Simulated TSS and Phosphorus Export to

Lake Winnebago and Green Bay from the Fox-Wolf River Basin

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Objective

The primary objective of the modeling project was to estimate total suspended solids (TSS) and total phosphorus export to Green Bay so that the relative loads within the Fox-Wolf River Basin could be compared. To accomplish this objective, the Soil and Water Assessment Tool (SWAT) and a GIS model were applied to the drainage basin. SWAT was developed by the USDA Agricultural Research Service to improve the technology used in the SWRRBWQ model (Arnold et al. 1996). SWAT is a computer 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 at the following Internet address: http://www.brc.tamus.edu/swat/.

This report describes: (1) overall GIS-SWAT approach used to derive TSS and phosphorus loads to Green Bay; (2) GIS layers, methods and other inputs; (3) SWAT methods; (4) delivery ratio and export coefficients; (5) simulated loads to watershed outlets, Green Bay and Lake Winnebago; and (6) other loads, sensitivity analysis and caveats; and (7) summary and conclusions.

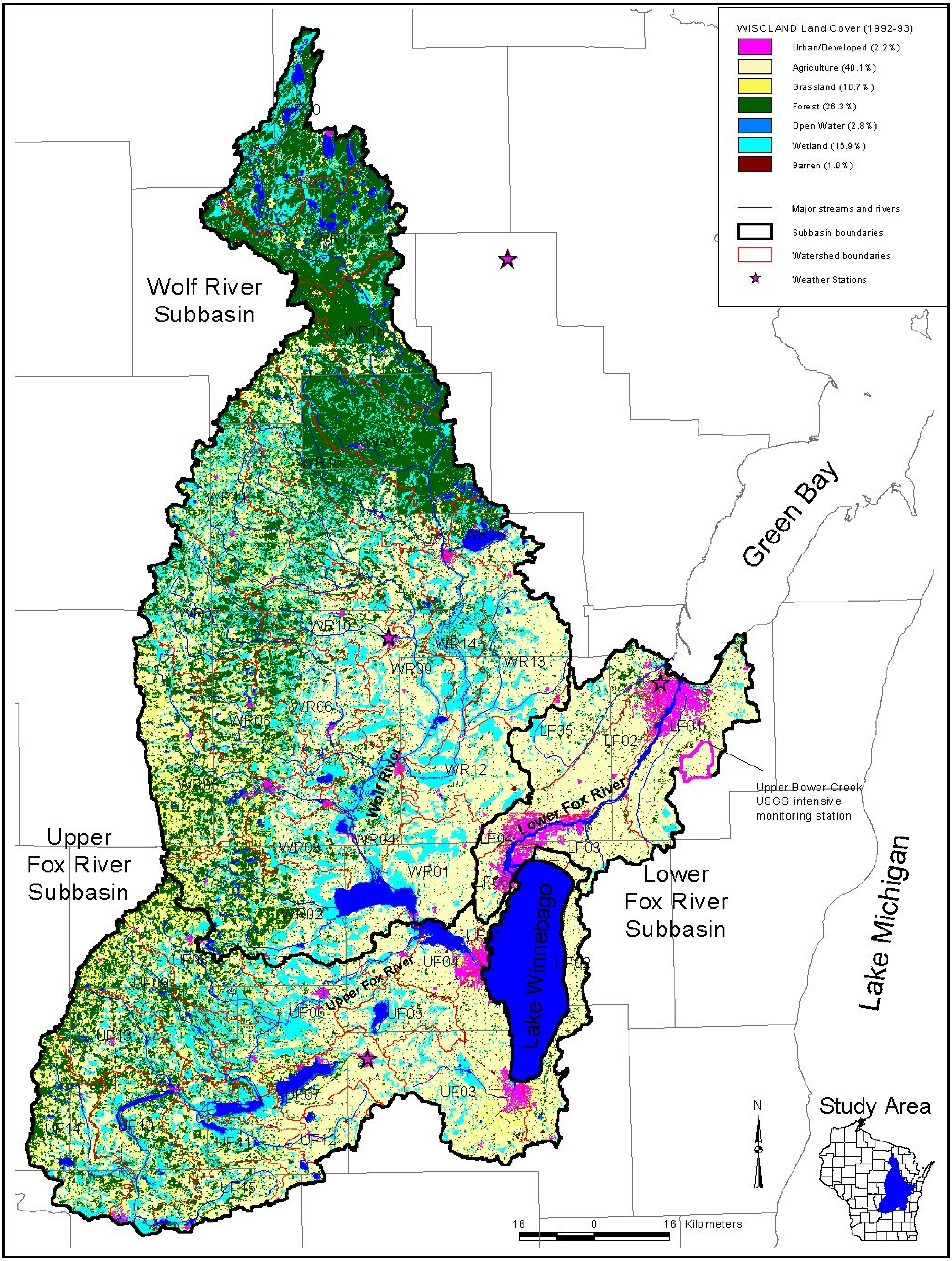
CHAPTER 1. GIS-SWAT MODELING OVERVIEW

Basin description

The Fox-Wolf River Basin drains 16,400 km^2 of Northeastern Wisconsin eventually emptying into Lower Green Bay at the Fox River mouth (Figure 1). In this report, the Fox-Wolf River Basin shall be referred to as the "Basin". The Basin is sub-divided by the Wisconsin Department of Natural Resources (WDNR) into three major hydrologic units (subbasins): (1) LF - Lower Fox River (1,600 km^2); (2) UF - Upper Fox River (5,100 km^2); and (3) WR - Wolf River (9,400 km^2). These subbasins are further delineated by the WDNR into a total of 41 watersheds as shown in Figure 1. The eastern two-thirds of the Basin is dominated by agriculture, primarily dairy-farm operations, northern watersheds are primarily forest, while the western watersheds are mixed agriculture and forests (Figure 1). Overall, agriculture is the dominant land cover in the basin (40%), followed by forest (26%) and wetland (18%).

Excessive algae and suspended solids in lower Green Bay and Lake Winnebago (Figure 1) reduce water clarity and impair the major uses of these water bodies (Harris 1993, WDNR 1993a). The lower Green Bay Remedial Action Plan (RAP) identified the reduction of phosphorus and suspended solids loadings to the Fox-Wolf Basin and the Green Bay Area of Concern as one of three priority issues necessary for improving the water quality of Green Bay (WDNR 1993a). Nearly 70% of the annual phosphorus load to Green Bay is from the Fox River (Klump et al. 1997). To reach the water quality goals for total phosphorus and suspended sediment in lower Green Bay, the Green Bay RAP Science and Technical Advisory Committeee recommended that total external loads of both constituents should be reduced by 50% (Green Bay RAP 2000).

Figure 1. Fox-Wolf River Basin Watersheds and Land Cover (WISCLAND 1992-1993) .



Similarly, the Winnebago Comprehensive Watershed Plan recommended that phosphorus loadings to the Winnebago Pool system be reduced by 33% to improve water clarity and reduce the frequency of algal blooms (WDNR 1989). At the watershed level, a majority have been ranked as high priority watersheds by the Wisconsin Department of Natural Resources (WDNR) due to impaired surface water quality related to nonpoint source pollution: all six watersheds in the Lower Fox River Subbasin, 7 of the 15 watersheds in the Upper Fox River, and 9 of the 20 watersheds in the Wolf River Subbasin

Model Overview

The overall approach used to estimate TSS and phosphorus loads in the Basin was to generate unit-area loads (UALs) with the SWAT model, which were applied to a GIS model that used land cover, soils and climate GIS layers to represent the 128 combinations of UALs that were determined for the Basin. Figure 2 summarizes the overall approach. The GIS model was used to assign to each 30 square meter grid cell in the Basin the appropriate unit-area load on the basis of which combination of 8 land cover types, 4 soil types, and 4 climates were present in that cell (8 * 4 * 4 = 128 combinations). Land cover within the Basin was determined from the Level 3 classification of the Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data 1992 land cover image (WISCLAND), which was based on LANDSAT Thematic Mapper images. Reclassification of the Level 3 classification produced eight land covers which were simulated by both SWAT and the GIS model: corn, forage/alfalfa, other row crops/soybeans, urban, grassland, forest, wetland and water.

Long-term unit-area loads were simulated with the SWAT model by applying it to a calibration watershed for the 1978-92 climatic period using a variety of inputs to generate results that were representative of 128 different combinations of land cover, soils and climate. Apart from these three major characteristics, overland slope and soil erodibility were accounted for by normalizing SWAT-simulated unit-area loads by dividing them by the Universal Soil Loss Equation (USLE) slope/slope-length factor (LS-factor) and the USLE soil erodibility factor (K-factor) of the Upper Bower Creek calibration watershed (35.6 sq. km) to provide base-level normalized unit area loads ($\mathrm{UAL}_{\text{n-base}}$). A modified form of the USLE is used by SWAT, and it is described in Chapter 3.

$$\mathrm{UAL}_{\text{n-base}} = (\text{8 land covers} * \text{4 soil permeabilities} * \text{4 climates}) \text{ modeled as SWAT norm. UAL's} \qquad \text{(Eq. 1)}$$

These loads were then multiplied by LS-factor and K-factor GIS layers within the GIS model to produce non-normalized (actual) base-level unit-area loads ($\mathrm{UAL}_{\text{base}}$).

$$\mathrm{UAL}_{\text{base}} = \mathrm{UAL}_{\text{n-base}} * \text{LS-factor} * \text{K-factor} \qquad \text{(Eq. 2)}$$

To further refine current load estimates, another GIS layer was created to reflect the average crop residue levels estimated to be present within each watershed in 1999 (TRANSECT survey data). Since the base-level unit-area loads assumed conventional (high tillage) conditions, the unit-area loads in the GIS model were reduced according to the percentage of each of the four crop residue categories reported in each watershed (Table 1). The fractional reductions shown in Table 1 were simulated with the SWAT model by applying different tillage practices to the calibration watershed.

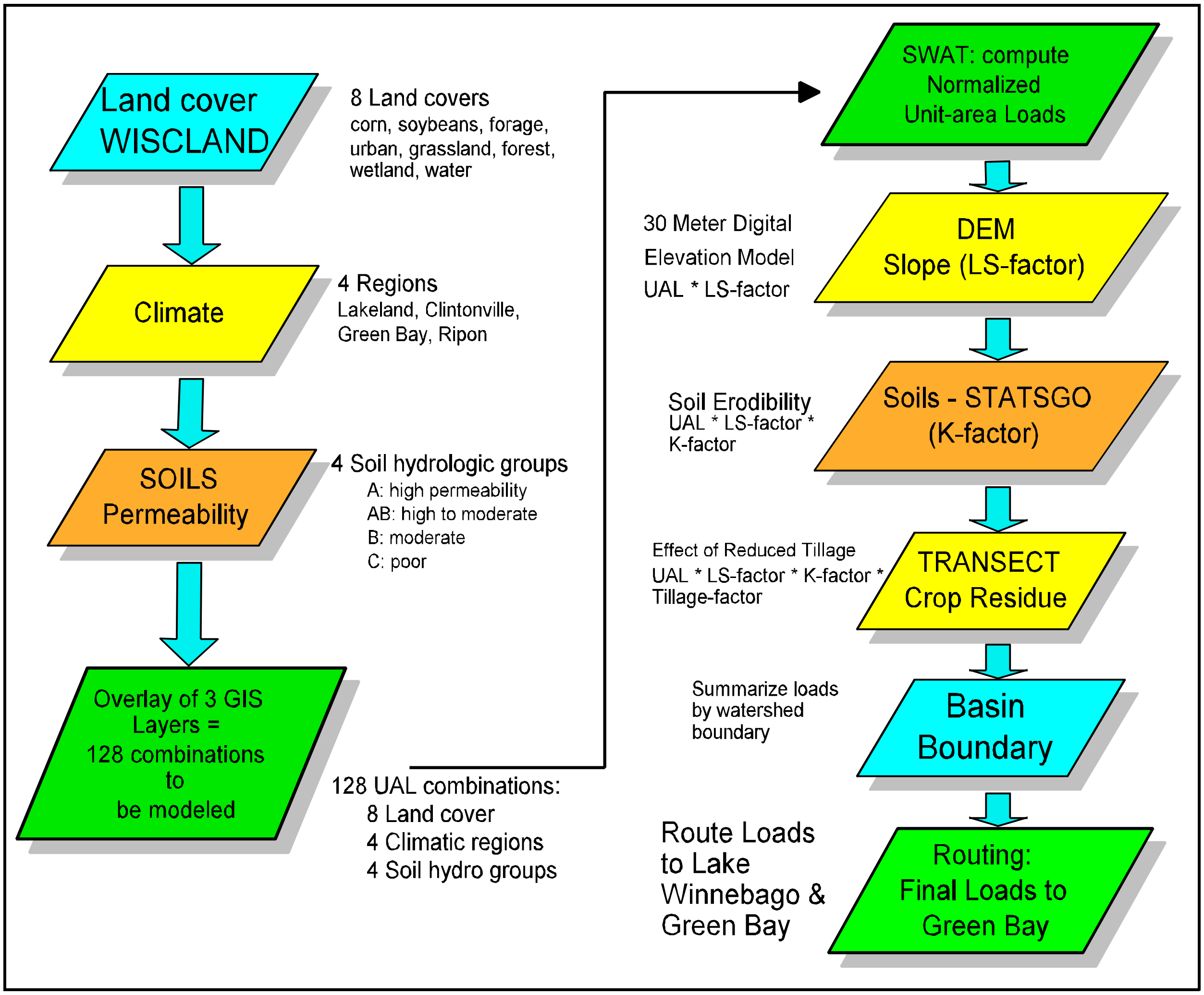


Figure 2. Overview of SWAT-GIS modeling scheme.

Table 1. Simulated reductions based on estimated crop residue present from Transect Surveys.

Crop Residue %	Tillage	Simulated Reduction					
		Corn			Soybeans/other row crops		
		TSS	part P	sol P	TSS	part P	sol P
0-15%	conventional	0.000	0.000	0.000	0.000	0.000	0.000
16-30%	low mulch-till	0.242	0.234	0.000	0.137	0.140	-0.056
>30%	mulch-till	0.483	0.469	-0.020	0.274	0.280	-0.111
N/A	no-till/ridge till	0.747	0.658	-0.223	0.599	0.520	-0.302

Each UAL_{base} within the GIS model was then reduced according to the proportion of conservation tillage reported to be present in each watershed by the Transect Survey data. Reductions listed in Table 1 for the corn crop would have been higher had corn silage not been included in the rotation. From the 1999 Transect survey data, an estimate of the crop residue present during the 1978-92 period was made, and used to simulate 1978-92 loads so they could be compared to loads computed by the U.S. Geological Survey (USGS) and others.

The final loads represent unit-area loads that reflect the land cover, soils, climatic region, topography and tillage practices presumed to be present in each grid cell for two periods: 1978-92; and current 1999 conditions. To obtain the estimated loads of TSS and particulate phosphorus that are delivered to the watershed outlet, Green Bay and Lake Winnebago, the unit-area loads were multiplied by a delivery ratio (DR) which roughly accounts for deposition in stream channels, impoundments and small lakes:

$$DR = DA^{-0.15}/DA_{UBC}^{-0.15} \qquad \text{(Eq. 3)}$$

where DA is the drainage area of the watershed in square kilometers, or the cumulative drainage area from the watershed to Green Bay or Lake Winnebago (i.e., the load must travel from the watershed outlet to Green Bay or Lake Winnebago). To account for the delivery ratio inherent to the loads generated in the calibration watershed, the un-weighted delivery ratio ($DA^{-0.15}$) was divided by the delivery ratio ($DA_{UBC}^{-0.15}$) of the Upper Bower Creek calibration watershed (35.6 sq. km).

These loads were then summed for each watershed to give an estimate of their respective contribution to Green Bay. In general, the DR decreases inversely as approximately the 0.2 power of the drainage area; that is, the delivery ratio decreases as drainage area increases (USDA-SCS 1983).

The delivery ratio exponent (-0.15) was set so that simulated loads for the Fox River and Menominee River (in Green Bay drainage basin) corresponded closely to the loads estimated by

USGS with a constituent transport model developed by Robertson (1996) which relied on continuous flow data and available concentration data. Where loads from point sources were determined to be significant, they were added to the non-point load estimates solely to compare the simulated loads to measured loads, or load estimates from other sources. Thus, Figures 4 through 8 and Table 4 show only the non-point loads, to facilitate relative comparisons of non-point sources. The delivery ratio is not intended to provide precise estimates at specific locations between watershed outlets and Green Bay; rather, it is assumed to integrate the effects of stream deposition/aggradation, and the effect of various lakes, reservoirs, dams and other impoundments that are located throughout the system.

Phosphorus trapping in the Winnebago pool system was set to correspond to deposition rates determined by Pierre-Gustin (1995). These same trapping efficiencies were also applied to determine the amount of TSS that was trapped in the Winnebago pool system because the composition of the suspended solids entering the Winnebago pool system is unlikely to be the same as that exiting the system. The local effects of impoundments (lakes, dams etc.), wetlands, and natural or man-made riparian filter strips were not directly considered in this model. Instead, some of these effects were partially accounted for through gross lumping or through the delivery ratio. The complex nature of the effects of these factors combined with the scale and time constraints of this project did not permit a thorough investigation of the these factors.

Loads were derived for the 1978-92 period so they could be compared to measured values; whereas, the simulated 1999 loads were generated to compare the relative contributions to Green Bay from watersheds in the Basin.

CHAPTER 2. GIS METHODS/ANALYSIS AND INPUTS

Application of Geographical Information System: PC ARC/INFO (vector-based GIS), ARCVIEW, and ARCVIEW Spatial Analyst (grid-based GIS) were used to construct, process and analyze GIS coverages. All of these software programs were developed by Environmental Systems Research Institute, Inc. (ESRI). All raster-based layers were processed with the same 30 square meter cell resolution of the WISCLAND land cover layer.

Land Cover Analysis with WISCLAND Classified Land Cover Image: Land cover within the Basin was determined from the Level 3 classification of the 1992 WISCLAND land cover image, which was obtained from the WDNR and is based on LANDSAT Thematic Mapper images. The 1992 land cover for the Basin, based on a six level classification of the WISCLAND land cover image, is illustrated in Figure 1. Most of the southern and southeastern watersheds are predominantly agricultural, while forest is the dominant land cover is in the north and northwestern watersheds.

The WISCLAND classified land cover image was reclassified to generate 8 major land covers/uses which were modeled with SWAT: agriculture (corn, forage, other row crops), urban, grassland, forest, wetland and surface water. For this project, it was assumed that "other row crops" was either soybeans or another fragile crop, so this land cover was simulated as soybeans in the SWAT model.

Watershed Delineation: The 1:24,000 statewide watershed boundary GIS layer (wsdnt024), provided by the Wisconsin Department of Natural Resources (WDNR) determined the Basin boundary, subbasin boundaries and watershed boundaries.

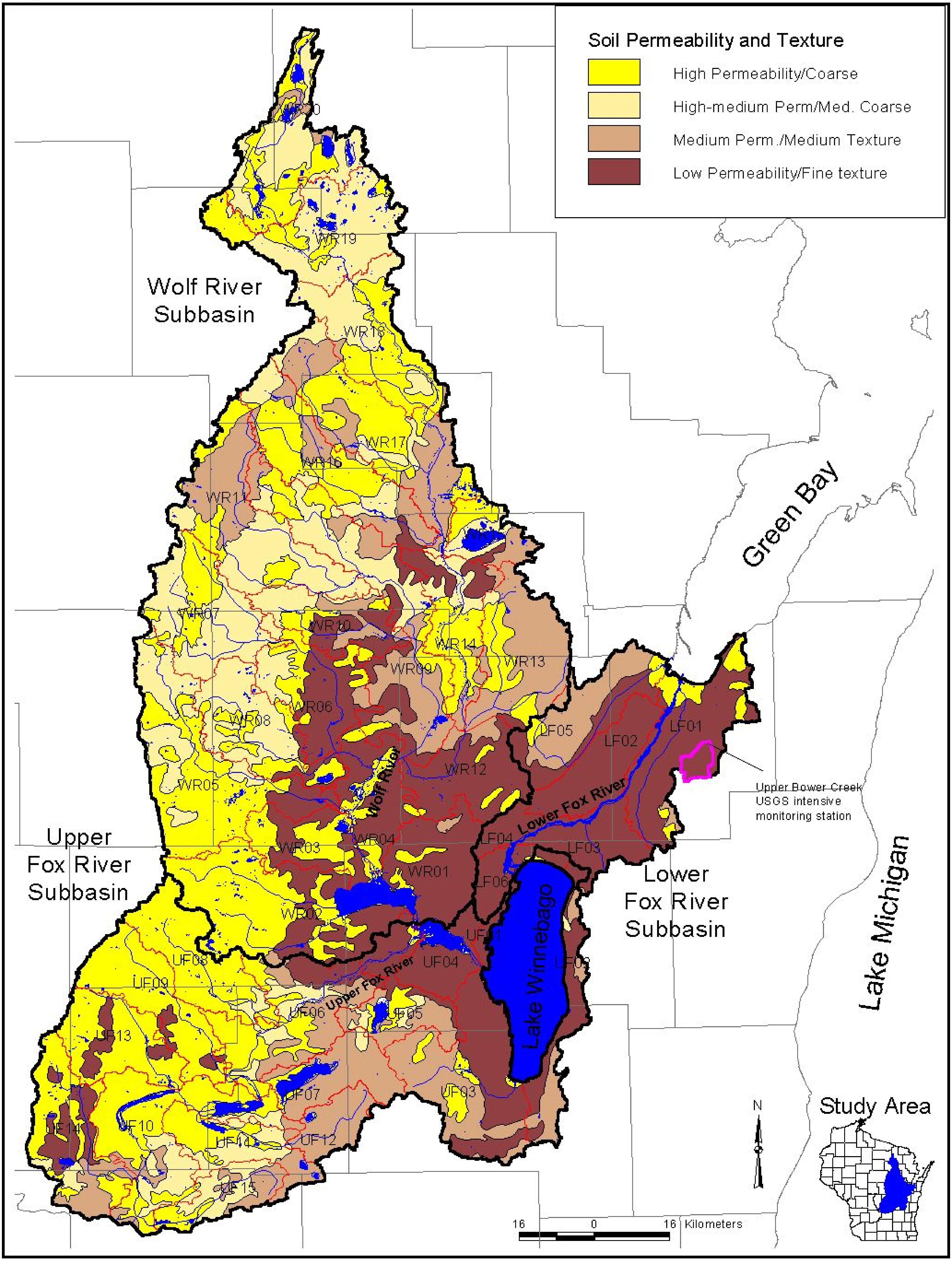
Hydrology: A statewide 1:24,000 hydrologic layer from the WDNR was used to define the highest resolution stream network. This coverage was provisional, so no annotation or hydrological attributes were available. Major tributaries were illustrated with the 1:2,000,000 stream hydrology layer from the WDNR.

Soils - Hydrological Group GIS Layer: Only four representative soils were utilized for this project to limit the number of model runs required to represent all possible combinations of soil, climate and land cover/use. In addition, the SWAT model is most sensitive to hydrologic Group, so this was the primary basis for choosing representative soil characteristics.

The soil permeability/texture GIS layer supplied by the WDNR (schpy250) was used to provide the soil hydrologic Group, which is a critical input parameter because it directly affects the NRCS curve number. Soil permeability/texture for soils in the Basin is shown in Figure 3. The following hydrologic Groups were assigned to each of the four soil permeability categories: (1) hydrologic Group A - high permeability; (2) hydrologic Group A to B - high/medium permeability; (3) hydrologic Group B - medium permeability; and (4) hydrologic Group C - low permeability.

Default NRCS curve numbers from SWAT documentation were then utilized for each combination of soil hydrologic Group and landuse during the creation of SWAT management

Figure 3. Soil permeability and texture in the Fox-Wolf Basin.



files. Curve numbers were decreased from the default values by 6 units for A soils (67 to 61), 3.5 units for AB soils (72.5 to 69) and 2 units for B soils (78 to 77). This change was made because loads were too high for agricultural crops with A soils, compared C soils, all else being equal. Available water capacity was also increased for A soils to better reflect the types of A soils where crops are grown, rather than an A soil whose dominant soil series might have 95% sand in the top layer, and would therefore have limited agricultural potential. The latter change seemed necessary because preliminary SWAT model results showed that total water yield increases substantially as the available water capacity decreases; whereas, it would seem more likely that only percolation and recharge increases as the AWC increases, not surface runoff. In addition, the seasonal curve numbers used in the management files may not vary as much for an A soil as they do for C soils; rather than have a different management file for each soil, it was more reasonable to simply reduce the curve number.

Soils - Erodibility GIS Layer: The STATSGO GIS soil layer supplied the WDNR (sgdpw92d), was combined with the STATSGO soil database, which was downloaded from the USDA-ARS, Temple Texas Internet site, to supply the USLE K-factor to the GIS model on an area-weighted basis. The K-factor determines the relative erodibility of various soils. An area-weighted soil hydrologic Group value was also generated from the STATSGO coverage and associated database, but the soil permeability layer was favored for determining hydrologic Group because by definition, it was delineated on the basis of soil permeability.

Slope/slope length (LS-factor) GIS Layer: The LS-factor was derived using the same method as in SWAT, except the maximum value of the slope length exponent was set to 0.5 instead of 0.6, and the minimum was set to 0.2 instead of 0.0. This modification conforms more closely with the values used in the EPIC model, as well as the values recommended by Wischmeier and Smith (1978) in USDA Agricultural Handbook #537. In addition, the modification made it possible to create the LS factor GIS layer with one equation/operation, rather than several operations.

The 30 meter resolution of the DEM did not permit the direct calculation of slope length. Instead, Equation 4 was used to calculate slope length on the basis of an empirical relationship between slope and slope-length.

$$\text{slope length (in feet)} = 350\text{ ft} / (\%\text{ slope} + 1)^{0.5} \qquad \text{(Eq. 4)}$$

This equation was set to conform closely with default values utilized by the Outagamie County LCD. Equation 4 was converted to meters in the GIS model. The Beta version of the BASIN's-SWAT ARCVIEW interface increases the slope length according to several slope intervals, so the approach used here seemed reasonable.

Precipitation and Temperature Data: The locations of the weather stations used in this study to provide measured daily precipitation and temperature data to the SWAT model are shown in Figure 1. These stations are located in Green Bay, Ripon, Clintonville and Lakewood, Wisconsin. The number of stations utilized in this project was limited to only 4 to reduce the number of model runs required to represent all possible combinations. The Green Bay site was the only

NOAA National Weather Service (NWS) Station utilized in this study. The remaining stations were official NWS cooperative observers. Daily precipitation and temperature from 1976-96 was input to the SWAT model to simulate TSS and phosphorus loads within this period. All of the daily weather data were supplied in ASCII format by the Geological and Natural History Survey State Climatology Office in Madison, Wisconsin. Only the Lakewood weather station was used to represent the fairly large northern area because about 10% of the daily precipitation recordings were missing from the Crivitz weather station; instead, data from this site was used to supplement data that was missing at the Lakewood station.

Days with trace amounts of precipitation were set to zero. Data from the closest available site were substituted whenever daily values were missing.

Watershed Climatological Assignment: The weather database furnished with the SWAT model was used to supply the SWAT weather generator with statistical weather information for the Green Bay NWS site. This information generates miscellaneous climatological data, such as rainfall intensity. General climatological data from the following weather stations was used to supply statistical weather inputs to the model that was associated with the daily weather data stations: Green Bay (Green Bay), Portage (Ripon), Laona (Lakewood), and Stevens Point (Clintonville) were used to assign SWAT with general climatological data inputs. In this project, the model was not sensitive to these inputs because measured precipitation and temperature was used instead of simulated data.

Transect Survey - crop residue levels: The 1999-2000 Conservation Technology Information Center (CTIC) Conservation Tillage Reports from counties within the Basin 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 estimate residue levels present on farm fields shortly after spring planting, as well as other information. Most of the information was gathered by county Land Conservation Departments. The data was analyzed with the Transect 2.13 software program produced by Purdue Research Foundation, Purdue University. Crop residue levels and tillage practices were summarized on a watershed basis by the program. Importantly, some of the watersheds may have contained too few points to be statistically reliable; however, most of the data seemed to be similar for adjacent watersheds. Where too few points were available, residue values were assigned on the basis of the average value from nearby watersheds.

Four residue categories were assigned based on the percent residue present and the level of no-till or ridge-till practiced: conventional tillage (CT: 0-15%); limited mulch tillage (MT15: 15-30%); mulch tillage (MT30: >30%); and no-till or ridge-till (NT). Where no-till or ridge-till were present, the amount of acres which qualified as mulch-till were reduced accordingly to prevent double-accounting. The data was summarized for two crop categories: corn, and a combination of soybeans, small grains and other crops. This data was then used to assign the appropriate tillage practices for the corn and soybean crop rotations. The level of residue present in alfalfa or forage fields was not directly related to the Transect survey data because there was limited data on this crop. Most of the time, no residue level was indicated even when the previous crop was alfalfa. For this project, moldboard plow tillage was utilized after the last alfalfa crop in the rotation was harvested.

Urban Areas: The median TSS yield from 15 urban streams in southeastern Wisconsin tills was reported by Corsi et al. (1997) to be 0.455 t/ha. The urban routine in SWAT98.2 did not function correctly, so the simulated TSS values were raised by a factor of 1.5 to give a yield closer to this median value, and a concentration of about 150 mg/L, which was found to be representative of values found in a previous literature review (Baumgart 1998). The simulated total phosphorus yield of 1.2 kg/ha is equivalent to 0.436 mg/L, given 275 mm of total water yield. This is the highest possible yield that was modeled for the Green Bay climatic region, so the average value is actually lower. This value falls between the median and maximum total phosphorus yields from urban areas in southeastern Wisconsin tills of 0.557 kg/ha and 2.12 kg/ha, respectively (Corsi et al. 1997).

CHAPTER 3. SWAT METHODS AND MODEL INPUTS

This section describes the methods used to generate the unit-area loads that were input to the GIS model. A modified version of SWAT98.2 model was applied in this project. The modifications were made prior to this project by Fox-Wolf Basin 2000 to make the model more flexible and suitable to conditions in Northeast Wisconsin. Most of the major code modifications are documented by Baumgart (1998).

SWAT was run on a daily time step, so daily precipitation and temperature data from four locations were input to the model to represent four climatic regions. The total simulation period was from 1976 to 1996; however, only the 15 year period between 1978 and 1992 was selected to generate the long-term average loads so that watershed yields and loads in the Basin could be compared. In addition, this period was utilized because it coincided most closely with periods for which loads were estimated by USGS: 1980-90 period (Robertson and Saad 1996) and 1975-90 period (Robertson 1996).

Land covers indicated by the reclassified WISCLAND Level 3 classification were directly modeled in SWAT's crop/management database as corn, forage, soybeans (other row crops), urban, grassland, forest, wetland and water. The agricultural land cover classes refer to the crop, not the management practice or typical crop rotation. That is, there is no direct way to differentiate between a corn field that is part of a dairy rotation or a cash-grain crop rotation. Therefore, only single-crop rotations were assumed, but two-thirds of the corn rotation and all of the alfalfa rotation were assumed to be under dairy management with associated manure applications (Table 2).

As shown in Table 2, a four year rotation was assumed for alfalfa, three years for corn and one year for soybeans. For each of the agricultural rotations, all possible phases were modeled in each simulation and the results were averaged to provide the UAL for each crop. Otherwise, large variations could occur depending on whether the most, or least erosive phase of the rotation happened to occur during a wet or dry year. All other land covers were modeled as single-year rotations.

Table 2. Land cover and simulated crop rotations.

	WISCLAND Land Classification		
Year/phase	corn/row crop	forage crop	other row crop (soybeans)
1	corn-grain, dairy	alfalfa, plant	soybean
2	corn-grain, cash crop	alfalfa	N/A
3	corn-silage, dairy	alfalfa	N/A
4	N/A	alfalfa, CT Till	N/A

To derive unit-area loads (UAL's), the model was applied to the Upper Bower Creek watershed (35.6 sq. km; USGS # 04085119), which is located in the East River watershed, LF01 (Figure 1). This site has been intensively monitored through a joint effort by both the USGS and WDNR. Extensive calibration and validation efforts were not undertaken because a previous version of the model had been successfully calibrated to data from Upper Bower Creek, and validated at nearby sites by Baumgart (1998). Instead, long-term average annual simulated flows (210 mm) and TSS loads (0.45 t/ha) derived by Baumgart (1998) were used to calibrate the model to the Bower Creek site. The simulated long-term TSS yield was close to the measured annual average TSS yield of 0.39 t/ha for the 1991-94 period (excluding 1993). The long-term average annual total phosphorus yield was set to 1.45 kg/ha for this same site. This figure falls between the observed 1991-94 average load of 1.79 kg/ha (with 1993), and the 1991-94 average load of 1.25 kg/ha (without 1993), and was based on assuming that the long-term simulated phosphorus yield is directly related to the long-term simulated TSS yield of 0.45 t/ha (1.25 kg/ha observed total phosphorus * 0.45 t/ha simulated TSS/0.39 t/ha observed TSS = 1.45 kg/ha total phosphorus. Data from 1993 was excluded during calibration because the model was unable to accurately simulate the loads under this unusually wet year. This problem was due in part, to the late planting and delayed growth of crops which occurred during this excessively wet year, which depressed evapotranspiration and greatly increased runoff. In addition, some of the reported loads in 1993 included some major events for which no samples were collected, but were instead estimated, and the loads seemed rather high for the time of year (mid June to July).

Detailed methods and procedures concerning inputs to SWAT and calibration can be found in Baumgart (1998, 2000). However, some specifics are included here. During calibration, the potential evapotranspiration coefficient (PET) was set to 0.77 for Lakewood and Green Bay climatic areas, and to 0.82 for Ripon and Clintonville climatic regions. This adjustment had the effect of raising initial stream water yields simulated by the model, to long-term expected yields normally found in streams. To calibrate the model to expected TSS yields, 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 5.

$$\text{MUSLE: } Y = a\,(Q)^{b}\,(q_p)^{c}\,(DA)^{d}\;[(K)\,(C)\,(PE)\,(LS)] \qquad \text{(Eq. 5)}$$

where:

Y = sediment yield in metric tons/ha (MT/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, set at $a = 0.0298$, $b = 1.7$, & $c = 0.0$, $d = 0.0$

The amount of manure applied in the model management files was more than doubled for the alfalfa crop, from the 56 MT/ha (25 t/acre) normally simulated in the 4 year alfalfa rotation, to 120 MT/ha (53.6 t/acre). This increase was required because the crop would otherwise be deficient in phosphorus, and the soil appeared to be depleted of soluble phosphorus in long model runs.

As shown in Table 3, annual simulated TSS and phosphorus loads from 1991 to 1996 in Upper Bower Creek were reasonably close to observed values with the exception of 1993.

Table 3. Observed and simulated TSS and phosphorus yields at Upper Bower Creek.

	TSS (t/ha)		Total Phosphorus (kg/ha)	
year[1]	observed	simulated	observed	simulated
1991	0.18	0.26	1.21	0.84
1992	0.37	0.44	1.38	1.38
1993	2.84	0.89	3.40	2.79
1994	0.62	0.68	1.17	2.04
1995	no data	0.25	no data	0.81
1996[1]	0.39	0.44	0.98	1.46

After calibration of the model was complete, the remaining UAL's were developed for other areas by altering the daily precipitation, daily temperature, general climatic data, soils, NRCS curve numbers, and land cover inputs. UAL's from the SWAT model were normalized to the average LS-factor of the calibration watershed so that the GIS model could account for local slopes and slope-lengths (LS-factor) throughout the Basin.

To reflect an expected reduction in the phosphorus enrichment ratio with reduced clay content, the maximum phosphorus enrichment ratio was set to 6.55 for C soils, 5.5 for B soils, 5.0 for AB soils, and 4.5 for A soils. Still, the SWAT-simulated ratio of soluble phosphorus to total phosphorus was fairly low for agricultural crops (approximately 7.5%). This result was primarily due to the need to calibrate the model to observed values; that is, simulated total phosphorus levels were too low until certain parameters were adjusted to raise the phosphorus level, which in turn increased the relative proportion of particulate phosphorus to soluble phosphorus. In addition, if the relative proportion of simulated soluble phosphorus levels were set to be more representative of expected in-stream values, then SWAT-simulated reductions of total phosphorus due to conservation tillage became too low.

Phosphorus associated with soil particles and large molecular weight organic matter generally accounts for 60-95% of phosphorus transported from cultivated lands during flow events (60-90%: Pietilainen and Rekolainen 1991; 75-95%: Sharpley et al. 1994). Local sampling efforts show a range of 10% to 90% between individual water samples, with a trend toward greater particulate phosphorus during larger events (unpublished results, Fox-Wolf Basin 2000, 1999-2000). Bannerman (1984) reported soluble phosphorus to total phosphorus ratios of 0.37 in

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[1] Observed annual loads are from October 1 to September 31 (USGS water years); simulated loads are for calendar years. The observed 1996 yields are from April 1996 to Sept. 31, 1996.

1980, 0.17 in 1981 and 0.06 in 1982 for the Fox River at Rapide Croche dam; however, some of the non-soluble phosphorus is of biological origin. To better reflect expected in-stream conditions, simulated soluble phosphorus was therefore increased by reapportioning 20% of the simulated particulate phosphorus fraction to the soluble phase. Unit-area loads for all land covers were altered in this fashion. The resulting soluble phosphorus fraction was generally 30% from agricultural sources.

Simulated unit-area particulate phosphorus yields (kg/ha) in the Fox-Wolf Basin are shown in Figure 4. These yields represent the yields of particulate phosphorus that would be expected if the phosphorus load was routed to the outlet of a subwatershed with an area close to that of the Upper Bower Creek reference site. Figure 4 is provided to show an interim work product of this project, as well as provide a more detailed picture of those areas with the greatest phosphorus yield potential.

Finally, the unit-area loads were multiplied by export coefficient(s) to provide the estimated load at the watershed outlet, to Green Bay, and where applicable, Lake Winnebago. This procedure is described in the following section.

CHAPTER 4. DELIVERY RATIO AND EXPORT COEFFICIENTS

This chapter describes the methods used to estimate the amount of TSS and total phosphorus delivered to Lake Winnebago and Green Bay. To estimate the amount of TSS and non-soluble phosphorus that are delivered to the watershed outlet, Lake Winnebago pool system, or to Green Bay, the annualized unit-area TSS and non-soluble phosphorus loads were multiplied by the sediment delivery ratio shown in Equation 3. These loads were then summed to give an estimate of each watershed's contribution at the watershed outlet, to the Lake Winnebago pool system, and to Green Bay. Soluble phosphorus was assumed to be conservative as it was routed throughout the Basin. In general, the delivery ratio decreases inversely as approximately the 0.2 power of the drainage area; that is, the delivery ratio decreases as drainage area increases (USDA-SCS 1983). The drainage area (DA) can be the watershed area, or the cumulative drainage area from the watershed to Green Bay or Lake Winnebago (i.e., the load must travel from the watershed outlet to Green Bay or Lake Winnebago). To account for the delivery ratio inherent to the loads generated for the outlet of the calibration watershed, the un-weighted delivery ratio ($DA^{-0.15}$) was divided by the delivery ratio ($DA_{UBC}^{-0.15}$) of the Upper Bower Creek calibration watershed (35.6 sq. km).

The exponent in the delivery ratio equation (-0.15) was set so that simulated loads for the Menominee and Fox Rivers corresponded closely to the loads estimated by the USGS with a constituent transport model which relied on continuous flow data and available concentration data (Robertson and Saad 1996; Robertson 1996). To compare simulated loads to measured loads, or load estimates from other sources, point source loads were added to the simulated non-point load estimates where loads from point sources were determined to be significant. The delivery ratio is not intended to provide precise estimates at specific locations between watershed outlets and Green Bay; rather, it is assumed to integrate the effects of stream deposition/aggradation, and the effect of various lakes, reservoirs, dams and other impoundments located throughout the drainage network.

Phosphorus trapping in the Winnebago pool system was set to correspond to deposition rates of 90,000 kg/yr for the upper pool lakes and 170,000 kg/yr for Lake Winnebago, which were determined by Pierre-Gustin (1995). Therefore, these amounts were subtracted from the simulated loads entering these lake systems. Point source loads of 22,674 kg/yr and 17,721 kg/yr contributed to the Upper Fox and Wolf Watersheds, respectively (WNDR 1993a), of which an estimated 25,000 kg/yr was assumed to make it to the Lake Winnebago outlet. The resulting average 1978-92 simulated load at the Winnebago outlet of 365,000 kg/yr corresponds well with a measured load estimate for 1990 of 360 MT (WDNR 1993a).

Based on a relationship between trapping efficiency and the reservoir capacity/average annual inflow ratio that was developed by Brune (1953) and extended by Dendy (1974), an estimated 5% of the Fox River TSS was assumed trapped between the Lake Winnebago outlet and the Little Rapids dam (10.6 km upstream from the DePere dam), while an additional 15% was assumed to be deposited between the Little Rapids dam and Fox River mouth. For phosphorus, 2.5% and 7.5% of the non-soluble fraction was assumed to be trapped between these two river reaches, respectively. Based on these net deposition rates, the simulated 1978-92 total phosphorus load at

Wrightstown after point sources and additional drainage area are added is 467,000 kg/yr; which includes an additional 60,000 kg/yr from point sources between the Lake Winnebago outlet and Rapide Croche dam near Wrightstown. This simulated load compares to 474,900 kg/year estimated by Robertson and Saad (1996) for a 1980-90 period using regression analysis of observed data.

The simulated 1978-92 phosphorus load at the Fox River outlet to Green Bay is 598,000 kg/yr, which includes another 60,000 kg/yr from point sources (LF05, Duck Creek is not included). If Duck Creek is included, the total load is 628,000 kg/yr. The former value falls within the 395,000 kg/yr to 719,000 kg/yr range of loads summarized by Klump et al. (1997) and close to the 500,000 kg/yr to 605,000 kg/yr range estimated by Robertson and Saad (1996) for a 1980-90 period using regression analysis.

The same trapping efficiencies that were utilized for phosphorus were also applied to determine the amount of TSS that was trapped in the Winnebago pool system. The composition of the suspended solids entering the Winnebago pool system is unlikely to be the same as that exiting the system, so a mass balance approach was not utilized in determining trapping efficiency of TSS. To compensate for any differences between the simulated 1978-92 average annual TSS load at Rapide Croche dam, near Wrightstown and the loads estimated for the same period and location with the constituent transport model of Robertson (1996) and Robertson and Saad (1996), a biotic solids component was added to the load at the Winnebago outlet so that the loads were reasonably close.

Pierre-Gustin (1995) used an estimated load at the Lake Winnebago outlet of 68,000 MT of TSS per year (1986-90) to construct the following sediment budget for the lake system: upper pool lakes could trap as much as 220,000 MT of TSS, with 200,000 MT input to Lake Winnebago at Oshkosh, about 80,000 to 120,000 coming from direct watershed discharges to the Lake (UF01, UF02, and UF03), 250,000 MT net burial of sediment, and about 68,000 MT exported to the Lower Fox River at the Lake Winnebago outlet. However, Robertson's (1996) regression equation was applied by Fox-Wolf Basin 2000 to estimate a TSS load of 97,000 MT at downstream Rapide Croche during 1986-90 period, and 130,000 MT of TSS for the 1978-92 simulation period. If the load at Rapide Croche is assumed to be directly proportional to the load at the Winnebago outlet, a TSS load of 91,000 MT at the outlet, instead of 68,000 MT, may be more appropriate for the 1978-92 period (68,000 MT TSS * 130,100/97,000).

The simulated 1978-92 TSS load at the Lake Winnebago outlet was 57,300 MT/yr, so a biotic TSS component of 33,700 MT was added to make up the difference (91,000 MT = 57,300 MT + 33,700 MT). Steuer et al. (1995; Fig. 5-60) estimated a point source load of 1,900 MT TSS and a river growth contribution of 14,600 MT TSS to the Lower Fox River between Lake Winnebago and the DePere dam in 1989. Therefore, if 70% of the river growth and all of the point source contributions are added to the simulated load at Rapide Croche dam, the resulting total simulated TSS load for the 1978-92 period is 117,500 MT/yr. This load is lower than the previous estimated load of 130,000 MT/yr which was derived with the constituent transport model developed by Robertson (1996), but it is still reasonable given the potential errors in this analysis.

Robertson and Saad (1996) estimated the average 1980-90 Fox River TSS load at Wrightstown to be 143,700 MT per year. Bannerman's (1984) annual load estimates of TSS at Wrightstown were 100,200 MT in 1980, 71,700 MT in 1981, and 99,700 MT in 1982, for an overall average of 90,500 MT; however, the estimated load in 1982 was not reliable because it was less than the 95% confidence interval. Smith et al. (1982) estimated an average annual load of 88,000 for the 1974-81 period. Therefore, even when measured data are involved, load estimates for this system vary substantially depending on the time period and the methodology used to calculate load estimates.

The simulated 1978-92 TSS load at the Fox River outlet to Green Bay is 136,000 MT/yr, compared to 151,000 MT/yr estimated by Robertson and Saad (1996) for a 1980-90 period using regression analysis. If Duck Creek is included, the total simulated load is 144,000 MT/yr. Both of these load estimates include point source contributions.

Importantly, the local effects of impoundments (lakes, dams etc.), wetlands, and natural and man-made riparian filter strips were not directly accounted for in this model. Instead, some of these effects were partially accounted for through gross lumping in SWAT simulations, or through the delivery ratio. The complex nature of the effects of these factors combined with the scale and time constraints of this project did not permit a precise accounting of all these factors.

CHAPTER 5. SIMULATED LOADS TO GREEN BAY AND LAKE WINNEBAGO

Simulated non-point source loads were generated for a fifteen year climatic period (1978-92) with inputs that reflect estimated crop residue levels in 1999 so that average annual watershed yields and loads within the Basin could be compared on a relative basis under "current" conditions. Data presented in previous sections was based on estimated 1987-92 crop residue levels so that comparisons between observed and simulated loads could be made. Simulated average annual TSS and total phosphorus contributions (yields: mass/ha) to Green Bay from each watershed are shown in Figures 5 and 6 respectively. <u>Point source contributions are not included in this analysis</u>. These figures clearly show that the majority of the TSS and phosphorus loads to Green Bay are from those areas closest to Green Bay, including all of the watersheds in the Lower Fox subbasin and some of the watersheds adjacent to Lake Winnebago (LF01, LF02, LF03, LF04, LF05, LF06; UF02, UF01, UF03). The Fond du Lac River watershed (UF03) was the only other watershed that had a total phosphorus yield to Green Bay greater than 0.5 kg/ha. The loads and yields of total phosphorus and TSS routed to the watershed outlet, Lake Winnebago and to Green Bay are summarized in Tables 4a (metric) and 4b (English units). The actual land area within each watershed was used to calculate yields (load/land area), rather than the entire watershed area, which can include a significant proportion of water (e.g., Shawano Lake in WR15).

The simulated average annual TSS and total phosphorus contributions (yields: mass/ha) to Lake Winnebago from each watershed are shown in Figures 7 and 8, respectively. Figure 8 clearly shows that the majority of the phosphorus load to Lake Winnebago is from those areas closest to the lake, with the greatest phosphorus yields coming from UF02, UF01, UF04, UF03, UF05, UF012 and UF07, with somewhat lower yields from WR01 and WR12. The contribution of TSS to Lake Winnebago is even more localized, where UF02 has much greater yields than the next highest contributors (UF01, UF04, UF05, UF03, UF07 and UF12). It should be recognized that the relative load contributions from UF07 and UF12 may be lower than indicated here because the delivery ratio used to route the constituent load did not directly account for deposition in Green Lake and Lake Puckaway.

The loads and yields of total phosphorus and TSS from non-point sources, as routed to the watershed outlet, Lake Winnebago and to Green Bay are summarized in Table 4a (metric units) and Table 4b (English units).

Cumulative phosphorus and TSS loads to Green Bay from watersheds in the Basin are displayed in Figure 9. The watersheds were ranked by TSS yields to Green Bay. If both phosphorus and TSS load reductions from non-point sources are desired to reach water quality objectives in Lower Green Bay, the cumulative ranking of watersheds in Figure 9 roughly corresponds to a ranking which indicates which watersheds to target in a cost-effective manner. With the exception of UF02, little change was observed when the watersheds were ranked by phosphorus yield to Green Bay. Importantly, contributions from all non-point sources, including agriculture and urban, are included in the simulated yields of phosphorus or TSS from a particular watershed.

Figure 5. Estimated 1999 TSS yields from non-point sources, routed to Green Bay from watersheds in the Fox-Wolf Basin. Yields are based on GIS model and SWAT simulated unit-area normalized loads.

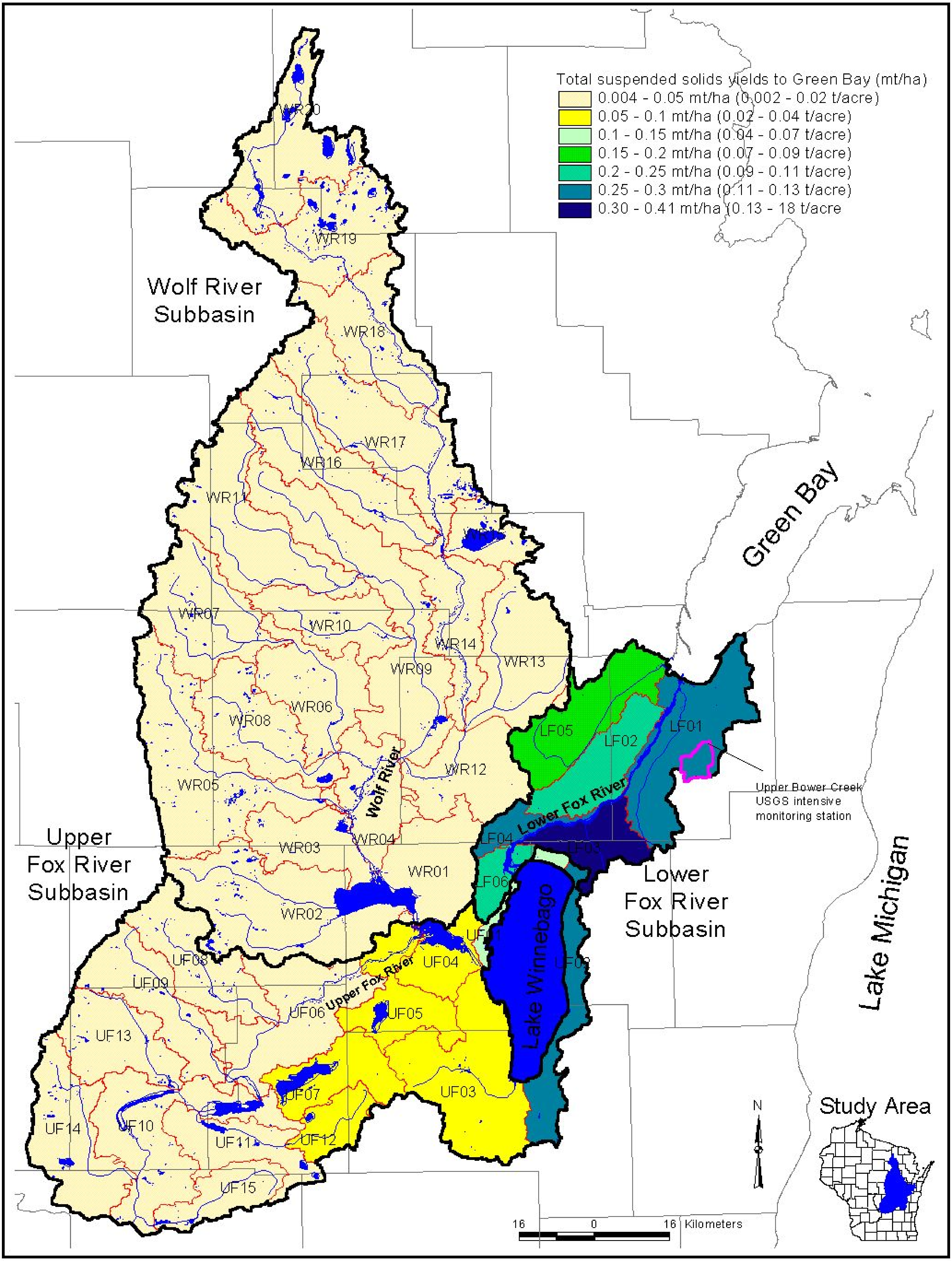


Figure 6. Estimated 1999 phosphorus yields from non-point sources, routed to Green Bay from watersheds in the Fox-Wolf Basin. Yields based on GIS model and SWAT simulated unit-area normalized loads.

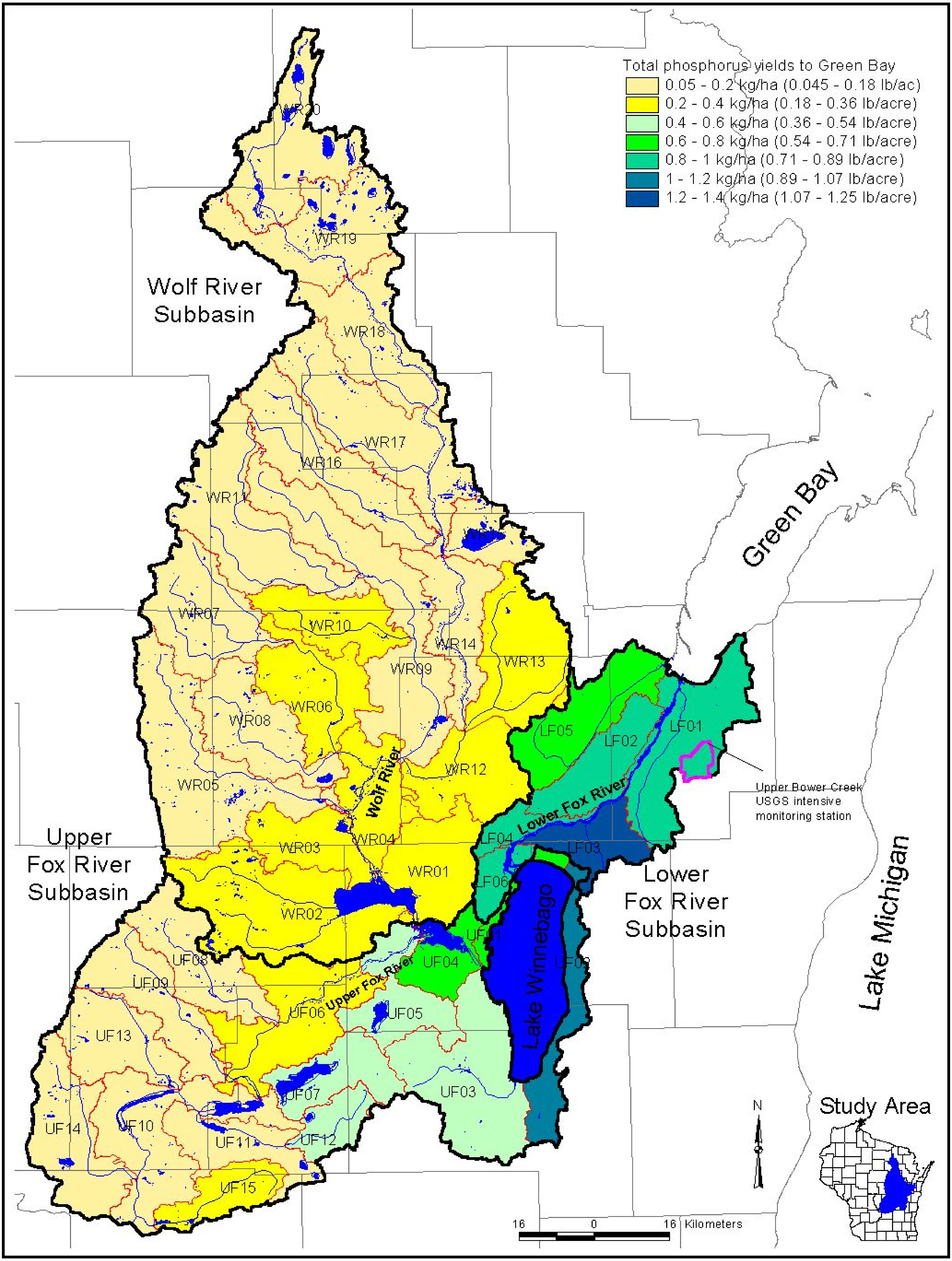


Figure 7. Estimated 1999 total suspended solids yields from non-point sources, routed to Lake Winnebago. Yields based on GIS model and SWAT simulated unit-area loads produced by Fox-Wolf Basin 2000.

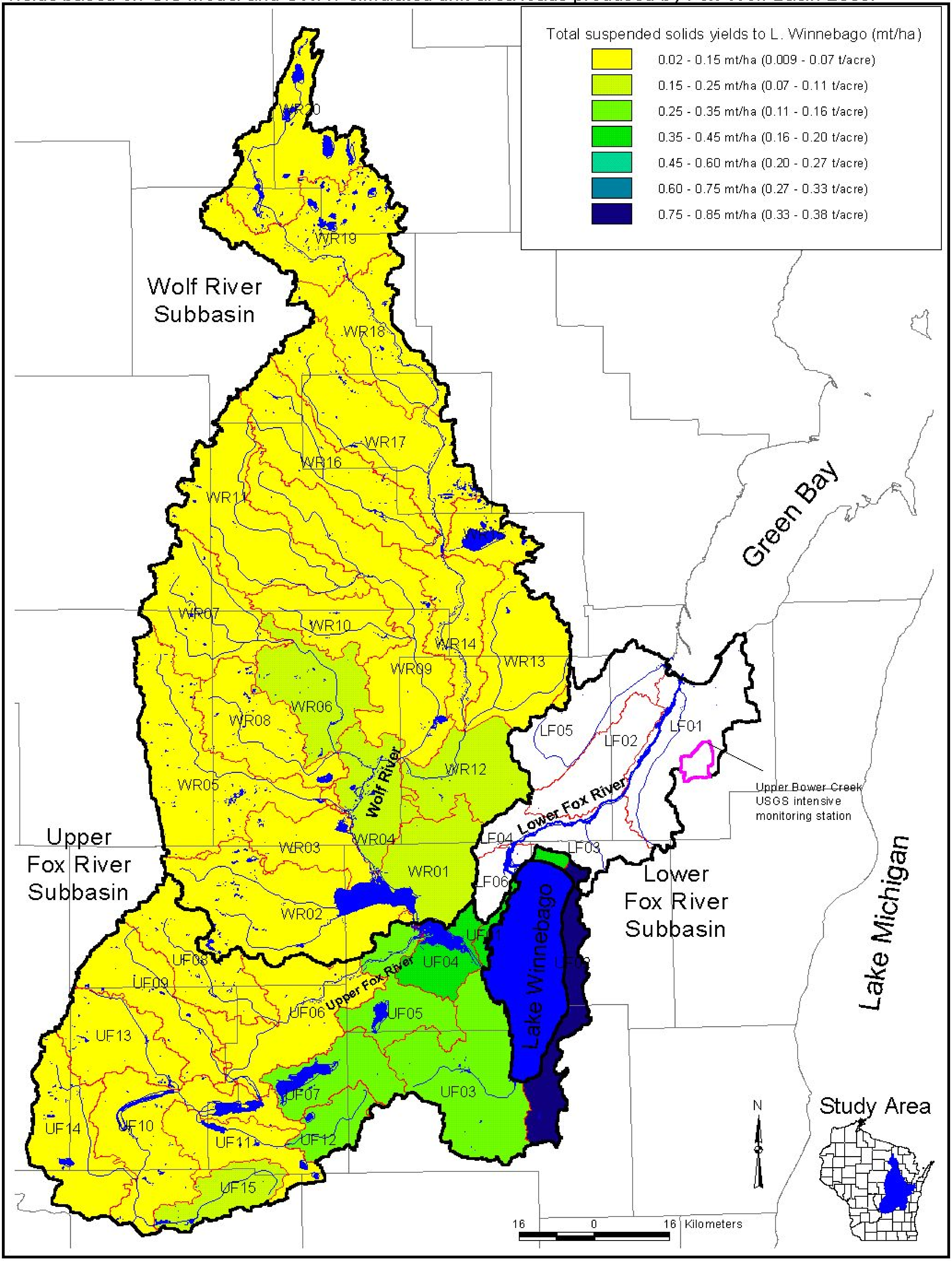


Figure 8. Estimated 1999 total phosphorus yields from non-point sources, routed to Lake Winnebago. Yields based on GIS model and SWAT simulated unit-area loads produced by Fox-Wolf Basin 2000.

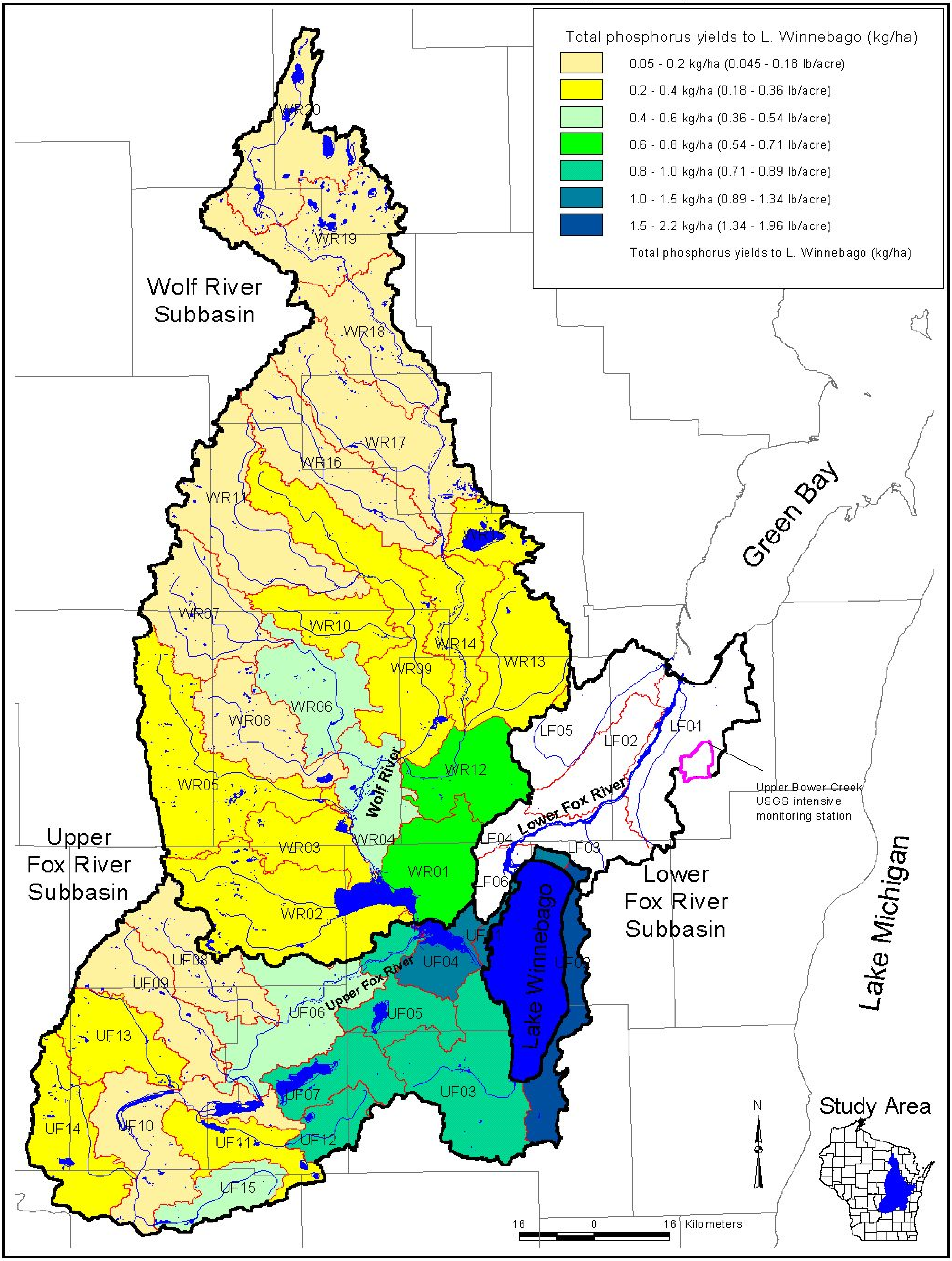


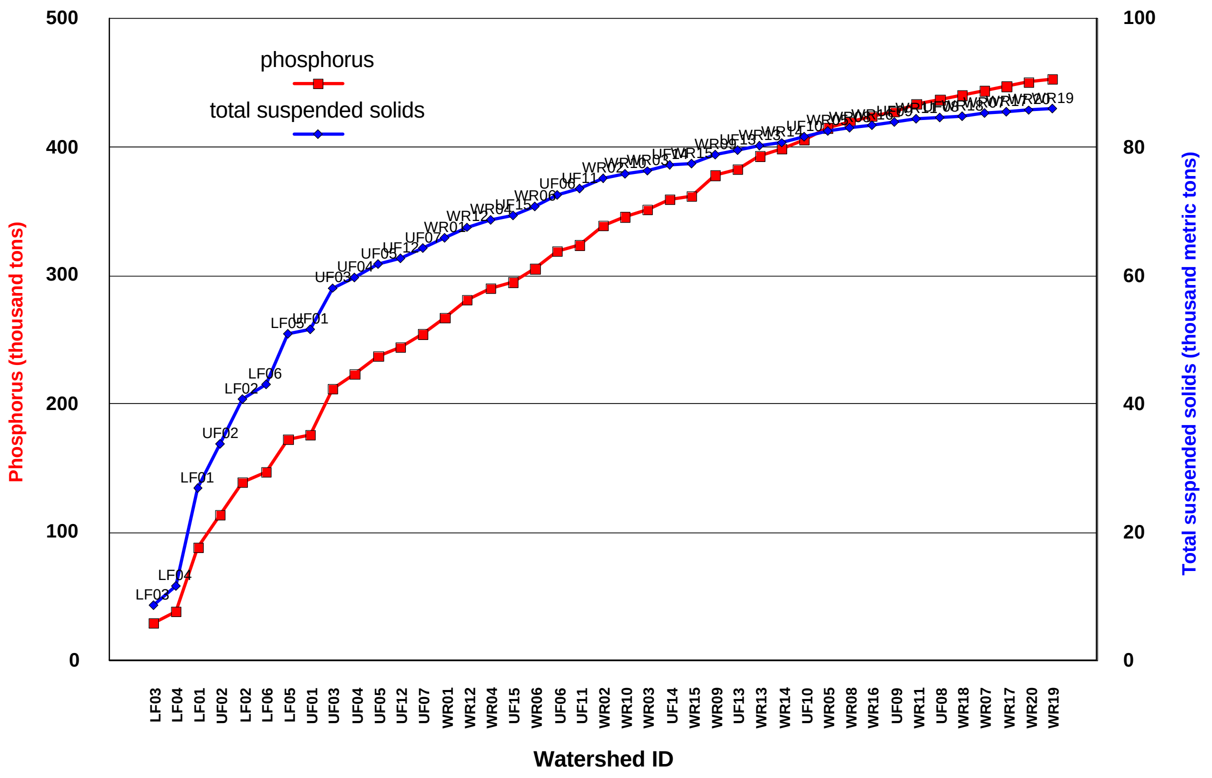
Table 4a. Simulated average annual TSS and total phosphorus yield and load to the watershed outlet, Lake Winnebago and Green Bay - 1999 landuse conditions (metric units, 1978-92 climatic period).

		Yield (mass/hectare)						Load (mass)					
		Watershed Outlet		Routed to L. Winn.		Routed to Green Bay		Watershed Outlet		Routed to L. Winn.		Routed to Green Bay	
ID	Watershed Name	TSS (MT/ha)	Tot. P (kg/ha)	TSS (MT/ha)	Tot. P (kg/ha)	TSS (MT/ha)	Tot. P (kg/ha)	TSS (MT)	Tot. P (kg)	TSS (MT)	Tot. P (kg)	TSS (MT)	Tot. P (kg)
LF01	East River	0.290	0.940	NA	NA	0.290	0.940	15,300	49,500	NA	NA	15,300	49,500
LF02	Apple and Ashwaubenon Creeks	0.280	0.870	NA	NA	0.240	0.830	8,200	25,600	NA	NA	6,900	24,300
LF03	Plum and Kankapot Creeks	0.500	1.480	NA	NA	0.410	1.370	10,800	31,800	NA	NA	8,700	29,400
LF04	Fox River/Appleton	0.370	1.010	NA	NA	0.300	0.940	3,600	10,000	NA	NA	2,900	9,300
LF05	Duck Creek	0.200	0.630	NA	NA	0.200	0.630	7,800	24,700	NA	NA	7,800	24,700
LF06	Little Lake Butte des Morts	0.280	0.880	NA	NA	0.220	0.820	3,000	9,400	NA	NA	2,400	8,800
UF01	Lake Winnebago/North and West	0.430	1.280	0.430	1.280	0.140	0.750	2,500	7,500	2,500	7,500	800	4,400
UF02	Lake Winnebago/East	0.840	2.150	0.840	2.150	0.270	1.020	21,400	55,200	21,400	55,200	6,900	26,100
UF03	Fond du Lac River	0.310	0.950	0.310	0.950	0.100	0.560	19,400	60,100	19,400	60,100	6,300	35,200
UF04	Lake Butte Des Mortes	0.420	1.300	0.420	1.300	0.091	0.670	7,200	22,500	7,200	22,500	1,600	11,500
UF05	Fox River	0.330	0.980	0.330	0.980	0.071	0.470	9,600	28,800	9,600	28,800	2,100	13,800
UF06	Fox River/Berlin	0.160	0.500	0.150	0.480	0.033	0.250	8,700	26,900	8,100	25,800	1,800	13,500
UF07	Big Green Lake	0.390	1.000	0.300	0.840	0.066	0.410	9,600	24,500	7,400	20,500	1,600	9,900
UF08	White River	0.042	0.130	0.035	0.120	0.008	0.083	1,600	5,000	1,300	4,600	290	3,200
UF09	Mecan River	0.049	0.150	0.038	0.140	0.008	0.094	1,800	5,800	1,400	5,200	310	3,500
UF10	Buffalo and Puckaway Lakes	0.085	0.220	0.061	0.190	0.014	0.120	4,600	12,100	3,600	10,500	770	6,400
UF11	Lower Grand River	0.190	0.460	0.132	0.380	0.030	0.200	5,100	12,600	3,700	10,300	810	5,400
UF12	Upper Grand River	0.470	1.230	0.303	0.910	0.066	0.460	7,400	19,400	4,800	14,400	1,000	7,200
UF13	Montello River	0.100	0.300	0.075	0.250	0.017	0.150	3,500	10,100	2,600	8,500	570	5,100
UF14	Neenah Creek	0.120	0.370	0.086	0.310	0.019	0.190	5,300	16,400	3,800	13,700	840	8,200
UF15	Swan Lake	0.260	0.620	0.170	0.460	0.037	0.240	5,400	12,800	3,500	9,400	750	4,900
WR01	Arrowhead River and Daggets Creek	0.230	0.750	0.230	0.750	0.050	0.380	8,000	26,300	8,000	26,300	1,700	13,500
WR02	Pine and Willow Rivers	0.110	0.370	0.110	0.370	0.023	0.210	7,800	27,000	7,800	27,000	1,700	15,200
WR03	Walla Walla and Alder Creeks	0.120	0.400	0.100	0.370	0.023	0.210	3,000	10,300	2,700	9,700	590	5,400
WR04	Lower Wolf River	0.190	0.620	0.170	0.580	0.037	0.300	5,700	18,800	5,200	17,700	1,100	9,100
WR05	Waupaca River	0.067	0.220	0.062	0.210	0.013	0.130	5,000	16,100	4,600	15,400	990	9,400
WR06	Lower Little Wolf River	0.200	0.620	0.160	0.530	0.035	0.260	7,900	24,300	6,400	20,900	1,400	10,300
WR07	Upper Little Wolf River	0.039	0.120	0.028	0.100	0.006	0.071	1,800	5,400	1,300	4,700	290	3,300
WR08	South Branch Little Wolf River	0.068	0.200	0.055	0.180	0.012	0.110	2,800	8,300	2,200	7,400	480	4,500
WR09	North Branch & Mainstem Embarrass	0.097	0.350	0.078	0.310	0.017	0.200	7,800	28,200	6,300	25,300	1,400	15,700
WR10	Pigeon River	0.160	0.490	0.100	0.380	0.023	0.220	4,600	14,500	3,100	11,400	680	6,400
WR11	Middle & South Branches Embarrass	0.051	0.160	0.037	0.130	0.008	0.089	3,300	10,100	2,400	8,700	510	5,700
WR12	Wolf River/New London and Bear Creek	0.270	0.830	0.210	0.690	0.045	0.370	10,100	30,700	7,600	25,400	1,600	13,400
WR13	Shioc River	0.100	0.390	0.074	0.330	0.016	0.220	5,000	19,100	3,600	16,300	790	10,800
WR14	Middle Wolf River	0.097	0.320	0.067	0.260	0.014	0.160	3,300	10,900	2,300	8,900	490	5,500
WR15	Shawano Lake	0.140	0.410	0.085	0.300	0.018	0.170	2,200	6,400	1,300	4,600	280	2,700
WR16	Red River	0.062	0.180	0.043	0.150	0.009	0.095	3,300	9,800	2,300	8,000	490	5,100
WR17	West Branch Wolf River	0.038	0.110	0.027	0.094	0.006	0.061	2,600	7,600	1,800	6,300	400	4,100
WR18	Wolf River/Langlade and Evergreen	0.045	0.120	0.030	0.100	0.006	0.069	2,100	5,600	1,400	4,600	300	3,200
WR19	Lily River	0.028	0.085	0.019	0.072	0.004	0.053	1,500	4,400	980	3,700	210	2,700
WR20	Upper Wolf River and Post Lake	0.035	0.100	0.023	0.086	0.005	0.061	1,700	5,100	1,100	4,200	250	3,000

Table 4b. Simulated average annual TSS and total phosphorus yield and load to the watershed outlet, Lake Winnebago and Green Bay - 1999 landuse conditions (English units, 1978-92 climatic period).

		Yield (mass/acre)						Load (mass)					
		Watershed Outlet		Routed to L. Winn.		Routed to Green Bay		Watershed Outlet		Routed to L. Winn.		Routed to Green Bay	
ID	**Watershed Name**	**TSS (ton/acre)**	**Tot. P (lb/acre)**	**TSS (ton/acre)**	**Tot. P (lb/acre)**	**TSS (ton/acre)**	**Tot. P (lb/acre)**	**TSS (ton)**	**Tot. P (lb)**	**TSS (ton)**	**Tot. P (lb)**	**TSS (ton)**	**Tot. P (lb)**
LF01	East River	0.130	0.840	NA	NA	0.130	0.840	16,800	109,100	NA	NA	16,800	109,100
LF02	Apple and Ashwaubenon Creeks	0.120	0.780	NA	NA	0.110	0.740	9,000	56,400	NA	NA	7,700	53,500
LF03	Plum and Kankapot Creeks	0.220	1.320	NA	NA	0.180	1.220	11,900	70,200	NA	NA	9,600	64,900
LF04	Fox River/Appleton	0.160	0.900	NA	NA	0.130	0.840	4,000	22,000	NA	NA	3,200	20,500
LF05	Duck Creek	0.089	0.560	NA	NA	0.089	0.560	8,600	54,400	NA	NA	8,600	54,400
LF06	Little Lake Butte des Morts	0.120	0.780	NA	NA	0.100	0.730	3,300	20,800	NA	NA	2,600	19,500
UF01	Lake Winnebago/North and West	0.190	1.140	0.190	1.140	0.061	0.670	2,700	16,400	2,700	16,400	880	9,700
UF02	Lake Winnebago/East	0.370	1.920	0.370	1.920	0.120	0.910	23,600	121,600	23,600	121,600	7,600	57,500
UF03	Fond du Lac River	0.140	0.850	0.140	0.850	0.044	0.500	21,400	132,500	21,400	132,500	6,900	77,700
UF04	Lake Butte Des Mortes	0.190	1.160	0.190	1.160	0.041	0.600	8,000	49,500	8,000	49,500	1,700	25,400
UF05	Fox River	0.150	0.870	0.150	0.870	0.032	0.420	10,500	63,400	10,500	63,400	2,300	30,400
UF06	Fox River/Berlin	0.073	0.450	0.068	0.430	0.015	0.230	9,600	59,300	9,000	56,800	1,900	29,800
UF07	Big Green Lake	0.170	0.900	0.140	0.750	0.029	0.360	10,500	54,100	8,200	45,200	1,800	21,800
UF08	White River	0.019	0.120	0.016	0.110	0.003	0.074	1,800	11,000	1,500	10,200	320	7,000
UF09	Mecan River	0.022	0.140	0.017	0.120	0.004	0.084	2,000	12,700	1,600	11,400	350	7,800
UF10	Buffalo and Puckaway Lakes	0.038	0.200	0.029	0.170	0.006	0.100	5,100	26,700	3,900	23,200	850	14,100
UF11	Lower Grand River	0.083	0.410	0.061	0.340	0.013	0.180	5,600	27,700	4,100	22,700	890	11,900
UF12	Upper Grand River	0.210	1.090	0.140	0.810	0.029	0.410	8,100	42,800	5,300	31,800	1,200	16,000
UF13	Montello River	0.046	0.260	0.034	0.220	0.007	0.130	3,900	22,300	2,900	18,800	620	11,200
UF14	Neenah Creek	0.054	0.330	0.039	0.280	0.008	0.170	5,800	36,200	4,200	30,200	920	18,000
UF15	Swan Lake	0.120	0.560	0.075	0.410	0.016	0.210	5,900	28,100	3,800	20,800	830	10,800
WR01	Arrowhead River and Daggets Creek	0.100	0.670	0.100	0.670	0.022	0.340	8,800	58,000	8,800	58,000	1,900	29,700
WR02	Pine and Willow Rivers	0.047	0.330	0.047	0.330	0.010	0.190	8,600	59,500	8,600	59,500	1,900	33,600
WR03	Walla Walla and Alder Creeks	0.051	0.350	0.046	0.330	0.010	0.190	3,300	22,800	3,000	21,400	650	12,000
WR04	Lower Wolf River	0.084	0.550	0.076	0.520	0.017	0.270	6,300	41,400	5,700	39,000	1,200	20,000
WR05	Waupaca River	0.030	0.190	0.028	0.190	0.006	0.110	5,500	35,600	5,000	34,000	1,100	20,600
WR06	Lower Little Wolf River	0.090	0.550	0.072	0.470	0.016	0.230	8,700	53,500	7,000	46,000	1,500	22,800
WR07	Upper Little Wolf River	0.017	0.100	0.013	0.091	0.003	0.063	2,000	12,000	1,500	10,500	320	7,300
WR08	South Branch Little Wolf River	0.030	0.180	0.024	0.160	0.005	0.098	3,000	18,200	2,500	16,200	530	9,800
WR09	North Branch & Mainstem Embarrass	0.043	0.310	0.035	0.280	0.008	0.170	8,600	62,200	6,900	55,700	1,500	34,700
WR10	Pigeon River	0.069	0.430	0.047	0.340	0.010	0.190	5,100	32,000	3,500	25,100	750	14,200
WR11	Middle & South Branches Embarrass	0.023	0.140	0.016	0.120	0.004	0.079	3,600	22,300	2,600	19,100	570	12,600
WR12	Wolf River/New London and Bear	0.120	0.740	0.092	0.620	0.020	0.330	11,100	67,700	8,300	56,100	1,800	29,600
WR13	Shioc River	0.046	0.350	0.033	0.300	0.007	0.200	5,600	42,100	4,000	35,900	870	23,900
WR14	Middle Wolf River	0.043	0.290	0.030	0.230	0.006	0.140	3,600	24,100	2,500	19,600	540	12,100
WR15	Shawano Lake	0.063	0.370	0.038	0.270	0.008	0.150	2,400	14,000	1,400	10,200	310	5,900
WR16	Red River	0.028	0.160	0.019	0.130	0.004	0.085	3,600	21,500	2,500	17,700	550	11,100
WR17	West Branch Wolf River	0.017	0.100	0.012	0.084	0.003	0.054	2,800	16,600	2,000	14,000	440	9,000
WR18	Wolf River/Langlade and Evergreen	0.020	0.110	0.013	0.090	0.003	0.061	2,300	12,400	1,500	10,200	330	7,000
WR19	Lily River	0.013	0.076	0.008	0.064	0.002	0.047	1,600	9,700	1,100	8,200	230	6,000
WR20	Upper Wolf River and Post Lake	0.016	0.092	0.010	0.077	0.002	0.054	1,900	11,200	1,300	9,300	270	6,600

Figure 9. Cumulative phosphorus and TSS loads to Green Bay, ranked by watershed TSS yield to Green Bay.



CHAPTER 6. OTHER LOADS, SENSITIVITY ANALYSIS AND CAVEATS

Barnyard runoff, gully erosion, streambank/shoreline erosion, and existing riparian buffers were not explicitly accounted for in the model framework, but will be discussed in this section. Also, a detailed sensitivity analysis is not warranted for this project; however, some information is provided in this section so that potential errors in the data presented in this report, as well as data interpretation, can be better understood. A more thorough analysis of the sensitivity of the SWAT model, as applied to the Duck Creek Watershed, was conducted by Baumgart (1998).

Existing riparian buffers: The modeling assumptions did not directly account for the riparian buffers that may exist in the Basin. As a result, the simulated load from a watershed which has a high percentage of cropland whose runoff drains through an existing riparian buffer may be overstated, while the simulated load from a watershed with a lower percentage of buffers may be understated. To attempt to determine what effect this might have on the simulated loads, a GIS analysis of WISCLAND land cover types that are intersected by the 1:24k hydrology network within the Green Bay Basin was conducted by Stratus Consulting. This analysis can be roughly interpreted to indicate whether riparian areas are already buffered by existing forest or wetland; however, it cannot show whether the upland source is a high contributor (cropland), or low contributor (forest or wetland). The results of this analysis are summarized in Table 6, which shows the percentage of forest and wetland land cover that is adjacent to surface waters for each watershed in the Green Bay Basin, as well as the Upper Bower Creek reference/calibration subwatershed. The resolution of the WISCLAND land cover image (30 m cells) is not sufficient to provide precise percentages of existing riparian forest or wetland buffers; rather, this analysis is primarily intended to provide relative values for comparison between watersheds in the Basin. The low resolution of the land cover image implies that the percentage of streams that are actually buffered is higher than estimated here.

Excluding the Duck Creek watershed, the percent forest and wetland land cover that intersect the 1:24k hydrology network ranged from 5.5% to 18% within the Lower Fox River Subbasin. These figures are similar to that found in the Upper Bower Creek reference/calibration subwatershed (13%). For the four Upper Fox River watersheds with the highest phosphorus yields to Green Bay, the percent forest and wetland that intersect the 1:24k hydrology network ranged from 16% to 36%, which is not that dissimilar from the Upper Bower Creek reference/calibration subwatershed (13%), given the rough nature of the buffer analysis. In general, watersheds with higher proportions of estimated riparian buffers have lower yields to Green Bay. Although existing riparian buffers were not directly accounted for in the modeling assumptions, the simulated total phosphorus yield to Green Bay was strongly correlated ($r^2 = 0.75$) to the percent forest and wetland land cover that intersected the 1:24 hydrology network.

A much more intensive effort would be required to more accurately estimate the amount of existing riparian buffer strips within the entire Basin, but the scale of the project area and the requisite land cover resolution precluded such an effort at this time. Consequently, no further adjustments of delivery ratios or unit-area loads were made to account for differences between watersheds with regards to the amount of estimated riparian buffer strips.

The strong relationship between phosphorus yield to Green Bay, and the GIS buffer analysis, is probably due to the strong positive relationship between simulated yields and the percent land cover that is cropland or urban; and conversely, the strong inverse relationship between simulated yields and the percent land cover that is forest or wetland. The GIS analysis did not distinguish between forested or wetland riparian areas that either had a high contributing upland source draining though it (e.g., cropland), or an upland source that was a low contributor (e.g., wetland or forest). Therefore, it is likely that in many cases, the indicated riparian wetland and forested buffers are often just an extension of the dominant land cover that is adjacent to the riparian wetland or forested buffer. Consequently, the higher the proportion of wetland and forest in a watershed, the greater the proportion of existing riparian buffers. But watersheds with high proportions of wetlands and forests are not large contributors of TSS or phosphorus to Green Bay. So the importance of the estimated riparian buffered areas is diminished because the GIS analysis did not distinguish between source areas to the riparian buffer, and the greatest contributions to Green Bay come from those watersheds with lower proportions of both upland and riparian forest or wetland land cover. Therefore, excluding the effects of existing riparian buffer strips is not believed to substantially alter the results and conclusions presented in this report.

Table 6. Percentage of riparian areas that are adjacent to forest or wetland.

Watershed ID	Watershed	Wetland & forest (%)
LF01	East River	18.0
LF02	Apple and Ashwaubenon Creeks	14.2
LF03	Plum and Kankapot Creeks	14.5
LF04	Fox River/Appleton	5.5
LF05	Duck Creek	34.0
LF06	Little Lake Butte des Morts	9.8
Reference	**Upper Bower Creek**	**12.9**
UF01	Lake Winnebago/North and West	19.4
UF02	Lake Winnebago/East	23.4
UF03	Fond du Lac River	36.2
UF04	Lake Butte Des Mortes	16.5
UF05	Fox River	48.7
UF06	Fox River/Berlin	62.7
UF07	Big Green Lake	44.8
UF08	White River	70.1
UF09	Mecan River	75.5
UF10	Buffalo and Puckaway Lakes	61.0
UF11	Lower Grand River	63.3
UF12	Upper Grand River	43.7
UF13	Montello River	67.0
UF14	Neenah Creek	61.0
UF15	Swan Lake	58.0
WR01	Arrowhead River and Daggets Creek	40.2
WR02	Pine and Willow Rivers	58.7

Table 6. Percentage of riparian areas that are adjacent to forest or wetland.

Watershed ID	Watershed	Wetland & forest (%)
WR03	Walla Walla and Alder Creeks	65.8
WR04	Lower Wolf River	65.2
WR05	Waupaca River	62.6
WR06	Lower Little Wolf River	67.1
WR07	Upper Little Wolf River	77.8
WR08	South Branch Little Wolf River	69.6
WR09	North Branch & Mainstem Embarrass River	64.6
WR10	Pigeon River	64.4
WR11	Middle & South Branches Embarrass River	77.8
WR12	Wolf River/New London and Bear Creek	49.5
WR13	Shioc River	42.3
WR14	Middle Wolf River	64.0
WR15	Shawano Lake	50.9
WR16	Red River	83.0
WR17	West Branch Wolf River	77.7
WR18	Wolf River/Langlade and Evergreen Rivers	77.7
WR19	Lily River	81.1
WR20	Upper Wolf River and Post Lake	83.6

Barnyard runoff: Barnyard contributions were not directly considered in the modeling assumptions. Instead, the effects of barnyards and upland practices were lumped together. As a result, phosphorus loads from upland sources should be somewhat lower than indicated in this analysis. Had barnyard runoff contributions been included as a separate phosphorus load, the effect of installing BMPs intended for upland or streambank controls, such as conservation tillage, grass waterways, vegetated buffer strip and streambank stabilization would be reduced. According to the Duck, Apple and Ashwaubenon Creeks Priority Watershed Project Plan (WNDR 1997), about 4% (9,000 lbs or 4,100 kg) of the phosphorus load delivered to streams is from barnyard runoff. However, when the same phosphorus load delivered to the stream (4,100 kg) is compared to the SWAT/GIS-simulated phosphorus load generated for the Duck, Apple and Ashwaubenon Creek watersheds (50,000 kg), the percent phosphorus from barnyard runoff is 8%. The barnyard runoff phosphorus load attributed to barnyard runoff in the Lake Winnebago East Priority Watershed Project was estimated to be 1,040 kg, or 2,300 lb (WDNR 1994), which is about 2% of the total phosphorus load simulated in this project. The barnyard runoff load of 1,870 kg (4,120 lbs) estimated for the East River Priority Watershed Project cannot be directly compared to the simulated loads generated by the SWAT model because the barnyard numbers were based on a single 10-year, 24-hour storm (WDNR 1993a), but this value is small compared to the total simulated phosphorus load of 49,500 kg in the East River. According to the Arrowhead River, Daggets Creek and Rat River Priority Watershed Project Plan (WDNR 1993b), barnyard runoff accounts for 10% (3,680 lbs/38,717 lbs) of the total phosphorus load in the watershed.

If the barnyard phosphorus load estimates are accurate, and if other watersheds have similar proportional contributions from barnyards, the effect of not including phosphorus loads from barnyards in the model framework should be small given the expected errors in the simulated results. However, expected load reductions may have to be decreased for BMP's that do not affect barnyard runoff.

Recent investigations by the USGS and DNR indicate that barnyards may actually contribute a significant portion of the phosphorus load in watersheds with relatively high numbers of barnyards (Stuntebeck 1995, Stuntebeck et al. 1996, Wierl et al. 1998). Previous BARNY-estimated loads for the Otter Creek watershed in Wisconsin indicated only 71 lbs due to a 10 year, 24 hour storm event (Wierl et al. 1996). However, during a single event in this watershed, the measured amount of phosphorus from a barnyard with 50 cows was essentially the same (about 70 lbs); furthermore, 5 out of 12 measured events from this barnyard exceeded 20 lbs of phosphorus duriing the April 1994 to October 1995 pre-BMP phase of the study (Figure 2; Stuntbeck and Bannerman 1998).

According to Wierl et al. (1998), controlling phosphorus from barnyards appears to be as important as reducing phosphorus in cropland runoff in watersheds where the ratio of farm fields to barnyards is about 20:1 or less. The ratio for Bower Creek, in the East River Watershed, is 15:1 (Wierl et al. 1998). If significant improvements have been made to barnyard-related problems in a particular watershed, and the barnyard load is substantially greater than previously estimated, then large reductions in the phosphorus load may have already taken place. Further investigation is recommended to ensure that estimated phosphorous loads associated with cropland and barnyard runoff are correct. Furthermore, a methodology to track trends in barnyard runoff is recommended for inclusion in the TMDL monitoring phase.

Streambank and shoreline contributions: The sediment load from streambanks and shorelines, estimated miles of eroding streambank, and the percentage of total sediment load that were estimated by LCD's in their respective priority watershed projects and water resource plans is summarized in Table 7.

Lake Winnebago East has the highest percentage of streambank and shoreline erosion compared to total sediment load (20%), followed by Winnebago County (18%), the Tomorrow/Waupaca Watershed (24%) and Waupaca County (12%). Of those watersheds that contribute the greatest proportion of the simulated TSS load to Green Bay, estimates from LCD's show that streambank and shoreline erosion contribute about 20% from the eastern and western watersheds surrounding Lake Winnebago, and 7.7% from the East River Watershed.

However, total sediment loads that were estimated for each of the Priority Watersheds do not correspond closely to the SWAT/GIS simulated loads, so relative loads based upon the aforementioned percentages are not necessarily appropriate. For example, the simulated TSS load for the East River Watershed was 15,300 MT, compared to the combined rural TSS load of 38,300 MT reported by WDNR (1993b) from all sources.

Table 7. Estimated sediment and phosphorus loads from streambank and shoreline erosion.

Watershed	WDNR ID	sediment (English tons)/ phosphorus (lbs)	miles of eroding stream-bank	Routed to Green Bay		Watershed fraction of total TSS and phosphorus		
				TSS (MT)	total phos. (kg)	to stream or watershed outlet (LCD estimate)	to Green Bay (FWB2k)	
							TSS	phos.
East River (WDNR 1993b)	LF01	3,250 current est.	15	1,370	580	7.7%	9.0%	1.2%
Duck Creek **Apple/Ashwaubenon (WNDR 1997c)**	LF05 LF02	2,330 4,710	14	1,030 2,180	430 960	8.5% 5.6%	13.3% 31.4%	1.8% 4.0%
Arrowhead/Rat/Daggets (Winn. Cty LCD 1997, WDNR 1993c)	WR01	> 880 Winn. Cty. only		> 85	> 84	7.8%	4.9%	0.6%
Tomorrow/Waupaca (WDNR 1995)	WR05	1,660	6	130	180	23.9%	13.4%	1.9%
Lower Little Wolf (WDNR 1997b)	WR06	1,920	10	150	150	6.7%	10.7%	1.4%
Neenah Creek (WDNR 1994b)	WR14	760		50	70	4.6%	6.3%	0.9%
Lake Winnebago East (WDNR 1994a)	UF02	3,430		700	390	20.0%	10.2%	1.5%
Fond du Lac (WDNR 2000)	UF03	9,170	24	1,400	1,000	5.6%	22.1%	3.0%
Lake Buttes des Morts (Winnebago Cty LCD 1997)	UF04	630		70	64	7.5%	4.2%	0.6%
Fox River/Rush Lake (Winnnebago Cty LCD 1997)	UF05	> 4,400 Winn. Cty. only		> 440	> 400	18%	21.1%	2.9%
Winnebago County (Winnebago Cty. LCD 1997)		11,500 tons/ 8,600 lbs of P		1,200	1,200	18% / 9% of Winn. Cty. rural load	NA	NA
Waupaca County (Waupaca Cty. LCD 1998)		8,500 tons/ 6,400 lbs of P		680	900	12% / 5.8% of Waupaca Cty. rural load	NA	NA

An even greater discrepancy occurs in the Duck, Apple and Ashwaubenon Watersheds where the simulated TSS load is 16,000 MT, compared to the combined rural TSS load of 101,000 MT reported by WDNR (1997c). However, the latter estimated total load may be sediment delivered to the stream, rather than sediment delivered to the watershed outlet. In addition, it can probably be assumed that reported streambank and shoreline erosion estimates are to the stream or lake, rather than to the watershed outlet, so actual sediment contributions to a watershed outlet from these sources ought to be lower when this material is transported downstream.

Therefore, to estimate the sediment export to Green Bay due to streambank erosion, the streambank loads estimated by LCD's were routed to Green Bay with the same delivery ratio equation and trapping efficiencies used here to route sediment and phosphorus to the watershed outlet and to Green Bay. An additional delivery ratio was added because unit-area loads were based on delivery to the outlet of the Upper Bower Creek reference subwatershed, which has an area of 35.6 sq. km. Potential phosphorus loads were estimated by assuming that there is 0.75 lbs of phosphorus per ton of eroded streambank (Winnebago Cty LCD 2000, Waupaca Cty. LCD 1999). The resulting streambank and shoreline load estimates routed to Green Bay, and the percent of each watershed's load routed to Green Bay, are summarized in Table 7.

The estimated percent of TSS due to streambank/shoreline erosion that reached Green Bay from each watershed ranged from 1.3% in the Pensaukee Watershed, to 31% from the Apple and Ashwaubenon Creek Watershed. Most of the watersheds were within the 4% to 14% range. The estimated percent of phosphorus associated with streambank/shoreline erosion that reached Green Bay from each watershed ranged from 0.5% in several watersheds, to 4.0% from the Apple and Ashwaubenon Creek Watershed.

As with barnyard runoff, expected load reductions may have to be decreased for BMP's that do not fully affect streambank or shoreline erosion.

Gully erosion: Gully erosion can contribute a significant proportion of the total TSS load from a watershed. However, both conservation tillage and vegetated buffer strips should reduce gully formation and resultant loads, especially when both practices are combined.

Climatic differences: For agricultural crops, the assumed unit-area loads that were assigned to watersheds in the Ripon climatic region were approximately 1.5 times greater than those watersheds within the Green Bay climatic regions. Therefore, simulated loads and the percent contribution to Green Bay from Upper Fox watersheds near Lake Winnebago would have been lower if Green Bay weather had been utilized instead of Ripon weather. While it is possible that Ripon may have experienced an unusually high number or intensity of precipitation events during the simulation period, the unit-area loads for the Lakeland climatic region were the same as the loads in the Ripon region. However, generating additional sets of unit-area loads by including other weather stations should improve confidence in the relative differences between watersheds (i.e., relative simulated loads, but not actual differences in loads).

Soil permeability: If all other parameters are kept constant, changing the soil from hydrologic Group B to Group C, would increase the simulated TSS and phosphorus unit-area loads by a factor of 1.55 and 1.6, respectively. Similarly, changing the soil from Group AB to Group B, would increase the simulated TSS and phosphorus unit-area loads by a factor of 1.35 and 1.85, respectively. Increasing the resolution of the soils databases by using individual digital county soil surveys would improve results. However, at this time, such an endeavor would be impractical because of the scale of the Fox-Wolf Basin; plus, many of the soil surveys within the Basin are not in a digital format yet. In addition, many models with an integrated GIS simply choose the dominant soil within the primary modeling unit (e.g., watershed or subwatershed), which defeats the purpose of utilizing a high resolution soil layer for input to a model.

CHAPTER 7. SUMMARY AND CONCLUSIONS

- The SWAT/GIS model was applied to simulate long-term average annual TSS and total phosphorus loads to Green Bay from watersheds in the Basin.

- Simulated TSS and phosphorus loads to Lake Winnebago, Rapide Croche dam near Wrightstown, and Green Bay were reasonably close to observed loads.

- The majority of the simulated TSS and phosphorus loads to lower Green Bay are from those areas closest to the Fox River mouth, including all of the watersheds in the Lower Fox subbasin and some of the watersheds adjacent to Lake Winnebago (LF01, LF02, LF03, LF04, LF05, LF06; UF02, UF01, UF04). The Fond du Lac River watershed (UF03) was the only other watershed that had a total phosphorus yield to Green Bay greater than 0.5 kg/ha.

- The majority of the simulated phosphorus load to Lake Winnebago is from those areas closest to the lake, with the greatest phosphorus yields coming from UF02, UF01, UF04, UF03, UF05, UF012 and UF07, with somewhat lower yields from WR01 and WR12. The contribution of TSS to Lake Winnebago is even more localized, where UF02 has much greater yields than the next highest contributors (UF01, UF04, UF05, UF03, UF07 and UF12).

- Existing riparian buffers were not explicitly accounted for in the model framework. Relative loads among the watersheds may therefore vary somewhat, depending on the extent of existing buffers in each watershed, but the major results and conclusions presented in this report are not expected to be substantially affected.

- Barnyard runoff, streambank/shoreline erosion, and gully erosion were not explicitly modeled, but loads to Green Bay were estimated where data was available for streambank/shoreline erosion. Estimated contributions from these sources can be significant, and should be accounted for when estimating reductions from BMP's that have little or no effect on the pollutant source.

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