St. Croix Watershed Research Station

SCWRS Fact Sheet 2017-01

Partnering with

Construction and Calibration of a Computer Model of the Kinnickinnic River Watershed

Summary

• A computer model of the Kinnickinnic River watershed can help identify sources and transport of non-point source pollutants (sediment, phosphorus, and nitrogen), thus informing management decisions on how to minimize this pollution.

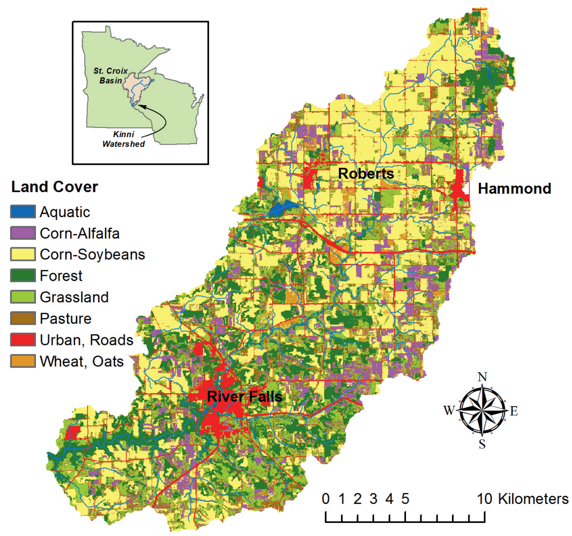

Figure 1. Land use in the Kinnickinnic watershed.

Issue: *Nonpoint-Source Pollution & Habitat Loss*

• The Kinnickinnic River ("the Kinni") in western Wisconsin is highly valued for its aesthetic and recreational qualities, notably its trout fishery. It is tributary to Lake St. Croix, which is part of the federal St. Croix National Scenic Riverway.

• Economic policy has driven agriculture to become dominated by row crops (mostly corn and soybeans), which occupy about 40% of the Kinni watershed (Figure 1). Row cropping efficiently produces high yields of grain but also reduces wildlife habitat.

• Because of fertilizer applications and tillage that leaves the fields without living cover for most of the year, croplands can be significant sources of sediment and nutrients that wash off the land and compromise our waterways. These "nonpoint-source" (NP-S) pollutants come from diffuse sources across the landscape. In particular, Lake St. Croix is impaired by eutrophication from excess NP-S phosphorus loads coming from tributaries like the Kinni.

General Approach: *Monitoring and Modeling*

• To better characterize the problem and figure out solutions, the first step is to measure the NP-S pollutants coming down the river. This was done in some detail by the U.S. Geological Survey during 2012-15 near the outlet of the Kinni on Lake St. Croix.

• The next steps are to figure out where these NP-S pollutants are coming from in the watershed, and, once these sources are identified, to design remediation methods to clean them up. 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.

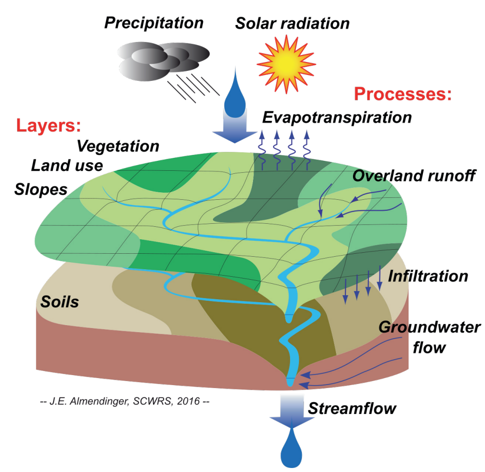

Figure 2. Components of a watershed model.

• One approach to dealing with the complexity of NP-S pollutants is to construct a computer model that tries to simulate the essential processes within a watershed (Figure 2). Input to such a model includes topography, soil type, land cover, agricultural practices (crop rotations, fertilizer applications, and manure management), 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.

Specific Approach: *SWAT Model Construction and Calibration*

• The model applied to the Kinni 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 the U.S. Geological Survey's digital elevation models (DEMs). Soils data were taken from the USDA's SSURGO database. Land cover and crop types were taken from the USDA's crop data layer (CDL) datasets for 2011-15. This 5-year sequence of crops, at 30-m spatial resolution, provided an objective method for inferring typical crop rotations and their locations in the watershed. We constructed the following rotations as input to the model: corn/soybean (CS), corn-silage/alfalfa (CA), continuous corn (C), sweet-corn/wheat (CW), and oats (O). Table 1 gives the areas of each rotation, and Figure 1 shows their spatial distribution, simplified by aggregating C with CS and CW with O. Manure was added as fertilizer to the CA rotations, and inorganic fertilizers to the other cropland. Pasture operations accounted for grass biomass to be both eaten and trampled and for manure deposition by livestock. Weather data (daily precipitation and temperature) were taken from two weather stations, one in New Richmond and the other near Hammond.

• 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 values (thick gray lines) and the modeled values (thin black lines) for monthly discharge (flow), sediment, total phosphorus, and total nitrogen. The Nash-Sutcliffe (NS) statistic shows the quality of the model fit, where 1.0 indicates a perfect fit, and a value of 0.5 or above indicates an adequate fit. The final model calibration was a compromise that balanced the NS values and percent errors for all the components.

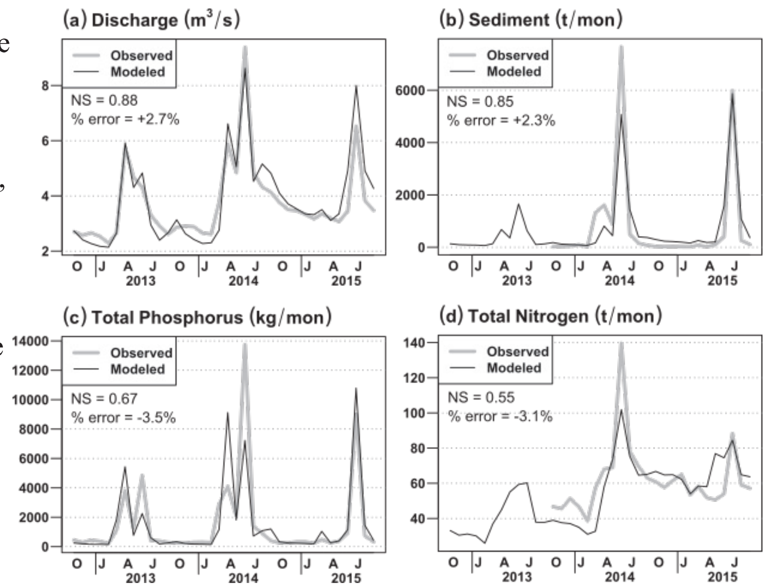

Figure 3. SWAT model calibration runs for discharge (flow), sediment, total phosphorus, and total nitrogen.

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 crop rotations and other land covers for a 10-year model run from 2006-15. The values here represent the amounts of NP-S pollutants mobilized on the landscape. Not all of this mass makes it to the watershed outlet; a significant portion gets trapped along the way in lowlands, channels, floodplains, and reservoirs.

• 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. Agriculture occupied

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	241.4	54.3%	4,291	71.3%	0.18	8,829	69.2%	0.37	395,664	71.8%	16.39
Corn-Soybeans	*106.2*	*23.9%*	*2,520*	*41.9%*	*0.24*	*4,917*	*38.6%*	*0.46*	*156,615*	*28.4%*	*14.74*
Corn-Alfalfa	*42.3*	*9.5%*	*472*	*7.9%*	*0.11*	*888*	*7.0%*	*0.21*	*62,062*	*11.3%*	*14.69*
Corn	*44.9*	*10.1%*	*970*	*16.1%*	*0.22*	*2,021*	*15.9%*	*0.45*	*132,099*	*24.0%*	*29.40*
Sweet Corn-Winter Wheat	*3.8*	*0.9%*	*24*	*0.4%*	*0.06*	*60*	*0.5%*	*0.16*	*7,117*	*1.3%*	*18.67*
Oats	*2.0*	*0.4%*	*10*	*0.2%*	*0.05*	*25*	*0.2%*	*0.13*	*1,383*	*0.3%*	*7.06*
Pasture	*42.2*	*9.5%*	*295*	*4.9%*	*0.07*	*917*	*7.2%*	*0.22*	*36,387*	*6.6%*	*8.63*
Developed	33.9	7.6%	394	6.5%	0.12	2,278	17.9%	0.67	54,937	10.0%	16.23
Roads	*22.4*	*5.0%*	*105*	*1.7%*	*0.05*	*944*	*7.4%*	*0.42*	*29,565*	*5.4%*	*13.20*
Urban	*11.5*	*2.6%*	*289*	*4.8%*	*0.25*	*1,334*	*10.5%*	*1.16*	*25,372*	*4.6%*	*22.14*
Undeveloped	169.4	38.1%	1,331	22.1%	0.08	1,645	12.9%	0.10	100,697	18.3%	5.94
Grassland	*95.0*	*21.4%*	*20*	*0.3%*	*0.00*	*367*	*2.9%*	*0.04*	*99,740*	*18.1%*	*10.50*
Forest	*72.9*	*16.4%*	*1,311*	*21.8%*	*0.18*	*1,277*	*10.0%*	*0.18*	*956*	*0.2%*	*0.13*
Aquatic	*1.6*	*0.4%*	*0*	*0.0%*	*0.00*	*1*	*0.0%*	*0.00*	*1*	*0.0%*	*0.01*
Total	444.6	100%	6,016	100%		12,752	100%		551,298	100%	

ABBREVIATIONS: km^2, square kilometers; t, metric tons; yr, year; ha, hectare; kg, kilogram.
NOTES: Values represent upland or edge-of-field loads and yields, before possible losses to wetlands, floodplains, or other sediment or nutrient traps.

a little more than half of the land area and generated about 70% of the sediment, phosphorus, and nitrogen loads in the watershed, most of which came from row crops (corn and soybeans).
• 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. Urban areas likewise had significant yields of phosphorus, but their footprint was just much smaller than agriculture. Nonetheless, compared to other watersheds, the yields of sediment and phosphorus from the Kinni were modest. In particular, yields exceeding 1 t/ha/yr for sediment and 1 kg/ha/yr for phosphorus are commonly reported for croplands, yet the yields in the Kinni were far below that. In contrast, the nitrogen yields (losses) from cropland were substantial, with most of the loss coming from leaching to the shallow aquifer.
• This pattern of sediment and nutrient yields was consistent with the hydrological calibration. Because sediment and phosphorus are transported by runoff, their modest yields indicated that the fairly permeable soils encouraged infiltration and limited overland flow. Because nitrogen (as nitrate) is commonly transported by groundwater, the substantial nitrogen yields also implied greater infiltration than runoff. The model calibration confirmed that the hydrology was dominated by infiltration and steady groundwater discharge to the baseflow of the Kinni, punctuated occasionally by large runoff events when rapid snowmelt or large storms overwhelmed the soil infiltration capacity across the watershed.

Results: *Spatial Distribution of Sediment and Nutrient Yields*

• Figure 4 shows yields of sediment, phosphorus, and nitrogen for each of the 254 modeled subbasins of the Kinni 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.
• Sediment and phosphorus yields are consistent with each other and are driven by sources (cropland or urban) that intersect with transport factors promoting overland flow (steeper slopes and tighter soils). Because these factors do not always neatly correspond, predicting the hot-spots for sediment and phosphorus would be difficult without the use of a model such as SWAT.

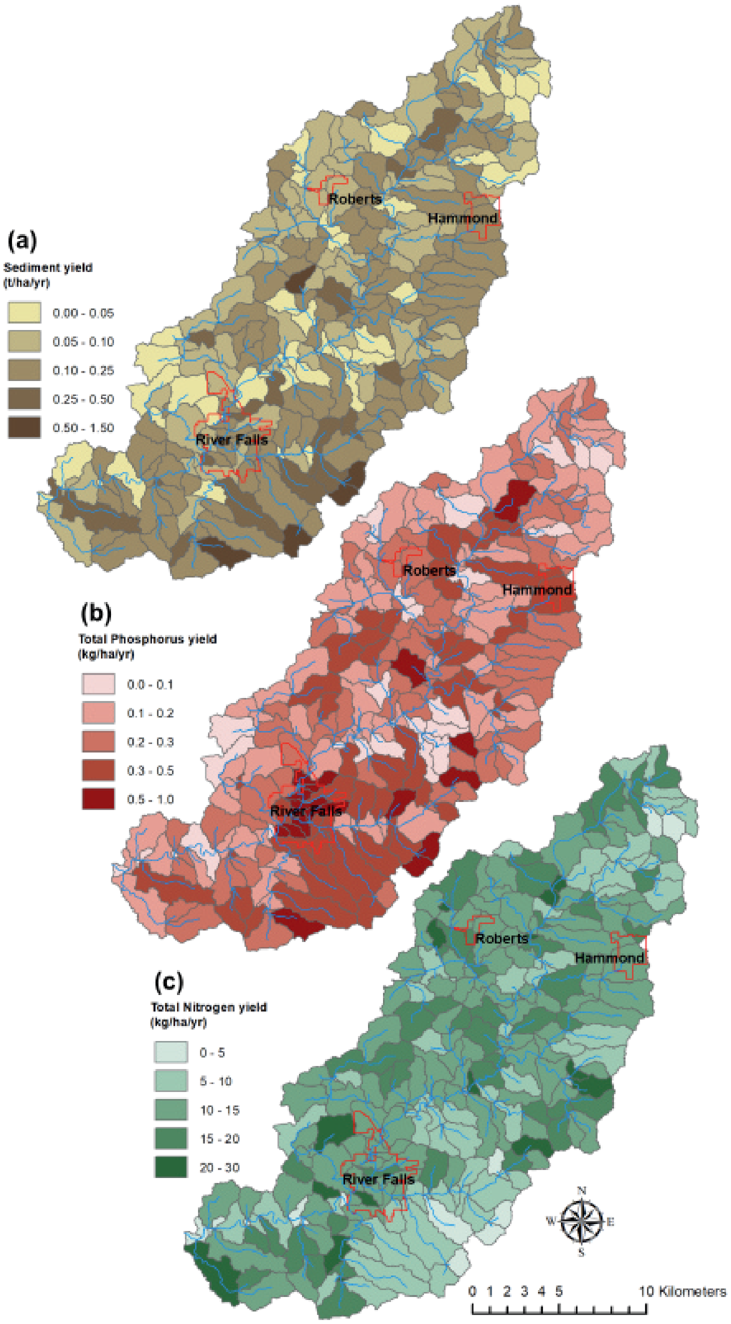

Figure 4. Spatial distribution of SWAT-modeled yields of sediment, total phosphorus, and total nitrogen across the Kinni watershed.

• The pattern for nitrogen yields is quite different and lines up with cropland on flatter, more permeable soils that promote infiltration. Because cropland is more common on flatter lands, the nitrogen hot spots more faithfully correspond to the occurrence of cropland, particularly row crops.

Summary and Conclusions

• The SWAT model for the Kinni watershed was able to simulate known flows and loads of sediment, phosphorus, and nitrogen arising 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.

St. Croix Watershed Research Station

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