SWAT Model Setup, Calibration, and Validation for the Upper Fox-Wolf Basins TMDL

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1 Introduction

This report outlines the setup, calibration, and validation of the Soil and Water Assessment Tool (SWAT) model for the Upper Fox and Wolf Basins (UFWB). The UFWB covers nearly 6,000 square miles of east-central Wisconsin. Several waterbodies in the UFWB are on Wisconsin's 2016 Impaired Waters List and require Total Maximum Daily Loads (TMDLs) to address issues of nutrient and sediment enrichment.

The UFWB SWAT model was created by The Cadmus Group, Inc. to support TMDL development efforts by the US Environmental Protection Agency (EPA) Region 5 and the Wisconsin Department of Natural Resources (WDNR). The UFWB SWAT model uses information on land cover, soils, slope, and land management practices in the watershed to provide estimates of phosphorus and sediment loads from nonpoint sources and average streamflow, phosphorus loads, and sediment loads to guide TMDL analysis.

The UFWB SWAT model was configured using the ArcSWAT2012 interface in ArcGIS 10.1 and run using SWAT 2012 Revision 664.

2 Model Setup

2.1 Subwatershed and Reach Delineation

The Upper Fox and Wolf River Basins, including the direct drainage area to Lake Winnebago, were divided into 218 subwatersheds for SWAT modeling. Subwatersheds were delineated based on:

- Topography (10-meter resolution digital elevation model). Cotter et al. (2003) report that SWAT predictions are sensitive to the resolution of the digital elevation model (DEM) used for model input and that prediction errors below 10% for streamflow, sediment, and phosphorus could be achieved with DEM resolutions of up to 300 meters. The DEM resolution used for the UFWB SWAT model (10 meters) is below this threshold.
- A drainage area threshold of 25 square miles. Jha et al. (2004) report that SWAT streamflow predictions are relatively insensitive to subwatershed size but recommend drainage area thresholds of 3% for predicting sediment loads and 5% for predicting phosphorus loads. The drainage area threshold used for the UFWB SWAT model (approximately 0.5% of the total basin area) is below the recommended values.
- TMDL subbasin boundaries[1] and streamflow/water quality monitoring locations.

[1] TMDL subbasins are the drainage area delineations used for TMDL development. A TMDL and allocations are calculated for each TMDL subbasin. TMDL subbasins are based on the location of impaired waters, point sources of discharge, and flow regimes of UFWB streams.

Subwatersheds were initially delineated using the ArcSWAT subwatershed delineator tool. Tool output was revised to adjust subwatershed boundaries in the City of Oshkosh and the City of Fond du Lac to match drainage boundaries provided by each city to better capture patterns of stormwater drainage. The revised subwatersheds were then input to ArcSWAT using the "user-defined watersheds" option.

Stream reaches input to ArcSWAT were based on the WDNR 1:24,000 scale hydrography geodatabase. WDNR hydrography was edited so that each subbasin contained only one reach. These edits were necessary because the presence of multiple reaches in a subwatershed can result in erroneous channel parameter calculations by ArcSWAT. The UFWB SWAT subwatersheds are displayed in Figure 1.

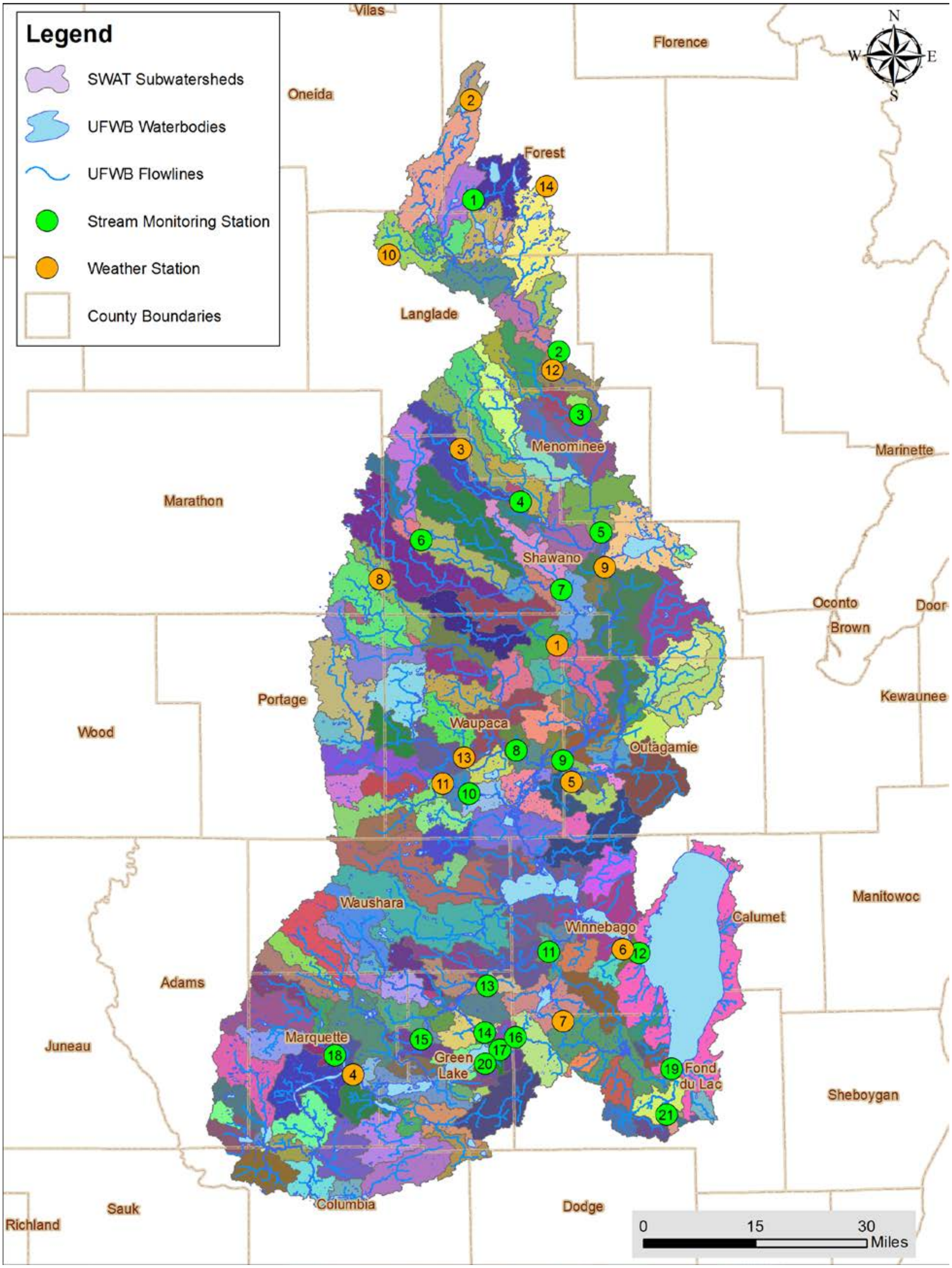

Figure 1. UFWB SWAT model subwatersheds.

2.2 Hydrologic Response Units

Hydrologic Response Units (HRUs) are unique land cover-soil-slope associations within a subwatershed and are the fundamental land units used for simulating water balance and water quality processes within SWAT. ArcSWAT software automatically delineates HRUs within the modeled watershed with user-supplied geospatial datasets on land cover, soil types, and slopes. This section summarizes the datasets used for, and approach to, HRU definition in the UFWB SWAT model.

2.2.1 Land Cover

A custom gridded land cover dataset for the UFWB SWAT model was developed using a combination of the 2006 National Land Cover Database (NLCD), a map layer of statewide crop rotations developed by WDNR (described below), information on agricultural practices from county land and water conservation departments, and boundaries for municipalities with Municipal Separate Storm Sewer System (MS4) permits. The following steps summarize the data sources and methods used to generate the custom land cover grid:

1. The 2006 NLCD land cover grid was aggregated into eight land cover types: open water (NLCD class 11), forest (NLCD classes 41, 42, 43, 52), agriculture (NLCD classes 71, 81, 82), forested wetland (NLCD class 90), herbaceous wetland (NLCD class 82), developed low density (NLCD class 21 and 22), developed medium density (NLCD class 23), and developed high density (NLCD class 24).
2. The developed land cover classes (low, medium, and high density) in step 1 output were further divided into "permitted MS4" and "non-permitted" classes to differentiate between developed lands located inside versus outside of areas regulated by MS4 permits. This step used municipal boundaries for municipalities with MS4 permits (Table 1). Municipal boundaries for the City of Appleton and the City of Fond du Lac were provided by each city in January 2015. Municipal boundaries for the remaining towns, villages, and cities with MS4 permits were acquired from the US Census Bureau website (the 2010 Census County Subdivision dataset). Boundaries for towns with MS4 permits were clipped to urban area boundaries in the 2010 Census Urban Area dataset because MS4 permits for towns only apply to the urbanized area within the town (not the entire town boundary). Note that while the Town of Clayton intersects the UFWB and is listed in Table 1, Clayton's urbanized area is entirely outside of the UFWB and all of the town's urban land cover was classified as "non-permitted" urban.
3. The agriculture land cover class in step 1 output was divided into four general crop rotations: dairy, cash grain, potato/vegetable, and pasture/grassland using a statewide crop rotation map layer developed by WDNR. The statewide crop rotation layer is based on US Department of Agriculture (USDA) Cropland Data Layers for the years 2008 to 2012 (see Section 3.2.1 CDL-Based Rotation Definition of L*and Cover and Agricultural Management Definition within the Upper Wisconsin River Basin* [WDNR 2014] for further details on general crop rotation mapping; these methods were applied by WDNR to create a statewide crop rotation map). General crop rotation acreages are listed in Table 2.
4. The four general crop rotations in step 3 output were further divided into 46 detailed agriculture classes. Each agriculture class is associated with a specific set of farming operations (crops planted, fertilizer applications, tillage, etc.). See Appendix A for details of agriculture class definition and mapping.

Table 1. MS4s with Wisconsin Pollutant Discharge Elimination System (WPDES) permits used to map "Permitted MS4" land cover types for the UFWB SWAT model.

MS4 Name	Urbanized Area
Town of Algoma	Oshkosh
City of Appleton	Appleton
Town of Black Wolf	Fond du Lac
Town of Clayton	Appleton
Village of Eden	Fond du Lac
Town of Empire	Fond du Lac
City of Fond du Lac	Fond du Lac
Town of Fond du Lac	Fond du Lac
Town of Friendship	Fond du Lac
Town of Grand Chute	Appleton
Town of Greenville	Appleton
Town of Harrison	Appleton
Village of Harrison	Appleton
City of Menasha	Appleton
Town of Menasha	Appleton
City of Neenah	Appleton
Town of Neenah	Appleton
Town of Nekimi	Oshkosh
Village of North Fond du Lac	Fond du Lac
Town of Omro	Oshkosh
City of Oshkosh	Oshkosh
Town of Oshkosh	Oshkosh
City of Portage	Portage
Village of Sherwood	Appleton
Town of Taycheedah	Fond du Lac
Town of Vinland	Appleton; Oshkosh

Table 2. Summary of land cover in the UFWB. For SWAT modeling, the Dairy, Cash Grain, and Potato/Vegetable classes were further divided 46 detailed agriculture classes; and the Developed (Non-Permitted) and Developed (Permitted) classes were divided into low, medium, and high density classes.

Land Cover Class	Area (acres)	% of UFWB
Forest	1,066,191	29.8%
Pasture	676,448	18.9%
Forested Wetland	547,691	15.3%
Cash Grain	428,023	12.0%
Dairy	391,312	10.9%
Herbaceous Wetland	164,376	4.6%
Developed (Non-Permitted)	154,990	4.3%
Open Water	78,579	2.2%
Potato/Vegetable	44,065	1.2%
Developed (MS4 Permitted)	27,222	0.8%

2.2.2 Soils

Soil types were defined using a custom soil dataset that combined two soil data products from the USDA Natural Resources Conservation Service: the Digital General Soil Map of the United States (STATSGO2) and the Soil Survey Geographic Database (SSURGO). The STATSGO2 map layer defines 57 different soil types in the UFWB. SSURGO is a higher-resolution soil map, with 2,062 different soil types defined in the UFWB. Each SSURGO and STATSGO2 soil type has a specific set of SWAT soil parameters listed in soil attribute data tables included with ArcSWAT 2012. The custom soil dataset input to SWAT defined most soil parameters at the scale of STATSGO2 soil types except for hydrologic soil group, which was characterized at the more detailed scale of SSURGO soil types. Hydrologic soil group describes the runoff potential of a soil type and is a key soil attribute for SWAT modeling.

The following steps were applied to merge the STATSGO2 and SSURGO datasets for the UFWB SWAT model:

1. Create a hydrologic soil group map layer from the SSURGO dataset for the UFWB.
2. Overlay the hydrologic soil group map layer created in step 1 with the STATSGO2 map layer. This step divided each STATSGO2 soil type into multiple subtypes based on SSURGO hydrologic soil group and resulted in 201 different soil types.
3. Create a custom soil attribute table for input to ArcSWAT. Each soil type in the custom soil map created in step 2 was assigned the attributes of the corresponding STATSGO2 soil type and the SSURGO-based hydrologic soil group.

2.2.3 Slope

A gridded slope dataset for the UFWB was automatically created by ArcSWAT from the 10-meter resolution digital elevation model used for subwatershed delineation. Three slope classes were defined for HRU definition using thresholds of 3.2% (the watershed average slope) and 10%. Slope classes were 0%-3.2%, 3.2%-10%, and >10%.

2.2.4 HRU Definition

HRUs were defined and mapped using the ArcSWAT HRU interface and the land cover, soil, and slope datasets described above. HRU definition involves selecting minimum area thresholds for land cover classes, soil types, and slope classes within a subwatershed that must be met in order for HRUs for those classes to be included in the model. The use of thresholds for HRU definition prevents the inclusion of land cover, soil, and slope classes with negligible areas in a subwatershed, thereby reducing the total number of HRUs and improving model efficiency.

Minimum area thresholds of 2%, 15%, and 20% were used for land cover, soils, and slope, respectively. Because small amounts of urban cover can impact runoff and water quality, developed land classes were exempted from the minimum area threshold. This process resulted in 8,295 HRUs for the UFWB SWAT model. The acreage of each land cover class following HRU definition are listed in Appendix C.

2.3 Weather

Daily precipitation and air temperature records from 14 weather stations over the period January 1990 through December 2013 were acquired from the National Climatic Data Center (NCDC) for input to the UFWB SWAT model. Weather files were pre-processed before loading to ArcSWAT to replace missing records with values observed at the nearest weather station with a non-missing record from the same day.

Model subwatersheds were assigned precipitation and temperature records from the nearest weather station using the ArcSWAT interface. Table 2 lists the weather stations used in the UFWB SWAT model. Weather station locations are mapped in Figure 1.

Table 3. Weather stations included in the UFWB SWAT model.

Station ID	Station Name	County	Latitude	Longitude	Map Label
USC00479176	Clintonville	Waupaca	44.62	-88.75	1
USC00473636	Hiles	Forest	45.68	-88.97	2
USC00475364	Merrill	Lincoln	45.00	-89.01	3
USC00475581	Montello	Marquette	43.78	-89.32	4
USC00475932	New London	Outagamie	44.35	-88.72	5
USC00476330	Oshkosh	Winnebago	44.02	-88.55	6
USC00477209	Ripon 5 NE	Fond du Lac	43.88	-88.75	7
USC00477349	Rosholt 9 NNE	Marathon	44.75	-89.23	8
USC00477708	Shawano 2 SSW	Shawano	44.77	-88.62	9
USC00478324	Summit Lake	Langlade	45.38	-89.20	10
USC00478951	Waupaca	Waupaca	44.35	-89.07	11
USC00479176	White Lake 3 NE	Langlade	45.18	-88.73	12
USC00479345	Wisc Rapids Grand Av B	Wood	44.40	-89.01	13
USC00474582	Laona 6 SW	Forest	45.51	-88.76	14

2.4 Point Sources

WDNR identified 91 point sources of discharge located in the UFWB during the model simulation period (2000 through 2013) (Table 4). Although 10 of these point sources have discontinued discharging as of the date of this report (see Table 4), all current and discontinued dischargers were included in the UFWB SWAT model to more accurately reflect existing conditions during the simulation period and therefore better estimate watershed runoff and pollutant loading parameters.

Point source flows, sediment loads, and phosphorus loads were estimated for each point source using annual discharge monitoring record summaries for the period 2000 through 2013 acquired from WDNR. Point source flows and loads were input to SWAT as average annual values by year. For years with missing records, the long-term annual average was used. Point sources were assigned to SWAT subwatersheds based on outfall latitude/longitude coordinates.

SWAT allows point source loads to be entered as soluble inorganic phosphorus, organic phosphorus, or a combination of the two. Point source phosphorus loads input to the UFWB SWAT model were assumed to take the form of soluble phosphorus. The effect of this assumption on total phosphorus predictions was tested as part of model calibration. The designation of point source loads as soluble phosphorus versus organic phosphorus was found to have a negligible influence on total phosphorus predictions because instream nutrient dynamics were not simulated in the UFWB SWAT model.

Table 4. Point sources included in the UFWB SWAT model. Facilities that have discontinued discharging as of the date of this report are marked with an asterisk (*).

Facility Name	WPDES Permit Number	Outfall Number	SWAT Subwatershed
Agropur Inc. Weyauwega Plant	1449	1	110
Amherst Wastewater Treatment Facility	23213	1	80
Bear Creek Wastewater Treatment Facility	28061	1	66
Berlin Wastewater Treatment Facility	21229	1	129
Birdseye Foods – Hortonville*	70777	1	98
Birnamwood Wastewater Treatment Facility	22691	2	48
Black Creek Wastewater Treatment Facility	21041	1	70
Bonduelle USA – Fairwater	2666	-	201
Bowler Wastewater Treatment Facility	21237	1	42
Butte Des Morts Consolidated SD 1	32492	1	127
Caroline SD 1 Wastewater Treatment Facility	22829	3	43
Clintonville Wastewater Treatment Facility	21466	1	53
Dale Sanitary District No 1 WWTF	30830	1	114
Darling International Inc.	38083	1	141
Del Monte Corporation Markesan Plant #116*	27448	1	201
Eden Wastewater Treatment Facility	30716	1	188
Embarrass Cloverleaf Lakes SD Lagoon System	23949	1	54
Fairwater Wastewater Treatment Facility	21440	4	201
Fond du Lac Water Pollution Control Plant	23990	3	115
Fremont Orihula Wolf River Joint S C	26158	1	117
Friesland Wastewater Treatment Facility	31780	1	207
Green Lake Sanitary District	36846	1	164
Green Lake Wastewater Treatment Facility	21776	1	163
Gresham Wastewater Treatment Facility	22781	1	38
Hortonville Wastewater Treatment Facility	22896	1	97
Iola Wastewater Treatment Facility	21717	3	77
Keshena Wastewater Treatment Facility	71315	1	35
Kingston Wastewater Treatment Facility	36421	1	195
Lakeside Foods Inc. Eden	485	2	188
Lakeside Foods Inc. Seymour Plant*	27634	1	70
Larsen Winchester SD WWTF	31925	1	120
Leach Farms – Auroraville	52809	-	123
Little Rapids Corp Shawano Specialty Papers	1341	2	74

Facility Name	WPDES Permit Number	Outfall Number	SWAT Subwatershed
Manawa Wastewater Treatment Facility	20869	1	84
Marion Wastewater Treatment Facility	20770	3	51
Markesan Wastewater Treatment Facility	24619	1	201
Michels Materials Fl&B Sheppard Quarry*	58564	1	127
Michels Materials Fl&B Sheppard Quarry*	58564	2	127
Michels Materials Fl&B Sheppard Quarry*	58564	3	127
Michels Materials Fl&B Sheppard Quarry*	58564	4	127
Milk Specialties – FDL*	132	-	184
Montello Wastewater Treatment Facility	24813	1	187
Neopit Wastewater Treatment Facility	73059	-	24
Neshkoro Wastewater Treatment Facility	60666	2	150
New London Wastewater Treatment Facility	24929	1	92
Nichols Wastewater Treatment Facility	20508	1	69
North Lake Poygan S D WWTF	36251	1	122
Oakfield Wastewater Treatment Facility	24988	1	203
Omro Wastewater Treatment Facility	25011	1	124
Oshkosh Wastewater Treatment Plant	25038	1	133
Oxford Wastewater Treatment Facility	32077	1	206
Power Packaging Inc.	69965	1	170
Poy Sippi SD Wastewater Treatment Facility	31691	1	121
Poygan Poysippi SD 1 WWTF	35513	1	122
Princeton Wastewater Treatment Facility	22055	1	161
Redgranite Wastewater Treatment Facility	20729	1	123
Ridgeway Country Club Inc. WWTF*	30643	1	120
Ripon Wastewater Treatment Facility	21032	1	162
Rosendale Wastewater Treatment Facility	28428	1	170
Saputo Cheese - New London*	159	-	92
Saputo Cheese USA Inc. Black Creek	27596	1	70
Saputo Cheese USA Inc. Black Creek	27596	3	70
Saputo Cheese USA, Fond du Lac (Scott St)	56120	1	115
Sara Lee Foods - New London	23094	1	103
Seneca Foods Corporation Oakfield*	2267	1	203
Seneca Foods Corporation Ripon*	1163	1	162
Seymour Wastewater Treatment Facility	21768	1	70
Shiocton Wastewater Treatment Facility	28100	1	78

Facility Name	WPDES Permit Number	Outfall Number	SWAT Subwatershed
Silver Lake Sanitary District	61301	1	136
Silver Moon Springs	64548	-	18
Sokaogon Chippewa Community Wastewater Treatment System	71501	1	5
Stephensville Sanitary District No 1	32531	1	96
Stockbridge Wastewater Treatment Facility	21393	1	125
Stockbridge-Munsee Community Wastewater Ponds	36188	10	29
Tigerton Wastewater Treatment Facility	22349	1	48
Utica Energy LLC*	63649	1	132
Waupaca Foundry Plant 1	26379	-	101
Waupaca Wastewater Treatment Facility	30490	1	101
Westfield Wastewater Treatment Facility	22250	1	160
Weyauwega Star Dairy	39527	-	110
Weyauwega Wastewater Treatment Facility	20923	1	110
WI DNR Wild Rose Fish Hatchery	22756	1	121
WI DNR Wild Rose Fish Hatchery	22756	2	121
WI DNR Wild Rose Fish Hatchery	22756	4	121
WI DNR Wild Rose Fish Hatchery	22756	18	121
Wild Rose Wastewater Treatment Facility	60071	2	121
Winneconne Wastewater Treatment Facility	21938	1	127
Wisconsin Veneer And Plywood Inc.	47929	1	29
Wittenberg Wastewater Treatment Facility	28444	2	36
Wolf River Ranch Wastewater Treatment Facility	71307	1	24
Wolf Treatment Plant	28452	1	74

2.5 Initial Soil Phosphorus

SWAT allows users to input estimates of initial soil phosphorus concentrations throughout the modeled area that serve as a starting point for simulating soil phosphorus dynamics. Soil phosphorus concentrations are updated in SWAT throughout the simulation period using algorithms that reflect phosphorus inputs, outputs, and transformations.

The initial soil phosphorus content of each soil type in the UFWB SWAT model was defined using estimates of average soil phosphorus by county and by 12-digit hydrologic unit (HUC12) (Table 5). Staff from county land and water conservation departments (LWCDs) were asked to provide estimates of average soil phosphorus by HU12. Some counties responded with a county-wide average soil phosphorus value or average values by HUC12 derived from a review of nutrient management plans. Values reported by LWCD staff were assigned to UFWB SWAT model soil types located in those counties and HUC12s. Other counties were not able to provide information on soil phosphorus content. For soil types in those counties, initial soil phosphorus was set to the county average reported by the University of Wisconsin Soil Testing Laboratories for the period 2005 through 2009 (http://uwlab.soils.wisc.edu/soilsummary/maps/).

The soil phosphorus concentrations acquired from county LWCDs and the University of Wisconsin Soil Testing Laboratories were assumed to be derived from the Bray-1 testing method and were divided by one-half for input as initial soil soluble phosphorus concentrations in SWAT, based on recommendations in Vadas and White (2010).

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Table 5. Initial soil phosphorus (P) concentrations used for the UFWB SWAT model in units of parts per million (ppm). Values were assigned to all soil types in each county or county-HUC12 combination.

County	HUC12 Name	HUC12 Code	Soil P (ppm)	Source
Adams	-	-	35	County LWCD
Calumet	-	-	41	County LWCD
Columbia	-	-	50	County LWCD
Dodge	-	-	51	UW Soils
Fond du Lac	Taycheedah Creek-Frontal Lake Winnebago	040302030302	27	County LWCD
Fond du Lac	De Neveu Creek-Frontal Lake Winnebago	040302030301	30	County LWCD
Fond du Lac	Willow Harbor-Frontal Lake Winnebago	040302030102	35	County LWCD
Fond du Lac	Village of Rosendale-Fond du Lac River	040302030201	35	County LWCD
Fond du Lac	Pipe Creek-Frontal Lake Winnebago	040302030303	38	County LWCD
Fond du Lac	Van Dyne Creek-Frontal Lake Winnebago	040302030103	40	County LWCD
Fond du Lac	Rush Creek	040302011002	44	County LWCD
Fond du Lac	Headwaters Grand River	040302010401	51	County LWCD
Fond du Lac	Eightmile Creek	040302011001	53	County LWCD
Fond du Lac	Eldorado Marsh-Fond du Lac River	040302030204	54	County LWCD
Fond du Lac	Silver Creek	040302010901	56	County LWCD
Fond du Lac	Parsons Creek-East Br. Fond du Lac River	040302030203	56	County LWCD
Fond du Lac	Sevenmile Creek-East Br. Fond du Lac River	040302030202	67	County LWCD
Forest	-	-	45	UW Soils
Green Lake	Little Green Lake-Grand River	040302010402	32	County LWCD
Green Lake	Grand River	040302010504	34	County LWCD
Green Lake	Grand Lake-Grand River	040302010502	38	County LWCD
Green Lake	Silver Creek	040302010901	42	County LWCD
Green Lake	Puchyan River	040302011103	49	County LWCD
Green Lake	City of Berlin-Fox River	040302011106	49	County LWCD
Green Lake	Sucker Creek	040302010805	52	County LWCD
Green Lake	Rush Creek	040302011002	52	County LWCD
Green Lake	Mill Race-Fox River	040302011102	52	County LWCD
Green Lake	Sand Spring Creek-Fox River	040302010101	54	County LWCD
Green Lake	Lake Emily	040302010501	54	County LWCD
Green Lake	White River	040302010806	56	County LWCD
Green Lake	Black Creek	040302011101	56	County LWCD
Green Lake	Town Ditch	040302011104	60	County LWCD
Green Lake	Puckaway Lake-Fox River	040302010605	64	County LWCD

County	HUC12 Name	HUC12 Code	Soil P (ppm)	Source
Green Lake	Big Green Lake	040302010902	65	County LWCD
Green Lake	Headwaters Grand River	040302010401	76	County LWCD
Green Lake	Belle Fountain Creek	040302010503	112	County LWCD
Langlade	-	-	108	UW Soils
Marathon	-	-	60	County LWCD
Marquette	-	-	57	UW Soils
Menominee	-	-	46	UW Soils
Oconto	-	-	47	UW Soils
Oneida	-	-	107	UW Soils
Outagamie	Herman Creek	040302020803	22.1	County LWCD
Outagamie	Town of Greenville-Bear Creek	040302021401	26.1	County LWCD
Outagamie	Maple Creek	040302021302	30	County LWCD
Outagamie	Medina Junction-Rat River	040302022101	30.8	County LWCD
Outagamie	Bear Creek	040302021303	30.9	County LWCD
Outagamie	Turney Hill-Bear Creek	040302021304	34	County LWCD
Outagamie	Municipality of Stephensville-Bear Creek	040302021402	37.8	County LWCD
Outagamie	Township of Deer Creek-Embarrass River	040302021301	39.4	County LWCD
Outagamie	Village of Shiocton-Wolf River	040302021403	50.9	County LWCD
Outagamie	Outagamie State Wildlife Area-Wolf River	040302020904	55.5	County LWCD
Outagamie	Town of Dale-Rat River	040302022102	59.6	County LWCD
Outagamie	Black Otter Lake-Wolf River	040302021404	70.1	County LWCD
Outagamie	Potters Creek	040302021901	70.6	County LWCD
Outagamie	Toad Creek	040302020804	25.7	County LWCD
Outagamie	Upper Black Creek	040302020805	29.4	County LWCD
Outagamie	Mink Creek-Shioc River	040302020807	33.3	County LWCD
Outagamie	Lower Black Creek	040302020806	38.5	County LWCD
Portage	-	-	50	County LWCD
Shawano	-	-	43	UW Soils
Waupaca	-	-	60	UW Soils
Waushara	Sucker Creek	040302010805	35	County LWCD
Waushara	Hogars Bayou-Fox River	040302011107	40	County LWCD
Waushara	Willow Creek	040302022006	40	County LWCD
Waushara	Town Ditch	040302011104	45	County LWCD
Waushara	Radley Creek	040302021807	45	County LWCD
Waushara	Alder Creek	040302022103	45	County LWCD

County	HUC12 Name	HUC12 Code	Soil P (ppm)	Source
Waushara	Hatton Creek	040302021903	50	County LWCD
Waushara	Pine River-Frontal Lake Poygan	040302022003	50	County LWCD
Waushara	Barnes Creek	040302011105	60	County LWCD
Waushara	Bruce Creek-Willow Creek	040302022004	60	County LWCD
Waushara	Humphrey Creek-Pine River	040302022001	65	County LWCD
Waushara	Little Lunch Creek-White River	040302010804	70	County LWCD
Waushara	Mosquito Creek	040302021905	70	County LWCD
Waushara	Weddle Creek	040302010701	80	County LWCD
Waushara	Lunch Creek	040302010803	80	County LWCD
Waushara	Carpenter Creek-Pine River	040302022002	80	County LWCD
Waushara	Cedar Springs Creek-Willow Creek	040302022005	125	County LWCD
Waushara	Soules Creek-White River	040302010802	50	County LWCD
Waushara	Chafee Creek	040302010702	80	County LWCD
Waushara	Little Pine Creek-Mecan River	040302010703	80	County LWCD
Waushara	West Branch White River	040302010801	80	County LWCD
Winnebago	Medina Junction-Rat River	040302022101	15	County LWCD
Winnebago	Van Dyne Creek-Frontal Lake Winnebago	040302030103	20	County LWCD
Winnebago	Pumpkinseed Creek	040302022104	24	County LWCD
Winnebago	Arrowhead River	040302022105	26	County LWCD
Winnebago	Brooks Cemetary	040302011203	27	County LWCD
Winnebago	Sawyer Creek	040302011204	27	County LWCD
Winnebago	Willow Harbor-Frontal Lake Winnebago	040302030102	28	County LWCD
Winnebago	Lake Butte des Mortes-Fox River	040302011205	29	County LWCD
Winnebago	Eightmile Creek	040302011001	32	County LWCD
Winnebago	City of Oshkosh-Frontal Lake Winnebago	040302030101	34	County LWCD
Winnebago	Lake Poygan	040302022106	35	County LWCD
Winnebago	Alder Creek	040302022103	37	County LWCD
Winnebago	Partridge Lake-Wolf River	040302021906	41	County LWCD
Winnebago	Town of Dale-Rat River	040302022102	41	County LWCD
Winnebago	Daggetts Creek	040302011202	22	County LWCD
Winnebago	Spring Brook	040302011201	29	County LWCD
Winnebago	Hogars Bayou-Fox River	040302011107	30	County LWCD
Winnebago	Rush Creek	040302011002	34	County LWCD

2.6 Baseflow Alpha Factor

The baseflow alpha factor (ALPHA_BF) is a relative measure of groundwater discharge in response to groundwater recharge. An initial baseflow alpha factor of 0.014 was estimated for the UFWB using daily streamflow records for 15 streams located in or near the UFWB acquired from the US Geological Survey (USGS) National Water Information System and BFLOW baseflow separation software acquired from the SWAT website (http://swat.tamu.edu/software/baseflow-filter-program) (Table 6). Stream gaging sites included in baseflow analysis were selected because they had at least six years of streamflow records and did not appear to be significantly influenced by regulation from lakes/reservoirs or point source discharges.

Table 6. USGS streamflow gaging stations used to estimate the initial value of the baseflow alpha factor parameter in the UFWB SWAT model.

USGS ID	**Gage Name**	**Start Year**	**End Year**	**Alpha Factor**
04074548	Swamp Creek below Rice Lake at Mole Lake, WI	2002	2008	0.0046
04074950	Wolf River at Langlade, WI	1981	2014	0.0073
04077000	Wolf River at Keshena Falls near Keshena, WI	1912	1984	0.0069
04073500	Fox River at Berlin, WI	1901	2014	0.0107
04080000	Little Wolf River at Royalton, WI	1914	1970	0.0117
040734644	Silver Creek at South Koro Road near Ripon, WI	1988	1994	0.0122
04079000	Wolf River at New London, WI	1914	2014	0.0123
04077630	Red River at Morgan Road near Morgan, WI	1993	2014	0.0133
04073473	Puchyan River Downstream N. Lawson Driver near Green Lake, WI	1997	2011	0.0136
0407809265	Middle Branch Embarrass River near Wittenberg, WI	1990	2005	0.0169
04073365	Fox River at Princeton, WI	2010	2013	0.0181
04078500	Embarrass River near Embarrass, WI	1994	2013	0.0207
05423000	West Branch Rock River near Waupun, WI	1950	1981	0.0217
04073050	Grand River near Kingston, WI	1967	1974	0.0254
04075365	Evergreen River Below Evergreen Falls Near Langlade, WI	2002	2008	0.0120
Average				**0.014**

2.7 Internally Drained Areas

Internally drained areas are areas where runoff flows to a depression on the landscape that has no surface connection to the stream channel network during and after storm events. Internally drained areas in the UFWB were mapped using the WDNR 1:24,000 scale hydrography geodatabase. The WDNR hydrography geodatabase maps surface water features in Wisconsin and their local drainage areas (i.e., the land area directly draining to the surface water feature). The geodatabase stores descriptive attributes of local drainage areas, including whether they are connected to the surface water network or isolated. The acreage of internally drained areas within each SWAT subwatershed was calculated as the area of isolated local drainages in the subwatershed from the WDNR hydrography geodatabase.

After mapping internally drained areas, a SWAT pond file (.PND) was setup for each subwatershed to account for internal drainage. Pond area and volume parameters were set to very large values so that the pond never overflowed and instead stored water away from the stream network for evaporation or groundwater recharge. Pond files were configured with the subwatershed fraction draining to the pond (parameter PND_FR) equal to the percentage of the subwatershed that was internally drained. Estimated percentages of internally drained areas in SWAT subwatersheds ranged from 0% to 51% of subwatershed area. In total, internally drained areas represent approximately 4% of the total UFWB area.

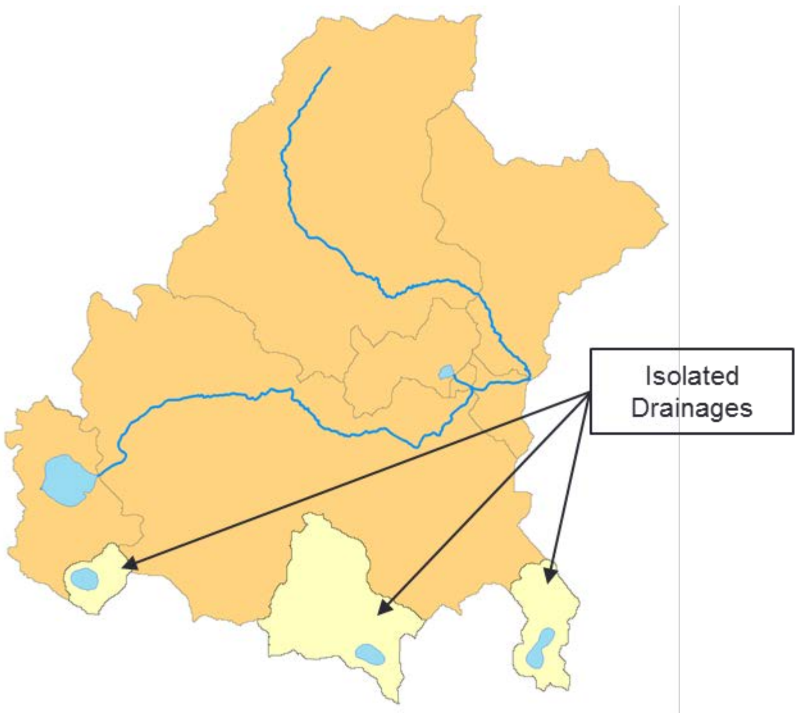

Figure 2. Example of isolated drainage areas in the WDNR 1:24,000 hydrography geodatabase. Isolated drainage areas were used to estimate internally drained areas in SWAT subwatersheds.

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2.8 <u>Manning's *n*</u>

Manning's roughness coefficient (Manning's *n*) values were initially estimated for the main channel of each SWAT subwatershed according to the extent of wetland cover in the 30 meter riparian buffer surrounding the stream reach. Riparian wetland cover was estimated from the 2011 NLCD land cover dataset (NLCD classes 90 and 95) and Manning's *n* values were assigned using thresholds displayed in Table 7.

Manning's *n* for tributary channels was set to 0.07 for all subwatersheds. Manning's *n* for overland flow was set to ArcSWAT default values for each land cover type.

Initial estimates of Manning's n for main channels and tributary channels were revised as part of model calibration. Calibrated values are discussed in the *Model Calibration and Validation Results* section of this report.

Table 7. Riparian wetland thresholds used for initial estimates of main channel Manning's n.

Wetlands in 30 Meter Channel Buffer	**Manning's *n***
0-10%	0.020
10-20%	0.035
20-30%	0.050
30-40%	0.065
40-50%	0.080
50-60%	0.095
60-70%	0.110
70-80%	0.125
80-90%	0.140
90-100%	0.155

2.9 Subwatershed Slope Length

Average slope length (parameter SLPSUBBSN) is the average distance within a subwatershed that sheet flow is the dominant form of surface runoff before becoming channelized. Initial slope length values calculated by ArcSWAT during subwatershed delineation were reviewed and determined to be overestimated. The SWAT manual lists 90 meters as an upper guideline for slope length (Arnold, et al., 2012) and most subwatersheds had slope length values well above the 90 meter guidance value. A correction was therefore applied using the equation reported in Baumgart (2005):

$$SLSUBBSN_{ADJ} = 91.4/(HRU\_SLP \ * 100) \ + 1)^{0.4}$$

where $SLSUBBSN_{ADJ}$ is the corrected slope length and HRU_SLP is the average slope steepness in the HRU calculated by ArcSWAT. After applying this correction, the maximum slope length for any subwatershed was 91 meters.

2.10 Simulation Period

The UFWB SWAT model was setup to run for the period January 1, 1990 to December 31, 2013. The period January 1, 1990 to December 31, 1999 is considered a "warm-up" period to allow initial condition settings, such as initial soil phosphorus concentrations, to equilibrate. Model output during 1990 through 1999 was not evaluated as part of model calibration and validation.

3 Calibration and Validation Approach

Model calibration is the process of iteratively adjusting model parameter estimates improve the fit between model predictions and real world observations. After calibration, model validation is performed by running the model with the calibrated parameter set and comparing predictions to additional observed data (i.e., observed data not used for calibration). Based on the level of agreement between predictions and these additional observations, the model is either validated for further use or model inputs and parameters are revisited for further calibration.

For the UFWB SWAT model, calibration consisted of adjusting parameters related to plant growth, streamflow, total phosphorus loads, and sediment loads. Two general methods of calibration were applied. Manual calibration involved manually adjusting parameter values, running the model, reviewing predictions, and repeating these steps until the model outputs of interest sufficiently matched observed data or expected results. Automated calibration was also completed using SWAT-Calibration and Uncertainty Program (SWAT-CUP; Version 2012) software. SWAT-CUP software provides users with the ability to select specific model parameters for auto-calibration within defined boundaries and executes hundreds of SWAT runs to find the optimal set of parameter values that minimize the error between model predictions and observed data (Abbaspour, 2014).

Parameter adjustments for subwatersheds with monitoring data were applied across multiple subwatersheds because observed streamflow and water quality data were not available for every subwatershed in the UFWB. For some parameters, adjustments were universally applied to all UFWB subwatersheds. Other parameters were adjusted regionally, with US EPA Level III ecoregions used as the basis of regional adjustments. The UFWB is divided into three Level III ecoregions: North Central Hardwood Forests, Northern Lakes and Forests, and Southeastern Wisconsin Till Plains (Figure 3).

The Nash-Sutcliffe Efficiency coefficient (NSE), the coefficient of determination (R^2), and percent bias (PBIAS) were used to evaluate calibration and validation performance of the UFWB SWAT model. Thresholds for evaluation of model performance followed guidelines outlined in Moriasi et al. (2007):

- "Very Good" performance
  - Flow: NSE ≥ 0.75 and PBIAS ≤ ±10%
  - Sediment: NSE ≥ 0.75 and PBIAS ≤ ±15%
  - Total Phosphorus: NSE ≥ 0.75 and PBIAS ≤ ±25%
- "Good" performance
  - Streamflow: NSE ≥ 0.65 and PBIAS ≤ ±15%
  - Sediment: NSE ≥ 0.65 and PBIAS ≤ ±30%
  - Total Phosphorus: NSE ≥ 0.65 and PBIAS ≤ ±40%
- "Satisfactory" performance
  - Streamflow: NSE ≥ 0.5 and PBIAS ≤ ±25%
  - Sediment: NSE ≥ 0.5 and PBIAS ≤ ±55%
  - Total Phosphorus: NSE ≥ 0.5 and PBIAS ≤ ±70%

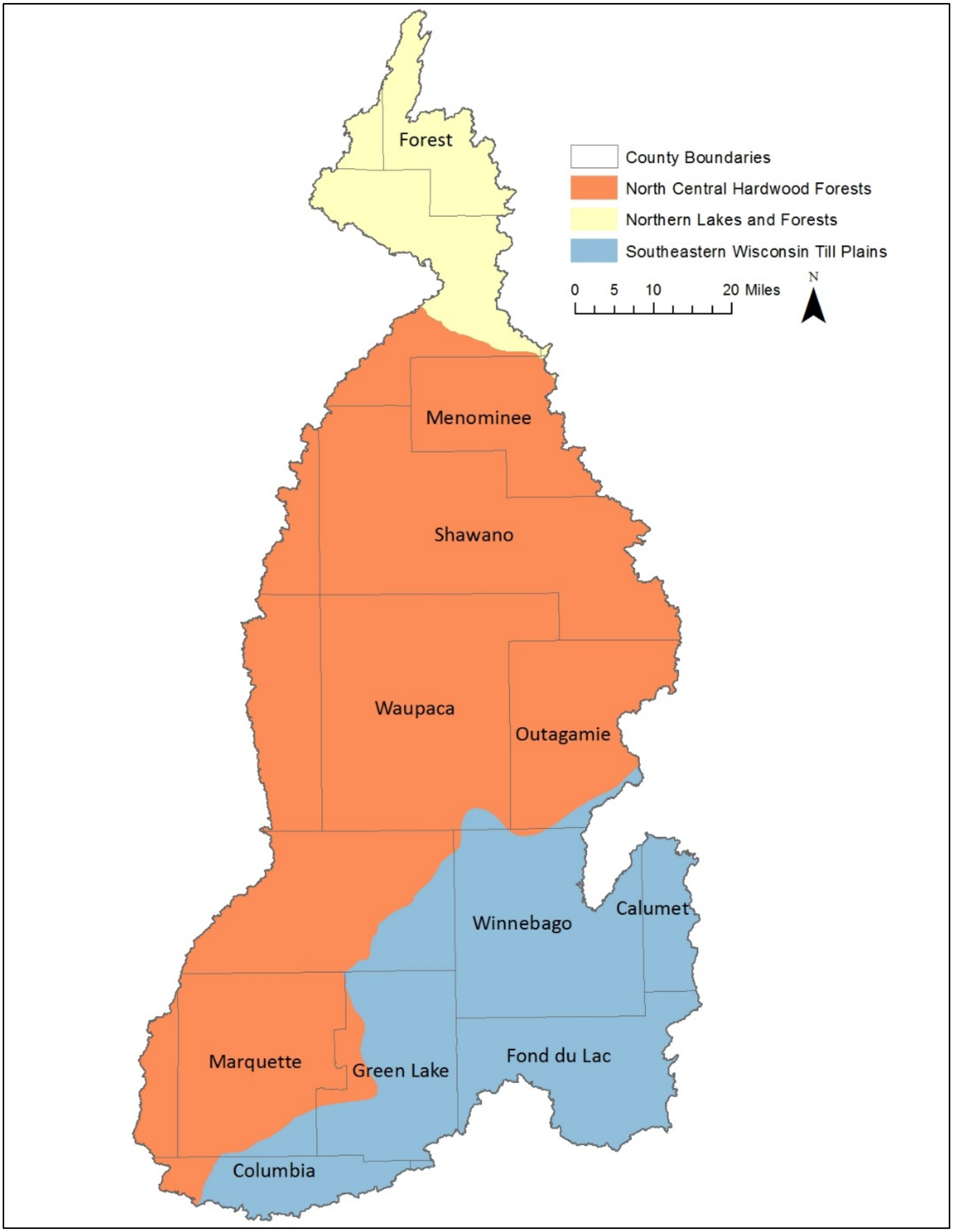

Figure 3. US EPA Level III Ecoregions in the UFWB.

4 Calibration and Validation Data

Data used for calibration and validation of the UFWB SWAT model included monthly observations of streamflow and stream water quality reported by the USGS and county crop yields reported by the USDA. This section describes the datasets used for model calibration and validation.

4.1 Streamflow Data

Twenty-three USGS stream gages in the UFWB have monthly streamflow records during the 2000-2013 simulation period (Table 8; Figure 1). Site information and streamflow records for these gages were reviewed to identify data that could be used for streamflow calibration and validation. Records from sites with less than two years of data (USGS ID 04083420, 04083423, 04083425) and sites with upstream flow regulation (USGS ID 0408100) were removed from the calibration/validation dataset. Also removed were records reported to be estimated from nearby sites or not approved for publication by USGS (USGS ID 04072845 from October 2007 through April 2008; USGS ID 04073468 from May 2012 through December 2013).

Additional streamflow records were removed from the calibration/validation dataset during the streamflow calibration process. These include records from Swamp Creek (USGS ID 04074538) and White Creek (USGS ID 04073462). These gages appear to drain watersheds with uncharacteristically high groundwater discharge (White Creek) or surface storage (Swamp Creek) and are therefore not suitable for determining regional and basin-wide adjustments to model parameters.

Monthly streamflow records were separated into a calibration dataset and a validation dataset. For sites with less than eight years of streamflow data, all records were added to the calibration dataset. For sites with eight or more years of streamflow data, average flow was calculated for each year and classified as dry (<25th percentile), average (25-75th percentile), or wet (>75th percentile). One-half of the dry years were randomly assigned to the calibration dataset and the other one-half assigned to the validation dataset. The same approach was used to divide average and wet years to the calibration and validation datasets. Table 9 lists the calibration and validation periods for each site.

4.2 Water Quality Data

Nine USGS stream gaging sites in the UFWB have monthly sediment loads[2] and total phosphorus loads reported for the 2000-2013 simulation period in the USGS National Water Information System (Table 8). Site information and water quality records for these nine sites were reviewed to identify data that could be used for water quality calibration and validation. Records from sites with less than two years of data (USGS ID 04083420, 04083423, 04083425) were excluded from calibration and validation. Also excluded were records from White Creek (USGS ID 04073462) due to uncharacteristically high groundwater discharge in the watershed above the stream gage.

Estimates of monthly sediment loads and total phosphorus loads at the Fox River at Berlin site (USGS ID 04073500) and the Wolf River at New London site (USGS ID 04079000) were also acquired from Dr. Dale Robertson of USGS via personal communication. These estimates were generated from the

[2] This report follows the approach of Baumgart (2005) and makes no differentiation between "suspended sediment" loads versus "total suspended solid (TSS)" loads. Both parameters were used for model calibration and are together referred to sediment loads throughout this report.

Weighted Regressions on Time, Discharge, and Season (WRTDS) technique for deriving a continuous time-series of constituent concentrations and loads from water quality sample data.

Water quality records were separated into a calibration dataset and a validation dataset. Most sites had a relatively short period of record (2-5 years) and all data from those sites were assigned to either the calibration dataset or the validation dataset. Three sites had more than 5 years of observed water quality data: Green Lake inlet, Fox River at Berlin, and Wolf River at New London. These records were divided into calibration and validation datasets based on annual streamflow percentiles as described in the previous section.

4.3 Crop Yield Data

Crop yield data from the USDA National Agricultural Statistics Survey QuickStats 2.0 database were acquired to guide calibration of plant growth parameters. The QuickStats database stores estimates of county-wide crop yields derived from USDA agricultural surveys. Estimates of county-wide crop yields for corn grain, corn silage, soybean, and alfalfa were exported for each county in the UFWB during the 2000-2013 model period. Yields for each crop were then averaged across all UFWB counties to create an estimate of the typical observed annual yield for each crop.

Table 8. USGS gages with monthly streamflow, sediment load, and total phosphorus load records during the 2000-2013 model simulation period.

USGS ID	Site Name	SWAT Subwatershed	Streamflow Record	Sediment Load Record	Total Phosphorus Load Record	Map Label
04074538	Swamp Creek Below Rice Lake At Mole Lake, WI	2	2000-2009			1
04074950	Wolf River at Langlade, WI	16	2000-2012			2
04075365	Evergreen River Below Evergreen Falls Near Langlade, WI	19	2002-2008			3
04077630	Red River at Morgan Road Near Morgan, WI	30	2000-2012			4
04077400	Wolf River Near Shawano, WI	35	2000-2001			5
0407809265	Middle Branch Embarrass River Near Wittenberg, WI	36	2000-2006			6
04078500	Embarrass River Near Embarrass, WI	46	2000-2012			7
04080000	Little Wolf River At Royalton, WI	85	2000-2012			8
04079000	Wolf River at New London, WI	90	2000-2012	2000-2013[a]	2000-2013[a]	9
04081000	Waupaca River Near Waupaca, WI	105	2000-2012			10
04073970	Waukau Creek Near Omro, WI	131	2007-2011	2007-2011	2007-2011	11
04082400	Fox River at Oshkosh, WI	134	2000-2012			12
04073500	Fox River at Berlin, WI	143	2000-2012	2000-2013[a]	2000-2013[a]	13
04073473	Puchyan River DS N. Lawson Drive Near Green Lake, WI	163	2000-2012			14
04073365	Fox River at Princeton, WI	164	2000-2012			15
04073466	Silver Creek at Spaulding Road Near Green Lake, WI	167	2012-2013	2012-2013	2012-2013	16
04073468	Green Lake Inlet at Ct Highway A Near Green Lake, WI	169	2000-2012	2000-2012	2000-2012	17
04072845	Montello River Near Montello, WI	172	2007-2011	2007-2011	2007-2011	18
04083545	Fond du Lac River @ W. Arndt St. At Fond du Lac, WI	179	2007-2011	2007-2011	2007-2011	19
04073462	White Creek At Spring Grove Road Near Green Lake, WI	178	2000-2012	2000-2012	2000-2012	20
04083420	Parsons Creek Upstream Site Near Fond du Lac, WI	199	2000-2001	2000-2001	2000-2001	-
04083423	Parsons Creek Middle Site Near Fond du Lac, WI	199	2000-2001	2000-2001	2000-2001	-
04083425	Parsons Creek Downstream Site Near Fond du Lac, WI	199	2000-2001	2000-2001	2000-2001	21

[a] Provided by Dr. Dale Robertson, USGS (personal communication). All other flow and load data acquired from the USGS National Water Information System.

Table 9. Streamflow calibration and validation data summary.

USGS ID	Site Name	SWAT Subwatershed	Calibration Years	Validation Years
04074950	Wolf River at Langlade, WI	16	2000;2002;2005;2006; 2007;2009;2011	2001;2003;2004; 2008;2010;2012
04075365	Evergreen River Below Evergreen Falls Near Langlade, WI	19	2002;2003;2004;2005; 2006;2007;2008	-
04077630	Red River at Morgan Road Near Morgan, WI	30	2000;2002;2004;2007;2011	2001;2003;2005; 2006;2009;2012
04077400	Wolf River Near Shawano, WI	35	2000;2001	-
0407809265	Middle Branch Embarrass River Near Wittenberg, WI	36	2000;2001;2002;2003; 2004;2005;2006	-
04078500	Embarrass River Near Embarrass, WI	46	2000;2002;2004;2005; 2006;2009;2010	2001;2003;2007; 2008;2011;2012
04080000	Little Wolf River At Royalton, WI	85	2008;2009;2010;2011;2012	-
04079000	Wolf River at New London, WI	90	2001;2003;2007;2008; 2011;2012	2000;2002;2004;2005; 2006;2009;2010
04073970	Waukau Creek Near Omro, WI	131	2007;2008;2009;2010	-
04082400	Fox River at Oshkosh, WI	134	2000;2003;2005;2006; 2009;2010;2012	2001;2002;2004; 2007;2008;2011
04073500	Fox River at Berlin, WI	143	2001;2002;2004;2006; 2009;2011;2012	2000;2003;2005; 2007;2008;2010
04073473	Puchyan River DS N. Lawson Drive Near Green Lake, WI	163	2000;2003;2005;2007; 2008;2012	2001;2002;2004;2006; 2009;2010;2011
04073365	Fox River at Princeton, WI	164	2002;2004;2011;2012	2001;2003;2005;2009;2010
04073466	Silver Creek at Spaulding Road Near Green Lake, WI	167	2012-2013	-
04073468	Green Lake Inlet at Ct Highway A Near Green Lake, WI	169	2001;2004;2006;2007; 2010;2011;2012	2000;2002;2003; 2005;2008;2009
04072845	Montello River Near Montello, WI	172	2007;2009;2010;2011	-
04083545	Fond du Lac River @ W. Arndt St. At Fond du Lac, WI	179	2007;2008;2009; 2010;2011	-

Table 10. Sediment load and total phosphorus load calibration and validation data summary.

USGS ID	Site Name	SWAT Subwatershed	Calibration Years	Validation Years
04079000	Wolf River at New London, WI	90	2001;2003;2007;2008 2011;2012;2013	2000;2002;2004;2005; 2006;2009;2010
04073970	Waukau Creek Near Omro, WI	131	-	2007-2011
04073500	Fox River at Berlin, WI	143	2001;2002;2004;2006; 2009;2011;2012	2000;2003;2005;2007; 2008;2010;2013
04073466	Silver Creek at Spaulding Road Near Green Lake, WI	167	-	2012-2013
04073468	Green Lake Inlet at Ct Highway A Near Green Lake, WI	169	2001;2004;2006;2007; 2010;2011;2012	2000;2002;2003; 2005;2008;2009
04072845	Montello River Near Montello, WI	172	2008-2011	-
04083545	Fond du Lac River @ W. Arndt St. At Fond du Lac, WI	179	2007-2011	-

5 Model Calibration and Validation Results

5.1 Crop Yield/Plant Growth Calibration

Model calibration was initiated by calibrating modeled crop yields to observed annual yields. Modeled yields were averaged across all years and all HRUs within the UFWB before comparing to observed yields. Because SWAT reports crop yields in units of kilograms of biomass per hectare, while USDA crop yields are reported in units of bushels per acre for corn and soybean, predicted corn and soybean yields were converted to bushels per acre using conversions listed in Murphy (1993). Additionally, since SWAT's crop yield outputs are dry weights of biomass, and corn silage yields reported by USDA tend to have a high moisture content, corn silage yield predictions from SWAT were multiplied by a factor of 1.65 for comparison to USDA corn silage yields (Lauer, 2006).

Crop yield calibration focused on adjusting the biomass-energy ratio (BIO_E) in the land cover/plant growth database file (crop.dat) for the major agricultural crops – corn grain, corn silage, soybean, and alfalfa. Additionally, the plant type for HRUs with pasture/grassland land cover was changed from Bermudagrass to Alfalfa. The Bermudagrass growth parameters in SWAT are appropriate for lower latitudes of the southern US but were not generating sufficient biomass in the UFWB.

During crop yield calibration, yields from non-agricultural HRUs (forests, wetlands, and urban) were also reviewed to verify that realistic values were being generated. During this step, the plant type for HRUs with urban/developed land cover was changed from Bermudagrass to Kentucky bluegrass because Bermudagrass growth parameters were generating minimal biomass.

Table 11 summarizes crop yield calibration results. Calibrated crop yields are in line with observed yields.

Table 11. Crop yield comparison between reported NASS yields and SWAT simulated yields.

Crop	**Average NASS Yield (2000-2013)**	**Average SWAT Yield (2000-2013)**	**Calibrated BIO_E (*default*)**
Corn Grain (bushels/acre)	137.9	110.2	52 (*39*)
Corn Silage (tons/acre)	15.78	9.4	52 (*39*)
Soybean (bushels/acre)	38.7	42.6	56 (*25*)
Alfalfa (tons/acre)	3.3	2.5	10 (*20*)

5.2 Streamflow Calibration and Validation

Streamflow calibration was initiated by reviewing the sensitivity of model streamflow predictions to parameter adjustments. This revealed the following surface runoff/storage parameters as having the highest influence on streamflow predictions: SCS curve number (CN2), the soil evaporation compensation factor (ESCO), the depth from the soil surface to the bottom of the soil layer (SOL_Z), the available water capacity of the soil layer (SOL_AWC), the surface runoff lag coefficient (SURLAG), and parameters controlling snowmelt (SMTMP, SFTMP, SMFMX, SMFMN, TIMP, SNOCOVMX). Groundwater parameters with the highest influence on streamflow predictions were groundwater delay (GW_DELAY), the baseflow recession constant (ALPHA_BF), the threshold depth of water in the shallow aquifer for return flow (GWQMN), the coefficient for determining water movement from the shallow aquifer to the overlying unsaturated zone (GW_REVAP), and the threshold depth for the water movement from the shallow aquifer to the overlying saturated zone to occur (REVAPMN).

After identifying sensitive parameters, BFLOW baseflow separation software was used to separate total observed streamflow into baseflow and surface flow components for sites listed in Table 9. Manual calibration was then initiated by comparing predicted and observed baseflow hydrographs to ensure that the model adequately captured the relative contributions of baseflow versus surface flow. Following manual calibration, SWAT-CUP software was used to further optimize streamflow parameters. SWAT-CUP was configured to maximize values of the NSE statistic. A final round of manual calibration was then completed based on SWAT-CUP results.

Streamflow parameters were adjusted separately for subwatersheds in each ecoregion of the UFWB to maximize the goodness-of-fit for calibration sites within each ecoregion. During this process, it was apparent that subwatersheds in the Fond du Lac River watershed needed a unique set of parameter values in order to achieve goodness-of-fit targets at the Fond du Lac River calibration site. Streamflow calibration for Fond du Lac River subwatersheds was therefore completed separately from other subwatersheds in the Southeastern Wisconsin Till Plains ecoregion.

The parameter defining the size of internal drained areas (PND_FR) was also adjusted during streamflow calibration to account for the prevalence of lakes, ponds, and bogs in the northernmost ecoregion of the UFWB (Northern Lakes and Forests). For subwatersheds in the Northern Lakes and Forests ecoregion, the subwatershed fraction draining to ponds (PND_FR) was incrementally increased to remove additional water from streamflow and improve the fit between predicted and observed flows.

Calibrated streamflow parameter values are listed in Table 12 and Table 13.

Table 12. Calibrated values of basin-wide streamflow parameters.

Parameter	**File**	**Units**	**Default Value**	**Calibrated Value**
SMTMP	.bsn	Degrees C	0.5	0.0
SFTMP	.bsn	Degrees C	1	3.0
SMFMX	.bsn	Degrees C	4.5	2.83
SMFMN	.bsn	Degrees C	4.5	1.4
TIMP	.bsn	-	1	0.17
SNOCOVMX	.bsn	mm H_20	0.5	15.0

Table 13. Calibrated values of streamflow parameters.

Ecoregion/ Watershed	Parameter	File	Units	Default Value	Calibrated Value
Northern Lakes and Forests	CN2	.mgt	-	Varies by HRU	-13% of Default
	GW_DELAY	.gw	days	31	1
	ALPHA_BF	.gw	-	0.014	0.001
	GWQMN	.gw	mm H_20	1000	0
	GW_REVAP	.gw	-	0.02	0.08
	REVAPMN	.gw	mm H_20	750	750
	ESCO	.hru	-	1	0.01
	SOL_Z, all layers	.sol	mm	Varies by Soil Type	+10% of Default
	SOL_AWC, all layers	.sol	mm H_20/mm soil	Varies by Soil Type	+20% of Default
	PND_FR	.pnd	-	Varies by Subwatershed	+175% of Default
	SURLAG	.hru	-	4	0.001, 0.03, or 0.05
North Central Hardwood Forests	CN2	.mgt	-	Varies by HRU	+4% of Default
	GW_DELAY	.gw	days	31	1
	ALPHA_BF	.gw	-	0.014	0.001
	GWQMN	.gw	mm H_20	1000	0
	GW_REVAP	.gw	-	0.02	0.02
	REVAPMN	.gw	mm H_20	750	2500
	ESCO	.hru	-	1	0.8
	SOL_Z, all layers	.sol	mm	Varies by Soil Type	+22% of Default
	SOL_AWC, all layers	.sol	mm H_20/mm soil	Varies by Soil Type	No Change
	SURLAG	.hru	-	4	0.025, 0.07, or 1.5
Southeastern Wisconsin Till Plains	CN2	.mgt	-	Varies by HRU	-7% of Default
	GW_DELAY	.gw	days	31	2
	ALPHA_BF	.gw	-	0.014	0.025
	GWQMN	.gw	mm H_20	1000	0
	GW_REVAP	.gw	-	0.02	0.05
	REVAPMN	.gw	mm H_20	750	500
	ESCO	.hru	-	1	0.95
	SOL_Z, all layers	.sol	mm	Varies by Soil Type	+27% of Default
	SOL_AWC, all layers	.sol	mm H_20/mm soil	Varies by Soil Type	-22% of Default
	SURLAG	.hru	-	4	0.001, 0.3, or 0.35
Fond du Lac River Watershed	CN2	.mgt	-	Varies by HRU	+3% of Default
	GW_DELAY	.gw	days	31	1
	ALPHA_BF	.gw	-	0.014	0.02
	GWQMN	.gw	mm H_20	1000	25
	GW_REVAP	.gw	-	0.02	0.06
	REVAPMN	.gw	mm H_20	750	10
	ESCO	.hru	-	1	0.99
	SOL_Z, all layers	.sol	mm	Varies by Soil Type	-20% of Default
	SOL_AWC, all layers	.sol	mm H_20/mm soil	Varies by Soil Type	0% of Default
	SURLAG	.hru	-	4	2

Table 14 lists streamflow calibration performance statistics by site (see Appendix D for streamflow calibration hydrographs). Model performance for streamflow calibration was good to very good for NSE (≥0.65) at 11 of 17 sites and for PBIAS (≤15%) at 14 of 17 sites. Two sites have NSE values below 0.5 (Silver Creek and Montello River) but only Silver Creek has a PBIAS value greater than ±25%.

Table 14. Performance statistics for monthly streamflow calibration.

Site Name	USGS ID	SWAT Subwatershed	NSE	PBIAS
Wolf River at Langlade, WI	04074950	16	0.71	11%
Evergreen River Blw Evergreen Falls	04075365	19	0.56	-6%
Red River at Morgan Road	04077630	30	0.55	-2%
Wolf River Near Shawano	04077400	35	0.86	-8%
Middle Branch Embarrass River	0407809265	36	0.72	-2%
Embarrass River Near Embarrass	04078500	46	0.71	13%
Little Wolf River At Royalton	04080000	85	0.78	-9%
Wolf River at New London	04079000	90	0.77	3%
Waukau Creek Near Omro	04073970	131	0.59	16%
Fox River at Oshkosh	04082400	134	0.68	8%
Fox River at Berlin	04073500	143	0.72	-7%
Puchyan River	04073473	163	0.81	0.7%
Fox River at Princeton	04073365	164	0.66	0.6%
Silver Creek at Spaulding Road	04073466	167	0.32	-26%
Green Lake Inlet	04073468	169	0.70	-16%
Montello River Near Montello	04072845	172	0.25	1%
Fond du Lac River @ W. Arndt St.	04083545	179	0.62	7%

Table 15 lists streamflow validation performance statistics by site (see Appendix D for streamflow validation hydrographs). Six of the nine sites show good to very good performance based on NSE (≥0.65) and seven of nine sites show good to very good performance based on PBIAS (≤15%). One site has an NSE value below 0.5 (Fox River at Princeton) but PBIAS for this site is within ±10%.

Table 15. Performance statistics for monthly streamflow validation.

Site Name	USGS ID	SWAT Subwatershed	NSE	PBIAS
Wolf River at Langlade	04074950	16	0.78	6%
Red River at Morgan Road	04077630	30	0.60	-2%
Embarrass River Near Embarrass	04078500	46	0.82	-2%
Wolf River at New London	04079000	90	0.69	8%
Fox River at Oshkosh	04082400	134	0.80	4%
Fox River at Berlin	04073500	143	0.50	-10%
Puchyan River	04073473	163	0.79	-18%
Fox River at Princeton	04073365	164	0.23	-6%
Green Lake Inlet	04073468	169	0.76	-24%

5.3 Sediment Calibration and Validation

Sediment parameters were calibrated following streamflow calibration. Calibration of sediment loading focused on parameters controlling landscape erosion and channel routing. Like streamflow calibration, sediment calibration consisted of an initial manual calibration step to match predicted and observed sediment loads followed by automated calibration with SWAT-CUP software to fine-tune parameter estimates and further manual calibration based on SWAT-CUP results.

SWAT parameters for the Modified Universal Soil Loss Equation (MUSLE) are the primary determinants of landscape erosion, while tributary and main channel parameters affect sediment deposition and resuspension within stream channels. Initial predictions of sediment loads with default sediment parameter values were very high (at least one order of magnitude greater than average observed loads at calibration sites). This was attributed to both over-estimated rates of landscape erosion from the MUSLE equation and under-estimated deposition of sediment between edge-of-field sources and subwatershed outlets. Two approaches were therefore used to reduce sediment loads within the model: (1) use the conservation practice (P) factor parameter to reduce erosion rates predicted by the MUSLE equation; and (2) simulate a vegetated filter strip to increase deposition of eroded sediment before it reached the subwatershed outlet.

Values of the conservation practice factor (USLE_P) and vegetated filter strip width (FILTERW) were adjusted for each HRU in the model, with values assigned according to the HRU's land cover type and ecoregion. For example, all HRUs with Dairy land cover in the North Central Hardwood Forest ecoregion were assigned the same value of USLE_P and FILTERW. Parameter values were adjusted until the percent bias between predicted and observed sediment loads at each calibration site was within ±30%. This step indicated that HRUs in the Fond du Lac River watershed needed lower USLE_P values than other HRUs in the Southeastern Wisconsin Till Plains ecoregion in order to achieve the percent bias target at the Fond du Lac River calibration site. Values of USLE_P and FILTERW for HRUs within the Fond du Lac River watershed were therefore calibrated separately from other HRUs in the Southeastern Wisconsin Till Plains ecoregion. Calibrated values of USLE_P and FILTERW are listed in Table 16.

The adjustment of USLE_P and FILTERW values provided sediment load predictions that acceptably matched long-term average loads observed at calibration sites (i.e., percent bias within ±30%). However, plots of predicted and observed monthly sediment loads at calibration sites showed that the model tended to over-predict sediment in peak loading months and under-predict loads in other months. Attempts were made to lag peak sediment loads over time using tributary channel and main channel routing parameters. Parameters affecting tributary and main channel routing include the linear parameter (SPCON) and exponential parameter (SPEXP) for calculating sediment deposition and resuspension, the peak rate adjustment factor for sediment routing in the main channel (PRF_BSN) and tributary channel (ADJ_PKR), Manning's *n* for the main channel (CH_N2) and tributary channel (CH_N1)

Simulated rates of channel deposition and resuspension using initial routing parameter estimates were highly variable between subwatersheds. For example, some subwatersheds showed up to 90% deposition of annual sediment loads while other subwatersheds had negligible deposition. The sensitivity of sediment deposition and resuspension to channel routing parameters also varied considerably between each subwatershed, likely due to differences in channel dimensions (length, width, and slope) and simulated peak flow rates, indicating that a unique set of channel routing parameter values would be needed for each subwatershed in order to accurately lag peak sediment loads over time. Because such an effort was beyond the scope of the modeling effort, parameters were adjusted to minimize channel routing so that the long-term average sediment deposition in all subwatersheds was zero.

Calibrated sediment routing parameters are listed in Table 17.

Table 16. Calibrated values of sediment loading parameters.

Ecoregion/ Watershed	Parameter	File	Units	Initial Value	Calibrated Value
Northern Lakes and Forests Ecoregion	USLE_P (Forest/Wetland HRUs)	.mgt	-	1	0.5
	USLE_P (Cash Grain & Dairy HRUs)	.mgt	-	1	0.25
	USLE_P (Potato/Vegetable HRUs)	.mgt			0.5
	USLE_P (Pasture HRUs)	.mgt	-	1	0.5
	USLE_P (Urban HRUs)	.mgt	-	1	0.5
	FILTERW (Forest/Wetland HRUs)	.mgt	meters	0	8
	FILTERW (Dairy HRUs)	.mgt	meters	0	16
	FILTERW (Cash Grain HRUs)	.mgt	meters	0	12
	FILTERW (Potato/Vegetable HRUs)	.mgt	meters	0	12
	FILTERW (Pasture HRUs)	.mgt	meters	0	14
	FILTERW (Urban HRUs)	.mgt	meters	0	14
North Central Hardwood Forests Ecoregion	USLE_P (Forest/Wetland HRUs)	.mgt	-	1	0.5
	USLE_P (Cash Grain & Dairy HRUs)	.mgt	-	1	0.25
	USLE_P (Potato/Vegetable HRUs)	.mgt			0.5
	USLE_P (Pasture HRUs)	.mgt	-	1	0.5
	USLE_P (Urban HRUs)	.mgt	-	1	0.5
	FILTERW (Forest/Wetland HRUs)	.mgt	meters	0	8
	FILTERW (Dairy HRUs)	.mgt	meters	0	16
	FILTERW (Cash Grain HRUs)	.mgt	meters	0	12
	FILTERW (Potato/Vegetable HRUs)	.mgt	meters	0	12
	FILTERW (Pasture HRUs)	.mgt	meters	0	14
	FILTERW (Urban HRUs)	.mgt	meters	0	14
Southeastern Wisconsin Till Plains Ecoregion	USLE_P (Forest/Wetland HRUs)	.mgt	-	1	0.5
	USLE_P (Cash Grain & Dairy HRUs)	.mgt	-	1	0.25
	USLE_P (Potato/Vegetable HRUs)	.mgt			0.25
	USLE_P (Pasture HRUs)	.mgt	-	1	0.5
	USLE_P (Urban HRUs)	.mgt	-	1	0.5
	FILTERW (Forest/Wetland HRUs)	.mgt	meters	0	8
	FILTERW (Dairy HRUs)	.mgt	meters	0	20
	FILTERW (Cash Grain HRUs)	.mgt	meters	0	18
	FILTERW (Potato/Vegetable HRUs)	.mgt	meters	0	18
	FILTERW (Pasture HRUs)	.mgt	meters	0	24
	FILTERW (Urban HRUs)	.mgt	meters	0	20
Fond du Lac River Watershed	USLE_P (Forest/Wetland HRUs)	.mgt	-	1	0.1
	USLE_P (Cash Grain & Dairy HRUs)	.mgt	-	1	0.1
	USLE_P (Potato/Vegetable HRUs)	.mgt			0.1
	USLE_P (Pasture HRUs)	.mgt	-	1	0.1

Ecoregion/ Watershed	Parameter	File	Units	Initial Value	Calibrated Value
	USLE_P (Urban HRUs)	.mgt	-	1	0.1
Fond du Lac River Watershed	FILTERW (Forest/Wetland HRUs)	.mgt	meters	0	10
	FILTERW (Dairy HRUs)	.mgt	meters	0	20
	FILTERW (Cash Grain HRUs)	.mgt	meters	0	20
	FILTERW (Potato/Vegetable HRUs)	.mgt	meters	0	20
	FILTERW (Pasture HRUs)	.mgt	meters	0	20
	FILTERW (Urban HRUs)	.mgt	meters	0	20

Table 17. Calibrated values of sediment channel routing parameters.

Parameter	File	Units	Initial Value	Calibrated Value
SPCON	.bsn	-	0.0001	9
SPEXP	.bsn	-	1	9
PRF_BSN	.bsn	-	1	2
ADJ_PKR	.bsn	-	1	2
CH_N2	.rte	-	Varies by reach	0.00
CH_N1	.sub	-	Varies by reach	0.01
CH_L1	.sub	kilometers	Varies by reach	0.05
CH_S1	.sub	meter/meter	Varies by reach	9
CH_W1	.sub	meters	Varies by reach	1

Table 18 lists sediment calibration performance statistics by site (see Appendix D for monthly sediment load plots). Model performance for sediment calibration was good (≤ ±30%) or very good (≤ 15%) for all five calibration sites based on PBIAS. NSE values for sediment calibration are below the satisfactory guideline (0.5) for four of five sites (the exception is Fond du Lac.River; NSE = 0.8). The low NSE values can be attributed to calibrated values of parameters that determine sediment routing in stream channels. These parameters were adjusted to effectively "turn off" channel routing, resulting in over-predicted sediment loading in peak months and under-predicted loading in other months. This approach produces low NSE values but good estimates of long-term average sediment loads at calibration sites, based on PBIAS.

Table 18. Performance statistics for monthly sediment calibration.

Site Name	**USGS ID**	**SWAT Subwatershed**	**NSE**	**PBIAS**
Green Lake Inlet	04073468	169	-0.56	-10%
Montello River Near Montello	04072845	172	-9.2	20%
Fond du Lac River @ W. Arndt St.	04083545	179	0.80	9%
Wolf River at New London	04079000	90	-3.0	19%
Fox River at Berlin	04073500	143	-7.8	-22%

Table 19 lists sediment validation performance statistics by site (see Appendix D for monthly sediment load plots). Model performance for sediment validation was good (≤ ±30%) or very good (≤ 15%) for four of five sites based on PBIAS and satisfactory (≤ ±55%) for Waukau Creek. Similar to calibration results, NSE values were below the satisfactory guideline (0.5) for four of five sites due to the lack of sediment routing simulation in stream channels within the model.

Table 19. Performance statistics for monthly sediment validation.

Site Name	**USGS ID**	**SWAT Subwatershed**	**NSE**	**PBIAS**
Green Lake Inlet	04073468	169	0.91	-29%
Waukau Creek Near Omro	04073970	131	-0.32	42%
Silver Creek at Spaulding Road	04073466	167	-2.01	25%
Wolf River at New London	04079000	90	-0.15	0.2%
Fox River at Berlin	04073500	143	-7.41	-29%

5.4 Total Phosphorus Calibration and Validation

Total phosphorus parameters were calibrated following sediment calibration. Like streamflow and sediment calibration, total phosphorus calibration consisted of an initial manual calibration step to match predicted and observed phosphorus loads, followed by automated calibration with SWAT-CUP software to fine-tune parameter estimates and additional manual calibration based on SWAT-CUP results.

Total phosphorus calibration focused on the following parameters based on a review of the sensitivity of model predictions to parameter changes: the phosphorus availability index (PSP), the phosphorus soil partitioning coefficient (PHOSKD), and the phosphorus uptake distribution parameter (P_UPDIS). The updated SWAT soil phosphorus routines were enabled by setting the soil phosphorus routine option (SOL_P_MODEL) to 1. Additionally, the phosphorus enrichment ratio for sediment (ERORGP) was adjusted for HRUs in the Fond du Lac watershed because these HRUs showed a low ratio of particulate phosphorus yield to sediment yield relative to other HRUs in the model with the default ERORGP setting.

Calibrated values of total phosphorus loading parameters are listed in Table 20.

Table 20. Total phosphorus calibration parameters.

Parameter	**File**	**Units**	**Initial Value**	**Calibrated Value**
PSP	.bsn	-	0.4	0.50
PHOSKD	.bsn	m^3/Mg	175	75
P_UPDIS	.bsn	-	20	75
ERORGP (Fond du Lac Watershed)	.hru	-	0	0.25
SOL_P_MODEL	.bsn	-	0	1

Table 21 lists total phosphorus calibration performance statistics by site (see Appendix D for monthly total phosphorus load plots). Model performance for total phosphorus calibration was very good (≤ ±25%) for all five sites sites based on PBIAS. Model performance was satisfactory (≥ 0.5) to very good (≥ 0.75) for all five calibration sites.

Table 21. Performance statistics for monthly total phosphorus calibration.

Site Name	**USGS ID**	**SWAT Subwatershed**	**NSE**	**PBIAS**
Green Lake Inlet	04073468	169	0.65	-2%
Montello River Near Montello	04072845	172	0.52	-17%
Fond du Lac River @ W. Arndt St.	04083545	179	0.75	2%
Wolf River at New London	04079000	90	0.68	8%
Fox River at Berlin	04073500	143	0.54	-13%

Table 22 lists total phosphorus validation performance statistics by site (see Appendix D for monthly total phosphorus load plots). Model performance for total phosphorus validation was very good (≤ ±25%) for all five sites based on PBIAS. Model performance was satisfactory (≥ 0.5) to very good (≥ 0.75) for four of the five validation sites (the exception is Silver Creek).

Table 22. Performance statistics for monthly total phosphorus validation.

Site Name	**USGS ID**	**SWAT Subwatershed**	**NSE**	**PBIAS**
Green Lake Inlet	04073468	169	0.80	-7%
Waukau Creek Near Omro	04073970	131	0.70	-25%
Silver Creek at Spaulding Rd.	04073466	167	-0.26	-2%
Wolf River at New London	04079000	90	0.59	-3%
Fox River at Berlin	04073500	143	0.45	-16%

6 Discussion of Calibration and Validation Results

An evaluation of the performance of the UFWB SWAT model should consider the intended application of model predictions. Key model outputs used to support the development of phosphorus and sediment TMDLs are listed below:

1. SWAT predictions of average annual streamflow in stream and river reaches for 2009-2013 are used in the calculation of allowable phosphorus and sediment loads for stream and river reaches;
2. SWAT predictions of average annual nonpoint source phosphorus and sediment loads for 2009-2013 are used in the calculation of the percent reduction from existing sources needed to achieve allowable phosphorus and sediment loads;
3. SWAT predictions of the relative magnitude of phosphorus and sediment loads from major land cover types are used to allocate total allowable phosphorus and sediment loads to nonpoint sources;
4. SWAT predictions of annual water volumes and phosphorus loads input to impaired lakes are used to calibrate lake response models for impaired lakes in the UFWB.

SWAT calibration and validation results show that satisfactory model performance guidelines for streamflow, sediment, and phosphorus are met or exceeded at most calibration and validation sites. All exceptions are discussed below.

- Streamflow NSE and PBIAS for the Silver Creek at Spaulding Road (PBIAS = -26%; NSE = 0.32). Performance statistics indicate that the UFWB SWAT model is under-predicting streamflow (negative PBIAS) and not accurately capturing month-to-month variation (low NSE) during the period of record (December 2011 to December 2013). However, the monthly hydrograph (Figure 4) shows that SWAT model predictions re-create the general pattern of observed flows in Silver Creek but dramatically underestimate flow magnitude during April and May of 2013. This discrepancy is likely due to low rainfall depths during April 2013 in the precipitation input dataset that are not representative of actual rainfall in the Silver Creek watershed. Because of the short duration of the calibration period for the Silver Creek site (26 months), inaccurate estimates of April 2013 rainfall can have a significant effect on values of NSE and PBIAS. Furthermore, performance statistics for the Green Lake Inlet calibration site, which is located immediately downstream of the Silver Creek site and includes a longer period of record, are within satisfactory guidelines (PBIAS = -16%; NSE = 0.70). Overall, these results do not point to a systemic issue within the SWAT model.

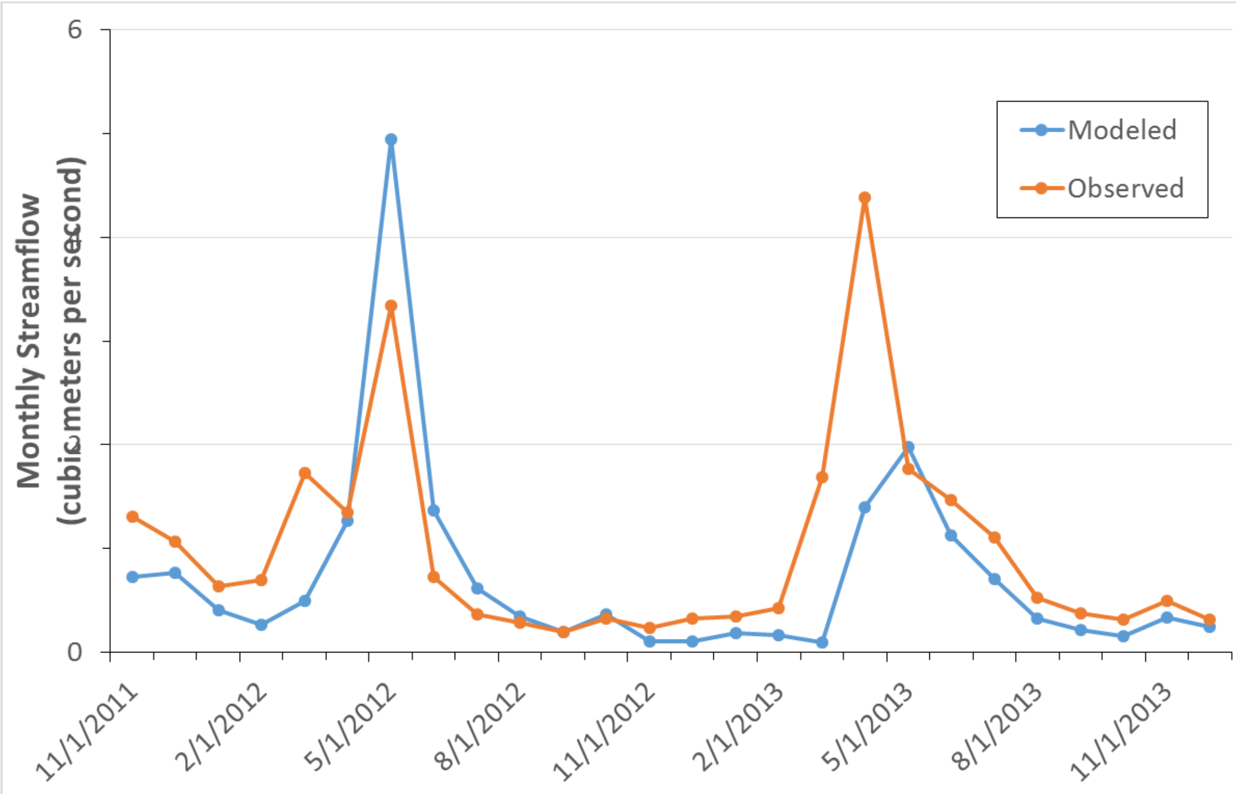

Figure 4. Streamflow calibration hydrograph for Silver Creek at Spaulding Road (USGS ID 04073466).

- Streamflow NSE for the Montello River near Montello calibration site (NSE = 0.25) and the Fox River at Princeton validation site (NSE = 0.23). Both the Montello River and Fox River at Princeton sites have streamflow NSE values below the satisfactory guideline but very good PBIAS values (PBIAS = 1% for Montello River and -6% for Fox River), indicating that the average streamflow magnitude is well-predicted but the model is not accurately recreating the month-to-month pattern in flows. Like the Silver Creek site, results for the Montello River site are likely due to precipitation estimates for individual months that differ from actual precipitation in the Montello River watershed. For the Fox River at Princeton site, the USGS reports that streamflow is affected by "occasional regulation by dams upstream" (USGS 2016) and the discrepancies in streamflow predictions for individual months may therefore be due to upstream dam operations that are not simulated in the SWAT model. Because the main objective of streamflow simulation is to accurately capture long-term average streamflow throughout the UFWB, these results were determined to be acceptable for TMDL development.
- Sediment NSE for calibration and validation sites. NSE values for sediment calibration and validation are below zero for most of the calibration and validation sites. As noted in the *Sediment Calibration and Validation* section of this report, these are attributed to the adjustment of channel sediment routing parameters to effectively "turn off" channel routing, resulting in over-predicted sediment loading in peak months and under-predicted loading in other months. Although an attempt was made to calibrate channel routing parameters to lag peak sediment loads over time, this process indicated that a unique set of channel routing parameters would need to be calibrated

for each subwatershed in the model. This was determined to be beyond the scope of the SWAT modeling effort because the key model outputs for sediment TMDL development depend on the accuracy of long-term average sediment loads (which are evaluated with PBIAS values) rather than the accuracy of within-year sediment load predictions.

- Phosphorus NSE for the Silver Creek at Spaulding Road calibration site (NSE = -0.26). The Silver Creek at Spaulding Road calibration site has a phosphorus NSE below the satisfactory guideline but a very good PBIAS value (PBIAS = -2%). These results show that the SWAT model accurately predicts the long-term average monthly phosphorus load but is not recreating the month-to-month pattern in phosphorus loading in Silver Creek. Similar to streamflow predictions for the Silver Creek site, the accuracy of monthly phosphorus predictions is likely degraded by precipitation estimates for individual months that do not reflect actual precipitation in the Silver Creek watershed and the short duration of the phosphorus load period of record for the Silver Creek site (December 2011 to December 2013). Phosphorus performance statistics for the Green Lake Inlet calibration site, which is located immediately downstream of the Silver Creek site and includes a longer period of record, are within satisfactory guidelines (PBIAS = -16%; NSE = 0.70)
- Phosphorus NSE for the Fox River at Berlin validation site (NSE = 0.45). The Fox River at Berlin site has a validation phosphorus NSE value slightly below the satisfactory guideline of 0.5 but a very good PBIAS values (PBIAS = -15%), indicating that average total phosphorus loading is well-predicted but the model is not accurately recreating the month-to-month pattern in loads. This is attributed to seasonal routing of the phosphorus load through the Upper Fox River Basin. The area above the monitoring site contains two relatively large lakes (Lake Puckaway and Green Lake) that have the potential to store phosphorus entering from tributaries and re-release stored phosphorus later in the year. This type of lag in phosphorus routing is not simulated in the UFWB model. Results were determined to be acceptable for use in TMDL analysis since the TMDL development method uses the multi-year average phosphorus loading predicted by SWAT.

As discussed above, performance statistics that are below guidelines are not common and their presence does not preclude the use of the UFWB SWAT model for development of phosphorus and sediment TMDLs. Performance statistics could be improved for any given location by further adjusting model parameters for the subwatersheds upstream of the monitoring site, however, the goal of calibration was to identify basin-wide and regional sets of parameter values that provide the best fit between model predictions and observations across all sites collectively.

Key assumptions and limitations of the UFWB SWAT model should be considered for other applications of the UFWB SWAT model or for future updates. These include:

- The UFWB SWAT model uses all available weather records as model inputs. If records from additional weather stations become available they could improve the accuracy of model predictions by providing a more complete representation of spatial variability in precipitation and temperature;
- The observed streamflow records used for calibration are assumed to be accurate, however, streamflow measurements can be subject to error during periods of ice cover. Errors in observed streamflow data were not taken into consideration during model calibration and validation;

- Calibration was completed for total phosphorus and sediment loads only. Predictions of individual forms of phosphorus (i.e., soluble phosphorus) or other water quality constituents should not be used without further calibration.
- Lakes and reservoirs are not simulated in the UFWB SWAT model. Output from the UFWB SWAT model should not be used to infer conditions within any given UFWB lake without coupling to a lake/receiving water model;
- Water storage parameters, such as the subwatershed fraction draining to ponds, could be estimated at a finer scale through a detailed geospatial analysis of depressions, ponds, and wetlands and their contributing areas. This level of analysis was beyond the scope of the UFWB SWAT modeling effort.

7 Application of UFWB SWAT Model Results

Based on calibration and validation performance, the UFWB SWAT model is able to simulate average annual streamflow, sediment loading, and phosphorus loading with good accuracy, as most PBIAS values for all three parameters fall in the "good" or "very good" rating categories reported in Moriasi et al. (2007). For the UFWB TMDL, the accuracy of average annual streamflow, sediment loading, and phosphorus loading predictions from SWAT is of primary importance since the analysis of allowable loads and load allocations uses multi-year average values. Because of the good agreement between predicted and observed average annual streamflow, sediment, and phosphorus loading, the UFWB SWAT model was determined to be well-suited for use in TMDL development. However, initial applications of SWAT model output revealed two cases where errors in monthly predictions and uncertainty in predictions for specific land use types pointed to the need for adjustments to model output. This section describes these cases and the steps taken to revise SWAT model outputs.

7.1 Winnebago Pool Lake Modeling

One use of UFWB SWAT model output in the TMDL study is to estimate existing water inflow and phosphorus loading to impaired lakes in the basin to calibrate lake models that predict in-lake phosphorus concentrations. Models for many of the lakes use annual average streamflows and phosphorus loads as inputs. However, the BATHTUB and Jensen models developed by USGS for the Winnebago Pool lakes (Lake Poygan, Lake Winneconne, Lake Butte des Morts, and Lake Winnebago) as part of a companion effort for the UFWB TMDL use either growing season (May through September) or daily estimates of total phosphorus loading as model inputs. SWAT predictions of sub-annual streamflow and phosphorus (seasonal, monthly) are generally less accurate than annual values, as evidenced by the higher proportion of NSE values that fall in the "satisfactory" rating range reported in Moriasi et al. (2007) relative to PBIAS values.

For Winnebago Pool lake modeling, seasonal and daily loads for the Fox River and Wolf River, and the accuracy of these loads, are particularly important since these are key inputs of water and phosphorus to the pool lakes. Because of the limited accuracy of SWAT sub-annual predictions relative to annual averages, direct SWAT outputs of seasonal and daily streamflow and phosphorus from the Fox River and Wolf River were not used for the Winnebago Pool lake models. Rather, annual SWAT predictions were divided into seasonal and daily values outside of SWAT in a post-model processing step. This approach used monthly patterns in streamflow and phosphorus loading observed at the two monitoring sites with monthly records (Wolf River at New London and Fox River at Berlin) to subdivide annual SWAT predictions. For each monitoring site, ratios of the monthly-to-annual observed phosphorus load and streamflow volume were calculated for every month during the simulation period. The monthly ratios were then applied to SWAT annual predictions to generate monthly time series of phosphorus loading and streamflow that matched the observed monthly patterns at the monitoring sites.

Monthly ratios calculated for the Wolf River at New London site were applied to SWAT annual predictions of streamflow and phosphorus loading at the New London site and to SWAT annual predictions of streamflow and phosphorus loading to Lake Poygan and Lake Winneconne from the Wolf River, smaller tributaries, and direct drainage area. Monthly ratios calculated for the Fox River at Berlin site were applied to SWAT annual predictions of streamflow and phosphorus loading at the Berlin site and to SWAT annual predictions of streamflow and phosphorus loading into Lake Butte des Morts from the Fox River. Monthly SWAT predictions for all other flows and loads to the Winnebago Pool lakes were not modified during this step.

After deriving monthly time series of streamflow and phosphorus loading to the Winnebago Pool lakes using SWAT annual totals and observed monthly ratios, growing season values were calculated for input to the Winnebago Pool lake models by summing May through September monthly values. Daily estimates of streamflow and phosphorus loading were also used for lake modeling and were calculated by evenly dividing monthly values between the corresponding number of days in each month.

Monthly streamflow and phosphorus loading data delivered to USGS to support Winnebago Pool lake modeling are listed in Appendix G.

7.2 Phosphorus Loading by Land Use Type

For the UFWB TMDL, the method used to allocate allowable phosphorus loads between sources considers the relative contribution of each source to the initial baseline load. The allocation method sets aside loading from background, non-controllable source categories (i.e., nonpoint source loading from forests and wetlands) and then allocates the remaining allowable load to controllable sources according to their baseline contribution.

Initial results of the allocation analysis indicated the need for very high reductions in loads from controllable sources (90-99%) to achieve water quality targets in several stream/river reach and lake subbasins. These high reductions were in part due to the magnitude of SWAT predictions of background loads from forest and wetland HRUs since background loading is set aside as a non-controllable portion of the allowable load. To evaluate SWAT predictions of phosphorus loading by land use type, results were compared to recommended values of phosphorus yields for different land uses reported by WDNR in the Wisconsin Lake Modeling Suite (WiLMS) (Wisconsin DNR, 2003). The recommended yields are not specific to the UFWB but are derived from two statewide studies of phosphorus yields from watersheds with varied land uses (Corsi et al. 1997; Panuska & Lilly 1995).

Table 23 displays recommended ranges of annual total phosphorus yields by land use type and median 2000-2013 annual yields from the UFWB SWAT model. Note that the SWAT forest and wetland yield (0.12 kilograms per hectare) is slightly above the "most likely" WiLMS value (0.09 kilograms per hectare). In contrast, most of the SWAT yields from agricultural and urban land use types are below the "most likely" WiLMS values and in some cases below the minimum recommended value. It may be possible that phosphorus yields from forests and wetlands in the UFWB are above-average and yields from anthropogenic lands are below-average compared to other watersheds in Wisconsin. Conversely, the UFWB SWAT model may be over-predicting phosphorus yields from forests and wetlands and under-predicting yields from agricultural and urban lands.

Table 23. Annual total phosphorus yields (in kilograms per hectare) by land use type from the UFWB SWAT model and ranges recommended in the WDNR WiLMS model. SWAT values are the median of 2000-2013 annual yields for all HRUs with the specified land use.

Land Use Type	**UFWB SWAT Model**	**WiLMS Recommended Range**		
		Minimum	**Most Likely**	**Maximum**
Forest and Wetland	0.12	0.05	0.09	0.18
Dairy (Mixed Agriculture)	0.3	0.3	0.8	1.4
Corn/Soybean (Row Crop Ag.)	0.36	0.5	1	3
Potato/Vegetable (Row Crop Ag.)	0.57	0.5	1	3
Pasture/Grassland	0.17	0.19	0.3	0.5
Urban Low Density	0.13	0.05	0.1	0.25
Urban Medium Density	0.21	0.3	0.5	0.8
Urban High Density	0.45	1	1.5	2

SWAT predictions of forest and wetland phosphorus loading were further evaluated using estimates of reference total phosphorus concentrations for Wisconsin streams and rivers reported in Robertson et al. (2006). In this study, reference concentrations of total phosphorus are defined as those found in streams and rivers draining watersheds with minimal human impacts. Reference concentrations are reported for three phosphorus zones and one ecoregion covering the UFWB, with estimates derived from a statistical regression model ranging from 12 to 21 micrograms per liter and estimates derived from the 25th percentile of field samples of total phosphorus ranging from 20 to 60 micrograms per liter (Table 24).

Table 24. Reference total phosphorus concentrations for regions covering the UFWB reported in Robertson et al. (2006).

Region	**Reference Total Phosphorus (µg/L)**	
	From Multiple Linear Regression	**From 25th Percentile of Samples**
Residualized Environmental Phosphorus Zone 1	12	20
Residualized Environmental Phosphorus Zone 2	21	30
Residualized Environmental Phosphorus Zone 3	21	60
Ecoregion 7 (Mostly Glaciated Dairy)	16	40
Median	21	

To compare the reference total phosphorus concentrations reported in Robertson et al. (2006) to SWAT model values, annual flow-weighted mean concentrations of total phosphorus from forest and wetland HRUs in the SWAT model were calculated as the total phosphorus load divided by the flow volume generated in the HRU. Calculated total phosphorus concentrations from SWAT forest and wetland HRUs covered a wide range, from less than 1 to over 100 micrograms per liter, with a median of 47 micrograms per liter. This value is on the upper end of reference concentrations reported in Robertson et al. (2006) and like phosphorus yields suggests that forest and wetland loading in the UFWB SWAT model is over-estimated.

Acknowledging the uncertainty and potential for error in SWAT predictions of phosphorus loading by land use, SWAT model outputs were adjusted for TMDL development in a post-model processing step so that annual flow-weighted mean total phosphorus concentrations for forest and wetland HRUs more closely matched reference values reported in Robertson et al. (2006). Phosphorus loads from forest and wetland HRUs with annual flow-weighted mean total phosphorus concentrations above 21 micrograms per liter (the median of reference concentrations in Table 24) were reduced so that the adjusted annual flow-weighted mean total phosphorus concentration in each HRU was equal to 21 micrograms per liter. To preserve the total mass of phosphorus predicted in the SWAT model, phosphorus loads for controllable source HRUs (non-forest and wetland) were increased by an equal amount. The method applied to adjust SWAT HRU outputs is further described below:

1. Calculate the 2000-2013 flow-weighted mean total phosphorus concentration in each forest and wetland HRU as the total phosphorus load divided by the flow volume generated in the HRU;
2. For all forest and wetland HRUs, calculate the percentage difference between the flow-weighted mean total phosphorus concentration calculated in step 1 and the reference concentration of 21 micrograms per liter;
3. For forest and wetland HRUs with flow-weighted mean total phosphorus concentrations above the reference concentration, reduce monthly total phosphorus loads using the percentage difference calculated in step 2;
4. Calculate the difference between original and adjusted monthly total phosphorus loads from forest and wetland HRUs;
5. Distribute the total phosphorus load calculated in step 4 between controllable source HRUs (non-forest and wetland) in the subwatershed according to the relative contribution of each HRU to the total controllable source HRU load in the subwatershed. For example, if a given HRU contributed 25% of the total phosphorus load from all controllable source HRUs in a subwatershed, then it was assigned 25% of the load calculated in step 4.

Average annual total phosphorus yields by land use after the adjustment described above are listed in Table 25. With the adjustment, the yield from forest and wetland HRUs better matches the general pattern of yields in the lower end of ranges listed in Table 23. Adjusted HRU loads were used in the UFWB TMDL to calculate baseline nonpoint source phosphorus loading by land use type and to determine the relative contribution of each source type for allocating allowable phosphorus loads.

Table 25. Annual total phosphorus yields by land use type from the UFWB SWAT model before and after the adjustment to match the reference total phosphorus concentration in forest and wetland HRUs.

Land Use Type	**Total phosphorus yield (kilograms/hectare)**	
	Before Reference Adjustment	**After Reference Adjustment**
Forest and Wetland	0.12	0.05
Dairy (Mixed Agriculture)	0.3	0.36
Corn/Soybean (Row Crop Ag.)	0.36	0.44
Potato/Vegetable (Row Crop Ag.)	0.57	0.59
Pasture/Grassland	0.17	0.23
Urban Low Density	0.13	0.16
Urban Medium Density	0.21	0.28
Urban High Density	0.45	0.54

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Appendix A. Summary of Agriculture Class Definition and Mapping

The custom land cover grid used for HRU definition in the UFWB SWAT model included 46 detailed agriculture classes. Each agriculture class is associated with a distinct set of farming operations, including crops planted, fertilizer and manure applications, and tillage.

The process of defining and mapping agriculture classes was initiated by submitting a questionnaire on farming practices to all county land and water conservation departments (LWCDs) in the Upper Fox-Wolf Basins. This approach of using land cover/land use datasets to map crop types and county land and water conservation departments to determine farming practices associated with each crop is consistent with methods described by Kirsch et al. (2002), Larose et al. (2007), and Heathman et al. (2008).

The goal of the questionnaire was to acquire information on farming practices relevant to SWAT at a scale that reasonably captured spatial variation across each county. LWCDs were asked to provide information on typical farming practices in their county at the scale of 12-digit hydrologic units (HUC12s). Questions dealt with the following topics:

- The extent of dairy, cash grain, potato/vegetable farms;
- The type and sequence of crops planted in a dairy rotation;
- Tillage timing (spring or fall) and intensity;
- Chemical fertilizer application timing and application rates;
- Cow manure application frequency, application timing, form (solid or liquid), application rates, and whether manure application is followed by incorporation into the soil;
- Planting/harvest dates; and
- Soil phosphorus content.

Questionnaire responses indicated that certain farming practices are consistent across counties in the UFWB:

- Nearly all counties reported six-year dairy sequences as 2-3 years of corn/soy/wheat plantings followed by 3-4 years of alfalfa;
- Most counties reported that corn is typically cut as silage in dairy sequences. Corn grain is less frequent in dairy sequences overall but is prominent in certain portions of the UFWB;
- Most HUC12s were reported to have predominantly 0-15% residue cover on both cash grain and dairy fields following tillage. Although higher residue levels (>15%) rarely dominate within a HUC12 they can have significant acreage;
- High intensity tillage (0% residue cover) is the typical practice for potato/vegetable farming;
- Annual manure applications averaged approximately 10,750 gallons/acre liquid and 17.8 tons/acre solid;
- Nearly all counties reported that hay is typically cut 4 times per year.

Typical practices per HUC12 were reviewed and used to define the 46 detailed agriculture classes for the UFWB SWAT model. The 46 agriculture classes include 36 dairy classes, 6 cash grain classes, 3 potato/vegetable classes, and 1 pasture/grassland class. Table A- 1 and Table A- 2 outline the distinguishing characteristics of the dairy, cash grain, and potato/vegetable classes. Each class corresponds to a specific set of farming practices applied to a given field over a six-year rotation. For example, dairy classes 1 through 6 all share the same crop sequence (2 years corn silage followed by 1 year winter wheat and 3 years alfalfa), which differs from the crop sequence in dairy classes 7 through 12 (1 year corn silage, 1 year corn grain, followed by 1 year winter wheat and 3 years alfalfa).

To account for the fact that all farms would not realistically start a given dairy or potato/vegetable rotation in the same calendar year, the classes also differ according to which year in the six-year rotation is applied at the onset of SWAT simulation. For example, the "Dairy 1, Year 1" class and the "Dairy 1, Year 3" class have the same set of practices applied over a six-year rotation but the "Dairy 1, Year 1" rotation starts with corn silage planting while "Dairy 1, Year 3" starts with alfalfa planting (i.e., practices in the "Dairy 1, Year 3" class are offset by 2 years).

The 6 cash grain classes are continuous corn and continuous soybean plantings with varied tillage levels. We recognize that a typical cash grain farm rotates corn and soybean plantings between years and that a wide variety of sequences are used (corn-soybean, corn-corn-soybean, etc.). Rather than imposing 1-2 cash grain sequences for the entire UFWB, we are using the continuous planting format to better simulate actual acreages of cash grain farmland in corn versus soybean.

The 46 agriculture classes reflect typical farming behaviors in the UFWB while capturing variation in factors that have the greatest impact on runoff volumes, soil erosion, and phosphorus loading. The selected classes are not an exact reflection of each and every farm in the UFWB and the ability simulate additional agricultural classes is limited by model processing times and data storage requirements. However, the selected classes do balance variability in farming practices with limitations imposed by the scale of the watershed modeling effort.

Each agriculture class has a unique agricultural management table that is input to SWAT that defines the order of farming operations for that class. Management tables for each class are provided in Appendix B.

Table A- 1. Defining characteristics of each dairy class selected for the UFWB watershed model. Classes differ in crops planted, intensity of tillage, and manure application

Class Name	**Crop Sequence**	**Tillage (% Residue Remaining)**	**Manure**
Dairy 1, Year 1	2 years corn silage followed by winter wheat and alfalfa	0-15%	Daily Haul
Dairy 1, Year 3			
Dairy 1, Year 5			
Dairy 2, Year 1			Storage
Dairy 2, Year 3			
Dairy 2, Year 5			
Dairy 3, Year 1		16-30%	Daily Haul
Dairy 3, Year 3			
Dairy 3, Year 5			
Dairy 4, Year 1			Storage
Dairy 4, Year 3			
Dairy 4, Year 5			
Dairy 5, Year 1		>30%	Daily Haul
Dairy 5, Year 3			
Dairy 5, Year 5			
Dairy 6, Year 1			Storage
Dairy 6, Year 3			
Dairy 6, Year 5			
Dairy 7, Year 1	1 year corn silage, 1 year corn grain followed by winter wheat and alfalfa	0-15%	Daily Haul
Dairy 7, Year 3			
Dairy 7, Year 5			
Dairy 8, Year 1			Storage
Dairy 8, Year 3			
Dairy 8, Year 5			
Dairy 9, Year 1		16-30%	Daily Haul
Dairy 9, Year 3			
Dairy 9, Year 5			
Dairy 10, Year 1			Storage
Dairy 10, Year 3			
Dairy 10, Year 5			
Dairy 11, Year 1		>30%	Daily Haul
Dairy 11, Year 3			
Dairy 11, Year 5			
Dairy 12, Year 1			Storage
Dairy 12, Year 3			
Dairy 12, Year 5			

Table A- 2. Defining characteristics of each cash grain and potato/vegetable class selected for the UFWB SWAT model. Classes differ in crops planted, intensity of tillage, and manure application.

Class Name	Crop Sequence	Tillage (% Residue Remaining)	Manure
Cash Grain 1	Continuous corn	0-15%	-
Cash Grain 2		16-30%	-
Cash Grain 3		>30%	-
Cash Grain 4	Continuous soybean	0-15%	-
Cash Grain 5		16-30%	-
Cash Grain 6		>30%	-
Potato/Vegetable Year 1	1 year potato followed by 2 years vegetable	0-15%	-
Potato/Vegetable Year 3			
Potato/Vegetable Year 5			

After defining agriculture classes, the classes were added to the custom land cover grid developed for input to ArcSWAT. The following steps were applied to map agriculture classes:

1. Identify agricultural lands using the 2011 NLCD land cover dataset (NLCD classes 71, 81, and 82).
2. Classify agricultural lands as dairy, cash grain, potato/vegetable, or pasture/grassland using the statewide general crop rotation map layer developed by WDNR (WDNR 2014).
3. Subdivide areas classified as dairy in the statewide general crop rotation map layer into the 36 dairy classes listed in Table A- 1. This step used a randomization approach, where each dairy grid pixel was randomly assigned to one of the 36 dairy classes. Randomization was constrained so that acreages in each UFWB HUC12 followed estimates provided by county staff in responses to agricultural practice questionnaires.
4. Subdivide areas classified as cash grain in the statewide general crop rotation map layer into the 6 different cash grain classes listed in Table A- 2. This step used a randomization approach, where each cash grain grid pixel was randomly assigned to one of the 6 cash grain classes. Randomization was constrained so that acreages in each UFWB HUC12 followed estimates provided by county staff in responses to agricultural practice questionnaires and estimates of average corn and soybean acreage per HUC12 in USDA Cropland Data Layers for the years 2008 through 2012.
5. Subdivide areas classified as potato/vegetable in the statewide general crop rotation map layer into the 3 different potato/vegetable classes listed in Table A- 2. This step used a randomization approach, where each potato/vegetable grid pixel was randomly assigned to one of the 3 potato/vegetable classes. Randomization was constrained so that acreages of each of the 3 potato/vegetable classes in the UFWB were equal.

Appendix B. SWAT Agricultural Management Tables

Table B- 1. SWAT agricultural management table for the "Dairy 1, Year 1" class. The “Dairy 1, Year 3” management table is offset by two years. The “Dairy 1, Year 5” management table is offset by four years.

DAIRY WITH CORN SILAGE, 0-15% TILLAGE, AND DAILY HAUL OF MANURE (Dairy 1)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	30	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	15	Tillage	Generic Fall Plowing Operation		
2	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	10	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	30	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Silage		
2	9	15	Harvest	Corn Silage		
2	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	11	15	Tillage	Generic Fall Plowing Operation		
3	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	10	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	30	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Generic Fall Plowing Operation		

Table B- 2. SWAT agricultural management table for the "Dairy 2, Year 1" class. The “Dairy 2, Year 3” management table is offset by two years. The “Dairy 2, Year 5” management table is offset by four years.

DAIRY WITH CORN SILAGE, 0-15% TILLAGE, AND MANURE STORAGE (Dairy 2)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	4	26	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	10	2	Tillage	Generic Fall Plow Ge15ft		
2	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	4	26	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Silage		
2	9	15	Harvest	Corn Silage		
2	10	1	Fertilizer	Manure	3083	kg/ha
2	10	2	Tillage	Generic Fall Plow Ge15ft		
3	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
3	4	26	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Generic Fall Plow Ge15ft		

Table B- 3. SWAT agricultural management table for the "Dairy 3, Year 1" class. The "Dairy 3, Year 3" management table is offset by two years. The "Dairy 3, Year 5" management table is offset by four years.

DAIRY WITH CORN SILAGE, 16-30% TILLAGE, AND DAILY HAUL OF MANURE (Dairy 3)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	30	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	15	Tillage	Tandem Disk Reg Ge19ft		
2	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	30	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Silage		
2	9	15	Harvest	Corn Silage		
2	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	11	15	Tillage	Tandem Disk Reg Ge19ft		
3	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	30	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Tandem Disk Reg Ge19ft		

Table B- 4. SWAT agricultural management table for the "Dairy 4, Year 1" class. The "Dairy 4, Year 3" management table is offset by two years. The "Dairy 4, Year 5" management table is offset by four years.

DAIRY WITH CORN SILAGE, 16-30% TILLAGE, AND MANURE STORAGE (Dairy 4)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	4	26	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	10	2	Tillage	Tandem Disk Reg Ge19ft		
2	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	4	26	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Silage		
2	9	15	Harvest	Corn Silage		
2	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	10	2	Tillage	Tandem Disk Reg Ge19ft		
3	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
3	4	26	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Tandem Disk Reg Ge19ft		

Table B- 5. SWAT agricultural management table for the "Dairy 5, Year 1" class. The "Dairy 5, Year 3" management table is offset by two years. The "Dairy 5, Year 5" management table is offset by four years.

DAIRY WITH CORN SILAGE, >30% TILLAGE, AND DAILY HAUL OF MANURE (Dairy 5)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	30	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	15	Tillage	Conservation Tillage		
2	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	30	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Silage		
2	9	15	Harvest	Corn Silage		
2	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	11	15	Tillage	Conservation Tillage		
3	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	30	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	50	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Conservation Tillage		

Table B- 6. SWAT agricultural management table for the "Dairy 6, Year 1" class. The "Dairy 6, Year 3" management table is offset by two years. The "Dairy 6, Year 5" management table is offset by four years.

DAIRY WITH CORN SILAGE, >30% TILLAGE, AND MANURE STORAGE (Dairy 6)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	4	26	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	10	2	Tillage	Conservation Tillage		
2	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	4	26	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Silage		
2	9	15	Harvest	Corn Silage		
2	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	10	2	Tillage	Conservation Tillage		
3	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
3	4	26	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Conservation Tillage		

Table B- 7. SWAT agricultural management table for the "Dairy 7, Year 1" class. The "Dairy 7, Year 3" management table is offset by two years. The "Dairy 7, Year 5" management table is offset by four years.

DAIRY WITH CORN GRAIN+CORN SILAGE, 0-15% TILLAGE, AND DAILY HAUL OF MANURE (Dairy 7)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	30	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	15	Tillage	Generic Fall Plow Ge15ft		
2	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	30	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Grain		
2	10	30	Harvest	Corn Grain		
2	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	12	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	12	5	Tillage	Generic Fall Plow Ge15ft		
3	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	30	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Generic Fall Plow Ge15ft		

Table B- 8. SWAT agricultural management table for the "Dairy 8, Year 1" class. The "Dairy 8, Year 3" management table is offset by two years. The "Dairy 8, Year 5" management table is offset by four years.

DAIRY WITH CORN GRAIN+CORN SILAGE, 0-15% TILLAGE, AND MANURE STORAGE (Dairy 8)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	4	26	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	10	2	Tillage	Generic Fall Plow Ge15ft		
2	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	4	26	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Grain		
2	10	30	Harvest	Corn Grain		
2	11	15	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	11	16	Tillage	Generic Fall Plow Ge15ft		
3	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
3	4	26	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Generic Fall Plow Ge15ft		

Table B- 9. SWAT agricultural management table for the "Dairy 9" class. The "Dairy 9, Year 3" management table is offset by two years. The "Dairy 9, Year 5" management table is offset by four years.

DAIRY WITH CORN GRAIN+CORN SILAGE, 16-30% TILLAGE, AND DAILY HAUL OF MANURE (Dairy 9)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	30	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	15	Tillage	Tandem Disk Reg Ge19ft		
2	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	30	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Grain		
2	10	30	Harvest	Corn Grain		
2	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	12	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	12	5	Tillage	Tandem Disk Reg Ge19ft		
3	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	30	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Tandem Disk Reg Ge19ft		

Table B- 10. SWAT agricultural management table for the "Dairy 10, Year 1" class. The "Dairy 10, Year 3" management table is offset by two years. The "Dairy 10, Year 5" management table is offset by four years.

DAIRY WITH CORN GRAIN+CORN SILAGE, 16-30% TILLAGE, AND MANURE STORAGE (Dairy 10)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	4	26	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	30070	kg/ha
1	10	2	Tillage	Tandem Disk Reg Ge19ft		
2	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	4	26	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Grain		
2	10	30	Harvest	Corn Grain		
2	11	15	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	11	16	Tillage	Tandem Disk Reg Ge19ft		
3	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
3	4	26	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Tandem Disk Reg Ge19ft		

Table B- 11. SWAT agricultural management table for the "Dairy 11, Year 1" class. The "Dairy 11, Year 3" management table is offset by two years. The "Dairy 11, Year 5" management table is offset by four years.

DAIRY WITH CORN GRAIN+CORN SILAGE, >30% TILLAGE, AND DAILY HAUL OF MANURE (Dairy 11)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	4	30	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
1	11	15	Tillage	Conservation Tillage		
2	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	4	30	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Grain		
2	10	30	Harvest	Corn Grain		
2	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	12	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
2	12	5	Tillage	Conservation Tillage		
3	3	31	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	25	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	4	30	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
3	11	1	Fertilizer	Dairy - Fresh Manure	2421	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Conservation Tillage		

Table B- 12. SWAT agricultural management table for the "Dairy 12, Year 1" class. The “Dairy 12, Year 3” management table is offset by two years. The “Dairy 12, Year 5” management table is offset by four years.

DAIRY WITH CORN GRAIN+CORN SILAGE, >30% TILLAGE, AND MANURE STORAGE (Dairy 12)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	4	26	Tillage	Field Cultivator Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Silage		
1	9	15	Harvest	Corn Silage		
1	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	10	2	Tillage	Conservation Tillage		
2	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	4	26	Tillage	Field Cultivator Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Grain		
2	10	30	Harvest	Corn Grain		
2	11	15	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	11	16	Tillage	Conservation Tillage		
3	4	25	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
3	4	26	Tillage	Field Cultivator Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Winter Wheat		
3	8	30	Harvest	Winter Wheat		
3	10	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft		
4	4	20	Plant	Alfalfa		
4	9	1	Harvest	Alfalfa		
5	5	15	Harvest	Alfalfa		
5	6	30	Harvest	Alfalfa		
5	8	15	Harvest	Alfalfa		
5	9	30	Harvest	Alfalfa		
6	5	15	Harvest	Alfalfa		
6	6	30	Harvest	Alfalfa		
6	8	15	Harvest	Alfalfa		
6	9	30	Harvest	Alfalfa		
6	10	15	Tillage	Conservation Tillage		

Table B- 13. SWAT agricultural management table for the "Continuous Corn 1" class.

CASH GRAIN - CORN COMPONENT, 0-15% TILLAGE (Continuous Corn 1)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	15	Tillage	Generic Fall Plow Ge15ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Grain		
1	10	30	Harvest	Corn Grain		
1	11	15	Tillage	Generic Fall Plow Ge15ft		
2	4	15	Tillage	Generic Fall Plow Ge15ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Grain		
2	10	30	Harvest	Corn Grain		
2	11	15	Tillage	Generic Fall Plow Ge15ft		
3	4	15	Tillage	Generic Fall Plow Ge15ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Corn Grain		
3	10	30	Harvest	Corn Grain		
3	11	15	Tillage	Generic Fall Plow Ge15ft		
4	4	15	Tillage	Generic Fall Plow Ge15ft		
4	5	1	Fertilizer	Elemental P	25	kg/ha
4	5	1	Plant	Corn Grain		
4	10	30	Harvest	Corn Grain		
4	11	15	Tillage	Generic Fall Plow Ge15ft		
5	4	15	Tillage	Generic Fall Plow Ge15ft		
5	5	1	Fertilizer	Elemental P	25	kg/ha
5	5	1	Plant	Corn Grain		
5	10	30	Harvest	Corn Grain		
5	11	15	Tillage	Generic Fall Plow Ge15ft		
6	4	15	Tillage	Generic Fall Plow Ge15ft		
6	5	1	Fertilizer	Elemental P	25	kg/ha
6	5	1	Plant	Corn Grain		
6	10	30	Harvest	Corn Grain		
6	11	15	Tillage	Generic Fall Plow Ge15ft		

Table B- 14. SWAT agricultural management table for the "Continuous Soybean 1" class.

CASH GRAIN - SOYBEAN COMPONENT, 0-15% TILLAGE (Continuous Soybean 1)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	15	Tillage	Generic Fall Plow Ge15ft		
1	5	15	Fertilizer	Elemental P	25	kg/ha
1	5	15	Plant	Soybean		
1	10	15	Harvest	Soybean		
2	4	15	Tillage	Generic Fall Plow Ge15ft		
2	5	15	Fertilizer	Elemental P	25	kg/ha
2	5	15	Plant	Soybean		
2	10	15	Harvest	Soybean		
3	4	15	Tillage	Generic Fall Plow Ge15ft		
3	5	15	Fertilizer	Elemental P	25	kg/ha
3	5	15	Plant	Soybean		
3	10	15	Harvest	Soybean		
4	4	15	Tillage	Generic Fall Plow Ge15ft		
4	5	15	Fertilizer	Elemental P	25	kg/ha
4	5	15	Plant	Soybean		
4	10	15	Harvest	Soybean		
5	4	15	Tillage	Generic Fall Plow Ge15ft		
5	5	15	Fertilizer	Elemental P	25	kg/ha
5	5	15	Plant	Soybean		
5	10	15	Harvest	Soybean		
6	4	15	Tillage	Generic Fall Plow Ge15ft		
6	5	15	Fertilizer	Elemental P	25	kg/ha
6	5	15	Plant	Soybean		
6	10	15	Harvest	Soybean		

Table B- 15. SWAT agricultural management table for the "Continuous Corn 2, Year 1" class.

CASH GRAIN - CORN COMPONENT, 16-30% TILLAGE (Continuous Corn 2)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	15	Tillage	Tandem Disk Reg Ge19ft		
1	5	1	Fertilizer	Elemental P	25	kg/ha
1	5	1	Plant	Corn Grain		
1	10	30	Harvest	Corn Grain		
1	11	15	Tillage	Tandem Disk Reg Ge19ft		
2	4	15	Tillage	Tandem Disk Reg Ge19ft		
2	5	1	Fertilizer	Elemental P	25	kg/ha
2	5	1	Plant	Corn Grain		
2	10	30	Harvest	Corn Grain		
2	11	15	Tillage	Tandem Disk Reg Ge19ft		
3	4	15	Tillage	Tandem Disk Reg Ge19ft		
3	5	1	Fertilizer	Elemental P	25	kg/ha
3	5	1	Plant	Corn Grain		
3	10	30	Harvest	Corn Grain		
3	11	15	Tillage	Tandem Disk Reg Ge19ft		
4	4	15	Tillage	Tandem Disk Reg Ge19ft		
4	5	1	Fertilizer	Elemental P	25	kg/ha
4	5	1	Plant	Corn Grain		
4	10	30	Harvest	Corn Grain		
4	11	15	Tillage	Tandem Disk Reg Ge19ft		
5	4	15	Tillage	Tandem Disk Reg Ge19ft		
5	5	1	Fertilizer	Elemental P	25	kg/ha
5	5	1	Plant	Corn Grain		
5	10	30	Harvest	Corn Grain		
5	11	15	Tillage	Tandem Disk Reg Ge19ft		
6	4	15	Tillage	Tandem Disk Reg Ge19ft		
6	5	1	Fertilizer	Elemental P	25	kg/ha
6	5	1	Plant	Corn Grain		
6	10	30	Harvest	Corn Grain		
6	11	15	Tillage	Tandem Disk Reg Ge19ft		

Table B- 16. SWAT agricultural management table for the "Continuous Soybean 2" class.

CASH GRAIN - SOYBEAN COMPONENT, 16-30% TILLAGE (Continuous Soybean 2)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	15	Tillage	Tandem Disk Reg Ge19ft		
1	5	15	Fertilizer	Elemental P	25	kg/ha
1	5	15	Plant	Soybean		
1	10	15	Harvest	Soybean		
2	4	15	Tillage	Tandem Disk Reg Ge19ft		
2	5	15	Fertilizer	Elemental P	25	kg/ha
2	5	15	Plant	Soybean		
2	10	15	Harvest	Soybean		
3	4	15	Tillage	Tandem Disk Reg Ge19ft		
3	5	15	Fertilizer	Elemental P	25	kg/ha
3	5	15	Plant	Soybean		
3	10	15	Harvest	Soybean		
4	4	15	Tillage	Tandem Disk Reg Ge19ft		
4	5	15	Fertilizer	Elemental P	25	kg/ha
4	5	15	Plant	Soybean		
4	10	15	Harvest	Soybean		
5	4	15	Tillage	Tandem Disk Reg Ge19ft		
5	5	15	Fertilizer	Elemental P	25	kg/ha
5	5	15	Plant	Soybean		
5	10	15	Harvest	Soybean		
6	4	15	Tillage	Tandem Disk Reg Ge19ft		
6	5	15	Fertilizer	Elemental P	25	kg/ha
6	5	15	Plant	Soybean		
6	10	15	Harvest	Soybean		

Table B- 17. SWAT agricultural management table for the "Continuous Corn 3" class.

CASH GRAIN - CORN COMPONENT, >30% TILLAGE (Continuous Corn 3)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	15	Tillage	Conservation Tillage		
1	5	1	Fertilizer	Elemental P	50	kg/ha
1	5	1	Plant	Corn Grain		
1	10	30	Harvest	Corn Grain		
1	11	15	Tillage	Conservation Tillage		
2	4	15	Tillage	Conservation Tillage		
2	5	1	Fertilizer	Elemental P	50	kg/ha
2	5	1	Plant	Corn Grain		
2	10	30	Harvest	Corn Grain		
2	11	15	Tillage	Conservation Tillage		
3	4	15	Tillage	Conservation Tillage		
3	5	1	Fertilizer	Elemental P	50	kg/ha
3	5	1	Plant	Corn Grain		
3	10	30	Harvest	Corn Grain		
3	11	15	Tillage	Conservation Tillage		
4	4	15	Tillage	Conservation Tillage		
4	5	1	Fertilizer	Elemental P	50	kg/ha
4	5	1	Plant	Corn Grain		
4	10	30	Harvest	Corn Grain		
4	11	15	Tillage	Conservation Tillage		
5	4	15	Tillage	Conservation Tillage		
5	5	1	Fertilizer	Elemental P	50	kg/ha
5	5	1	Plant	Corn Grain		
5	10	30	Harvest	Corn Grain		
5	11	15	Tillage	Conservation Tillage		
6	4	15	Tillage	Conservation Tillage		
6	5	1	Fertilizer	Elemental P	50	kg/ha
6	5	1	Plant	Corn Grain		
6	10	30	Harvest	Corn Grain		
6	11	15	Tillage	Conservation Tillage		

Table B- 18. SWAT agricultural management table for the "Continuous Soybean 3" class.

CASH GRAIN - SOYBEAN COMPONENT, >30% TILLAGE (Continuous Soybean 3)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	15	Tillage	Conservation Tillage		
1	5	15	Fertilizer	Elemental P	25	kg/ha
1	5	15	Plant	Soybean		
1	10	15	Harvest	Soybean		
2	4	15	Tillage	Conservation Tillage		
2	5	15	Fertilizer	Elemental P	25	kg/ha
2	5	15	Plant	Soybean		
2	10	15	Harvest	Soybean		
3	4	15	Tillage	Conservation Tillage		
3	5	15	Fertilizer	Elemental P	25	kg/ha
3	5	15	Plant	Soybean		
3	10	15	Harvest	Soybean		
4	4	15	Tillage	Conservation Tillage		
4	5	15	Fertilizer	Elemental P	25	kg/ha
4	5	15	Plant	Soybean		
4	10	15	Harvest	Soybean		
5	4	15	Tillage	Conservation Tillage		
5	5	15	Fertilizer	Elemental P	25	kg/ha
5	5	15	Plant	Soybean		
5	10	15	Harvest	Soybean		
6	4	15	Tillage	Conservation Tillage		
6	5	15	Fertilizer	Elemental P	25	kg/ha
6	5	15	Plant	Soybean		
6	10	15	Harvest	Soybean		

Table B- 19. SWAT agricultural management table for "Potato – Vegetable, Year 1" class. The "Potato-Vegetable, Year 3" management table is offset by two years. The "Potato-Vegetable, Year 5" management table is offset by four years.

POTATO-VEGETABLE ROTATION (Potato Vegetable)						
YEAR	**MONTH**	**DAY**	**OPERATION**	**TYPE**	**AMOUNT**	**UNITS**
1	4	30	Tillage	Moldboard Plow Ge7b		
1	4	30	Plant	Potato		
1	4	30	Fertilizer	Elemental P	39	kg/ha
1	8	20	Harvest	Potato		
1	8	25	Plant	Rye		
2	5	15	Tillage	Tandem Disk Reg Ge19ft		
2	5	20	Plant	Green Beans		
2	5	20	Fertilizer	Elemental P	39	kg/ha
2	7	15	Harvest	Snap Beans		
2	7	18	Plant	Rye		
3	5	15	Tillage	Tandem Disk Reg Ge19ft		
3	5	20	Plant	Sweet Corn		
3	5	20	Fertilizer	Elemental P	39	kg/ha
3	8	30	Harvest	Sweet Corn		
3	9	2	Plant	Rye		
1	4	30	Tillage	Moldboard Plow Ge7b		
1	4	30	Plant	Potato		
4	4	30	Fertilizer	P_2O_5	39	kg/ha
4	8	20	Harvest	Potato		
4	8	25	Plant	Rye		
5	5	15	Tillage	Tandem Disk Reg Ge19ft		
5	5	20	Plant	Green Beans		
5	5	20	Fertilizer	Elemental P	39	kg/ha
5	7	15	Harvest	Snap Beans		
5	7	18	Plant	Rye		
6	5	15	Tillage	Tandem Disk Reg Ge19ft		
6	5	20	Plant	Sweet Corn		
6	5	20	Fertilizer	P_2O_5	39	kg/ha
6	8	30	Harvest	Sweet Corn		
6	9	2	Plant	Rye		

Appendix C. SWAT Land Cover

Figure C- 1. SWAT land cover for UFWB after HRU development.

Land Cover	Landover Code	Area (acres)	% Watershed
Forest-Deciduous	FRSD	1,066,191	29.8%
Pasture	FESC	676,258	18.9%
Wetlands-Forested	WETF	547,691	15.3%
Wetlands-Non-Forested	WETN	164,376	4.6%
Non-Permitted Urban Open Space	URLD	106,612	3.0%
Continuous Soybean 1	CG02	98,229	2.7%
Continuous Corn 1	CG01	96,550	2.7%
Water	WATR	78,579	2.2%
Continuous Corn 2	CG03	72,069	2.0%
Continuous Soybean 2	CG04	72,049	2.0%
Dairy 1, Year 5	D015	62,228	1.7%
Dairy 1, Year 3	D013	61,596	1.7%
Dairy 1, Year 1	D011	60,925	1.7%
Continuous Soybean 3	CG06	45,024	1.3%
Continuous Corn 3	CG05	44,102	1.2%
Non-Permitted Urban Low Density	URMD	40,267	1.1%
Dairy 10 Year, 5	D105	18,905	0.5%
Dairy 10 Year, 1	D101	18,887	0.5%
Dairy 10 Year, 3	D103	18,826	0.5%
Dairy 4, Year 1	D041	16,061	0.4%
Dairy 4, Year 3	D043	15,921	0.4%
Dairy 4, Year 5	D045	15,917	0.4%
Potato Vegetable, Year 2	POT3	14,890	0.4%
Potato Vegetable, Year 1	POT1	14,742	0.4%
Potato Vegetable, Year 3	POT5	14,433	0.4%
MS4 Permitted Urban Low Density	MRMD	13,115	0.4%
Dairy 2 Year, 5	D025	8,018	0.2%
Dairy 2 Year, 3	D023	7,960	0.2%
Dairy 3 Year, 1	D031	7,856	0.2%
Dairy 3 Year, 5	D035	7,765	0.2%
Dairy 2 Year, 1	D021	7,510	0.2%
Dairy 3 Year, 3	D033	7,435	0.2%
MS4 Permitted Urban Medium Density	MRHD	6,832	0.2%
Non-Permitted Urban Medium Density	URHD	6,048	0.2%
Dairy 8, Year 5	D085	5,619	0.2%
Dairy 8, Year 1	D081	5,595	0.2%
Dairy 8, Year 3	D083	5,591	0.2%
MS4 Permitted Urban Open Space	MRLD	4,609	0.1%
Dairy 12, Year 5	D125	3,215	0.1%
Dairy 12, Year 1	D121	3,148	0.1%
Dairy 12, Year 3	D123	3,138	0.1%
Dairy 11, Year 5	D115	2,910	0.1%
Dairy 11, Year 1	D111	2,702	0.1%
Dairy 11, Year 3	D113	2,668	0.1%
MS4 Permitted Urban High Density	MIDU	2,666	0.1%
Dairy 5, Year 5	D055	2,478	0.1%

Land Cover	Landover Code	Area (acres)	% Watershed
Dairy 5, Year 1	D051	2,368	0.1%
Dairy 5, Year 3	D053	2,358	0.1%
Non-Permitted Urban High Density	UIDU	2,063	0.1%
Dairy 9, Year 3	D093	1,914	0.1%
Dairy 9, Year 1	D091	1,914	0.1%
Dairy 9, Year 5	D095	1,870	0.1%
Dairy 6, Year 1	D061	1,488	0.04%
Dairy 6, Year 5	D065	1,483	0.04%
Dairy 6, Year 3	D063	1,470	0.04%
Dairy 7, Year 5	D075	1,214	0.03%
Dairy 7, Year 3	D073	1,189	0.03%
Dairy 7, Year 1	D071	1,170	0.03%
Pasture	SWRN	190	0.01%

Appendix D. Streamflow Calibration and Validation Time Series Plots

Figure D- 1. Monthly streamflow calibration hydrograph for USGS site 0407495 (Wolf River at Langlade, WI).

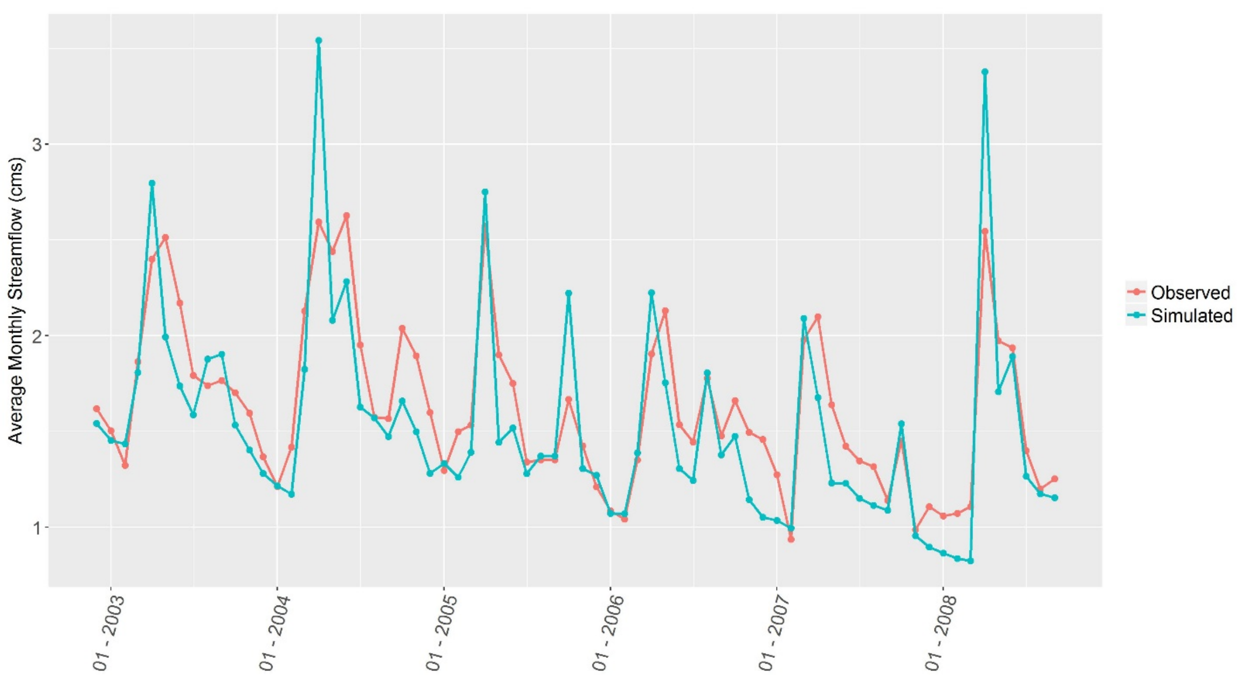

Figure D- 2. Monthly streamflow calibration hydrograph for USGS site 04075365 (Evergreen River below Evergreen Falls near Langlade, WI).

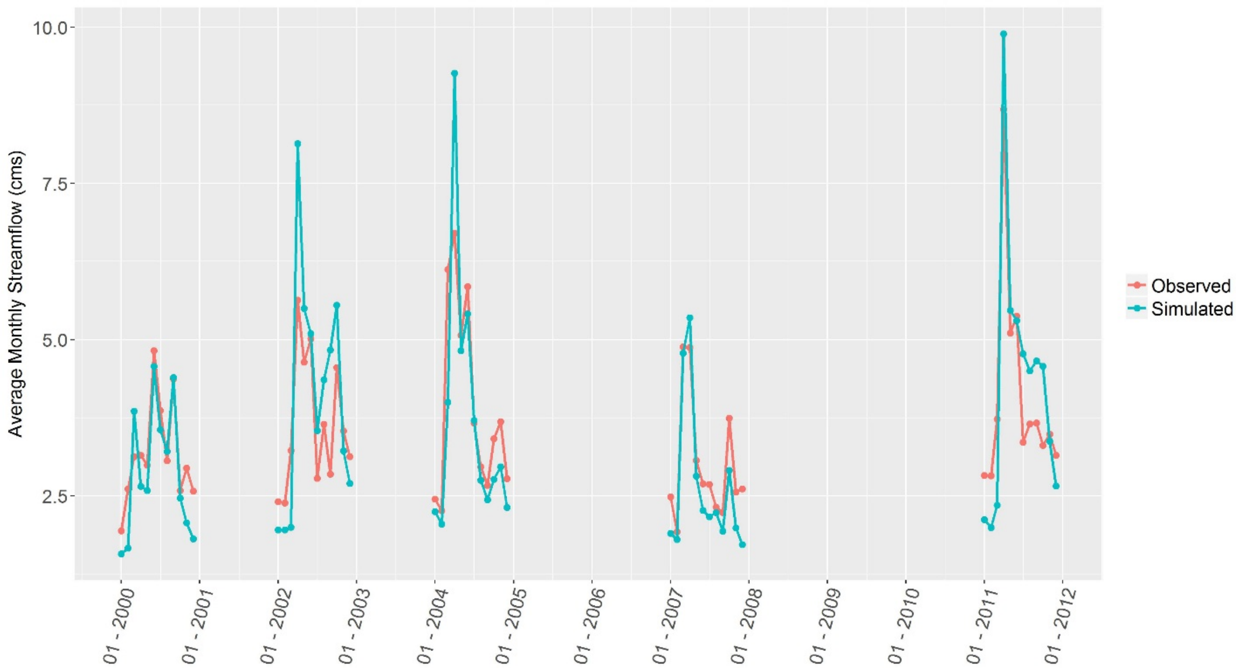

Figure D- 3. Monthly streamflow calibration hydrograph for USGS site 04077630 (Red River at Morgan Road near Morgan, WI).

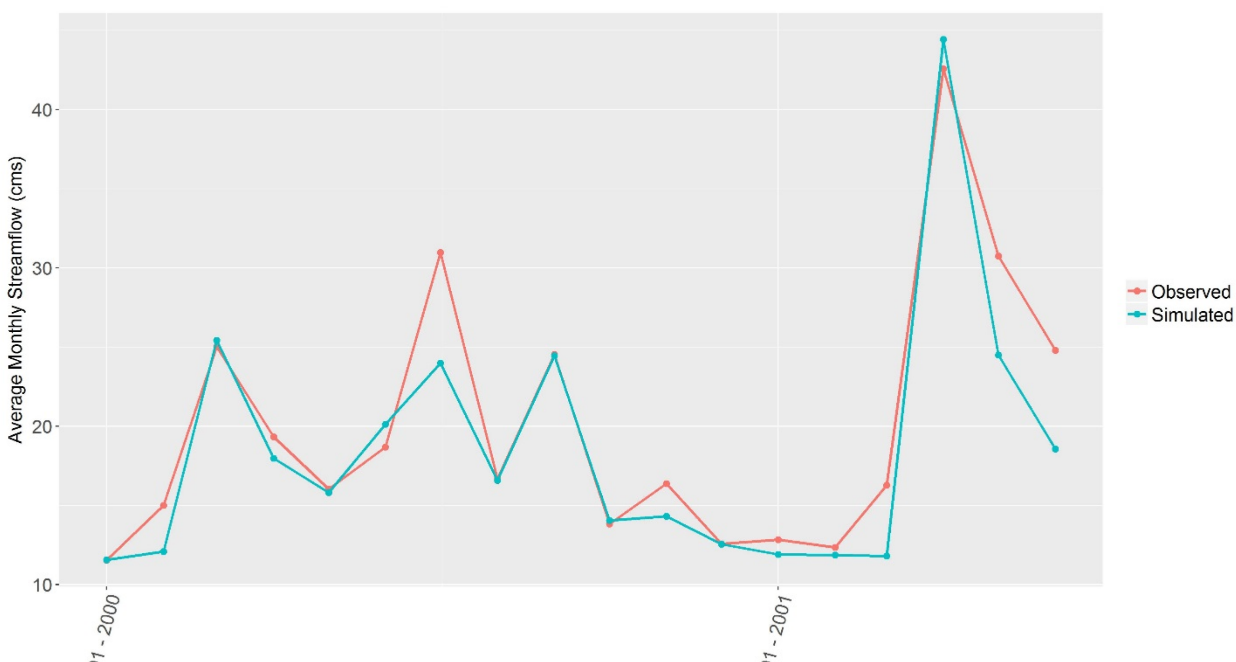

Figure D- 4. Monthly streamflow calibration hydrograph for USGS site 04077400 (Wolf River near Shawano, WI).

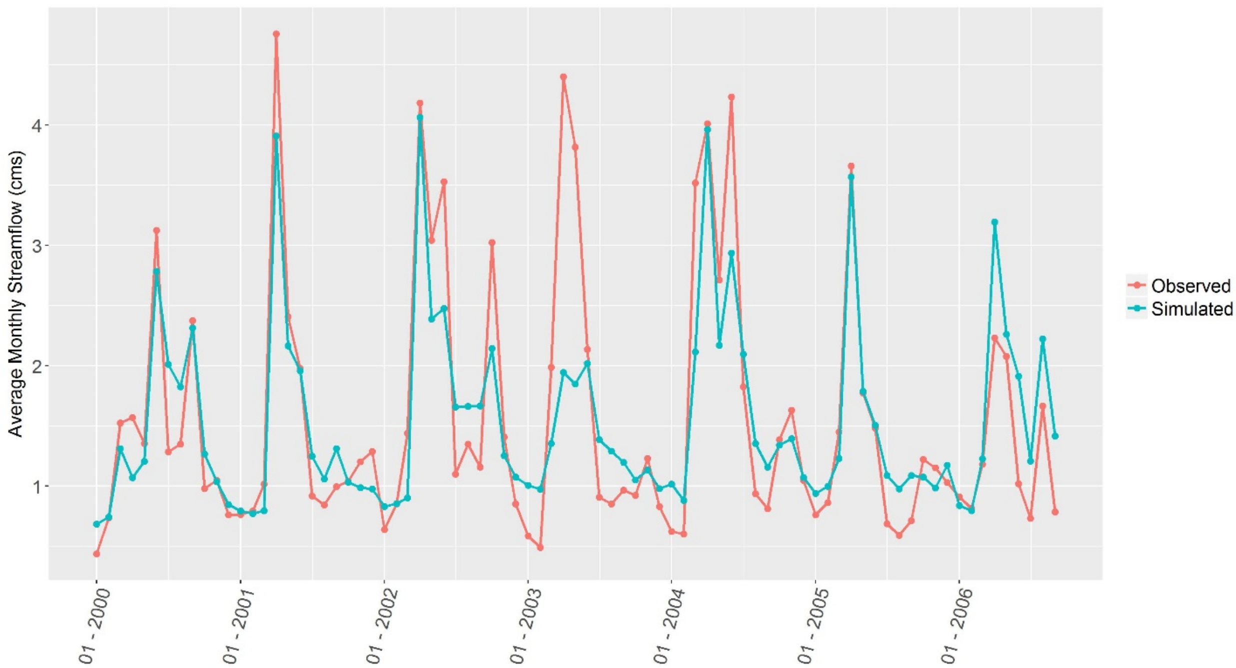

Figure D- 5. Monthly streamflow calibration hydrograph for USGS site 0407809265 (Middle Branch Embarrass River near Wittenberg, WI).

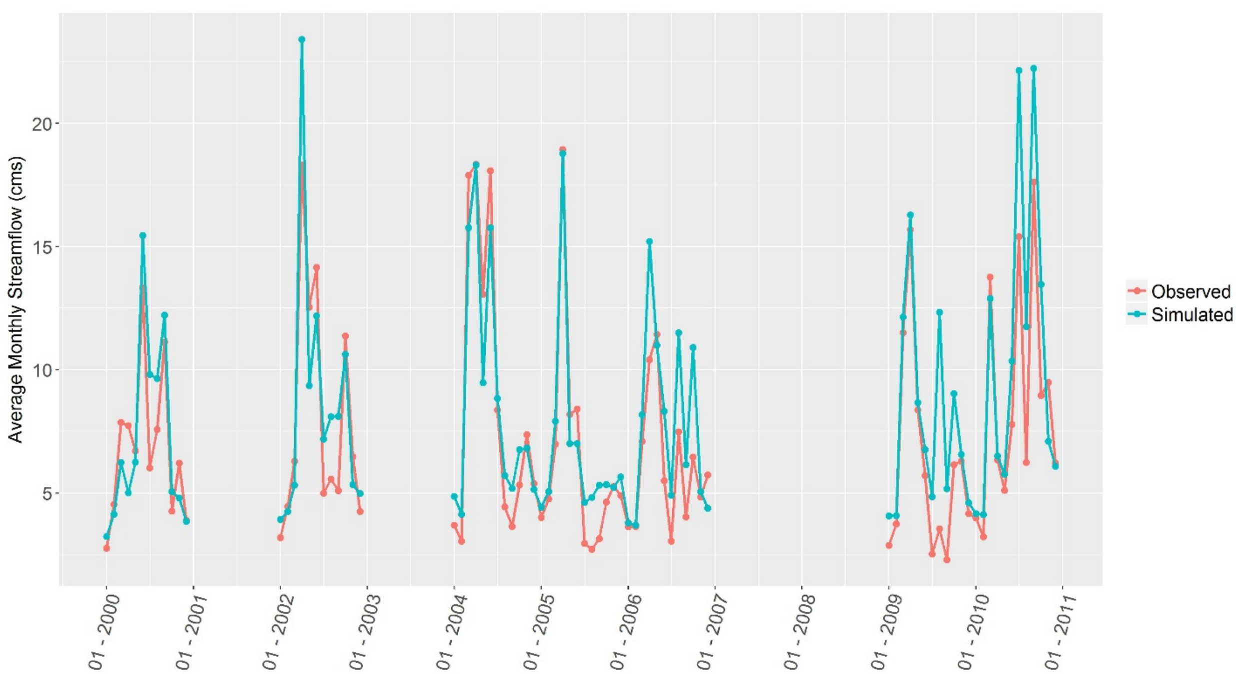

Figure D- 6. Monthly streamflow calibration hydrograph for USGS site 04078500 (Embarrass River near Embarrass, WI).

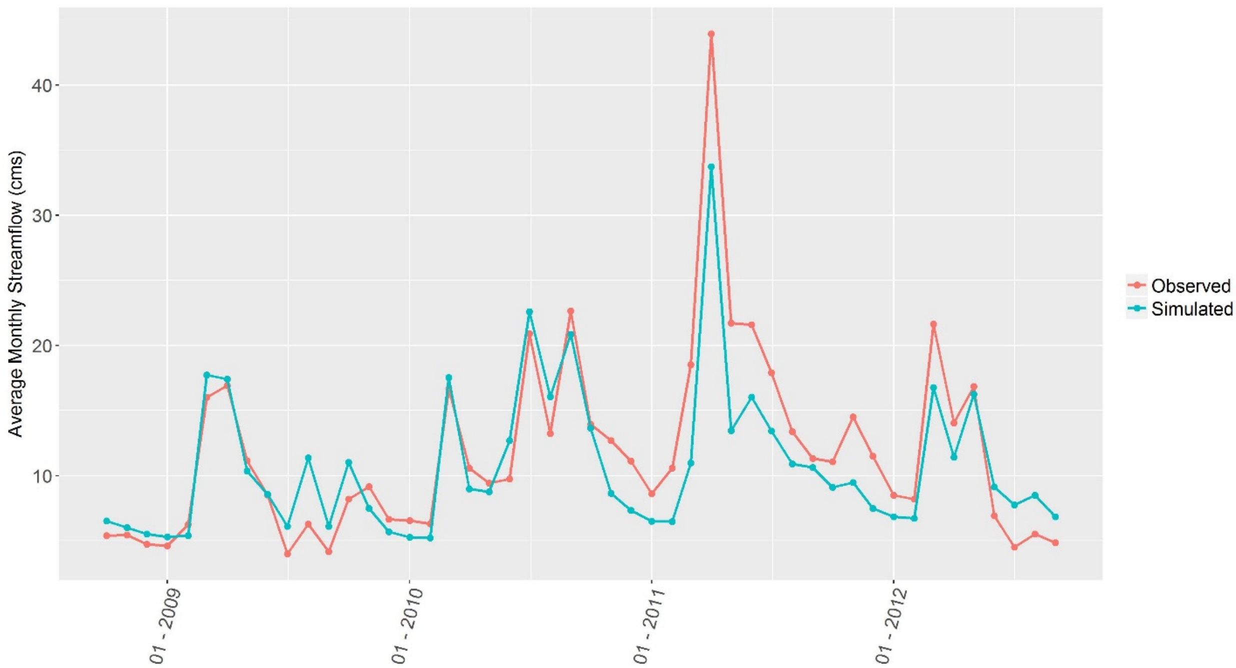

Figure D- 7. Monthly streamflow calibration hydrograph for USGS site 04080000 (Little Wolf River at Royalton, WI).

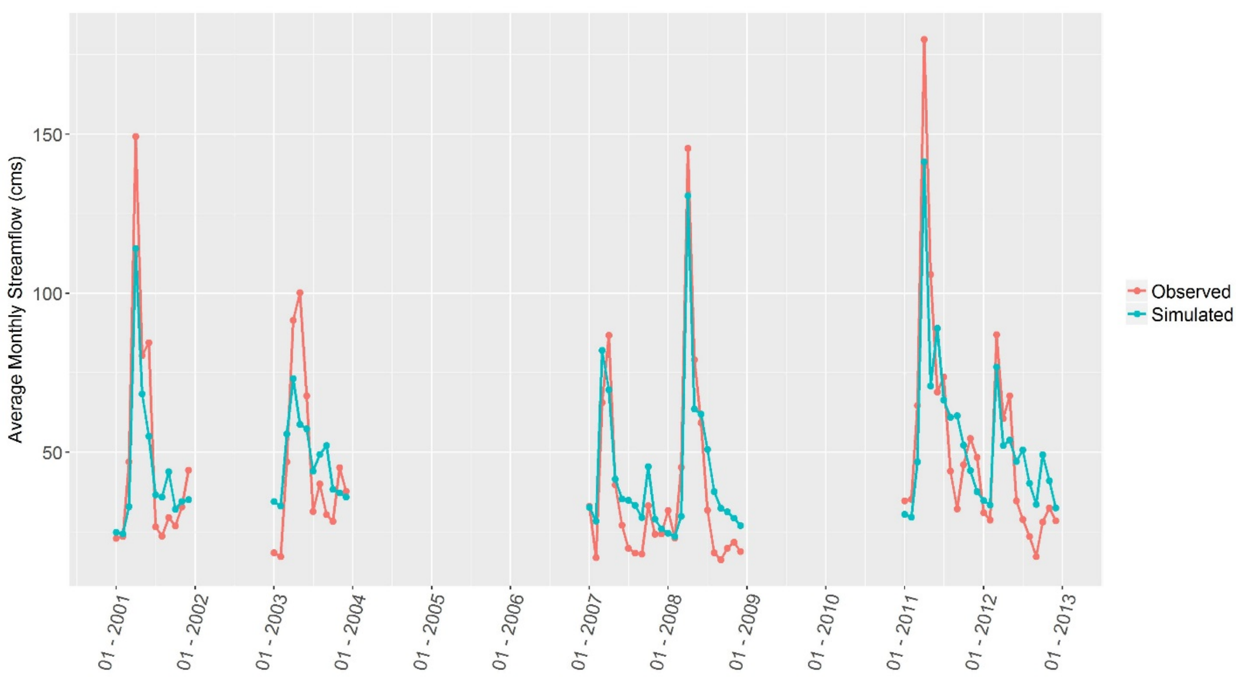

Figure D- 8. Monthly streamflow calibration hydrograph for USGS site 04079000 (Wolf River at New London, WI).

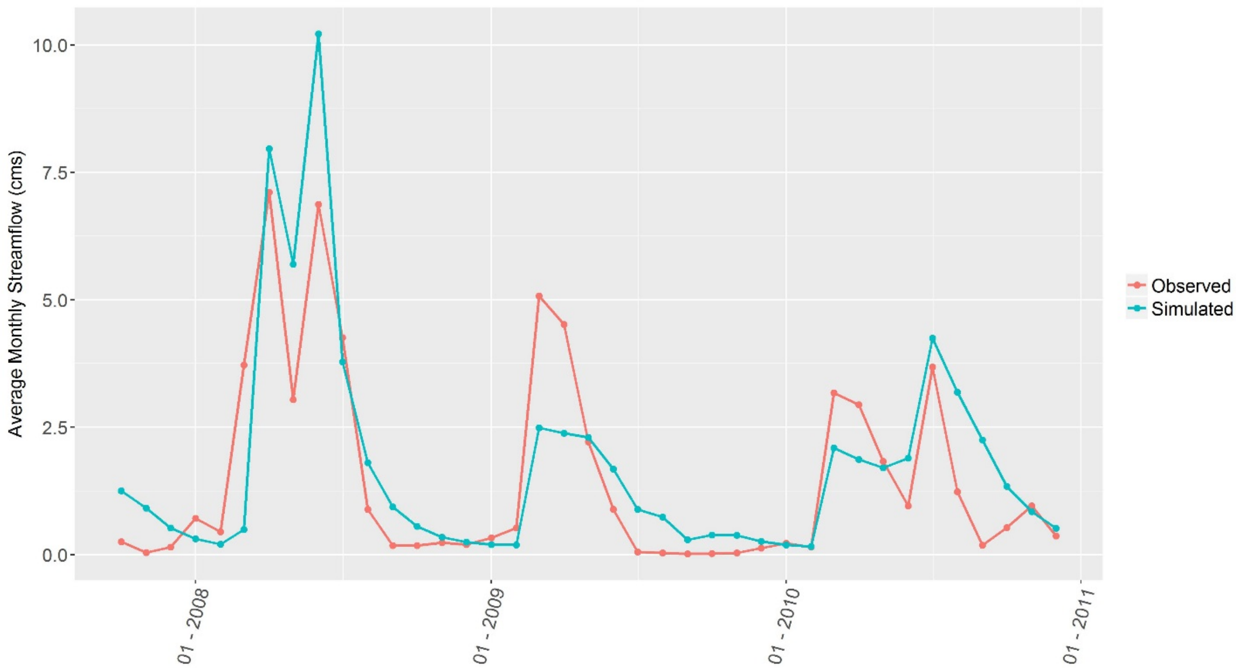

Figure D- 9. Monthly streamflow calibration hydrograph for USGS site 04073970 (Waukau Creek near Omro, WI).

Figure D- 10. Monthly streamflow calibration hydrograph for USGS site 04082400 (Fox River at Oshkosh, WI).

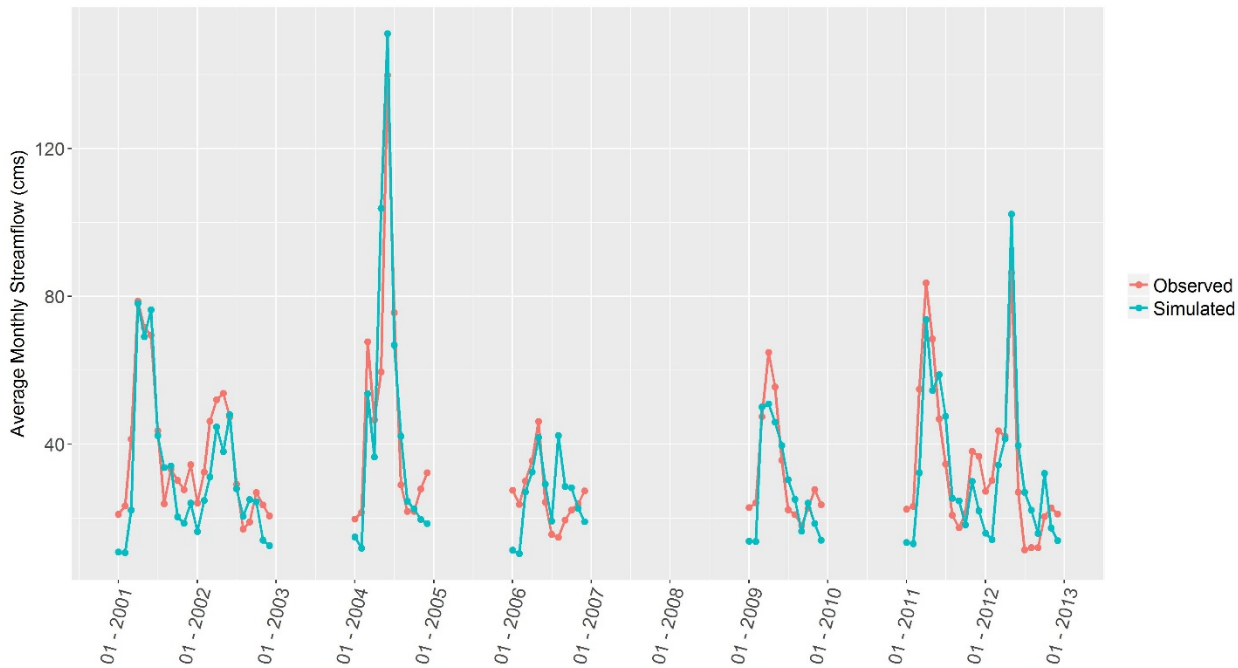

Figure D- 11. Monthly streamflow calibration hydrograph for USGS site 04073500 (Fox River at Berlin, WI).

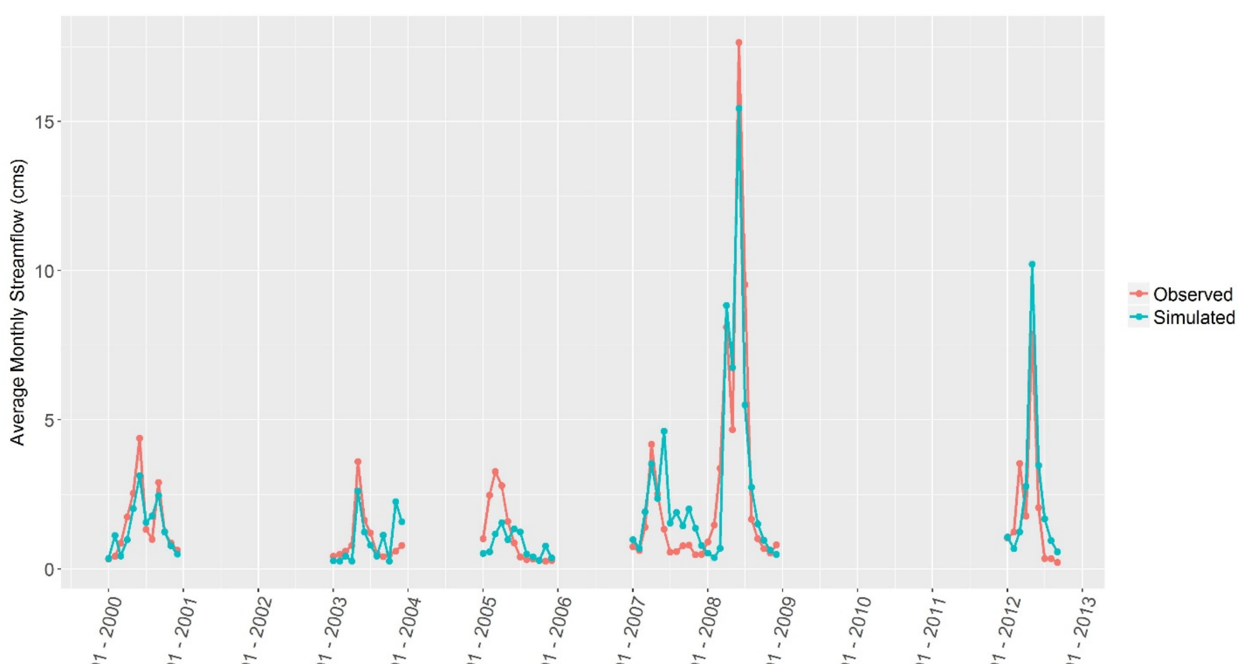

Figure D- 12. Monthly streamflow calibration hydrograph for USGS site 04073473 (Puchyan River DS N. Lawson Drive near Green Lake, WI).

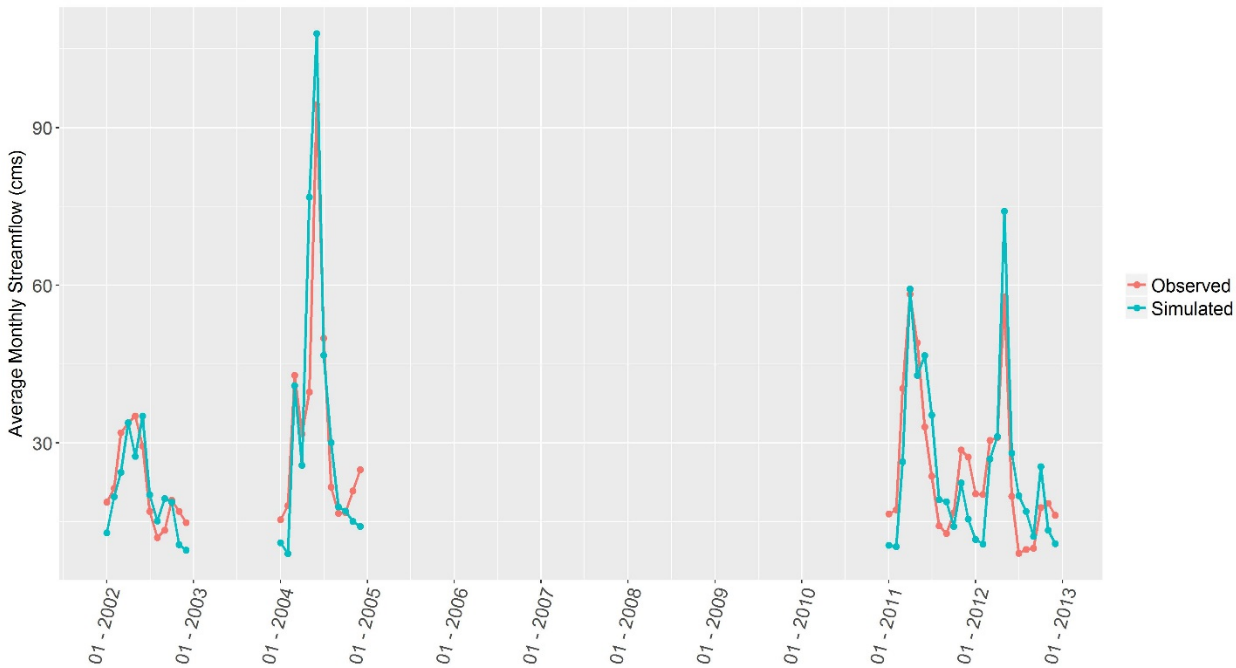

Figure D- 13. Monthly streamflow calibration hydrograph for USGS site 04073365 (Fox River at Princeton, WI).

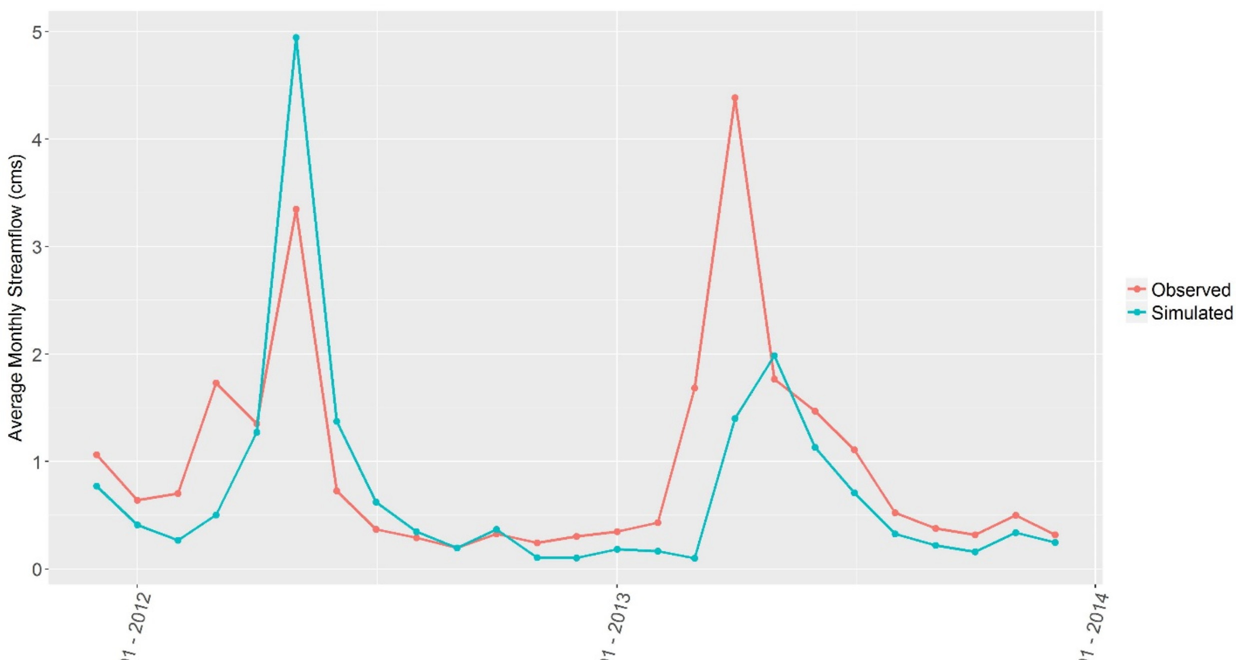

Figure D- 14. Monthly streamflow calibration hydrograph for USGS site 04073466 (Silver Creek at Spaulding Road near Green Lake, WI).

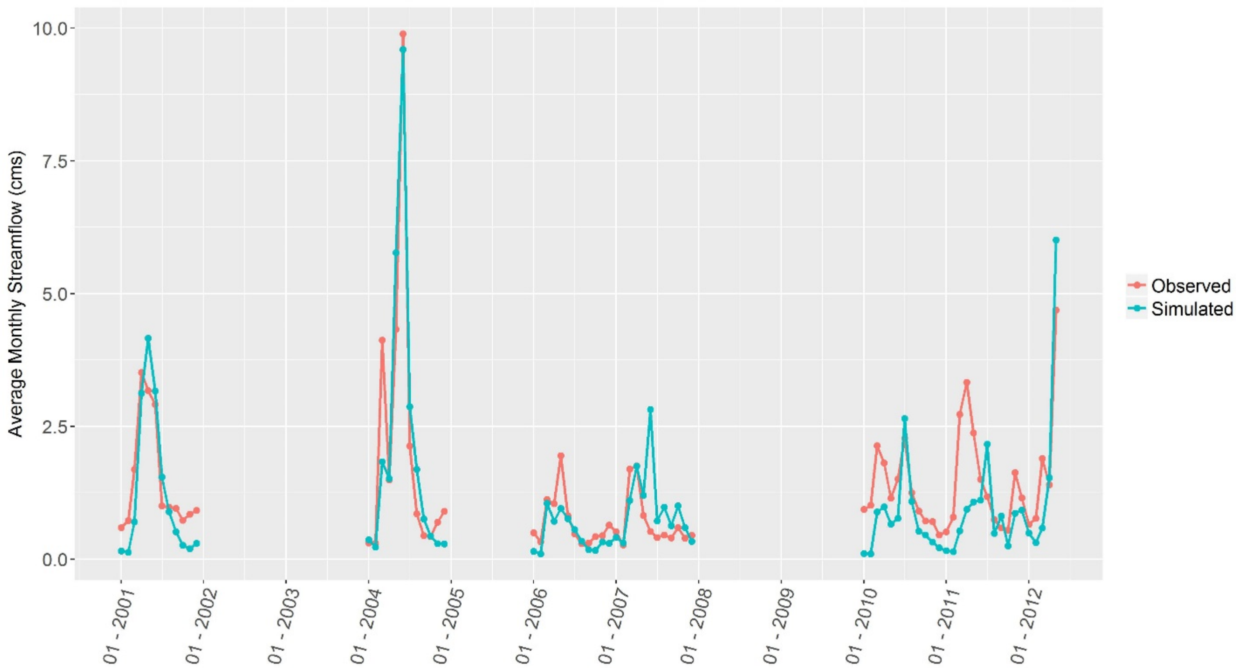

Figure D- 15. Monthly streamflow calibration hydrograph for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

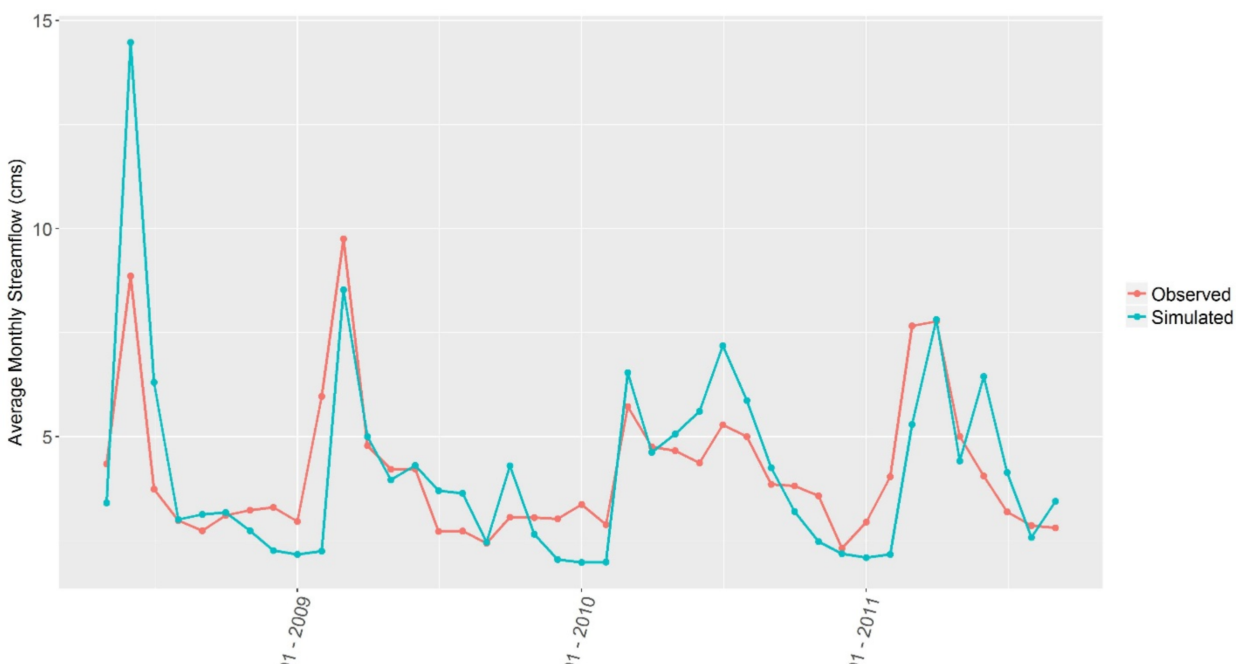

Figure D- 16. Monthly streamflow calibration hydrograph for USGS site 04072845 (Montello River near Montello, WI).

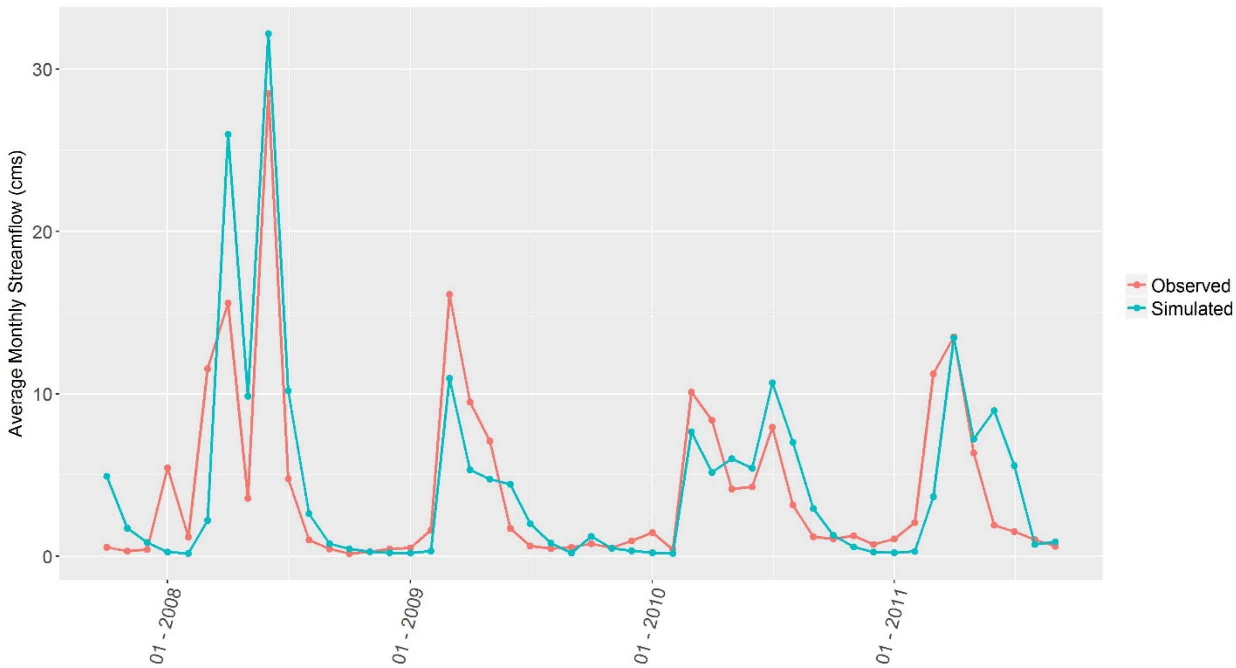

Figure D- 17. Monthly streamflow calibration hydrograph for USGS site 04083545 (Fond du Lac River @ W. Arndt St. at Fond du Lac, WI).

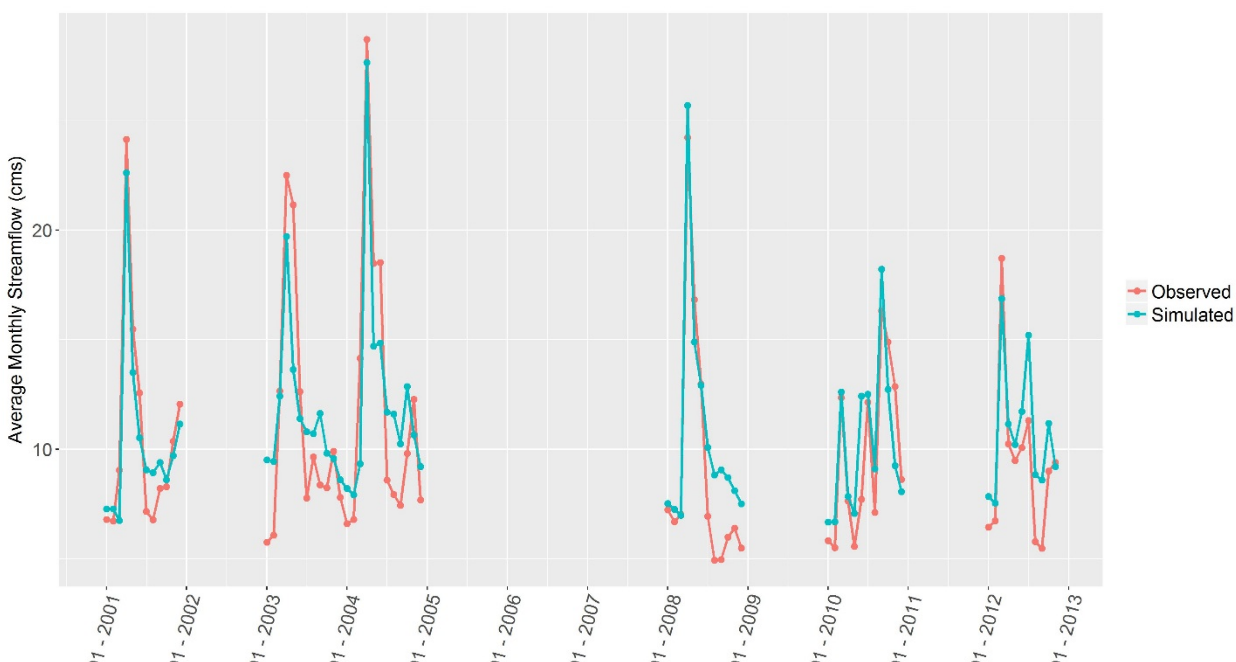

Figure D- 18. Monthly streamflow validation hydrograph for USGS site 04074950 (Wolf River at Langlade, WI).

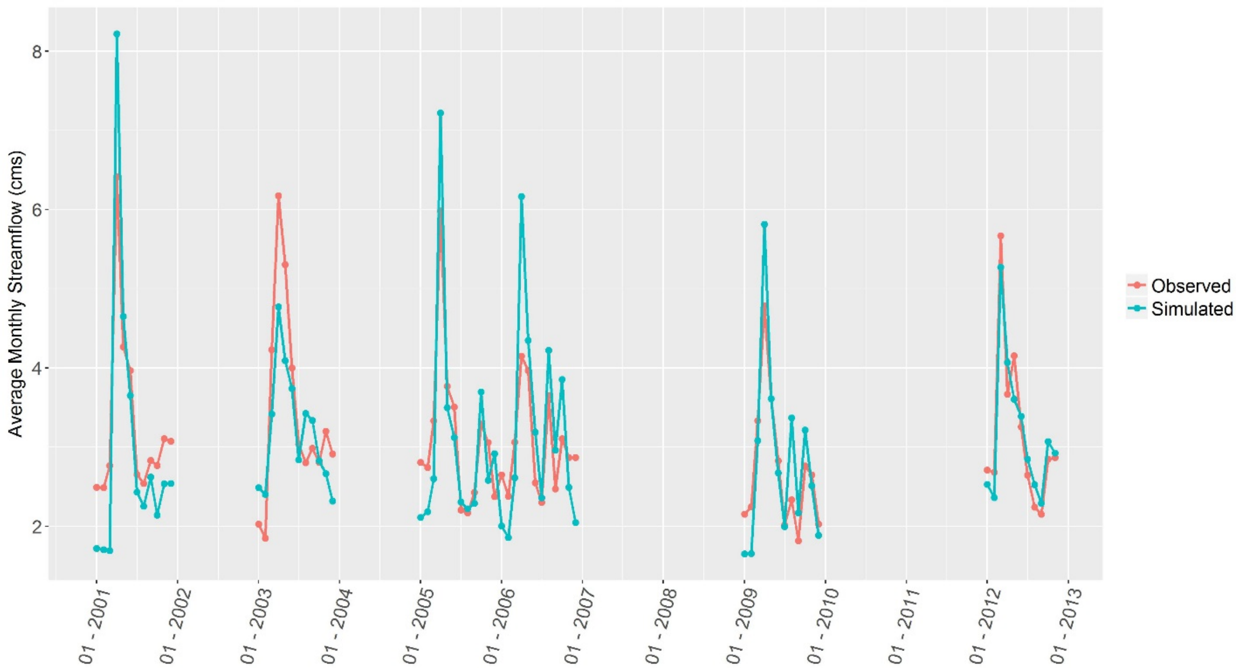

Figure D- 19. Monthly streamflow validation hydrograph for USGS site 04077630 (Red River at Morgan Road near Morgan, WI).

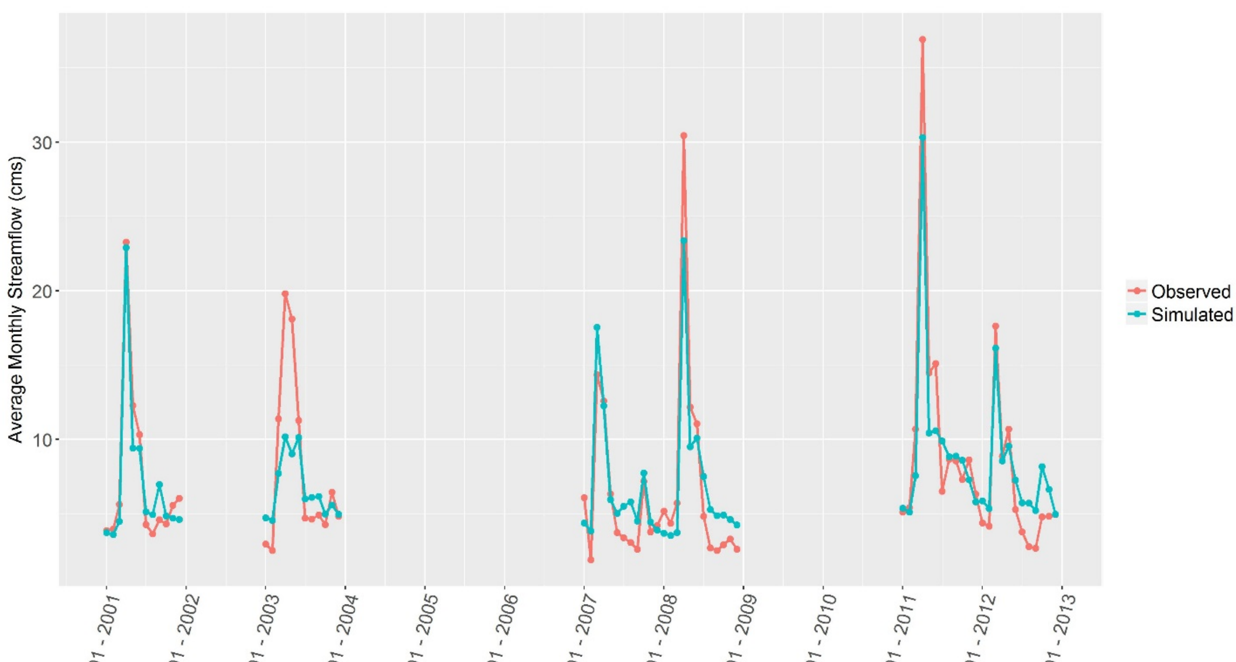

Figure D- 20. Monthly streamflow validation hydrograph for USGS site 04078500 (Embarrass River near Embarrass, WI).

Figure D- 21. Monthly streamflow validation hydrograph for USGS site 04079000 (Wolf River at New London, WI).

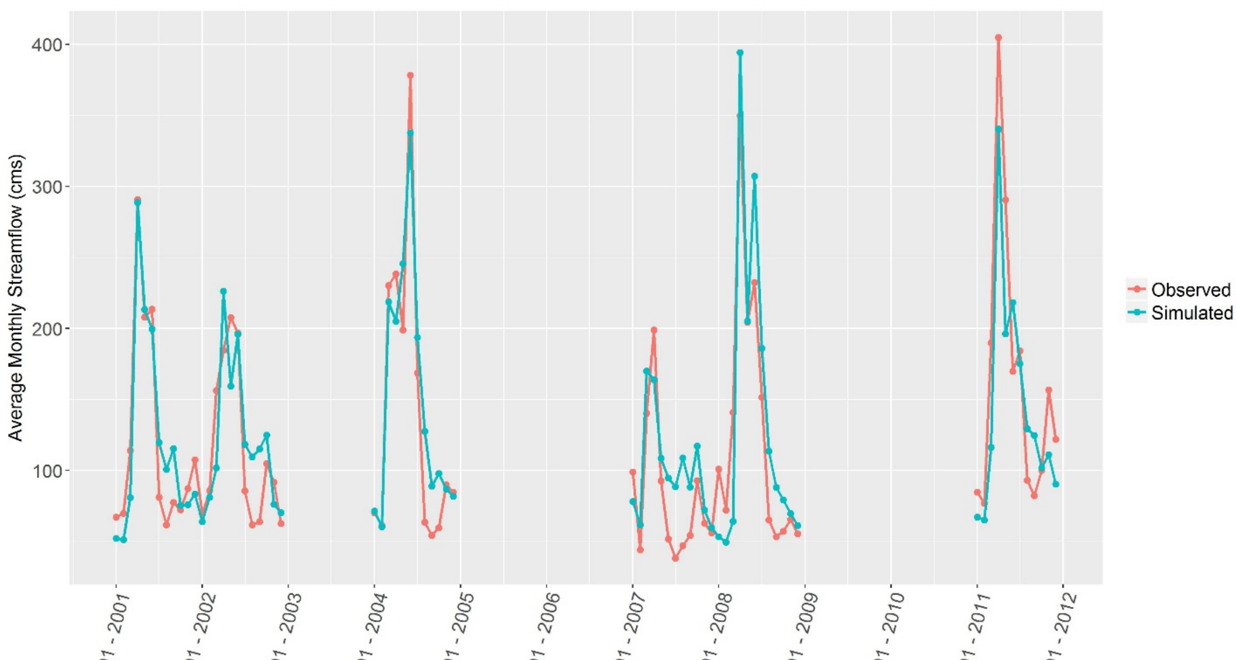

Figure D- 22. Monthly streamflow validation hydrograph for USGS site 04082400 (Fox River at Oshkosh, WI).

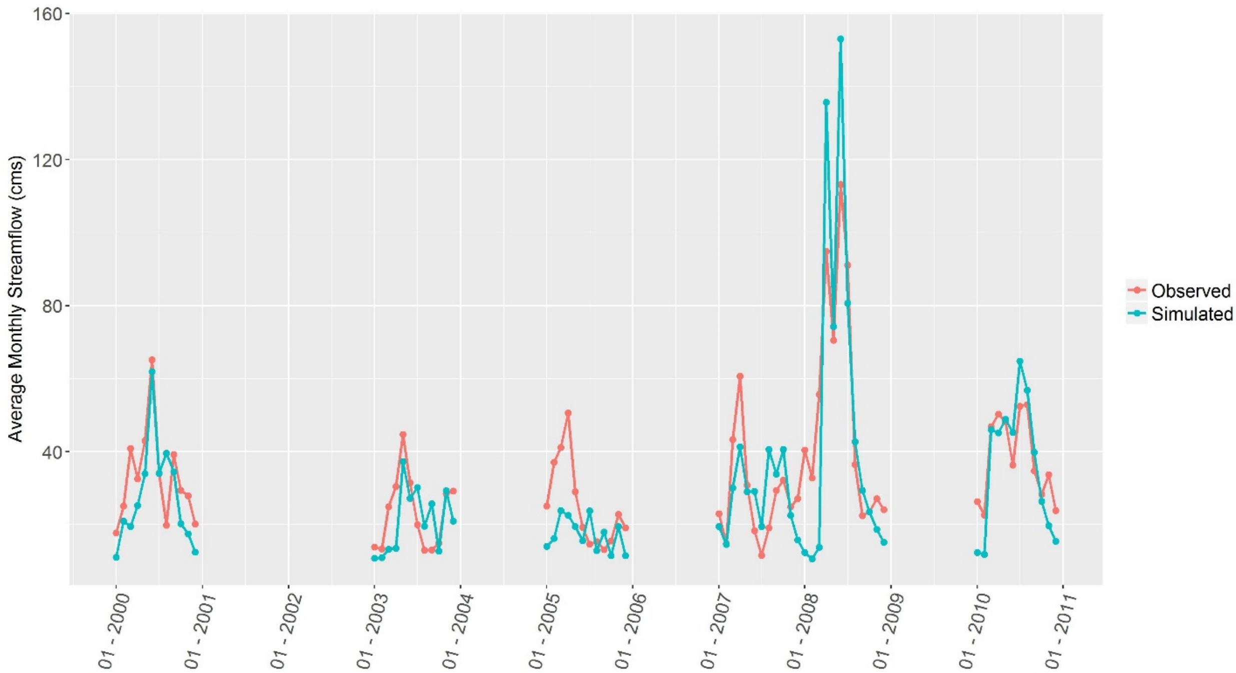

Figure D- 23. Monthly streamflow validation hydrograph for USGS site 04073500 (Fox River at Berlin, WI).

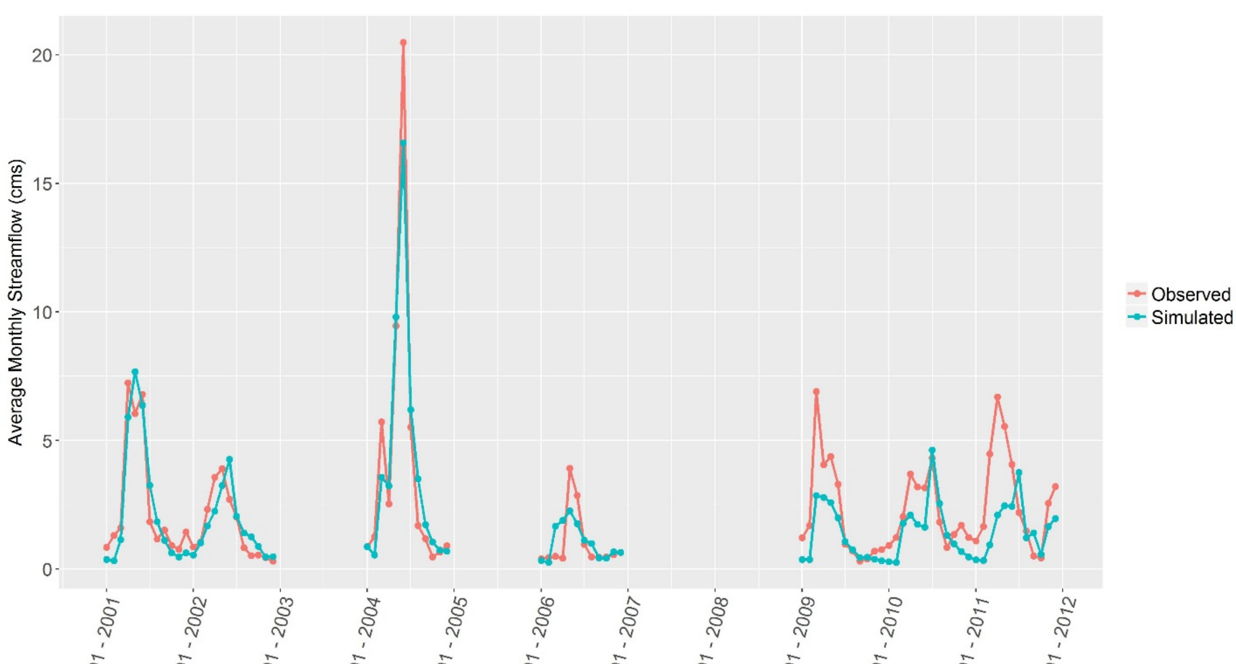

Figure D- 24. Monthly streamflow validation hydrograph for USGS site 04073473 (Puchyan River DS N. Lawson Drive near Green Lake, WI).

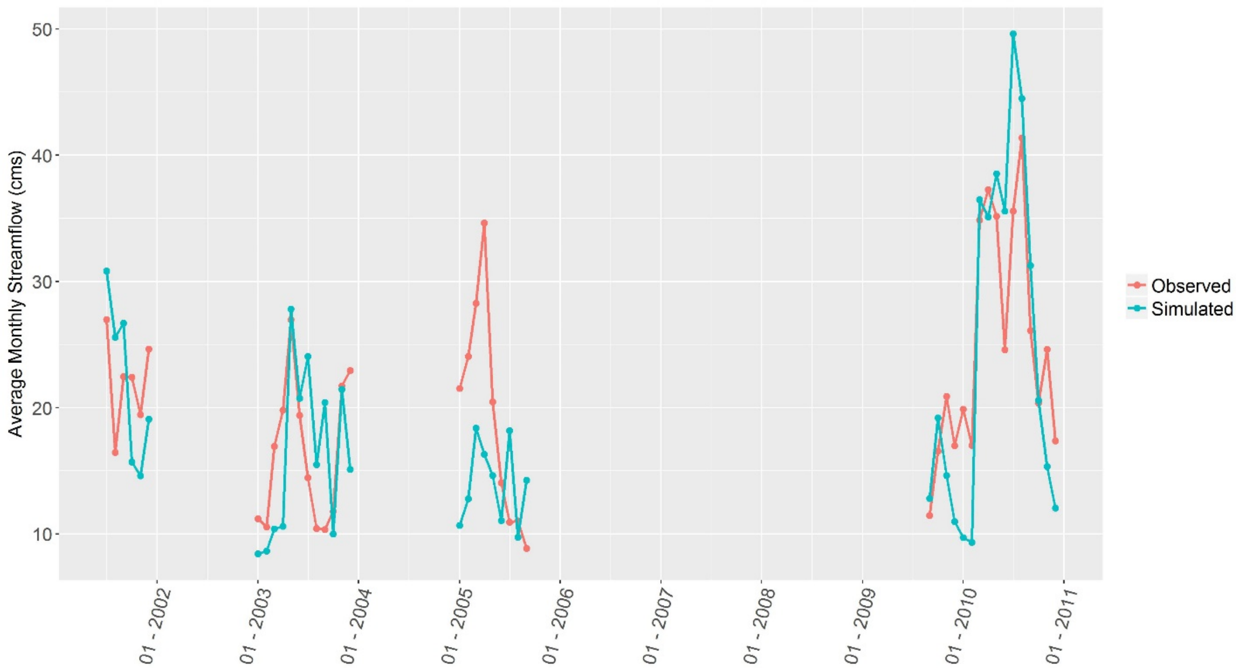

Figure D- 25. Monthly streamflow validation hydrograph for USGS site 04073365 (Fox River at Princeton, WI).

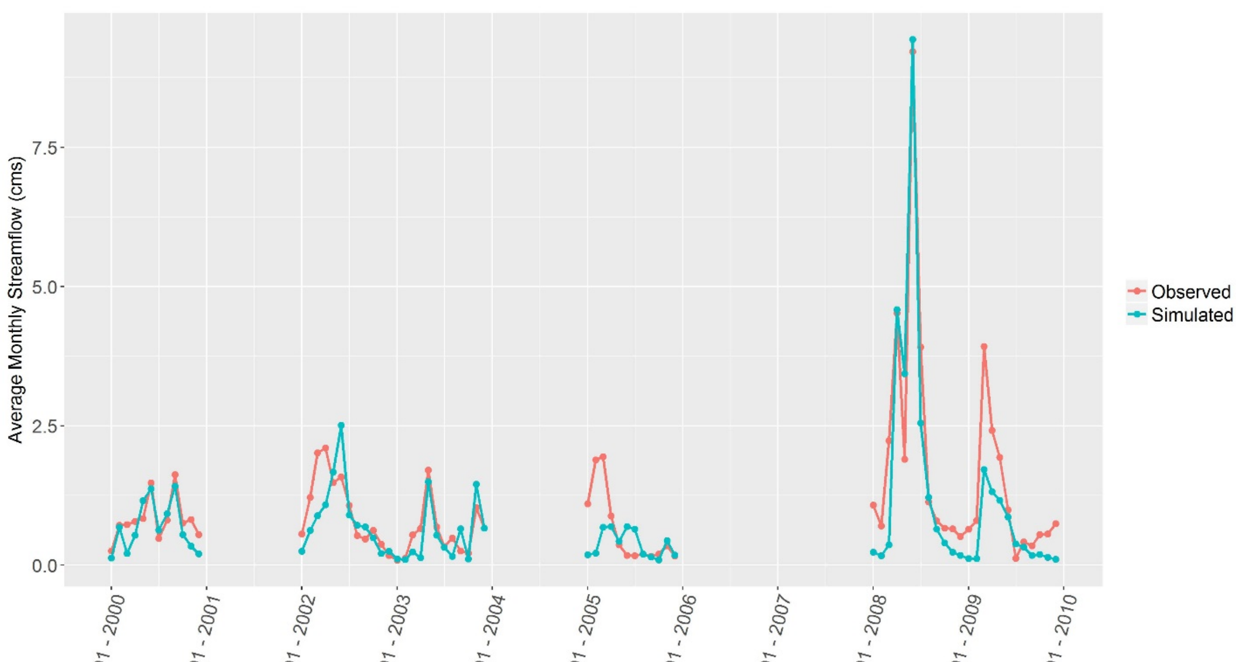

Figure D- 26. Monthly streamflow validation hydrograph for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

Appendix E. Sediment Calibration and Validation Time Series Plots

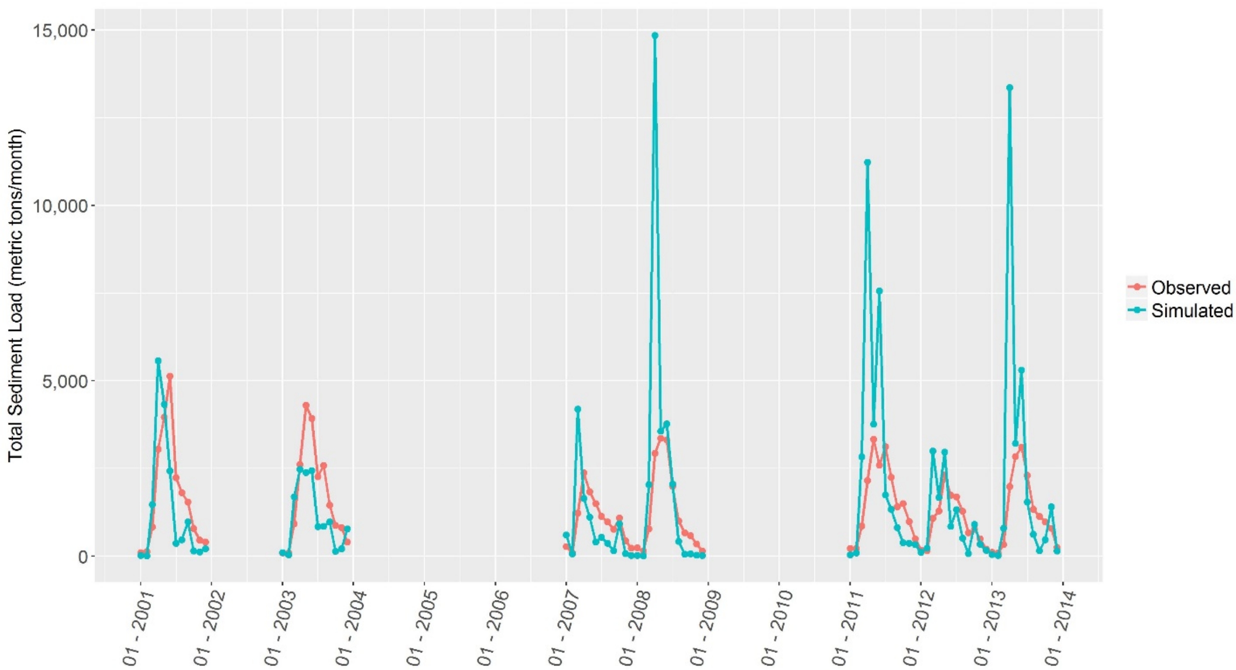

Figure E- 1. Monthly sediment calibration plot for USGS site 04079000 (Wolf River at New London, WI).

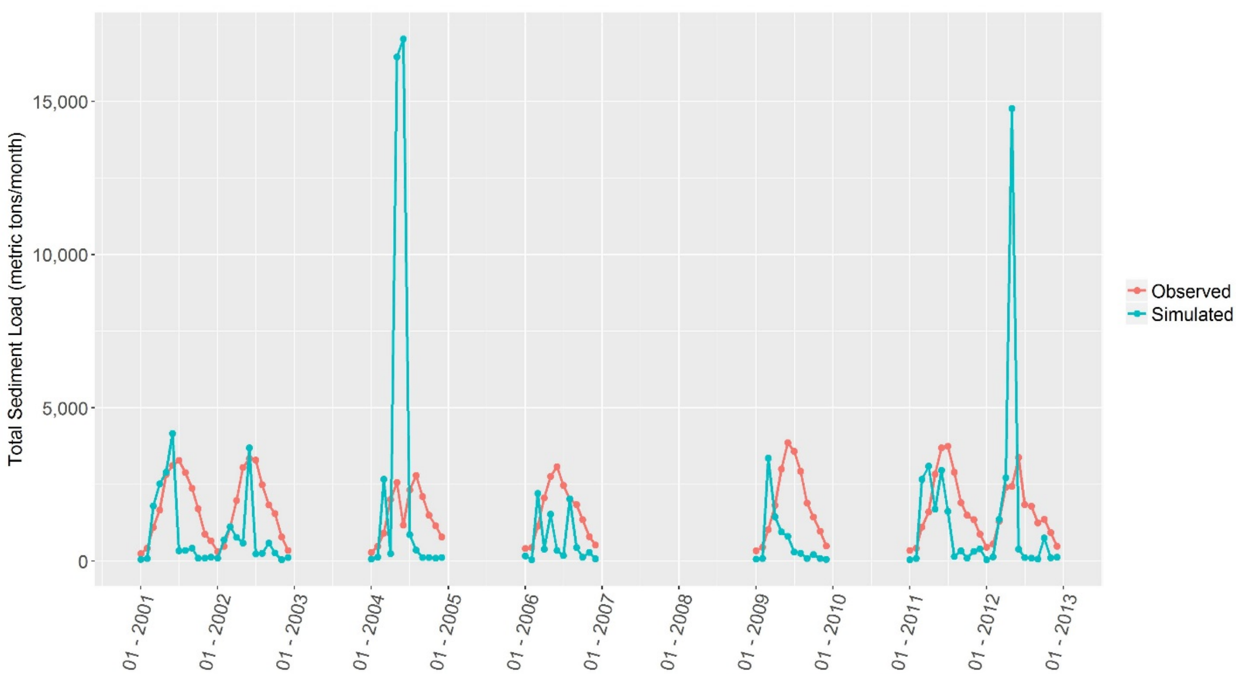

Figure E- 2. Monthly sediment calibration plot for USGS site 04073500 (Fox River at Berlin, WI).

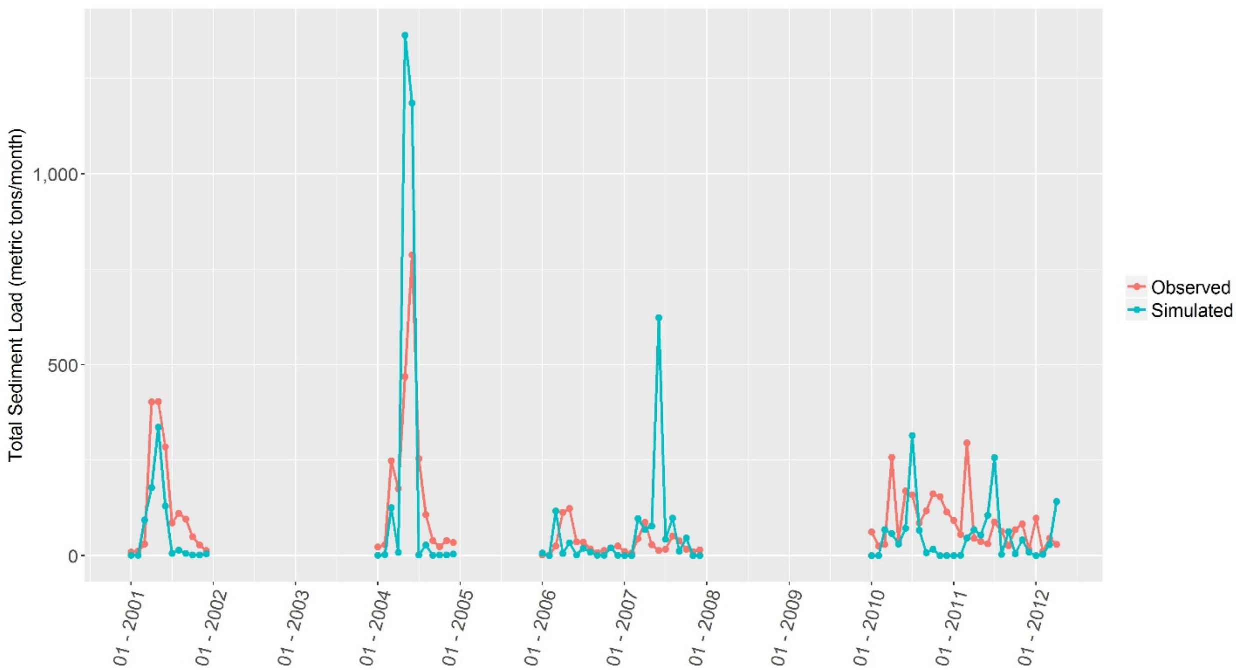

Figure E- 3. Monthly sediment calibration plot for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

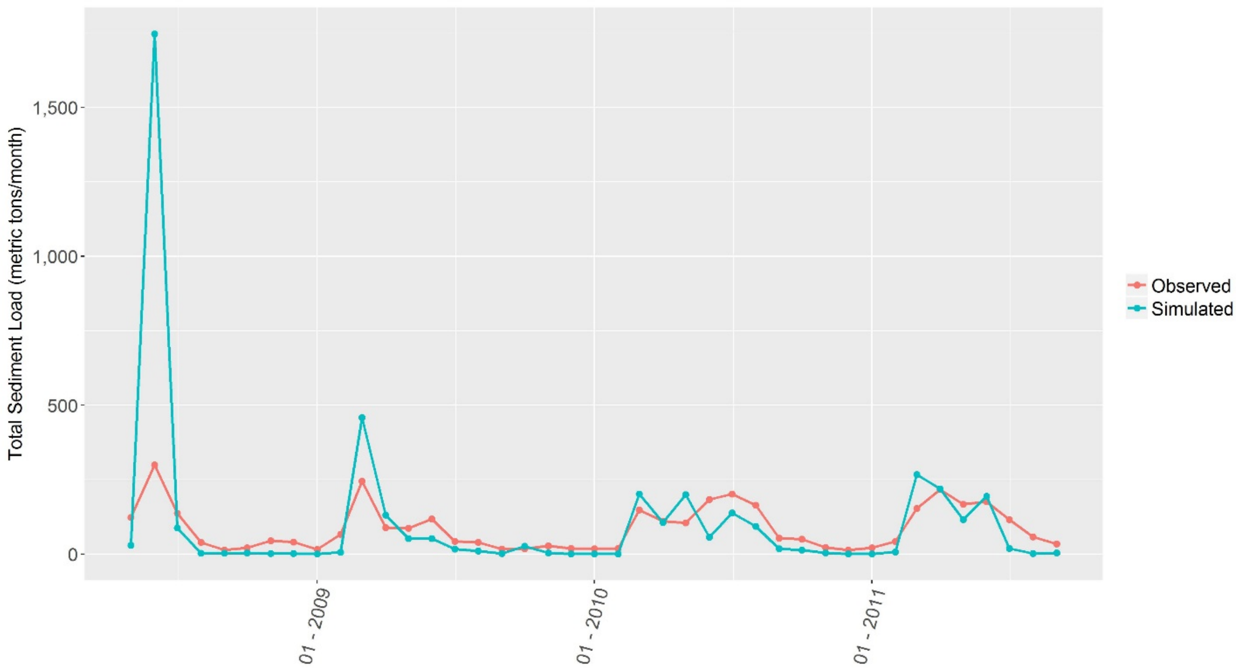

Figure E- 4. Monthly sediment calibration plot for USGS site 04072845 (Montello River near Montello, WI).

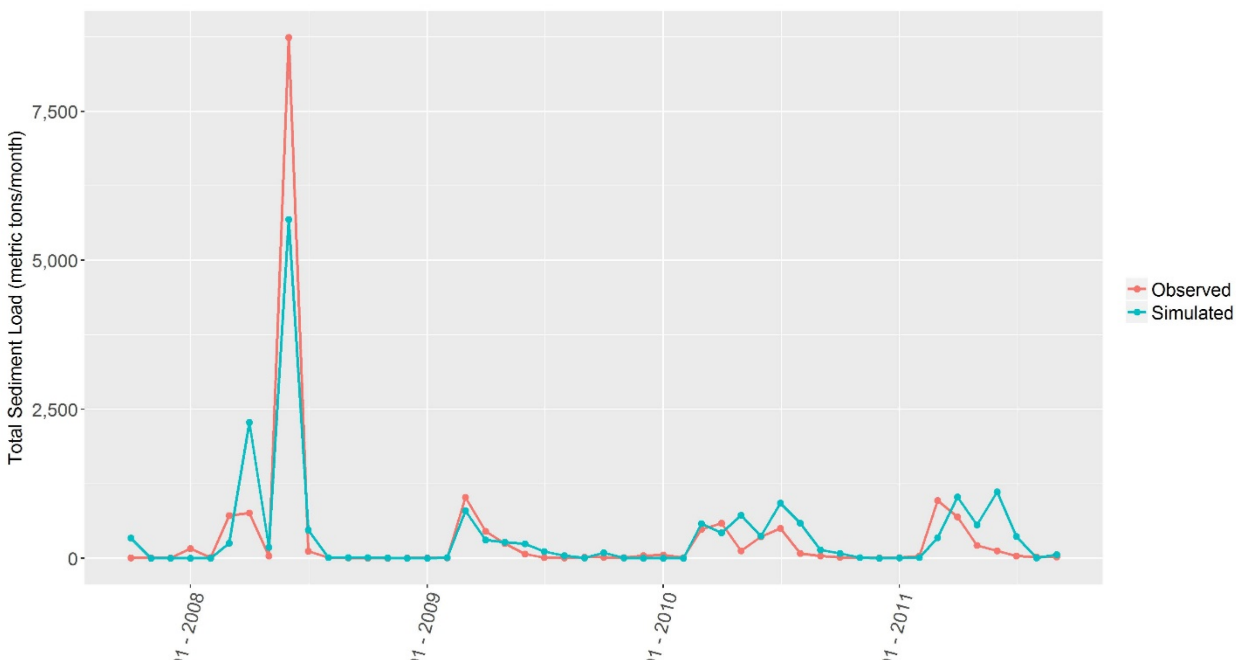

Figure E- 5. Monthly sediment calibration plot for USGS site 04083545 (Fond du Lac River @ W. Arndt St. At Fond du Lac, WI).

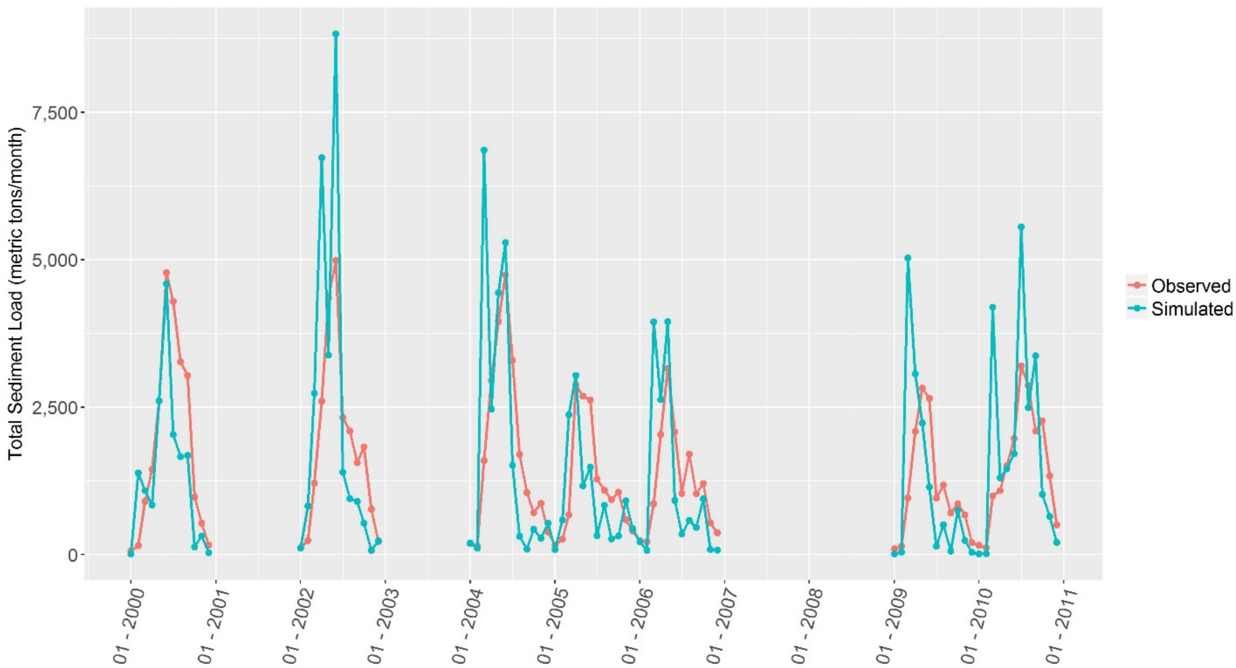

Figure E- 6. Monthly sediment validation plot for USGS site 04079000 (Wolf River at New London, WI).

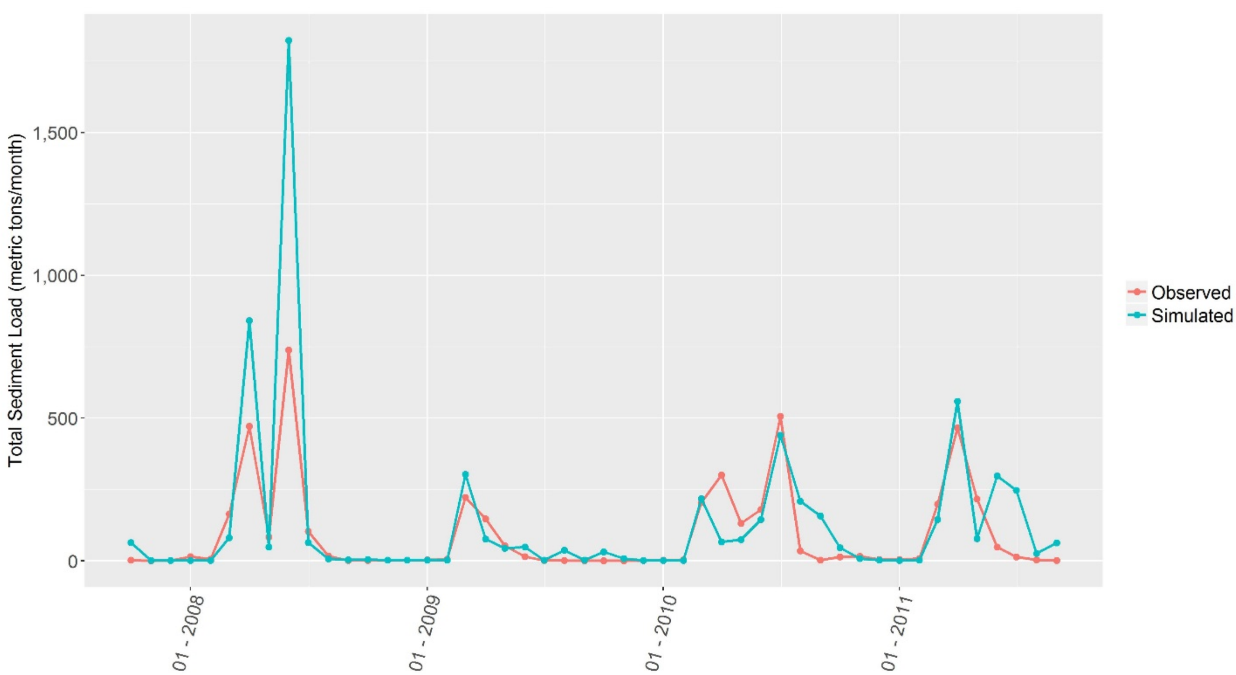

Figure E- 7. Monthly sediment validation plot for USGS site 04073970 (Waukau Creek near Omro, WI).

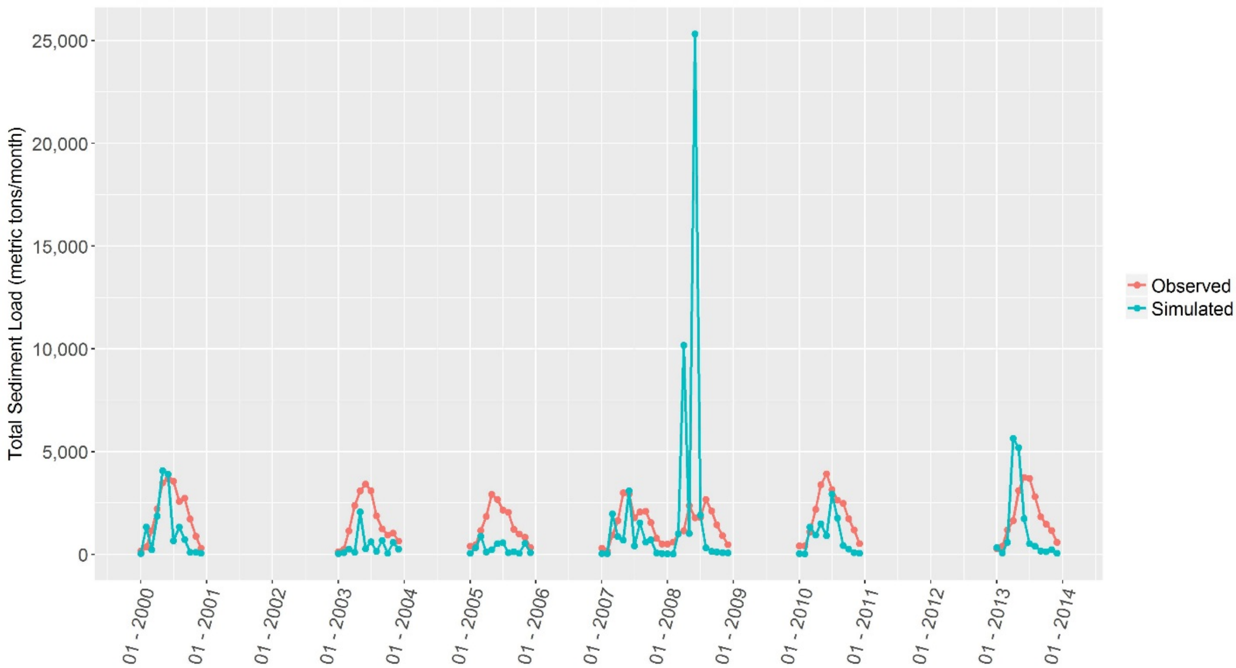

Figure E- 8. Monthly sediment validation plot for USGS site 04073500 (Fox River at Berlin, WI).

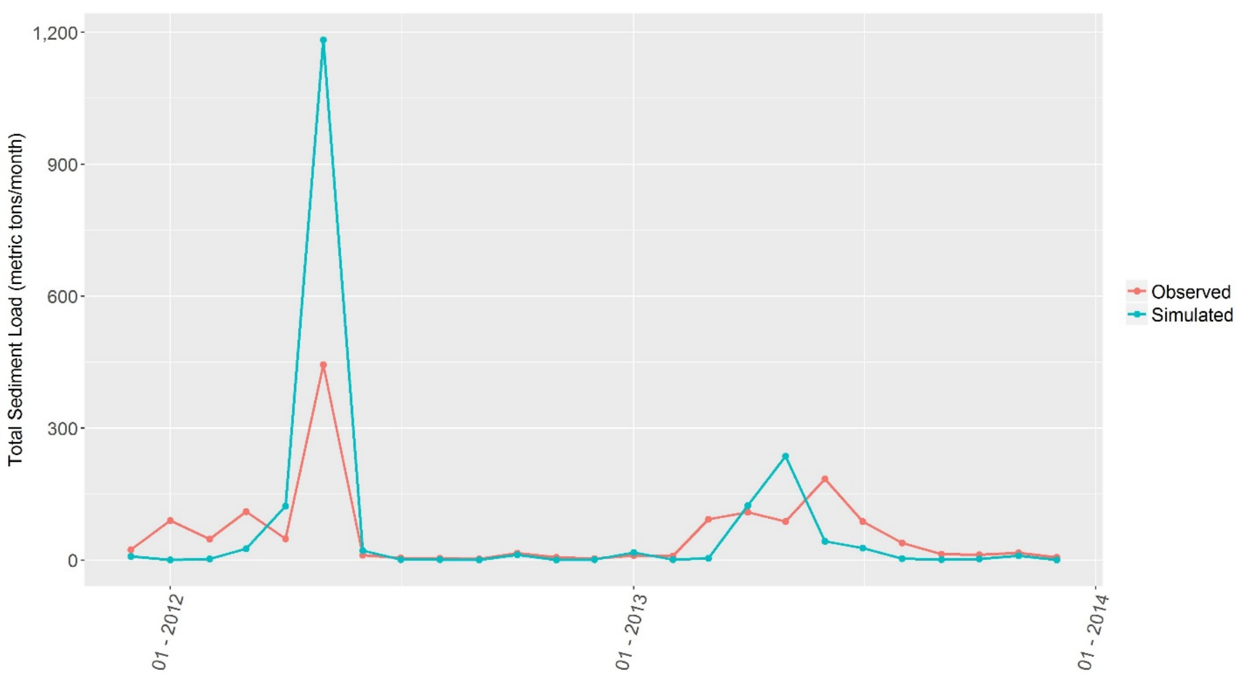

Figure E- 9. Monthly sediment validation plot for USGS site 04073466 (Silver Creek at Spaulding Road near Green Lake, WI).

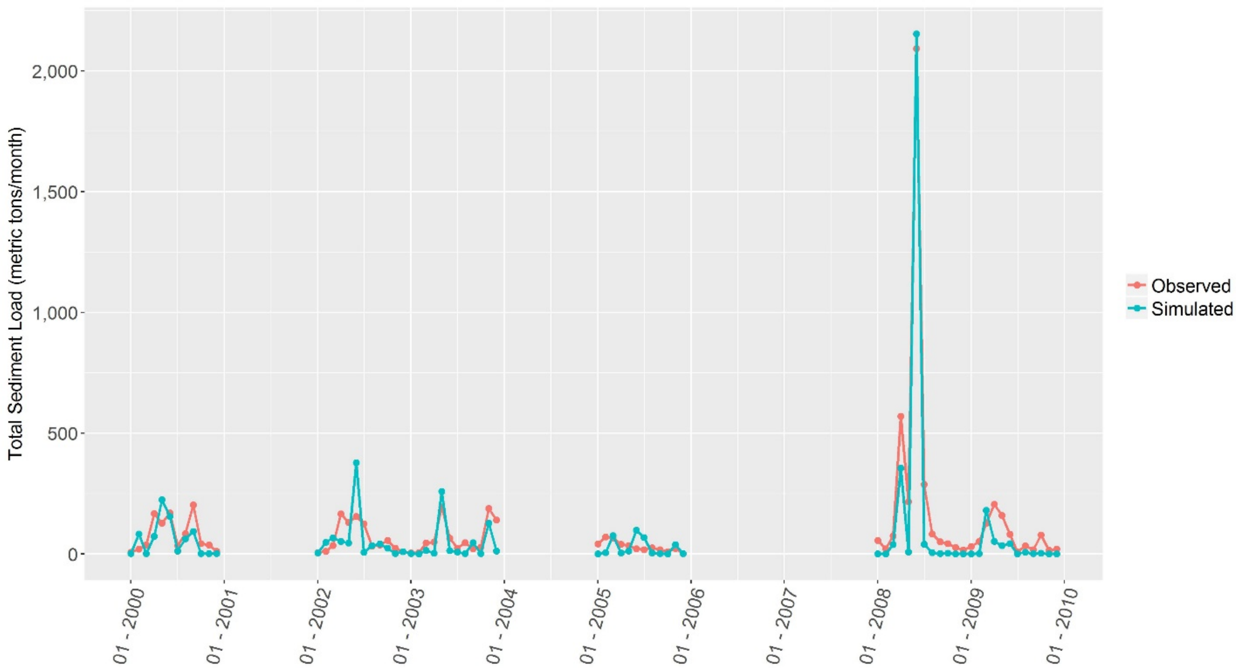

Figure E- 10. Monthly sediment validation plot for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

Appendix F. Phosphorus Calibration and Validation Time Series Plots

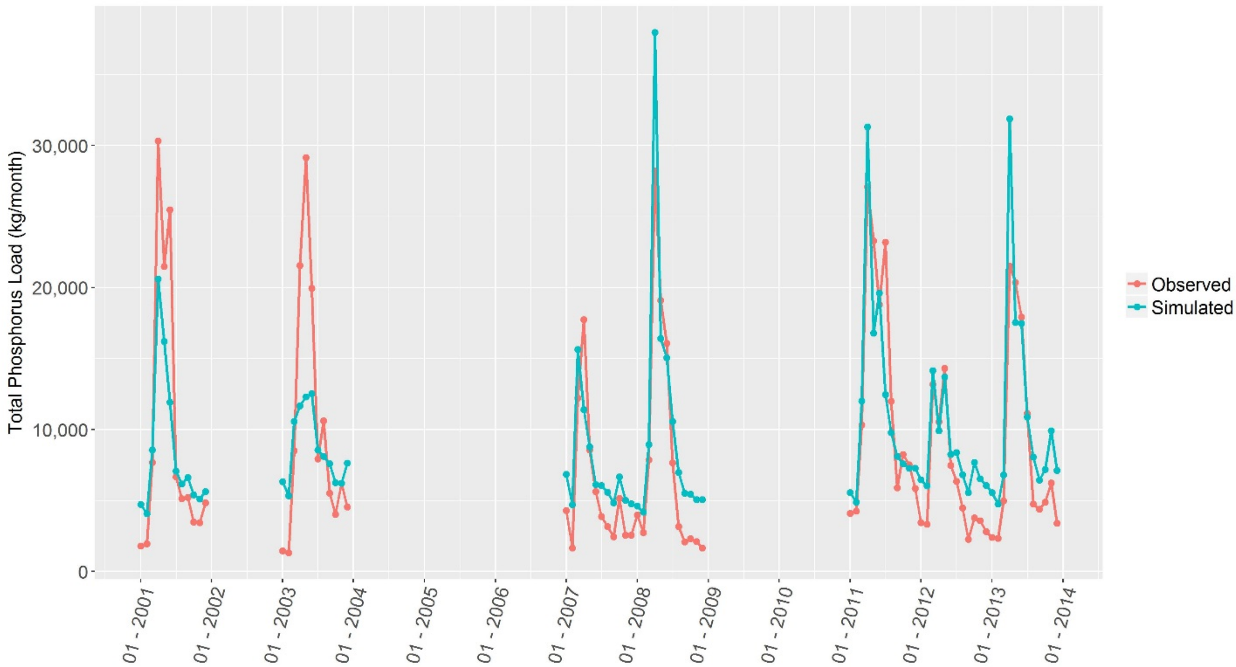

Figure F- 1. Monthly total phosphorus calibration plot for USGS site 04079000 (Wolf River at New London, WI).

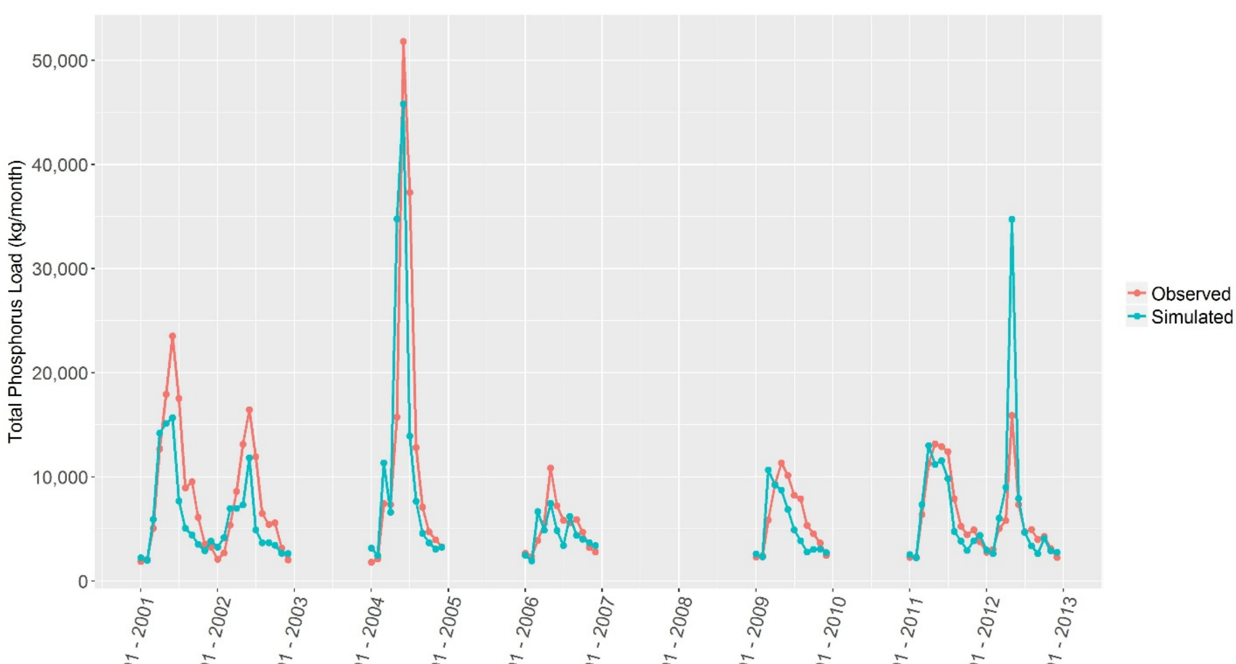

Figure F- 2. Monthly total phosphorus calibration plot for USGS site 04073500 (Fox River at Berlin, WI).

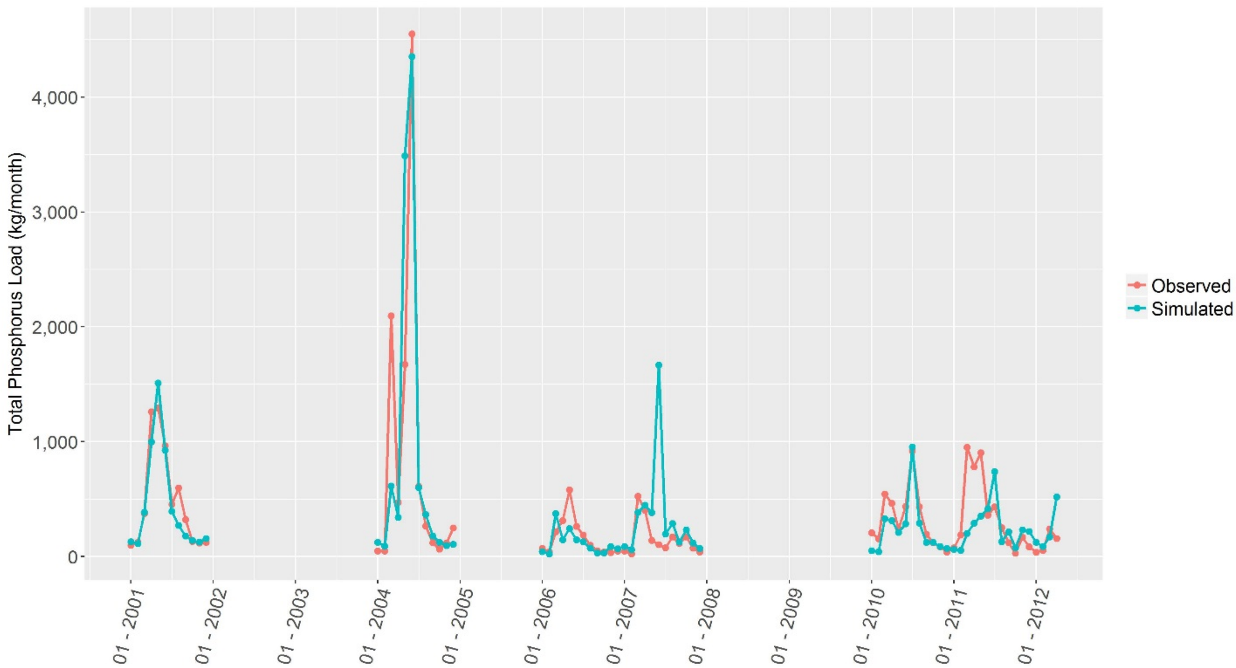

Figure F- 3. Monthly total phosphorus calibration plot for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

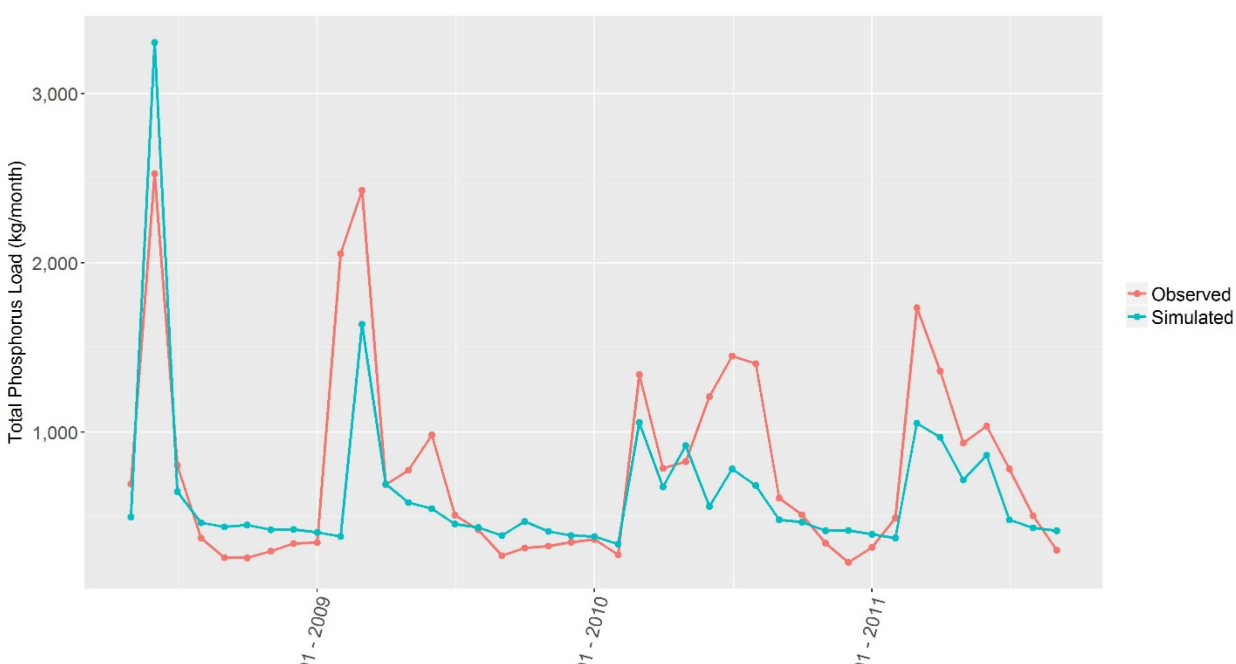

Figure F- 4. Monthly total phosphorus calibration plot for USGS site 04072845 (Montello River near Montello, WI).

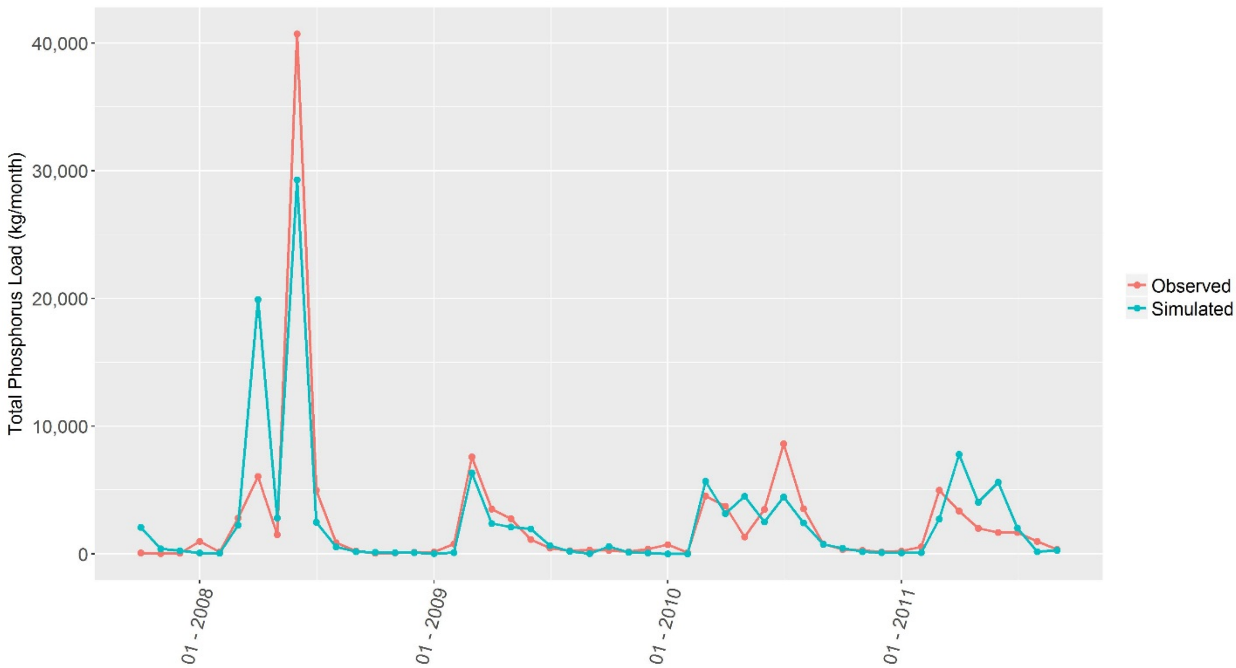

Figure F- 5. Monthly total phosphorus calibration plot for USGS site 04083545 (Fond du Lac River @ W. Arndt St. at Fond du Lac, WI).

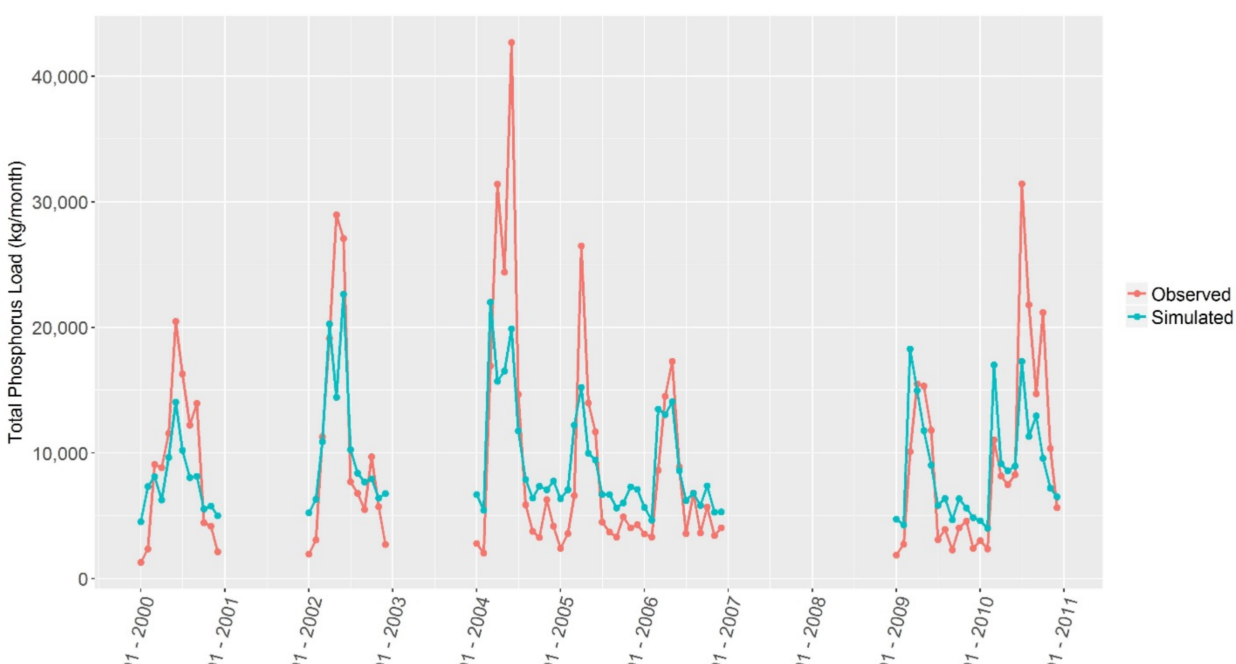

Figure F- 6.Monthly total phosphorus validation plot for USGS site 04079000 (Wolf River at New London, WI).

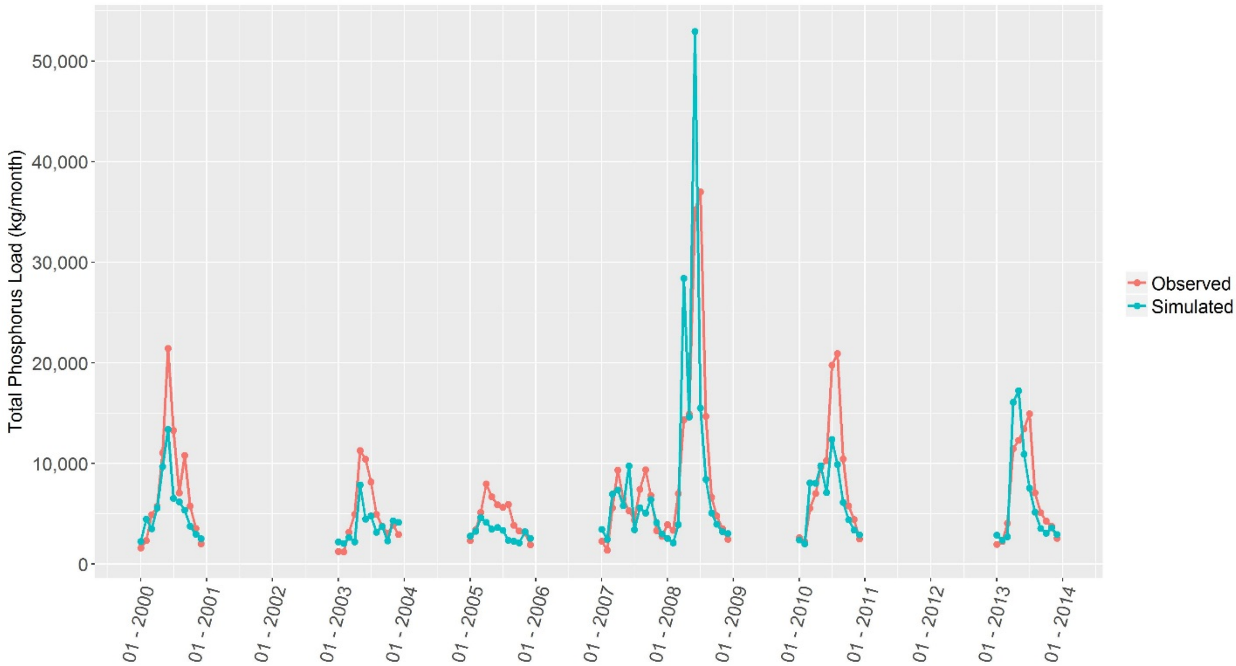

Figure F- 7. Monthly total phosphorus calibration plot for USGS site 04073500 (Fox River at Berlin, WI).

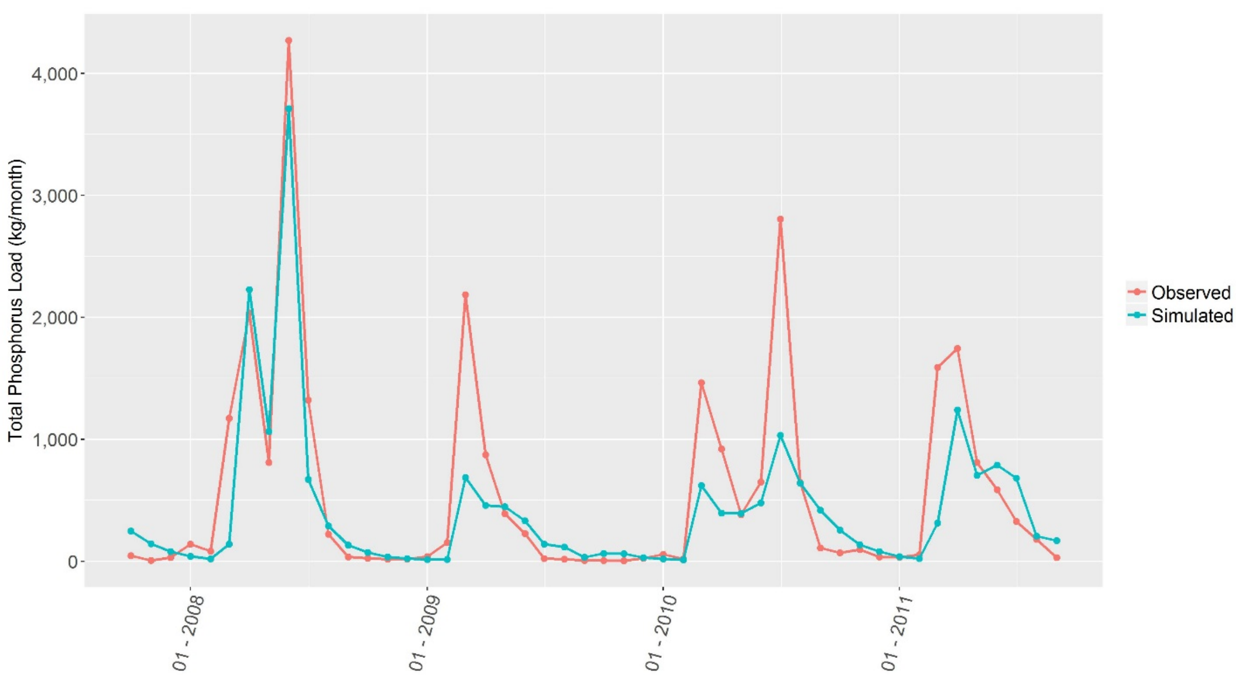

Figure F- 8. Monthly total phosphorus validation plot for USGS site 04073970 (Waukau Creek near Omro, WI).

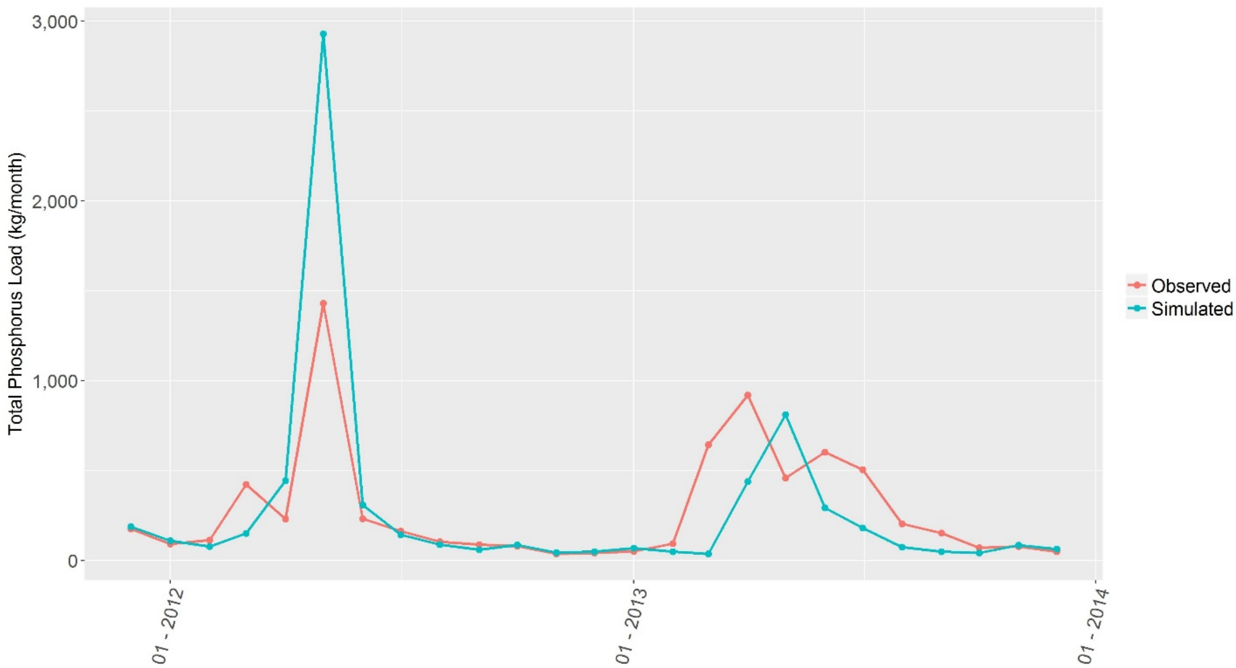

Figure F- 9. Monthly total phosphorus validation plot for USGS site 04073466 (Silver Creek at Spaulding Road near Green Lake, WI).

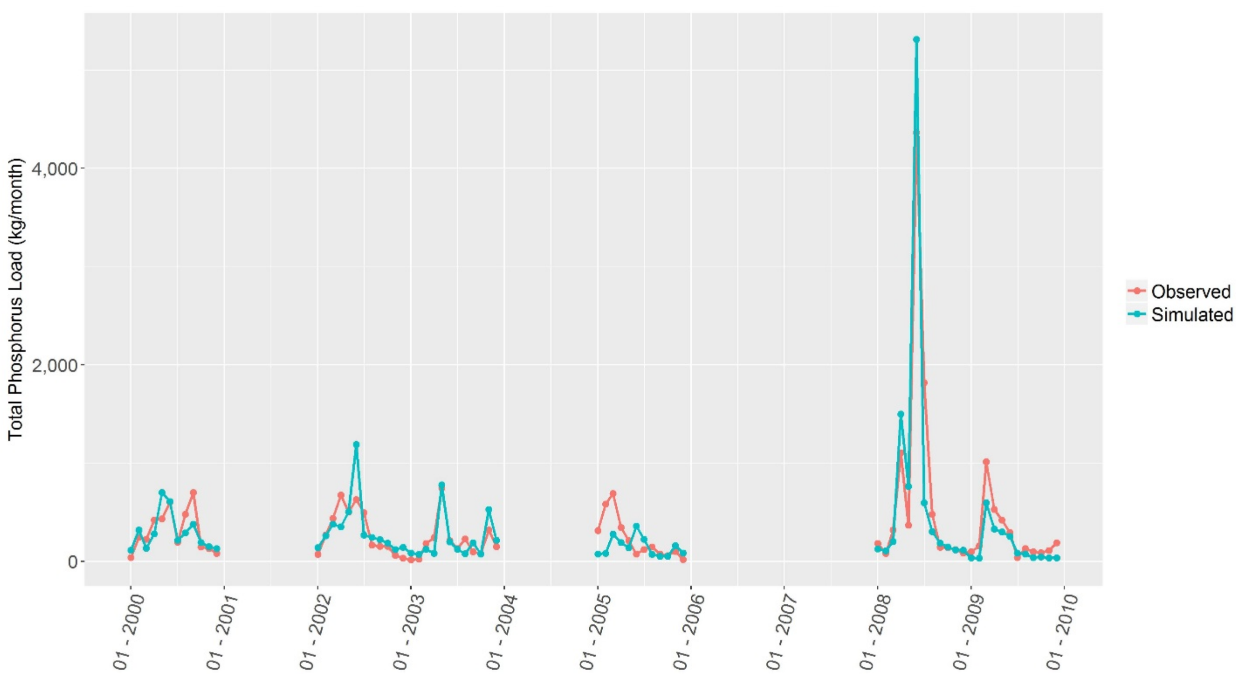

Figure F- 10. Monthly total phosphorus validation plot for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

Appendix G. Streamflow and Phosphorus Loads Prepared for Winnebago Pool Lake Modeling

This appendix contains streamflow and phosphorus loading data prepared from UFWB SWAT model output for the Winnebago Pool lake modeling effort completed by USGS. The methods used to prepare SWAT outputs for Winnebago Pool lake modeling are described in Section 7.2 of this report. Flows and phosphorus loads were summarized for nine distinct regions of the UFWB. The nine regions are mapped in Figure G- 1 and described below:

1. Wolf River at New London. Includes the watershed above the Wolf River at New London USGS station (04079000);
2. Wolf River into Lake Poygan. Includes the watershed above the Wolf River inlet of Lake Poygan;
3. Lake Poygan and Winneconne Watershed. Includes the entire watershed of Lake Poygan and Lake Winneconne, including the Wolf River, smaller tributaries, and direct drainage area;
4. Fox River at Berlin. Includes the watershed above the Fox River at Berlin USGS station (04073500);
5. Fox River into Lake Butte des Morts. Includes the watershed above the Fox River inlet of Lake Butte des Morts;
6. Lake Butte des Morts Direct Drainage Area. Includes the drainage area between the outlet of Lake Winneconne and the outlet of Lake Butte des Morts. This does not include the Fox River watershed upstream of Lake Butte des Morts;
7. Fox River Direct Drainage Area. Includes the drainage area between the outlet of Lake Butte des Morts and the Fox River inlet of Lake Winnebago;
8. Fond du Lac River at W. Arndt St. Includes the watershed above the Fond du Lac River at West Arndt Street USGS station (04083545);
9. Lake Winnebago Direct Drainage Area. Includes the drainage area between the Fox River inlet of Lake Winnebago to the Lake Winnebago outlet. This does not include the Fond du Lac River watershed.

Streamflow and phosphorus loading estimates for the nine regions described above are listed in Table G- 1 and Table G- 2. The data listed in Table G- 1 and Table G- 2 were delivered to the USGS to support the development and application of BATHTUB and Jensen lake models for evaluating phosphorus concentrations in the Winnebago Pool lakes under alternative phosphorus loading scenarios.

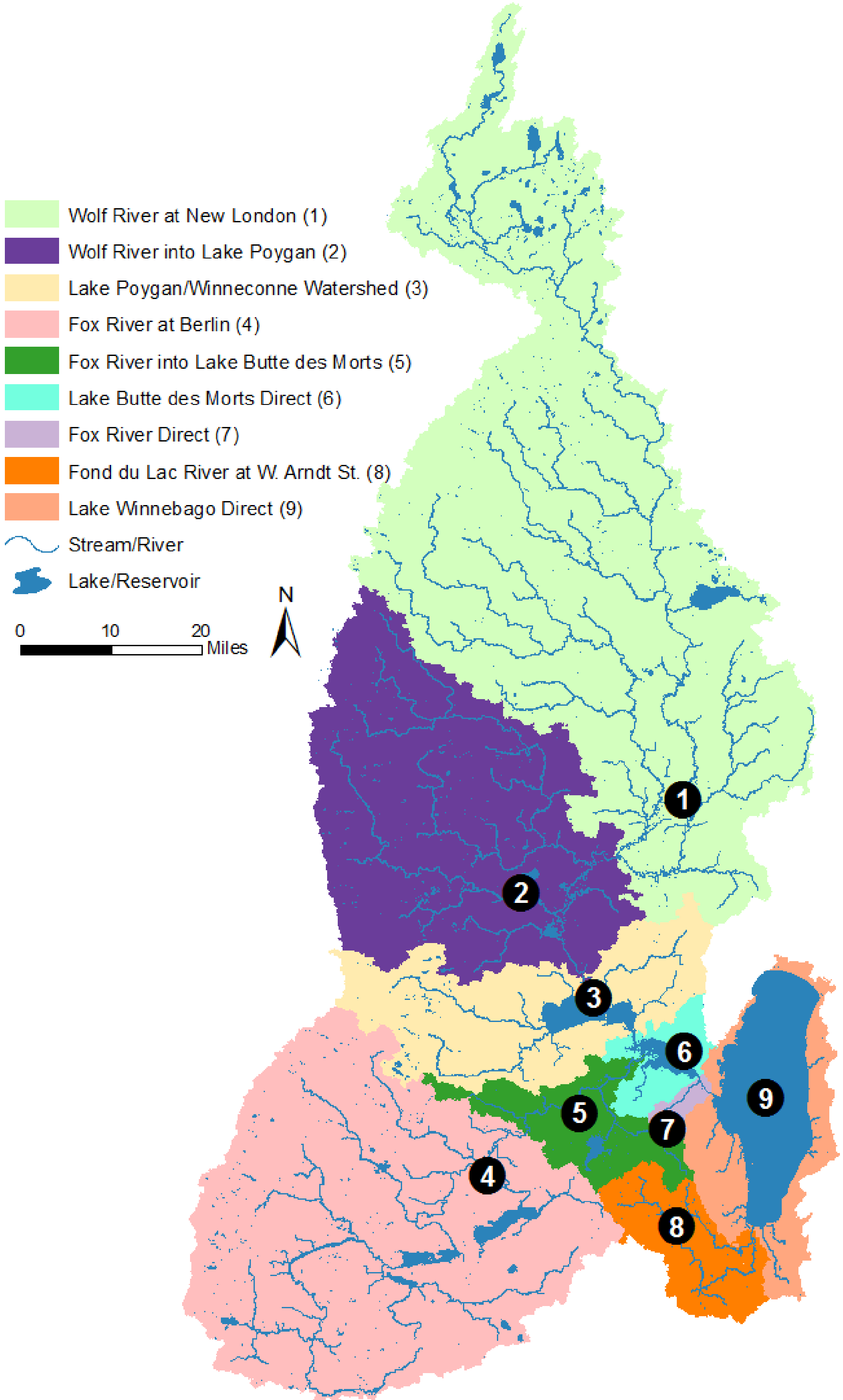

Figure G- 1. Nine regions of the UFWB used to summarize SWAT model estimates of streamflow and phosphorus loading for Winnebago Pool lake modeling.

Table G- 1. SWAT model estimates of streamflow (in cubic meters per second) prepared for Winnebago Pool lake modeling.

Year	Month	Wolf River at New London	Wolf River into Lake Poygan	Lake Poygan and Winneconne Watershed	Fox River at Berlin	Fox River into Lake Butte des Morts	Lake Butte des Morts Direct Drainage Area	Fox River Direct Drainage Area	Fond du Lac River at W. Arndt St	Lake Winnebago Direct Drainage Area
2008	10	21.10	30.46	36.11	22.60	25.18	1.23	0.83	0.47	3.53
2008	11	23.10	33.35	39.54	26.12	29.11	1.04	0.78	0.28	2.96
2008	12	19.98	28.85	34.21	23.22	25.88	0.95	0.74	0.22	2.74
2009	1	21.97	31.98	36.99	20.36	21.97	0.86	0.64	0.20	2.48
2009	2	27.58	40.14	46.43	21.52	23.21	0.88	0.69	0.31	2.46
2009	3	68.20	99.27	114.82	42.24	45.58	2.37	1.80	10.95	5.05
2009	4	92.33	134.38	155.43	57.78	62.34	2.09	1.10	5.32	6.08
2009	5	76.40	111.20	128.62	49.41	53.32	2.39	1.10	4.75	7.25
2009	6	55.27	80.45	93.05	31.80	34.31	2.26	1.20	4.45	6.45
2009	7	19.99	29.09	33.65	19.79	21.36	1.70	0.87	2.01	5.13
2009	8	24.33	35.41	40.96	18.64	20.12	1.27	0.80	0.81	3.79
2009	9	19.36	28.18	32.59	16.05	17.31	1.02	0.72	0.21	2.95
2009	10	32.94	47.94	55.45	20.10	21.69	0.93	0.70	1.22	2.68
2009	11	41.68	60.67	70.17	24.69	26.64	1.02	0.71	0.50	2.77
2009	12	27.96	40.70	47.08	21.05	22.71	1.00	0.68	0.33	2.71
2010	1	27.69	40.95	47.92	25.04	27.22	0.87	0.71	0.22	2.38
2010	2	22.54	33.34	39.01	21.53	23.40	0.81	0.72	0.17	2.22
2010	3	69.06	102.15	119.52	44.45	48.32	1.51	1.20	7.67	3.63
2010	4	47.05	69.60	81.43	47.68	51.83	1.97	1.20	5.16	4.84
2010	5	38.07	56.31	65.88	45.77	49.76	1.88	1.10	6.02	5.48
2010	6	37.51	55.48	64.91	34.45	37.45	2.45	1.50	5.43	6.07
2010	7	87.97	130.12	152.25	49.76	54.09	4.89	3.20	10.69	9.71
2010	8	67.31	99.55	116.48	50.24	54.61	3.00	1.30	7.02	8.68
2010	9	57.35	84.83	99.25	33.02	35.89	2.20	1.10	2.94	6.36
2010	10	83.72	123.83	144.89	26.87	29.21	1.69	1.00	1.31	4.89
2010	11	67.29	99.53	116.46	32.02	34.81	1.59	0.86	0.58	4.36
2010	12	47.13	69.71	81.57	22.63	24.60	1.34	0.81	0.25	3.68
2011	1	32.23	46.43	54.16	19.76	21.59	1.14	0.79	0.22	3.03
2011	2	32.67	47.06	54.89	20.47	22.37	1.06	0.81	0.30	2.78
2011	3	60.07	86.53	100.94	48.46	52.95	1.66	1.30	3.67	3.63
2011	4	166.81	240.30	280.29	73.82	80.67	2.96	1.80	13.47	7.03
2011	5	98.23	141.51	165.06	60.39	65.99	3.53	1.40	7.21	9.59
2011	6	63.94	92.10	107.43	41.35	45.18	2.67	1.30	8.97	7.93
2011	7	68.35	98.46	114.84	30.52	33.35	1.95	1.10	5.59	6.31
2011	8	40.94	58.97	68.79	18.37	20.07	1.37	0.80	0.73	3.97

Year	Month	Wolf River at New London	Wolf River into Lake Poygan	Lake Poygan and Winneconne Watershed	Fox River at Berlin	Fox River into Lake Butte des Morts	Lake Butte des Morts Direct Drainage Area	Fox River Direct Drainage Area	Fond du Lac River at W. Arndt St	Lake Winnebago Direct Drainage Area
2011	9	29.84	42.99	50.14	15.36	16.78	1.15	0.80	0.89	3.41
2011	10	42.80	61.65	71.91	18.81	20.55	1.03	0.80	0.35	2.95
2011	11	50.47	72.71	84.81	33.62	36.73	1.49	1.00	1.95	3.85
2011	12	44.97	64.78	75.56	32.36	35.36	1.73	1.03	2.23	4.61
2012	1	36.06	52.02	60.72	28.86	32.02	1.28	0.77	0.50	3.54
2012	2	33.45	48.26	56.33	31.96	35.46	1.10	0.77	0.80	2.88
2012	3	101.28	146.10	170.56	46.21	51.27	1.98	1.30	4.07	4.03
2012	4	70.61	101.86	118.91	44.65	49.55	2.59	1.30	5.93	6.78
2012	5	78.85	113.74	132.78	91.45	101.47	5.00	2.80	18.55	12.65
2012	6	40.46	58.37	68.14	28.62	31.76	2.73	1.10	3.17	8.04
2012	7	33.68	48.59	56.72	12.06	13.38	1.87	1.00	0.62	5.18
2012	8	27.39	39.51	46.13	12.73	14.13	1.34	0.81	0.29	3.73
2012	9	20.09	28.98	33.83	12.79	14.19	1.08	0.71	0.16	2.97
2012	10	32.69	47.16	55.05	21.66	24.03	1.18	0.90	2.03	3.07
2012	11	37.82	54.56	63.70	24.12	26.76	1.04	0.73	0.42	2.97
2012	12	33.19	47.88	55.89	22.36	24.81	1.01	0.70	0.68	2.92
2013	1	27.23	38.04	43.87	18.21	19.82	1.08	0.85	1.27	2.85
2013	2	25.78	36.02	41.54	22.10	24.05	0.98	0.81	0.18	2.56
2013	3	38.64	53.99	62.26	33.43	36.37	0.92	0.78	0.74	2.37
2013	4	153.62	214.65	247.53	87.42	95.11	4.26	2.80	16.65	8.45
2013	5	110.17	153.94	177.52	64.83	70.54	4.57	2.00	11.80	11.90
2013	6	80.23	112.10	129.28	49.70	54.08	3.32	1.50	8.55	9.25
2013	7	48.60	67.91	78.31	41.36	45.00	2.27	1.10	4.07	6.63
2013	8	27.71	38.71	44.64	17.81	19.37	1.57	0.90	2.20	4.50
2013	9	30.07	42.02	48.45	15.70	17.08	1.27	0.86	0.71	3.52
2013	10	38.15	53.30	61.46	18.98	20.65	1.23	0.86	0.64	3.36
2013	11	55.27	77.22	89.05	26.90	29.27	1.81	1.10	1.31	4.29
2013	12	36.99	51.68	59.60	22.46	24.44	1.62	0.90	0.49	4.29

Table G- 2. SWAT model estimates of phosphorus loading (in kilograms per month) prepared for Winnebago Pool lake modeling.

Year	Month	Wolf River at New London	Wolf River into Lake Poygan	Lake Poygan and Winneconne Watershed	Fox River at Berlin	Fox River into Lake Butte des Morts	Lake Butte des Morts Direct Drainage Area	Fox River Direct Drainage Area	Fond du Lac River at W. Arndt St	Lake Winnebago Direct Drainage Area
2008	10	3,003.64	4,365.63	4,983.91	4,644.53	5,176.17	197.00	840.00	120.30	1,029.70
2008	11	2,727.84	3,964.76	4,526.27	3,413.23	3,803.92	163.00	810.00	99.85	930.15
2008	12	2,142.67	3,114.26	3,555.31	2,403.07	2,678.14	163.00	830.00	93.06	956.94
2009	1	2,338.58	3,363.96	3,802.13	1,900.11	2,072.74	151.00	740.00	37.44	782.56
2009	2	3,426.80	4,929.34	5,571.40	1,992.24	2,173.24	133.00	679.00	90.70	689.30
2009	3	12,597.17	18,120.60	20,480.85	4,848.79	5,289.33	470.00	930.00	6,327.00	1,283.00
2009	4	19,322.22	27,794.35	31,414.63	7,668.84	8,365.58	340.00	800.00	2,373.00	1,347.00
2009	5	19,087.65	27,456.93	31,033.26	9,390.68	10,243.86	419.00	830.00	2,102.00	1,608.00
2009	6	14,731.04	21,190.10	23,950.17	8,379.17	9,140.45	380.00	800.00	1,957.00	1,393.00
2009	7	3,869.53	5,566.19	6,291.20	6,821.13	7,440.85	284.00	780.00	643.50	1,196.50
2009	8	4,885.76	7,028.00	7,943.41	6,533.67	7,127.28	208.00	770.00	205.70	964.30
2009	9	2,843.61	4,090.44	4,623.23	4,421.39	4,823.10	154.00	730.00	24.34	755.66
2009	10	5,046.03	7,258.54	8,203.98	3,768.48	4,110.86	160.00	760.00	586.30	823.70
2009	11	5,702.48	8,202.82	9,271.26	3,007.72	3,280.98	173.00	730.00	125.00	815.00
2009	12	3,014.14	4,335.74	4,900.48	2,024.77	2,208.72	176.00	760.00	66.97	893.03
2010	1	2,437.08	3,680.01	4,207.47	1,994.42	2,206.90	159.00	860.00	9.89	920.11
2010	2	1,898.96	2,867.45	3,278.44	1,701.87	1,883.19	127.00	780.00	0.17	777.83
2010	3	8,903.51	13,444.40	15,371.38	4,198.49	4,645.79	297.00	940.00	5,679.00	1,151.00
2010	4	6,593.96	9,956.94	11,384.07	5,310.53	5,876.32	369.00	930.00	3,150.00	1,330.00
2010	5	6,026.79	9,100.52	10,404.89	7,281.38	8,057.14	330.00	930.00	4,516.00	1,364.00
2010	6	6,677.92	10,083.74	11,529.04	7,787.36	8,617.03	438.00	950.00	2,493.00	1,477.00
2010	7	25,326.87	38,243.84	43,725.33	14,948.21	16,540.80	750.00	1,130.00	4,441.00	1,919.00
2010	8	17,564.05	26,521.89	30,323.27	15,828.27	17,514.61	480.00	950.00	2,430.00	1,860.00
2010	9	11,864.67	17,915.78	20,483.64	7,911.19	8,754.05	342.00	890.00	748.00	1,472.00
2010	10	17,071.62	25,778.32	29,473.12	4,361.94	4,826.67	274.00	900.00	458.50	1,241.50
2010	11	8,353.33	12,613.62	14,421.53	3,358.51	3,716.33	241.00	860.00	182.20	1,147.80
2010	12	4,557.24	6,881.48	7,867.80	1,889.83	2,091.17	215.00	880.00	97.89	1,102.11
2011	1	3,870.25	5,813.71	6,596.67	2,019.04	2,238.40	174.00	940.00	73.08	986.92
2011	2	4,020.06	6,038.75	6,852.02	2,045.38	2,267.60	146.00	850.00	112.60	827.40
2011	3	9,767.75	14,672.64	16,648.69	5,686.00	6,303.77	338.00	1,040.00	2,739.00	1,131.00
2011	4	25,682.00	38,578.29	43,773.82	10,073.57	11,168.03	550.00	1,080.00	7,777.00	1,723.00
2011	5	22,068.49	33,150.24	37,614.75	11,701.98	12,973.37	610.00	1,070.00	4,029.00	2,161.00
2011	6	17,817.52	26,764.64	30,369.17	11,499.45	12,748.83	440.00	1,000.00	5,598.00	1,732.00
2011	7	21,969.33	33,001.29	37,445.74	11,059.49	12,261.07	300.00	980.00	2,029.00	1,371.00
2011	8	11,358.06	17,061.54	19,359.31	7,025.96	7,789.31	202.00	960.00	173.20	1,036.80

Year	Month	Wolf River at New London	Wolf River into Lake Poygan	Lake Poygan and Winneconne Watershed	Fox River at Berlin	Fox River into Lake Butte des Morts	Lake Butte des Morts Direct Drainage Area	Fox River Direct Drainage Area	Fond du Lac River at W. Arndt St	Lake Winnebago Direct Drainage Area
2011	9	5,594.59	8,403.93	9,535.73	4,663.27	5,169.92	171.00	910.00	282.00	928.00
2011	10	7,807.23	11,727.64	13,307.07	3,971.80	4,403.32	165.00	940.00	83.64	926.36
2011	11	7,119.65	10,694.80	12,135.13	4,378.11	4,853.78	257.00	950.00	937.20	1,122.80
2011	12	5,543.06	8,326.53	9,447.90	3,346.96	3,710.60	303.00	990.00	1,344.00	1,326.00
2012	1	4,527.78	6,655.06	7,626.16	3,642.17	4,078.98	217.00	1,000.00	143.10	1,206.90
2012	2	4,389.83	6,452.29	7,393.80	4,013.34	4,494.66	167.00	940.00	373.60	996.40
2012	3	17,366.68	25,526.01	29,250.75	6,671.94	7,472.11	333.00	1,070.00	2,658.00	1,282.00
2012	4	13,895.47	20,423.94	23,404.18	7,673.91	8,594.25	450.00	1,070.00	5,565.00	1,735.00
2012	5	18,858.28	27,718.40	31,763.05	21,045.12	23,569.07	1,370.00	1,560.00	23,730.00	3,540.00
2012	6	9,845.28	14,470.85	16,582.43	9,731.77	10,898.91	425.00	1,020.00	676.70	1,793.30
2012	7	8,367.30	12,298.48	14,093.07	6,258.45	7,009.03	283.00	1,020.00	128.30	1,321.70
2012	8	5,894.63	8,664.09	9,928.35	6,545.76	7,330.80	194.00	1,000.00	31.01	1,088.99
2012	9	2,974.96	4,372.68	5,010.73	5,287.41	5,921.53	149.00	950.00	14.61	935.39
2012	10	4,959.40	7,289.45	8,353.12	5,673.50	6,353.93	191.00	1,000.00	706.30	1,023.70
2012	11	4,710.40	6,923.46	7,933.73	4,130.93	4,626.36	154.00	960.00	95.45	1,014.55
2012	12	3,684.98	5,416.29	6,206.63	3,015.71	3,377.39	154.00	990.00	314.80	1,065.20
2013	1	3,082.91	4,414.08	4,972.71	1,820.16	1,998.82	173.00	1,100.00	875.10	1,014.90
2013	2	2,977.29	4,262.86	4,802.35	2,113.87	2,321.35	139.00	970.00	10.82	829.18
2013	3	6,378.10	9,132.12	10,287.83	3,812.83	4,187.08	149.00	1,080.00	417.40	882.60
2013	4	27,550.21	39,446.18	44,438.30	10,777.34	11,835.18	930.00	1,450.00	11,240.00	2,210.00
2013	5	26,087.77	37,352.26	42,079.39	11,549.30	12,682.91	860.00	1,300.00	7,475.00	2,695.00
2013	6	22,962.67	32,877.78	37,038.64	12,617.06	13,855.48	550.00	1,170.00	3,240.00	2,010.00
2013	7	14,263.96	20,423.03	23,007.67	14,034.02	15,411.52	344.00	1,130.00	937.50	1,502.50
2013	8	6,093.86	8,725.14	9,829.35	6,658.50	7,312.06	229.00	1,090.00	656.00	1,174.00
2013	9	5,611.41	8,034.37	9,051.16	4,779.76	5,248.91	175.00	1,050.00	187.80	982.20
2013	10	6,254.24	8,954.78	10,088.05	4,019.25	4,413.75	182.00	1,090.00	278.80	1,041.20
2013	11	7,994.87	11,446.99	12,895.67	3,544.29	3,892.18	307.00	1,100.00	635.40	1,234.60
2013	12	4,334.72	6,206.41	6,991.87	2,395.63	2,630.77	279.00	1,110.00	185.00	1,285.00