Science Museum of Minnesota

St. Croix Watershed Research Station

SCWRS Fact Sheet, 2012

Reductions in phosphorus loading in the Sunrise River watershed from changing selected characteristics of developed land

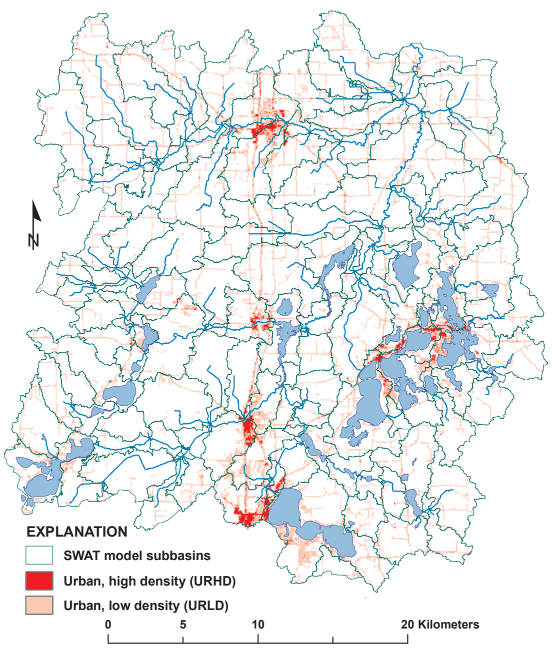

Figure 1. Urban lands in the Sunrise River watershed and model subbasin delineation.

Issue and Approach

Developed land, i.e., urban and rural residential, currently occupies about 16% of the area of the Sunrise River watershed but accounts for about 27% of the nonpoint-source phosphorus load reaching aquatic resources (wetlands, rivers, and lakes) (Figure 1, Table 1). Furthermore, by the year 2030 developed lands are projected to occupy about 24% of the watershed area and deliver 38% of the nonpoint phosphorus load. Too much phosphorus in receiving waters can degrade water quality because of excessive algal growth. Phosphorus can also come from point sources such as wastewater treatment plants, but improvements in treatment technology suggests that loads from point sources will remain small despite projected population increases (notes, Table 1). To estimate nonpoint phosphorus loads, a computerized watershed model was constructed for the Sunrise River watershed with the Soil and Water Assessment Tool (SWAT), which can take into account the many factors that affect the runoff processes that transport phosphorus from the land to receiving waters. We here report on efforts to use SWAT to predict reductions in nonpoint phosphorus loads from developed lands by changing selected characteristics of these lands in the model.

Table 1. Phosphorus yields, relative areas, and relative phosphorus loads for basic land-cover types in the Sunrise River watershed

	Phosphorus Yield (kg/ha)	% Watershed Area: Baseline 2000s (%)	% Watershed Area: 2030 (%)	% Phosphorus Load: Baseline 2000s (%)	% Phosphorus Load: 2030 (%)
Developed		16%	24%	27%	38%
Urban, high density	*2.18*	*0.4%*	*1%*	*2%*	*3%*
Urban, low density	*0.85*	*10%*	*14%*	*23%*	*31%*
Rural residential	*0.21*	*6%*	*9%*	*2%*	*4%*
Agricultural		21%	18%	55%	46%
Row crop rotations	*1.34*	*13%*	*11%*	*51%*	*43%*
Pasture and hay	*0.34*	*8%*	*7%*	*4%*	*3%*
Other (forest, grassland)	0.11	63%	58%	17%	16%
		Total watershed area:		*Total Phosphorus Load:*	
		991 km^2	991 km^2	52,200 kg/yr	55,600 kg/yr

NOTES: Loads here refer to nonpoint upland loads of phosphorus delivered to the surface-water resources in the watershed (wetlands, ponds, lakes, and streams). Point-source loads from wastewater treatment plants are not included here but were relatively small (1000 kg/yr for baseline conditions, 1450 kg/yr for 2030 conditions).

SWAT Model Hydrology and Developed Lands

The SWAT model subdivided the Sunrise watershed into 142 subbasins, each of which was composed of many land use and soil combinations that represent uplands (Figure 1). The model routes some stormflow and snowmelt from the uplands

to wetlands (if present in a subbasin), which remove some phosphorus before delivering outflow to streams and lakes. Three types of developed uplands were modeled: high-density urban (URHD), low-density urban (URLD), and rural residential (RRES). URHD corresponds to commercial properties and apartment-style residences. URLD corresponds to single-family homes in villages and lakeshores, about two homes per three acres, and also to the roadway network in the watershed, which adds considerable area to the URLD land-use type beyond municipal boundaries. RRES lands were modeled with soil permeabilities and phosphorus contents about mid-way between pristine conditions (grassland and woodland) and URLD lands.

By default, SWAT estimates phosphorus yields (load per unit area) from URHD and URLD based on regression equations developed in the 1980s. URHD lands had the highest phosphorus yield of all land-use types, exceeding even that of row-crop agriculture (Table 1). URLD lands had phosphorus yields within the range of agricultural lands. RRES lands had lower phosphorus yields than agricultural land but still about twice that of undeveloped land (forest and grassland).

Modeled Scenarios to Reduce Phosphorus Loads from Developed Lands

Phosphorus loads from uplands can be reduced in either of two ways. First, the amount of surface (overland) runoff that transports the phosphorus can be reduced. Second, the phosphorus content of that runoff can be reduced. Modeled upland phosphorus loads from scenarios attempting to use these methods were compared to current baseline (2000-10) loads, as well as to projected loads for the year 2030 (Figure 2). Note that the watershed-wide total phosphorus load from the uplands exceeds 50 metric tons per year (bars, Figure 2), which is far greater than the total load delivered from the Sunrise to the St. Croix River (cross-hair symbols, Figure 2). The difference is caused by the trapping of phosphorus in lowlands (ponds, wetlands) and lakes. These water bodies help protect the St. Croix River from excess phosphorus but can suffer from impaired water quality themselves as a consequence.

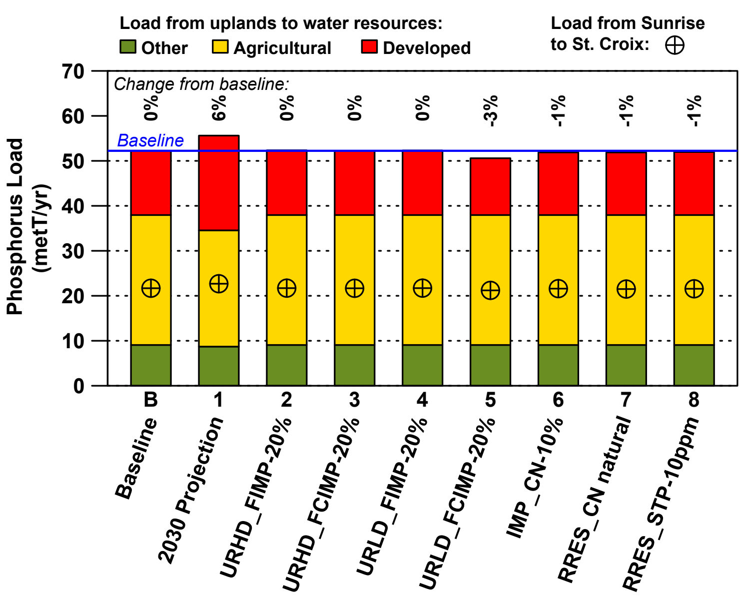

Figure 2. Upland phosphorus loads for basic land-cover types under selected scenarios to reduce loads from developed lands (URHD, URLD, and RRES).

URHD = urban high-density, URLD = urban low-density, RRES = rural residential, FIMP = fraction impervious, FCIMP = fraction connected impervious, IMP = impervious, CN = curve number, STP = soil-test phosphorus.

• *Baseline and 2030 Projection Model Runs (Figure 2, scenarios B and 1):* Baseline upland phosphorus loads totaled about 52.2 met T (metric tons; 1 met T = 2,200 pounds, or 1.1 short tons), about 27% of which comes from developed lands (Table 1). Expansion of existing urban and rural residential areas to accommodate projected population increases by 2030 may increase the upland phosphorus load by 6%, to 55.6 met T. This increase assumes conventional urban development as characterized by the 1980s regression equations.

• *Scenarios to Reduce Runoff (Figures 2 and 3, scenarios 2-7):* Runoff from urban lands can be greatly influenced by the fraction of impervious cover (FIMP) and connected impervious cover (FCIMP), which are directly connected to channelized flow paths provided

by curbs, gutters, and storm sewers. SWAT defaults to FIMP and FCIMP values of 0.6 and 0.44 for URHD, and 0.12 and 0.10 for URLD lands. For each scenario, Figure 3 shows total runoff volume from developed lands as well as from other (forest and grassland) and agricultural lands for perspective. Note that of the developed lands, most runoff is generated by URLD lands (Figure 3, pink) because of their larger area than URHD lands (Table 1) and lower infiltration capacity than RRES lands.

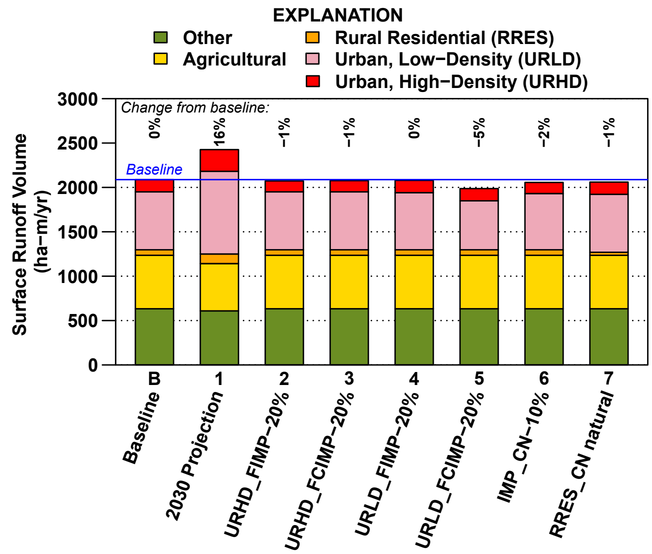

Figure 3. Surface runoff volumes for selected land-cover categories in the Sunrise River watershed for developed land-cover scenarios.

One ha-m is the volume needed to cover a hectare with 1 m of water. URHD = urban high-density, URLD = urban low-density, RRES = rural residential, FIMP = fraction impervious, FCIMP = fraction connected impervious, IMP = impervious, CN = curve number.

Scenarios 2-5 tested the effect of reducing FIMP and FCIMP by 20% in URHD and URLD lands, respectively. Runoff was in fact reduced, but only slightly, about 1% or less for scenarios 2-4 and 5% for scenario 5. Consequently, modeled reductions in upland phosphorus loads were insubstantial, essentially zero for scenarios 2-4 and only 3% for scenario 4. Reductions in impervious cover of 20% is a fairly dramatic change, and equations in the SWAT theory manual suggest that both runoff and phosphorus loads should be reduced substantially. Scenario 6 tested the effect of changing totally impervious surfaces to having some infiltration capacity, for example by having pervious pavement. (Technically, this was done by reducing the curve number (CN) of impervious surfaces by 10%, from 98 to 88.) Again, reductions in runoff volume (2%, Figure 3) and upland phosphorus load (1%, Figure 2) were insubstantial. *The minimal changes seen in our model runs suggest that there are errors or inaccuracies in the SWAT code dealing with URHD and URLD lands that need to be addressed.*

Scenario 7 modeled the effect of increasing the infiltration capacity of RRES lands to the natural state of grasslands or woodlands. However, runoff was not large from RRES lands in the baseline model (Figure 3, orange segment), and so reducing runoff further resulted in only minor reductions in the total volume of runoff and in upland phosphorus loads (Figure 2).

• *Scenario to Reduce Phosphorus Content of Runoff (Figure 2, scenario 8):* The phosphorus content of runoff can be reduced by reducing the phosphorus content of the surface soil in contact with the runoff. Scenario 8 tested the effect of reducing the soil-test phosphorus (STP) levels in RRES soils by half, from 20 ppm (part per million) to 10 ppm. Again, because RRES lands delivered a fairly small load in the baseline run, reducing the load further resulted in only a 1% drop in the total upland phosphorus load (Figure 2, scenario 8).

Phosphorus Loading to Lakes and Treatment of Urban Runoff by Wetlands or Ponds

Lakes are among the most highly valued aquatic resources in the Sunrise River watershed, thereby attracting the very development that can contribute to their impairment. Figure 4 shows phosphorus loads to ten selected lakes in the Sunrise River watershed for all the scenarios discussed above, with similarly disappointingly small load reductions.

An alternative to reducing the runoff and phosphorus loads generated by upland urban surfaces is to treat the runoff by routing it through a wetland before discharging it to receiving waters. Scenario 9 (Figure 4) tested the effect of routing an additional 20% of runoff through wetlands for each of the nine subbasins in

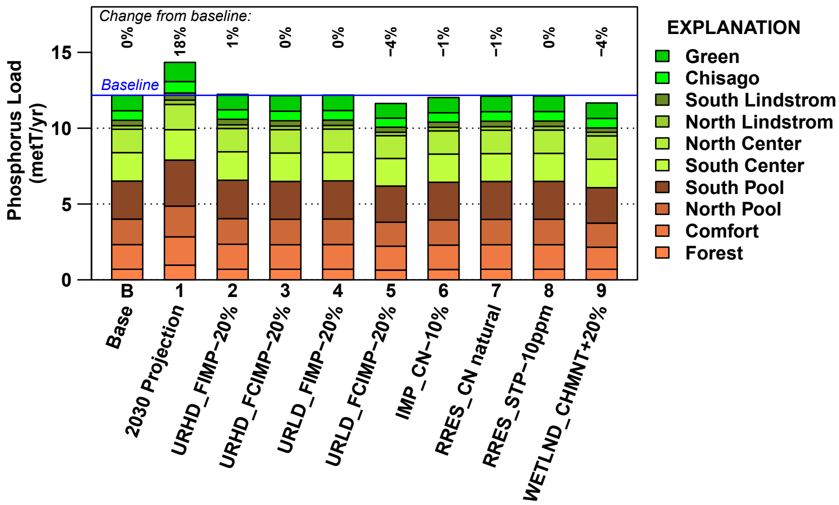

Figure 4. Phosphorus loads to selected lakes in the Sunrise River watershed under developed land-cover scenarios.
URHD = urban high-density, URLD = urban low-density, RRES = rural residential, FIMP = fraction impervious, FCIMP = fraction connected impervious, IMP = impervious, CN = curve number, STP = soil-test phosphorus, CHMNT = catchment.

the model that contained URHD lands, i.e., the most densely urban subbasins. Loads from each of these urban subbasins were reduced substantially, but the total load received by these ten lakes was reduced by only by 4%, which is somewhat disappointing in face of the projected 18% increase in loads by the year 2030. The larger message is that phosphorus loads to these lakes is controlled by more than simply the nine URHD-containing subbasins. In particular, growth of URLD land in other nearby subbasins is the source of most of the projected increase in phosphorus loads, and these subbasins likewise need mitigation efforts.

Conclusions

The SWAT model gave reasonable phosphorus loads from developed lands (URHD, URLD, and RRES) for baseline and 2030-projected model runs. However, the model proved ineffectual in testing scenarios for reducing these loads by changing the character of URHD and URLD lands. We suggest that the SWAT model code needs examination and adjustment to allow for better implementation of urban best management practices. SWAT was much more effective in altering non-urban lands and in treating runoff by wetlands to reduce phosphorus loads. Finally, despite the undoubted influence of URHD lands on nearby lakes, protecting these lakes will require addressing development elsewhere in their catchments as well.

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