Maple Grove, MN | HEI No. 8177_003
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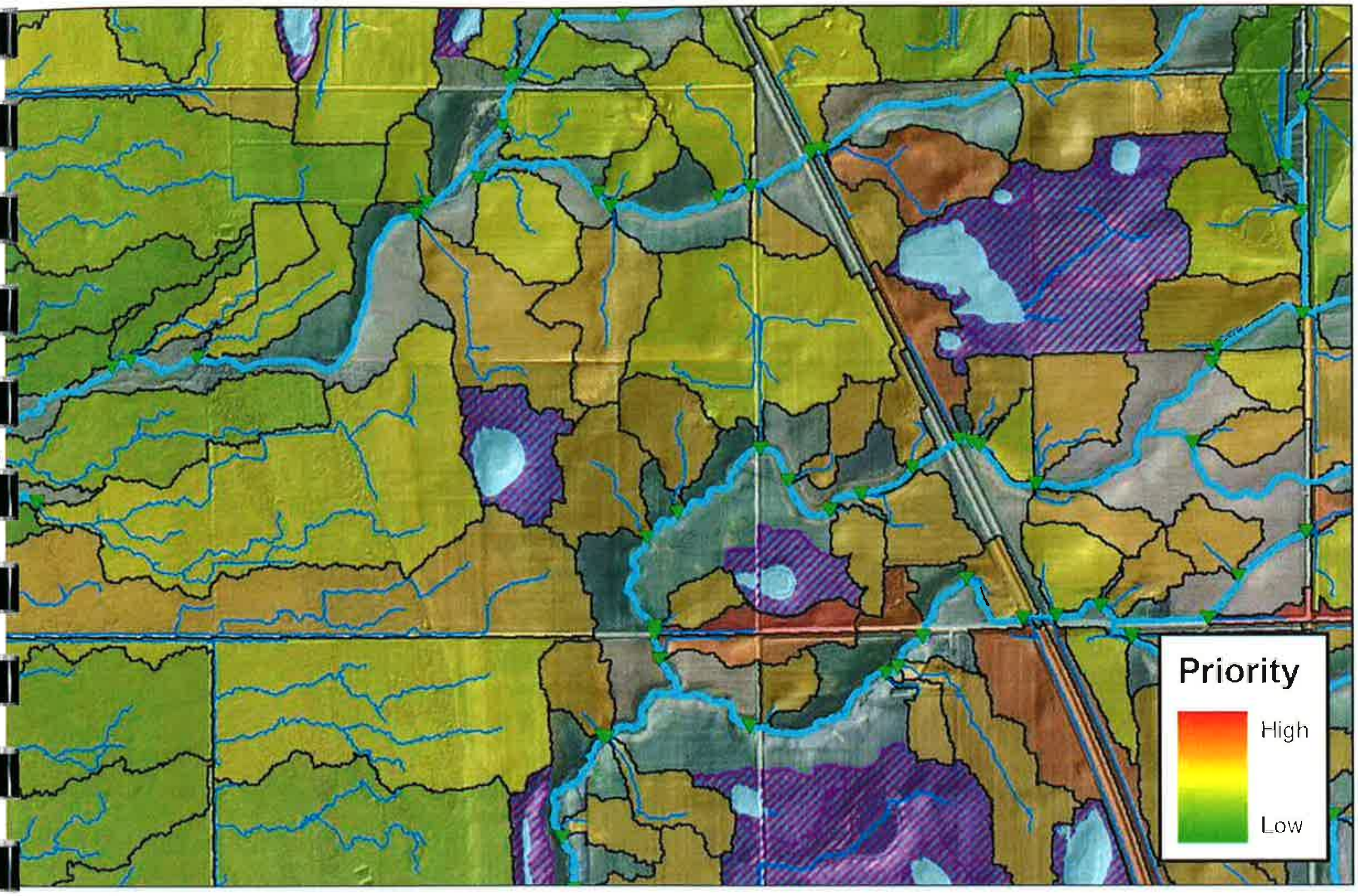

HYDROLOGIC CONDITIONING AND TERRAIN ANALYSIS REPORT – LAKE EMILY WATERSHED

Pope County SWCD

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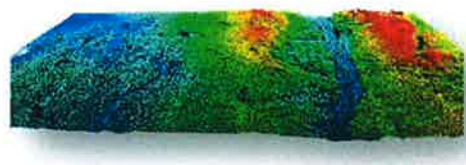
APPENDICES

1 SCOPE AND PURPOSE

1.1 INTRODUCTION

The Lake Emily Best Management Practice (BMP) Implementation Prioritization project is being performed with the goal of identifying locations suitable for BMPs and Conservation Practices (CPs) to pro-actively protect the lake's water quality. This is achieved through a process often referred to as "Terrain Analysis" which uses Geographic Information Systems (GIS) and high resolution topographic data collected using Light Detection and Ranging (LiDAR) technology combined with soil and land use information to identify critical areas across the watershed where nutrient loading, erosion, and sediment loss are greatest may be caused by surface water runoff. This analysis is consistent with Lake Minnewaska watershed BMP prioritization project completed in 2014.



This project includes creating a GIS raster layer of Stream Power Index (SPI) values, which provides a relative indication of the erosive power of overland, concentrated, and surface water runoff at locations across the landscape. In addition to GIS layers for annual yields of Total Phosphorus (TP), Total Nitrogen (TN) and sediment, and their delivery to downstream locations. The yield and delivery data are then "ranked" to establish priority areas for implementing conservation practices. Areas which only contribute runoff for a relatively "large" precipitation event (10-year, 24-hour) for water quality analysis purposes are identified to facilitate discussions about where the benefits of BMPs and CPs can be maximized. The products have also been used to identify potential locations for two commonly used practices; i.e., water and sediment control basins and filter strips.

1.2 STUDY AREA

The Lake Emily watershed comprises an area of approximately 132 square miles in Pope County, with the City of Starbuck located at its east side, Lake Reno at the northern boundary and Lake Emily at the southern boundary. The lake's watershed consists of seven 12-digit Hydrologic Unit Code (HUC) watersheds, two of which were analyzed during the Lake Minnewaska BMP prioritization project in 2014 (070200050301-Pelican Lake and 070200050302-Lake Minnewaska). The five 12-digit HUCs analyzed in the Lake Emily project include: 070200050301-Lake Reno-Little Chippewa River, 070500050202-Erickson Lake, 070500050203-Little Chippewa River, 070500050303-Outlet Creek, and 070200050304-Lake Emily. **Figure 1** shows the 12-digit HUC watershed boundaries and the Minnesota Department of Natural Resources (DNR) Minor watershed boundaries.

2 DATA SOURCES

Several data sources were used during the GIS based terrain analysis work. Descriptions of the primary data sources used and a summary of their origin and content follows.

2.1 TOPOGRAPHIC DATA

This study utilizes the State of Minnesota's Elevation Mapping Project's[1] Light Detection and Ranging (LiDAR) elevation data collected to a vertical root mean square error (RMSE) of plus or minus six inches. For purposes of this work, the bare earth LiDAR points were interpolated into a digital elevation model (DEM) at a 3 meter by 3 meter resolution.

2.2 RAINFALL FREQUENCY/DURATION DATA

The hydrologic conditioning process included analysis to identify areas that contribute runoff downstream during a 10-year 24-hour rainfall event and area considered "noncontributing). The National Oceanic and Atmospheric Administration (NOAA) Atlas 14 (NOAA, 2013) precipitation data were used for the rainfall depths for the 10-year, 24-hour event to generate runoff volume estimates used to identify areas that contribute runoff downstream to Lake Emily.

2.3 LAND USE/LAND COVER

The 2011 National Land Cover Dataset[2] (NLCD) was used to develop runoff Curve Numbers, and to generate estimates of Total Nitrogen and Total Phosphorus loading. The National Agricultural Statistics Service[3] (NASS) 2013 Cropland Data Layer (CDL) was used for assigning cover management values for various land cover types in the revised universal soil lose equation (RUSLE).

2.4 SOILS

Hydrologic Soil Group designations from the Natural Resources Conservation Service's (NRCS) SSURGO[4] database were also used in the developing Curve Numbers for hydrologic conditioning of the DEM. Soil Erodibility Factors (K_w) from these data were used as inputs for RUSLE.

2.5 RAINFALL-RUNOFF (R-FACTOR) VALUES

Information on R-factors used in RUSLE is available from the NRCS MN Field Guide. The R-factor accounts for the impact of meteorological characteristics on erosion rates.

3 METHODS

3.1 HYDROLOGIC CONDITIONING

Hydrologic conditioning is the process of modifying the topographic data represented as the raw or "bare earth" DEM through a series of GIS processing steps to more accurately represent the movement of water on the

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[1] http://www.mngeo.state.mn.us/committee/elevation/mn_elev_mapping.html

[2] 2011 National Land Cover Database (NLCD), Website: http://www.mrlc.gov/nlcd2011.php

[3] National Agricultural Statistics Service (NASS), 2013 Cropland Data Layer (CDL), Website: http://www.nass.usda.gov/

[4] Natural Resource Conservation Service (NRCS), Soil Survey Geographic Database (SSURGO). Website: http://soildatamart.nrcs.usda.gov/

landscape. Upon completion of the hydrologic conditioning process the DEM becomes modified to reflect the movement of water not only based on topography, but the presence of other factors affecting water movement like the locations of culverts, drains, or other structures. The hydrologic conditioning process is iterative, because adding the presence in an upstream area, modifies how water moves downstream. Several iterations are generally needed to achieve the final conditioned DEM. The modification process typically involves lowering elevations within the DEM to ensure the water flow direction includes the presence of culverts, breeching digital dams (lowering the outlet) and elevating user-defined sinks to ensure that water flow paths are accurately represented in the conditioned DEM.

The level of detail in the conditioning process can vary significantly depending on the purpose and need of the conditioned DEM's uses. **Figure 2** displays the range of conditioning scale and some basic explanation of their differences. The Lake Emily DEM conditioning was performed to the A standard to provide a large range of functionality in the output data products.

The quality of the final conditioned products and their usability is completely dependent upon the number of "burn lines" used to condition the DEM. The number of burn lines can range from none to literally thousands and in part drives the level of effort to complete the conditioning and the detail of the resulting products. Decisions related to burn line placement and their location is part of the deliverable provided by HEI within the geodatabase. Only through this type of documentation can data be compared from analyst to analyst and location to location. More detail about the importance of the conditioning process is included within this section of the report.

Figure 2 - Hydrologic DEM Conditioning and Data Product Scale

	Minimum Criteria	DEM Reconditioning and Data Product Scale				
		Fine			*Coarse*	
		A	B	C	D	E
1	**Elevation Source Data**	High Resolution Topographic Data (e.g., using LIDAR)				**USGS National Elevation Dataset**
2	**Mininum drainage area threshold used for Quality Control**	< 1 sq. mile	1 - 5 sq. miles	5 - 10 sq. miles	> 10 sq. miles	**All Ranges**
3	**Maximum Digital Elevation Model and Raster Data Product Resolution**	5 meter	5 meter	10 meter	30 meter	**Any**
4	**Hydrologic Boundary and Vector Data Product Resolution**	160 acres maximum *(ideally 40 acres)*	1 square mile maximum	5-10 sq. mile maximum	> 10 square mile maximum	**12-digit HUC**
5	**Source of Reconditioning Data**	User intrepretation using source elevation data, supplemented with field-verified data where required	User intrepretation using source elevation data, supplemented with field-verified data where required	User intrepretation	User intrepretation	**Existing GIS dataset (NHD, MnDNR 24k Streams, etc...)**
6	**Intensity of Recondition**	High *Several iterations by experienced hydrologist to meet Criteria 2*	Moderately High *Several iterations by experienced hydrologist to meet Criteria 2*	Moderate *Minimal iterations by experienced hydrologist to meet Criteria 2*	Low *Minimal iterations by experienced hydrologist to meet Criteria 2*	**None**
7	**Data Products and Functionality**	BMP Design Water Quality Overland Flow On-the-fly Watershed Delineation Hydrographics Gridded Parameter Modeling "Lumped" Parameter Modeling	On-the-fly Watershed Delineation Hydrographics "Lumped" Parameter Modeling	Hydrographics "Lumped" Parameter Modeling	Hydrographics "Lumped" Parameter Modeling	**NHD Plus**

**"User interpretation" implies photographic interpretation combined with the source elevation data to make assumptions on drainage characteristics.*

3.1.1 DEM MODIFICATIONS

Conditioning the DEM is an iterative process that requires user interpretation of runoff characteristics within the watershed. The "bare earth" DEM fails to account for sub-surface drainage structures, such as culverts and flood control structures, and creates false digital dams in the DEM. Conditioning involves interpreting the location of these structures and accounting for them by "burning in" their location to the "bare earth" DEM. The term "burning in" refers to artificially lowering the DEM along the alignment of the subsurface drainage structure to allow flow accumulation through a digital dam. The alignments of the subsurface drainage paths are referred to as burn lines. Conversely, wall lines are needed in some instances to raise the elevation values in order to create accurate flow paths and delineations. For this project wall lines were utilized less frequently than burn lines. The resultant DEM is referred to as the AgreeDEM. The AgreeDEM was then ran through a series of GIS watershed processing techniques to determine drainage lines and catchment polygons for the analyzed watershed. These drainage lines and catchment polygons were validated by experienced hydrologists and are also used in subsequent watershed analysis. This process was iterated until the conditioned DEM allowed for accurate representation of the area's hydrology.

3.1.2 NON-CONTRIBUTING ANALYSIS

Depressional areas (e.g., sinks, wetlands, potholes) are a naturally-occurring feature in many landscapes. During runoff events the runoff volume reaching a depressional area is not contributed downstream until the runoff volume exceeds the depressional area's volume. If the runoff volume does not exceed the depressional area volume, the area was categorized as "non-contributing". This determination is dependent on the size of the runoff event analyzed. For the purposes of this study, non-contributing areas were defined as areas that contain the runoff volume corresponding to the 10-year, 24-hour precipitation event. For the study area, this event was 3.7-3.95 inches of precipitation, as defined by the National Oceanic and Atmospheric Administration (NOAA) in the Atlas 14 Precipitation-Frequency Atlas of the United States (NOAA, 2013). The non-contributing determination was performed using a series of iterative GIS processes in which the available storage of a depressional area was compared to the runoff volume generated from the contributing watershed of the depressional area. This is an iterative "fill and spill" process in which the excess runoff of contributing areas is routed through subsequent downstream depressional areas until no excess runoff was produced. This process resulted in a hydrologically conditioned DEM that accounts for non-contributing areas, often referred to as the HydroDEM or conditioned DEM. All depressional areas determined to be contributing were "filled" by adjusting their elevation values to equal the surface spill out elevation to create a continuous flow path that traverses the depressional area. Flow paths terminate at the minimum elevation cell within each non-contributing depressional area.

3.1.3 HYDROLOGIC CONDITIONING OUTPUT

Various layers are generated from the conditioned DEM and are available in the provided geodatabase files. Several layers are referred to often in this report and are defined here for clarity.

- Flow Accumulation – The accumulated number of cells (or drainage area) upstream of each cell within the contributing watershed.
- Overland Flowpaths – It is derived from the flow accumulation raster. Any cell having a contributing area less than 124 acres and an upstream flow length longer than 300 feet.
- Overland Catchments – The drainage area to the location where the flow transitions to in-channel. .

- Overland Catchment Outlet – The point at which flow transitions from overland to in-channel. The drainage area to the overland catchment outlet is the overland catchment.
- In-channel Flowpaths – Areas receiving greater than 124 acres of contributing drainage area.

3.2 TIME OF TRAVEL

A travel time raster was used to estimate the quantity of sediment and nutrients delivered to downstream water resources of concern. The travel time raster was developed using an ArcGIS script available from the Minnesota DNR. Flow direction, flow accumulation and slope derived from the conditioned DEM were used along with land cover to compute hydrologic velocities between each cell. The velocities for each cell were converted to a travel time based on the length between cells and then accumulated in the downstream direction, creating a raster of travel time to the watershed outlet.

Travel times within non-contributing areas were computed using the DNR script as described. Flow paths were terminated at the non-contributing depression's minimum elevation cell. Since the travel time was computed using flow paths derived from the conditioned DEM, travel times also terminate at the minimum elevation cell. In some instances a non-contributing depression is drained via sub-surface tile for agricultural production purposes. A travel time terminating in a drained depression would not represent the true travel time to downstream resources. Non-contributing areas were connected to the nearest downstream drainage line with at least 124 acres of contributing area and an adjusted travel time was calculated based upon this connection.

3.3 ENHANCED GEOSPATIAL WATER QUALITY DATA PRODUCTS

The enhanced geospatial water quality data products developed for this project consisted of a Stream Power Index (SPI), annual yields (mass/area/year) of total phosphorus (TP), total nitrogen (TN), and sediment, all of which were developed as derivatives of the conditioned DEM at a 3 meter spatial resolution.

3.3.1 STREAM POWER INDEX

The Stream Power Index accounts for physical characteristics of a landscape to estimate the potential of overland and concentrated surface water flow to cause erosion. SPI values are computed by multiplying the slope of a point on the landscape by its contributing drainage area.

$$SPI = \ln[(flow\ accumulation)\ x\ (slope)]$$

Higher SPI values indicate greater energy in moving surface water and thus a greater likelihood of sediment erosion. SPI is a simple analysis, not accounting for land cover, land use, soil type or other factors that impact surface water erosion. For this reason, it is best to compare SPI values across areas with similar land management practices, land covers, and soils.

SPI values were computed across the study area using derivatives of the conditioned DEM. Landscape slope was determined from the raw "bare earth" DEM. Contributing areas were determined using the flow accumulation raster created from the conditioned DEM. SPI values across the study area were computed by multiplying the two rasters together.

The primary focus of the SPI analysis was to locate areas with high potential for erosion and subsequently gully formation. Since the likelihood of gully erosion is generally low where rill and interrill flow occurs, areas of the watershed where the upstream flow length is less than 300 feet were eliminated from the SPI analysis. In-channel flow areas were also removed from the SPI raster, since this method focuses on overland and concentrated surface flow and not channelized flow.

3.3.2 SEDIMENT YIELD

Sediment yields are estimated based on the implementation of the RUSLE. RUSLE accounts for land cover, soil type, topography, and management practices to determine an average annual sediment yield estimate as a result of rill and interrill flow. RUSLE requires several input parameters to be developed and multiplied in the equation to form the estimated annual sediment yield. The following section summarizes the development of input variables to RUSLE. The RUSLE was calculated as:

$$A = R \text{ x } K \text{ x } LS \text{ x } C \text{ x } P$$

where, R is the Rainfall and Runoff Factor, K is the Soil Erodibility Factor, LS is the Length-Slope Factor, C is the Cover and Management Factor, and P is the Support Practice Factor. Figures are included in Appendix A that show the input variables and their variation across the project area.

3.3.2.1 RUSLE INPUTS

Rainfall and Runoff Factor (R-factor) – The R-factor accounts for the impact of meteorological characteristics of the watershed on erosion rates. Information on R-factors across the State of Minnesota is available from the NRCS Field Guide, on a county-by-county basis (NRCS, 1996)

Soil Erodibility Factor (K-factor) – Soil erodibility factors used in this analysis were taken directly from the NRCS's SSURGO Database. The K factor accounts for the effects of soil characteristics on erosion rates.

Length-Slope Factor (LS-factor) – The LS-factor accounts for physical characteristics of the landscape on erosion rates. The US Department of Agriculture's (USDA) Predicting Soil Erosion by Water: A Guide to Conservation Planning with RUSLE, Agricultural Handbook No. 703 summarizes the methodology used to derive the LS-factors for this work. Length data was derived from the conditioned DEM and slope data was derived from the raw "bare earth" DEM.

Cover and Management Factor (C-factor) – The C-factor accounts for land cover effects on erosion rates. C-values in the NRCS's MN Field Office Technical Guide and were used as the basis for developing the values used in this analysis. The USDA's 2013 National Agricultural Statistics Service's (NASS) Cropland Data Layer (CDL) was used to define land cover and crop type in the study area. Table 1 summarizes 2013 NASS land cover classification in the study area and the corresponding C-factors used.

The C-factors used in this project were generalized due to the scale of the project watershed. Since future crop rotations are unknown and outputs of this project are planned to be used for future implementation, C-factors were generalized under the assumption that row crops will typically be rotated with other row crops. These types of crops were given a common value. Other crops and land cover types were given the appropriate C-factor. Because of this generalization, it is recommended that the RUSLE analysis be used mainly in comparison to other areas in the project watershed for purposes of prioritizing land use management.

Table 1: Cover and Management Factors for NASS Cropland Data Layer Categories

C- Factor	NASS CDL Classification
0.200	Corn, Sweet Corn, Soybeans, Sunflower, Barley, Spring Wheat, Durum Wheat, Winter Wheat, Buckwheat, Rye, Oats, Canola, Flaxseed, Peas, Herbs, Dry Beans, Potatoes, Other Crops, Fallow/Idle Cropland, Sugarbeets, Sorghum, Millet
0.100	Alfalfa, Other Hay/Non Alfalfa, Sod/Grass Seed, Herbs
0.005	Clover/Wildflowers

C- Factor	NASS CDL Classification
0.003	Developed/Open Space, Developed/Low Intensity, Developed/Medium Intensity, Developed/High Intensity, Barren
0.002	Deciduous Forest, Evergreen Forest, Shrubland, Mixed Forest
0.001	Grassland Herbaceous, Woody Wetlands, Herbaceous Wetlands
0.000	Open Water

Support Practice Factor (P-factor) – The P-factor accounts for the impact of support practices on erosion rates. Examples of support practices include contour farming, cross-slope farming, and buffer strips. For the purposes of this analysis, variations in P-factors across the study area were not accounted for since there is not sufficient information to derive P-factors at the scale required for this analysis. Support practice P-factors are typically less than one and result in lower estimates of sediment yield than if the support practices were not accounted for. As such, the results of the RUSLE analysis in this work are conservative estimates of soil erosion, not accounting for support practices that may be in-place.

3.3.2.2 DOWNSTREAM SEDIMENT DELIVERY

Once the sediment yield leaving the landscape is estimated for a cell, the sediment reaching a channel at the overland catchment outlet is estimated using a sediment delivery ratio (SDR). The estimated SDR for the catchment is a function of area (Maidment, 1993).

$$Overland\ SDR = 0.41 * catchment\ drainage\ area\ (sq.km)^{-0.3}$$

The SDR for each cell within an overland catchment is estimated as a function of the catchment SDR adjusted by the distance from a cell to the flowline.

$$Overland\ SDR\ Adjustment\ Factor = 1 - \frac{\frac{Flow\ Length}{Maximum\ Flow\ Length\ in\ Catchment}}{0.75 + \frac{Flow\ Length}{Maximum\ Flow\ Length\ in\ Catchment}}$$

Therefore, the SDR for each cell is computed as Overland SDR (for the catchment) multiplied by Overland SDR Adjustment Factor (for the cell).

The sediment transported downstream to subwatershed and watershed outlets is further reduced using a first-order transport function. In-channel downstream transport and loss follows an exponential decay function (i.e., first order loss) using travel time and median diameter of sediment:

$$SY = Ye^{-\beta T\sqrt{d_{50}}}$$

Where Y is sediment yield from sub-basin, β is transport coefficient, T is travel time, d_{50} is mean sediment diameter. Values of 0.2 and 0.1 are used for β and the d_{50}, respectively.

Essentially, four products were produced for each cell in the raster: 1) sediment yield leaving the landscape; 2) sediment yield reaching the overland catchment outlet; 3) sediment yield delivered to a user defined downstream subwatershed outlet; and 4) sediment yield reaching the watershed outlet. The user defined points included the lake outlet for Lake Emily and the HUC 12 outlet approximately 1 mile west of Lake Emily.

3.3.3 TOTAL NITROGEN AND TOTAL PHOSPHORUS YIELD

Nutrient annual yields leaving the landscape are estimated using a method similar to sediment (i.e., they are computed for each cell in the raster). Yields for TP and TN follow an empirical approach using land use export coefficients from literature values. TP and TN annual yields are estimated using the values in **Table 2** and **Table 3** applied to each National Land Cover Dataset (NLCD) land use class.

Table 2: Total Phosphorus Loading for NLCD Land Use Classifications

NLCD Classification	Description	TP Loading [kg/ha/yr]	Source
11	Open Water	0	MPCA 2004
21	Developed, Open Space	1	US EPA, Lin 2004
22	Developed, Low Intensity	0.91	LimnoTech 2007
23	Developed, Medium Intensity	1.15	LimnoTech 2007
24	Developed, High Intensity	1.5	LimnoTech 2007
31	Barren Land	1	MPCA 2004
41	Deciduous Forest	0.075	LimnoTech 2007
42	Evergreen Forest	0.075	LimnoTech 2007
43	Mixed Forest	0.075	LimnoTech 2007
52	Shrub/Scrub	0.075	LimnoTech 2007
71	Grassland/Herbaceous	0.17	LimnoTech 2007
81	Pasture/Hay	0.17	LimnoTech 2007
82	Cultivated Crops	0.38	LimnoTech 2007
90	Woody Wetlands	0	LimnoTech 2007
95	Emergent Herbaceous Wetlands	0	LimnoTech 2007

Table 3: Total Nitrogen Loading for NLCD Land Use Classifications

NLCD Classification	Description	TP Loading [kg/ha/yr]	Source
11	Open Water	3.5	MPCA 2013
21	Developed, Open Space	3.5	MPCA 2013
22	Developed, Low Intensity	5.4	US EPA 1983
23	Developed, Medium Intensity	9.6	US EPA 1983
24	Developed, High Intensity	18.0	US EPA 1983
31	Barren Land	3.5	MPCA 2013
41	Deciduous Forest	2	US EPA 1999
42	Evergreen Forest	2	US EPA 1999
43	Mixed Forest	2	US EPA 1999
52	Shrub/Scrub	2	US EPA 1999
71	Grassland/Herbaceous	1.3	USDA MANAGE[5] database
81	Pasture/Hay	2.4	USDA MANAGE[5] database

[5] U.S. Department of Agriculture – Agricultural Research Station. Nutrient Loss Database for Agricultural Fields in the US. (http://www.ars.usda.gov/Research/docs.htm?docid=11079)

NLCD Classification	Description	TP Loading [kg/ha/yr]	Source
82	Cultivated Crops	7.8	USDA MANAGE[5] database
90	Woody Wetlands	3.5	MPCA 2013
95	Emergent Herbaceous Wetlands	3.5	MPCA 2013

3.3.3.1 DOWNSTREAM TOTAL NITROGEN AND TOTAL PHOSPHORUS DELIVERY

The mass leaving each cell comprising the raster can be "routed" downstream to: 1) the overland catchment outlet 2) a subwatershed outlet and 3) the watershed outlet, using a first order decay computed as a function of overland and in-channel flow travel times. The decay or loss of mass after leaving the landscape is used to represent the reduction in mass from physical, chemical and biological processes. The computed travel time raster is used in estimating the first order loss coefficient. The calculation methods for downstream routing can be subdivided into two parts 2) transport to the channel, and 3) an in-channel routing routine.

The nutrient mass loss as it is transported downstream was represented using a first order loss equation for both, as a function of travel time:

$$W = \exp(-kT)$$

where W is the portion of the yield leaving the landscape and delivered to the downstream, k is the decay rate and T is travel time from one location to the next The default values used for k was 0.1 for travel to the overland catchment outlet and 0.4 for in-channel transport. The delivery raster was created using the travel time raster to determine the portion of the mass reaching the overland catchment, subwatershed, and watershed outlets.

3.4 SUBWATERSHED RANKING AND FIELD TARGETING

3.4.1 SPI PERCENTILE RANKING

The results of the SPI analysis are most valuable when compared relative to one another across similar landscape, soil, and land management settings. To make the relative comparisons for the project watershed, SPI raster values were given a percentile ranking using a log-normal distribution. The percentile ranking represents a cell's relative rank for potential erosion issues.

3.4.2 SEDIMENT, TOTAL PHOSPHORUS AND TOTAL NITROGEN PERCENTILE RANKING

GIS layers for sediment, TP and TN were individually analyzed and given a percentile ranking using a log-normal distribution. The percentile ranking represented a cell's relative rank for potential erosion, sediment, TP or TN loading. The result of the percentile ranking provide context for the various parameters by showing the severity of the values relative to others in the study area. Rankings were computed for 3 scenarios: 1) sediment, TP and TN yields leaving the landscape; 2) sediment, TP and TN yields reaching the overland catchment outlet; 3) sediment, TP and TN yields reaching Lake Emily.

3.4.3 WATER QUALITY INDEX

A Water Quality Index (WQI) value was created that combines the sediment, TP and TN ranked rasters into one composite ranking computed as follows.

$$Water\ Quality\ Index\ (WQI) = 0.5\ x\ Sediment\ Rank + (0.25\ x\ TN\ Rank + 0.25\ x\ TP\ Rank)$$

This formula gives equal weighting to both sediments and nutrients to identify areas contributing relatively high proportions of both sediment and nutrients downstream.

3.4.4 AGGREGATED PRODUCTS

For the purposes of making the results more easily interpretable and useable, the water quality products and the derived ranking and index raster layers were summarized by catchment areas. Summary statistics calculated within overland catchments include sums of sediment, TP and TN loads leaving the landscape and yields delivered to the catchment outlets, Lake Emily outlet and at the confluence with the Chippewa River. Additionally the mean Water Quality Index and SPI Rank values are computed for catchments.

3.5 BMP SUITABILITY

The implementation of BMPs and CPs such as Sediment Basins, Grassed Waterways, Riparian Buffers, Cover Crops and others are largely dependent upon a site's suitability to a given practice based on the topographic characteristics and land use. Many other factors such as land owner willingness and the proximity to priority water resources are also important items. The conditioned DEM layers make it possible to identify potential locations based on topography and other design factors that are most suitable for certain practices over the watershed. The locations identified through this analysis should be considered preliminary, and require field verification. The following criteria was applied to the Lake Emily watershed for Sediment Basins, Controlled Drainage and Riparian Buffer Strips to predict suitable locations.

Table 4: BMP Suitability Criteria

BMP	Suitability Criteria
Sediment Basin/ WASCOB	Accumulated sediment delivered to flow line percentile ranking > 75th; and Contributing Area < 40 acres.
Riparian Buffers/ Filter Strips	Within 100 ft. of waterway; NLCD 2006 is cultivated lands; < 8.1 tons/year of sediment load; and Contributing area < 124 acres.

4 PRODUCTS AND RESULTS

4.1 GEODATABASE PRODUCTS

The number of GIS products resulting from the conditioning process is large. Therefore, developing maps for each product is prohibitive and only example products are included in the body of the report. To facilitate subsequent use and ensure protection of the fiscal investment in creating the products, HEI has developed a method to document all the products. Products resulting from completing the terrain analysis process are grouped into four types and provided in four separate GIS file geodatabases. The product types are:

- Input Data geodatabase – includes the raw digital elevation model derived from LiDAR, wall lines, and burn lines with notes from the analyst documenting their location and reasons for use. Documenting the burn line decisions is critical and without documentation, the comparison of products between geographic areas and analysts is tenuous;
- Hydrologic Conditioning and Hydrology Products geodatabase – includes the products from the conditioning process including the flow direction raster, the flow accumulation raster, the conditioned DEM, flowlines, non-contributing area polygons, overland catchments and subwatershed boundaries;
- Water Quality Products geodatabase – includes all of the water quality products including the sediment, TN, TP yields leaving the landscape and reaching pre-defined downstream locations such as specific lakes and rivers.

- Derived Water Quality Products geodatabase – primarily includes products derived from the sediment, total phosphorus and total nitrogen rasters within the Water Quality Products geodatabase. This includes the results of the raster ranking process and yields and rankings for sediment, TP and TN summarized within each overland catchment and non-contributing area. It also includes the results of the BMP suitability analysis.

Results, example products and a brief description of their use follow within the remainder of this section.

4.2 RESULTS AND EXAMPLE PRODUCTS

4.2.1 HYDROLOGICALLY CONDITIONED DEM

A hydrologically conditioned DEM was derived from the conditioning process from which accurate water flow paths were developed. Approximately 4,200 individual burnlines were created to condition the DEM and 727 separate non-contributing depressions with drainage areas totaling 38.2 square miles determined using the 10-year, 24-hour non-contributing analysis leaving 94.3 square miles contributing to the Lake Emily HUC 12 outlet. **Figure 3** displays the conditioned DEM, major drainage paths derived from the conditioned DEM and results from the non-contributing analysis. These data are useful in planning water quality improvements. Those areas which primarily contribute runoff to a downstream lake for precipitation events equaling or exceeding the 10-year, 24-hour precipitation event could be considered lower priority for implementing BMPs and CPs. The reason is that these areas contribute runoff downstream on average once every ten years, reducing effectiveness of BMPs placed within these areas at downstream locations. However, there may be additional reasons for implementing BMPs and CPs within the areas (e.g., a lake or stream of interest within the non-contributing areas).

4.2.2 TIME OF TRAVEL

The computed travel times to Lake Emily for contributing and non-contributing areas are shown in **Figure 4**. The times represent the computed time of travel in hours from the individual cell downstream to Lake Emily. The largest travel time values are near 140 hours and are located within the Lake Reno watershed. The travel times do not account for the temporary storage of runoff that occurs in within the intervening lakes and depressions. This information is useful in judging how rapidly water reaches the lake in the absence of accounting for the effects of storage.

4.2.3 ENHANCED GEOSPATIAL WATER QUALITY DATA PRODUCTS FOR RANKING AND TARGETING

A variety of products were developed using the enhanced geospatial water quality data products. For example, the cell values comprising a raster within a catchment or subwatershed can be summed, providing total yields at the catchment or subwatershed outlets. The yield data can be "ranked" at the raster scale according to each cell's relative pollutant contribution to a downstream point in order to establish priority cells or catchments for implementing conservation practices. The following sections describe the GIS layers derived from the enhanced geospatial water quality data products and their application.

4.2.3.1 STREAM POWER INDEX

The mean SPI percentile rank for each overland catchments area is shown in **Figure 5.** The high-ranking areas as expected are at locations with greater slopes. These data can be used to identify potential locations on the landscape where the erosive forces of moving water are greatest. These locations would likely manifest as locations with field erosion or gully erosion.

4.2.3.2 SEDIMENT, TP AND TN YIELDS

The estimated sediment, TP and TN yields leaving the landscape (as a raster) are shown on **Figures 6**, **7** and **8**. The estimated loadings for sediment, TP and TN delivered to Lake Emily (as a raster) are shown on **Figures 9**, **10**, and **11**. It is important to recognize that the estimated amount delivered downstream to Lake Emily does not include reductions in the load which may occur within intervening depressional areas or lakes which cause long periods of water detention. These same data can be summarized by catchment, which generally average 40 acres in size, but range up to a maximum size of approximately 125 acres. The highest areas of TP and TN loading are generated from agricultural land uses and once downstream routing techniques are applied, the highest load deliveries to Lake Emily are from areas closest to the lake with shorter travel times. From these observations, the highest loading is from agricultural land near Lake Emily.

This information is useful for prioritizing potential locations for BMPs and CPs, based solely on water quality considerations; i.e., the mass of sediment, total phosphorus or total nitrogen expected to reach a lake, without consideration with regard to whether BMPs and CPs could physically be placed in these catchments or other factors like landowner willingness.

4.2.3.3 SEDIMENT, TP AND TN PERCENTILE RANKING

The percentile ranking represents a cell's relative rank for sediment, TP or TN yields for both the load leaving the landscape and delivery to downstream locations, compared to all other cells within the drainage area. The results of the percentile ranking provide context for the various parameters by showing the severity of the values relative to others in the study area. Rankings were computed for three scenarios: 1) sediment yield leaving the landscape; 2) sediment yield reaching the overland catchment outlet; and 3) sediment yield reaching Lake Emily.

This information is useful for prioritizing potential locations for BMPs and CPs, based solely on water quality considerations, but relative to all other cells in the watershed. These data can be categorized based on the percentile rank according to implementation potential based on water quality considerations alone as follows:

- Low implementation potential - rank equaling or less and 0.1 (in bottom 10 percent for yield delivered)
- Moderately low implementation potential - rank exceeding 0.1 but less than or equal to 0.25
- Moderate implementation potential - rank exceeding 0.25 but less than 0.75 (in middle 50% for yield delivered)
- Moderately high implementation potential - rank equaling or exceeding 0.75 but less than 0.9
- High implementation potential - rank equaling or exceeding 0.9 (in top 10 percent for yield delivered)

These data can be used to easily visualize along with other data potential preferred locations for BMPs and CPs.

4.2.3.4 WATER QUALITY INDEX

WQI values are shown on **Figure 12** based on sediment and nutrients deliveries to Lake Emily and are summarized by overland catchment.

This information is useful for prioritizing potential locations for BMPs and CPs, if the combined effects of nutrients and sediment are being considered.

4.2.4 BMP SUITABILITY ANALYSIS

Overland catchments limited to 40 acres in size (coinciding with the NRCS practice standards) are shown on **Figure 13** and symbolized by rankings based on the relative amount of sediment delivered to each respective outlet. This ranked catchment layer can be used to select areas based on their sediment delivery amount to a potential WASCOB location. A separate layer is also provided called Ranked Flowpaths with rankings based on the sediment amount delivered to the flowpath. This layer can be used to site effective WASCOB locations within selected 40 acre overland catchment.

In addition, locations where vegetated filter strips could be implemented based on suitability criteria are shown on **Figure 14**. A total area of 3,029 acres of buffer strips were identified with a treatable area of 9,510 acres in the Lake Emily watershed. This data is useful because they show potential locations for filter strips based on feasibility, but in the absence of the sediment yield delivered to these locations.

By combining these data along with the overland catchment maps and layers, implementation priority can be based on both the amount of sediment delivered to Lake Emily and whether locations in the overland catchment appear physically feasible. The locations identified through this analysis should be considered preliminary, and require field verification.

Table 5: BMP Suitability Results

BMP	Output Products	Product Description
Sediment Basin/ WASCOB	Sediment Catchments 40 acres	Overland catchments less than 40 acres in size attributed with the mean accumulated sediment rank value of flow paths within the catchment.
	Ranked Sediment Flowpaths	Flowpaths classified based on their relative accumulated sediment rank. They are classified into 5 implementation priority levels: Very High, High, Moderate, Low and Extremely Low.
Riparian Buffers/ Filter Strips	Filter Strips	The areas within 100 feet of streams that meet the suitability criteria.
	Filter Strip Drainage Area	The area draining to the Buffer Area.

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Appendix A: Additional Figures