Mississippi River-Winona SWAT Modeling Project and LiDAR Analysis

Prepared by:

Emmons & Olivier Resources, Inc.
651 Hale Avenue North
Oakdale, MN 55128

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EXECUTIVE SUMMARY

The purpose of this project was to determine the potential flow, sediment, nitrate and phosphorus reductions from implementing agricultural best management practices (BMPs) in the Whitewater and Garvin Brook/Rollingstone Creek watersheds of southeastern Minnesota. This was accomplished by constructing a SWAT model for each watershed to represent existing conditions and then simulating watershed load reductions of sediment and nitrate resulting from implementation of BMP scenarios.

This project also included a significant public outreach effort which consisted of working with the local Farmer Led Council (FLC). The FLC provided invaluable information on current farming practices and enabled the SWAT models to represent existing agricultural conditions as accurately as possible. The FLC also fostered long-term public participation in surface water protection and restoration activities throughout the watersheds.

The area is dominated by agricultural lands. The western portion begins in Olmsted County and is part of the Rochester Plateau, with gently rolling land that is heavily row cropped. The eastern portion of the watershed changes near the Winona County border to a more rolling landscape, and is dissected by steep valleys with wooded slopes. The crop fields in the Eastern portion are smaller, with more hay and pasture present. The eastern portion of the watershed supports a healthy population of brown trout, and the lower portion of the main Whitewater River flows through the 27,000-acre Whitewater Wildlife Management Area. The Minnesota Department of Natural Resources' Crystal Springs Fish Hatchery is located on the Whitewater-South Branch, while Whitewater State Park lies on the Middle Branch of the main Whitewater River.

Non-field erosion (i.e., streambanks and ravines) is likely a significant contributor to the suspended sediment load in the rivers. While it was not modeled explicitly, 60% of total sediment loads at the watershed outlets were attributed to non-field sediment sources. This field/non-field split (40%/60%) is supported by current research in the area.

Agricultural operations are the principal source of nitrate loading in the watersheds through commercial fertilizer and manure application. However, atmospheric deposition and point sources also contribute appreciable nitrate loads. Likewise, phosphorus loading is primarily a function of commercial and manure application. Nitrate and phosphorus agricultural inputs were accurately accounted for using feedback received from the FLC.

Six potential BMP conservation scenarios were modeled. These included:

1. ***Adding grassed waterways on all crop/pasture/alfalfa land with Stream Power Index values greater or equal to 4***. Stream Power Index (SPI) measures the combined effects of landscape slope and drainage area. Areas of higher SPI generally indicate the presence of a channelized flowpath. Even higher SPI indicate the potential for an eroding channel and/or a channel that receives significant sediment inputs from drainage area field erosion. Thus, SPI can be used to target lands most suitable for grassed waterways. SPIs >= 4 were selected because they most closely represented the flowpaths where grassed waterways are currently implemented within the watersheds. It was assumed this would serve as a practical starting point for implementation planning.

2. ***Dredging existing ponds back to design standard.*** It was suggested by the FLC that many existing ponds have been filled with sediment, decreasing their storage by 50% or more. Thus, this scenario did not add any ponds but would increase functionality of

existing ponds by doubling the volumes of existing ponds.

3. ***Adding ponds to conform to the "average condition".*** Average condition was defined as the average ratio (across all subwatersheds) of row-crop area draining to ponds to the total row-crop drainage area. Any subwatershed with a ratio lower than the average condition was increased to equal it. Any subwatersheds at or above the average condition were not changed. This approach was thought to be a more practical alternative to increasing ponds by a certain percentage (e.g., 25%, 50%), for example, which would result in adding the most ponds where they exist already and the least where little or no ponds exist.

4. ***Longer crop rotations including more years of alfalfa.*** This scenario implements 6-year corn/silage/alfalfa (two years each) and 6-year corn/soybean/alfalfa (two years each) rotations on existing continuous corn and corn/soybean rotations, respectively.

5. ***Adding fall cover crop.*** This scenario adds a late season winter rye crop to corn and corn/soybean rotations.

6. ***No-till practices on soybeans.*** This scenario implements no-till during soybean years in corn/soybean and sweet corn/soybean rotations.

These scenarios were first simulated in all applicable subwatersheds (as defined by SWAT). However, in an effort to explore the most efficient solutions, they were also simulated exclusively in the top 25% and 50% most erodible subwatersheds as ranked by average annual sediment load under existing conditions. Therefore, including these three levels (i.e., All, top-25 and 50% most erodible) tests the effectiveness of only implementing BMPs where the biggest water quality problems are currently predicted to exist.

The results of these modeling runs show the most efficient solutions involve those utilizing a combination of conservation practices in only the top 25% most erodible subwatersheds. Scenarios combining increased ponds (scenario-1) and grassed waterways (scenario-2), and modified cropping practices (scenarios 4-6) yielded a 22% reduction of sediment/TP and 10% reduction of nitrate can be achieved at the Whitewater watershed outlet. In Garvin Brook, 8% and 5% reductions in sediment/TP and nitrate can be achieved.

However, to put these results into proper context, the maximum attainable reductions (resulting from 100% row-crop to cool-season grass conversion) were simulated to be 37% and 65% for sediment and nitrate in Whitewater and, 38% and 78% in Garvin Brook. Therefore, as an example, the 22% sediment reduction in the Whitewater is very significant when one takes into account a maximum reduction of 37%.

The maximum attainable reductions for sediment and TP (but not nitrate) are a reflection of the assumed 40%/60% split between field and non-field sources in the watersheds. In other words, there is a limit to which reductions in field sediment can influence total watershed sediment load given 60% of the latter is composed of non-field sediment.

There was interest in determining the effects of potential BMP scenarios on total volume and peak flows, particularly those pertaining to ponds in the Garvin Brook watershed. Resulting SWAT predictions demonstrated that, while existing and increased pond volume/drainage area scenarios were predicted to have significant effects on sediment, TP and nitrate reductions, there was very little flow response (<1% reduction) predicted for both overall volume and peak flows.

This is due to the fact that the proportion of effective pond volumes vs. the total volume of flow in the watersheds is very low (<1%); there is simply is not enough storage capacity and thus, evaporative potential, to affect overall watershed volumes or peak flows in a significant way. Volume control scenarios for flood mitigation would have to assume substantial storage increases to see any appreciable effect.

BACKGROUND AND PURPOSE

The Minnesota Pollution Control Agency (MPCA) has adopted a watershed approach to monitor and assess water quality and aquatic life in the state's 81 major (8-digit HUC scale) watersheds. The watershed approach, based on a 10-year cycle, is designed to intensively monitor streams and lakes within a major watershed to determine the overall health of the water resources. The watershed approach is designed to identify impaired waters, identify waters in need of additional protection efforts to prevent impairments, and identify where issues exist within the watershed that impact these waters.

The steps within this watershed approach include:

- Intensive watershed monitoring (IWM)
- Stressor identification (SID)
- Modeling
- Public Outreach and Engagement (CE)
- Strategy development

The goal of this project is to construct Soil and Water Assessment Tool (SWAT) watershed models for Total Maximum Daily Load (TMDL) targets and development of management strategies with scenarios designed to improve and protect water resources. The project focused on two areas within the Mississippi River Winona Watershed (MRWW); the Farmer-Led Council (FLC) area which encompasses the Middle and Logan Branches of the Whitewater River System and the Garvin Brook Watershed which is a direct tributary to the Mississippi River. Scenarios were developed and simulated for these areas and then extrapolated to areas of the MRWW with similar geology, hydrology, landuses, topography, and meteorology.

The FLC was instrumental in the development of scenarios in the Middle Branch of the MRWW. Those scenarios were simulated in the rest of the Whitewater River System.

This project also focused on identifying critical pollutant source areas, areas that contribute a disproportionate amount of nonpoint source pollution, so their effects on water quality can be mitigated or minimized with the installation of BMPs. This was done through LiDAR analysis and ground truthing in FLC subwatersheds and the Garvin Brook watershed and then extrapolated to the remaining portions of the Mississippi River Winona watershed (MRWW).

MRWW is dominated by agricultural lands. The western portion begins in Olmsted County and is part of the Rochester Plateau, with gently rolling land that is heavily row cropped. The eastern portion of the watershed changes near the Winona County border to a more rolling landscape, and is dissected by steep valleys with wooded slopes. The crop fields in the Eastern portion are smaller, with more hay and pasture present.

The eastern portion of the watershed supports a healthy population of brown trout, and the lower portion of the main Whitewater River flows through the 27,000-acre Whitewater Wildlife Management Area. Minnesota Department of Natural Resources' (DNR) Crystal Springs Fish Hatchery is located on the Whitewater-South Branch, while Whitewater State Park lies on the Middle Branch of the main Whitewater River. The Whitewater River discharges to the Mississippi River at Weaver Bottoms, an important Mississippi River backwater and waterfowl staging area. In addition to the Whitewater River, there are direct Mississippi River tributaries in the southeast portion of the watershed that are popular for trout fishing. Garvin Brook, Rollingstone Creek, Peterson Creek and Stockton Valley Creek converge near Minnesota City and discharge to the Mississippi River. Farther southeast, other unnamed tributaries within the watershed discharge directly to the Mississippi River.

In past efforts, the main focus has been on the Whitewater River, mainly due to the Joint Powers Board associated with the watershed. The Whitewater River alone is a 10-HUC watershed, but the Whitewater combined with Garvin Brook and other direct Mississippi River tributaries is an 8-HUC watershed.

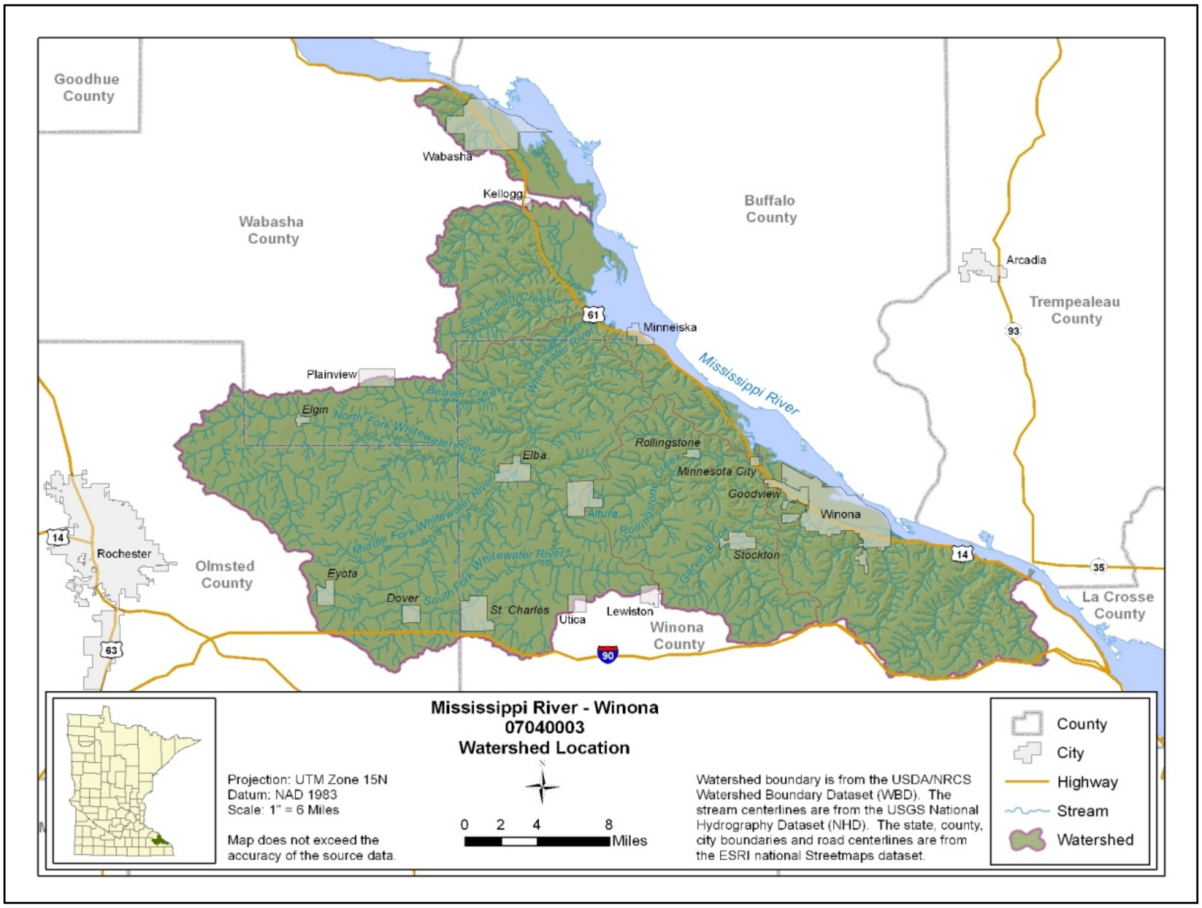

Figure 1. Mississippi River – Winona Watershed.

The intensive Watershed Monitoring, as part of the watershed approach, began in 2010. At the same time, civic engagement work funded by the American Recovery and Reinvestment Act (ARRA) grant was in full swing. A farmer-led council was formed as part of the ARRA grant, and has become a self-sustaining, progressive grass roots effort within portions of the Whitewater River watershed.

The Mississippi River-Winona SWAT Modeling and LiDAR Analysis project will help the recently established farmer-led council be more effective and further their efforts by providing important information for targeting areas within the watershed. MPCA will be working with them to get the best input for scenarios possible to make their group successful. In addition to the farmer-led council, civic engagement was developed with non-producers in the watershed with the formation of the Community Advisory Panel.

SUMMARY OF SWAT MODEL CONSTRUCTION

The Whitewater River and Garvin Brook models were initially created in SWAT2009 with ArcSWAT2009.93.7b, running under ArcGIS 9.3.1 SP2. At the time, SWAT2012 was only available as a beta version and had not reached a level of stability thought adequate. However, some issues were encountered hereafter in the SWAT2009 models during calibration and scenario simulations. Because of this and the fact that a stable, production version of SWAT2012 existed at this point, it was decided to rebuild the model in SWAT2012 thereby providing functioning models in the current release of SWAT. Appendices A and B contain additional figures and discussion regarding SWAT model construction.

Spatial extent and resolution: Separate SWAT models were constructed for the Whitewater (831 km^2) and Garvin Brook (257 km^2) watersheds. See Table 1.

Table 1. Subwatershed Summary.

	# of subwatersheds	Mean subwatershed area (ac)	Minimum subwatershed area (ac)	Maximum subwatershed area (ac)
Whitewater River Watershed	135	1,512	5	5150
Garvin Brook and Rollingstone Creek	61	1,030	4	3699

Temporal range: The models were constructed based on recent (2007-11) land use, but when possible were run with long enough weather data sets to allow model calibration against existing monitoring data and to obtain meaningful average annual values in the face of interannual weather variability. Model runs for Whitewater consisted of three periods: 1975-1985, 1993-1999 and 2008-2010 based on flow data availability at the USGS gage near Beaver, MN. In contrast, because of limited flow data, the Garvin Brook (including Rollingstone Creek) model was run for the period 2009-2010.

Hydrography and topography: Model stream and subwatershed delineation used the MDNR's fine-resolution, hydrologically corrected flow net for the study area. This flow network was "burned" into the study area 3-meter LiDAR-based digital elevation model (DEM) to force watershed boundaries to be consistent with the current MDNR data sets.

Land-use: Land cover was determined from the USDA Crop Data Layer (CDL) data sets for the last five years (2007-11). Crop types were extracted from these data layers to obtain average total and relative areas of each crop, thereby suggesting representative crop rotations (sequences). Data layers were combined to indicate where these rotations are located within the study watersheds.

NASS tabular data for Wabasha, Winona, and Olmsted counties was downloaded and analyzed for crop areas and yields, and for livestock populations. Manure production has been calculated based on livestock populations and apportioned to the study watersheds based on area. Manure is applied to selected crop rotations and pastureland, based on the advice from the Farmer Led Council (FLC) and local agricultural agency personnel. Tillage practices and fertilizer applications were determined likewise in consultation with the FLC and local agricultural agency personnel.

Soils: The SSURGO database shows that 195 different soil types exist in the study area. Given the computational requirements of generating HRUs using 195 soil types, soil groups were combined based on similar characteristics. The following parameters were defined for each of the soil types based on parameterization recommendations from SWAT model developers at Texas A&M University.

- Hydrologic Soil Group
- Depth of Soil Layer
- Moist bulk density
- Available water capacity of the soil layer
- Saturated Hydraulic Conductivity
- Organic carbon content
- Clay content
- Silt content
- Sand content
- Rock content
- Moist soil albedo
- USLE soil erodibility

Karst Geology: Karst geologic features are understood to have significant local scale hydrologic effects in the Whitewater and Garvin Brook/Rollingstone watersheds. But after reviewing karst spring, sinkhole and dye tracer GIS layers provided by MPCA it was determined that it would be difficult to derive and justify any modifications to subwatershed boundaries or modeled hydrologic pathways. This is due mainly to uncertainties in discerning how and to what extent any one feasture or group of features affects hydrology at a scale relevant to model simulation (i.e., SWAT sub-watershed scale). Therefore, it was decided to address karst hydrology if SWAT simulations showed systemic errors predicting the proper fractions of surface and subsurface flows that were consistent with possible karst effects. However, calibrated model results did not suggest such an issue, indicating model predictions were not sensitive to karst effects at the Beaver gauge, located a relatively long distance downstream from the areas with karst features.

Meteorology: Two different sources were explored to download weather data; BASINs and USDA SWAT-ready data. Seven weather stations were found in BASINs within the Whitewater River watershed. Additional stations were found by using the SWAT-ready data from the USDA. Some of these stations are in the counties outside of the watershed; 5 stations in Winona County, 5 in Wabasha County, and 2 in Olmsted County. On the Wisconsin side, Buffalo County has two stations, and Trempleau County has 5. Each of these has daily precipitation and temperature data going back to 1950, with all gaps filled in. The SWAT ready data was used for model development because it contains a more complete record than that from BASINs.

Ponds: Known farm ponds were included in the model. A GIS point shapelayer showing the location of ponds was received from Winona County. This layer was used as a starting point and ponds from Olmsted and Wabasha counties were added via heads-up aerial photo interpretation using the 2012 aerial photography from the MN DNR. Once the locations of the ponds were complete filled sinks were created from the LiDAR 3 meter DEM and intersected with the point files to estimate the surface area (SWAT parameter: PSA) of each pond. Based on discussions with local SWCDs it was estimated that the ponds average approximately 0.5 meters of depth across the surface area and this was used to calculate the SWAT pond volume. (SWAT parameter: P_VOL) It was assumed 25% of the total volume was present as emergency pond volume (SWAT parameter: E_VOL).

For the Middle and Logan Branches of the Whitewater, the watershed to each of the ponds was delineated to determine the percentage of each subwatershed that is directed to a pond. (SWAT parameter: PND_FR) Because resources were not available to delineate the watersheds to each of the 1000+ ponds in the HUC-8, a more generalized approach was taken for areas outside of the Middle and Logan. Logic follows that if subwatershed contains a greater number of ponds, then a higher percentage of the subwatershed would be directed to a pond. Based on the delineations within the Logan and Middle, a regression equation was written to correlate the number of ponds in each subwatershed with the percentage of the subwatershed that is direct to a pond (Figure 2). This relationship was applied to all subwatersheds within the Whitewater and Garvin Brook watersheds that contained ponds.

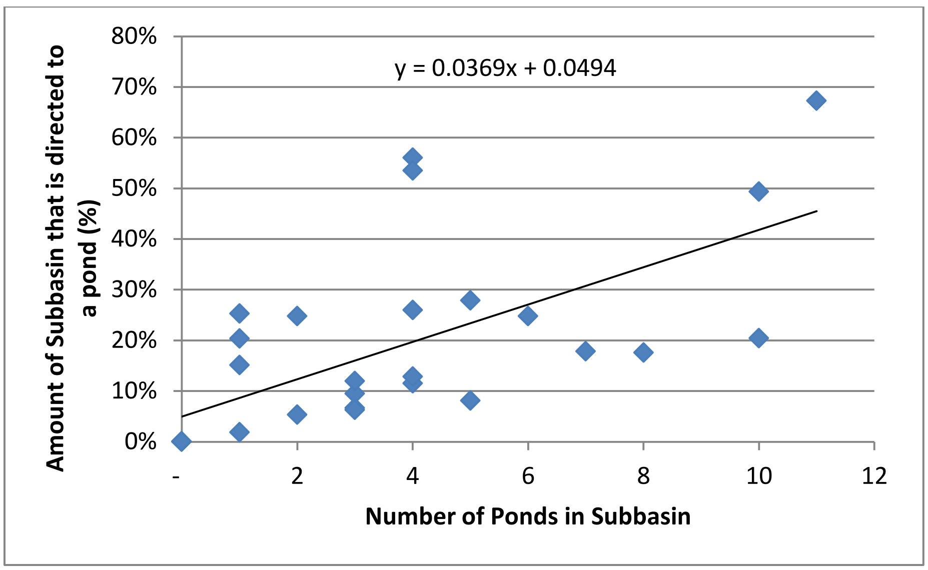

Figure 2. Regression equation used to assign SWAT parameter PND_FR in watersheds outside of the Middle and Logan Branches. PND_FR was calculated explicitly within the Middle and Logan Branches.

Grassed Waterways: Similar to the incorporation of ponds, a shapefile was received from Winona County showing the grassed waterways in the county. This layer was used as a starting point and grassed waterways from Olmsted and Wabasha counties were added via heads-up aerial photo interpretation using the 2012 aerial photography from the MN DNR.

Because grassed waterways are input on an HRU basis, through the Scheduled Management Operations file (.ops), a different approach was needed to incorporate them into the model. The length of grassed waterways within each subwatershed was calculated and the length was distributed per HRU according to the percent of total cropping HRU that occur within each subwatershed. This method removes the issue of grassed waterways being placed on pasture or woodlots. Other grassed waterway parameters were left as SWAT defaults.

Management Operations: Management operations include all field operations such as tillage, fertilization, manure applications, planting, crop rotation and harvest. They were extensively developed based on NASS data and discussions with the farmer-led council and the local staff. The result of this effort was very detailed information about the land management in the

Whitewater Watershed (See Appendix B) and the definition of 5 cropping rotations in the model; Corn-Peas-Oats (XCPO), Sweet Corn –Soybean (XSCS), Corn-Alfalfa (XXCA), Continuous Corn (XXCC) and Corn-Soybean (XXCS).

Because of the differing management practices that occur with different crops, it was important to stagger the management practices so that each rotation was evenly distributed during each modeled year. To accomplish this, subrotations were created. For instance, the corn-soybean rotation has two subrotations, one that starts as soybeans in year #1 and the other that starts as corn in year #1. This prevents all corn-soybean fields from being in corn in year #1 and then soybeans in year #2. On fields that received manure, operations were also controlled and subrotations created (see Table 2).

Table 2. Distribution of subrotations in SWAT. Corn-Peas-Oats (XCPO), Sweet Corn –Soybean (XSCS), Corn-Alfalfa (XXCA), Continuous Corn (XXCC) and Corn-Soybean (XXCS)

Subrotation ID	Rotation ID				
	XCPO	XSCS	XXCA	XXCC	XXCS
a	50%	50%	20%	33%	50%
b	50%	50%			50%
Bman (Beef Manure Spring)				33%	
Dman (Dairy Manure Spring)				33%	
dairy falla (Dairy Manure Fall)			80%		

Once management operations and subrotations were decided upon, the distribution of each within the landscape was input using the "Extend to other HRUs" function in ArcSWAT. Each management practice was extended so that the overall distribution of the rotations on the landscape was consistent with the FLC recommendations as well as to ensure a relatively even distribution across high vs. low infiltration soils.

Tillage (types of spring/fall plowing and extent of conservation tillage) was based primary on recommendations by the FLC. A detailed Winona county tillage transect survey was also consulted showing fractions of different spring tillage practices. Based on both sources a basic regime of spring field cultivation and fall chisel plowing with no appreciable conservation or no-till practices was adopted for all row-cropping rotations. See Appendix B for detailed information of cropping, tillage, fertilizer and manure parameterization.

Point Sources: See Table 3 for point sources set up in SWAT. NPDES point source data were downloaded and incorporated into both the Whitewater and Garvin Brook models. While significant, their cumulative TP and NO3 loadings are relatively small compared to other inputs in the watersheds.

Table 3. SWAT point sources for Whitewater and Garvin Brook watersheds

	Daily load inputs to SWAT				
Whitewater Point Sources	**Q (m^3)**	**TSS (tons)**	**NO3 (kg)**	**TP (kg)**	**Subbasin#**
Altura WWTP	397	0.01	6.0	1.7	60
MDNR Crystal Springs State Fish Hatchery	10766	0.05	12.0	2.8	68
North Star Foods Inc	429	0.00	0.5	0.1	124
Plainview WWTP + Milk Coop	3922	0.02	53.9	12.0	21
Utica WWTP	151	0.00	2.3	0.6	106
Whitewater River Regional WWTP	2606	0.01	39.1	14.6	120
Garvin Brook Point Sources					
Rollingstone WWTP	408	0.01	6.12	1.0	9
Stockton WWTP	456	0.01	6.84	1.1	37
Technical Die Casting Inc	59	0.00	0.08	0.0	37

SWAT MODEL CALIBRATION

The calibration of the Whitewater River SWAT model was conducted based on calibration procedures described in recent literature (Arnold et al, 2012; TAMU, 2012). It is generally recommended that calibration starts with flows, followed by sediment, and then nutrients. This method also progresses from calibrating long term total volumes (and loads) to annual comparisons, to monthly timeframes.

The models have been calibrated to daily flows, monthly loads of sediment and average annual flow-weighted mean concentration of nitrate for the Whitewater watershed and daily flows for the Garvin Brook watershed. The differences between field and non-field sediment sources have been taken into account during calibration to the degree possible. Based on discussions in 2012 with Shawn Schottler of the St Croix Research Station, approximately 60% of the sediment load can be attributed to non-field (streambank and ravine erosion). For model calibration purposes, the measured load was reduced to 40% and field erosion calibration was conducted.

Monitored Data

Flow: Within the Whitewater River Watershed there are 5 flow monitoring stations. The longest record of flows is at HWY 4 south of Beaver, MN (S001-742). This location is also the furthest downstream site, capturing the majority of the watershed as a whole and was the focus of the calibration. In the Garvin Brook watershed, flow was calibrated to both Garvin Brook and Rollingstone Creek monitoring stations. However, data at these stations was only available for 2009-2010, greatly reducing the certainty of the modeling results.

Sediment: S001-742 also had the most (93) water quality samples under a good range of flows. (Figures 3 and 4) Water quality samples were taken at the Beaver site regularly during 2008-2011 allowing for a good relationship between sediment and flow to be established. Because the relationship was not linear, the regression was stratified by flow and the TSS concentration was calculated according to the following procedures:

for Q<535 cfs: TSS Concentration [mg/l] = 5.1128 e^0.0076Q
for Q>535 cfs: TSS Concentration [mg/l] = 0.5177Q + 30.

To convert the water quality samples to a load, this regression equation was used on a daily timestep to calculate the daily sediment load based on total daily flow volume; these daily values were then summarized by year and month.

Because of the limited sediment data availability in the Garvin Brook watershed, sediment was not calibrated for this watershed.

Nitrate: Nitrate monitoring at S001-742 has only occurred during 2009 when 27 samples were taken and 1973-1974 when 10 samples were taken. The vast majority of nitrate monitoring that has occurred in the watershed is located in the upper south fork due to the presence of the Whitewater Regional WWTP. Other short term monitoring has also occurred in the watershed. The 2009 samples were calculated to have a flow-weighted mean concentration (FWMC) of 5.28 mg/l. These samples were assumed to be most representative of the periods modeled and a non-varying monthly FWMC of 5.28 mg/l was used as the calibration target for the 2008-2010 calibration period. Without detailed fertilizer and manure application data, nitrate was not calibrated for model periods prior to 2008.

Because of the limited nitrate data availability in the Garvin Brook watershed, it was not calibrated for this watershed.

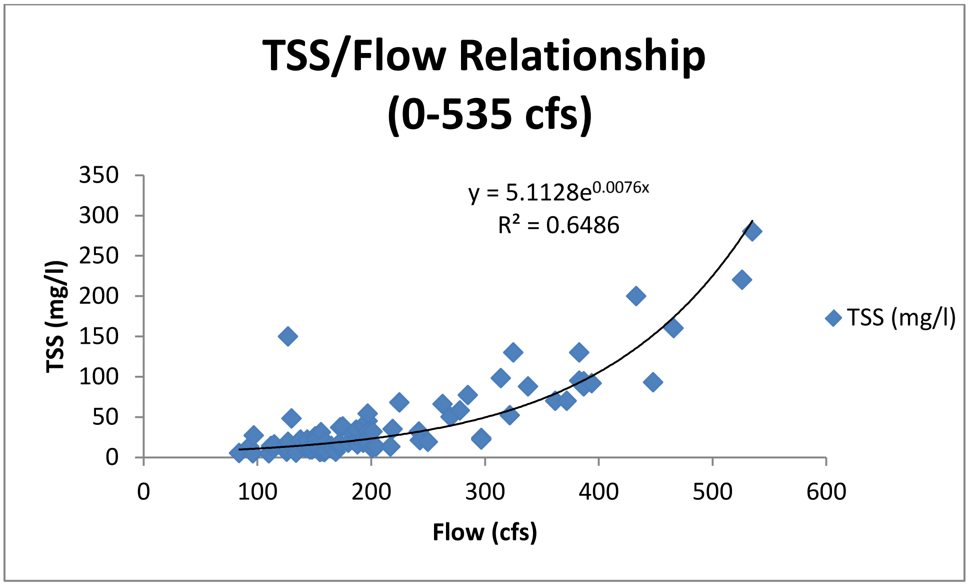

Figure 3. TSS/Flow Relationship at the Whitewater River near Beaver, MN.

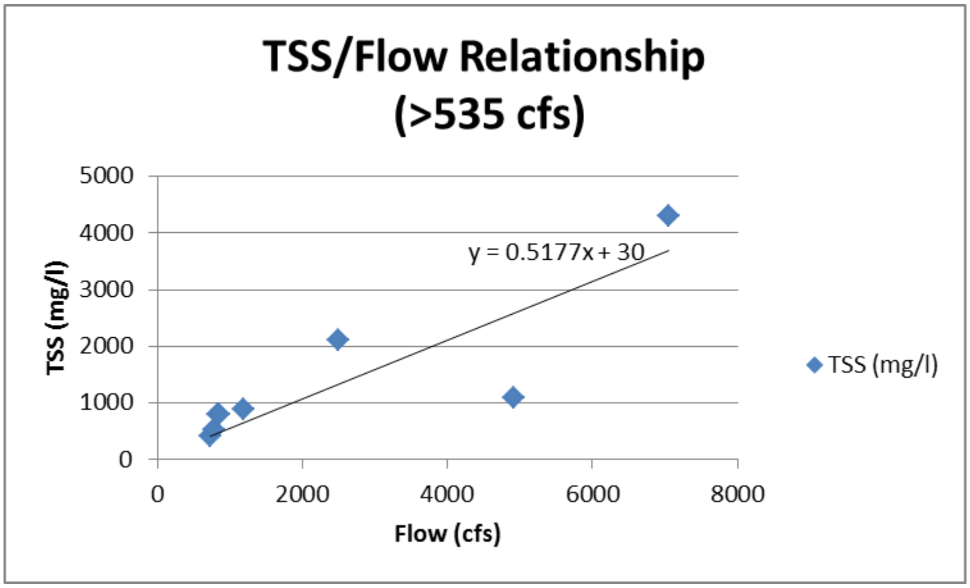

Figure 4. TSS/Flow Relationship at the Whitewater River near Beaver, MN.

SWAT versions and model versions

The SWAT model code has evolved considerably over the years, the last two major releases being SWAT2009 and its replacement, SWAT2012. At the time that this project was begun, the decision was made to use SWAT2009, which appeared to be more stable than the newly released SWAT2012. Hence the Whitewater River and Garvin Brook SWAT models (hereafter abbreviated as WW and GAR) were originally constructed in SWAT2009 with its associated GIS interface, ArcSWAT for ArcGIS 9. However, by that time the models were completed, a new version of ArcSWAT for ArcGIS 10 was released, which was compatible with only SWAT2012 (now stable), making the SWAT2009 WW and GAR models obsolete for users with ArcGIS 10 or later. Consequently, in October 2013 the decision was made to re-build the WW and GAR models in SWAT2012 to extend the useful life of these models.

With SWAT2012, the USDA/ARS development team in Texas began keeping close track of each revision of the code. There can be dozens of revisions each year as bugs get repaired or new algorithms added. As of today, the current SWAT2012 code is at revision (rev) 616, having incorporated a repair to the grassed waterway algorithm. Model calibration took place largely under rev613 in Oct-Nov 2013, and then re-done again in January 2014 under rev614 (which altered the hydrology slightly compared to rev613). Model results under rev615 and rev616 are identical to the WW and GAR results obtained under rev614, so for all intents and purposes, the models are calibrated to the most current release.

Hydrology Calibration

See Table 4 for model performance statistics. See Figures 5-11 for calibration plots for flow and sediment.

Whitewater model (WW)

For the WW model, the intent was to calibrate to flows at Beaver for the 2008-10 period and validate against flows during the 1993-99 period. However, model results were fairly different between these two periods, such that the best parameterization for the 2008-10 period resulted in poor fits for the 1993-99 period. We considered that the poor fit for the 1990s was perhaps a result of land-use change and the gradual replacement of dairy by row crops. However, when we modeled flows for an even early period (1975-85), model fit was reasonably good with the 2008-10 parameters, implying that land use (which in the 1970s and 80s should have been more similar to the 1990s than the 2000s) was not the principal cause of poor fits for the 1990s. We see no clear explanation for the poor fits for the 1990s versus the 2000s and 1970-80s.

For calibration purposes, rather than ignore the 1990s altogether, we slightly compromised the parameterization for the 2008-10 and 1975-85 periods to obtain a reasonable (but less good) fit for the 1990s, so that the model gives reasonable results for the entire 1970-2010 period. In other words, the model was calibrated to the entire data set, rather than being calibrated to part of the record and validated against the remaining part.

Modeled flows were checked against monitored flows at sites other than Beaver, but the model was not specifically altered in an attempt to improve the fit at these sites. Flow on the North Branch fit quite well without adjustment (NSE = 0.59 for 2009-10). On the Middle Branch, the model greatly underpredicted storm peaks; increasing curve numbers within that subwatershed would thus improve the fit. On Logan Branch, the model overpredicted flows, but all flows were quite small, less than 1 cfs. Decreasing curve numbers and allowing loss to deep recharge would improve model fit in this subwatershed. In a karst region such as the WW, with a steep gradient from table lands down gorges to the Mississippi valley, it is entirely understandable that headwater creeks such as the Logan Branch would be losing water to deep recharge, which could be recovered as groundwater discharge to baseflow in downgradient reaches. It is also understandable that, with thin soils over bedrock, that some sites may be flashier than expected, whereas sites with similar soils but access to fractured bedrock may be less flashy than expected. Hence, parameterization specific to each subwatershed may be more important in karst regions than elsewhere.

Hydrologic calibration was achieved by adjusting parameters that altered the water balance, surface-water/groundwater interactions, overland flow, and snow melt. The Hargreaves potential evapotranspiration (PET) method gave a slightly better water balance than the Penman-Monteith method. Water yield was slightly too large, and so loss of water to deep aquifer recharge (RCHRG_DP; here, really, loss of groundwater to the Mississippi River) was set to 0.1 (a 10% loss of groundwater recharge). Other parameters commonly used in SWAT to adjust the water balance were not invoked: soil available water capacity (AWC), soil evaporation compensation factor (ESCO), and phreatophytic evapotranspiration (GW_REVAP) were left at default values. Alternate calibrations probably could have been achieved by altering these parameters in combination with, or in place of, those selected here. All curve numbers (CN2 and CNOP values) were reduced by 15% to reduce storm peaks and to increase infiltration and baseflow. The plant evapotranspiration method of adjusting curve numbers was developed for shallow soils and gave a better fit than the more traditional soil-moisture adjusted curve numbers. The groundwater delay (GW_DELAY) parameter was designed to account for the travel time of percolating water in the vadose zone between the bottom of the soil profile and the water table, with a default value of 30 days. In practice, GW_DELAY adjusts the seasonal amplitude of baseflow and was greatly increased to 500 days to make baseflow nearly constant throughout each year. The surface-runoff lag factor (SURLAG) was reduced, which lowered flood peaks while lengthening the period of runoff. Snowmelt parameters were adjusted to allow more snowfall accumulation, followed by a large snowmelt runoff peak in the spring, but without much success. Like other watershed models, SWAT has difficulty in accurately simulating the timing and magnitude of snow melt in the spring, and the Whitewater SWAT model routinely misses large snowmelt peaks in the spring, which greatly reduced the model goodness-of-fit parameters. On the other hand, SWAT also has difficulties in accommodating daily rainfalls exceeding 2-3 inches (50-75 mm) per day. Rainfalls exceeding these amounts often results in excessively large storm peaks. Consequently, the precipitation data were censored to a maximum of 75 mm per day (i.e. values larger than this were replaced with 75 mm/day). This reduced a few over-predicted storm peaks while maintaining baseflow and smaller peaks.

Garvin Brook model (GAR)

Calibration of the GAR model was limited to a single 2008-10 period, but for two sites: the station on Garvin Brook itself and a station on its main tributary, Rollingstone Creek. In the GAR model, the Penman-Monteith evapotranspiration method gave a better water balance than did the Hargreaves method. To boost water yield slightly, available water capacity (AWC) was reduced to 70% of initial values, and loss to deep recharge (RCHRG_DP) was kept at zero (default). To make baseflow nearly constant, GW_DELAY was extended to 730 days (two years). Snowmelt parameters were set the same as for the WW model, and precipitation was censored to 75 mm/day. Model fits were a compromise between the two stations. The model tended to underpredict peaks for the Rollingstone and overpredict peaks for Garvin Brook. The model fits could be much improved at both sites if calibration parameters (namely, curve numbers) were altered separately for the subwatersheds specific to each site. As noted above, karst regions may be more needy of subwatershed-specific parameterization than other terrains.

Sediment

Whitewater model (WW)
Sediment loads for the Whitewater at Beaver were estimated by Tom Miller at EOR prior to his departure. Miller fit two regression equations to monitored suspended sediment concentrations as a function of flow at Beaver, one for low flows and one for high flows. These equations were then used to translate daily flows to daily sediment loads. Daily loads were aggregated to monthly loads for calibration purposes. Loads so calculated were presumed to represent total sediment loads at Beaver, although they likely excluded bedload materials.

Total sediment loads were assumed to be a mix of field and nonfield sediment components, where nonfield includes material from bank, bluff, and ravine erosion. From sediment fingerprinting studies in the Root River watershed in similar karst terrain, the field component may constitute about 40% of the total sediment load. Clearly nonfield erosion is important (dominant, apparently), but SWAT's strength is lies in its field runoff and erosion algorithms, and not channel erosion. Hence we made the decision to focus on calibrating to the field component of erosion alone, which will lead to implementation of upland BMPs in SWAT to reduce these loads. To clarify the field component and its transport, we turned off all channel deposition and erosion processes in the model, so that all sediment delivered to the channel is transported downstream, with no gains or losses to the channel itself. To do this, the sediment entrainment parameters in SWAT were set to large values, giving such a large sediment transport capacity to the creek that no sediment was deposited in the channel (SPCON = 0.01 and SPEXP = 3). Erosion cover factors were kept at zero (CH_COV1 and 2) to preclude any channel erosion.

Further assumptions were required to appropriately reduce total loads down to the 40% attributed to fields. We assumed field sediment was delivered to the channel only during storm flows. Hence we subtracted out sediment loads at baseflow with a sedigraph separation, much like a hydrograph separation. This was done with a very simple 7-day running minimum formula, i.e., baseflow sediment load for a day is the minimum value of loads extending back one week. This algorithm effectively clips off the sediment peaks. Baseflow loads amounted to about 12% of the total loads, and the remaining 88% of the loads -- all occurring during stormflows -- was split between nonfield (54%) and field (46%) components such that, of the total sediment load, 40% was attributed to field, and 60% to nonfield (channel). As noted, we here ignored the nonfield component and aimed to simulate the field component.

Under this series of linked assumptions (which should be regarded as having significant uncertainty), a single parameter change was used in calibrating sediment loads: the USLE_P factor was set at 0.68, down from the default value of one. A number of alternative calibrations were attempted by altering slopes, slope lengths, erodibility, and peak runoff rates, but in the end no combination seemed to warrant a more complicated parameter set than simply altering USLE_P. Model fits were within acceptable standards for the 2008-10 and 1975-85 periods, but again (as for hydrology) much degraded for the 1993-99 period. Even where the NSE indicated "good" fits to the pattern of monthly sediment loads, the total sediment load during selected periods was underpredicted by 25% during 2008-10 and overpredicted by 16% during 1975-85. Loads during the poor-fit period of 1993-99 were vastly overpredicted, by a factor of four. We did not find a robust method of parameterizing the model that could improve the 1993-99 fit without simultaneously ruining the fits during the earlier and later periods. We see no obvious reason for why sediment loads were so overestimated during the 1990s by the model. Massive loads during March 1997 accounted for much of the mis-fit, but even there, modeled flows were overestimated by only a factor of two, whereas sediment loads were overestimated by nearly a factor of ten.

A probable factor in the relatively poor sediment fits is the 40%/60% field to non-field assumption. While the assumption is reasonable it is an uncertain estimate. Further, the split would most likely not be constant but would be expected to vary storm-to-storm, season-to-season, and year-to-year based on flow conditions and the moisture and vegetated conditions of streambanks. Further work is likely necessary to improve understanding of the extent and timing of this field/non-field split, and how it affects total stream sediment load.

Garvin Brook model (GAR)
As discussed previously, because we had no suspended sediment data from the Garvin Brook watershed, no calibration was attempted. We simply applied the same parameterization (USLE_P = 0.68) to Garvin Brook as was determined for the Whitewater.

Nitrate

Whitewater model (WW)
Nitrate was calibrated in a more simplified manner than flow or sediment. The only recent nitrate data (after 1973-74) at the Beaver monitoring station was from 2009. This data had a flow weighted mean concentration (FWMC) of 5.28 mg/l and did not vary appreciably during the sample year. Therefore, the model was calibrated such that the simulated annual average FWMC (over the 40 year modeling period) matched 5.28 mg/l as closely as possible. However, nitrate was under-predicted in WW model and the best calibration was 5.1 mg/l; further, to attain it two nitrate parameters were adjusted to the limits of accepted values (CDN=denitrification rate coeff=0.1, accepted=0.0-3.0, default=1.4; NPERCO=nitrate percolation coeff=1.0, accepted=0.01-1.0, default=0.2). This most likely indicates a missing nitrate source in the WW. Because significant point sources and fertilizer/manure applications were accounted for in the model, the issue may be atmospheric deposition. SWAT assumes a certain NO3 concentration deposited by rain and no dry deposition (as far as we could discern). In the model across all areas and simulation years NO3 rain deposition averaged 7.5 lb/ac/yr whereas a recent MPCA publication predicted a combined wet/dry deposition for the WW at 13 lb/ac/yr (MPCA, 2012). Further examination may be necessary to better understand the apparent nitrate shortfall.

Garvin Brook model (GAR)

As discussed previously, similar to the case with GAR sediment, nitrate calibration was not done due to the lack of nitrate data, and nitrate parameters were set equal to the calibrated WW values. Because the GAR has significantly less fertilized/manured area proportional to watershed size than the WW, and less point sources, it was not considered reasonable to apply the WW FWMC of 5.28 mg/l to the GAR.

Phosphorus

Total phosphorus (TP) was not calibrated in either watershed for this study. Instead, it was assumed that TP was principally a function of sediment. SWAT predicted that roughly 6% of the TP load was in the dissolved form while the remainder (94%) was split roughly 50/50 between mineral and organic particulate (sediment-borne) phosphorus. Thus, TP predictions depended on the accuracy of the sediment calibration. This was viewed as a reasonable assumption given project objectives were concerned with relative changes resulting from BMP implementations.

Table 4. Goodness-of-fit statistics for calibrated SWAT models.

Model	Component	Site	Period	Daily NSE	Daily % Error	Daily R^2	Monthly NSE	Monthly % Error	Monthly R^2
Whitewater River watershed									
ww02	flow	Beaver	2008-10	0.55	-12.3%	0.62	0.72	-13.2%	0.83
			1993-99	0.28	5.8%	0.39	0.54	5.7%	0.59
			1975-85	0.38	7.0%	0.42	0.68	7.2%	0.73
ww02	sediment	Beaver	2008-10				0.63	-24.8%	0.86
			1993-99				-12.20	431.7%	0.32
			1975-85				0.69	15.8%	0.79
Garvin Brook watershed									
gar02	flow	Rollingstone	2009-10	0.30	4.6%	0.66	0.49	5.8%	0.61
		Garvin Brook	2009-10	0.55	6.0%	0.67	-1.07	6.0%	0.60

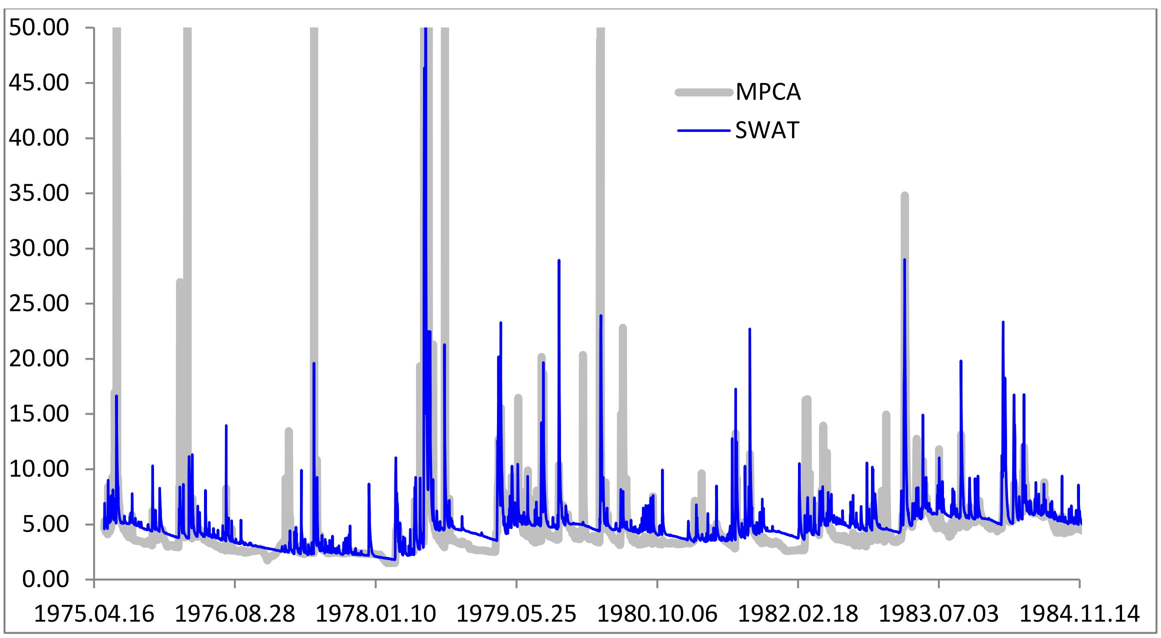

Figure 5. Whitewater Flow Calibration Results: 1975-1985. Cfs.

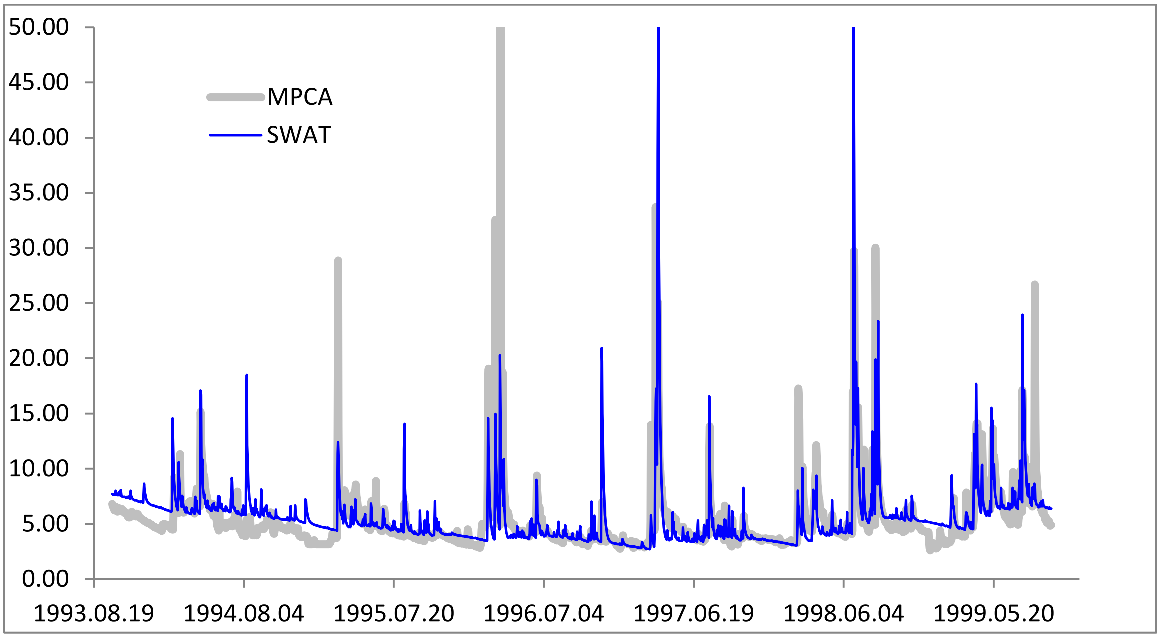

Figure 6. Whitewater Flow Calibration Results: 1993-1999. Cfs.

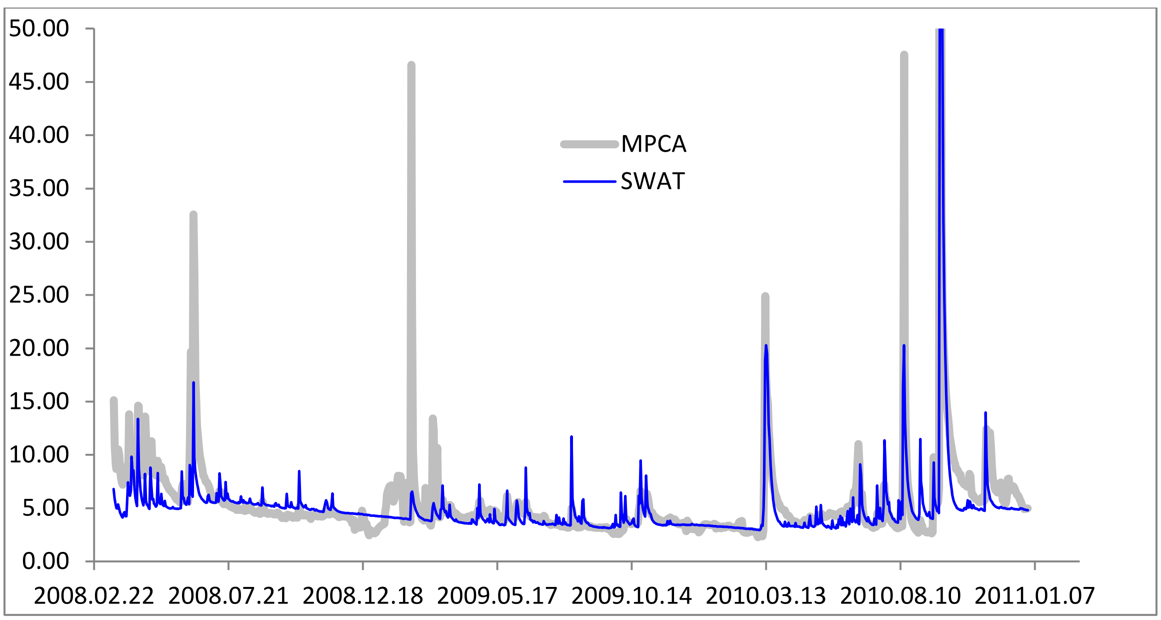

Figure 7. Whitewater Flow Calibration Results: 2008-2010. Cfs.

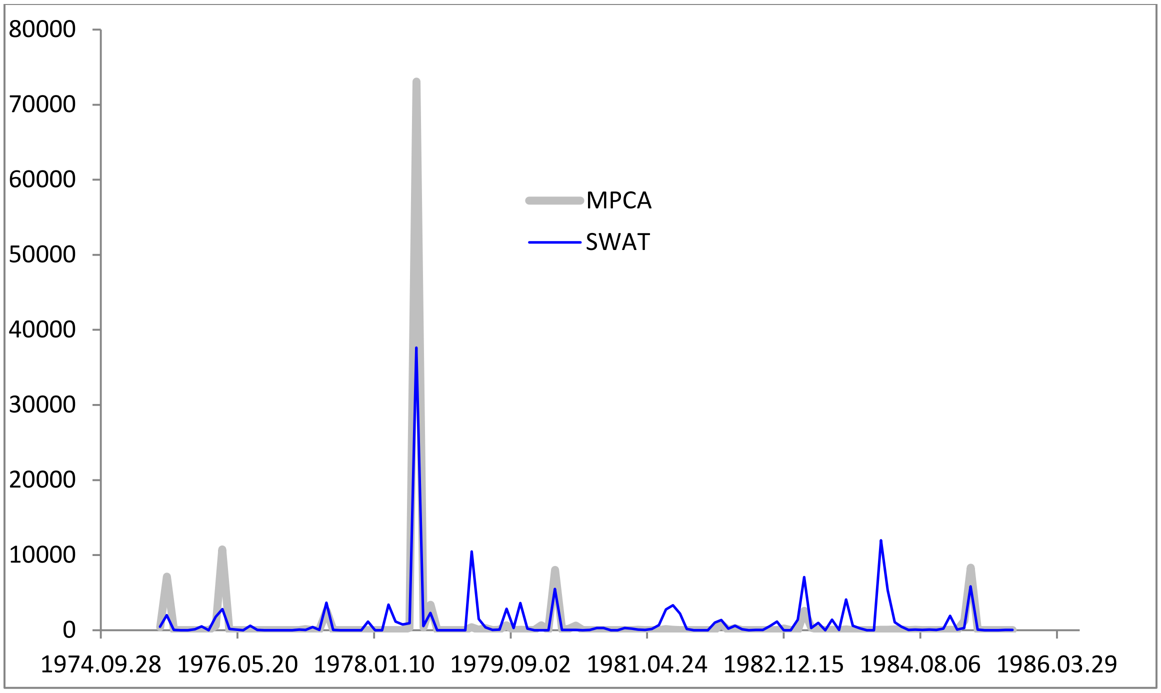

Figure 8. Whitewater Sediment Calibration Results: 1975-1985. Tons/month.

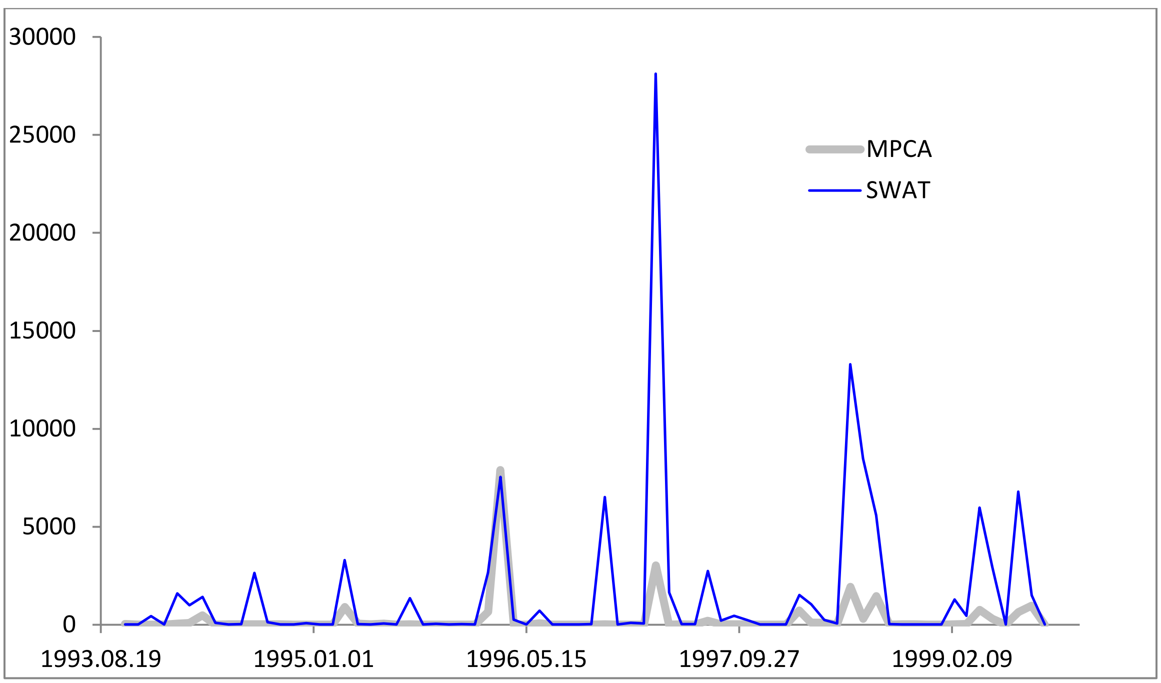

Figure 9. Whitewater Sediment Calibration Results: 1993-1999. Tons/month.

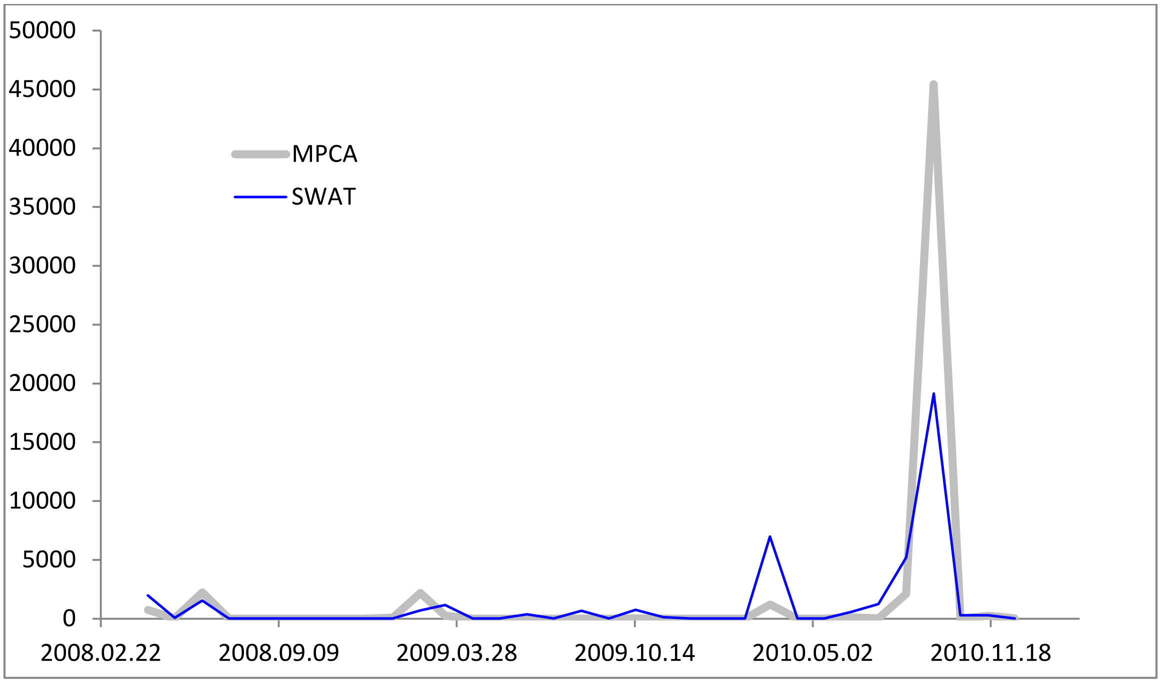

Figure 10. Whitewater Sediment Calibration Results: 2008-2010. Tons/month.

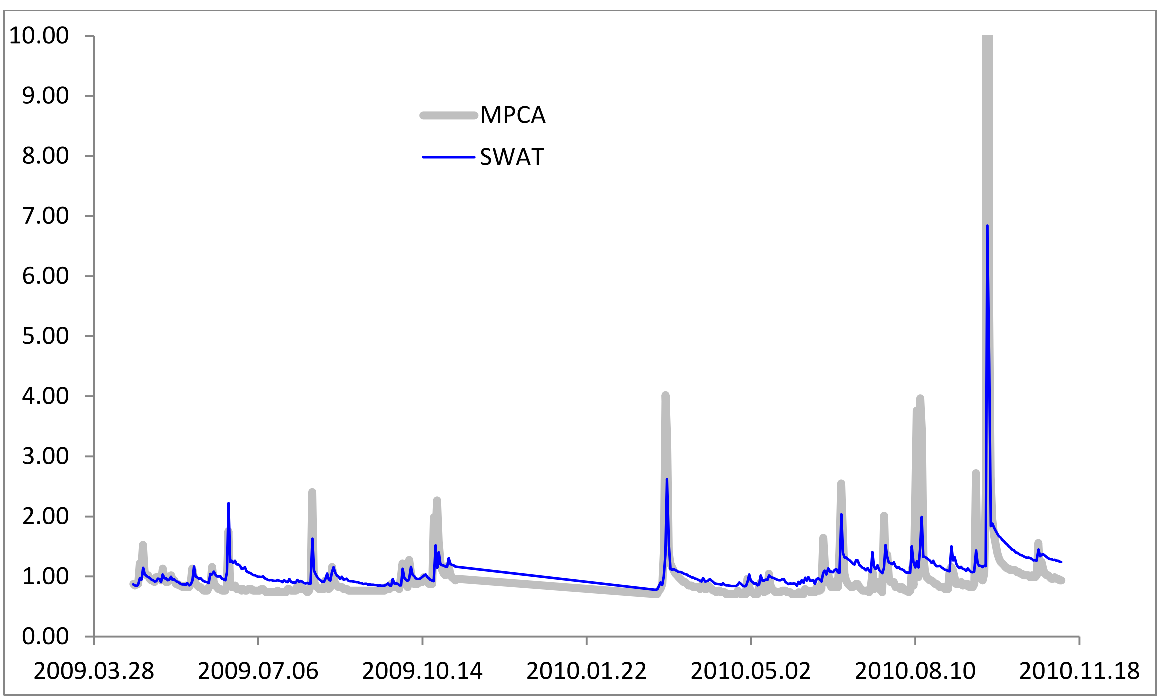

Figure 11. Garvin Brook/Rollingstone Creek Flow Calibration Results: 2009-2010. Cfs.

CONSERVATION SCENARIOS AND POLLUTANT REDUCTIONS

Discussions with the Farmer-led council (FLC) focused on the impacts of improving water quality through in-field practices. Six potential BMP conservation scenarios were modeled based on those discussions:

1. ***Adding grassed waterways on all crop/pasture/alfalfa land with Stream Power Index values greater or equal to 4***. Stream Power Index (SPI) measures the combined effects of landscape slope and drainage area. Areas of higher SPI generally indicate a presence of a channelized flowpath. Even higher SPI indicate the potential for an eroding channel and/or a channel that receives significant sediment/TP inputs from drainage area field erosion. Thus, SPI can be used to target lands most suitable for grassed waterways. SPIs >= 4 were selected because they most closely represented the flowpaths where grassed waterways are currently implemented within the watersheds. It is assumed this would serve as a practical starting point for implementation planning. (See Appendix C for details on SPI analyses)

2. ***Dredging existing ponds back to design standard.*** It was suggested by the FLC that many existing ponds have been filled with sediment, decreasing their storage by 50% or more. Thus, this scenario did not add any ponds but would increase functionality of existing ponds by doubling the volumes of existing ponds.

3. ***Adding ponds to conform to the "average condition".*** Average condition was defined as the average ratio (across all subwatersheds) of row-crop area draining to ponds to the total row-crop drainage area. Any subwatershed with a ratio lower than the average condition was increased to equal it. Any subwatersheds at or above the average condition were not changed. This approach was thought to be a more practical alternative to increasing ponds by a certain percentage (e.g., 25%, 50%), for example, which would result in adding the most ponds where they exist already and the least where little or no ponds exist.

4. ***Longer crop rotations including more years of alfalfa.*** This scenario implements 6-year corn/silage/alfalfa (two years each) and 6-year corn/soybean/alfalfa (two years each) rotations on existing continuous corn and corn/soybean rotations, respectively.

5. ***Adding fall cover crop.*** This scenario adds a late season winter rye crop to corn and corn/soybean rotations.

6. ***No-till practices on soybeans.*** This scenario implements no-till during soybean years in corn/soybean and sweet corn/soybean rotations.

These scenarios were first simulated in all applicable subwatersheds (as defined by SWAT). However, in an effort to explore the most efficient solutions, they were also simulated exclusively in the top 25% and 50% most erodible subwatersheds as ranked by average annual sediment load under existing conditions (see Figures 12-13). Therefore, including these three levels (All, top-25%, top-50%) tests the effectiveness of only implementing BMPs where the biggest water quality problems are currently predicted to exist. However, it is important to note that this approach results in different amounts of BMP increase per scenario, per watershed, as opposed to selecting a non-varying percent increase. See Table 5 for details on extent of implementation per scenario and level. Changes in SWAT parameters were directed by current literature outlining appropriate SWAT calibration and BMP parameterization methods (Arabi et al, 2007; Arnold et al, 2012; TAMU, 2012; Waidler et al, 2009)

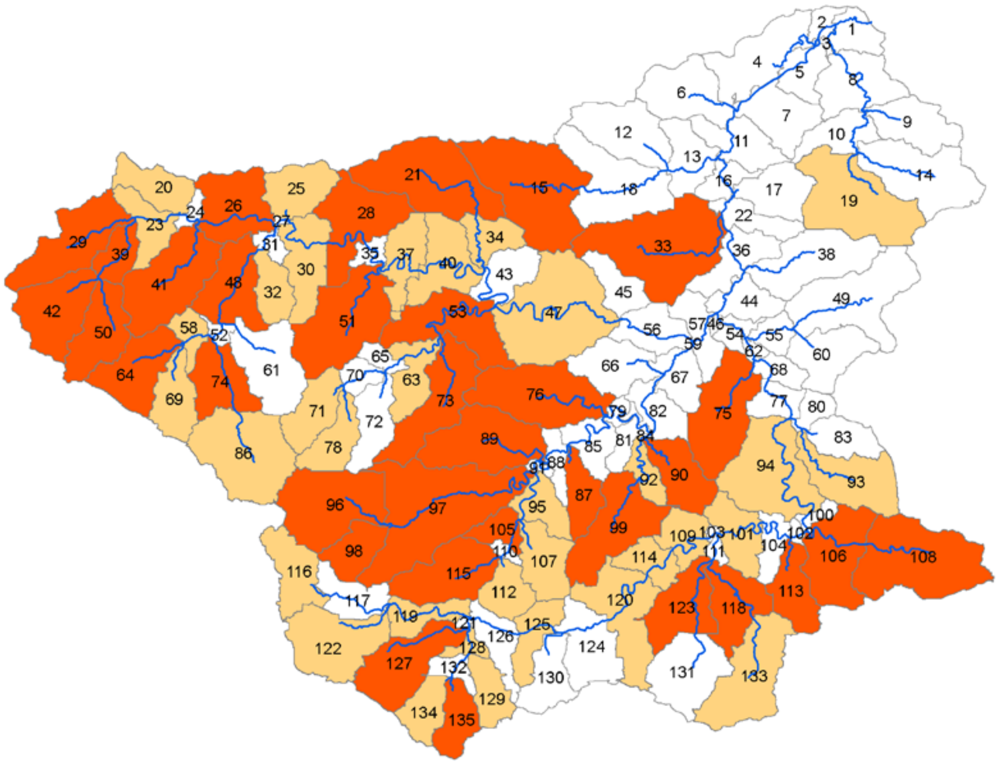

Figure 12. Whitewater watershed showing top 25% (dark orange) and 50% (dark + light orange) sediment loading SWAT subwatersheds. (by SWAT index number).

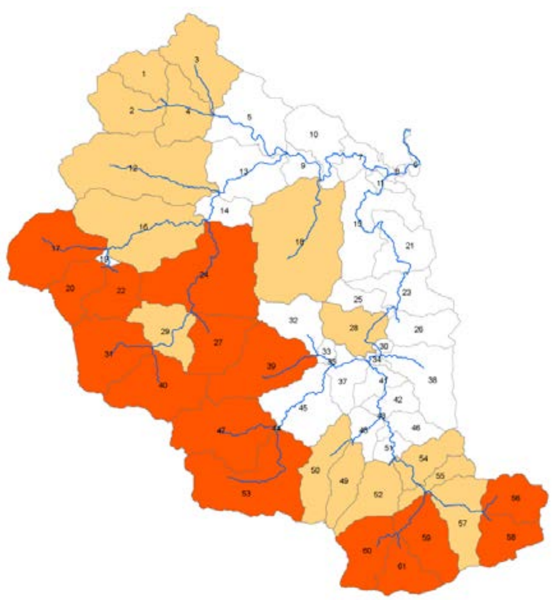

Figure 13. Garvin Brook/Rollingstone Creek watershed showing top 25% (dark orange) and 50% (dark + light orange) sediment loading SWAT subwatersheds. (by SWAT index number).

Table 5. BMP extent of implementation per scenario and level (all-subwatersheds; top 25% and top 50% most erodible subwatersheds, as per sediment load under existing conditions). CC= continuous corn rotation, CS=corn/soybean rotation, SCS=sweet corn/soybean rotation. WW=Whitewater, GAR=Garvin Brook. Example: Total Grassed Waterways length was increased 43% in the WW watershed for the top-25% level; Longer Crop Rotations were implemented on 60% of the total CC and CS area in the WW watershed for the top-25% level.

Conservation Scenario	Increased Unit	Wshed	Top 25%	Top 50%	All
			Percent Increase over Existing		
Grassed Waterways (SPI>=4)	Length	WW	43%	66%	77%
		GAR	66%	116%	174%
Ponds (Dredged)	Volume	WW	40%	73%	100%
		GAR	43%	77%	100%
Ponds (Avg condition)	Drainage Area	WW	11%	19%	25%
		GAR	8%	12%	19%
			Percent of Total Applicable Crop Area		
Longer Crop Rotations	CC and CS area	WW	60%	89%	100%
		GAR	66%	83%	100%
Cover Crops	CC and CS area	WW	60%	89%	100%
		GAR	66%	83%	100%
No-Till	CS and SCS area	WW	60%	89%	100%
		GAR	65%	83%	100%

Conservation Scenarios Results

Results of conservation scenarios are presented in Table 6. In general, there was significant reduction in all scenarios except the Ponds-Dredged scenario. Note the maximum attainable sediment and nitrate reductions of 37% and 74% (averaged) in the Whitewater and Garvin Brook watersheds, respectively, by converting all row-crop agriculture to cool season grasses (smooth brome). Keeping in mind these max reductions, the sometimes modest BMP scenario reductions are much more profound.

It is important to be aware of the influence of the 40%/60% assumption between field and non-field sediment sources. A change in this assumption would change BMP reduction predictions by a significant amount. For example, if one assumes the split to be 60/40 or 20/80 the reductions achievable from field BMPs would change by 50% and -50%, respectively. The maximum attainable reduction of 37% (from row-crop to grass conversion) is also fundamentally tied to this assumption. This scenario is predicted to reduce sediment loading from fields by 90+% but after applying the 40/60 assumption the resulting reduction is 37%. Revisiting this 40/60 split assumption with further research is likely necessary to add confidence to the reduction predictions for sediment. However, nitrate is not subject to this assumption as the majority originates in areas of nitrogen fertilization and manure application.

Regarding efficiency of implementations, in almost every scenario, the top-25% and top-50% levels offer the greatest reduction for the least investment (i.e., least increase in the extent of a particular BMP) over the all-subwatersheds level. Comparison of Tables 5 and 6 illustrate this assertion. Each scenario's results are discussed below.

Table 6. Conservation scenario results for sediment, nitrate and TP reductions at the outlets of the Whitewater and Garvin Brook watersheds. "All" indicates BMP implementation in all SWAT subwatersheds; "top 25%" and "top 50%" indicates BMP implementation in the top 25 and 50% most erodible SWAT subwatersheds, respectively, as ranked by sediment load under existing conditions. Row-crop conversion to grasses represents the maximum attainable reduction.

	Whitewater			**Garvin Brook**		
Conservation Scenario	**SED**	**NO3**	**TP**	**SED**	**NO3**	**TP**
Row-crop Conv. to Grasses	37%	78%	35%	38%	65%	36%
Grassed Waterways (SPI>=4)						
All	5%	<1%	4%	6%	<1%	6%
top 25%	4%	<1%	4%	4%	<1%	4%
top 50%	5%	<1%	4%	4%	<1%	4%
Ponds (Dredged)						
All	<1%	<1%	<1%	<1%	<1%	<1%
top 25%	<1%	<1%	<1%	<1%	<1%	<1%
top 50%	<1%	<1%	<1%	<1%	<1%	<1%
Ponds (avg condition)						
All	4%	6%	10%	3%	4%	3%
top 25%	3%	2%	8%	2%	1%	2%
top 50%	4%	3%	10%	3%	2%	2%
Longer Crop Rotations						
All	10%	22%	10%	3%	6%	3%
top 25%	9%	12%	8%	2%	4%	2%
top 50%	10%	19%	10%	2%	5%	2%
Cover Crops						
All	11%	<1%	11%	3%	0%	3%
top 25%	9%	<1%	9%	2%	0%	2%
top 50%	11%	<1%	10%	3%	0%	2%
No-Till						
All	7%	-2%	7%	2%	-1%	2%
top 25%	6%	-1%	6%	1%	<1%	1%
top 50%	7%	-2%	7%	2%	<1%	1%

1. *Adding grassed waterways on all crop/pasture/alfalfa land with SPI values >=4*

Grassed waterways (GWWs) were simulated to provide significant sediment reductions in both watersheds but very little reduction in NO3. Sediment and TP reductions ranged from 4-5% and 4-6%, depending on implementation level, in the WW and GAR, respectively.

Slightly higher reductions in the GAR watershed compared to WW can be attributed to the higher extent row-crop and pasture land with an SPI of 4 or greater (i.e., more length of GWW was added relative to existing conditions – see Table 5)

It is important to note how GWWs are simulated in SWAT to gain context around the predicted sediment/TP reductions. From a SWAT perspective, GWWs principal effect is to slow down sediment-laden flows from up-gradient fields, thereby depositing a certain proportion of sediment before it can enter the stream channel. No GWW flow is infiltrated, thus the absence of a NO3 reduction. Further, SWAT does not directly account for GWW protection against gullying through vegetative armoring and reduced flow velocity. Some research has been conducted (Arabi, 2007) to simulate this effect by changing other SWAT parameters such as channel cover and manning's n when SWAT's channel erosion algorithm is enabled; however, as discussed previously, channel erosion was turned off in both models and channel erosion was fixed at 60% of the total stream sediment load. As a result, reductions in gullying were not simulated and predicted results shown are most likely under-estimations of GWW sediment efficacy.

2. *Dredging existing ponds back to design standard.*

To simulate a depth and volumetric increase in ponds after dredging, pond volumes were doubled resulting in an average depth of 1 meter (from 0.5 meter; surface areas were kept constant). However, this resulted in very little sediment or NO3 reduction in SWAT. This is a result of the relative insensitivity of pond volume compared to pond drainage area parameters. It is likely computed pond drainage areas are well within the existing pond capacities to attenuate flow and sediment/TP; thus, increasing volumes had little additional effect. Because it seems reasonable that dredging ponds would indeed reduce sediment/TP (and possibly NO3) loads, it may suggest that existing pond drainage areas, estimated using a regression equation for a subset of WW subwatersheds, may not be applicable in every subwatershed (perhaps over-estimated). Alternatively, it may suggest an issue with the realism of the SWAT pond algorithm.

3. *Adding ponds to conform to the "average condition".*

Pond drainage areas and volumes were increased in subwatersheds that were less than their respective watershed's average condition. Average condition for each watershed (WW and GAR) was calculated as the area-weighted average ratio of pond drainage area to total drainage area (SWAT's PND_FR parameter; average conditions: WW =0.36, GAR=0.34). Each subwatershed with a ratio less than the average condition had its PND_FR parameter increased to the average condition, with the pond volume increased by the proportion of PND_FR increase.

Simulated results indicate that significant reductions of sediment/TP can be achieved by increasing ponds to the average condition with reductions ranging from 3-4% and 2-3%, depending on implementation level, in the WW and GAR, respectively; NO3 reductions were similar to sediment for both watersheds (3-6% and 1-4%). In hindsight, proposing a higher increase in pond extent (e.g., average condition +25%) would have yielded more substantive results. Reductions from increases above the average condition can be estimated to further reduce sediment and nitrate at a rate proportional to increased pond drainage area.

4. *Longer Crop rotations including more years of alfalfa*.
In this scenario, continuous corn (CC) and corn/soybean (CS) rotations were replaced by corn/silage/alfalfa (2 years each) and corn/soybean/alfalfa (2 years each) six-year rotations. Results show sediment/TP reductions ranging from 9-10% and 2-3%, depending on implementation level, in the WW and GAR, respectively; NO3 reductions were more significant ranging from 19-22% and 4-6%. Disparity between WW and GAR is a function of the current extent of CC and CS area in each. Therefore, because CC and CS constitute a larger proportion of total watershed area in the WW than in the GAR (29% vs. 8%, respectively), reductions in the former were profoundly higher.

Model reduction predictions can be attributed to the added alfalfa rotational years during which: (1) The MUSLE C factor and curve number were decreased resulting in erosion reductions and (2) nitrogen fertilizer was not applied resulting in NO3 reductions.

5. *Adding fall cover crop*
A winter rye crop was planted November 1st during CC and CS rotational years. Because winter rye provides cover during normally bare soil conditions (late-fall to spring planting) less erosion is expected to occur during this period. SWAT reduction prediction is driven by decreasing MUSLE C factor and runoff curve number from rye planting to spring plowing. Results show significant decreases in sediment/TP, ranging from 9-11% and 2-3%, depending on implementation level, in the WW and GAR, respectively; As with Longer Crop Rotations, differences between sediment reductions in the WW and GAR can be attributed to the areal differences in existing CC and CS areas between the two watersheds.

Additionally, it is understood that cover crops can significantly decrease nitrate losses due to leaching during fall-spring; however, this effect does not appear to be simulated properly with SWAT in the current parameterization as NO3 was not predicted to be reduced appreciably. This is likely at least partly attributable to the fertilizer regime associated with the scenario. Given cover crops conserve soil NO3, less fertilizer should have to be applied the next planting period. However, N fertilizer application rates were not reduced in conjunction with cover crops thereby dampening their reductive effect. Further, SWAT soil-water nutrient processes relating to NO3 were not evaluated as to their accuracy or reasonableness. Additional investigation and effort, taking into account these two factors, will be needed to ensure the current SWAT model is properly predicting cover crop NO3 response.

6. *No-till practices on soybeans*
No-till was implemented on all CS areas following harvest of the corn crop. Thus, the scenario was simulated with no plowing after corn (prior to spring soybean planting) and the presence of corn residue on the fields until fall plowing during the soybean year.

Predicted sediment/TP reductions are significant ranging from 6-7% and 1-2%, depending on implementation level, in the WW and GAR, respectively; however, NO3 was predicted to increase slightly (less than or equal to 2%) as a result of the corn residue left after harvest and its subsequent decomposition. As with Longer Crop Rotations and Cover Crops, differences between sediment/TP reductions in the WW and GAR can be attributed to the areal differences in existing CC and CS areas between the two watersheds.

Effects of scenarios on volumes and peak flows

There was interest in determining the effects of potential BMP scenarios on total volume and peak flows, particularly those pertaining to ponds in the Garvin Brook watershed. Resulting SWAT predictions demonstrated that, while existing and increased pond volume/drainage area scenarios were predicted to have significant effects on sediment, TP and nitrate reductions, there was very little flow response (<1% reduction) predicted for both overall volume and peak flows. This is due to the fact that the proportion of effective pond volumes vs. the total volume of flow in the watersheds is very low (<1%); there is simply is not enough storage capacity and thus, evaporative potential, to affect overall watershed volumes or peak flows in a significant way. Volume control scenarios for flood mitigation would have to include substantial storage increases to see any appreciable effect.

Scenario Recommendations

Combining individual conservation scenarios yields the cumulative reduction of sediment and nitrate. Given the significant but somewhat modest reductions of any one scenario, combining two or more practices will yield the most substantive results. Generally, the relationship is additive but with small redundancy penalty. The redundancy is a function of certain processes overlapping and reducing their cumulative effect. With each practice combined, simulations showed a roughly 7% "cost" (i.e., * 0.93) to the combined reduction. For example, combining grassed waterways and ponds in all subwatersheds in the Whitewater, the combined sediment reduction would be approximately (5% + 4%) * 0.93 = 8.4%; likewise, combining grassed waterways, ponds and Longer Crop rotations would yield (5% + 4% + 10%) * 0.86 = 16% combined reduction. These relations can be used estimate combined reductions from future ad hoc analyses. In most cases, combining three or more practices on the top-25% most erodible subwatersheds (by sediment load under existing conditions) will result in the most cost-effective solutions. See Table 7 for combined results.

Of the combined scenarios, grasses waterways, ponds and any of the three cropping practices at the top-25% level would yield substantial sediment/TP reduction results: 11-14% and 6-7% in the WW and GAR. Of these three combinations, only that including Longer Crop rotations reduced nitrate by an appreciable amount: 13% and 5% in the WW and GAR. Combining all give BMP scenarios yielded generous reductions of 22% and 10%, and 8% and 5% for sediment/TP and nitrate for WW and GAR, respectively.

However, to put these results into proper context, the maximum attainable reductions (resulting from 100% row-crop to cool-season grass conversion) were simulated to be 37% and 65% for sediment and nitrate in Whitewater and, 38% and 78% in Garvin Brook. Therefore, as an example, the 22% sediment reduction in the Whitewater (All-BMP scenario in top 25% erodible subwatersheds) is very significant when one takes into account a maximum reduction of 37%.

The maximum attainable reductions for sediment/TP (but not nitrate) are a reflection of the assumed 40%/60% split between field and non-field sources in the watersheds. In other words, there is a limit to which reductions in field sediment can influence total watershed sediment load given 60% of the latter is composed of non-field sediment.

Table 7. Combined conservation scenario results for sediment, nitrate and TP reductions at the outlets of the Whitewater and Garvin Brook watersheds. "All" indicates BMP implementation in all SWAT subwatersheds; "top 25%" and "top 50%" indicates BMP implementation in the top 25% and 50% most erodible SWAT subwatersheds, respectively, as ranked by sediment load under existing conditions. Row-crop conversion to grasses represents the maximum attainable reduction.

		Whitewater			Garvin Brook		
Conservation Scenario		**SED**	**NO3**	**TP**	**SED**	**NO3**	**TP**
Row-crop Conv. to Grasses		37%	78%	35%	38%	65%	36%
Grassed Waterways (SPI>=4) Ponds (avg condition) Longer Crop Rotations							
	All	17%	26%	16%	10%	10%	10%
	top 25%	14%	13%	13%	7%	5%	6%
	top 50%	16%	21%	15%	8%	7%	7%
Grassed Waterways (SPI>=4) Ponds (avg condition) Cover Crops							
	All	17%	6%	16%	11%	4%	10%
	top 25%	14%	2%	13%	7%	1%	7%
	top 50%	17%	3%	16%	8%	2%	8%
Grassed Waterways (SPI>=4) Ponds (avg condition) No-Till							
	All	14%	4%	13%	9%	4%	9%
	top 25%	11%	1%	11%	6%	1%	6%
	top 50%	13%	1%	13%	7%	2%	7%
All five scenarios							
	All	27%	20%	26%	12%	8%	11%
	top 25%	22%	10%	21%	8%	5%	7%
	top 50%	27%	16%	25%	10%	7%	9%

Further Model Development

Several amendments could be made to these models to improve their accuracy and utility.

Ponds

Pond parameterization certainty would benefit from further analysis to more accurately account for pond drainage areas. Also, a determination of trap efficiencies under different levels of depth (depth varying by degree of pond sediment deposition) would provide better constraints for simulated pond performance. Both would improve realism and predictive capability of Whitewater and Garvin Brook ponds.

Grassed waterways
SWAT computer code for these was fixed but is still showing some anomalies; a bug-free fix would ensure best possible predictions. Also, as discussed the model did not simulate armoring and reduced flow velocities by grasses waterways; it is conceivable that in channels with high SPI, the channel erosion reductions could exceed that of attenuation of field sediment. Further model work could properly parameterize this behavior.

Observed data
More flow, sediment and nitrate data in the Garvin Brook watershed would enable that watershed to be properly calibrated.

*Field/non-field sediment assumptio*n
As discussed previously, sediment prediction would benefit from further work to determine whether the 40%/60% field to non-field split is accurate and under what climatic conditions it applies (e.g., wet and dry seasons/years). Minnesota DNR has done extensive stream bank erosion monitoring throughout the watershed and this work should be greatly beneficial in reevaluating field vs non-field sediment sources.

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APPENDIX A: MODEL PARAMETERIZATION AND CALIBRATION

This appendix provides detailed guidance regarding the initial parameterization as well as the calibration adjustments made to the SWAT models.

Table A1. Parameter set used for the Mississippi River--Winona area SWAT model (for SWAT2012, rev. 614), with channel erosion disallowed and remainder (field erosion) set to 40% of total measured sediment load.

NOTES: *Alphabetical by table or file name; tables in project database; dat files in ArcSwat\Databases folder. Parameter values, where HRU or subbasin-specific, were applied only to those HRUs and subbasins upstream from the monitoring point. Blanks designate the same parameter values as for the main monitoring station at Sunrise.*

File & Parameter	Description	units	Default	Whitewater at Beaver	Garvin Bk & Rollingstone	Rationale
Data filtering						
Precipitation data censored to 75 mm/day maximum						SWAT can vastly overestimate flows and erosion for large daily events exceeding 50-75 mm (2-3")
table bsn						
IPET	Potential evapotranspiration	unitless	1	2	1	1 = Penman-Monteith, 2 = Hargreaves
SFTMP	Snowfall temperature	deg C	1	2	2	Larger values increase snow amounts.
SMTMP	Snowmelt base temperature	deg C	0.5	2	2	Larger values delay snow melt causing a larger event in spring
SMFMX	Snowmelt melt factor, max	mmH2O/deg-day	4.5			
SMFMN	Snowmelt melt factor, min	mmH2O/deg-day	4.5			
TIMP	Snowpack temperature lag factor	unitless	1	0.5	0.5	Adjusts timing of melt
SNOCOVMX	Snowpack water content at which coverage is 100%	mmH2O	1	20	20	Assuming 1 mm H2O = 1 cm of snowpack, default seems much too low for 100% snow cover. 20 cm snow (8") seems better.

SNO50COV	Fraction of SNOCOVMX volume when coverage is 50%	unitless	0.5	0.1	0.1	
SURLAG	Surface runoff lag coefficient	unitless	4	0.2		Lowering SURLAG reduces and delays peaks. The much-lower than default value improved hydrologic fit. Unclear why runoff is delayed.
ICN	Curve number method	unitless	0	1	1	0 = soil moisture, 1 = plant ET
CNCOEFF	Plant ET CN coefficient	unitless	1		1.3	Larger values increase peaks
SPCON	Linear parameter, channel sediment transport	unitless	0.0001	0.01	0.01	Higher value essentially stops deposition of sediment in channel for "passive channel" model version. Lower value used to trap sediment in "active channel" model version.
SPEXP	Exponent parameter, channel sediment transport	unitless	1	3	3	Left at default; used SPCON to stop deposition
CDN	CDN, denitrification parameter	unitless	0 => 1.4			Table bsn shows default of 0, but I/O manual says default = 1.4. (Previous versions were negative; use only positive values here.)
SNDCO	SNDCO, soil water denitrification point parameter	unitless	0 => 1.10			Table bsn shows default of 0, but I/O manual says default = 1.10.
PSP	Phosphorus availability index	unitless	0.4			Set to achieve realistic total phosphorus concentrations in top layer of agricultural soils, after setting SOL_LABP1 to soil-test phosphorus levels
PHOSKD	Phosphorus soil partitioning coefficient	m^3/T (T = Mg)	175			To get more phosphorus in runoff, reduce either PSP (giving less soluble P) or reduce PHOSKD (giving more soluble P).
PPERCO			10			

table chm

SOL_LABP1	Soil labile P content, layer 1	ppm	5	Assumed to be soil-test P values. Rural residential HRUs would retain their former STP. Entries of zero in the table actually default to 5 ppm.

Table A2. Parameter set used for the Mississippi River--Winona area SWAT model (for SWAT2012, rev. 614), with channel erosion disallowed and remainder (field erosion) set to 40% of total measured sediment load.

NOTES: *Alphabetical by table or file name; tables in project database; dat files in ArcSwat\Databases folder. Parameter values, where HRU or subbasin-specific, were applied only to those HRUs and subbasins upstream from the monitoring point. Blanks designate the same parameter values as for the main monitoring station at Sunrise.*

File & Parameter	Description	units	Default	Whitewater at Beaver	Garvin Bk & Rollingstone	Rationale
file crop.dat						
BIO_E for CORN	Radiation use efficiency, or biomass-energy ratio	$(kg/ha)/(MJ/m^2)$	39			Used to adjust crop yields, beyond effects of water and nutrient stresses
BIO_E for CSIL	Radiation use efficiency, or biomass-energy ratio	$(kg/ha)/(MJ/m^2)$	39			Used to adjust crop yields, beyond effects of water and nutrient stresses
BIO_E for ALFA	Radiation use efficiency, or biomass-energy ratio	$(kg/ha)/(MJ/m^2)$	20			Used to adjust crop yields, beyond effects of water and nutrient stresses
BIO_E for SOYB	Radiation use efficiency, or biomass-energy ratio	$(kg/ha)/(MJ/m^2)$	25			Used to adjust crop yields, beyond effects of water and nutrient stresses
HVSTI for CORN	Harvest index (fraction of above-ground biomass removed)	unitless	0.5			
CPYLD for CORN	Normal fraction of phosphorus in yield for corn-grain	unitless	0.0016			Literature indicated value different from default
CPYLD for CSIL	Normal fraction of phosphorus in yield for corn-silage	unitless	0.0016			Literature indicated value different from default
CPYLD for SOYB	Normal fraction of phosphorus in yield for soybeans	unitless	0.0091			Kept at default

WSYF for SOYB	Water-stress yield factor (minimum HVSTI when dry)	unitless	0.01			
USLE_C for CORN, CSIL, and SOYB	Minimum C_{USLE} for corn-grain, corn-silage, and soybeans	unitless	0.2			Kept at default; relative erosion rates for these crops were in order as expected: SOYB>CSIL>CORN
USLE_C for BROS	Minimum C_{USLE} for smooth brome	unitless	0.003			Sunrise: start with default. For the Willow: to make erosion rates from brome about half that from alfalfa
USLE_C for ALFA	Minimum C_{USLE} for alfalfa	unitless	0.01			Sunrise: start with default. For the Willow: to make erosion rates from alfalfa about 1/3 to 1/4 that from cultivated crops
RSDCO_PL for CORN	Plant residue decomposition coefficient for corn-grain	unitless	0.05			Increased decomposition allowed residue (a) to approach zero at the time of planting the following year under conventional tillage, so it would not build up to unrealistic levels, and (b) to approach appropriate levels for reduced tillage practices, to result in targeted C_{USLE} factors
RSDCO_PL for CSIL	Plant residue decomposition coefficient for corn-silage	unitless	0.05			ditto
RSDCO_PL for SOYB	Plant residue decomposition coefficient for soybeans	unitless	0.05			ditto
table gw						
GW_DELAY	Groundwater delay time	days	30	500	730	Large values smooth contribution by groundwater to baseflow

ALPHA_BF	Baseflow recession constant	1/days	0.048		Commonly from just above 0 to 1; smaller units have slower (less steep) baseflow recession
RCHRG_DP	Fraction of recharge lost to deep aquifer	unitless	0	0.1	Useful for adjusting overall water balance. Positive values cause losses; negative values add to baseflow.
GWSOLP	Phosphorus concentration in groundwater	mg/L	0		Values of 0.01-0.02 mg/L found in some studies (Nolan and Stoner)
table hru					
SLSUBBSN	Slope length	m	50-120		If no values are entered, SWAT default = 50 m. But, ArcSWAT will calculate values, commonly in the range of 90-120 m.
SLOPE	Slope	m/m (unitless)	by hru		Previously, SWAT used the subbasin-wide slope for all hrus; the current SWAT is improved by calculating a slope for each hru individually.
OV_N	Overland runoff Manning's N	unitless	by hru (about 0.05 to 0.14)		Previous default of 0.014 was too low, but now ArcSWAT seems to assign reasonable values by hru.
SLSOIL	Slope length for lateral flow in soil	m	by subbasin		Same as for SLSUBBSN
ESCO	Soil evaporation compensation factor	unitless	0.95		Smaller values reduce overall water yield from basin. A table entry of zero (which is default) will result in SWAT using 0.95. The default basin-wide value of ESCO is set in

Table bsn; I presume any value here overrides the default for that hru.

Table A3. Parameter set used for the Mississippi River--Winona area SWAT model (for SWAT2012, rev. 614), with channel erosion disallowed and remainder (field erosion) set to 40% of total measured sediment load.

NOTES: *Alphabetical by table or file name; tables in project database; dat files in ArcSwat\Databases folder. Parameter values, where HRU or subbasin-specific, were applied only to those HRUs and subbasins upstream from the monitoring point. Blanks designate the same parameter values as for the main monitoring station at Sunrise.*

File & Parameter	Description	units	Default	Whitewater at Beaver	Garvin Bk & Rollingstone	Rationale
table mgt1						
BIOMIX	Biological mixing efficiency	unitless	0.2			Increased for reduced tillage scenarios; however note we may be increasing this too much. See WiscoDisco Farms, where no-till did not reduce P yields.
CN2	Curve number, initial, soil moisture condition 2	unitless	by land cover	85% of initial value	75% of initial value	Decreasing CN increases infiltration and baseflow, reduces hydrograph spikes
USLE_P	USLE support practice factor, nominally	unitless	1	0.6	0.6	Used as a primary calibration scaling parameter to reduce sediment delivery from subbasins; applied here to all HRUs

table mgt2						
CNOP	Curve number for scheduled ag operation	unitless	CN2 above	85% of initial value	75% of initial value	CNOP set in rotations each year based on crop, soil hydrologic group, and tillage level.
table pnd						
PND_FR	Pond drainage fractional area in subbasin	unitless	0	0 to 1	0 to 0.71	Fractional area of subbasin land draining to ponds, here aggregated into one composite Pond per subbasin. Determined from GIS analysis.
PND_PSA	Pond principal surface area	ha	0	0 to 178	0 to 46	Determined from GIS analysis.
PND_PVOL	Pond principal volume	ha-m	0	0.5* PND_PSA	0.5* PND_PSA	Assumes average depth of 0.5 m for each pond.
PND_ESA	Pond emergency surface area	ha	0	1.5* PND_PSA	1.5* PND_PSA	Area of Pond at emergency (maximum) level, guessed at 1.5X principal area
PND_EVOL	Pond emergency volume	ha-m	0	2* PND_PVOL	2* PND_PVOL	Volume of Pond at emergency (maximum) level, guessed at 2X principal volume
NDTARG	Number of days to reach target storage	days	15	3	3	Days to reach target volume. Determines recession of outflow after storm event.
IFLOD1	Last month of flood season	unitless	0	12	12	Force all 12 months to be "flood season," so pond outflow responds to target volume and recesses via NDTARG.
IFLOD2	First month of flood season	unitless	0	1	1	Otherwise, ponds during "non-flood" months fill to EVOL and spill all excess, with no storage effect.

PND_NSED	Equilibrium sediment concentration	mg/L	1	50	50	Large values trap less sediment, allow more delivery to stream, characteristic of shallow ponds.
PND_K	Pond hydraulic conductivity	mm/hr, to nearest 0.001	0.5	0	0	Zero stops all seepage from ponds.
PSETL1 (for Ponds)	Phosphorus settling rate, settling season 1, ponds	m/yr	1			

Table A4. Parameter set used for the Mississippi River--Winona area SWAT model (for SWAT2012, rev. 614), with channel erosion disallowed and remainder (field erosion) set to 40% of total measured sediment load.

NOTES: *Alphabetical by table or file name; tables in project database; dat files in ArcSwat\Databases folder. Parameter values, where HRU or subbasin-specific, were applied only to those HRUs and subbasins upstream from the monitoring point. Blanks designate the same parameter values as for the main monitoring station at Sunrise.*

File & Parameter	Description	units	Default	Whitewater at Beaver	Garvin Bk & Rollingstone	Rationale
table rte						
CH_N2	Main channel Manning's N	unitless	0.014			Left at default; perhaps too low for natural channels.
CH_K2	Channel hydraulic conductivity	mm/hr	0.5	0	0	Zero precludes water loss by outseepage
CH_COV1	Channel erodibility factor	cm/hr/Pa	0	0	0	Zero stops channel erosion.
CH_COV2	Channel cover factor	unitless	0	0	0	Ditto.
table sol						
SOL_K1, 2, and 3	Hydraulic conductivity of soil layers 1, 2, and 3	mm/hr	soil database			K values could be reduced to slow lateral flow in soil, somewhat reducing hydrograph peaks; after experimental model runs we decided to leave these values alone.

SOL_AWC1, 2, and 3	Available water capacity of soil layers 1, 2, and 3	mm	soil database	Default	70% of initial value	Lower AWC can force more runoff, percolation, and lateral flow. Lower AWC increases overall water yield by decreasing ET.
table sub						
CH_K1	Tributary channel hydraulic conductivity	mm/hr	0.5	0	5	Small effect. Some transmission loss likely from ephemeral runoff flow paths.
CH_N1	Tributary channel Manning's N	unitless	0.014			Left at default; perhaps too low for natural channels.

Table A5. Parameter set used for the Mississippi River--Winona area SWAT model (for SWAT2012, rev. 614), with channel erosion disallowed and remainder (field erosion) set to 40% of total measured sediment load.

NOTES: *Alphabetical by table or file name; tables in project database; dat files in ArcSwat\Databases folder. Parameter values, where HRU or subbasin-specific, were applied only to those HRUs and subbasins upstream from the monitoring point. Blanks designate the same parameter values as for the main monitoring station at Sunrise.*

File & Parameter	Description	units	Default	Whitewater at Beaver	Garvin Bk & Rollingstone	Rationale
file swq.dbf						
RS5	Organic phosphorus settling rate	1/day	0.05			This parameter is not used in the "passive channel" model version. In the "active channel" version, RS5 is used to trap excess phosphorus in the floodplain and channel system.
file till.dat						
EFTMIX for 47 MLDBOARD	Mixing efficiency of moldboard plow	unitless	0.95			Kept at default

EFTMIX for 48 CHISPLOW	Mixing efficiency of chisel plow	unitless	0.3		Increased to reduce surface residue to selected levels under different tillage levels
EFTMIX for 50 DISKPLOW	Mixing efficiency of disk plow	unitless	0.85		Increased to reduce surface residue to selected levels under different tillage levels
file wwq.dbf					
AI2	Fraction of algal biomass that is phosphorus	mg P / mg algae	0.015		This parameter is not relevant to the "passive channel" model version. However, when stream-water quality processes are activated for the "active channel" version, AI2 must be set low to avoid spurious phosphorus input.

APPENDIX B: AGRICULTURAL MANAGEMENT OPERATIONS

This appendix provides detailed information on specific rotation, planting, tillage, fertilizer and manure operations used in the SWAT model.

Table B1. Corn-soybean (CS) cash-crop rotation.

				Metric:				
Year	**Date**	**Operation**	**Item**	**Rate**	**Units**	**N (kg/ha)**	**P (kg/ha)**	**Notes**
Year 1	21-Apr	Fertilize	46-0-0	337	kg/ha	155		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	21-Apr	Fertilize	9-23-30	270	kg/ha	24	27	LY1 = 0
	26-Apr	Till	Field Cultivator					
	1-May	Plant	Corn-Grain					CNOP A = 67, B = 77, C = 83, D = 87
	28-Oct	Harvest&Kill	Corn-Grain					
	30-Oct	Till	Chisel					
Year 2	15-May	Till	Field Cultivator					
	20-May	Plant	Soybeans					CNOP A = 67, B = 78, C = 85, D = 89
	15-Oct	Harvest&Kill	Soybeans					
	31-Oct	Till	Chisel					
Nutrient additions:								
Year 1						179	27	
Year 2						0	0	
Annual average						90	14	

Table B2. Continuous Corn Rotation

Year	Date	Operation	Item	Rate	Units	N (kg/ha)	P (kg/ha)	Notes
Year 1	21-Apr	Fertilize	46-0-0	337	kg/ha	155		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	21-Apr	Fertilize	27-15-15	225	kg/ha	61	15	LY1 = 0
	26-Apr	Till	Field Cultivator					
	1-May	Plant	Corn-Grain					CNOP A = 67, B = 77, C = 83, D = 87
	28-Oct	Harvest&Kill	Corn-Grain					
	31-Oct	Till	Chisel					
Nutrient additions:								
Year 1						216	15	
Annual average						216	15	

Table B3. Continuous corn (CC) rotation with beef manure application, for Whitewater and Garvin Brook watersheds.

Year	Date	Operation	Item	Rate	Units	N (kg/ha)	P (kg/ha)	Notes
Year 1	18-Apr	Fertilize	46-0-0	112	kg/ha	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	21-Apr	Fertilize	Beef manure	8,500	kg/ha	340	94	
	26-Apr	Till	Field Cultivator					
	1-May	Plant	Corn-Grain					CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	61	15	LY1 = 0
	28-Oct	Harvest&Kill	Corn-Grain					
	31-Oct	Till	Chisel					
Nutrient additions:								
Year 1						452	108	
Annual average						452	108	

Table B4. Continuous corn (CC) rotation with beef manure application, for Whitewater and Garvin Brook watersheds.

Year	Date	Operation	Item	Rate	Units	N (kg/ha)	P (kg/ha)	Notes
Year 1	18-Apr	Fertilize	46-0-0	112	kg/ha	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	21-Apr	Fertilize	Dairy manure	9,500	kg/ha	361	76	
	26-Apr	Till	Disk					
	1-May	Plant	Corn-Grain					CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	61	15	LY1 = 0
	28-Oct	Harvest&Kill	Corn-Grain					
	31-Oct	Till	Chisel					
Nutrient additions:								
Year 1						473	91	
Annual average						473	91	

Table B5. Corn-alfalfa (CA) rotation with spring dairy manure applications.

Year	Date	Operation	Item	Rate	Units	N (kg/ha)	P (kg/ha)	Notes
Year 1	18-Apr	Fertilize	46-0-0	112	kg/ha	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	22-Apr	Fertilize	Dairy manure	14,250	kg/ha	542	114	
	26-Apr	Till	Field Cultivator					
	1-May	Plant	Corn-Grain					CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	61	15	LY1 = 0
	28-Oct	Harvest&Kill	Corn-Grain					
	15-Nov	Till	Chisel					
Year 2	18-Apr	Fertilize	46-0-0	112	kg/ha	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	22-Apr	Fertilize	Dairy manure	14,250	kg/ha	542	114	
	26-Apr	Till	Field Cultivator					
	1-May	Plant	Corn-Silage					CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	61	15	LY1 = 0
	25-Sept	Harvest&Kill	Corn-Silage					
	15-Nov	Till	Chisel					
Year 3	18-Apr	Fertilize	46-0-0	112	kg/ha	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	22-Apr	Fertilize	Dairy manure	14,250	kg/ha	542	114	
	26-Apr	Till	Field Cultivator					
	1-May	Plant	Corn-Silage					CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	61	15	LY1 = 0
	25-Sept	Harvest&Kill	Corn-Silage					
	15-Nov	Till	Chisel					
Year 4	14-Apr	Fertilize	Dairy manure	14,250	kg/ha	542	114	
	19-Apr	Till	Field Cultivator					
	23 April	Plant	Alfalfa					CNOP A = 31, B = 59, C = 72, D = 79
	5-Sep	Harvest	Alfalfa					
Year 5	25-Jun	Harvest	Alfalfa					
	1-Aug	Harvest	Alfalfa					
	10-Sep	Harvest	Alfalfa					

Year 6	25-Jun	Harvest	Alfalfa
	1-Aug	Harvest	Alfalfa
	10-Sep	Harvest	Alfalfa
	7-Nov	Till	Chisel

Manure application rates and nutrient additions:	Manure rate:			
Year 1	14,250	kg/ha	654	129
Year 2	14,250	kg/ha	654	129
Year 3	14,250	kg/ha	654	129
Year 4	0		0	0
Year 5	0		0	0
Year 6	14,250	kg/ha	542	114
Annual average	9,500	kg/ha	417	83

Table B6. Corn-alfalfa (CA) rotation with fall dairy manure applications.

Year	Date	Operation	Item	Rate	Units	Rate	Units	N (kg/ha)	P (kg/ha)	Notes
Year 1	18-Apr	Fertilize	46-0-0	112	kg/ha	100	lb/acre	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	26-Apr	Till	Field Cultivator							
	1-May	Plant	Corn-Grain							CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	200	lb/acre	61	15	LY1 = 0
	28-Oct	Harvest&Kill	Corn-Grain							
	7-Nov	Fertilize	Dairy manure	4,250	kg/ha	45.3	sh T/acre, fresh	542	114	
	15-Nov	Till	Chisel							
Year 2	18-Apr	Fertilize	46-0-0	112	kg/ha	100	lb/acre	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	26-Apr	Till	Field Cultivator							
	1-May	Plant	Corn-Silage							CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	200	lb/acre	61	15	LY1 = 0
	25-Sept	Harvest&Kill	Corn-Silage							
	7-Nov	Fertilize	Dairy manure	4,250	kg/ha	45.3	sh T/acre, fresh	542	114	
	15-Nov	Till	Chisel							
Year 3	18-Apr	Fertilize	46-0-0	112	kg/ha	100	lb/acre	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	26-Apr	Till	Field Cultivator							
	1-May	Plant	Corn-Silage							CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	200	lb/acre	61	15	LY1 = 0
	25-Sept	Harvest&Kill	Corn-Silage							
	7-Nov	Fertilize	Dairy manure	14,250	kg/ha	45.3	sh T/acre, fresh	542	114	
	15-Nov	Till	Chisel							
Year 4	16-Apr	Till	Disk							
	23 April	Plant	Alfalfa							CNOP A = 31, B = 59, C = 72, D = 79
	5-Sep	Harvest	Alfalfa							
Year 5	25-Jun	Harvest	Alfalfa							

	1-Aug	Harvest	Alfalfa						
	10-Sep	Harvest	Alfalfa						
Year 6	25-Jun	Harvest	Alfalfa						
	1-Aug	Harvest	Alfalfa						
	10-Sep	Harvest	Alfalfa						
	1-Nov	Fertilize	Dairy manure	14,250	kg/ha	45.3	sh T/acre, fresh	542	114
	7-Nov	Till	Moldboard plow						
Manure application rates and nutrient additions:				Manure rate:		Manure rate:			
Year 1				14,250	kg/ha	45.3	st T/acre, fresh	654	129
Year 2				14,250	kg/ha	45.3	st T/acre, fresh	654	129
Year 3				14,250	kg/ha	45.3	st T/acre, fresh	654	129
Year 4				0		0		0	0
Year 5				0		0		0	0
Year 6				14,250	kg/ha	45.3	st T/acre, fresh	542	114
Annual average				9,500	kg/ha	30.2	st T/acre, fresh	417	83

Table B7. Corn-alfalfa (CA) rotation with daily-haul dairy manure applications, simplified as monthly applications.

Year	Date	Operation	Item	Rate	Units	Rate	Units	N (kg/ha)	P (kg/ha)	Notes
Year 1	15-Jan	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Feb	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Mar	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Apr	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	18-Apr	Fertilize	46-0-0	112	kg/ha	100	lb/acre	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	26-Apr	Till	Field Cultivator							
	1-May	Plant	Corn-Grain							CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	200	lb/acre	61	15	LY1 = 0
	28-Oct	Harvest&Kill	Corn-Grain							
	5-Nov	Till	Chisel							
	15-Nov	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Dec	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
Year 2	15-Jan	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Feb	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Mar	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Apr	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	18-Apr	Fertilize	46-0-0	112	kg/ha	100	lb/acre	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	26-Apr	Till	Field Cultivator							
	1-May	Plant	Corn-Silage							CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	200	lb/acre	61	15	LY1 = 0
	25-Sept	Harvest&Kill	Corn-Silage							
	5-Nov	Till	Chisel							
	15-Nov	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Dec	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
Year 3	15-Jan	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Feb	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Mar	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Apr	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1

	18-Apr	Fertilize	46-0-0	112	kg/ha	100	lb/acre	52		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	26-Apr	Till	Field Cultivator							
	1-May	Plant	Corn-Silage							CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	200	lb/acre	61	15	LY1 = 0
	25-Sept	Harvest&Kill	Corn-Silage							
	5-Nov	Till	Chisel							
	15-Nov	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Dec	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
Year 4	20-Apr	Till	Disk							
	23-Apr	Plant	Alfalfa							CNOP A = 31, B = 59, C = 72, D = 79
	15-Jun	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Aug	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	10-Sep	Harvest	Alfalfa							
	15-Sep	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Oct	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Nov	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Dec	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
Year 5	15-May	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Jun	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	25-Jun	Harvest	Alfalfa							
	15-Jul	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	1-Aug	Harvest	Alfalfa							
	15-Aug	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	10-Sep	Harvest	Alfalfa							
	15-Sep	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Oct	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
Year 6	15-May	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	15-Jun	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	25-Jun	Harvest	Alfalfa							
	15-Jul	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	1-Aug	Harvest	Alfalfa							
	15-Aug	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
	10-Sep	Harvest	Alfalfa							

15-Sep	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
15-Oct	Fertilize	Dairy manure	1,600	kg/ha, dry	5.09	sh T/acre, fresh	61	13	LY1 = 1
1-Nov	Till	Chisel							

Manure application rates and nutrient additions:	Manure rate:		Manure rate:		Nutrient totals, inorganic fertilizer plus manure:	
Year 1	9,600	kg/ha, dry	30.5	sh T/acre, fresh	477	92
Year 2	9,600	kg/ha, dry	30.5	sh T/acre, fresh	477	92
Year 3	9,600	kg/ha, dry	30.5	sh T/acre, fresh	416	79
Year 4	9,600	kg/ha, dry	30.5	sh T/acre, fresh	365	77
Year 5	9,600	kg/ha, dry	30.5	sh T/acre, fresh	304	64
Year 6	9,600	kg/ha, dry	30.5	sh T/acre, fresh	365	77
Annual average	9,600	kg/ha, dry	30.5	sh T/acre, fresh	401	80

Table B8. Corn-alfalfa (CA) rotation with daily-haul dairy manure applications, simplified as monthly applications.

Year	Date	Operation	Item	Rate	Units	Rate	Units	N (kg/ha)	P (kg/ha)	Notes
Year 1	21-Apr	Fertilize	46-0-0	337	kg/ha	300	lb/acre	155		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	26-Apr	Till	Field Cultivator							
	1-May	Plant	Sweet Corn							CNOP A = 67, B = 77, C = 83, D = 87
	1-May	Fertilize	27-15-15	225	kg/ha	200	lb/acre	61	15	LY1 = 0
	15-Sep	Harvest&Kill	Sweet Corn							
	30-Oct	Till	Chisel							
Year 2	10-May	Fertilize	9-23-30	225	kg/ha	200	lb/acre	20	23	LY1 = 0
	15-May	Till	Field Cultivator							
	20-May	Plant	Soybeans							CNOP A = 67, B = 78, C = 85, D = 89
	15-Oct	Harvest&Kill	Soybeans							
	31-Oct	Till	Chisel							
Nutrient additions:										
Year 1								216	15	
Year 2								20	23	
Annual average								118	19	

Table B9. Corn-peas rotation (CPO), with rye planted as a fall cover crop following peas.

				Metric:		*English:*				
Year	**Date**	**Operation**	**Item**	**Rate**	**Units**	**Rate**	**Units**	**N (kg/ha)**	**P (kg/ha)**	**Notes**
Year 1	21-Apr	Fertilize	46-0-0	337	kg/ha	300	lb/acre	155		NSTR=0.99, EFF=2, NMXS=30, LY1=1, NMXA=155.02
	21-Apr	Fertilize	27-15-15	225	kg/ha	200	lb/acre	61	15	LY1 = 0
	26-Apr	Till	Field Cultivator							
	1-May	Plant	Corn-Grain							CNOP A = 67, B = 77, C = 83, D = 87
	28-Oct	Harvest&Kill	Corn-Grain							
	30-Oct	Till	Chisel							
Year 2	20-Apr	Fertilize	9-23-30	225	kg/ha	200	lb/acre	20	23	LY1 = 0
	25-Apr	Till	Field Cultivator							
	1-May	Plant	Peas							CNOP A = 67, B = 78, C = 85, D = 89
	20-Aug	Harvest&Kill	Peas							
	25-Aug	Till	Chisel							
	30-Aug	Till	Field Cultivator							
	1-Sep	Plant	Winter Rye							
	30-Dec	Kill	Winter Rye							
Nutrient additions:										
Year 1								216	15	
Year 2								20	23	
Annual average								118	19	

APPENDIX C: DIGITAL TERRAIN ANALYSIS

Process Overview

Terrain Analysis is the use of remote sensing data for mapping, analysis, and interpretation of geographic information on the natural and man-made features of the terrain. Through this process both Primary Terrain attributes and Secondary Terrain attributes are generated. Primary terrain attributes are those that can be calculated directly from elevation data, in this case the 3-meter LIDAR-derived Digital Elevation Model (DEM). Secondary terrain attributes are the combinations of primary attributes and are indices that describe the spatial variability of specific process occurring on the landscape such as the potential for erosion. The secondary terrain attribute of interest in this project is the SPI.

The Terrain Analysis conducted for this project is based on the work of Jake Galzki and Joel Nelson of the University of Minnesota Department of Soil, Water and Climate (U of M) under Minnesota Department of Agriculture (MDA) project managers Adam Birr and Barbara Weisman. Under the "Conservation Applications of LIDAR" project, three training modules were created and posted at http://wrc.umn.edu/randpe/agandwq/tsp/lidar/trainingvideos/index.htm At the time of this memo the entire body of work represented by the "Conservation Application of LIDAR" project was available at http://wrc.umn.edu. All commands to complete this terrain analysis are completed in ArcMap from the ArcToolbox under the hydrology tools in Spatial Analyst.

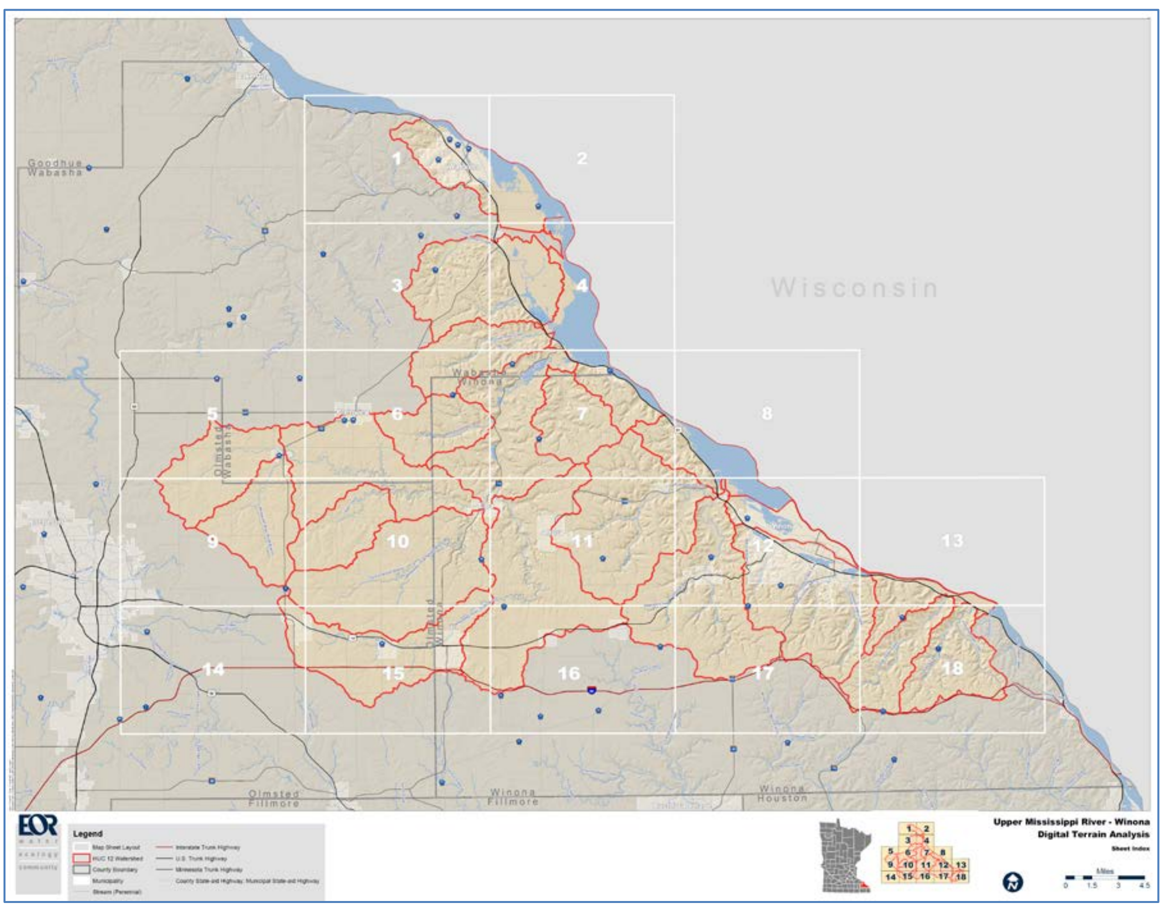

Figure C1. Location map and Sheet Index.

Sink (Pit) filling the Digital Elevation Model (DEM)

Sink filling was conducted on the DEM to remove areas that terminate flow. Sinks are created when cells cannot be assigned a valid value in a flow direction raster. This occurs in low spots in the landscape such as ponds or on the upstream side of road crossings. The sink-filling command can be used to create a depressionless DEM without dead ends in flow lines. In areas of rolling to hilly topography, this assumption is generally valid and is recommended in many situations.

Primary Terrain Attributes

Primary terrain attributes were generated based on the 3-meter DEM. Flow direction and flow accumulation were calculated using the hydrology tools of the ArcToolbox. Flow direction was calculated using the Sink-filled DEM as the input file and default settings. Flow accumulation used the flow direction raster as input and default settings. Slope is calculated from the Surface tool in the ArcToolbox specifying the DEM as the input file and percent slope is specified as within the slope options. Using the raster calculator the slope raster is divided by 100 to get the raster in proper units for calculating the SPI.

Secondary Terrain Attributes

Secondary terrain attributes are generated based on performing computations on the primary attributes. The secondary terrain attribute calculated for this project is the stream power index (SPI). The SPI is the slope multiplied by the natural log of the flow accumulation. Before conducting this calculation the flow accumulation raster was reclassified to remove any “NoData” values using the Spatial Analyst reclassify command. Similarly 0.001 was entered in the calculation of SPI to ensure that no zero values were erroneously calculated in the SPI. The following formula was used to calculate the SPI in the raster calculator:

$$SPI = \ln[(\text{Flow Accumulation} + 0.001) * (\text{Slope} + 0.001)]$$

The result of this calculation has been ranked at three different magnitudes on the 18 maps accompanying this memo. The different classifications were determined within ArcMap by removing the lower SPI values from visibility. Red indicates that the calculated SPI is greater than 4. These cells (3m x 3m) are 1.2% of the totals cells in the watershed and represent the locations with the most potential for erosion in the watershed. The yellow cells (0.9%) on the map show an SPI that is between 3 and 4 and the cyan cells (1.2%) show an SPI that is between 2 and 3. Together, these three SPIs are a total of 4.5% of the total watershed area.

Field Survey

Field survey (ground truthing) is an important consideration when verifying the accuracy of the stream power index. Additionally, as you travel from east to west in the watershed the topography changes from steep and wooded to rolling with less woodlands. Because of these differences in topography, two different subwatersheds were ground truthed, the Garvin Brook and Middle Fork of the Whitewater. This was accomplished through a windshield survey of areas that the SPI identified as high erosive risk. A total of 36 locations were visited to assess the erosion potential at each site. Table 1 summarizes the notes from each location.

Twenty five locations within the Garvin Brook subwatershed were windshield surveyed (Sheet 17) and notes were recorded on each site. In general, the sites indicating SPIs greater than 2 were experiencing some erosion. The exception to this is in unpastured woodlots the SPI required to identify erosive areas was approximately 3 although a SPI of 2 did predict large slumps in very steep (near vertical) woodlands. It was apparent in this watershed that the most erosion was coming from steep wooded areas. Another interesting observations was that gully erosion was most pronounced in areas of wooded pasture. It is apparent that in an open pasture, grass was effectively preventing erosion and where a high SPI occurred on cropland there was often a grassed waterway, but in forested pasture the lack of understory due to grazing was contributing to erosion.

Eleven locations in the Middle fork of the Whitewater River watershed were windshield surveyed (Sheet 10) as well. Generally speaking SPI values higher than 2 accurately predicted areas of high erosive potential. These areas of high erosive potential were almost always the locations of grassed waterways on the landscape and no active erosion was documented at most locations. It is apparent that farmers in this watershed have taken an active role in protecting highly erodible areas.

Table C1. Field Survey Table of Errors.

Subwatershed	Map ID	Notes	Erosion Correctly Identified	Existing Conservation Practice	Incorrect Identification (SPI of 2 or greater and no erosion present)
Garvin	0	Photo 493; grassed waterway, tile		x	
	1	Planted to grassed waterway		x	
	2	Wetland		x	
	3	Photo 494; high eroision potential	x		
	4	high erosion, pasture	x		
	5	Photos 487, 488; hay field		x	
	6	Cattle activity in pasture	x		
	7	Grassed waterway		x	
	8	Gully erosion at culvert crossing	x		
	9	Photo 489; culvert erosion to bedrock	x		
	10	cut to bedrock	x		
	11	Eroding channel	x		
	12	Eroding channel	x		
	13	Eroding channel	x		
	14	Slip failure	x		
	15	No erosion			x
	16	Bank failure	x		
	17	Excessive erosion	x		
	18	Stable			x
	19	Erosion to bedrock	x		
	20	Photo 491; slip failure	x		
	21	Erosion along entire road	x		

	22	Dry	x		
	23	Stable		x	
	24	Stable		x	
Middle	25	County Road Right of Way			x
	26	Dry gully	x	x	
	27	New grassed waterway planted		x	
	28	No erosion, depression			x
	29	No erosion, depression			x
	30	Not intermittent	x		
	31	Barn drain	x		
	32	Photo 492, pasture, stable			x
	33	No erosion			x
	34	Cut to bedrock	x		
	35	Cut to bedrock	x		
	36	Cut to bedrock	x		

Urban areas and the Mississippi River Floodplain

The SPI was impacted in urban areas where artificial drainage networks are the primary water delivery method. Although the preceding analysis covered urban areas, any use of the data in these areas is strongly cautioned. Likewise in the Mississippi River floodplain, primarily areas to the east of Highway 61 the results should for the most part be disregarded.

Findings

Critical areas are defined on the eighteen 1”= ¼ mile sheets accompanying to this memo. The SPI has been presented at three different levels indicating the relative levels of erosive potential with red being the highest (SPI>4), followed by yellow (SPI between 3 and 4) and blue (SPI between 2 and 3). This study, through field work, found that SPI values less than 2 were of low risk for erosion and are not displayed on the maps.

As a prioritization scheme, the red areas should be addressed first, followed by the yellow and blue. In practice, yellow and blue areas are often associated with adjacent red areas. In this type of situation, it may be beneficial to address all three critical categories on the site at the same time. However, the existing scale and placement of grassed waterways in the watershed most closely aligns with SPI>=4; these SPI values are perhaps the most practical locations to focus on initially.