

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

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 2014 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 in-stream flow, 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 a modified version of SWAT 2012 Revision 637.

2 Model Setup

2.1 Subwatershed and Reach Delineation

The Upper Fox and Wolf River Basins were divided into 218 subwatersheds for SWAT modeling. Subwatersheds were delineated based on topography (10-meter resolution digital elevation model), TMDL subbasin boundaries¹, streamflow/water quality monitoring locations, and a drainage area threshold of 25 square miles. 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 and stream reaches are displayed in Figure 1.

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.

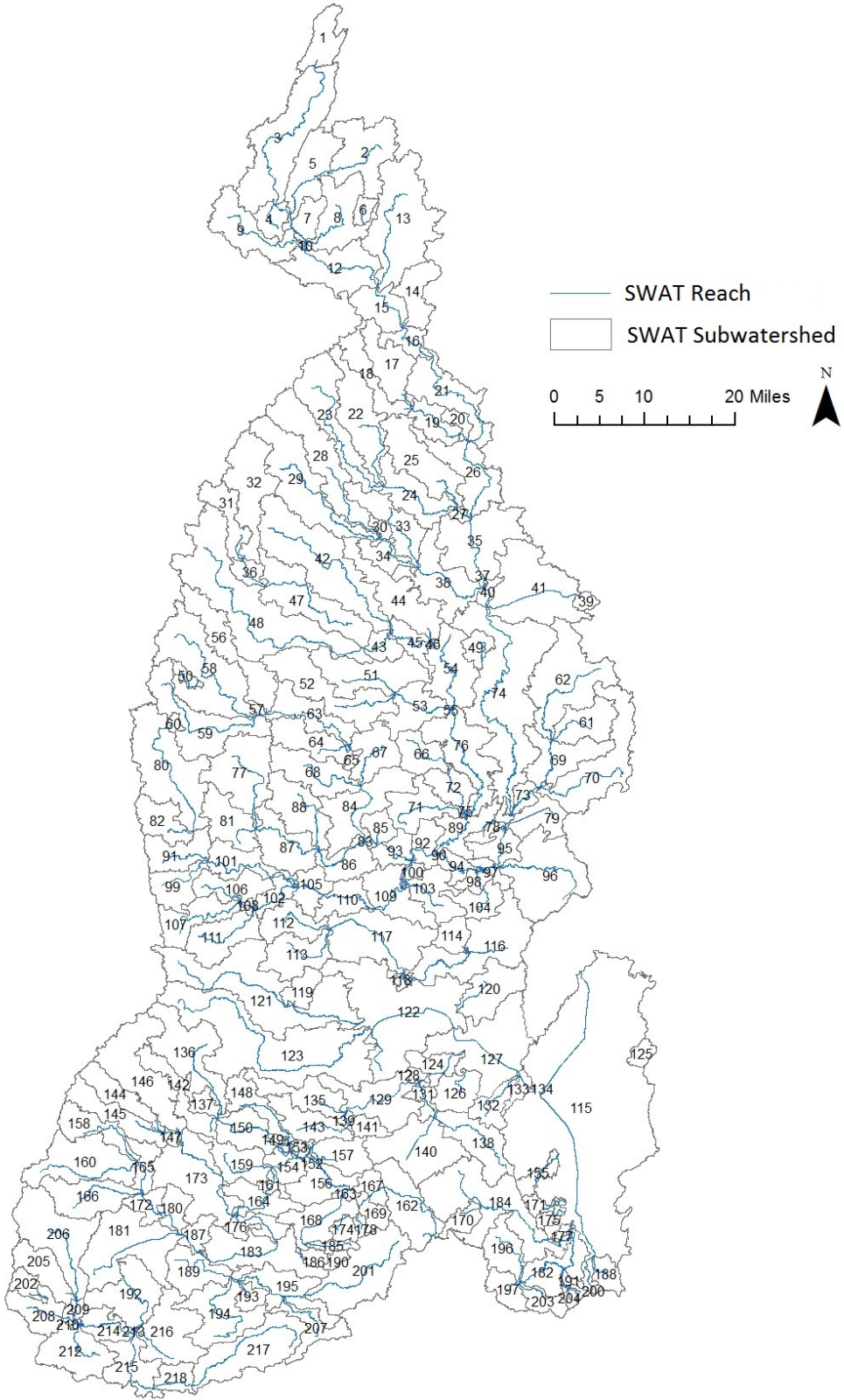


Figure 1. UFWB SWAT model subwatersheds and reaches.

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 statewide crop rotation map layer developed by WDNR, 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 process 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.
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 *Land Cover and Agricultural Management Definition within the Upper Wisconsin River Basin* [WDNR 2014] for further details on general crop rotation mapping). 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	1,058,779	28
Pasture/Grassland	680,740	18
Forested Wetland	547,689	15
Cash Grain	405,078	11
Dairy	145,833	10
Water	295,645	8
Herbaceous Wetland	164,377	4
Developed (Non-Permitted)	154,988	4
Potato/Vegetable	44,065	1
Developed (Permitted MS4)	27,218	1

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 8,290 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.

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

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

2.4 Point Sources

Ninety point sources of discharge are located in the UFWB (Table 4). Point source flows, sediment loads, and phosphorus loads were estimated for each point source using annual discharge monitoring record summaries for the period 1999 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.

Table 4. Point sources included in the UFWB SWAT model.

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
Manawa Wastewater Treatment Facility	20869	1	84

Facility Name	WPDES Permit Number	Outfall Number	SWAT Subwatershed
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
Seymour Wastewater Treatment Facility	21768	1	70
Shiocton Wastewater Treatment Facility	28100	1	78
Silver Lake Sanitary District	61301	1	136
Silver Moon Springs	64548	-	18

Facility Name	WPDES Permit Number	Outfall Number	SWAT Subwatershed
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 Soil Phosphorus

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 counties 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://uwlabs.soils.wisc.edu/soilsummary/maps/>). Note that SWAT allows estimates of initial soil phosphorus to be defined as soluble and/or organic phosphorus forms. In general, total phosphorus delivery to stream channels increases with a higher ratio of soluble soil phosphorus to organic soil phosphorus input to SWAT. Information on the ratio of soluble to organic phosphorus was not available for soil total phosphorus concentrations acquired from county land and water conservation staff and the University of Wisconsin Soil Testing Laboratories. Soil concentrations were therefore assumed to be 50% soluble phosphorus and 50% organic phosphorus for input to SWAT.

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 Stephenville-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.

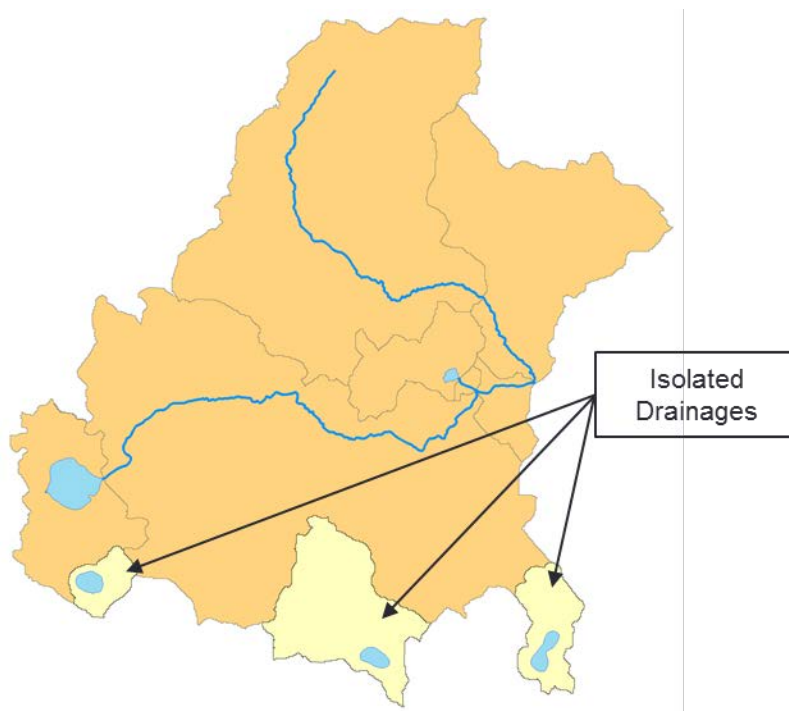


Figure 2. Example of isolated drainage areas in the WDNR 1:24,000 hydrography geodatabase. Isolated drainage areas were used to estimate internally drained areas in SWAT subwatersheds.

2.8 Wetlands

SWAT includes a wetland module for simulating the storage effects of wetlands on streamflow and water quality. The 2011 National Land Cover Database (NLCD) land cover dataset was used to map the extent of wetlands in the UFWB (NLCD classes 90 and 95) and to calculate the percentage of each SWAT subwatershed with wetland cover. After mapping wetlands, wetland parameters in the SWAT pond file (.PND) were updated using values specific to each subwatershed. The normal surface area of wetlands (parameter WET_NSA) was set to the 2011 NLCD wetland area and the subwatershed fraction draining to wetlands (parameter WET_FR) was set to the percent area of 2011 NLCD wetlands. The wetland normal volume (parameter WET_NVOL) was estimated as the normal surface area multiplied by a depth of one meter. The wetland maximum surface area (parameter WET_MXSA) was estimated as the normal surface area multiplied by 1.25. The maximum volume (parameter WET_MXVOL) was estimated as the maximum surface area multiplied by a depth of three meters.

2.9 Manning's n

Manning's roughness coefficient (Manning's n) was 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.

Table 7. Riparian wetland thresholds used for estimating 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

2.10 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):

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

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

2.11 Simulation Period

The UFWB SWAT model was setup to run for the period January 1, 1996 to December 31, 2013. The period January 1, 1996 to December 31, 1999 is considered a "warm-up" period to allow initial condition settings, such as initial soil phosphorus concentrations, to equilibrate.

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: $NSE \geq 0.75$ and $PBIAS \leq \pm 10\%$
 - Sediment: $NSE \geq 0.75$ and $PBIAS \leq \pm 15\%$
 - Total Phosphorus: $NSE \geq 0.75$ and $PBIAS \leq \pm 25\%$
- “Good” performance
 - Streamflow: $NSE \geq 0.65$ and $PBIAS \leq \pm 15\%$
 - Sediment: $NSE \geq 0.65$ and $PBIAS \leq \pm 30\%$
 - Total Phosphorus: $NSE \geq 0.65$ and $PBIAS \leq \pm 40\%$
- “Satisfactory” performance
 - Streamflow: $NSE \geq 0.5$ and $PBIAS \leq \pm 25\%$
 - Sediment: $NSE \geq 0.5$ and $PBIAS \leq \pm 55\%$
 - Total Phosphorus: $NSE \geq 0.5$ and $PBIAS \leq \pm 70\%$

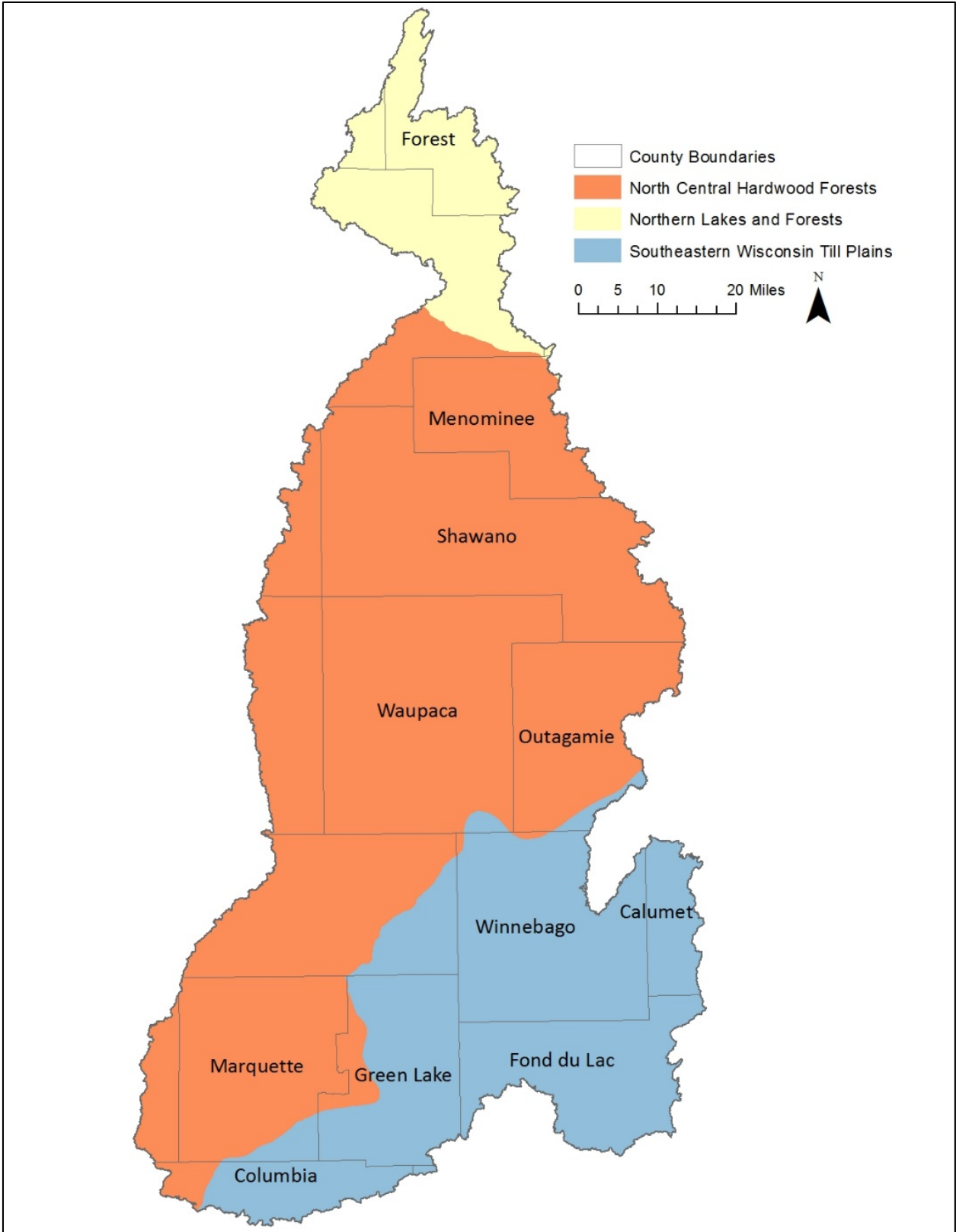


Figure 3. US EPA Level III Ecoregions in the UFWB.

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). 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 loads² 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 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. Because these

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.

estimates did not undergo the same quality assurance/quality control (QA/QC) protocols as data in the USGS National Water Information System, model calibration and validation at the Fox River at Berlin and the Wolf River at New London sites focused on matching long-term average loads using the percent bias (PBIAS) statistic rather than matching month-to-month variation using the Nash-Sutcliffe Efficiency statistic.

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. Surveyed 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
04074538	Swamp Creek Below Rice Lake At Mole Lake, WI	2	2000-2009		
04074950	Wolf River at Langlade, WI	16	2000-2012		
04075365	Evergreen River Below Evergreen Falls Near Langlade, WI	19	2002-2008		
04077630	Red River at Morgan Road Near Morgan, WI	30	2000-2012		
04077400	Wolf River Near Shawano, WI	35	2000-2001		
0407809265	Middle Branch Embarrass River Near Wittenberg, WI	36	2000-2006		
04078500	Embarrass River Near Embarrass, WI	46	2000-2012		
04080000	Little Wolf River At Royalton, WI	85	2000-2012		
04079000	Wolf River at New London, WI	90	2000-2012	2000-2013 ^a	2000-2013 ^a
04081000	Waupaca River Near Waupaca, WI	105	2000-2012		
04073970	Waukau Creek Near Omro, WI	131	2007-2011	2007-2011	2007-2011
04082400	Fox River at Oshkosh, WI	134	2000-2012		
04073500	Fox River at Berlin, WI	143	2000-2012	2000-2013 ^a	2000-2013 ^a
04073473	Puchyan River DS N. Lawson Drive Near Green Lake, WI	163	2000-2012		
04073365	Fox River at Princeton, WI	164	2000-2012		
04073466	Silver Creek at Spaulding Road Near Green Lake, WI	167	2012-2013	2012-2013	2012-2013
04073468	Green Lake Inlet at Ct Highway A Near Green Lake, WI	169	2000-2012	2000-2012	2000-2012
04072845	Montello River Near Montello, WI	172	2007-2011	2007-2011	2007-2011
04083545	Fond Du Lac River @ W. Arndt St. At Fond Du Lac, WI	177	2007-2011	2007-2011	2007-2011
04073462	White Creek At Spring Grove Road Near Green Lake, WI	178	2000-2012	2000-2012	2000-2012
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

^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	177	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	177	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 because the Bermudagrass growth parameters were not generating sufficient biomass.

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	119	52 (39)
Corn Silage (tons/acre)	15.78	14	52 (39)
Soybean (bushels/acre)	38.7	36.2	56 (25)
Alfalfa (tons/acre)	3.3	2.6	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 completed 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.

Parameters related to internally drained areas and surface water storage were 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.

Calibration of the surface runoff lag coefficient (SURLAG) was based on subwatershed area. A value of 0.15 was found to be appropriate for HRUs in most subwatersheds. However, subwatersheds with large areas required a higher SURLAG value (2.5). A subwatershed area threshold of 180 km² was identified for assigning high (2.5) versus low (0.15) SURLAG based on a review of the distribution of subwatershed areas.

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

Table 12. Streamflow parameters calibrated at the basin-wide scale.

Parameter	File	Units	Default Value	Calibrated Value
SMTMP	.bsn	Degrees C	0.5	0.72
SFTMP	.bsn	Degrees C	1	0.23
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 ₂ O	0.5	14.87
SURLAG (subwatersheds 3,42,48,74,115,121,122,184)	.hru	-	4	2.5
SURLAG (all other subwatersheds)	.hru	-	4	0.15

Table 13. Streamflow parameters calibrated at the Level III Ecoregion scale.

Ecoregion	Parameter	File	Units	Default Value	Calibrated Value
Northern Lakes and Forests	CN2	.mgt	-	Varies by HRU	-11% of Default
	GW_DELAY	.gw	days	31	345
	ALPHA_BF	.gw	-	0.014	0.037
	GWQMN	.gw	mm H ₂ O	1000	1116
	GW_REVAP	.gw	-	0.02	0.18
	REVAPMN	.gw	mm H ₂ O	750	2034
	ESCO	.hru	-	1	0.58
	SOL_Z, all layers	.sol	mm	Varies by Soil Type	-9% of Default
	SOL_AWC, all layers	.sol	mm H ₂ O/mm soil	Varies by Soil Type	-9% of Default
	PND_FR	.pnd	-	Varies by Subwatershed	+300% of Default
North Central Hardwood Forests	CN2	.mgt	-	Varies by HRU	No Change from Default
	GW_DELAY	.gw	days	31	321
	ALPHA_BF	.gw	-	0.014	0.032
	GWQMN	.gw	mm H ₂ O	1000	820
	GW_REVAP	.gw	-	0.02	0.09
	REVAPMN	.gw	mm H ₂ O	750	897
	ESCO	.hru	-	1	0.77
	SOL_Z, all layers	.sol	mm	Varies by Soil Type	-0.14% of Default
	SOL_AWC, all layers	.sol	mm H ₂ O/mm soil	Varies by Soil Type	No Change from Default
	Southeastern Wisconsin Till Plains	CN2	.mgt	-	Varies by HRU
GW_DELAY		.gw	days	31	268
ALPHA_BF		.gw	-	0.014	0.045
GWQMN		.gw	mm H ₂ O	1000	112
GW_REVAP		.gw	-	0.02	0.13
REVAPMN		.gw	mm H ₂ O	750	191
ESCO		.hru	-	1	0.93
SOL_Z, all layers		.sol	mm	Varies by Soil Type	-4% of Default
SOL_AWC, all layers		.sol	mm H ₂ O/mm soil	Varies by Soil Type	+12% of Default

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 most sites ($NSE \geq 0.65$; $PBIAS \leq 10\%$). Four sites have NSE values below 0.5 (Evergreen River, Red River, Silver Creek, Montello River) but PBIAS values for three of the four sites are within $\pm 15\%$, indicating that errors are not strongly biased as over- or under-predictions.

Table 14. Performance statistics for monthly streamflow calibration.

Site Name	USGS ID	SWAT Subwatershed	R ²	NSE	PBIAS
Wolf River at Langlade, WI	04074950	16	0.66	0.58	13.8%
Evergreen River Blw Evergreen Falls	04075365	19	0.63	0.45	-2.8%
Red River at Morgan Road	04077630	30	0.60	0.34	14.1%
Wolf River Near Shawano	04077400	35	0.82	0.70	-9.5%
Middle Branch Embarrass River	0407809265	36	0.59	0.58	5.9%
Embarrass River Near Embarrass	04078500	46	0.68	0.62	13.3%
Little Wolf River At Royalton	04080000	85	0.78	0.73	9.9%
Wolf River at New London	04079000	90	0.74	0.67	10.8%
Waukau Creek Near Omro	04073970	131	0.67	0.65	-6.5%
Fox River at Oshkosh	04082400	134	0.66	0.61	11.0%
Fox River at Berlin	04073500	143	0.67	0.64	-9.1%
Puchyan River	04073473	163	0.80	0.77	-10.5%
Fox River at Princeton	04073365	164	0.72	0.72	-0.4%
Silver Creek at Spaulding Road	04073466	167	0.55	0.42	-35.2%
Green Lake Inlet	04073468	169	0.76	0.68	-30.2%
Montello River Near Montello	04072845	172	0.51	0.16	11.1%
Fond Du Lac River @ W. Arndt St.	04083545	177	0.68	0.56	-40.1%

Table 15 lists streamflow validation performance statistics by site (see Appendix D for streamflow validation hydrographs). Five of the nine sites show good to very good performance ($NSE \geq 0.65$; $PBIAS \leq \pm 10\%$). Two sites have a NSE value below 0.5 (Red River and Fox River at Princeton) but the PBIAS values for both sites are within $\pm 15\%$.

Table 15. Performance statistics for monthly streamflow validation.

Site Name	USGS ID	SWAT Subwatershed	R ²	NSE	PBIAS
Wolf River at Langlade	04074950	16	0.74	0.65	9.9%
Red River at Morgan Road	04077630	30	0.54	0.11	15.0%
Embarrass River Near Embarrass	04078500	46	0.80	0.73	9.9%
Wolf River at New London	04079000	90	0.62	0.60	7.6%
Fox River at Oshkosh	04082400	134	0.74	0.72	5.1%
Fox River at Berlin	04073500	143	0.65	0.57	-12.8%
Puchyan River	04073473	163	0.77	0.66	-27.9%
Fox River at Princeton	04073365	164	0.51	0.46	-1.9%
Green Lake Inlet	04073468	169	0.88	0.80	-25.2%

5.3 Sediment Calibration and Validation

Sediment loading 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.

SWAT parameters for the Modified Universal Soil Loss Equation (MUSLE) are the primary determinants of landscape erosion. Default values of MUSLE equation parameters overestimated sediment loading in initial simulations and required adjustment. These included the minimum cover-management C factor (USLE_C) and the conservation practice P factor (USLE_P). Additionally, a buffer strip was simulated to account for sediment deposition in vegetated areas between a farm field edge and channelized flow using the edge-of field filter strip parameter (FILTERW).

The following additional sediment parameters were selected for calibration based on a review of the sensitivity of predicted sediment loads: the linear parameter for calculating the maximum amount of sediment that can be reentrained during sediment routing (SPCON), the exponent parameter for calculating sediment reentrained in channel sediment routing (SPEXP), the peak rate adjustment factor for sediment routing in the main channel (PRF_BSN), the peak rate adjustment factor for sediment routing in the tributary channels (ADJ_PKR), the biological mixing efficiency (BIOMIX), the initial sediment concentration in wetland water (WET_SED), and the equilibrium sediment concentration in wetland water (WET_NSED).

Manning's n for the main channel (CH_N2) of each subwatershed was also adjusted during sediment calibration. For subwatersheds with long channel lengths and/or extensive riparian wetland zones, a Manning's n value of 0.02 was found to improve sediment load predictions.

Main channel slopes (CH_S2) calculated by ArcSWAT were found to be extremely low for some reaches, resulting in excessive sediment deposition in those reaches. A minimum channel slope of 0.001 was enforced during sediment calibration to prevent excess sediment deposition in these channels. Main channel widths (CH_W2) calculated by ArcSWAT also appeared unrealistically high for several reaches. Channels widths greater than 100 meters were reduced by 50% during sediment calibration to reduce excess sediment deposition.

Lastly, channel erosion parameters CH_COV1 and CH_COV2 were increased from 0 to 0.1 to account for resuspension of deposited sediment in each reach.

Calibrated sediment loading parameter values are listed in Table 16.

Table 16. Calibrated values of sediment loading parameters.

Parameter	File	Units	Initial Value	Calibrated Value
SPCON	.bsn	-	0.0001	0.000335
SPEXP	.bsn	-	1	1.33
PRF_BSN	.bsn	-	1	1.01
ADJ_PKR	.bsn	-	1	1.05
CH_COV1	.bsn	-	0	0.1
CH_COV2	.bsn	-	0	0.1
USLE_C (corn grain)	.plant	-	0.2	0.1
USLE_C (corn silage)	.plant	-	0.2	0.15
USLE_C (sweet corn)	.plant	-	0.2	0.1
USLE_C (soybean)	.plant	-	0.2	0.1
USLE_C (green bean)	.plant	-	0.2	0.1
USLE_C (potato)	.plant	-	0.2	0.1
USLE_P (cropped HRUs)	.mgt	-	1	0.55
FILTERW (cropped HRUs)	.mgt	meters	0	10
BIOMIX (all HRUs)	.mgt	-	0.2	0.17
WET_NSED	.pnd	mg/L	0	6
WET_SED	.pnd	mg/L	0	3.3
CH_N2 (reaches with extensive riparian wetlands)	.rte	-	Varies by reach	0.02
CH_S2 (where slope < 0.001)	.rte	-	Varies by reach	0.001
CH_W2 (where width > 100 meters)	.rte	meters	Varies by reach	-50%

Table 17 lists sediment calibration performance statistics by site (see Appendix D for monthly sediment load plots). Model performance for sediment calibration was satisfactory ($\leq \pm 55\%$) or very good ($\leq 15\%$) for all five calibration sites based on PBIAS. NSE values for sediment calibration met satisfactory (≥ 0.5) or good (≥ 0.65) guidelines for two of the calibration sites. As described in Section 4.2, NSE was not evaluated for the Wolf River at New London and Fox River at Berlin sites because of uncertainty in the accuracy of observed monthly sediment load estimates derived from water quality monitoring data.

Table 17. Performance statistics for monthly sediment calibration.

Site Name	USGS ID	SWAT Subwatershed	R ²	NSE	PBIAS
Green Lake Inlet	04073468	169	0.65	0.55	-37.6%
Montello River Near Montello	04072845	172	0.52	0.49	-7%
Fond Du Lac River @ W. Arndt St.	04083545	177	0.91	0.68	-36.6%
Wolf River at New London	04079000	90	0.24	-	41.5%
Fox River at Berlin	04073500	143	0.03	-	30.2%

^a Performance statistics with 2008 excluded from Montello River site

Table 18 lists sediment validation performance statistics by site (see Appendix D for monthly sediment load plots). Model performance for sediment validation was satisfactory to very good for all five sites based on PBIAS. Model performance was satisfactory to good for the three sites where NSE was evaluated.

Table 18. Performance statistics for monthly sediment validation.

Site Name	USGS ID	SWAT Subwatershed	R ²	NSE	PBIAS
Green Lake Inlet	04073468	169	0.93	0.66	-50.2%
Waukau Creek Near Omro	04073970	131	0.63	0.58	-37.2%
Silver Creek at Spaulding Road	04073466	167	0.77	0.57	-52.6%
Wolf River at New London	04079000	90	0.38	-	16.2%
Fox River at Berlin	04073500	143	0.03	-	14.2%

5.4 Total Phosphorus Calibration and Validation

Total phosphorus loading 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.

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), the phosphorus uptake distribution parameter (P_UPDIS), the residue decomposition coefficient (RSDCO), the phosphorus settling rate in wetlands (PSETLW1 and PSETLW2), and bedload phosphorus parameters (RS2 and RS5). Additionally, the updated SWAT soil phosphorus routines were enabled by setting the soil phosphorus routine option (SOL_P_MODEL) to 1 and instream water quality was simulated by setting the in-stream water quality code (IWQ) to 1. Calibrated values of total phosphorus loading parameters are listed in Table 19.

Table 19. Total phosphorus calibration parameters.

Parameter	File	Units	Initial Value	Calibrated Value
PSP	.bsn	-	0.4	0.43
PHOSKD	.bsn	m ³ /Mg	175	250
P_UPDIS	.bsn	-	20	27
RSDCO	.bsn	-	0.05	0.0256
SOL_P_MODEL	.bsn	-	0	1
IWQ	.bsn	-	0	1
RS2	.swq	-	0	1.74
R25	.swq	-	0	0.21
PSETLW1	.pnd	m/year	0	20
PSETLW2	.pnd	m/year	0	20

Table 20 lists total phosphorus calibration performance statistics by site (see Appendix D for monthly total phosphorus load plots). Model performance for total phosphorus calibration was satisfactory ($\leq \pm 70\%$) or very good ($\leq \pm 25\%$) for all five sites based on PBIAS. Model performance was satisfactory (≥ 0.5) to good (≥ 0.65) for all three calibration sites where NSE was evaluated. As described in Section 4.2, NSE was not evaluated for the Wolf River at New London and Fox River at Berlin sites because of uncertainty in the accuracy of the observed monthly phosphorus load estimates derived from water quality monitoring data.

Table 20. Performance statistics for monthly total phosphorus calibration.

Site Name	USGS ID	SWAT Subwatershed	R ²	NSE	PBIAS
Green Lake Inlet	04073468	169	0.75	0.67	2.2%
Montello River Near Montello	04072845	172	0.55	0.52	-9.0%
Fond Du Lac River @ W. Arndt St.	04083545	177	0.91	0.53	-57.7%
Wolf River at New London	04079000	90	0.37	-	1.3%
Fox River at Berlin	04073500	143	0.53	-	-10.8%

Table 21 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 for all five sites based on PBIAS. Model performance was satisfactory to good for two of the three validation sites where NSE was evaluated. Note that the very low NSE for the Silver Creek site is primarily due to a large discrepancy between predicted and observed loads for a single month (NSE is 0.43 if May 2012 is excluded).

Table 21. Performance statistics for monthly total phosphorus validation.

Site Name	USGS ID	SWAT Subwatershed	R ²	NSE	PBIAS
Green Lake Inlet	04073468	169	0.88	0.70	12.3%
Waukau Creek Near Omro	04073970	131	0.69	0.64	-23.4%
Silver Creek at Spaulding Rd.	04073466	167	0.65	-1.71 (0.43 ^a)	20.2% (-24.6% ^a)
Wolf River at New London	04079000	90	0.62	-	-18.3%
Fox River at Berlin	04073500	143	0.51	-	-15.2%

^a Performance statistics with May 2012 excluded from Silver Creek site

6 Discussion and Conclusions

SWAT calibration and validation results show that satisfactory model performance guidelines for streamflow, sediment, and phosphorus are generally met or exceeded at streamflow and water quality monitoring locations. Performance statistics that are below guidelines do 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.

Model performance statistics that are below satisfactory guidelines can also be attributed in part to inaccuracies in model input data. Figure 4 illustrates observed and modeled streamflow at a calibration site that did not meet the satisfactory guideline for model performance (Silver Creek at Spaulding Road; USGS ID 04073466; NSE = 0.42; PBIAS = -35%). SWAT model predictions mostly re-create the pattern of observed flows at the Silver Creek gage but underestimate flow magnitude during April 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 Nash Sutcliffe Efficiency and Percent Bias.

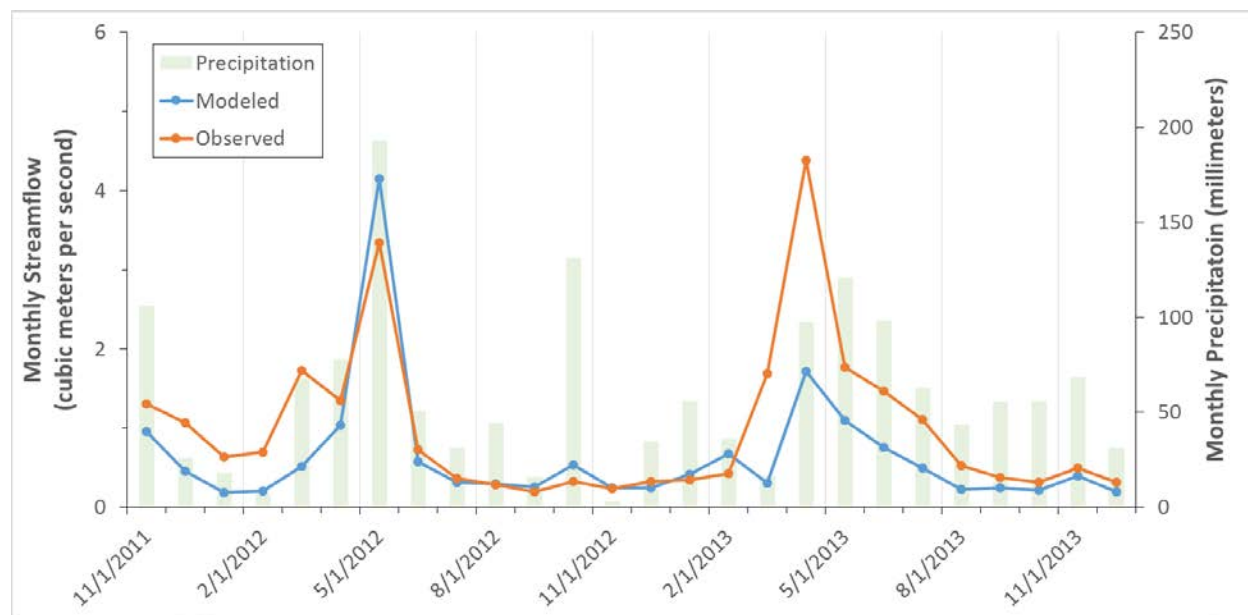


Figure 4. Streamflow calibration hydrograph for Silver Creek at Spaulding Road (USGS ID 04073466).

Overall, the differences between observations and SWAT predictions are greater for sediment relative to streamflow and phosphorus. Errors in SWAT sediment load predictions result from inaccurate simulation of surface erosion and/or routing of eroded sediment across the landscape and through the channel network. SWAT uses the modified universal soil loss equation (MUSLE) to quantify surface erosion. In the MUSLE, erosion is based on surface runoff and parameters related to soil erodibility, vegetative cover, and topography that vary with each hydrologic response unit in the

model. Eroded sediment is routed through ponds, wetlands, and filter strips before it is delivered to the main channel of the subwatershed, where channel deposition and erosion are simulated. Although initial estimates of erosion and sediment routing parameters were adjusted during model calibration, additional fine-tuning of parameter values would improve predictions of sediment loading by the UFWB model. However, further calibration requires additional sediment monitoring data to better characterize variation in erosion and sediment routing parameters across the basin.

SWAT predictions should ultimately be evaluated in the context of the intended application of model output. Key outputs from the UFWB SWAT model for use in supporting phosphorus and sediment TMDL development are:

- Average annual streamflow in stream and river reaches;
- Average annual phosphorus and sediment loads in stream and river reaches;
- Average annual water volumes and phosphorus loads input to impaired lakes in the UFWB;
- The relative magnitude of phosphorus and sediment loads from each major land cover type (forest, wetland, agriculture, urban);

Based on calibration and validation performance, the UFWB SWAT model adequately simulates the characteristics listed above and is suitable for use in the development of sediment and phosphorus TMDLs for the UFWB. 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. Records from additional weather stations, if available, would improve the accuracy of model predictions by providing a more complete representation of spatial variability in precipitation and temperature;
- 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 and wetlands, 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 References

- Abbaspour, K. C. (2014). *SWAT-CUP 2012 User Manual*. Retrieved from http://www.neprashtechology.ca/Downloads/SwatCup/Manual/Usermanual_Swat_Cup_2012.pdf
- Arnold, J., Allen, P., Muttiah, R., & Bernhard, G. (1999). *Baseflow Filter Program*. Retrieved from Soil and Water Assessment Tool: http://swat.tamu.edu/media/70814/baseflow_inst_2006-06.pdf
- Arnold, J., Kiniry, J., Srinivasan, R., Williams, J., Haney, E., & Neitsch, S. (2012). *SWAT Documentation*. Retrieved from Soil and Water Assessment Tool (SWAT) Website: <http://swat.tamu.edu/media/69296/SWAT-IO-Documentation-2012.pdf>
- Baumgart, P. (2005). *Lower Green Bay and Lower Fox Tributary Modeling Report*.
- Ecoregion Maps and GIS Resources*. (2015). Retrieved May 2015, from Environmental Protection Agency: www.epa.gov/wed/pages/ecoregions.htm
- Lauer, J. (2006, December). *Corn Agronomy*. Retrieved from University of Wisconsin - Madison: <http://corn.agronomy.wisc.edu/AA/pdfs/A045.pdf>
- Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Binger, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans. ASABE*, 885-900.
- Murphy, W. J. (1993). *Tables for Weights and Measurement: Crops*. MU Extension. Retrieved from www.extension.missouri.edu/publications/DisplayPub.aspx?P=G4020
- WDNR. (2014). *Land Cover and Agricultural Management Definition within the Upper Wisconsin River Basin*. Wisconsin Department of Natural Resources. Retrieved from <http://dnr.wi.gov/topic/TMDLs/documents/WisconsinRiver/Technical/WRBLndCvrLndMngmntJuly2014RevFeb2015.pdf>

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. 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			Storage
Dairy 1, Year 5			
Dairy 2, Year 1			
Dairy 2, Year 3			
Dairy 2, Year 5			
Dairy 3, Year 1		16-30%	
Dairy 3, Year 3			Storage
Dairy 3, Year 5			
Dairy 4, Year 1			
Dairy 4, Year 3			
Dairy 4, Year 5			
Dairy 5, Year 1		>30%	
Dairy 5, Year 3			Storage
Dairy 5, Year 5			
Dairy 6, Year 1			
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%	
Dairy 7, Year 3			Storage
Dairy 7, Year 5			
Dairy 8, Year 1			
Dairy 8, Year 3			
Dairy 8, Year 5			
Dairy 9, Year 1		16-30%	
Dairy 9, Year 3			Storage
Dairy 9, Year 5			
Dairy 10, Year 1			
Dairy 10, Year 3			
Dairy 10, Year 5			
Dairy 11, Year 1		>30%	
Dairy 11, Year 3			Storage
Dairy 11, Year 5			
Dairy 12, Year 1			
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	0-15%	-
Potato/Vegetable Year 3	2 years vegetable		
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	25	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	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	25	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	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	25	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	25	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	25	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	25	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	25	1	Fertilizer	Manure	3083	kg/ha
2	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	25	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	25	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	25	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	25	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
2	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	1	Fertilizer	Dairy - Fresh Manure	30070	kg/ha
1	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	1	Fertilizer	Dairy - Fresh Manure	3083	kg/ha
1	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	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	25	15	Harvest	Soybean		
2	4	15	Tillage	Conservation Tillage		
2	5	15	Fertilizer	Elemental P	25	kg/ha
2	5	15	Plant	Soybean		
2	25	15	Harvest	Soybean		
3	4	15	Tillage	Conservation Tillage		
3	5	15	Fertilizer	Elemental P	25	kg/ha
3	5	15	Plant	Soybean		
3	25	15	Harvest	Soybean		
4	4	15	Tillage	Conservation Tillage		
4	5	15	Fertilizer	Elemental P	25	kg/ha
4	5	15	Plant	Soybean		
4	25	15	Harvest	Soybean		
5	4	15	Tillage	Conservation Tillage		
5	5	15	Fertilizer	Elemental P	25	kg/ha
5	5	15	Plant	Soybean		
5	25	15	Harvest	Soybean		
6	4	15	Tillage	Conservation Tillage		
6	5	15	Fertilizer	Elemental P	25	kg/ha
6	5	15	Plant	Soybean		
6	25	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 ₂ O 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 ₂ O 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	1,058,779	28.32
Pasture/Grassland	FESC	680,740	18.21
Wetlands-Forested	WETF	547,689	14.65
Water	WATR	295,645	7.91
Wetlands-Non-Forested	WETN	164,377	4.4
Residential-Low Density	URLD	106,610	2.85
Continuous Soybean 1	CG02	98,229	2.63
Continuous Corn 1	CG01	96,550	2.58
Continuous Corn 2	CG03	71,258	1.91
Continuous Soybean 2	CG04	71,219	1.9
Dairy 1, Year 5	D015	62,228	1.66
Dairy 1, Year 3	D013	61,596	1.65
Dairy 1, Year 1	D011	60,925	1.63
Residential-Medium Density	URMD	40,263	1.08
Continuous Soybean 3	CG06	34,369	0.92
Continuous Corn 3	CG05	33,453	0.89
Dairy 4, Year 1	D041	16,061	0.43
Dairy 4, Year 3	D043	15,921	0.43
Dairy 4, Year 5	D045	15,917	0.43
Potato Vegetable, Year 2	POT3	14,890	0.4
Potato Vegetable, Year 1	POT1	14,742	0.39
Potato Vegetable, Year 3	POT5	14,433	0.39
MS4 Urban Medium Density	MRMD	13,114	0.35
Dairy 10 Year, 1	D101	8,564	0.23
Dairy 10 Year, 3	D103	8,509	0.23
Dairy 10 Year, 5	D105	8,595	0.23
Dairy 2 Year, 3	D023	7,960	0.21
Dairy 2 Year, 5	D025	8,018	0.21
Dairy 3 Year, 1	D031	7,856	0.21
Dairy 3 Year, 5	D035	7,765	0.21
Dairy 3 Year, 3	D033	7,435	0.2
Dairy 2 Year, 1	D021	7,510	0.2
MS4 Urban High Density	MRHD	6,831	0.18
Residential-High Density	URHD	6,051	0.16
Dairy 8, Year 1	D081	5,594	0.15
Dairy 8, Year 3	D083	5,591	0.15
Dairy 8, Year 5	D085	5,619	0.15
MS4 Urban Low Density	MRLD	4,608	0.12
Dairy 12, Year 5	D125	3,215	0.09
Dairy 11, Year 5	D115	2,910	0.08
Dairy 12, Year 1	D121	3,148	0.08
Dairy 12, Year 3	D123	3,138	0.08
Dairy 11, Year 1	D111	2,702	0.07

Land Cover	Landover Code	Area (acres)	% Watershed
Dairy 11, Year 3	D113	2,668	0.07
Dairy 5, Year 5	D055	2,478	0.07
MS4 Urban Industrial	MIDU	2,665	0.07
Industrial	UIDU	2,063	0.06
Dairy 5, Year 1	D051	2,368	0.06
Dairy 5, Year 3	D053	2,358	0.06
Dairy 9, Year 1	D091	1,914	0.05
Dairy 9, Year 3	D093	1,914	0.05
Dairy 9, Year 5	D095	1,870	0.05
Dairy 6, Year 1	D061	1,488	0.04
Dairy 6, Year 3	D063	1,470	0.04
Dairy 6, Year 5	D065	1,483	0.04
Dairy 7, Year 1	D071	1,170	0.03
Dairy 7, Year 5	D075	1,214	0.03
Dairy 7, Year 3	D073	1,189	0.03

Appendix D. Streamflow Calibration and Validation Time Series Plots

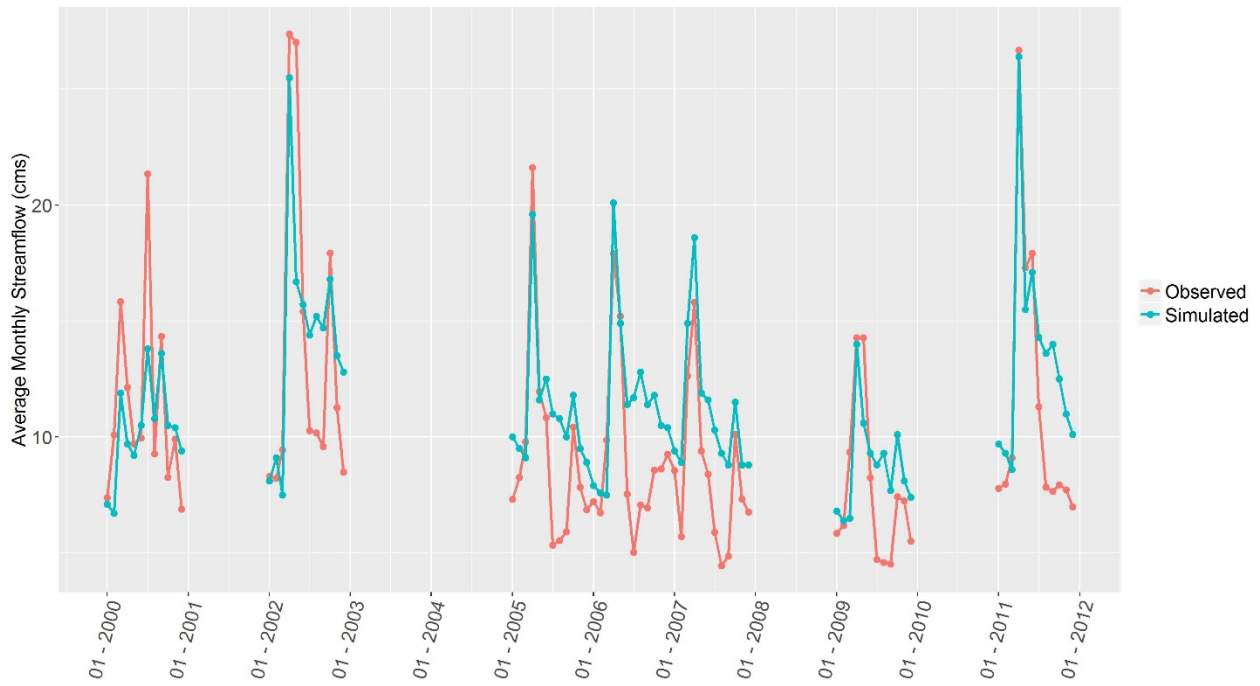


Figure D- 1. Monthly streamflow calibration hydrograph for USGS site 0407495 (Wolf River at Langlade, WI).

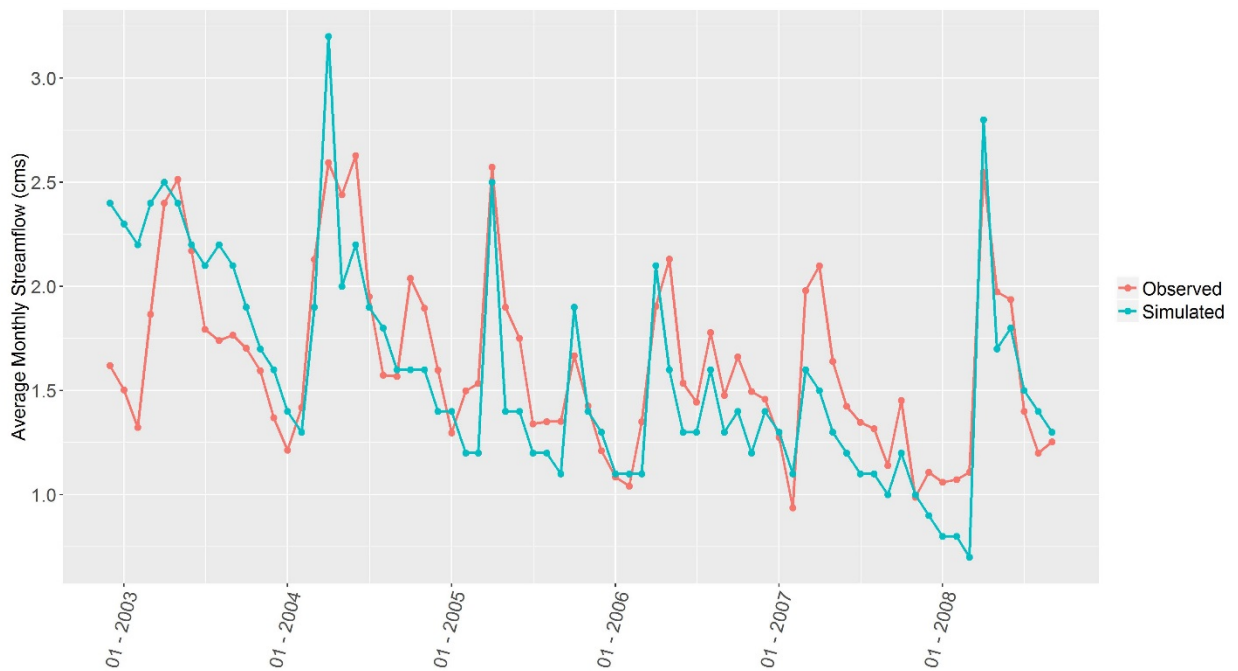


Figure D- 2. Monthly streamflow calibration hydrograph for USGS site 04075365 (Evergreen River below Evergreen Falls near Langlade, WI).

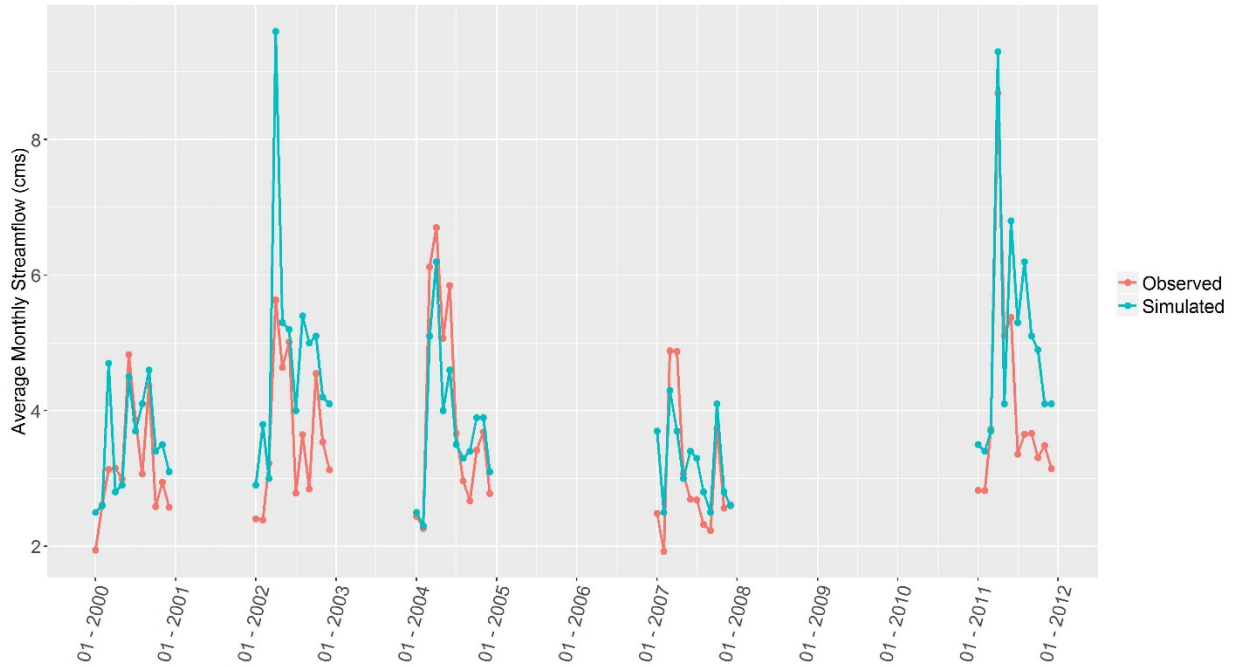


Figure D- 3. Monthly streamflow calibration hydrograph for USGS site 04077630 (Red River at Morgan Road near Morgan, WI).

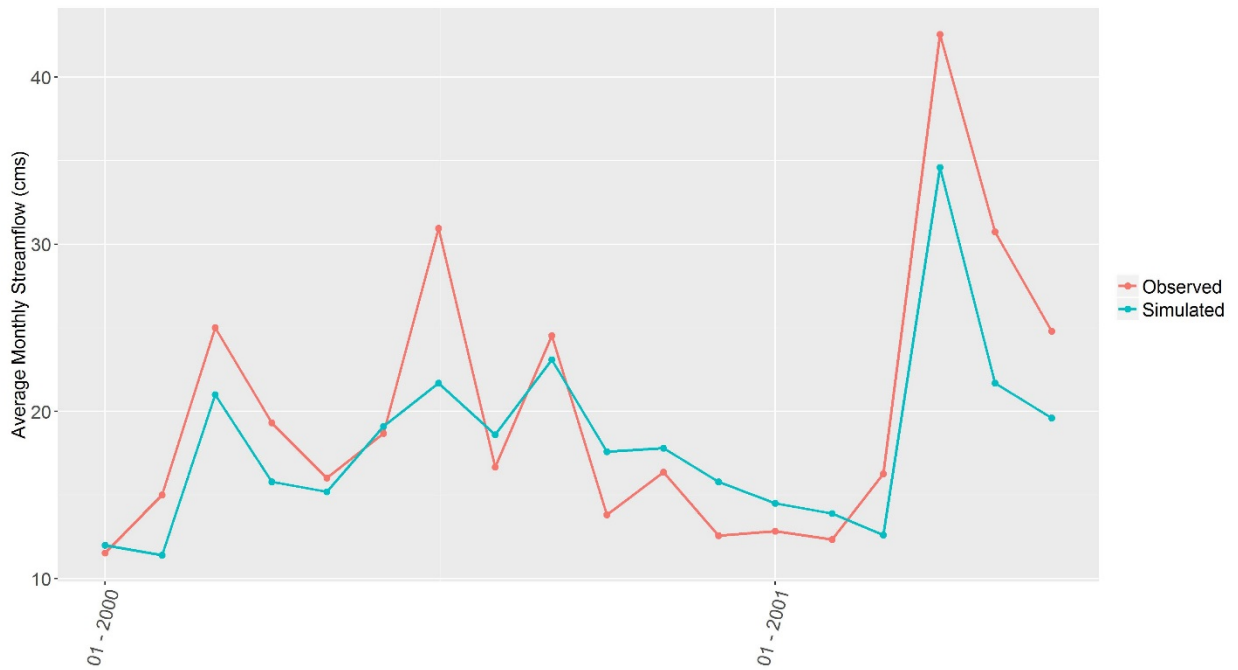


Figure D- 4. Monthly streamflow calibration hydrograph for USGS site 04077400 (Wolf River near Shawano, WI).

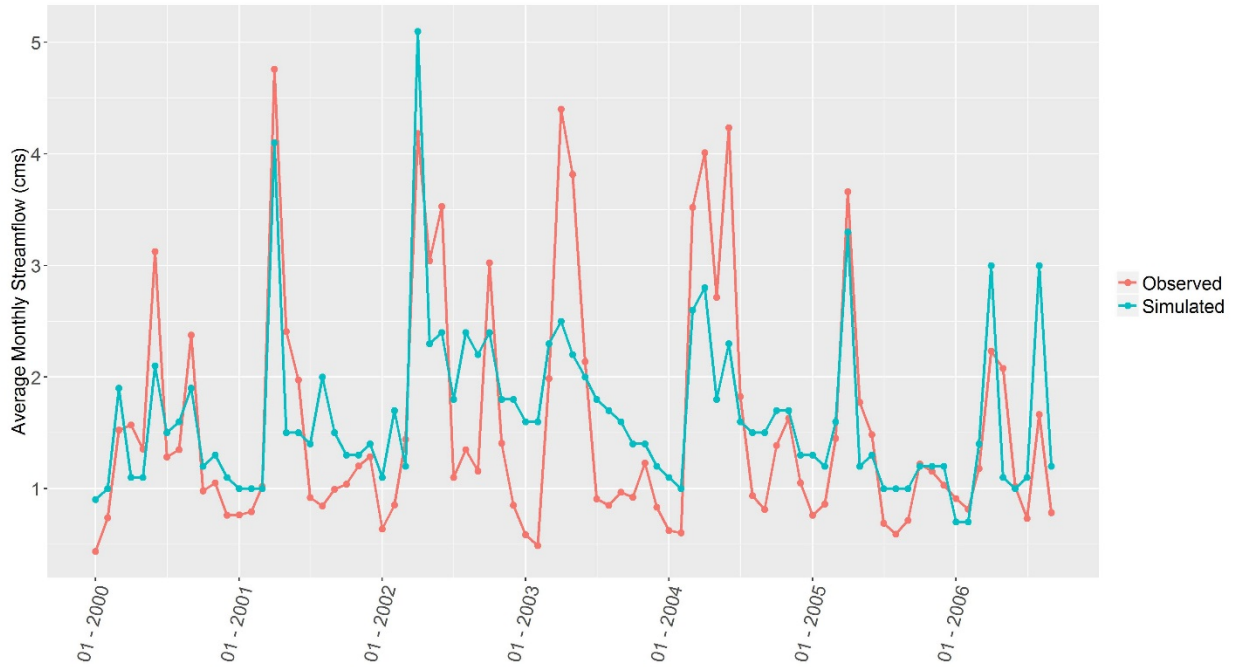


Figure D- 5. Monthly streamflow calibration hydrograph for USGS site 0407809265 (Middle Branch Embarrass River near Wittenberg, WI).



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

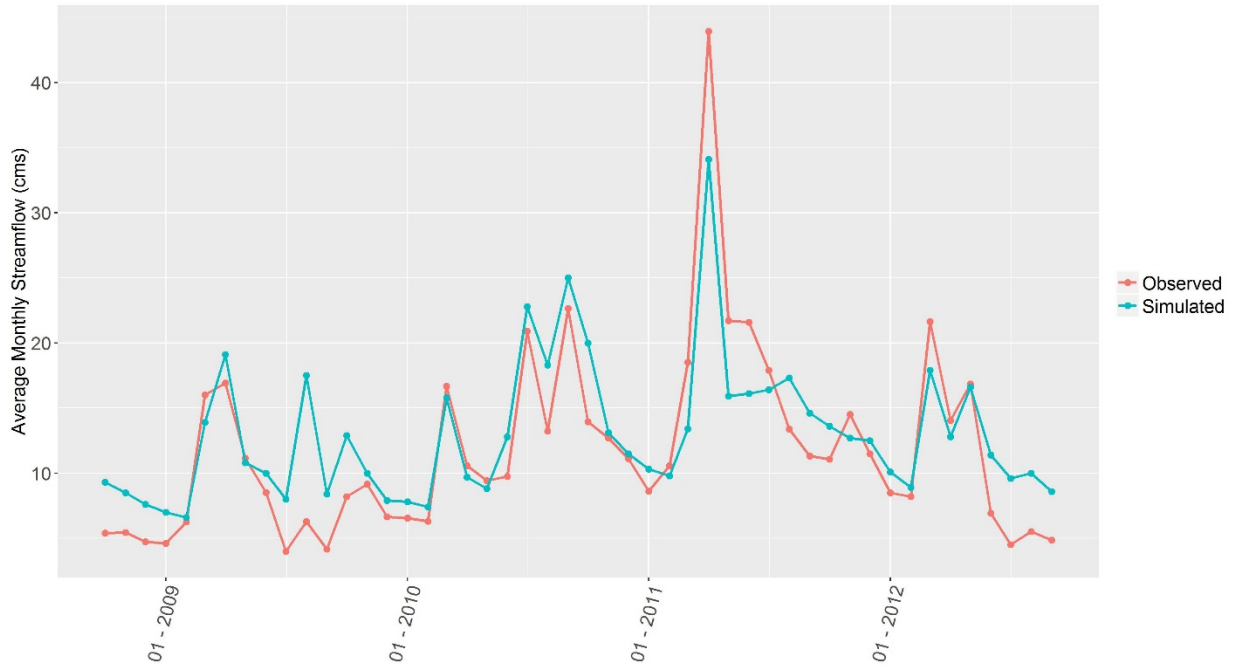


Figure D- 7. Monthly streamflow calibration hydrograph for USGS site 04080000 (Little Wolf River at Royalton, WI).

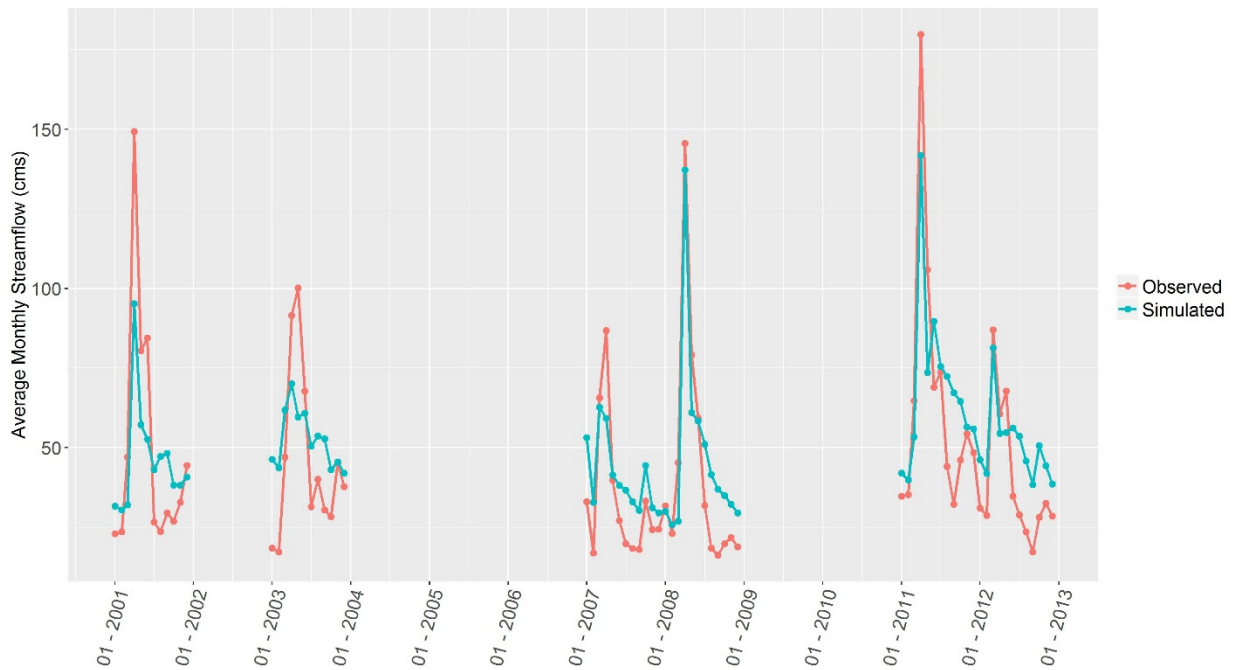


Figure D- 8. Monthly streamflow calibration hydrograph for USGS site 04079000 (Wolf River at New London, WI).

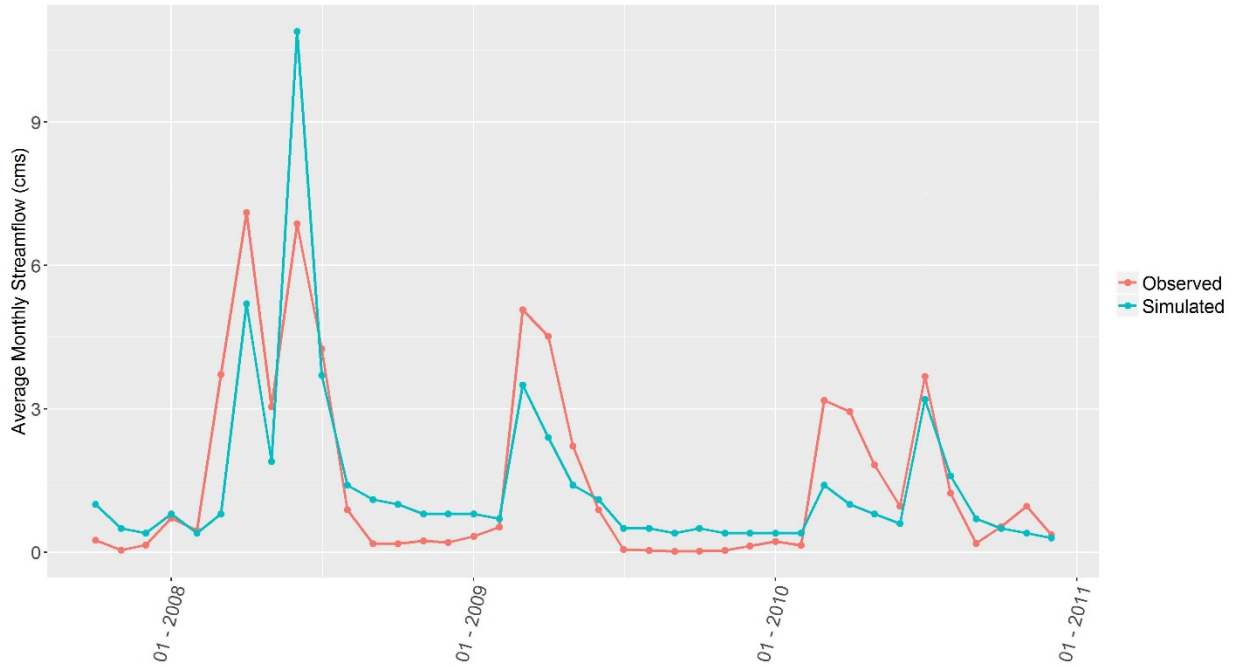


Figure D- 9. Monthly streamflow calibration hydrograph for USGS site 04073970 (Waukau Creek near Omro, WI).

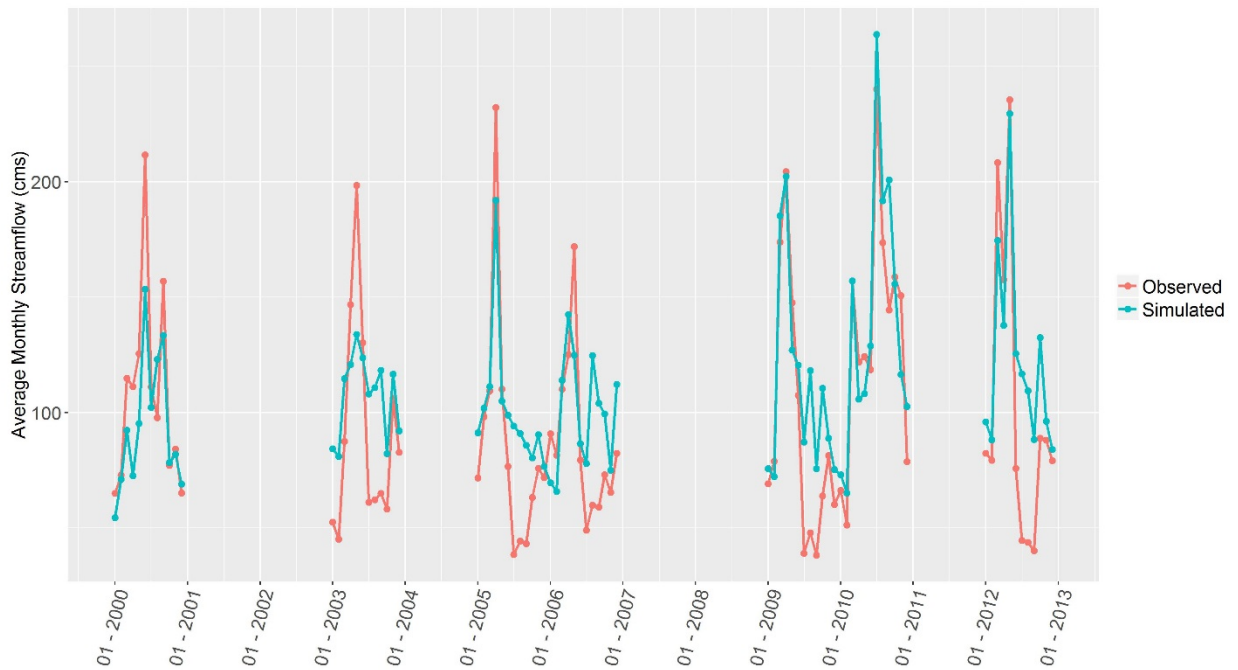


Figure D- 10. Monthly streamflow calibration hydrograph for USGS site 04082400 (Fox River at Oshkosh, WI).



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

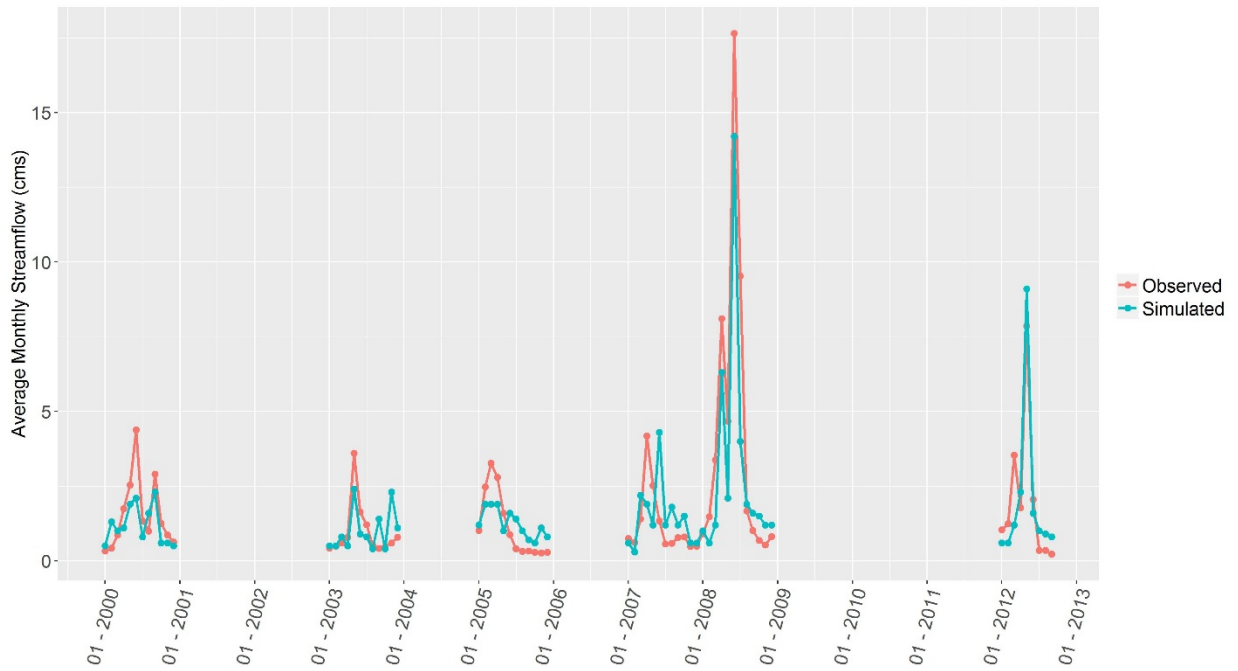


Figure D- 12. Monthly streamflow calibration hydrograph for USGS site 04073473 (Puchyan River DS N. Lawson Drive near Green Lake, WI).

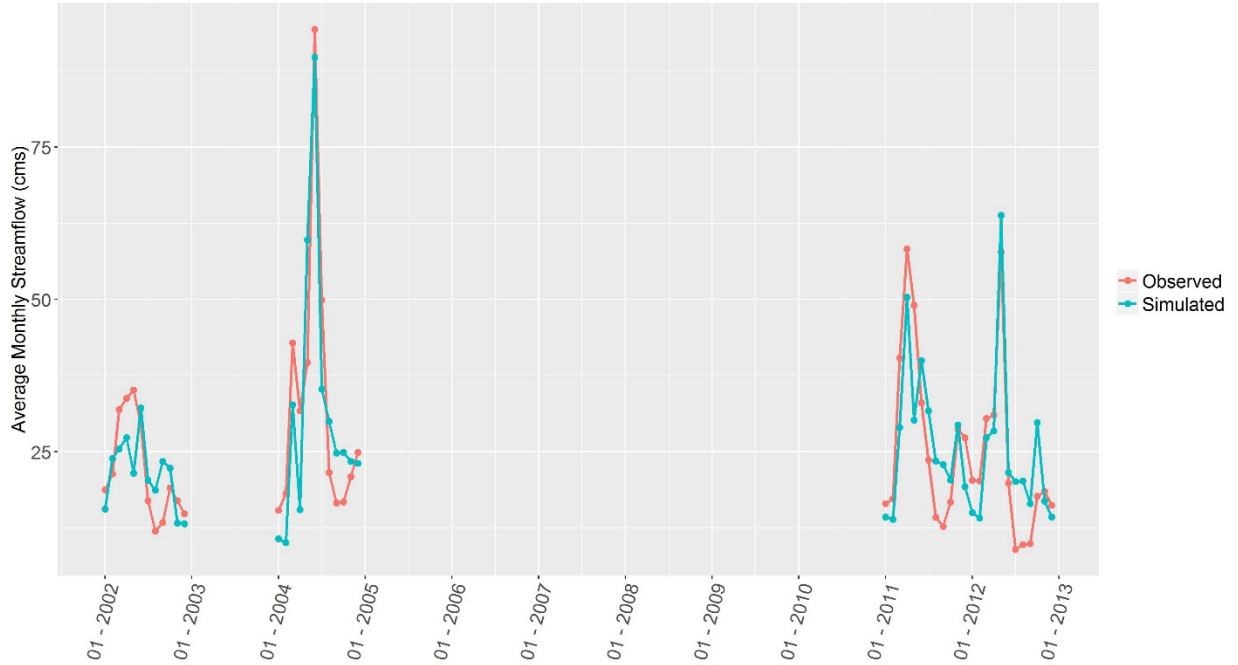


Figure D- 13. Monthly streamflow calibration hydrograph for USGS site 04073365 (Fox River at Princeton, WI).

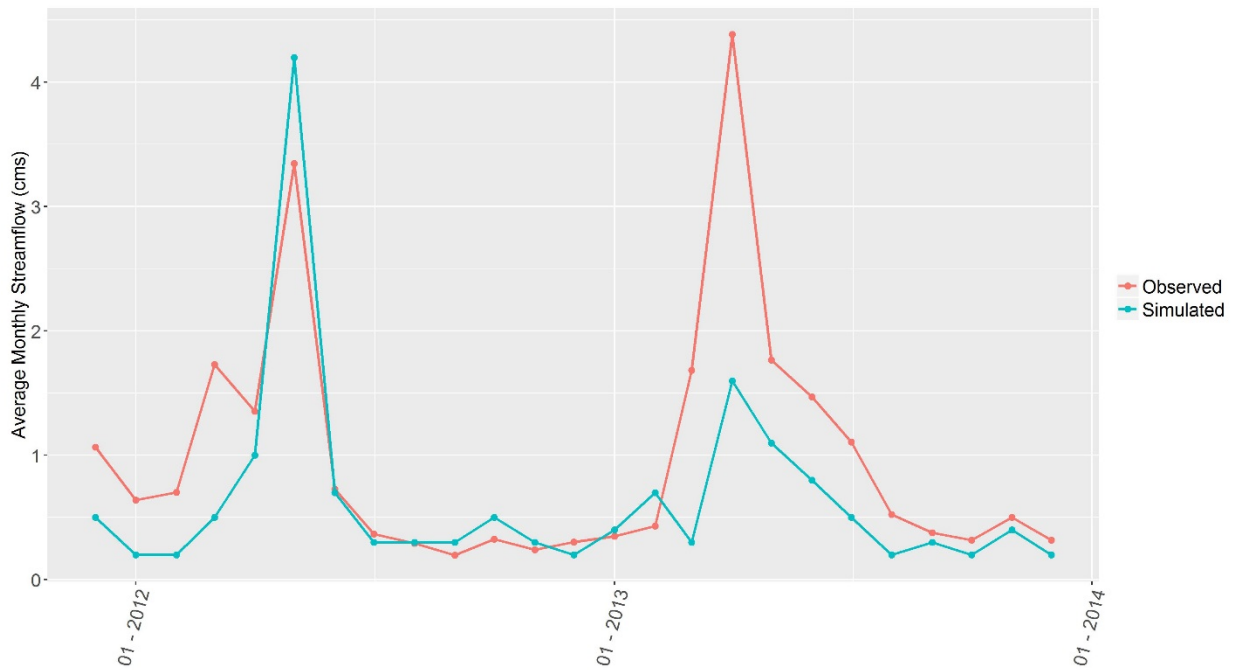


Figure D- 14. Monthly streamflow calibration hydrograph for USGS site 04073466 (Silver Creek at Spaulding Road near Green Lake, WI).

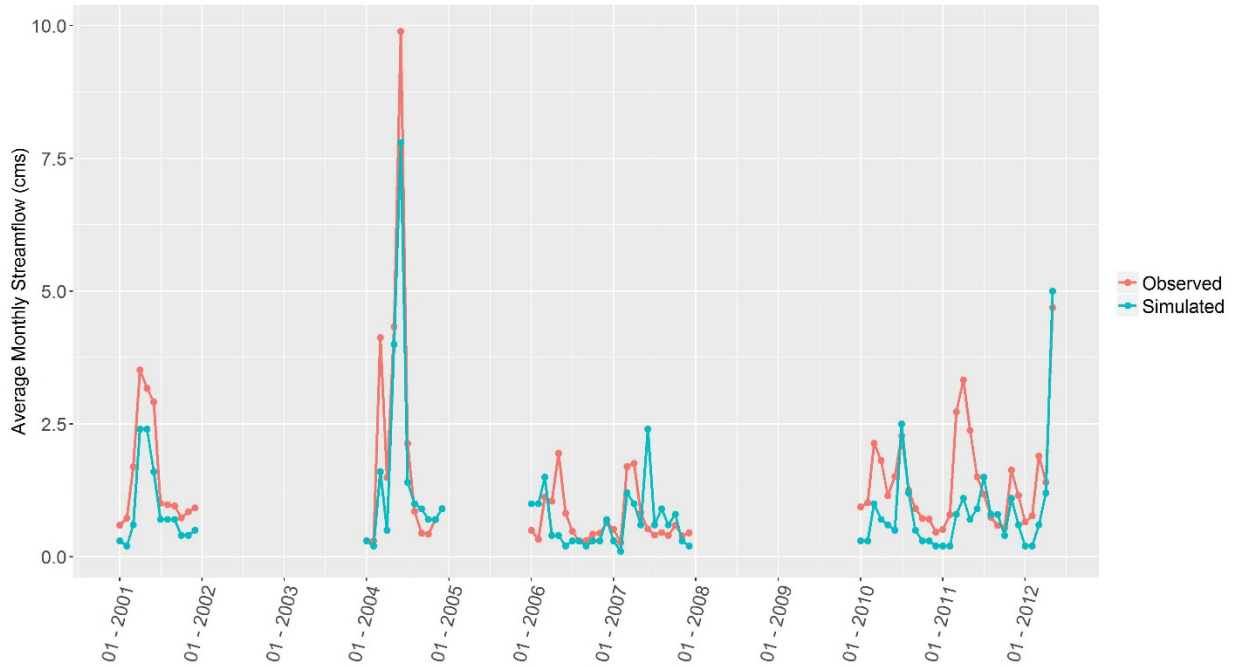


Figure D- 15. Monthly streamflow calibration hydrograph for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

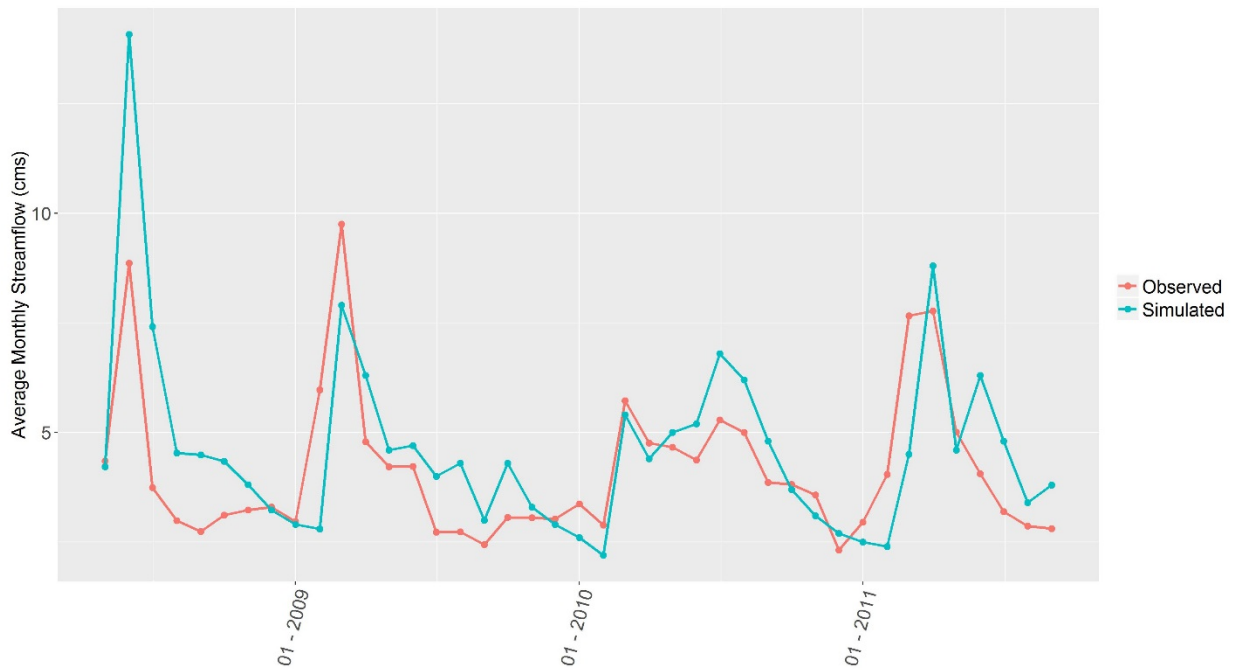


Figure D- 16. Monthly streamflow calibration hydrograph for USGS site 04072845 (Montello River near Montello, WI).

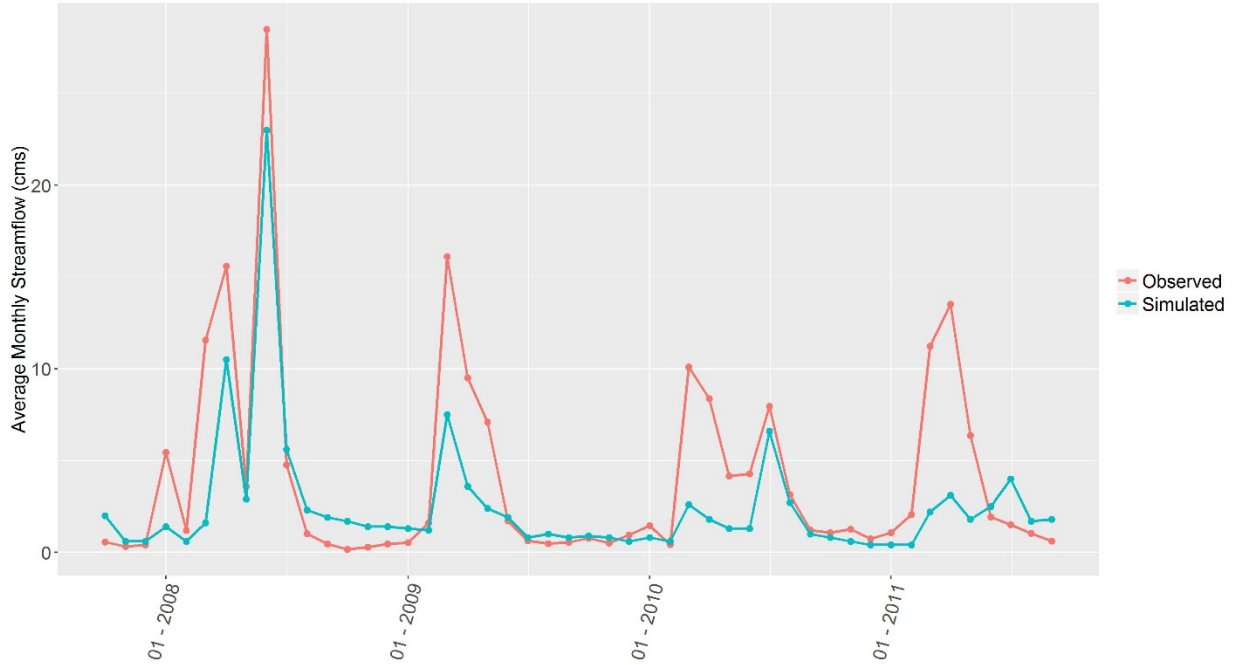


Figure D- 17. Monthly streamflow calibration hydrograph for USGS site 04083545 (Fond Du Lac River @ W. Arndt St. at Fond Du Lac, WI).

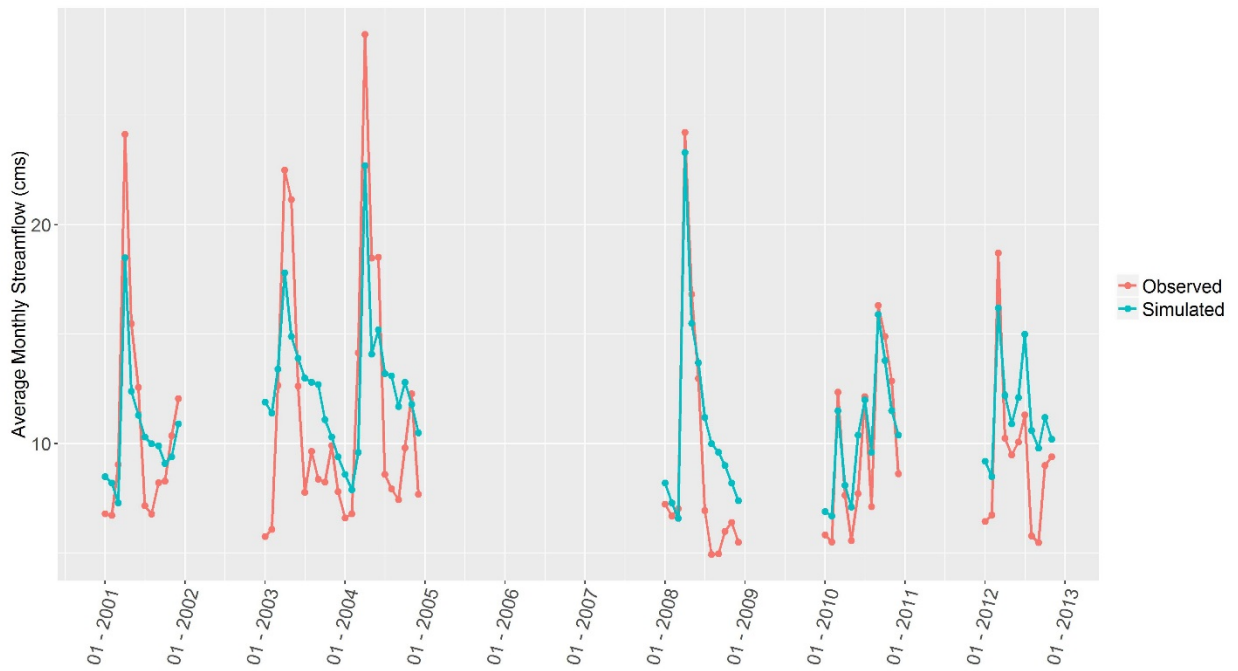


Figure D- 18. Monthly streamflow validation hydrograph for USGS site 04074950 (Wolf River at Langlade, WI).

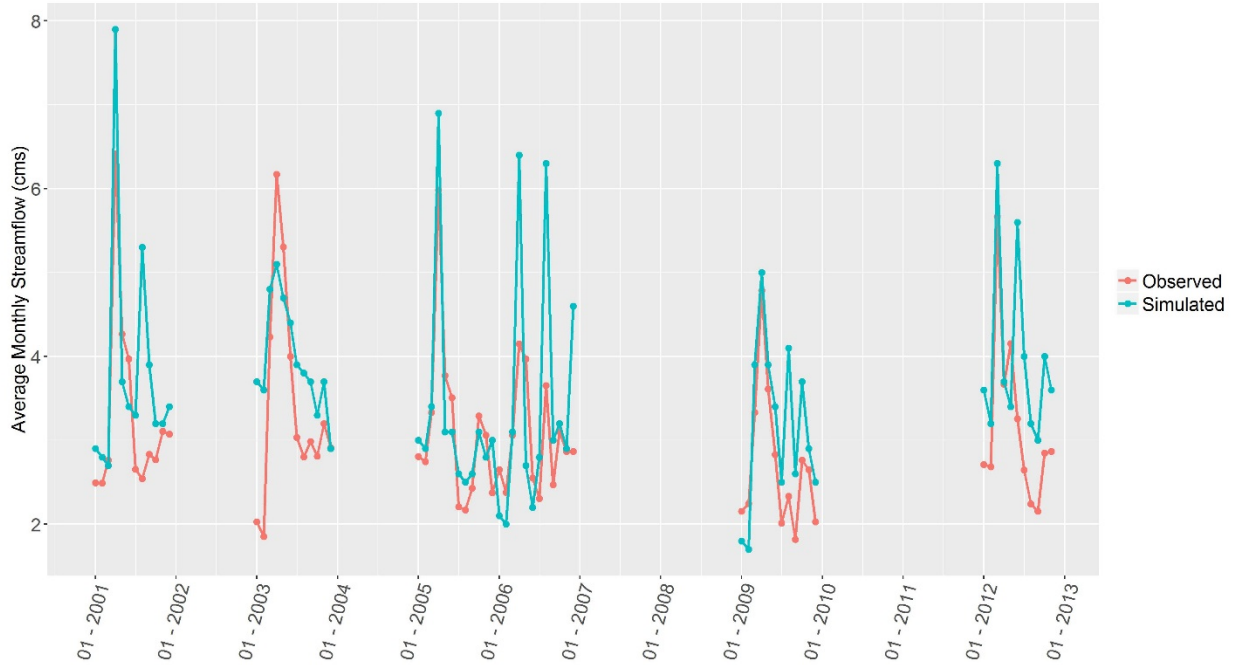


Figure D- 19. Monthly streamflow validation hydrograph for USGS site 04077630 (Red River at Morgan Road near Morgan, WI).

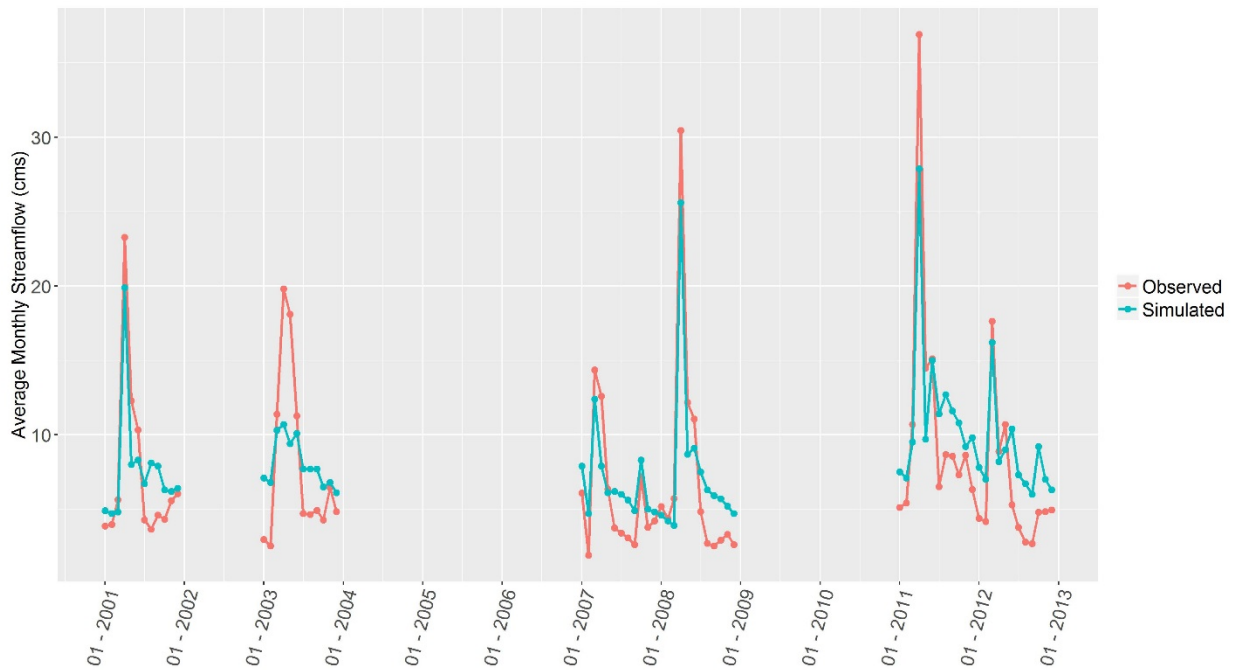


Figure D- 20. Monthly streamflow validation hydrograph for USGS site 04078500 (Embarrass River near Embarrass, WI).

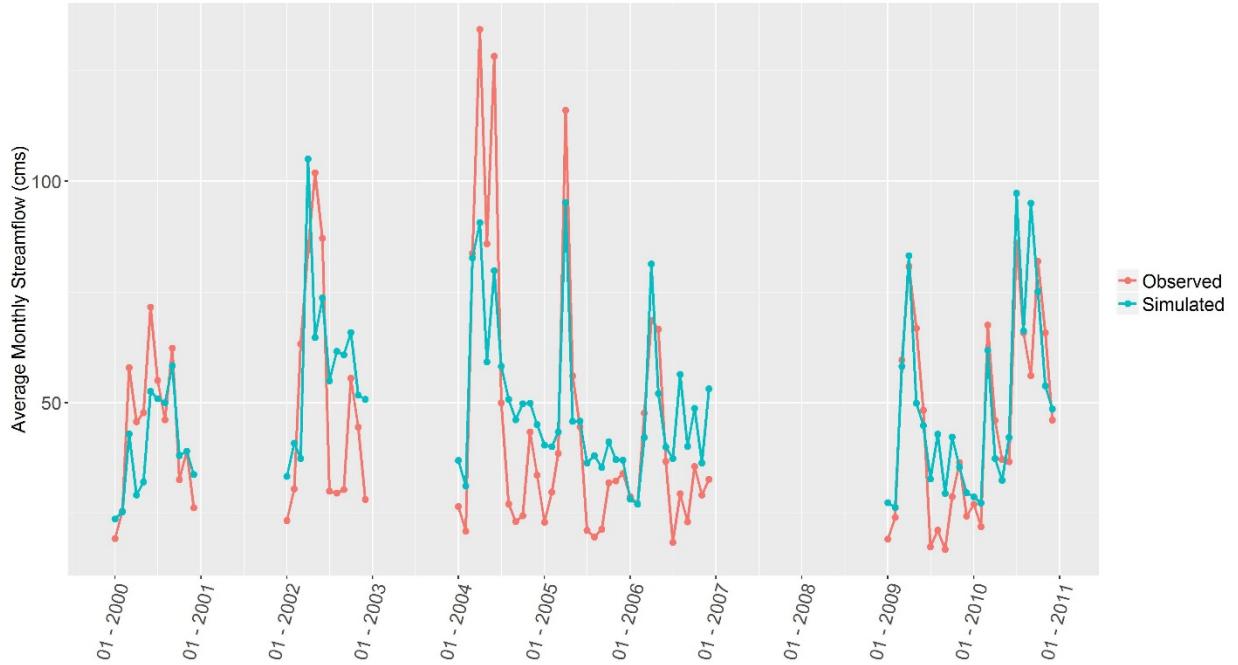


Figure D- 21. Monthly streamflow validation hydrograph for USGS site 04079000 (Wolf River at New London, WI).

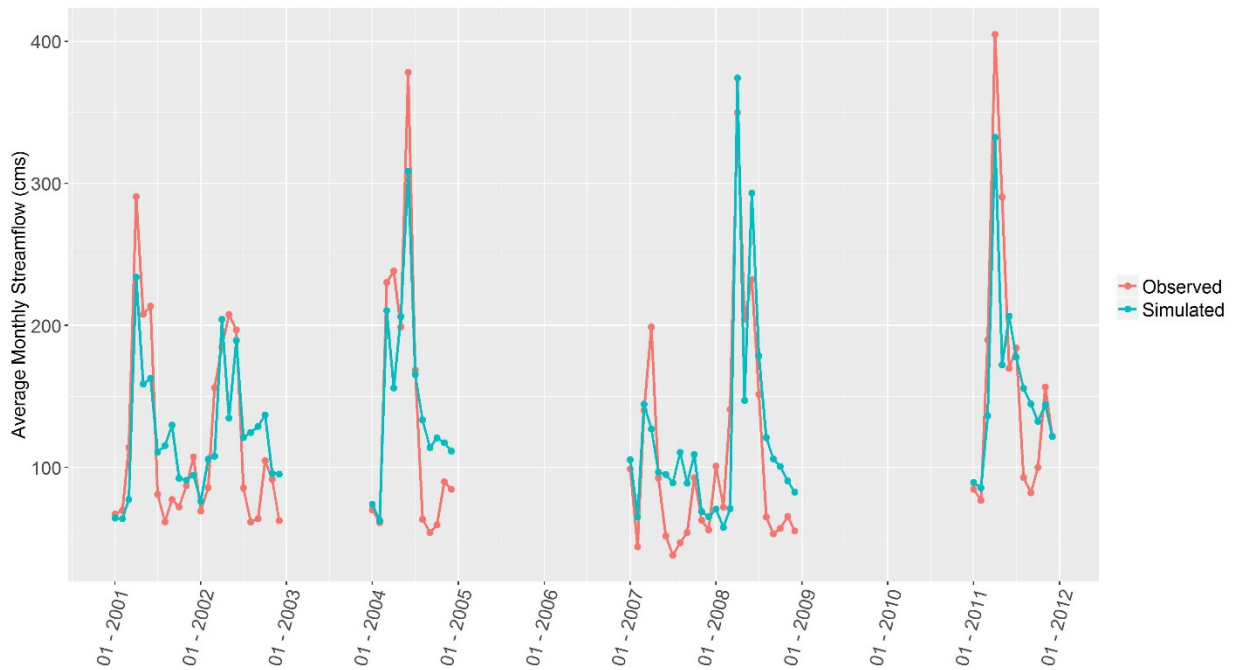


Figure D- 22. Monthly streamflow validation hydrograph for USGS site 04082400 (Fox River at Oshkosh, WI).



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

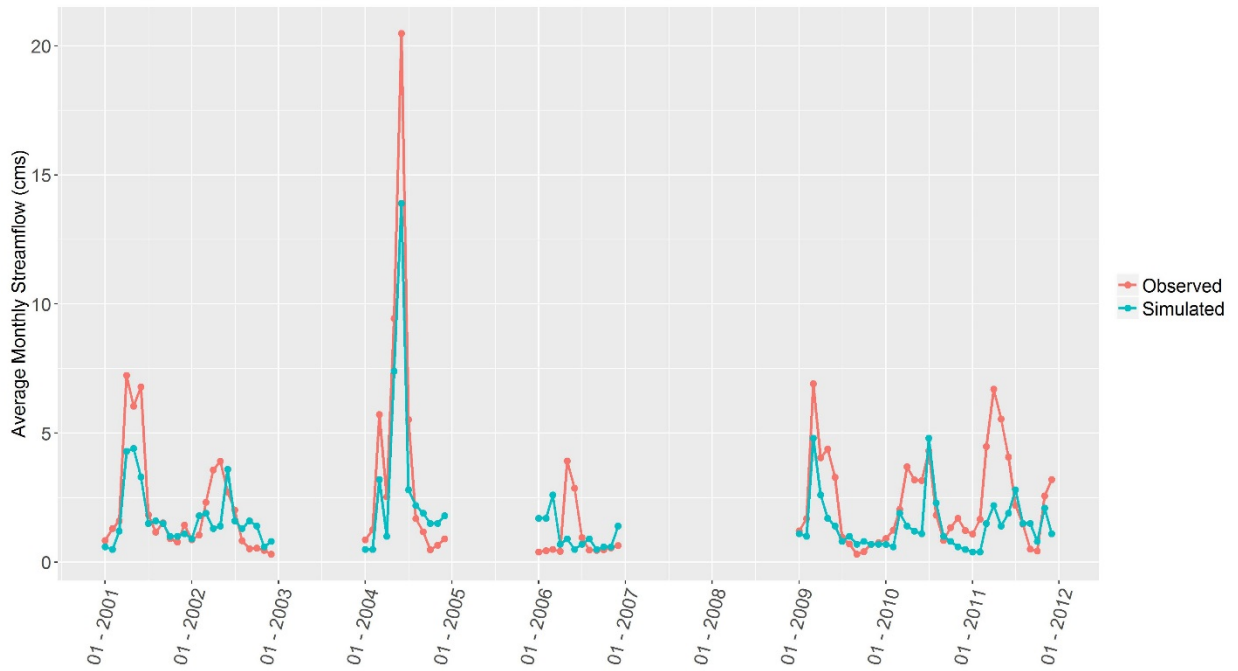


Figure D- 24. Monthly streamflow validation hydrograph for USGS site 04073473 (Puchyan River DS N. Lawson Drive near Green Lake, WI).

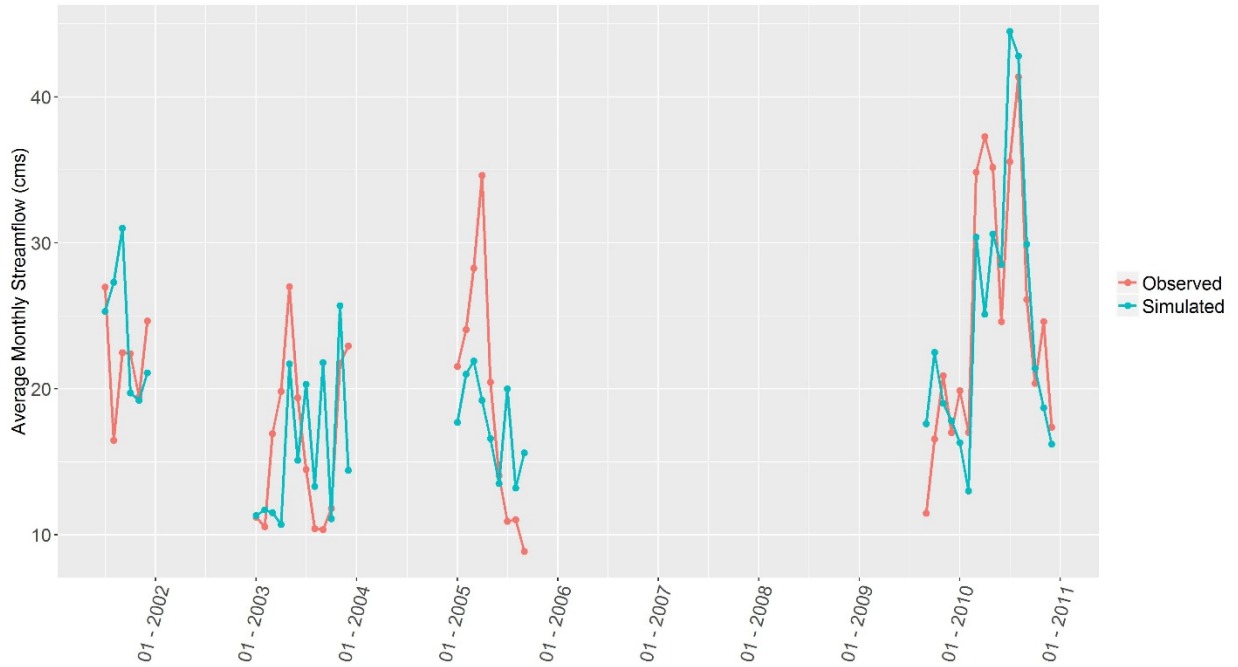


Figure D- 25. Monthly streamflow validation hydrograph for USGS site 04073365 (Fox River at Princeton, WI).

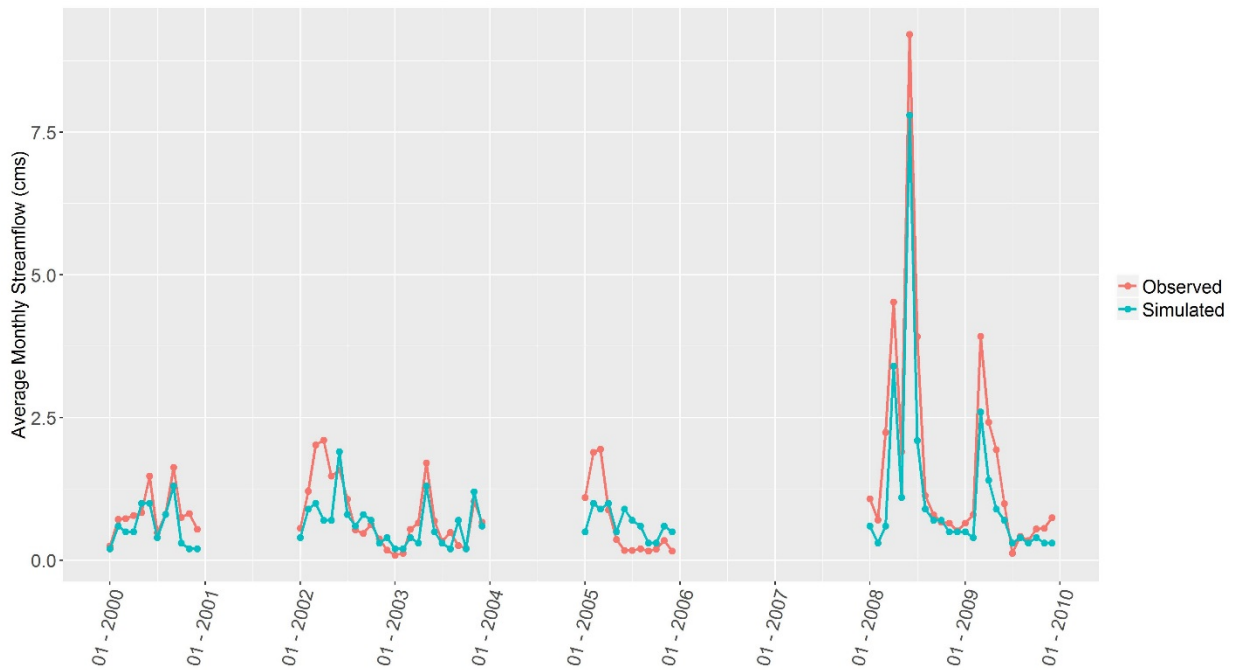


Figure D- 26. Monthly streamflow validation hydrograph for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

Appendix E. Sediment Calibration and Validation Time Series Plots

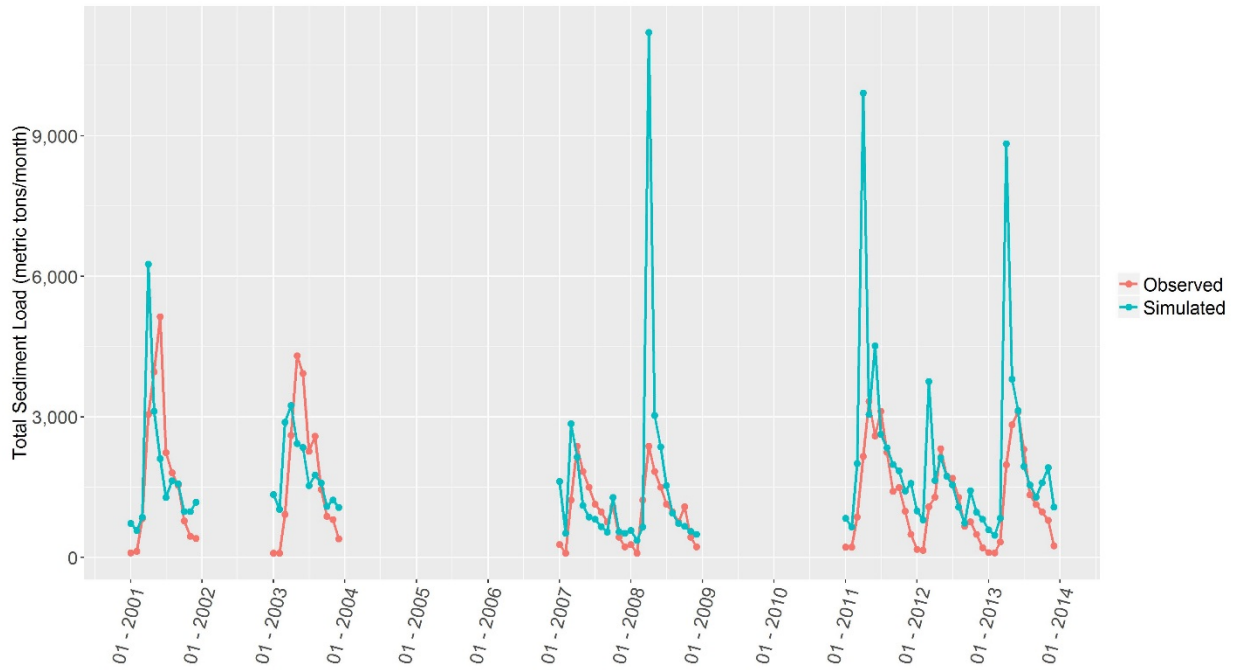


Figure E- 1. Monthly sediment calibration plot for USGS site 04079000 (Wolf River at New London, WI).

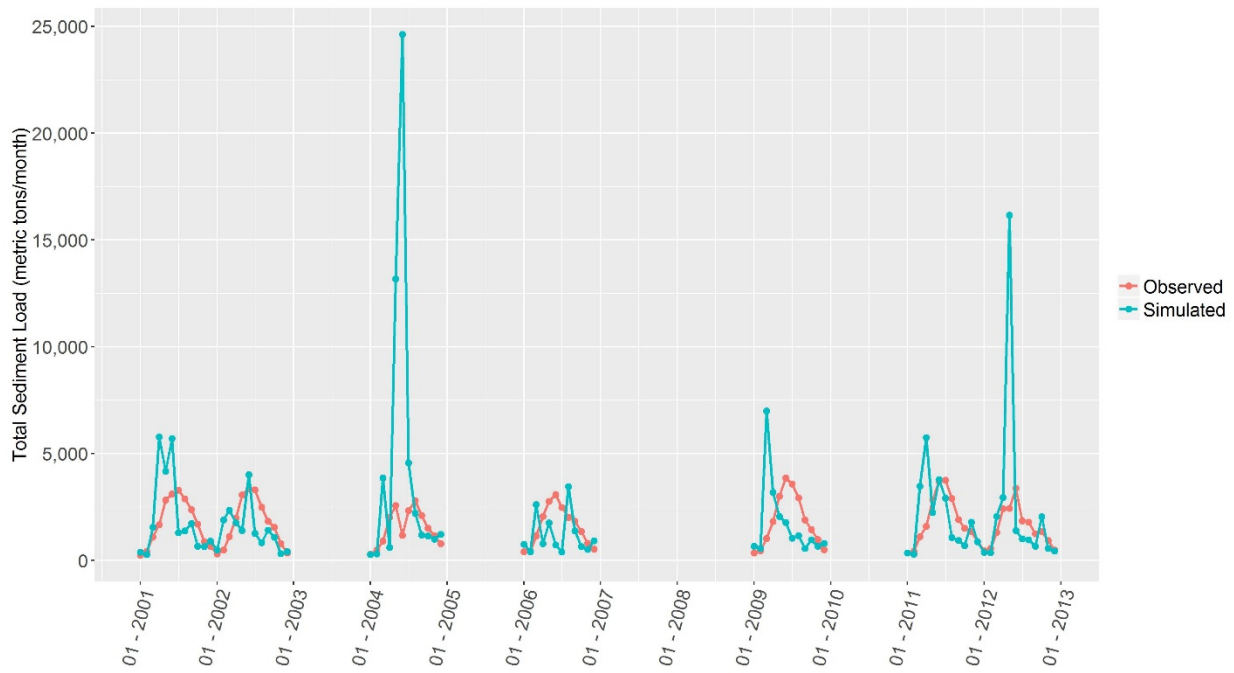


Figure E- 2. Monthly sediment calibration plot for USGS site 04073500 (Fox River at Berlin, WI).

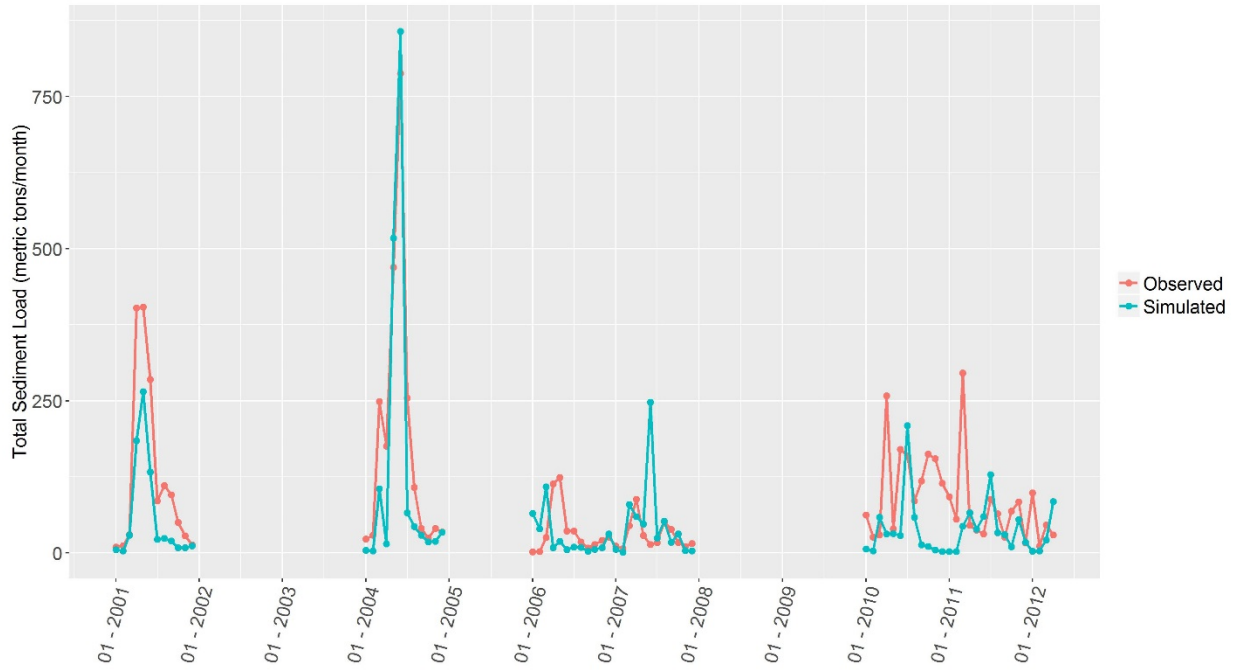


Figure E- 3. Monthly sediment calibration plot for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

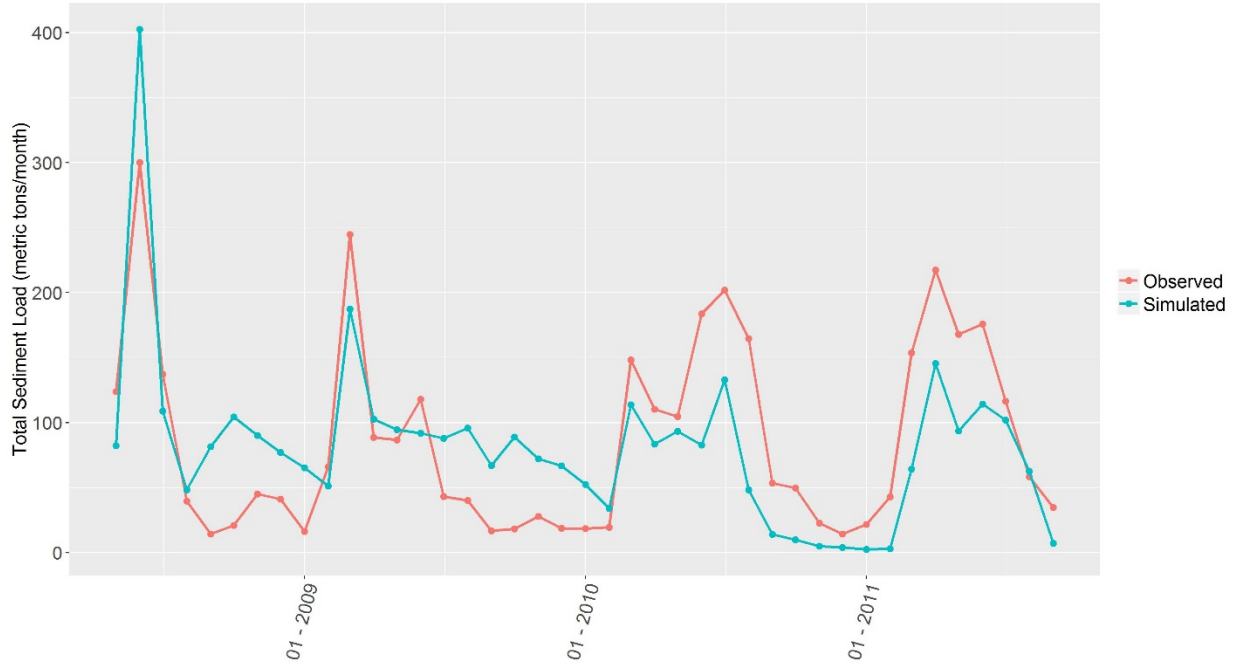


Figure E- 4. Monthly sediment calibration plot for USGS site 04072845 (Montello River near Montello, WI).

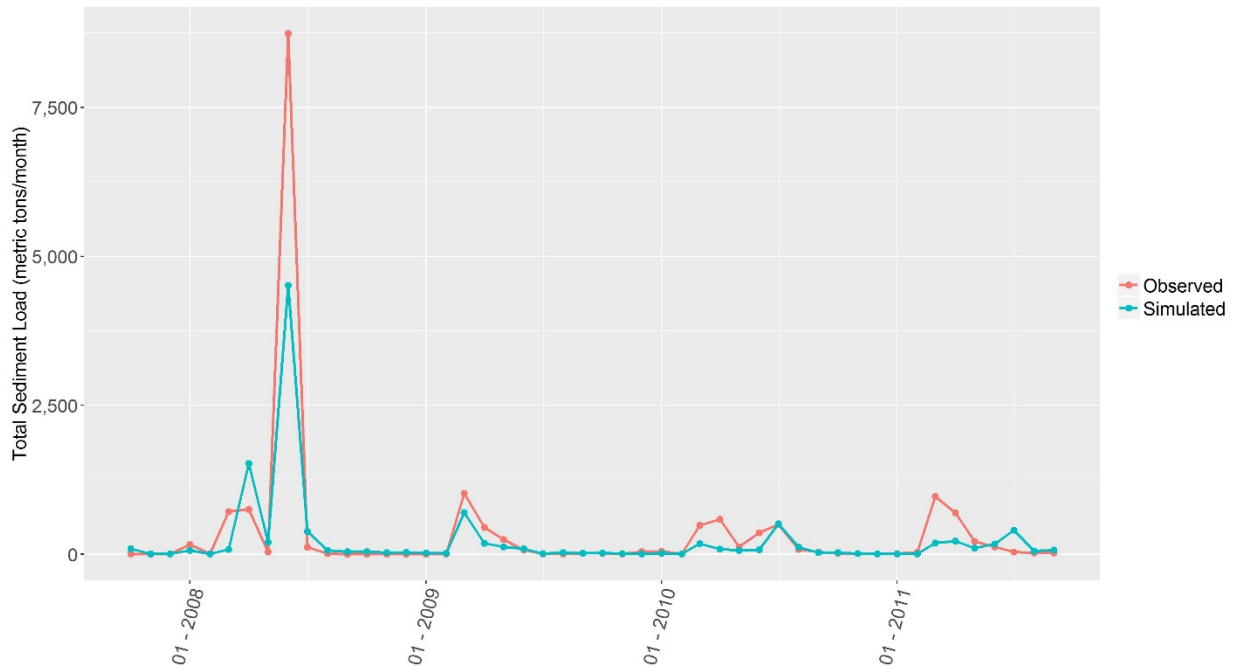


Figure E- 5. Monthly sediment calibration plot for USGS site 04083545 (Fond Du Lac River @ W. Arndt St. At Fond Du Lac, WI).

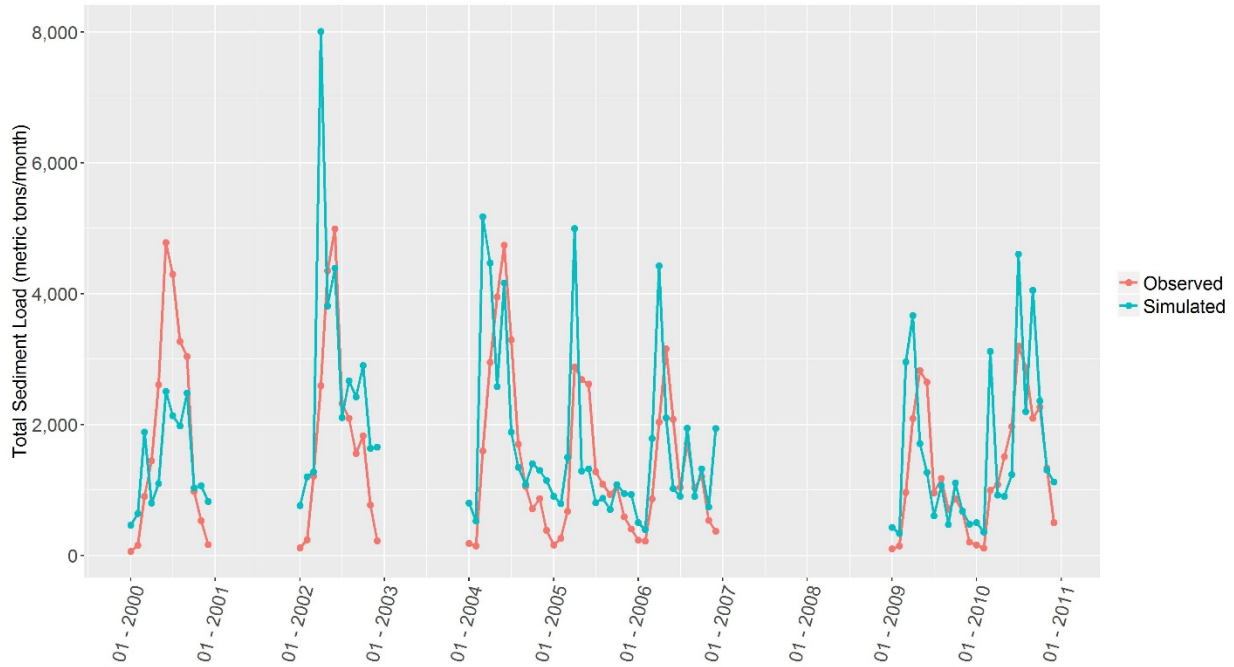


Figure E- 6. Monthly sediment validation plot for USGS site 04079000 (Wolf River at New London, WI).

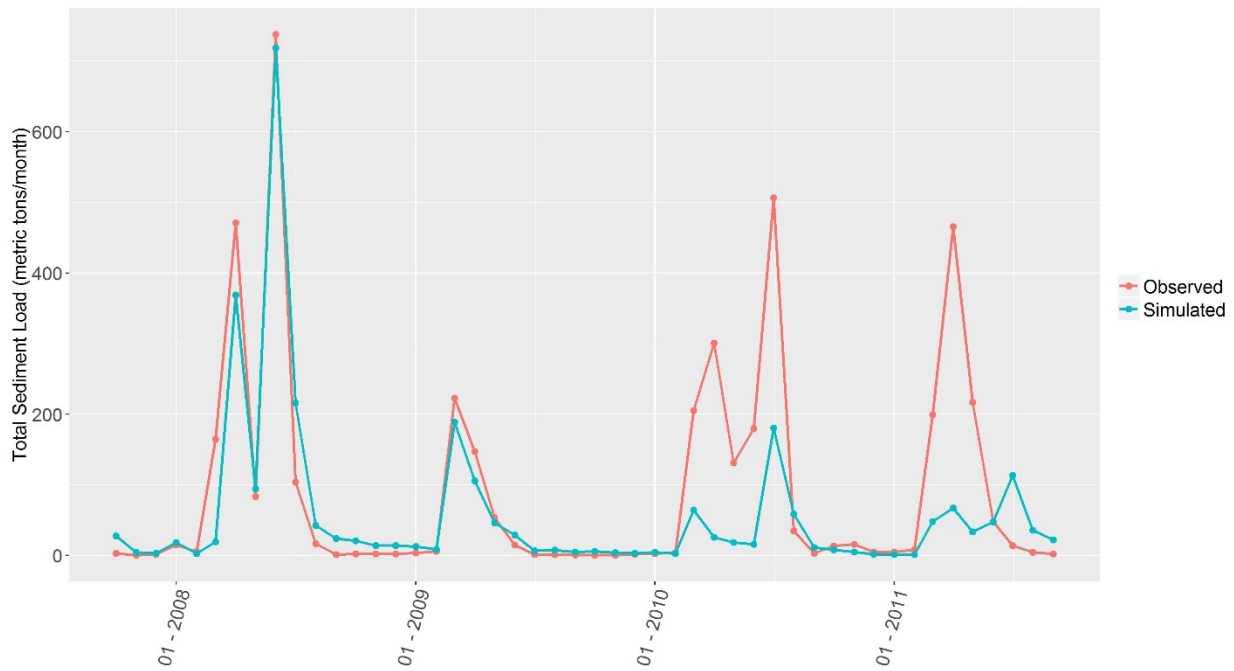


Figure E- 7. Monthly sediment validation plot for USGS site 04073970 (Waukau Creek near Omro, WI).

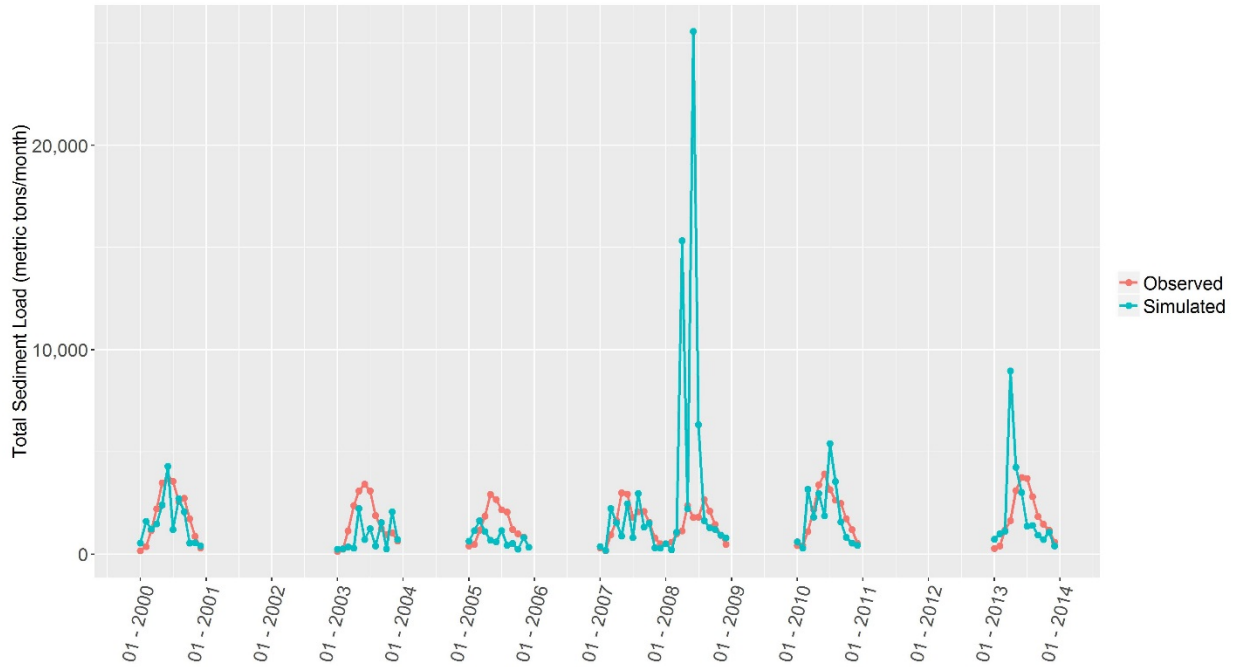


Figure E- 8. Monthly sediment validation plot for USGS site 04073500 (Fox River at Berlin, WI).

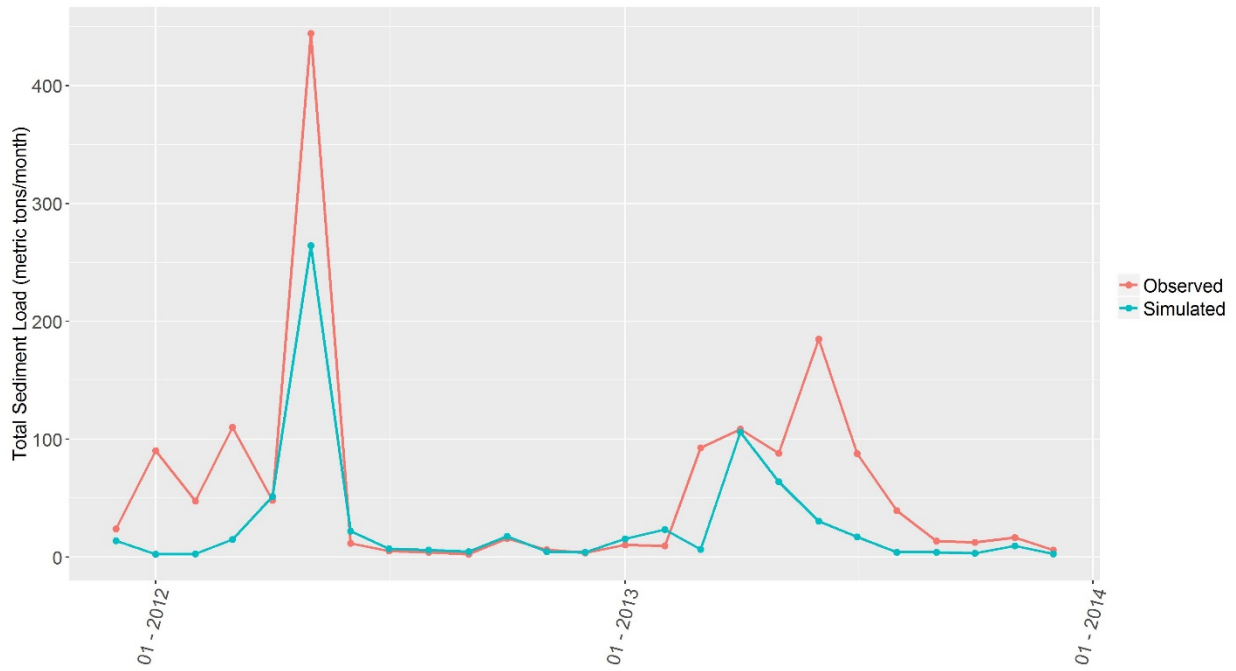


Figure E- 9. Monthly sediment validation plot for USGS site 04073466 (Silver Creek at Spaulding Road near Green Lake, WI).

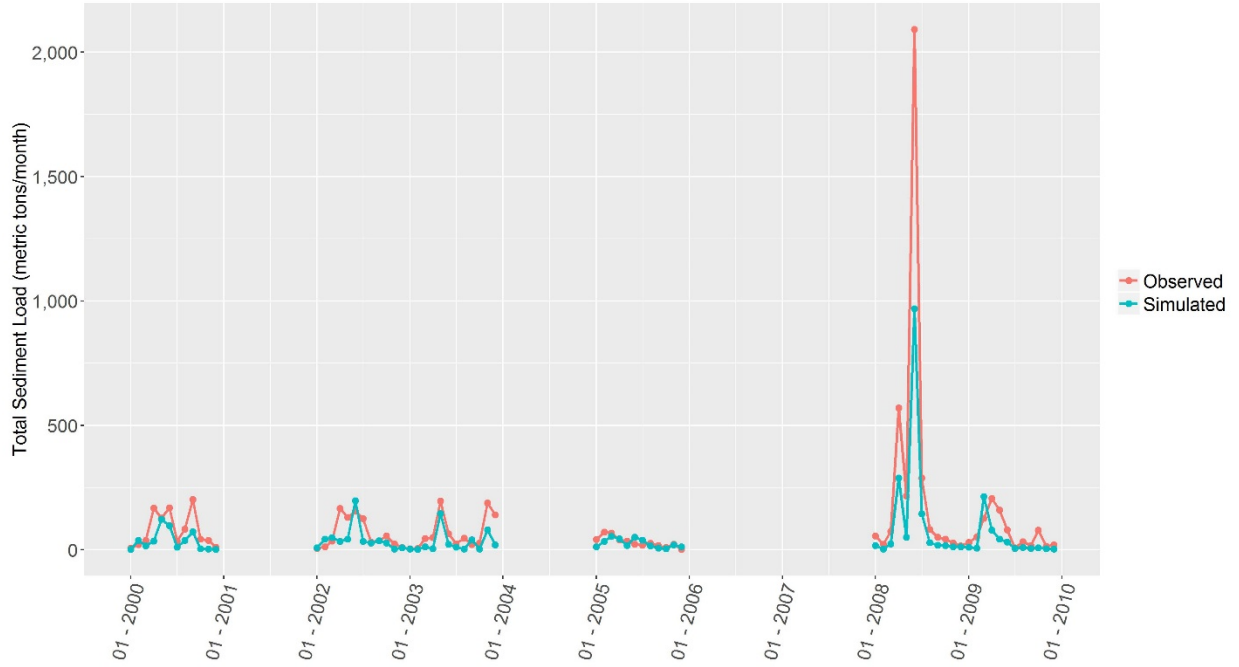


Figure E- 10. Monthly sediment validation plot for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

Appendix F. Phosphorus Calibration and Validation Time Series Plots

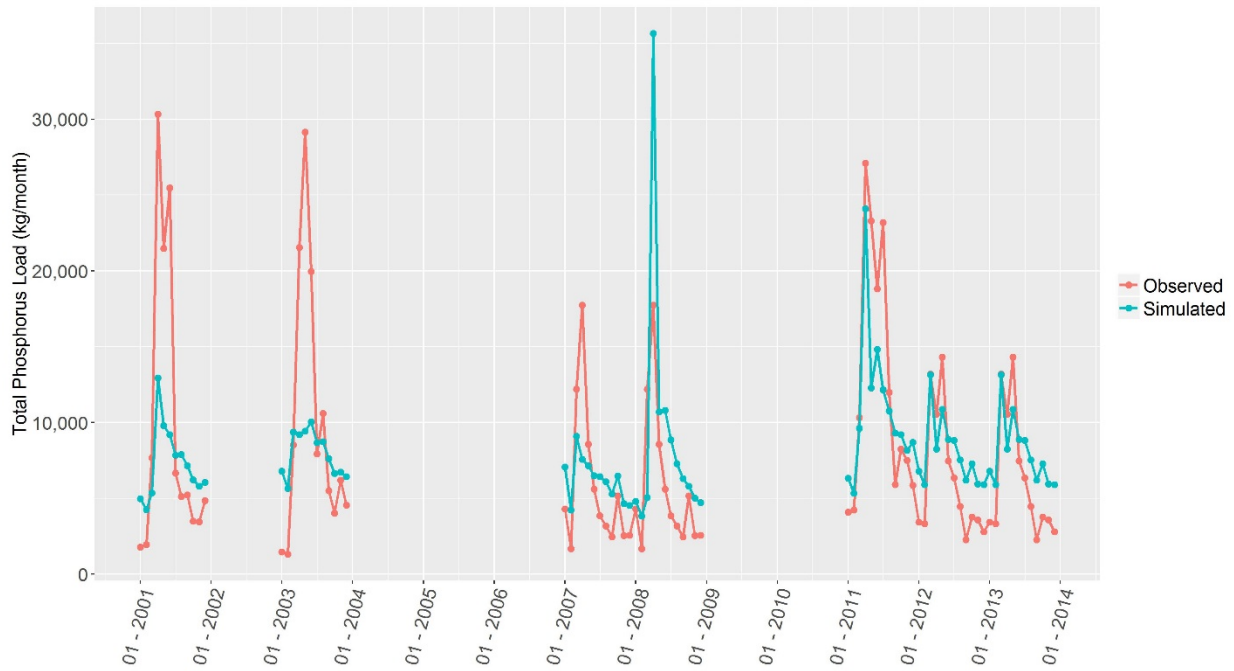


Figure F- 1. Monthly total phosphorus calibration plot for USGS site 04079000 (Wolf River at New London, WI).

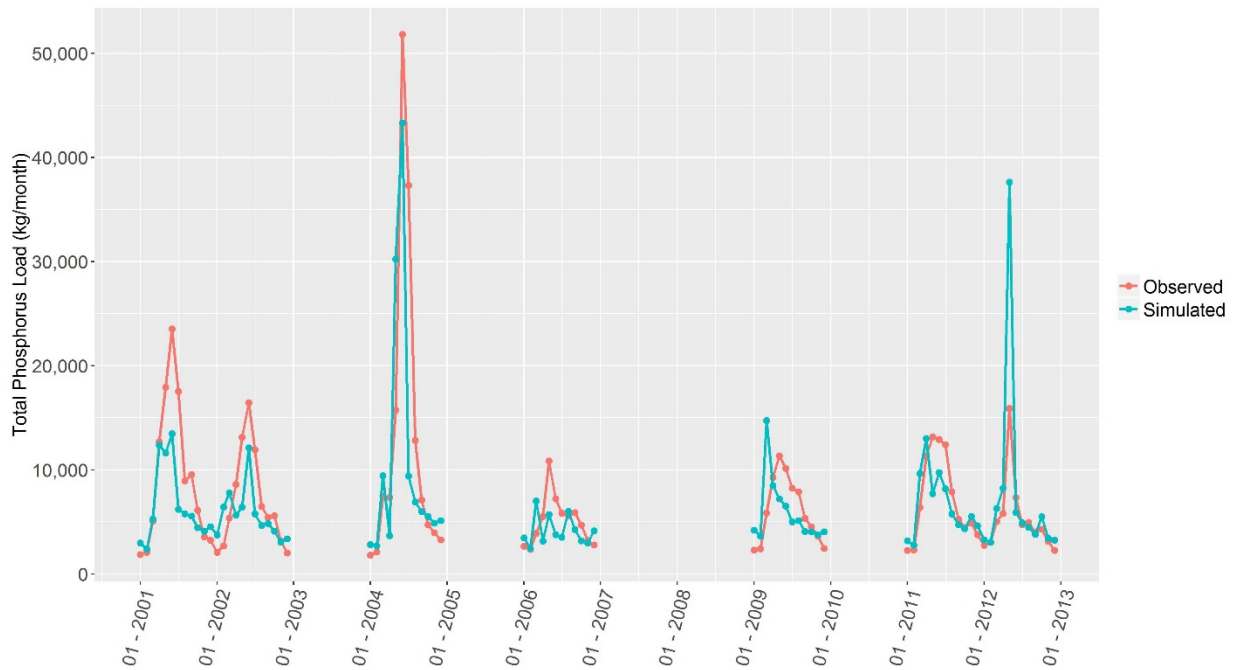


Figure F- 2. Monthly total phosphorus calibration plot for USGS site 04073500 (Fox River at Berlin, WI).

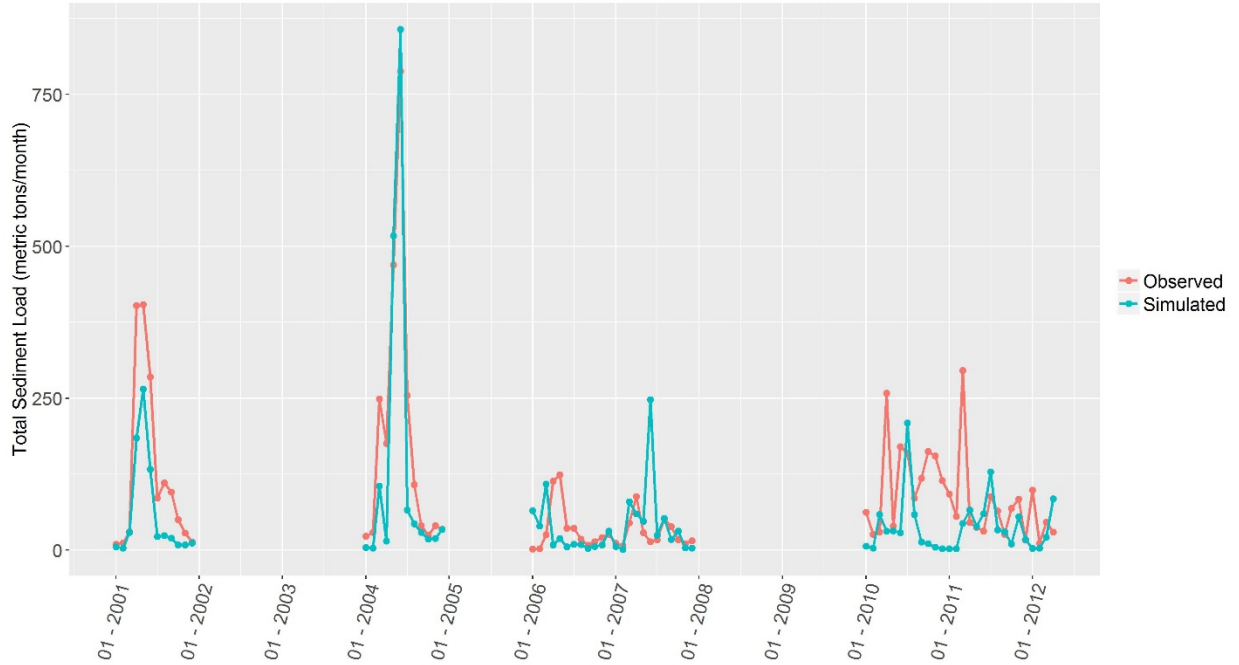


Figure F- 3. Monthly total phosphorus calibration plot for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).

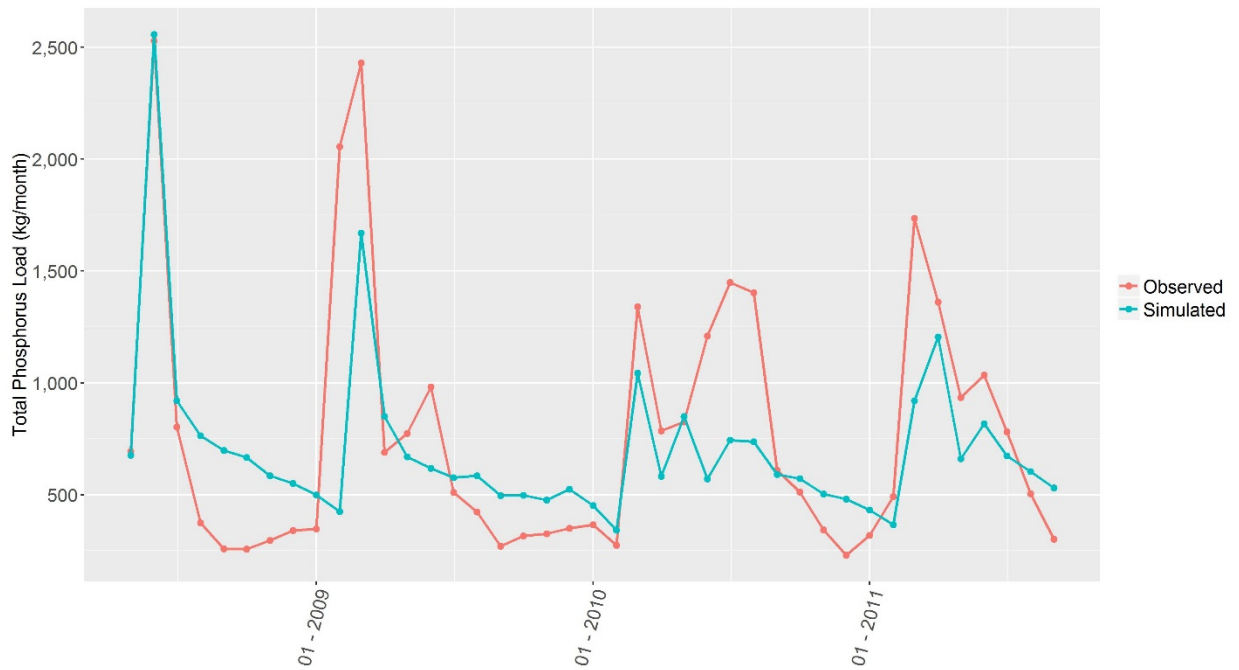


Figure F- 4. Monthly total phosphorus calibration plot for USGS site 04072845 (Montello River near Montello, WI).

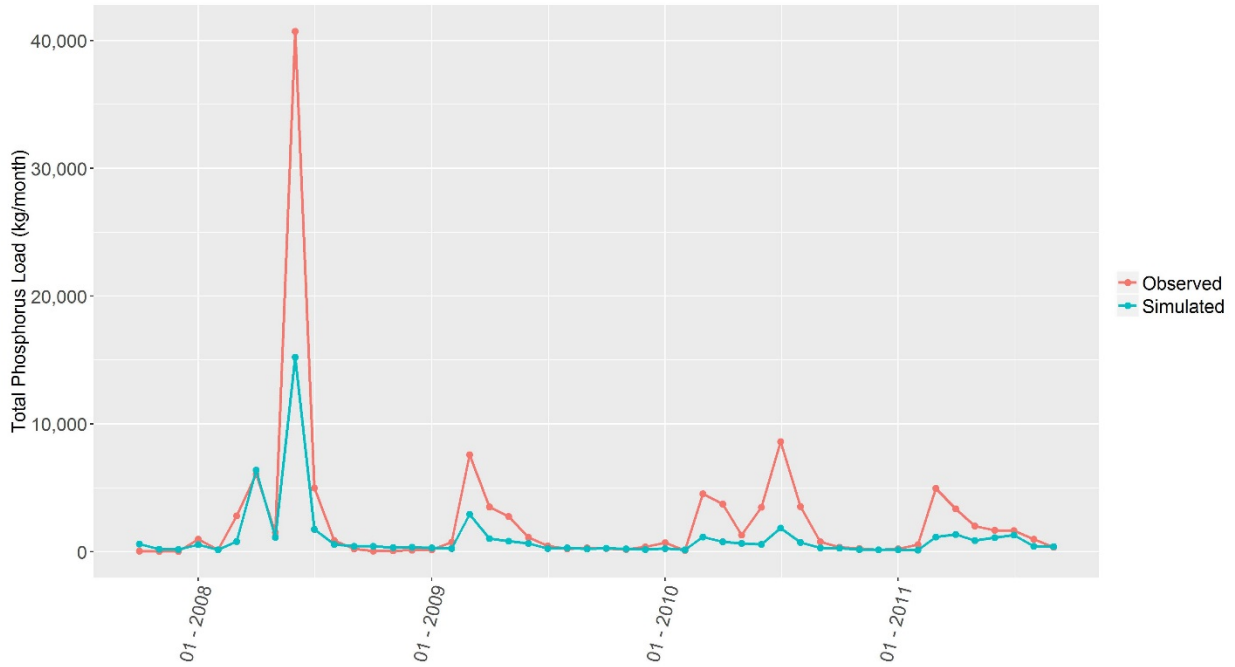


Figure F- 5. Monthly total phosphorus calibration plot for USGS site 04083545 (Fond du Lac River @ W. Arndt St. at Fond du Lac, WI).

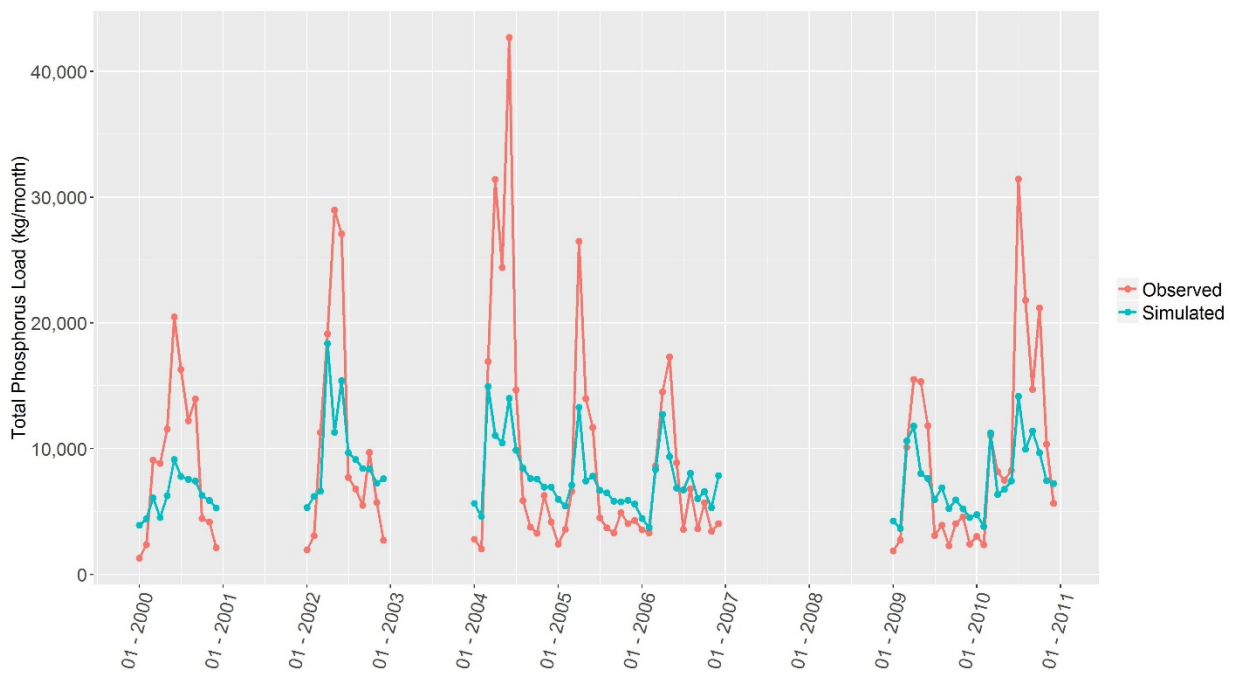


Figure F- 6. Monthly total phosphorus validation plot for USGS site 04079000 (Wolf River at New London, WI).

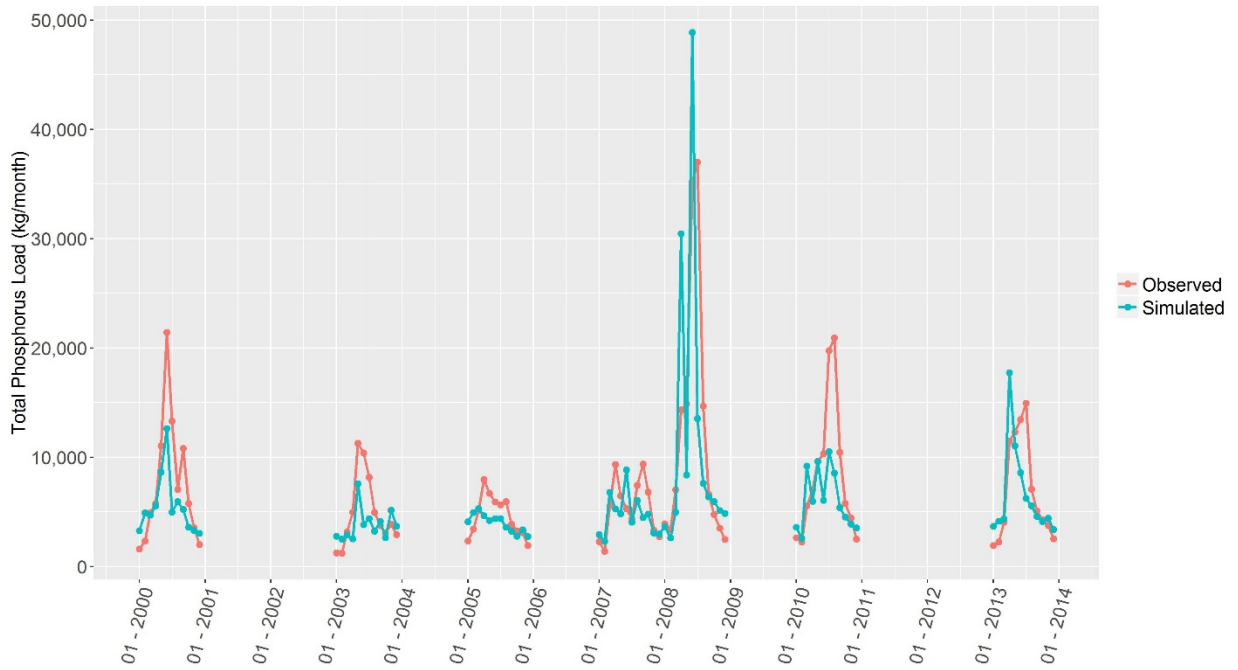


Figure F- 7. Monthly total phosphorus calibration plot for USGS site 04073500 (Fox River at Berlin, WI).

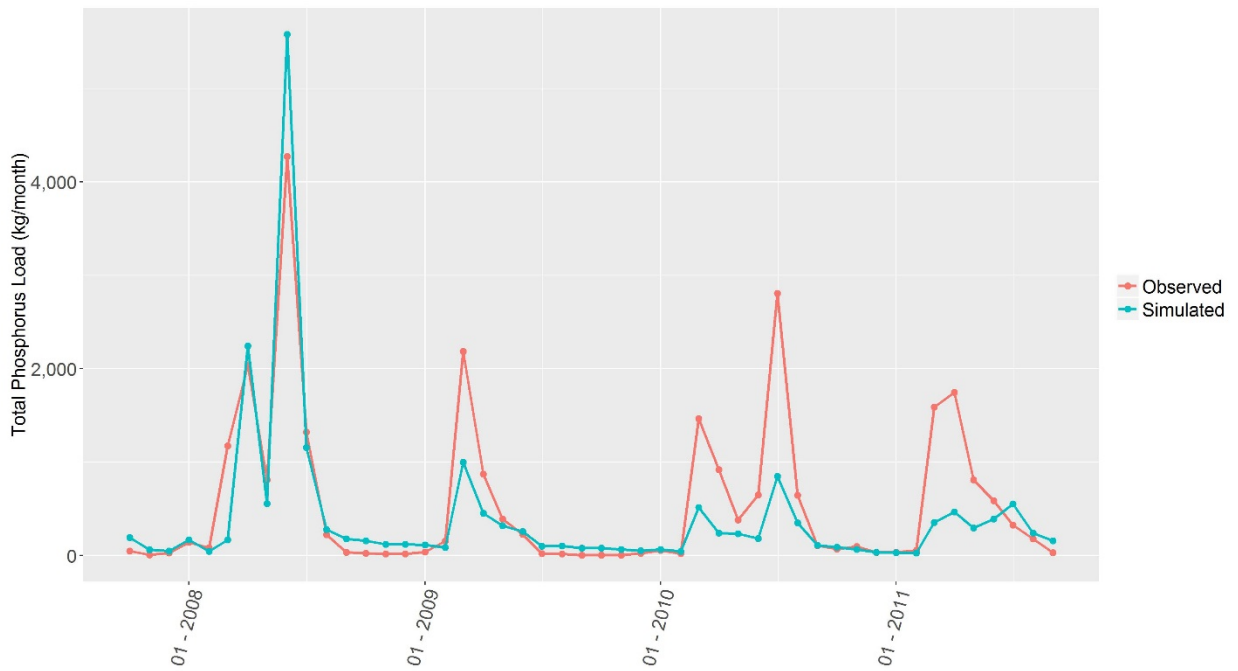


Figure F- 8. Monthly total phosphorus validation plot for USGS site 04073970 (Waukau Creek near Omro, WI).

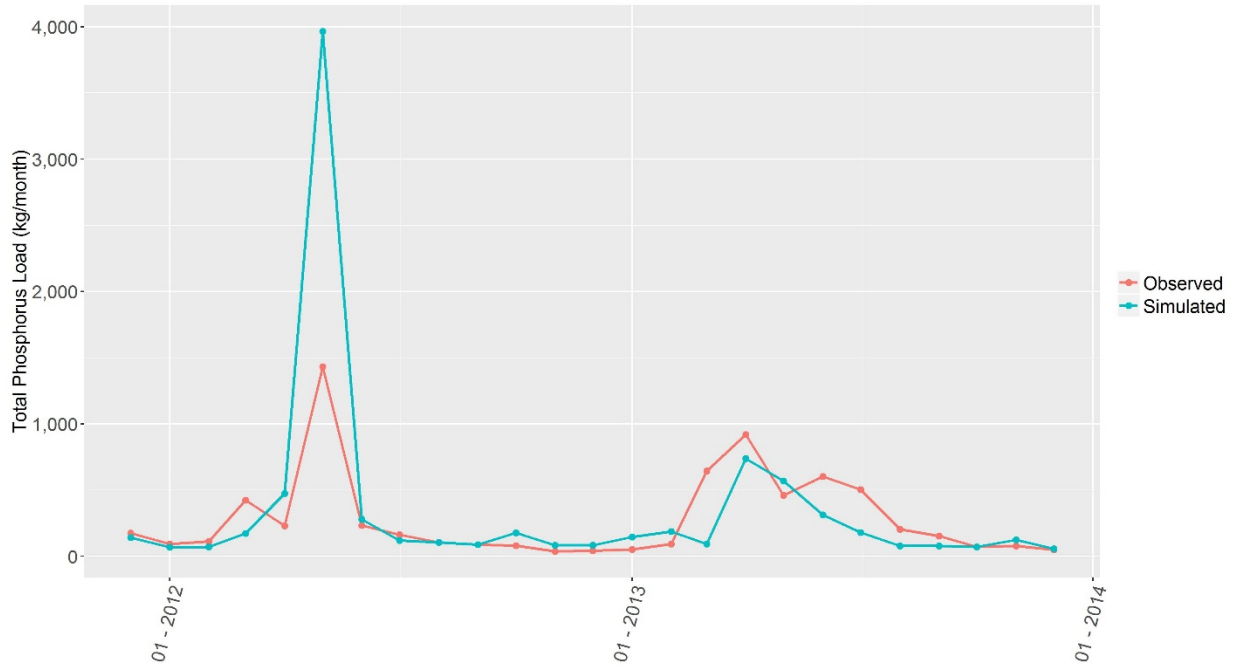


Figure F- 9. Monthly total phosphorus validation plot for USGS site 04073466 (Silver Creek at Spaulding Road near Green Lake, WI).

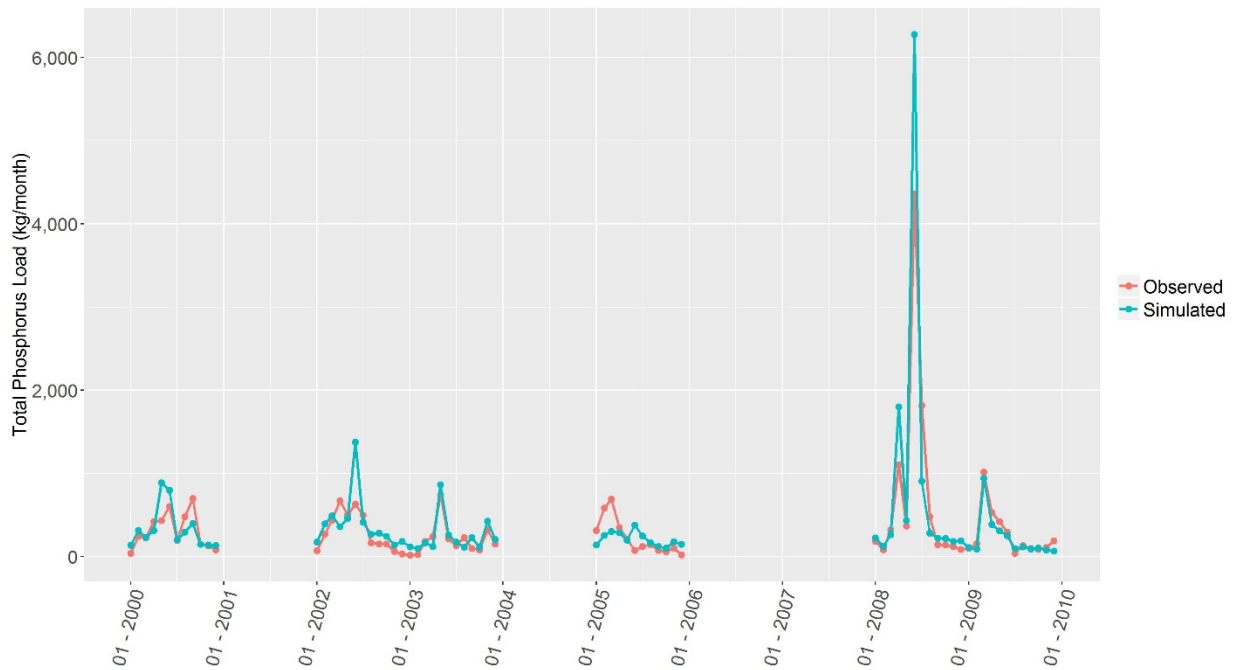


Figure F- 10. Monthly total phosphorus validation plot for USGS site 04073468 (Green Lake Inlet at Ct Highway A near Green Lake, WI).