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TETRA TECH

Tetra Tech, Inc.
One Park Drive, Suite 200 • PO Box 14409
Research Triangle Park, NC 27709
Tel 919-485-8278 • Fax 919-485-8280

MEMORANDUM

To:	Emily Zanon (MPCA)
Cc:	Jennifer Olson (Tetra Tech)
From:	Michelle Schmidt, Cole Blasko, Afshin Shabani, Maddie Keefer (Tetra Tech)
Date:	March 16, 2022
Subject:	DRAFT HSPF Model Extension for the Root River Watershed and Minnesota Drainage Areas of the Upper Iowa and Mississippi River-Reno Watersheds

1.0 INTRODUCTION

The Minnesota Pollution Control Agency (MPCA) actively maintains Hydrologic Simulation Program – FORTRAN (HSPF) models for watersheds in the state to support various planning and restoration efforts. HSPF models of the Root (HUC 07040008) and Upper Iowa/Mississippi River – Reno (HUC 07060002 and 07060001) watersheds were designed to simulate hydrologic and water quality processes through Water Year (WY) 2015 (Figure 1; Tetra Tech, 2018). Note only the Minnesota portions of the Upper Iowa/Mississippi River – Reno watersheds are included in the HSPF model. To support upcoming Cycle 2 Watershed Restoration and Protection Strategy (WRAPS) work, the two HSPF models were extended through WY 2021. This required extension of model input time series for meteorology (i.e., weather), atmospheric deposition, and permitted point sources. The methods employed to extend the time series are discussed in this memorandum. No updates were made to the model build (e.g., stream routing, hydraulics, land use/cover representation) and no model recalibration occurred. A brief review of the model performance in regard to hydrology and water quality is also provided for key downstream locations. Recommendations for fine tuning the calibration are also provided. Note that the new model input files are named “Root_WY1994_WY2021.uci” and “UpperIA_Reno_WY1993_WY2021.uci”.

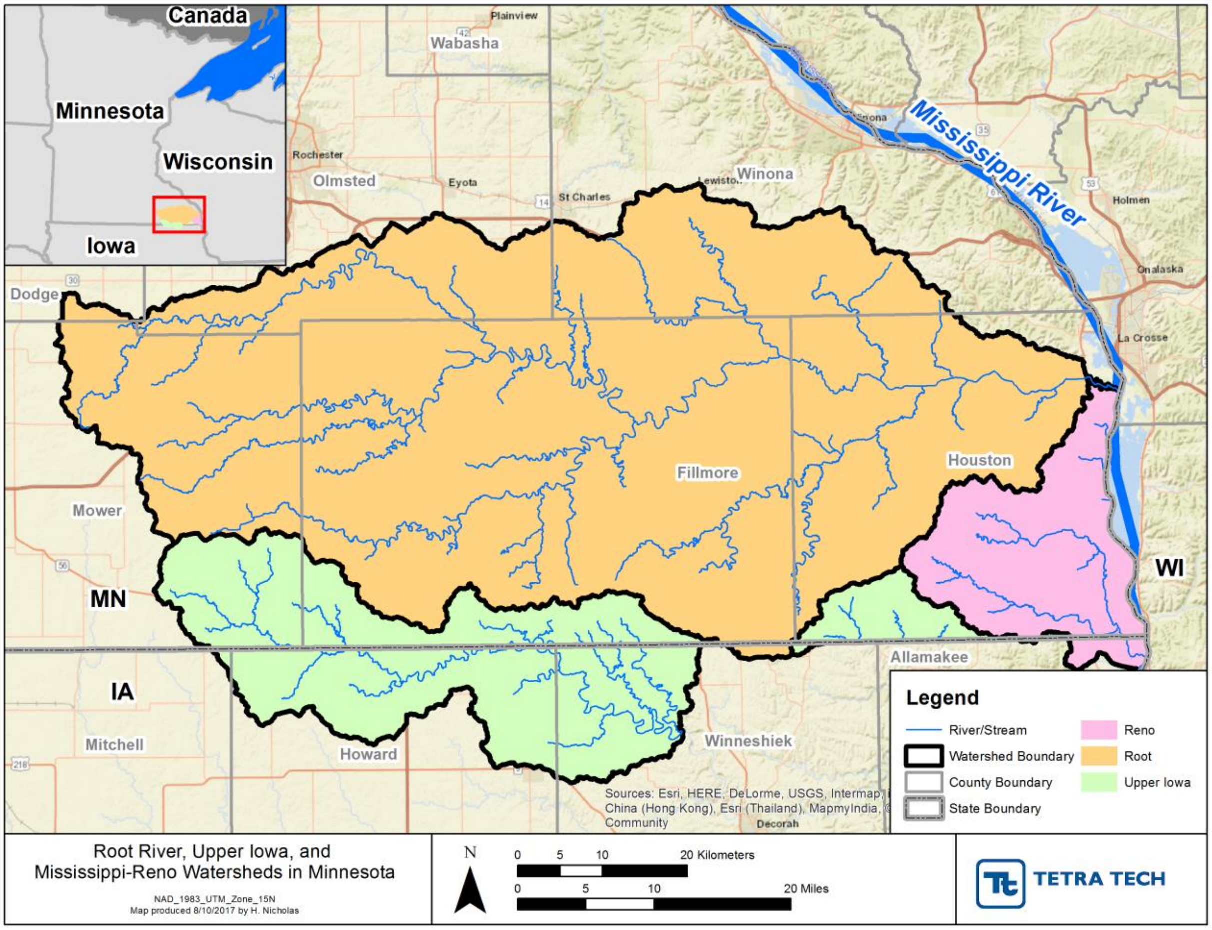

Figure 1. Extent of the HSPF Models

1.0 MODEL EXTENSION

The approaches used to extend the input time series for weather (Section 1.1), permitted point sources (Section 1.2), and atmospheric deposition (Section 0) through WY 2021 are discussed in the following subsections. A review of model performance following the temporal extension is provided in Section 2.0.

1.1 METEOROLOGY

Weather zones (also called hydrozones) and subbasin delineations represented in the original HSPF models were maintained for the model extension as were model Hydrologic Response Units (HRUs), which represent unique combinations of land use, soil type, and management practices (e.g., agricultural land under conventional or conservation tillage) for pervious and impervious upland segments. The weather zones delineated previously align with long-term precipitation and air temperature patterns from the PRISM (Parameter-elevation Relationships on Independent Slopes Model) database.

Because point-in-space station monitoring records are often not representative of integrated weather over a surrounding model area, the HSPF models apply gridded meteorological data sources. Gridded weather products can be used to better represent climatic variations across a diverse landscape, and these products also directly provide hourly air temperature, wind, and solar radiation data as well as parameters for computing cloud cover, dew point temperature, and potential evapotranspiration. Another benefit of gridded meteorological products is that these sources provide continuous data without gaps. This is not the case for point-in-space stations. Significant quality control work is required to process station-based records, potentially including patching missing records and developing proximity-based composite time series. Gridded products simplify and streamline the process of extending the spatial domain of the HSPF model and/or lengthening the simulation period.

PRISM provides annual, monthly, and daily gridded precipitation data for the conterminous United States (Daly et al., 2008; daily output was added to PRISM in 2015). PRISM calculates a climate-elevation regression function for each grid cell and the regression is used to distribute station-based precipitation data to the grid cell. Approximately 13,000 precipitation stations are used in the analysis. For each grid cell, precipitation stations are assigned weights based on location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of the terrain; the stations are then entered into the regression function to establish the gridded precipitation product.

Another gridded product is the North American Land Data Assimilation System (NLDAS-2) meteorological time-series (Mitchell et al., 2004). NLDAS-2 (http://ldas.gsfc.nasa.gov/nldas/NLDAS2forcing.php) provides continuous hourly data from 1979 to present on a 1/8-degree grid that has been processed to fill gaps. The precipitation data in NLDAS-2 are based on interpolation of daily gauge precipitation including orographic adjustments based on PRISM and temporally disaggregated using Doppler radar and satellite data. NLDAS-2 also provides solar radiation, wind at 10 m (which can be scaled to wind at 2 m), and absolute humidity plus air pressure, from which dew point can be calculated. Cloud cover (which is only needed to estimate long wave radiation exchange with the atmosphere) is not included in the NLDAS output, but can be back-calculated from the ratio of estimated incident solar radiation to cloud free solar radiation during daylight hours using the regression relationship developed by Davis (1996).

Gridded meteorological data are available through the National Centers for Environmental Prediction (NCEP) North American Regional Reanalysis (NARR), which is an extension of the NCEP Global Reanalysis. NARR leverages the regional and high-resolution Eta Model, applies the Noah-Multiparameterization Land Surface Model, and incorporates other advancements in data assimilation (Mesinger et al., 2006) to produce gridded meteorological datasets for North America. Temperature, wind, precipitation, and pressure data collected from numerous sources serve as inputs to the model. Data products include 3-hourly, daily, and monthly means from 1979 to present (with a half-month delay in availability), on a 32-km grid. Hundreds of meteorological and hydrological parameters are available through NARR, including total cloud cover, air temperature, precipitation, wind, dew point temperature, potential evapotranspiration (PET), and solar radiation. Additional information is provided on the NARR website: https://www.esrl.noaa.gov/psd/data/gridded/data.narr.html.

Meteorological data from PRISM, NLDAS, and NARR were used to develop hourly weather forcing series for the extension of the HSPF models for the Root River watershed and drainage areas within Minnesota for the Upper Iowa and Mississippi River-Reno watersheds. The basic overview of each meteorological input, data source, and processing notes are provided in Table 1. The Gridded Weather Data Processing Tool (MetTool), developed by Tetra Tech for MPCA, was used to download, extract, and process data for the grids intersecting the watershed and to aggregate the time series to the model weather zones. A comprehensive discussion of the methods implemented in the MetTool can be found in Tetra Tech (2020).

Table 1. Summary of HSPF Meteorological Input Time Series

HSPF Model Input	Description (units)	Parameter Source	Processing Notes
PREC	Precipitation (in)	PPT (PRISM), APCP (NLDAS)	Daily PRISM precipitation data are disaggregated using either NLDAS hourly patterns or the random cascade method on days where NLDAS reports zero precipitation
ATEM	Air Temperature (°F)	TMP (NLDAS)	Hourly air temperature, used directly
SOLR	Solar Radiation (Ly)	DSWRF (NLDAS)	Hourly shortwave radiation, used directly
CLOU	Cloud Cover (tenths; 0-10)	DSWRF (NLDAS)	Inferred from hourly shortwave radiation at 2 meters, and estimated cloudless-sky short wave radiation
DEWP	Dew Point Temperature (°F)	SPFH, PRES, TMP (NLDAS)	Function of hourly specific humidity, air pressure, and air temperature
WIND	Wind Travel (mi)	UGRD, VRGD (NLDAS)	Net wind travel from component vectors
PEVT	Potential Evapotranspiration (in)	DSWRF, TMP, WIND, SPFH, PRES (NLDAS)	Computed from solar radiation, air temperature, wind travel, and dew point temperature

1.2 POINT SOURCES

Point sources included in the HSPF models include 31 facilities in the Root River watershed (Table 2) and nine facilities in the Upper Iowa and Mississippi River-Reno drainage areas (Table 3). Facilities include industrial facilities, and hatchery operations but are primarily WWTPs of class A through D. Some facilities are wastewater ponds with controlled, intermittent surface discharges that generally occur in the spring and fall. The largest dischargers by volume are the Lanesboro (Subbasin 119) and Peterson (Subbasin 117) State Fish Hatcheries in the Root River watershed.

The development of point source time series for the original model were derived from monthly records. For the model extension period (October 2015 through September 2021), flow and chemistry data for permitted point sources in the modeled area were downloaded from MPCA's Wastewater Data Browser (https://www.pca.state.mn.us/data/wastewater-data-browser) and were also provided by MPCA via Discharge Monitoring Reports (DMRs). The approaches to extend the flow and point source discharge loads of carbonaceous biochemical oxygen demand (CBOD), organic N, total ammonia (TAM), nitrate (NO3), orthophosphate (PO4), organic P, dissolved oxygen (DO), total suspended solids (TSS), and heat are summarized in Table 4.

When constituents were not monitored, typical effluent concentrations of wastewater treatment facilities (specified by size), industrial facilities, and mining operations were employed. Because a constant concentration is assumed when this is the case an input time series was not necessary, and input loads are instead calculated from flow using a multiplier in the EXT SOURCES block of HSPF. If a constituent was calculated from flow using a multiplier in the previous model period, it was also calculated this way in the extended model period.

When surface discharge records were available for a constituent, load time series (calculated from flow and concentration) were generated and stored in the point sources WDM (Watershed Data Management) file to be read in by the model during a run. When a month was missing data for a specific constituent or when the reported value was flagged as not passing a QA check, the data in the extended model period were filled using one or a combination of the following methods: (1) the monthly median value from the discharger's extended model period of record was used; (2) the monthly average value from the discharger's previous model period of record was used; (3) the typical effluent concentration by wastewater treatment facility class (specified by size), industrial facility or mining operation was used as a surrogate value or; (4) the constituent concentration was calculated using other reported constituents (e.g., total organic N from TKN and TAM).

Most stabilization ponds only discharge on a limited number of days per year. The records give the total flow in a month but do not state which days the discharge occurs on. Because the exact timing of these loads is unknown, the total load as spread evenly across the month in the model.

Two of the more significant point sources within the model domain are Spring Valley WWTP (discharging to Spring Valley Creek in the Root watershed) and Caledonia WWTP (discharging to South Fork Crooked Creek in the Reno watershed).

Table 2. Permitted Point Source Discharges in the Root River HSPF Model

NPDES Code	Discharger Name	Watershed	Model Subbasin	Previous Avg. Flow (MGD) [a]	Extended Avg Flow (MGD) [b]
MN0053589	Advance Transformer Co.	Root	132	0.038	0
MN0057789	BP Products Spring Valley	Root	141	0.0024	0
MN0023001	Canton WWTP	Root	112	0.026	0.018
MN0021857	Chatfield WWTP	Root	158	0.252	0.302
MNG585228	Dexter WWTP (pond)	Root	156	0.056	0.061
MN0001333	Foremost Farms USA Cooperative	Root	125	0.108	0.033
MN0050873	Fountain WWTP	Root	137	0.0048	0.0256
MN0023558	Grand Meadow WWTP (pond)	Root	142	0.382	0.334
MN0067717	Great River Energy - Pleasant Valley Station	Root	156	0.0024	0.0027
MNG585071	Haven Hutterian Brethren (pond)	Root	156	0.022	0.021
MN0021458	Hokah WWTP	Root	102	0.058	0.061
MN0023736	Houston WWTP	Root	106	0.118	0.151
MNG255021	Lanesboro Public Utilities	Root	119	0.0048	0
MN0020044	Lanesboro WWTP	Root	119	0.070	0.067
MN0023965	Lewiston WWTP (pond)	Root	164	0.140	0.095
MN0020877	Mabel WWTP	Root	110	0.089	0.114
MN0004430	MDNR - Lanesboro State Fish Hatchery	Root	119	7.277	7.536
MN0061221	MDNR - Peterson State Fish Hatchery	Root	117	2.674	3.708
MN0069531	Milestone Materials - Panhandle Quarry	Root	153	0.394	0
MN0048844	MNDOT Enterprise Rest Area (pond)	Root	163	0.0014	0.0104
MN0044377	MNDOT High Forest Rest Area (pond)	Root	152	0.0006	0.0004

MN0024449	Ostrander WWTP	Root	131	0.031	0.013
MN0024490	Peterson WWTP	Root	117	0.014	0.017
MN0064017	POET Biorefining – Preston (pond)	Root	133	0.041	0.009
MN0020745	Preston WWTP	Root	125	0.269	0.344
MN0024554	Racine WWTP (pond)	Root	144	0.087	0.054
MN0024678	Rushford WWTP	Root	161	0.158	0.109
MN0051934	Spring Valley WWTP	Root	183	0.475	0.466
MN0020681	Stewartville WWTP	Root	151	0.391	0.592
MN0020826	Wykoff WWTP	Root	191	0.0288	0.0222

Note: For stabilization pond systems that discharge only during spring and fall windows, the flow reported is the average for months with discharge. If the average flow is zero, the facility is no longer active.
a. The average flow in million gallons per day for the previous model period (October 1993 – September 2015).
b. The average flow in million gallons per day for the extended model period (October 2015 - September 2021).

Table 3. Permitted Point Source Discharges in the Upper Iowa and Mississippi River-Reno HSPF Model

NPDES Code	Discharger Name	Watershed	Model Subbasin	Previous Avg. Flow (MGD) [a]	Extended Avg Flow (MGD) [b]
MN0053562	Brownsville WWTP	Reno	514	0.028	0.031
MN0020231	Caledonia WWTP	Reno	511	0.290	0.205
MN0049531	Eitzen WWTP (pond)	Reno	502	0.041	0.037
MNG255082	Granger Farmers Coop Creamery	Upper Iowa	305	0.0003	0
MN0022322	Harmony WWTP	Upper Iowa	327	0.091	0.066
MN0064475	Koch Inc - Quarry 1	Upper Iowa	314	0.032	0
MNG490112	Koch Inc - Quarry 3	Upper Iowa	317	0.024	0.066
MN0021041	Le Roy WWTP (pond)	Upper Iowa	309	0.283	0.283
MN0021440	Spring Grove WWTP	Upper Iowa	336	0.143	0.205

Note: For stabilization pond systems that discharge only during spring and fall windows, the flow reported is the average for months with discharge. If the average flow is zero, the facility is no longer active.
a. The average flow in million gallons per day for the previous model period (October 1993 – September 2015).
b. The average flow in million gallons per day for the extended model period (October 2015 - September 2021).

Table 4. Summary of Approach to Develop Load Time Series for Point Sources

Constituent	Time Series Development Approach
BOD	Facility monitoring records for CBOD5 were used to develop a time series for each facility.
DO	Calculated using a multiplier on flow in the EXT SOURCES block of HSPF because constituent was modeled as a multiplier on flow in the existing HSPF model that is being extended.
Heat	Calculated using a multiplier on flow in the EXT SOURCES block of HSPF because constituent was modeled as a multiplier on flow in the existing HSPF model that is being extended.
NO2+NO3	Facility monitoring records of NO2+NO3 were used to develop a time series for each facility.
PO4	Facility TP monitoring records were available, but PO4 samples were not. PO4 loading time series were therefore developed for each facility by assuming 0.7235 of TP was PO4.
Refractory organic N	Facility records were not available for organic N. There are labile and refractory components of organic N. Labile organic N is embedded in CBODu and HSPF computes this portion based on stoichiometric ratios for organic matter. Refractory organic N concentrations were established by subtracting the labile organic N concentration (derived from CBODu and stoichiometric relationships) from the total organic N concentration (assumed to be 2 mg/L for “Class D”; Weiss 2012).
Refractory organic P	Facility records were not available for organic P. There are labile and refractory components of organic P. Labile organic P is embedded in CBODu and HSPF computes this portion based on stoichiometric ratios for organic matter. Refractory organic P concentrations were established by subtracting the labile organic P concentration (derived from CBODu and stoichiometric relationships) from the total organic P concentration (fraction of TP that was assumed to be organic P was 0.2775).
TAM	Facility monitoring records of TAM were used to develop a time series for each facility.
TSS	Facility monitoring records were used to develop a TSS (clay) time series for each facility.

1.3 ATMOSPHERIC DEPOSITION

The original HSPF models simulate wet and dry deposition of ammonia-N and nitrate-N to pervious surfaces, impervious surfaces, and water bodies. N deposition time series were extended and incorporated into the updated Root River model and Upper Iowa/Mississippi River-Reno model. Wet deposition concentrations of ammonia and nitrate N (as mg/L) from weekly data recorded at the National Atmospheric Deposition Program (NADP) stations IA08 (Big Springs Fish Hatchery) and WI98 (Wildcat Mountain) were used for incorporation into the Root River watershed model previously. WI98 stopped recording data on December 13, 2013, therefore IA08 data were applied for the model extension through WY 2021. Dry deposition rates of ammonia and nitrate N (as lb/ac) are taken from EPA Clean Air Status and Trends (CASTNET) monitoring network (https://www.epa.gov/castnet). The nearest station with adequate data for the extension period was Perkinstown in Taylor County, Wisconsin (PRK134). In all cases, reported data were converted from molar units to mass or mass-based concentration as N to be compatible with HSPF.

Both dry and wet deposition of phosphorus to water were represented in the models based on the 2007 update to Detailed Assessment of Phosphorus Sources to Minnesota Watersheds - Atmospheric Deposition (Twaroski, et al., 2007). The phosphorus dry deposition rate is about 0.240 kg/ha/yr and the wet deposition concentration for phosphorus is around 22.1 µg/L for this region. This information was previously used to parameterize wet and dry atmospheric deposition of phosphorus to river and reservoir/lake water surfaces and it was maintained. Atmospheric deposition of phosphorus to the uplands is not simulated because it is implicit in the sediment potency representation of pervious land loading and the buildup/washoff representation of impervious land loading of phosphorus.

2.0 MODEL PERFORMANCE REVIEW AND RECOMMENDATIONS

The performance of the HSPF models following the temporal extension was evaluated at key downstream locations. Parameter values previously calibrated for hydrology and water quality through WY 2015 were maintained and no recalibration occurred. The high-level status of the extended, but not yet recalibrated, models is presented in the following subsections. A review of the strengths and weaknesses of the models are summarized and recommendations for refinements that could be made to the model prior to using it for application studies are presented.

2.1 HYDROLOGY

Daily flow records from two gages were used to evaluate the representation of watershed hydrology provided by the models. The streamflow gages used in the assessment are Root River near Houston (USGS 05385000) and Upper Iowa River near Bluffton, Iowa (USGS 05387440). Model performance was evaluated with visual and statistical comparisons of model predictions and monitoring records. Summary statistics for the flow gages are provided in Table 5 for both the previous calibration period (10/1/2007 to 9/30/2015) and that period with the extension (10/1/2007 to 9/30/2021).

Table 5. Streamflow Summary Statistics following the Model Extensions

Flow Summary Statistic	Root River near Houston (USGS 05385000, Reach 114)		Upper Iowa River near Bluffton, Iowa (USGS 05387440, Reach 301)	
	10/1/2007 to 9/30/2021 (extended)	10/1/2007 to 9/30/2015	10/1/2007 to 9/30/2021 (extended)	10/1/2007 to 9/30/2015
Error in total volume	-9.01	-7.26	5.15	7.35
Error in 50% lowest flows	-11.45	-16.01	6.92	9.66
Error in 10% highest flows	-8.71	-9.19	6.73	8.71
Error in summer flow	-7.90	-12.01	17.81	10.31
Error in fall flow	-12.86	-14.69	10.31	15.60
Error in winter flow	-17.30	-13.78	-12.49	-7.54
Error in spring flow	-4.17	-1.50	4.68	7.87
Error in storm volumes	-12.37	-16.60	-2.20	-10.29
Error in summer storm vols	-0.19	2.23	39.17	16.92
Daily NSE	0.639	0.665	0.492	0.516
Monthly NSE	0.919	0.947	0.861	0.895

Based on these two locations, the model performance is generally similar for the previous calibration period and that period with the more recent years included. Nevertheless, some calibration refinements would be beneficial as the daily and monthly Nash-Sutcliffe Coefficient of Efficiency (NSEs) were degraded at both locations as were some other metrics, such as relative errors on winter and spring seasonal flows at Root River near Houston, for example. Our general recommendations for adjusting the hydrology calibration include:

- Review model performance at other streamflow gaging locations.
- Incorporate new data to improve the karst representation and surface-subsurface flow interactions (e.g., dye study results), if available; note the karst geology is modeled in HSPF with a subsurface reach network.
- Review and recalibrate monthly evaporation patterns and volumes (e.g., to see if improvements can be made to the summer flow error for Upper Iowa near Bluffton).
- Recalibrate the snow simulation (e.g., to see if improvements can be made to the winter and spring seasonal flows in the Root River).
- Fine tune the hydrologic parameterization to improve the representation of summer stormflows, low flow periods, and seasonal flow characteristics.

Root River near Houston (USGS 05385000)

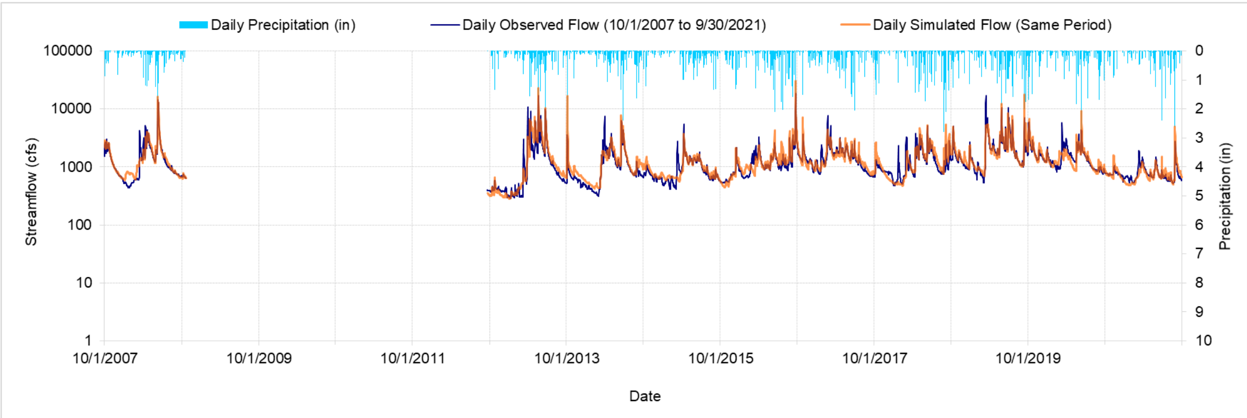

Figure 2. Flow Time Series Plot for Root River near Houston

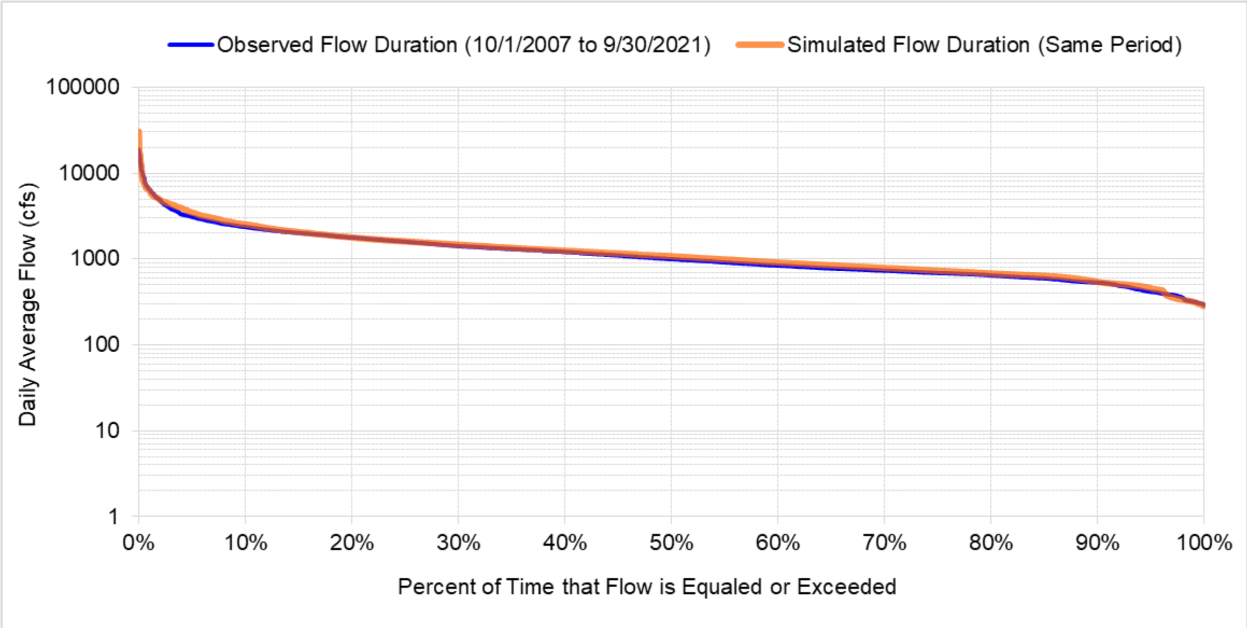

Figure 3. Flow Duration Curve for Root River near Houston

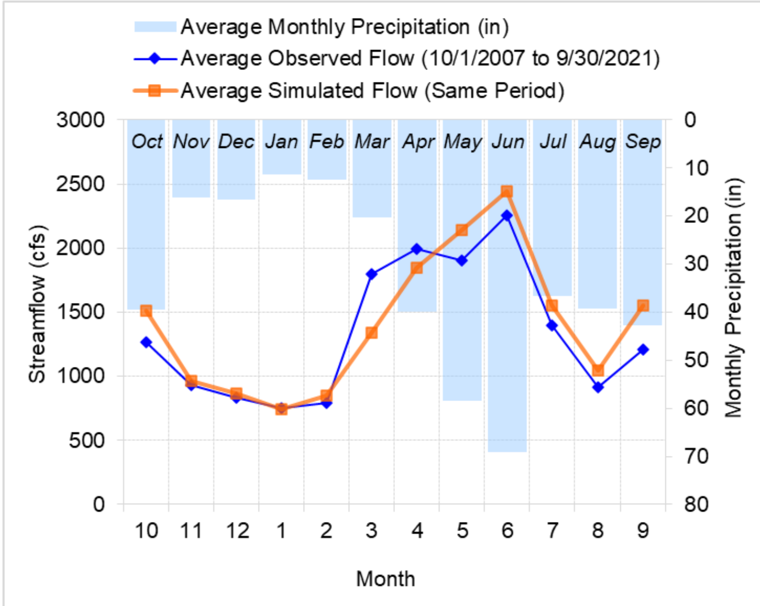

Figure 4. Average Monthly Streamflow for Root River near Houston

Upper Iowa River near Bluffton, Iowa (USGS 05387440)

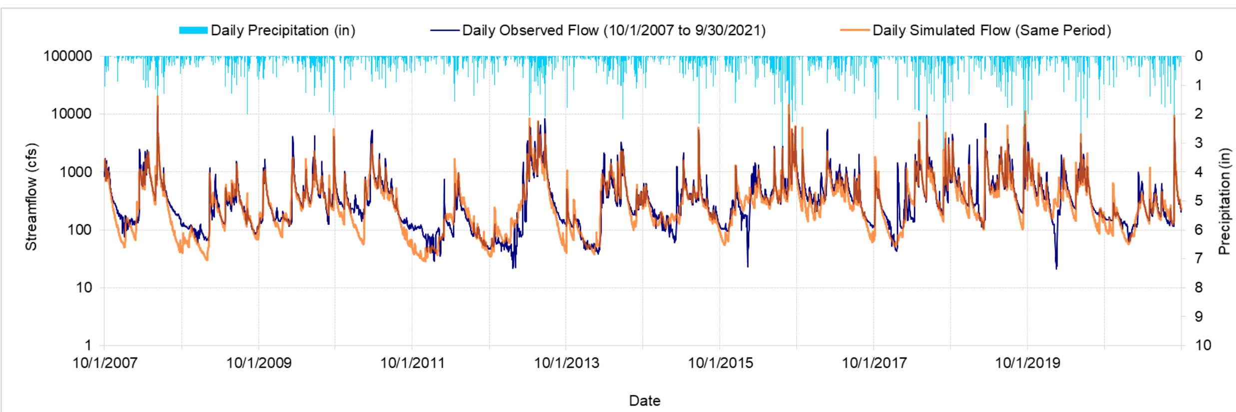

Figure 5. Flow Time Series Plot for Upper Iowa River near Bluffton, Iowa

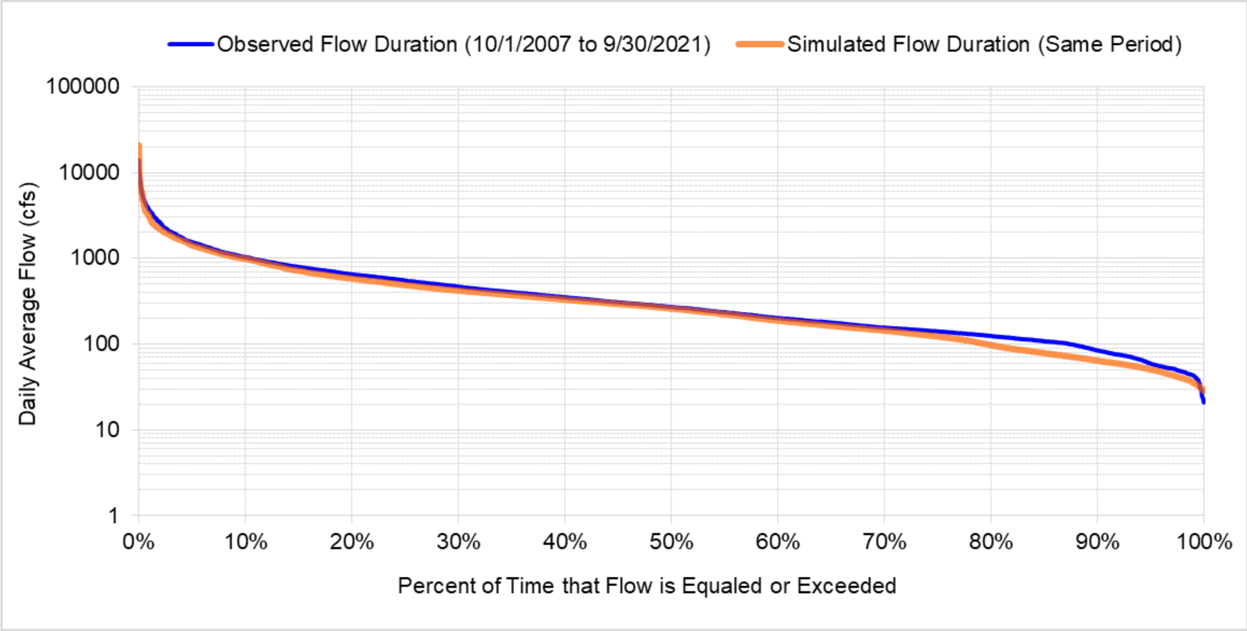

Figure 6. Flow Duration Curve for Upper Iowa River near Bluffton, Iowa

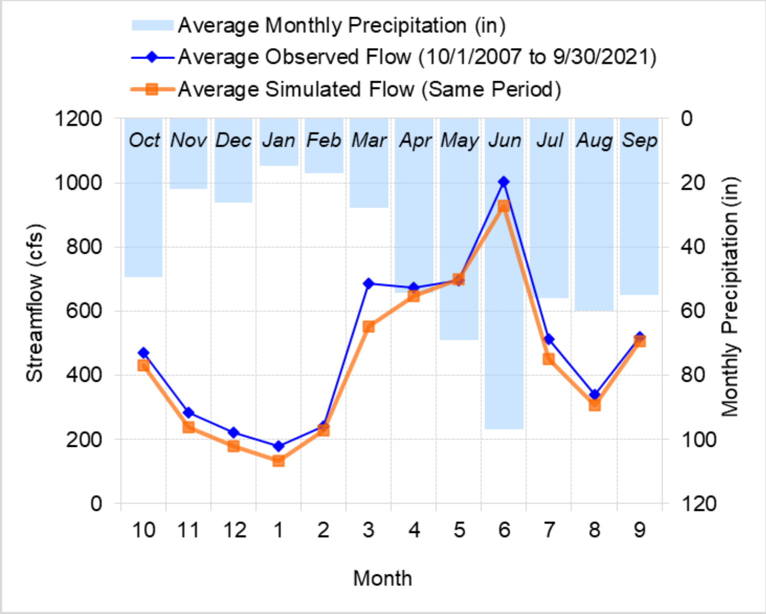

Figure 7. Average Monthly Streamflow for Upper Iowa River near Bluffton, Iowa

2.2 WATER QUALITY

2.2.1 Sediment and Nutrients

The model performance for water quality using existing parameters was also reviewed. Future adjustments made to the hydrology calibration would alter the representation of sediment and nutrient concentrations and loads, and the water quality performance would need to be reevaluated before further tuning. However, results for water quality are discussed to provide a broad picture of the model performance and its suitability for the application study. Summary statistics for sediment (TSS) and nutrient species are shown in Table 6.

Relative errors on average and median TSS and TKN concentrations are improved for the extended period compared to the previous calibration period. Model performance for NO_x and TP is similar for the two periods, with slightly higher relative errors on average concentration for the extended period at this site.

Our general recommendations for adjusting the water quality calibration include:

- Review the model performance at this and other monitoring locations following updates to the hydrology simulation as those will impact the water quality representation.
- Fine tune the water quality parameterization to improve aspects such as:
    - The seasonality for TSS because the model is currently underpredicting concentrations in the late winter, early spring and overpredicting concentrations in the fall (Figure 9).
    - Based on Figure 13, the model is not replicating the spread of TKN observations at this location; simulated low TKN concentrations are higher than observations suggest.
    - The model is biased high on TP concentrations during high flows (Figure 17). Fine tuning should seek to reduce this bias.

Table 6. Water Quality Model Performance Summary for Root River at Mound Prairie (S004-858, R103)

Constituent	Relative Error on Average Concentration (Simulated-Observed)		Relative Error on Median Concentration (Simulated-Observed)	
	3/26/2008 to 9/30/2021 (extended)	3/26/2008 to 9/23/2015	3/26/2008 to 9/30/2021 (extended)	3/26/2008 to 9/23/2015
Total Suspended Solids	-21.4%	-25.6%	-3.4%	-5.0%
Total Phosphorus	4.5%	1.1%	7.4%	8.0%
Nitrite-nitrate	-2.5%	-1.2%	0.2%	-3.3%
Total Kjeldahl Nitrogen	6.2%	8.0%	39.0%	42.5%

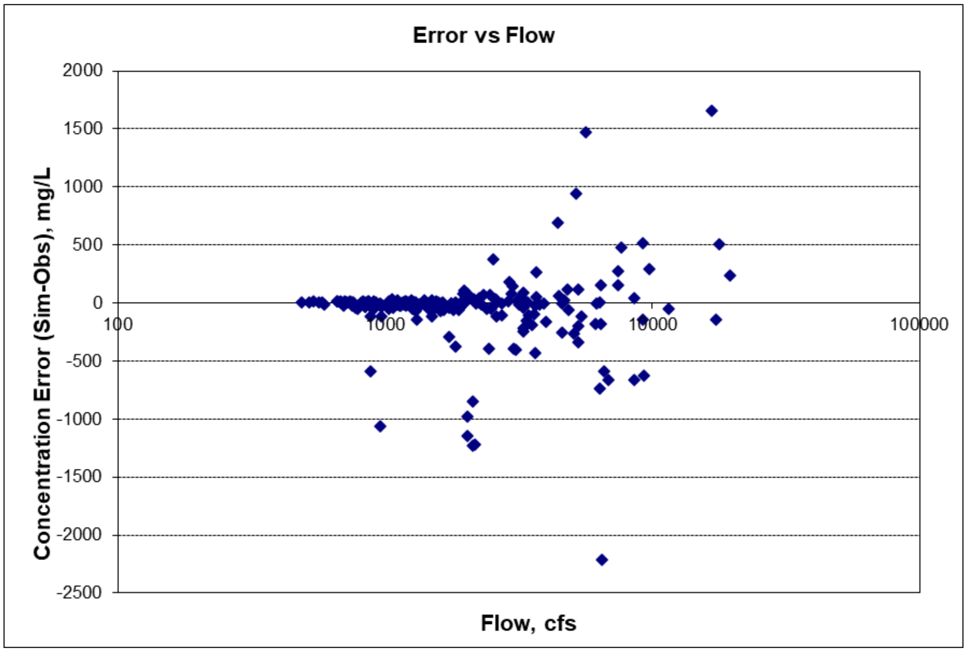

Figure 8. Relative TSS Concentration Error (Sim-Obs) Relative to Flow at Root River at Mound Prairie (S004-858, R103)

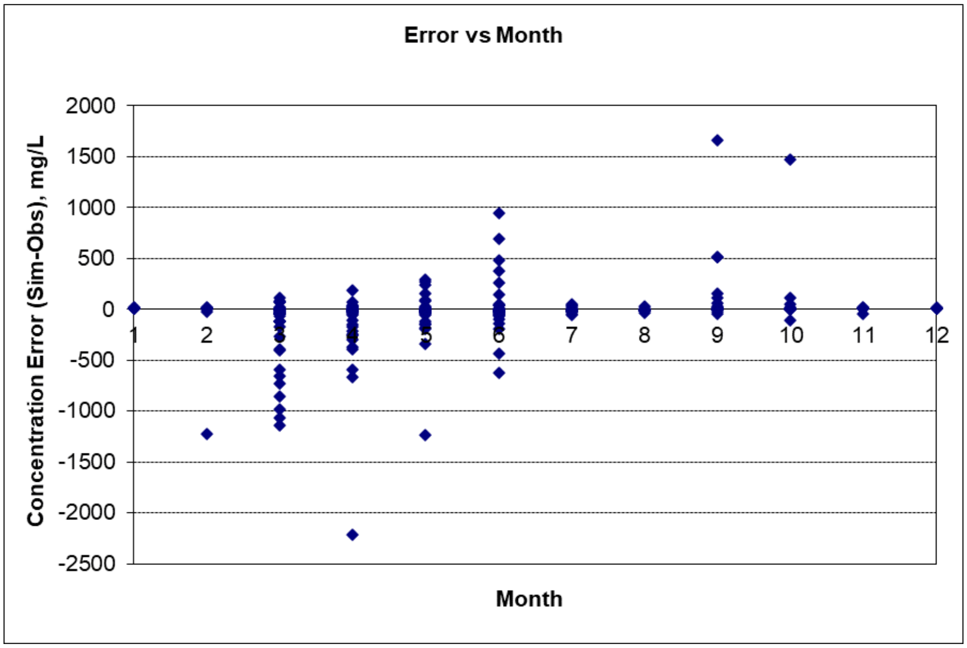

Figure 9. Relative TSS Concentration Error by Month at Root River at Mound Prairie (S004-858, R103)

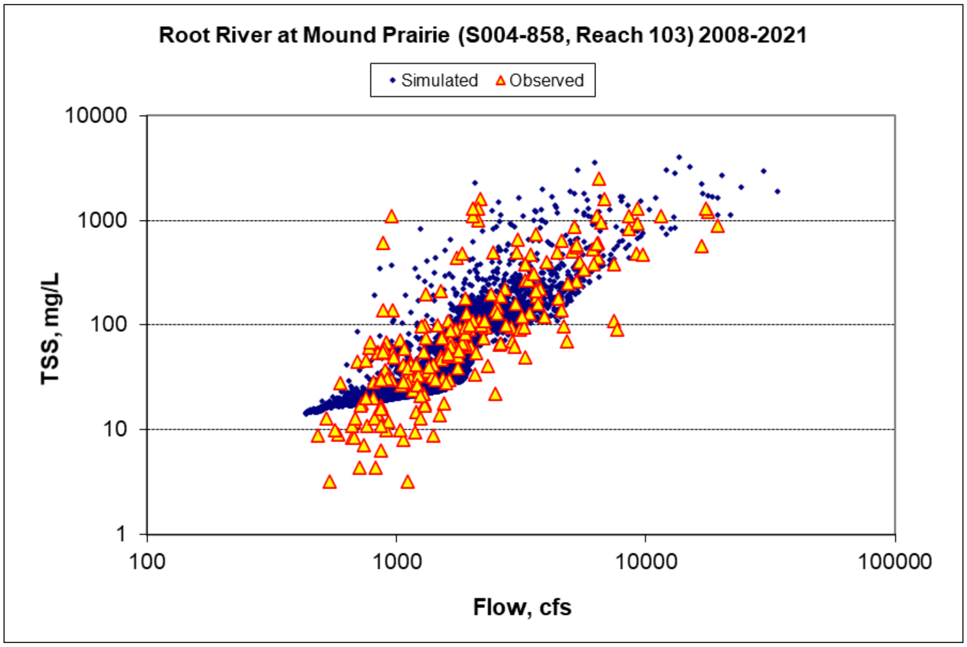

Figure 10. Simulated and Observed TSS Concentration Relative to Streamflow at Root River at Mound Prairie (S004-858, R103)

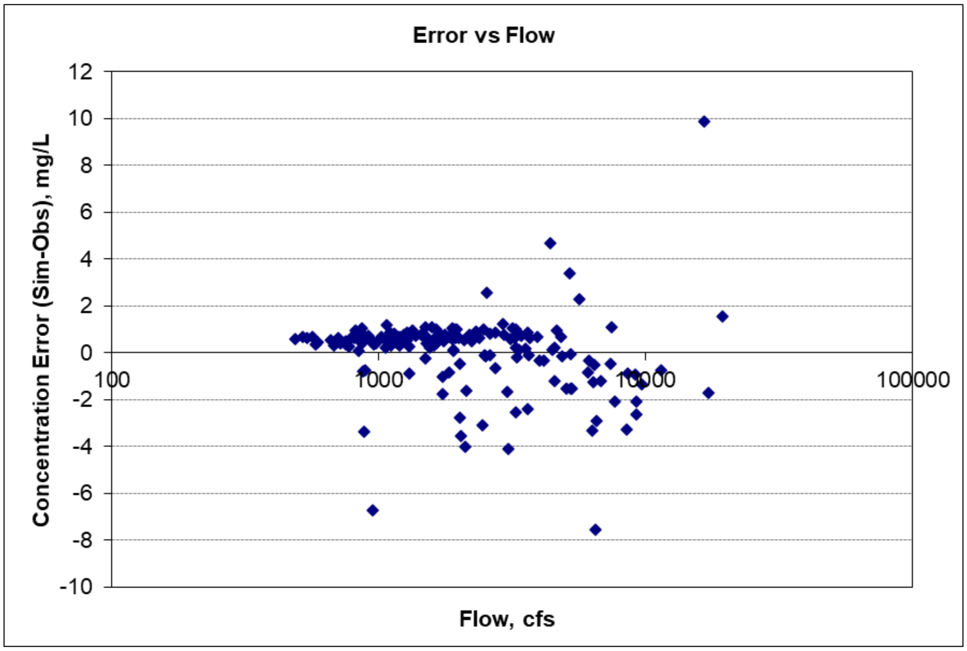

Figure 11. Relative TKN Concentration Error (Sim-Obs) Relative to Flow at Root River at Mound Prairie (S004-858, R103)

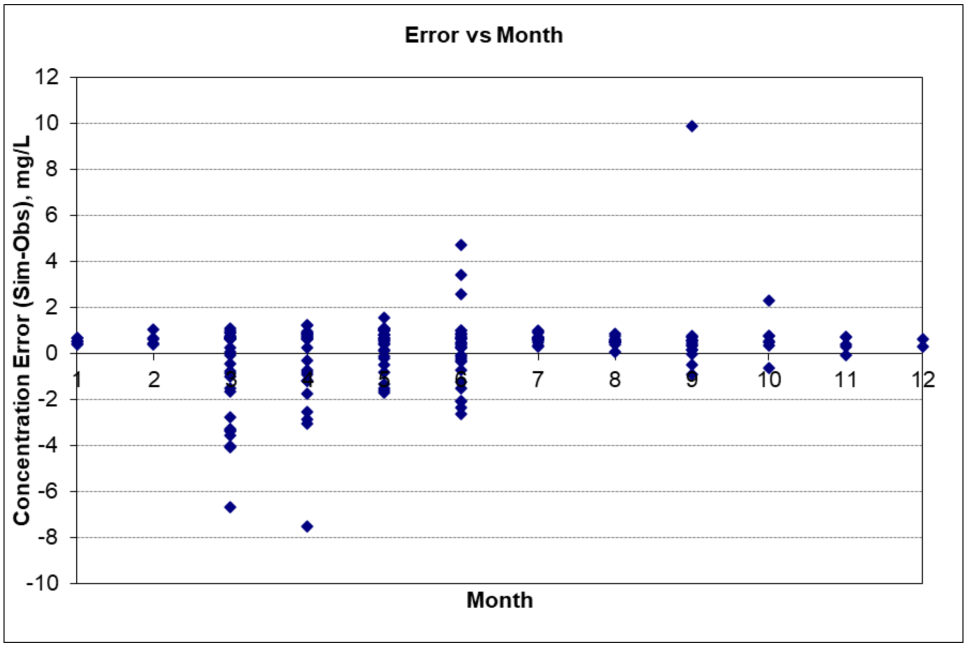

Figure 12. Relative TKN Concentration Error by Month at Root River at Mound Prairie (S004-858, R103)

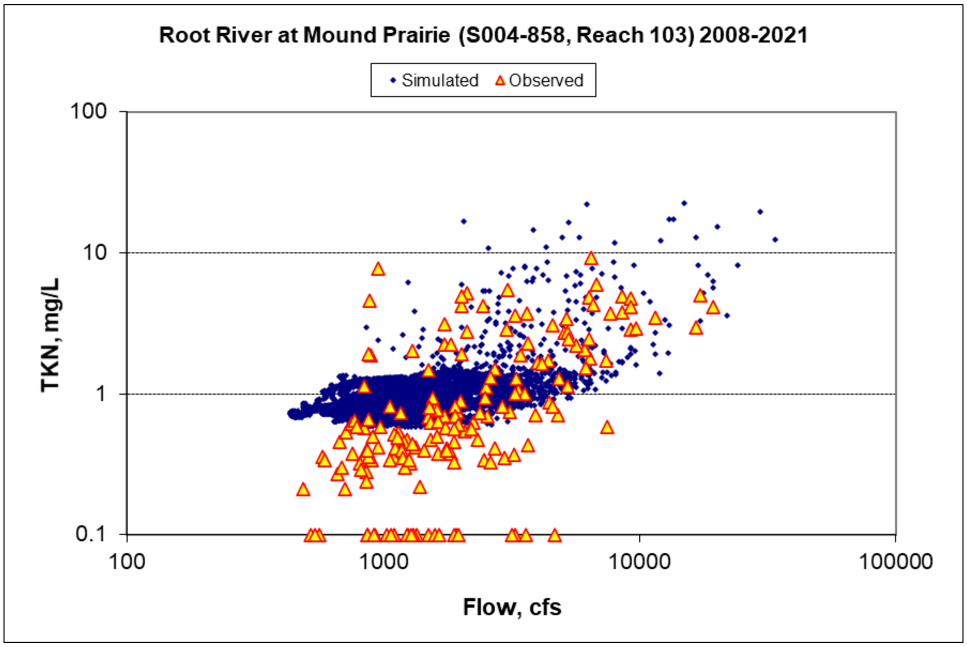

Figure 13. Simulated and Observed TKN Concentration Relative to Streamflow at Root River at Mound Prairie (S004-858, R103)

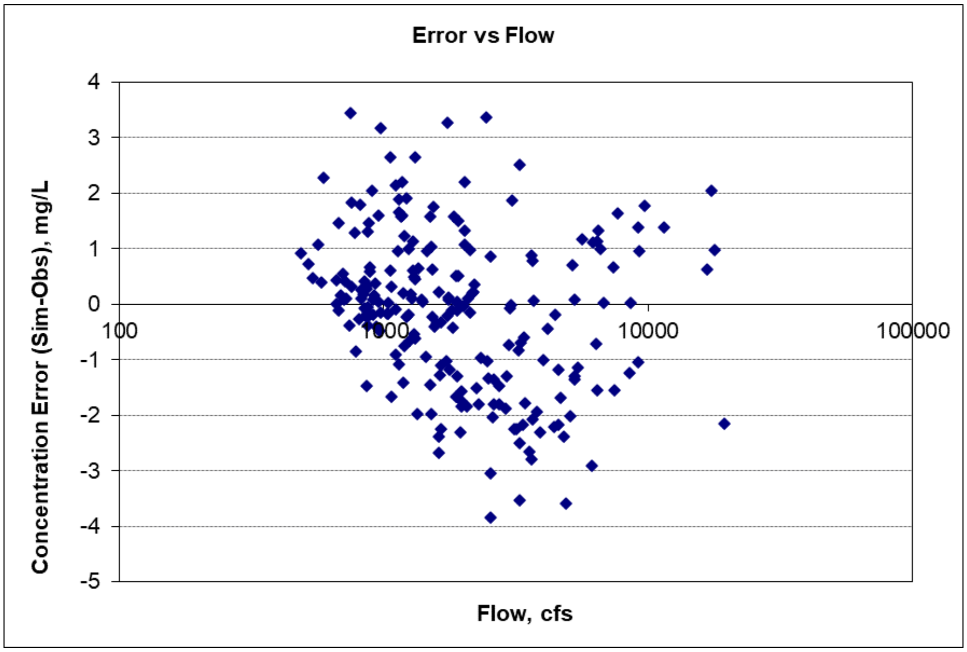

Figure 14. Relative Nitrite+Nitrate N (NOx) Concentration Error (Sim-Obs) Relative to Flow at Root River at Mound Prairie (S004-858, R103)

Figure 15. Relative Nitrite+Nitrate N (NOx) Concentration Error by Month at Root River at Mound Prairie (S004-858, R103)

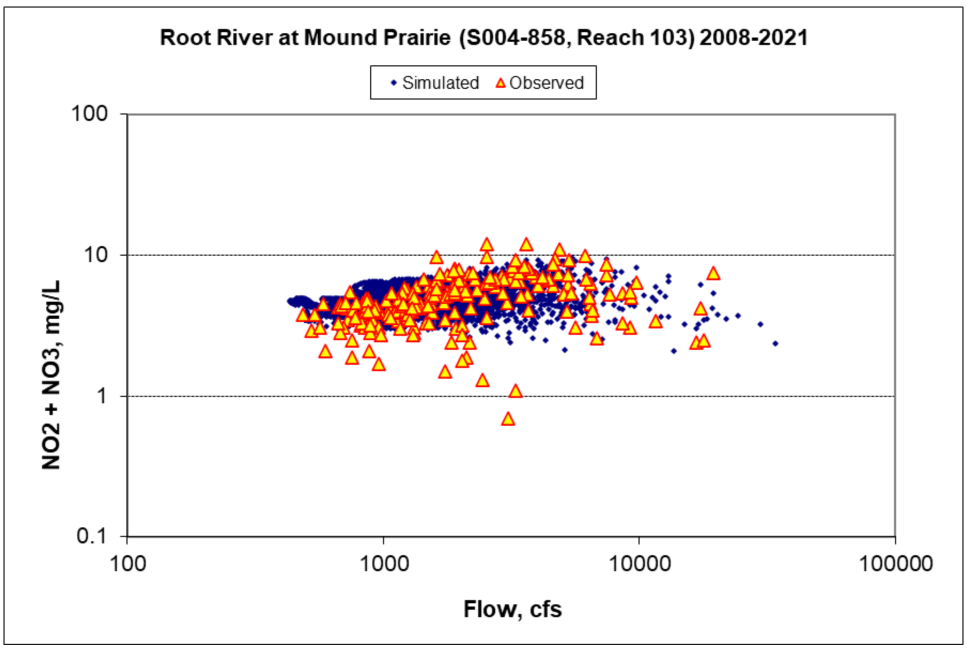

Figure 16. Simulated and Observed Nitrite+Nitrate N (NOx) Concentration Relative to Streamflow at Root River at Mound Prairie (S004-858, R103)

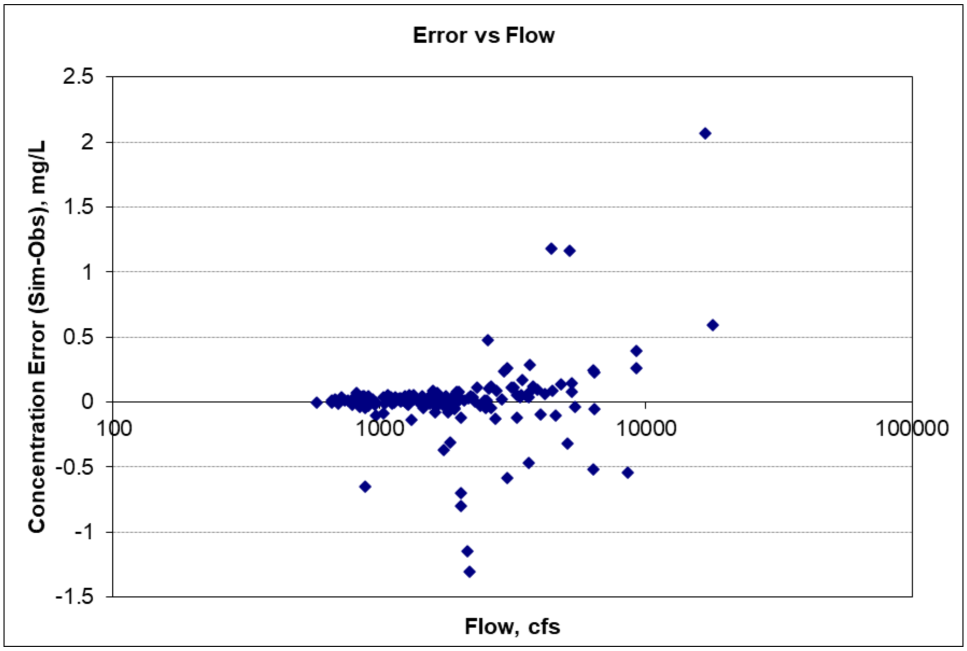

Figure 17. Relative Total P Concentration Error (Sim-Obs) Relative to Flow at Root River at Mound Prairie (S004-858, R103)

Figure 18. Relative Total P Concentration Error by Month at Root River at Mound Prairie (S004-858, R103)

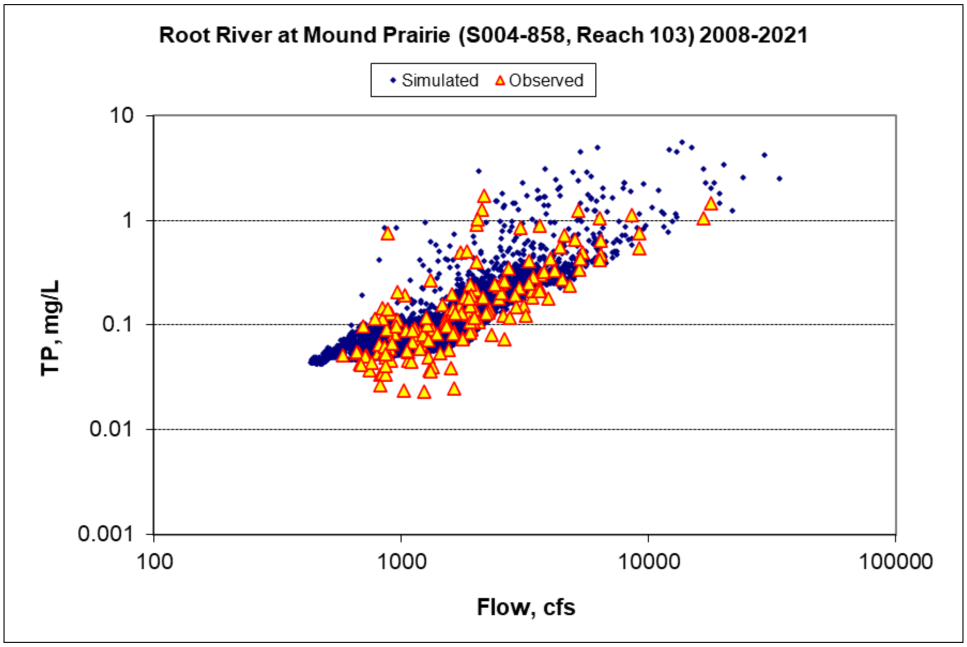

Figure 19. Simulated and Observed Total P Concentration Relative to Streamflow at Root River at Mound Prairie (S004-858, R103)

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