Appendix H

SWAT – Soil and Water Assessment Tool

Predicting Phosphorus and TSS Export with the Soil and Water Assessment Tool (SWAT) to Evaluate Alternative Agricultural Management Practices in the Big Green Lake Watershed, Wisconsin

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Objective

The primary objective of this modeling project was to provide a predictive tool that could be used to estimate the potential for phosphorus and TSS load reductions in the Big Green Lake Watershed by assessing the impact of alternative management scenarios on total phosphorus and TSS loads to Big Green Lake. To accomplish this objective, the Soil and Water Assessment Tool (SWAT) was applied to the Big Green Lake Watershed. SWAT was developed by USDA-ARS to improve the technology used in the SWRRBWQ model (Arnold et al. 1996). SWAT is a distributed parameter, daily time step model that was developed to assess non-point source pollution from watersheds and large river basins. SWAT simulates hydrologic and related processes to predict the impact of management on water, sediment, nutrient and pesticide export from rural basins. A more detailed description of this model can be found in Appendix A.

This report describes: (1) the derivation of SWAT inputs; (2) model set up, calibration and assessment; and (3) the predicted impacts of alternative management scenarios on simulated loads of phosphorus and TSS to Big Green Lake.

Watershed description

The Big Green Lake Watershed is located primarily in Green Lake and Fond du Lac Counties, but a small portion of the watershed is located in Winnebago County (Figure 1). Big Green Lake is the deepest lake in Wisconsin, and it is the primary surface water feature in the watershed with an area of 7,325 acres (29.6 km^2). Other lakes in the watershed include Spring, Big Twin and Little Twin. As shown in Figure 1, the dominant land cover in the 244 km^2 Big Green Lake Watershed is agriculture (area without Big Green Lake).

SWAT Model Inputs

GIS layers: The following GIS data layers were used to provide inputs to the SWAT model and to prepare a various GIS-based maps and analyzes:

1. 1:24k WDNR watershed boundaries; subwatersheds were added as part of this project
2. USGS 1:24k Quadrangle Images - digital topo maps (used to delineate subwatersheds)
3. WISCLAND 1992 Land Cover from WDNR
4. NRCS certified digital soil surveys from Fond du Lac and Green Lake counties, and the Winnebago County digital soil surveys (combined into a single watershed coverage)
5. 30 meter digital elevation model (DEM), primarily used to derive overland slope
6. 1:24k surface water hydrology
7. Miscellaneous: roads, county boundaries, etc.

All the GIS coverages and images were obtained from the WDNR, except the county soil surveys. All GIS coverages were projected into WTM-NAD83/91 coordinates. The watershed was divided into 25 subwatersheds by using the DEM and USGS 1:24k digital quadrangle images to directly digitize the boundaries from the computer screen. Through this project, it was determined that subwatersheds 24 and 25 do not appear to drain to Big Green Lake. Subwatershed names and areas are provided later in the report in Table 2.

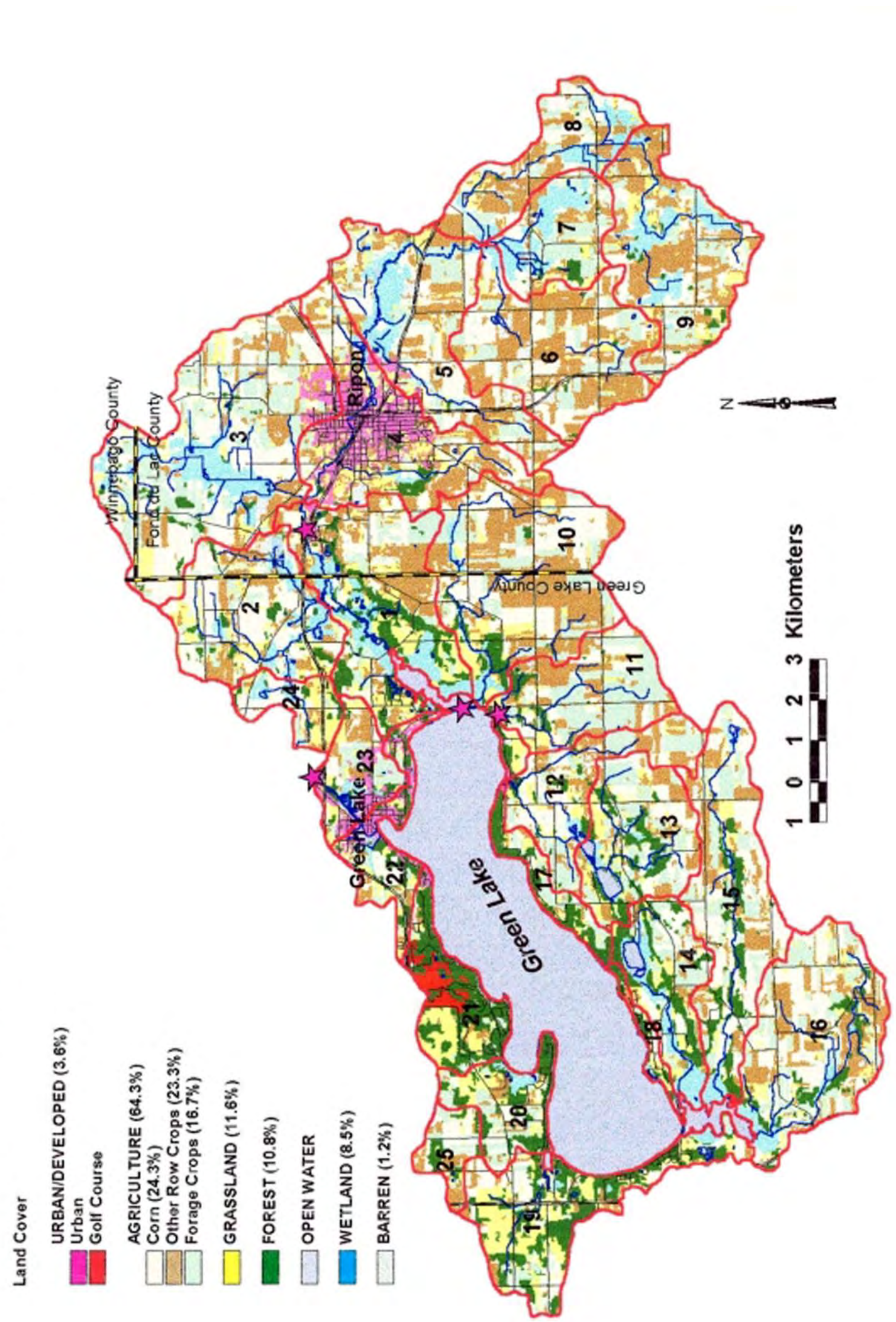

Figure 1. Big Green Lake Land Cover (based on WISCLAND 1992).

Land cover/use: Land cover within the watershed (Figure 1) was determined from the Level 3 classification of the 1992 WISCLAND land cover image, which was based on LANDSAT Thematic Mapper images. Because of the nature of interpretation and classification, forested urban areas that surround Green Lake were classified as forest in the WISCLAND coverage. The actual proportion of urban area in the entire watershed is therefore somewhat greater than that shown in Figure 1, which was based on the WISCLAND image. A GIS coverage was created to correct for this problem, and this layer was based in part on digitized USGS 1:24k quadrangle images. Another GIS coverage was later obtained from Big Green Lake county which had these types of urban areas delineated around Big Green Lake. This coverage was then used to refine the other, and the proportion of urban areas within the subwatersheds surrounding Big Green Lake were adjusted accordingly.. At this time, Figure 1 does not show these additional urban areas surrounding Big Green Lake.

The WISCLAND classified land cover image was used to assign 6 major land covers/uses which were modeled within the watershed: agriculture, urban, golf course, forest, grassland and wetland. These land covers were further divided into 11 "Hydrologic Response Units" which were directly modeled in the following fashion:

Agriculture - Dairy
1 Conventional tillage practice
2 Mulch-till
3 No-till

Agriculture - Cash crop
4 Conventional tillage practice
5 Mulch-till
6 No-till

7 Urban
8 Grassland
9 Forest
10 Wetland (or Golf Course in a subwatershed that had no significant amount of wetlands)

HRU's basically represent areas within a subwatershed that are similar in a hydrologic or management sense, but are not necessarily contiguous. No one specific farming practice could be used to model the entire watershed; therefore, various proportions of six possible agricultural practices (6 HRU's) were used to simulate what occurred in each subwatershed. For simplicity, every subwatershed was modeled as though it contained 10 HRU's in the order shown above. Since there were 25 subwatersheds, the total number of modeled HRU's was 250. A GIS overlay operation was used to derive the proportional area of the major HRU's within each of the 25 modeled subwatersheds. The next section describes how the agricultural areas were further divided in 6 agricultural HRU's. Where a subwatershed did not contain all of the landuses, the area of the non-existent landuse was assigned a negligible fraction of the total area (0.000001).

Management Practices and Hydrological Response Units (HRU)

SWAT requires detailed information regarding landuse management practices. For example, the type of crop, the date it was planted and harvested, tillage practices and dates, fertilizer applications and dates, and NRCS curve number for each period, are just some of the information that is input into SWAT's management files. The following discussion describes how these inputs were obtained.

Farm crops: The Level 3 classification of the 1992 WISCLAND classified land cover image has 3 primary crops classified within the Big Green Lake Watershed: "corn", "forage" and "other row crops". For this project, it was assumed that "other row crops" was either soybeans or another fragile crop. Unfortunately, the relatively small size of the delineated subwatersheds made it unreasonable to assume that the proportions of each crop within each subwatershed, as derived from GIS analysis of the 1992 WISCLAND image, were consistent from year to year. In some areas, the field sizes were sufficiently large that a different phase in the crop rotation would have sharply changed the proportion of the crops classified in the WISCLAND image for some of the subwatersheds. In addition, the image of the Green Lake Watershed was actually based on three separately classified scenes, which decreases the reliability of the data, particularly at the detailed Level 3 classification. Therefore, the subwatershed crop percentages derived from the WISCLAND data were not directly used as inputs. Instead, the proportion of dairy and cash cropping in each of the subwatersheds was derived by generalizing the subwatershed-specific data into two agricultural regions within the watershed: (dairy) 50% dairy and 50% cash crop; and (cash crop) 67% cash crop and 33% dairy. This task was accomplished by looking at all the sources of data including: 1) visual inspection of the WISCLAND image; 2) the proportions of each crop within each subwatershed, as indicated by the WISCLAND image; and 3) a watershed inventory conducted by Fond du Lac and Green Lake counties. The cash crop region encompassed subwatersheds 1-11 (except #3), and the remainder of the subwatersheds were assigned to the dairy regions.

Tillage practices: An inventory of farm practices within the Green Lake Watershed was gathered by the Fond du Lac and Green Lake and LCD's, in part, to support the modeling requirements of SWAT. However, the person gathering this information did not transfer this data into a database before leaving their position for different employment. Therefore, the data could only be roughly translated into a spreadsheet information system, but the accuracy of this rough translation was questionable. Therefore, management practice inputs to SWAT were based on generalizations of the collected data, as input to a spreadsheet, augmented by information obtained from the Fond du Lac and Green Lake LCD's. In addition, the Conservation Technology Information Center (CTIC) Conservation Tillage Reports from Green Lake and Fond du Lac Counties were analyzed to determine the primary tillage practice inputs to SWAT. These "Transect Survey" reports were based on statistical sampling procedures of farm fields to determine residue levels present on farm fields shortly after spring planting, as well as other information. The assumptions about current tillage practices that were utilized as data inputs for the management files in the model are summarized below. This data is based solely on the transect survey data for Green Lake County. There were probably too few data points to use the combined watershed data from both counties, particulary since data from hay/alfalfa fields were included in residue/tillage summaries for Fond du Lac County. The details of how these assumptions were derived will be described in the final report.

Summary of farm crop and management assumptions:

Crop practices

Cash crop subwatersheds: 1-11, except #3

2/3 cash crop rotation
1/3 dairy rotation

Dairy subwatersheds: (remaining subs 12-25, and #3)

50% dairy rotation (corn-grain, corn-silage, a, a, a, a)
50% cash crop rotation (corn, soybean)

Primary tillage practices

tillage	corn	soybeans
conventional practice (CT)	fall moldboard plow	fall chisel plow
mulch till (MT)	fall chisel plow	spring field cultivator, or disk
no-till (NT)	none	none

	CT	MT	NT
Dairy - present practices	61.0%	36.0%	3.0%
Cash Crop - present practices	36.0%	46.0%	18.0%
Combined Present practices	46.2%	41.7%	12.1%
Alternative A		87.9%	12.1%
Alternative B		46.2%	53.8%
Alternative C			100.0%
Alternative D		**update**	**%**

Nutrients and Nutrient Management: The following assumptions concerning commercial fertilizer and manure applications were utilized as model inputs.

Dairy rotation (cg,cs, oat/a, a,a,a) - options: moldboard plow, chisel or mulch till, no-till
1 corn grain ---- 250 lbs/acre (9-23-30 prior to planting); 30 tons manure in fall after harvest
1 corn silage ---- 250 lbs/acre (9-23-30 prior to planting)
1 oat/alfalfa
3 alfalfa ---- 2nd & 3rd year 18 lbs/acre of 0-10-60 each year; after 4th year, apply 30 t/acre manure in fall (it was assumed that only 10% of farmers apply 180 lbs/acre of 0-10-60; hence, the rate of 18 lbs/acre of fertilizer applied)

30 ton/acre/yr of dairy manure is applied for two years of this rotation (total 60 tons in 6 years)

Cash crop rotation (corn, soybeans) - options: moldboard plow, chisel mulch till, no-till
1 year corn 125 lbs/acre Anhydrous ammonia prior to planting; 280 lbs of 9-23-30 @planting

1 year soybean (soybeans serve as the legume crop or fragile crop in the cash crop rotation)
200 lbs/acre 9-23-30 @ planting (this could instead be applied during corn season; at this time the model did not show a difference; note that the nitrogen was not necessary of soybeans)

Nutrient management was not modeled at this time.

Climatological inputs: Precipitation data from Ripon, temperature data from Fond du Lac and general weather statistics from Portage were used for climatological inputs to SWAT.

Soils and overland slopes: County soil surveys were processed and combined into a single GIS coverage, and projected into WTM-NAD83 coordinates. This coverage was intersected/combined with both the WISCLAND land cover image (used to delineate HRU's), and the subwatershed delineated GIS layer, to produce soils information that was specific to each of the HRU's within each of the 25 subwatersheds. For each HRU within a subwatershed, and for each of the soil parameters required by SWAT, an area-weighted average value was assigned based on the area of each of the soil series within that HRU. A somewhat simpler procedure was conducted with the 75 meter digital elevation map to produce average slopes for each of the HRU's, within each of the 25 subwatersheds.

HRU-specific information was deemed important because slopes and soils often vary between different landuses. For example, compared to agricultural land (average slope = 3.6%), the average slope of forested land was approximately twice as steep (7.1%), and the average slope of grassland was 4.5%. This level of analysis is even more critical where there is a large proportion of wetlands, for which the average slope would substantially reduce the slope of the other HRU's in the subwatershed (unless other procedures are taken to not include the slopes from wetland areas). However, for other critical model parameters, this procedure was not as important because of the relatively homogeneous nature of the soils in the watershed. For example, the hydrologic soil group (A, B, C, D), which helps determine the NRCS curve number, did not vary much throughout the watershed, nor between the different HRU's (excluding wetlands). This was not the case when this same procedure was used in to determine subwatershed-specific soil parameters in the Lower Fox River Basin.

As previously mentioned, hydrologic soil groups varied little throughout the watershed, and therefore curve numbers also varied little. There are only four categories for hydrologic group, so this outcome is not unexpected. However, saturated conductivity did vary substantially; thereby, indicating that surface runoff and recharge proportions are unlikely to be the same throughout the watershed. Therefore, saturated conductivity was used to differentiate those subwatersheds whose soils were much more permeable than the rest. Essentially, this procedure was akin to assigning a "low B" soil hydrologic group to subwatersheds whose soils were much more permeable than others. Curve numbers for subwatersheds 18-21 were reduced by 3 units, while the curve numbers of 22-23 were reduced by 1.5 units, to reflect the reduced runoff potential expected in areas which had soils that were much more permeable than in other subwatersheds.

Stream characteristics: Geomorphic relationships between drainage area and stream channel characteristics were used to calculate both the main and routing channel depths and widths at different locations in the watershed.

Stream flows and loads: For purposes of calibrating and validating the SWAT model, stream flow, and phosphorus and total suspended solids (TSS) loads were obtained from USGS for the following locations in the watershed: Silver Creek at Koro Rd. (USGS # 040734644; 1987-96), Silver Creek at Big Green Lake inlet (USGS # 04073468; 1987-98), and White Creek at Spring Grove Road (USGS # 04030201; 1982-88; 1997-98). These monitoring sites were jointly funded by USGS, WDNR and the Green Lake Sanitary District. The monitoring locations are shown in Figure 1. Observed data from the Silver Creek-Koro Rd. station, for the 1987-92 period, was chosen to calibrate the model. Observed data from the remaining years (1993-96) at this site, and data from the Silver Creek at Big Green Lake Inlet (1987-98) were used to assess the validity of the model (validation period).

Unfortunately, the observed data from the White Creek station could not be directly utilized for calibration or validation for two reasons: (1) the annual stream flows were unusually high given the drainage area of this subwatershed; and (2) there appears to have been a substantial change in water quality between the 1982-88 period, and the 1997-98 period. Whereas the long-term stream flow on an areal basis for Silver Creek was about 250 mm (annualized over 1987-96 period), the measured flows at White Creek were much higher than could reasonably be expected (Table 1) given the amount of measured precipitation, and assumed evapotranspiration. There are at least two possible explanations for this disparity. First, the surface water drainage area of the White Creek subwatershed may be much greater than the areas delineated by either the USGS or Fox-Wolf Basin 2000. Second, the groundwater drainage area may be substantially greater than the surface water drainage areas delineated by either the USGS or Fox-Wolf Basin 2000. Further review of the 1:24,000 topological maps indicated that the eastern drainage area divide is not clearly defined, and there are also many springs in the White Creek subwatershed. In addition, road ditches may also cross the natural drainage divide at an elevation sufficiently low that large amounts of water are transferred to the White Creek subwatershed from adjacent subwatersheds. Further analysis of the White Creek data also showed that substantial changes may have occurred as result of efforts to reduce stream bank and possible gully erosion. This inference was drawn because phosphorus to TSS ratios have risen markedly, in association with what appears to be a sharp drop in TSS loads (instantaneous TSS concentrations of over 50,000 mg/L were recorded in the 1982-88 period). For example, the volumetric concentration of TSS in 1982 (calendar year) was 905 mg/L compared to a concentration of 47 mg/L in 1998 (water year), even though the total annual flows were nearly identical (1,250 cfs). In addition, the average ratio of phosphorus to TSS in the 1982-88 period was 0.93 lbs of phosphorus per ton TSS, compared to the more recent average in the 1997-98 period of 4.0 lbs of phosphorus per ton TSS.

Given the unusual water budget, and the potential temporal change in water quality over the monitoring period, it was determined that it would not be reasonable to calibrate the SWAT model with observed data from the White Creek monitoring location. This determination was particularly unfortunate because it precluded calibrating the SWAT model in two separate phases, as originally intended: (1) calibrate the subwatershed component of the model first by using a simple approach which involved modeling the White Creek subwatershed as a single subwatershed, without any routing required; and (2) then calibrating the routing component of the SWAT model by modeling the larger Silver Creek watershed, which is composed of many subwatersheds, while adjusting only those parameters that affect routing. By separating the subwatershed load-generating routines from the routing component, a more robust and predictive model may have been developed for the Big Green Lake watershed.

Table 1. Annual flows at White Creek station (areal basis) and precipitation at Ripon.

Year	Precip. mm	Flow mm	Flow % of Precip.
1982*	790	347	44%
1983	826	593	72%
1984	893	527	59%
1985	885	553	62%
1986	998	777	78%
1987	651	192	30%
1988*	574	137	24%

* all are full calendar years, except 1982 and 1988 are incomplete years

SWAT Model Setup - summary

A total of 25 subwatersheds were delineated for this project (# 24 and # 25 do not drain to Green Lake). Each of the subwatersheds contained 10 hydrologic response units (HRU's), which were based on these primary land uses: agriculture (6 HRU's), urban, grassland, forest, and wetland (or golf course). HRU's basically represent areas within a subwatershed that are similar, but are not necessarily contiguous. No one specific farming practice could be used to model the entire watershed; therefore, various proportions of six possible agricultural practices (6 HRU's) were used to simulate what occurred in each subwatershed.

The agricultural HRU's consisted of two potential farming practices:

1) Dairy-based (6 year rotation: corn-grain, corn silage, oats/alfalfa, alfalfa, alfalfa, alfalfa)

2) Cash crop (2 year rotation: corn, soybeans).

Under each of the two potential farming practices, three tillage practices were simulated: a) conventional tillage with fall moldboard plow as the primary tillage implement for corn and fall chisel plow for soybeans; b) mulch till, or chisel plow tillage in fall; and c) no-till. Hence, a total of six HRU's were used to represent agricultural areas.

SWAT98.2 was tested and modified to suit conditions in Wisconsin. Many of these code modifications were to bring in prior modifications that we made with SWAT97.2. In our testing of SWAT98.2, we have found some additional errors that required fixing. These errors have now been fixed by Fox-Wolf Basin 2000 or the model developers at USDA-ARS in Temple, Texas.

Model Calibration and Assessment

Flow Calibration: The Priestly-Taylor evapotranspiration equation was utilized for this project. The following coefficients were added to the model code which allowed adjustment of the simulated water balance to obtain a reasonable fit with the observed stream flows: Priestley-Taylor ET equation (0.77), NRCS curve number input (0.99), and available water capacity soils input (0.92).

TSS calibration: Parameters in the modified universal soil loss equation (MUSLE) were adjusted to obtain a reasonable fit between observed and simulated TSS loads. MUSLE is shown in Equation 1.

$$\text{MUSLE: } Y = a\,(Q)^b\,(q_p)^c\,(DA)^d\,[(K)\,(C)\,(PE)\,(LS)] \qquad \text{(Eq. 1)}$$

where:

Y	=	sediment yield in metric tons/ha (Mg/ha)
Q	=	surface runoff volume in mm
q_p	=	peak flow rate in mm/hr
DA	=	drainage area in hectares
K	=	soil erosion factor
C	=	crop management factor
LS	=	slope-length and slope-steepness factor
PE	=	erosion control practice factor
a,b,c,d	=	constants normally set at a = 1.586, b & c = 0.56, d = 0.12 (user-specified values can be used where there are sufficient data for calibration)

The following values were utilized in the MUSLE equation for this project: a = 0.01, b = 1.6, c = 0.0 , and d = 0.0.

Annual flow and loads: Simulated and observed annual flows (mm, on an areal basis), TSS loads (metric ton) and phosphorus loads (kg) are compared in Table 2 and Figures 2a, 2b and 2c respectively, for the monitoring site located on Silver Creek at Koro Road (drainage area of 94.7 km^2). The annual totals correspond to USGS water years (October 1 to Sept 30). Annual precipitation (mm) is shown on the second y-axis in Figure 2, so precipitation and stream flow can be compared. Despite wide fluctuations in annual precipitation, observed and simulated annual values for TSS and phosphorus loads as well as annual water balance all coincide fairly well at Silver Creek during the calibration period (1987-92). However, during the validation, or assessment period (1993-96), TSS and phosphorus loads were substantially under predicted for 1993, and somewhat under predicted for 1994. Exceptionally high runoff occurred in 1993. The observed annual flow of 560 mm in 1993 represented 63% of the precipitation measured at Ripon during that year (890 mm); plus, the flow in 1993 was more than two times greater than the second highest annual flow which occurred during the 1987-96 period. Evapotranspiration must have been greatly suppressed to produce such a high flow to precipitation ratio. Spring planting was delayed during 1993, and high soil moisture levels further delayed plant emergence and growth early in the year. As a result, evapotranspiration and protective plant canopy from annual crops were lower than normal during the early growing season. Plant stress due to wet soil conditions (including reduced availability of nitrogen) is not simulated by the model, and only the average planting dates were input to the model. If these factors had been accounted for by model simulations, both of these factors would have increased simulated flows and loads, and produced a closer correspondence between observed and simulated values. Only average planting/tillage dates were input to the model to reduce the number of input files and simplify the model set up.

Silver Creek at Green Lake inlet: The model was not calibrated with data from this site, so the entire 1987-98 period could be considered a validation/assessment period; however, since this site is downstream of the primary calibration site, it may be more appropriate to consider separating the data into two periods (1987-92: calibration period; 1993-98 validatation period). Simulated and observed annual flows (mm), TSS loads (metric ton) and phosphorus loads (kg) are compared in Table 3 and Figures 3a, 3b and 3c respectively, for the monitoring site located on Silver Creek

Table 2. Observed and simulated annual flow and loads - Silver Creek at Koro Rd. Calibration period (1989-92) and Validation period (1993-96).

	Ripon Precip.	Flow (mm)		TSS (MT)		Total Phosphorus (kg)	
	(mm)	Observed	SWAT	Observed	SWAT	Observed	SWAT
1987*	640	150	160	280	380	2,640	3,480
1988	570	120	90	330	170	2,780	2,280
1989	680	200	200	1,530	1,620	9,810	10,030
1990	1,000	250	310	700	910	7,480	6,360
1991	790	240	250	780	540	3,990	4,550
1992	750	250	220	540	480	3,380	4,020
1993	890	560	440	1,530	960	10,640	6,760
1994	730	170	110	480	230	4,650	2,670
1995	840	240	220	480	630	3,910	4,810
1996*	540	250	260	510	710	3,980	4,810
Totals							
1987-92	4,440	1,210	1,220	4,150	4,110	30,070	30,710
1993-96	3,000	1,230	1,030	3,000	2,530	23,180	19,060
1987-96	7,440	2,440	2,260	7,150	6,640	53,260	49,770

* values are totals for calendar years, except 1987 (started Feb 1), and 1996 (ended Sept. 30)

Table 3. Observed and simulated annual flow and loads - Silver Cr. at Green Lake Inlet. Calibration period (1989-92) and Validation period (1993-98).

	Ripon Precip.	Flow (mm)		TSS (MT)		Total Phosphorus (kg)	
	(mm)	Observed	SWAT	Observed	SWAT	Observed	SWAT
1987*	640	160	150	520	410	2,610	3,770
1988	570	130	80	320	170	2,700	2,310
1989	680	220	200	1,790	2,170	10,570	11,200
1990	1,000	270	310	1,420	1,150	8,270	6,800
1991	790	230	250	500	610	4,160	4,980
1992	750	230	210	750	460	3,470	4,200
1993	890	560	440	3,290	1,160	12,580	7,390
1994	730	190	110	540	260	6,450	2,720
1995	840	260	210	720	640	4,370	5,150
1996	660	300	280	790	920	5,100	5,650
1997	710	240	160	740	390	4,230	3,580
1998*	620	180	150	870	610	3,230	4,240
Totals							
1987-92	4,440	1,260	1,200	5,300	4,980	31,800	33,260
1993-98	4,460	1,740	1,350	6,950	3,990	35,970	28,720
1987-98	8,900	3,000	2,550	12,260	8,970	67,760	61,990

* values are totals for calendar years, except 1987 (started Feb 1), and 1998 (ended Sept. 30)

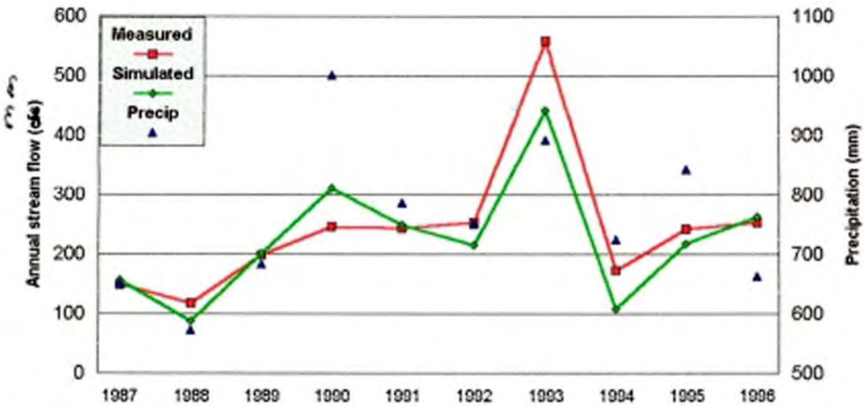

Figure 2a. Observed and simulated annual stream flow - Silver Cr. at Koro Rd.

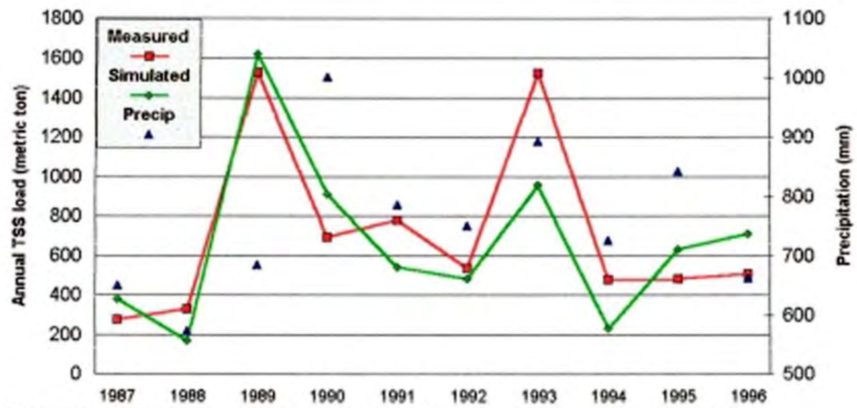

Figure 2b. Observed and simulated annual TSS load - Silver Cr. at Koro Rd.

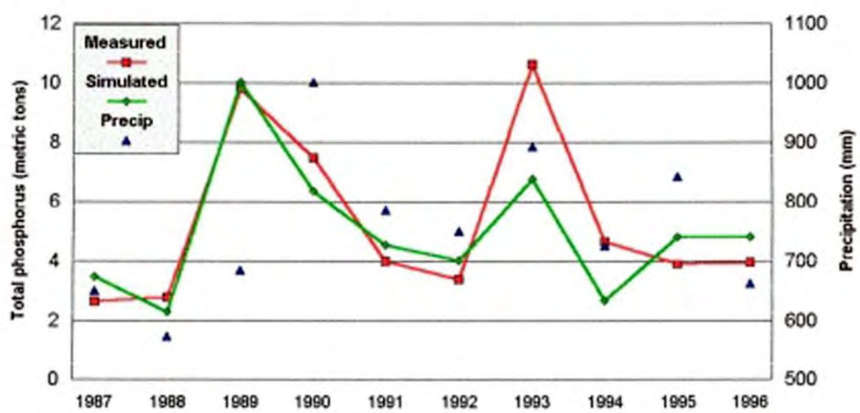

Figure 2c. Observed and simulated annual total phophorus load - Silver Cr. at Koro Rd.

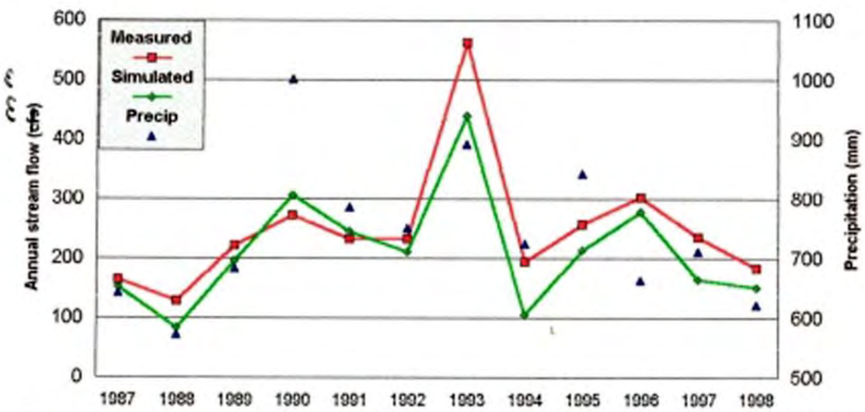

Figure 3a. Observed and simulated annual stream flow - Silver Cr. at Green Lake Inlet.

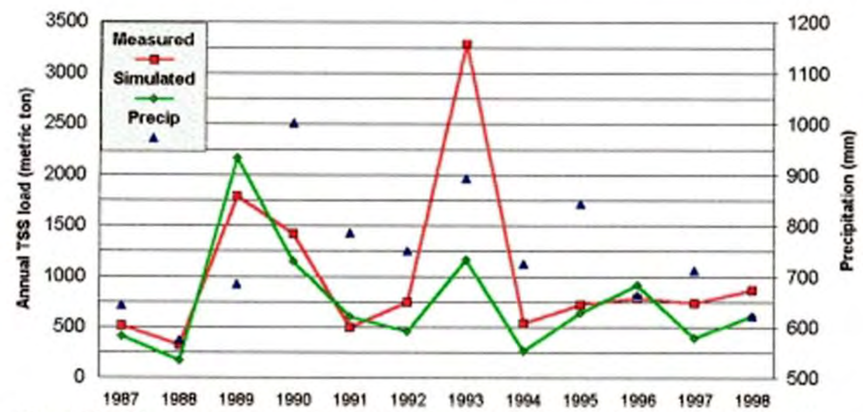

Figure 3b. Observed and simulated annual TSS load - Silver Cr. at Green Lake Inlet.

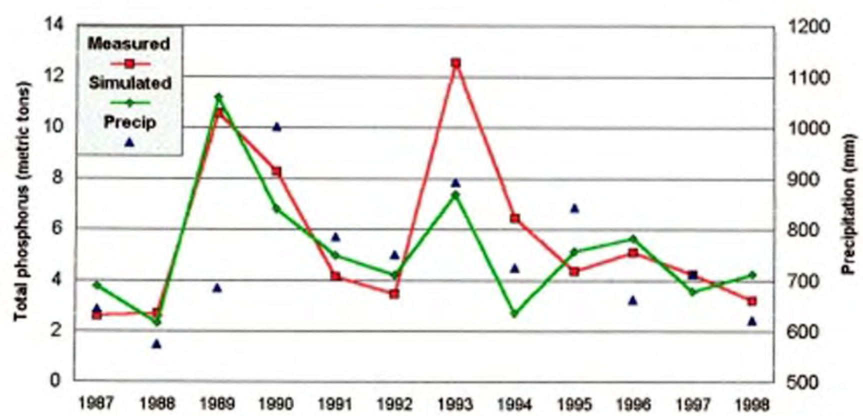

Figure 3c. Observed and simulated annual total phophorus load - Silver Cr. at Green Lake Inlet.

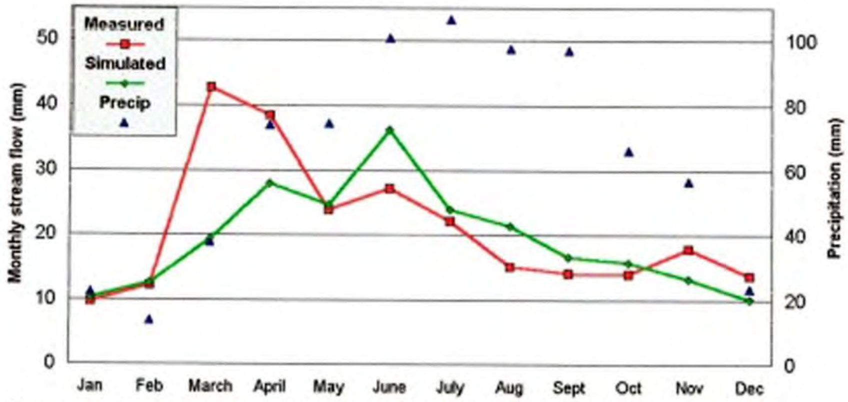

Figure 4a. Observed and simulated monthly stream flow - Silver Cr. at Koro Rd.

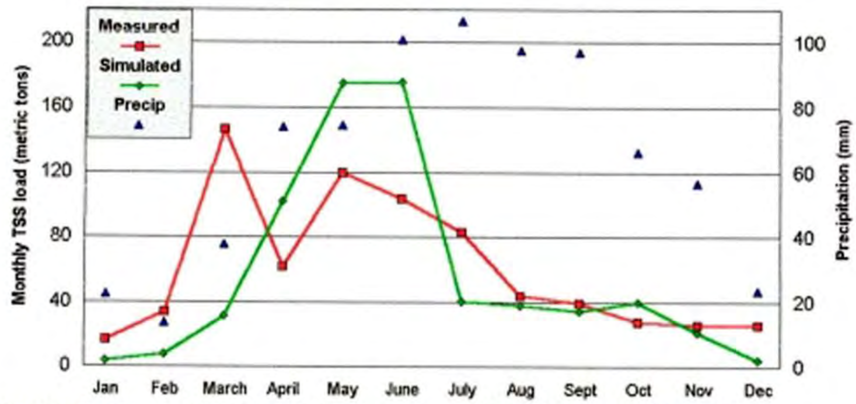

Figure 4b. Observed and simulated monthly TSS load - Silver Cr. at Koro Rd.

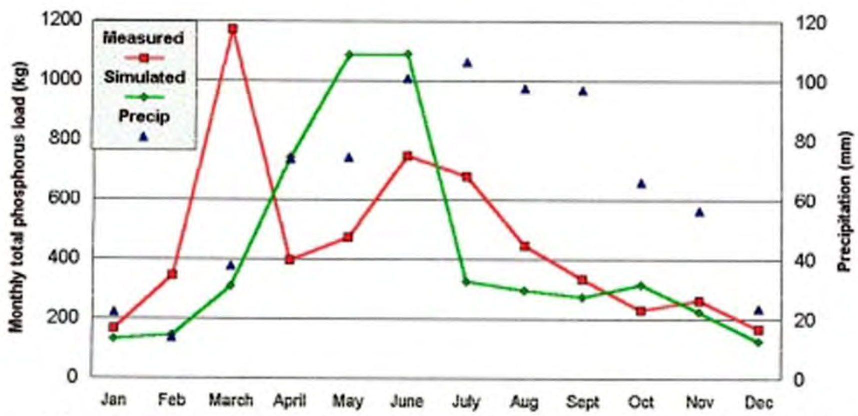

Figure 4c. Observed and simulated monthly total phophorus load - Silver Cr. at Koro Rd.

at the Green Lake inlet (drainage area of 122 km^2). Again, despite wide fluctuations in annual precipitation, observed and simulated annual values for TSS and phosphorus loads as well as annual water balance all coincide fairly well during the entire 1987-98 period, except during 1993 and 1994. Phosphorus loads were substantially under predicted in 1993 and 1994. However, TSS loads were greatly under predicted in 1993 when the simulated load was about one third of the observed load; the difference is much greater than it was for the upstream monitoring site. One potential explanation that deserves further analysis is that the model, as currently set up, is settling too much TSS within some or all of the stream reaches. Unaccounted channel degradation occurring during the high flows in 1993 could also have been responsible for the high TSS loads in 1993. It appears unlikely that delayed planting and slow early crop growth during 1993 will be sufficient to account for the discrepancy between simulated and observed TSS loads at this location. I recommend that any further refinement of the model should utilize the 1993 data for calibration purposes at this site.

Monthly flow and loads: Simulated and observed monthly average stream flow (mm), TSS loads (metric ton) and phosphorus loads (kg) are compared in Figures 4a, 4b and 4c respectively, for the monitoring site located on Silver Creek at Koro Road. The monthly values were averaged over the 1987-96 period. Monthly precipitation (mm) is shown on the second y-axis in Figure 4, so precipitation and stream flow can be compared.

In general, monthly average simulated flows were close to observed flows except during March, when the simulated average flow was less than half the observed average, while flow during April was somewhat lower than the observed average value (Figure 4a). Except for these excursions, the model was able to reliably track seasonal changes in flow despite the less than direct correspondence between observed monthly flow and preciption. It is understandable that the SWAT-estimated March flow (19.4 mm on an areal basis) did not match the observed flow because the average March precipitation at Ripon is 37.8 mm, which is lower than the observed flow of 42.7 mm (1987-96 averages). A number of conditions could contribute to the high flows observed in March including: a large groundwater storage component, high proportion of runoff due to frozen ground conditions, frozen surface water and snow storage in wetlands that thaws in spring, snow melt, and delayed groundwater flow over winter. In addition, some of the measured discharges in March may have been affected by ice conditions which would tend to overstate flow whenever the ice caused the water to backup. Therefore, while attempts may be made to refine the model and improve the fit between observed and simulated flows, it must be recognized that many of the conditions that cause the average March flow in Silver Creek to exceed the average March precipitation are likely to be difficult to model with SWAT.

Compared to stream flow, simulated TSS and phosphorus loads were much lower than the observed values during the month of March, suggesting that surface water contributions were also understated by the model simulations (Figure 4b, 4c). If only stream flow had been under-predicted by the simulations, while the loads had been closely estimated, it would have indicated that the groundwater contributions were not well predicted. Simulated TSS and phosphorus loads were substantially greater than observed loads during the months of April, May and June (Figure 4b, 4c). Phosphorus loads were particularly overstated. The precise cause of these over predications is not yet known, but further attempts may be made to refine the model and produce a better fit in the near future. Given these results, I am forced to conclude that the model as currently set up, does only a fair job of accurately representing the observed TSS and phosphorus loads during the months of April through July; while the model performs poorly in simulating loads during March. This conclusion is especially applicable to simulated phosphorus loads.

However, it is also important to note that the total simulated TSS and phosphorus loads during the March through July period were essentially identical to the observed values.

White Creek at Spring Grove Road: For reasons previously stated, TSS and phosphorus loads from the White Creek monitoring station could not be directly utilized for calibration purposes, particularly for the 1982-88 period. However, simulated and observed TSS and phosphorus loads from the 1997-98 period were compared to see how well the model could perform, given the caveat about the high observed stream flows from this drainage area. The average simulated flow for the 1997-98 calendar year period was about half of the observed average during the 1997-98 water year. The simulated average TSS load during the 1997-98 calendar year period was 102 metric tons compared to the observed average TSS load of 230 metric tons during the 1997-98 water year period. However, the simulated average phosphorus load (1997-98 calendar year) was within 10% of the observed average (1997-98 water year).

Evaluation of Alternative Management Practices

Four alternative agricultural management practices were simulated to evaluate the impact of each alternative on TSS and phosphorus loads, as routed to the outlet of each subwatershed, and routed to Big Green Lake. The four alternative management scenarios include: (A) those cropped areas practicing conventional tillage (corn - fall moldboard plow; soybeans - fall chisel plow) switched to mulch-till (corn - fall chisel plow; soybeans - field cultivator or disk in spring); (B) conventional tilled acres switched to mulch-till, plus all cropped areas practicing mulch-till switched to no-till; (C) no-till was practiced on all cropped agricultural land; and (D) no-till was practiced on all cash-crop farms, but dairy farms only switched to mulch-till, unless they were already practicing no-till. The cost to switch to mulch-till was assumed to be $30/acre for cash-crop rotations, and $15/acre for dairy rotations. The cost was lower for dairy rotations because the alfalfa acreage was only affected prior to planting or after the last harvest. To switch to no-till, the cost was assumed to be $50/acre for cash-crop rotations, and $25/acre for dairy rotations. These costs were used as examples, and different costs can be substituted in the provided spreadsheet.

Simulated subwatershed TSS and phosphorus loads for the current condition and four alternative management scenarios are shown in Tables 4 and 5, respectively (1987-98 average). The loads for subwatershed #4 do not include the discharge of the Ripon Wastewater Treatment Plant. Phosphorus loads as routed to Big Green Lake are also shown in Table 5, which includes the discharge from the Ripon Wastewater Treatment Plant. The simulated 1987-98 average annual phosphorus load from Silver Creek to Green Lake is 5,200 kg (11,500 lbs), and the total load routed to the lake is 13,700 kg (30,200 lbs).[1] The simulated 1987-98 average annual TSS load from Silver Creek to Green Lake is 750 metric tons (830 Eng. tons), and the total load routed to the lake 2,600 metric tons (2,900 Eng. tons). The simulated TSS loads are probably less reliable than phosphorus loads because of the difficulty in modeling sediment loads that are caused from stream bank erosion or severe gully erosion, which can be specific to individual subwatersheds. In addition, phosphorus is more conservative than TSS as it is routed through stream reaches, so the

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[1]The total simulated load to the lake is somewhat less than this total because the upper portion of the Hill Creek watershed was not routed through the lower portion or the Twin Lakes system. Subwatershed #12 should be routed through the lake system and through subwatershed #13, but this was not done at this time to simplify the modeling process. Therefore, the actual load from sub. #12 to Green Lake should be less than indicated in this report; however, the impact of sub. #12 on the Twin Lakes system is also important.

simulated TSS loads are more sensitive to possible errors in the routing process.

The subwatersheds were also ranked and sorted on the basis of total reduced phosphorus load, as routed to Big Green Lake. Based on this ranking, the phosphorus loads, reduced loads, associated cost to reduce the load, and the unit cost to reduce the loads are shown in Table 6. These rankings show how the simulated results can be used to determine where the greatest reductions might best be targeted.

The simulated phosphorus loads for each of the four alternative scenarios, as routed to Big Green Lake, are combined with the associated cumulative cost to reduce the load in Figure 5. Each dot in the figure represents the impact of adding another subwatershed to each of the alternative management scenarios (going from left to right). Thus, if the goal is to achieve an average annual total phosphorus load to Big Green Lake of 20,000 lbs (reduce load by 33%), then Alt. C and D have nearly the same cost of $600,000/year, Alt. B will require implementation in all subwatersheds and cost $800,000/year, and Alt. A will only be able to reach a load of 24,500 lbs. The simulated data in Figure 5 suggests that the different alternative scenarios do not differ much in cost-effectiveness until the 10 least important subwatersheds undergo the management change, at which point the lines tend to diverge. The information shown in Figure 5 is summarized in Table 7.

Model limitations

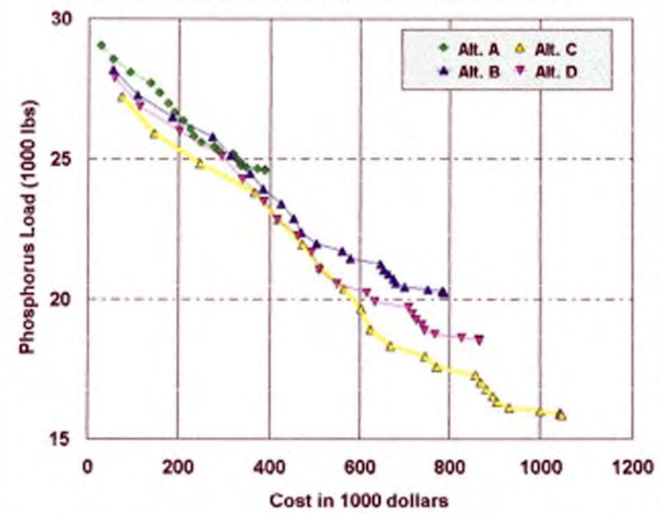
This section describes some of the limitations inherent to the simulations. These limitations should be considered when evaluating absolute and relative loads, as well as the costs to reduce these loads, within the Big Green Lake Watershed.

Until very recently, the model dealt with inorganic phosphorus fertilizer incorrectly; that is, the addition of inorganic fertilizer had no effect on the levels of phosphorus supposedly attached to sediment during erosion events. While this component of the model has been fixed, there has been insufficient time to thoroughly calibrate the response of the model to various inputs related to phosphorus. For example, the relative proportions of soluble, sediment-attached and organic phosphorus need to be adjusted to reflect results from published data for a variety of management practices. One reason the proportion of soluble phosphorus is important is that the model routes 100% of this form of phosphorus to the watershed outlets. Therefore, a pound of soluble phosphorus discharged from either an upper or a lower reach are both treated as though all of it reaches the lake.

The version of the SWAT model used in this project does not route sediment and sediment-attached phosphorus in the same manner, and this aspect of the model resulted in some undesired outcomes. In some stream reaches, sediment-attached phosphorus is settling out in the stream at a higher rate than the sediment, which is not appropriate. In addition, within every stream reach, the non-soluble portion of the phosphorus load is being trapped at a very consistent rate of about 33%. That is, on a long-term net basis, 67% of the non-soluble phosphorus that enters a stream reach passes through the reach, while 33% remains as deposited material. This is true of every reach, which seems unreasonable since there are major differences in the stream gradients. These odd results may be due to my not knowing, until recently, that the model was using a new, much more complex routine for routing phosphorus. Thus, the model results are based on the default nutrient routing parameters, without any changes to adjust these values to give better results. Without further refinement, it must be understood that the modeled results do not currently mimic the physical world in a realistic manner, but the results are still useful for comparison purposes. If the model is showing more deposition of phosphorus when routing through Silver Creek than actually occurs, then the relative load from Silver Creek is greater than indicated by the model (compared to the rest of the watershed). The same logic holds if the relative amount of soluble phosphorus is too low, because routing through the reaches of Silver Creek would have little effect on this form of phosphorus.

For a number of reasons, the predicted load reductions associated with the alternative management scenarios are probably overly optimistic. Phosphorus reductions resulting from conservation tillage may be too high because I used management inputs which distributed manure at a deeper level than actually occurs. In addition, the amount of soluble phosphorus simulated by the model with the current settings may be too low. Soluble phosphorus is more difficult to control with conservation tillage, which cannot only increase the concentration of soluble phosphorus, but actually increase the load as well. Time did not permit testing these aspects of the model thoroughly enough to be confident that the inputs that affect manure depth or the proportion of soluble P are reasonable. Another modeling assumption that may lower the reduction potential, is the proportion of land that is assumed to be under conventional tillage. These numbers were based on the county transect survey, in which an estimate was made of the residue on the fields just after planting. If it was estimated that the residue percentage directly after planting was lower than 15% for a particular field, then "conventional tillage" was assigned to that field, even though substantial protective residue may have been present between the fall harvest and spring planting period. If the prior crop was soybeans, very little residue might remain for detection after planting the next crop because of spring tillage, even if the residue was undisturbed until the soil was tilled. Yet undisturbed residue should substantially reduce TSS and phosphorus loads until spring tillage occurs. This aspect of erosion control is important because approximately 30% of the TSS load and 42% of the phosphorus load measured at the Silver Creek-Koro Road monitoring station (1987-96) occurs between the period between typical fall harvest and spring tillage.

Figure 5. Simulated Phosphorus Loads to Green Lake for Alternative Management Scenarios and Associated Cost to Reduce - 3/28/2000.



Cost Assumptions

	Dairy	Cash Crop
Alt. A	CT > MT	CT > MT
Alt. B	CT > MT MT > NT	CT > MT MT > NT
Alt. C	all NT	all NT
Alt. D	all MT	all NT
MT cost	$15/acre	$30/acre
NT cost	$25/acre	$50/acre

Table 7. Cumulative cost to reduce phosphorus loads, and associated load reduction to Big Green Lake.

Cumulative Cost to reduce Phosphorus				Cumulative total Phosphorus Reduction						
Alt. A	Alt. B	Alt. C	Alt. D	Alt. A	Alt. B	Alt. C	Alt. D		sub#	subwatershed
$28,300	$56,600	$74,500	$58,100	1,110	2,000	2,940	2,270	1	16	Wurchs Creek
$55,800	$109,400	$146,600	$114,400	1,620	2,900	4,250	3,300	2	15	Roy Creek
$92,600	$185,900	$247,700	$201,700	2,000	3,610	5,270	4,190	3	10	Dakin Creek
$137,600	$274,100	$365,800	$294,000	2,450	4,380	6,370	5,060	4	3	Silver Cr. 3 (routed, est.
$156,600	$313,400	$417,800	$338,800	2,820	5,050	7,330	5,900	5	1	Silver Cr. 1
$176,700	$355,100	$472,900	$386,400	3,170	5,690	8,230	6,680	6	2	Silver Cr. 2 (routed, est.
$191,700	$384,600	$512,400	$417,300	3,490	6,250	9,040	7,320	7	13	Hill Creek Twin Lake
$210,300	$423,100	$563,300	$461,200	3,770	6,760	9,770	7,950	8	11	White Creek
$225,200	$452,300	$602,500	$491,800	4,060	7,270	10,510	8,540	9	12	Hill Creek Lower
$233,200	$468,200	$623,700	$508,400	4,350	7,780	11,260	9,120	10	14	Spring Creek
$249,700	$502,400	$668,900	$547,400	4,580	8,190	11,840	9,620	11	4 (b)	Silver Cr. 4 (routed, est.
$277,700	$560,400	$745,600	$613,700	4,730	8,450	12,200	9,940	12	5	Silver Cr. 5 (routed, est.
$287,100	$576,800	$770,200	$632,900	4,880	8,720	12,590	10,250	13	19	Beyers Cove
$319,200	$645,300	$858,100	$708,800	4,990	8,910	12,850	10,480	14	6	Silver Cr. 6 (routed, est.
$322,900	$652,500	$867,800	$716,300	5,100	9,110	13,140	10,710	15	22	Green Lake North (f)
$328,000	$662,600	$881,300	$726,800	5,200	9,280	13,390	10,900	16	23	Green Lake North (f)
$333,400	$673,300	$895,600	$738,000	5,290	9,440	13,620	11,080	17	20	Norwegian Bay
$336,400	$679,000	$903,300	$744,000	5,380	9,600	13,860	11,270	18	17	South Shore
$346,300	$699,700	$930,600	$767,600	5,460	9,730	14,040	11,420	19	7	Silver Cr. 7 (routed, est.
$371,500	$751,800	$999,500	$827,100	5,520	9,830	14,170	11,550	20	9	Silver C. 9 (routed, est.)
$387,100	$784,200	$1,042,200	$864,000	5,540	9,880	14,230	11,600	21	8	Silver C. 8 (routed, est.)
$387,400	$784,800	$1,043,000	$864,600	5,560	9,910	14,280	11,640	22	18	SW Shore
$388,400	$786,700	$1,045,600	$866,600	5,580	9,930	14,320	11,670	23	21	Pigeon Cove/Malcolm E

Table 5. Big Green Lake watershed simulated average annual phosphorus loads and yields (1987-98) - English units.
(as simulated with modified SWAT98 model: 3/28/2000)

Sub-id	Subwatershed Name	Current Practices CT, MT & NT(a) Area (sq. mi)	Total-Phosphorus lbs	Total-Phosphorus lb/acre	Alternative A CT > MT Total-Phos. lbs	lb/acre	percent reduced	Alternative B CT > MT MT > NT Total-Phos. lbs	lb/acre	percent reduced	Alternative C all NT (no-till) Total-Phos. lbs	lb/acre	percent reduced	Alternative D Dairy MT; Cash Crop (no-till) Total-Phos. lbs	lb/acre	percent reduced	% Ag area	Total Cost to reduce Alt. A CT>MT	Alt. B CT>MT MT>NT	Alt. C CT>NT MT>NT	Alt. D Dairy MT Cash crop all NT	Cost per lb total Phos. reduced Alt. A	Alt. B	Alt. C	Alt. D	
1	Silver Cr. 1	6.01	1,849	0.481	1,483	0.385	19.8%	1,176	0.306	36.4%	891	0.232	51.8%	1,016	0.264	45.0%	48.0%	$18,900	$39,200	$51,900	$44,800	$52	$58	$54	$54	1
2	Silver Cr. 2	4.49	2,302	0.800	1,801	0.626	21.7%	1,376	0.478	40.2%	976	0.339	57.6%	1,152	0.401	49.9%	68.2%	$20,100	$41,700	$55,100	$47,600	$40	$45	$42	$41	2
3	Silver Cr. 3	9.35	3,019	0.504	2,392	0.400	20.8%	1,905	0.318	36.9%	1,393	0.233	53.9%	1,746	0.292	42.2%	75.3%	$45,000	$88,300	$118,200	$92,300	$72	$79	$73	$73	3
4 (b)	Silver Cr. 4	5.39	2,476	0.717	2,165	0.627	12.6%	1,896	0.549	23.4%	1,644	0.476	33.6%	1,755	0.508	29.1%	46.6%	$16,500	$34,200	$45,200	$39,000	$53	$59	$54	$54	4
5	Silver Cr. 5	5.70	1,491	0.409	1,199	0.329	19.6%	944	0.259	36.7%	705	0.193	52.7%	806	0.221	46.0%	74.9%	$28,000	$58,000	$76,700	$66,200	$96	$106	$98	$97	5
6	Silver Cr. 6	5.33	1,522	0.446	1,215	0.356	20.2%	950	0.278	37.6%	703	0.206	53.8%	808	0.237	46.9%	91.7%	$32,100	$66,500	$87,900	$75,900	$104	$116	$107	$106	6
7	Silver Cr. 7	2.45	968	0.617	755	0.482	21.9%	568	0.362	41.3%	390	0.249	59.7%	469	0.299	51.6%	61.9%	$10,000	$20,700	$27,300	$23,600	$47	$52	$47	$47	7
8	Silver Cr. 8	3.10	378	0.190	309	0.155	18.4%	247	0.124	34.6%	191	0.096	49.5%	214	0.108	43.3%	76.7%	$15,600	$32,300	$42,800	$36,900	$225	$247	$229	$226	8
9	Silver Cr. 9	5.22	1,162	0.348	921	0.276	20.7%	718	0.215	38.2%	530	0.159	54.4%	612	0.183	47.4%	73.5%	$25,200	$52,200	$68,900	$59,500	$105	$118	$109	$108	9
10	Dakin Creek	6.84	1,889	0.432	1,509	0.345	20.1%	1,178	0.269	37.6%	870	0.199	54.0%	999	0.228	47.1%	82.3%	$36,900	$76,500	$101,100	$87,300	$97	$108	$99	$98	10
11	White Creek	3.39	1,329	0.612	1,055	0.486	20.6%	822	0.379	38.2%	605	0.279	54.5%	698	0.322	47.5%	83.5%	$18,600	$38,500	$50,900	$43,900	$68	$76	$70	$70	11
12	Hill Creek Lower	2.96	1,353	0.714	1,061	0.560	21.6%	839	0.443	38.0%	606	0.320	55.2%	767	0.405	43.3%	78.9%	$14,900	$29,200	$39,200	$30,600	$51	$57	$52	$52	12
13	Hill Creek Twin Lake	3.60	1,464	0.635	1,144	0.496	21.9%	903	0.392	38.3%	651	0.283	55.5%	825	0.358	43.7%	65.4%	$15,000	$29,500	$39,500	$30,900	$47	$53	$49	$48	13
14	Spring Creek	2.82	1,305	0.725	1,017	0.565	22.1%	794	0.441	39.2%	559	0.310	57.2%	726	0.403	44.4%	44.9%	$8,100	$15,900	$21,200	$16,600	$28	$31	$28	$29	14
15	Roy Creek	5.58	2,358	0.660	1,846	0.517	21.7%	1,458	0.408	38.2%	1,051	0.294	55.4%	1,334	0.374	43.4%	77.0%	$27,400	$53,800	$72,100	$56,300	$54	$60	$55	$55	15
16	Wurchs Creek	5.66	4,896	1.350	3,784	1.044	22.7%	2,895	0.799	40.9%	1,954	0.539	60.1%	2,621	0.723	46.5%	78.3%	$28,300	$55,600	$74,500	$58,100	$25	$28	$25	$26	16
17	South Shore	1.42	597	0.657	507	0.558	15.1%	438	0.482	26.7%	366	0.403	38.7%	416	0.457	30.4%	32.4%	$2,900	$5,700	$7,700	$6,000	$32	$36	$33	$33	17
18	SW Shore	0.46	189	0.640	172	0.584	8.8%	159	0.538	15.9%	145	0.489	23.5%	155	0.525	18.0%	10.2%	$300	$590	$790	$620	$18	$20	$18	$18	18
19	Beyers Cove	4.29	853	0.311	702	0.256	17.7%	585	0.213	31.4%	465	0.169	45.5%	549	0.200	35.6%	34.2%	$9,400	$18,400	$24,600	$19,200	$62	$69	$63	$63	19
20	Norwegian Bay	1.98	499	0.394	407	0.321	18.4%	338	0.267	32.3%	265	0.209	46.9%	317	0.250	36.5%	43.1%	$5,400	$10,600	$14,300	$11,200	$59	$66	$61	$61	20
21	Pigeon Cove/Malcolm Bay	2.40	331	0.216	315	0.206	4.8%	303	0.198	8.3%	291	0.190	12.1%	300	0.196	9.4%	6.4%	$970	$1,910	$2,560	$2,000	$62	$69	$64	$64	21
22	Green Lake North (f)	1.80	817	0.709	702	0.609	14.0%	613	0.532	24.9%	519	0.450	36.5%	587	0.509	28.2%	32.0%	$3,700	$7,200	$9,700	$7,500	$32	$35	$33	$33	22
23	Green Lake North (f)	1.74	772	0.693	676	0.607	12.4%	602	0.541	22.0%	526	0.472	31.9%	580	0.521	24.9%	46.2%	$5,100	$10,000	$13,500	$10,500	$53	$59	$55	$55	23
24 (c)	Puchyan	1.21	557	0.721	431	0.558	22.6%	336	0.434	39.7%	234	0.303	57.9%	306	0.396	45.0%	48.9%	$3,800	$7,400	$9,900	$7,700	$30	$33	$31	$31	24
25 (c)	Fox R./Berlin - UF06	0.98	379	0.601	299	0.474	21.2%	239	0.379	36.9%	178	0.282	53.1%	220	0.349	41.9%	77.4%	$4,900	$9,600	$12,800	$10,000	$61	$69	$64	$63	25
1	Silver Cr. 1	6.01	1,849	0.481	1,483	0.385	19.8%	1,176	0.306	36.4%	891	0.232	51.8%	1,016	0.264	45.0%	48.0%	$18,900	$39,200	$51,900	$44,800	$52	$58	$54	$54	1
2	Silver Cr. 2 (routed, est.)	4.49	1,582	0.550	1,226	0.426	22.6%	945	0.328	40.3%	681	0.237	57.0%	796	0.277	49.7%	68.2%	$20,100	$41,700	$55,100	$47,600	$56	$65	$61	$61	2
3	Silver Cr. 3 (routed, est.)	9.35	2,115	0.353	1,669	0.279	21.1%	1,348	0.225	36.3%	1,012	0.169	52.2%	1,240	0.207	41.3%	75.3%	$45,000	$88,300	$118,200	$92,300	$101	$115	$107	$106	3
4 (b)	Silver Cr. 4 (routed, est.)	5.39	1,753	0.508	1,521	0.441	13.2%	1,343	0.389	23.4%	1,177	0.341	32.9%	1,249	0.362	28.7%	46.6%	$16,500	$34,200	$45,200	$39,000	$71	$84	$78	$77	4
5	Silver Cr. 5 (routed, est.)	5.70	763	0.209	614	0.168	19.6%	503	0.138	34.1%	400	0.110	47.6%	440	0.121	42.3%	74.9%	$28,000	$58,000	$76,700	$66,200	$187	$223	$211	$205	5
6	Silver Cr. 6 (routed, est.)	5.33	573	0.168	462	0.135	19.4%	386	0.113	32.8%	316	0.093	44.9%	341	0.100	40.4%	91.7%	$32,100	$66,500	$87,900	$75,900	$269	$354	$342	$327	6
7	Silver Cr. 7 (routed, est.)	2.45	329	0.210	253	0.161	23.1%	199	0.127	39.5%	149	0.095	54.9%	170	0.108	48.5%	61.9%	$10,000	$20,700	$27,300	$23,600	$132	$159	$151	$148	7
8	Silver C. 8 (routed, est.)	3.10	171	0.086	146	0.074	14.7%	128	0.064	25.5%	112	0.056	34.6%	117	0.059	31.8%	76.7%	$15,600	$32,300	$42,800	$36,900	$621	$741	$721	$677	8
9	Silver C. 9 (routed, est.)	5.22	337	0.101	276	0.083	18.3%	236	0.071	30.0%	202	0.060	40.2%	214	0.064	36.5%	73.5%	$25,200	$52,200	$68,900	$59,500	$409	$515	$508	$482	9
	Silver Cr. sub-wsheds (1-9) (b,d)	47.06	15,168	0.504	12,241	2.601	19.3%	9,780	2.078	35.5%	7,424	1.578	51.1%	8,578	1.823	43.4%		$211,300	$433,100	$573,900	$485,800	$72	$80	$74	$74	
	Silver Cr. (Routed to Lake) (e)(g)	47.06	11,515	0.382	9,865	2.096	14.3%	8,613	1.830	25.2%	7,393	1.571	35.8%	8,018	1.704	30.4%		$211,300	$433,100	$573,900	$485,800	$128	$149	$139	$139	
	subwatersheds (10-23)	44.94	18,652	0.649	14,899	3.316	20.1%	11,928	2.654	36.1%	8,871	1.974	52.4%	10,874	2.420	41.7%		$177,100	$353,700	$471,700	$380,800	$47	$53	$48	$49	
	Subs (10-23) & Silver Cr. (Lake Loads)	91.99	30,167	0.512	24,764	2.692	17.9%	20,541	2.233	31.9%	16,264	1.768	46.1%	18,892	2.054	37.4%		$388,400	$786,700	$1,045,600	$866,600	$72	$82	$75	$77	
	subwatersheds 1-23 (drain to Lake) (b)	91.99	33,820	0.574	27,139	2.950	19.8%	21,708	2.360	35.8%	16,295	1.771	51.8%	19,452	2.115	42.5%		$388,400	$786,700	$1,045,600	$866,600	$58	$65	$60	$60	
	all subwatersheds (1-25)	94.19	34,756	0.577	27,889	2.959	19.8%	22,283	2.366	35.9%	16,707	1.774	51.9%	19,978	2.121	42.5%		$397,000	$803,600	$1,068,300	$884,400	$58	$64	$59	$60	

(a) Assumptions:
Cash Crop Region: 1/3 dairy, 2/3 cash crop — Dairy Region: 1/2 dairy, 1/2 cash crop
cash crop rotation: corn, soybeans — dairy rotation: corn-grain, corn-silage, 4 years alfafa

Conventional Practice (CT) — corn - fall moldboard plow; soybeans - fall chisel plow
Mulch Till (MT) — corn is chisel plowed, soybeans are field cultivated in spring
No-till (NT) — no cultivation except planting
* assumed primary tillage for alfalfa in dairy rotation is same as for corn crop

	Dairy	Cash Crop
Alt. A	CT>MT	CT>MT
Alt. B	CT>MT MT>NT	CT>MT MT>NT
Alt. C	all no-till (NT)	all no-till (NT)
Alt. D	CT>MT	all no-till (NT)

	CT	MT	NT
Dairy - present practices	61.0%	36.0%	3.0%
Cash Crop - present practices	36.0%	46.0%	18.0%
Combined Present practices	46.2%	41.7%	12.1%
Alternative A		87.9%	12.1%
Alternative B		46.2%	53.8%
Alternative C			100.0%
Alternative D			

Cost Assumptions

Cost of BMP	CT>MT	MT>NT	CT>NT
dairy: $/acre	$15	$15	$25
cash crop: $/acre	$30	$30	$50

(b) Doesn't include Ripon MTP discharge of: 1,361 kg of total phosphorus per year
(c) Drains outside Green Lake Watershed
(d) Silver Cr. subwatershed loads simply added, not routed, and without Ripon MTP discharge
(e) Silver Cr. watershed, subwatershed loads routed to Lake inlet; includes Ripon MTP & effect of Ripon Mill Pond
(f) Only a portion of the loads from subwatersheds 22 & 23 actually enter into Green Lake
(g) Reduction percentages for phosphorus from Silver Cr. are lower than elsewhere, in part because Ripon MTP load remains constant, and is a significant fraction of the total load.

Table 4. Big Green Lake watershed simulated average annual TSS loads and yields (1987-98) - English units.
(as simulated with modified SWAT98 model: 3/28/2000)

Sub-id	Subwatershed Name	Current Practices CT, MT & NT(a) Area (sq. mi)	TSS tons	TSS t/acre	Alternative A (a) CT > MT TSS tons	t/acre	percent reduced	Alternative B (a) CT > MT MT > NT TSS tons	t/acre	percent reduced	Alternative C (a) all NT (no-till) TSS tons	t/acre	percent reduced	Alternative D (a) Dairy MT; Cash Crop (no-till) TSS tons	t/ha	percent reduced	% Ag area	Total Cost to reduce Alt. A CT>MT	Alt. B CT>MT MT>NT	Alt. C CT>NT MT>NT	Alt. D Dairy MT Cash crop all NT	Cost per ton TSS reduced Alt. A	Alt. B	Alt. C	Alt. D	
1	Silver Cr. 1	6.01	238	0.062	187	0.048	21.6%	142	0.037	40.1%	100	0.026	57.8%	120	0.031	49.4%	48.0%	$18,900	$39,200	$51,900	$44,800	$367	$410	$377	$381	1
2	Silver Cr. 2	4.49	257	0.090	198	0.069	23.2%	146	0.051	43.4%	96	0.034	62.5%	120	0.042	53.6%	68.2%	$20,100	$41,700	$55,100	$47,600	$337	$374	$342	$345	2
3	Silver Cr. 3	9.35	311	0.052	239	0.040	23.4%	180	0.030	42.1%	117	0.020	62.3%	163	0.027	47.6%	75.3%	$45,000	$88,300	$118,200	$92,300	$617	$673	$609	$623	3
4 (b)	Silver Cr. 4	5.39	265	0.077	229	0.066	13.5%	198	0.057	25.3%	168	0.049	36.8%	182	0.053	31.5%	46.6%	$16,500	$34,200	$45,200	$39,000	$459	$509	$464	$466	4
5	Silver Cr. 5	5.70	155	0.043	120	0.033	22.6%	89	0.024	42.8%	59	0.016	62.2%	73	0.020	53.1%	74.9%	$28,000	$58,000	$76,700	$66,200	$800	$873	$795	$803	5
6	Silver Cr. 6	5.33	183	0.054	141	0.041	23.1%	103	0.030	43.8%	66	0.019	63.8%	84	0.025	54.4%	91.7%	$32,100	$66,500	$87,900	$75,900	$758	$827	$751	$761	6
7	Silver Cr. 7	2.45	59	0.038	45	0.029	23.4%	33	0.021	44.2%	21	0.014	63.9%	27	0.017	55.0%	61.9%	$10,000	$20,700	$27,300	$23,600	$721	$789	$720	$723	7
8	Silver Cr. 8	3.10	28	0.014	21	0.011	23.7%	16	0.008	44.2%	10	0.005	64.7%	13	0.006	55.3%	76.7%	$15,600	$32,300	$42,800	$36,900	$2,348	$2,604	$2,357	$2,380	8
9	Silver Cr. 9	5.22	141	0.042	108	0.032	23.5%	78	0.023	44.4%	51	0.015	64.0%	64	0.019	54.9%	73.5%	$25,200	$52,200	$68,900	$59,500	$763	$834	$765	$771	9
10	Dakin Creek	6.84	210	0.048	163	0.037	22.5%	120	0.027	42.9%	79	0.018	62.3%	98	0.022	53.5%	82.3%	$36,900	$76,500	$101,100	$87,300	$782	$849	$773	$778	10
11	White Creek	3.39	159	0.073	123	0.057	22.6%	91	0.042	43.0%	61	0.028	62.0%	75	0.034	53.0%	83.5%	$18,600	$38,500	$50,900	$43,900	$512	$563	$515	$520	11
12	Hill Creek Lower	2.96	179	0.094	136	0.072	24.0%	102	0.054	43.0%	66	0.035	63.3%	92	0.049	48.5%	78.9%	$14,900	$29,200	$39,200	$30,600	$347	$380	$346	$353	12
13	Hill Creek Twin Lake	3.60	202	0.088	154	0.067	23.8%	116	0.050	42.4%	76	0.033	62.4%	105	0.046	47.7%	65.4%	$15,000	$29,500	$39,500	$30,900	$313	$345	$314	$321	13
14	Spring Creek	2.82	130	0.072	100	0.056	22.8%	77	0.043	40.6%	52	0.029	59.7%	70	0.039	45.9%	44.9%	$8,100	$15,900	$21,200	$16,600	$274	$301	$273	$279	14
15	Roy Creek	5.58	289	0.081	220	0.062	23.7%	166	0.047	42.4%	109	0.030	62.3%	151	0.042	47.7%	77.0%	$27,400	$53,800	$72,100	$56,300	$400	$440	$401	$409	15
16	Wurchs Creek	5.66	343	0.095	262	0.072	23.7%	196	0.054	42.9%	126	0.035	63.2%	177	0.049	48.4%	78.3%	$28,300	$55,600	$74,500	$58,100	$348	$378	$343	$349	16
17	South Shore	1.42	89	0.098	72	0.080	18.9%	59	0.065	34.0%	45	0.049	50.2%	55	0.061	38.4%	32.4%	$2,900	$5,700	$7,700	$6,000	$172	$188	$172	$175	17
18	SW Shore	0.46	12	0.039	10	0.035	10.3%	9	0.032	18.1%	8	0.026	26.6%	9	0.031	20.0%	10.2%	$300	$590	$790	$620	$253	$283	$257	$269	18
19	Beyers Cove	4.29	148	0.054	122	0.044	17.6%	101	0.037	31.7%	79	0.029	46.4%	95	0.035	35.7%	34.2%	$9,400	$18,400	$24,600	$19,200	$360	$392	$358	$363	19
20	Norwegian Bay	1.98	81	0.064	65	0.051	20.3%	52	0.041	36.3%	38	0.030	53.2%	48	0.038	40.5%	43.1%	$5,400	$10,600	$14,300	$11,200	$328	$358	$330	$340	20
21	Pigeon Cove/Malcolm Bay	2.40	42	0.027	39	0.025	6.5%	37	0.024	12.5%	34	0.022	18.8%	36	0.023	14.2%	6.4%	$970	$1,910	$2,560	$2,000	$365	$384	$326	$338	21
22	Green Lake North (f)	1.80	96	0.083	84	0.072	12.6%	74	0.064	23.0%	63	0.055	33.8%	71	0.062	25.8%	32.0%	$3,700	$7,200	$9,700	$7,500	$302	$327	$300	$303	22
23	Green Lake North (f)	1.74	88	0.079	73	0.065	17.7%	60	0.054	31.4%	47	0.043	46.1%	57	0.051	35.2%	46.2%	$5,100	$10,000	$13,500	$10,500	$328	$362	$332	$339	23
24 (c)	Puchyan	1.21	52	0.067	39	0.051	24.0%	30	0.039	42.2%	20	0.025	61.9%	27	0.035	47.3%	48.9%	$3,800	$7,400	$9,900	$7,700	$308	$339	$309	$315	24
25 (c)	Fox R./Berlin - UF06	0.98	70	0.111	53	0.085	23.5%	40	0.064	41.9%	27	0.043	61.4%	37	0.059	46.9%	77.4%	$4,900	$9,600	$12,800	$10,000	$269	$329	$299	$306	25
																	48.0%	$18,900	$39,200	$51,900	$44,800					
																	68.2%	$20,100	$41,700	$55,100	$47,600					
																	75.3%	$45,000	$88,300	$118,200	$92,300					
																	46.6%	$16,500	$34,200	$45,200	$39,000					
																	74.9%	$28,000	$58,000	$76,700	$66,200					
																	91.7%	$32,100	$66,500	$87,900	$75,900					
																	61.9%	$10,000	$20,700	$27,300	$23,600					
																	76.7%	$15,600	$32,300	$42,800	$36,900					
																	73.5%	$25,200	$52,200	$68,900	$59,500					
	Silver Cr. sub-wsheds (1-9) (b,d)	47.06	1,639	0.054	1,288	0.043	21.4%	985	0.033	39.9%	689	0.023	58.0%	844	0.028	48.5%		$211,300	$433,100	$573,900	$485,800	$802	$862	$804	$811	
	Silver Cr. (Routed to Lake) (e)(g)	47.06	828	0.028	724	0.024	12.6%	606	0.020	26.9%	480	0.016	42.1%	545	0.018	34.2%		$211,300	$433,100	$573,900	$485,800	$2,019	$1,944	$1,646	$1,714	
	subwatersheds (10-23)	44.94	2,068	0.072	1,623	0.056	21.5%	1,261	0.044	39.0%	884	0.031	57.3%	1,141	0.040	44.9%		$177,100	$353,700	$471,700	$380,800	$398	$438	$398	$411	
	Subs (10-23) & Silver Cr. (Lake Loads)	91.99	2,896	0.315	2,346	0.255	19.0%	1,866	0.203	35.6%	1,364	0.148	52.9%	1,686	0.183	41.8%		$388,400	$786,700	$1,045,600	$866,600	$706	$764	$682	$716	
	subwatersheds 1-23 (drain to Lake) (b)	91.99	3,707	0.063	2,911	0.049	21.5%	2,246	0.038	39.4%	1,573	0.027	57.6%	1,985	0.034	46.5%		$388,400	$786,700	$1,045,600	$866,600	$488	$538	$490	$503	
	all subwatersheds (1-25)	94.19	3,828	0.064	3,003	0.050	21.5%	2,316	0.038	39.5%	1,620	0.027	57.7%	2,046	0.034	46.5%		$397,000	$803,600	$1,068,300	$884,400	$481	$531	$484	$497	

(a) Assumptions:
Cash Crop Region: 1/3 dairy, 2/3 cash crop — Dairy Region: 1/2 dairy, 1/2 cash crop
cash crop rotation: corn, soybeans — dairy rotation: corn-grain, corn-silage, 4 years alfafa

18976840
2381970

Conventional Practice (CT) — corn - fall moldboard plow; soybeans - fall chisel plow
Mulch Till (MT) — corn is chisel plowed, soybeans are field cultivated in spring
No-till (NT) — no cultivation except planting
* assumed primary tillage for alfalfa in dairy rotation is same as for corn crop

	Dairy	Cash Crop
Alt. A	CT>MT	CT>MT
Alt. B	CT>MT MT>NT	CT>MT MT>NT
Alt. C	all no-till (NT)	all no-till (NT)
Alt. D	CT>MT	all no-till (NT)

	CT	MT	NT
Dairy - present practices	61.0%	36.0%	3.0%
Cash Crop - present practices	36.0%	46.0%	18.0%
Combined Present practices	46.2%	41.7%	12.1%
Alternative A		87.9%	12.1%
Alternative B		46.2%	53.8%
Alternative C			100.0%
Alternative D			

Cost Assumptions

Cost of BMP	CT>MT	MT>NT	CT>NT
dairy: $/acre	$15	$15	$25
cash crop: $/acre	$30	$30	$50

(b) Doesn't include Ripon MTP discharge of: 1,361 kg of total phosphorus per year
(c) Drains outside Green Lake Watershed
(d) Silver Cr. subwatershed loads simply added, not routed, and without Ripon MTP discharge
(e) Silver Cr. watershed, subwatershed loads routed to Lake inlet; includes Ripon MTP & effect of Ripon Mill Pond
(f) Only a portion of the loads from subwatersheds 22 & 23 actually enter into Green Lake
(g) Reduction percentages for phosphorus from Silver Cr. are lower than elsewhere, in part because Ripon MTP load remains constant, and is a significant fraction of the total load.

Table 6. Phosphorus Loads Routed to Big Green Lake, and Cost to Reduce Loads: Ranked by Total Reduction.

		Current Practices CT, MT and NT (a)			Cost/lb Phos. reduced				Alternative A CT > MT				Alternative B CT > MT MT > NT			
		Area (sq. mi)	Total-Phosphorus lbs	lb/acre	Alt. A	Alt. B	Alt. C	Alt. D	Total Phosphorus lbs	lb/acre	percent reduced	total reduced	Total Phosphorus lbs	lb/acre	percent reduced	total reduced
16	Wurchs Creek	5.63	4,896	1.350	$25	$28	$25	$26	3,784	1.044	22.7%	1,112	2,895	0.799	40.9%	2,001
15	Roy Creek	5.53	2,356	0.660	$54	$60	$55	$55	1,846	0.517	21.7%	511	1,458	0.408	38.2%	900
10	Dakin Creek	6.84	1,889	0.432	$97	$108	$99	$98	1,509	0.345	20.1%	381	1,178	0.269	37.6%	711
3	Silver Cr. 3 (routed, est.)	9.35	2,115	0.353	$101	$115	$107	$106	1,669	0.279	21.1%	446	1,348	0.225	36.3%	767
1	Silver Cr. 1	8.01	1,849	0.481	$52	$58	$54	$54	1,483	0.385	19.8%	366	1,176	0.306	36.4%	673
2	Silver Cr. 2 (routed, est.)	4.49	1,582	0.550	$56	$65	$61	$60	1,226	0.426	22.6%	357	945	0.328	40.3%	638
13	Hill Creek Twin Lake	3.60	1,464	0.635	$47	$53	$49	$48	1,144	0.496	21.9%	320	903	0.392	38.3%	560
11	White Creek	3.39	1,329	0.612	$68	$76	$70	$70	1,055	0.486	20.6%	274	822	0.379	38.2%	507
12	Hill Creek Lower	2.93	1,353	0.714	$51	$57	$52	$52	1,061	0.560	21.6%	292	839	0.443	38.0%	514
14	Spring Creek	2.82	1,306	0.725	$28	$31	$28	$29	1,017	0.565	22.1%	288	794	0.441	39.2%	511
4	Silver Cr. 4 (routed, est.)	5.39	1,753	0.508	$71	$83	$78	$77	1,521	0.441	13.2%	232	1,343	0.389	23.4%	410
5	Silver Cr. 5 (routed, est.)	5.70	763	0.209	$187	$223	$211	$205	614	0.168	19.6%	149	503	0.138	34.1%	260
19	Beyers Cove	4.29	853	0.311	$62	$69	$63	$63	702	0.256	17.7%	151	585	0.213	31.4%	268
6	Silver Cr. 6 (routed, est.)	5.33	573	0.168	$288	$354	$342	$327	462	0.135	19.4%	111	386	0.113	32.8%	188
22	Green Lake North (f)	1.60	817	0.709	$32	$35	$32	$33	702	0.609	14.0%	115	613	0.532	24.9%	204
23	Green Lake North (f)	1.74	772	0.693	$53	$59	$55	$55	676	0.607	12.4%	96	602	0.541	22.0%	170
20	Norwegian Bay	1.93	499	0.394	$59	$66	$61	$61	407	0.321	18.4%	92	338	0.267	32.3%	161
17	South Shore	1.42	597	0.657	$33	$36	$33	$33	507	0.558	15.1%	90	438	0.482	26.7%	159
7	Silver Cr. 7 (routed, est.)	2.45	329	0.210	$131	$159	$151	$147	253	0.161	23.1%	76	199	0.127	39.5%	130
9	Silver Cr. 9 (routed, est.)	5.22	337	0.101	$408	$515	$508	$482	276	0.083	18.3%	62	236	0.071	30.0%	101
8	Silver Cr. 8 (routed, est.)	3.10	171	0.086	$621	$742	$721	$677	146	0.074	14.7%	25	128	0.064	25.5%	44
18	SW Shore	0.46	189	0.640	$18	$20	$18	$18	172	0.584	8.8%	17	159	0.538	15.9%	30
21	Pigeon Cove/Malcolm Bay	2.40	331	0.216	$62	$69	$64	$64	315	0.206	4.8%	16	303	0.198	8.3%	28

	Alternative C all NT (no-till)				Alternative D Dairy MT; Cash Crop (no-till)				Total Cost to reduce Phosphorus Load					
	Total Phosphorus lbs	lb/acre	percent reduced	total reduced	Total Phosphorus lbs	lb/acre	percent reduced	total reduced	Alt. A CT>MT	Alt. B CT>MT MT>NT	Alt. C CT>NT MT>NT	Alt. D Dairy MT Cash crop all NT	rank	
Wurchs Creek	1,954	0.539	60.1%	2,942	2,621	0.723	46.5%	2,275	$28,325	$55,585	$74,468	$58,141	1	16
Roy Creek	1,051	0.294	55.4%	1,306	1,334	0.374	43.4%	1,023	$27,426	$53,821	$72,105	$56,296	2	15
Dakin Creek	870	0.199	54.0%	1,019	999	0.228	47.1%	890	$36,898	$76,495	$101,094	$87,295	4	10
Silver Cr. 3 (routed, est.)	1,012	0.169	52.2%	1,103	1,240	0.207	41.3%	874	$44,952	$88,213	$118,181	$92,269	3	3
Silver Cr. 1	891	0.232	51.8%	958	1,016	0.264	45.0%	833	$18,949	$39,285	$51,918	$44,831	5	1
Silver Cr. 2 (routed, est.)	681	0.237	57.0%	902	796	0.277	49.7%	787	$20,110	$41,691	$55,098	$47,577	6	2
Hill Creek Twin Lake	651	0.283	55.5%	812	825	0.358	43.7%	639	$15,034	$29,505	$39,527	$30,861	7	13
White Creek	605	0.279	54.5%	724	698	0.322	47.5%	631	$18,568	$38,494	$50,872	$43,929	10	11
Hill Creek Lower	606	0.320	55.2%	747	767	0.405	43.3%	586	$14,910	$29,260	$39,199	$30,605	8	12
Spring Creek	559	0.310	57.2%	746	726	0.403	44.4%	579	$8,076	$15,850	$21,234	$16,579	9	14
Silver Cr. 4 (routed, est.)	1,177	0.341	32.9%	576	1,249	0.362	26.7%	504	$16,495	$34,198	$45,195	$39,026	11	4 (b)
Silver Cr. 5 (routed, est.)	400	0.110	47.6%	363	440	0.121	42.3%	323	$28,002	$58,052	$76,720	$66,247	13	5
Beyers Cove	465	0.169	45.5%	388	549	0.200	35.6%	304	$9,362	$18,371	$24,613	$19,216	12	19
Silver Cr. 6 (routed, est.)	316	0.093	44.9%	257	341	0.100	40.4%	232	$32,075	$66,498	$87,881	$75,885	15	6
Green Lake North (f)	519	0.450	36.5%	298	587	0.509	28.2%	230	$3,677	$7,215	$9,666	$7,547	14	22
Green Lake North (f)	526	0.472	31.9%	246	580	0.521	24.8%	192	$5,130	$10,066	$13,486	$10,529	16	23
Norwegian Bay	265	0.209	46.9%	234	317	0.250	36.5%	182	$5,444	$10,682	$14,311	$11,173	17	20
South Shore	366	0.403	38.7%	231	416	0.457	30.4%	182	$2,939	$5,769	$7,729	$6,034	18	17
Silver Cr. 7 (routed, est.)	149	0.095	54.9%	181	170	0.108	48.5%	160	$9,957	$20,642	$27,280	$23,556	19	7
Silver Cr. 9 (routed, est.)	202	0.060	40.2%	136	214	0.064	36.6%	124	$25,150	$52,141	$68,907	$59,501	20	9
Silver Cr. 8 (routed, est.)	112	0.056	34.6%	59	117	0.059	31.8%	55	$15,605	$32,352	$42,755	$36,919	21	8
SW Shore	145	0.489	23.5%	44	155	0.525	18.0%	34	$300	$589	$790	$617	22	18
Pigeon Cove/Malcolm Bay	291	0.190	12.1%	40	300	0.196	9.4%	31	$975	$1,913	$2,563	$2,001	23	21