Project Report

Comprehensive GIS Analysis of Groundwater Influenced Shallow Wetlands in the Anoka Sand Plain Ecological Subsection

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I. Executive Summary

Critical Connections Ecological Services has completed a remote sensing analysis of a 3.3 million acre project area that encompasses the entire 1.1 million acre Anoka Sand Plain Ecological Subsection. The purpose of this remote sensing analysis was to predict potential locations of ASP groundwater influenced shallow wetlands as these wetland systems are known to contain unique native species assemblages including rare vascular plant species such as *Xyris torta* (MN-Endangered), *Juncus marginatus* (MN-Endangered), *Aristida longespica* var. *geniculata* (MN-Endangered), and *Polygala cruciata* (MN-Endangered). CCES utilized known locations of rare vascular plant species, associated soil catenas, and color infra-red aerial photograph imagery to develop a GIS-based spatial model that could prioritize areas within the project boundary down to the Minnesota DNR Level 07 Minor Watershed level that would be most likely to contain ASP groundwater influenced shallow wetlands. The results of this modeling effort will be used to direct future ground-truthing, research, and survey efforts which will allow for better rare plant and habitat mitigation and protection efforts. Of the 3.3 million acre project area, CCES has created a spatial model which has targeted approximately 207,000 acres (or 6% of the total project area) which should become the priority areas for next steps pertaining to on the ground surveys, research and protection efforts related to these unique ASP groundwater influenced shallow wetlands. The methods used and results obtained from this project are presented in the report below.

II. Introduction and Background Information

<u>Landscape Context</u>

The Anoka Sand Plain (hereafter, the ASP) is one of twenty-six (26) ecological subsections classified within the State of Minnesota. According to the Minnesota DNR, subsections are defined using glacial deposition processes, surface bedrock formations, local climate, topographic relief, and the distribution of plants, especially trees. The ASP is 1.1 million acres in size and is located in central Minnesota, with its western boundary following the Mississippi River. The ASP is mainly composed of a broad, sandy lake plain and the topography is mostly level to gently rolling.

Soils are derived primarily from fine sands of the sandy lake plain. Most of these sandy soils are droughty, upland soils (Psamments), but there are organic soils (Hemists) in the ice block depressions and tunnel valleys, and poorly drained prairie soils (Aquolls) along the Mississippi River (Cummins and Grigal 1981). Seventy to eighty% of the soils are excessively well drained sands and another 20% are very poorly drained (Dept. of Soil Science, Univ. of Minnesota 1980b).

At the time of pre-settlement, the excessively to well drained upland soils were dominated by scrubby oak barrens and openings. Tree species included bur oak, and northern pin oak. Marshes and swamps were also extensive in portions of the subsection in areas with poorly drained soils. Pre-settlement vegetation patterns were strongly influenced by climate, frequent fire and hydrology. Frequent fires helped to maintain open vegetation patterns (prairie, savanna) while preventing the development of more mature forest systems.

Wetland pockets exist throughout the ASP where poorly drained soils accumulated in glacial lake troughs and are scattered throughout the region amongst slightly topographically higher, droughty sandy soils. Pre-settlement vegetation records circa 1850 classified these areas as wet prairies, marshes and sloughs which contained a wide range of vegetation from seasonally inundated grasslands on mineral soils to cattail marshes and sedge dominated peatlands.

Background Information

After re-discovering a rare vascular plant species, *Xyris torta* in 1999, a species that had not been detected in the State since 1967 in Cedar Creek Ecosystem Reserve, Critical Connections Ecological Services (hereafter, CCES) began more comprehensive work on a subset of wetland areas within the southeastern ASP. CCES as well as others (Minnesota County Biological Survey, etc.) learned that a portion of these wetland systems are unique in that they are ground water influenced shallow wetlands. Furthermore, these systems often occur within a specific soil formation along slight topographic transitions between saturated peat deposits and dry sandy uplands or can occur within deep (18+ feet) saturated peatlands and isolated depressions over shallow saturated peat. Further investigations of these unique ASP groundwater influenced shallow wetlands have documented that when detected in a fairly undisturbed state, they can support a unique assemblage of native plant species. Often these higher quality ASP groundwater influenced shallow wetlands contain a high diversity of native species (CCES has documented up to 320+ native vascular plant species within one 60-acre example within the City of Blaine, Minnesota). The plant community is often low in stature, between 0.5 and 1.0 meters in height at maturity and often supports some of Minnesota's rarest vascular plant species.

CCES has dedicated numerous hours over fifteen years of surveying the flora of these unique wetland systems which are only known to occur within the 1.1 million acre ASP within the State of Minnesota. Similar habitats have been documented in states to the east of Minnesota in States such as Wisconsin, Michigan and Illinois as well as others. Through extensive and ongoing field research, CCES has further documented that a number of endangered, threatened, and special concern vascular plant species are closely associated with the ASP groundwater influenced shallow wetlands. These species include but are not limited to *Xyris torta* (MN-Endangered), *Juncus marginatus* (MN-Endangered), *Aristida longespica* var. *geniculata* (MN-Endangered), *Platanthera flava* var. *herbiola* (MN-Threatened), and *Polygala cruciata* (MN-Endangered).

Project Purpose and Need

As described above, ASP groundwater influenced shallow wetlands are unique ecological features limited to a small geographical area in the state of Minnesota. Documentation showing that these features are highly capable of supporting some of the most unique and rare vascular plant species and native species assemblages in the State provide further justification as to why these areas should be surveyed for and protected. In order to effectively protect these features, it is necessary to understand their spatial extent with the landscape so that further survey work can be conducted as time and funding allows. Furthermore, understanding the spatial extent of these features can assist local agencies in their permitting processes. The main purpose and object of this project is to develop a GIS-based modeling procedure which will predict potential locations of ASP groundwater influenced shallow wetlands within the entire ASP. The results of this effort will be used to inform future research and survey efforts by the MN DNR, local permitting agencies, as well as others.

CCES has proposed that the locations of these unique ASP groundwater influenced shallow wetlands and the rare vascular plant species assemblages that they often support can likely be predicted through the use of remote sensing. Relying heavily on the soils formations typically observed in relationship to ASP groundwater influenced shallow wetlands, as well as known locations of rare vascular plant species associated with these systems, and specific aerial photograph signatures, CCES has developed a GIS-based modeling approach to assist in identifying the potential extent and locations of ASP groundwater influenced shallow wetlands within central Minnesota. This modeling process was completed across the entire extent of the ASP (1.1 million acres) and adjacent suitable landscapes. It should be noted that the development of this GIS-based model is the first step of many related to predicting the potential extent and locations of ASP groundwater influenced shallow wetlands. Follow-up work will include ground-truthing of the model output as well as refinement of the model to further improve outputs which can be use to direct future survey work as well as permitting an mitigation efforts.

The timing of the completion of this project is imperative as ASP groundwater influenced shallow wetland systems are currently under pressure and threatened by many landscape variables and may become severally degraded or completely lost if not detected and documented. These potential threats include, but are not limited to, past and ongoing ditch maintenance and drainage projects, groundwater use and groundwater appropriations, municipal wells, increased watershed imperviousness, wetland draining and filling, altered hydroperiods, altered water chemistry and nutrient inputs, fire suppression, invasive species dominance, and overall plant community stagnation resulting from a general lack of a natural disturbance regime.

As municipalities within the ASP become increasingly built-out, development within increasingly marginal lands (such as lands containing wetlands) is becoming more common. In addition, agencies responsible for reviewing development plans (Cities, Counties, Local Watersheds, etc.) are more frequently encountering projects that may involve the protection these unique ASP groundwater influenced shallow wetlands and the rare vascular plant features often contained within them. By remotely predicting the potential extent of ASP groundwater influenced shallow wetlands, agencies will better be able to assist in the protection of these unique features, associated rare species, and the landscapes that support them. In addition, mitigation efforts may be streamlined as the MN DNR will be better able to direct future rare features survey efforts to areas most likely to support rare plant communities and rare features. Having a better understanding of where these rare features may exist within the overall ASP landscape, will allow for more efficient and thorough documentation and protection of these features and allow for better mitigation planning when rare species impacts must occur due to the impending development in more urban areas of the ASP.

III. Methods

To develop a spatially comprehensive model which could predict the extent and locations of ASP groundwater influenced shallow wetlands, CCES ecologist utilized three major parameters. These parameters included soils, known locations of rare vascular plant species associated with ASP groundwater influenced shallow wetlands, and infra-red aerial photograph signatures as they relate to known occurrences of ASP groundwater influenced shallow wetlands.

Project Area

To begin this project, CCES ecologists first defined the project area. The overall goal of this project was to spatially asses the entire 1.1 million acre ASP ecological subsection and any nearby outlying portions of the historic Glacial Lake Anoka lake plain. To create the overall project boundary, CCES utilized the Ecological Subsections of Minnesota data layer (Minnesota DNR - Division of Forestry, 1999) in combination with the Minnesota DNR's Level 07 Minor Watersheds (Minnesota DNR - Division of Waters - Watershed Delineation Project, 2009) and surficial geology and soils. The project boundary was set by selecting all Level 07 Minor Watersheds which were contained by or crossed the boundary of the Anoka Sand Plain Ecological Subsection Boundary, as well as subcatchments that potentially included isolated lake plain fragments. The final project boundary measures 3.3 million acres in size and is shown in **Appendix A, Figure 1**.

Minnesota DNR's Level 07 Minor Watersheds - Catchments

According to available metadata, "these data consist of approximately 5,680 watershed delineations in one seamless dataset of drainage areas called Minnesota Department of Natural Resources (DNR) Minor Watersheds. DNR Minor Watersheds are the smallest administrative Minnesota watershed unit delineation existing at the 7th level defined in the Minnesota DNR watershed unit hierarchy. These modern DNR Minor Watersheds are derived from the DNR Catchment base-watershed dataset. Although the lineage of these watershed delineations dates back to the early 1970's, this data is an updated version of the DNR Minor legacy watershed dataset that has been in existence in various published formats since 1979. This new line work represents the general appearance of the legacy data. However, the geometry is considerably different. This has resulted from the DNR Watershed Delineation Projects methodology, which incorporates modern data sources to delineate watersheds that reflect the current hydrology and topography of the landscape. These modern DNR Minor Watershed delineations have been clipped to the Minnesota state boundary."

Because these data have been derived from actual hydrology and topography, CCES utilized this spatial information as a uniform way of dividing and ranking portions of the Anoka Sand Plain assessment area based on model parameters as described below. The MN DNR Level 07 catchments utilized in this project are depicted in **Appendix A, Figure 2.**

Natural Heritage Information Systems Database - Known Locations of Rare Vascular Plant Species

CCES referenced and queried the NHIS database (February 2015, MNDNR) for documented records of rare plant species that are known to occur within the ASP and that are either obligate to or commonly associated within ASP groundwater influenced shallow wetlands. These species were selected from the NHIS database to create a separate data layer of rare vascular plant species specific to the ASP and ASP groundwater influenced shallow wetlands. For new detection records that had been recently found by CCES (Jason Husveth) but had not yet incorporated into the 2005 NHIS database, CCES added these precise locations (totaling 135 additional records) into the rare vascular plant species analysis database. A total of three hundred and ninety (390) spatially documented rare species detections were selected for use in this analysis based on the query. Selected plant species are listed below in Table 1.0, and known locations are represented in **Appendix A, Figure 3.**

Table 1.0 Rare Vascular Plant Species Associated with ASP Groundwater Influenced Shallow Wetlands

Scientific Name	Common Name	MN Listing	# of Records
Agalinis purpurea	Purple gerardia	Tracked	9
Aristida longespica var. *geniculata*	Slimspike three-awn	Endangered	6
Bartonia virginica	Yellow bartonia	Endangered	4
Botrychium simplex	Least moonwort	Special Concern	7
Fimbristylis autumnalis	Autumn fimbry	Special Concern	28
Juncus marginatus	Marginated rush	Endangered	14
Platanthera clavellata	Small green wood orchid	Special Concern	2
Platanthera flava var. herbiola	Tubercled rein orchid	Threatened	83
Polygala cruciata	Cross-leaved milkwort	Endangered	19
Potamogeton bicupulatus	Snailseed Pondweed	Endangered	3
Rotala ramosior	Toothcup	Threatened	12
Rubus fulleri	Bristle-berry	Threatened	3
Rubus missouricus	Missouri dewberry	Endangered	1
Rubus semisetosus	Swamp blackberry	Threatened	17
Rubus stipulatus	Bristle-berry	Endangered	8
Rubus vermontanus	Vermont blackberry	Special Concern	6
Rubus wheeleri	Wheeler's bristle-berry	Tracked	1
Sceptridium rugulosum	St. Lawrence grapefern	Special Concern	10
Scleria triglomerata	Tall nutrush	Endangered	3

Trichophorum clintonii	Clinton's bulrush	Threatened	13
Utricularia geminiscapa	Hidden-fruit bladderwort	Threatened	1
Viola lanceolata var. *lanceolata*	Lance-leaved violet	Threatened	130
Xyris torta	Twisted yellow-eyed grass	Endangered	10

SSURGO Soils (Soil Survey Geographic Database)

Soils information used for this project was obtained from the USDA Natural Resources Conservation Service's SSURG Database. According to the USDA NRCS, "the SSURGO database contains information about soil as collected by the National Cooperative Soil Survey over the course of a century. The information can be displayed in tables or as maps and is available for most areas in the United States and the Territories, Commonwealths, and Island Nations served by the USDA-NRCS. The information was gathered by walking over the land and observing the soil. Many soil samples were analyzed in laboratories. The maps outline areas called map units. The map units describe soils and other components that have unique properties, interpretations, and productivity. The information was collected at scales ranging from 1:12,000 to 1:63,360. More details were gathered at a scale of 1:12,000 than at a scale of 1:63,360. The mapping is intended for natural resource planning and management by landowners, townships, and counties." CCES Ecologists obtained the majority of the State SSURGO coverage from the MNDNR (Bart Richardson), and downloaded the remainder of the county coverages from the SSURGO online database (Isanti, Crow Wing). Pine County did not have completed or useable SSURGO data at the time of this study.

Color Infrared (CIR) Aerial Imagery

The final data set used in this project included color infra-red aerial photographs (NAIP 2008 CIR JPEG2000) which are available for each county within the defined project area including all or portions of the following fourteen (14) counties: Anoka, Benton, Cass, Chisago, Crow Wing, Hennepin, Isanti, Mille Lacs, Morrison, Ramsey, Sherburne, Stearns, Washington, and Wright. According to the Minnesota Geospatial Information Office, "CIR imagery is good at penetrating atmospheric haze and for determining the health of vegetation. CIR imagery can also be useful for identifying plant species, estimating biomass of vegetation, assessing soil moisture, and assessing water clarity (i.e. turbidity)." Based on past field research, CCES ecologists have noted that ASP groundwater influenced shallow wetlands are often associated with somewhat unique CIR signatures (attribute classes). As part of this project, CCES was able to use GIS-based technology to classify existing CIRs for known signatures and patterns associated with documented ASP shallow groundwater wetlands.

The Modeling Process

Using the data layers described above, CCES created a GIS-based model to automate the process of spatially analyzing the entire project area in an effort to predict the potential locations and spatial extents of ASP groundwater influenced shallow wetlands. The modeling process was completed as follows:

Step 1: Correlation between Soil Types and Rare Species Locations to Determine Suitable Soils

Based on previously collected data, on-going field observations as well as herbarium notes, CCES field ecologists have long noted an association between select soil catenas, rare species locations, and known locations of ASP groundwater influenced shallow wetlands. To develop a GIS-based data layer which could depict this understanding and be used to inform the model which could predict additional locations of ASP groundwater influenced shallow wetlands CCES completed first completed an analysis to determine which soil types were most commonly associated with rare plant species known to occur within ASP groundwater influenced shallow wetlands (species are listed in **Table 1.0**, above).

To complete this portion of the assessment, the precise locations of 390 known rare species detections was intersected with the SSURGO soils data layer for the ASP Ecological Subsection. Based on this intersection, CCES ecologists were able to determine which soil types were most commonly associated with known rare features often found within ASP groundwater influenced shallow wetlands. Through this effort, CCES ecologists noted that there were nineteen (19) soil types which could be broken in to two major soil catenas associated with the 390 known rare features locations.

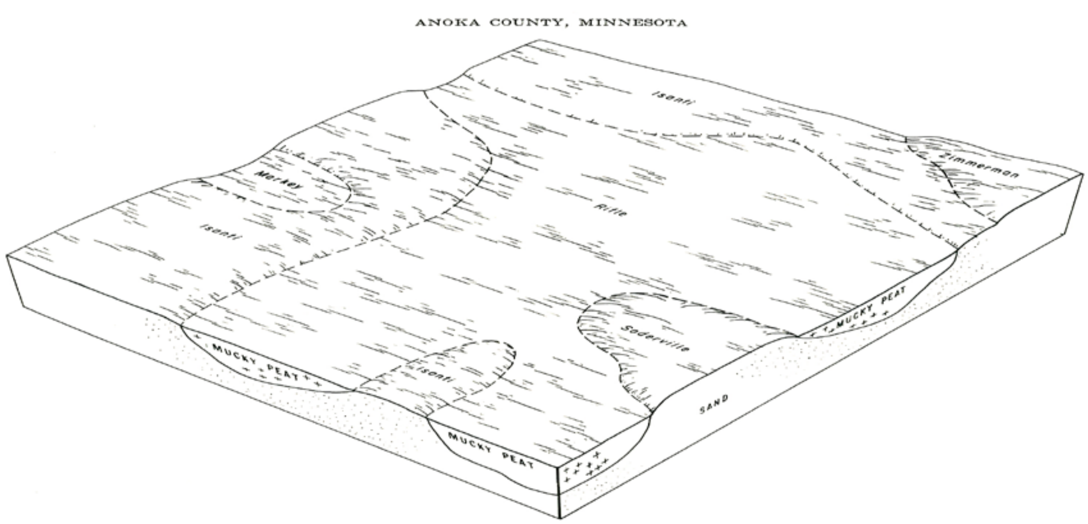


Diagram 1: Isometric cross-section of the Zimmerman, Isanti, Rifle soil catena (Anoka County Soil Survey)

These two catenas were generally separated geographically within the project area; Catena A soils were most abundant within the south central portion of the project area including Anoka, Isanti and Sherburne Counties while Catena B soils were most abundant in the north western portion of the project area including Benton, Morrison and Stearns County. Areas mapped by SSURGO as "Water" within the project area were included in the analysis but were analyzed separately. All remaining soil types were classified as "NON" meaning not suitable to support the subject wetlands and associated rare features. Once the soils were classified in to two catenas plus water, the soil types were further sorted by their assigned hydrologic group/landscape position, ranging from those within A1 or B1 - excessively drained, A2 or B2 - somewhat poorly drained to poorly drained, and A3 or B3 - very poorly drained (tending to be peat or muck soils). The breakdown occurred as follows in **Table 2.0.**

Table 2.0: Soils Associated with Rare Species and ASP Groundwater Influenced Shallow Wetlands

Soil Catena A		
Hydrologic Group	**Soil Name**	**# of Rare Species Occurrences**
A1	Zimmerman	45
A2	Isanti	142
A2	Soderville	41
A2	Lino	12
A2	Beaches	2
A3	Markey	74
A3	Rifle	28
A3	Seelyeville	5
Soil Catena B		
Hydrologic Group	**Soil Name**	**# of Rare Species Occurrences**
B1	Duelm	5
B1	Sartell	5
B1	Menahga	3
B2	Isan	7
B2	Cantlin	5
B2	Dundas	1
B2	Meehan	1
B2	Watab	1
B3	Prebish	4
B3	Dassel	3
B3	Lupton	2
WATER		
Water	Water	4
	Grand Total	**390**

Step 2: Determining Suitability by Catchment

Using the information obtained in Step 1 of the modeling process, CCES ecologists then worked to assign a suitability rating to each Level 07 minor watershed catchment located within the project area. The higher the suitability, the more likely the catchment was to contain ASP groundwater influenced shallow wetlands. Suitability was based on percent of suitable soils within each catchment using soils information as determined during Step 1. To complete Step 2, all soils classified within "Catena A or Catena B" were merged. The merged soils shapefile was then clipped to all Level 07 catchment boundaries. An analysis was then completed to calculate the percentage of each Level 07 minor watershed catchment that was comprised of soils suitable for supporting ASP groundwater influenced shallow wetlands. Catchments with the highest percentage of suitable soils, at least 50% by area of the catchment by soil Catena A, or at least 34% by area of soil Catena B, were determined to be of the highest priority for further investigation as described in step 3.

Step 3: Heads Up Delineation of Priority Analysis Areas

Catchments which contained at least 50% by area of suitable soils were displayed in a GIS. In addition, a suitable soils layer arranged by catena type was also displayed. Based on the extent of large and contiguous suitable soils areas a "heads up" digitizing approach was used to delineate eight Priority Analysis Areas of various sizes which would be targeted for additional analysis and refinement. The eight Priority Analysis Areas are depicted in **Appendix A, Figure 6**.

Step 4: Infra-Red Aerial Photography Analysis of Priority Analysis Areas

The final step in the modeling process was to complete a remote sensing analysis though the sampling of color infra-red aerial photographs within the eight Priority Analysis Areas. In order to complete this process, CCES utilized an automated sampling procedure, known as supervised and unsupervised image classification. This procedure was used to identify locations within the Priority Analysis Areas that displayed similar aerial photography attributes (infra-red pixel signatures), as compared to the attributes of known locations of ASP groundwater influenced shallow wetlands located in Anoka County. To complete this process, CCES first ran an unsupervised classification of the 2008 Anoka County NAIP CIR aerial photography using ArcGIS Spatial Analyst's unsupervised image classification tool. Through this unsupervised classification, the infra-red photograph of the Priority Search Area within Anoka County was classified into fifty (50) different attribute classes. Of these 50 attribute classes, CCES selected twelve (12) of these attribute classes that were commonly observed within known examples of ASP groundwater influenced shallow wetlands located in Anoka County (e.g. Blaine Preserve SNA, Anoka County Airport SNA, Pioneer Park, Woolan's Park, Carlos Avery WMA). The twelve attribute classes that were selected were reclassified as "true" and the remaining attribute classes were reclassified as "false". The result of this procedure was the creation of a new raster based signature file that could be used to complete a supervised classification procedure on the remaining Priority Analysis Areas. Through the completion of a supervised classification effort, all areas containing the "true" attributes were selected from the color infra-red aerial photography within all portions of the Priority Analysis Areas. This effort provided a final raster output which identified areas within the Priority Analysis Areas that displayed unique CIR photography signatures similar to known locations of ASP groundwater influenced shallow wetlands. In some instances, "true" attribute classes may include cropfields, areas of reed canary grass, and other vegetation types not associated with high quality ASP groundwater influenced shallow wetlands. To remove/reduce the occurrence of these areas, the raster output was clipped by select soils A2, A3, B2, B3, and Water (see Table 2.0, above), as these soil types are most commonly associated with ASP groundwater influenced shallow wetlands.

IV. Results

Results of Analysis to Determine Correlation Between Soil Types and Rare Species Locations within the Project Boundary

The results of the soils analysis described in Step 1 in the above methods section are summarized here. 349 of 390, or 89%, of known locations of select rare vascular plant species known to occur within ASP groundwater influenced Shallow Wetlands occur within "Soil Catena A" , the Zimmerman, Isanti, Lino, Soderville, Seelyeville, Rifle soil association, as described above and shown in Table 2.0. Our analysis revealed that this soil association, Catena A, is limited to certain portions of the Anoka Sand Plain and surrounding areas (see **Appendix A, Figure 4**) where Glacial Lake Anoka left lacustrine deposits. Within this soil Catena A, Catena A1, Zimmerman soils, are topographically highest in the landscape (although just slightly), and are excessively drained and the driest of this soil association. The Catena A2 Soils, Isanti, Lino, and Soderville soils are mesic to somewhat poorly drained to sometimes poorly drained transitional soils that occur on benches and shallow swales also formed by Glacial Lake Anoka. The Catena A3 soils, Seelyeville and Rifle Muck soils are organic peat soils at the lowest and wettest end of this soil association. These wet organic (A3) soils occur within topographical depressions formed by melt water, glacial lake bottoms and ice block depressions. According to our analysis, 197 of 390, or 50% of known rare plant detections occurred within "Catena A2" soils (Isanti, Soderville, Lino, Beaches). The A2 soils are the transitional soil types between well drained sands and poorly drained muck soils. However, our past field observations commonly note the entire soil Catena A is typically present when rare vascular plant features are encountered. Therefore, just the presence of Catena A2 soils alone, do not necessarily create suitable conditions for detecting ASP groundwater influenced shallow wetlands.

The second soil association noted during this analysis has been classified as soil Catena B. This second association of soils is also capable of supporting select rare vascular plant species commonly associated with ASP groundwater influenced shallow wetlands. Soil Catena B is an association of Duelm, Sartell, Menahga, Isan, Cantlin, Dundas, Meehan, Watab, Prebish, Dassel, and Lupton soils. 37 of 390, or 10%, of known locations of select rare vascular plant species known to occur within ASP groundwater influenced shallow wetlands were detected within Soil Catena B. Our analysis found that Soil Catena B, is concentrated more densely in the north western portion of our project boundary in Morrison and Crow Wing Counties. Soil Catena B1 (excessively drained) soils included Duelm, Sartell, and Menahga soil types and contained 13 of the 390 rare vascular plant species detections, 3%. B2 soils (moderately to poorly drained, transitional soils) included Isan, Cantlin, Dundas, Meehan, and Watab soil types and contained 15 of the 390 detections, 3%. Finally, B3 soils (poorly drained) included Prebish, Dassel, and Lupton soil types and contained 9 of 390 detections, 2%.

Finally, areas classified as "Water" were also classified separately as rare features also occurred within areas mapped by SSURGO as "Water". 4 of 390 rare vascular plant species, or 1% were located within areas mapped as "water". These species included *Potamogeton bicupulatus* and *Rotala ramosior* both of which commonly occur on shorelines or in areas of seasonal inundation or water level fluctuations. Given the habitat requirements of these species, "Water" was included in our overall analysis for this project. **Diagram 2**, below shows the distribution of rare vascular plant species by soil type.

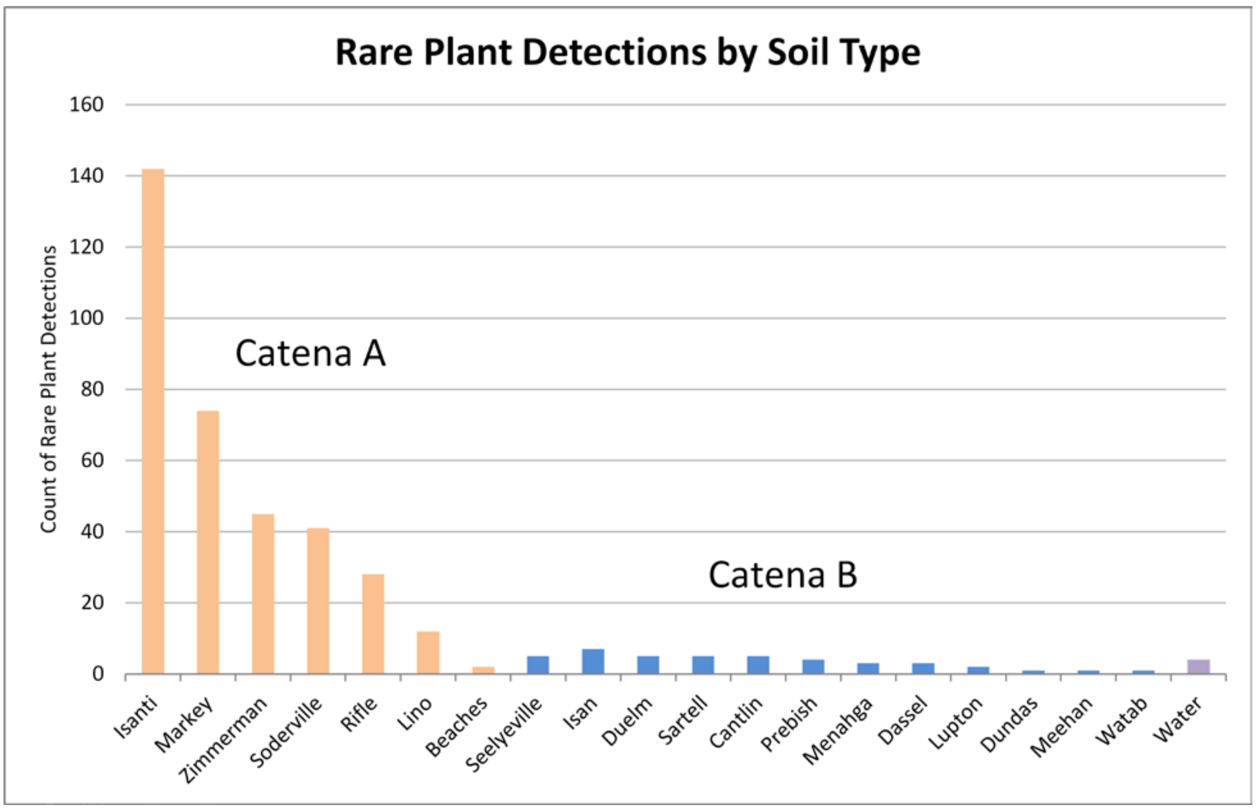


Diagram 2: Histogram depicting the number of rare vascular plant species located in each soil type, displayed by Catena.

Results of Analysis to Determine Suitability by Catchment

Results of the percent soil suitability rating by catchment described above in Step 2 are depicted in **Appendix A, Figure 5a and 5b.** For soil Catena A, catchments comprised of at least 50% suitable soils were considered to be of high priority and warranting further investigation. Of the 341 catchments located within the project boundary, 74 catchments, or 22% of catchments, contained at least 50% cover by area of suitable soils from soil Catena A. These 74 catchments totaled 559,304 acres in size, or 875 square miles. Therefore, of the total project area (3.3 million acres), 17% of the total area as described by catchments had enough dominance by soils categorized in soil Catena A to necessitate additional analysis.

The same procedure was completed for soil Catena B, with catchments comprised of at least 34% suitable soils were considered to be of high priority and needing further analysis. Of the 341 catchments located within the project boundary, twelve catchments, or 3% of catchments, contained at least 34% cover by area of suitable soils from soil Catena B. These twelve catchments totaled 121,825 acres in size, or 190 square miles. Therefore, of the total project area (3.3 million acres), 3% of the total area as described by catchments had enough dominance by soils categorized in soil Catena B to necessitate additional analysis (see **Appendix A, Figure 5b**).

Table 3.0: Results of Analysis to Determine Most Suitable Areas by Catchment

Soil Catena A		
No. of Catchments with 50% Areal Cover by Soil Catena A	**Total Acres of Selected Catchments**	**% of Total Project Area 3.3 Million Acres**
74	559,304 Acres	17%
Soil Catena B		
No. of Catchments with 34% Areal Cover by Soil Catena B	**Total Acres of Selected Catchments**	**% of Total Project Area 3.3 Million Acres**
12	121,825 Acres	3%
Totals		
96	**681,129**	**20%**

Results of Analysis to Determine Priority Analysis Areas

Once priority catchments were selected based on percent areal cover by suitable soils, a heads up delineation was completed as described above in Step 3 of the modeling process. As a result of this step in the process, priority areas for further analysis were more thoroughly defined by contiguous areas of suitable soils. A total of eight areas were selected as final Priority Analysis Areas. These final areas were assigned a name based on their geographical location. Geographical names and total size in acres and square miles are provided in Table 4 below. There areas comprise 1,011,698 acres of the total 3.3 million acre project area (or 30.6% of the total project area). Locations and extents of these eight areas are depicted in **Appendix A, Figure 6.**

Table 4.0: Eight Priority Analysis Areas

Priority Analysis Area Name	Area in Acres	Area in Square Miles
Glacial Lake Anoka	642,511	1003.92
St. Cloud	4,382.09	6.84701
Watab Township	17,026.7	26.6042
Lake Oneka	12,521.1	19.5643
Crane Meadows	126,135	197.086
Crow Wing	180,165	281.507
Fort Ripley Township	3,721.84	5.81537
Roosevelt Township	25,235.5	39.4304
Grand Total	**1,011,698 Acres**	**1,580.8 Square Miles**

Color Infra-Red Aerial Image Classification Results and GIS Raster Output

The 2008 NAIP color infra-red (CIR) aerial images for each county within the Priority Analysis Areas were analyzed using ARGIS 10.4 Spatial Analyst's supervised and unsupervised image classification tools. 50 vegetation signature classes were classified for each county CIR. Known ASP groundwater influenced shallow wetland reference sites were compared to the supervised image classification raster classes.

Of the 50 raster classes described, vegetation classes 23, 24, 31-42 (fourteen of fifty total classes) were most consistent with known ASP groundwater influenced shallow wetland reference sites with moderate to high quality herbaceous vegetation. Furthermore, the fourteen vegetation classes corresponded with 256 of 390 (65.6%) of the rare vascular plant feature points. The spatial distribution of these fourteen vegetation signature classes were overlain and clipped to priority soil types A2, A3, and B2 and B3 with the eight Priority Analysis Areas. 463,000 acres (approximately 14% of the total project area) of land areas exhibited both high priority soils and were located within the Priority Analysis Areas. The resulting raster coverage depicts priority vegetation signatures (from 2008) occurring within priority soils and landscape positions within our identified Priority Analysis Areas. This area comprises approximately 207,193.97 acres of the project area, about 6% of the total project area (see **Appendix A, Figure 7**). This raster coverage (named ASP_VEGCIR) is the final product of the modeling process. This final predictive model output provides spatial information as to where potential moderate to high quality ASP groundwater influenced shallow wetlands are most likely to occur throughout the Anoka Sand Plain. Appendix A, Figure 8 provides

VI. Discussion

Using known locations of rare indicator plant species and know ASP groundwater influenced shallow wetlands, CCES developed a GIS based model that predicts the likely pre-settlement extent and present day locations of moderate to high quality ASP groundwater influenced shallow wetlands with the Anoka

Sand Plain ecological section and adjacent landscapes. As with all models, our model is limited by the quality of the input data. This model is limited by the number of known reference site locations and their limited spatial concentration to Anoka County, the limited number and spatial accuracy of rare plant indicator species locations, and most of all the limited quality, resolution, and age (i.e. 2008) of the available NAIP color infra-red multi-spectral digital aerial photographs for the project area. Nonetheless, CCES was able to narrow down a 3.3 million acre potential search area to eight Priority Analysis Areas consisting of 1.0 million acres. Within the Priority Analysis areas, CCES was able to further define 207,193.67 acres that are likely to support ASP groundwater influenced shallow wetlands that may support moderate to high quality vegetation and/or rare plant species associated with these systems.

These data may be used to prioritize and guide assessment, field survey, and conservation efforts with the Anoka Sand Plain and adjacent landscapes in the future. Additional detections of rare species and new detections of high quality examples throughout the project area will further enhance and refine the model inputs and outputs. Furthermore, access to improved imagery, such as current, higher resolution CIR aerials, or hyper-spectral imagery will further improve our ability to discern representative native vegetation assemblages from non-representative herbaceous cover.

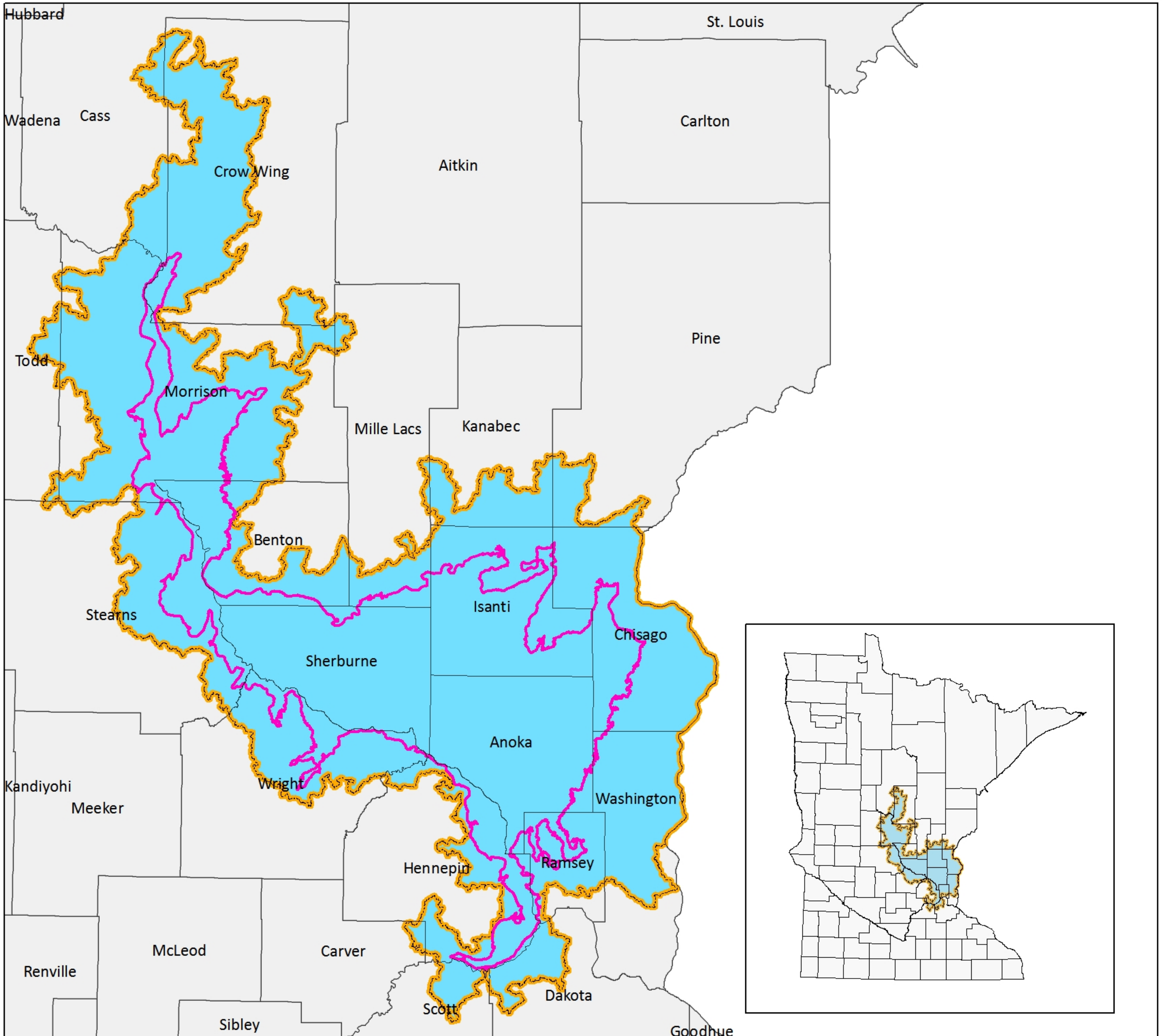
The next step is to use the model outputs to direct field surveys within priority areas. These would likely be conducted within large public lands and accessible private lands with high potential. Furthermore, we recommend that the identified Priority Analysis Areas should be used by the Minnesota Department of Natural Resources to inform local municipalities and watersheds as to where focused rare plant surveys and wetland assessments should be completed.

VII. Conclusion

Critical Connections Ecological Services has completed a remote sensing analysis of a 3.3 million acre project area that encompasses the entire 1.1 million acre Anoka Sand Plain Ecological Subsection. The purpose of this remote sensing analysis was to predict potential locations of ASP groundwater influenced shallow wetlands as these wetland systems are known to contain unique native species assemblages including rare vascular plant species such as *Xyris torta* (MN-Endangered), *Juncus marginatus* (MN-Endangered), *Aristida longespica* var. *geniculata* (MN-Endangered), and *Polygala cruciata* (MN-Endangered). CCES utilized known locations of rare vascular plant species, associated soil catenas, and color infra-red aerial photograph imagery to develop a GIS-based spatial model that could prioritize areas within the project boundary down to the Minnesota DNR Level 07 Minor Watershed level that would be most likely to contain ASP groundwater influenced shallow wetlands. The results of this modeling effort will be used to direct future ground-truthing, research, and survey efforts which will allow for better rare plant and habitat mitigation and protection efforts. Of the 3.3 million acre project area, CCES has created a spatial model which has targeted approximately 207,000 acres (or 6% of the total project area) which should become the priority areas for next steps pertaining to protection of these unique ASP groundwater influenced shallow wetlands.

APPENDIX A

SUPPORTING FIGURES



Appendix A, Figure 1
Location Map and Project Boundary

Key to Features

- Project Boundary Based on DNR Catchments
- Anoka Sand Plain Subsection
- County Boundaries

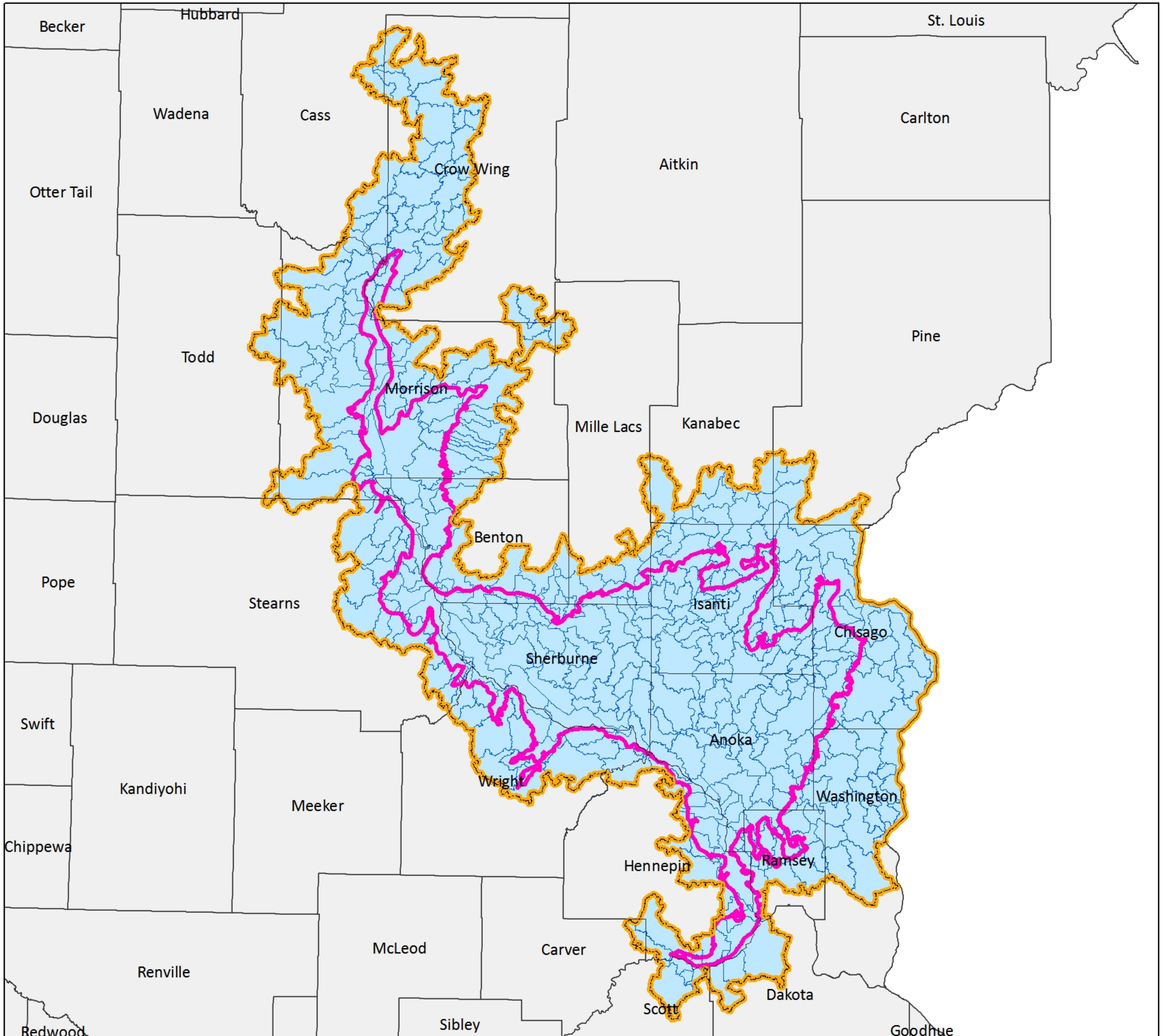
Total Project Size: 3.3 Million Acres

Critical Connections Ecological Services, Inc.

N

0 10 20 40 Miles

December 31, 2016



Appendix A, Figure 2
MN DNR Level 07
Minor Watershed Catchments

Key to Features

- Mn DNR Level 07 Watershed Catchments*
- Project Boundary
- Anoka Sand Plain Subsection
- County Boundary

Level 07 minor watershed catchments within the project boundary range in size from1,000 acres up to 40,800 acres in size

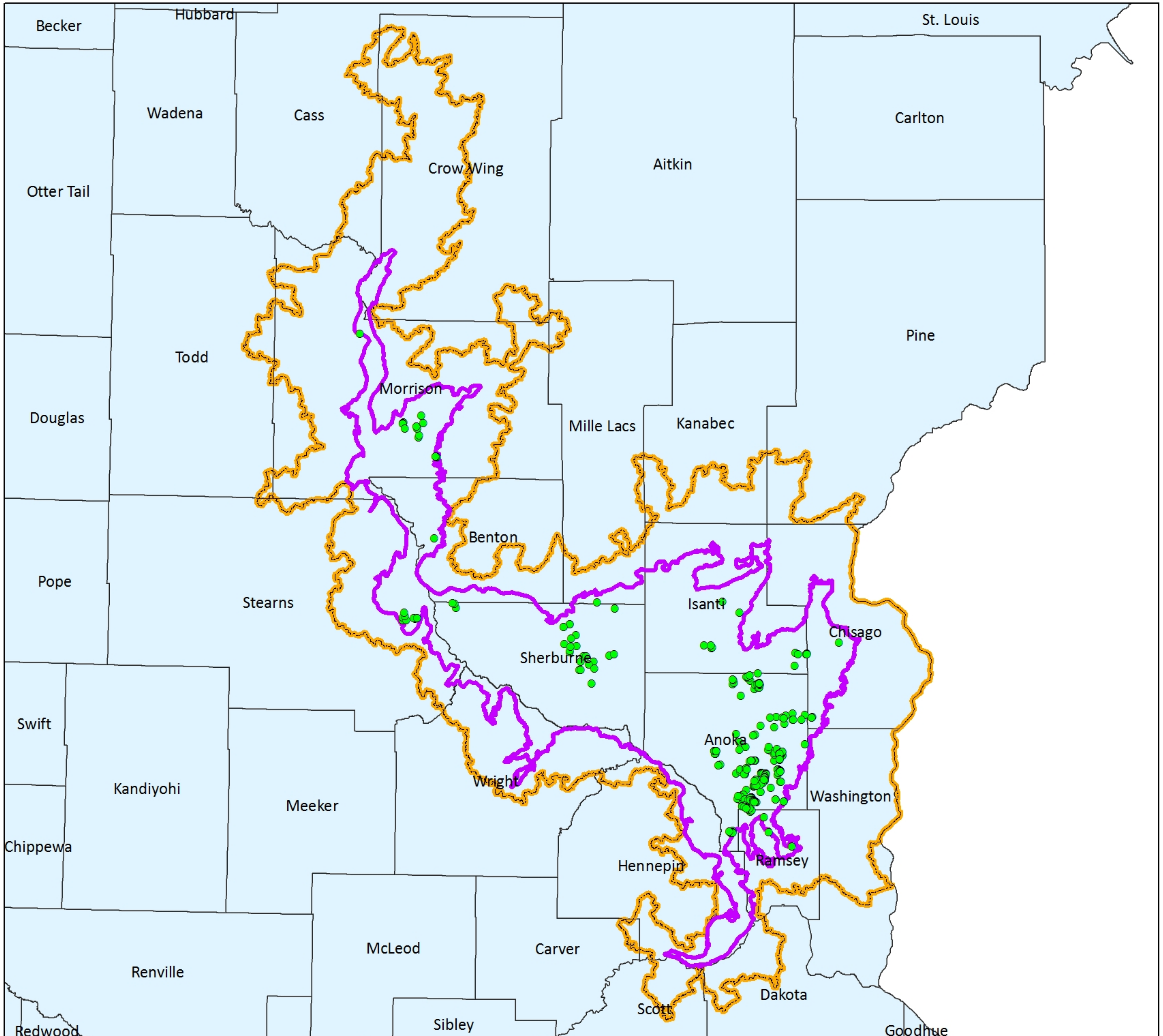
Critical Connections Ecological Services, Inc.

N

0 10 20 40 Miles

December 31, 2016

Appendix A, Figure 3
Locations of Rare Vascular Plant Species Associated with ASP Groundwater Influenced Shallow Wetlands



Key to Features

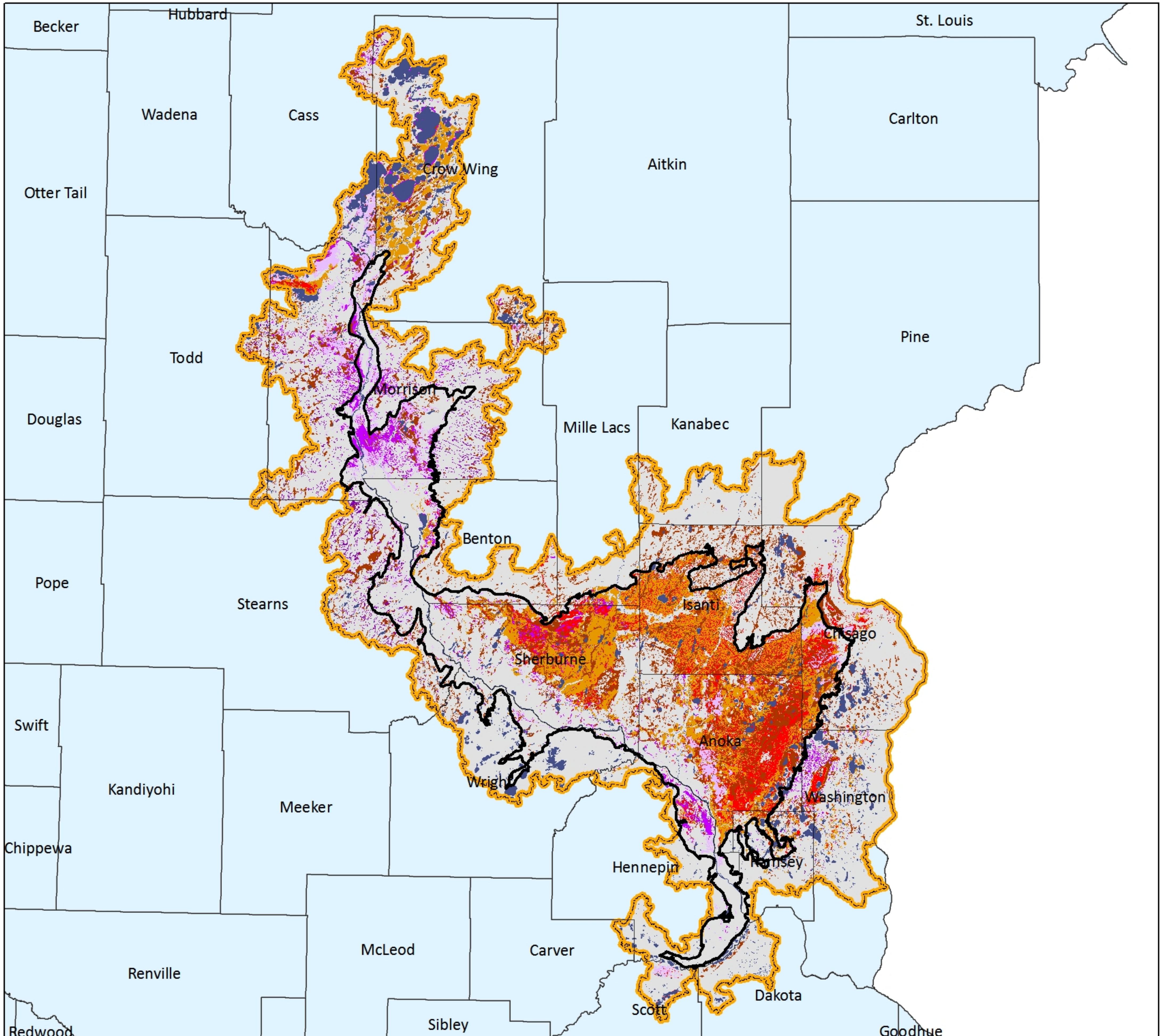
- 390 Rare Plant Locations Used in Analysis
- Anoka Sand Plain Subsection
- Project Boundary
- County Boundary

Critical Connections Ecological Services, Inc.

N

0 10 20 40 Miles

December 31, 2016



Appendix A, Figure 4
Soils Associated with Rare Species and ASP Groundwater Influenced Shallow Wetlands

Key to Features

- Project Boundary
- Anoka Sand Plain Subsection
- County Boundary

Suitable Soil Types

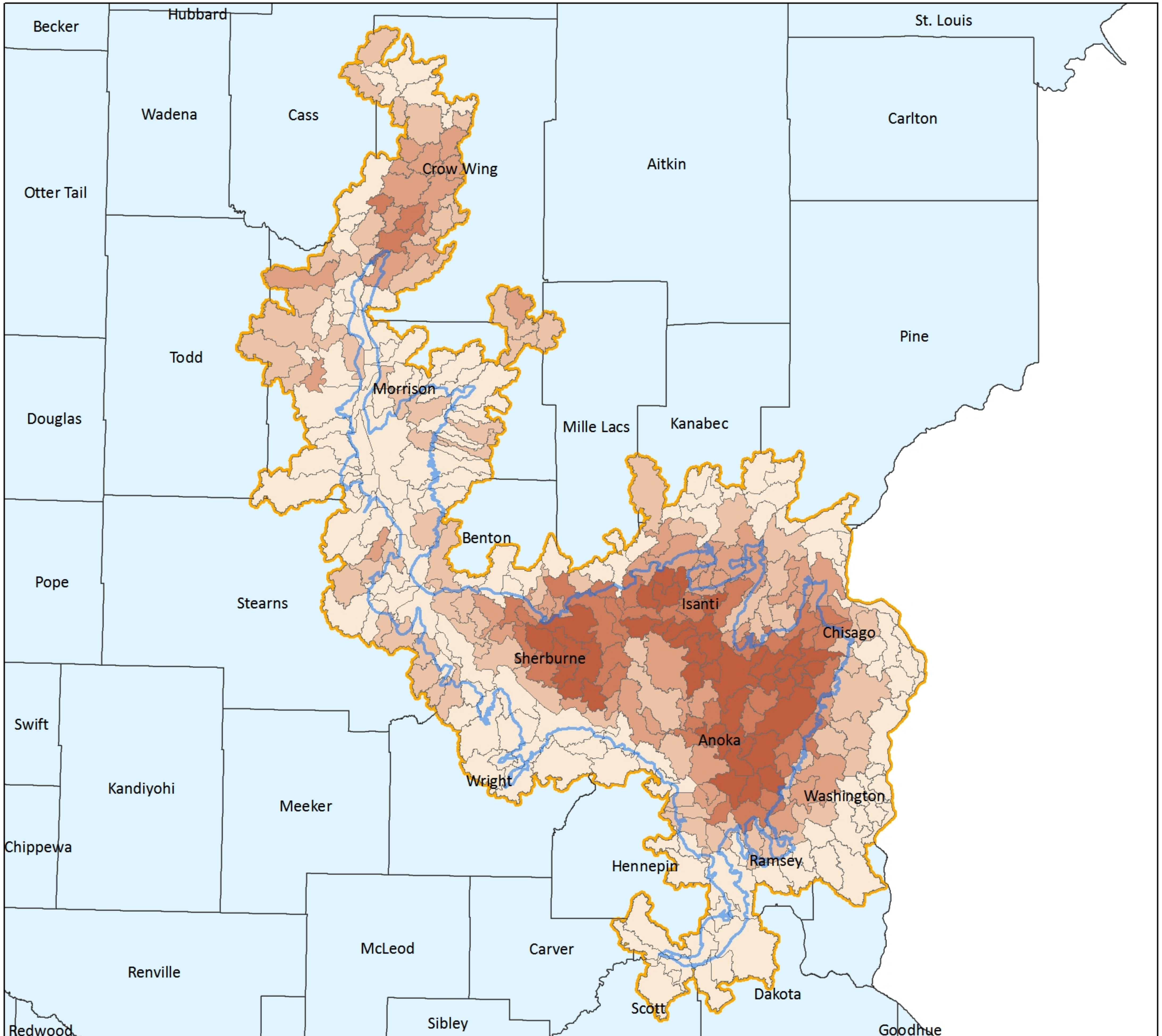
- A1: Zimmerman
- A2: Isanti, Soderville, Lino, Beaches
- A3: Markey, Rifle, Seelyville
- B1: Duelm, Sartell, Menahga
- B2: Isan, Cantlin, Dundas, Meehan, Watab
- B3: Prebish, Dassel, Lupton
- Non-Suitable Soils
- Water

Critical Connections Ecological Services, Inc.

N

0 10 20 40 Miles

December 31, 2016



Appendix A, Figure 5a
Percent Soil Suitability Rating by Catchment, Catena A

Key to Features

Percent of Suitable Soils by Catchment

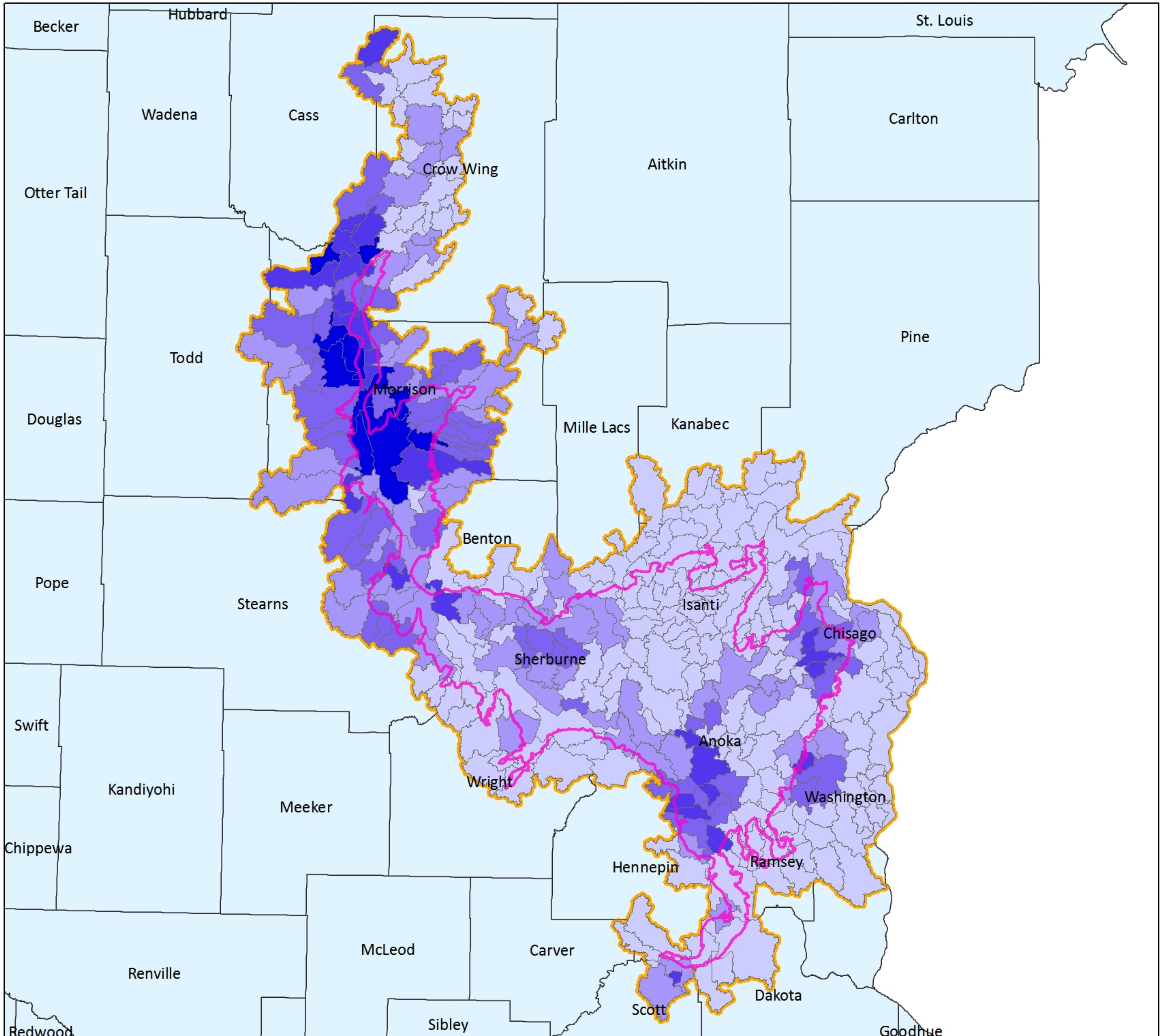
- 0% to 10%
- 10% to 25%
- 25% to 50%
- 50% to 75%
- 75% to 100%
- Project Boundary
- County Boundaries
- Anoka Sand Plain Ecological Subsection

Critical Connections Ecological Services, Inc.

N

0 10 20 40 Miles

December 31, 2016



Appendix A, Figure 5b
Percent Soil Suitability Rating by Catchment, Catena B

Key to Features

Percent of Suitable Soils by Catchment

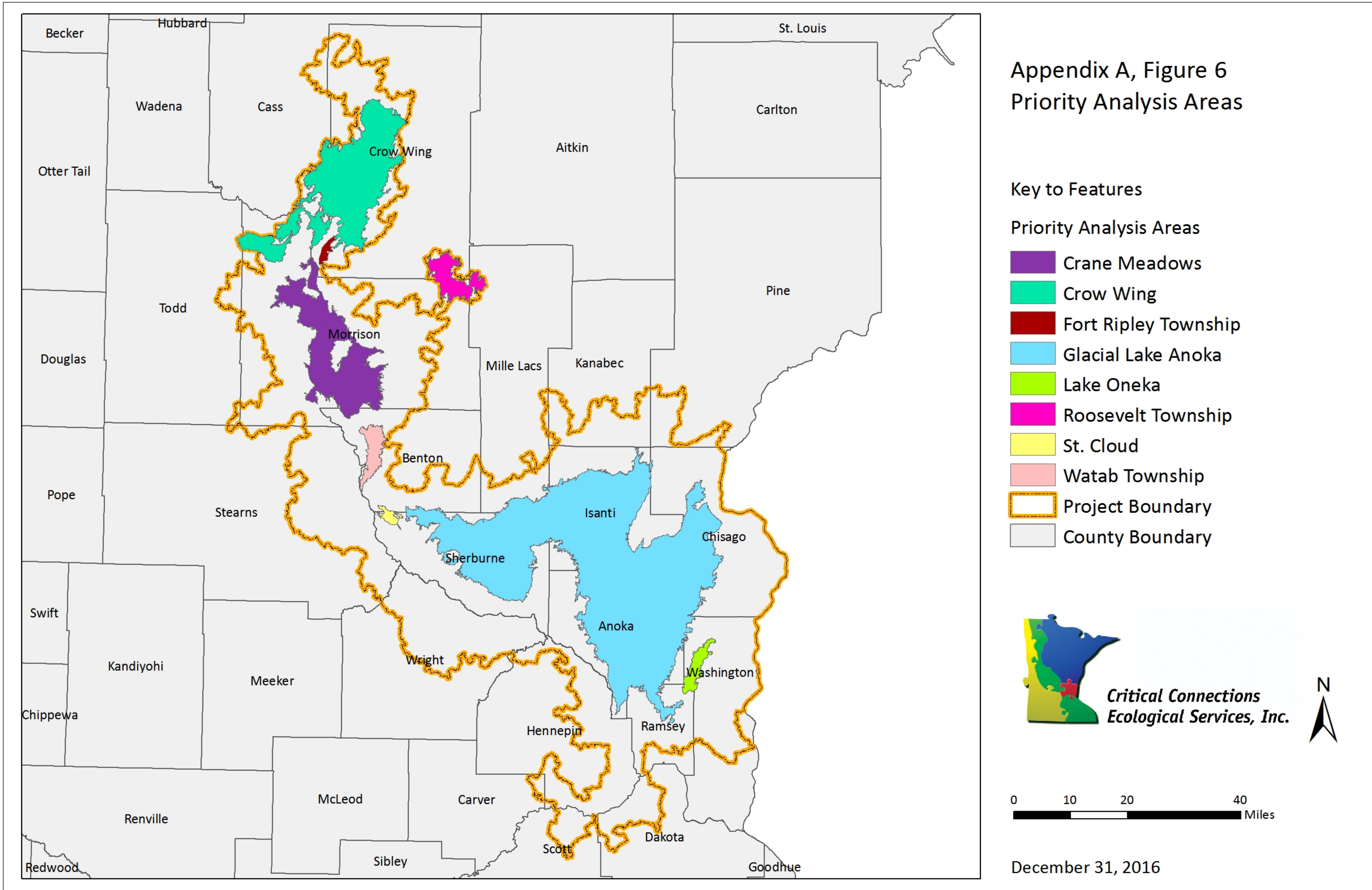
- 0% to 3%
- 3% to 8%
- 8% to 18%
- 18% to 34%
- 34% to 70%
- County Boundaries
- Project Boundary
- County Boundaries
- Anoka Sand Plain Subsection

Critical Connections Ecological Services, Inc.

N

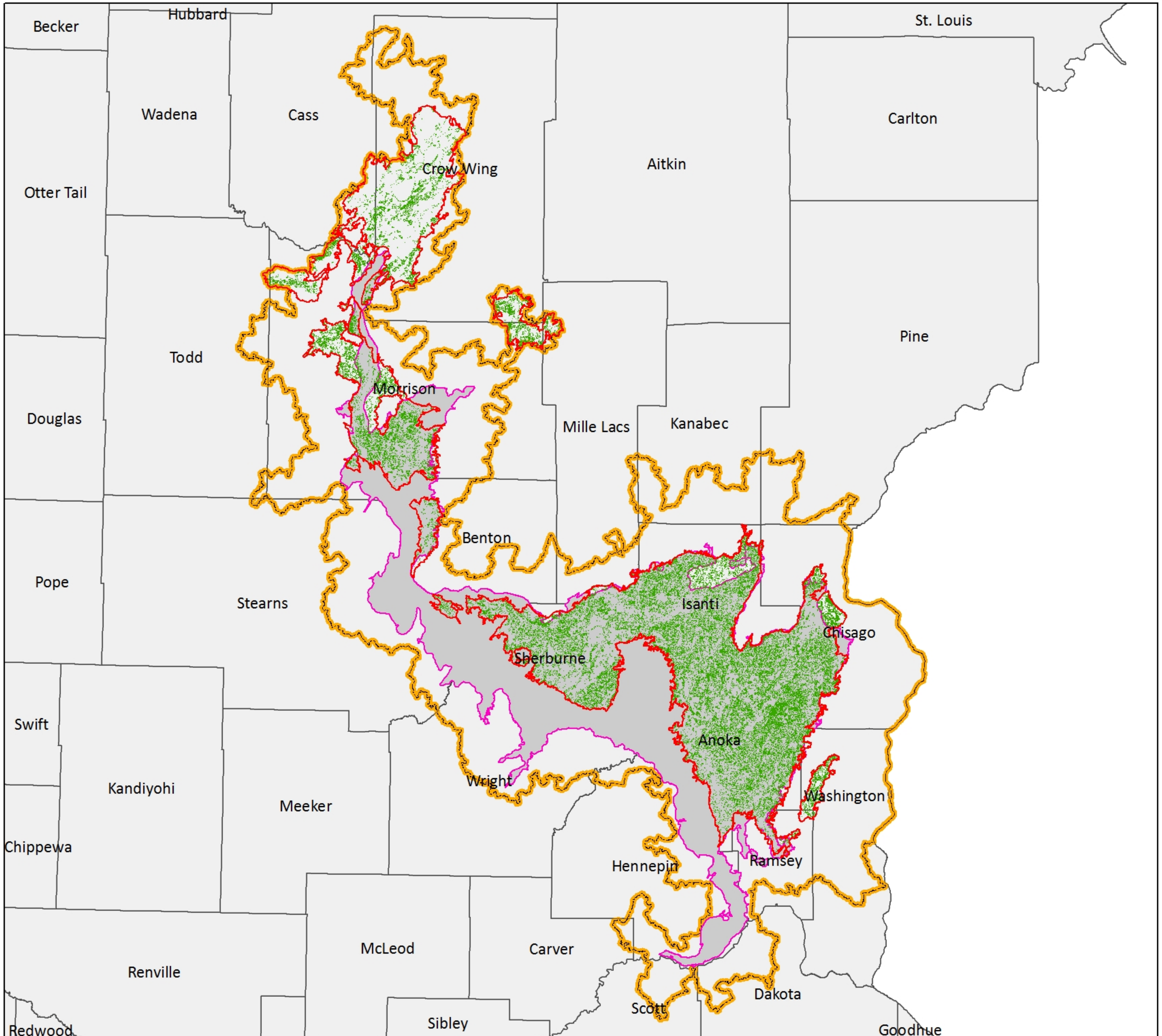
0 10 20 40 Miles

December 31, 2016



Appendix A, Figure 6
Priority Analysis Areas

Appendix A, Figure 7
Final Model Output Based On: Suitable Vegetation Signatures And Priority Soil Types



Key to Features

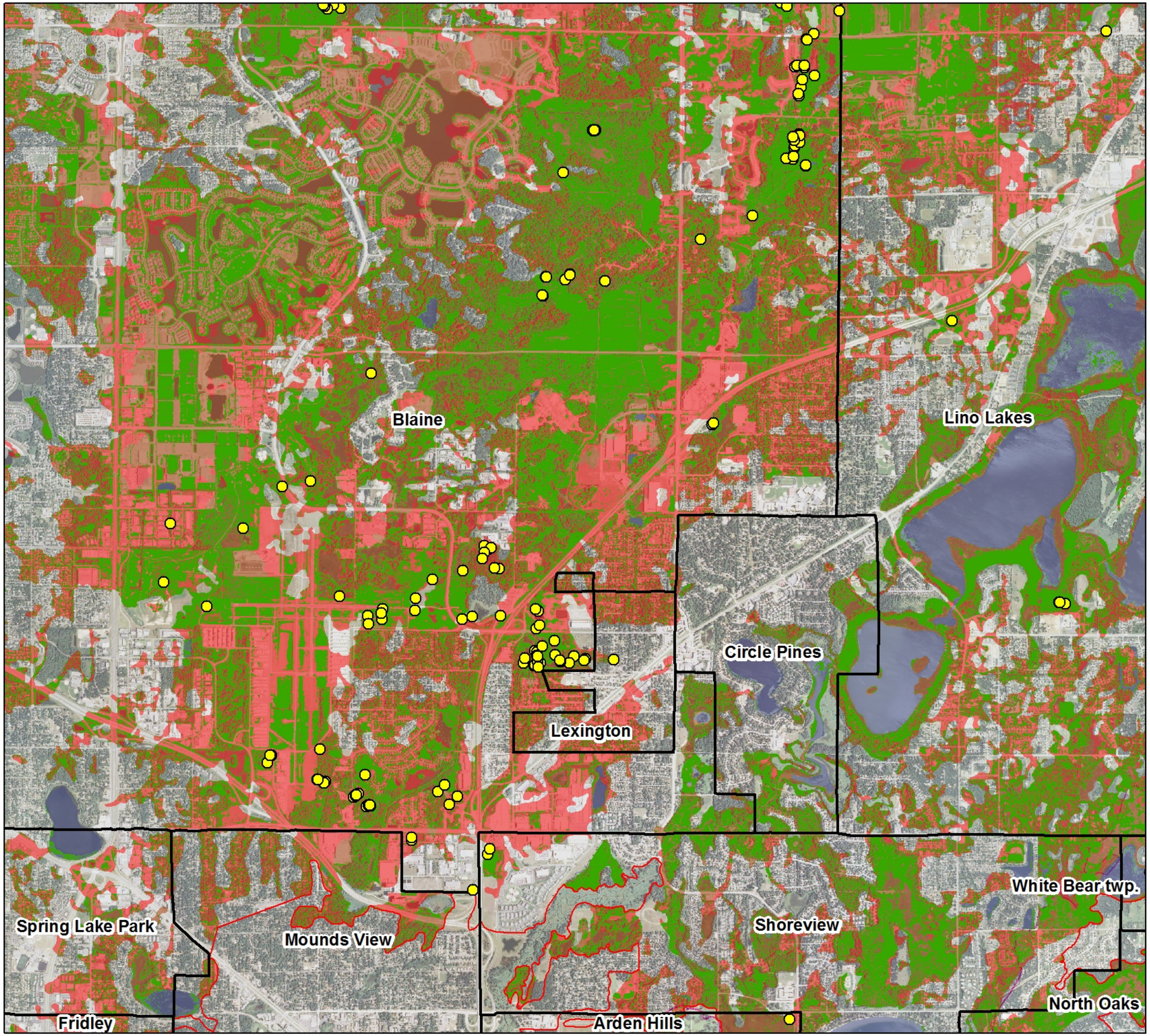
- Project Boundary
- Anoka Sand Plain Subsection
- Priority Analysis Areas
- County Boundaries
- 2008 Color Infra-Red Aerial Pixels With Priority Soil Types (A2, A2, B2, B3, Water) and Compatable Vegetation Signatures (Classes 24, 31-42 of 50)

Critical Connections Ecological Services, Inc.

N

0 10 20 40 Miles

December 31, 2016



Appendix A, Figure 8
Example of Final Model Output
SE Blaine and SW Lino Lakes
Based On:
Suitable Vegetation Signatures
And Priority Soil Types

Key to Features

- City Boundaries
- Compatible 2008 CIR Pixel Vegetation Signatures Suitable Prioirty Soils (A2, A3)
- A2 Soils with Non-Compatible CIR Vegetation Signatures
- A3 Soils with Non-Compatible CIR Vegetation Signatures
- Water with Non-Compatible CIR Vegetation Signatures
- Rare Vascular Plant Records Indicator Species of ASP Groundwater Influenced Shallow Wetlands

Critical Connections Ecological Services, Inc.

N

0 0.5 1 2 Miles

December 31, 2016