St. Croix Watershed Research Station

SCWRS Fact Sheet 2019-01

Construction and Calibration of a Computer Model of the Madison Lake Watershed

Summary

• A computer model of the Madison Lake watershed can help identify sources and transport of nonpoint-source pollutants (sediment, phosphorus, and nitrogen), thus informing management decisions on how to clean up these pollutants and reduce noxious algal blooms in the lake.

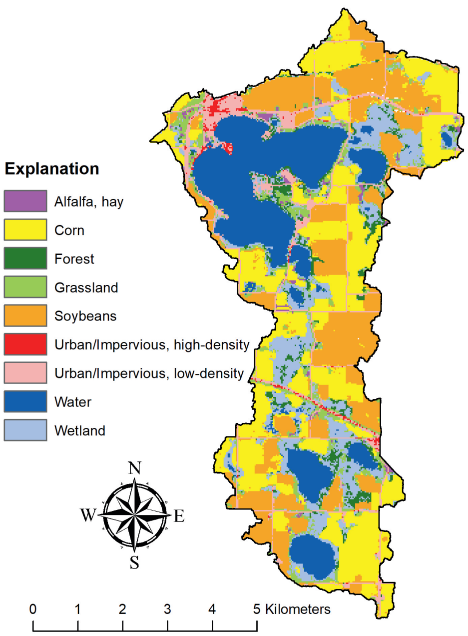

Figure 1. Land use in the Madison Lake watershed.

Issue: *Nonpoint-Source Pollution*

• Madison Lake is a relatively deep (18 m maximum) lake with high recreation value in an agricultural region where shallow lakes are more typical. The Minnesota Department of Natural Resources (MDNR) has deemed Madison Lake as one of their "Sentinel Lakes," a set of 25 representative lakes from across Minnesota selected for detailed studies on how landscapes and climate impact lake ecology.

• Economic policy has driven agriculture to become dominated by row crops (corn and soybeans), which occupy about 50% of the 45-km^2 Madison Lake watershed (Figure 1). Row cropping efficiently produces high yields of grain, but its monoculture nature reduces biodiversity and wildlife habitat.

• Because of fertilizer applications and tillage that leaves the fields without living cover for most of the year, row crops can be significant sources of sediment and nutrients that wash off the land and compromise our waterways. These pollutants are called "nonpoint-source" (NP-S) pollutants because they come from diffuse sources across the landscape. In particular, Madison Lake is impaired by eutrophication, i.e., noxious algal blooms, caused by excess NP-S phosphorus and nitrogen loads.

General Approach: *Monitoring and Modeling*

• To better characterize the problem and create solutions, the sources and quantities of nutrients entering Madison Lake need to be determined. The most direct way is to monitor (measure) the inputs where possible, such as the inlet streams to the lake. Our project partners at the U.S. Geological Survey (USGS) monitored lake inflows and outflows for the 2014-18 ice-free seasons. However, monitoring is relatively expensive and limited to just the few selected sites. What is going on in the rest of the watershed?

• A complementary approach is to construct a computer model that simulates the essential eco-hydrological processes within a watershed (Figure 2). Input to such a

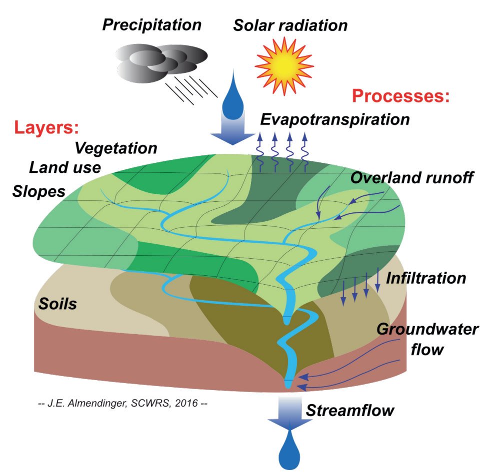

Figure 2. Components of a watershed model.

model includes topography, soil type, land cover, agricultural practices (crop rotations, tillage practices, and fertilizer applications), and daily precipitation and temperature. Output includes daily flows and export of sediment and nutrients from each land-use type as well as from the watershed as a whole.

• The best studies combine (a) monitoring data to measure observed flows and nutrient loads, with (b) modeling efforts to figure out how the watershed works -- that is, what are the landscape and weather processes that generated the observed data?

• The next steps would be to design remediation methods to clean up the sources of nutrients across the watershed. Innovative farming practices (i.e., best management practices, or BMPs) that introduce more diversity in the timing and spatial pattern of crop rotations could simultaneously increase habitat, improve soil fertility, and protect streams and lakes.

Specific Approach: *SWAT Model Construction and Calibration*

• The model applied to the Madison Lake watershed is called the Soil and Water Assessment Tool, or SWAT for short. SWAT was developed by the U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) to help understand and predict loads of NP-S pollutants (sediment and nutrients) from large river basins over long periods of time.

• Input to the SWAT model relies on readily-available data from government agency web sites. Topography was taken from LiDAR digital elevation models (DEMs) made available by the MDNR at a 3-m (meter) horizontal resolution. The DEM was hydro-modified to include drainage features (e.g., culverts) that correct for the false water impoundment by roads and other embankments. Soils data were taken from the SSURGO database made available by the USDA, which is the most spatially detailed soil data available.

• Land cover and crop types were taken from the USDA's crop data layer (CDL) datasets for 2014-18. This 5-year sequence of crops on the ground, at 30-m spatial resolution, provided an objective method for inferring typical crop areas, rotations, and locations in the watershed. Table 1 gives the areas of each crop, and Figure 1 shows their spatial distribution. Corn and soybeans were the most common crops by far, with minor amounts of alfalfa and even less of small grains. Representative amounts of inorganic fertilizer were added to all crops at the time of planting. Conservation tillage was assumed for all cropland, consisting of fall chisel plowing followed by spring disking or field cultivation.

• Weather data (daily precipitation and temperature) were taken from six weather stations (Amboy, LeSueur, Mankato, St. Peter, Waseca, and Faribault) and averaged for the watershed centroid by simple inverse-distance weighting.

• After watershed models are constructed, they need to be adjusted ("calibrated") so that their output matches known monitoring data from the watershed. Figure 3 shows the comparison between observed daily flows out of Madison Lake (thick gray lines) and the modeled values (thin black lines) for 2015-16. The Nash-Sutcliffe (NS) statistic shows the quality of the model fit (fraction of observed variance explained by the model). An NS value of 1.0 indicates a perfect fit, and a value of 0.5 or above indicates a good fit. The NS values were 0.65 and 0.76 for 2015 and 2016, respectively, indicating a very good fit. Unfortunately, observed data were not available for loads of sediment, phosphorus, and nitrogen entering the lake, and so the quality of these modeled quantities cannot be determined.

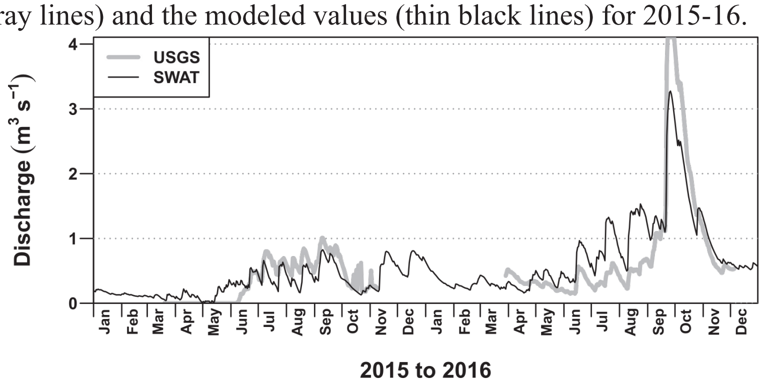

Figure 3. SWAT model calibration runs for daily flow out of Madison Lake, 2015-16
Observed = USGS, Modeled = SWAT

Table 1. SWAT-modeled loads and yields of sediment, total phosphorus, and total nitrogen from different land uses.

Land Cover	Area		Sediment			Total Phosphorus			Total Nitrogen		
	(km^2)	(%)	(t/yr)	(%)	(t/ha/yr)	(kg/yr)	(%)	(kg/ha/yr)	(kg/yr)	(%)	(kg/ha/yr)
Agricultural Lands	23.7	52.6%	5,546	98.6%	2.34	12,968	97.6%	5.47	63,045	97.3%	26.59
Corn	*12.9*	*28.6%*	*2,601*	*46.2%*	*2.02*	*6,193*	*46.6%*	*4.81*	*33,718*	*52.0%*	*26.20*
Soybeans	*10.6*	*23.6%*	*2,944*	*52.3%*	*2.77*	*6,772*	*51.0%*	*6.37*	*29,309*	*45.2%*	*27.55*
Alfalfa	*0.2*	*0.4%*	*1*	*0.0%*	*0.07*	*3*	*0.0%*	*0.16*	*18*	*0.0%*	*0.91*
Developed	3.2	7.1%	66	1.2%	0.21	234	1.8%	0.73	1,179	1.8%	3.71
Roads	*3.0*	*6.7%*	*38*	*0.7%*	*0.13*	*179*	*1.3%*	*0.60*	*1,047*	*1.6%*	*3.49*
Urban	*0.2*	*0.4%*	*29*	*0.5%*	*1.56*	*55*	*0.4%*	*3.00*	*132*	*0.2%*	*7.17*
Undeveloped	18.2	40.3%	14	0.3%	0.01	87	0.7%	0.05	560	0.9%	0.31
Grassland	*2.1*	*4.6%*	*4*	*0.1%*	*0.02*	*35*	*0.3%*	*0.17*	*363*	*0.6%*	*1.75*
Forest	*1.1*	*2.4%*	*2*	*0.0%*	*0.02*	*5*	*0.0%*	*0.05*	*24*	*0.0%*	*0.22*
Aquatic	*15.0*	*33.4%*	*8*	*0.1%*	*0.01*	*47*	*0.4%*	*0.03*	*173*	*0.3%*	*0.12*
Total	45.1	100%	5,626	100%		13,289	100%		64,785	100%	

Results: *Land-Use Sources of Sediment and Nutrients*

• A *load* is a mass of a constituent during a selected time period, e.g., metric tons per year (t/yr) or kilograms per year (kg/yr). A *yield* is a load per unit area of a selected land unit, e.g., tons per hectare per year (t/ha/yr) or kilograms per hectare per year (kg/ha/yr). We will use metric units in this report, even though in US agriculture, English units of short tons per acre, or pounds per acre, are far more commonly used.

• Table 1 shows average annual loads and yields of sediment, phosphorus, and nitrogen from different crops and other land covers for a 10-year model run from 2009-18. The values here represent the amounts of NP-S pollutants mobilized on the landscape. Not all of this mass makes it to Madison Lake; a significant portion gets trapped along the way in wetlands and ponds.

• Loads of all constituents were dominated by agriculture, both because it is the most prevalent land use in the watershed and because its yields tend to be higher than most other land uses. According to the model, corn and soybeans occupied a little more than half of the land area and generated about 98% of the sediment, phosphorus, and nitrogen loads in the watershed.

• Yields told a clearer story about which land uses were more “leaky” with regard to NP-S pollutants. Again, per unit area, row crops generated more sediment, phosphorus, and nitrogen than other land uses. Corn and soybeans had similarly large yields of sediment (over 2 t/ha/yr), phosphorus (about 5-6 kg/ha/yr), and nitrogen (26-27 kg/ha/yr). Urban areas likewise had significant yields of sediment and phosphorus, but their footprint was much smaller than agriculture. Highly permeable soils can limit yields of NP-S pollutants in surface runoff, but apparently these soil types are not significant in the Madison Lake watershed.

Results: *Spatial Distribution of Sediment and Nutrient Yields*

• Figure 4 shows yields of sediment, phosphorus, and nitrogen for each of the 197 modeled subbasins of the Madison Lake watershed. The darker colors represent “hot spots” of sediment and nutrient sources in the watershed. Yields here represent the amount of each constituent delivered to the stream reach via overland flow and groundwater, i.e., the initial mass mobilized in the uplands minus any losses to sediment and nutrient traps (e.g., wetlands) encountered between field and stream.

• In the Madison Lake watershed, sediment, phosphorus, and nitrogen yields are consistent with each other and are driven primarily by sources, namely, location of corn and soybean fields. Wetland, forest, and grasslands produce minimal yields of these NP-S pollutants. The cropland hot-spots of high yields are areas to target for remediation by alternative farming practices that reduce soil erosion and nutrient loss.

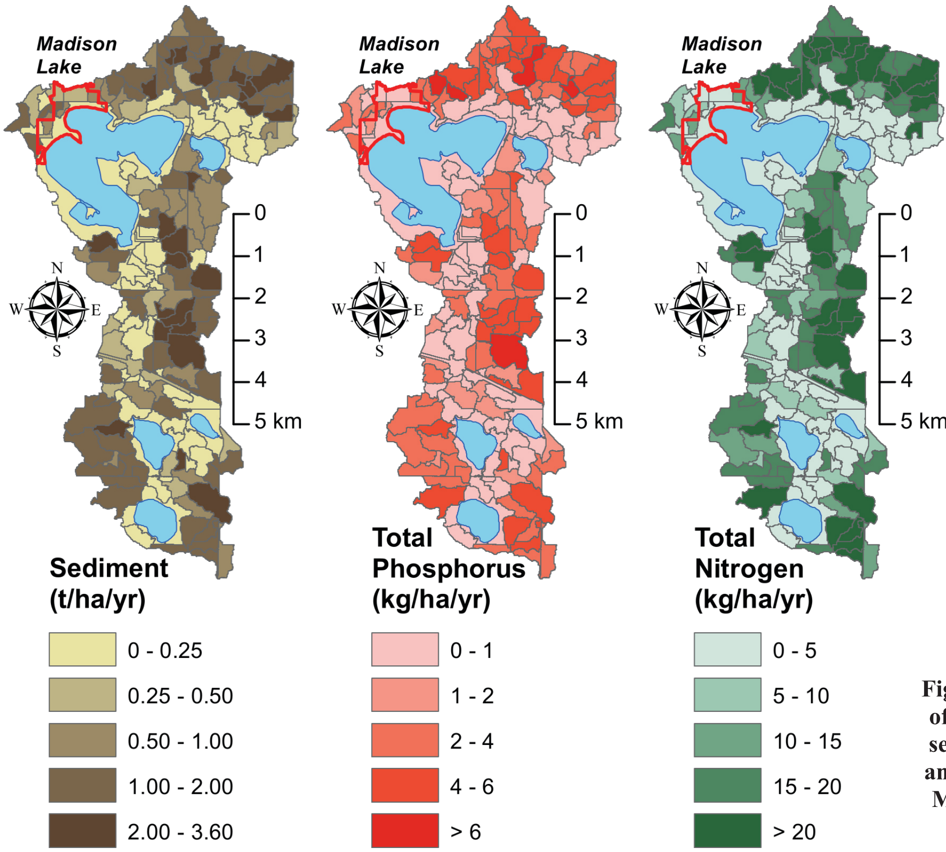

Figure 4. Spatial distribution of SWAT-modeled yields of sediment, total phosphorus, and total nitrogen across the Madison Lake watershed.

Summary and Conclusions

• The SWAT model for the Madison Lake watershed was able to simulate known stream flows in the watershed, and to identify the probable sources (land use and subbasin) of these constituents. The next steps will be to simulate possible remediation scenarios to see which ones will most efficiently reduce these pollutants while increasing landscape biodiversity and habitat, without undue burden on the farmers who are stewards of the land.

Acknowledgment

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ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

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