Polk County LiDAR Final Grant Report
Planning for Lake Protection and Improvement Using LiDAR LPT-475-15

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Introduction

In 2015 Ayres Associates completed a LiDAR data acquisition project for Polk County. LiDAR mapping for Polk County will be the basis for developing county-wide phosphorus reduction strategies for lake protection. LiDAR provides agricultural producers, developers, lake organizations, and resource managers with a highly accurate elevation model to identify which watersheds and subwatersheds contribute the greatest nutrient loads to Polk County waterbodies.

This project identified the fields in the Horse Creek Watershed with the highest Phosphorus Index values. LiDAR was used to determine which of these fields generate runoff which actually reaches surface waters. When paired, these data sets prioritize BMP implementation based on which fields contribute the greatest phosphorus load to surface waters. Delineation of watersheds and subwatersheds, along with contributing areas for monitoring stations, are crucial to the success of lake protection.

LiDAR was used to delineate watershed boundaries and determine areas of highest nutrient loading for the Cedar Lake TMDL.

Additionally, since the project area for the Farmer Led Watershed Council is in the Horse Creek Watershed, the benefits of LiDAR to this watershed will have direct impacts on the Cedar Lake TMDL and ultimately the Lake St. Croix and Squaw Lake TMDL's. LiDAR data will be used to assist the Farmer Led Watershed Council, a joint project involving local area farmers, UW-Extension, the McKnight Foundation, Wisconsin Farmers Union, and County Land Conservation Departments.

The products of this project will advance the goals of the current Polk County Land and Water Resource Management Plan and will be useful in prioritizing goals when the Polk County Land and Water Management Plan is updated. LiDAR will be integral to updating comprehensive Lake Management Plans for current TMDL and Impaired Waters lake protection programs. Additionally, data will be integral to updating and developing comprehensive Lake Management Plans for unimpaired lakes in Polk County and for design installation and maintenance of agricultural and urban best management practices.

Set-up and data processing preparation

In order to delineate the watershed for the Cedar Lake inlet that is being monitored for the Horse Creek Farmer Led Watershed Council, the ArcGIS Spatial Analyst Toolbox was used to manipulate LiDAR data and satellite derived land cover to model the hydrological conditions and flow patterns entering the culvert at the Cedar Lake inlet where water level and atmospheric data loggers are deployed. The data loggers were placed in October of 2015 and have been continuously recording water level year round. Nutrient samples have been collected five times to determine phosphorus and nitrogen loads.

First, an area of interest (AOI) was selected and a polygon was constructed in order to analyze the area. Then the county LiDAR derived Digital Elevation Model (DEM) was extracted using the Extraction tool and was extracted by mask. The extraction creates a subset of the larger LiDAR-derived 1 meter resolution DEM (AOI DEM) so it only includes the area for the study. The AOI and AOI DEM are shown in figure 1.

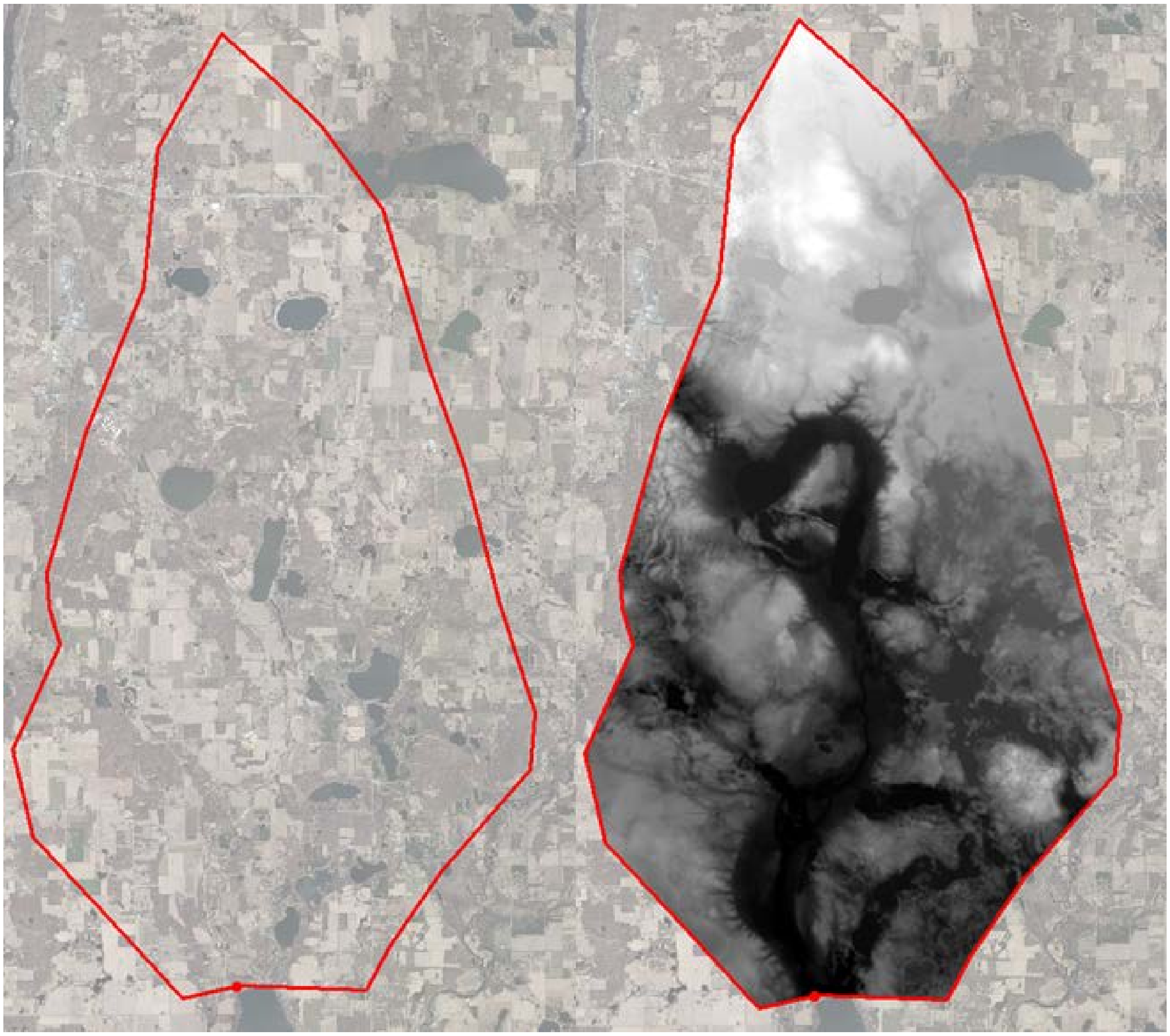

Figure 1: Area of Interest and AOI DEM

The fill command from the hydrology toolbox was then used to fill pits in the AOI DEM. Pits are local depressions along where a stream would be expected to flow. Since a DEM is a representation of a waterless terrain, and the flow algorithms used in the hydrology tools of ArcGIS are programmed on this basis, the watershed processing routine begins by filling the pits. To visualize the pits that are filled in the minus tool in the math toolbox was used. Figure 2 below represent the areas or pits that were filled.

Figure 2: Areas or Pits Filled

Analysis and Processing

To analyze the area of interest, the flow direction was determined using the flow direction tool in the hydrology toolbox. This tool uses the D8 discreet categorization, where the water flows from a cell to an adjacent cell in one of 8 directions. The flow direction layer created contains a direction coding with a set of numbers that define the cardinal and sub-cardinal direction and color codes it as seen in figure 3.

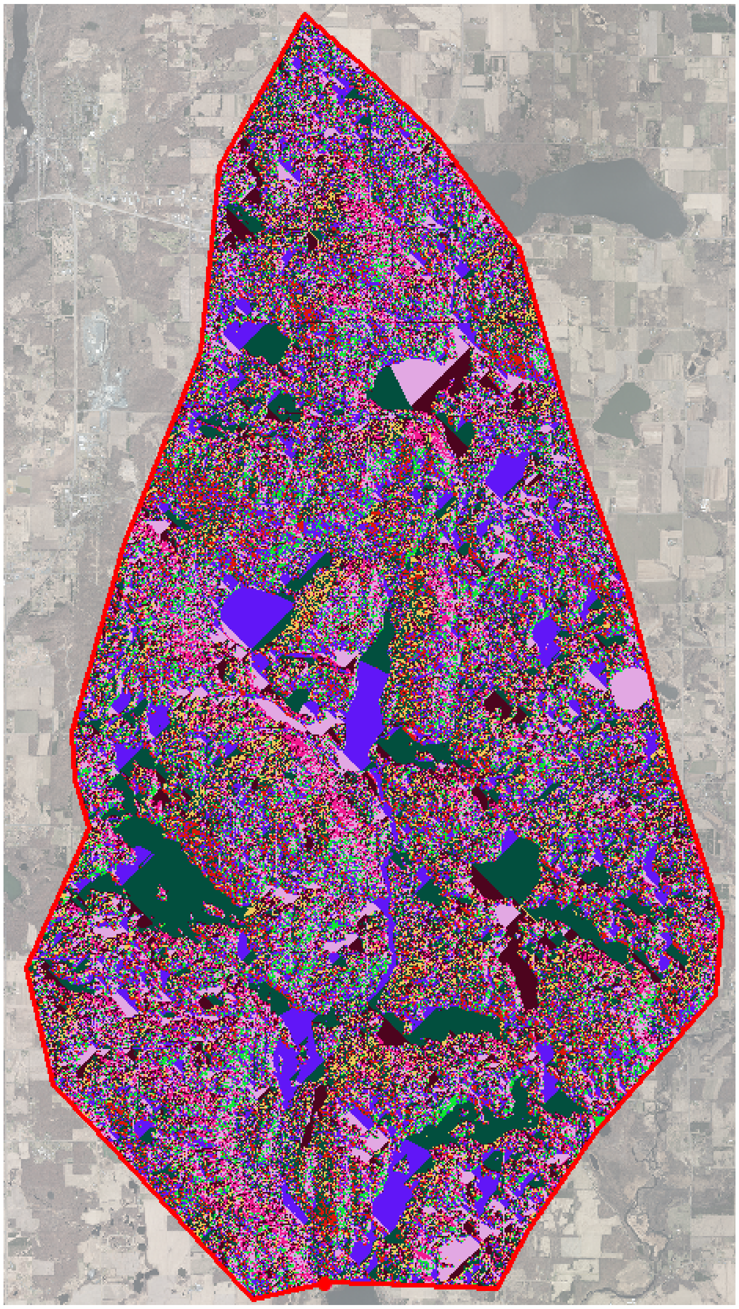

Figure 3: Flow Accumulation

Next, the flow accumulation tool from the ArcToolbox was used to determine the flow across the DEM raster. This tool finds the highest points, and accumulates the area downhill according to the flow directions that was computed. The data was then reclassified to show the stream path using the Reclass Tool in the Spatial Analyst Toolbox and converted to a vector layer. The flow accumulation and digitized stream pathways are shown in figure 4.

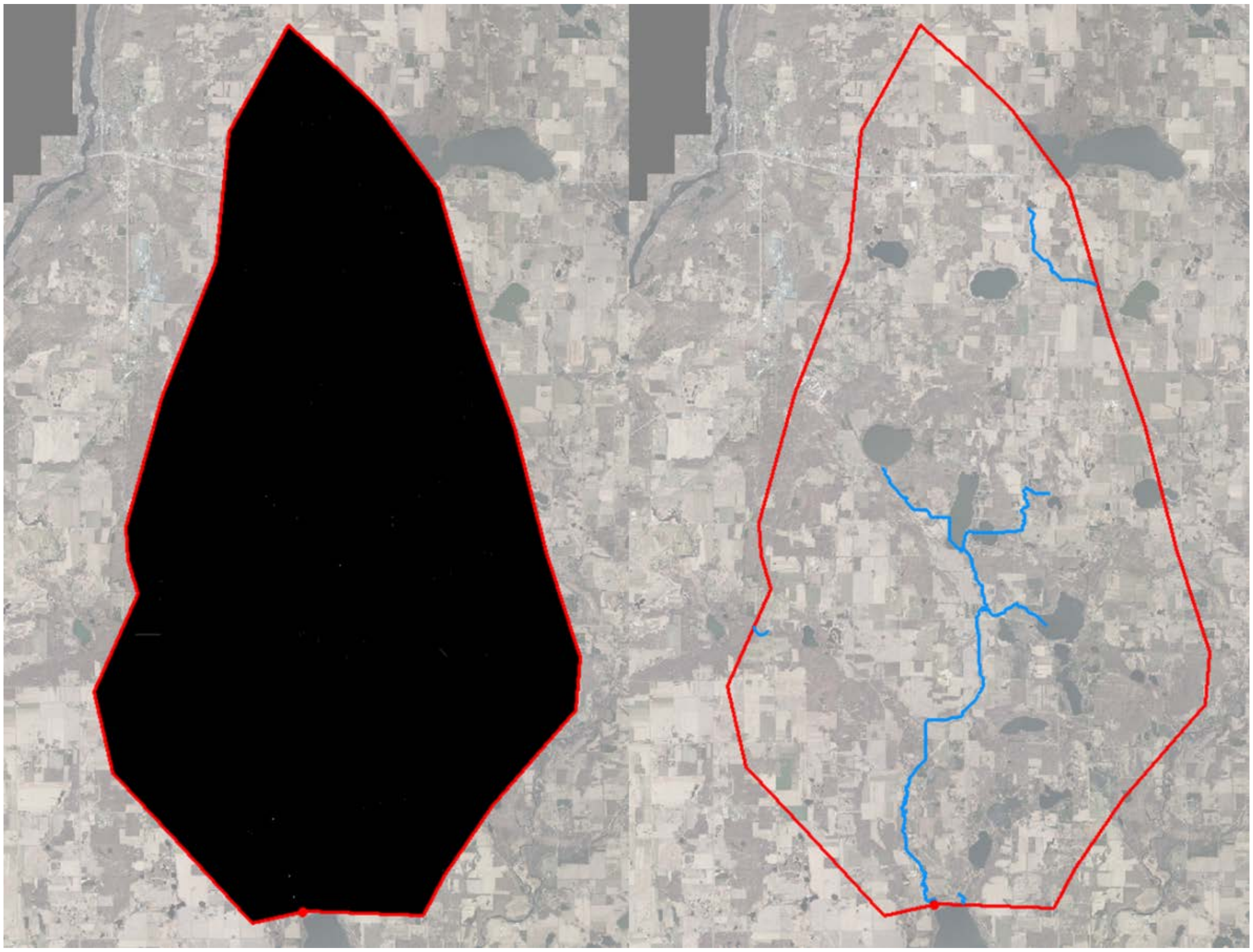

Figure 4: Flow Accumulation and Digitized Stream Pathways

This data can now be used to delineate a watershed. First, the outlet point was digitized at the culvert where the atmospheric and water level data loggers are placed and compared with the flow accumulation grid. Then the Snap Pour Point tool was used from the Hydrology Toolbox. The Snap Pour Point tool uses the flow accumulation raster that was computed and the outlet that was digitized and is show in figure 5.

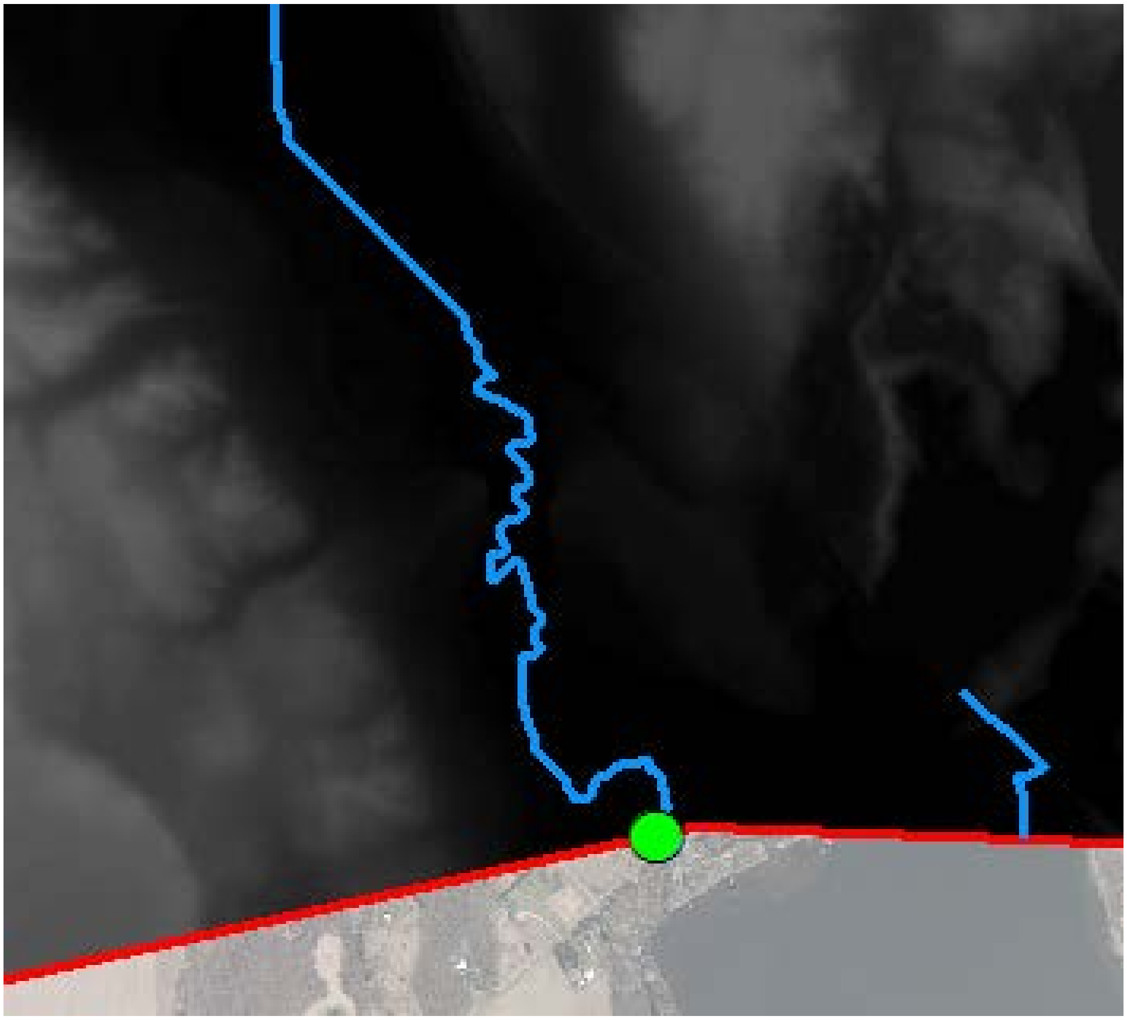

Figure 5: Pour Point

The Watershed tool was used from the Hydrology Toolbox in the Spatial Analyst Extention in ArcGIS. The Watershed tool uses the flow direction and pour point that were created earlier in this process. The raster based watershed was then converted to a vector layer to be used for modeling show in Figure 6.

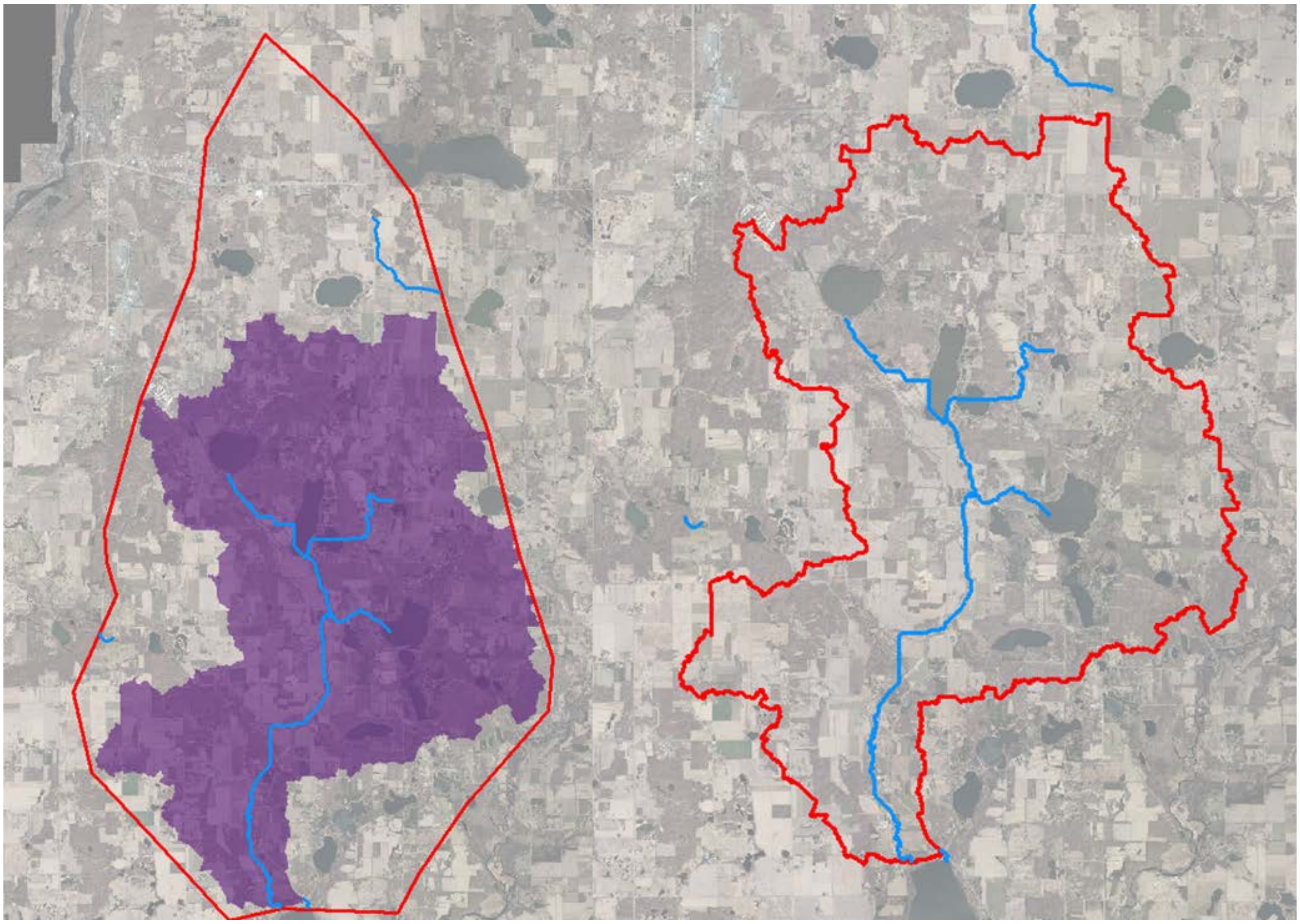

Figure 5: Raster Watershed Derived from LiDAR Data and the Vector Version of Watershed

This watershed that was derived from the recently acquired LiDAR data was used to attempt to run the Wisconsin Department of Natural Resources' (DNR) Pollutant Load Ratio Estimation Tool (PRESTO). However, the one meter grid size proved to be too much data for the model pollutant load to the inlet of Cedar Lake. Additional attempts were made to use the raw Python script acquired from DNR's GitHUB page. This attempt proved futile as well so it was determined to use the DNR's Erosion Vulnerability Assessment of Agricultural Lands (EVAAL) model.

EVAAL

The Erosion Vulnerability Assessment for Agricultural Lands (EVAAL) ArcGIS toolset was developed by the Wisconsin Department of Natural Resources (WDNR) to help watershed managers assess the vulnerability of erosion within a watershed. EVAAL uses topographic, soil, rainfall, and land cover datasets to determine areas vulnerable to erosion. It can be used to prioritize areas within a watershed that have a higher vulnerability to water erosion, and therefore, the potential of sediment and nutrient transport to surface waters. By identifying areas with the highest erosion potential, watershed managers can concentrate best management practices on these vulnerable areas.

EVAAL uses a combination of readily available datasets to run the analysis. The LiDAR DEM supplied by this grant is the key dataset used by EVAAL as it provides the topographic data. Soils data is also necessary to assess soil erodibility and hydrologic soil groups. This dataset is provided by USDA-NRCS's gridded Soil Survey Geographic Dataset (gSSURGO). Precipitation data is provided by the National Weather Service. Land cover is used to estimate crop rotations and is available from USDA-NASS National Cropland Data Layer (CDL). Other layers used for the analysis are an area of interest boundary, culvert lines, and a zone boundary layer. EVAAL consists of 10 steps that ultimately calculates an erosion vulnerability index that can be analyzed at its base resolution or aggregated to zonal boundary layer like field boundaries or tax parcels.

EVAAL was chosen to identify areas of the Horse Creek watershed that have the highest potential for water erosion. By identifying areas vulnerable to erosion, management options can be concentrated towards those areas first. The Horse Creek watershed boundary delineated from the LiDAR data was used for this evaluation. Due to size limitations in the EVAAL toolbox, only the southern half of the watershed was analyzed for this report. Figure 7 delineates the EVAAL analysis boundary.

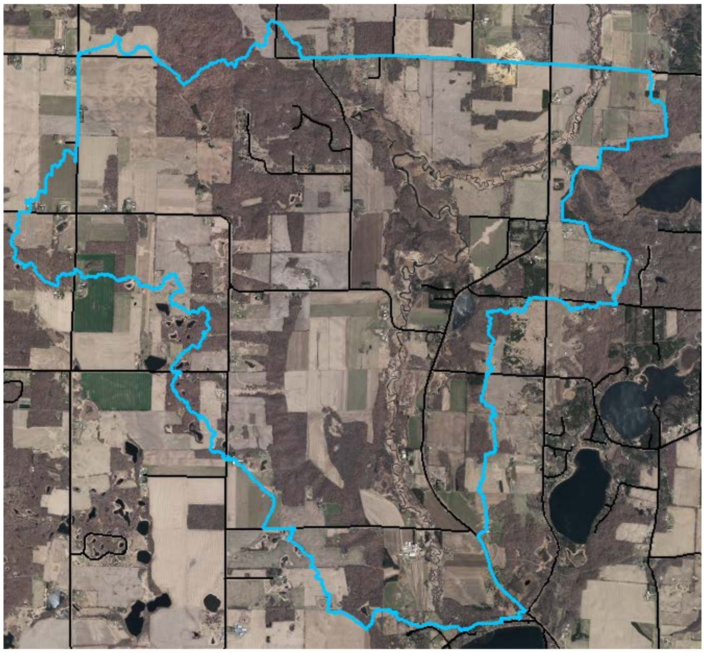

Figure 7: EVAAL Study Boundary

The first step in EVAAL is to condition the raw DEM. This creates a DEM where all water flows off the elevation model. The raw DEM only shows ground elevation and cannot determine where areas of concentrated flow travel under berms or roadways. These "digital dams" prevent the toolbox from properly calculating surface flow. A layer delineating culverts is used to break these "digital dams". The culvert layer for this analysis was created using known culvert locations as well as a digital evaluation of probable culvert locations. A more precise inventory of culverts in the watershed should be conducted to properly determine surface flow. Figures 8 and 9 show the DEM before and after conditioning. As you can see the conditioned DEM allows Horse Creek to flow through the roadway.

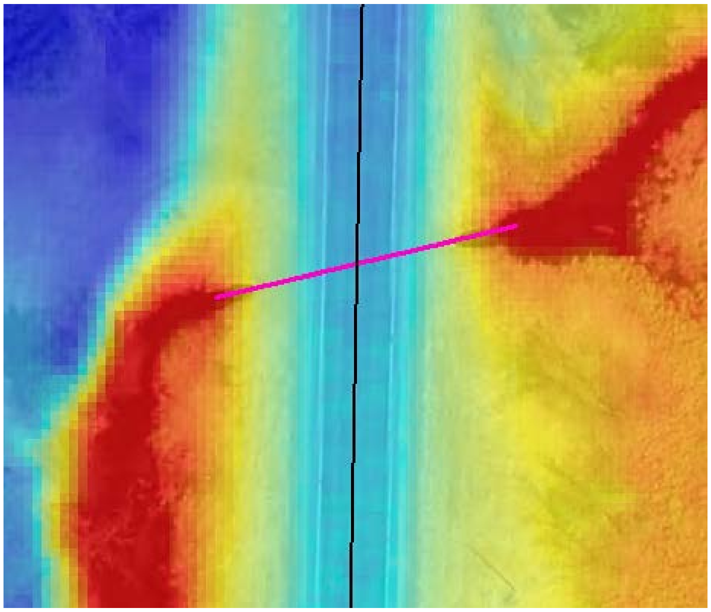

Figure 8: Raw DEM

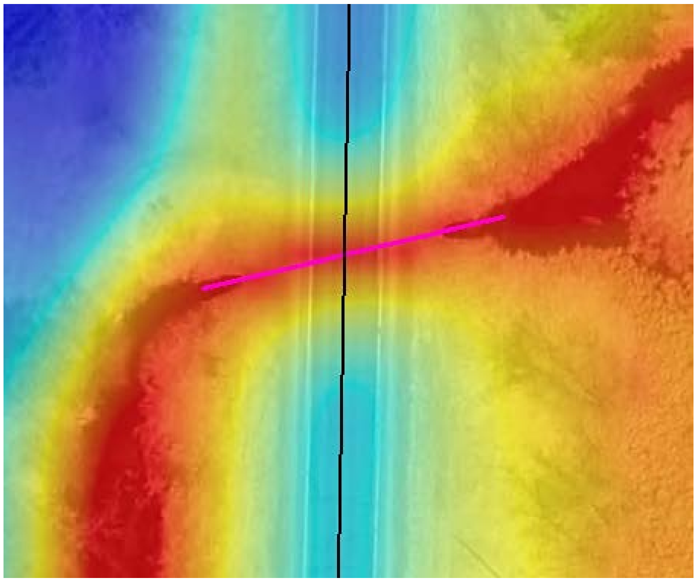

Figure 9: Conditioned DEM

The next set of steps prioritizes surface areas that contribute runoff directly to surface water. EVAAL deprioritizes surface runoff that is determined to be internally draining. To determine internally draining area, the toolbox used a precipitation and curve number raster. The precipitation raster is derived from the Nation Weather Service on-line datasets. For this study a 10 year 24 hour storm was used. The curve number raster, based on land cover, cover condition, and hydrologic soil group, is calculated from the gSSURGO soils layer and the CDL. The precipitation and curve number raster are used to calculate areas that are internally drained and therefore noncontributing to surface water runoff. Internally drained areas are removed from the conditioned DEM. Figure 10 shows the conditioned DEM and delineates the areas that are internally drained. The grey areas are internally drained and do not contribute surface runoff to Cedar Lake via Horse Creek. The DEM shows high elevation as blue and lower elevations transition to red. As you can see a large portion of the watershed is considered to be internally drained based on a 10 year 24 hour storm event. On-site observations could be conducted in these areas to determine if they are indeed internally drained. Keep in mind that just because these areas don't reach the surface water of Horse Creek does not mean they are not contributing surface runoff or erosion within their internally drained basin.

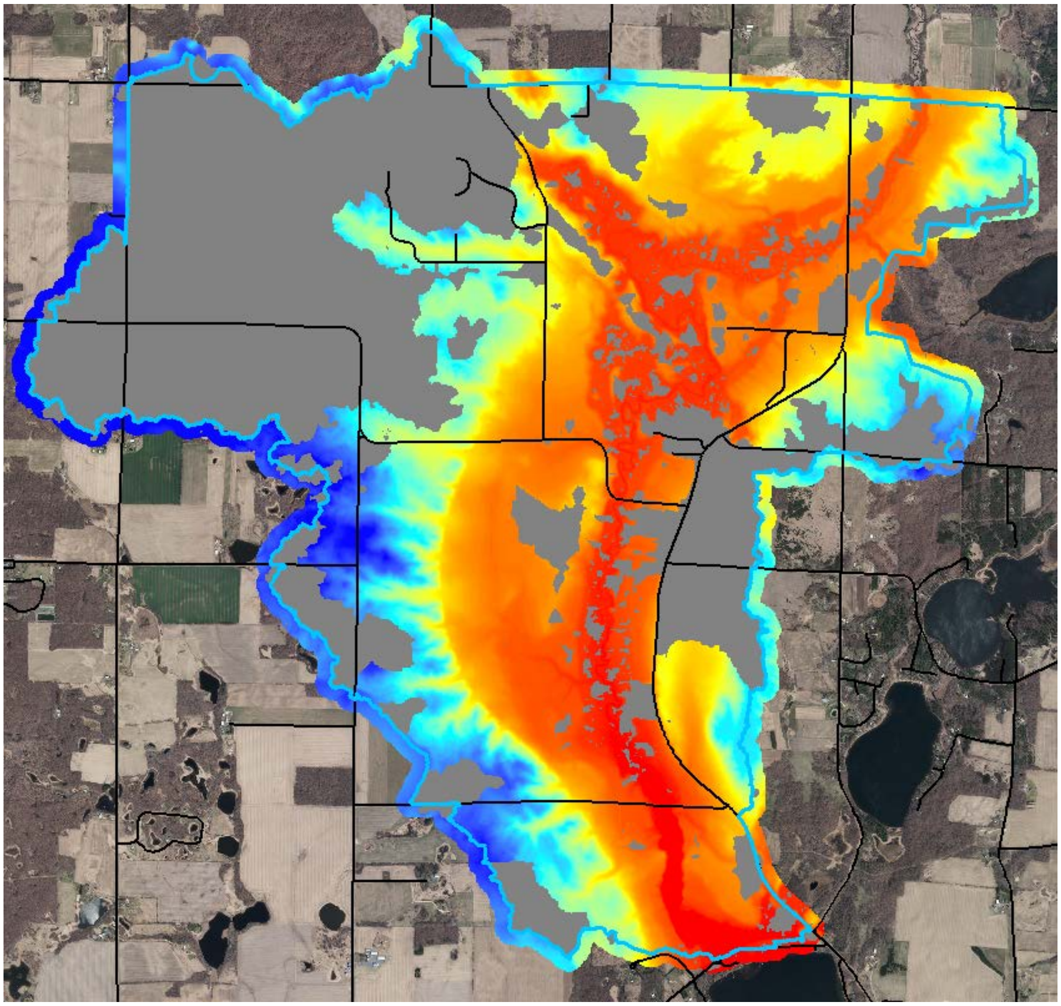

Figure 10: DEM Excluding Internally Draining Areas

Once the internally draining areas are removed, Stream Power Index (SPI) is calculated. SPI is the measure of the erosive power of flowing water. This step uses slope and flow accumulation calculated from the LiDAR DEM to determine areas of concentrated flow and where gullies are likely to form. Gullies are likely to form where sheet and rill erosion accumulates. SPI is calculated until an accumulation threshold is met at which point flow is considered to be perennial flow. SPI can be seen in Figure 11.

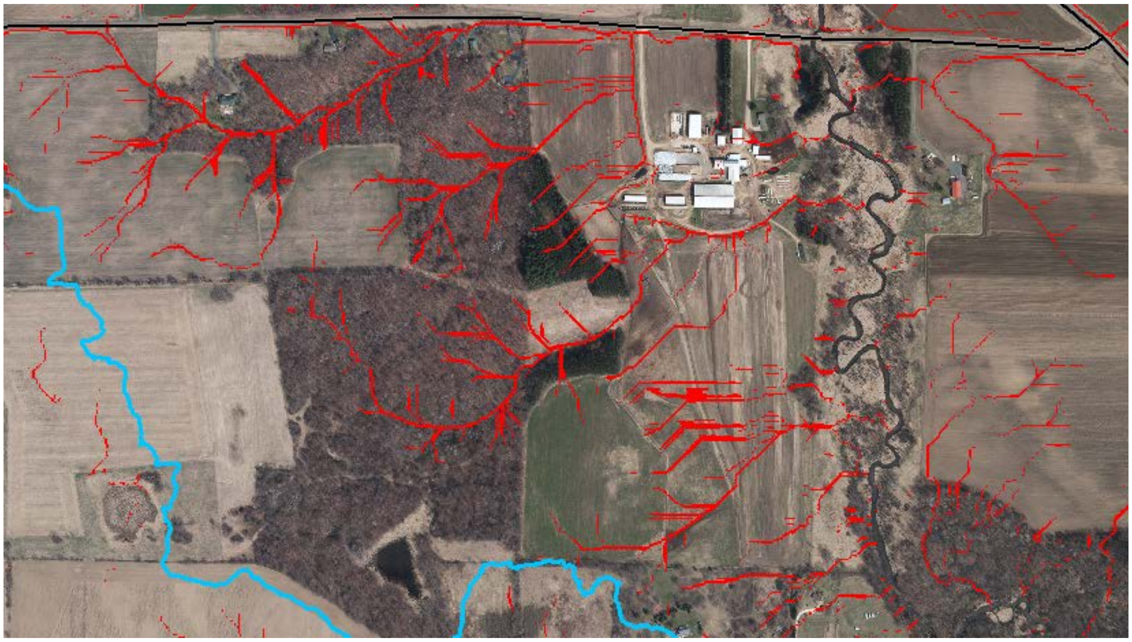

Figure 11: Stream Power Index

Soil loss potential is the next calculation in the EVAAL toolbox. Soil loss due to sheet and rill erosion is calculated using the Universal Soil Loss Equation (USLE). EVAAL uses the soil erodability factor, slope and slope length, and land cover factor to calculate potential soil loss. The rainfall erosivity or R factor is removed from the calculation because it can be assumed to be a constant across such a small watershed. The practice factor, P factor, is considered to be 1 for this calculation because field specific information is not available for this analysis. LiDAR DEM dataset is used to calculate slope and slope length as part of the USLE. Multiple years of the CDL are used to determine a generalized crop rotation. A rotation raster, Figure 12, is produced identifying areas of similar cropping practices. This crop rotation raster is then used to determine a rotational land cover, C factor, as part of the USLE. The USLE soil erodability, K factor, is used from the gSSURGO soil data layer. The USLE output raster, figure 13, identifies areas in the watershed with higher soil loss potential.

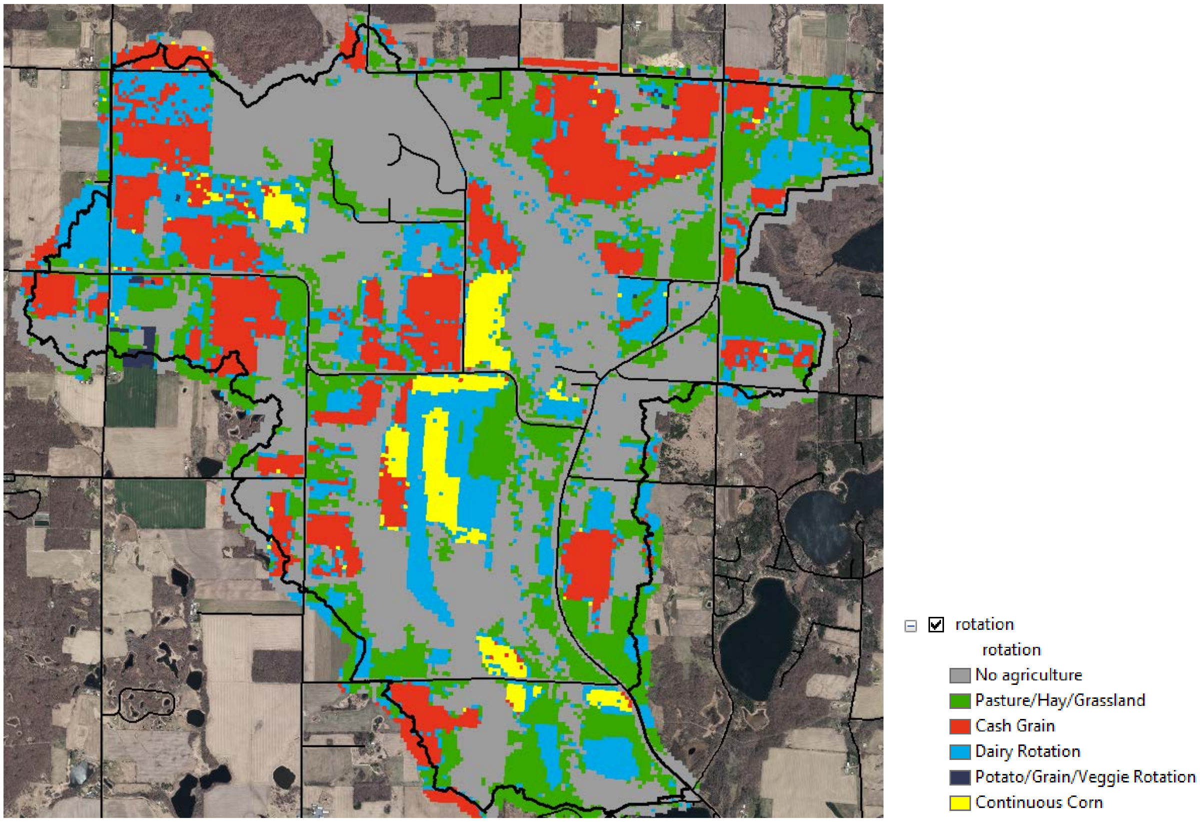

Figure 12: Rotation Raster

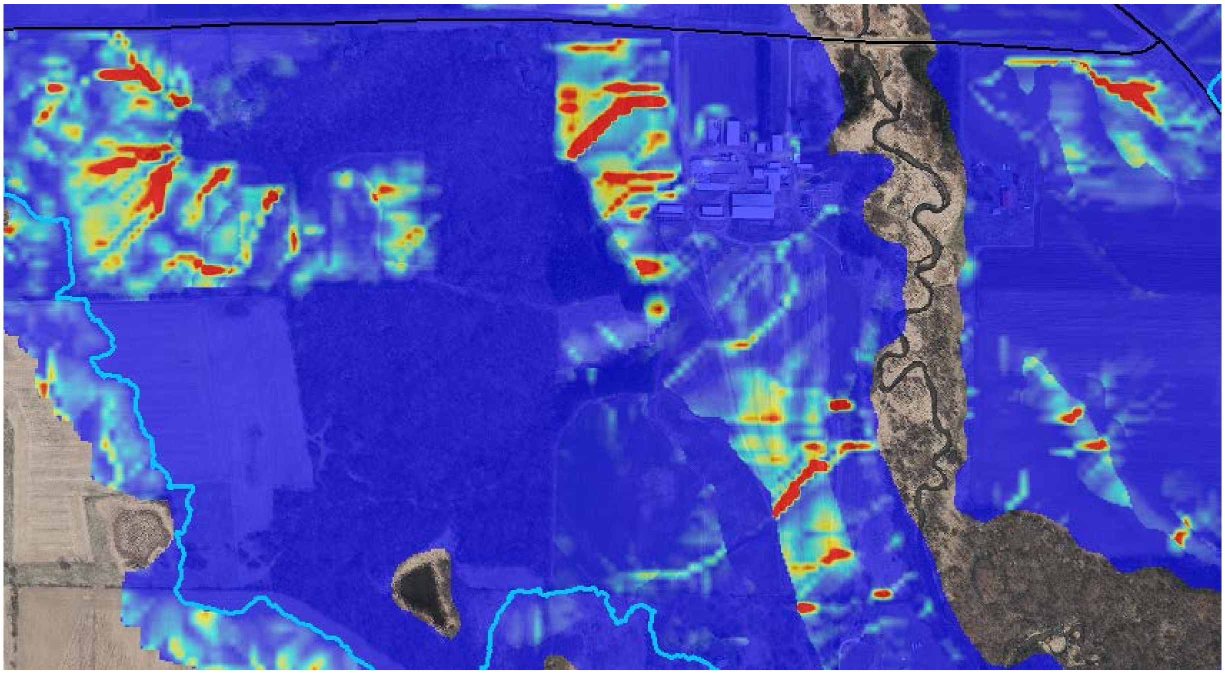

Figure 13: Soil Loss Potential

Once SPI and soil loss potential are calculated, the erosion vulnerability index (EVI) can be calculated. EVAAL calculates EVI by using the SPI, soil loss potential, and internally draining area. The primary EVI output, figure 14, is a raster grid layer. Areas of highest erosion vulnerability are displayed as red. Erosion vulnerability decreases as the color transitions to blue. The dark blue areas are the internally drained areas of the watershed and are removed from the calculation. The uncolored areas are areas of mucky soils where the gSSURGO soils layer doesn't have a K factor.

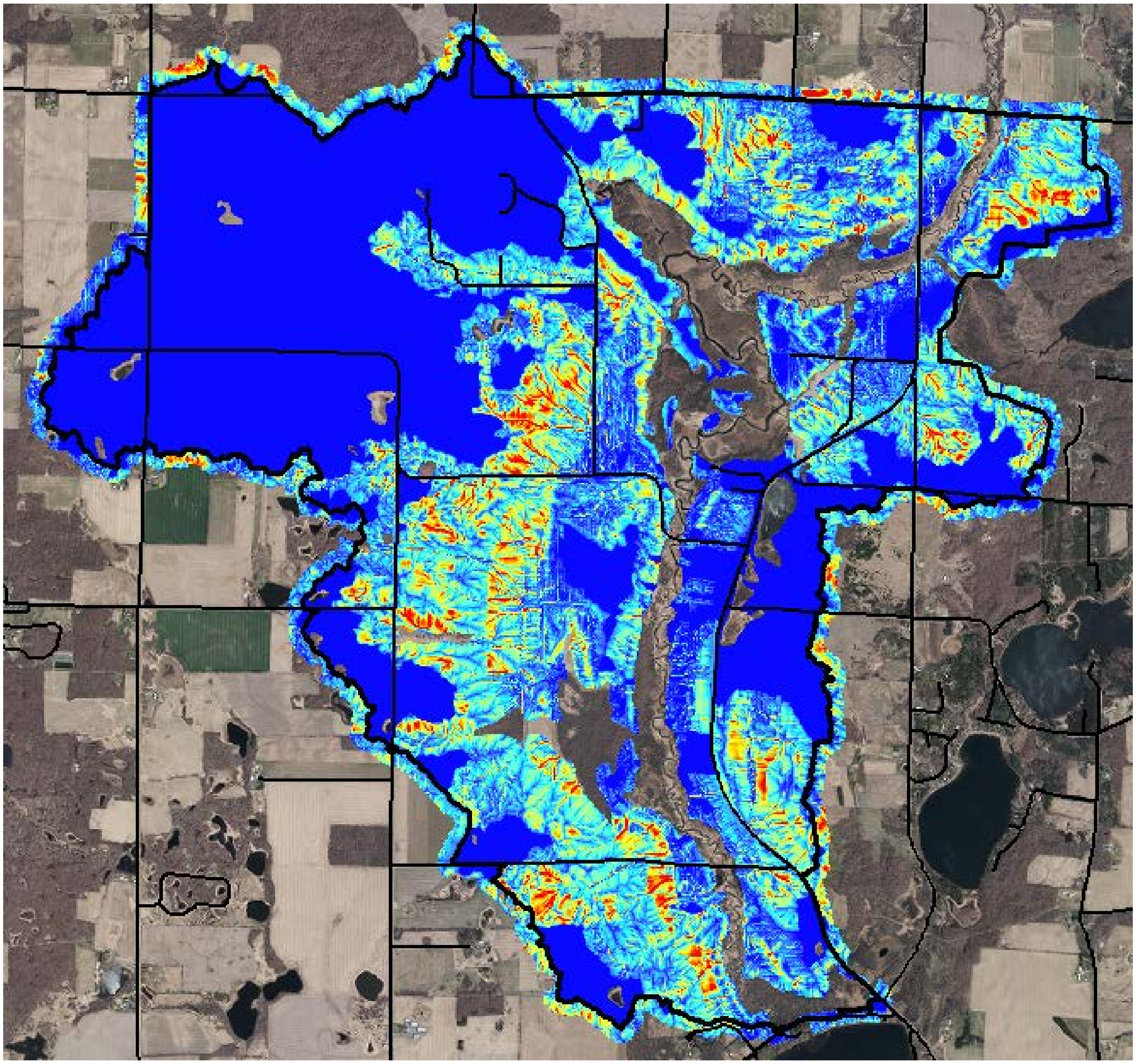

Figure 14: Erosion Vulnerability Index (EVI)

By using a parcel zonal boundary layer, the erosion vulnerability can be aggregated by parcel (figure 15). Erosion vulnerability can now be identified in each parcel compared to the other parcels within the watershed. Red represents higher erosion vulnerability while green means low erosion vulnerability. As you can see the majority of the green parcels lie within the internally draining areas of the water shed.

The red parcels correlate to the areas of cropland or steep forested areas. When analyzing parcels, we need to remember we are calculating erosion vulnerability or the potential for that parcel to produce runoff to surface waters. EVAAL is not calculating actual sediment or nutrient loading to surface waters. The EVAAL analysis needs to be verified by an on-site investigation to determine what is actually occurring at that site. By identifying parcels with higher erosion vulnerability, we can prioritize investigating those parcels first and find potential solutions to reduce that vulnerability.

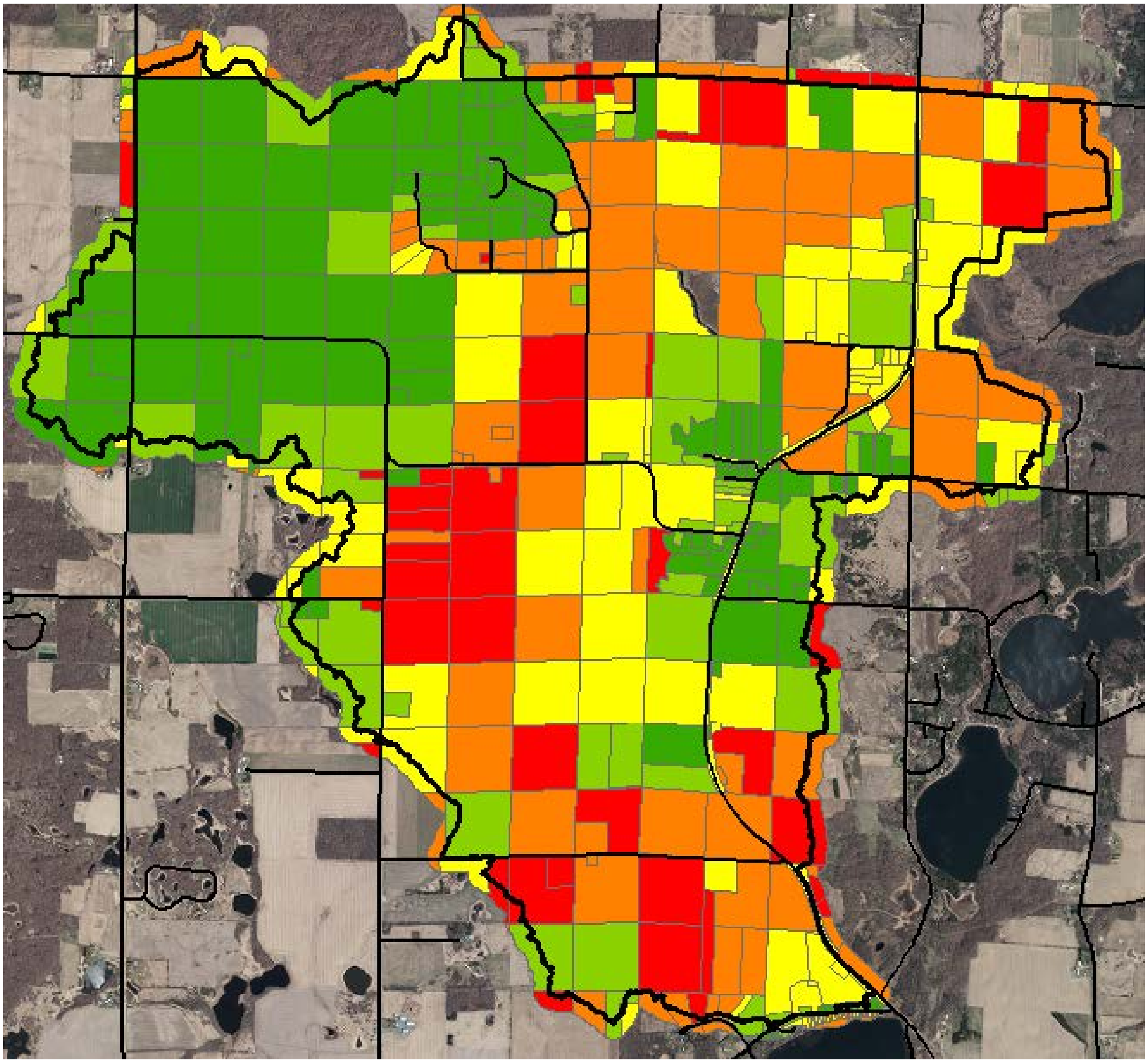

Figure 15: Erosion Vulnerability by Parcel

This report summarizes a basic analysis of using LiDAR data to delineate watersheds and use the EVAAL toolbox. Further analysis can be done with EVAAL by changing some of the inputs. Different steps in EVAAL produce high and low values for K factors (soil erodibility) and C factors (cover). Running multiple analyses can produce outcomes that plan for a watershed that uses no conservation practices verses a watershed where conservation practices like no-till planting are utilized. The two outputs can be compared to determine where a change in management practices can have the potential to produce the largest improvements in water quality. The tax parcel layer was chosen for the EVAAL analysis for this report because it is a readily available data layer. It also allows for analysis of non-agricultural land use.

Polk County LWRD is attempting to acquire an accurate county agricultural field boundary layer to use for future evaluations. This will allow LWRD to address erosion vulnerability exclusively from agricultural land uses. BMPs can then be targeted to those fields with the highest erosion potential. A more intensive analysis of the watershed could be done by delineating subwatersheds within the Horse Creek Watershed. These subwatersheds could be used as the zonal boundary layer in EVAAL. The EVI could then be aggregated by subwatershed to determine which subwatershed has the highest erosion vulnerability. Conservation efforts could then be targeted at individual subwatersheds.

This preliminary EVAAL analysis has been presented to the Horse Creek Farmer Led Watershed Council as a tool to implement conservation practices in their watershed. It has already prompted conversations about how to utilize the data to accomplish their watershed goals of improving water quality and soil health. This has been reflected in their 2017 incentive list by offering an incentive to establish permanent vegetative cover in areas of a field that is less productive and prone to erosion. The LiDAR data can be used to plan BMP practice installation by identifying areas of concentrated flow and higher vulnerabilities to erosion. A study comparing field Phosphorous Index values could not be completed at this time due to the lack of soil phosphorous concentration data. However, EVAAL is able to determine which fields actually contribute surface runoff directly to Horse Creek and Cedar Lake (see figure 10). These fields can be prioritized before fields that are internally draining. This will assist with addressing nutrient loading identified in the Cedar Lake TDML. Further work with the Horse Creek Farmer Led Watershed Council and watershed producers would be needed to secure soil test data that is available to the public.

The LiDAR data supplied through this grant has provided LWRD with a valuable dataset to utilize in all aspects of our conservation work. The analysis discussed in this report is only scratching the surface on how the data can be utilized. LiDAR data provided by this grant will prove beneficial to all lakes and rivers in Polk County. It will be especially useful in guiding nutrient reductions for the Cedar Lake, Squaw Lake, and Lake St. Croix TMDL's and Polk County Impaired Waters. Lake organizations will be able to use the data to update their existing Lake Management Plans, and new plans can be developed for lakes without a current plan. The data can be used for planning and designing conservation practices. By using models like EVAAL, LiDAR will provide agricultural producers, developers, lake organizations, and resource managers with a highly accurate elevation model to identify which watersheds and subwatersheds have the greatest potential to contribute sediment and nutrient loads to Polk County waterbodies. This will allow Polk County to develop county-wide phosphorus reduction strategies for lake protection and to meet the goals of the Cedar Lake, Lake St. Croix, and Squaw Lake TMDL's.