Buffalo River Watershed HSPF Modeling

Final Report December 31, 2013

Houston Engineering Inc.

BUFFALO - RED RIVER WATERSHED DISTRICT

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1.0 INTRODUCTION

The Buffalo-Red River Watershed District (BRRWD) and MN Pollution Control Agency (MPCA) are currently undertaking a Watershed Restoration and Protection (WRAP) project in the Buffalo River Watershed (BRW). The WRAP effort is a state-wide program sponsored by the MPCA and supported through use of the Clean Water Legacy Fund. In an effort to expedite the completion of WRAPs, the MPCA is constructing watershed models, which have the potential to support simultaneous development of restoration and protection strategies for all waters within a given watershed. The Hydrologic Simulation Program-FORTRAN (HSPF) model was chosen for use in the BRW.

A series of reports and memoranda have been written and previously submitted to the MPCA to explain different components of the BRW HSPF model, including: model segmentation and development, the availability and selection of flow data for hydrologic calibration/validation, the simulation of point sources and atmospheric deposition within the model, hydrologic calibration and validation, and sediment sourcing and calibration. This report serves as the final report for the BRW HSPF model and summarizes the modeling project.

1.1 Purpose and Objective

The overall goal of this project is to successfully develop, calibrate, and validate a HSPF model for the BRW. The fully functioning HSPF model will successfully simulate the following at a 12-didgit Hydrologic Unit Code (HUC; or similar scale) level:

- Hydrology;
- Sediment;
- Water temperature;
- Dissolved oxygen (DO);
- Biologic oxygen demand (BOD);
- Phosphorus (P);
- Nitrogen (N); and
- Chlorophyll-*a* (Chl-*a*).

1.2 Watershed Description

The BRW (HUC 09020106) is located in Northwestern Minnesota in parts of Becker, Clay, Ottertail, and Wilkin Counties. The watershed is comprised of two main rivers, the South Branch of the Buffalo River and the Mainstem of the Buffalo River. The area is approximately 1130 square miles in size and is dominated by agricultural land uses with cultivated crops comprising 66% of the area. Forests (9%), grasslands (2%), pasture (7%), wetlands (7%), open water (4%), and urban areas (5%) make up the rest of the watershed. The BRW was split into two areas for HSPF model development, as summarized in the June 27, 2011 memorandum on the model framework. Splitting the study area into two was necessary to achieve the desired level of spatial detail in the resultant models for a watershed of this size. The segmentation of the BRW HSPF models is shown in **Figure 1**.

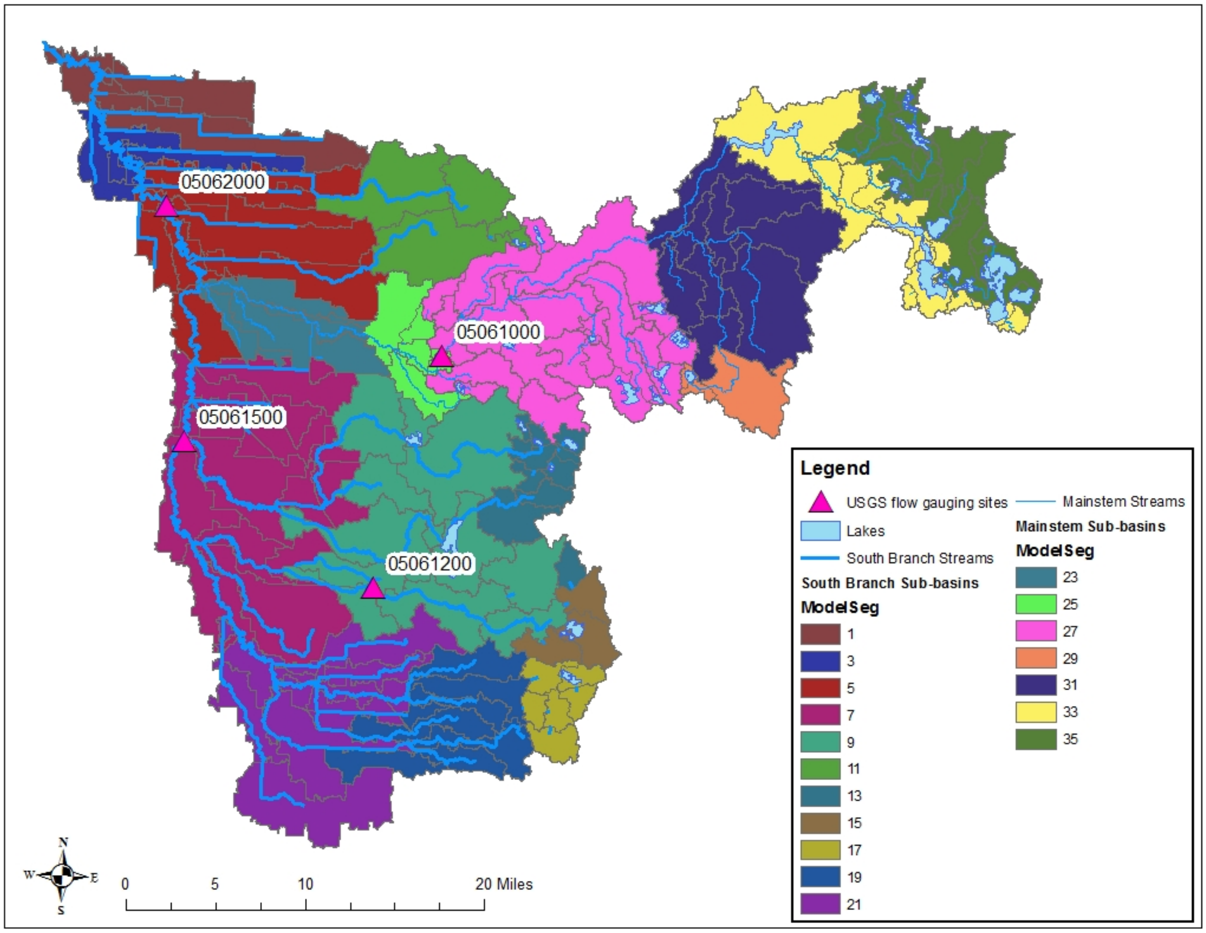

Figure 1: BRW HSPF Model(s) Framework and Hydrologic Calibration/Validation Locations.

1.3 Work Order Tasks

The content of this report was developed between 2011 and 2013. Three work orders covering three phases were issued to build the BRW HSPF model and calibrate/validate its simulation of hydrology, sediment, and water quality. The objectives of these work orders are presented below. Also noted is any documentation that was submitted to the MPCA to describe the work completed.

1. Compile both the geographic and time-series data required to construct the model framework.
2. Develop representation of watershed area and drainage network.
    - *Summary of Work under the Buffalo River Watershed HSPF Model Framework Development Work Plan (MPCA Work Plan #B55117)* (Memorandum, HEI, dated: June 27, 2011).
3. Develop and implement a strategy for the representation of point sources within the HSPF model domain.
    - *Representation of point sources and atmospheric deposition in the Buffalo River Watershed HSPF Model* (Memorandum, HEI, dated: Feb. 20, 2012).
4. Formulate time-series from observed flow and water quality monitoring data to be used for modeling calibration and validation.
    - *Flow Calibration Locations for BRW HSPF Model* (Memorandum, HEI, dated: Jan. 10, 2012).
    - *Proposed approach for simulating, calibrating, and validating water quality within the BRW HSPF models* (Memorandum, HEI, dated: June 29, 2012).
5. Perform the hydrologic calibration and validation and show the model accurately simulates the water balance.
    - *Hydrologic Calibration and Validation Approach for the Buffalo River Watershed HSPF Model* (Memorandum, HEI, dated: May 25, 2012).
    - *Buffalo River Watershed HSPF Model Hydrologic Calibration and Validation Report* (HEI, 2012).
    - *Buffalo River Watershed HSPF Model Hydrologic Calibration and Validation Report-Amended* (HEI, 2013c).
6. Define the sources of sediment within the watershed and conduct sediment calibration and validation.
    - *Sediment Source Partitioning and Calibration Targets for the BRW HSPF Models* (Memorandum, HEI, dated: Jan. 28, 2012).
    - *BRW HSPF Model Sediment Calibration* (Memorandum, HEI, dated: Aug. 29, 2013).
7. Conduct water quality calibration, validation, and model evaluation.
    - This Report
8. Create GenScn project containing output from the BRW.

The memoranda, reports, GenScn project, HSPF model files, and Geographic Information Systems (GIS) data were provide separately in deliverable packages throughout the project timeframe (2011-2013). Memoranda and reports include detailed discussion of the approaches used to develop and implement the BRW HSPF model, the calibration and validation results, and any shortcomings/uncertainty in the models.

2.0 MODEL SETUP AND APPROACH

The HSPF model application for the BRW represents the connected watershed and in-stream processes. The model set-up focuses on incorporating major sources of flow and water quality loads into the model. The calibration and validation of the model involves adjustments to model parameters that cannot reasonably be estimated from watershed characteristics to obtain a reasonable fit to observed data. Results from the calibration and validation can be found in **Section 3** through **Section 5**. The following section provides a summary of the model setup and model performance criteria. A full description of the model setup can be found in (HEI, 2011). A full description of the hydrologic calibration process can be found in (HEI, 2012c), of the sediment calibration process (HEI, 2013a), and of the water quality setup (HEI, 2012d).

2.1 Model Setup

The BRW was split into two areas for HSPF model development, as summarized in the June 27, 2011 memorandum on the model framework. Splitting the study area into two was necessary to achieve the desired level of spatial detail in the resultant models for a watershed of this size. Model set up and segmentation was based on meteorological data, land-use and the underlying soils' hydrologic class (i.e., runoff potential).

2.1.1 Meteorological Data

Eighteen separate meteorological zones (seven in the Mainstem model and eleven in the South Branch model) were used in the BRW model application. The meteorological zones were based on available precipitation stations, as shown in **Figure 2**. The meteorological zones were developed using stations from the Environmental Protection Agency's (EPA) Better Assessment Science Integrating point and Nonpoint Sources (BASINS) database (five stations) and supplemented with data from the High Spatial Density, Daily Operations (HIDEN) database (thirteen stations), provided by MPCA personnel. The meteorological parameters used in the HSPF models include:

- Precipitation;
- Air temperature;
- Solar radiation;
- Wind speed;
- Dew point; and
- Cloud cover.

For each meteorological parameter, a continuous, hourly time series was developed for the period January 1, 1995 to December 31, 2006. Stations with incomplete data for the modeling period were filled with available data from the closest station.

BASINS's meteorological data provide potential evaporation values computed using the Harmon approach. The MPCA has determined that the Penman Pan method, which estimates daily pan evaporation values, better represents the amount and pattern of evaporation seen in the State of MN. Therefore, the BASINS-provided potential evaporation values were disregarded for this project and hourly pan evaporation values were computed using the Penman Pan method. Stations with incomplete data for the modeling period were filled with available data from the closest station.

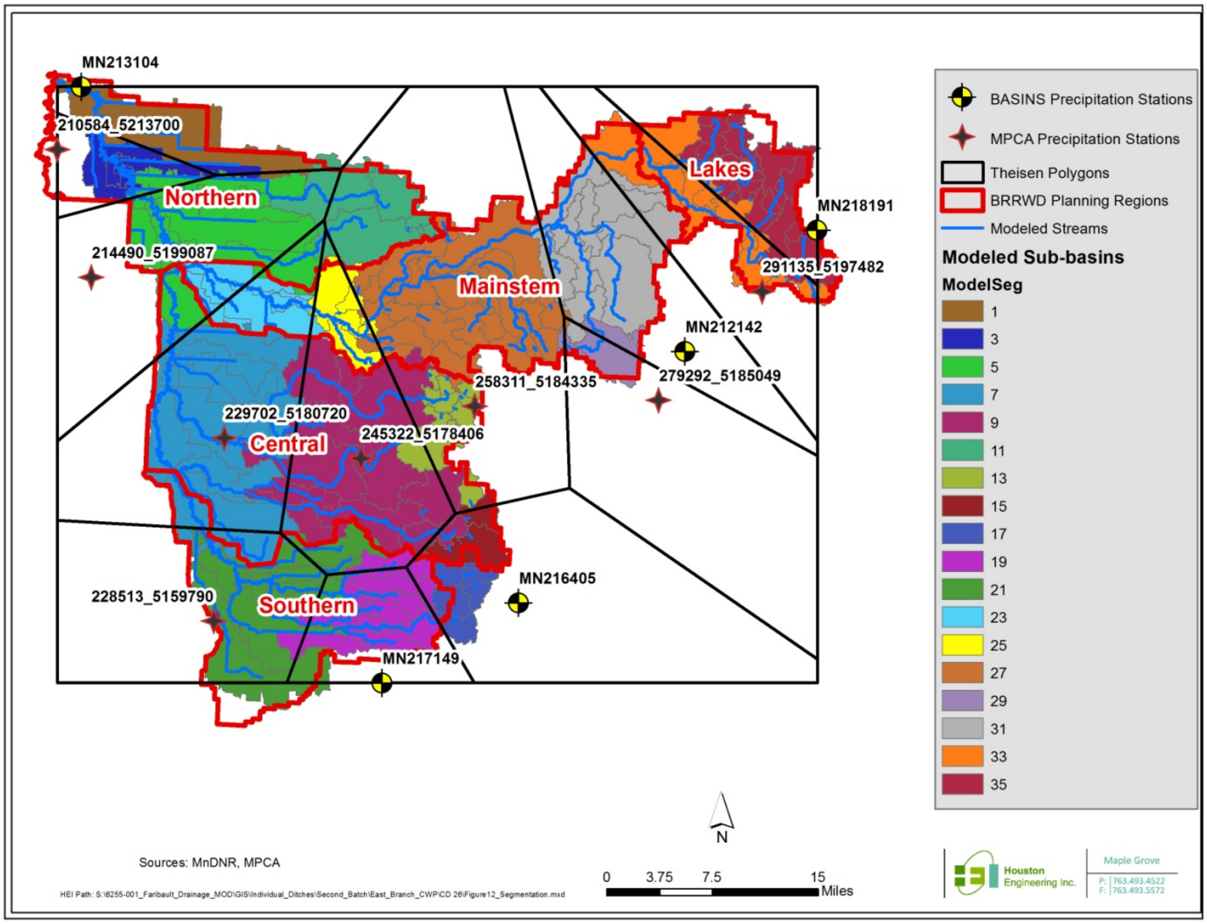

Figure 2: BRW HSPF Model Segments.

2.1.2 Land Use

The HSPF model applications for the BRW simulate watershed processes for six broad land uses. To better represent watershed conditions and aid potential management strategies, the six broad land uses were further categorized into 11 unique land uses, based on the soil hydrologic class and runoff potential. The 10 Pervious Land Segments (PLS) and 1 impervious land segment for the BRW HSPF model application are shown in **Table 2.1**. The 11 land uses were represented in each of the 18 meteorological zones resulting in a total of 198 unique land uses (70 PERLNDs and 7 IMPLNDs in the Mainstem Model; 110 PERLNDs and 11 IMPLNDs in the South Branch Model).

Table 2.1 Land Use Classification for Buffalo River Watershed HSPF Model Applications.

NLCD Land Use Category	Model Land Use	Drainage Class	Land Segment Name	Area (Sq. miles)	% of Watershed
11-Open Water	Open Water	N/A	N/A	21.9	1.94%
21-Developed, Open Space	Urban	Pervious	Urban (PERLND)	52.8	4.68%
22-Developed, Low Intensity					
23-Developed, Medium Intensity		Impervious	Urban (IMPLND)	1.74	0.15%
24-Developed, High Intensity					
41-Deciduous Forest	Forest	A/B	Forest, Low Runoff Potential	76.4	6.77%
42-Evergreen Forest					
43-Mixed Forest		C/D	Forest, High Runoff Potential	29.4	2.60%
82-Cultivated Crops	Cropland	A/B	Cropland, Low Runoff Potential	474.2	42.01%
		C/D	Cropland, High Runoff Potential	268.6	23.80%
52-Shrub/Scrub	Grassland	A/B	Grassland, Low Runoff Potential	20.7	1.83%
31-Barren Land					
71Grassland/Herbaceous		C/D	Grassland, High Runoff Potential	5.8	0.51%
81-Pasture/Hay	Pasture	A/B	Pasture, Low Runoff Potential	58.7	5.20%
		C/D	Pasture, High Runoff Potential	18.5	1.64%
90-Woody Wetlands	Wetlands	N/A	Wetlands	100	8.86%
95-Emergent Herbaceous Wetlands					

2.1.3 Point Sources

During the time period of model simulation (1995-2006), there were seven minor wastewater treatment plants (WWTPs) in the BRW. These plants are all pond-type treatment plants with primary and secondary treatment lagoons; their locations are shown in **Figure 3**. The Barnesville WWTP consists of multiple treatment lagoons with multiple surface water effluents. All other plants have a single surface water effluent. Monthly flow and water quality data for the effluent wastewater from these facilities were provided by personnel at the MPCA, who obtained the records from the Delta and Permit Compliance System (PCS) database programs. The data records provided range in length, with the earliest records extending back to 1989. All records are current through the end of 2011. Since the time period simulated with the BRW HSPF model is 1995-2006, all discharge data records were trimmed to reflect only this time period for inclusion within the watershed model.

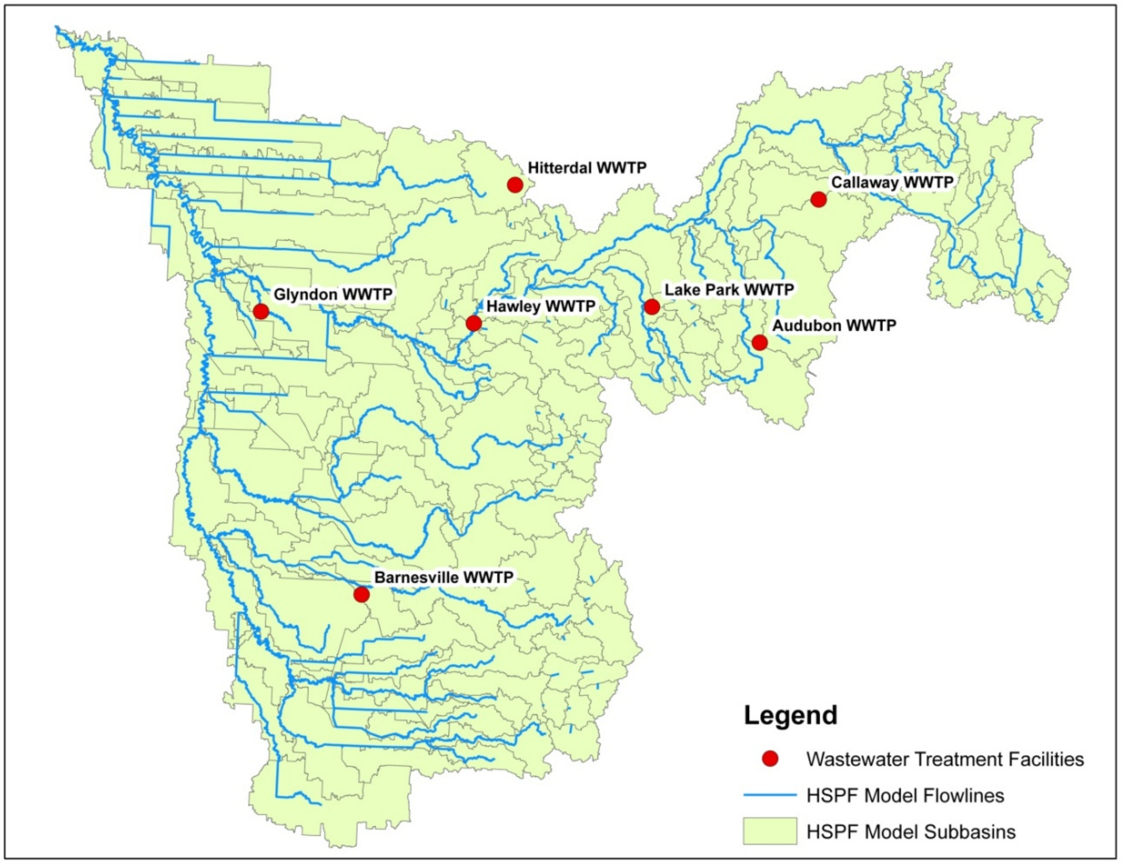

Figure 3: Location of Minor WWTPs in the BRW

A basic summary of the seven WWTP locations in the BRW is shown in **Table 2.2**; the average monthly mean daily discharge value gives a sense of the size of each of the plants. The general operation of the WWTPs in the BRW is to discharge their treated waste into the surface water system in the spring/early summer and again in the late fall of each year. The most typical windows for releases are in April – June and then again in September – November. The exact timing of these releases depends on a number of factors, including the amount of water in the receiving waters. The observed outflow data include total discharge and average concentration data for BOD, total phosphorus (TP), and total suspended solids (TSS).

No observed information was available for nitrogen constituents (total ammonia (TAM or NH3), inorganic nitrogen (NO2-NO3), total Kjeldahl nitrogen (TKN), and total nitrogen (TN)) in the WWTPs' effluent. As such, average concentrations were assumed for these constituents based on their type (Weiss, 2012). All of the BRW WWTPs are Class D municipal treatment ponds and, as such, were assigned average effluent concentrations of 6 mg/L of TN, 3 mg/L of NO2-NO3, 3 mg/L of TKN, and 1 mg/L of TAM (Weiss, 2012). Nitrogen loads were then calculated by applying the assumed concentration to the total discharge of the WWTP.

Table 2.2: Summary of Wastewater Treatment Plants in the BRW

Facility Name	Permit #	1995-2009 Avg Monthly Mean Daily Discharge (mgd)
Audubon	MN0022675	0.61
Barnesville: 8-acre Pond	MN0022501	1.59
Barnesville: 10.9-acre Pond	MN0022501	2.00
Barnesville: 24-acre Pond	MN0022501	2.69
Callaway	MN0022985	0.47
Glyndon	MN0020630	1.57
Hawley	MN0020338	2.73
Hitterdahl	MN0025925	0.28
Lake Park	MN0023892	1.30

2.2 Model Performance Criteria

Model performance was evaluated using a weight-of-evidence approach described in Donigian (2002). The weight-of-evidence approach uses both visual and statistical methods to collect evidence showing and defining the performance of the model. Graphical plots were used to visually evaluate the model performance, while model results were compared to observed data for various statistical metrics.

Table 2.3 lists general calibration/validation tolerances or targets that have been provided to model users as part of HSPF training workshops over the past 10 years (e.g. Donigian, 2000). The values in **Table 2.3** provide general guidance, in terms of the percent mean errors or differences between simulated and observed values, so that the model could be gaged for its level of agreement or accuracy (i.e. very good, good, fair).

Table 2.3: General Calibration/Validation Targets/Tolerances for HSPF Applications (Donigian, 2002).

	% Difference Between Simulated and Recorded Values		
	Very Good	**Good**	**Fair**
Hydrology/Flow	< 10	10 - 15	15 - 25
Sediment	< 20	20 - 30	30 - 45
Water Temperature	< 7	8 - 12	13 - 18
Water Quality/Nutrients	< 15	15 - 25	25 - 35
Pesticides/Toxics	< 20	20 - 30	30 - 40

CAVEATS: Relevant to monthly and annual values; storm peaks may differ more
Quality and detail of input and calibration data
Purpose of model application
Availability of alternative assessment procedures
Resource availability (i.e. time, money, personnel)

Figure 4 provides value ranges for both correlation coefficients (R) and coefficients of determination (R^2) for assessing model performance for both daily and monthly flows. The figure shows the range of values that may be appropriate for judging how well the model is performing based on the daily and monthly simulation results. As shown, the ranges for daily values are lower to reflect the difficulties in exactly duplicating the timing of flows, given the uncertainties in the timing of model inputs, mainly precipitation.

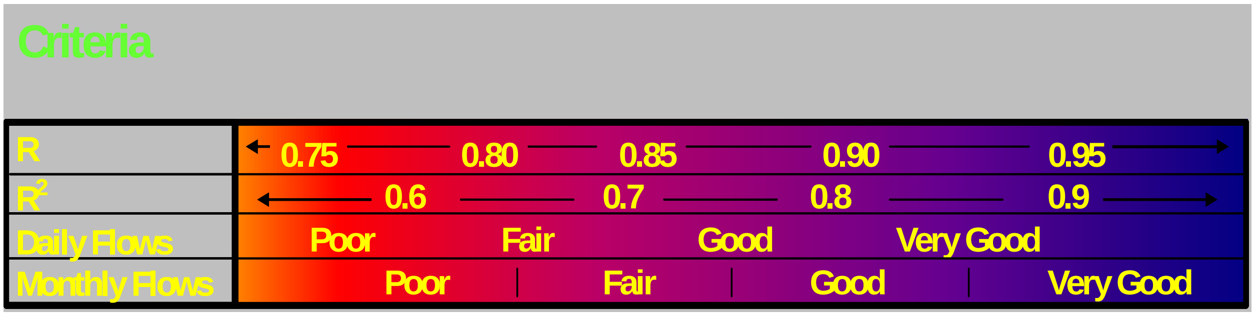

Figure 4: R and R^2 value ranges for model performance. (Donigian, 2002)

In recent years the Nash-Sutcliffe Coefficient of Efficiency or Model Fit Efficiency has become another common measure of the strength of a calibration. The Nash-Sutcliffe statistic produces a number between minus infinity and 1; the closer the number is to 1, the more accurate the model is.

It should be noted, for any watershed modeling effort, the level of expected agreement is tempered by the complexities of the hydrologic system, the quality of the available precipitation and flow data, and the available information to help characterize the watershed and quantify the human impacts on water-related activities.

For the BRW, the modeling period is January 1, 1995 through December 31, 2006. The models were calibrated using data from January 1, 2001 through December 31, 2006 and validated using the time period January 1, 1996 through December 31, 2000. The first simulation year, 1995, was considered a warm-up period to initialize the models.

3.0 HYDROLOGY

Hydrology provides the basis of the model application and includes streamflow and lake levels. Water quality simulations, including sediment, are highly dependent on the hydrologic processes. Therefore, water quality calibration could not begin until after the hydrologic calibration was considered acceptable. This section provides a summary of the final hydrology results. A detailed description of the calibration/validation of hydrology can be found in (HEI, 2013c). Some differences between results provided in this report and the final hydrologic calibration report (HEI, 2012) may be present. This is due to small changes made to the model described in the (HEI, 2012) document, as requested during a model review by AQUA TERRA Consultants.

Three calibration points were used to calibrate the hydrology of the BRW HSPF models: one in the Mainstem model and two in the South Branch model. **Table 3.1** lists the USGS flow gauging stations where calibration of the model occurred.

Table 3.1: Available USGS Flow Gaging Stations used for Calibration of BRW HSPF Model.

USGS Station Number	USGS Station Name	Beginning Date	End Date	Model	RCHRES ID
05061000	Buffalo River nr Hawley, MN	4/1/1945	11/17/2010	Mainstem	104
05061500	South Branch Buffalo River at Sabin, MN	4/1/1945	11/18/2010	South Branch	127
05062000	Buffalo River nr Dilworth, MN	4/1/1931	11/17/2010	South Branch	101

3.1 Hydrology Results

Model performance was evaluated using a weight-of-evidence approach described in **Section 2.2** and the hydrologic calibration approach memorandum (HEI, 2012c). **Table 3.2** shows the calibration statistics at the primary calibration sites for the BRW model application. **Table 3.3** shows the validation statistics at the primary calibration sites. **Table 3.4** summarizes average annual water balance at various locations for the modeling period (1996-2006). Additional results and commentary can be found in (HEI, 2012e).

Table 3.2: Hydrology Calibration Summary Statistics.

USGS Flow Gage	HSPF RCHRES I.D.[1]	Total Runoff Vol			Monthly			Daily			Storm % Error	
		Obs (in)	Sim (in)	%Δ	*R*	*R^2*	*N.S.*[2]	*R*	*R^2*	*N.S.*[2]	Vol	Peak
05061000	104a	4.72	4.65	-1.4	0.939	0.822	0.877	0.896	0.802	0.796	1.4	-2.4
05061500	127b	3.34	3.24	-3.0	0.931	0.867	0.863	0.793	0.629	0.623	0.3	-2.5
05062000	101b	6.41	6.58	2.6	0.935	0.873	0.864	0.834	0.696	0.690	4.3	15.0

[1] a = Mainstem Model; b= South Branch model; [2] N.S. = Nash-Sutcliffe Statistic

Table 3.3: Hydrology Validation Summary Statistics.

USGS Flow Gage	HSPF Reach I.D.[1]	Total Runoff Vol			Monthly			Daily			Storm % Error	
		Obs (in)	Sim (in)	%Δ	*R*	*R^2*	*N.S.*[2]	*R*	*R^2*	*N.S.*[2]	Vol	Pea k
05061000	104a	6.82	6.54	-4.1	0.883	0.779	0.699	0.802	0.644	0.603	-3.5	-6.1
05061500	127b	3.90	4.80	23	0.939	0.881	0.694	0.875	0.766	0.702	19.1	3.0
05062000	101b	8.97	9.62	7.3	0.914	0.836	0.805	0.837	0.700	0.668	14.6	32.8

[1] a = Mainstem Model; b= South Branch model; [2] N.S. = Nash-Sutcliffe Statistic

Table 3.4: Summary of Water Balance Component Depths for Calibration Period (2001-2006).

Water Balance Component	Water Balance Component Description	RCHRES 104[a] (in)	RCHRES 127[b] (in)	RCHRES 101[c] (in)	Outlet (in)
SUPY	Water supply to soil surface	30.40	27.17	27.49	27.58
SURO	Surface outflow	0.15	0.36	0.39	0.44
IFWO	Interflow outflow	1.24	1.24	1.38	1.53
AGWO	Active groundwater outflow	5.45	3.23	3.32	3.27
PERO	Total outflow from pervious land	6.81	4.79	5.06	5.21
IGWI	Inflow to inactive groundwater	0.03	0.01	0.01	0.01
PET	Potential evaporation	42.24	43.66	44.16	44.47
CEPE	Evaporation from interception storage	5.52	5.18	5.20	5.17
AGWET	Evaporation from active groundwater storage	0.33	0.26	0.23	0.21
UZET	Evaporation from upper zone	4.31	4.63	4.63	4.70
LZET	Evaporation from lower zone	12.94	11.85	11.89	11.84
BASET	Evaporation from active groundwater outflow (baseflow)	0.59	0.64	0.65	0.64
TAET	Total simulated evaporation	23.71	22.57	22.61	22.55

[a] USGS site 05061000; [b] USGS site 05061500; [c] USGS site 05062000

4.0 SEDIMENT

Following MPCA guidance, the approach for modeling suspended sediment and the development of initial calibration parameters (when deemed appropriate) for the BRW models followed the Minnesota River HSPF Model (Tetra Tech, 2008). The resultant model is capable of identifying sources of sediment and the processes that drive sediment erosion, delivery, and transport in the watershed. Sediment modeling is highly dependent on the hydrology and streamflow in the modeled system and, therefore, sediment was calibrated after the hydrology was deemed acceptable.

Sediment calibration for the BRW HSPF model followed the guidance provided by the MPCA (AQUA TERRA, 2012) and EPA (USEPA, 2006). Sediment calibration involves numerous steps from initial parameterization to mimicking sediment transport behavior in-stream and at the calibration points. The calibration processes can be summarized in these steps:

1. Estimate target sediment loading rates from the landscape using the RUSLE equation and a Sediment Deliver Ratio;
2. Calibrate the simulated sediment loading rates to the estimated target rates;
3. Adjust the scour, deposition, and transport parameters for the stream channel to mimic expected behavior of the stream;
4. Analyze the sediment bed behavior and transport in each RCHRES;
5. Analyze overall sediment budgets for the landscape and stream contributions, along with stream aggrading and degrading behavior;

6. Compare simulated and observed sediment concentrations, along with size distributions and loadings, at the calibration points;
7. Repeat 1-6 as needed to develop a reasonable overall representation of the sediment sources, delivery, and transport throughout the watershed system.

The BRW HSPF sediment calibration took a weight-of-evidence approach, considering all of the following: comparisons between observed TSS concentrations and simulated concentrations, observed and simulated sediment loadings, and landscape loadings compared to estimated RUSLE values. Judgment of the value of the models' calibration for sediment followed MPCA and EPA guidance (AQUA TERRA 2012; USEPA 2006), which state that a properly-calibrated HSPF model should have less than 20% error in sediment simulations.

A detailed description of the sediment sourcing and calibration/validation can be found in memoranda dated Jan 28, 2013 (HEI, 2013a) and Aug 29, 2013 (HEI, 2013b). **Figure 5** shows the location of the sediment calibration sites. **Table 4.1** provides a summary of the sediment calibration and **Table 4.2** provides a summary of the sediment validation. It should be noted that no observed TSS or turbidity data was available during the validation period. Sediment loads during this time were extrapolated using simulated flows and the relationships developed, in the Army Corps of Engineers' FLUX program, between flow and observed TSS concentrations during the calibration period.

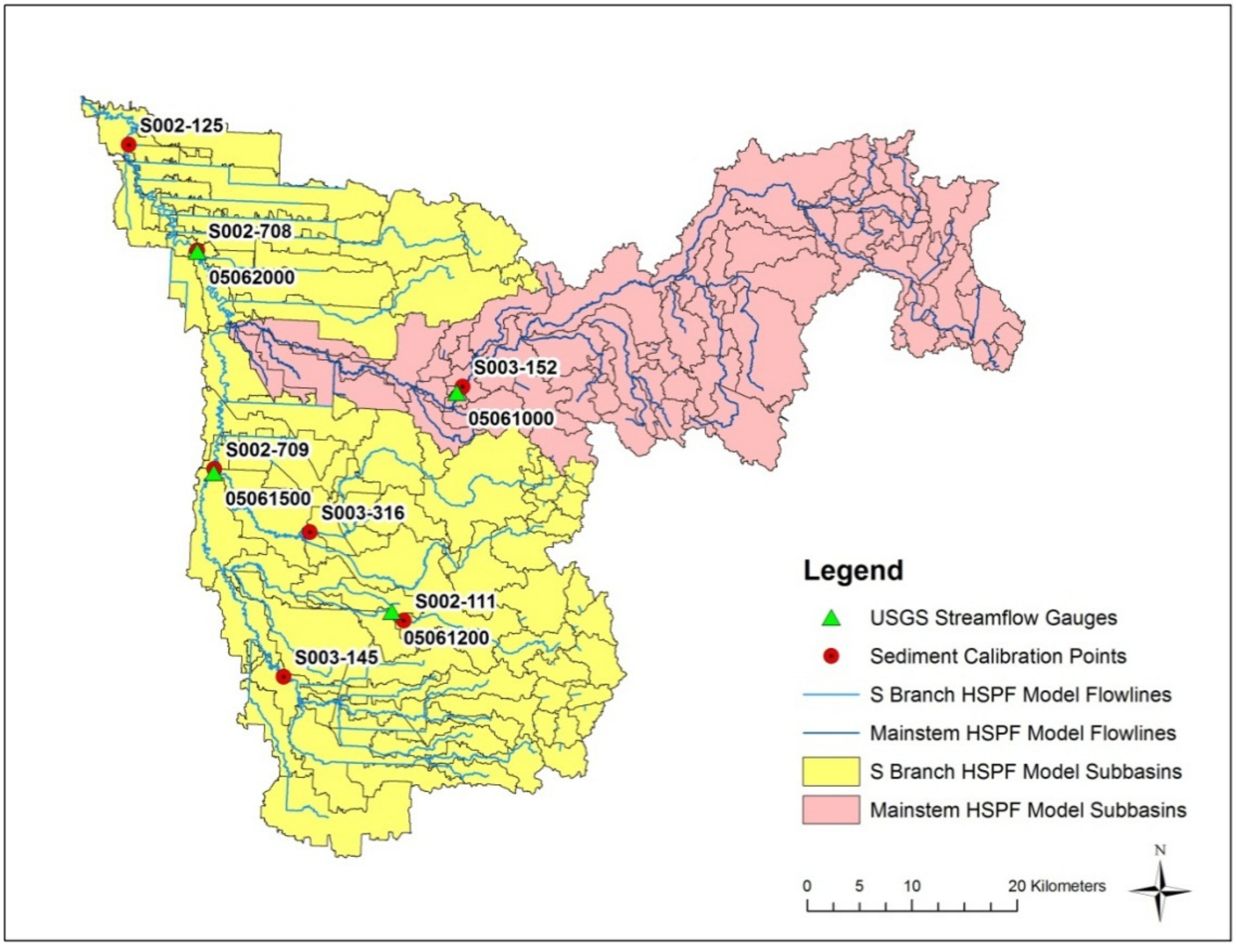

Figure 5: Sediment Calibration/Validation Locations.

Table 4.1: Summary Sediment Calibration Statistics.

MPCA Water Quality Site	HSPF RCHRES ID	# of TSS Obs.	TSS Concentration [mg/L]			Total Sediment Load [tons]		
			Obs.	Sim.	%Δ	Obs.	Sim.	%Δ
S002-111	14	49	26	27.2	4.7%	1,318	1,330	0.8%
S002-125	75	81	135.3	133.4	-1.5%	280,136	305,022	8.9%
S003-145	68	25	36.8	38.1	3.5%	6,468	7,560	16.9%
S003-152	91	37	40.8	36.7	-10.0%	43,049	39,303	-8.7%
S003-316	104	31	39	43.2	10.3%	5,116	5,603	9.5%

Table 4.2: Summary Sediment Validation Statistics.

MPCA Water Quality Site	HSPF RCHRES ID	# of TSS Obs.	TSS Concentration [mg/L]			Total Sediment Load [tons]		
			Obs.	Sim.	%Δ	Obs.	Sim.	%Δ
S002-111	14	0	N/A	N/A	N/A	1,304	1,338	2.6%
S002-125	75	0	N/A	N/A	N/A	489,722	626,369	27.9%
S003-145	68	0	N/A	N/A	N/A	5,377	4,729	-12.0%
S003-152	91	0	N/A	N/A	N/A	59,623	58,203	-2.4%
S003-316	104	0	N/A	N/A	N/A	5,272	6,336	20.2%

Overall, the BRW HSPF models performed at a rating of **Very Good** for both sediment concentrations and sediment loadings during the calibration period (**Table 4.1**). The model performs at a rating of **Good to Very Good** for sediment loading during the validation period (**Table 4.2**). The overall performance of the HSPF models is shown by the performance at the water quality locations near the outlet (S002-125). The models were able to simulate concentrations with an error of -1.5% and loads to within 8.9% during the calibration period, when actual observed data were available; errors were higher during the validation period when loads were estimated based on other relationships. The model performed very well at the calibration locations with the "best" data (S002-125 in the South Branch model and S003-152 in the mainstem model). The sediment distribution into sand, silt, and clay match the assumed distribution (9% sand, 49% silt, and 42% clay). Model results show that croplands provide the highest loadings of sediment in the watershed. More information on the sediment sourcing and calibration can be found in memoranda dated Jan. 28, 2012 (HEI, 2013 a) and Aug. 29, 2013 (HEI, 2013b), respectively.

5.0 WATER QUALITY

Similar to the sediment simulation, the approach taken to modeling temperature, DO/BOD dynamics, and nutrients in the BRW was modeled after the Minnesota River HSPF application's approach. The BRW model application simulates in-stream temperature (using HTRCH), organic and inorganic nitrogen, total ammonia, organic and inorganic phosphorus (using NUTRX), DO and BOD (using OXRX), and algae (using PLANK). The adsorption/desorption of orthophosphate to sediment was also simulated.

Overall sources considered for nutrients included point sources (such as WWTPs) and nonpoint sources from the watershed, atmospheric deposition (nitrite-nitrate and ammonia), subsurface flow, and soil-bed contributions. WWTP contributions were explicitly modeled. Nonpoint sources of total ammonia, inorganic nitrogen, orthophosphate, and BOD were simulated through accumulation and depletion/removal and a first-order washoff rate from overland flow. All simulated in-stream parameters were specified for total ammonia, inorganic nitrogen, orthophosphate, and BOD. Atmospheric deposition of nitrite-nitrate and ammonia were applied to all of the land areas and provide a contribution to the nonpoint-source load through the buildup and washoff processes. Atmospheric deposition onto water surfaces was represented in the model as a direct input to the lakes and river systems. Subsurface flow concentrations were estimated on a monthly basis for calibration.

Biochemical reactions that affect DO were represented in the model. Overall sources considered for BOD and DO include point sources such as WWTPs, nonpoint sources from the watershed, interflow, and active groundwater flow. The model addresses BOD accumulation, storage, decay rates, benthic algal oxygen demand, settling rates, and re-aeration rates. The model also represents respiration, growth, settling rates, density, and nutrient requirements of benthic algae and phytoplankton.

5.1 Nutrient Landscape Loading

The BRW HSPF model follows the approach used by the Minnesota River HSPF model to simulate overland water quality and uses the PSTEMP module (water temperature), the PWTGAS module (dissolved oxygen), and the PQUAL module (ammonia, nitrates and nitrites, orthophosphate, and BOD) for PERLND and respective modules (IWTGAS and IQUAL) for IMPLNDs.

Phosphorus loading from the landscape is usually particle-related. It is simulated in the model based on a sediment potency factor (pounds of phosphorus per ton of sediment). As such, the quality of the phosphorus calibration is largely dependent on the sediment calibration. Phosphorus is also simulated in interflow and groundwater flow.

Nitrogen loading from the landscape is simulated as ammonia and nitrate-nitrite. Nitrate-nitrite represents the oxidized inorganic nitrogen loads from the landscape and is represented as a buildup-washoff parameter on the land surface and is associated with groundwater and interflow. Unlike phosphorus, nitrate-nitrite is not simulated as a sediment-associated (sediment dependent) variable. The buildup/washoff (WSQO) parameter is dependent on a monthly accumulation rate (ACCUM), accumulation limit (SQOLIM), and depth of runoff resulting in 90 percent removal of the surface storage (WSQOP). SQOLIM values determine the maximum amount that can be washed off during a runoff event. ACCUM values represent the rate the available storage approaches the maximum storage (SQOLIM), i.e. the rate that available (at the surface) nitrate-nitrite is replenished. Ammonia is a minor constituent of the total nitrogen loading for most land uses. Ammonia is simulated in the same fashion as nitrate-nitrite. Nitrate-nitrite loading also comes from groundwater and interflow sources. Loading from subsurface sources is simulated by providing a month concentration in groundwater and interflow. Monthly values are used to provide seasonality.

Organic matter is simulated as a generic loading from the landscape and is transformed at the landscape's edge into equivalent concentrations of organic nitrogen, organic phosphorus, organic carbon, and BOD. The partitioning of organic material into the various constituents follows the Minnesota River HSPF model and is handled in the MASS-LINK block.

5.1.1 Atmospheric Deposition

As a non-trivial source of nitrogen to Minnesota watersheds, the MPCA has requested that dry and wet atmospheric deposition of nitrate and ammonia be included in the BRW HSPF model. Atmospheric deposition of nitrate and ammonia was explicitly accounted for in the BRW HSPF models by the input of separate wet and dry deposition fluxes. Wet atmospheric deposition data were downloaded from the National Atmospheric Deposition Program (NADP) (http://nadp.sws.uiuc.edu/). The NADP site chosen for wet deposition in the BRW was MN23. Wet deposition accounts for the deposition of pollutants from the atmosphere during precipitation events. Therefore, nitrate and ammonia wet deposition was applied to the landscape in the model as concentrations (mg/L) to observed precipitation.

Dry atmospheric deposition data were downloaded from the EPA's Clean Air Status and Trends Network (CASTNET) (http://epa.gov/castnet/javaweb/index.html). The CASTNET site used for the BRW HSPF model was the VOY413. Dry deposition is reported on a weekly basis. Therefore, the observed weekly timeseries was transformed into a daily timeseries assuming a constant flux over the week of observation. Dry deposition is applied as a load (lbs/acre). A full discussion on the atmospheric loading in the BRW HSPF model can be found in the memorandum dated Feb 20, 2012 (HEI, 2012b).

5.1.2 Landscape Loading Targets

Table 5.1 lists the average annual landscape loading rates for total phosphorus and total nitrogen used to calibrate landscape loading rates in the BRW HSPF model. These annual average rates were used to inform and calibrate phosphorus and nitrogen loadings in the BRW HSPF model.

Table 5.1 Overland Loading Targets for TP and TN by Land Use (LimnoTech, 2007).

Land Use	TP [lbs/ac/yr]	TN [lbs/ac/yr]
Urban	0.81	0.48
Forest	0.12	1.8
Row Crops	0.35	7
Grassland	0.14	2.1
Pasture	0.22	2.1

5.1.3 Partitioning at the Water's Edge

Although HSPF simulates ammonia, nitrate-nitrite, phosphorus, and BOD, portions of these components are reassigned into various constituents at the water's edge. The partitioning of the water quality parameters simulated in PQUAL into the various constituents in-stream follows the Minnesota River HSPF model and is handled in the MASS-LINK block.

Phosphorus, although simulated in PQUAL as sediment-associated and dissolved, needs to be reassigned into portions not included within the HSPF upland model network. It is necessary to re-divide the total inorganic phosphorus load into sorbed and sediment-associated components, including three fractions of sediment (sand, silt, and clay), whereas the upland model only simulates a generalized sediment fraction. The partitioning of inorganic phosphorus in the BRW surface washoff was assumed to be similar to the MN River Model (TetraTech, 2009). As such, the model uses an empirical partitioning of 10 percent dissolved, 58 percent associated with silt, and 32 percent associated with clay. The subsurface components of phosphorus loading are assigned entirely to the dissolved fractions. Additional phosphorus will come from BOD as the organic component.

Organic matter is simulated as a generic pollutant from the landscape and is transformed at the landscape's edge into equivalent concentrations of organic nitrogen, organic phosphorus, organic carbon, and BOD. BOD is transformed into 1:2500 parts organic nitrogen to BOD, 1:2000 parts organic phosphorus to BOD, and 1:2500 parts organic carbon to BOD.

5.2 In-stream Processes

The BRW HSPF model simulates in-stream water temperature (using HTRCH), DO and BOD (using OXRX), organic and inorganic phosphorus, organic and inorganic nitrogen, total ammonia (using NUTRX), and algae (using PLANK). The modeling approach follows Tetra Tech's Minnesota River HSPF (TetraTech, 2008) model's approach and the calibration follows the EPA's guidance materials (USEPA, 2006).

The in-stream water quality parameters simulated (and calibrated) include water temperature, DO, BOD, ammonia, nitrate, nitrite, orthophosphate, organic nitrogen, organic phosphorus, TKN, TN, and TP. Water temperature is mostly independent of the other water quality parameters and calibrated separately. All of the other water quality parameters are interdependent through the reaction in the stream. Therefore, they were calibrated at the same time.

The following lists some of the key parameters used to calibrate water quality in the BRW HSPF model (USEPA, 2006):

In-stream Nitrification/De-nitrification

- Reaction rates (KTAM20, KNO220, KNO320)

DO/ BOD

- Reaeration rate (REAK, TCGINV, EXPRED, EXPREV)
- BOD decay rate (KBOD20)
- BOD settling rate (KODSET)
- Benthal oxygen demand (BENOD, EXPOD)
- DO supersaturation factor (SUPSAT)

Phytoplankton and Benthic Algae Parameters

- Algal growth rate (MALGR)
- Algal respiration rate (ALR20)
- Phytoplankton settling rate (PHYSET)
- Maximum benthic algae density (MBAL)
- Ratio of benthic algae to phytoplankton growth rate (CFBALG)
- Ratio of benthic algae to phytoplankton respiration rate (CFBALR)
- Fraction of N-requirements satisfied by NO_3 (ALNPR)

In-stream water quality calibration was performed by varying the above parameters until the in-stream concentration and loadings were within respectable tolerances of observed values. In places where little to no observed data was available to make reasonable comparisons, typical values found in the scientific literature were used as a surrogate for observed data.

5.2.1 Observed Water Quality Data/ Typical Values

The sites used for calibrating water quality are the same as those used for sediment calibration, shown in **Figure 3**. **Table 5.2** shows the available water quality data in the BRW during the modeling period. Water temperature and DO is well represented at most sites, but observed nutrient data is lacking.

Table 5.2: Number of available water quality observations, by constituent, during the modeling period (1995-2006).

Site	Temp	DO	BOD	NH3	NO23	TKN	Org N	TN	Org P	PO4	TP	Chl-*a*
S003-152	41	39	0	2	5	0	0	0	0	0	5	0
S002-111	48	47	0	0	15	0	0	0	0	12	16	0
S003-145	25	25	0	0	5	0	0	0	0	0	4	0
S003-316	31	30	0	0	0	0	0	0	0	0	0	0
S002-709	9	8	0	0	0	0	0	0	0	0	0	0
S002-708	16	16	3	0	6	7	0	0	0	1	8	7
S002-125	82	81	0	1	73	1	1	0	0	79	78	1

*Temp = water temperature; DO = dissolved oxygen; BOD = biological oxygen demand; NH3 = total ammonia; NO23 = inorganic nitrogen; TKN = total Kjeldahl nitrogen; Org N = organic nitrogen; TN = total nitrogen; Org P = organic phosphorus; PO4 = orthophosphate; TP = total phosphorus; Chl-a = chorophyll-a.

In accordance with the work order, nutrient simulations were compared to typical values reported in the scientific literature. Typical ranges for annual average nutrient concentrations by ecoregion are provided in **Table 5.3**. Calibration site S003-152, in the Mainstem model, used typical values for the North Central Hardwood Forest ecoregion. For the remaining sites, in the South Branch model, the Red River Valley ecoregion was used.

Table 5.3: Typical annual average stream water quality conditions in Minnesota's ecoregions (from: MPCA, 2003; McCollor & Heiskary, 1993).

Parameter	Red River Valley	North Central Hardwood Forest	Northern Lakes and Forest
TSS	11.0 – 59.0	4.8 – 16.0	1.8 – 6.0
TAM	0.05 – 1.5	0.02 – 0.26	0.02 – 0.11
NO2-NO3	0.01 – 0.21	0.04 – 0.26	0.01 – 0.09
TP	0.11 – 0.3	0.06 – 0.15	0.02 – 0.05
Temperature	0.0 – 2.1	2.0 – 21.0	0.5 – 17.0
BOD	1.8 – 4.1	1.5 – 3.2	0.8 – 1.7

5.3 Results

5.3.1 Water Temperature

All seven calibration sites had enough observed data during the calibration period for water temperature calibration. For calibration, all sites ranked at least **Good** for water temperature (**Table 5.4**). The percent differences ranged from -10.8% to 4.3%, with a general trend of under-predicting water temperature.

No observed data (at any of the sites) were available during the validation period. As such, validation results were compared to typical annual average values (**Table 5.5**). All sites were within typical ranges of water temperatures. **Figure 6** shows the simulated and observed water temperatures at the watershed outlet (site S002-125) for the modeling period.

Table 5.4: Summary calibration information for water temperature simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Water Temperature (°F)		
			Obs.	Sim.	%Δ
S002-111	14	49	58.9	56.4	-4.3%
S002-125	75	82	62.3	57.8	-7.2%
S003-145	68	24	59.8	53.7	-10.2%
S003-152	91	41	55.9	58.3	4.3%
S003-316	104	30	58.6	54.9	-6.3%
S002-708	101	16	70.4	62.8	-10.8%
S002-709	127	9	63.0	56.6	-10.2%

Table 5.5: Summary validation information for water temperature simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Water Temperature (°F)		
			Obs.	Sim.	%Δ
S002-111	14	0	32 - 70	48.4	N/A
S002-125	75	0	32 - 70	47.2	N/A
S003-145	68	0	32 - 70	46.8	N/A
S003-152	91	0	35.6 - 70	47.1	N/A
S003-316	104	0	32 - 70	45.5	N/A
S002-708	101	0	32 - 70	47.3	N/A
S002-709	127	0	32 - 70	47.5	N/A

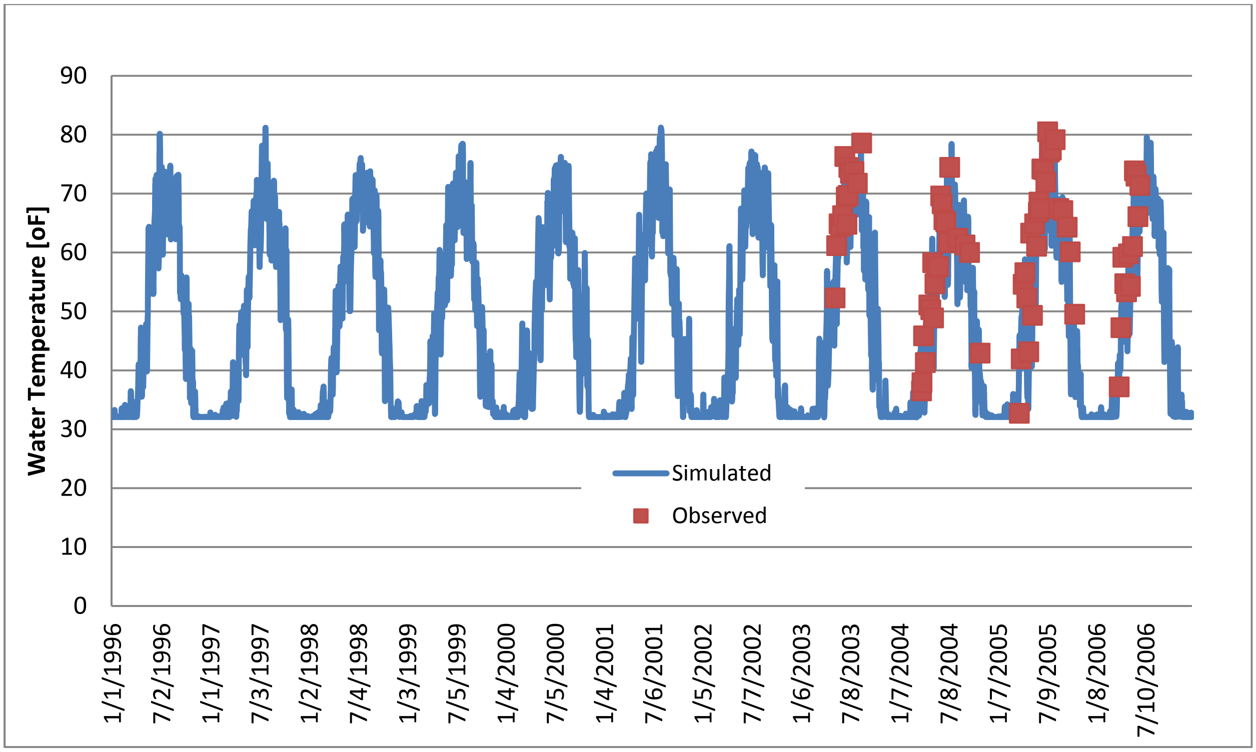

Figure 6: Simulated and observed water temperatures at Site S002-125 (RCHRES 91).

5.3.2 Dissolved Oxygen

All seven calibration sites had enough observed data during the calibration period for DO calibration. Most sites ranked at least **Good** for the calibration performance (**Table 5.6**); site S002-709 is slightly in the fair range. The percent differences ranged from -1.0% to 26.4%, with a general trend of over-predicting DO. No observed data were available during the validation period. As such, validation results were compared to typical annual average values (**Table 5.7**). All sites were within typical ranges of DO (Heiskary, 2013). **Figure 7** shows the simulated and observed DO concentrations at the watershed outlet (site S002-125) for the modeling period.

Table 5.6: Summary calibration information for dissolved oxygen simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Dissolved Oxygen [mg/L]		
			Obs.	Sim.	%Δ
S002-111	14	47	9.7	10.2	5.1%
S002-125	75	81	8.2	9.5	15%
S003-145	68	25	9.2	10.5	14%
S003-152	91	39	8.9	10.0	13%
S003-316	104	30	9.8	10.2	4.7%
S002-708	101	16	8.6	8.5	-1.0%
S002-709	127	8	8.4	10.6	26%

Table 5.7: Summary validation information for dissolved oxygen simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Dissolved Oxygen [mg/L]		
			Obs[a]	Sim.	%Δ
S002-111	14	0	5.4 – 13.0	11.3	N/A
S002-125	75	0	5.4 – 13.0	11.2	N/A
S003-145	68	0	5.4 – 13.0	11.5	N/A
S003-152	91	0	5.4 – 13.0	11.9	N/A
S003-316	104	0	5.4 – 13.0	11.6	N/A
S002-708	101	0	5.4 – 13.0	11.8	N/A
S002-709	127	0	5.4 – 13.0	12.0	N/A

[a]Typical annual range is taken as the 25% and 75% for state-wide observations(Heiskary, 2013).

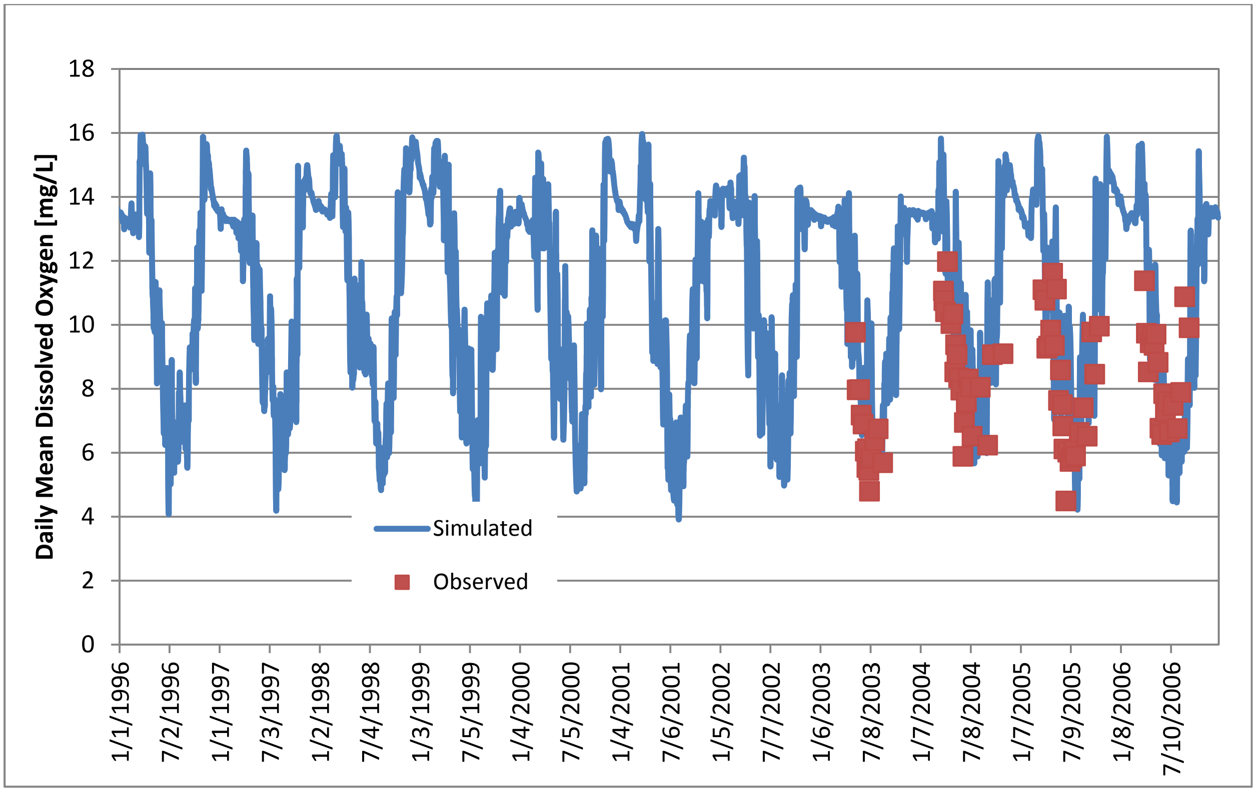

Figure 7: Simulated and observed dissolved oxygen at Site S002-125 (RCHRES 91).

5.3.3 Biological Oxygen Demand

No observed BOD data was available at most sites in the BRW; site S002-708 has three observations (not enough for any type of reasonable calibration). Given the lack of data, simulated results were compared to typical annual average concentrations (**Table 5.**3) for both the calibration (**Table 5.8**) and validation periods (**Table 5.9**). Simulated values compared well.

Table 5.8: Summary calibration information for BOD simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Biological Oxygen Demand [mg/L]			Biological Oxygen Demand Load [lbs/year]		
			Obs.	Sim.	%Δ	Obs.	Sim.	%Δ
S002-111	14	0	1.8 - 4.1	2.21	N/A	-	-	-
S002-125	91	0	1.8 - 4.1	1.98	N/A	-	-	-
S003-145	75	0	1.8 - 4.1	3	N/A	-	-	-
S003-152	104	0	1.5 - 3.2	3.6	N/A	-	-	-
S003-316	68	0	1.8 - 4.1	4.1	N/A	-	-	-
S002-708	101	0	1.8 - 4.1	2.7	N/A	-	-	-
S002-709	127	0	1.8 - 4.1	2.65	N/A	-	-	-

Table 5.9: Summary validation information for BOD simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Biological Oxygen Demand [mg/L]			Biological Oxygen Demand Load [lbs/year]		
			Obs.	Sim.	%Δ	Obs.	Sim.	%Δ
S002-111	14	0	1.8 - 4.1	3.16	N/A	-	-	-
S002-125	91	0	1.8 - 4.1	2.42	N/A	-	-	-
S003-145	75	0	1.8 - 4.1	3.14	N/A	-	-	-
S003-152	104	0	1.5 - 3.2	3.79	N/A	-	-	-
S003-316	68	0	1.8 - 4.1	4.38	N/A	-	-	-
S002-708	101	0	1.8 - 4.1	3.04	N/A	-	-	-
S002-709	127	0	1.8 - 4.1	3.04	N/A	-	-	-

5.3.4 Phosphorus

The simulation of phosphorus in HSPF includes the modeling of PO4 (dissolved and particulate), organic phosphorus, and TP. For calibration, total PO4 and TP were used in calibration. Sufficient observed TP concentration data for calibration was only available at site S002-125 and no observed concentration data was available during the validation period. Typical average annual concentrations of TP were used for sites without observed data (**Table 5.2**). Typical average annual concentrations of PO4 were found by using a ratio of PO4 to TP at sites with data outside of the modeling period (sites S002-125, S003-152, S002-708, S002-709). For the three sites in the BRW with observed TP and PO4 data, the overall ratio of PO4 to TP ranged from 0.4 to 0.8, resulting in an average annual PO4 concentration ranging from 0.04 mg/L to 0.26 mg/L.

PO4 and TP loadings were estimated using the FLUX program and observed flow and phosphorus data at three sites (S003-152, S002-708, and S002-709). Most of the observed phosphorus data was outside of the modeling period but relationships between flow and phosphorus were found and loadings were extrapolated for the modeling period using observed flow.

Calibration results for PO4 are provided in **Table 5.10**, validation results are shown in **Table 5.11**. Site S002-125 shows PO4 calibration in the **Good** range and most other sites have an average annual PO4 concentration within the typical range. PO4 loadings for the calibration period are in the **Good** to **Very Good** range. PO4 loadings for the validation period are in the **Fair** to **Very Good** range (see **Table 2.3**). **Figure 8** shows monthly PO4 loadings at site S002-708 for the modeling period (the most downstream site with available data).

Table 5.10: Summary calibration information for orthophosphate simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Orthophosphate [mg/L]			Orthophosphate Load [lbs/year]		
			Obs.	Sim.	%Δ	Obs.[a]	Sim.	%Δ
S002-111	14	12	0.04-0.26	0.27	N/A	-	-	-
S002-125	91	79	0.12	0.10	-15.9	-	-	-
S003-145	75	0	0.04-0.26	0.13	N/A	-	-	-
S003-152	104	0	0.04-0.26	0.053	N/A	40,722	42,818	5.1%
S003-316	68	0	0.04-0.26	0.17	N/A	-	-	-
S002-708	101	1	0.04-0.26	0.07	N/A	169,046	146,629	-13%
S002-709	127	0	0.04-0.26	0.14	N/A	102,662	83,740	-18%

[a] Observed loading rates are extrapolated using the FLUX program and data outside of the modeling time frame.

Table 5.11: Summary validation information for orthophosphate simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Orthophosphate [mg/L]			Orthophosphate Load [lbs/year]		
			Obs.	Sim.	%Δ	Obs.[a]	Sim.	%Δ
S002-111	14	0	0.04-0.26	0.18	N/A	-	-	-
S002-125	91	0	0.04-0.26	0.07	N/A	-	-	-
S003-145	75	0	0.04-0.26	0.13	N/A	-	-	-
S003-152	104	0	0.04-0.26	0.042	N/A	50,880	43,995	-13%
S003-316	68	0	0.04-0.26	0.16	N/A	-	-	-
S002-708	101	0	0.04-0.26	0.07	N/A	192,583	248,603	29%
S002-709	127	0	0.04-0.26	0.14	N/A	102,342	88,952	-13%

[a] Observed loading rates are extrapolated using the FLUX program and data outside of the modeling time frame.

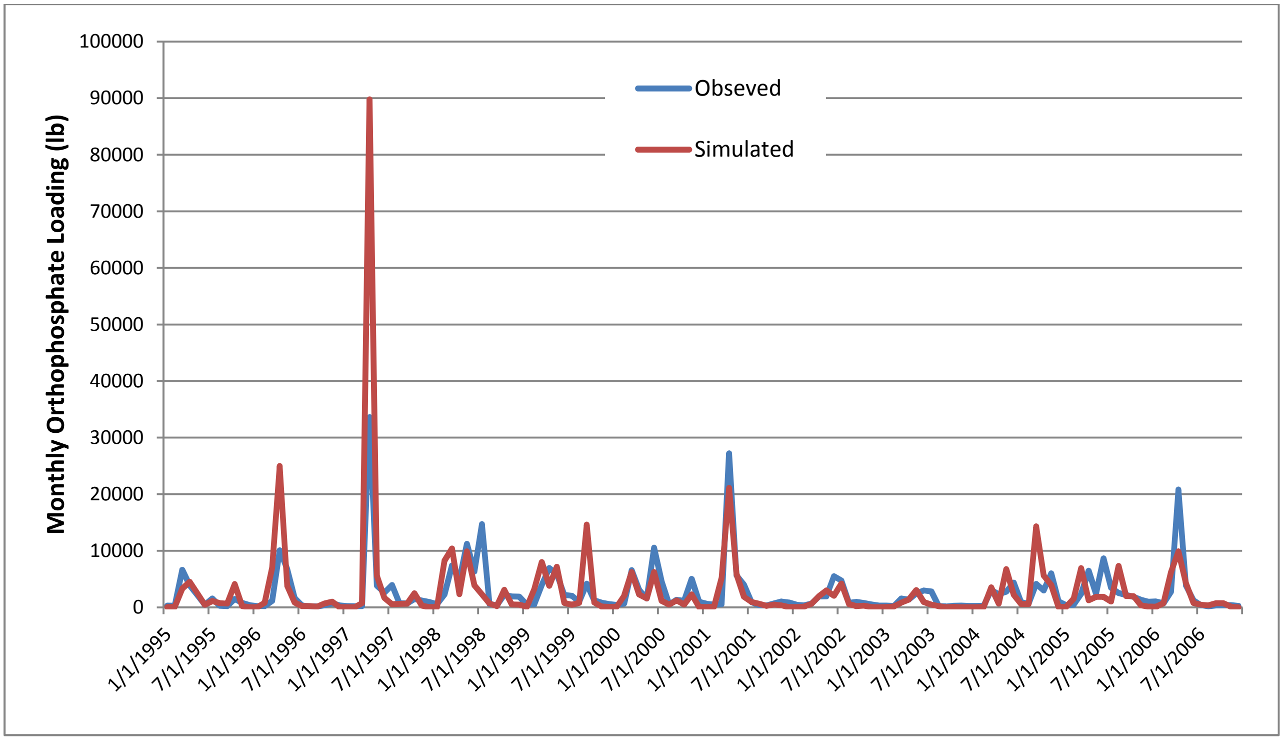

Figure 8: Simulated and observed orthophosphate loadings at Site S002-709 (RCHRES 101).

Calibration results for TP are provided in **Table 5.12**, validation results are shown in **Table 5.13**. Site S002-125 shows TP calibration in the **Fair** range and most other sites have an average annual TP concentration within the typical range. TP loadings for the calibration period are in the **Good** to **Very Good** range. TP loadings for the validation period are in the **Fair** to **Good** range (see **Table 2.3**). **Figure 9** shows monthly TP loadings at site S002-708 for the modeling period.

Table 5.12: Summary calibration information for total phosphorus.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Total Phosphorus [mg/L]			Total Phosphorus Load [lbs/year]		
			Obs.	Sim.	%Δ	Obs.[a]	Sim.	%Δ
S002-111	14	16	0.11 - 0.3	0.3	N/A	-	-	-
S002-125	91	78	0.27	0.19	-30.6%	-	-	-
S003-145	75	0	0.11 - 0.3	0.18	N/A	-	-	-
S003-152	104	0	0.06 - 0.15	0.125	N/A	135,494	106,497	-21%
S003-316	68	0	0.11 - 0.3	0.22	N/A	-	-	-
S002-708	101	8	0.11 - 0.3	0.13	N/A	299,066	302,915	1.3%
S002-709	127	0	0.11 - 0.3	0.19	N/A	126,631	140,727	11%

[a] Observed loading rates are extrapolated using the FLUX program and data outside of the modeling time frame.

Table 5.13: Summary validation information for total phosphorus.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Total Phosphorus [mg/L]			Total Phosphorus Load [lbs/year]		
			Obs.	Sim.	%Δ	Obs.[a]	Sim.	%Δ
S002-111	14	0	0.11 - 0.3	0.23	N/A	-	-	-
S002-125	91	0	0.11 - 0.3	0.13	N/A	-	-	-
S003-145	75	0	0.11 - 0.3	0.19	N/A	-	-	-
S003-152	104	0	0.06 - 0.15	0.119	N/A	171,206	119,684	-30%
S003-316	68	0	0.11 - 0.3	0.22	N/A	-	-	-
S002-708	101	0	0.11 - 0.3	0.13	N/A	335,849	489,267	45%
S002-709	127	0	0.11 - 0.3	0.19	N/A	126,047	153,354	22%

[a] Observed loading rates are extrapolated using the FLUX program and data outside of the modeling time frame.

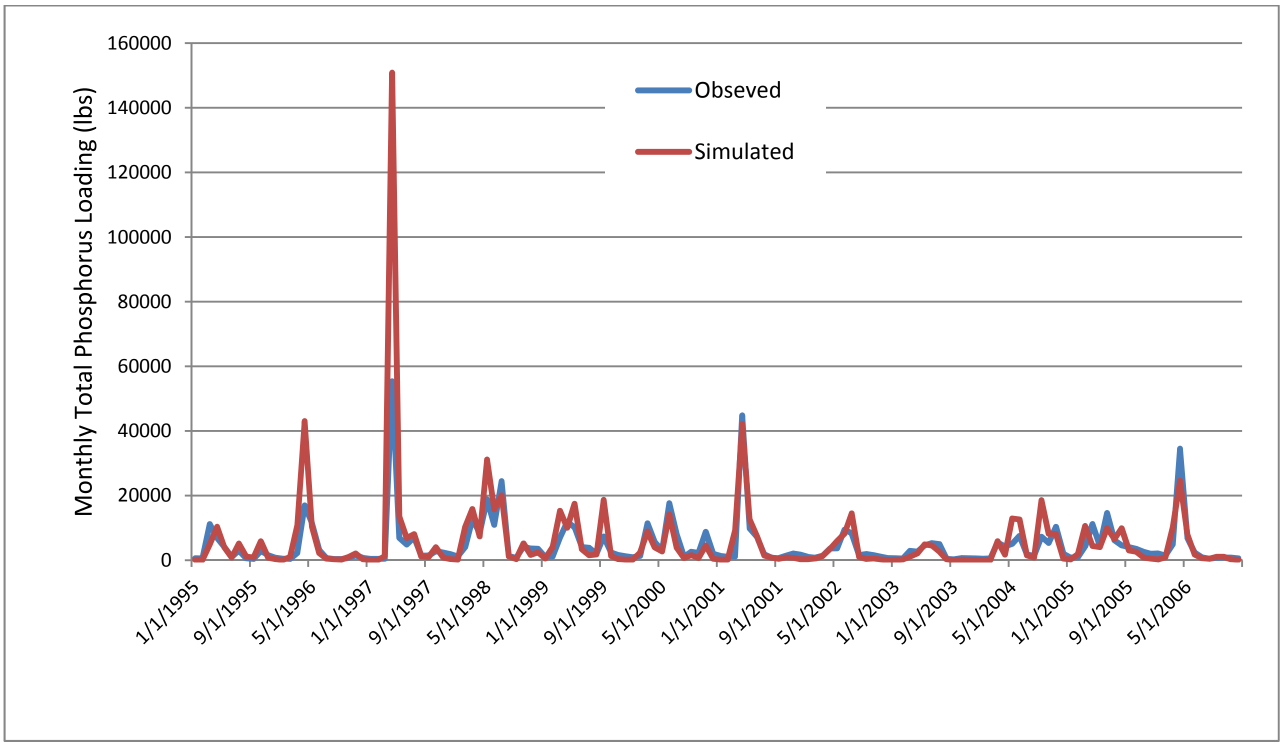

Figure 9: Simulated and observed total phosphorus loadings at Site S002-709 (RCHRES 101).

5.3.5 Nitrogen

The simulation of nitrogen in HSPF includes the modeling of NH3, NO2-NO3, and organic nitrogen. Three types of nitrogen were used for calibration: NH3, NO2-NO3, and TKN. TKN is the sum of total ammonia and organic nitrogen; summing TKN and NO2-NO3 provides TN.

Little to no observed in-stream nitrogen data is available during the modeling period. Site S002-125 has observed inorganic nitrogen concentrations during the calibration data. For all other sites and nitrogen species, typical annual average values (**Table 5.3)** were used for calibration and validation.

Nitrogen loads were estimated at three sites (S003-152, S002-708, and S002-709) using the FLUX program and observed flow and nitrogen data. These sites have observed data outside of the modeling period (after 2006). These data were used to create relationships between observed flow and nitrogen concentrations during this time period; those relationships were then used to estimate loads during the modeling period through extrapolation. This approach allowed the nitrogen constituents to be calibrated.

Table 5.14 shows the results of the simulation of ammonia in the BRW during the calibration period. Most sites are within the typical annual average values. The ammonia loadings at the three available sites are in the **Fair** to **Good** range with the percent difference ranging from -34.7% to 15.8%. **Table 5.15** shows the results of the simulation of ammonia for the validation period. Most sites are within the typical annual average values. The ammonia loadings at the three available sites are in the **Good** range with the percent difference ranging from -20.0% to 15.4%. **Figure 10** shows the simulated and observed monthly loadings of ammonia at site S002-708.

Table 5.14: Summary calibration information for ammonia simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Total Ammonia [mg/L]			Total Ammonia [lbs/yr]		
			Obs.	Sim.	%Δ	Obs.[a]	Sim.	%Δ
S002-111	14	0	0.05 - 1.5	0.08	N/A	-	-	-
S002-125	91	1	0.05 - 1.5	0.02	N/A	-	-	-
S003-145	75	0	0.05 - 1.5	0.07	N/A	-	-	-
S003-152	104	2	0.02 - 0.26	0.14	N/A	71,391	82,652	15.8%
S003-316	68	0	0.05 - 1.5	0.21	N/A	-	-	-
S002-708	101	0	0.05 - 1.5	0.04	N/A	102,551	66,958	-34.7%
S002-709	127	0	0.05 - 1.5	0.08	N/A	44,336	36,623	-17.4%

[a] Observed loading rates are extrapolated using the FLUX program and data outside of the modeling time frame.

Table 5.15: Summary validation information for ammonia simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Total Ammonia [mg/L]			Total Ammonia [lbs/yr]		
			Obs.	Sim.	%Δ	Obs.[a]	Sim.	%Δ
S002-111	14	0	0.05 - 1.5	0.13	N/A	-	-	-
S002-125	91	0	0.05 - 1.5	0.02	N/A	-	-	-
S003-145	75	0	0.05 - 1.5	0.07	N/A	-	-	-
S003-152	104	0	0.02 - 0.26	0.07	N/A	83,612	66,882	-20.0%
S003-316	68	0	0.05 - 1.5	0.19	N/A	-	-	-
S002-708	101	0	0.05 - 1.5	0.04	N/A	110,510	126,723	14.7%
S002-709	127	0	0.05 - 1.5	0.1	N/A	43,454	50,135	15.4%

[a] Observed loading rates are extrapolated using the FLUX program and data outside of the modeling time frame.

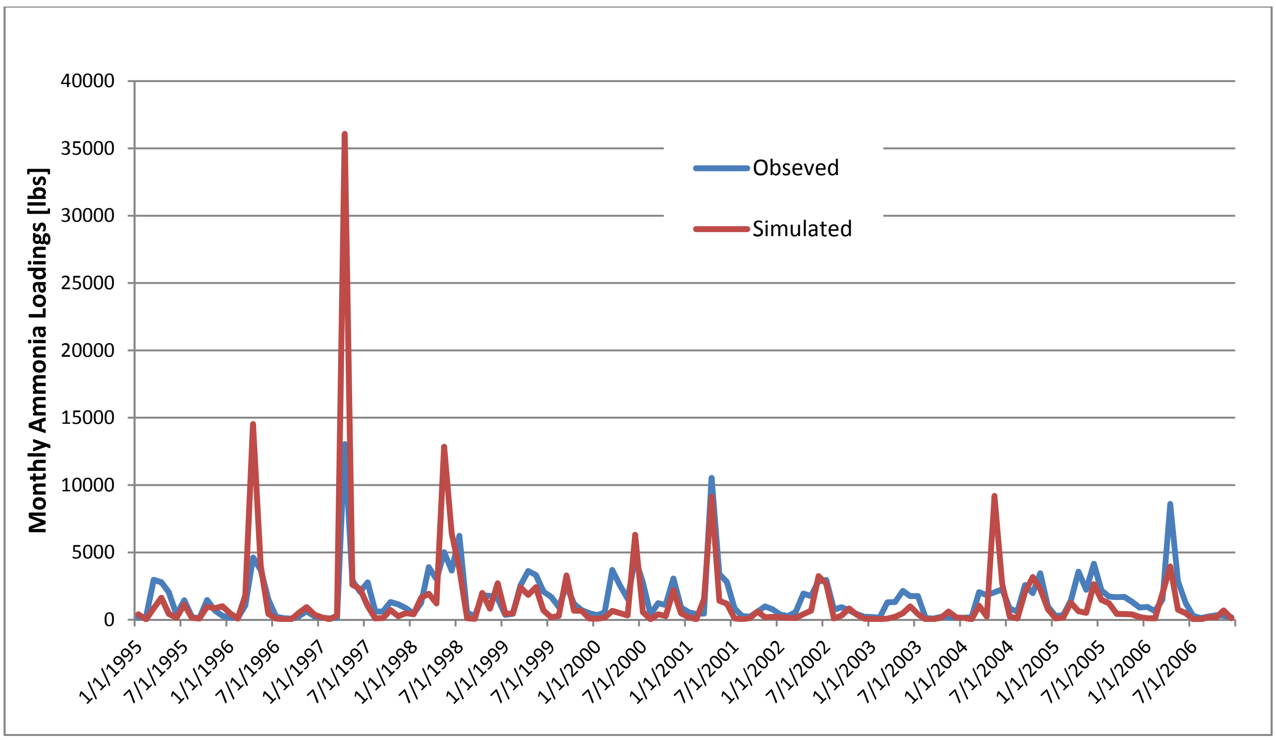

Figure 10: Simulated and observed total ammonia loadings at Site S002-709 (RCHRES 101).

Table 5.16 shows the results of the simulation of inorganic nitrogen. Most sites are within the typical annual average values. The NO2-NO3 loadings at the three available sites are in the **Good** to **Very Good** range with the percent difference ranging from -20.9% to 19.2%. **Table 5.17** shows the results of the simulation of NO2-NO3 for the validation period. Again, most sites are within the typical annual average values. The NO2-NO3 loadings at the three available sites are in the less than **Fair** to **Very Good** range with the percent difference ranging from -2.6% to 63.7%. The high over-prediction of NO2-NO3 at site

S002-708 is largely due to the extreme flood flow in 1997. **Figure 11** shows the simulated and observed monthly loadings of NO2-NO3 at site S002-708.

Table 5.16: Summary calibration information for inorganic nitrogen simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Inorganic Nitrogen [mg/L]			Inorganic Nitrogen Load [lbs/year]		
			Obs.	Sim.	%Δ	Obs.[a]	Sim.	%Δ
S002-111	14	15	0.01 - 0.21	0.08	N/A	-	-	-
S002-125	91	73	0.52	0.34	-34.6%	-	-	-
S003-145	75	5	0.01 - 0.21	0.15	N/A	-	-	-
S003-152	104	5	0.04 -0.26	0.382	N/A	341,437	406,887	19.2%
S003-316	68	0	0.01 - 0.21	0.16	N/A	-	-	-
S002-708	101	6	0.01 - 0.21	0.28	N/A	567,215	617,461	8.9%
S002-709	127	0	0.01 - 0.21	0.37	N/A	250,176	198,656	-20.6%

[a] Observed loading rates are extrapolated using the FLUX program and data outside of the modeling time frame.

Table 5.17: Summary validation information for inorganic nitrogen simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Inorganic Nitrogen [mg/L]			Inorganic Nitrogen Load [lbs/year]		
			Obs.	Sim.	%Δ	Obs.[a]	Sim.	%Δ
S002-111	14	0	0.01 - 0.21	0.12	N/A	-	-	-
S002-125	91	0	0.01 - 0.21	0.21	N/A	-	-	-
S003-145	75	0	0.01 - 0.21	0.16	N/A	-	-	-
S003-152	104	0	0.04 -0.26	0.30	N/A	493,549	480,546	-2.6%
S003-316	68	0	0.01 - 0.21	0.16	N/A	-	-	-
S002-708	101	0	0.01 - 0.21	0.25	N/A	685,908	1,122,806	63.7%
S002-709	127	0	0.01 - 0.21	0.43	N/A	259,567	281,149	8.3%

[a] Observed loading rates are extrapolated using the FLUX program and data outside of the modeling time frame.

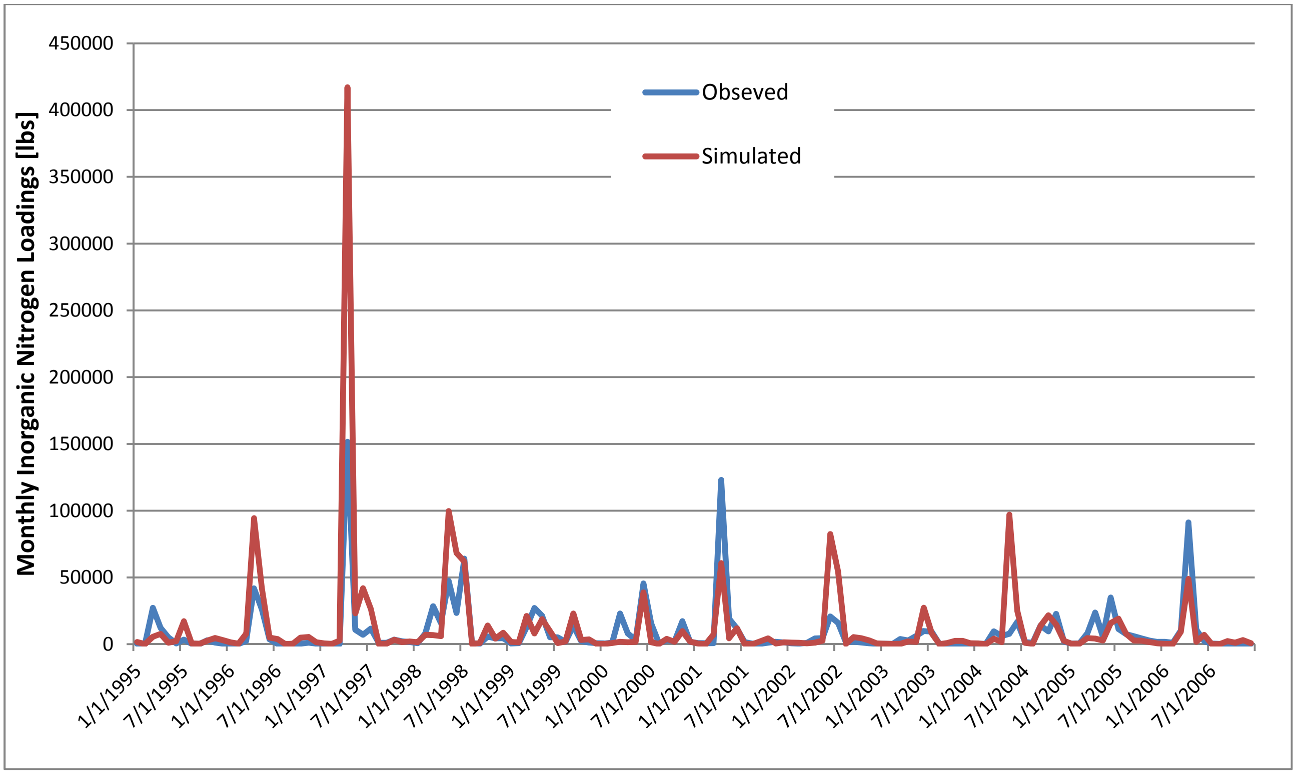

Figure 11: Simulated and observed total ammonia loadings at Site S002-709 (RCHRES 101).

Table 5.18 shows the results of the simulation of TKN in the BRW for the calibration period. Most sites are within the typical annual average range (Wall, 2013). The TKN loadings at the three available sites are in the **Good** to **Very Good** range with the percent difference ranging from -10.9% to 17.6%. **Table 5.19** shows the results of the simulation of ammonia for the validation period. Most sites are within the typical annual average range (Wall, 2013). The TKN loadings at the three available sites are in the **Good** range with the percent difference ranging from 2.8% to 48.2%. The high over-prediction of TKN at site S002-708 is largely due to the extreme flood flow in 1997. **Figure 12** shows the simulated and observed monthly loadings of ammonia at site S002-708.

Table 5.18: Summary calibration information for TKN simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Total Kjeldahl Nitrogen [mg/L]			Total Kjeldahl Nitrogen Load [lbs/year]		
			Obs.	Sim.	%Δ	Obs.[a]	Sim.	%Δ
S002-111	14	0	0.7 - 1.6	0.48		-	-	-
S002-125	91	1	0.7 - 1.6	0.10		-	-	-
S003-145	75	0	0.7 - 1.6	0.67		-	-	-
S003-152	104	0	0.7 - 1.6	0.96		696,793	819,396	17.6%
S003-316	68	0	0.7 - 1.6	0.98		-	-	-
S002-708	101	7	0.7 - 1.6	0.66		1,630,797	1,758,761	7.8%
S002-709	127	0	0.7 - 1.6	0.60		731,236	651,237	-10.9%

[a] Observed loading rates are extrapolated using the FLUX program and data outside of the modeling time frame.

Table 5.19: Summary validation information for TKN simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Total Kjeldahl Nitrogen [mg/L]			Total Kjeldahl Nitrogen Load [lbs/year]		
			Obs.	Sim.	%Δ	Obs.[a]	Sim.	%Δ
S002-111	14	0	0.7 - 1.6	0.48	N/A	-	-	-
S002-125	91	0	0.7 - 1.6	0.63	N/A	-	-	-
S003-145	75	0	0.7 - 1.6	0.69	N/A	-	-	-
S003-152	104	0	0.7 - 1.6	0.95	N/A	902,031	937,927	4.0%
S003-316	68	0	0.7 - 1.6	1.00	N/A	-	-	-
S002-708	101	0	0.7 - 1.6	0.74	N/A	1,807,222	2,679,123	48.2%
S002-709	127	0	0.7 - 1.6	0.70	N/A	723,934	744,463	2.8%

[a] Observed loading rates are extrapolated using the FLUX program and data outside of the modeling time frame.

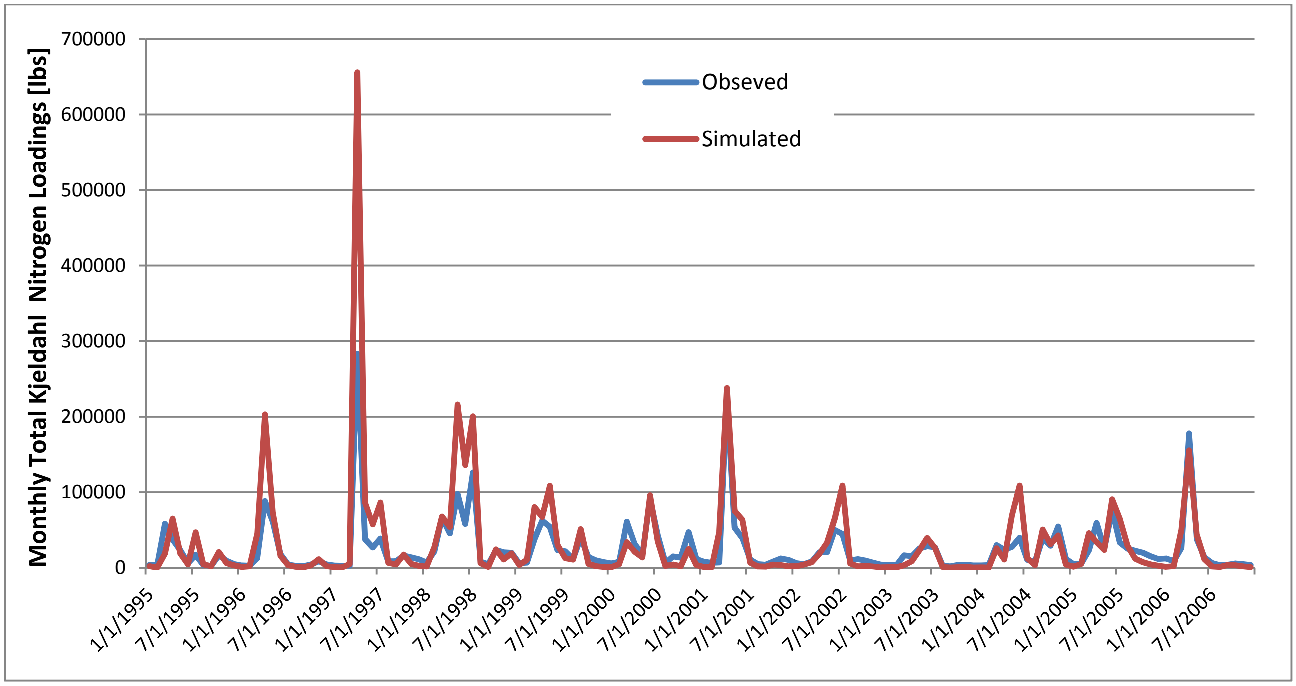

Figure 12: Simulated and observed TKN loadings at Site S002-709 (RCHRES 101).

5.3.6 Chlorophyll-*a*

Little to no observed chlorophyll-*a* data were available at most sites in the BRW. Site S002-708 has seven observations and S002-125 has one (not enough for a reasonable calibration). Given the lack of data, simulated results were compared to typical annual average concentrations for both the calibration (**Table 5.20**) and validation periods (**Table 5.21**). Simulated values were under-predicted when compared to state-wide averages (Heiskary et al., 2013) for both periods. It should be noted, the typical annual averages used for comparison are state-averaged summer concentrations. Annual averages are most likely lower than summer averages due to low concentrations during the winter months. Also, chlorophyll-*a* values in northern MN should be significantly lower than in southern portions of the state. If/when the models are updated/extended, comparisons should be made to observed data.

Table 5.20: Summary calibration information for chlorophyll-*a* simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Chlorophyll-*a* [µg/L]			Chlorophyll-*a* Load [lbs/year]		
			Obs.[a]	Sim.	%Δ	Obs.	Sim.	%Δ
S002-111	14	0	11 - 62	0.83	N/A	-	-	-
S002-125	75	0	11 – 62	4.01	N/A	-	-	-
S003-145	68	0	11 - 62	1.7	N/A	-	-	-
S003-152	91	0	11 - 62	5.8	N/A	-	-	-
S003-316	104	0	11 - 62	2.41	N/A	-	-	-
S002-708	101	0	11 - 62	3.36	N/A	-	-	-
S002-709	127	0	11 - 62	2.61	N/A	-	-	-

[a] Typical annual averages taken as statewide summer averages from (Heiskary et al., 2013).

Table 5.21: Summary validation information for chlorophyll-*a* simulation.

MPCA Water Quality Site	HSPF RCHRES ID	# of Obs.	Chlorophyll-*a* [µg/L]			Chlorophyll-*a* Load [lbs/year]		
			Obs.[a]	Sim.	%Δ	Obs.	Sim.	%Δ
S002-111	14	0	11 - 62	1.77	N/A	-	-	-
S002-125	75	0	11 - 62	3.07	N/A	-	-	-
S003-145	68	0	11 - 62	1.71	N/A	-	-	-
S003-152	91	0	11 - 62	7.8	N/A	-	-	-
S003-316	104	0	11 - 62	3.04	N/A	-	-	-
S002-708	101	0	11 - 62	4.71	N/A	-	-	-
S002-709	127	0	11 - 62	3.23	N/A	-	-	-

[a] Typical annual averages taken as statewide summer averages from (Heiskary et al., 2013).

6.0 UNCERTAINTY

To effectively judge the validity of a water quality model, an understanding of the uncertainty inherent with model predictions must be understood. As stated in the Minnesota River HSPF model report (TetraTech 2008), the major sources of model uncertainty include the following:

- **Mathematical Formulation**. A real water system is too complex for a mathematical model to represent all the dynamics, therefore, no matter how sophisticated a mathematical water quality model is, it is based on a simplified mathematical formulation. The simplifications in general neglect processes that are considered to be insignificant, thus the model can capture the general trend of the real system. In other words, a mathematical model is designed to represent the trend, rather than provide exact replication of the real system. Thus, uncertainty exists when those neglected factors start to play some detectable roles.

- **Data Uncertainty**. Site-specific data are the basis for developing a water quality model for a specific water body. A water quality model requires data from different sources and for a large number of parameters. Many of these data are subjected to either systematic or random errors. Also, data are always limited in both time and space, thus an interpolation method has to be used to represent continuous inputs. In most cases, monitoring data are not available for all the water quality parameters; thus, they have to be derived based on some empirical method. All these can contribute to uncertainty in the model.
- **Parameter Specification**. In a water quality model, parameters quantify the relationships in the major dynamic processes. The values of parameters are generally obtained through the model calibration process while constrained by a range of reasonable values documented in literature. Due to the sparseness and uncertainty in data used to configure and calibrate a water quality model, the model parameterization is also subjected to uncertainty.

The primary suggestion for reducing the level of uncertainty in the BRW HSPF model is to extend the modeling time frame. The majority of available water quality observations in the watershed were collected after 2006. Extending the modeled time frame into the more recent time period would allow for use of this data in model calibration/validation. In the current application, much of the calibration and most of the validation comparisons for water quality used typical annual average values because not enough observed data was available. Extending the modeling period would greatly lower the uncertainty within the model.

7.0 RECOMMENDATIONS

The BRW HSPF model provided good results for a wide range of parameters at multiple locations throughout the watershed. Recommendations for future modeling efforts were created based on "lessons learned" during the modeling processes of segmenting, calibrating, and executing the models. These recommendations include:

1. The models would greatly benefit from extending the modeling time period to include more observed data. Extending the model through at least 2009 would allow much more water quality data, at numerous sites, to be included for calibration purposes. Extending the model through 2010 would include data from the period of intensive water quality monitoring performed as part of the WRAP process.
2. Better understanding of the groundwater linkage between the Buffalo River and its many closed basin lakes could improve both the hydrology (especially low flows) and water quality simulations in the model.
3. Better stream cross-sectional information and lake outlet hydraulics information could improve the hydrologic, sediment, and water quality calibrations.
4. These points being made, overall, the BRW models are well-calibrated and can be used for future evaluations including their use in judging management strategies in the watershed and to inform the prioritization of restoration and protection projects.

8.0 SUMMARY

The BRW HSPF models have been developed, calibrated, and validated to simulate hydrology, sediment, water temperature, DO, BOD, phosphorus, nitrogen, and chlorophyll-*a*. In general, the models performed well and, according to the weight of evidence collected, the models' performance was ranked **Good**. On average, the models are within all acceptable tolerances proposed in the model performance criteria. The finished BRW HSPF models can be used to simulate management strategies for planning restoration/protection projects.

The hydrology in the BRW HSPF model performed well and, according to the weight of evidence collected, the model's performance was ranked **Good** to **Very Good**. On average, the models are within all acceptable tolerances proposed in the model performance criteria. The Mainstem model performed better than the South Branch model, with nearly all metrics rating in the **Very Good** category (HEI, 2012e). Ratings for the South Branch model ranged from Poor to Very Good, with the majority being Very Good. The lowest rating metrics for the South Branch model were associated with the accurate simulation of daily flows. As a watershed loading model, the accurate simulation of daily flows is not typically expected or necessary. Although the model performed well overall, there are notable limitations. Calibration of snow hydrology in the watershed was a challenge, resulting in an over-estimation of snow pack in the South Branch model in the years 1996 and 1997. Winter high and low flows have higher errors. The fact that "observed" winter flows in this watershed are not actually observed, but rather estimated, contributes to these errors. Finally, the routing of flows during major flood events was not accurately captured, resulting in errors in timing and peak flows. Given the design of the HSPF model, these types of errors were expected.

The calibration and validation of the water quality portion of the BRW HSPF was adequate. Most water quality constituents were simulated at a level of **Good**. The calibration of nutrients was considered good. As expected, croplands contribute the greatest sediment and nutrient loads in the watershed. DO is highly influenced by plankton growth, BOD decay, and re-aeration. A major issue with the simulation of water quality was the lack of useable observed data. The BRW has little observed water quality data available during the modeling period. Most concentration comparisons for calibration and validation of water quality were performed on typical average annual values. Most loading comparisons were made using extrapolated relationship developed using data outside the modeling time period. Extending the modeling period to include most of the observed water quality data may increase the validity of the water quality in the BRW HSPF.

9.0 REFERENCES

AQUA TERRA. 2012. Modeling Guidance for BASINS/HSPF Applications Under the MPCA One Water Program. Prepared for Minnesota Pollution Control Agency, St. Paul, MN. 79pp.

Donigian, Jr., A.S. 2002. Watershed Modeling Calibration and Validation: The HSPF Experience. *Proceedings, WEF National TMDL Science and Policy 2002*, November 13-16, 2002, Phoenix, AZ.

Heiskary, S., Bouchard, Jr. , R.W. and Markus, H. 2013. Minnesota Nutrient Criteria. Draft Report. Environmental Analysis and Outcomes Division. Minnesota Pollution Control Agency, St. Paul, MN. 197pp.

Houston Engineering Inc. 2011. *Summary of Work under the Buffalo River Watershed HSPF Model Framework Development Work Plan (MPCA Work Plan #B55117)*. Memorandum to MPCA Dated: June 27, 2011.

Houston Engineering Inc. 2012a. *Flow Calibration Locations for BRW HSPF Model.* Memorandum to MPCA Dated: Jan. 10, 2012.

Houston Engineering Inc. 2012b. *Representation of point sources and atmospheric deposition in the Buffalo River Watershed HSPF Model.* Memorandum to MPCA Dated: Feb. 20, 2012.

Houston Engineering Inc. 2012c. *Hydrologic Calibration and Validation Approach for the Buffalo River Watershed HSPF Model.* Memorandum to MPCA Dated: May 25, 2012.

Houston Engineering Inc. 2012d. *Proposed approach for simulating, calibrating, and validating water quality within the BRW HSPF models.* Memorandum to MPCA Dated: June 29, 2012.

Houston Engineering Inc. 2012e. *HSPF Model Hydrologic Calibration and Validation Report* . Prepared by HEI, Maple Grove, MN, for Minnesota Pollution Control Agency, St. Paul, MN.

Houston Engineering Inc. 2013a. *Sediment Source Partitioning and Calibration Targets for the BRW HSPF Models.* Memorandum to MPCA Dated: Jan. 28, 2012.

Houston Engineering Inc. 2013b. *BRW HSPF Model Sediment Calibration* Memorandum to MPCA Dated: Aug. 29, 2013.

Houston Engineering Inc. 2013c. *HSPF Model Hydrologic Calibration and Validation Report-Amended* Prepared by HEI, Maple Grove, MN, for Minnesota Pollution Control Agency, St. Paul, MN.

McCollor, S. and Heiskary, S. 1993. Selected water quality characteristics of minimally impacted streams from Minnesota's seven ecoregions. Minnesota Pollution control Agency, Water Quality Division, St. Paul, MN.

Minnesota Pollution Control Agency. 2003. Comparison of typical Minnesota water quality conditions. Water Quality/Surface Water #1.02, July 2003. Minnesota Pollution Control Agency, St. Paul, MN. http://www.pca.state.mn.us/index.php/data/eda-surface-water-searches/eda-guide-to-typical-minnesota-water-quality-conditions.html

TetraTech, 2009. Minnesota River Basin Turbidity TMDL and Lake Pepin Excessive Nutrient TMDL Model Calibration and Validation Report, prepared by TetraTech, Research Triangle Park, NC, for Minnesota Pollution Control Agency, St. Paul, MN.

United States Environmental Protection Agency (USEPA). 2006. BASINS Tutorial and Training Materials. http://water.epa.gov/scitech/datait/models/basins/userinfo.cfm

Wall, D. 2013. Chapter B1: Monitoring Stream Nitrogen Concentrations. In: Nitrogen in Minnesota Surface Waters, Report by Minnesota Pollution Control Agency, St. Paul, MN. http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/nutrient-reduction/nitrogen-study-looks-at-sources-pathways.html

Weiss, S. 2012. *Point Sources Nitrogen Loading Estimates for Minnesota*. Minnesota Pollution Control Agency, St. Paul, MN.