LAKE PUCKAWAY AND TERRELL'S ISLAND
ANALYSIS OF WIND FETCH AND PROBABILTY OF WAVE GENERATED SEDIMENT SUSPENSION

1. BACKGROUND

Lake Puckaway and Terrell's Island are shallow lakes located in central Wisconsin. They once supported abundant beds of aquatic vegetation which provided habitat for macroinvertebrates, fish, waterfowl, and other wildlife. However, both locations have experienced a significant loss in aquatic vegetation which led to the collapse of fish and wildlife communities dependent on this habitat. The Wisconsin Department of Natural Resources (WDNR) studied the lakes and determined that turbidity caused by algal blooms, bottom feeding fish, and wave generated sediment suspension were the main drivers in leading to degradation in the lakes.

Wind fetch is defined as the unobstructed distance that wind can travel over water in a constant direction. Fetch is an important characteristic of open water because longer fetches can result in larger wind-generated waves. The larger waves, in turn, can increase shoreline erosion and sediment resuspension.

Figure 1. Water collected at the upstream end of Lake Puckaway to the downstream end, from left to right.

The WDNR requested support from the U.S. Army Corps of Engineers - Detroit District (USACE) through the Planning Assistance to the States Program to provide wind fetch and sediment suspension modeling for Lake Puckaway and Terrell's Island. Initial modeling provided information on the locations and intensity of impacts caused by wind and wave action at the sites. The WDNR used this information to explore various management actions, including the construction of islands to break up wind fetch and reduce wave-generated sediment suspension. Several island alignments were modeled to examine their effectiveness in reducing wind fetch and sediment suspension. This report documents the processes used and the results of these modeling efforts.

1.1 TOOLS

The USACE and the Upper Midwest Environmental Sciences Center (UMESC) of the U.S. Geological Survey (USGS) have developed a series of geospatial tools able to model wind fetch and several other variables used to predict the probability of wave-generated sediment suspension (Rohweder et al. 2008). This series of models has been used successfully on several Upper Mississippi River Restoration Program projects to design islands and compare the effectiveness of different alignments.

1.2 DATA

Raster layers of land/water and bathymetry are required spatial inputs to run the models. In addition, wind data is needed to create weighted values based on actual conditions experienced in the field.

1.2.1 LAND/WATER

Raster layers depicting areas of land and water were created for each location to allow for the calculation of wind fetch from all directions. Land and water were delineated using aerial images in ArcMap 10.3.1 (Figure 2 & Figure 3). The polygons were then converted to a raster with binary values of 1 (land) or 0 (water).

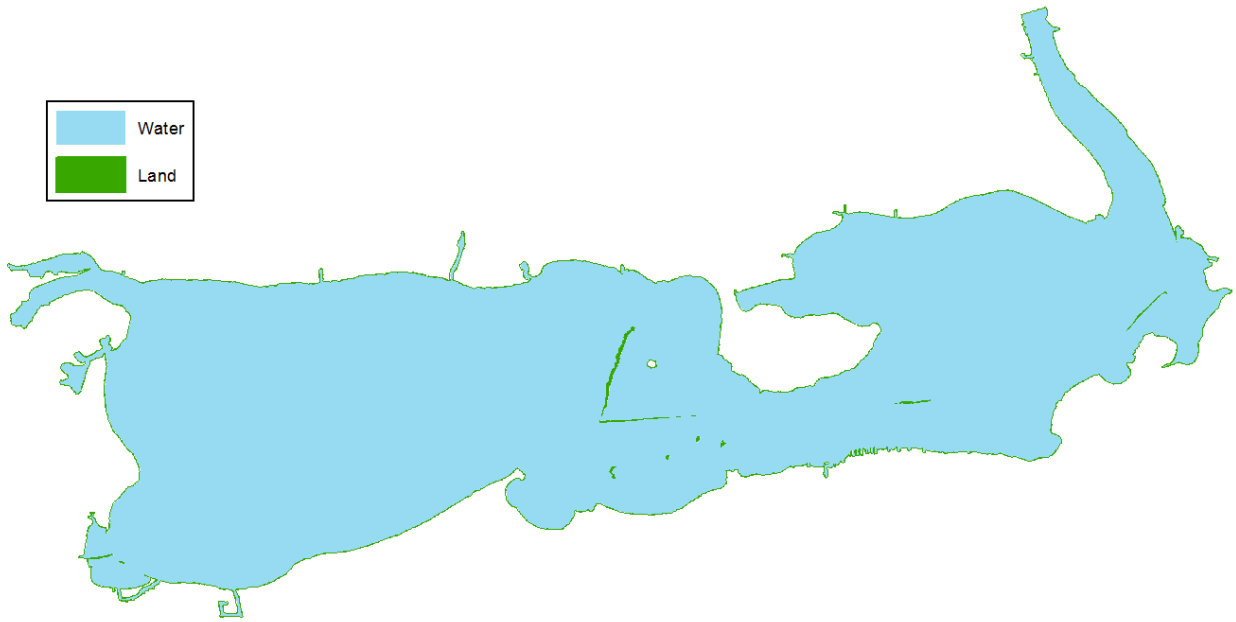

Figure 2. The land/water layer used in the models for Lake Puckaway.

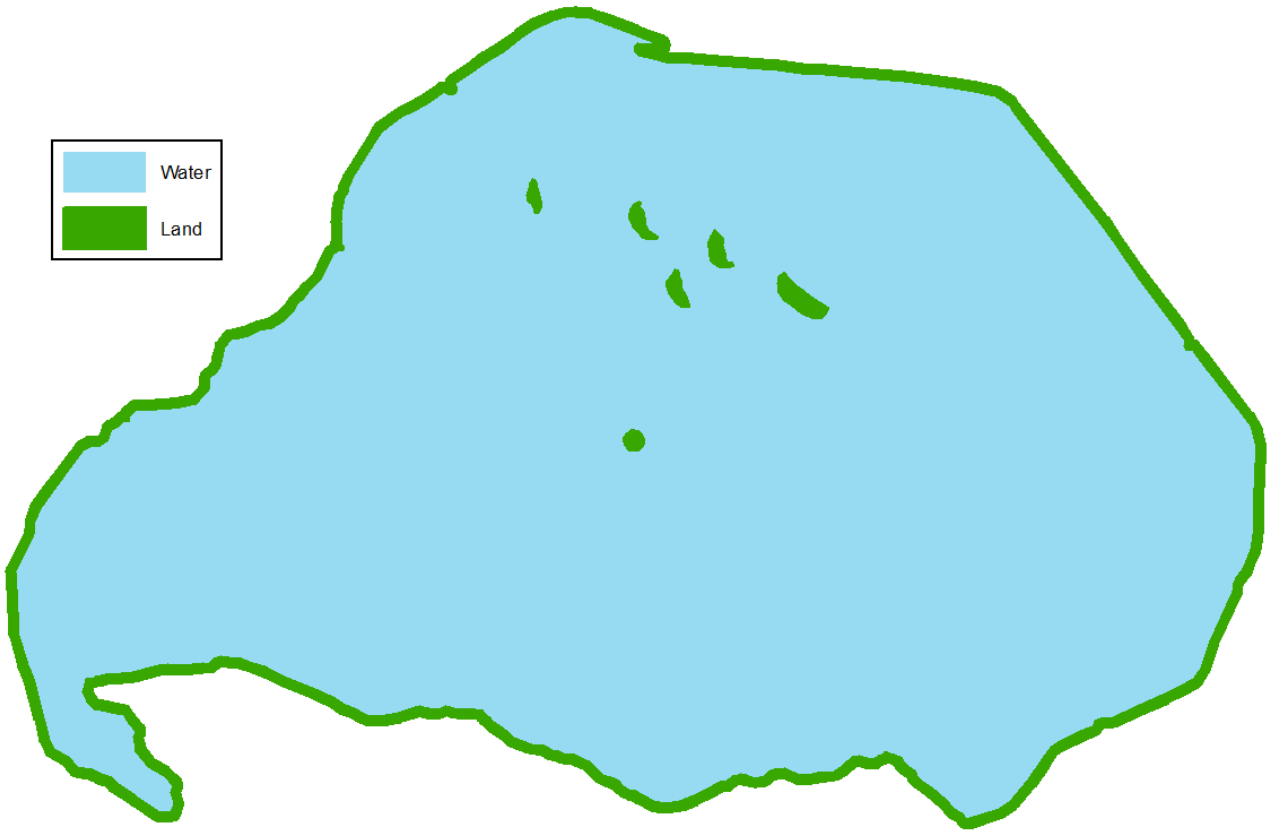

Figure 3. The land/water layer used for Terrell's Island.

1.2.2 WIND

Wind data is used to determine the directional frequency as well as the intensity. The nearest source of acceptable wind data for both Lake Puckaway and Terrell's Island was the Fond du Lac County Airport (Station WBAN:04840). This data was downloaded from the National Oceanic and Atmospheric Administration (NOAA) Local Climatological Data and was formatted to be input into the models (Attachment 1). The data used consisted of the maximum daily sustained (2-min) wind speed and direction from April – July 2012 to 2016. April – July was the chosen timeframe as these are the most critical months for the establishment and growth of most aquatic vegetation in the region.

The wind data collected at the Fond du Lac County Airport revealed that the most prominent wind directions are from the SE (150°; relative to a northing value of 0°), NE (30°), SW (190°), and the NW (300°) with frequencies of 7.4, 7.2, 4.9, and 4.9 percent, respectively (Figure 4).

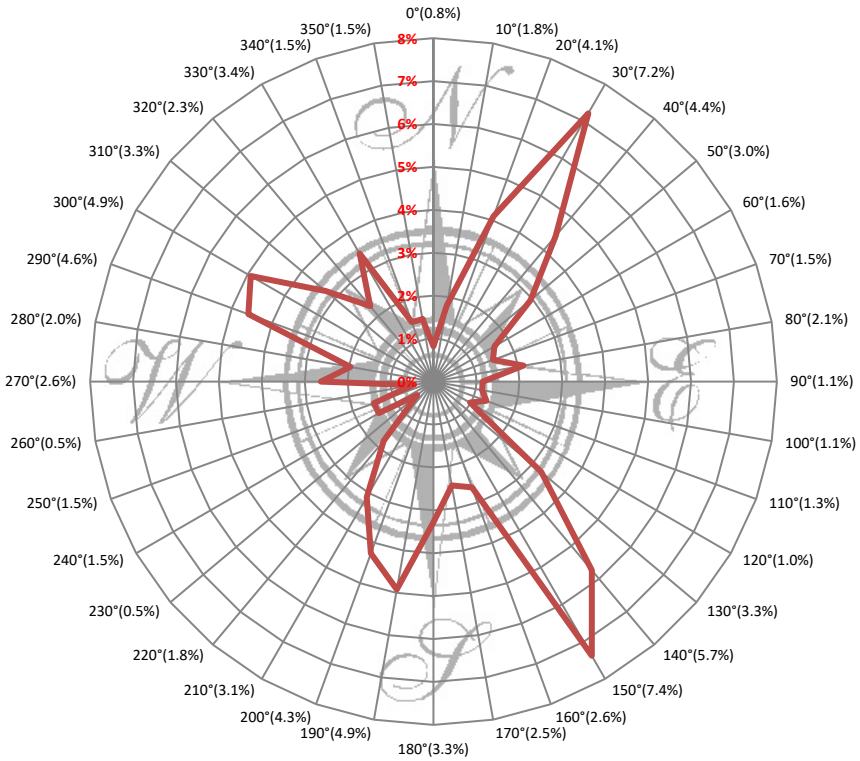

Figure 4. Wind rose displaying the frequency for which top daily sustained wind speeds were recorded at the Fond du Lac County Airport (April-July, 2012-2016).

1.2.3 BATHYMETRY

Lake Puckaway Bathymetry

A bathymetric layer for Lake Puckaway was developed using depth readings collected by Onterra LLC. The depth readings had been collected in the summer of 2015 and the spring of 2016 and had been adjusted to a surface water elevation of 764.375 MSL. Each data point consisted of a depth reading and was accompanied by the corresponding lat/long coordinates. The data points were imported into ArcGIS. Spacing between points were approximately 24-27.5 feet apart.

Several points from the readings taken in the summer of 2015 and in the spring of 2016 overlapped and were used to check consistency between the layers. Points within 24 feet of one another were compared between the datasets. Despite being adjusted to the same surface elevation, the data from the spring of 2016 was on average 0.56 feet deeper than the corresponding points collected in the summer of 2015. Resource managers familiar with the area indicated that the 2016 data appeared to overestimate depth. Therefore 0.56 feet was subtracted from the 2016 data points to allow for a more seamless combination of the data sets. A triangulated irregular network (TIN) dataset was created from the points. Linear interpolation was then used to create 5-meter continuous bathymetry of the study area.

The bathymetric layer produced was sent to WDNR resource managers for review. At the WDNR's request, alterations were made to decrease the overall lake depth and to include historic dredge spoil berms that failed to show up on the map of Lake Puckaway. Points were adjusted to include the dredge spoil berm at a depth of 2.5 feet.

Water surface elevation readings taken at the Fish Camp gage were used to examine the seasonal fluctuation of lake stage for Lake Puckaway and chose a level appropriate for running the models. Available readings were from 2009 to 2016 (Figure 5). The average annual lake elevation in April appeared to be close to that for which the lake depth points had been adjusted (764.375 MSL); however, lake elevations drop by approximately 1.5 feet during the growing season. A bathymetric layer reflective of these mid-summer conditions was used in this analysis, as shallower water is more sensitive to sediment suspension.

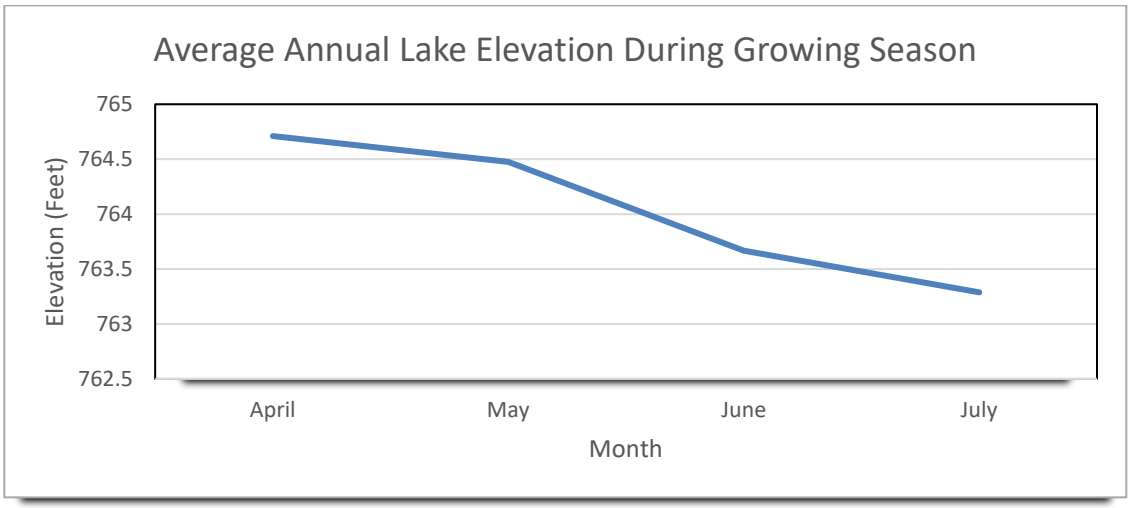

Figure 5. Average annual water surface elevations at the Fish Camp gage on Lake Puckaway (2009 – 2016).

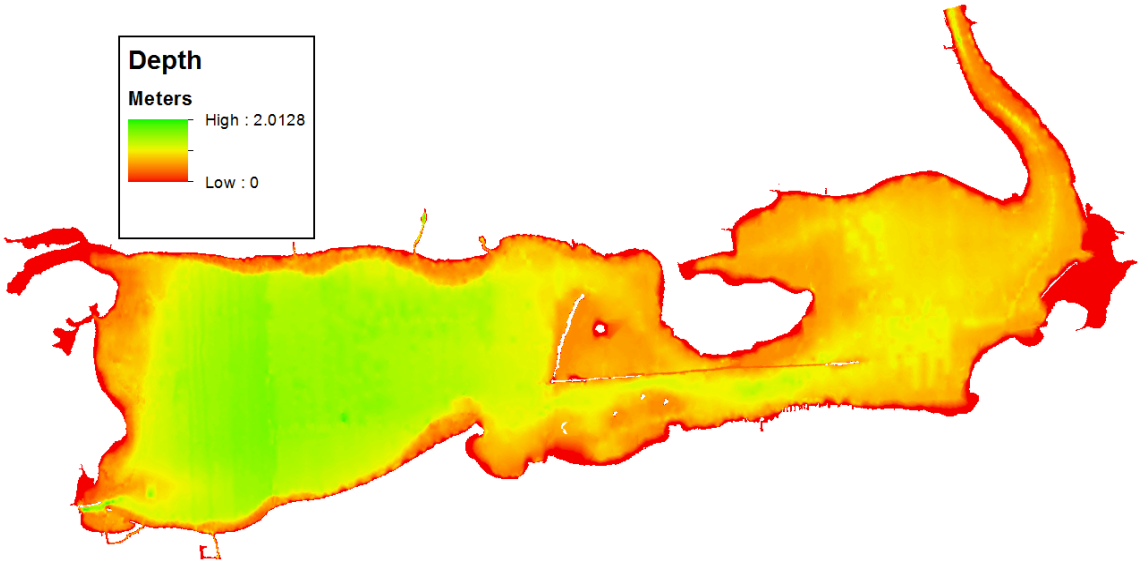

Figure 6. Lake Puckaway bathymetry used in the modeling.

Terrell's Island Bathymetry

The bathymetry for Terrell's Island was obtained from the offices of Green Lake County, WI. Personnel at Green Lake County had generated the bathymetry from data points collected for the USACE in June/July of 2015. Data points were interpolated into a DEM with 100-foot resolution using a Kriging method. Note that the adjustments discussed in the previous paragraphs resulted in depths at or below zero feet in several areas around the periphery of the map and are not reflective of actual conditions.

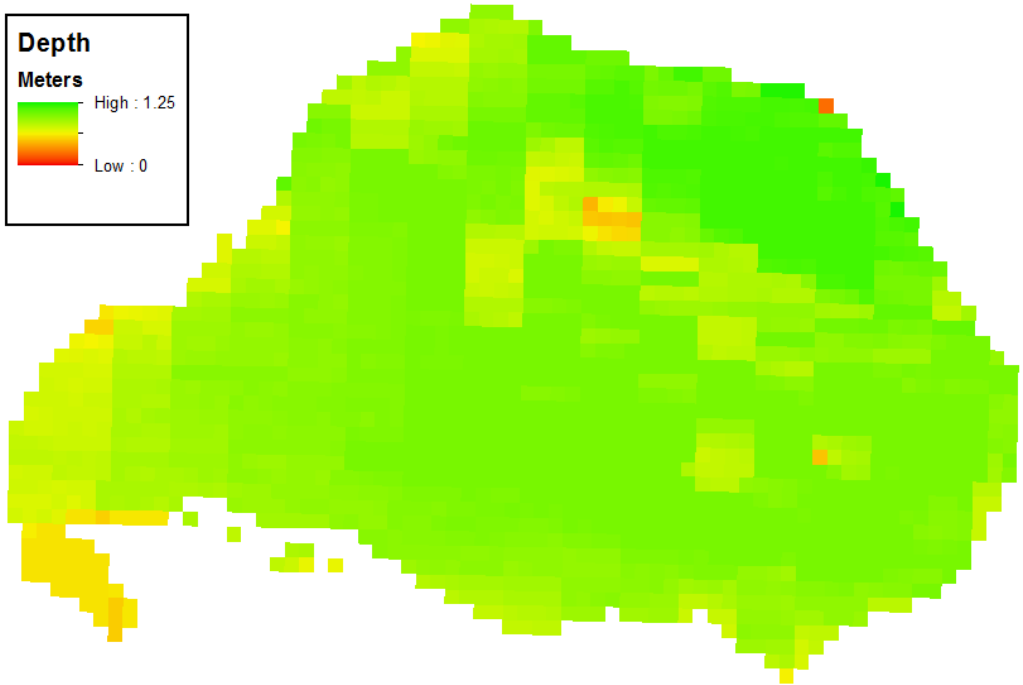

Figure 7. Terrell's Island bathymetry used in the modeling.

1.2.1 WIND FETCH MODEL

Figure 8. An example of how the SPM method is used to calculate the fetch of a single radial. Figure courtesy of Rohweder et al. 2008.

Wind fetches were calculated using a procedure recommended in the Shore Protection Manual (SPM) (USACE 1984). The SPM method is more likely to accurately represent real-world conditions than straight-line wind fetch. The SPM method uses the average of nine radials spread three degrees apart to calculate the fetch of a single, central radial (Figure 8).

Wind fetches were calculated for the project areas at 10 degree increments through 360 degrees (10°, 20°, 30°, etc.) and recorded in the form of raster layers. Rasters for each 10 degree increment were available to compare the fetches from each direction; however, comparing individual fetches is a tedious task and fails to take into account the frequency for which wind originates in each direction. Therefore, a weighted wind fetch was created to look at the cumulative average seasonal fetch experienced.

To create the weighted wind fetch a list of the wind direction along with the frequency of daily predominance was generated. Each raster created at the 10 degree increments was multiplied by the corresponding frequency and combined with the others to produce the weighted wind fetch.

1.2.2 SEDIMENT SUSPENSION PROBABILITY

The suspension of sediment varies based on a number of factors, including but not limited to, depth, substrate composition, and wave energy. The maximum orbital wave velocity (MOWV) to suspend sediments can be adjusted in the wave model based on the substrate. For Lake Puckaway and Terrell's Island, a MOWV of 0.1 meters per second was used to represent the velocities required to suspend fine unconsolidated sediments (Håkanson and Jansson 1983).

2. RESULTS

The primary results from the modeling efforts are raster layers with cell values corresponding to weighted wind fetch and the probability of sediment suspension. A number of figures have been created to display the results described in the following sections (Attachment 2). The results section of this report provides a qualitative description of the modeling results. Additional quantification could be calculated from the raster layers in the future if specific questions are presented.

2.1 LAKE PUCKAWAY

The weighted wind fetch and sediment suspension models were initially run for the existing conditions at Lake Puckaway to identify locations experiencing the greatest amount of disturbance in the study area. Several alternative island designs were considered to assist in breaking up wind fetch and reducing sediment suspension on Lake Puckaway (Attachment 2-1). Recreational concerns from the lakes stakeholders influenced the WDNR's decision to limit island construction to the eastern lake basin.

Since model runs require extensive processing it was determined that a select few design alternatives could be completed to sufficiently capture the impacts of islands at different locations. Alternatives 1, 2, and 5b were chosen for modeling. Alternative 1 included three small islands north of the "haystack islands" running north-south in the middle of the lake and the addition of material to the historic dredge spoil banks on the eastern end of the lake and just north of Marquette, WI. The three islands were offset from one another with approximately 150 feet between each island. Alternative 2 also includes the addition of material on the historic dredge banks but further extends the islands eastward from Marquette approximately half a mile. In addition, Alternative 2 includes three small islands to break up wind fetch between Marquette and the dredge bank. Alternative 5b consists of all features included in Alternative 1 with the addition of two rows of offset islands (six in each row; twelve total) spanning the eastern basin from southwest to northeast. The spacing between islands was approximately 400 feet within the same row and 300 feet between the islands in alternate rows.

2.1.1 LAKE PUCKAWAY WEIGHTED WIND FETCH

The open basins on the western and eastern ends of the lake showed the greatest values for weighted wind fetch under the existing conditions (Attachment 2-2). The central areas of these open basins are unable to block wind from any direction and therefore had the highest fetches, as expected. Alternative 1 resulted in a moderate wind fetch decrease around the historic dredge bank and slight, localized decreases near all other features. Alternative 2 provided moderate to high localized decreases south of the spoil bank and east of Marquette. The wind fetch for Alternative 5b significantly reduced the wind fetch in the eastern basin. The remaining portion of the study area was similar to the fetch observed in Alternative 1.

2.1.2 LAKE PUCKAWAY SEDIMENT SUSPENSION

Due to the shallow nature of Lake Puckaway, the probability of sediment suspension appears to be near or in excess of fifty percent for much of the study area with the existing conditions (Attachment 2-3). One particular area of high suspension probability is just east of the central peninsula. The high wind fetch and shallow depths of this area have resulted in a pocket with probabilities greater than 75 percent. The results of Alternative 1 appear to have little influence on reducing sediment suspension. The reduction in wind fetch for this area may have a lesser impact on sediment suspension relative to other areas due to slightly deeper water. Alternative 2

provides moderate reductions in the probability of sediment suspension east of Marquette. Alternative 5b has a moderate to high level of influence on reducing sediment suspension for a large area.

2.2 TERRELL'S ISLAND

2.2.1 TERRELL'S ISLAND WEIGHTED WIND FETCH

The weighted wind fetch of Terrell's Island was greatest in the south-central for the existing conditions (Attachment 3-1). This portion of the lake does not have any islands and is exposed from all directions. The cluster of five islands in the northern portion of the complex appear to significantly decrease wind fetch. In addition, interest had been given to removing all but one of the islands and that scenario was modeled as well.

2.2.2 TERRELL'S ISLAND SEDIMENT SUSPENSION

The probability of sediment suspension was modeled for the existing conditions and the scenario with the removal of islands at Terrell's Island (Attachment 3-2). The results show that sediment suspension has the greatest probability in the southeastern portion of the lake. However, the highest probability of sediment suspension was relatively low at just under 43 percent of the days evaluated. Upon review of the existing probability of sediment suspension the WDNR did not see sediment suspension as a primary cause of degradation in the lake; therefore, the modeling of island designs to break up wind fetch was not pursued further. The removal of the islands resulted in slightly higher sediment suspension throughout the area.

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Håkanson, L., and Jansson, M. 1983. Principles of lake sedimentology. Second edition. The Blackburn Press, New Jersey, 316 p.

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Research and Applications, v. 23, no. 3, p. 343-349.

Rohweder, J., J. Rogala, B. Johnson, D. Anderson, S. Clark, F. Chamberlin, D. Potter and K. Runyon. 2012. Application of wind fetch and wave models for Habitat Rehabilitation and Enhancement Projects – 2012 Update. Contract report prepared for the U.S. Army Corps of Engineers' Upper Mississippi River Restoration – Environmental Management Program.

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USACE. 2012. Upper Mississippi River Restoration - Environmental Management Program Environmental Design Handbook. U.S. Army Corps of Engineers.

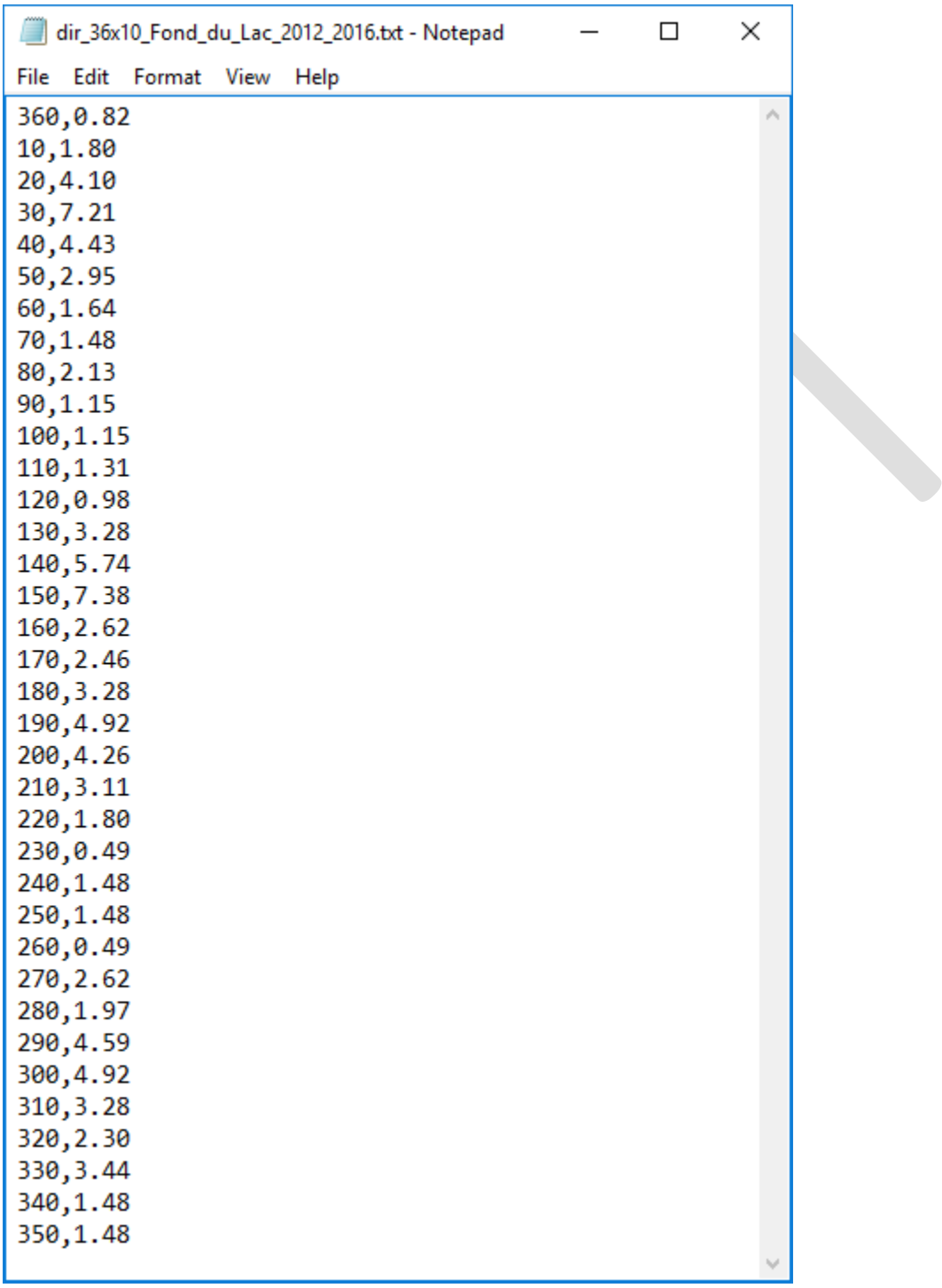
Attachments

Attachment 1

Wind Data

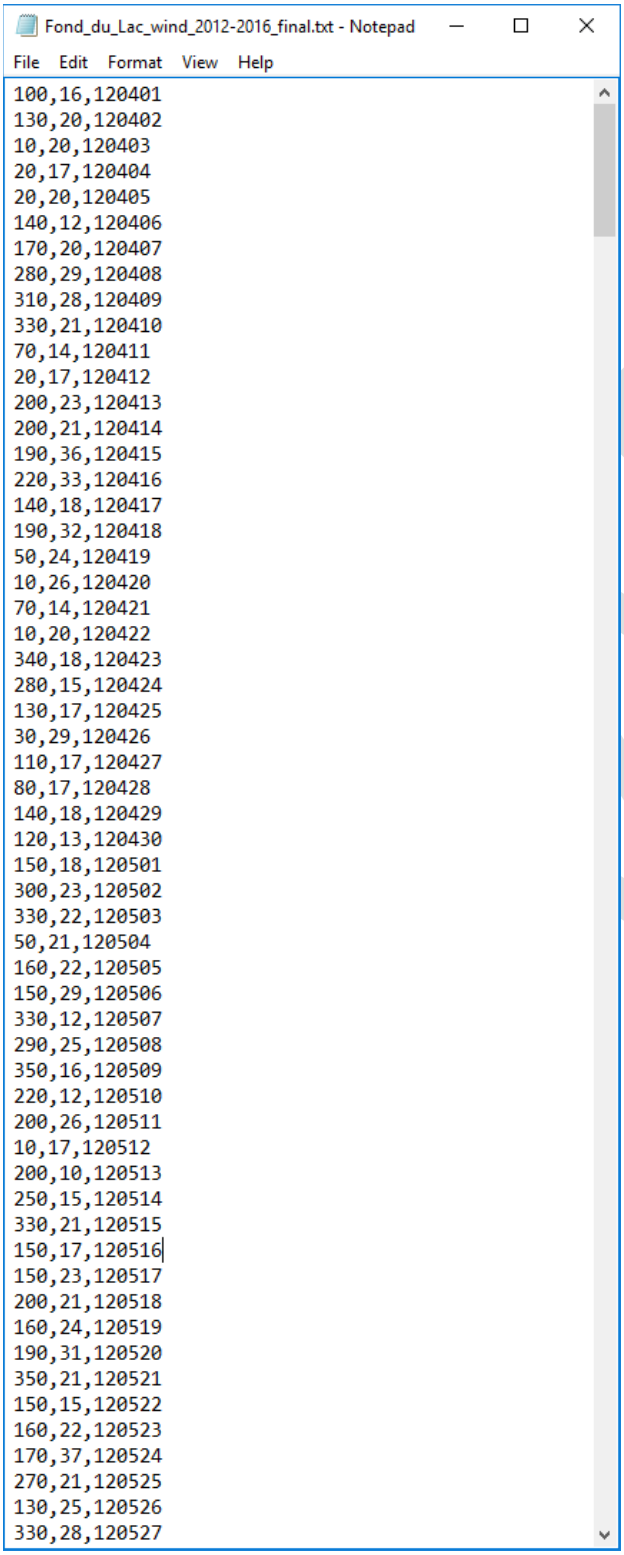
Attachment 1-1: Wind frequency list

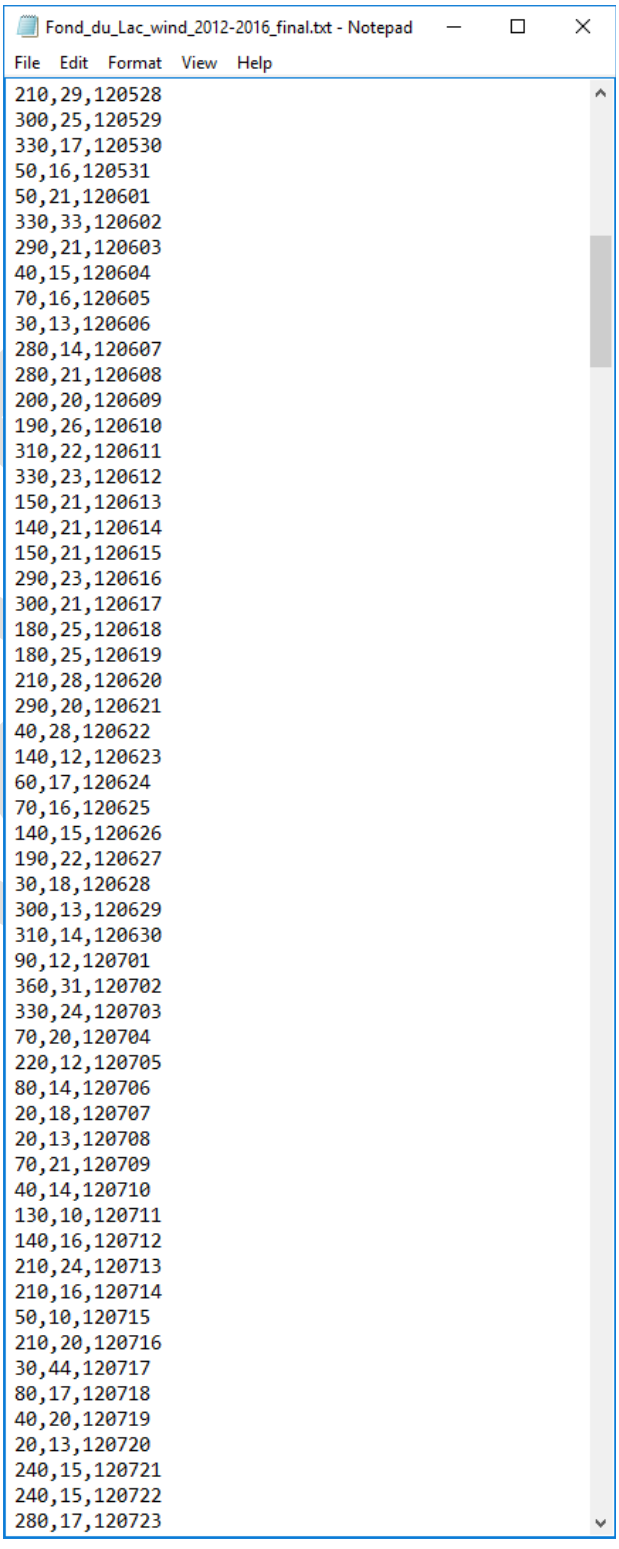
Copy of the .txt file used to calculate weighted wind fetch. Numbers represent the wind direction and the frequency in which the maximum 2-min wind speed originated from each. Data was collected at the Fond du Lac County Airport (April-July, 2012-2016).



Attachment 1-2: Daily wind frequency and intensity

Copy of the .txt file used to calculate the likelihood of wind-generated sediment suspension in April – July from 2012- 2016. Data was collected at the Fond du Lac County Airport. Format: Origin of Maximum 2-min Sustained Wind Speed, Maximum 2-min Sustained Wind Speed, Date.





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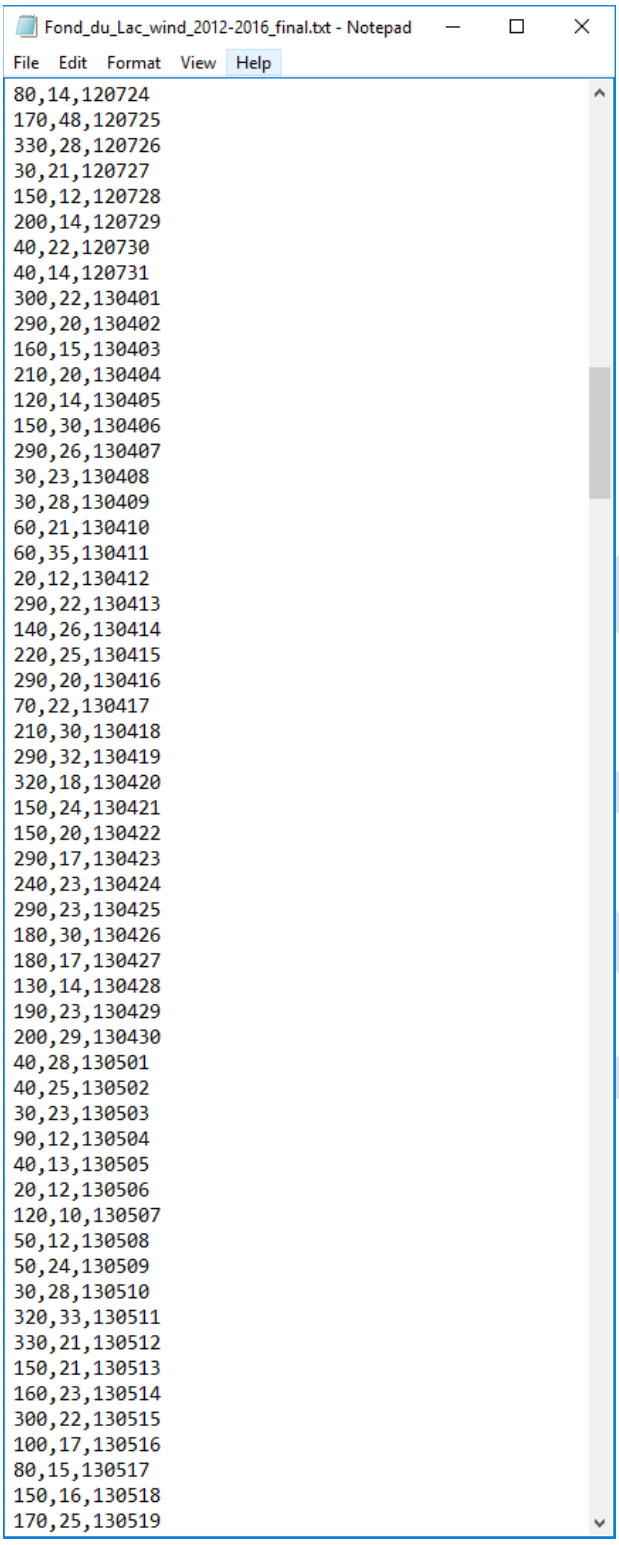

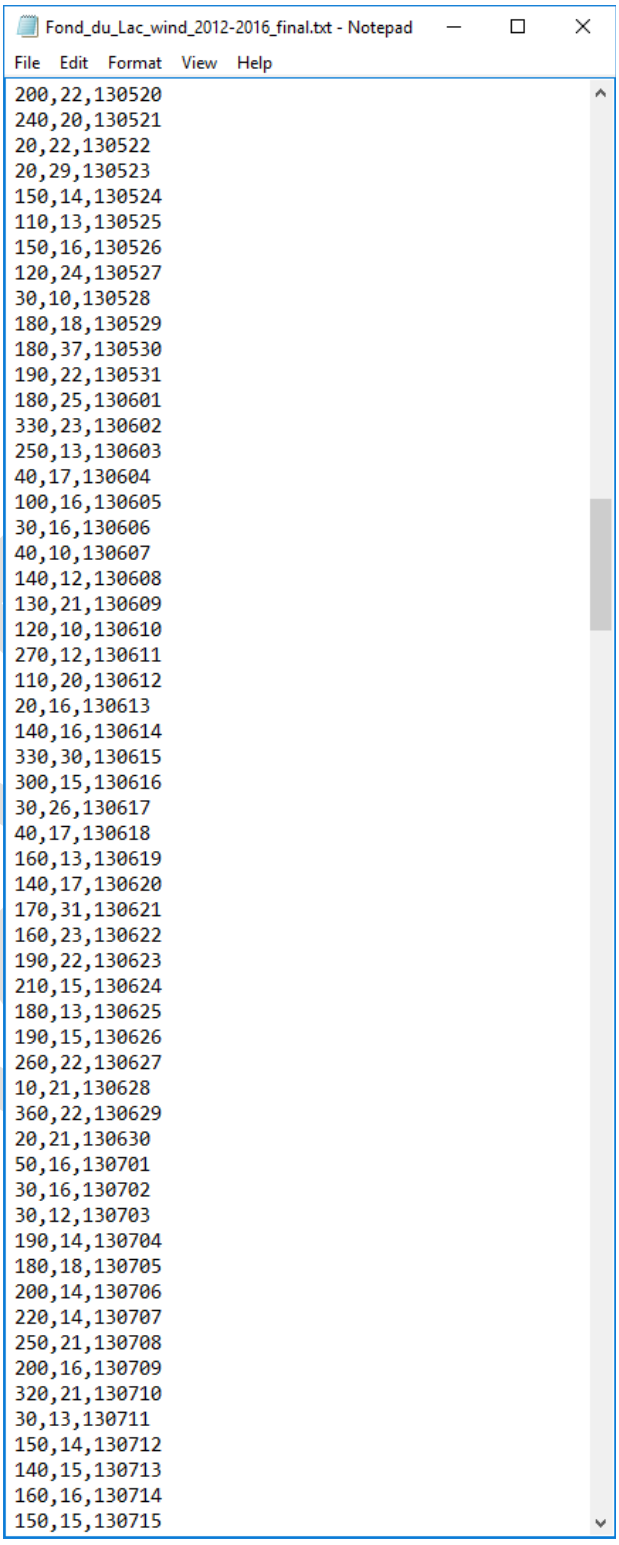

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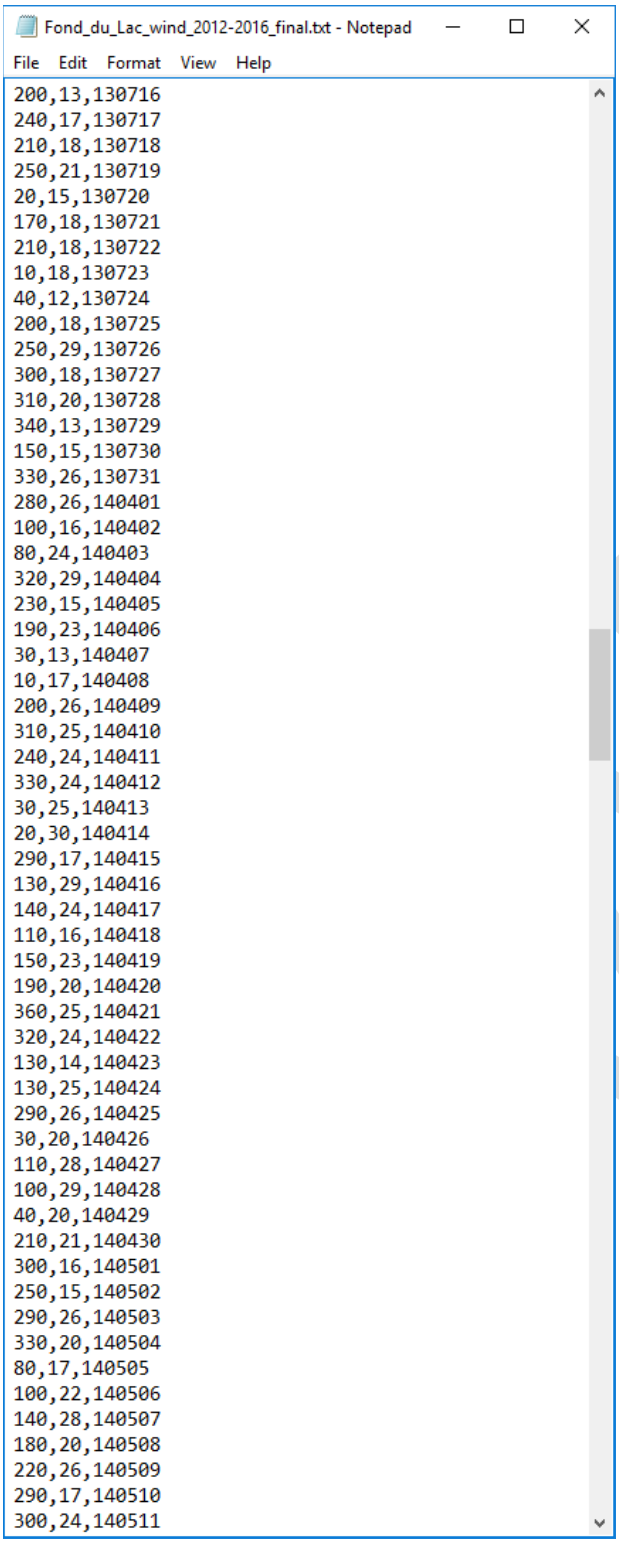

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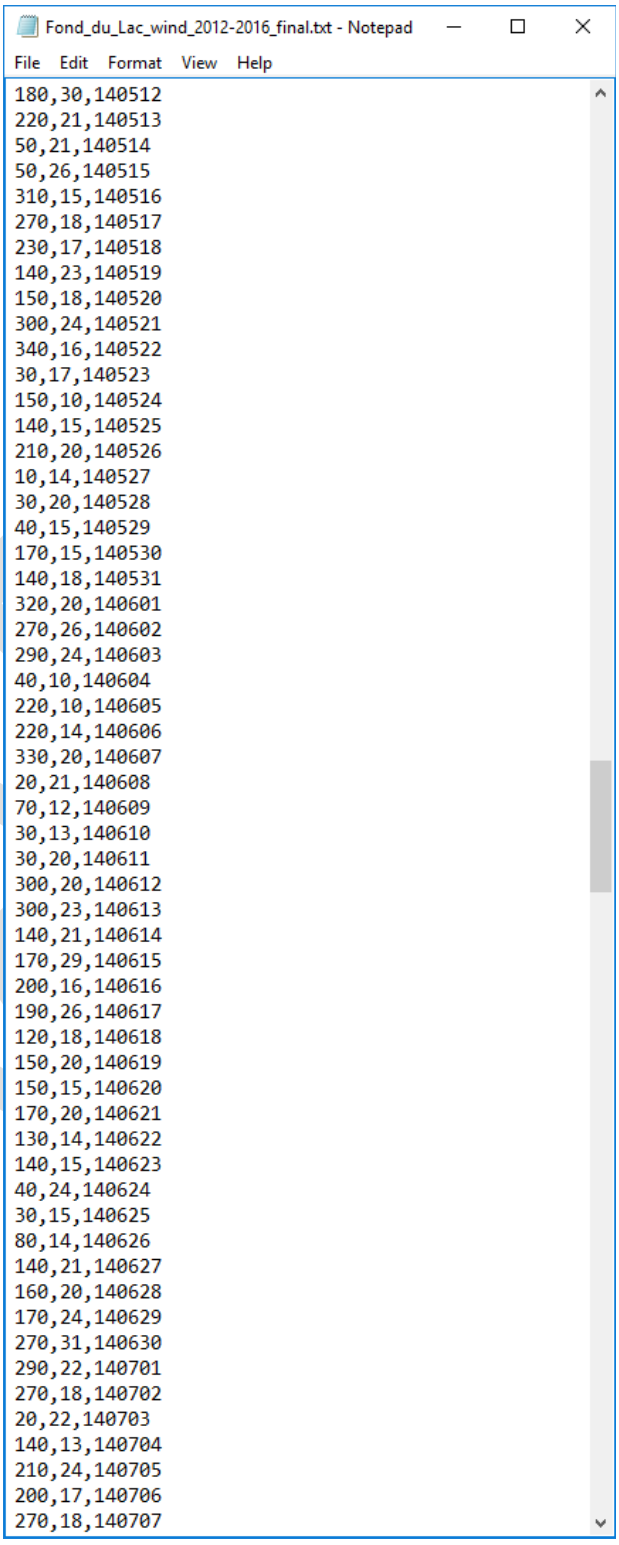

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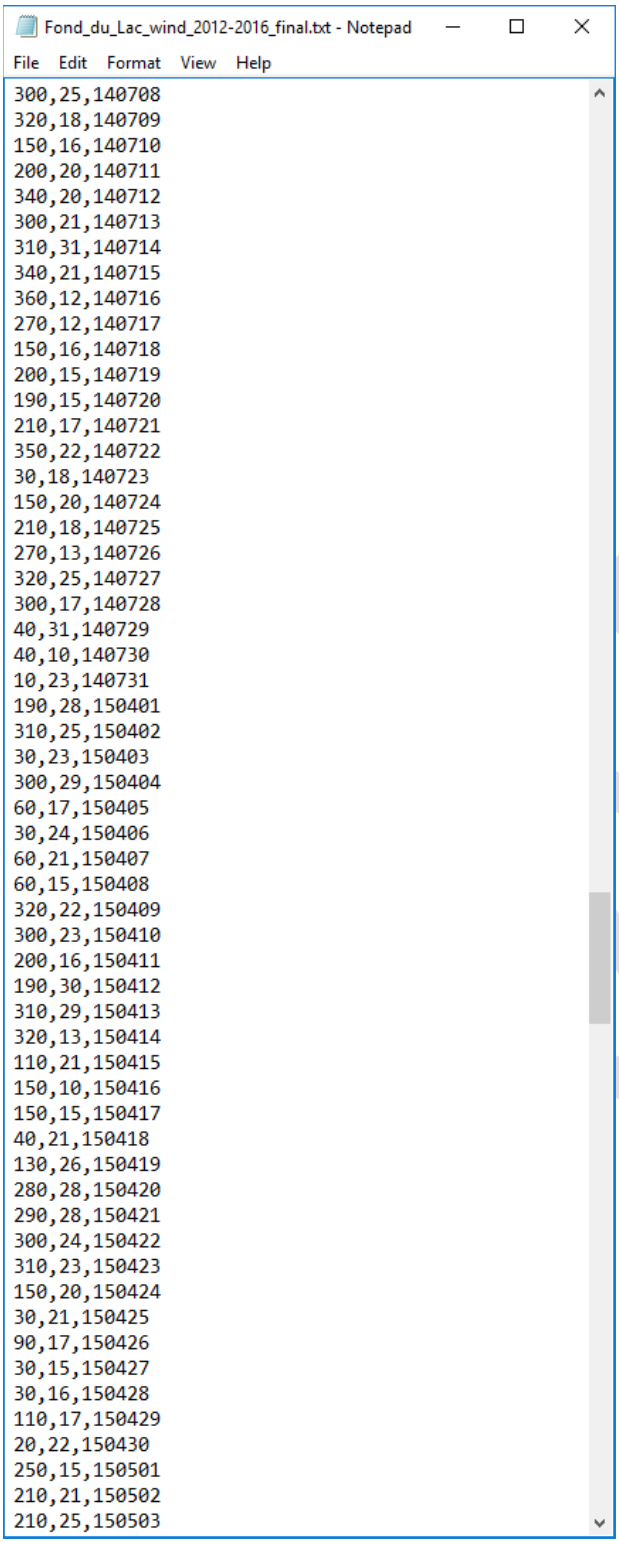
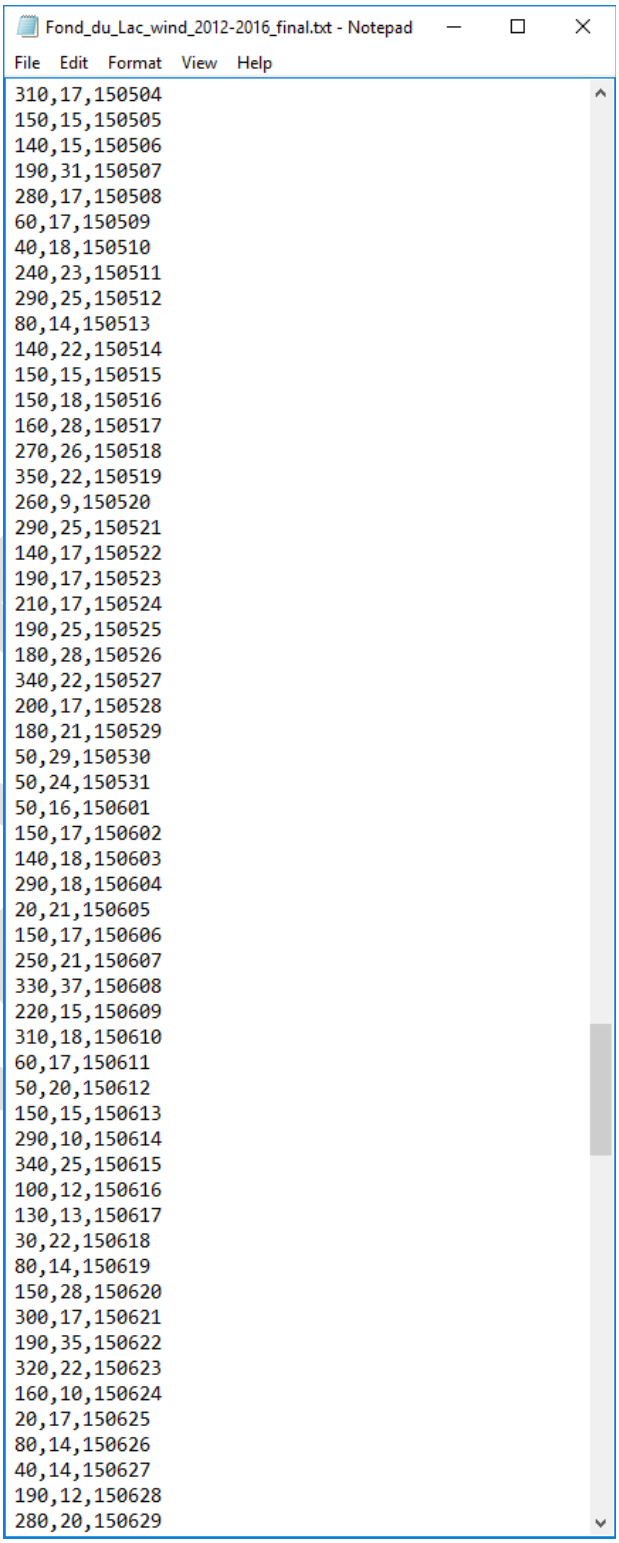
Attachment 1-2: Daily wind frequency and intensity





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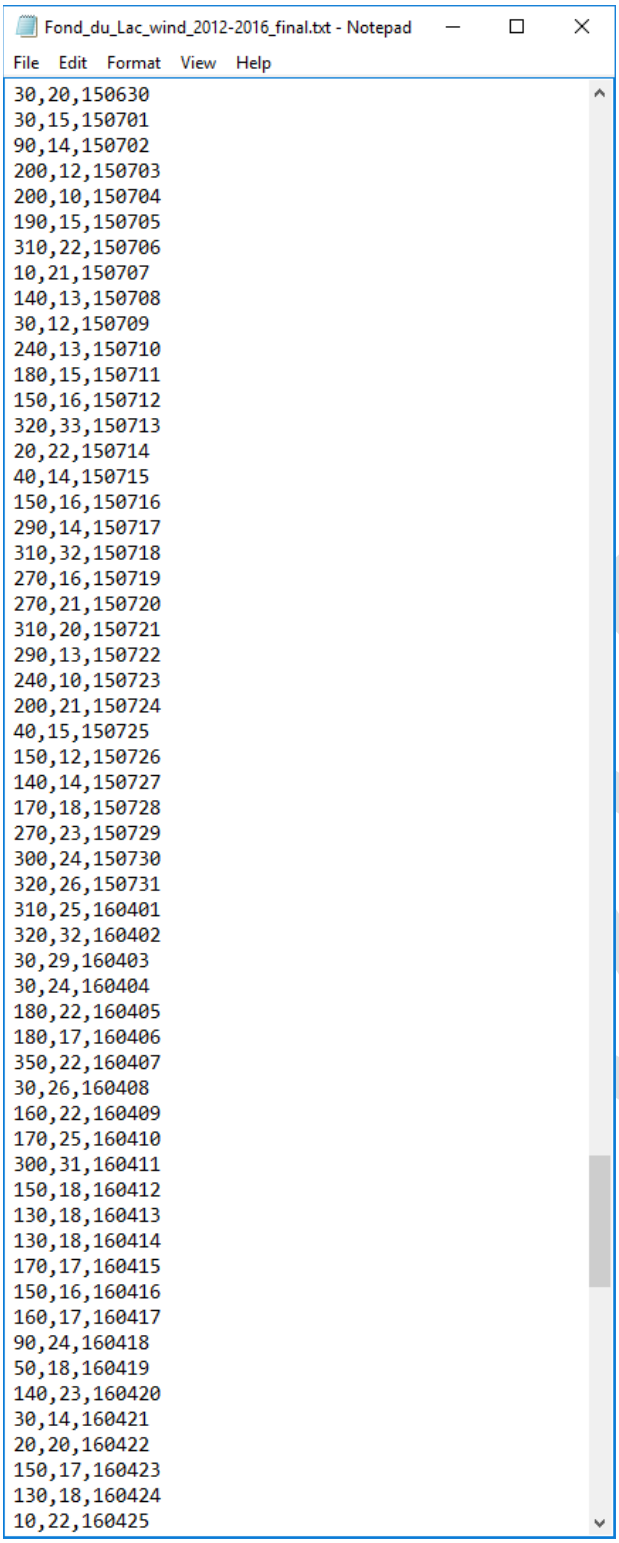

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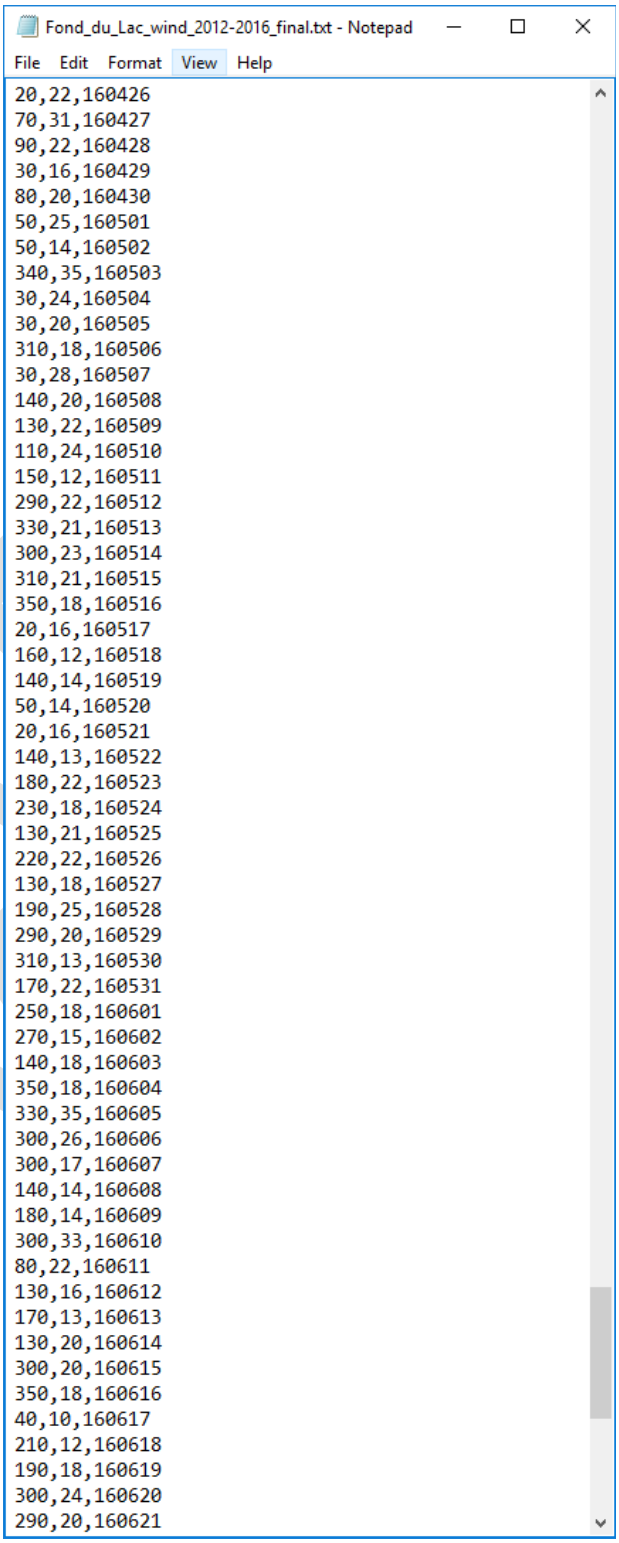

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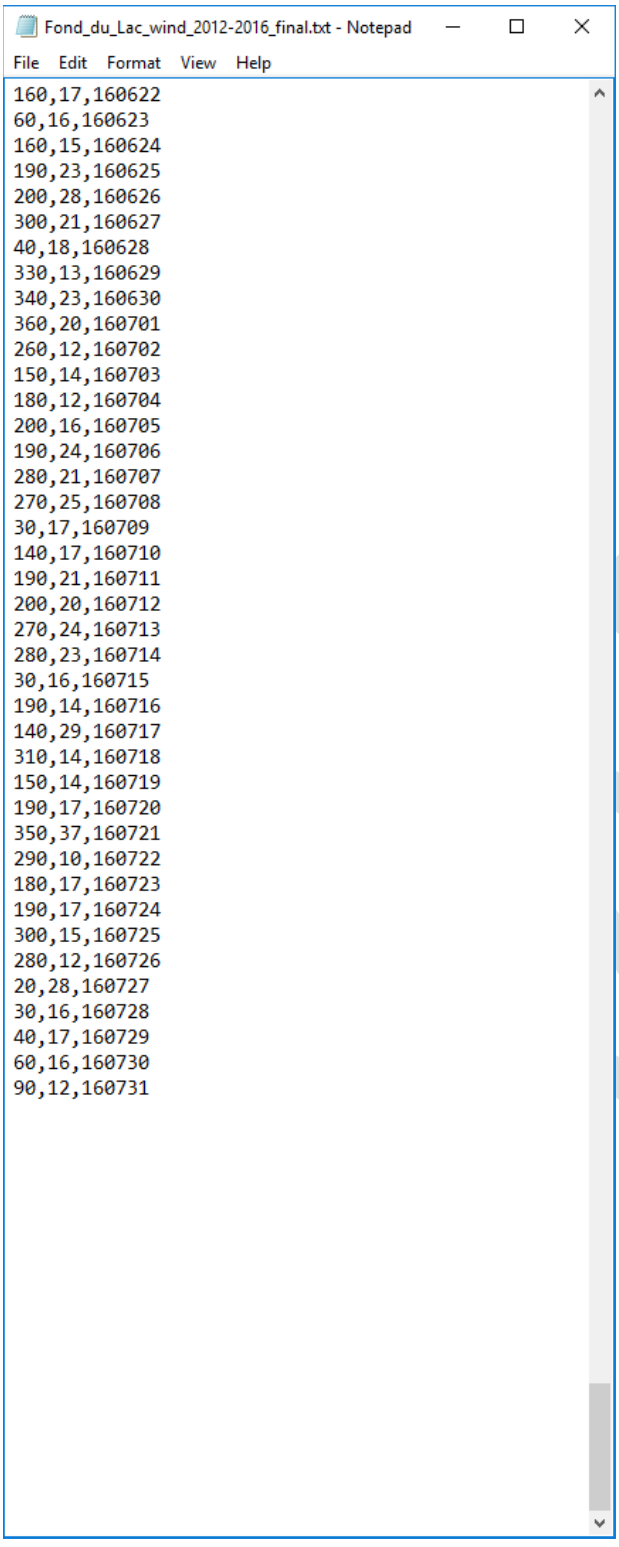
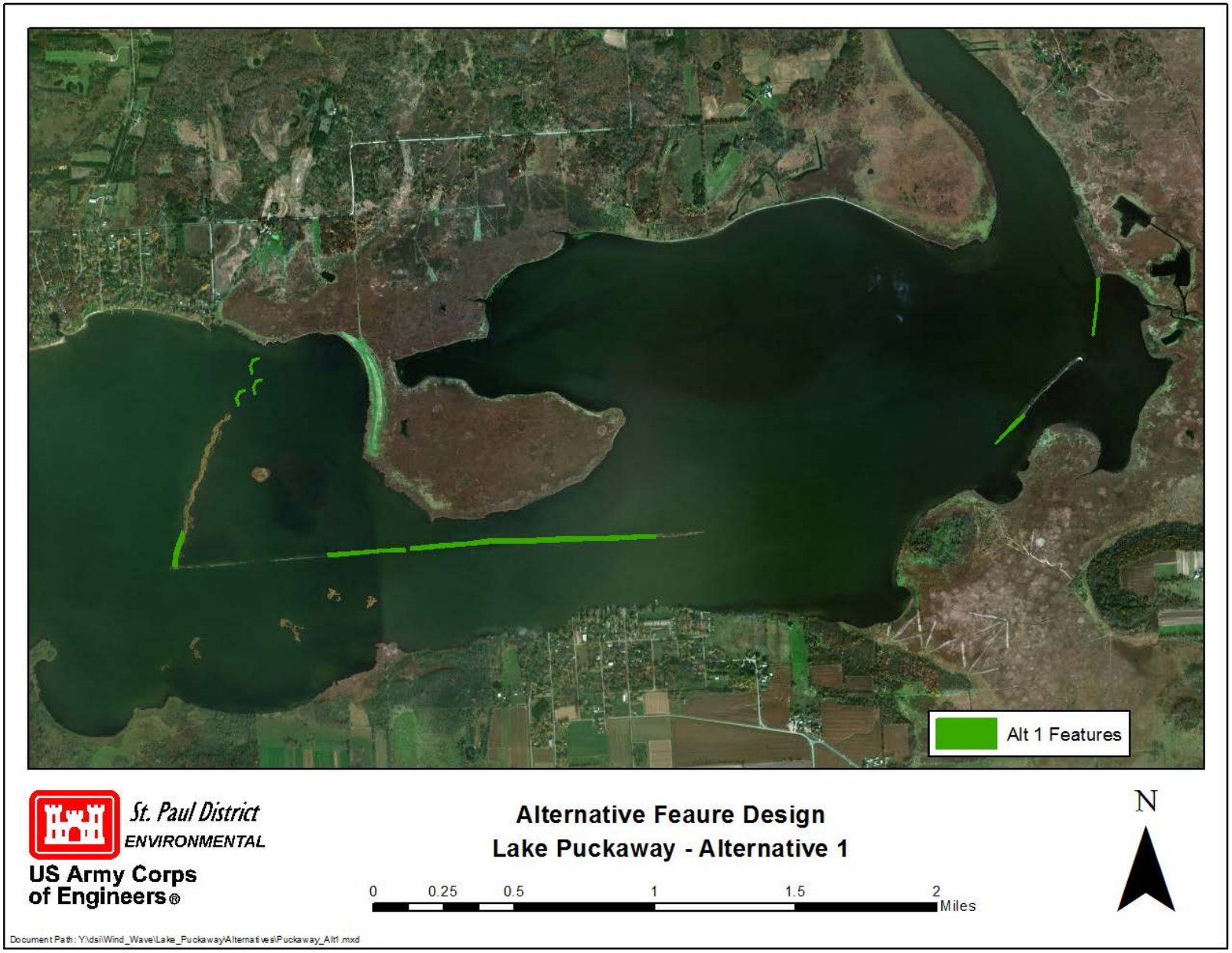
Attachment 1-2: Daily wind frequency and intensity



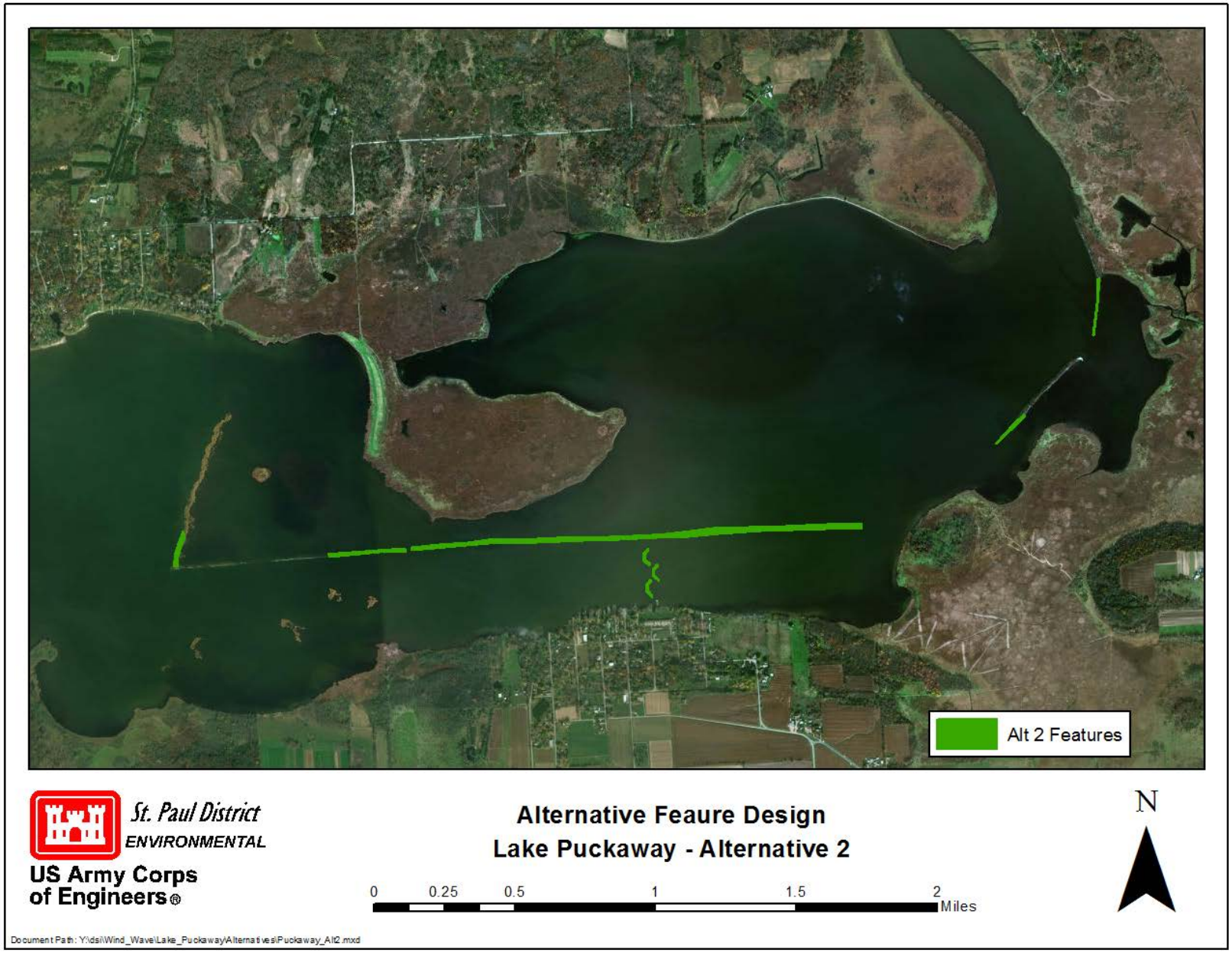
Attachment 2

Lake Puckaway Figures and Model Results

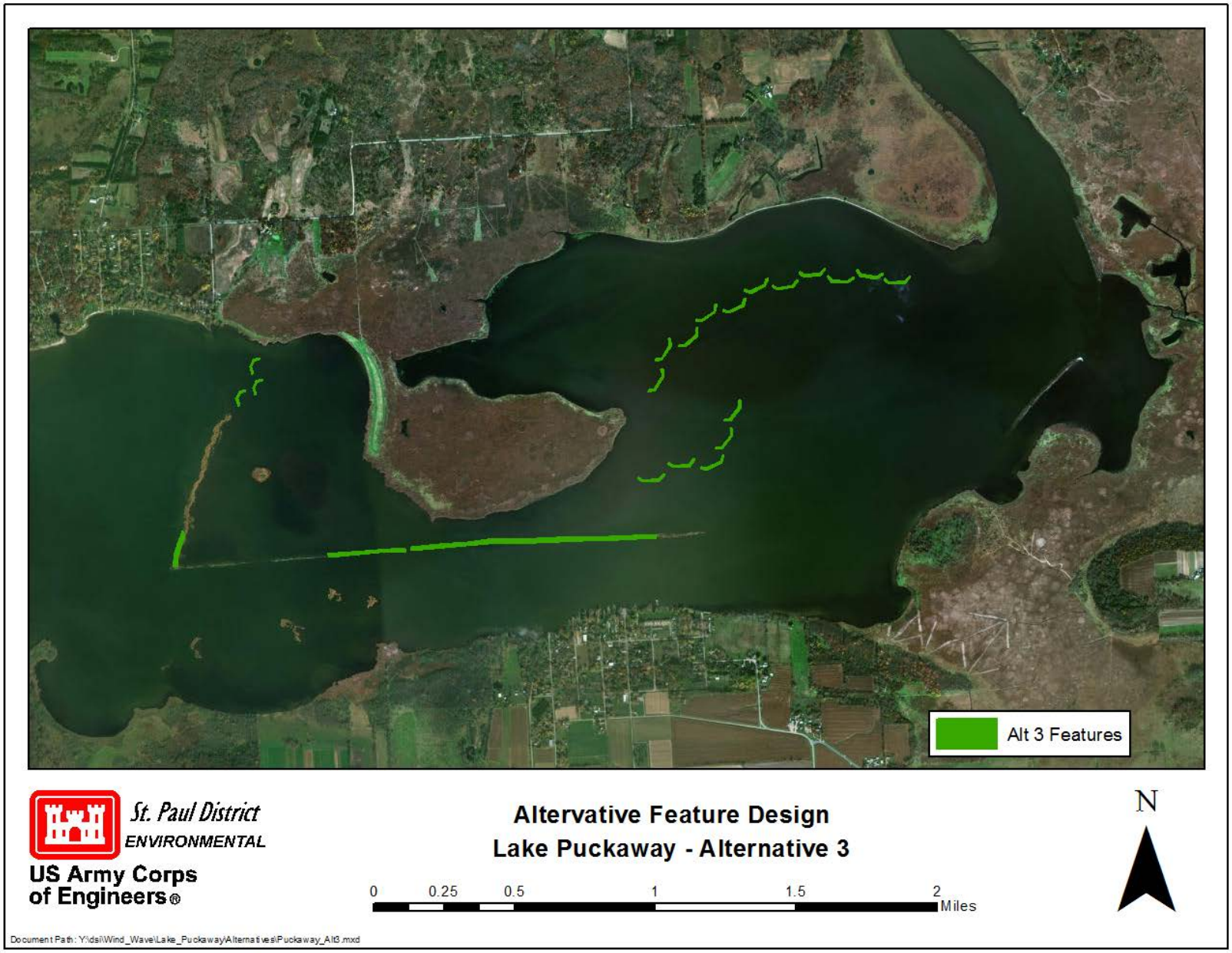
Attachment 2-1: Potential feature designs



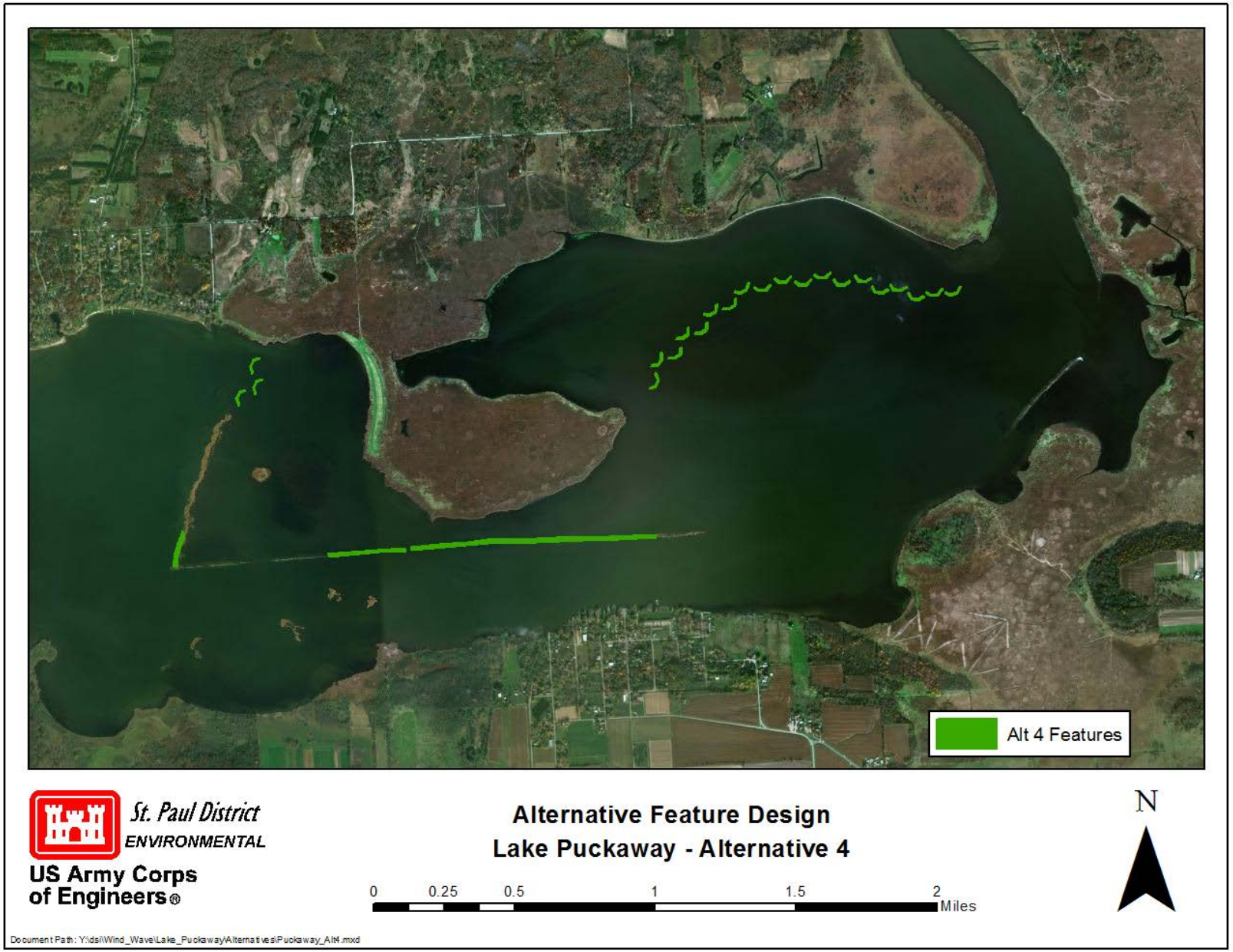
Attachment 2-1: Potential feature designs



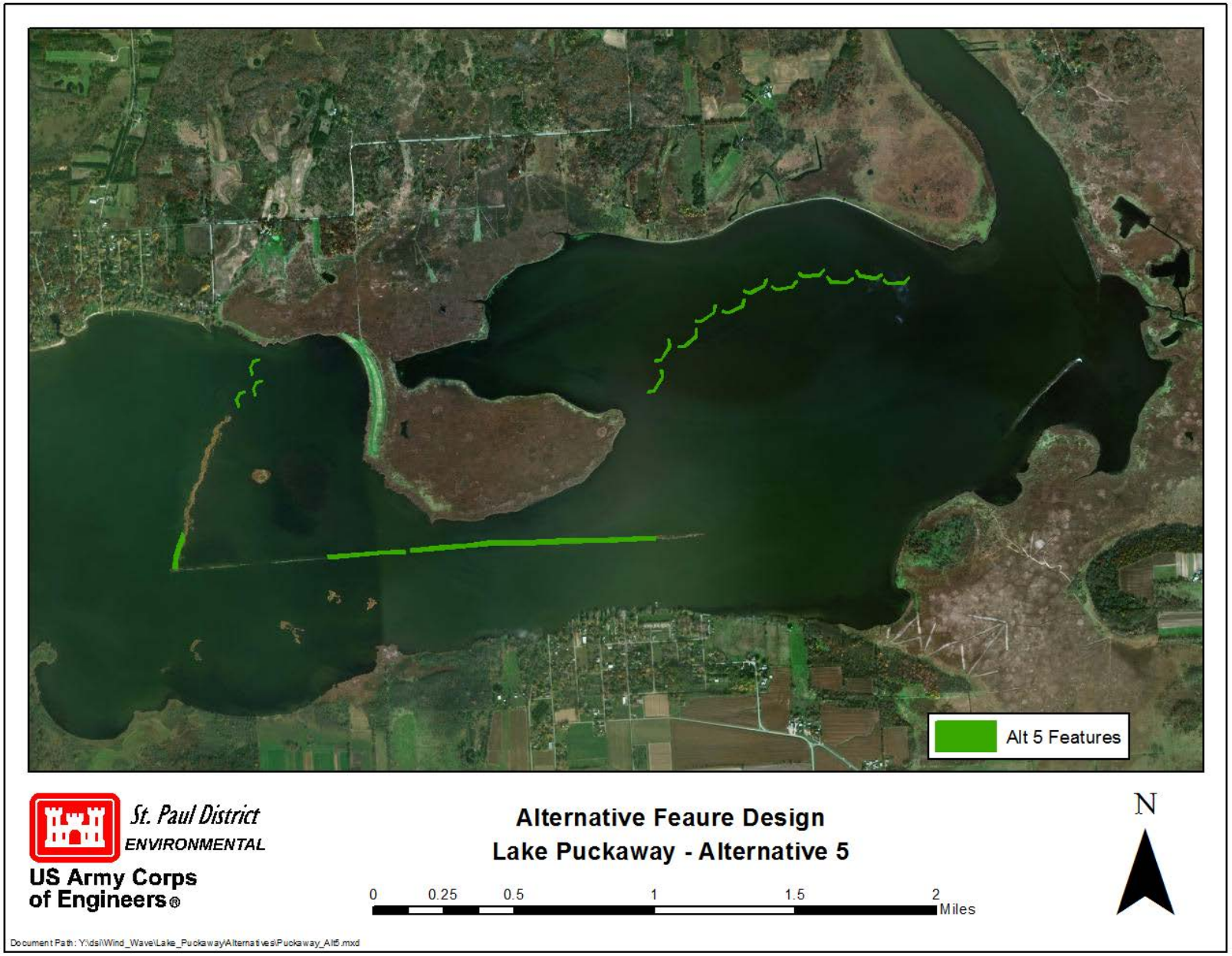
Attachment 2-1: Potential feature designs



Attachment 2-1: Potential feature designs

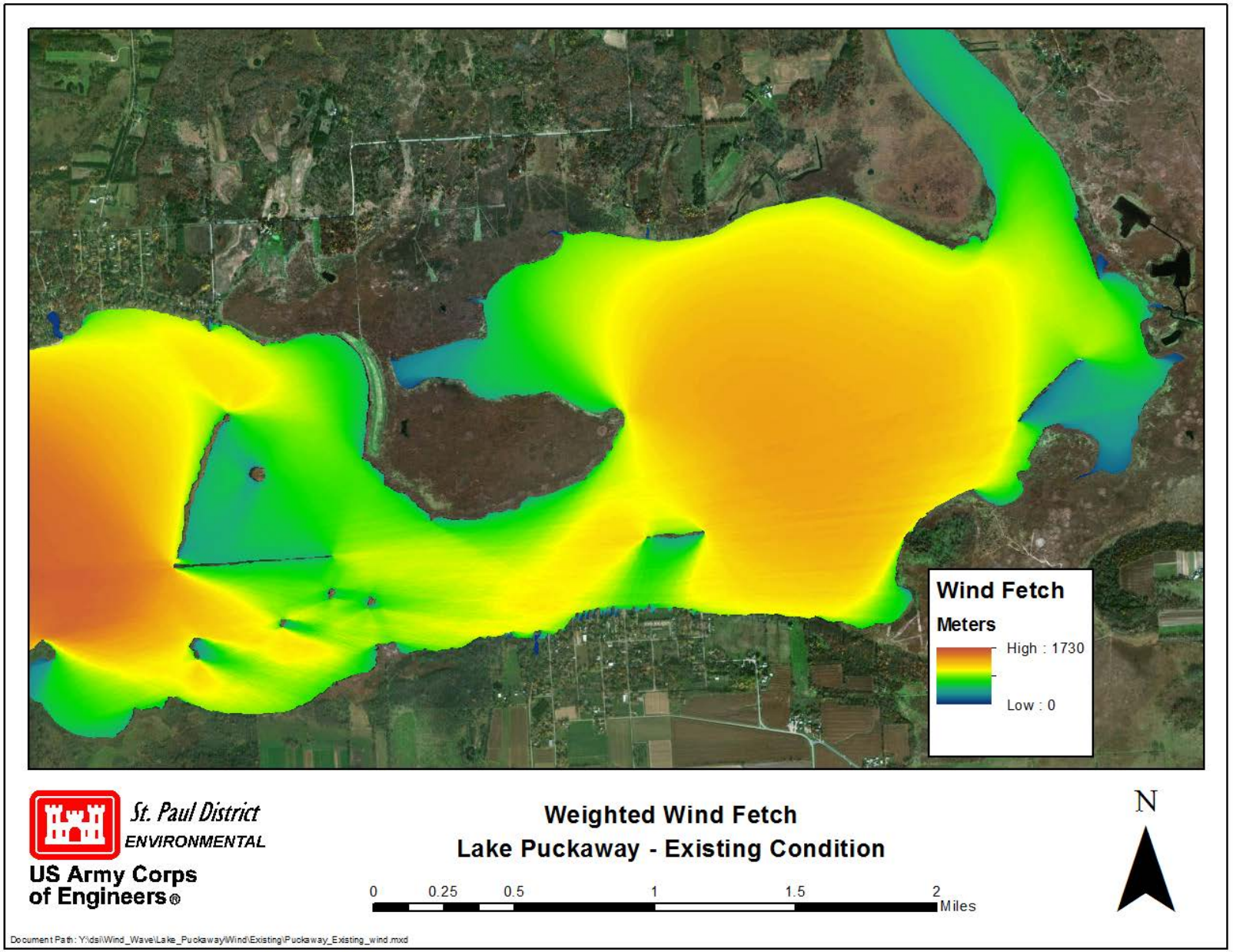


Attachment 2-1: Potential feature designs

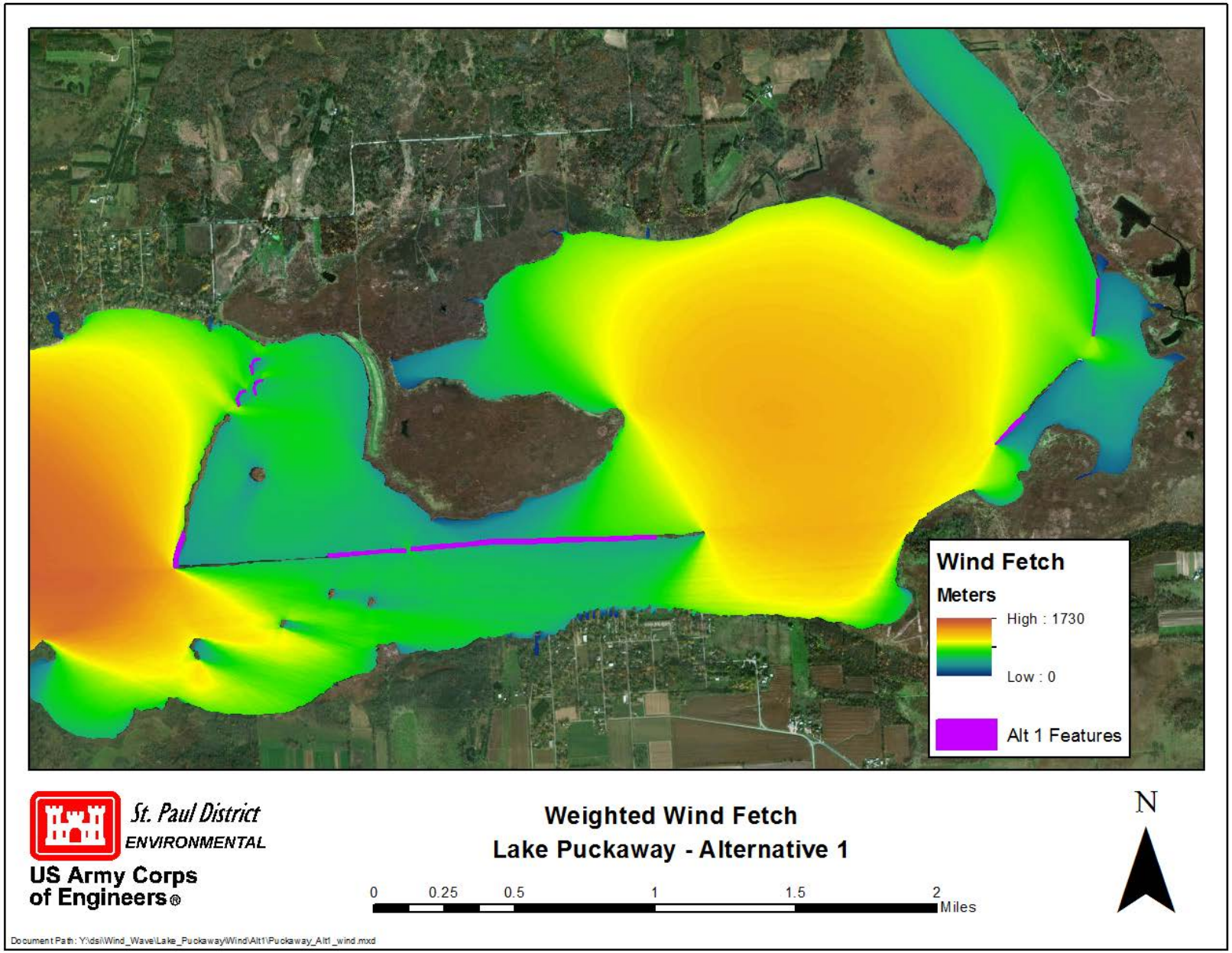


Attachment 2-1: Potential feature designs

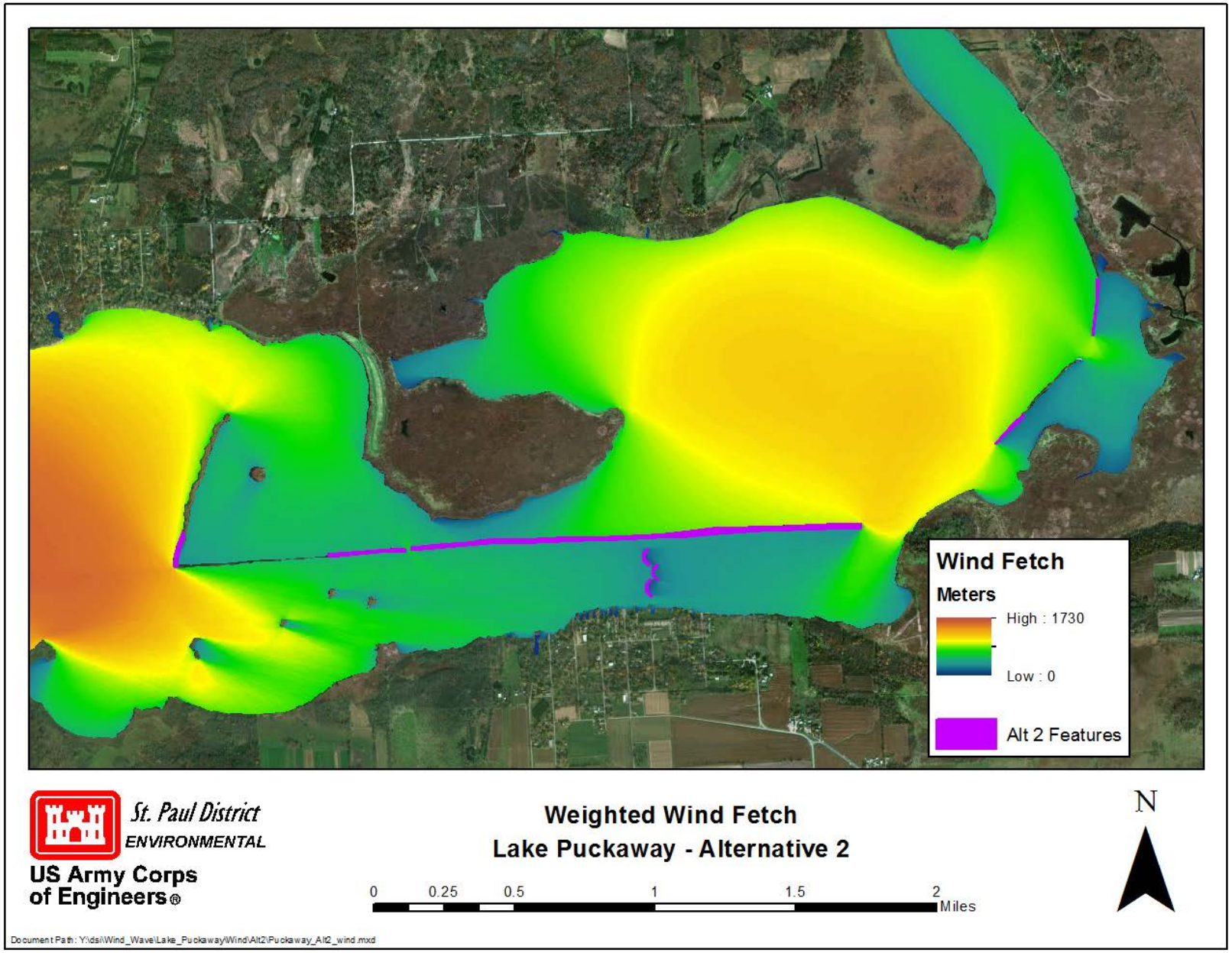
Attachment 2-2: Weighted wind fetches



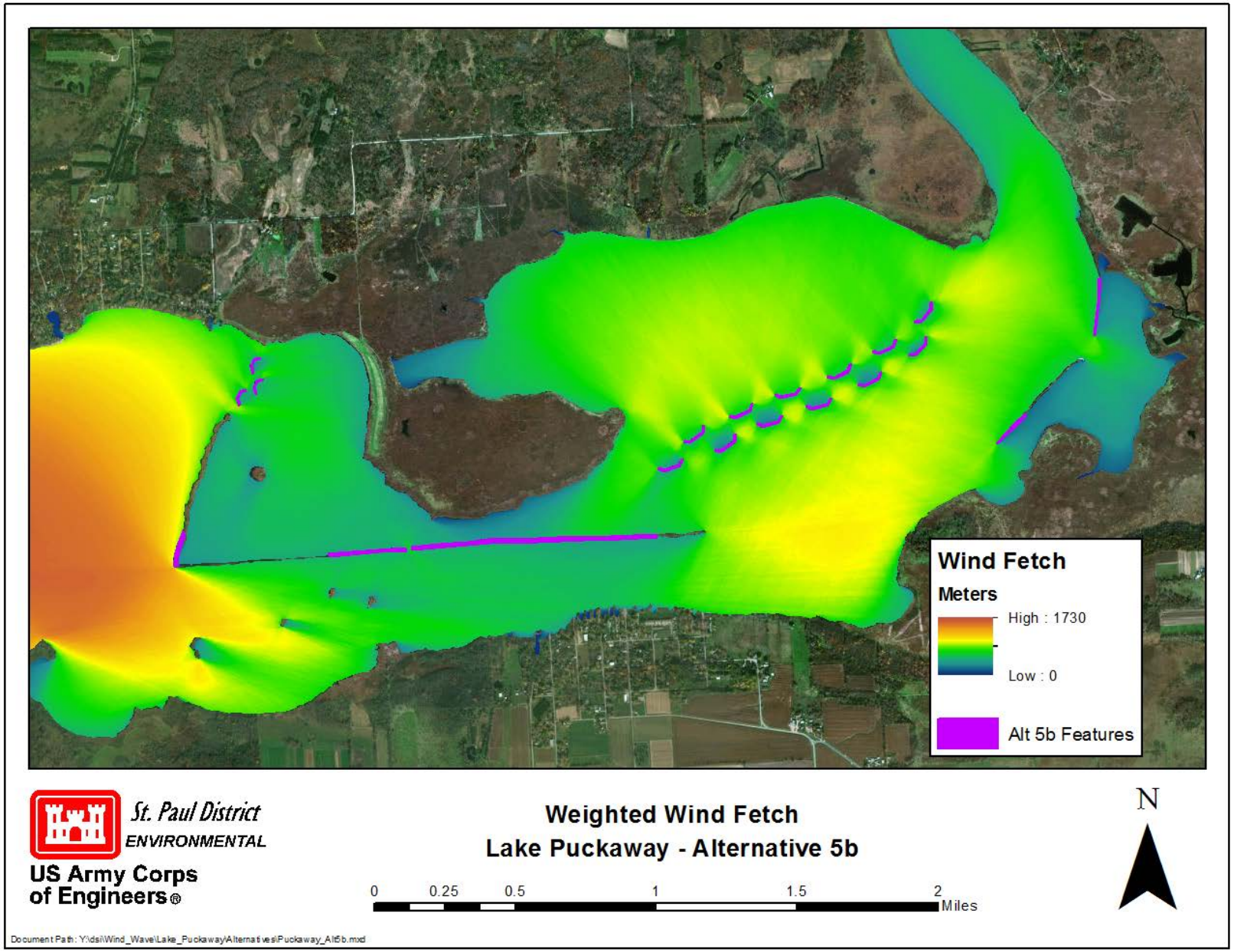
Attachment 2-2: Weighted wind fetches



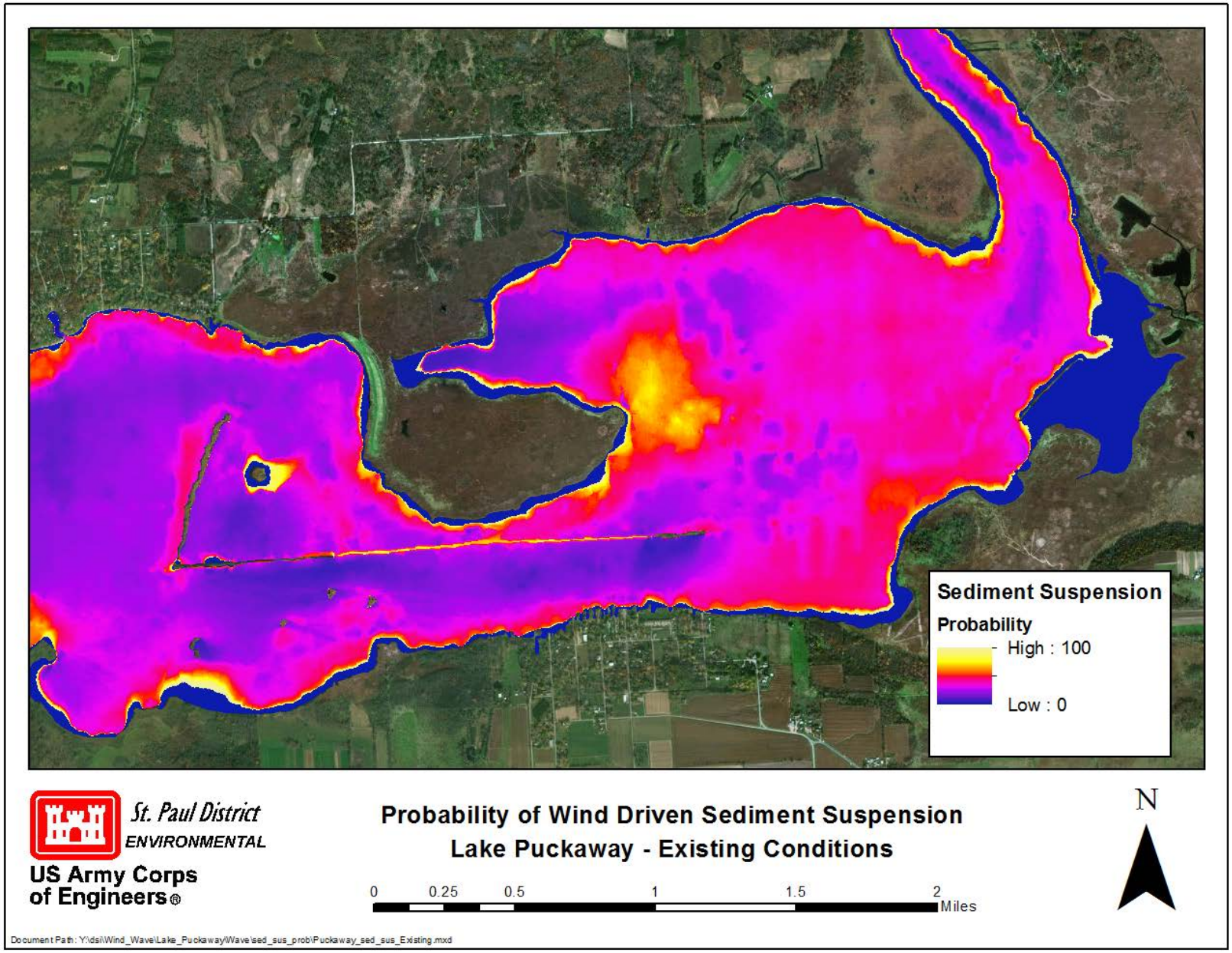
Attachment 2-2: Weighted wind fetches



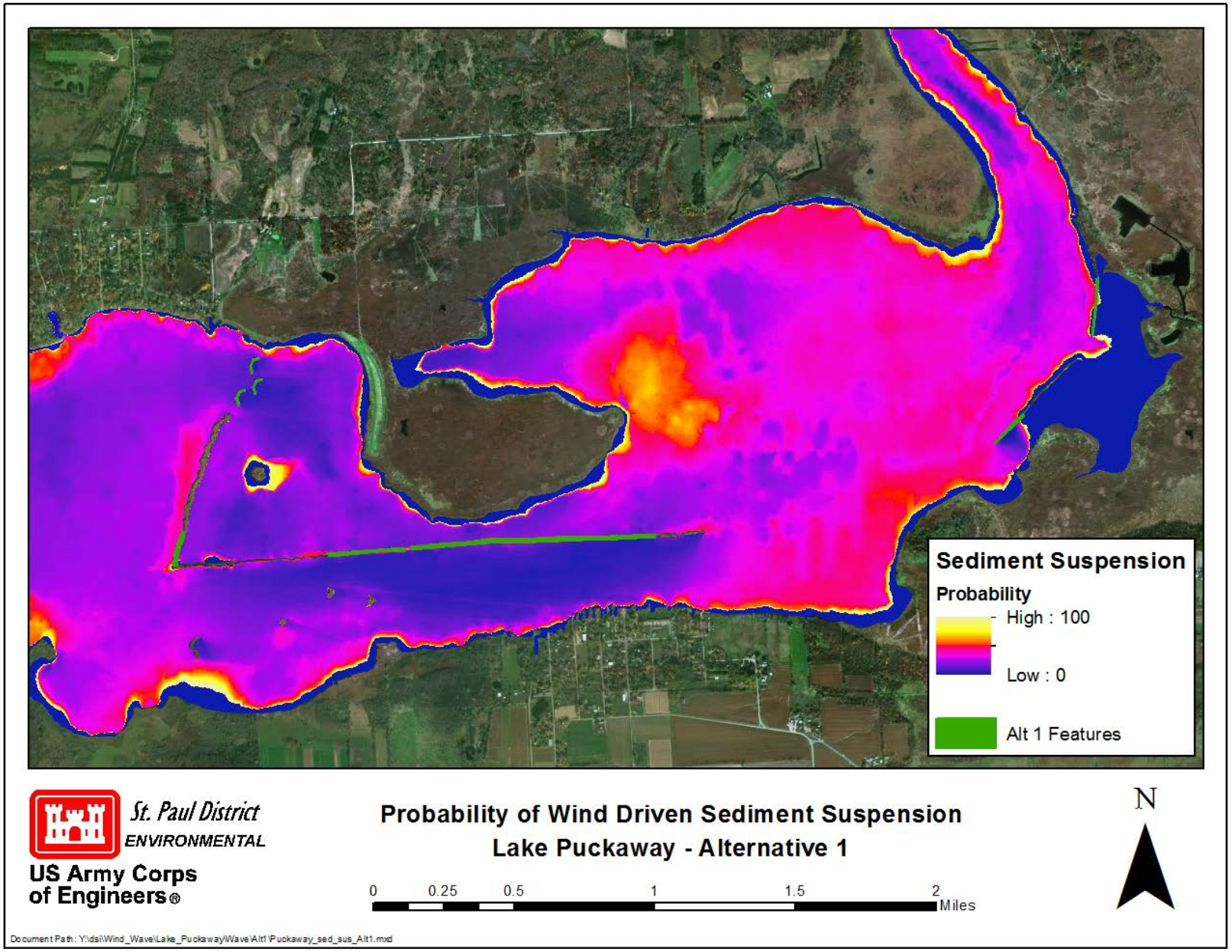
Attachment 2-2: Weighted wind fetches



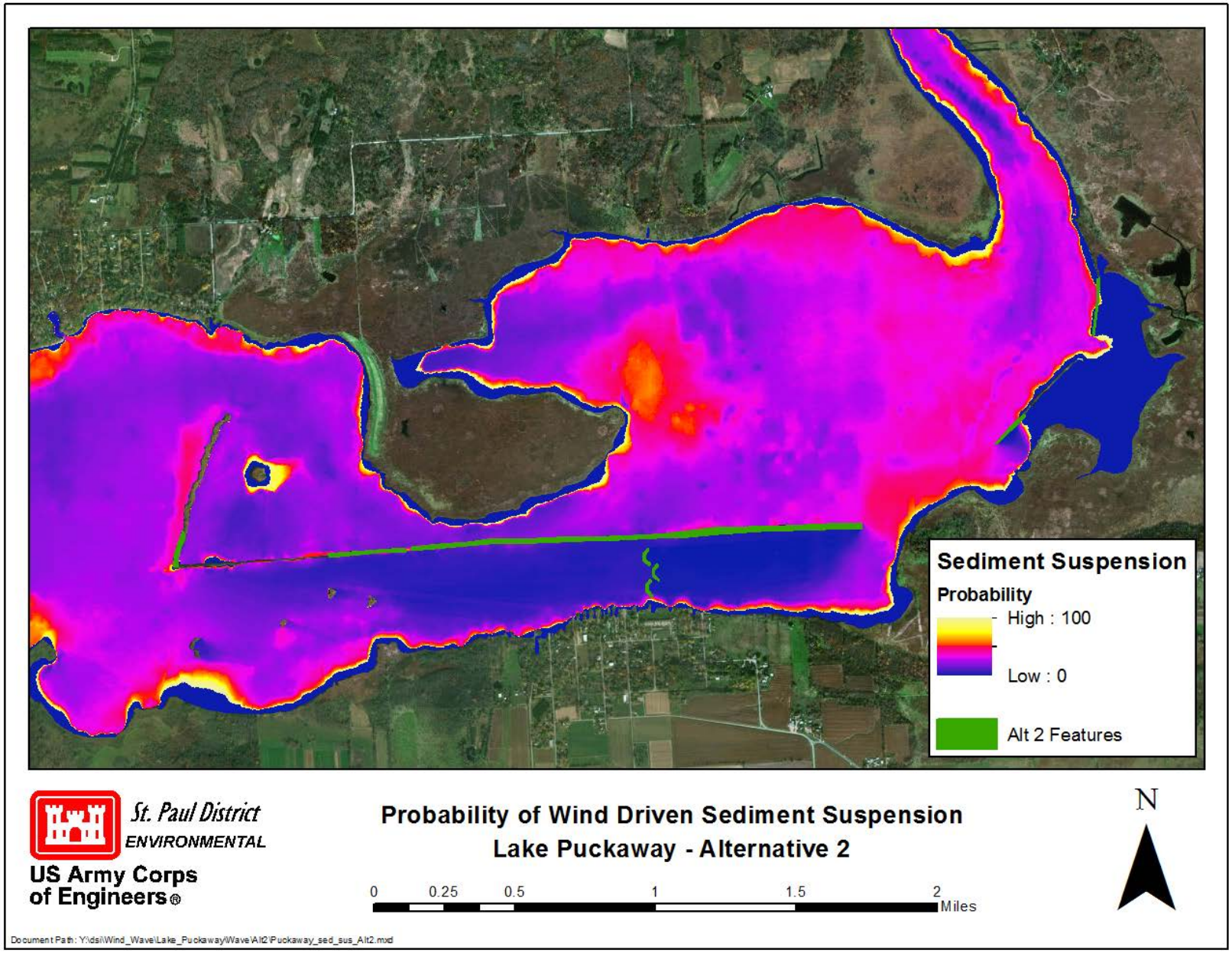
Attachment 2-3: Wind driven sediment suspension probabilities



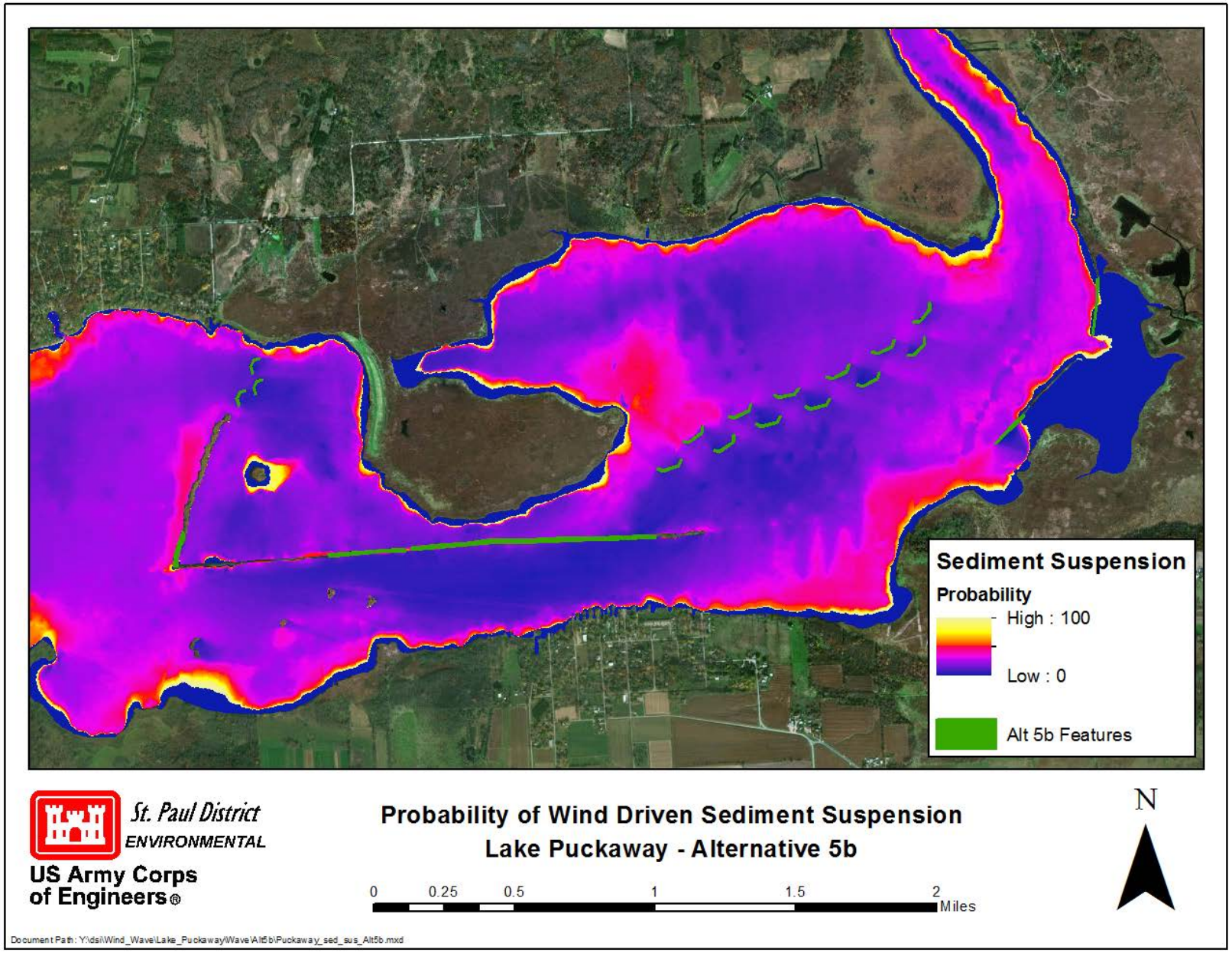
Attachment 2-3: Wind driven sediment suspension probabilities



Attachment 2-3: Wind driven sediment suspension probabilities



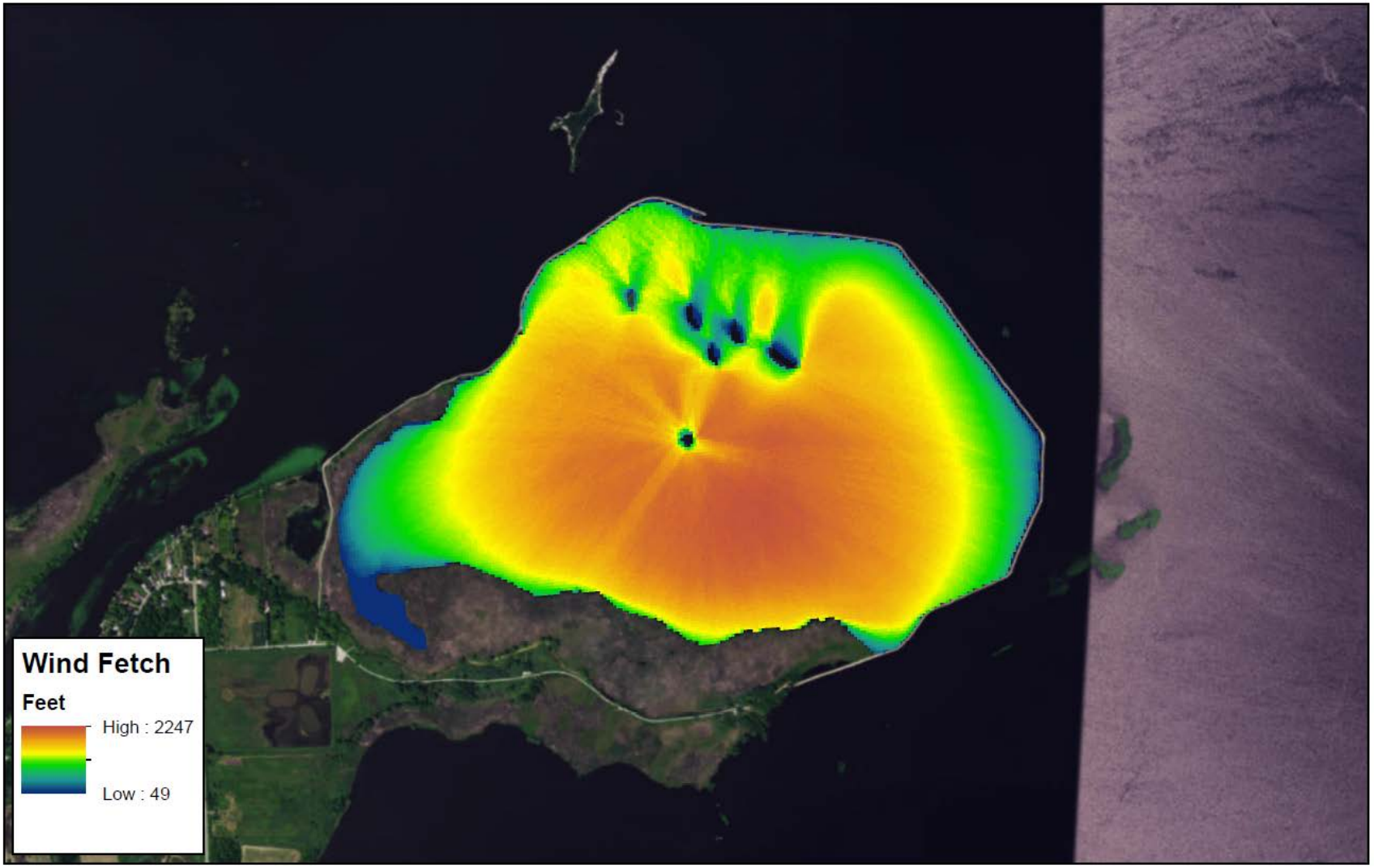
Attachment 2-3: Wind driven sediment suspension probabilities



Attachment 3

Terrell's Island Figures and Model Results

Attachment 3-1: Terrell's Island weighted wind fetch



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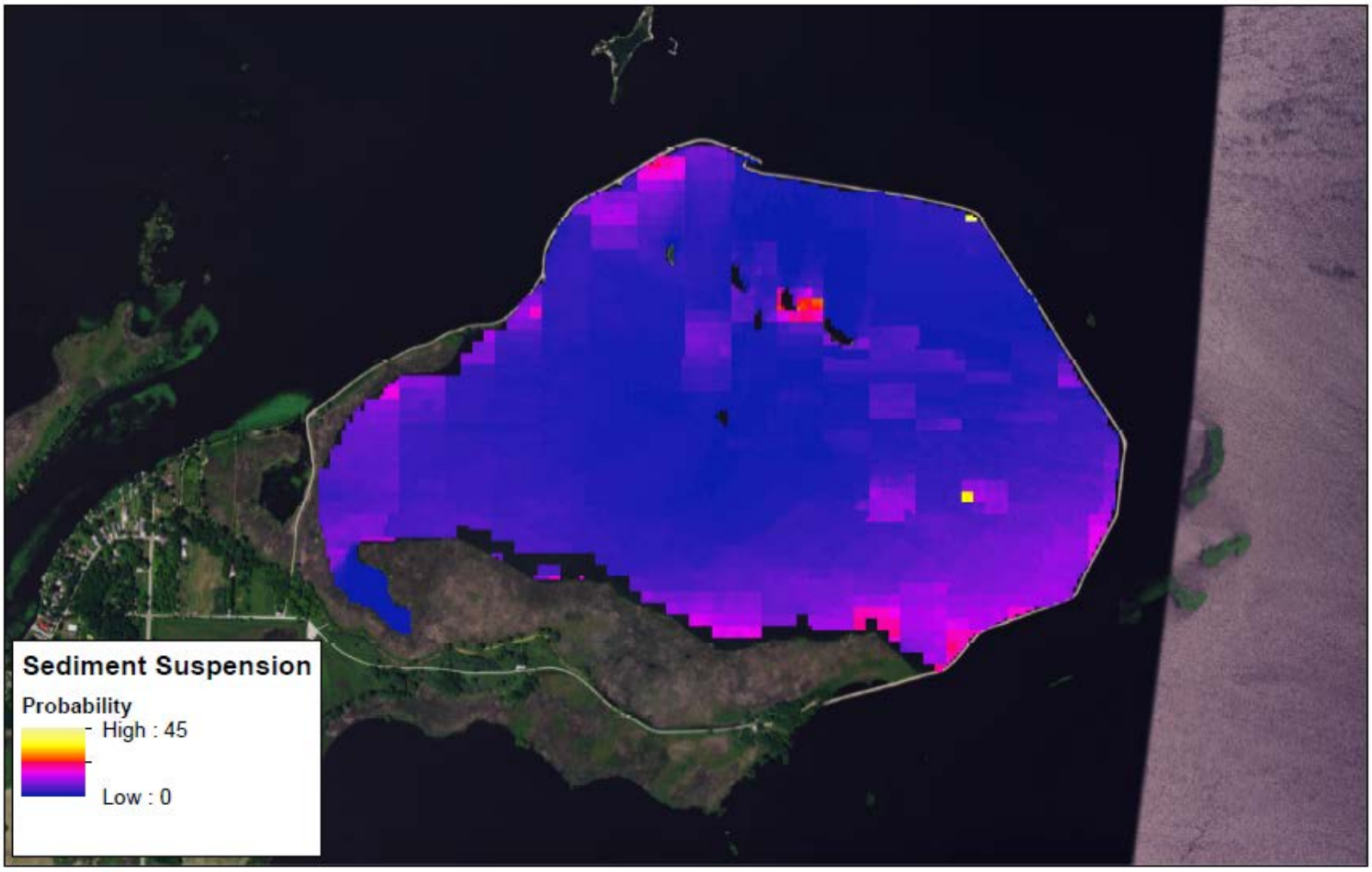
Weighted Wind Fetch
Terrell's Island

0 0.125 0.25 0.5 0.75 1 Miles

N

Attachment 3-2: Terrell's Island sediment suspension probability



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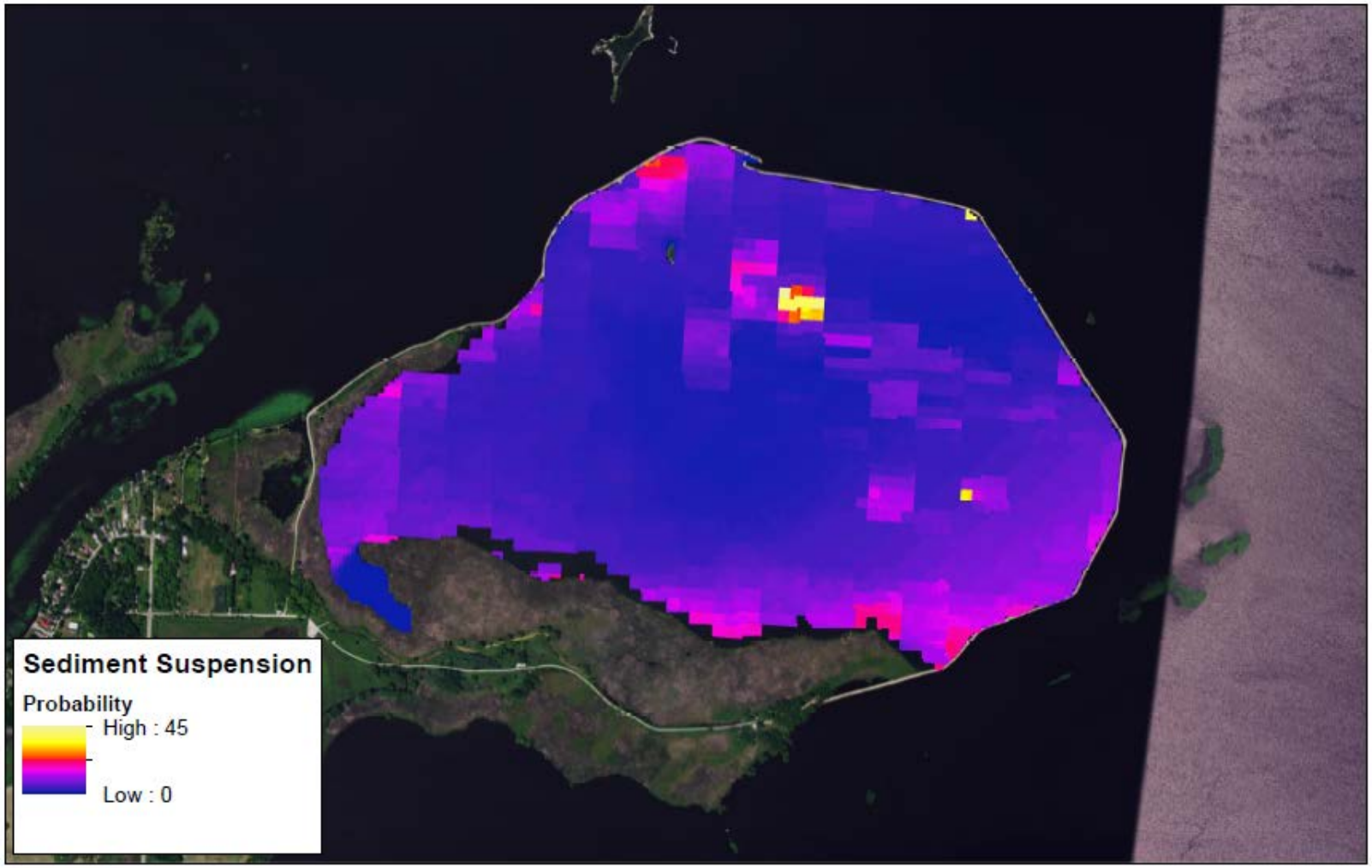
Probability of Wind Driven Sediment Suspension
Terrell's Island - Existing Conditions

0 0.125 0.25 0.5 0.75 1 Miles

N

Attachment 3-2: Terrell's Island sediment suspension probability



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Probability of Wind Driven Sediment Suspension
Terrell's Island - Island Removal

0 0.125 0.25 0.5 0.75 1 Miles

N