Hotspot Analysis of Potential Vernal Pool Locations in Southeastern Wisconsin

Anna Ormiston, Madeline Kubica and Nick Exley

Introduction

1.1. Background

Vernal pools are temporary wetlands that fill depressions with snowmelt and rain water in the early spring, and dry by summer or the beginning of fall (Bernthal et al. 2014; Wetlands of Wisconsin 2016). Vernal pools are critical habitat that support a diverse array of taxa. Amphibian species take advantage of ephemeral ponds, because these pools do not have fish that pose a predation risk to amphibian eggs and larva and last long enough for the development period of breeding amphibians (Bernthal et al. 2014; Thomas 2010). To be considered a vernal pool, pools must dry up at least 50 % or show the bottom of the pool (Thomas 2010). Vernal pools are in forested areas but can be found in open areas that were historically forested (Bernthal et al. 2014). Vernal pools are found in close proximity to upland forested habitats, which are required by adult amphibian species (Thomas 2010).

Vernal pools provide optimal breeding locations for a variety of amphibian species, which are strongly tied to water in their development process (Calhoun and deMaynadier 2008). Migrating salamander species that inhabit vernal pools in southeastern WI include the following: Tiger Salamanders (*Ambystoma tigrinum*), Blue Spotted Salamanders (*Ambystoma laterale*), Spotted Salamanders (*Ambystoma maculatum*) and Four-Toed Salamanders (*Hemidactylium scutatum*) (USGS Upper Midwest Environmental Science Center 2010). Additionally, migrating frog species including Wood Frogs and Spring Peepers use vernal pools for breeding (Yeagar 2016). These amphibian species migrate to vernal pools during the first warm spring rains, which puts them at risk to potential hazards such as road crossings (Beebee 2013). University of Missouri herpetologist, Raymond Semlitsh (1997), created the phrase "life zone" about protection of amphibian species. The life zone is the minimum area, including the pool, necessary for the protection and maturation of juvenile and adult amphibian species. The concept of a "life zone" which will be the basis for the size of the buffers used around the vernal pool locations. The maximum life zone area for a WI amphibian species is the Wood Frog's life zone of 800.1m

(2625 ft), which is the maximum area required for the maturation of the Wood Frog (Semlitsch 1997).

There are several environmental factors that define presence of vernal pools. Pools are often located in depressions near upland forested habitat. Glacial history plays a key role in determining the presence of vernal pools in the landscape. Vernal pools are often found in glacial moraines and glacial lake plains (Calhoun and deMaynadier 2008). Vernal pools have hydric soils, which are dark rich soils that have been chemically changed due to long periods of inundation (Thomas et al. 2010; Smith, D. W. 1995). Soil texture of vernal pools is important because certain soils retain water longer. Vernal pool soil texture is characterized by fine silts and clays, which retain water (Thomas et al. 2010; Smith, D. W. 1995). Vernal pools can be found in areas where bedrock is conducive for pooling water due to bedrock type and depth. The closer the bedrock is to the surface, the more likely pooling can occur, because of low water infiltration (Calhoun and deMaynadier 2008).

There are several anthropogenic threats to vernal pools and to amphibian species. Habitat fragmentation from land use such as urbanization, and agriculture threatens connectivity of amphibian life zones. Additionally, roads can intersect amphibian life zone habitat, which disrupts the connectivity from upland habitat to pools. Amphibian populations are put at risk, because they will still cross the roads to get to the pools, but traffic could potentially eliminate a large number of individuals during spring migrations (Beebee 2013). Finally, wetlands are often thought to be biological indicators when it comes to pollution. Proximity to pollution such as herbicides, pesticides, fertilizers, wastewater, solvents, road salts and fuels can affect vernal pool conditions and be detrimental to amphibian health (Taylor et al. 2005). Amphibians are closely connected to water due their life history and development. They are often thought as bio-indicators, due to their life history being so closely connected to water and their semi-permeable skin (Taylor et al. 2005). This sensitivity to environmental stressors is an important reason for mapping vernal pools, so these bio-indicator species can be monitored.

Due to their small size, temporary nature and location in forested areas, vernal pools are difficult to map at a large scale. Several techniques have been tested in attempt to alleviate the time and monetary cost it takes to find vernal pools. Bourgeau-Chavez et al. (2016) utilize SAR ALOS PALSAR data, LiDAR data, DEM products and random forest classification to find vernal pools.

Bernthal et al. (2009) used aerial photo interpretation via stereo-pair images along with topographic contours and soil type information. Another study by Faccio et al. (2016), found high-resolution spring (no leaves on trees) CIR imagery and LiDAR intensity data as successful methods to predict vernal pools.

1.2. Capstone Statement

Vernal pools are critical breeding habitats for migrating amphibian species. Due to the small scale, ephemeral nature, and varied locations of vernal pools, efforts to protect these amphibian species can be difficult. Our goal is to locate potential hotspots of vernal pools in southeastern Wisconsin and determine whether those potential hotspots align with environmental variables.

Study Area/ Conceptualization/Implementation/Methods

2.3 Selection of Study Area

The following study focuses on southeastern Wisconsin (Figure 1), including the following: Fond du Lac, Sheboygan, Ozaukee, Milwaukee, Washington, Racine, Waukesha, and Kenosha counties. Southeastern Wisconsin is composed of a variety of urban, suburban, rural and uninhabited areas. Southeastern Wisconsin counties were selected for the study extent because confirmed vernal pools (CVPs) are located within these counties (Bernthal et al. 2014).

2.1. Conceptualization

The following project was broken down into the key concept: Pool Locations. Variables, operationalized variables and data layers are discussed sections 2.2.1 and 2.2.2.

2.2.1. Key Concept: Pool Locations

Figure 1 describes the variables, operationalized variables and data layers for the Pool Locations Key Concept. The following variables define habitat and landscape that is conducive to vernal pools as discussed in Section 1.1.

Elevation and Slope

Elevation and slope was operationalized by using a Boolean value from a 10-meter Digital Elevation Model (DEM) to create a topographic position index image (TPI). TPI calculates the mean elevation of a raster pixel based on the pixels surrounding it.

Isolated Depressions

Isolated depressions were operationalized using a Boolean value using a 10 m DEM. Vernal pools by definition are isolated depressions unrelated to hydrology.

Potential Pool Sites

Another variable included in our conceptualization was potential sites, which will be operationalized by a Boolean value using ALOS PALSAR radar imagery, including a spring thresholded image, a summer image and a seasonal change image. The methodology on obtaining this variable is described is section 2.3.1 – 2.3.3.

Bedrock Type

Another variable used to determine optimal vernal pool locations was bedrock type. The operationalized variable was dolomite, which is the type of bedrock that is the optimal type for water retention for vernal pools.

Bedrock Depth

Bedrock depth is another variable that determines vernal pool location. Bedrock close to the surface of the ground allows for water retention, which is a factor that allows for vernal pools. The operationalized variable for this was bedrock presence occurred less than 5 feet below the surface.

Water Table Depth

Water table occurring close to the surface allows for conditions that favor pooling of water to occur. The operationalized variable used for this was a water table that was less than 20 feet was a favorable condition for potential vernal pool sites.

Soil Hydrology

Soil hydrology is another variable that dictates the presence of vernal pools. The operationalize variable for soil hydrology is the presence of fine silts and clays, which holds water to create ephemeral ponds. Hydro group B soils is the group that meets this optimal condition of retaining water with some infiltration. A USGS soil map will be utilized to access this data.

Landcover

Vernal pools occur in forested regions and in areas near wetlands. The operationalize variable will be these two types of landcover classes, where forested areas will be considered the most optimal land cover class and wetlands will be considered the second most optimal class.

Remote Sensing Methods for Potential Pool Locations

2.3.1 Remote Sensing Datasets

ALOS PALSAR L-Band, Fine Single Beam, HH polarization imagery and Wisconsin DNR (WDNR) 10-meter DEM are the datasets used to evaluate the study area for potential vernal pools (PVPs) as described in the supervised random forest classification using SAR data methodology of the Bourgeau-Chavez et al. study (2016). L-band radar data can penetrate cloud cover and forest canopy, allowing for the backscatter of vernal pools to be received (Bourgeau-Chevez et al. 2016).

2.3.2 SAR Data

The following SAR data method was conducted as described in the Bourgeau-Chevez et al. (2016). ALOS PALSAR is an archival synthetic aperture radar product (2006-2011) available from the Alaska Satellite Facility (ASF). Images over the study area with no trace of rain within the 24 hours prior to the collection date (to reduce backscatter interference) were acquired through ASF for the wet (spring) and dry (summer) seasons. Images that were radiometrically corrected, georeferenced to UTM, and geocorrected to each other were downloaded from ASF. Spring images were mosaicked together to produce an image of our full study area extent and the same was done for the summer images. The spring mosaic and summer mosaic were converted using the raster calculator to decibels (dB) and filtered to reduce speckle. First, the spring mosaic was thresholded to show pixels only with backscatter values of -6.23 Db or greater because this value is indicative of flooded forest (Bourgeau-Chevez et al. 2016). This value was selected based on values of pixels verified pool locations in the spring image. Using the raster calculator, the spring image was subtracted from the summer image. The resulting seasonal change image showed that negative areas were indicative of drying suggesting potential vernal (PVP) locations (Bourgeau-Chevez et al. 2016).

2.3.3. WDNR 10 m DEM

The following two 10 m DEM products were derived based on the methods described in the following SAR data method was conducted as described in Bourgeau-Chevez et al. (2016). The WDNR 10 m DEM is derived from the National Elevation Dataset. Two products were created from the 10 m DEM: an isolated depressions map and a topographic position index (TPI). Using hydrological GIS tools, a depression less DEM was made. This depression-less DEM product was then subtracted from the original 10 m DEM to create the isolated depressions map (Bourgeau-Chevez et al. 2016). Isolated depressions are independent of hydrology, which in theory defines the depression characteristic of a vernal pool (Bourgeau-Chevez et al. 2016). TPI allows for slope to be interpreted and elevation to be averaged. For this study's TPI, pixels identified as lower than their eight surrounding neighbors were then filled to the level of their lowest neighbor (Bourgeau-Chevez et al. 2016).

2.4. Supervised Classification-Random Forests (RF) Classifier

The random forest classification method using 10 m DEM products and ALOS PALSAR imagery was modeled after the methods described in the following SAR data method was conducted as described in the Bourgeau-Chevez et al. (2016). The ALOS PALSAR spring thresholded image, ALOS PALSAR summer image, ALOS PALSAR seasonal change image, isolated depressions map, TPI, vernal pool training polygons derived from the verified vernal pools (VVPs) (Bernthal et al. 2014), and non-vernal pool (NVPs) training polygons were inputted into a Random Forests (RF) classifier. RF is a machine learning supervised classification method that utilizes multiple decision trees. The output of the classifier will generate potential vernal pools (PVPs) (Bourgeau-Chevez et al. 2016).

2.5. Accuracy Assessment

To assess the accuracy of the PVPs map, an error matrix will be created to evaluate the user's, producer's, and overall accuracies. The validation data used to assess accuracy will be derived from the CVPs. We will split the CVPs into polygons that will be used as training data and polygons that will be used as validation data (Bourgeau-Chevez et al. 2016).

GIS Methods for Suitable Areas for Potential Pool Locations

The goal is to identify areas in southeastern Wisconsin that meet the specific conditions for vernal pool habitat. Bedrock type, bedrock depth, water table depth, soil hydrology and landcover layers were created using the conceptualization process described in Section 2.2.1 (Figure 2). To obtain optimal sites of potential pool locations, raster layers showing land cover, soil hydrology, depth to bedrock, bedrock type, and depth to bedrock were reclassified to score certain features higher (operationalized variables) than others. The original raster layers representing the relevant features of land cover, soil hydrology, bedrock type, depth to bedrock and depth to water table in the appendix (Figures A, B, C, D, and E). The optimal assignments for each variable are the following: optimal bedrock depth was less than 5 feet (score =100), optimal bedrock type was dolomite (score =100), optimal water table depth was less than 20 feet (score = 100), soil hydrology was soil group type B which represents fine silts and loamy clays that have some water infiltration (score = 100) and land cover was forested areas (score =100) and wetland areas (Score = 75).

After all variables were reclassified a weighted sum overlay was conducted to produce optimal sites of vernal pool locations. All variables were weighted equally. Since, this provides an output with general areas of vernal pools, it is necessary to overlay the verified vernal pools (WDNR) and the random forest classified potential pool sites. This was then used as the input for the hotspot analysis to find the optimal vernal pool locations, which should focus ground truthing to specific areas. This provides a map of potential pool locations in suitable conditions for vernal pool habitats.

2.6. Implementation/Methods Workflow

Figure 3 illustrates the implementation of the study. Data layers used for this study include the following: 10 m WI DEM, ALOS PALSAR L-band HH polarization imagery of spring and summer for SE WI, verified vernal pool points and polygons provided by the WDNR, geology map, soil hydrology map and Wiscland Landcover Map. Orange rectangles describe the techniques used to provide input layers (yellow rectangles). Red rectangles are final inputs which included potential vernal pool points and map of optimal potential site. Purple rectangles are the final two outputs which include two hotspot maps, one with just verified vernal pools and one with verified and potential vernal pools.

Figure 4 depicts the work flow of the project's methodology. Remote sensing data including TPI, depressions, ALOS PALSAR spring thresholded image, ALOS PALSAR summer image and the spring – summer change image inputted into a random forest classifier will result in an output of potential vernal pool site locations (specific pools). Operationalized variables for soil hydrology, water table depth, landcover type, bedrock type, and bedrock depth were reclassified and inputted into a weighted sum overlay to create an optimal potential area map. These two outputs will be overlayed and a hotspot analysis was conducted to show hotspots of vernal pool locations.

Results

3.1 Supervised Random Forest Accuracy Assessment

Table 1 depicts accuracy results of this study's supervised random forest classifier. Test data of a subset of the entire study area put through the random forest classifier had an overall accuracy output of 92 percent. The kappa accuracy was 85.1 percent. The user's and producer's accuracies for potential vernal pools were 50 and 16 percent. There was 50 percent commission error and 84 percent omission error.

3.2 Supervised Random Forest Classification

The whole study area extent was not inputted into the supervised random forest classifier due to issues with misclassification with vernal pools and agricultural areas. Instead, forested habitats were focused on, because this is the optimal landcover for vernal pool locations. Two zones were mapped (Figure 5 and Figure 6) to find potential vernal pool locations. Dark gray areas represent permanent water bodies or bare land (classified as same class due to similar radar backscatter values), red polygons represent verified vernal pools (WDNR provided), black points represent the points used to mark location of pools, light blue areas represent potential vernal pools. A total of 51 potential vernal pools were classified in Zone 1 (Figure 5). Verified vernal pools (red polygons) were identified accurately by the classifier as vernal pools (light blue pixels). A total 174 potential vernal pools were identified in Zone 2 (Figure 6). These pools were then used in the hotspot analysis discussed in the following section.

3.3 GIS Results of Overlay & Hotspot Analysis of Potential Pool Locations

The vernal pool optimal locations from the weighted sum overlay are shown in Figure 7. The areas on the overlay map are arranged by level of suitability with green being highly optimal, yellow being moderately optimal and orange being slightly optimal. These levels were determined in the raster overlay by how many of the desired features were present in the area represented, with green areas representing spots where all preferred features were present. There are locations around our study area that are slightly optimal with a couple of areas that are highly optimal for potential vernal pool locations. When compared with Figure 8, which shows the overlay map with verified pool locations added, the optimal areas shown in the overlay analysis line up with the pool locations that have been verified by the Wisconsin DNR. This revealed that the operationalized variables selected for this study can accurately show where vernal pools could potentially be found, because several verified pools are located in these optimal areas (Figure 8).

We then conducted a hotspot analysis of the verified vernal pool locations to determine if there were any specific patterns or hotspots among the pool locations (Figure 9). In Figure 9, the hotspot analysis shows one specific hotspot of pools in the southwestern area of our map extent with 95% confidence. However, the pool locations are spread out enough that there are no other hotspots identified, but not far enough apart that any specific cold spots are identified either. Figure 10 reveals a different pattern in the hotspot analysis when the potential vernal pools obtained from the supervised random forest classifier. Some single pools were marked as hotspots (90% confidence).

Discussion

4.1 Supervised Random Forest Classification and Accuracy Assessment

Test data of a subset of the entire study area put through the random forest classifier had an overall accuracy output of 92 percent. Overall, our random forest classification has a high accuracy. The user’s and producer’s accuracies for potential vernal pools were 50 and 16 percent. The producer’s accuracy is low, but the potential vernal pool outputs did capture the verified vernal pools. A lower producer’s accuracy was expected at this map extent because there was not enough training data at that extent. With an 84 percent omission error, there is potential for improvement especially considering the interference of the urban and agriculture pixels. The potential pools scattered across the forested areas are more likely to be accurate because there is less interference than from the urban and agriculture pixels. Inputting larger extents of our study area into the random forest classifier resulted in an artifact where vernal pools were being classified along the borders of agricultural classes consistently. This pattern did not make sense, and therefore areas with forested regions were focused on at zoomed in extents. The map output shows single or a few pixels classified as vernal pools which means the radar picked up these areas on the ground by penetrating the forest canopy and hitting the water on the ground which is backscattered to the scanner. The Kappa coefficient of the output was 84 percent. This supports that the vernal pools classified by the random forest classified were less likely to be random chance.

4.2 Vernal Pool Optimal Site Locations/ Hot Spot Analysis Comparison

Southwestern extent of the study area meets our operationalized variables the best. Northern extent of our map is moderately optimal for vernal pools based on our operationalized vernal pools. By adding the potential pools, the hotspot for pool locations shifts from the southwestern cluster of pool locations to a different cluster in the central area of the map. This is because the Random Forest Classifier placed many new potential pools in that area, which caused that area to be designated as a hotspot even though it has lower numbers of verified vernal pools. Verified vernal pool hotspots align with our optimal site locations based on environmental variables. Adding potential pool sites to hotspot analysis shows that the moderately optimal areas in our NE extent could support vernal pools. Single pools marked with 90% confidence as a hotspot for vernal pools, suggest that additional pools could be in these areas.

4.3 Future Directions

A future direction would be to characterize the results of the output and create a general profile of the areas in which the potential vernal pools were outputted to aid in conservation efforts to protect these vernal pools. A scoring system is one way to profile these areas. We created a scoring method of many variables to give an overall sense of the barriers to the vernal pools and to give a sense of the direction and degree of conservation effort needed. Sub regions were grouped from the entire study extent. These sub regions contain clusters of vernal pools, either close together or separated from each other. The sub regions do not cross areas that would impose significant barriers such as railroads, divided highways, and multiple major road intersections. The first scoring sets characterize these sub regions overall: road density, land condition index, percent of natural land cover, percent of wetlands remaining, and percent of hubs and corridors. Each of these variables is evaluated on a scale of 1-5 by comparing the sub regions values of these variables to the entire study extent's values of these variables. These scales can be flexible on which method to use to compare values (such as comparing the sub regions to the quartiles of the entire study extent). The second scoring set that characterizes the extent of public lands within the sub regions. These lands were evaluated on a scale of 1-5:

1=Conservation land, conservation easement, and wildlife refuge/migration

2=State park, resource management areas, military land, and Native American land

3=Education, cultural, and historic areas

4=Agricultural and forest easements

5=Recreation areas and recreation easements

The third scoring set is based on variables within the sub regions—roads, landfills, life zone aggregation, and fragmentation. Each variable is evaluated on a 1-5 scale:

Roads	Landfills	Life Zone Aggregation
1=0	1=0	1=Large aggregates
3=1	5=1 or greater	3=Separate aggregates are close
5=2 or greater		5=1 life zone

Fragmentation

1=Pools located in continuous habitat

3=Pools are in patches in proximity to one another

5=Heavy separation between pools

These scales are then weighted and summed together: (Roads * weight) + (Landfills * weight) + (Life zone aggregation * weight) + (Fragmentation * weight)

4.4 Conclusion

Mapping vernal pools over large areas can be a difficult, time consuming and expensive task due to their ephemeral nature, forested location and small size. Supervised random forest classification utilizing ALOS PALSAR L-band products and 10 m DEM products can produce potential vernal pools sites. In addition to our potential vernal pool sites, our optimal site selection defined by specific environmental variables can be used to narrow down regions where potential pool locations should be ground truthed. Hot spot analysis can be applied to help determine new locations where potential pools are more likely to be found, based on verified and potential vernal pools sites. Identifying these hotspots and potential pool locations can be used for conservation and management strategies in a cost-effective manner.

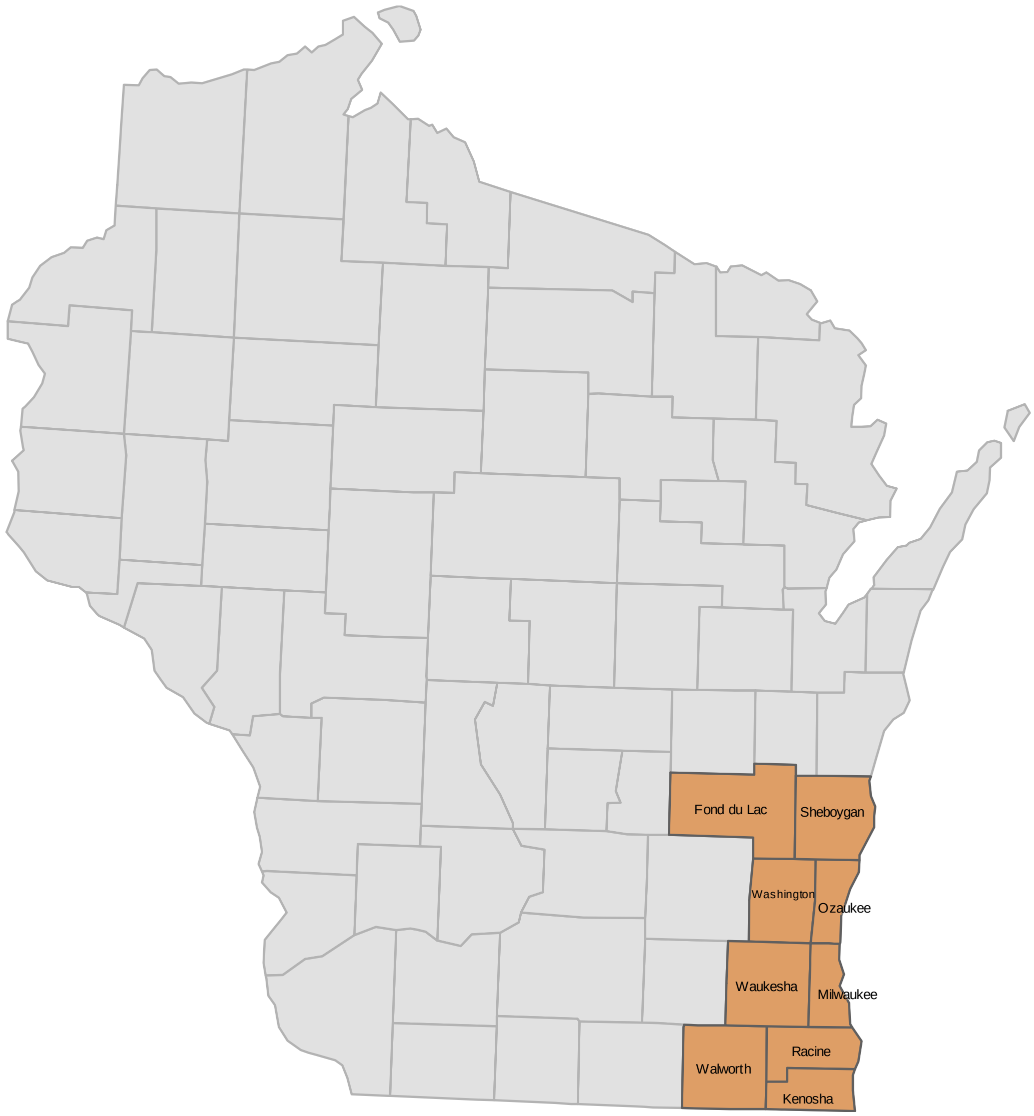

Figure 1: Study Area. Southeastern counties in the study area included the following: Fond du Lac, Sheboygan, Washington, Ozaukee, Waukesha, Milwaukee, Walworth, Racine and Kenosha (orange).

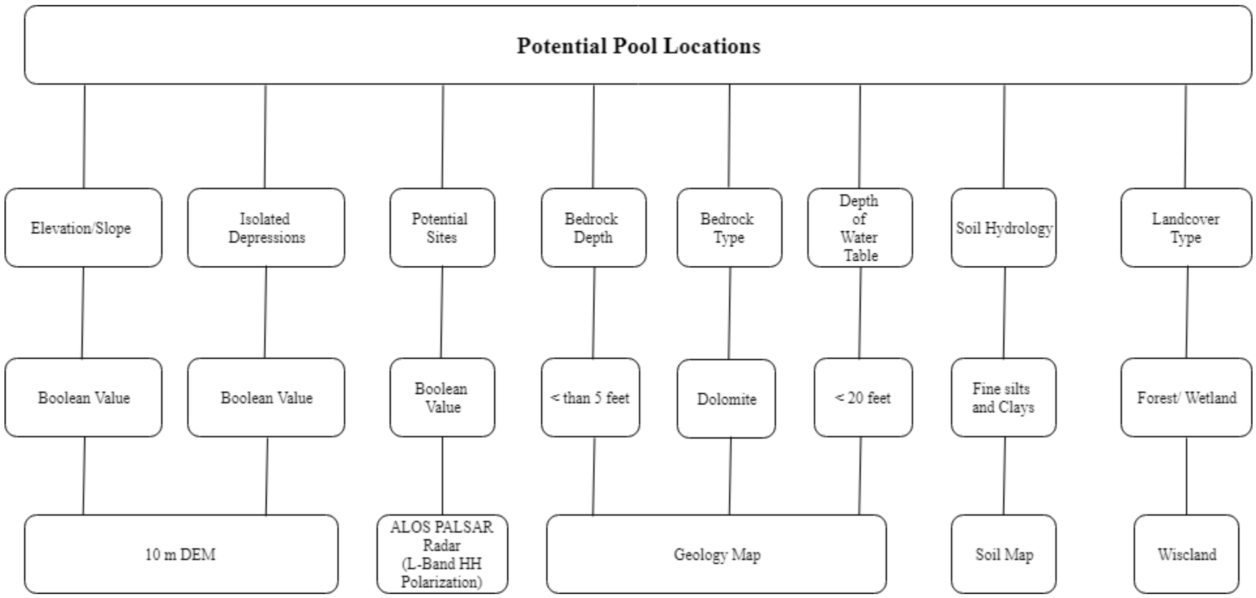

Figure 2: Vernal Pool Locations Conceptualization

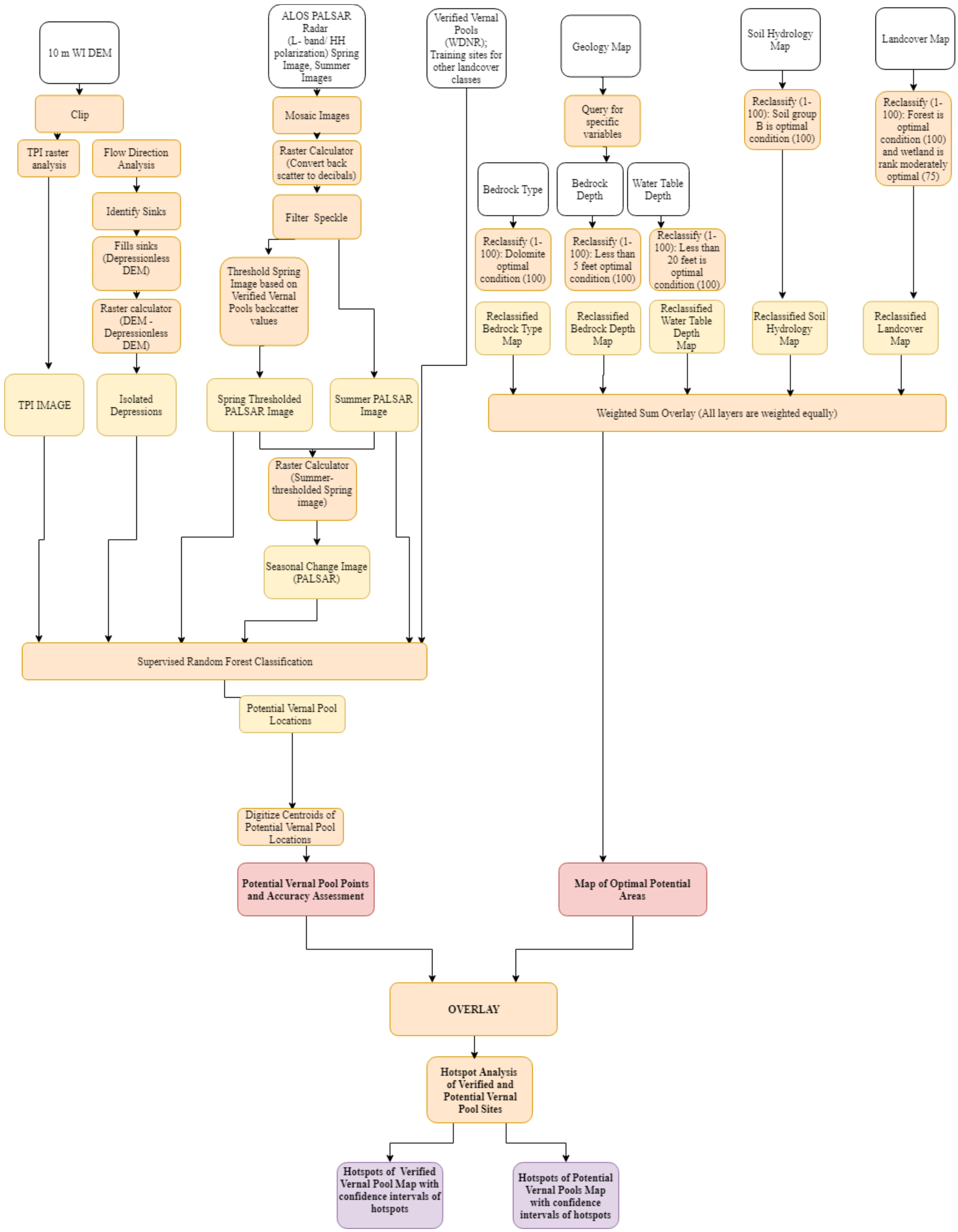

Figure 3: Implementation. Orange rectangles describe the techniques used to provide input layers (yellow rectangles). Red rectangles are final inputs. Purple rectangles are the final two outputs.

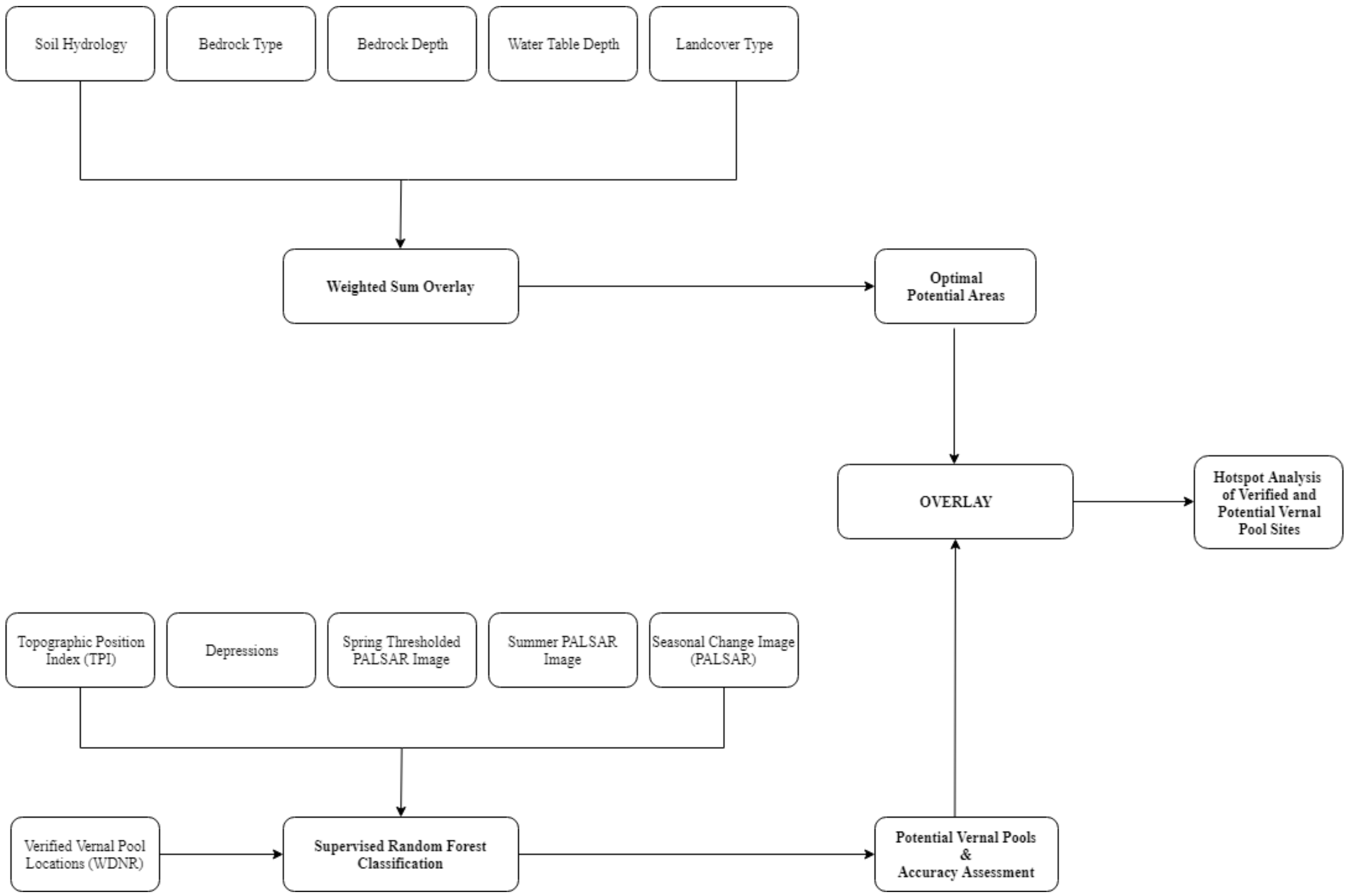

Figure 4: Work Flow of Project

Accuracy Assessment for Supervised Random Forest Classification	
Overall Accuracy	92.2 %
Kappa	85.1 %
Vernal Pool User's Accuracy	50 %
Vernal Pool Producer's Accuracy	16 %
Vernal Pool Commission Error %	50 %
Vernal Pool Omission Error	84 %

Table 1: Accuracy Assessment for Supervised Random Forest Classification.

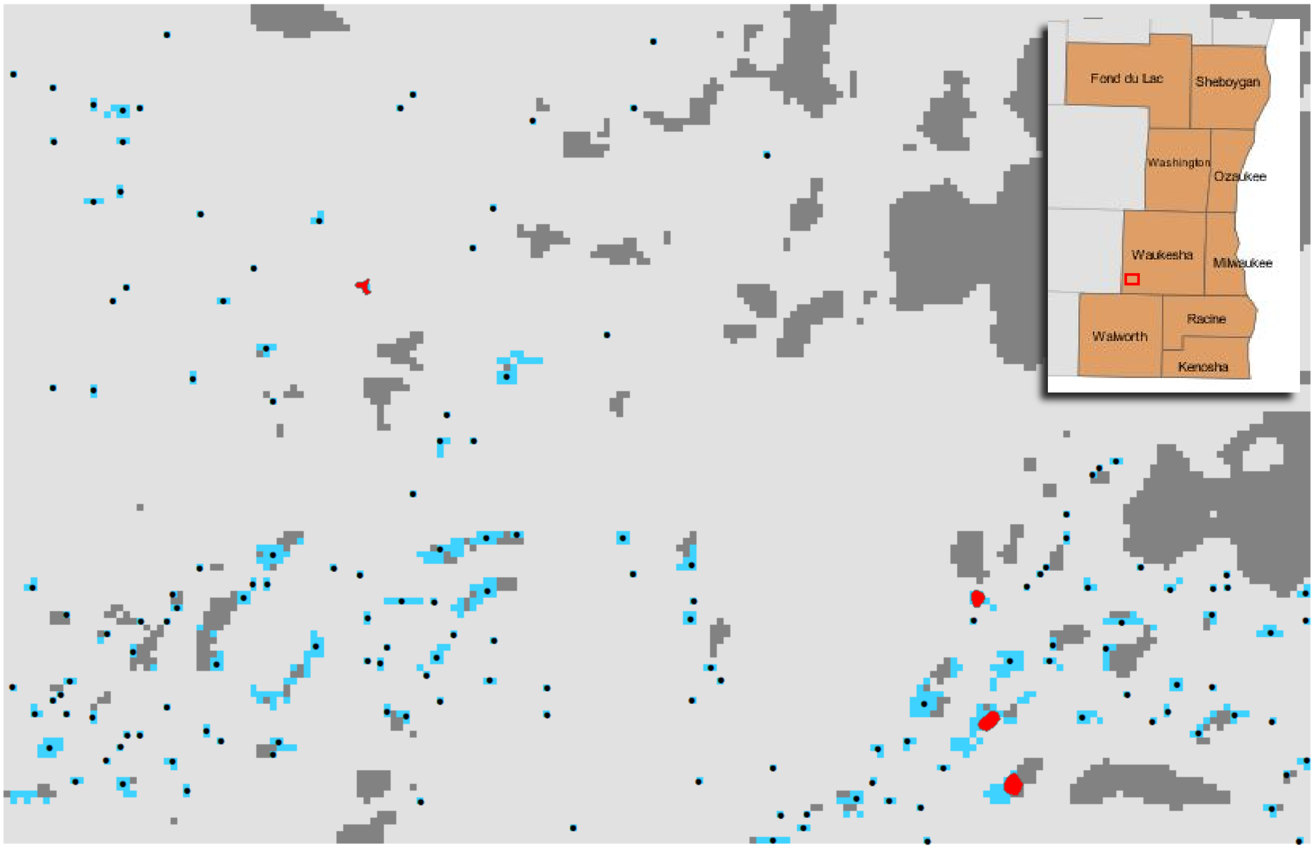

Figure 5: Potential Vernal Pools Zone 1. Inset map shows the location of Potential Vernal Pools Zone 1. Light gray areas represent forested areas. Dark gray areas represent permanent water bodies or bare land (classified as same class due to similar radar backscatter values), red polygons represent verified vernal pools (WDNR provided), black points represent the points used to mark location of pools, light blue areas represent potential vernal pools. A total of 51 potential vernal pools were classified in this image. Verified pools match RF classification, as seen in the above image.

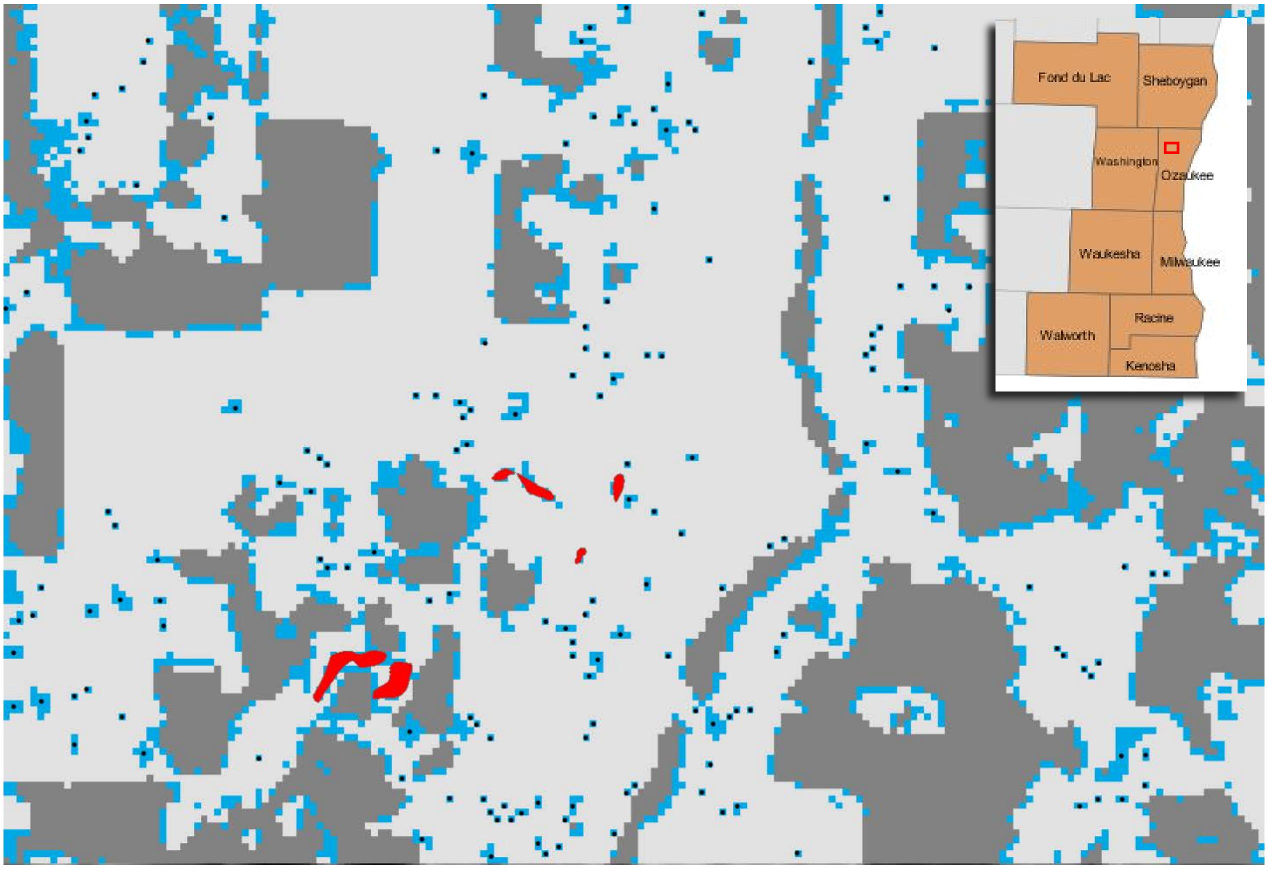

Figure 6: Potential Vernal Pools Zone 2. Inset map shows the location of Potential Vernal Pools Zone 2. Light gray areas represent forested areas. Dark gray areas represent permanent water bodies or bare land (classified as same class due to similar radar backscatter values), red polygons represent verified vernal pools (WDNR provided), black points represent the points used to mark location of pools, light blue areas represent potential vernal pools. A total of 174 potential vernal pools were classified in this image. Verified pools match RF classification, as seen in the above image. In this image, areas that were classified as permanent water bodies or bare land tended to have a border of pixels classified as vernal pools. This phenomenon was seen over a larger extend within heavily agricultural areas. It was decided that these areas are most likely not potential vernal pool sites due to the nature of following the border of these other landcover classes, but perhaps these areas could be considered for vernal pool habitat restoration.

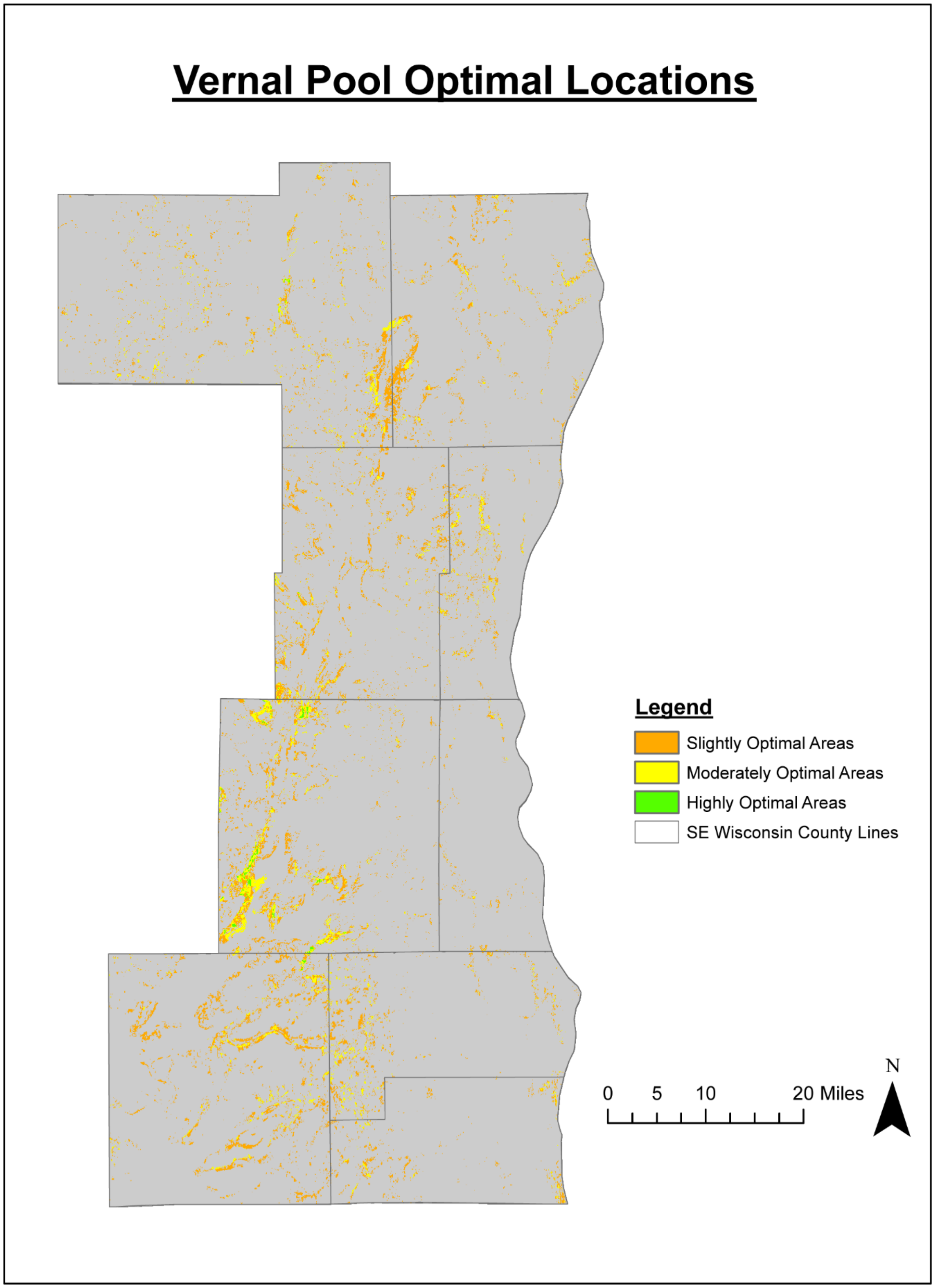

Figure 7: Map of study area showing optimal pool locations based on overlay of features from environmental variables.

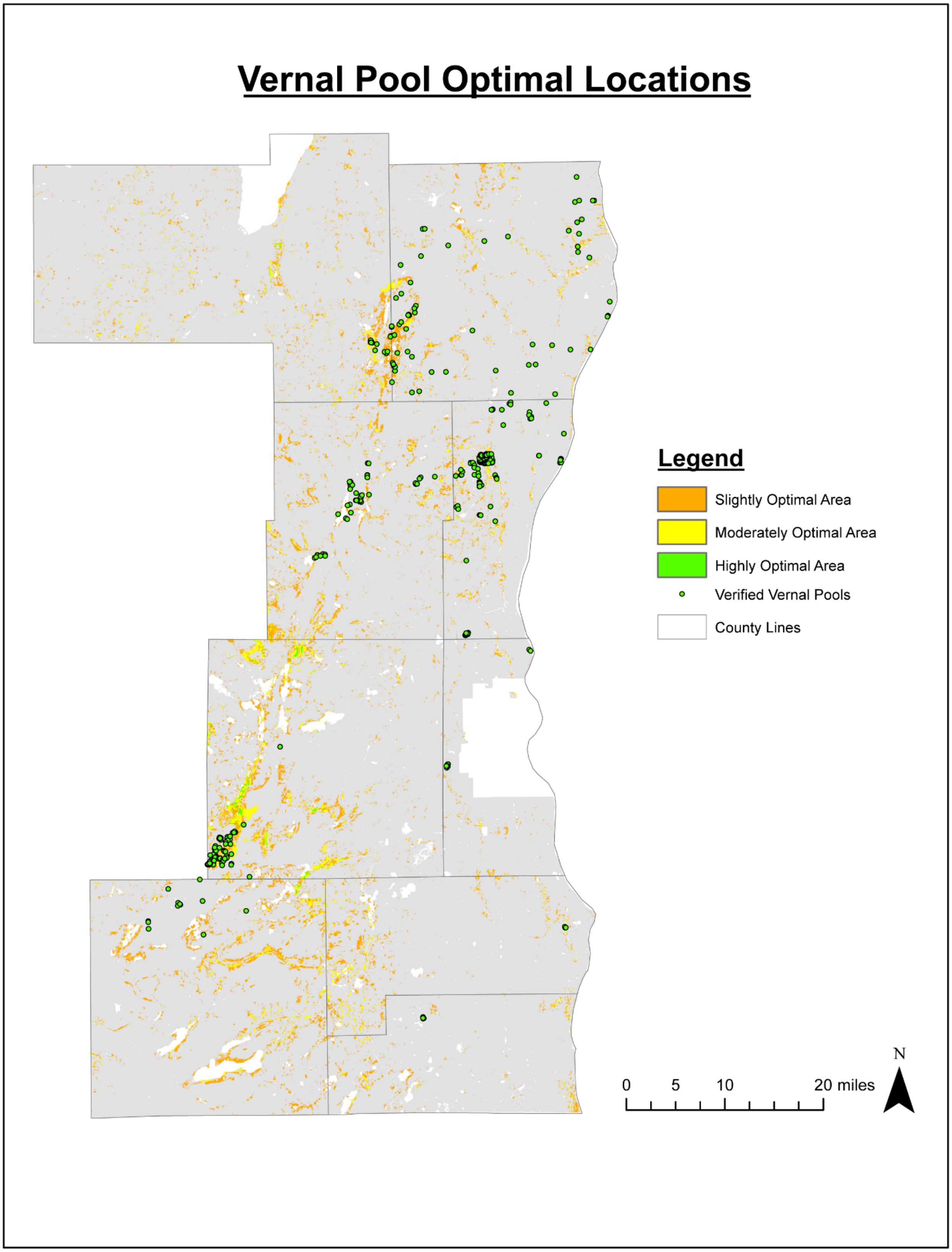

Figure 8: Map of optimal pool locations from overlay including verified vernal pool locations.

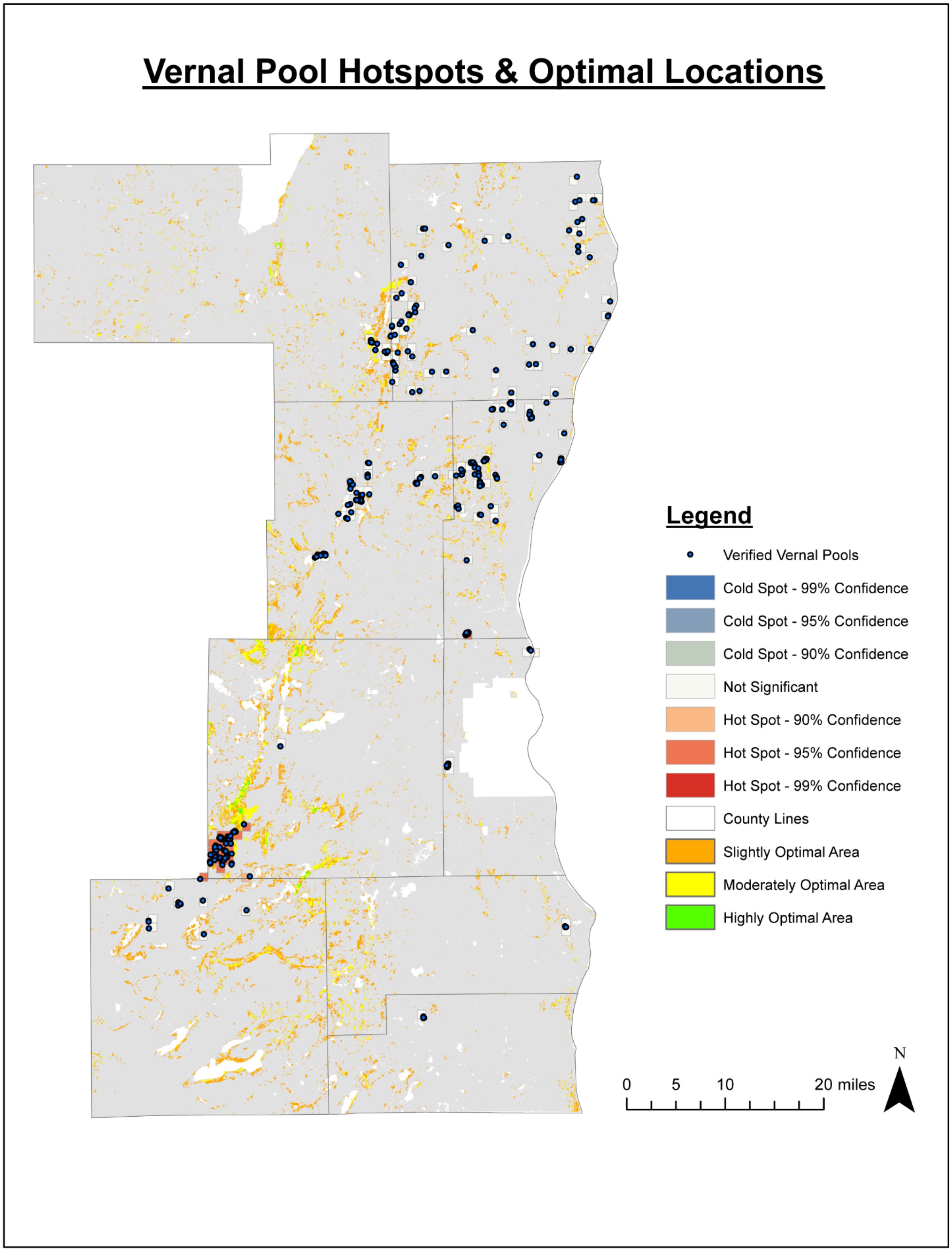

Figure 9: Optimal pool locations including verified vernal pools & results of hotspot analysis.

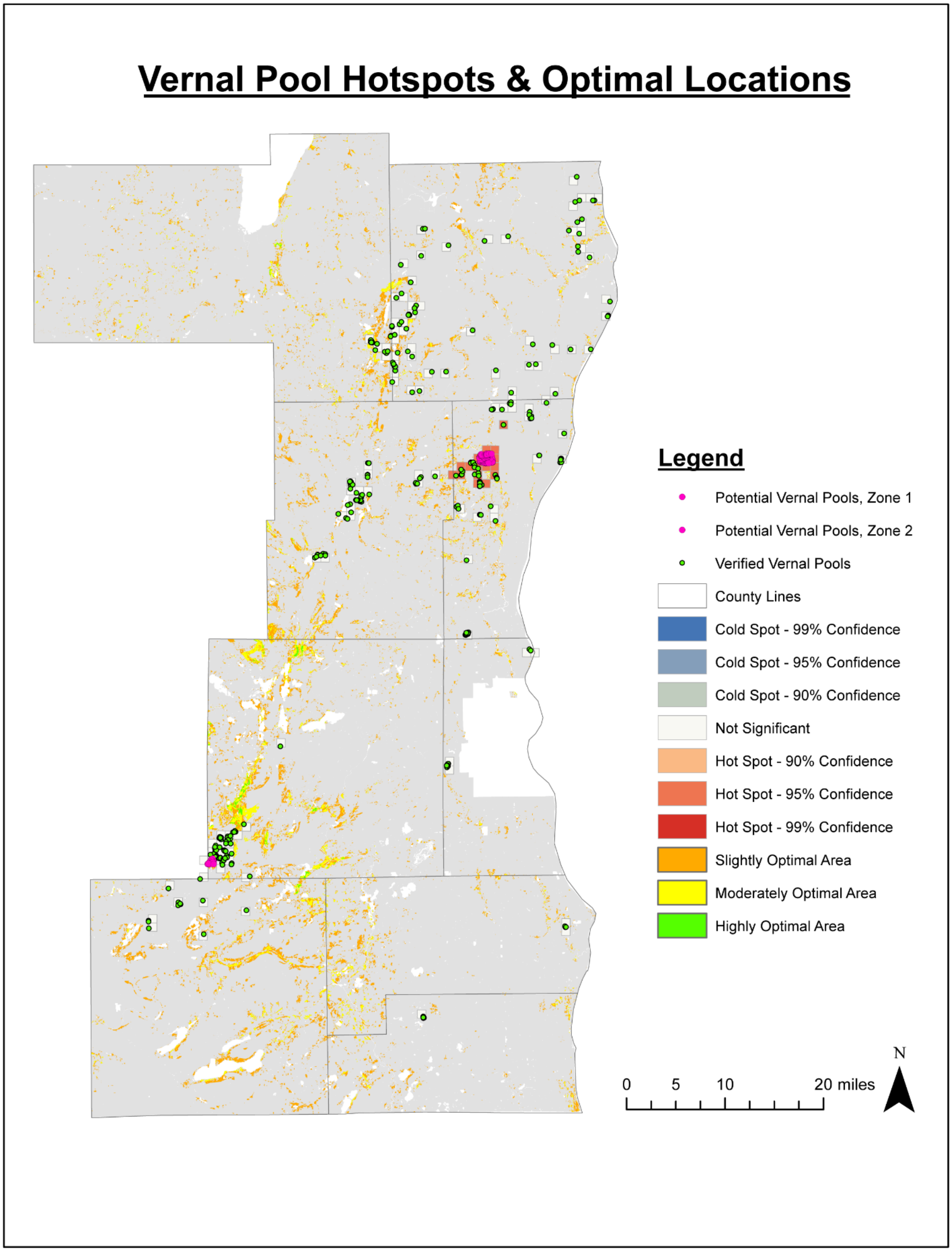

Figure 10: Optimal pool locations from overlay including verified vernal pool locations and potential pool locations & results of hotspot analysis.

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Appendix: Reference Maps

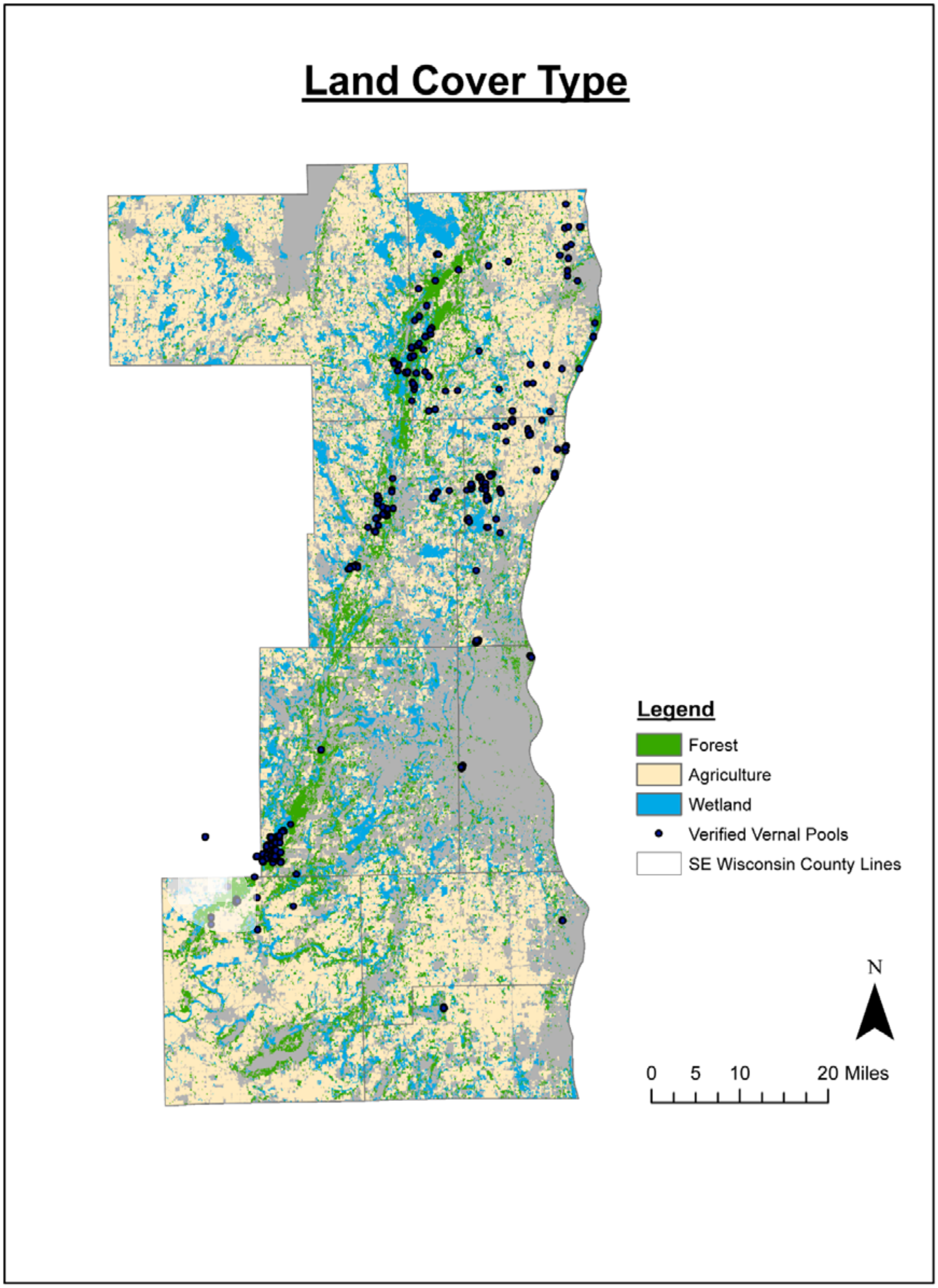

Figure A: Map of land cover for study area, emphasizing forest, wetland and agricultural areas.

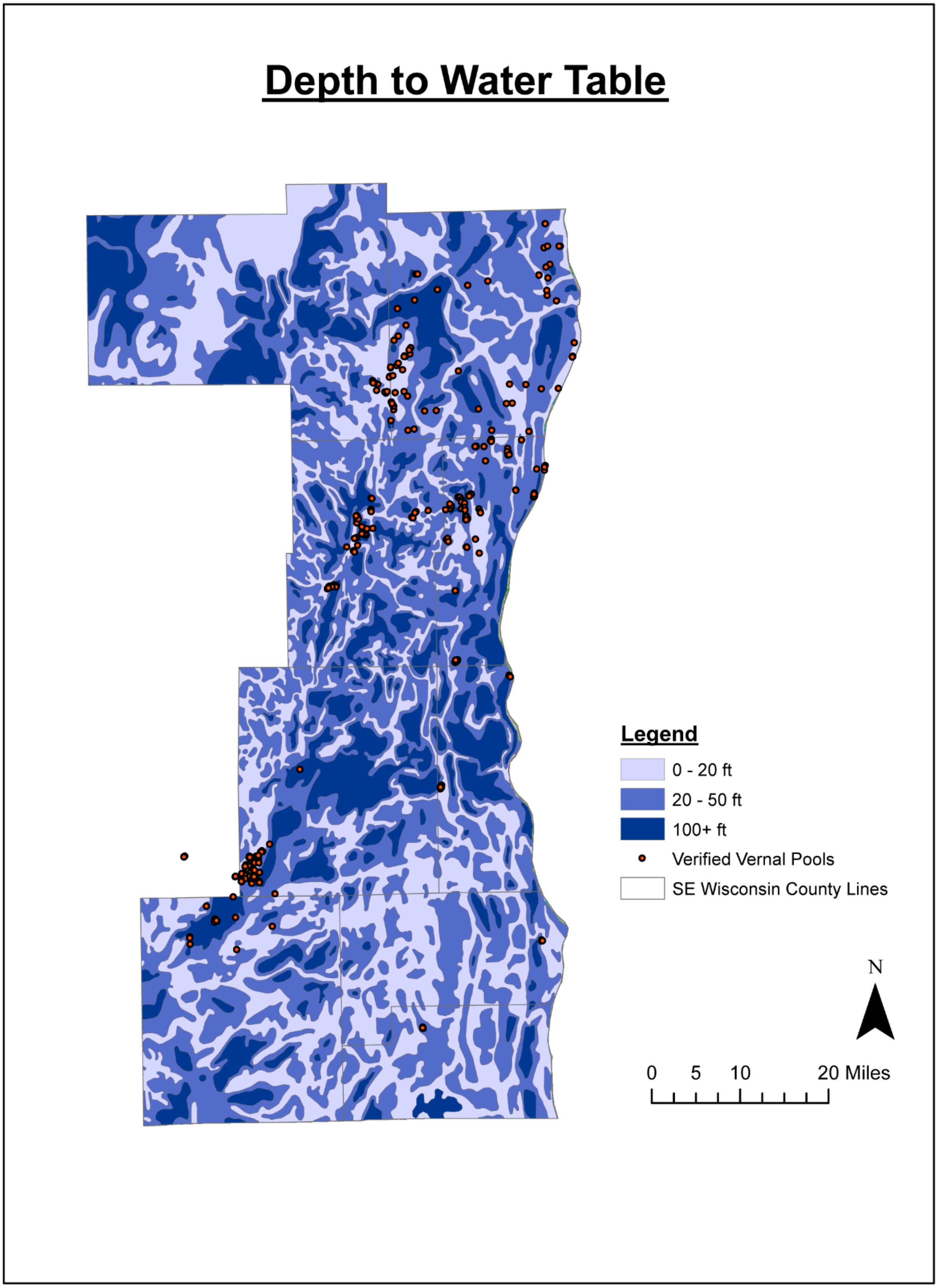

Figure B: Map of depth to water table over study area.

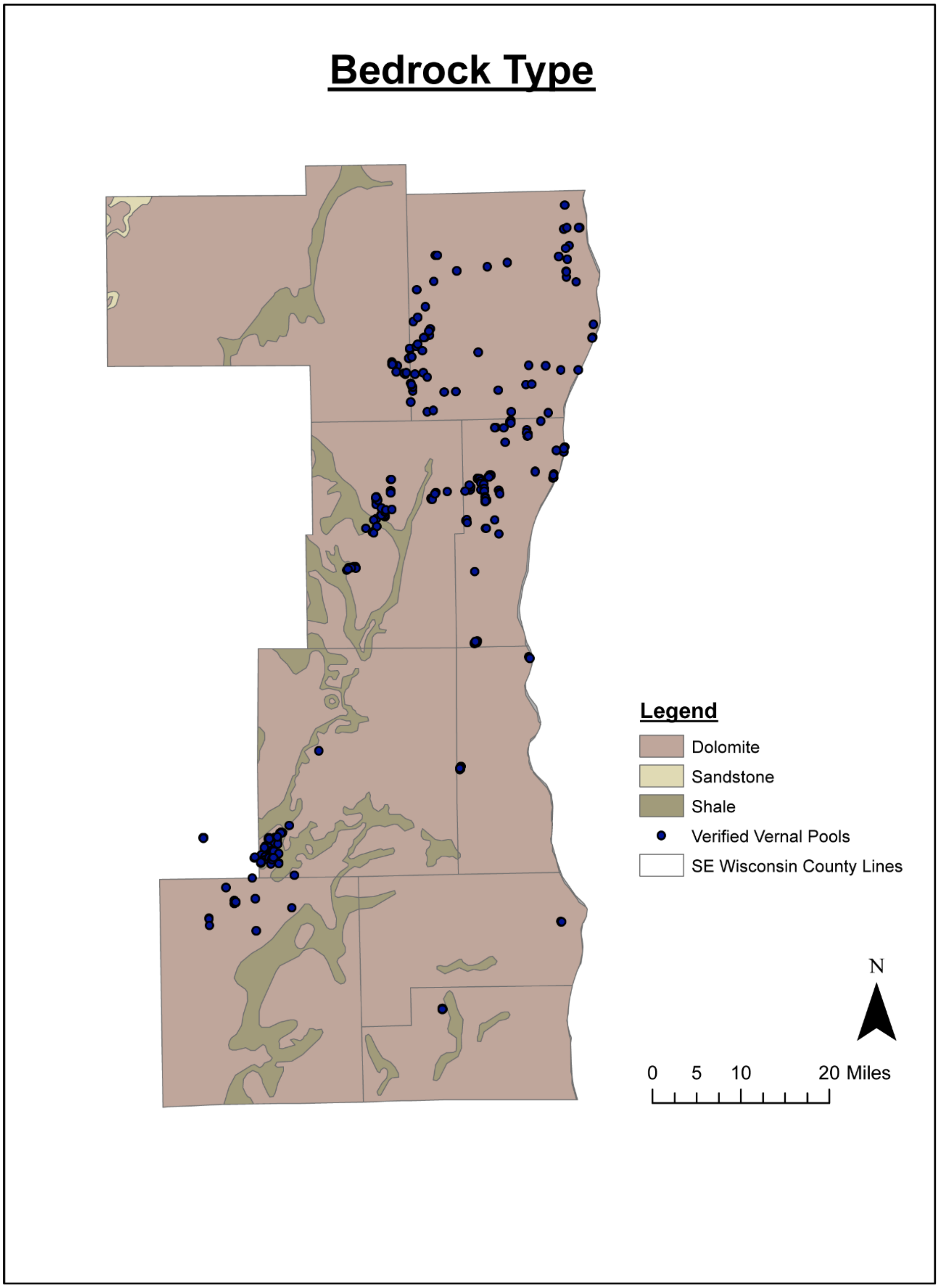

Figure C: Map of bedrock type over study area.

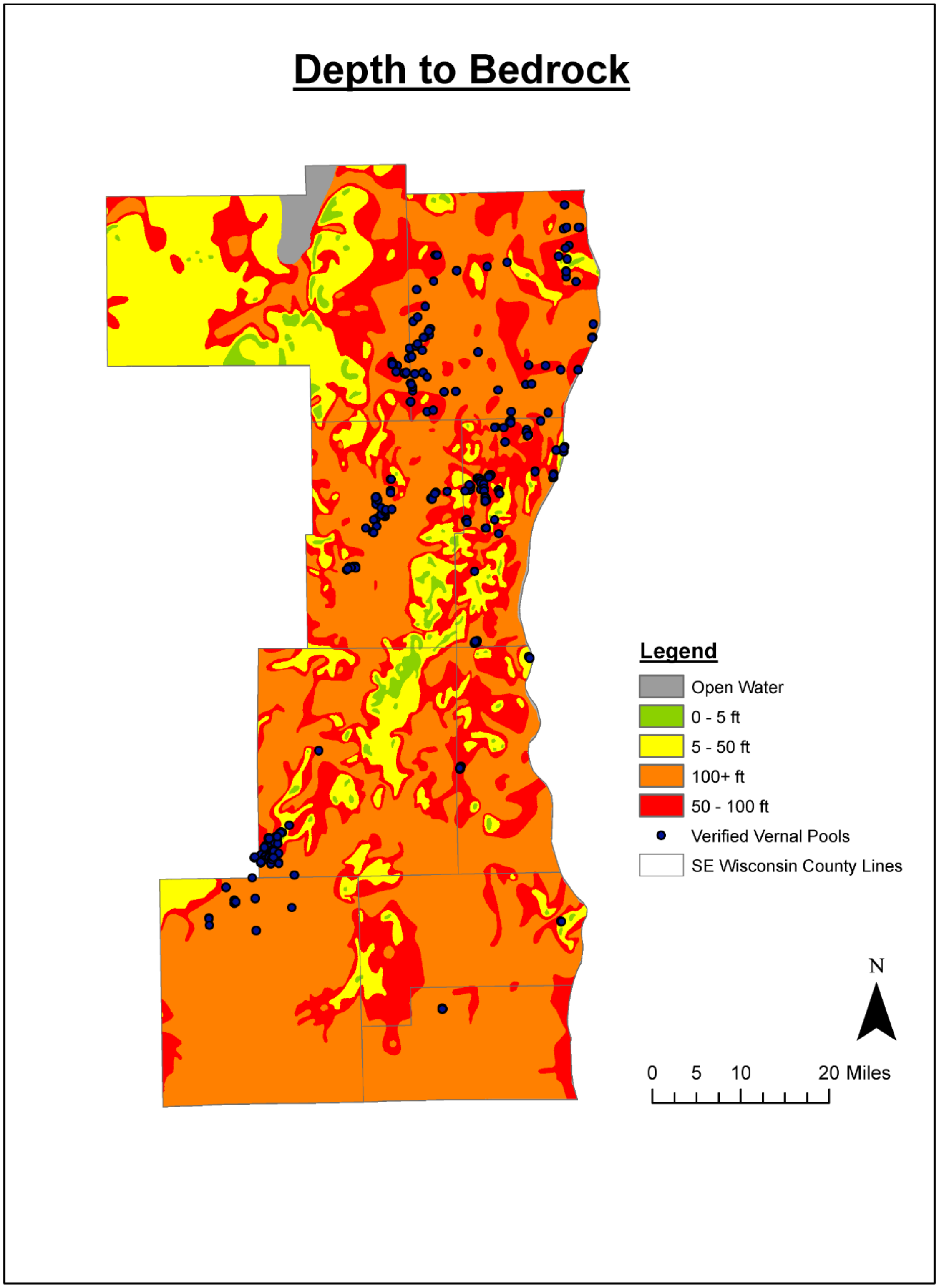

Figure D: Map of bedrock depth over study area.

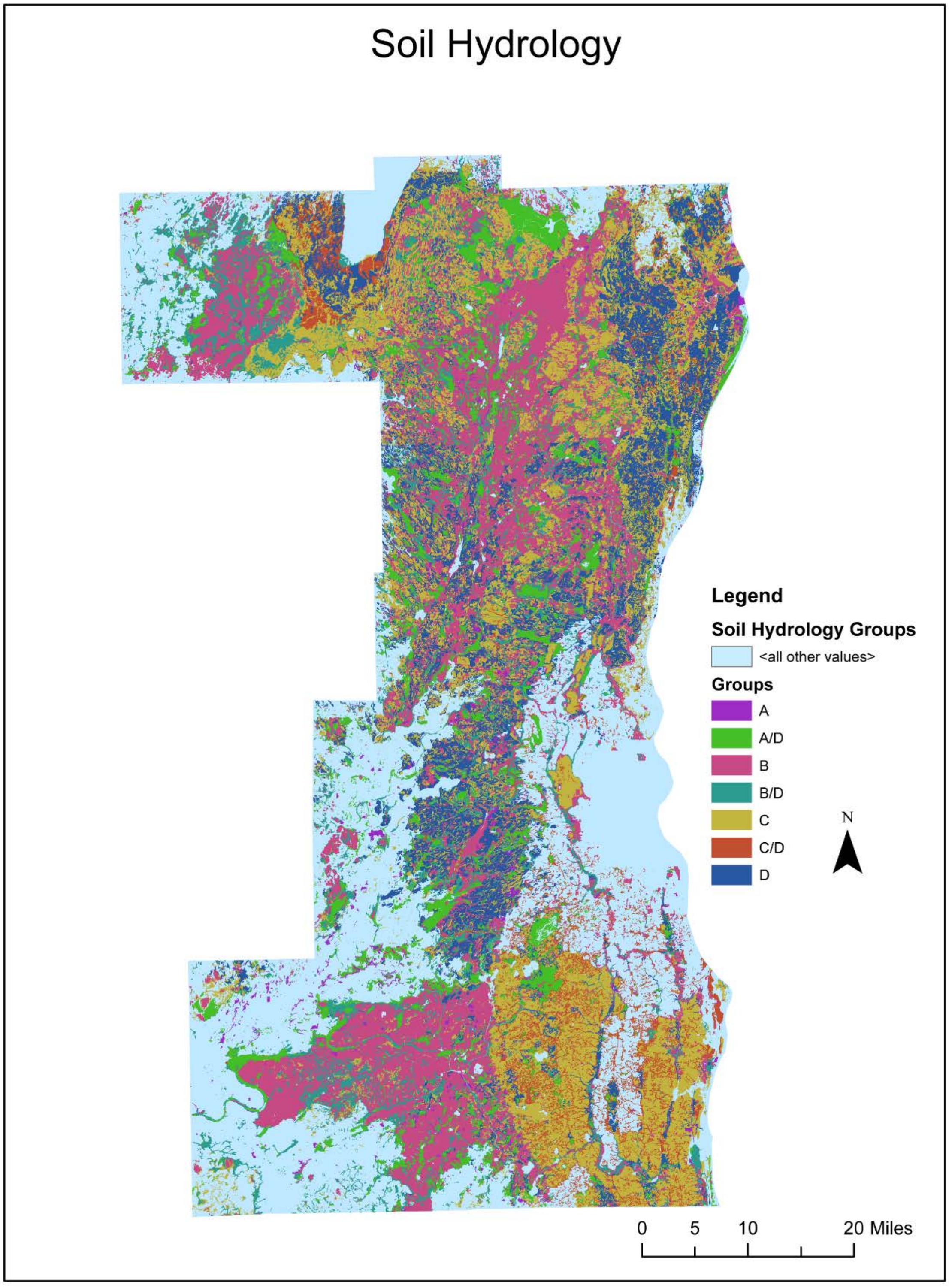

Figure E: Map of Soil Hydrology over study area.