Science Museum of Minnesota

St. Croix Watershed Research Station

SCWRS Fact Sheet, 2008

Modeled Phosphorus Exports from the Willow River Watershed

Summary

• The Willow River carries excess phosphorus which has degraded Lake Mallalieu and Lake St. Croix, but careful land-use practices can help reduce the problem.

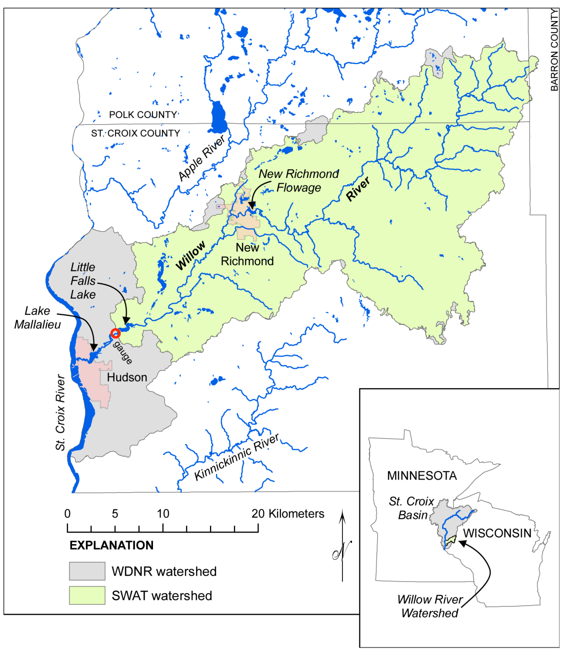


Figure 1. Willow River watershed in western Wisconsin.

Issue

• The Willow River in western Wisconsin is a highly valued resource that sustains trout, defines a state park, feeds several heavily used reservoirs, and is tributary to the St. Croix River, a national scenic and recreational riverway (*Figure 1*).

• However, the Willow has become degraded by excess nutrients, especially phosphorus. Too much phosphorus can cause algae to grow so prolifically that reservoirs lose water clarity. When the algae die, they can create foul odors and reduce dissolved oxygen so much that fish die.

• Phosphorus is an essential nutrient required by all organisms. However, human activities such as agriculture, residential development, and wastewater treatment can increase the transport of phosphorus to water bodies, where it causes problems. Society must weigh the undeniable benefits from these human activities against their considerable environmental costs.

Approach

• To understand the problem and figure out solutions, the first step is to collect measurements of phosphorus coming down the river. This was done in some detail during 1999 and 2006 at the watershed outlet, with various other spot measurements collected elsewhere along the river.

• These detailed measurements were taken mostly in the lower watershed, at the gauge below the outlet of Little Falls Lake (*Figure 1*). How can these measurements tell us where the phosphorus came from, and how we might be able to address the problem?

• One approach is to construct a model of the watershed. By "model" we don't mean a physical model; we mean a computer model that tries to simulate the essential processes

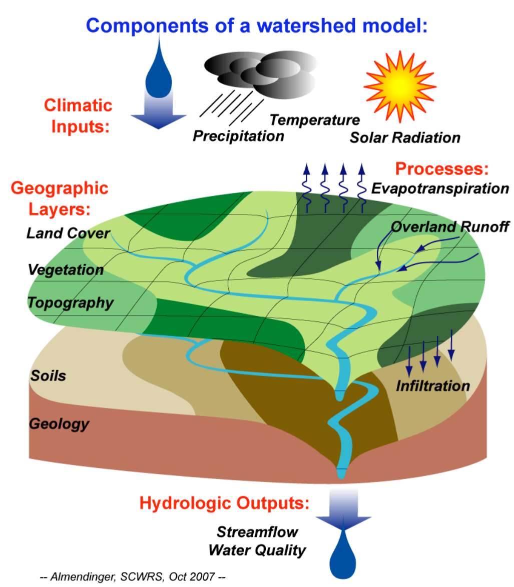


Figure 2. Components of a watershed model.

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.

• The model applied to the Willow River watershed is called the Soil and Water Assessment Tool, or SWAT for short. SWAT was developed by the USDA Agricultural Research Service to help understand and predict loads of nonpoint-source pollutants (sediment and nutrients) from large river basins over long periods of time.

Phosphorus: How much? From where? To where?

• Based on recent (2005-06) agricultural practices, land cover, soils, and slopes, the model calculated that at least 74 tons of phosphorus is mobilized every year in the Willow River watershed; we call this value the "gross" load (by "ton" we mean the English short ton, or 2000 lb). Much of this phosphorus gets trapped in small field depressions or field edges. Still, about 45 tons of phosphorus is delivered from the uplands to our streams, ponds, and wetlands; we call this value the "upland" load. This is the phosphorus load that can impact our waterways.

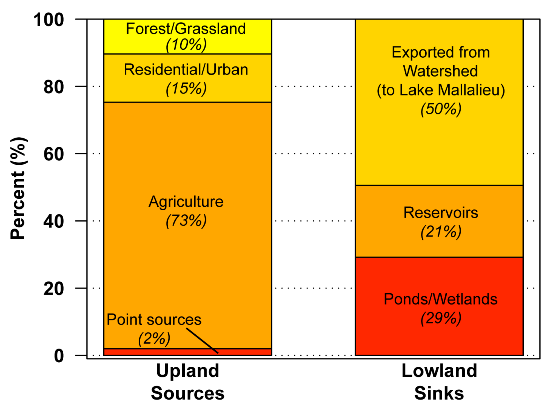


Figure 3. Upland sources and lowland traps of phosphorus.

• Most of this phosphorus comes from agricultural lands, including cropland (corn, soybeans, and alfalfa) and pasture (*Figure 3*). A significant portion comes from rural residential and urban lands, in part a consequence of new residential developments being built on agricultural lands with a high level of phosphorus in the soil and in installed turf. Only 2% of the phosphorus load currently comes from point sources (municipal and commercial wastewater treatment plants), down from about 20% a decade ago. This reduction is due mostly to improvements in treatment technology. However, as population continues to rise, phosphorus from municipal point sources is expected to rise again, unless further technological improvements are implemented.

• A significant portion (29%) of this phosphorus gets trapped in closed-drainages (called "ponds" in the model) and wetlands. These closed drainages resulted from ice-melt and drainage processes at the end of the last glacial period. Another part (21%) gets trapped in the sediments of the New Richmond Flowage (also called the "Widespread") and Little Falls Lake. Half of the phosphorus leaving the uplands is exported from the watershed and enters Lake Mallalieu, which also receives phosphorus inputs from urbanized Hudson and North Hudson.

What can be done about it?

• To reduce the phosphorus loads to our waterways, we can address all those sources that humans influence (see *Figure 3*). While we can't improve upon yields from forest and grassland, we can work to reduce the nonpoint loads from rural-residential and urban lands, and we can improve wastewater treatment technology to limit point-source loads.

• However, the biggest contributor of phosphorus is agriculture, and consequently the greatest potential to reduce phosphorus loads comes from agricultural best-management practices, or BMPs. *Figure 4* shows field-scale yields of phosphorus from croplands; a "yield" is simply the annual load (in lb) divided by the area of cropland (in acres), to give pounds per acre of phosphorus coming off the land. (These units are similar to the metric kilograms per hectare.)

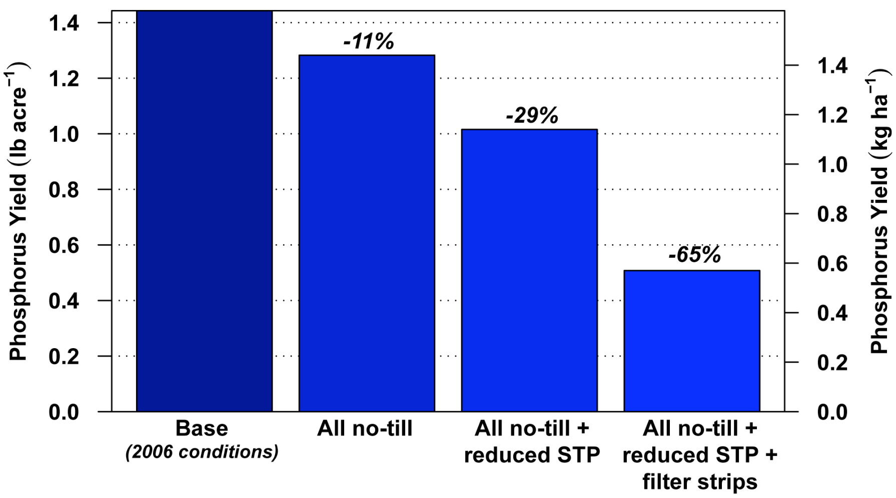


Figure 4. Phosphorus yields from cropland under selected agricultural BMPs.

• One agricultural BMP would be to convert row crops to no-till, thereby decreasing soil disturbance and erosion. Our current SWAT model indicates that converting all row crops to no-till would reduce phosphorus loads by about 11% compared to 2006 conditions in the watershed. (Conditions in 2006 are assumed to approximate mulch-tillage conditions, defined here as 15-50% coverage by residue at the time of planting). Data from Wisconsin Discovery Farms and from some published literature suggest that this estimate is conservative and that actual reductions may be greater.

• A further BMP would be to reduce application of phosphorus fertilizer so that soil-test phosphorus (STP) levels decreased. The current average STP in St. Croix County is 41 ppm. According to agronomists, corn and soybeans need only 20 ppm, and alfalfa needs only 30 ppm. If – in addition to the no-till scenario above – STP were lowered to 20 ppm in for corn-soybean rotations and 30 ppm for the rotations that include alfalfa, then modeled phosphorus yields would decrease by 29%.

• Another BMP would be to add grass filter strips and grassed waterways to intercept sheet flow in fields and stop the formation of rills and gullies. If – in addition to the no-till and reduced STP scenarios above – such filter strips were fully implemented, the model indicates that phosphorus yields would be reduced by 65%. Full implementation, however, would require a very large number of filter strips.

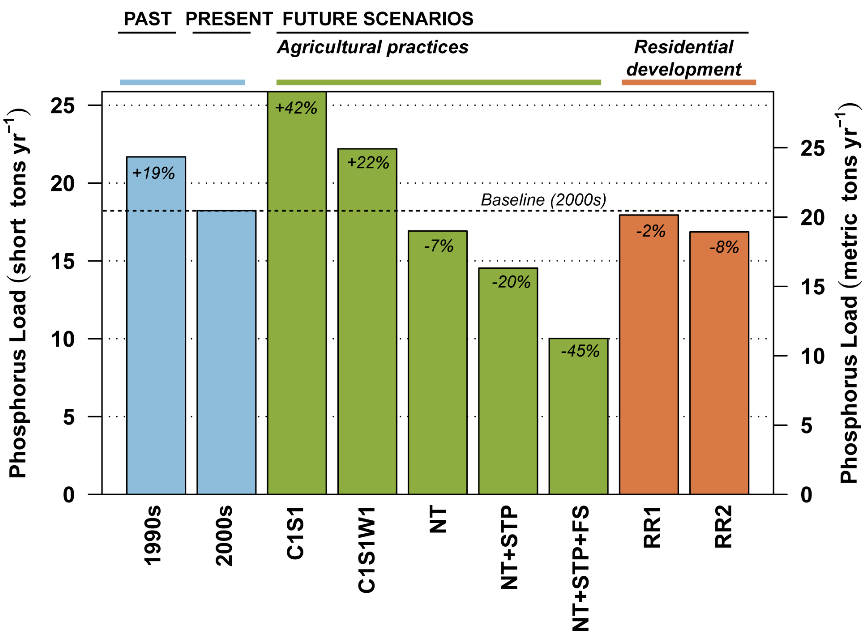
Overall changes in phosphorus export from the Willow River watershed

• How do these changes in phosphorus export from cropland (*Figure 4*) affect the overall export of phosphorus from the watershed? The relation between what happens on the land and what ultimately comes out the watershed is complicated by the mixture of land uses and by the incremental trapping of sediment and nutrients along the way by ponds, wetlands, and reservoirs (as shown in *Figure 3*).

• Hence the 11%, 29%, and 65% phosphorus reductions on cropland translate into only 7%, 20%, and 45% phosphorus reductions at the watershed outlet for, respectively, converting all cropland to no-till, reducing soil-test phosphorus, and adding filter strips (*Figure 5*).

• Other agricultural scenarios included converting all cropland to a corn-soybean rotation (C1S1 in *Figure 5*), which would increase phosphorus export by 42%. Adding a year of winter wheat to the rotation would help, but phosphorus exports would still be 22% larger than today.

• Conversion of cropland to rural-residential development was modeled by planting grass, reducing infiltration to account for soil compaction and scattered impervious surfaces, and leaving soil-test phosphorus at agricultural levels (41 ppm). Under these conditions the land will continue to deliver significant amounts of phosphorus, although this should abate over time if phosphorus fertilizers are not added. Rural-residential development in the model subbasins adjacent to Hudson and New Richmond (RR1 in *Figure 5*) had only a tiny effect (-2%) on phosphorus export. Converting all cropland in the lower basin (from Hudson to New Richmond) to rural-residential development (RR2 in *Figure 5*) lowered phosphorus export by only 8%.



NOTES: C1S1 = all cropland in corn-soybean rotation; C1S1W1 = all cropland in corn-soybean-wheat rotation; NT = all cropland in same rotations as in baseline and all in no-till; STP = soil-test phosphorus reduced to 20 ppm for corn-soybean rotations and 30 ppm for rotations with alfalfa; FS = filter strip 3-m wide implemented essentially at the base of every slope in cropland; RR1 = rural residential development near Hudson and New Richmond; RR2 = rural-residential development of all farmland between Hudson and New Richmond.

Figure 5. Export of phosphorus from the Willow River watershed under selected scenarios.

What did the model miss?

• The model did not account for increased sewage due to urban population rise, which could be significant. The model further assumed all rural residential sewage was trapped by individual drain fields. Feedlot operations were not explicitly modeled; all manure was applied to fields and incorporated within five days, except for daily-haul and grazing acreages. All channel processes were ignored; i.e., we assumed no net channel erosion or deposition, and no significant nutrient processing. The settling of sediment and phosphorus in reservoirs is governed by very simple algorithms in the model yet is a principal control on export of these constituents from the watershed. The conversion of [1]CRP and CREP grasslands back into cropland was not modeled but would clearly increase phosphorus export.

Conclusions

• The SWAT model of the Willow River watershed demonstrated that several agricultural best-management practices (BMPs) could significantly reduce phosphorus export. These BMPs included implementing no-till agriculture, reducing soil-test phosphorus, and adding filter strips. Conversion of cropland to rural residential development would have a minor effect on phosphorus export. However, with the exception of the filter-strip BMP, these scenarios were modeled to produce conservative estimates of phosphorus reductions; actual reductions may be larger than suggested here.

• We note that there are other agricultural and urban BMPs, not modeled here, that can also reduce nonpoint-source loads of sediment and nutrients.

[1]CRP = Conservation Reserve Program; CREP = Conservation Reserve Enhancement Program

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