Application of the Soil and Water Assessment Tool (SWAT) to Evaluate Non-Point Source Phosphorus and TSS Loads in the Big Green Lake Watershed, Wisconsin

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Objective

The primary objective of this modeling project was to estimate non-point phosphorus and TSS loads within the Big Green Lake Watershed and to Big Green Lake. To accomplish this objective, the 2009 version of the Soil and Water Assessment Tool (SWAT; ArcSWAT 2009) 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, Neitsch et al. 2001). 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.

This report describes: (1) the derivation of SWAT inputs and model setup; (2) model calibration and assessment; and (3) modeled results of long-term simulated average annual SWAT loads of phosphorus and TSS within the watershed and 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 240 km^2 Big Green Lake Watershed is agriculture (total area without water from Big Green Lake).

SWAT Model Inputs

Model simulation periods and climatological inputs: The model was run for different periods representing: 1) a calibration period to calibrate key model parameters to obtain the best fit between simulated and observed stream flow, TSS and phosphorus data; and 2) validation periods which coincided with observed stream monitoring data so simulated results could be compared to observed data without changing model parameters; and 3) a 15 year watershed evaluation period which was used to compare the loads and yields of modeled sub-watersheds. A 1998 to 2012 year climatic period was used as input to the model for the watershed evaluation period.

Precipitation and temperature data from the Ripon NE National Weather Service Cooperative Station were used as inputs to the model, except data from the Fond du Lac NWS cooperative station was used when data were missing. Importantly, the Ripon station was outside of the watershed, so obtaining a good fit between observed and simulated stream flow and loads was later found to be difficult. <u>The lack of an appropriately placed rain gauge network likely resulted in a model that could otherwise have been improved with a reliable station or set of stations within, or more near the drainage area upstream of the monitoring gauges</u>.

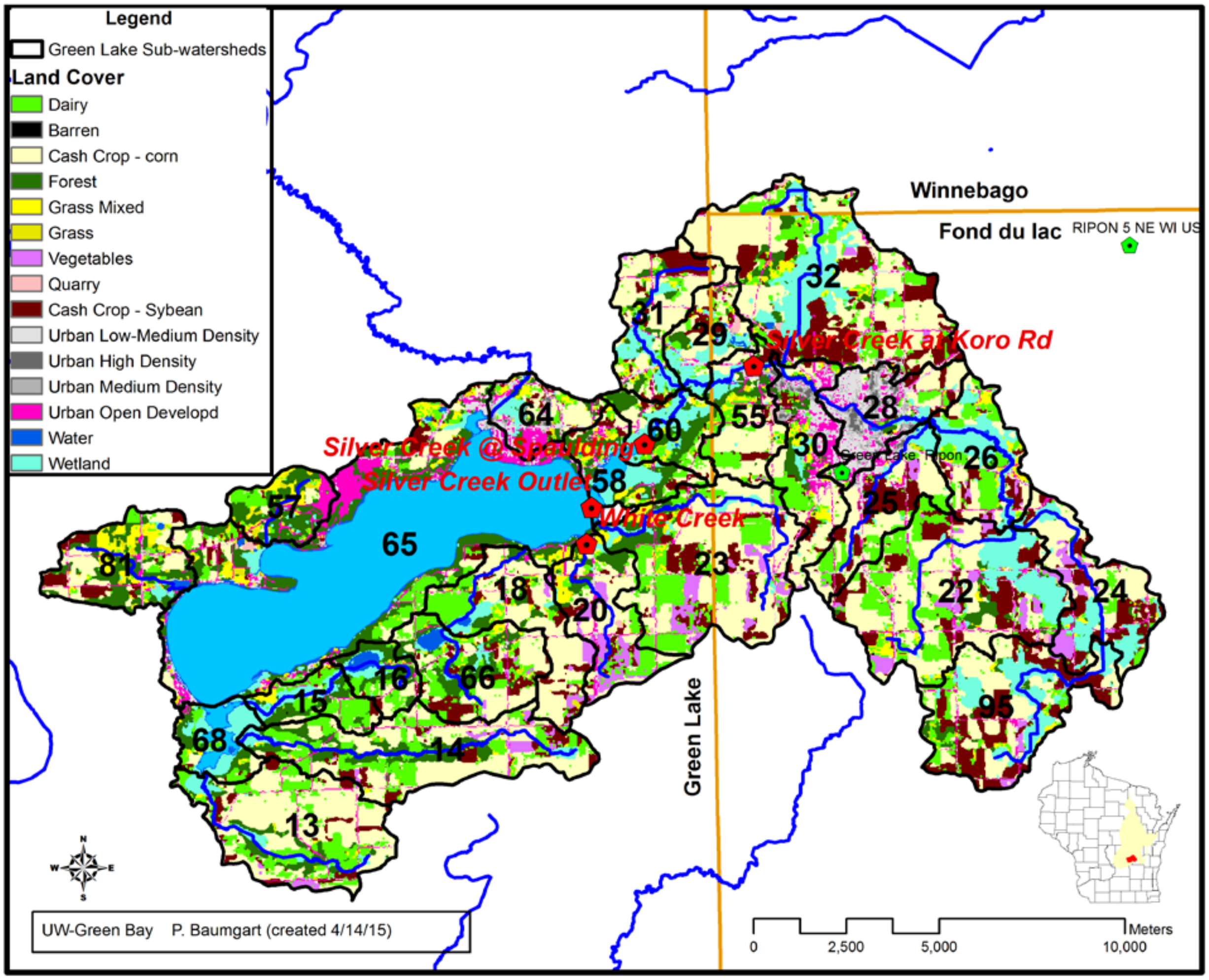

Figure 1. Land cover and stream monitoring stations in the Big Green Lake Watershed (2011).

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

1. 1:24k WDNR watershed boundaries; sub-watersheds were added as part of this project
2. USDA National Agricultural Statistics Service (NASS) 2006 to 2011 Cropland images
3. NRCS digital soil surveys merged into a single Fox-Wolf basin shapefile
4. 10 meter digital elevation model (DEM) merged from NRCS county files
5. 1:24k surface water hydrology from WDNR
6. Miscellaneous: roads, county boundaries, etc.

All GIS coverages were projected into WTM-NAD83/91 coordinates. The watershed was divided into sub-watersheds within SWAT, based as closely as possible to delineations created by Fox-Wolf Basin 2000 in 2000. Sub-watershed SWAT ids are shown in Figure 1; the names and areas are provided later in the report in Table 2. Sub-watershed #64 does not appear to drain to Big Green Lake.

Land cover/use: Land cover within the watershed (Figure 1) was determined from a combination of the USDA National Agricultural Statistics Service (NASS) 2006 to 2011 Cropland images from 2006 to 2011 (base layer of 2011) and wetlands from the WDNR 1992 WISCLAND land cover image. The six NASS Cropland images were utilized to differentiate dairy areas from cash crop areas by ascribing the dairy rotation class to areas that had at least one year of alfalfa.

The combined final classified GIS image was used to assign major land covers/uses which were modeled within the watershed. These land cover classes were further divided into "Hydrologic Response Units" which were directly modeled in the following fashion:

Agriculture – Dairy 6 year Rotation (corn silage, corn-grain/silage[1], winter wheat, 3 years alfalfa); and then split into three tillage classes:
1 Conventional tillage practice (CT)
2 Mulch-till (MT)
3 No-till or ridge-till (NT)

Agriculture - Cash crop (three separate classes: corn grain, soybean or vegetable) and each then split into three tillage classes:
4 Conventional tillage practice (CT)
5 Mulch-till (MT)
6 No-till or ridge-till (NT)

7 Urban (four classes: high, medium, and low density; open-area developed
8 Grassland
9 Forest
10 Wetland
11 Quarry
12 Barren

HRU's basically represent areas within a sub-watershed 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; for example, different tillage practices including conventional, mulch and no-till. Therefore, various proportions of the possible agricultural practices were used to simulate what occurred in each sub-watershed. For areas classified as agricultural dairy crop rotation areas, the HRU’s were further split into six different phases of a rotation so that each phase would run simultaneously. This procedure was employed to prevent the model from simulating any year of the rotation all at the same time (e.g., all alfalfa during 2011, or all corn in 2012).

[1] Harvest setting in model was set to essentially simulate two crop fields under the corn grain/silage year: one as purely corn-grain, and the other as purely corn silage. In this way, the overall 6 year dairy rotation essentially assumed that 2/3 of the corn was grown as silage, and the remaining third as corn grain.

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.

Tillage practices: 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, during calibration and validation periods, as well as the present day evaluation period (approximately 2013). 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.

Summary of farm crop and management assumptions:

Primary tillage practices

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

	CT	MT	NT
Fond du lac (Silver Creek 2014)	43.1%	29.4%	27.5%
Green Lake (2012)	40.1%	39.6%	20.3%

Nutrients and Nutrient Management: Soil phosphorus inputs within each sub-watershed were based on area-weighted county average Soil Test Bray P values that were associated with each modeled period. Manure application rates were based on area-weighted county averages of the number of dairy cattle in each county during each modeled period. It was assumed that most of the manure that was applied was incorporated within three days of application during recent years (roughly 70%), but less incorporation during the earliest model runs (25%).

Soil hydrologic group and USLE K factor: The hydrologic soil group (A, B, C, D) was numerically averaged for each landuse class within a sub-watershed, and was input to the modified SWAT 2009 model via the soil files. In this way, each simulated HRU within a sub-watershed was assigned a specific NRCS curve number based on a normalized standard curve number of 78 (corn, good cropping conditions), which was then used to adjust the curve numbers input from the HRU management files according to the soil hydrologic group. This method greatly reduced the number of agricultural management files that were needed to adequately simulate the diversity present within the watershed. A somewhat similar procedure was utilized for the USLE soil K value, to reduce the number of soil types that were simulated.

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 the 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; 1987-2013), White Creek at Spring Grove Road (USGS # 04030201; 1982-88; 1997-2012); Silver Creek at Spaulding Road (USGS # 04073466); 2012-2013). These monitoring sites were jointly funded by the 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 1987-91 period, were chosen to calibrate the model. Observed data from the remaining years (1992-96) at this site, and data from both Silver Creek at Big Green Lake Inlet (1987-2013) and Silver Creek at Spaulding Road (2012-2013) were used to assess the validity of the model (validation period). Data from other sites within the Upper Fox sub-basin, including Waukau Creek and Montello River were also used to validate the SWAT model.

Average annual discharge and loads from the Ripon Municipal Wastewater Treatment Plant were included in the model calibration and validation simulations. However, the Ripon MTP was generally not included in the non-point source sub-watershed analysis except where stated.

Unfortunately, the observed data from the White Creek station could not be directly utilized for calibration or validation because the annual stream flows were unusually high given the drainage area of this sub-watershed. Whereas the long-term stream flow on an area basis for Silver Creek at CTH A was about 282 mm (annualized over 1997 - 2012 period), the measured area-weighted flow (assuming 7.47 km^2) of 391 mm for this same period at White Creek was much higher than could reasonably be expected. This disparity presents an issue, unless it could be found that the precipitation was very different, but there was only one reliable NWS cooperator station nearby, and even this site northeast of Ripon was outside of the entire watershed. There are at least two possible explanations for this disparity. First, the surface water drainage area of the White Creek sub-watershed appears to be greater than the areas delineated by either the USGS or through this project with the 10 m DEM. Second, the groundwater drainage area may be substantially greater than the surface water drainage areas delineated by either the USGS or through this project. 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 sub-watershed. 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 sub-watershed from adjacent sub-watersheds. Further analysis of the White Creek data also showed that substantial changes may have occurred as a result of efforts to reduce stream bank and possible gully erosion.

Given the unusual water budget, it was determined that it would not be reasonable to calibrate or validate the SWAT model with observed data from the White Creek monitoring location at this time.

Model Calibration and Assessment

Flow Calibration: The Hargreaves and Samani (1982) 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: Hargreaves-Samani ET equation (0.971), NRCS curve number input (0.98), soil temperature when considered frozen (-0.1 C), NRCS curve number when soil frozen (0.99). The surface lag variable SURLAG was set to 0.5.

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 the below equation.

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 = 0.0067, b = 1.6, c = 0.0 , and d = 0.0.

Model Calibration and Validation Statistics: Simulated and observed monthly statistics for stream flow (mm), TSS loads (metric ton) and phosphorus loads (kg) are compared in Table 1 for all of the monitoring sites, except White Creek. Nash-Sutcliffe Coefficient of Efficiencies (1970; NSE) were fairly good during the 1987-91 calibration period at Silver Creek at Koro Road for flow (0.71), TSS (0.82) and phosphorus (0.63). An NSE value of 1 indicates a perfect fit, and values of less than 0.2 indicate a poor fit. R-squared values were slightly higher. After calibrating the model to this site and period, the model was capable of producing reasonable results during the validation periods at Koro Road: relative differences ranged from -11.8% for flow to plus 13.8% for TSS during the validation period and NSE values were above 0.60.

Model validation statistics at the Silver Creek site on CTH A (1987-2013) were also within the acceptable range as the NSE was 0.58 or greater for all parameters and the model bias ranged from – 20.1% for flow to plus 20.0% for phosphorus. While not ideal, the biases were acceptable given that the precipitation station is well outside the watershed. Similar results were observed for the Silver Creek validation site located at Spaulding Road (2011-2012), where the model bias was sufficiently close given the less than ideal location of the precipitation gauge used to run the model. NSE statistics for the Spaulding Road site ranged from 0.48 for TSS to 0.73 for flow.

Two other sites located within the Upper Fox River sub-basin were also used to validate the model (i.e., without changing model calibration parameters). Model statistics from these two sites located on the Montello River and Waukau Creek ranged from fairly good (NSE of 0.81 for phosphorus) at Waukau Creek, to acceptable (NSE of 0.41 for phosphorus at Montello Creek). Most of the relative differences (model bias), were well under 20%.

Overall, the model does a fair to good job of accurately representing the observed flow, TSS and phosphorus loads at all of the sites and validation periods. Therefore, it was possible to proceed to apply the model for evaluating the loads and yields of TSS and phosphorus within the watershed for potential targeting purposes.

Table 2 compares the observed and simulated average annual stream flow and constituent yields at the streams used for calibration and validation purposes within the Big Green Lake watershed.

Table 1. SWAT model calibration and validation monthly statistics and model bias at streams within Green Lake watershed and Upper Fox sub-basin.

Stream	Period	Area (km2)	Flow			TSS			Phosphorus		
			R^2	NSE	% diff	R^2	NSE	% diff	R^2	NSE	% diff
Silver Cr at Koro CALIBRATION	1987-91	95.6	0.72	0.71	1.0%	0.82	0.82	-1.2%	0.64	0.63	-1.1%
Validation Sites/Periods											
Silver Cr at Koro	1992-96	95.6	0.84	0.80	-11.8%	0.77	0.63	13.8%	0.72	0.72	2.7%
Silver Cr at CTH A	1987-2013	123.4	0.79	0.73	-20.1%	0.63	0.60	-4.8%	0.69	0.58	20.0%
Silver Cr at Spaulding	2012-13	118.5	0.87	0.73	-22.2%	0.51	0.48	-1.2%	0.74	0.64	13.2%
Montello River	2008-11	335.1	0.62	0.59	-7.3%	0.66	0.52	-20.2%	0.57	0.41	-8.8%
Waukau Creek	2008-11	230.0	0.75	0.73	8.7%	0.62	0.61	2.0%	0.81	0.81	-1.7%

Table 2. Observed and simulated average annual flow, TSS and phosphorus yields in streams within Green Lake watershed.

Stream	Period	Area (km2)	Flow (mm)		TSS (t/ha)		Phosphorus (kg/ha)	
			Obs.	SWAT	Obs.	SWAT	Obs.	SWAT
Silver Cr at Koro Calibration	1987-91	95.6	169	170	0.068	0.067	0.51	0.50
Silver Cr at Koro Validation	1992-96	95.6	305	269	0.079	0.090	0.57	0.59
Silver Cr at CTH A	1987-2013	123.4	270	216	0.087	0.082	0.39	0.46
Silver Cr at Spaulding	2012-13	118.5	267	208	0.062	0.061	0.29	0.33

Long-term Sub-watershed Simulated Loads and Yields

The average annual results from a 15 year model simulation are presented in this section. These results serve as a comparison to evaluate which sub-watersheds may be more likely to produce greater yields or loads compared to others. A climatic period from 1998 to 2012 was used for this sub-watershed evaluation period. All results presented here were simulated with the SWAT model, except for those representing the White Creek watershed (sub # 20). At White Creek the observed average annual loads from 1997 to 2012 were utilized, except 2008 data were excluded from the average because it was an unusually high discharge year (869 mm if one assumes a drainage area of 7.47 km^2).

Simulated 15 year average annual yields of TSS (tons/acre) are depicted on a sub-watershed basis in Figure 2. The upper portion of Wurchs Creek and White Creek appear to have the highest simulated yields, followed by the lower portion of Hill Creek. Yields of phosphorus (lbs/acre) are depicted on a sub-watershed basis in Figure 3. The upper portion of Wurchs Creek has the highest simulated yield, followed by the lower portion of Hill Creek and White Creek. Simulated average annual sub-watershed loads of TSS and phosphorus are shown in Figures 4 and 5 respectively.

Simulated phosphorus and TSS yields are summarized on a sub-watershed basis in English and metric units in Table 2. The sub-watersheds were also ranked on a yield basis (not necessarily routed to Big Green Lake). These rankings show how the simulated results can be used to determine where the greatest reductions might best be targeted. The simulated average annual load to Green Lake is 2,950 tons of TSS (2,670 metric tons) and 24,000 lbs of total phosphorus (10,900 kg) during the 1998 to 2012 simulation period.

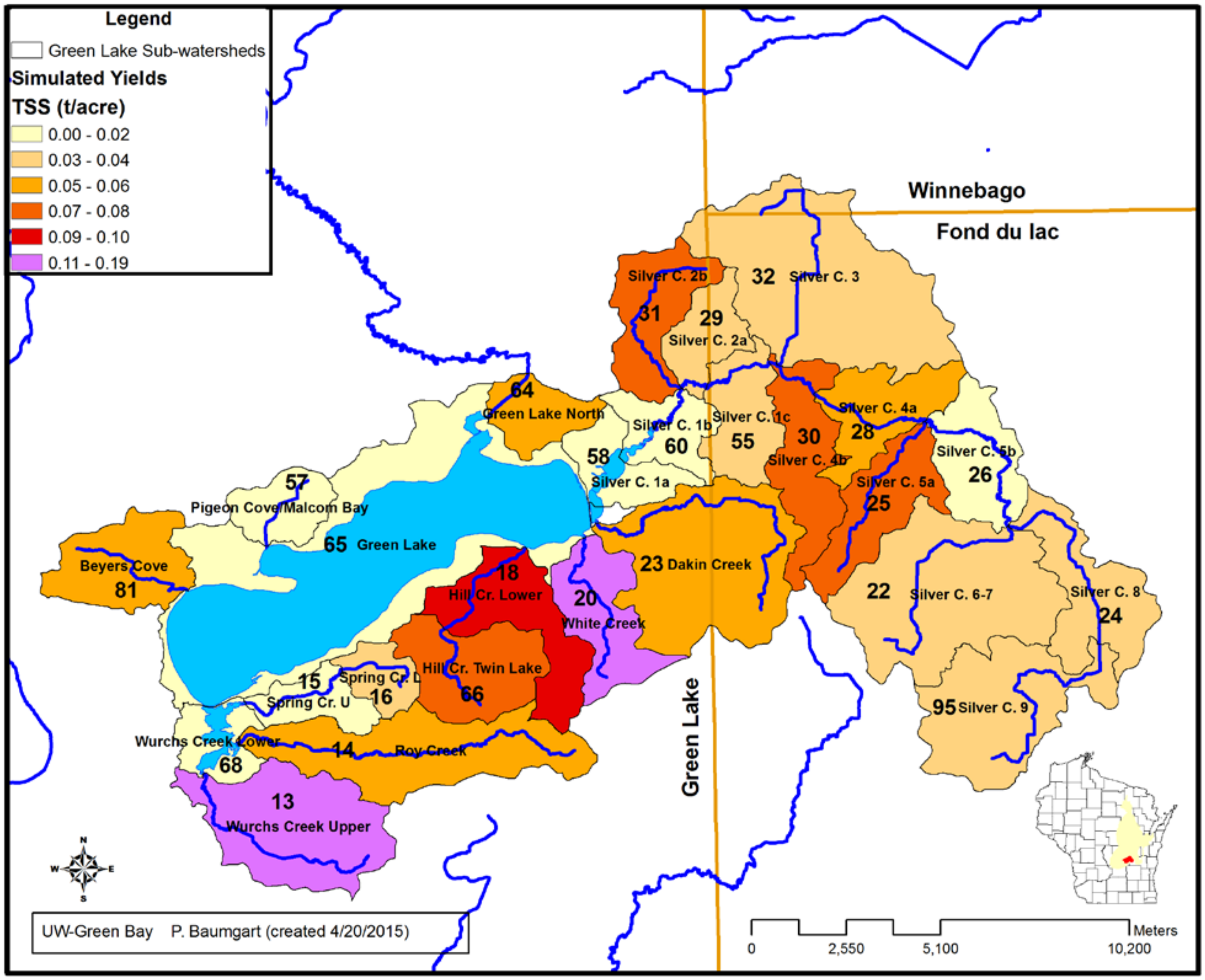

Figure 2. Green Lake simulated non-pt. source sub-watershed average annual TSS yields (ton/acre; 1998-2012 weather).

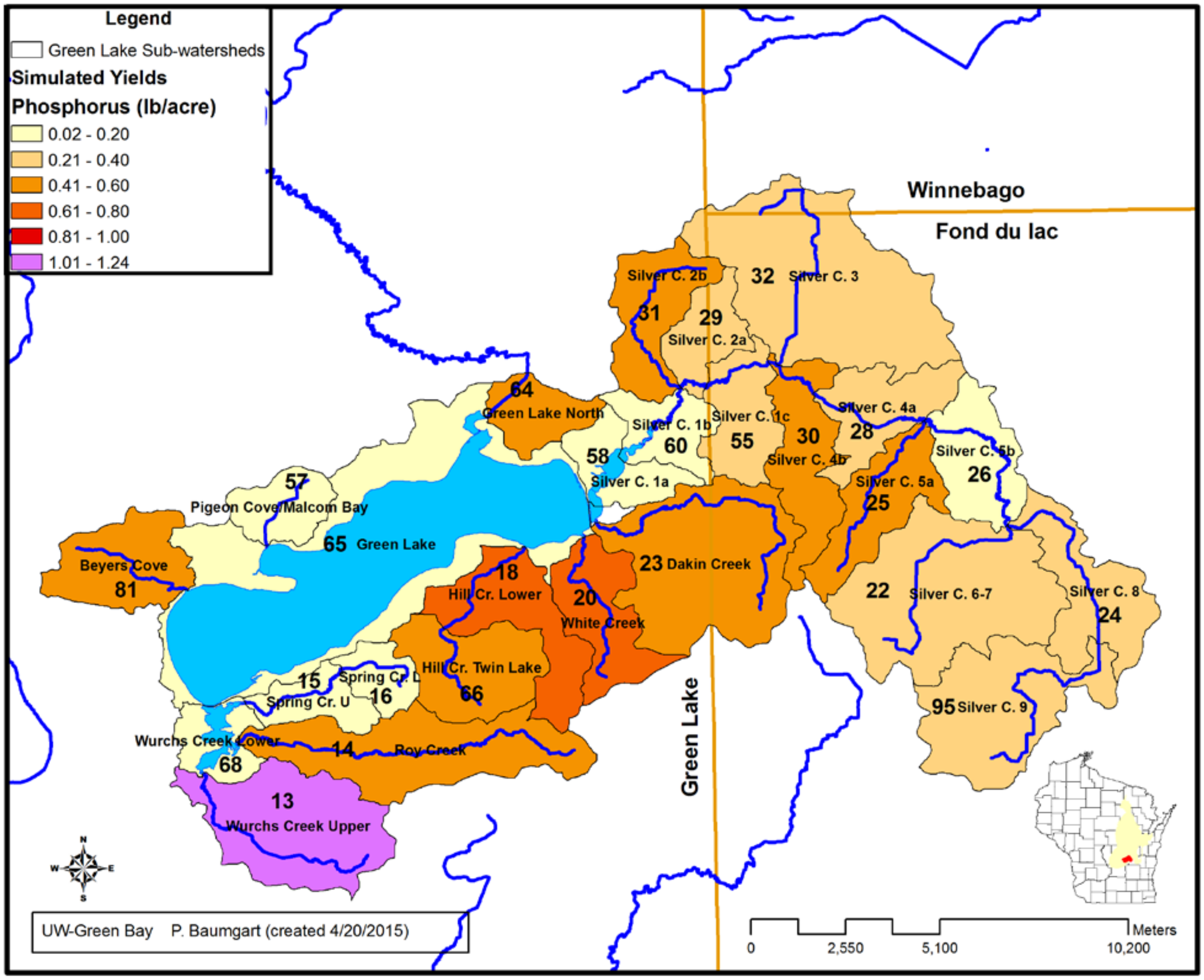

Figure 3. Green Lake simulated non-pt. source sub-watershed average annual phosphorus yields (lbs/acre; 1998-2012 weather).

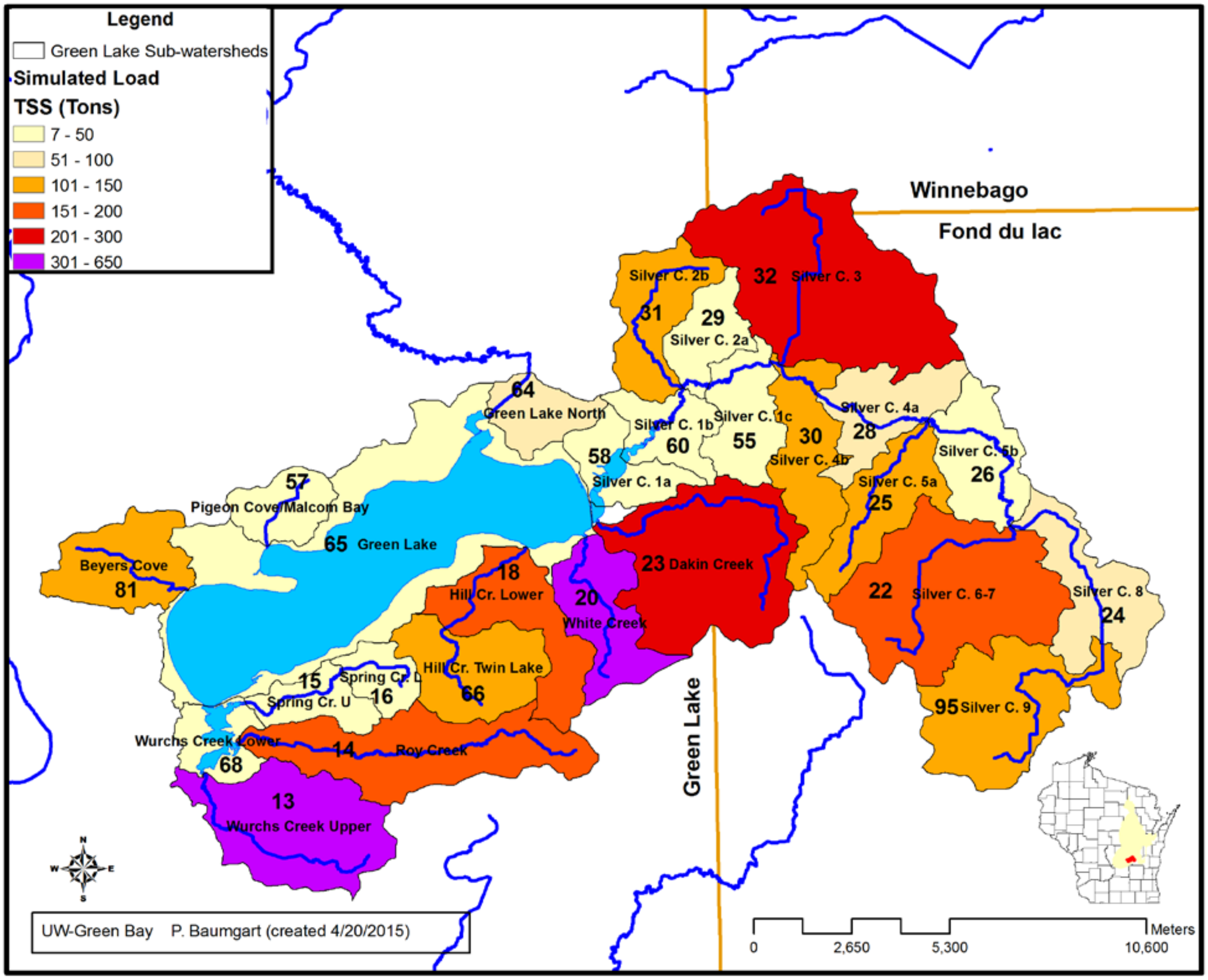

Figure 4. Green Lake simulated non-pt. source sub-watershed average annual TSS loads (tons; 1998-2012 weather).

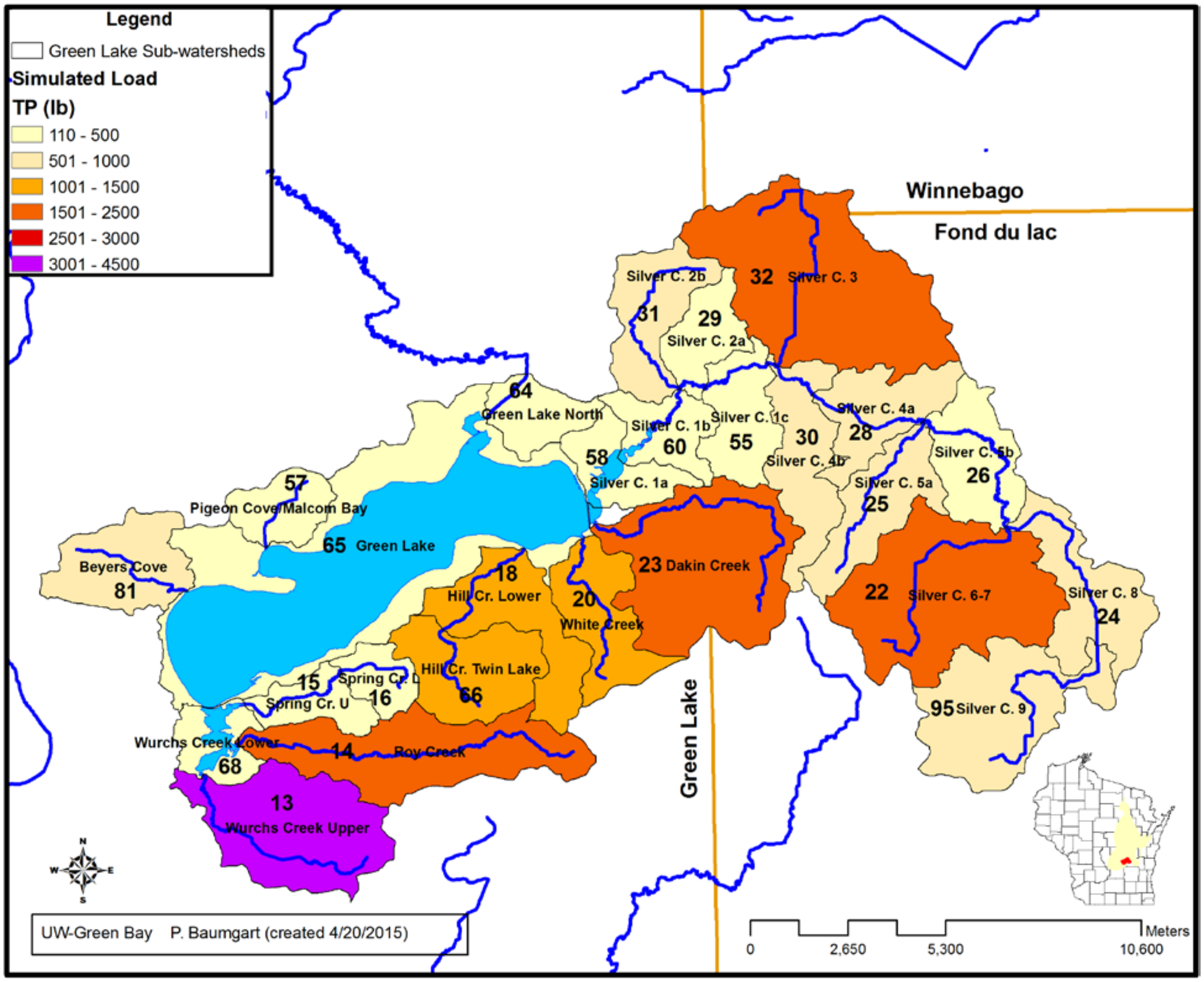

Figure 5. Green Lake simulated non-pt. source sub-watershed average annual phosphorus loads (tons; 1998-2012 weather).

Table 3: SWAT-simulated Green Lake non-point sub-watershed average annual TSS and total phosphorus yields and loads (1998-2012 weather inputs).

SWAT id		AREA	Current Conditions (~Year 2013) English Units				AREA	Current Conditions (~Year 2013) Metric Units				RANK (yield)	
Sub-wate	Name (& 2000 SWAT IDs)	(mile²)	TSS (t/acre)	TP (lb/acre)	TSS (ton)	TP (lb)	(km²)	TSS (mt/ha	TP (kg/ha)	TSS (mt)	TP (kg)	TSS	TP
81	Beyers Cove	3.06	0.058	0.42	113	815	7.93	0.13	0.47	102	370	9	10
23	Dakin Creek	7.09	0.060	0.51	271	2,298	18.36	0.13	0.57	246	1,043	8	6
65	Green Lake (other areas)	6.79	0.009	0.09	37	380	17.57	0.02	0.10	34	172	25	26
64	Green Lake North (e)	1.67	0.056	0.43	60	463	4.31	0.13	0.49	54	210	10	9
18	Hill Cr. Lower	3.47	0.081	0.66	180	1,458	9.00	0.18	0.74	164	661	3	2
66	Hill Cr. Twin Lake	3.32	0.061	0.48	130	1,027	8.59	0.14	0.54	118	466	6	7
57	Pigeon Cove/Malcom Bay	1.68	0.019	0.18	20	195	4.35	0.04	0.20	18	88	21	19
14	Roy Creek	5.56	0.056	0.52	199	1,845	14.41	0.13	0.58	180	837	12	5
58	Silver Cr. 1a	1.88	0.015	0.13	18	154	4.86	0.03	0.14	17	70	22	23
60	Silver Cr. 1b	1.86	0.013	0.13	16	161	4.83	0.03	0.15	14	73	23	22
55	Silver Cr. 1c	2.35	0.029	0.22	43	336	6.08	0.06	0.25	39	153	16	17
29	Silver Cr. 2a	1.75	0.025	0.21	28	237	4.53	0.06	0.24	26	107	18	18
31	Silver Cr. 2b	2.88	0.066	0.52	122	961	7.46	0.15	0.58	110	436	5	4
32	Silver Cr. 3	9.10	0.036	0.31	211	1,814	23.58	0.08	0.35	191	823	14	14
28	Silver Cr. 4a	2.69	0.056	0.32	97	558	6.96	0.13	0.36	88	253	10	12
30	Silver Cr. 4b	3.14	0.073	0.41	147	831	8.14	0.16	0.46	133	377	4	11
25	Silver Cr. 5a	2.91	0.060	0.46	112	848	7.54	0.14	0.51	102	384	7	8
26	Silver Cr. 5b	2.84	0.011	0.12	19	227	7.36	0.02	0.14	18	103	24	24
22	Silver Cr. 6-7	7.60	0.040	0.32	193	1,575	19.69	0.09	0.36	175	715	13	13
24	Silver Cr. 8	3.46	0.024	0.25	53	549	8.96	0.05	0.28	48	249	19	16
95	Silver Cr. 9	5.18	0.032	0.26	106	846	13.41	0.07	0.29	97	384	15	15
16	Spring Cr. L	1.18	0.026	0.17	20	125	3.07	0.06	0.19	18	57	17	20
15	Spring Cr. U	1.48	0.020	0.14	19	135	3.83	0.04	0.16	17	61	20	21
20	White Creek (obs. Data)	2.89	0.192	0.62	354	1,152	7.47	0.43	0.70	322	522	1	3
68	Wurchs Creek Lower	1.56	0.007	0.11	7	110	4.04	0.02	0.12	6	50	26	25
13	Wurchs Creek Upper	5.29	0.191	1.23	648	4,156	13.70	0.43	1.38	588	1,885	2	1
(a)	Silver Creek (all, not routed)	47.6	0.038	0.30	1,166	9,097	123.4	0.086	0.334	1,058	4,126		
(b)	Silver Creek (all, routed; without Ripon MTP(d))				948	8,792				860	3,988		
(c)	Silver Creek (all, routed; WITH Ripon MTP(d))				948	10,263				860	4,655		
	Simulated estimated load to Green Lake (excludes #64)				**2,946**	**23,960**				**2,673**	**10,868**		

(d) Ripon MTP discharge of: 667 kg of total phosphorus per year ---- or 1,472 lbs/year (2008 to 2012 average)

(e) Drains outside Green Lake Watershed

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