the electrical interconnection of offshore wind farms resembles that of onshore wind farms. In both cases, each wind turbine has its own transformer to convert the power produced by the generator to the voltage of the collector system. The principle difference of the offshore interconnection design is the frequency of the built-in redundancy; depending on the design, size and layout of the wind farm, there can be one or multiple offshore sub-stations as well as one or multiple submarine cables connecting the sub-station to shore. The central sub-station(s) converts the power to a higher voltage to reduce energy losses stemming from transmission. The objective of the redundancy is to reduce the impact should there be a problem with one of the components of the system. Depending on the distance to the transformer and the size of the project, the power is sometimes converted into high-voltage direct current (HVDC) to reduce the losses. Once on shore, power is transmitted to the transmission grid via overhead or underground cables.

Interconnection costs of an offshore wind farm are greater than those onshore principally due to the submarine cables as well as additional redundancy in the system. Submarine cables are generally buried between 1-3 m underground depending on maritime traffic, fluctuation of the water levels and environmental sensitivity.

5.2.1.4 Other Factors

Other factors that will influence the capital costs of offshore wind power in the Great Lakes include the available offshore construction expertise, availability of vessels and offshore equipment, prices of steel and copper, and the experience of the stakeholders. It should be noted however that the market is continuously evolving and that by the time an offshore project in Ontario reaches advanced stages of development, the turbine and construction costs presented herein may no longer be representative.

5.2.2 Hélimax's Capital Budget

Hélimax has calculated the median and lower and upper bounds of the capital costs of a generic project to be installed at an average location in the Great Lakes based on European industry experience, appropriate hypotheses and adjustments for the Ontario context, and Hélimax's professional experience. The costs include the offshore collector system and the offshore substation but include neither the cost to bring the power to the shoreline nor to the transmission grid. The results are provided in Table 5-1. The median values are representative of a project between 200 and 300 MW located within 20 km of the coast and in water less than 20 m deep. Significant deviations from these estimates can be expected from one project to another, as actual figures will greatly depend on the following factors:

- Model of wind turbine generator selected;
- Market conditions affecting the cost of the turbine;
- Site conditions during construction and operation;
- Water depth;
- Type of foundation required
- Distance to shore and point of interconnection.

Table 5-1: Project Budget of Generic Offshore Wind Farm[15]

	Cost per MW Installed [1000s C$] (April 2008 $)			Proportion of Overall Budget [%]
	Lower Bound	Median	Upper Bound	
Design engineering and project management	105	120	135	**3**
Hard costs	3109	3514	3919	93
Soft costs	70	80	90	2
Project contingencies	70	80	90	2
Total Project Budget	**3354**	**3794**	**4234**	**100**

5.3 Operation and Maintenance Budget

Inadequate reserves or cost provisions of a poorly planned operation and maintenance O&M budget can compromise project operability and trigger significant revenue losses of even a well-designed project. This is particularly true for offshore wind farms as their repairs are significantly more costly and time-consuming than those performed onshore. While offshore turbines must first be designed for greater durability to reduce the frequency and severity of interventions, the O&M program must then be optimized to ensure that limited access to the site and its infrastructure does not severely reduce the availability of the turbines and their profitability.

[15] It should be noted that these costs do not include the cost of interconnection.

5.3.1 Factors Influencing O&M Budget

Though it is true that wind turbine technology evolution has lessened the burden of O&M on wind farms, especially those offshore, a well-designed O&M program is still required to achieve expected levels of performance and, in turn, consistent revenues. The O&M budget depends on a range of variables such as the type of technology, location of the site, distance to port, local meteorological conditions, and the O&M program implemented by the project proponent.

Offshore O&M budgets are more costly than onshore because of the need for specialized equipment such as vessels for transporting cranes, and the cost of commuting to and from site. Additionally, offshore turbines generally experience lower availability levels as a result of longer wait times for spare parts, crew and equipment; increased frequency of site inaccessibility due to inclement weather; longer repair times due to the environment; etc.

5.3.2 Hélimax's O&M Budget

O&M budgets vary from one wind farm to another and from one project owner to another. Hélimax has modelled the O&M costs over the project lifetime based on realistic assumptions of the statistical long-term failure rates of major components, the cost to repair or replace these components, labour costs, the number of repair crews, as well as the type and number of vessels available to access the site. The assumptions are based on data from the lifecycle performance of recently installed equipment, industry data, operational experience of offshore wind farms, and Hélimax's own experience. The results are provided in Table 5-2Table 5-2 below. The median values are representative of a project between 200 and 300 MW located within 20 km from the shore. It should be noted that these forecasts have a certain degree of error associated with them given the limited amount of data available on the operating experience of offshore turbines, as well as the fact that both project owners and manufacturers can be reluctant to share their experience.

Table 5-2: O&M Budget for Offshore Wind Farms [¢/kWh]

Lower Bound	Median	Upper Bound
2.3	2.6	3.1

In comparison, onshore O&M costs generally range between 1.8¢/kWh and 2.2¢/kWh. The cost will depend a number of factors, including:

- Type of O&M program implemented by the project owner;
- Failure rates of the major components and the cost to repair the components;
- Crane availability;
- Labour costs for corrective and preventive maintenance.

6 GENERIC SCHEDULE OF PROJECT ACTIVITIES

This section provides a simplified schedule for the development of a generic offshore wind farm. The Gantt chart provided in Figure 6-1 below outlines this schedule, which has been divided into five principle activities.

The timeline is provided to serve as an approximate guideline only; a more detailed work plan would be drawn up by the project proponent for the specific site prior to construction. The schedule does not consider the current shortage of wind turbine generators in today's market. It also assumes that neither the interconnection to the electrical grid nor obtaining a power purchase agreement is on the critical path. No contingencies have been included for exceptional conditions or other events that might delay construction.

The project schedule is decidedly longer than what is typically observed for projects onshore. The entire process is expected to last 5½ years, with the development process lasting three years; the design, one year; procurement and transportation, two years; construction, 1½ years; and testing and commissioning, 3 months.

ID	Task Name	Duration
1	**Development**	**156 wks**
2	Wind resource assesment	104 wks
3	Interconnection assessment and permitting	104 wks
4	Land options and permitting	156 wks
5	Environmental assessment	104 wks
6	Geotechnical assessment	104 wks
7	**Design and Engineering**	**52 wks**
8	Interconection design	52 wks
9	Collector design	52 wks
10	Foundation design	52 wks
11	**Procurement and Transportation**	**104 wks**
12	WTG	39 wks
13	Cables	26 wks
14	Substation	78 wks
15	Transportation	26 wks
16	**Construction and WTG Erection**	**78 wks**
17	Civil works	39 wks
18	Onshore cables & substation	39 wks
19	Offshore cables & substation	39 wks
20	WTG erection	39 wks
21	**Testing and Commissioning**	**12 wks**
22	Testing & Commissioning	12 wks

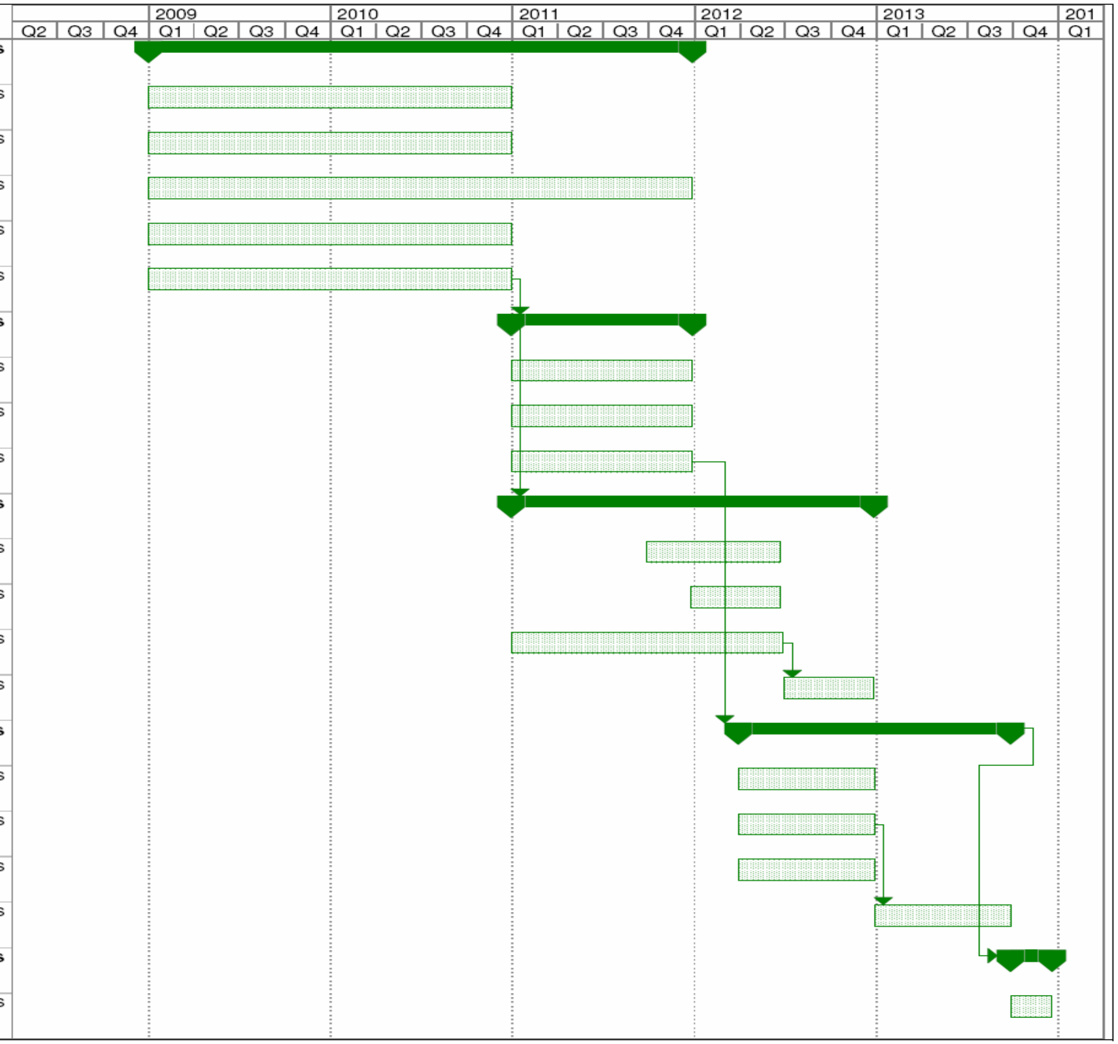


Figure 6-1: Generic Project Construction Schedule

7 CONCLUSION

Hélimax has completed a high-level technical analysis of the exploitable offshore wind resource in Ontario's Great Lakes. Hélimax has identified 64 sites that meet a number of criteria and are thus considered conducive to offshore development. All selected sites exhibit mean wind speeds above 8.0 m/s, are in water depths of between 5 m and 30 m, and have been filtered for constraints as defined in Table 2-1. Each of the sites has a sufficiently large water sheet to accommodate at least 100 MW of installed capacity. In all, the sites retained offer a potential total of nearly 34,500 MW of capacity. Hélimax then ranked these sites by their potential to be developed.

Before realistically considering any of these sites suitable for development, further studies would be indispensable, including:

- Detailed technical analysis such as ice loading condition and geotechnical analysis;
- Thorough environmental impact assessment (including social aspects);
- In-depth economic analysis;
- Wind resource assessment program with on-site measurements.

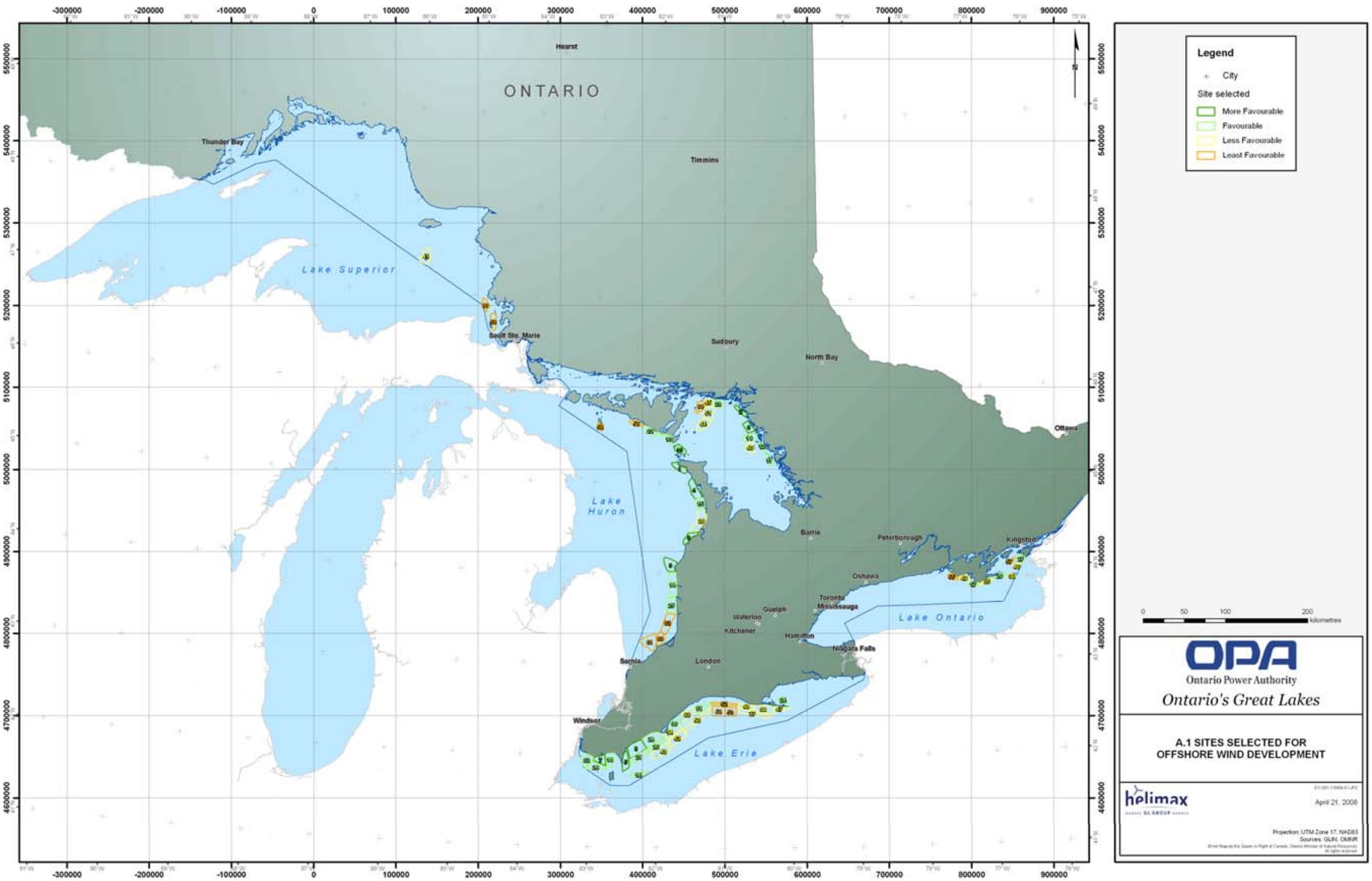
Hélimax makes no claims with respect to the economic or technical viability of the sites retained in the present analysis. Any of the sites selected may eventually prove to be unsuitable for offshore wind farm development once any or all of the above studies have been completed.

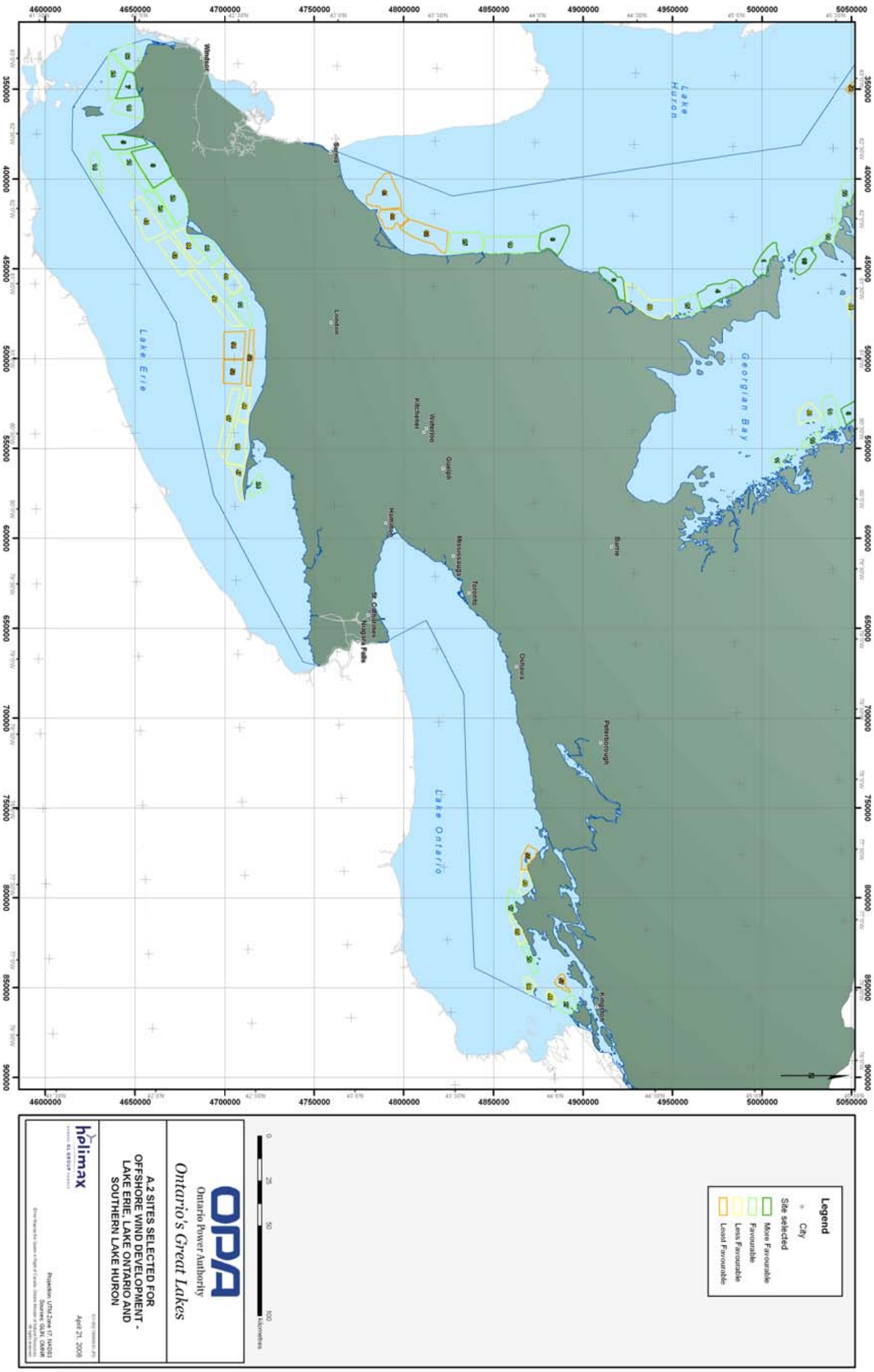
Hélimax also emphasizes that the sites it has selected do not necessarily correspond to the projects currently being developed. This report by no means seeks to disparage any sites currently under development which are not part of the 64 sites selected. There are wind power projects that can be feasibly developed beyond the sites that are identified in the present study.

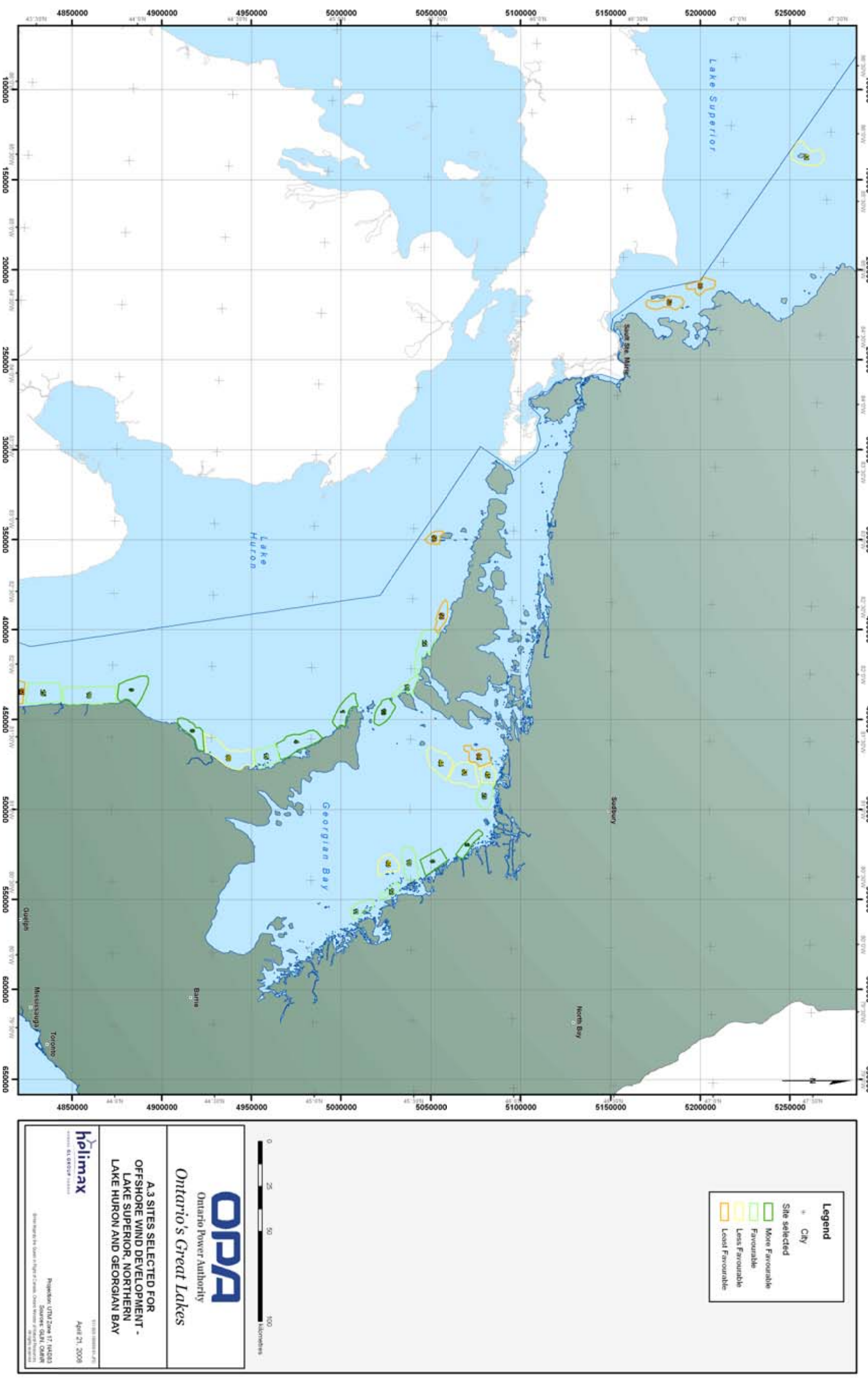
APPENDIX MAPS

Five maps are provided in this appendix and are presented in the order given below.

- A.1. Sites Selected for Offshore Wind Development
- A.2. Sites Selected for Offshore Wind Development – Lake Erie, Lake Ontario and Southern Lake Huron
- A.3. Sites Selected for Offshore Wind Development – Lake Superior, Northern Lake Huron and Georgian Bay
- A.4. Bathymetry and Selected Sites
- A.5. Wind Speeds and Selected Sites


ONTARIO
Hearst
Thunder Bay
Timmins
Lake Superior
Sault Ste. Marie
Sudbury
North Bay
Lake Huron
Barrie
Peterborough
Kingston
Ottawa
Oshawa
Toronto
Mississauga
Guelph
Waterloo
Kitchener
Hamilton
Niagara Falls
Lake Ontario
Sarnia
London
Windsor
Lake Erie
Legend
City
Site selected
More Favourable
Favourable
Less Favourable
Least Favourable
0 50 100 200 kilometres
OPA
Ontario Power Authority
Ontario's Great Lakes
A.1 SITES SELECTED FOR
OFFSHORE WIND DEVELOPMENT
helimax
April 21, 2008
Projection: UTM Zone 17, NAD83
Sources: GLIN, OMNR


Lake Huron
Georgian Bay
Lake Erie
Lake Ontario
Windsor
Sarnia
London
Kitchener
Waterloo
Guelph
Hamilton
Mississauga
Toronto
Barrie
St Catharines
Niagara Falls
Oshawa
Peterborough
Kingston
Legend
City
Site selected
More Favourable
Favourable
Less Favourable
Least Favourable
0
25
50
100
Kilometres
OPA
Ontario Power Authority
Ontario's Great Lakes
A.2 SITES SELECTED FOR OFFSHORE WIND DEVELOPMENT - LAKE ERIE, LAKE ONTARIO AND SOUTHERN LAKE HURON
April 21, 2008
Projection: UTM Zone 17, NAD83
Sources: GLIN, OMNR
helimax


Lake Superior
Lake Huron
Georgian Bay
Sault Ste. Marie
Sudbury
North Bay
Barrie
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Guelph
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Site selected
More Favourable
Favourable
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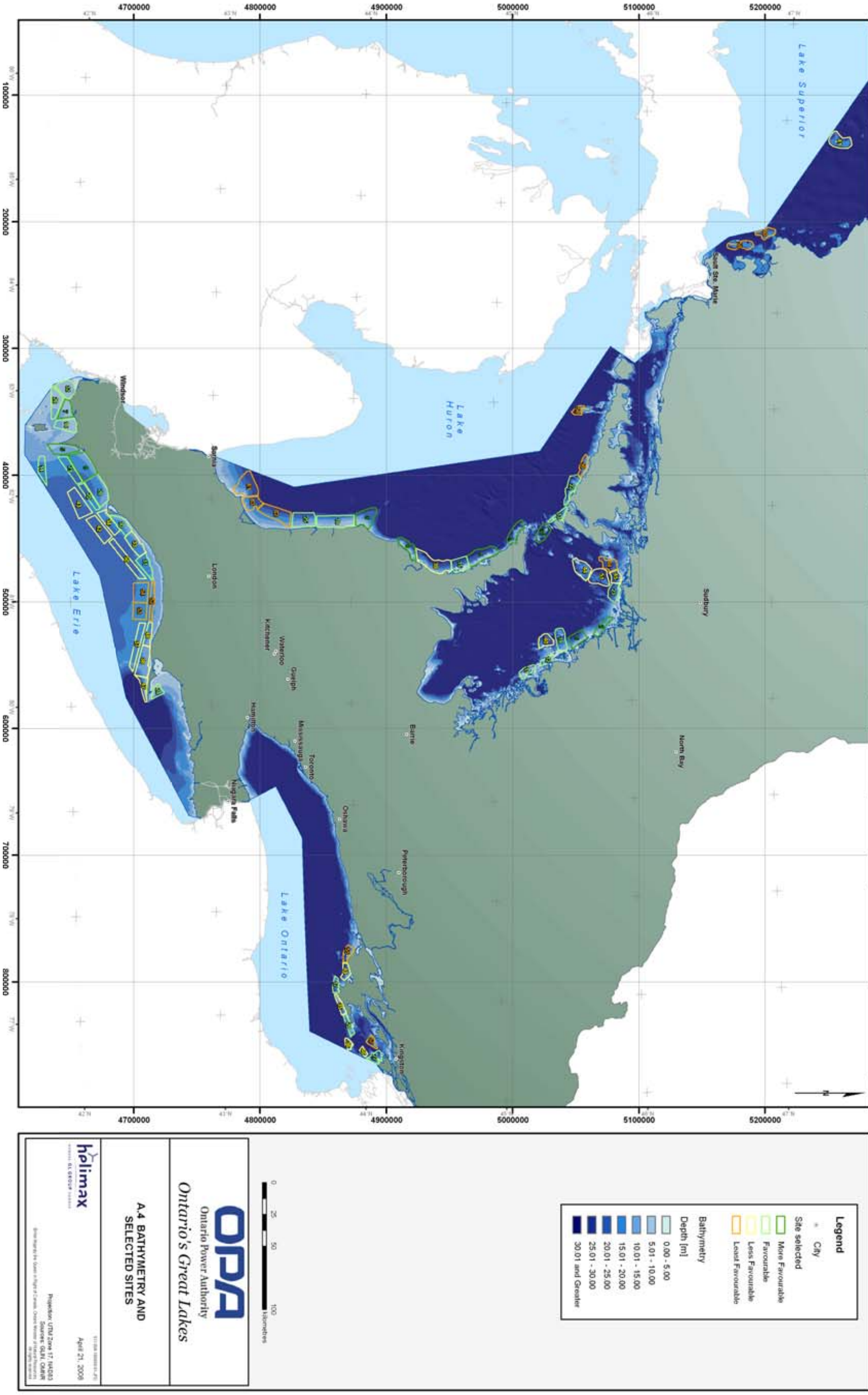
OPA
Ontario Power Authority
Ontario's Great Lakes
A.3 SITES SELECTED FOR
OFFSHORE WIND DEVELOPMENT -
LAKE SUPERIOR, NORTHERN
LAKE HURON AND GEORGIAN BAY
helimax
April 21, 2008
Projection: UTM Zone 17, NAD83
Sources: GLIN, OMNR


Lake Superior
Lake Huron
Lake Erie
Lake Ontario
Sault Ste. Marie
Sudbury
North Bay
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Waterloo
Guelph
Hamilton
Mississauga
Toronto
Barrie
Oshawa
Niagara Falls
Peterborough
Kingston
Legend
City
Site selected
More Favourable
Favourable
Less Favourable
Least Favourable
Bathymetry
Depth [m]
0.00 - 5.00
5.01 - 10.00
10.01 - 15.00
15.01 - 20.00
20.01 - 25.00
25.01 - 30.00
30.01 and Greater
0
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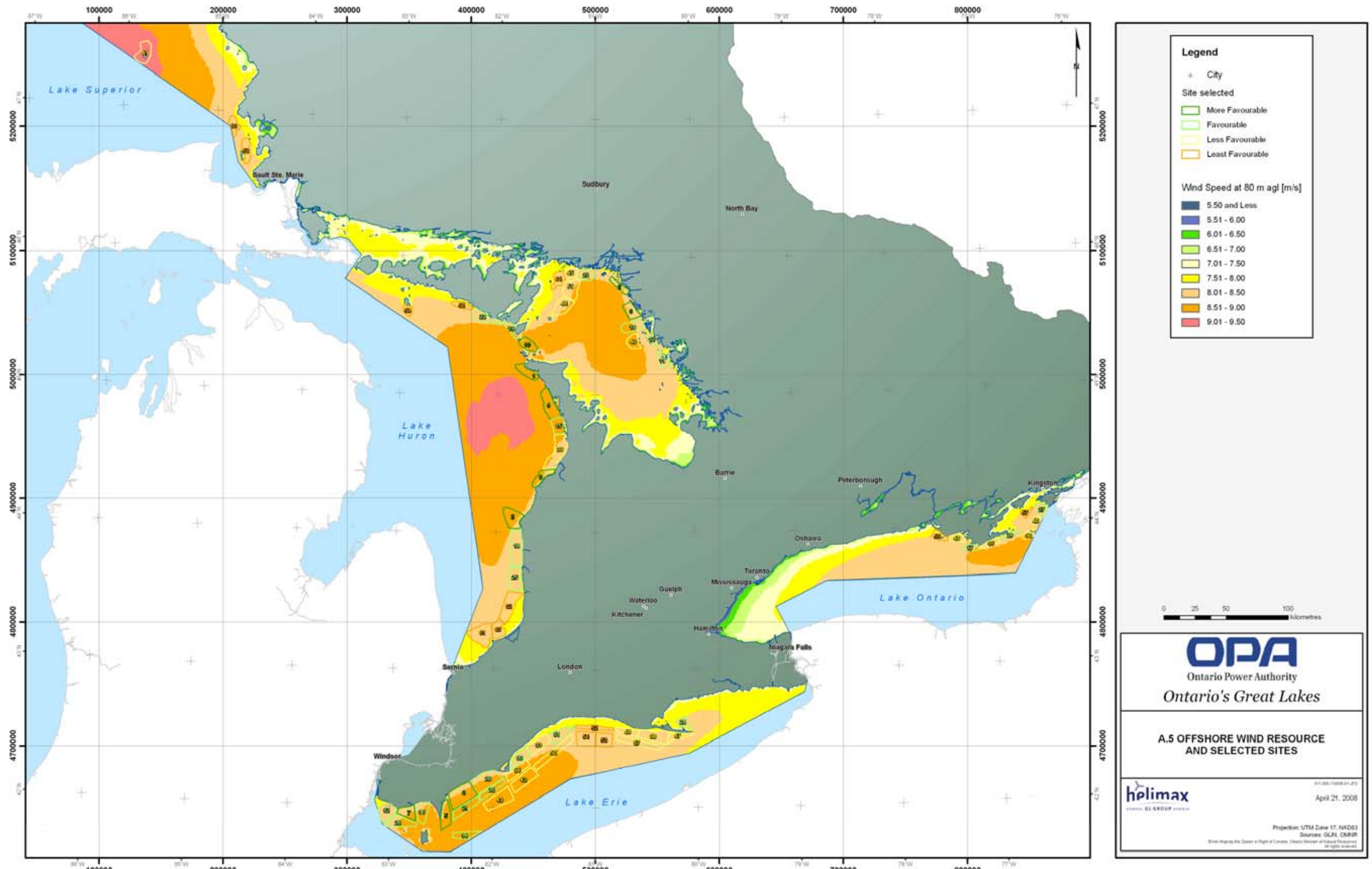
50
100
Kilometres
OPA
Ontario Power Authority
Ontario's Great Lakes
A.4 BATHYMETRY AND SELECTED SITES
April 21, 2008
Projection: UTM Zone 17, NAD83
Sources: GLIN, OMNR
helimax


Lake Superior
Lake Huron
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Waterloo
Kitchener
Hamilton
Niagara Falls
Sarnia
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Windsor
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4900000
5000000
5100000
5200000
Legend
City
Site selected
More Favourable
Favourable
Less Favourable
Least Favourable
Wind Speed at 80 m agl [m/s]
5.50 and Less
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 8.50
8.51 - 9.00
9.01 - 9.50
0
25
50
100
kilometres
OPA
Ontario Power Authority
Ontario's Great Lakes
A.5 OFFSHORE WIND RESOURCE AND SELECTED SITES
helimax
April 21, 2008
Projection: UTM Zone 17, NAD83
Sources: GLIN, OMNR

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