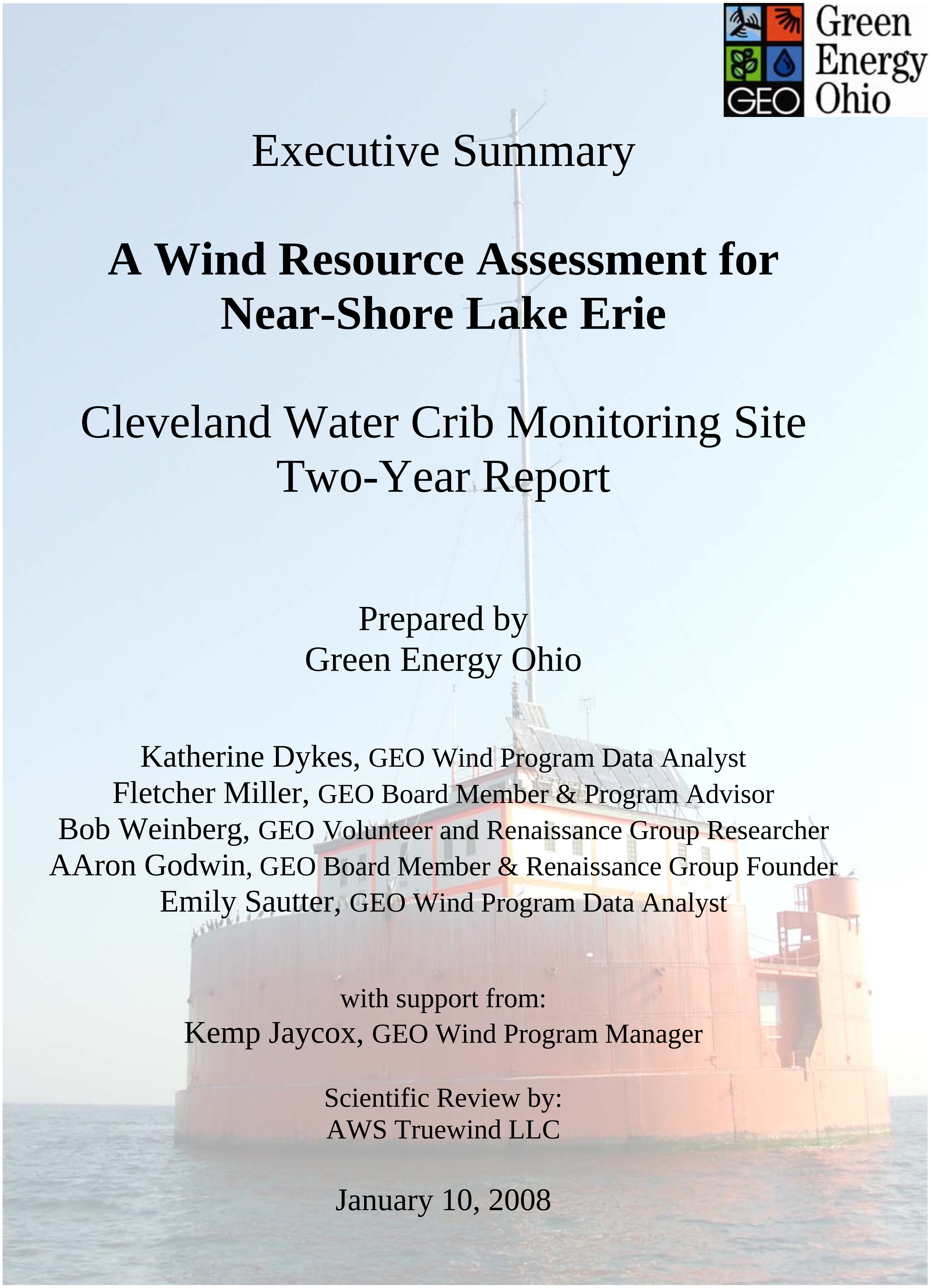

Executive Summary

A Wind Resource Assessment for Near-Shore Lake Erie

Cleveland Water Crib Monitoring Site
Two-Year Report

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Executive Summary

Green Energy Ohio (GEO) is a nonprofit, state-wide organization dedicated to promoting environmentally and economically sustainable energy policies and practices in Ohio. For over ten years GEO has been performing land-based wind resource assessments in Ohio, and conducting public education regarding the economic and environmental benefits of wind energy. This project's inception began in the mid-1990s in group discussions, followed by a literature review leading to the preliminary conclusion that the state's strongest winds existed over Lake Erie. However, given the lack of measured data from Lake Erie, GEO realized that a reliable quantification of this resource would be needed in order for the citizens of the state, and their governmental representatives, to determine the best use of the resource. With this in mind, GEO volunteers began developing a feasibility plan for how such data could be captured in peer reviewable program utilizing the existing Cleveland Water Intake Crib as a foundation for an off shore wind monitoring station.

The formal vision for this study, and for offshore wind on Lake Erie in general, was put forth in a GEO document prepared for the Lake Front Advisory Committee in 2002 (Appendix H). Subsequently, in March 2004 **Green Energy Ohio** (GEO) received a grant from **The Cleveland Foundation** to install wind monitoring equipment on the Cleveland Water Crib for the purpose of assessing the wind power potential of near-shore Lake Erie. This grant, which brought the first financial support to a project that had been several years in the planning stages, was followed closely by additional financial support from the **George Gund Foundation,** the **Steffee Foundation,** and the **City of Cleveland** to assist with the equipment installation. In August 2006, the Cuyahoga County Commissioners formed the **Cuyahoga County Regional Energy Development Task Force,** now the **Great Lakes Energy Development Task Force**, to report on future energy options for the region, and the Task Force chose wind energy as their first study topic. In December 2006, **Cuyahoga County** awarded GEO funding to assist with the data analysis and the compilation of this two year report (the two-year point in the data gathering phase was reached in October 2007). Many other organizations and individuals have contributed specifically to this project and to the advancement of wind power for Lake Erie in general, and are listed in the Acknowledgments section of this report.

The first phase of the project involved detailed engineering design of the tower, and the formation of a large project team of volunteers and partners from many organizations and government agencies. The Cleveland Water Crib[1] was chosen as the installation site since it is the only structure in the Lake that could economically support a tower of the height needed for a reasonable estimate of the wind potential. Prior to this study, the only wind data from the Lake were from National Oceanic and Atmospheric Administration (NOAA) buoys at water level, and those data were only available for about six months of the year (no late fall, winter, or early spring data).

The actual installation of the tower system began in June 2005 and proceeded in four phases: the installation of the building anchors and reinforcements to the existing structure; installation of lower tower section; installation of the upper instrumented tower section in August; and finally the establishment of the full data link via radio on September 20, 2005. The Renaissance Group (TRG) was contracted by GEO to manage the tower installation portion of the project, which was nevertheless accomplished primarily by volunteers including a great deal of pro bono work by TRG and others. Construction Helicopters, of Detroit Michigan, performed the crucial task of lowering the monitoring tower sections onto the Crib using an aerial crane.

Measurement heights were established at nominal heights of 30, 40, and 50 meters above the water level, with two booms at each level. An anemometer and a vane were placed on each boom to record wind velocity and direction, respectively, and to allow the calculation of wind shear[2] above the water. Additional instruments included air temperature, a NOAA wind system near the top of the Crib, a humidity meter, lake water temperature, solar radiation and power system diagnostics. A web-camera was also installed to show the Lake

[1] The Cleveland Water Crib is the intake for the city's water supply and is about 100 feet in diameter and 50 feet high at its highest point. It is located in Lake Erie about 3.5 miles north-northwest of downtown Cleveland.
[2] Wind shear is a measure of how the wind velocity increases as a function of height above the surrounding surface and is a key factor in determining wind turbine tower height.

conditions including wave action, winter icing development and city of Cleveland via a real-time link displayed on a web page.

Data from the water Crib were collected for two years and are summarized in this report, although the data collection is continuing. Data collection has been conducted by GEO volunteer and Renaissance Group partner Bob Weinberg working pro bono. The raw data were filtered and validated using macros developed by Katherine Dykes at GEO, detailed in Appendix E, resulting in a data retention rate of 96%. The filtered data excluded data corrupt due to icing events, tower shadowing, missing data or extremely low wind. From the filtered data a wide variety of meteorological quantities were calculated, including standard average and cubic average monthly and annual wind speeds, wind shear, Weibull parameters, wind direction, turbulence intensity, and the wind power class (see Table 1 for a summary). Historical wind data from an Ohio Agricultural Research and Development Center (OARDC) weather station located in Hoytville, Ohio were used to compare the Lake Erie Crib data to data taken at Bowling Green in 2000, since Bowling Green is the only site in Ohio with commercial wind turbines. Historical data collected from the Burke Lakefront Airport are included in this report as an additional reference. The Crib data were compared against data obtained from the Burke and Hoytville reference sites to determine correction factors for long-term trends. As an indicator of energy potential, the data were used to estimate the annual energy production and capacity factors for four representative commercial wind turbines, including one from Bowling Green, which serves as the only current benchmark site for Ohio. The data also provides a valuable calibration for computer generated wind resource maps.

Table 1: Crib Site Summary Statistics

Crib Summary Statistics (Oct. 2005 - Sept. 2007)			
	30M	40M	50M
Average Wind Speed [m/s]	7.14	7.25	7.34
Cubic Average Wind Speed [m/s]	8.51	8.61	8.69
Prevailing Incident Wind Direction	SW	SW	SW
Turbulence Intensity [std dev / m/s]	0.163	0.143	0.137
Wind Power Density [W / m^2]	446.1	453.9	466.5
Calculated Weibull Parameters (k)			2.15
Calculated Weibull Parameters (c)			8.3

As predicted, the wind speeds indicate that the Lake Erie wind resource is the best measured to date by GEO, compared to over ten onshore locations. An average annual wind speed of 7.3 m/s, and cubic average wind speed[3] of 8.7 m/s were found for the two-year period at 50 meters. These compare to Bowling Green, OH values of 5.8 m/s and 6.7 m/s, respectively, for the study period in 1999-2000. The annual average wind power density[4] at 50 meters was found to be 467 W/m^2, approximately double that found in Bowling Green at 50 m (note that without detailed historical average correction it is difficult to compare precisely the past two years on the crib with the period 1999-2000 in Bowling Green). In terms of the National Renewable Energy Laboratory (NREL) Wind Classification System (originally developed by Battelle Northwest Laboratories), the Crib site ranks as a strong Class 4 location.

Graphs in the main body of the report show how this wind resource is distributed throughout the year. As with other Ohio sites, the wind is strongest in the late fall and winter, and weakest in the summer. The best months of the year have approximately four times more wind energy than the least windy. Distribution of wind speed over the day was also calculated, and only a slight variation annually was found, with wind speeds the lowest between 8 AM and noon, by a slight margin.

[3] Cubic average wind speed is a more accurate measure of the wind potential, since the power in the wind depends on the cube of the wind speed.
[4] Wind power density is the most accurate way to characterize a site, and is directly proportional to how much energy can be generated at a particular location.

The predominant wind direction was found to be from the southwest, in agreement with land-based sites. A small, secondary peak in the wind direction frequency is seen from the northeast. When adjusted for energy content, winds out of the southwest were the strongest, followed by winds out of the west. While the layout of a wind farm was beyond the scope of this report, this directional information has implications for how a series of turbines would be arranged on the water so as to avoid blocking one another.

Perhaps the most unusual finding of this study was the low measured wind shear, which ranged from 0.02 to 0.04 averaged over the year. The offshore winds exhibit extremely low wind shear, in particular relative to land-based sites, but even when compared to what would be expected over water based on computer models and other information. As noted below, this finding warrants further examination due to the unusual values found and the importance this factor has on determining wind turbine tower height and on projecting wind speeds at heights higher than those monitored. If validated, this low wind shear suggests that lower tower heights can be utilized and lower turbine blade stresses with better performance are possible; however, it also means higher winds may not available for taller offshore turbines. If, on the other hand, the shear is found to be higher than measured, stronger winds would available at the higher heights. Calculations based on several commercial turbines showed power production would increase 7% if a standard shear value, rather than the measured shear values is used.

The wind speed, direction, shear, and power density measured on the Crib are compared to values obtained from Ohio Wind Resource Explorer, a state-of-the-art software tool developed by AWS Truewind, LLC (AWS) of Albany, New York for NREL. This software determines the projected quantities at different heights when given a particular location. Small differences were found as described in the report, but in general the predictions from Wind Explorer matched the measured data quite well. This gives welcome confidence to using Wind Explorer to conduct a preliminary evaluation of other sites in the lake where turbines could potentially be installed.

Using the measured data, annual energy production for four different wind turbines was calculated to give an estimate of the amount of energy that a single turbine could produce at the Crib location. It is understood that output in an actual wind park may vary somewhat due to turbine interactions and other factors. Using the conservative measured value of the shear, the turbines used at Bowling Green, Vestas V80[5], are predicted to produce approximately 5 million kWh (compared to 3.3 million kWh actual annual production in Bowling Green), while a large GE offshore machine could produce over 10 million kWh. Thus, six turbines of the GE size could, in theory, produce the electricity needed for 6,000 homes as called for by the Great Lakes Energy Development Task Force[6]. If the higher predicted value of the wind shear is used, the Crib numbers are even higher. See Table 2 below (Table 10 in the full report).

Also shown in the table are predictions from Ohio Wind Explorer using the shear value calculated from that program. (Ohio Wind Explorer does not give shear values, but they were calculated by us based on other values.) Ohio Wind Explorer predicts even higher annual energy production. After discussions with AWS, we believe this is due to the fact that Ohio Wind Explorer uses estimated averages and frequency distributions based on 15 years of wind data, whereas our study was based on 2 years of data, the latter which were slightly below normal wind years. This difference amounts to about 9% and shows the importance of continuing the Crib as a long-term measurement station to determine averages and frequency distributions over longer time periods.

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[5] The Vestas V80 is not considered an off-shore turbine and is given here for comparison purposes only.
[6] Cuyahoga County Commissioners Energy Task Force and recommendations February 2007: http://development.cuyahogacounty.us/en-US/energy-task-force.aspx

Table 2: Summary of Turbine Characteristics, Estimated Energy Output for 12-Month Period and Projected Capacity Factor

Crib Estimated Energy Output and Turbine Characteristics (using m/s data in 1 m/s steps)									
				Actual Crib data, shear = 0.0254		Actual Crib data, shear = 0.12		Ohio Wind Explorer, shear = 0.12	
Manufacturer	Model	Capacity	Rotor Diameter	12 month Energy Output (kWh)	Capacity Factor	12 month Energy Output (kWh)	Capacity Factor	12 month Energy Output (kWh)	Capacity Factor
Vestas	V80	1800kW	80 m	5,044,819	31.99%	5,386,703	34.16%	5,908,782	37.47%
Vestas	V90	3000kW	90 m	7,584,086	28.86%	8,098,054	30.81%	8,913,969	33.92%
GE	3.6sl	3600kW	111 m	10,452,779	33.15%	11,161,157	35.39%	12,267,903	38.90%
Clipper	2.5	2500kW	93 m	7,201,347	32.88%	7,689,378	35.11%	8,442,255	38.55%

This study was the first major step in determining the viability of offshore wind power for Lake Erie. It is not intended to give a yes/no answer to the question of whether the wind resource is worthy of development, or even economically wise. Many factors outside the scope of this assessment influence that question. What this study does provide is the first direct, detailed measurements and analysis of the winds on Lake Erie at heights relevant for modern wind turbines. The results showed the site to be the best in the state, with approximately twice as much extractable energy at 50 m than the only site developed on land so far at Bowling Green. It is important to note that, while having a good wind resource, Bowling Green is not the best site on land in the State.

As described in more detail in the main body of the report, several suggestions for future work in the area of wind assessment are made:

- Continue supporting the existing Crib data collection system and utilize the Crib as a base for future research. This is the only such station in existence and long-term data records are critical to following and establishing long-term trends. If a wind farm is constructed in Lake Erie, the ongoing Crib monitoring provides the important parallel performance reference.

- Determination of wind shear characteristics between the 50 m measurement height and potential large turbine blade tip heights of up to 200 m. As discussed above, the measured wind shear was well below the expected over-water value, and has a critical influence on selecting the appropriate tower height. We suggested previously, and reiterate here, that a SoDAR or preferably newer LiDAR based study be undertaken from the Cleveland Intake Crib, similar to offshore studies conducted recently in Europe.

- Development of a computational fluid dynamics model of the effect of the crib structure on the measured data. There was some concern at the time of installation that the large structure could affect the lower anemometer readings, and now that the data has been collected the structure is seen as a possible source of the apparently low wind shear measured.

- A more detailed analysis of the various sources of uncertainty in the existing data set as recommended by AWS during the study's peer review process.

- Validation of the historical trends seen at Burke Lakefront Airport, Hoytville and other reference sites in order to build an understanding as to the source of the downward trend in the historical data.

- Further analysis of the potential effects of the proximity of the Lake Erie Crib structure to the shoreline.

- The Task force may look into acquiring better access to long-term easily usable data sets from Burke Lakefront Airport, NOAA, the Coast Guard station, The Great Lakes Science Center, SteelWinds, and other such reference sites deemed appropriate for long-term trend analysis.

Next steps that go beyond the scope of monitoring the wind resource include:

- Incorporation of information on losses that would be expected from operation of a full wind farm (including turbine array factors, electrical, etc) as recommended by AWS during the study's peer review process.

- An economic feasibility study that incorporates the above mentioned data and corrections, and considers the project costs, environmental impact, utility rate structure, uncertainty and forecasts of alternative electricity sources, as well as government incentives that may be available for wind projects.

- Installation of monitoring towers on the best possible regional shoreline sites for overall comparison and better characterization of near-shore and offshore transitional zones.

- Further analysis of existing or possible regional renewable energy companies that might benefit from the existence of the project.

- Analysis of the environmental impacts of such a wind farm including potential negative externalities such as issues of avian migration, bat migration, and effects to marine life as well as potential positive externalities such as reduction in emissions due to sulfur oxides (SO_x), nitrogen oxides (NO_x) and carbon dioxide (CO_2) gases and particulate matter.

- A strong public engagement effort to bring the case for near-shore and offshore wind power to the general public and address any concerns at an early stage.

Green Energy Ohio is proud as a nonprofit organization to have had the foresight many years ago to see the potential for wind power to bring not only clean energy, but also jobs and a new icon to Cleveland and the region (see appendix H). We have worked for nearly a decade to bring the concept to fruition before the public and government officials. It was an honor to have been chosen and funded to quantify this wind resource. As of December 10, 2007, GEO transferred ownership of the tower and instrumentation to the City of Cleveland so that they may continue acquiring data for as long as feasible from the site, and so that reliable long-term trends can be documented for offshore Lake Erie winds. It is our expectation that, soon, research and commercialization efforts will continue this effort and bring wind power to its full potential on Lake Erie for the benefit of citizens of our entire region. As of this writing, several offshore projects are in the planning stages for coastal U.S. ocean waters, but the Crib data represent a unique contribution to the possibility of a fresh water installation. None of the other projects are yet installed, so that Ohio has the opportunity to be a pioneer in the important area of U.S. offshore wind energy development.