Final Scientific/Technical Report

Project Title: Development of a GIS-based decision support tool for evaluating wind farm sitings in Great Lakes aquatic habitats

Covering Period: April 1, 2012 to June 30, 2012
Date of Report: July 31, 2011

Recipient: University of Michigan
Award Number: DE-10EE0003537

Working Partners: Drs. Kevin Wehrly (wehrlyke@michigan.gov) and Lizhu Wang (wangl@michigan.gov), Michigan Dept Natural Resources and Environment, 734 663-3554,; Jason Breck (jbreck@umich.edu) and Lacey Mason (lmas@umich.edu), University of Michigan School of Natural Resources and Environment (UM-SNRE); Edward Rutherford (Ed.Rutherford@noaa.gov), NOAA Great Lakes Environmental Research Laboratory; and Scott Nelson (snelson@usgs.gov), USGS Great Lakes Science Center.

Executive Summary: As an outcome of our research project, we developed software and data for the Lakebed Alteration Decision Support Tool (LADST), a web-based decision support program to assist resource managers in making siting decisions for offshore wind farms (as well as other lakebed-altering projects) in the United States' waters of the Great Lakes. Users of the LADST can create their own offshore wind farm suitability maps, based upon suitability criteria of their own choosing by visiting a public web site. The LADST can be used to represent the different priorities or values of different Great Lakes stakeholders for wind farm siting, as well as the different suitability requirements of wind farms (or different types of development projects) in a single suitability analysis system. The LADST makes this type of customized suitability analysis easily accessible to users who have no specialized software or experience with geographic information systems (GIS). It also may increase the transparency of the siting and permitting process for offshore wind farms, as it makes the suitability analysis equally accessible to resource managers, wind farm developers, and concerned citizens.

Objectives and Accomplishments:

The specific objectives in our grant proposal were these:

1) **Create high-resolution spatial data of relevant biological, political, physical, cultural, and environmental features for Great Lakes aquatic landscapes.**

We successfully obtained data and processed many of these data layers. The current version of the LADST for the U.S. waters of the Great Lakes uses data layers with the following list of themes to make suitability maps according to user-supplied criteria:

Biological: fish spawning sites for several species, lake trout refuges
Political: airports, national parks, national lakeshores, recommended course lines (i.e. shipping lanes), special use airspace
Physical: bathymetry, wind speed, islands, shorelines

Cultural:
Environmental: EPA areas of concern

During the course of the grant period, other possible data layers were investigated, but were determined to be presently unavailable or incomplete (eg. shipwreck locations) for the Great Lakes. For example, the U.S. Fish and Wildlife Service has a number of ongoing projects which will produce, in the near future, data sets related to the use of offshore areas by birds and bats. NOAA GLERL has an ice map database that will be available soon. The LADST is designed to be able to incorporate these and other new data sets easily, so we anticipate being able to add such data sets soon after they become available.

2) **Develop a GIS-based tool to aid managers, developers, and the public to evaluate scenarios for windfarm siting in Great Lakes aquatic environments.**

The LADST online tool is a GIS-based tool, incorporated into a public web site, which allows anyone to perform this type of suitability analysis. Its main function is to produce suitability maps based on a list of user-supplied site-suitability criteria. For example, the user could define suitable areas as those that are at least six miles from shore, at least one mile from a shipping lane, at least half a mile from a known fish spawning site, outside of special use airspace and trout refuges, and shallower than 45 meters of water depth. Of course, the user is free to choose other distance thresholds or other criteria than these when using the tool. The resulting suitability map would display the U. S. waters of the Great Lakes using a continuous color scale from most suitable (dark blue) to least suitable (white) according to how many of the user's criteria were passed or failed at any given location. If a user supplies a weight value for each criterion, then the color shown at each location will be based upon the total weight of passed criteria divided by the total weight of all criteria. This basic form of Multi-Criteria Decision Analysis (MCDA) allows users to express the relative importance of some criteria with respect to others. Users can download their suitability maps in the KML file format, for sharing with other people or for further GIS analysis using other software.

3) **Disseminate project findings to managers, developers and the public.**

The LADST web site (http://glgis.org/ladst/) is the primary means of disseminating results to the all users, since the tool itself is a part of that web site, and it is open to the public. However, we also presented a poster at the September 2010 meeting of the Great Lakes Wind Collaborative, and we gave presentations about this project at the Coastal Zone 2011 national conference in July 2011, and as part of the Cooperative Institute for Limnology and Ecological Research seminar series through the National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory in September of 2011, and as part of the Great Lakes Wind Collaborative's 2012 webinar series on wind GIS tools in April 2012. At a Great Lakes Wind Collaborative workshop in August 2012, we worked with other regional wind stakeholders to develop a plan for the next generation of wind siting tools for the Great Lakes region, drawing upon the work done in this project as well as work done by other groups.

Activities:

Task 1. *Assess data needs for windfarm siting. :*

In assessing data needs, we were mostly guided by our past work with the Michigan Great Lakes Wind Council and our ongoing participation in the Great Lakes Wind Collaborative.

Many of the data sets that we needed for this new tool were the same as those used in our previous decision support tool, which was designed for Michigan's waters only.

Task 2. *Acquire data for aquatic physicochemical and biological habitats, temporal and spatial patterns of wind and animal migrations, and relevant political environmental data in the great Lakes region.*

We acquired data sets for airports, EPA areas of concern, fish spawning sites for several species, islands, national parks, national lakeshores, recommended course lines (i.e. shipping lanes), shorelines, special use airspace, trout refuges, water depth, and wind speed. The fish spawning site data set was updated by means of a literature review, followed by data entry from the publications found during that literature review. Most of the other data sets were obtained either from the Great Lakes GIS project hosted at the Institute for Fisheries Research, or by downloading data sets from the Internet, or by contacting the owners of other data sets. We were unable to acquire some data sets that we believed would be useful, such as the Important Bird Areas data set produced by the Audubon Society; that data set is maintained on a state-by-state basis, and we were not able to obtain the data and permission to use the data for every state. Other data sets, such as the data from ongoing U. S. Fish and Wildlife Service studies of birds' use of offshore Great Lakes Areas, are not yet available. We believe that our decision support tool is still very useful without such data, and that it will be able to incorporate such data when they do become available.

Task 3. *Prepare data for inclusion in the tool and create metadata for all spatial layers.*

Preparing data sets consisted of some manual work using the ArcGIS software package, as well as a series of processing steps that we automated using the Python programming language, and also the writing of metadata records. A significant amount of time during this project was spent designing and building the automated data processing scripts, because the design of these, together with the design of the suitability mapping program, is largely responsible for the speed and responsiveness of the online decision support tool. The responsiveness of the online tool, in turn, makes the system more accessible to novice users, and in particular, makes it easier to iteratively refine suitability criteria and ask "what-if" questions, because all of those things are much easier when suitability maps can be produced quickly.

Task 4. *Develop improved interface design and add sophistication to analysis.*

One of our first improvements to the data analysis was the addition of basic Multi-Criteria Decision Analysis (MCDA) in the form of user-controlled weighting of criteria. We evaluated some more complicated forms of MCDA, but decided that a simple weighting system was most appropriate for the very easy-to-use and highly responsive online tool that we wanted to build. Later in the project, we added two features to the online tool that allow users to save their work, one that allows users to save a web link (or "URL") to their set of suitability criteria, and another that allows users to save their suitability map in the form of a KMZ file. Both of these features effectively allow users to share their work with other people or post the result on a web site. A saved KMZ file also functions as a starting point for further GIS analysis using other software for users who have that capability. We believe that allowing users to save and share their work is very important because it gives users some assurance that they will get a tangible result from the time that they invest in building a suitability map.

Task 5. *Upgrade tool by modifying GUIs and scripts.*

The task of actually programming the tool probably took more time than any other task during this project. This programming consisted of designing and programming several parts. First, the server-side suitability mapping program and data pre-processing scripts were designed; these produce an image file showing the suitability map based on a set of suitability criteria expressed in a simple code, together with the pre-processed data sets. Next, the client-side program (which is a plug-in for the commercial ArcGIS Server Flex Viewer web application) was designed. The client-side program is designed to present an easy user interface for entering suitability criteria, encode the user's suitability criteria and send them to the server-side program, wait for a response, and then draw the resulting suitability map alongside base map layers and data overlays. These basic features, together with several more advanced features, were designed and built during this project. We believe that the resulting tool has reached a state where it will prove useful in practice.

Task 6. *Program the tool for the Internet*

A significant amount of the programming described for task 5 was specifically related to designing an Internet-based tool. In particular, issues such as choosing and setting up a web hosting service, writing secure programs, and remote maintenance and backups required special attention. Again, we believe that the tool has reached a useful state in these respects.

Products:

The main product of this research is the web site of the Lakebed Alteration Decision Support Tool, at http://glgis.org/ladst which includes the online suitability mapping system. The online tool uses a combination of custom-written software and a piece of commercial software called ArcGIS Server (produced by Esri, Inc.). The custom software written during this project includes a suitability mapping backend program that runs on the web server, a client program that provides the web site's graphical user interface in which the user create and view their suitability maps, and a number of pre-processing scripts that prepare the data to be used in the mapping system.

We formed collaborations with other members of the Great Lakes Wind Collaborative, which is resulting in use of our decision support tool as a foundation for a proposal to expand wind farm siting decision support for the Great Lakes. This proposal was presented to potential funders by our partners in the Great Lakes Wind Collaborative at their 5th annual meeting.

Computer Model: The LADST does not have a typical scientific model per se, in that it does not try to predict a feature that is directly observable; however, it can be considered a system for predicting the suitability of Great Lakes waters for various types of offshore development projects, and in this respect it has some of the features of a typical scientific model.

a. *Model description, key assumptions, version, source and intended use;*

The LADST models suitability according to user-defined suitability criteria, drawing upon a fixed pool of data sets. It uses a grid laid out over the U. S. waters of the Great Lakes, with each grid cell having 200 meters on a side. The LADST mapping system uses its internal data sets to decide whether each grid cell passes or fails each of the user's suitability criteria. For example, if the user specifies that cells must have water no deeper than 30 meters, the system

will judge cells to have passed or failed that criterion based upon the water depth data set, which specifies the average depth of the water in each cell. Likewise, if the user specifies that cells are suitable if they are at least six miles from shore, then the system will judge cells to have passed or failed that criterion based upon the shorelines data set, which specifies, for each cell, the distance between the centroid of that cell and the nearest point of the Great Lakes shoreline. An overall suitability score is calculated for each point using the pass/fail outcome of each criterion, together with user-assigned weight values for each criterion, which default to having equal value. One important caveat of this system is that the system is designed to be used as a screening tool for suitable areas; it is not a micro-siting tool, in which, for example, the placement of individual wind turbines might be decided. This is partly because the grid cell size is relatively large, at 200 meters, but that grid cell size, in turn, was chosen because several of the data sets are probably not accurate to a distance less than 200 meters. In general, users must consult the metadata for any of the data sets used to produce their suitability maps in order to make sure their intended interpretation is reasonable.

b. *Performance criteria for the model related to the intended use;*

The goal of this model is to provide a large-scale suitability screening process for offshore wind farm siting.

c. *Test results to demonstrate the model performance criteria were met (e.g., code verification/validation, sensitivity analyses, history matching with lab or field data);*

An older version of the LADST, which functioned only on the State of Michigan's waters of the Great Lakes, and was not an Internet application, was used by the Michigan Great Lakes Wind Council to select the most favorable "Wind Resource Areas" in Michigan's waters of the Great Lakes. Its suitability calculation and list of data sets were designed partly in consultation with the Michigan Great Lakes Wind Council. The new, online version of the LADST, which functions on all the U.S. waters of the Great Lakes, performs a similar calculation, albeit with the reduced number of data sets that we were able to obtain for the larger geographic extent. Also, the LADST's suitability calculation and data sets already offer most of the basic functions that were selected as important for the design of the next-generation of wind siting tools for the Great Lakes region at a recent workshop of the Great Lakes Wind Collaborative. As a result of the good match between the LADST's design and the goals expressed by the Michigan Great Lakes Wind Council and Great Lakes Wind Collaborative, we believe that the online LADST meets the criterion of being a well-designed suitability screening tool for offshore wind farm siting.

d. *Theory behind the model, expressed in non-mathematical terms;*

The theory behind this simple model is that a collection of criteria related to water depth, wind speed, distance from shore, distance from environmentally sensitive features, and distance from competing human uses of the water (e.g. shipping lanes) provides a good first set of screening criteria for siting wind farms.

e. *Mathematics to be used, including formulas and calculation methods;*

We calculate suitability score at each grid cell from the pass/fail status of each criterion at each grid cell, together with the user-specified weights of criteria like this:

S := the suitability score
w_i := the weight of the i^{th} criterion

$$S = \frac{\Sigma_{t \in passed\ criteria} w_t}{\Sigma_{t \in all\ criteria} w_t}$$

In words, the score equals the sum of the weights of the criteria that were passed (not failed) divided by the sum of the weights of all criteria. The score is therefore a real number between 0 and 1. This suitability score is displayed on the map using a color scale in which completely unsuitable grid cells are white, completely suitable grid cells are dark blue, and scores in between have a color in between white and dark blue.

f. *Whether or not the theory and mathematical algorithms were peer reviewed, and, if so, include a summary of theoretical strengths and weaknesses;*

This system was not peer-reviewed.

g. *Hardware requirements; and*

Users of the online LADST only need to have a broadband Internet connection and a web browser that includes the Adobe Flash Plug-In. The LADST is designed to be easily accessible even to users whose desktop computers are several years old.

In order for a web server administrator to host the LADST on their web server, a Windows computer is required, and that computer must meet the hardware requirements of the version of ArcGIS Server that they are using.

h. *Documentation (e.g., users guide, model code).*

During the course of this project, a documentation page for users was produced, and this is available on the LADST web site. A copy of that documentation page has been added as an appendix to this report. A manual for web server administrators who want to host the LADST also was written.

Appendix: Instructions for Using the LADST

1. To begin using the LADST, open either **the State of Michigan Decision Support Tool** or the **the Great-Lakes-wide Decision Support Tool** in a web browser. (These links will open the LADST in a new web browser window.) We recommend that you make your web browser maximized or full-screen in order to get the best possible view of the LADST's maps.

2. After the LADST loads in your web browser, you will be presented with a basic map of the Great Lakes, and a gray window on the left labeled "Suitability Mapping". You can zoom the map in and out by clicking on the vertical gray bar in the upper-left corner of the map, or by using the wheel on your mouse. You can pan the map around by clicking on the map and dragging left, or right, or up, or down. To get a better view of the map, you can close the "Suitability Mapping" window by clicking the "X" in its upper-right corner. You can bring back that same window by clicking the button at the top of the screen labeled "Suitability Mapping." There is also a "Data Overlays" window that you can open by clicking the "Data Overlays" button at the top of the screen. Finally, in the upper-right-hand corner of the screen, you can find a link that says "Help", which contains some basic information and a link back to the online documentation page.

3. To begin making a suitability map, first, open the "Suitability Mapping" window if it is not already open, by clicking the "Suitability Mapping" button at the top of the screen.

4. On the "Suitability Mapping" window, click the button labeled "Choose Data Sets" at the top of the window, if it is not already selected.

5. You should see a list of names of data sets (such as "Fish Spawning Sites") with gray square check-boxes next to their names. On the right side of the "Suitability Mapping" window, you should see a gray vertical bar that you can click and drag up and down in order to scroll through the list of data sets.

6. Now, choose some data sets to use in making your suitability map. For example, imagine that you are trying to choose a good site for an offshore wind farm. You might think that a *very basic* set of criteria would say that wind turbines should be at least six miles away from the shore, so that they do not disturb views of the Lakes or the environmentally sensitive areas near the shore, and should be in waters that are no deeper than 30 meters, so that it is not too expensive to construct and install the turbines. (These are only an example, however; you may choose whatever suitability criteria you wish.) If you wanted to use those criteria, you would click on the check-boxes next to "Shorelines" and "Water Depth", but you may choose any or all of the data sets that you think are appropriate. To find out more information about a data set, click on the word "(info)" next to its name.

7. Next, click the button labeled "Set Criteria" at the top of the "Suitability Mapping" window.

8. On the "Set Criteria" page, you are presented with a list of controls for designing suitability criteria based upon the information in the data sets you've just chosen. There are three types of controls for constructing the three types of criteria that the LADST knows about: (1) buffer zone criteria, (2) variable criteria, and (3) categorical criteria. Each data set is pre-assigned to one of those three types of criteria, because it would only make sense to use that data set to construct a criterion of that type.

    - Buffer Zone Criteria: Most data sets are assigned to this type of criterion. These are used to create a protective "buffer zone" around some type of environmentally sensitive feature or competing human use of the water. You specify a distance in miles, thereby excluding development projects from waters that are less than that distance away from that feature. For example, if you chose the "Shorelines" data set, you can type in a distance of 9 miles here if you want to exclude development projects from the area within 9 miles of the shoreline. You may specify whatever distances you wish for buffer zones around the feature types you chose.

    - Variable Criteria: The "Water Depth" data set is a good example of this type of data set. For this type of criterion, there is some value (such as depth) that has a numerical value at each point in the Great Lakes. You can specify that areas are suitable for development if that numerical value is below some threshold, or above a different threshold, or both. Below the name of your chosen data set (such as "Water Depth"), you should see two boxes, labeled with the words "at most" and "at least". If you want to specify that your project should be in waters no deeper than 60 meters, you would type the number 60 into the "at most" box. If you want to specify that 10 meters would be too shallow, you could type 10 into the "at least" box. You may leave either of the boxes blank if you wish.

    - Categorical Criteria: The "Bottom Type" data set uses this type of criterion. In this case, you are presented with a list of categories, representing, for example, that the lake bottom is of a certain type, such as sand, clay, or mud. You can click on those category names to highlight them in blue, or click them again to un-highlight them. Whichever categories you think are suitable for your project, you should leave highlighted. For example, if you think that hard-bottom substrates (which includes bedrock) or a clay makes a location suitable for your project, you should click on "hard" and "clay" to highlight those names in blue.

9. Once you are happy with your criteria, click on the button labeled "View Results" at the top of the "Suitability Mapping" window. After a few seconds, a blue-and-white suitability map should appear in the waters of the Great Lakes.

10. To interpret this map, consult the band of color at the top of the "Suitability Mapping" window, which goes from grayish-white to blue. Areas shown in dark blue are the ones that passed most or all of your criteria. The darkest blue areas are the ones that you are probably most interested in, as they faired best according to your criteria. Areas shown in lighter colors failed some of your criteria. If you have many different criteria, then there

may be many gradations of color between blue and white on your map. The more dark and blue an area is, the more criteria it passed, and likewise the more white an area is, the more criteria it failed. (Note: Presently, the waters of Canada are excluded from the LADST's analysis, and will always appear white.) Remember that you can still zoom in and out and pan the map around in order to get a better view of your suitability map.

11. If you have a lot of criteria, then your suitability map is showing you a lot of information at once, and you might not be certain exactly why any given location was assigned a certain color. To see what's happening at any given location on the suitability map, just click the mouse on that location. In the "Suitability Mapping" window (if it's still on the "View Results" page), you'll see a table of your criteria along with the words "PASS" or "FAIL". This tells you whether your chosen point passed or failed each of your criteria, and it therefore explains the reason that that point was assigned its color.

12. At any time, you may revisit the "Choose Data Sets" or "Set Criteria" pages of the "Suitability Mapping" window by clicking those buttons at the top of the "Suitability Mapping" window. Change any of the settings there as you like. When you want to create a suitability map based on your new settings, just click "View Results" again to update the map. *Note: The map will not update until you click on "View Results" again after having changed some settings.*

13. To see where your locations of interest are in comparison with other features or landmarks, you can bring up data overlays. To begin, click the "Data Overlays" button at the very top of the LADST screen.

14. On the "Data Overlays" window, you are presented with a list of data overlay names with gray square check-boxes to the left of them. Click on any check-box to bring up the named data overlay. Note that the data overlay may take a few seconds to appear. On the "Data Overlays" window, you will see a representation of what that data overlay will look like in the map view. (That is, you will see a map legend for that data overlay.) For most of the data overlays, such as "Federal Lands", you can click on each feature in the map view, such as the various green patches representing national forests, to get more information about that particular feature.

Advanced Features

1. You can access several advanced features by clicking on the "More" tab at the top of the suitability mapping window. First of all, you will find a checkbox that says "Allow weighting of criteria". When you check this box and then return to the "Set Criteria" page, you will see that some new controls have been added. You should see slider controls, which you can drag to the left or right using the mouse. These allow you to set the weight, or importance, of each of your criteria. After changing the weights, you can calculate a new suitability map by clicking on "View Results". The criteria with higher weights will have a stronger influence on the suitability map color. So, for example, if you have a lot of criteria, but you believe that your "distance from shore" and "water depth" criteria are much more important than the others, you can give those two criteria

higher weights so that they stand out from the other criteria instead of getting lost in the mix.

2. A second advanced feature can be found on the "More" page of the Suitability Mapping window. This one allows you to save your suitability map so that you can return to it later, or share it with other people. To use this feature, first create your suitability map as described above, and then click on the "Generate Link (and copy to clipboard)" button in the middle of the "More" page. This will generate a URL, or web link, in the box below the button. You can copy and paste this link anywhere; for example, you can put it in a web page, an e-mail, or any other sort of document. When someone visits your web link, they will be taken to the Lakebed Alteration Decision Support Tool web site, and, after a few moments, the tool will automatically load up your suitability criteria and map. In this way, you can easily save your results and observations and share them with other people. Please note that your generated web link will only store your criteria as they were at the moment you clicked the "Generate Link" button. If you update your criteria later and you want to share the updated suitability map, you will have to generate a new link and share it.

3. Finally, at the bottom of the "More" page of the Suitability Mapping window, you can find a feature that lets you export your suitability map for use in other software. If you click the "Download Google Earth KMZ File" button, you will be able to download your suitability map as a file in the KMZ file format, which is compatible with many computer mapping programs. When you click this button, you may have to wait a short time for your file to be produced. Within many pieces of software, such as Google Earth, you may be able to click on different regions of your suitability map to see the suitability level at any given region, along with a web link that, if clicked, will take you back to the LADST web site and re-load the mapping scenario that you used to generate the KMZ file.