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wq-iw7-44r

May 30, 2014

Dr. Charles Regan
Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, MN 55155

Dear Dr. Regan:

RE: Hydrology and Water-Quality Calibration and Validation of Big Sioux and the Little Sioux-Missouri River Watershed Model Applications

Please review the following methodology and results for hydrologic and water-quality calibration and validation of the Big Sioux River, Little Sioux River, and Rock River **HSPF** Watershed model applications. This memorandum refers to all areas collectively as the Missouri River Watershed.

Hydrologic calibration is critical to parameter development for an **HSPF** model application, particularly for parameters that cannot be readily estimated by characteristics of the watershed. Calibrating hydrology is also necessary to form the basis for a sound water-quality calibration. Calibrating an **HSPF** model application is a cyclical process of making parameter changes, running the model, producing graphical and statistical comparisons of simulated and observed values, and interpreting the results. Observed data for hydrology and water-quality calibration include continuous stream flow (collected at gaging stations) for hydrology and ambient water quality samples obtained from reputable sources. Calibration is typically evaluated with visual and statistical performance criteria and a validation of model performance that is separate from the calibration effort. Methods and results for hydrologic calibration are explained first, followed by methods and results for water-quality calibration.

HYDROLOGIC CALIBRATION DATA

The continuous, observed stream-flow data required for calibration are available at ten gages within the Missouri River Watershed. The mainstem calibration/validation gages are located on Pipestone Creek (three gages), Rock River (four gages), and Little Sioux River (one gage). The ninth gage is located on Ocheyedan River, and the tenth gage is on a small tributary near Pipestone, Minnesota. Table 1 provides the stream flow gages and their period of record to support model calibration and validation of hydrology, with the most downstream mainstem gage shown in bold. Locations of flow gages for Rock River Watershed are illustrated in Figure 1, and the locations for the rest of the model applications are shown in Attachment A. Flow data were downloaded from the U.S. Geological Survey (USGS) National Water Information System Web Interface (*http://waterdata.usgs.gov/mn/nwis/dv/?referred_module=sw*).

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Table 1. Discharge Calibration Gages Within the Missouri River Watershed

Model Application	Gage	Gage Description	HSPF Reach I.D.	Drainage Area (mi^2)	Data Availability	Sample Count
Big Sioux River	H82042001	North Branch Pipestone Creek near Airlie, CR71	70	62.7	2004	160
Big Sioux River	H82035001	Pipestone Creek at Pipestone, MN23	105	30.4	1999–2009	2,171
Big Sioux River	H82015001	Split Rock Creek nr Jasper, 201st St	270	331	2008–2009	391
Big Sioux River	**6482610**	**Split Rock Creek at Corson**	**350**	**482**	**2001–2009**	**2,922**
Little Sioux River	6605000	Ocheyedan River near Spencer, IA	251	433	1995–2009	5,113
Little Sioux River	**6605850**	**Little Sioux River at Linn Grove, IA**	**350**	**1,559**	**1995–2009**	**5,113**
Rock River	H83027001	Rock River nr Hardwick, CR8–USGS 6482945	130	306	1998–2009	3,082
Rock River	H83016001	Rock River at Luverne, CR4–USGS 6483000	170	419	1995–2009	3,761
Rock River	6483290	Rock River below Tom Creek at Rock Rapids, IA	310	851	2001–2009	3,166
Rock River	**6483500**	**Rock River near Rock Valley, IA**	**370**	**1,590**	**1995–2009**	**5,113**

Typically, calibration is performed over at least a 5-year period with a range of hydrologic conditions from wet to dry and then validated over a separate period of time (i.e., a split-sample validation). A single User Control Input (UCI) was used for calibrating each model application. The calibration period is from 1996 to 2009 (based on the National Land Cover Database [NLCD] 2006); the initial year (1995) was simulated to let the model adjust to existing conditions. The availability of flow data allowed for a long-term (at least 5 years) calibration to be performed at all but except H82042001.

For the validation, separate UCIs were created to represent land-use changes over the simulation period [Love, 2011]. One UCI represents 1995 through 2003 and was developed using land-cover data derived from the NLCD 2001. The other represents 2004 through 2009 and was developed by using the NLCD 2006. The primary calibration period is from 2004 to 2009 (based on the NLCD 2006), and the validation period is from 1996 to 2003 (based on the NLCD 2001). Additionally, the model application’s ability to maintain a high-quality calibration at multiple gages that represent the variability of the watershed while maintaining consistent parameters throughout the watershed is, in itself, a form of validation.

After the model applications were calibrated and validated for the two time periods with alternate land-use configurations, a single application was developed for each model. These full-time period applications can be used for long-term scenario simulations.

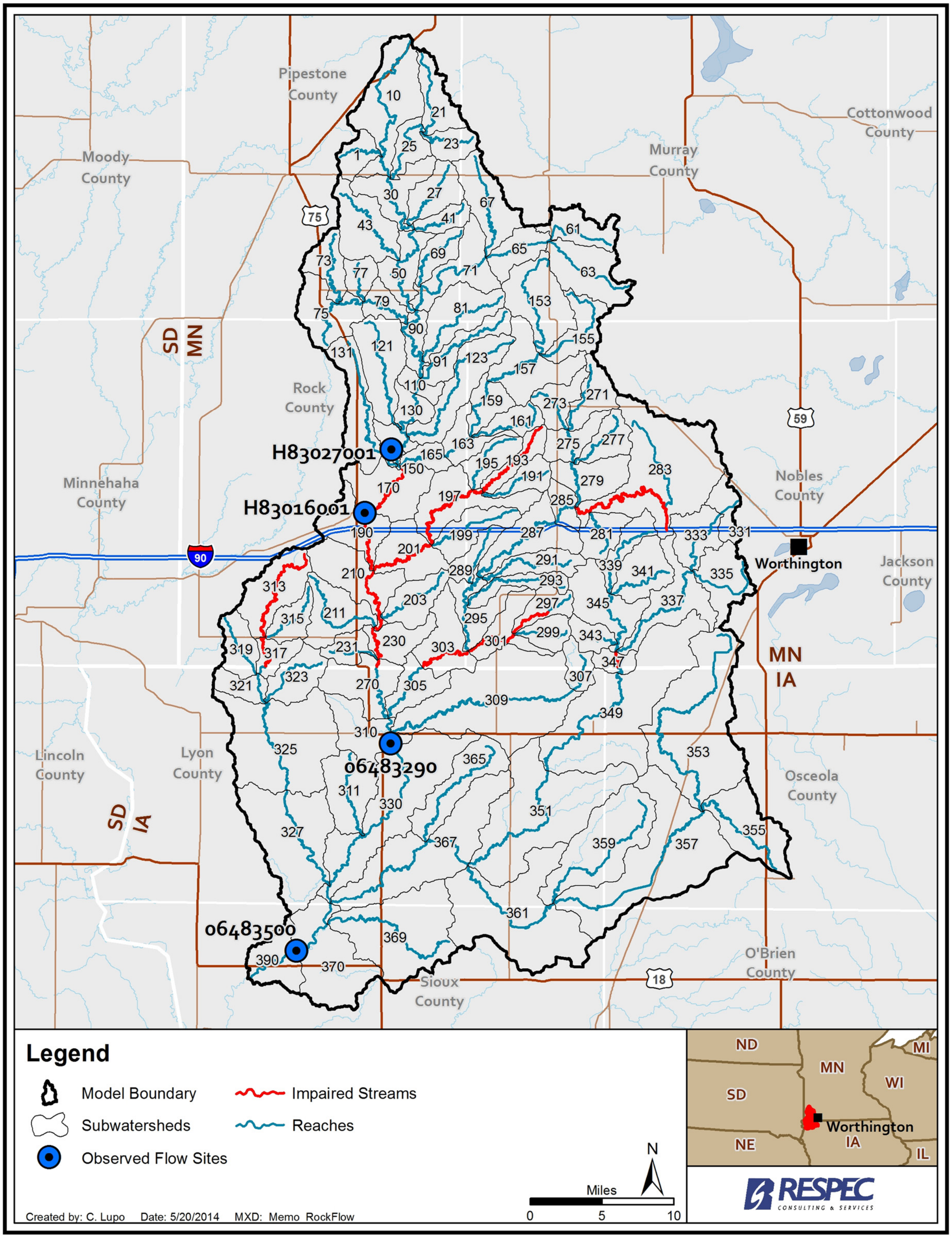

Figure 1. Flow Calibration Gages Within the Rock River Watershed.

STANDARD HYDROLOGIC CALIBRATION

The standard hydrologic calibration is an iterative process intended to match simulated flow to observed flow by methodically adjusting model parameters. Water-quality simulations depend highly on the hydrology process. Therefore, water-quality calibration cannot begin until the hydrology calibration is considered acceptable. The standard **HSPF** hydrologic calibration is divided into four sequential phases of adjusting appropriate parameters to improve the performance of their respective components of watershed hydrology simulation. The following four phases are described in order of application:

- **Establish an annual water balance.** This consists of comparing the total annual simulated and observed flows (in inches) and is governed by meteorological inputs (rainfall and evaporation); the listed parameters LZSN (lower zone nominal storage), LZETP (lower zone evapotranspiration parameter), DEEPFR (deep groundwater recharge losses), and INFILT (infiltration index); and the factor applied to pan evaporation to calculate potential evapotranspiration.
- **Make seasonal adjustments.** Differences in the simulated and observed total flow over summer and winter are compared to see if runoff (defined for calibration purposes as total stream discharge) needs to be shifted from one season to another. These adjustments are generally accomplished by using seasonal (monthly variable) values for the parameters CEPSC (vegetal interception), UZSN (upper zone storage), and LZETP. LZETP will vary greatly by land use, especially during summer months, because evapotranspiration differs. KVARY (variable groundwater recession) and BASETP (baseflow ET index) as well as snow accumulation and melt parameters are also adjusted.
- **Adjust low-flow/high-flow distribution.** This phase compares high- and low- flow volumes by using flow-percentile statistics and flow-duration curves. Parameters typically adjusted during this phase include INFILT, AGWRC (groundwater recession), and BASETP.
- **Adjust storm flow/hydrograph shape.** Storm flow, which is largely composed of surface runoff and interflow, is evaluated by using daily and hourly hydrographs. Adjustments are made to the UZSN, INTFW (interflow parameter), and IRC (interflow recession). INFILT may also be adjusted slightly.

Monthly variation of the CEPSC and LZETP parameters was initially applied to all pervious (PERLND) categories. Monthly variations in UZSN, NSUR, INTFW, and IRC parameters were applied, as necessary, to improve model performance.

By iteratively adjusting specific calibration parameter values within accepted ranges, the simulation results were improved until an acceptable comparison of simulated results and measured data was achieved. The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. [1984] and in the **HSPF** hydrologic calibration expert system (**HSPEXP**) [Lumb et al., 1994].

Land cover properties typically control most of the variability in the hydrologic responses of a watershed; thus, they were the basis for estimating initial hydrologic parameters. The land cover characteristics primarily affect water losses from evaporation or transpiration by vegetation. The movement of water through the system is also affected by vegetation cover and associated characteristics (e.g., type, density, and roughness). Initial parameter estimates and their relative variances between land segment categories are crucial to maintaining an appropriate representation of the hydrologic components. Engineering judgment is used to adjust parameters congruently within land segment categories during model calibration because of parameter diversity and spatial distribution within the watershed.

INITIAL SNOW ACCUMULATION AND MELT CALIBRATION

Snow accumulation and melt are significant elements of hydrology in Minnesota; thus, snow simulation is an integral part of the hydrology calibration (especially during the winter and spring). The snow calibration is generally completed early in the calibration process along with the seasonal phase of the standard calibration procedure. Snow is simulated in **HSPF** with meteorological time-series data (precipitation, air temperature, solar radiation, wind, and dew point temperature) with a suite of adjustable parameters. Two options are available when simulating snowmelt with **HSPF**: the energy-balance method and the degree-day method. Both methods were evaluated, and the degree-day method was chosen because it resulted in a better hydrologic calibration. Initial values for the wet bulb air temperature below which precipitation occurs as snow under saturated conditions (TSNOW), the factor to adjust the rate of heat transfer from the atmosphere to the snowpack because of condensation and convection (CCFACT), the maximum rate of snowmelt by ground heat (MGMELT), the maximum snowpack at which the entire pervious land segment will be covered with snow (COVIND), monthly values of the degree-day factor (MON-MELT-FAC), a catch-efficiency factor (SNOWCF), a reference temperature (TBASE), the factor to adjust evaporation/sublimation from the snowpack (SNOEVP), and the maximum water content of the snow pack (MWATER) were attained from previous **HSPF** applications in Minnesota and were adjusted as necessary. The initial snow parameter calibration was supported by using comparisons of observed and simulated snowfall and snow-depth data to verify a reasonable representation of snow accumulation and melt processes. A more detailed calibration of snow parameters was based heavily on comparisons of observed and simulated flow data during the standard hydrologic calibration process. Observed data were downloaded from the Minnesota Climatology Working Group website (*http://climate.umn.edu/HIDradius/radius.asp*) and the National Climate Data Center (*https://www.ncdc.noaa.gov/*) for 17 locations within and near the Missouri River Watershed, illustrated in Figure 2. Greater weight was given to gages with a full period of record and located within the watershed. Calibration figures were constructed to compare observed snowfall to simulated snowfall, illustrated in Figure 3 (top), and observed snow depth to simulated snow levels (bottom). Air temperature is included on the snowfall figure to help estimate parameters such as TSNOW and to verify the accuracy of the snowfall data.

HYDRAULIC CALIBRATION

Because of the high number of lakes occurring in these watersheds, lake level is considered an important factor for the hydrology calibration. Lake level data are available for approximately 7 of the 16 modeled lakes, and it can be used for comparison to simulated lake

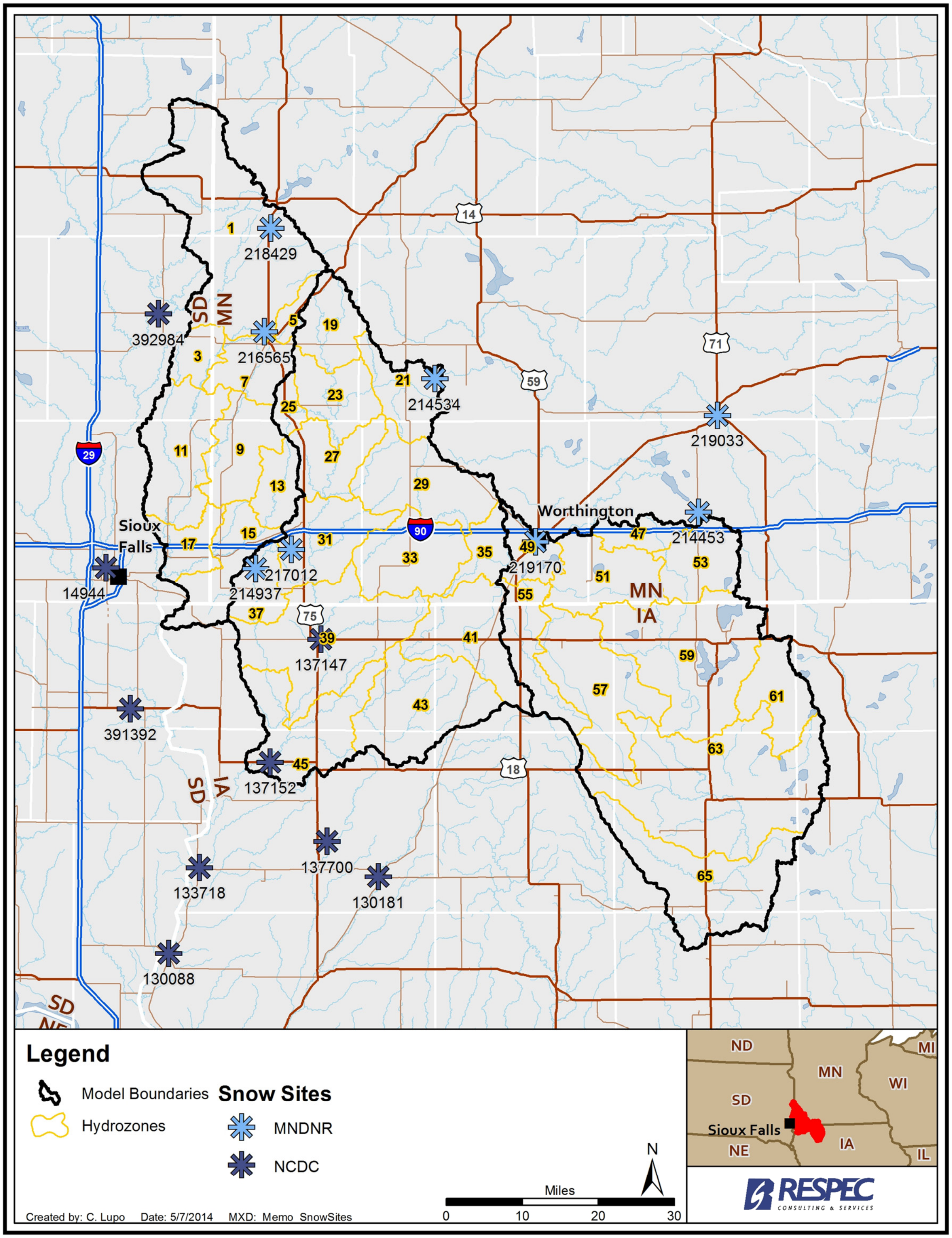

Figure 2. Meteorological Stations With Snow Data Used for Calibration.

levels. The initial lake level calibration, which was completed as an early portion of the hydrology calibration, involved adjusting the reference outlet elevations to accurately represent lake volumes before outflow occurs. Lake geometry parameters as well as outlet depths and outflow calculations were adjusted to modify the F-tables in congruence with the storm flow phase of the standard calibration with the overall goal of adequately representing lake volumes and outflows. Figure 4 illustrates an example of the calibration figures constructed for comparing observed lake-level data and simulated lake level. In cases where multiple lakes are represented as one F-table, simulated lake levels could not be effectively compared to observed lake levels because the combined F-table represents cumulative volume and surface area with absolute depths. Outlet levels can be adjusted but lake level variations will be less variable because of greater storage volumes associated with the same depths. These combined F-tables will be evaluated by comparing patterns in the lake level data instead of actual lake level values.

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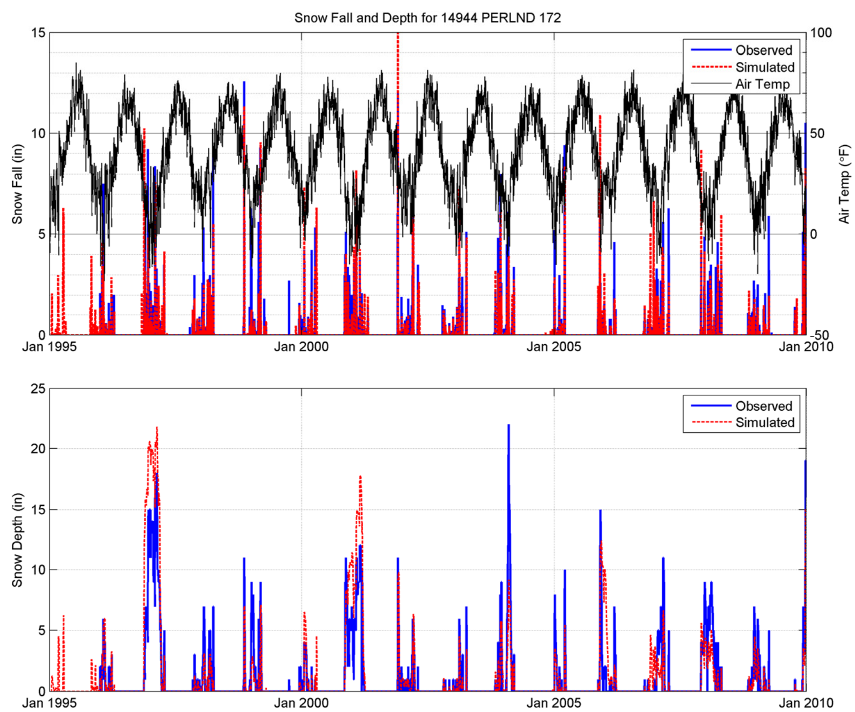

Figure 3. Snowfall (Top) and Snow Depth (Bottom) Calibration Figures.

WEIGHT-OF-EVIDENCE APPROACH

Model performance was evaluated by using a weight-of-evidence approach described in Donigian [2002]. This type of approach uses both visual and statistical methods to best define the performance of the model. The approach was integrated into the hydrologic calibration to continuously evaluate model results to efficiently improve calibration performance until there was no apparent improvement from further parameter adjustments. This process was performed at each flow gage by adjusting parameters for land segments upstream. Moreover, greater weight was applied to the performance of the model at gages where there is a larger contributing area and a longer period of record. Maintaining comparable parameter values and intraparameter variations for each land-segment category throughout the watershed are also preferred. The following specific comparisons of simulated and observed data for the calibration period are grouped with their associated phase of the standard hydrologic calibration:

- **Establish an annual water balance**
  - Total runoff volume errors for calibration/validation period
  - Annual runoff-volume errors
- **Make seasonal adjustments**
  - Monthly runoff-volume errors
  - Monthly model-fit statistics
  - Summer/winter runoff-volume errors
  - Summer/winter storm-volume errors
- **Adjust low-flow/high-flow distribution**
  - Highest 5 percent, 10 percent, and 25 percent of flow-volume errors
  - Lowest 5 percent, 10 percent, 15 percent, 25 percent, and 50 percent of flow-volume errors
  - Flow frequency (flow-duration) curves
- **Adjust storm flow/hydrograph shape**
  - Daily/hourly flow time-series graphs to evaluate hydrograph shape
  - Daily model-fit statistics
  - Average storm peak-flow errors
  - Summer/winter storm volume errors.

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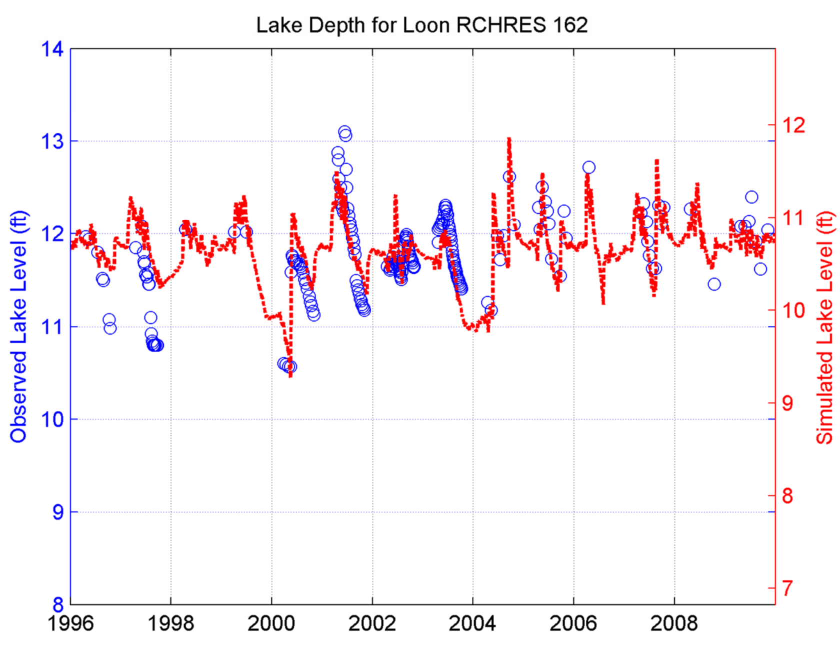

Figure 4. Lake Level Calibration.

Common model-fit statistics used for evaluating hydrologic model applications include a correlation coefficient (*r*), a coefficient of determination (r^2), Nash-Sutcliffe efficiency (NSE), mean error, mean absolute error, and mean square error. Statistical methods help to provide definitive answers but are still subject to the modeler's best judgment for the overall model performance.

Annual and monthly plots were used to visually compare runoff volumes over the contributing area. This method includes transferring the amount of flow, measured at each calibrated gage, to a volume of water, measured in inches and spread over the entire contributing area, to normalize the data for the drainage area. Monthly plots help to verify the model's ability to capture the variability in runoff among the watersheds and also to verify that the snowfall and snowmelt processes are simulated accurately. Average yearly plots help to verify that the annual water balances are reasonable and allow trends to be considered. Flow-frequency distributions, or flow-duration curves, present measured flow and simulated flow versus the corresponding percent of time the flow is exceeded. Thus, the flow-duration curves provide a clear way to evaluate model performance for various flow conditions (e.g., storm events or baseflow) and to determine which parameters to adjust to better fit the data. Daily flow time-series plots allow for the analyses of individual storm events, snow accumulation and snowmelt processes, and baseflow trends. Examples of the daily flow time-series plots, monthly plots, annual plots, and flow-duration curves used for the calibration/validation process are illustrated in Figures 5 through 8, respectively.

In addition to the aforementioned comparisons, the water balance components of watershed hydrology were reviewed. This involved summarizing outflows from each individual land-use and soil group classification for the following hydrologic components:

- **Precipitation**
- **Total Runoff (Sum of Following Components)**
  - – Overland flow
  - – Interflow
  - – Baseflow
- **Potential Evapotranspiration (ET)**
- T**otal actual ET (Sum of Following Components)**
  - – Interception ET
  - – Upper zone ET
  - – Lower zone ET
  - – Baseflow ET
  - – Active groundwater ET
- **Deep Groundwater Recharge/Losses**

Although observed values are not available for each of the water balance components previously listed, the average annual values must be consistent with expected values for the region and for the individual land-use and soil group categories.

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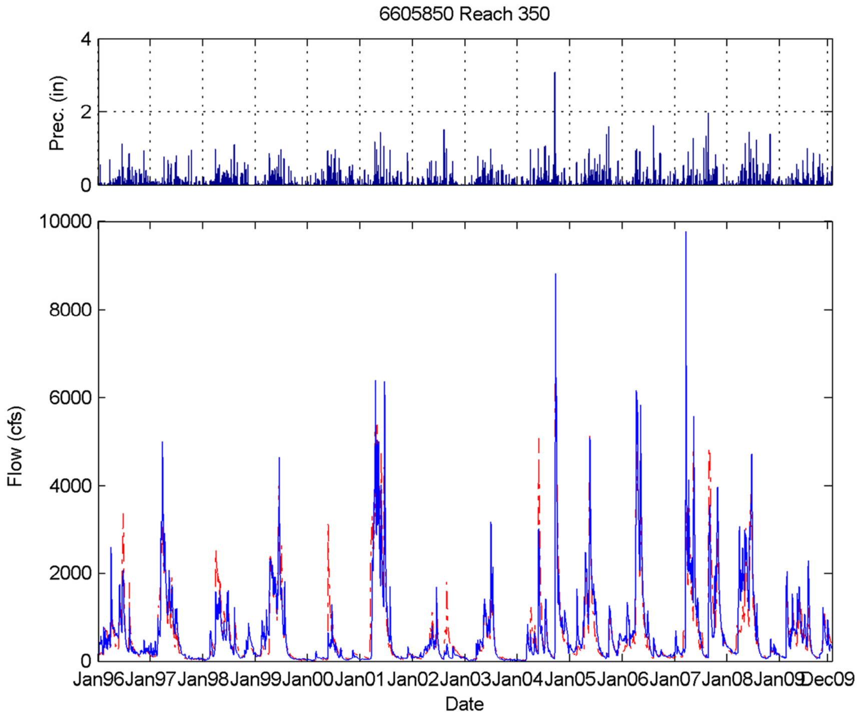

Figure 5. Daily Flow Time-Series Plot Example.

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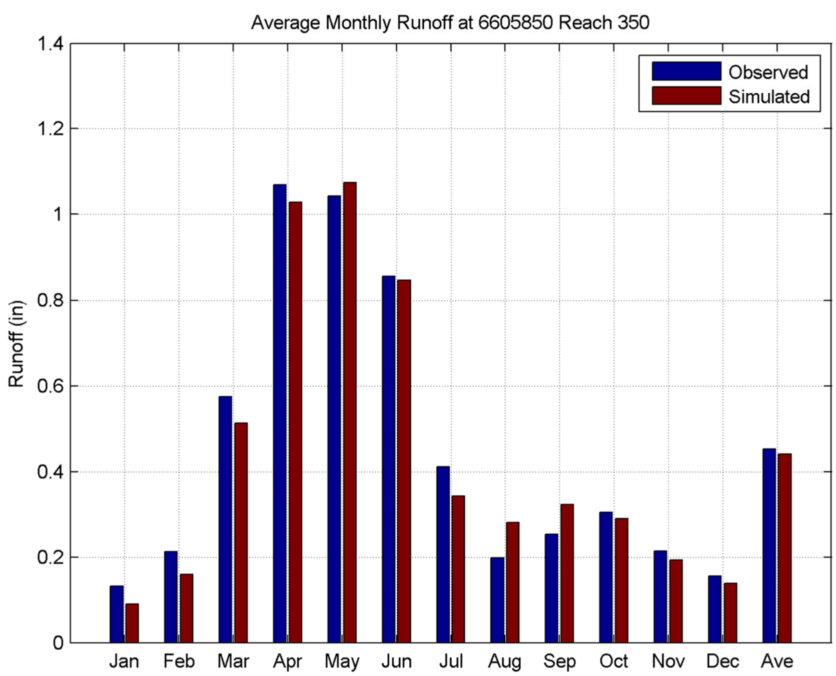

Figure 6. Average Monthly Runoff Plot Example.

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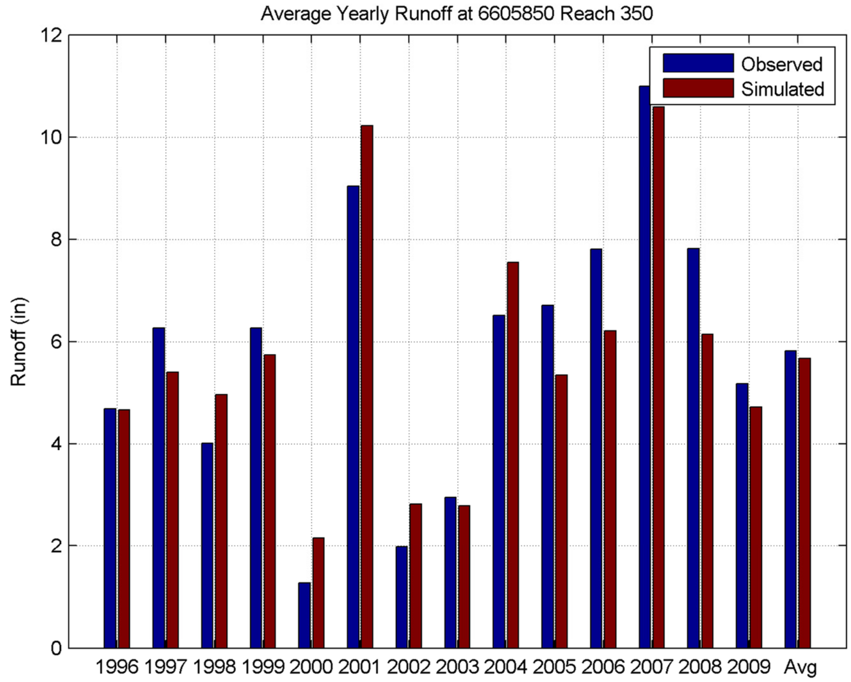

Figure 7. Average Yearly Runoff Plot Example.

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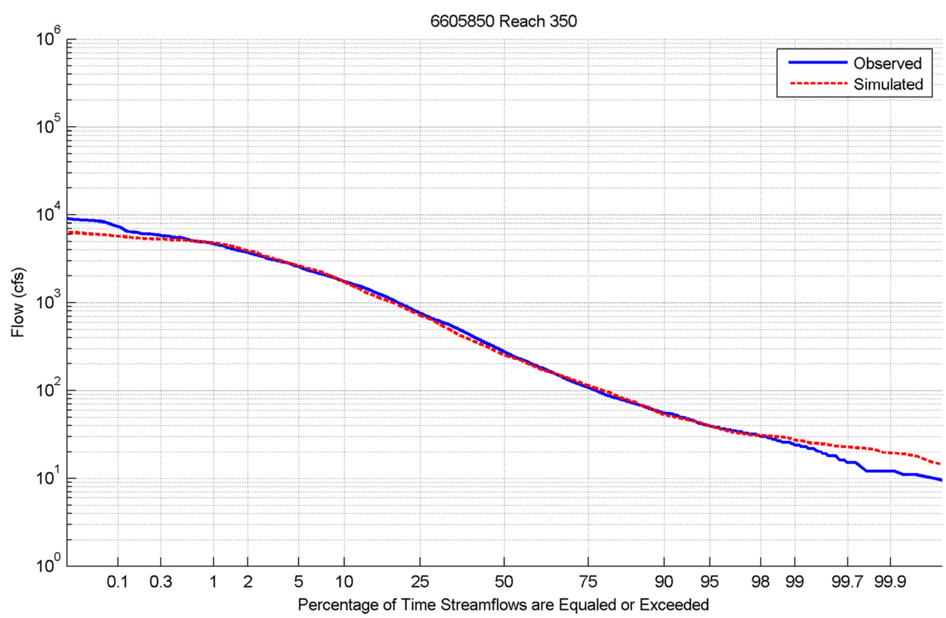

Figure 8. Flow-Duration Curve Example.

MODEL PERFORMANCE CRITERIA

The calibration parameters were adjusted to improve the performance of the model until the desired performance criteria were met or there was no apparent improvement from parameter refinement. The graphical plots were visually evaluated to objectively assess the model performance and the statistics were compared to objective criteria developed from 20 years of experience with **HSPF** applications. The percent-error statistics were evaluated with the hydrology criteria in Table 2. The correlation coefficient (r) and the coefficient of determination (r^2) were compared with the criteria illustrated in Figure 9 to evaluate the performance of the daily and monthly flows. These measures allow the user to assess the quality of the overall model application performance in descriptive terms to aid in deciding to accept or reject the model application. The developed performance criteria are explained in detail in Donigian [2002].

Table 2. General Calibration/Validation Targets or Tolerances for HSPF Applications

	Difference Between Simulated and Recorded Values (%)		
	Fair	**Good**	**Very Good**
Hydrology/Flow	15–25	10–15	<10

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, and personnel).
Source: Donigian [2000].

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Figure 9. General Calibration/Validation R and R^2 Targets for **HSPF** Applications.

CALIBRATION RESULTS

The initial calibration was performed by using the primary downstream gages for each of the three model applications in the Missouri River Watershed. The gages on the smaller tributaries were used to help calibrate parameters for less influential land-segment categories; however, the focus of this hydrology calibration was the mainstem gages. The initial calibration results for the Missouri River Watershed most downstream, mainstem gages range from fair to very good with respect to the calibration and validation targets (Figure 9). Parameters were set to achieve a balance between the best possible results at the tributary gages and the best possible results at the mainstem gages. Table 3 displays the results for the Missouri River Watershed model applications, with the most downstream mainstem reaches shown in bold. Table 4 summarizes the weighted water balance components at the outlets of the Missouri River Watershed model applications, and Attachment B contains initial hydrologic calibration figures for primary gages in the Missouri River Watershed.

WATER-QUALITY CALIBRATION

The water-quality constituents that were modeled in the Missouri River Watershed include total suspended solids (TSS), temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), and nutrients. The methods described in the following section provide RESPEC with the ability to estimate turbidity, temperature, DO, and nutrient loads; calculate contributions from point, nonpoint, and atmospheric sources where necessary; and provide a means of evaluating the impacts of alternative management strategies to reduce these loads and improve water-quality conditions. The model applications apply empirical build-up/washoff functions. Separate UCIs were created to represent land-use changes for the hydrology calibration. To use the largest possible dataset, the water-quality calibration was completed on the entire modeling period (1995 through 2009) and was based on the NLCD 2006 land-use data.

Turbidity Approach

TSS was used as a surrogate for turbidity, based on an observed, strong correlation between the two. A regression analysis can be completed to determine the relationship of TSS and turbidity, allowing the model TSS predictions to support future total maximum daily load (TMDL) studies. The calibration focus was at locations where TSS concentration data are available, and TSS was used as a surrogate for turbidity. TSS concentration data are widely available, while suspended sediment concentrations (SSC) are more limited. The model application is capable of identifying sources of sediment and the processes that drive sediment erosion, delivery, and transport in the watersheds as well as point-source sediment contribution.

The sediment-parameter estimation and calibration was performed according to guidance from the U.S. Environmental Protection Agency (EPA) [2006]. The steps for sediment calibration included estimating model parameters, adjusting parameters to represent estimated landscape erosion loading rates and delivery to the stream, adjusting parameters to represent in-stream transport and bed behavior, and analyzing sediment budgets for landscape and in-stream contributions. Initial sediment parameters were estimated from nearby models, when appropriate, and adjusted iteratively to match observations. Data are rarely sufficient to accurately calibrate all parameters for all model land uses for each stream and waterbody reach. Therefore, the majority of the calibration is based on sites with observed data. Simulations in all parts of the watershed were reviewed to ensure that the model results are consistent with congruent analyses, field observations, historical reports, and expected behavior from past experience. This was especially critical for sediment modeling because the behavior of sediment erosion and transport processes is extremely dynamic [EPA, 2006].

Sediment erosion and delivery and in-stream sediment transport were represented in the sediment model application. Parameters predicting sediment erosion from the landscape and

Table 3. Summary Statistics for Calibration Gages in the Missouri River Watershed

Model Application	Observed Flow Gage	HSPF Reach	Total Runoff Volume			Monthly			Daily			Storm % Error	
			Obs (in)	Sim (in)	% Δ	*R*	R^2	MFE	*R*	R^2	MFE	Volume	Peak
Big Sioux River	H82042001	70	2.96	2.03	–31.5	0.99	0.99	0.86	0.89	0.79	0.63	–32.9	–56.8
Big Sioux River	H82035001	105	3.78	3.31	–12.3	0.81	0.65	0.57	0.76	0.58	0.04	–11.9	14.9
Big Sioux River	H82015001	270	0.87	1.51	73.3	0.60	0.36	–2.17	0.51	0.27	–2.75	46.7	57.7
Big Sioux River	**6482610**	**350**	**2.95**	**2.94**	**–0.44**	**0.92**	**0.84**	**0.84**	**0.82**	**0.68**	**0.67**	**0.25**	**–10.2**
Little Sioux River	6605000	251	5.52	5.6	0.08	0.92	0.84	0.82	0.80	0.63	0.61	0.91	–22.5
Little Sioux River	**6605850**	**350**	**5.82**	**5.66**	**–2.69**	**0.94**	**0.89**	**0.89**	**0.91**	**0.82**	**0.82**	**–2.30**	**–11.9**
Rock River	H83027001	130	3.56	4.29	20.6	0.77	0.59	–0.21	0.73	0.54	–0.21	33.1	21.4
Rock River	H83016001	170	4.64	4.82	3.85	0.93	0.87	0.84	0.69	0.48	0.43	6.75	–17.3
Rock River	6483290	310	4.94	5.11	3.37	0.91	0.83	0.77	0.81	0.65	0.50	11.3	–0.19
Rock River	**6483500**	**370**	**5.67**	**5.57**	**–1.86**	**0.92**	**0.84**	**0.83**	**0.83**	**0.68**	**0.66**	**1.19**	**–10.7**

delivery to the stream were estimated and compared with results from the Revised Universal Soil Loss Equation (RUSLE). RUSLE provides an estimate of the average soil loss in tons per acre, based on numerical factors developed from spatial soil and land-use characterization data, slope, and rainfall and runoff-intensity estimates. A detailed procedure for RUSLE analysis is described by the EPA [2006]. A sediment delivery ratio (SDR), based on watershed area and slope, was applied to the average soil loss because RUSLE provides gross erosional estimates that are greater than the sediment load that is actually delivered to the stream. HSPF landscape loading rates represent the predicted sediment load delivered to the stream from the landscape. The annual sediment loads per acre, predicted by the model on a subwatershed scale, were compared to RUSLE loading rates adjusted with the SDR by using appropriate parameterization. Model sediment loading rates were also compared to typical ranges of expected erosion rates from literature for applicable land-use categories, as provided in Table 5, and to surficial geology and soils maps for information on particle size distribution.

Table 4. Summary of Water Balance Components

Water Balance Component	Water Balance Component Description	Percent of Water Supply		
		Big Sioux River	Little Sioux River	Rock River
SURO	Surface outflow	3.25	0.71	1.20
IFWO	Interflow outflow	6.98	11.79	9.21
AGWO	Active groundwater outflow	7.50	8.65	9.99
IGWI	Inflow to inactive groundwater	0.48	0.32	0.35
CEPE	Evaporation from interception storage	19.29	20.23	19.56
UZET	Evapotranspiration from upper zone	16.57	14.96	17.54
LZET	Evapotranspiration from lower zone	44.08	41.24	40.26
AGWET	Evapotranspiration from active groundwater storage	0.04	0.28	0.11
BASET	Evapotranspiration from active groundwater outflow (baseflow)	1.81	1.82	1.78

Sediment erosion and delivery and in-stream sediment transport were represented in the sediment model application. Parameters predicting sediment erosion from the landscape and delivery to the stream were estimated and compared with results from the Revised Universal Soil Loss Equation (RUSLE). RUSLE provides an estimate of the average soil loss in tons per acre, based on numerical factors developed from spatial soil and land-use characterization data, slope, and rainfall and runoff-intensity estimates. A detailed procedure for RUSLE analysis is described by the EPA [2006]. A sediment delivery ratio (SDR), based on watershed area and slope, was applied to the average soil loss because RUSLE provides gross erosional estimates that are greater than the sediment load that is actually delivered to the stream. HSPF landscape loading rates represent the predicted sediment load delivered to the stream from the landscape. The annual sediment loads per acre, predicted by the model on a subwatershed scale, were compared to RUSLE loading rates adjusted with the SDR by using appropriate parameterization. Model sediment loading rates were also compared to typical ranges of expected erosion rates from literature for applicable land-use categories, as provided in Table 5, and to surficial geology and soils maps for information on particle size distribution.

Table 5. Typical Ranges of Expected Erosion Rates [EPA, 2006]

Land Use	Erosion Rates (Tons/Acre)
Forest	0.05–0.4
Pasture	0.3–1.5
Conventional Tillage	1.0–7.0
Conservation Tillage	0.5–4.0
Hay	0.3–1.8
Urban	0.2–1.0
Highly Erodible Land	> ~15.0

The primary calibration parameters involved in landscape erosion simulation are the coefficients and exponents from three equations representing different soil detachment and removal processes. KRER and JRER are the coefficient and exponent, respectively, from the soil detachment from rainfall impact equation; KSER and JSER are the coefficient and exponent, respectively, from the soil washoff or transport equation; and KGER and JGER are the coefficient and exponent, respectively, from the matrix soil equation, which simulates gully erosion. KRER was estimated as the soil erodibility coefficient from the RUSLE equation, which can be estimated from the Soil Survey Geographic (SSURGO) spatial soils database. Landscape fractionation of sand, silt, and clay were represented by using data from the SSURGO spatial soils database. The remaining parameters were initially given a combination of the recommended initial values from the EPA [2006] and values from the Minnesota River model application.

After landscape sediment erosion rates were adjusted to provide the expected loading to the stream channel, calibration was continued with adjusting parameters governing the processes of deposition, scour, and transport of sediment within the stream. Calibration was performed on a reach-by-reach basis from upstream to downstream because downstream reaches are influenced by upstream parameter adjustments. Bed behavior and sediment budgets were analyzed at each reach to ensure that results are consistent with field observations, historical reports, and expected behavior from past experience. The initial composition of the channel beds was estimated using available particle-size distribution data.

The primary parameters that were involved in calibrating in-stream sediment transport and bed behavior include critical shear stresses for deposition and scour for cohesive sediment (silt and clay) and the coefficient and exponent in the noncohesive (sand) transport power function. TAUCD and TAUCS are the critical deposition and scour shear stress parameters, respectively. They were initially estimated as the 25^{th} percentile of the simulated bed shear stress for TAUCD and the 75^{th} percentile for TAUCS and iteratively adjusted until predicted sediment concentrations matched the observed data. Cohesive sediment is transported when the bed shear stress is higher than TAUCD, and it settles and deposits when the bed shear stress is lower than TAUCD. Sediment is scoured from the bed when the shear stress is greater than TAUCS. The erodibility parameter (M) for silt and clay determines the intensity of scour when it is occurring. KSAND and EXPSAND are the coefficient and exponent of the sand transport power function, respectively.

TEMPERATURE, DISSOLVED OXYGEN, BIOCHEMICAL OXYGEN DEMAND DYNAMICS, AND NUTRIENT APPROACH

The approach for modeling temperature, DO and BOD dynamics, and nutrients was similar to the Minnesota River model application's approach. The model application simulates in-stream temperature (using HTRCH), organic and inorganic nitrogen, total ammonia, organic and inorganic phosphorus (using NUTRX), dissolved oxygen and biochemical oxygen demand (using OXRX), and algae (using PLANK). The adsorption/desorption of total ammonia and orthophosphate to sediment was also simulated. The modeled output can be used to support the MPCA's activities for TMDL development, in-stream nutrient criteria compliance testing, and support for point-source permitting. Initial calibration parameters were estimated from the Minnesota River model application and nearby calibrated models.

The overall sources considered for nutrients included point sources, such as water treatment facilities, nonpoint sources from the watershed, atmospheric deposition (nitrate, ammonia, and phosphorus), subsurface flow, and soil-bed contributions. Point-source facility contributions were explicitly modeled for future permitting purposes. Nonpoint sources of total ammonia, nitrate-nitrite, 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 nitrogen and ammonia were applied to all of the land areas and provide a contribution to the nonpoint-source load through the buildup/washoff process. 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. Septic system loads in the watersheds were estimated for Kittson and Marshall Counties by using information provided by the MPCA [2004]. 2010 census information was used for South Dakota (SD) and Iowa (IA) counties because of the absence of data in the MPCA Individual Sewage Treatment Systems (ISTS) report [MPCA, 2004]. The number of ISTS in each subwatershed were estimated by using Geographic Information System (GIS). The average number of individuals per household was then used to estimate the number of persons served by ISTS. Loading rates, which incorporated septic failure rates, were developed for ammonia, nitrate, orthophosphate, carbonaceous biochemical oxygen demand – ultimate (CBODU), and water on a per capita basis and were applied to each reach through a mass link.

Biochemical reactions that affect DO were represented in the model application. The overall sources considered for BOD and DO include point sources such as wastewater treatment facilities, nonpoint sources from the watershed, interflow, and active groundwater flow. The model application 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.

AMBIENT WATER-QUALITY DATA AVAILABLE

A watershed model application that represents nutrients, DO and BOD dynamics, and primary production requires observed values of temperature, DO, BOD, nitrogen species (nitrate/nitrite, ammonia, and Kjeldahl nitrogen), phosphorus species (total and inorganic phosphorus), organic carbon, and chlorophyll *a* (representing phytoplankton) throughout the watershed for comparison to simulated results.

Observed ambient water-quality data were obtained from the MPCA, IA Department of Natural Resources (IADNR), EPA's STOrage and RETrieval Data Warehouse (STORET), and the U.S. Geological Survey (USGS). Tables 6 through 8 provide available stream and lake data of applicable constituents for the Big Sioux River, Little Sioux River, and Rock River Watersheds, respectively. These sites for the Rock River model application are illustrated in Figure 10, and the sites for the Big and Little Sioux model applications are shown in Attachment C. TSS, water temperature, DO, BOD, chlorophyll *a*, ammonia, Kjeldahl nitrogen, nitrate/nitrate, orthophosphate, and total phosphorus ambient water-quality monitoring data are available throughout the watershed for both lakes and streams.

Total nitrogen is generally not available in either of the ambient water-quality datasets, but it can be calculated by summing concurrent samples of nitrate, nitrite, and Kjeldahl nitrogen. Similarly, organic nitrogen can be calculated as the difference between concurrent samples of Kjeldahl nitrogen and ammonia-nitrogen.

ATMOSPHERIC DEPOSITION DATA AVAILABLE

Atmospheric deposition of nitrate and ammonia was explicitly accounted for in the Missouri River Watershed model applications by input of separate wet and dry deposition fluxes. Wet atmospheric deposition data were downloaded from the National Atmospheric Deposition Program (NADP). The NADP site chosen to represent the Missouri River Watershed wet deposition was MN27. Wet deposition includes the deposition of pollutants from the atmosphere that occur during precipitation events. Thus, nitrate and ammonia wet deposition was applied as concentrations (milligrams per liter [mg/L]) to the precipitation input time series.

Dry atmospheric deposition data were downloaded from the EPA's **Clean Air Status and Trends Network** (**CASTNet**). The **CASTNet** site chosen to represent the Missouri River Watershed dry deposition was PRK134. Dry deposition does not depend on precipitation; therefore, nitrate and ammonia dry deposition data (originally in kg/ha) were applied in the model application by using a pound-per-acre approach. Both the wet and dry atmospheric deposition sites are illustrated in Figure 11. Atmospheric deposition of phosphorus is estimated to account for approximately 4.4 percent of the total phosphorus load in the Missouri River Basin [Barr Engineering, 2007] and was included in the Missouri River Watershed model applications. Because of the lack of temporal data, atmospheric phosphors deposition was represented by using monthly values of daily dry fluxes using the MONTH-DATA block in **HSPF**. A value of 0.27 kg/ha/yr (0.00066 lbs/ac/day) was provided by Barr Engineering and was distributed throughout the months with higher values in the summer and lower values in the winter.

Original dry deposition data were supplied at a weekly time-step as kg/ha. To transform the data into daily time series, they were divided by the number of days in the sampling period. Similarly, the wet deposition was obtained at a weekly time-step, plus or minus multiple days. Because wet deposition was in units of concentration, it did not need to be divided by the number of days in the sampling period. Instead, the concentration was assigned to each day of

Table 6. Big Sioux River Watershed Stream Sites With any Applicable Constituent (Page 1 of 3)

Big Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		Biochemical Oxygen Demand	Chlorophyll *a*	Dissolved Oxygen	Suspended Solids	Total Ammonia	Water Temperature	Total Kjeldahl Nitrogen	Nitrate Nitrite	Dissolved Orthophosphate	Total Orthophosphate	Total Phosphorus	Total
11MS049	10			1	1	1	1		1			1	6
11MS056	30			1	1	1	1		1			1	6
11MS055	41			1	1	1	1		1			1	6
S002-380	50			1			1						2
S001-904	70		3	47	47		155	45	45		24	43	409
11MS050	90			1	1	1	1		1			1	6
07MS001	101			1	1	1	1		1			1	6
10EM124				2	2	2	2		2			2	12
S000-644					12			12				12	36
11MS057	103			1	1	1	1		1			1	6
S000-646	105		3	103	128	66	224	126	126		104	123	1003
04MS055	107				1	1			1			1	4
S000-650							1						1
04MS021	109			1	1	1	1		1			1	6
11MS038				1	1	1	1		1			1	6
11MS019	150			1	1	1	1		1			1	6
S000-099	170	16	15	75	42	65	63	1	66		1	41	385
CENTBSRT28	190			15	38	38	16	38	38		38		221
CENTBSRT29	210			15	18	18	16	18	18		18		121
WSDP99-0667				2	1		2						5
S004-530	230			16	2		16				2	2	38
04MS031	233			2	2	2	2		2			2	12
S004-529	237			12			12						24
04MS005	239			1	1	1	1		1			1	6
S002-358				16		1	16					1	34
S001-144	241			18		1	18					1	38
11MS060	243			1	1	1	1		1			1	6
S001-142	245			18		1	18					1	38

Table 6. Big Sioux River Watershed Stream Sites With any Applicable Constituent (Page 2 of 3)

Big Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		Biochemical Oxygen Demand	Chlorophyll *a*	Dissolved Oxygen	Suspended Solids	Total Ammonia	Water Temperature	Total Kjeldahl Nitrogen	Nitrate Nitrite	Dissolved Orthophosphate	Total Orthophosphate	Total Phosphorus	Total
11MS052	247			1	1	1	1		1			1	6
S001-139				19		1	19					1	40
S001-141				18		1	18					1	38
11MS058	261			1	1	1	1		1			1	6
11MS046	263			1	1	1	1		1			1	6
11MS045	265			1	1	1	1		1			1	6
11MS013	270			1	1	1	1		1			1	6
S004-528				42	31	18	42	31	31		31	31	257
CENTBSRT30	290			15	16	16	16	16	16		16		111
11MS042	309			1	1	1	1		1			1	6
CENTBSRT26	315			14	14	14	14	14	14		14		98
CENTBSRT27	317			16	17	17	17	17	17		17		118
11MS043	371			1	1	1	1		1			1	6
11MS044	373			1	1	1	1		1			1	6
11MS040	375			1	1	1	1		1			1	6
11MS039	377			1	1	1	1		1			1	6
11MS012	379			1	1	1	1		1			1	6
S004-811	379			35	39	39	35	39	39			39	265
04MS027	381			1	1	1	1		1			1	6
11MS036				1	1	1	1		1			1	6
11MS041	383			1	1	1	1		1			1	6
CENTBSRT32	385			16	19	19	17	19	19		19		128
CENTBSRT33				17	17	17	17	17	17		17		119
WSDP02-R016				1			1						2
11MS030	421			1	1	1	1		1			1	6
11MS026	505			1	1	1	1		1			1	6
11MS007	509			1	1	1	1		1			1	6
CENTBSRT07				16	17	17	17	17	17		17		118

Table 6. Big Sioux River Watershed Stream Sites With any Applicable Constituent (Page 3 of 3)

Big Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		Biochemical Oxygen Demand	Chlorophyll *a*	Dissolved Oxygen	Suspended Solids	Total Ammonia	Water Temperature	Total Kjeldahl Nitrogen	Nitrate Nitrite	Dissolved Orthophosphate	Total Orthophosphate	Total Phosphorus	Total
11MS032	521			1	1	1	1		1			1	6
11MS035	525			1	1	1	1		1			1	6
04MS052	527			1	1	1	1		1			1	6
11MS140				1	1	1	1		1			1	6
11MS031	529			1	1	1	1		1			1	6
11MS034	531			1	1	1	1		1			1	6
11MS005	537			1	1	1	1		1			1	6
46BSA8				11	12		12	12	12		12		71
CENTBSRT12				15	17	17	15	17	17		17		115
WSDP04-R051							1						1

Table 7. Little Sioux River Watershed Stream Sites With any Applicable Constituent (Page 1 of 3)

Little Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD[a]	Chlorophyll *a*	DO[b]	Suspended Solids	TAM[c]	Water Temperature	TKN[d]	NO2+NO3[e]	D-ORTHO[f]	T-ORTHO[g]	T-P[h]	Total
04MS014	1			1	1	1	1		1			1	6
11MS067				1	1	1	1		1			1	6
11MS078	3			1	1	1	1		1			1	6
11MS068	5			1	1	1	1		1			1	6
11MS143	30			1	1	1	1		1			1	6
11MS077	41			1	1	1	1		1			1	6
11MS072	50			1	1	1	1		1			1	6
S004-922				31	19	19	32						101
S004-921	85			24	14	14	25						77
11MS010	90			1	1	1	1		1			1	6
S004-219								46				46	92
12300001	110	1	1	1	1	1	1	1		1		1	9
11MS079	111			1	1	1	1		1			1	6
11MS023	113			1	1	1	1		1			1	6
04MS018	117			1	1	1	1		1			1	6
11MS066				1	1	1	1		1			1	6
S004-923				35	21	21	36						113
53-0007-00-201	119		8	6			8					8	30
11MS065	123			1	1	1	1		1			1	6
32-0069-00-101	124		10	23	10		23	10	10			10	96
11MS073	131			1	1	1	1		1			1	6
11MS062	135			1	1	1	1		1			1	6
S004-924				35	21	21	36						113
11MS008	137			1	1	1	1		1			1	6
S000-100								45				45	90
22300007	142		56	54	57	45	57	30	56	50		54	459
10300001	150	161	164	164	164	164	164	164	164	161		164	1634
12300002		1	1	1	1	1	1	1		1		1	9
32-0022-00-201	152		5	15	5		15	5				5	50

Table 7. Little Sioux River Watershed Stream Sites With any Applicable Constituent (Page 2 of 3)

Little Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temperature	TKN[(d)]	NO2+NO3[(e)]	D-ORTHO[(f)]	T-ORTHO[(g)]	T-P[(h)]	Total
32-0022-00-202			49	50			50	49				50	248
11MS024	153			1	1	1	1		1			1	6
11MS144	155				1	1	1		1			1	5
32-0020-00-101			4	11	4		11	4				4	38
32-0020-00-102	162		1	2	1		2	1				1	8
32-0020-00-201			46	50			50	48				50	244
32-0024-00-201	164		48	48			48	49				50	243
22300014	172		50	51	51	40	52	26	52	45		49	416
22300009	174		50	46	49	40	50	26	52	45		49	407
11300004	176			2	2	2	2	2	2	2		2	16
22300008			51	50	50	40	52	26	52	45		49	415
11300001		12	4	14	14	14	14	14	14	14		14	128
11300003				2	2	2	2	2	2	2		2	16
22300001			38	38	39	27	40	13	39	33		37	304
22300004	178		36	36	37	24	38	11	36	30		34	282
22300011			51	49	52	39	51	26	51	44		49	412
22300012			22	22	22	22	22	23	23	22		22	200
22300013			22	21	22	22	22	23	23	22		22	199
11300002		29	6	28	29	29	28	29	29	29		29	265
11300012	179	4	4	4	4	4	4	4	4	4		4	40
11300015		4	4	4	4	4	4	4	4	4		4	40
10210002	210	151	153	157	154	154	157	154	157	154		154	1545
11MS075	211			1	1	1	1		1			1	6
04MS025	213			1	1	1	1		1			1	6
53-0028-00-101	214		76		76	56	15	75	69			75	442
11MS063	215			1	1	1	1		1			1	6
53-0024-02-201	218											1	1
53-0024-03-201												1	1
11MS076	221			1	1	1	1		1			1	6

Table 7. Little Sioux River Watershed Stream Sites With any Applicable Constituent (Page 3 of 3)

Little Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temperature	TKN[(d)]	NO2+NO3[(e)]	D-ORTHO[(f)]	T-ORTHO[(g)]	T-P[(h)]	Total
53-0024-01-202	222		17		17							17	51
53-0024-01-203												1	1
11MS022	224			1	1	1	1		1			1	6
53-0045-00-201			18		18							18	54
16210005	249		1	1	1	1	1	1	1	1		1	9
6605000	251			2									2
10210001		164	163	170	167	167	170	167	170	167		167	1672
16210002			2	2	2	2	2	2	2	2		2	18
12210001	265	1	1	1	1	1	1	1	1	1		1	10
10210003	270	151	154	157	154	154	157	154	157	154		154	1546
16210004			1	1	1	1	1	1	1	1		1	9
13210001	271					9		9	9	9		9	45
13210004						5		5	5	5		5	25
13210005						5		5	5	5		5	25
13300001						5		5	5	5		5	25
11210001	272		11	11	13	13	11	13	13	13		13	111
11210002			10	10	10	18	10	18	18	18		18	130
22210001			56	55	57	44	56	31	58	51		54	462
16210003	303		1	1	1	1	1	1	1	1		1	9
11210005	321	30	30	15	30	30	15	30	30	30		30	270
11210003	323	38	38	20	38	38	20	38	38	38		38	344
11210004		36	36	18	36	36	18	36	36	36		36	324
16210001			2	2	2	2	2	2	2	2		2	18
22110002	330		6	6	6	6	6		6	5		5	46

(a) BOD = Biochemical Oxygen Demand
(b) DO = Dissolved Oxygen
(c) TAM = Total Ammonia
(d) TKN = Total Kjeldahl Nitrogen
(e) NO2 + NO3 = Nitrate Nitrite
(f) D-ORTHO = Dissolved Orthophosphate
(g) T-ORTHO = Total Orthophosphate
(h) T-P = Total Phosphorus

Table 8. Rock River Watershed Stream Sites With any Applicable Constituent (Page 1 of 4)

Rock River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD[a]	Chlorophyll *a*	DO[b]	Suspended Solids	TAM[c]	Water Temperature	TKN[d]	NO2+NO3[e]	D-ORTHO[f]	T-ORTHO[g]	T-P[h]	Total
04MS009	10			3	3	3	3		3			3	18
04MS051				1	1	1	1		1			1	6
11MS116				1	1	1	1		1			1	6
11MS136				1	1	1	1		1			1	6
04MS035	21			1	1	1	1		1			1	6
11MS145				1	1	1	1		1			1	6
04MS012	25			1	1	1	1		1			1	6
11MS088				1	1	1	1		1			1	6
11MS117	27			1	1	1	1		1			1	6
11MS147	30			1	1	1	1		1			1	6
11MS089	43			1	1	1	1		1			1	6
11MS138				1	1	1	1		1			1	6
04MS010	50			1	1	1	1		1			1	6
11MS011				1	1	1	1		1			1	6
11MS124	61			1	1	1	1		1			1	6
11MS122	63			1	1	1	1		1			1	6
11MS091	65			1	1	1	1		1			1	6
10EM142	67			1	1	1	1		1			1	6
11MS123				1	1	1	1		1			1	6
04MS026	71			1	1	1	1		1			1	6
11MS016				1	1	1	1		1			1	6
11MS121				1	1	1	1		1			1	6
11MS093	73			1	1	1	1		1			1	6
11MS096	77			1	1	1	1		1			1	6
11MS014	79			1	1	1	1		1			1	6
11MS113	81			1	1	1	1		1			1	6
04MS032	90			1	1	1	1		1			1	6
11MS083	91			1	1	1	1		1			1	6
S000-147	110			19	18	6	19		20		20	20	122

Table 8. Rock River Watershed Stream Sites With any Applicable Constituent (Page 2 of 4)

Rock River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD[a]	Chlorophyll *a*	DO[b]	Suspended Solids	TAM[c]	Water Temperature	TKN[d]	NO2+NO3[e]	D-ORTHO[f]	T-ORTHO[g]	T-P[h]	Total
11MS081	121			1	1	1	1		1			1	6
11MS084	123			1	1	1	1		1			1	6
11MS114	130			1	1	1	1		1			1	6
S004-390				19	18	6	19		20		20	20	122
11MS082	131			1	1	1	1		1			1	6
11MS003	150			1	1	1	1		1			1	6
11MS097	153			1	1	1	1		1			1	6
11MS094	155			1	1	1	1		1			1	6
11MS098	159			1	1	1	1		1			1	6
11MS095	161			1	1	1	1		1			1	6
S005-809	163			19	23		23						65
10EM014	165			2	2	2	2		2			2	12
6483000	170			15								1	16
04MS019				3	3	3	3		3			3	18
S005-381				30	31	31	30	31	31		31	31	246
11MS148	190			1	1	1	1		1			1	6
S001-359				1	1		1	1	1		1	1	7
11MS119	191			1	1	1	1		1			1	6
11MS118	193			1	1	1	1		1			1	6
11MS099	195			1	1	1	1		1			1	6
11MS100	197			1	1	1	1		1			1	6
07MS002	199			2	2	2	2		2			2	12
11MS020	201			1	1	1	1		1			1	6
04MS016	210			1	1	1	1		1			1	6
S000-687				19	18	6	19		20		20	20	122
04MS002	211				1	1	1		1			1	5
11MS085				1	1	1	1		1			1	6
11MS108	231			1	1	1	1		1			1	6

Table 8. Rock River Watershed Stream Sites With any Applicable Constituent (Page 3 of 4)

Rock River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD[a]	Chlorophyll *a*	DO[b]	Suspended Solids	TAM[c]	Water Temperature	TKN[d]	NO2+NO3[e]	D-ORTHO[f]	T-ORTHO[g]	T-P[h]	Total
11600002	270			21	21	21	21	21	21	21		21	168
11MS001				1	1	1	1		1			1	6
S000-097		16	16	82	59	66	82		80		20	60	481
04MS008	271			1	1	1	1		1			1	6
11MS126				1	1	1	1		1			1	6
11MS125	273			1	1	1	1		1			1	6
11MS127	277			1	1	1	1		1			1	6
11MS004	279			1	1	1	1		1			1	6
04MS034	281			3	3	3	3		3			3	18
04MS050	283			1	1	1	1		1			1	6
11MS018				1	1	1	1		1			1	6
11MS109				1	1	1	1		1			1	6
S004-927				36	45	45	40	45	45			45	301
04MS020	285			1	1	1	1		1			1	6
11MS101	287			1	1	1	1		1			1	6
11MS129	291			1	1	1	1		1			1	6
11MS128	293			1	1	1	1		1			1	6
11MS102	297			1	1	1	1		1			1	6
11MS086	301			1	1	1	1		1			1	6
S001-016				38	45	45	41	45	45			45	304
11MS006	303			1	1	1	1		1			1	6
S004-717				37	45	45	93	45	45			45	355
11600001	310			23	23	23	23	23	23	23		23	184
11MS106	313			1	1	1	1		1			1	6
11MS107	315			1	1	1	1		1			1	6
11MS021	317			1	1	1	1		1			1	6
S004-391				31	18	6	31		20		20	20	146
10EM001	319			1	1	1	1		1			1	6
11600003	321			21	21	21	21	21	21	21		21	168

Table 8. Rock River Watershed Stream Sites With any Applicable Constituent (Page 4 of 4)

Rock River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temperature	TKN[(d)]	NO2+NO3[(e)]	D-ORTHO[(f)]	T-ORTHO[(g)]	T-P[(h)]	Total
16600003	325		1	1	1	1	1	1	1	1		1	9
11600004	327			23	26	26	23	26	26	26		26	202
16600004			1	1	1	1	1	1	1	1		1	9
04MS003	331			1	1	1	1		1			1	6
11MS110	333			1	1	1	1		1			1	6
11MS111	335			1	1	1	1		1			1	6
04MS053	337			1	1	1	1		1			1	6
11MS047				1	1	1	1		1			1	6
11MS132	339			1	1	1	1		1			1	6
04MS011	341			2	2	2	2		2			2	12
11MS104				1	1	1	1		1			1	6
11MS105	343			1	1	1	1		1			1	6
11MS009	345			1	1	1	1		1			1	6
11720001	347			21	21	21	21	21	21	21		21	168
11MS002				1	1	1	1		1			1	6
S004-928				21			21						42
11MS115	349			1	1	1	1		1			1	6
12600001	351	1	1		1	1		1		1		1	7
11MS087	353			1	1	1	1		1			1	6
11600005	367			21	22	22	21	22	22	22		22	174
6483500	370			3								1	4
11840002				22	23	23	22	23	23	23		23	182
16840002			2	2	2	2	2	2	2	2		2	18

(a) BOD = Biochemical Oxygen Demand
(b) DO = Dissolved Oxygen
(c) TAM = Total Ammonia
(d) TKN = Total Kjeldahl Nitrogen
(e) NO2 + NO3 = Nitrate Nitrite
(f) D-ORTHO = Dissolved Orthophosphate
(g) T-ORTHO = Total Orthophosphate
(h) T-P = Total Phosphorus

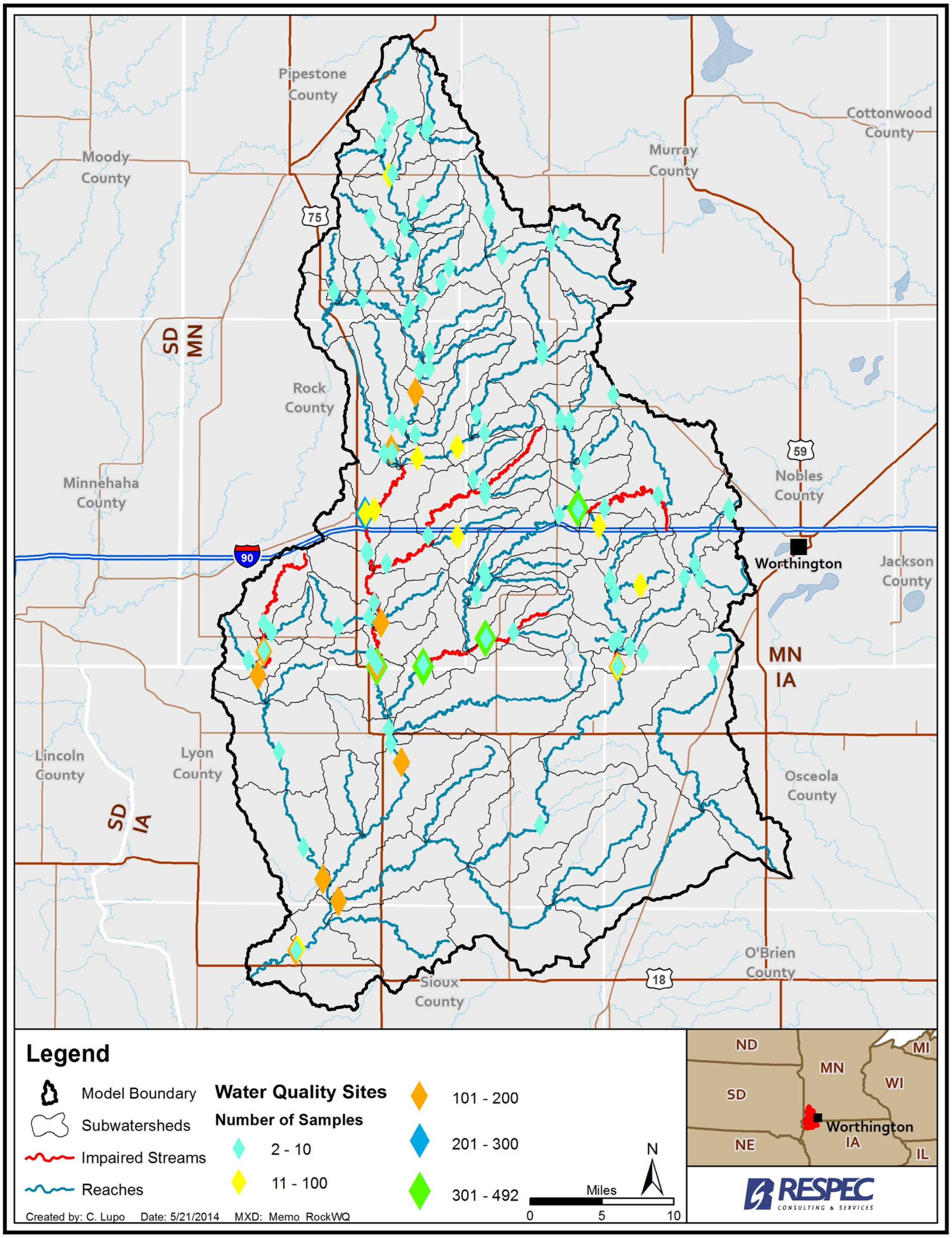

Figure10. Ambient Water-Quality Monitoring Sites Within the Rock River Watershed.

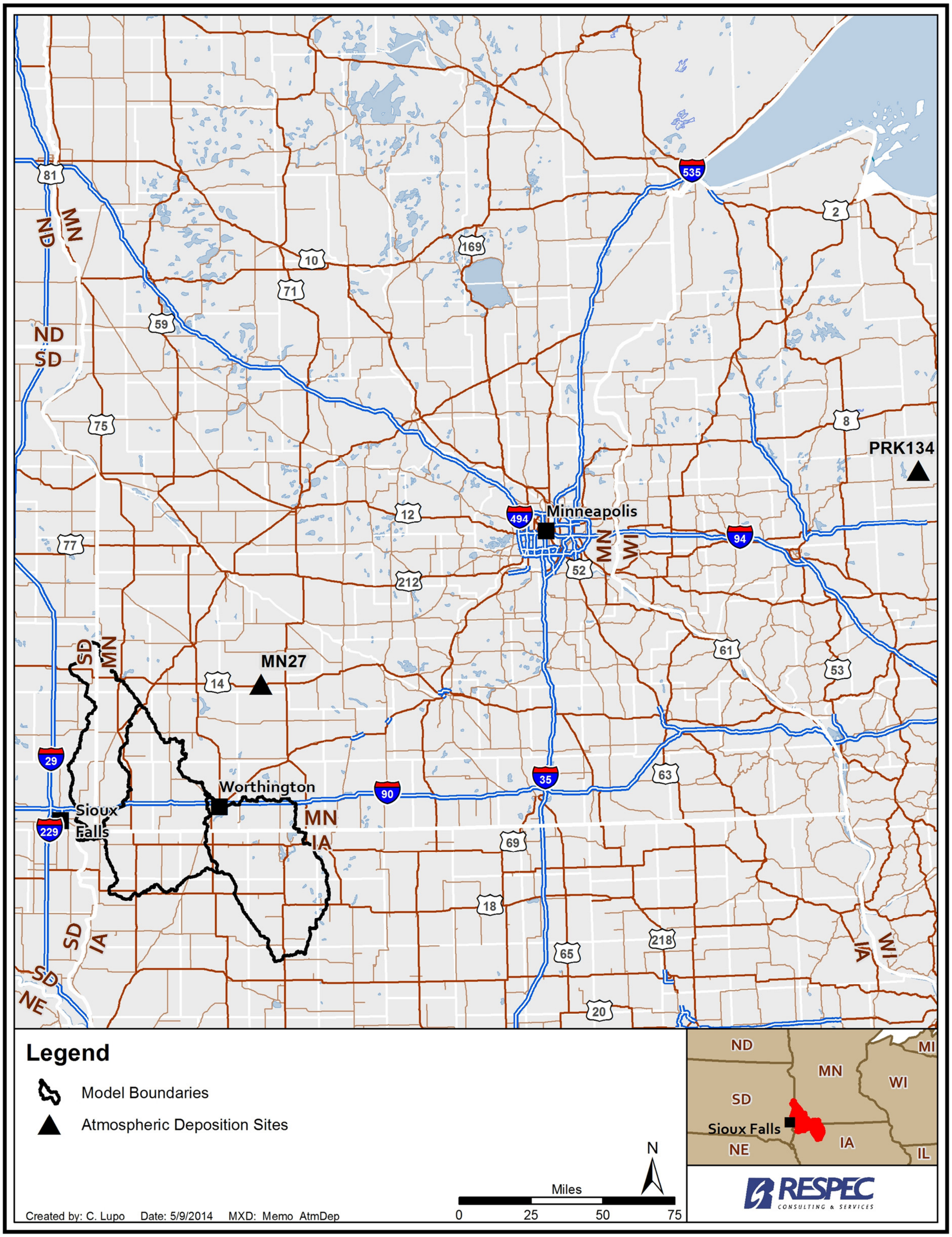

Figure 11. Atmospheric Wet and Dry Deposition Sites.

the sampling period. Once transformed to daily time-series data, missing dry and wet deposition data were patched by using interpolation between the previous and later dates, when fewer than 7 days occurred between values (rare with this dataset), and by using monthly mean values, when more than 7 days occurred between values (likely scenario).

POINT-SOURCE DATA AVAILABLE

Three major point sources and 53 minor point sources are located in the Missouri River Watershed. The point source locations for the Rock River model application are illustrated in Figure 12 and the sites for the Big and Little Sioux model applications are illustrated in Attachment D. Four of the 55 facilities are mechanical and the remaining 51 point sources in the watersheds are controlled ponds. Controlled ponds generally discharge intermittently for variable lengths of time, and data for the sites were provided as a combination of monthly volumes and monthly average flow. If a controlled pond was missing monthly discharge, it was assumed that the pond did not release effluent to the surface water during that month. An estimate of the number of discharge days was supplied by the MPCA and was incorporated by using the following logic supplied by Henningsgaard [2012]:

1. If there are only a few discharge days followed by a month with only a few discharge days, or if the first month has only a couple and the next month has up to approximately 10 discharge days, they should be placed at both the end and beginning of the 2 months.

2. If there are over 6 discharge days in a month, but fewer than about 18, they can be placed anywhere consecutively.

3. If there are over approximately 18 discharge days, half should be placed in the first half of the month and half should be placed in the second half of the month.

For each facility, the period of record and completeness were assessed. Available constituents from point sources applicable for modeling purposes include carbonaceous 5-day biochemical oxygen demand (CBOD5), TSS, total phosphorus (TP), and DO. Point-source water-quality data were filled using monthly mean values. Where monthly means were unavailable, interpolation was used. The available effluent water-quality parameters vary by site, but in general, most parameters were available from wastewater treatment facilities (WWTF).

Nitrogen species data and orthophosphate-phosphorus were largely unavailable in the minor point-source data. Classes for each point source are provided in Table 9 [Weiss, 2012a]. Point-source loads for nitrogen species were calculated by using numbers supplied by Weiss [2012b] and are provided in Table 10. The facility classes applicable to the Missouri River Watershed are shown in bold. Methods for estimating other phosphorus species from point sources were derived from methods similar to those used in the Minnesota River model application [Tetra Tech, 2009]. The nutrient portions of the Missouri River Watershed external sources blocks contain estimates where nutrient data were unavailable. Temperature data were derived from a minor wastewater treatment facility located in the Sauk River Watershed and were adjusted for differences in temperature between the two watersheds. All available data for model inputs have been uploaded into the project Watershed Data Management (WDM) file, and all available data used for comparison to model simulations are in an observed data Excel file.

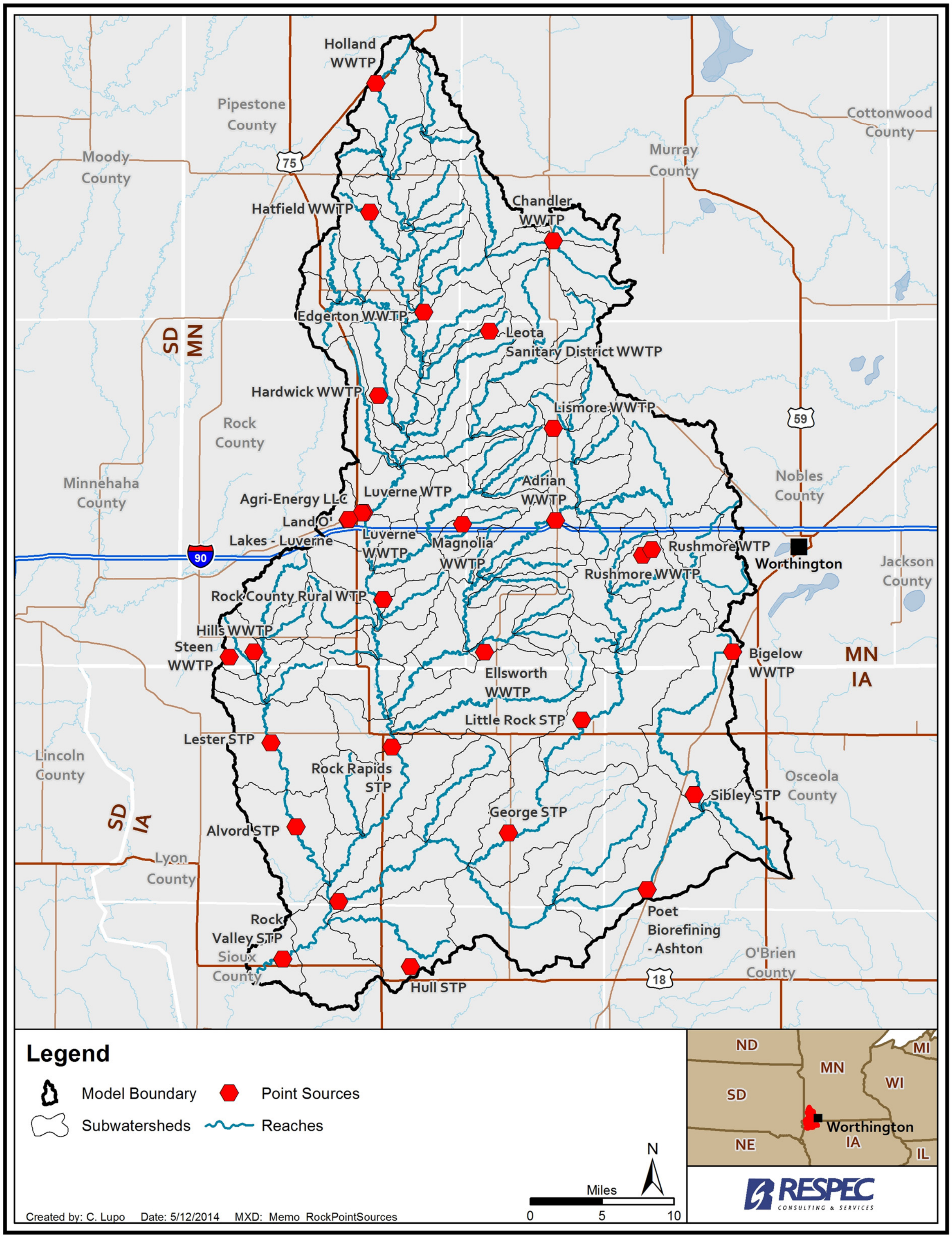

Figure 12. Minor Point Sources in the Rock River Watershed.

Table 9. Categorical Concentration Assumptions (m/L) [Weiss, 2012a] (Page 1 of 2)

Model Application	Site I.D.	Facility Name	Type
Big Sioux River	MNG580195	Heartland Colonies Residential WWTP	D
Big Sioux River	MN0064351	Lincoln Pipestone Rural Wtr Holland Well	WTP[a]
Big Sioux River	MNG580192	Woodstock WWTP	D
Big Sioux River	MN0054801	Pipestone WWTP	C
Big Sioux River	MNG790055	Clipper Oil Bassett Texaco	D[a]
Big Sioux River	MNG580026	Jasper WWTP	D
Big Sioux River	SD0000299	USGS - EROS Data Center	D
Big Sioux River	SD0022560	City of Garretson	D
Big Sioux River	MN0003981	TYSON FOODS	D[a]
Big Sioux River	MNG580055	Beaver Creek WWTP	D
Little Sioux River	IA3045001	Lake Park City of STP	D[a]
Little Sioux River	IA7128001	Hartley City of STP	D[a]
Little Sioux River	IA7222001	Harris City of STP	D[a]
Little Sioux River	IA3050901	Iowa Great Lakes Sanitary District STP	C[a]
Little Sioux River	IA2100100	Corn Belt Power Cooperative - Wisdom Station	POWER[a]
Little Sioux River	IA7239001	Ocheyedan City of STP	D[a]
Little Sioux River	IA2166001	Royal City of STP	D[a]
Little Sioux River	IA2171004	Spencer City of STP	D[a]
Little Sioux River	IA7465001	Ruthven City of STP	D[a]
Little Sioux River	IA2122001	Fostoria City of STP	D[a]
Little Sioux River	IA3080001	Terril City of STP	D[a]
Little Sioux River	IA2115001	Everly City of STP	D[a]
Little Sioux River	IA2109001	Dickens Wastewater Treatmet Facility	D[a]
Little Sioux River	IA1175001	Sioux Rapids City of STP	D[a]
Little Sioux River	IA2133001	Greenville City of STP	D[a]
Rock River	MN0021270	Holland WWTP	D
Rock River	MN0023604	Hatfield WWTP	D[a]
Rock River	MN0039748	Chandler WWTP	D
Rock River	MNG580011	Edgerton WWTP	D
Rock River	MNG580219	Leota Sanitary District WWTP	D
Rock River	MNG580194	Hardwick WWTP	D
Rock River	MN0020141	Luverne WWTP	A
Rock River	MNG640056	Luverne WTP - Plant 1	D(a)
Rock River	MNG255020	LAND O' LAKES INC-LUVERNE	D(a)
Rock River	MN0064033	Agri-Energy LLC	POWER(a)

Table 9. Categorical Concentration Assumptions (m/L) [Weiss, 2012a] (Page 2 of 2)

Model Application	Site I.D.	Facility Name	Type
Rock River	MNG580190	Magnolia WWTP	D
Rock River	MNG640079	Rock County Rural WTP	D(a)
Rock River	MNG580076	Lismore WWTP	D
Rock River	MNG580001	Adrian WWTP	D
Rock River	MNG580015	Ellsworth WWTP	D
Rock River	MNG580196	Hills WWTP	D
Rock River	MNG580199	Steen WWTP	D
Rock River	IA6055001	LESTER CITY OF STP	D(a)
Rock River	IA6003001	ALVORD CITY OF STP	D(a)
Rock River	IA6065001	ROCK RAPIDS CITY OF STP	D(a)
Rock River	MNG580201	Rushmore WWTP	D
Rock River	MNG640080	RUSHMORE WTP	D(a)
Rock River	IA6060001	LITTLE ROCK CITY OF STP	D(a)
Rock River	IA6028001	GEORGE CITY OF STP	D(a)
Rock River	MNG580224	Bigelow WWTP	D
Rock River	IA7245001	SIBLEY CITY OF STP	D(a)
Rock River	IA7200108	POET BIOREFINING - ASHTON	D(a)
Rock River	IA6015001	DOON CITY OF STP	D(a)
Rock River	IA8444001	HULL CITY OF STP	D(a)
Rock River	IA8482001	ROCK VALLEY CITY OF STP	D(a)

(a) Assumed based on description of treatment and flow

Besides temperature, the concentrations of all available constituents, including BOD as CBODU (converted from CBOD5 using Equation 1 [Chapra, 1997]), were converted from concentration (mg/L) to load (lb/day), using a conversion factor of 8.34. Temperature was converted from degrees F to a heat load in British Thermal Units (BTU) per day (temperature × flow × conversion factor, conversion factor = 8,339,145).

$$L_0 = \frac{y_5}{1 - e^{-k_1(5)}} \tag{1}$$

where:

$L_0 = \mathrm{CBOD}_u$

$y_5 = \mathrm{CBOD}_5$

$k_1 = 0.10$, minimum value after primary treatment.

Estimated daily time series were then imported into the binary WDM files, and loads were applied to the corresponding stream in the external sources block in the model input file.

Table 10. Categorical Concentration Assumptions (mg/L) [Weiss, 2012b]

Category	General Description	TN[(a)]	NOx[(b)]	TKN[(c)]	NHx[(d)]
A	**Class A municipal - large mechanical**	**19**	**15**	**4**	**3**
B	Class B municipal - medium mechanical	17	10	7	4
C	**Class C municipal—small mechanical/ pond mix**	**10**	**7**	**3**	**1**
D	**Class D municipal—mostly small ponds**	**6**	**3**	**3**	**1**
O	Other—generally very low volume effluent	10	7	3	2
PEAT	Peat mining facility—pump out/drainage from peat	10	7	3	2
T	Tile Line to Surface Discharge	10	7	3	3
P	Paper industry	10	7	3	2
NCCW	Noncontact cooling water	4	1	3	2
POWER	**Power Industry**	**4**	**1**	**3**	**2**
WTP	**Water treatment plant**	**4**	**3**	**1**	**1**
GRAV	Gravel mining wash water	2	1	1	1
GW	Industrial facilities—primarily private groundwater well	0.25	0.25	0	0

(a) TN = Total Nitrogen
(b) NOx = Inorganic Nitrogen
(c) TKN = Total Kjeldahl Nitrogen
(d) NHx = Ammonia

The final results from the most data-intensive downstream reaches in the Missouri River Watershed are included in Attachment E. Three figures are included for each available water-quality constituent at this location. The figures show comparisons of observed data (blue) and model simulations (red) and include a concentration duration curve, a monthly average plot, and a time-series plot for each site. Results at additional water-quality monitoring sites are included in the Missouri River deliverables results folder.

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Weiss, S., 2012a. Personal communication between C. McCutcheon, RESPEC, Rapid City, SD, and S. Weiss, Minnesota Pollution Control Agency, St. Paul, MN, February 1.

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U.S. Environmental Protection Agency, 2006. *EPA Basins Technical Note 8: Sediment Parameter and Calibration Guidance for HSPF*, U.S. Environmental Protection Agency Office of Water, Washington, DC.

We would be happy to discuss these methods with you and hear any feedback you may have regarding the calibration and validation of the Missouri River **HSPF** Watershed model applications.

Sincerely,

Seth J. Kenner
Staff Engineer

SJK:blp

cc: Project Central File 2216 — Category A

ATTACHMENT A

OBSERVED FLOW GAGE LOCATIONS FOR THE LITTLE AND BIG SIOUX WATERSHED MODEL APPLICATIONS

RSI-2279-14-030

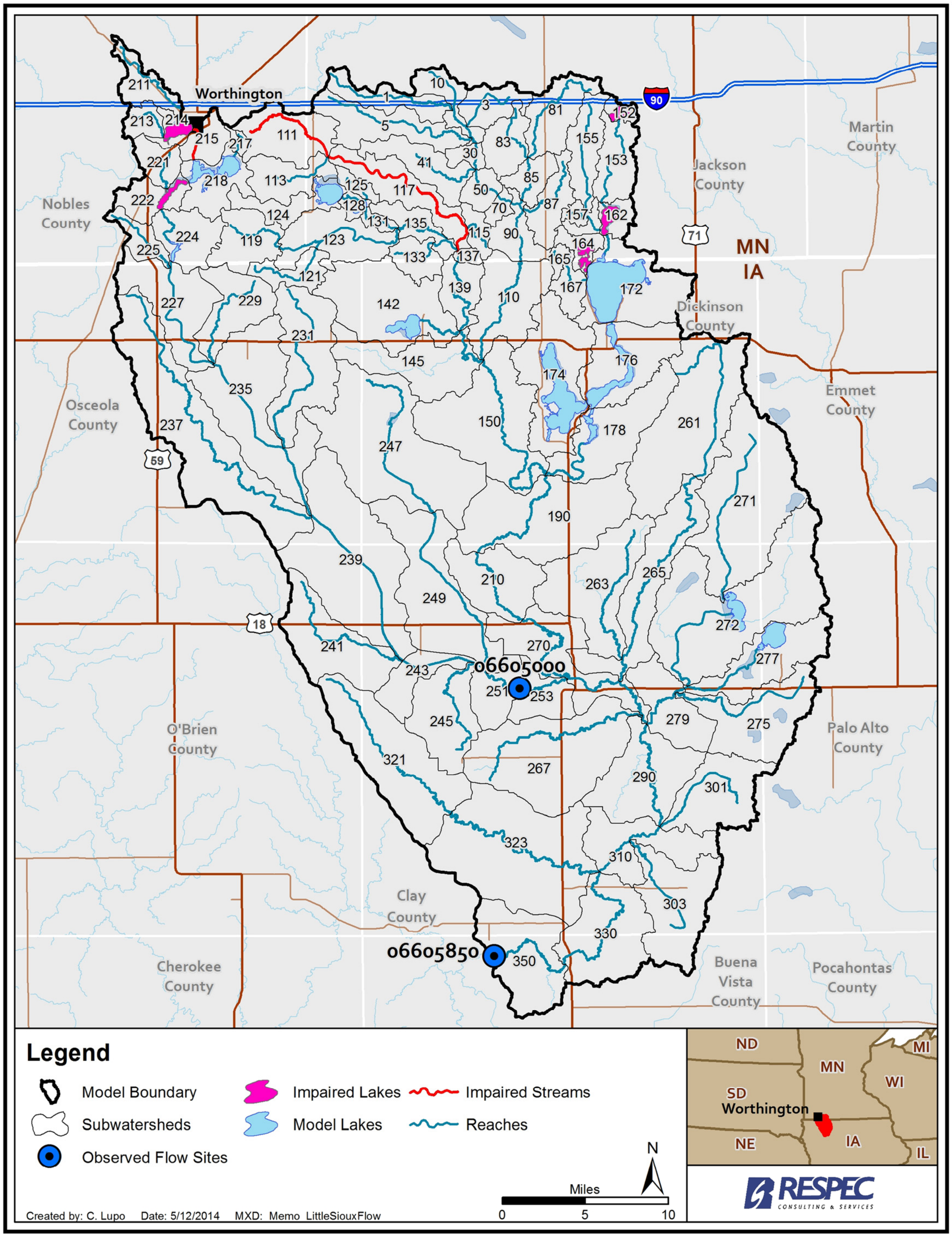

Figure A-1. Flow Calibration Gages Within the Little Sioux River Watershed.

RSI-2279-14-031

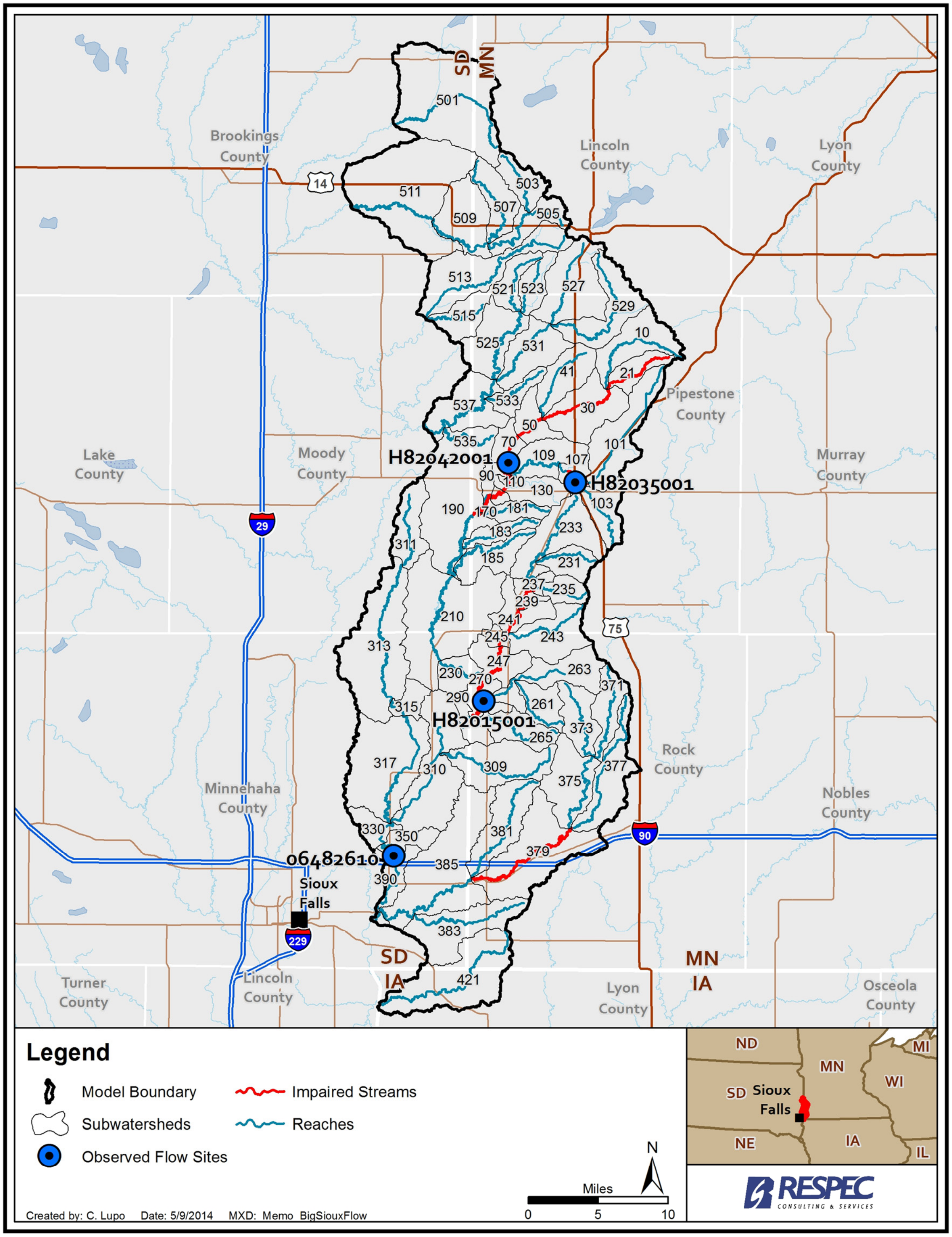

Figure A-2. Flow Calibration Gages Within the Big Sioux River Watershed.

ATTACHMENT B

HYDROLOGY CALIBRATION RESULTS AT PRIMARY GAGES FOR THE MISSOURI RIVER WATERSHED MODEL

RSI-2279-14-032

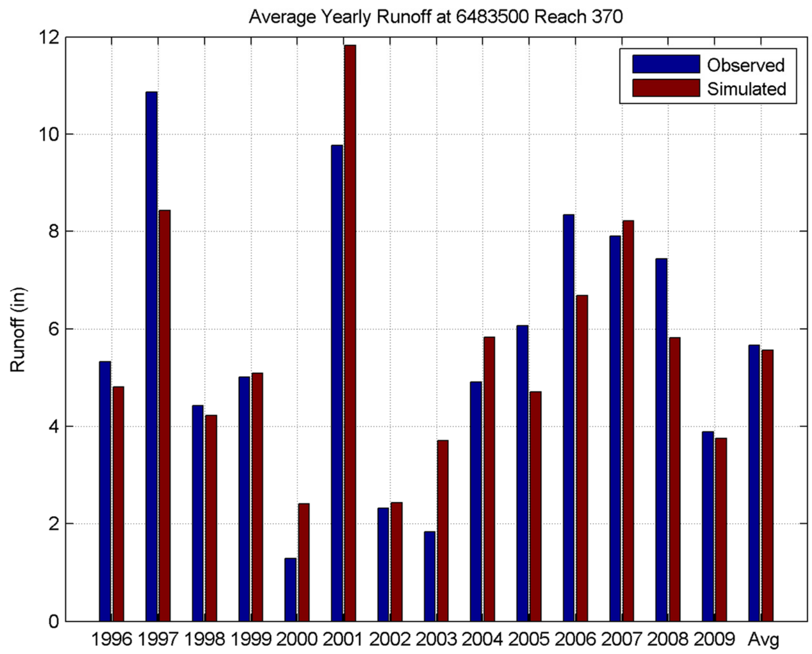

Figure B-1. Average Yearly Runoff – Rock River (Reach 370).

RSI-2279-14-033

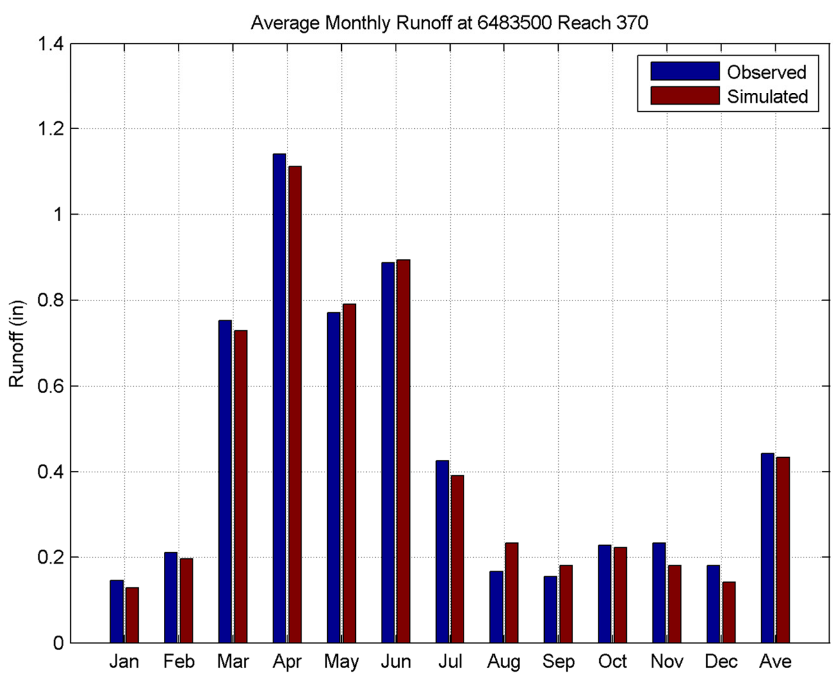

Figure B-2. Average Monthly Runoff – Rock River (Reach 370).

RSI-2279-14-034

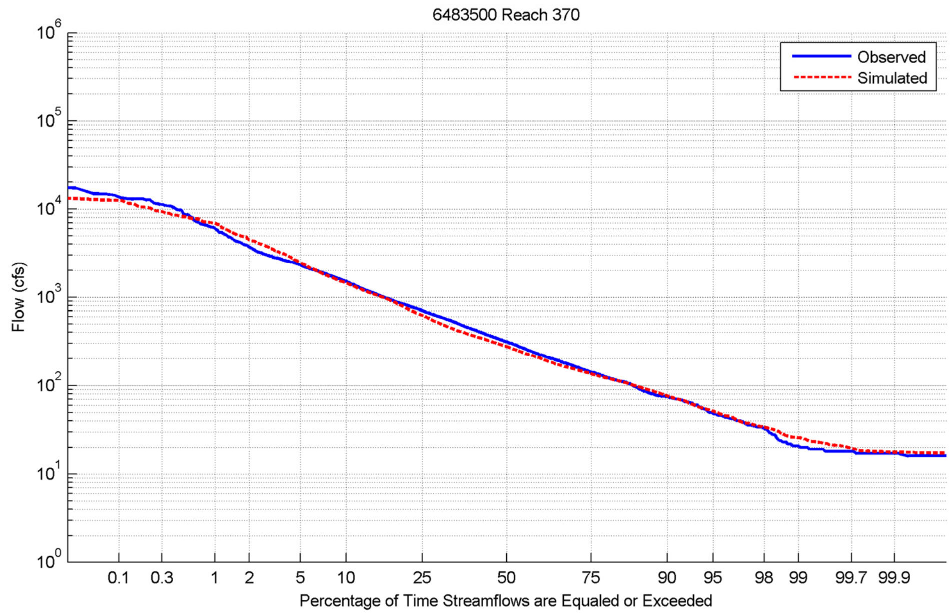

Figure B-3. Flow-Duration Plot – Rock River (Reach 370).

RSI-2279-14-035

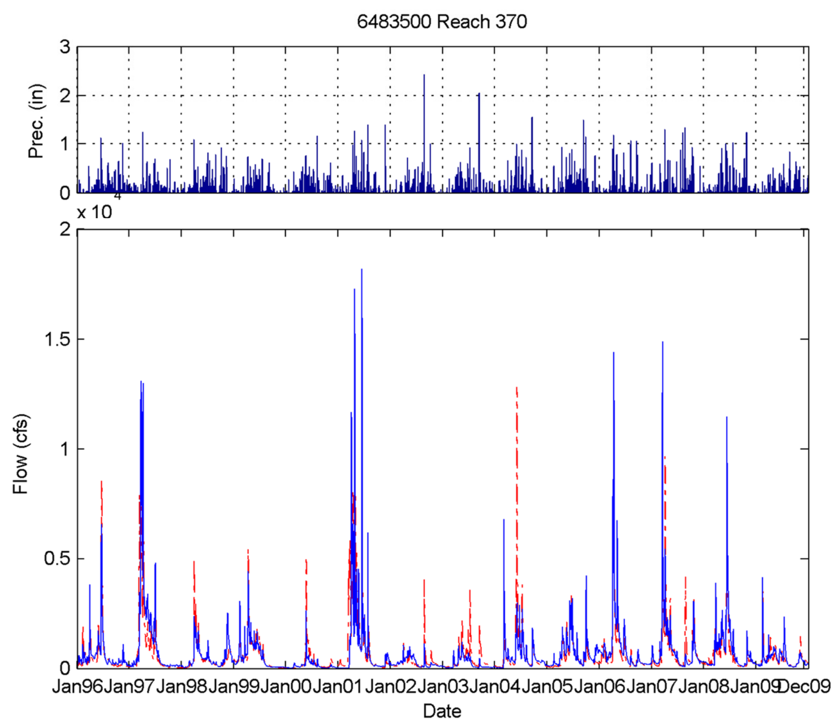

Figure B-4. Daily Hydrographs – Rock River (Reach 370).

RSI-2279-14-036

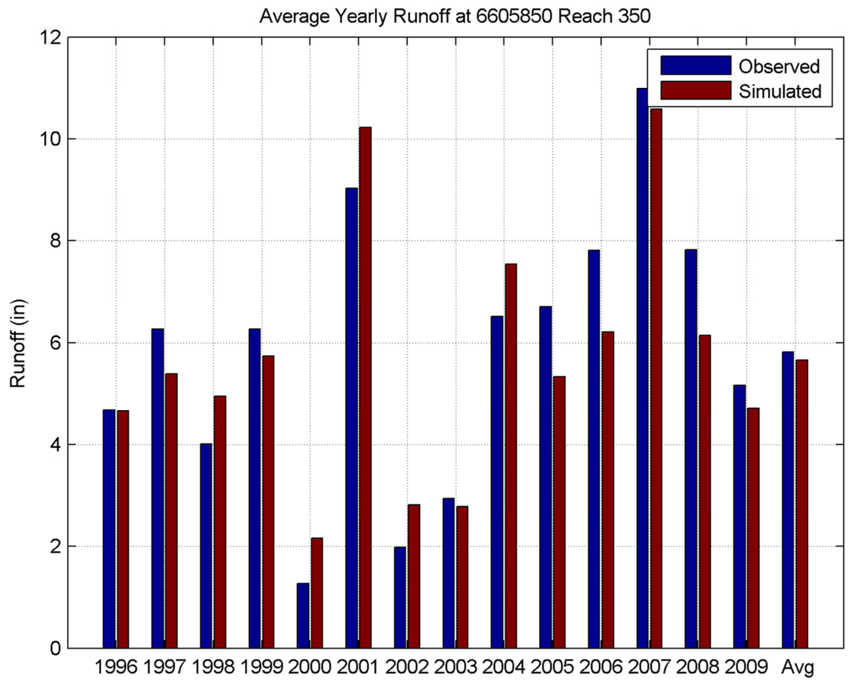

Figure B-5. Average Yearly Runoff – Little Sioux (Reach 350).

RSI-2276-14-037

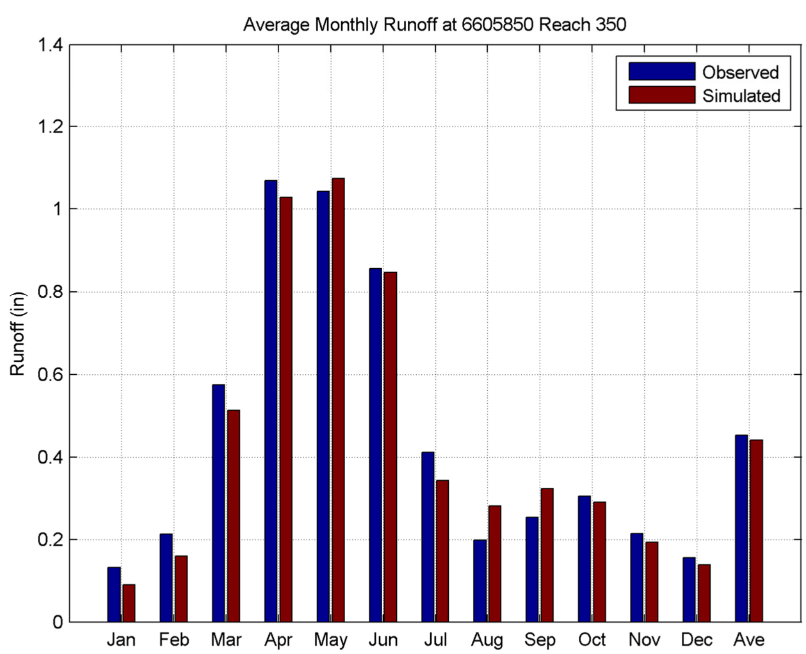

Figure B-6. Average Monthly Runoff – Little Sioux (Reach 350).

RSI-2276-14-038

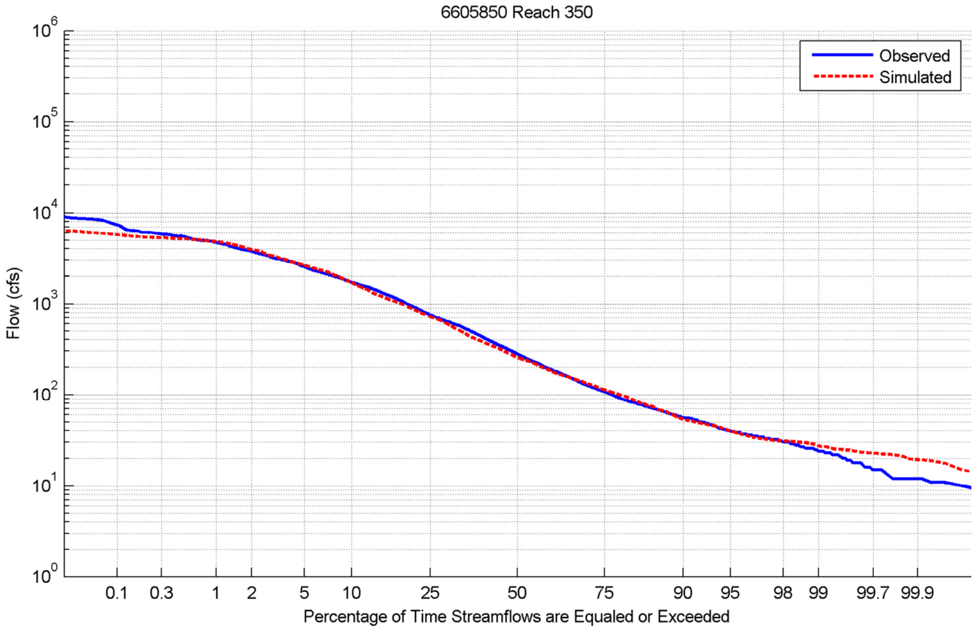

Figure B-7. Flow-Duration Plot – Little Sioux (Reach 350).

RSI-2276-14-039

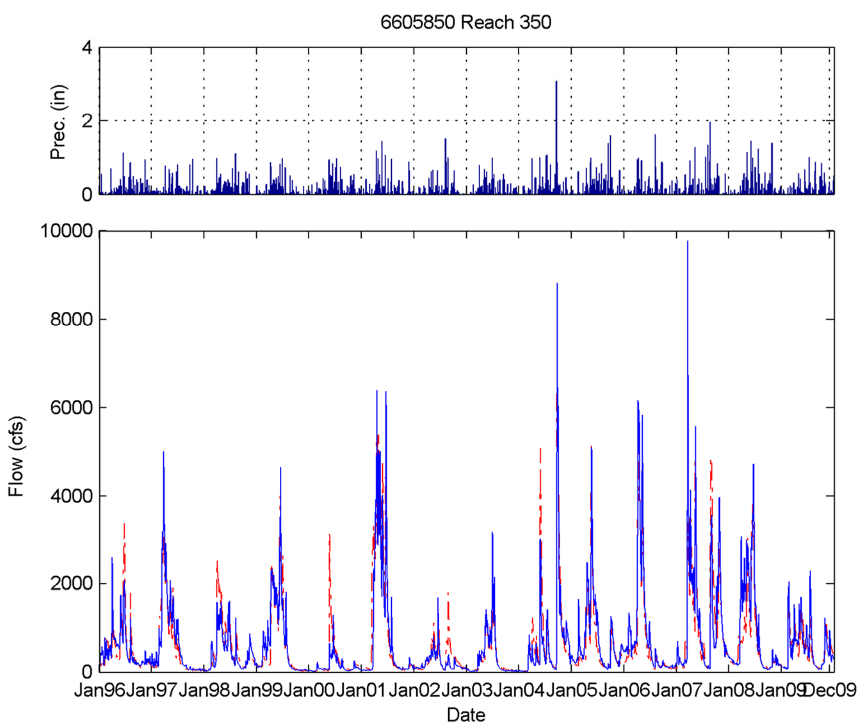

Figure B-8. Daily Hydrographs – Little Sioux (Reach 350).

RSI-2279-14-040

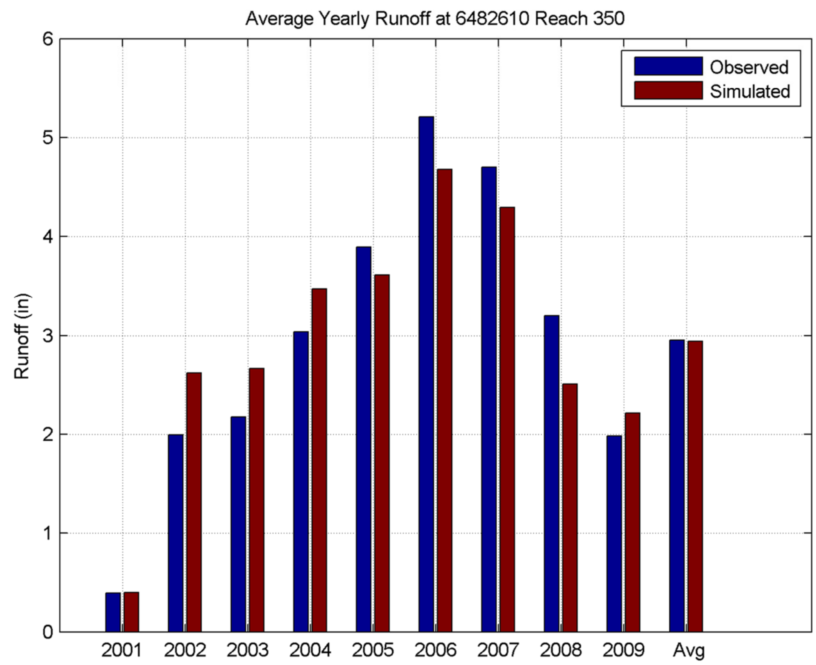

Figure B-9. Average Yearly Runoff – Big Sioux (Reach 350).

RSI-2276-14-041

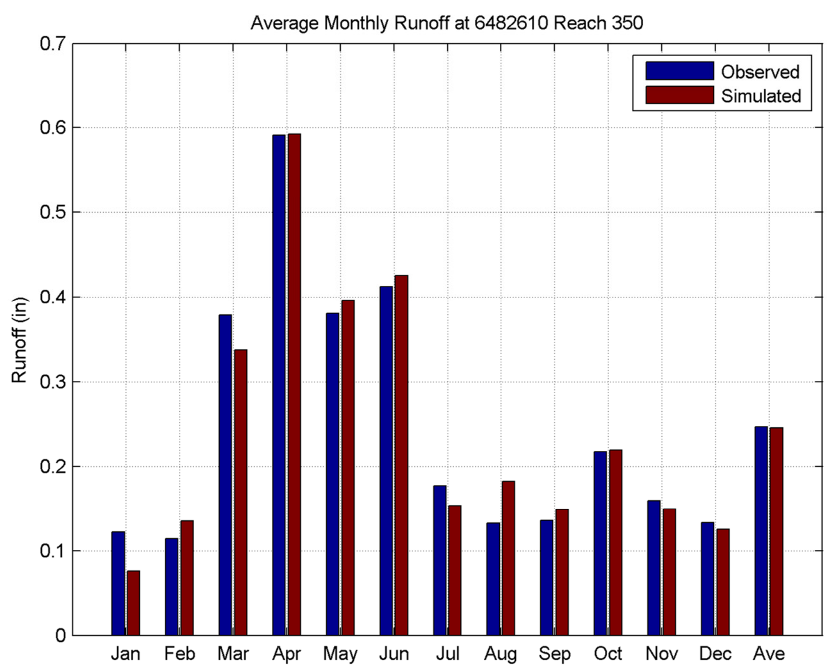

Figure B-10. Average Monthly Runoff – Big Sioux (Reach 350).

RSI-2279-14-042

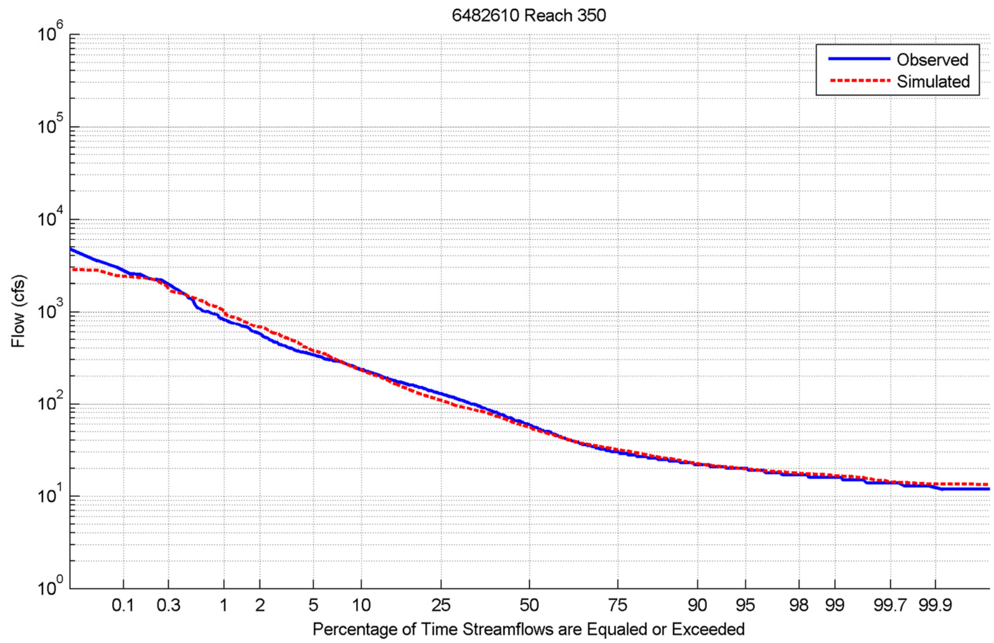

Figure B-11. Flow-Duration Plot – Big Sioux (Reach 350).

RSI-2279-14-043

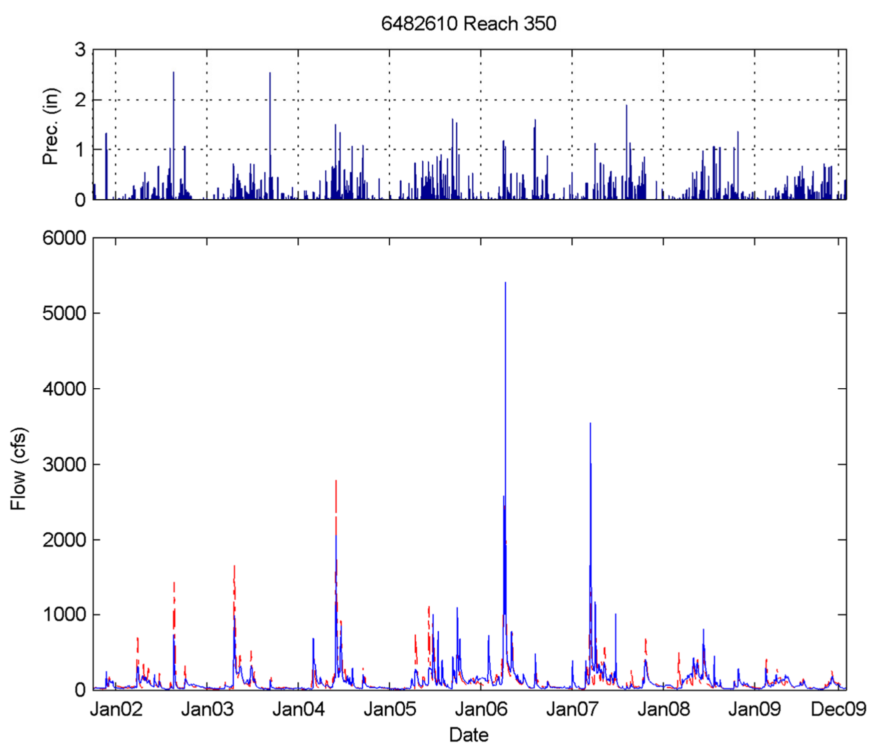

Figure B-12. Daily Hydrographs – Big Sioux (Reach 350).

ATTACHMENT C

OBSERVED WATER-QUALITY LOCATIONS FOR THE LITTLE AND BIG SIOUX WATERSHED MODEL APPLICATIONS

RSI-2279-14-044

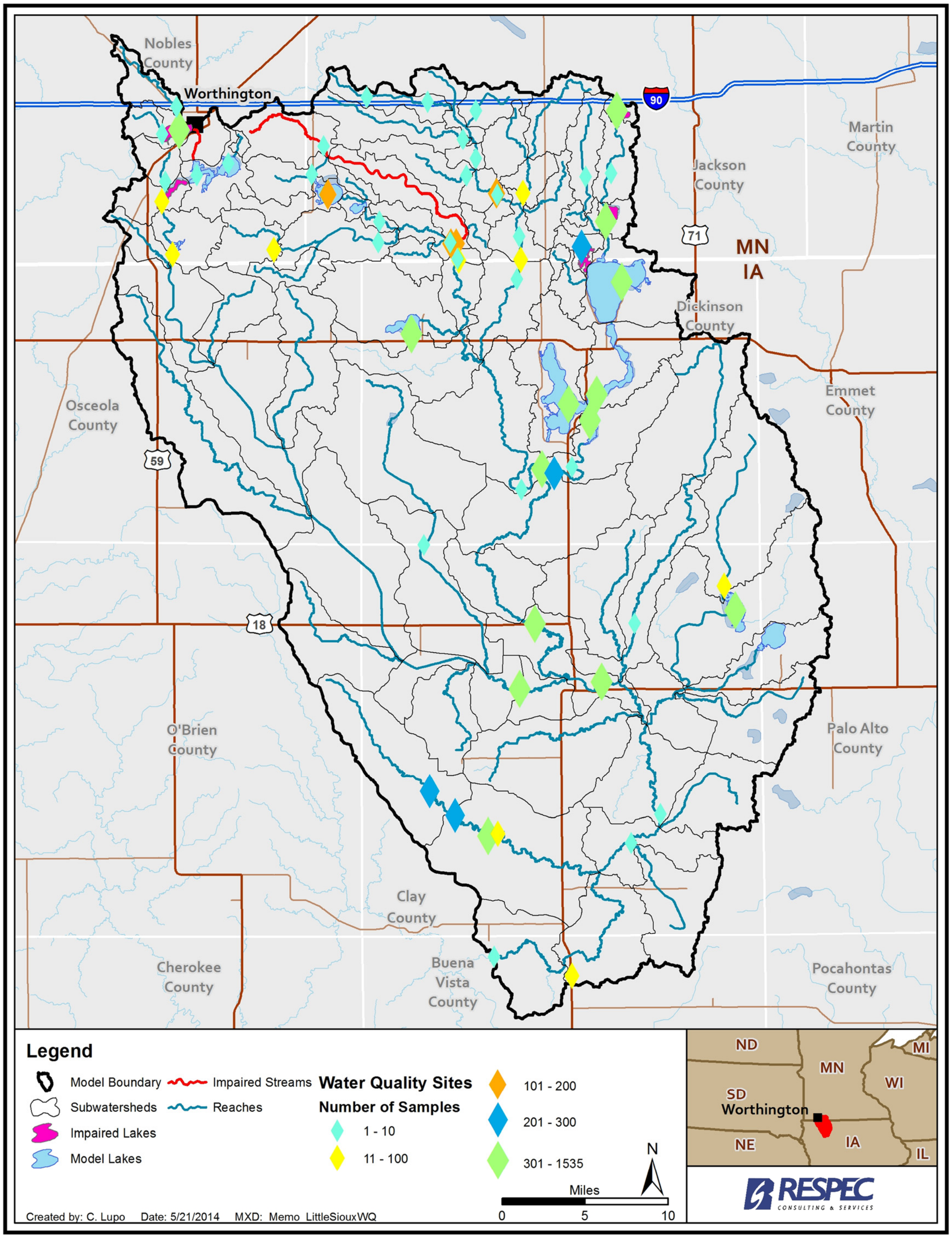

Figure C-1. Observed Water-Quality Locations Within the Little Sioux River Watershed.

RSI-2279-14-045

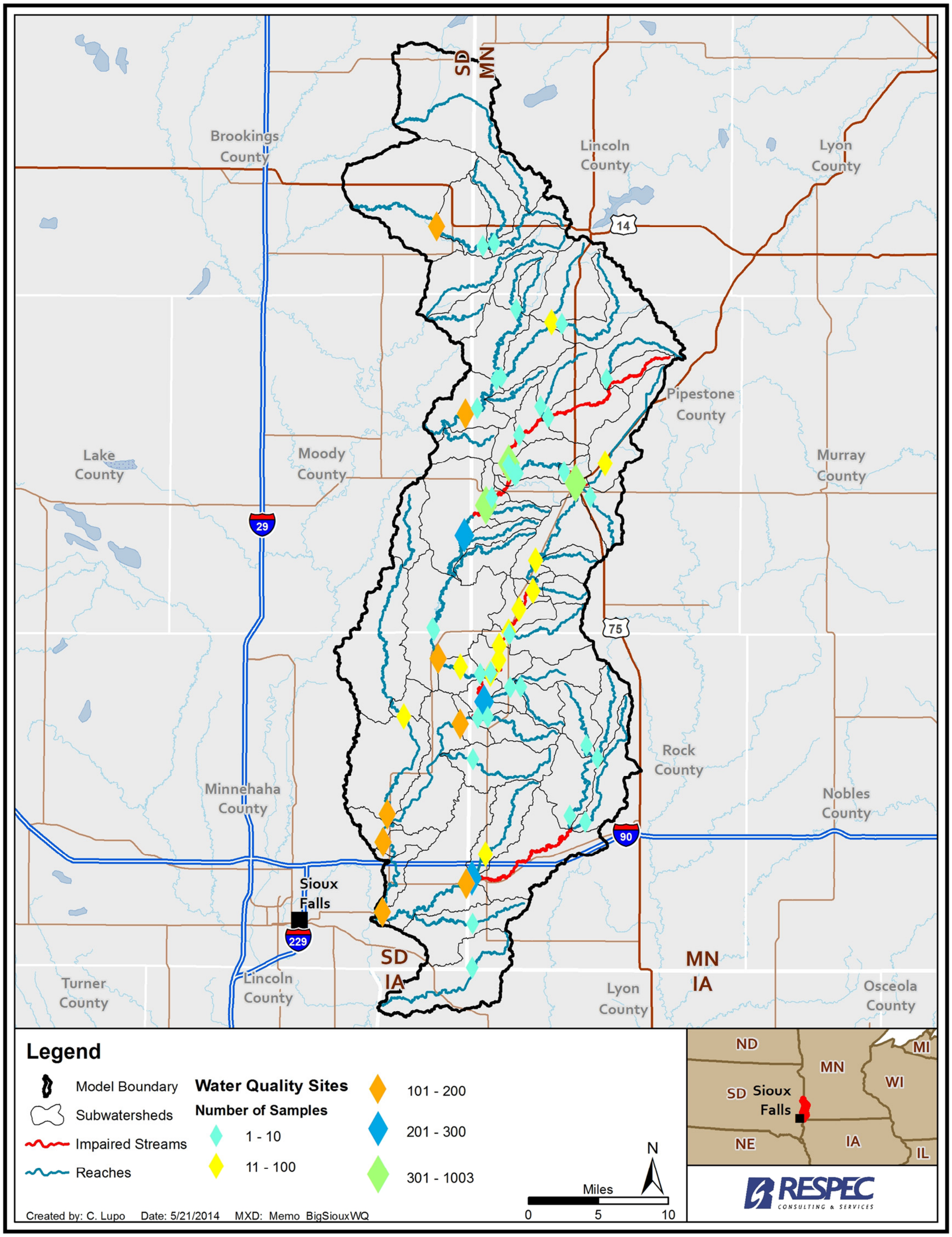

Figure C-2. Observed Water-Quality Locations Within the Big Sioux River Watershed.

ATTACHMENT D

POINT-SOURCE LOCATIONS FOR THE LITTLE AND BIG SIOUX WATERSHED MODEL APPLICATIONS

RSI-2279-14-046

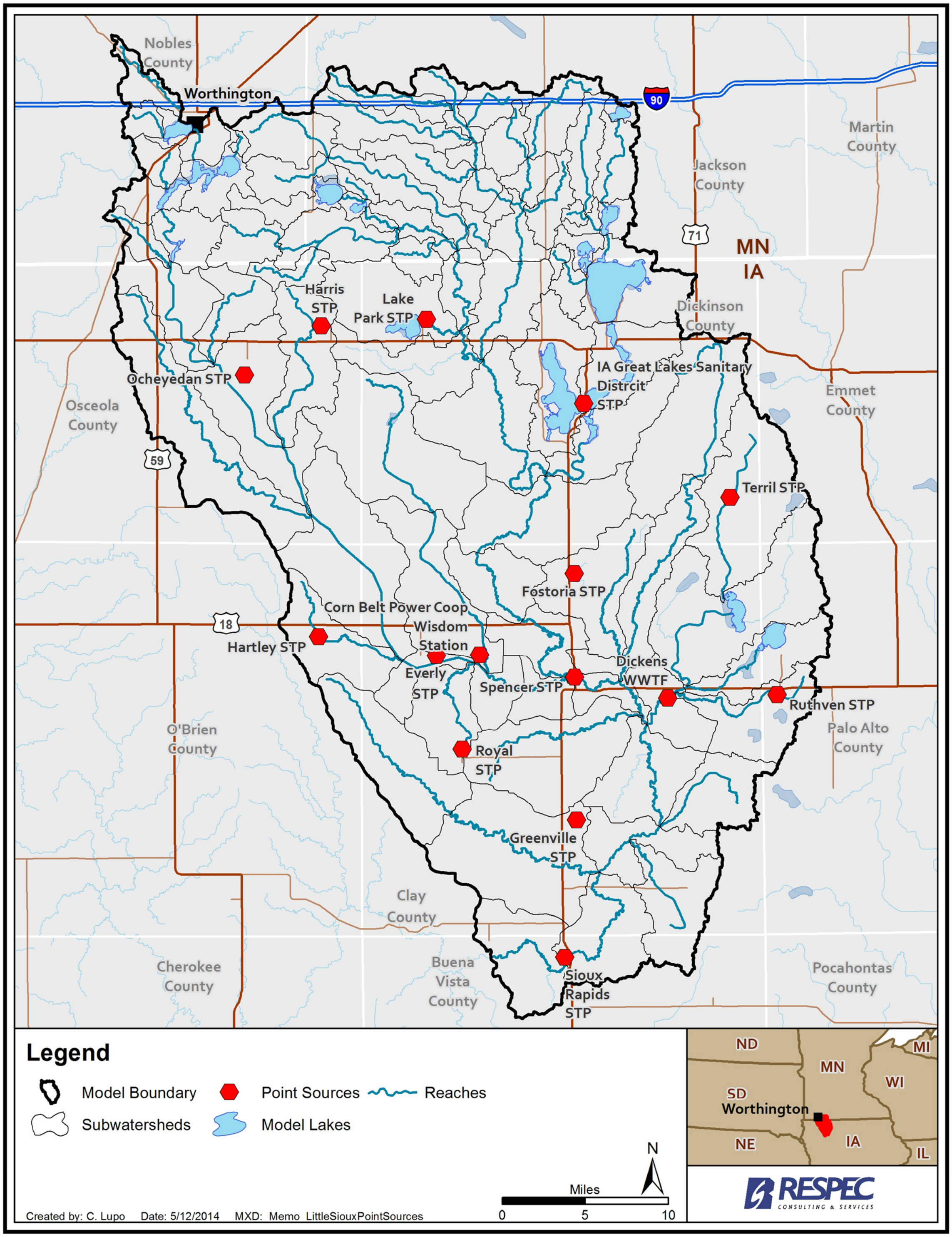

Figure D-1. Point-Source Locations Within the Little Sioux River Watershed.

RSI-2279-14-047

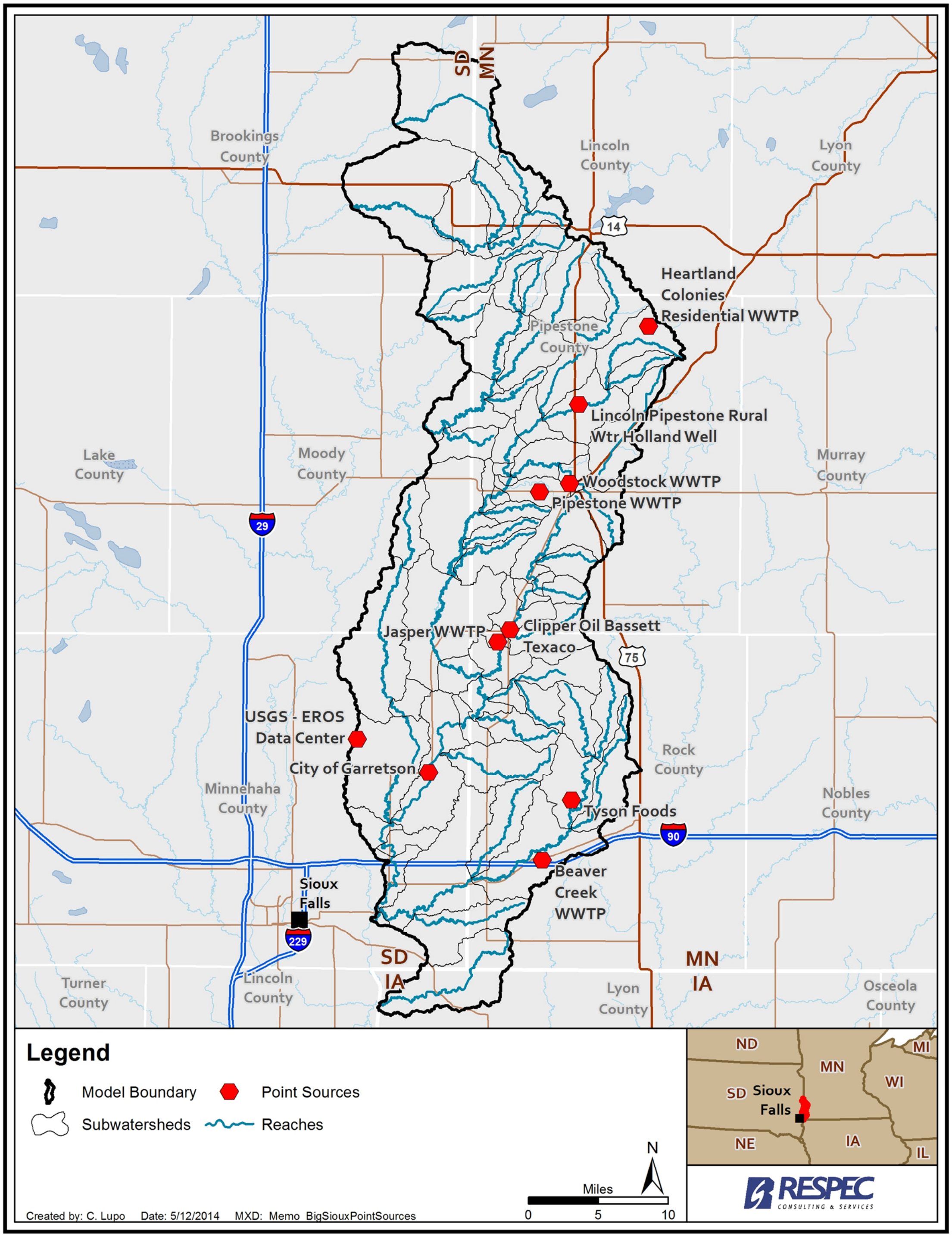

Figure D-2. Point-Source Locations Within the Big Sioux River Watershed.

ATTACHMENT E

MISSOURI RIVER WATERSHED
WATER-QUALITY CALIBRATION FIGURES

RSI-2279-14-048

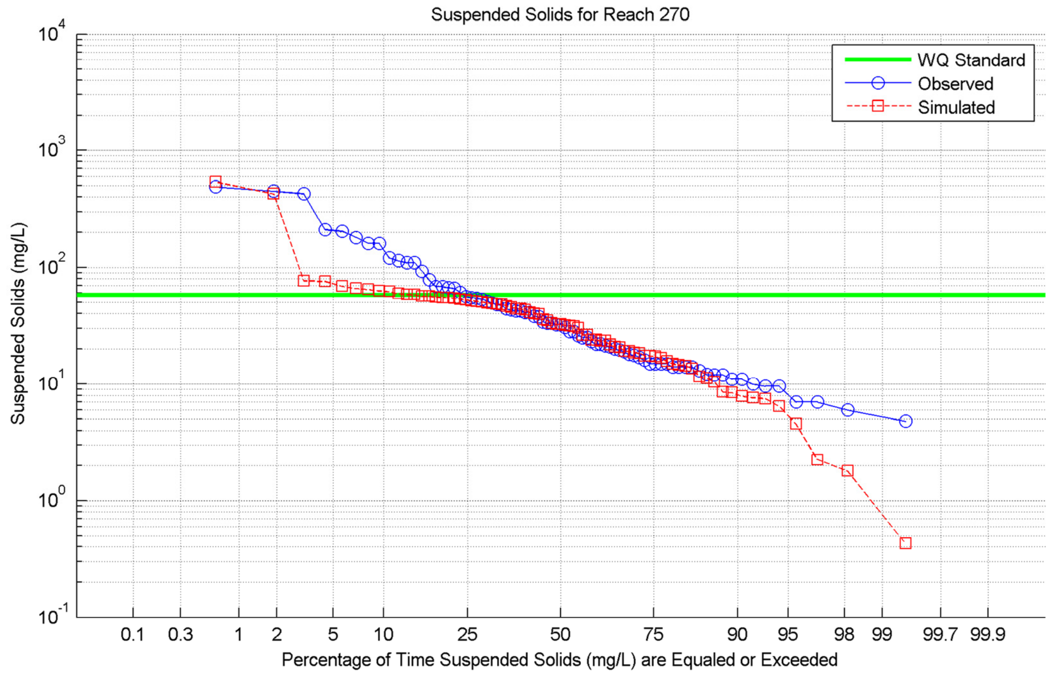

Figure E-1. Suspended Solids Duration Curve–Rock River (Reach 270).

RSI-2279-14-049

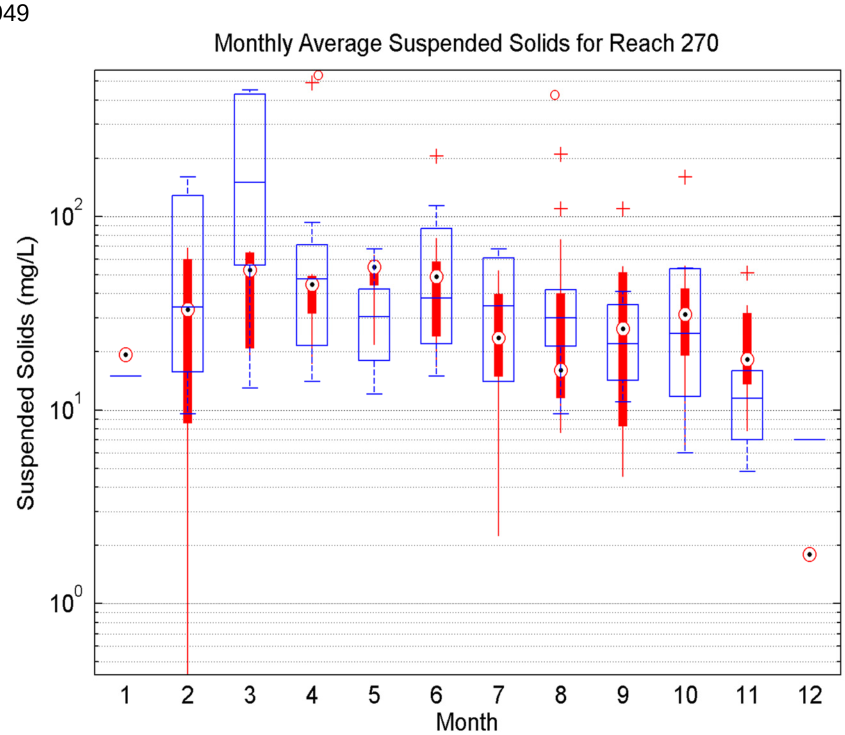

Figure E-2. Suspended Solids Monthly Averages–Rock River (Reach 270).

RSI-2279-14-050

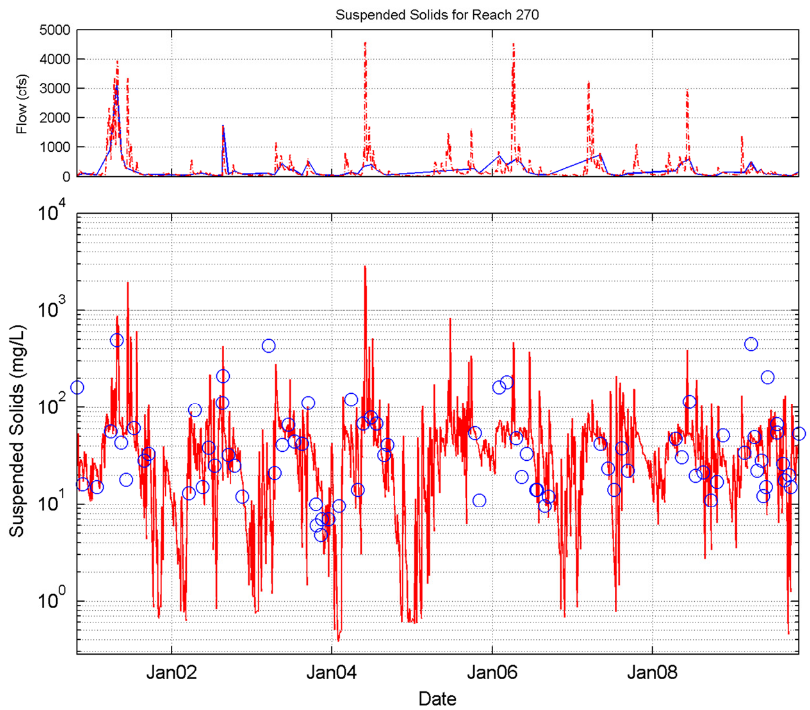

Figure E-3. Suspended Solids Daily Time Series–Rock River (Reach 270).

RSI-2279-14-051

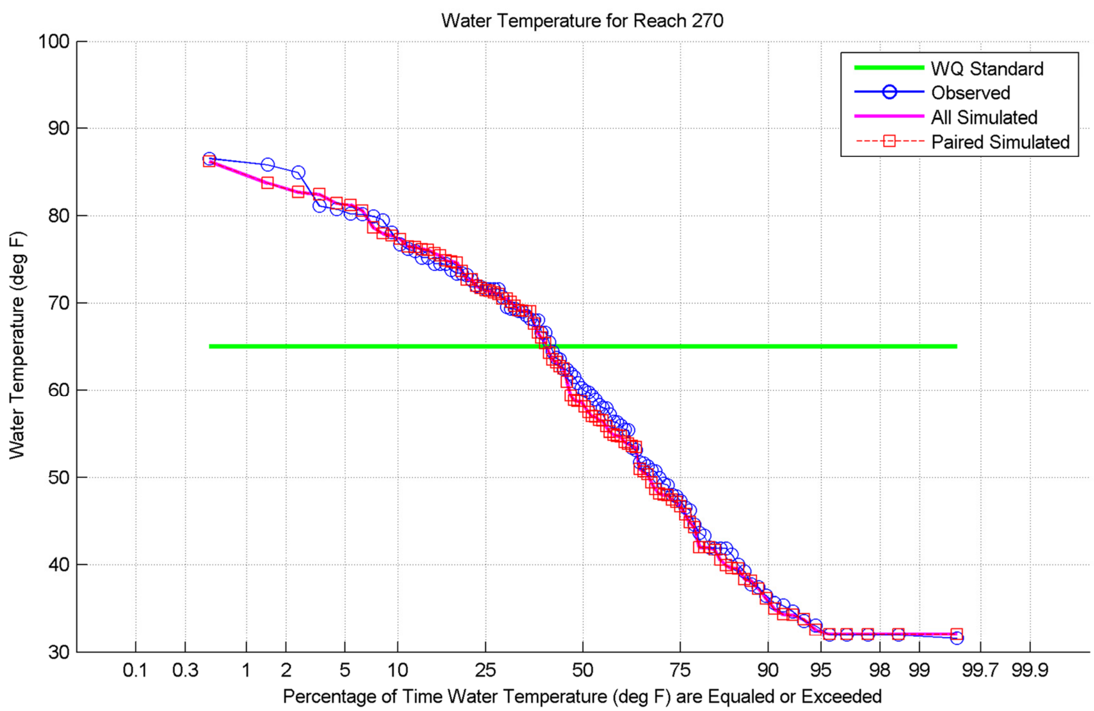

Figure E-4. Water Temperature Duration Curve–Rock River (Reach 270).

RSI-2279-14-052

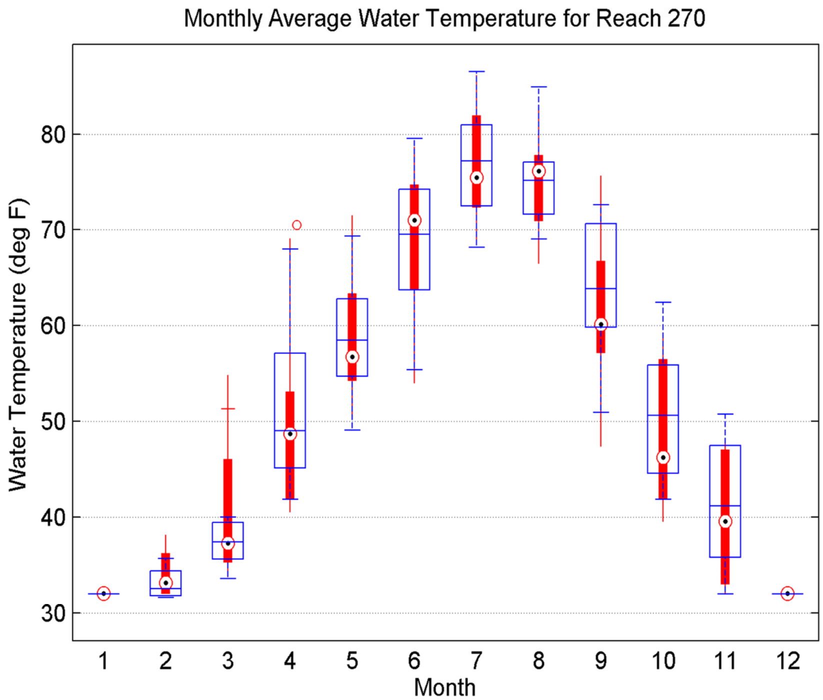

Figure E-5. Water Temperature Monthly Averages–Rock River (Reach 270).

RSI-2279-14-053

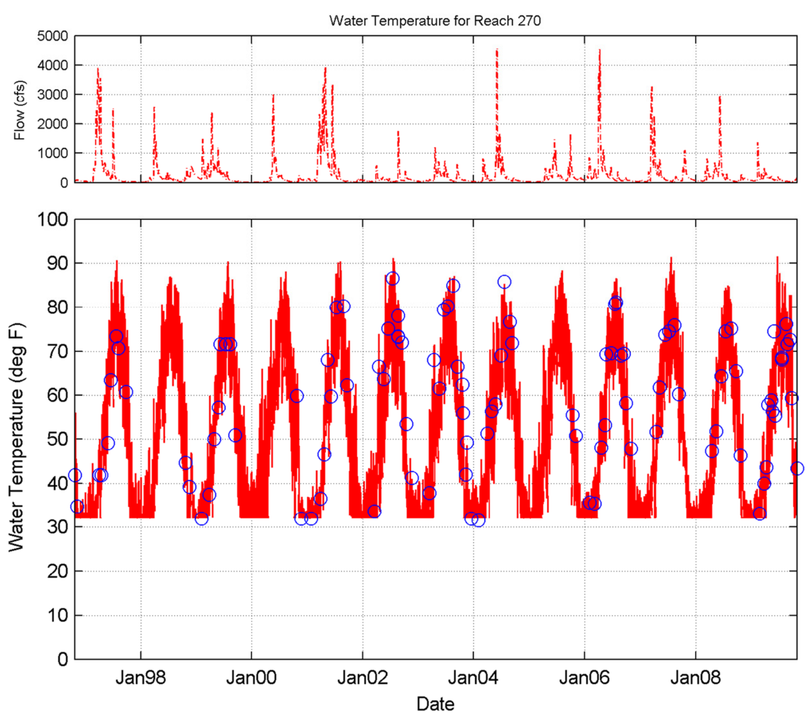

Figure E-6. Water Temperature Daily Time Series–Rock River (Reach 270).

RSI-2279-14-054

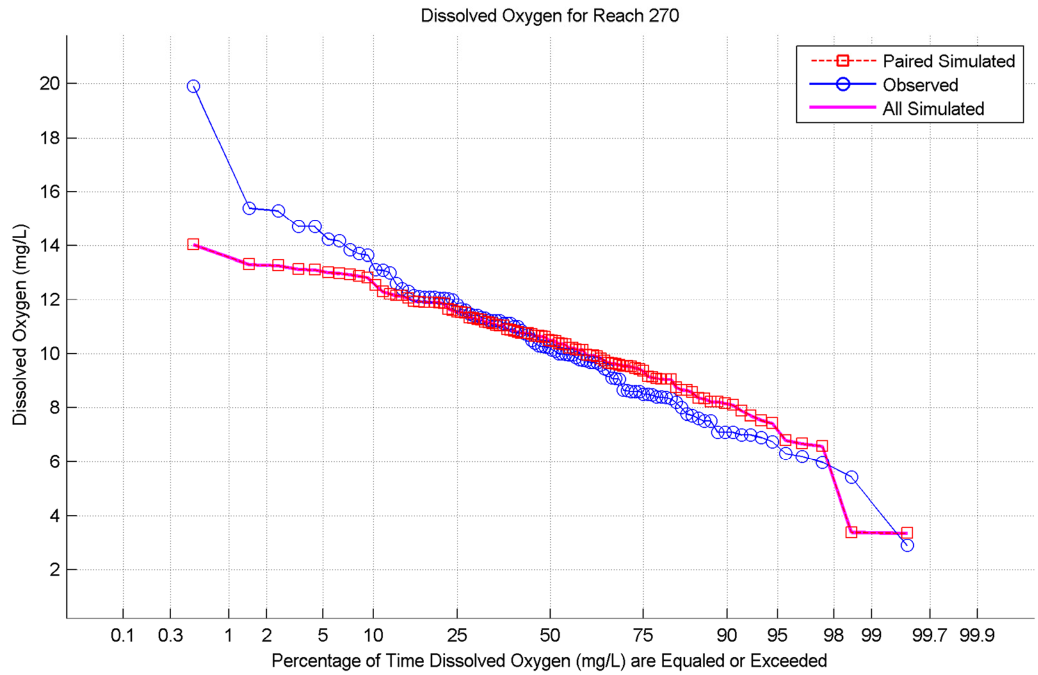

Figure E-7. Dissolved Oxygen Duration Curve–Rock River (Reach 270).

RSI-2279-14-055

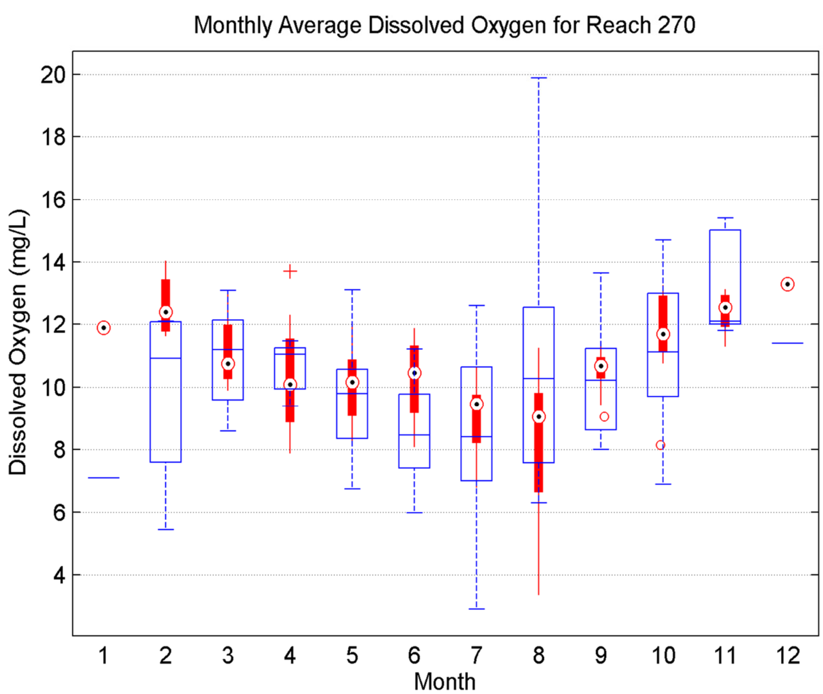

Figure E-8. Dissolved Oxygen Monthly Averages–Rock River (Reach 270).

RSI-2279-14-056

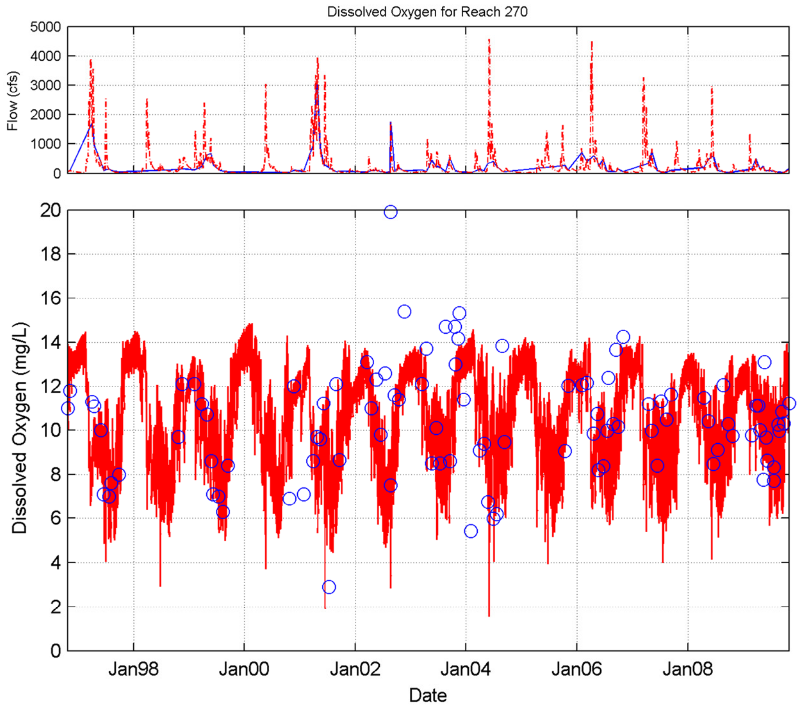

Figure E-9. Dissolved Oxygen Daily Time Series–Rock River (Reach 270).

RSI-2279-14-057

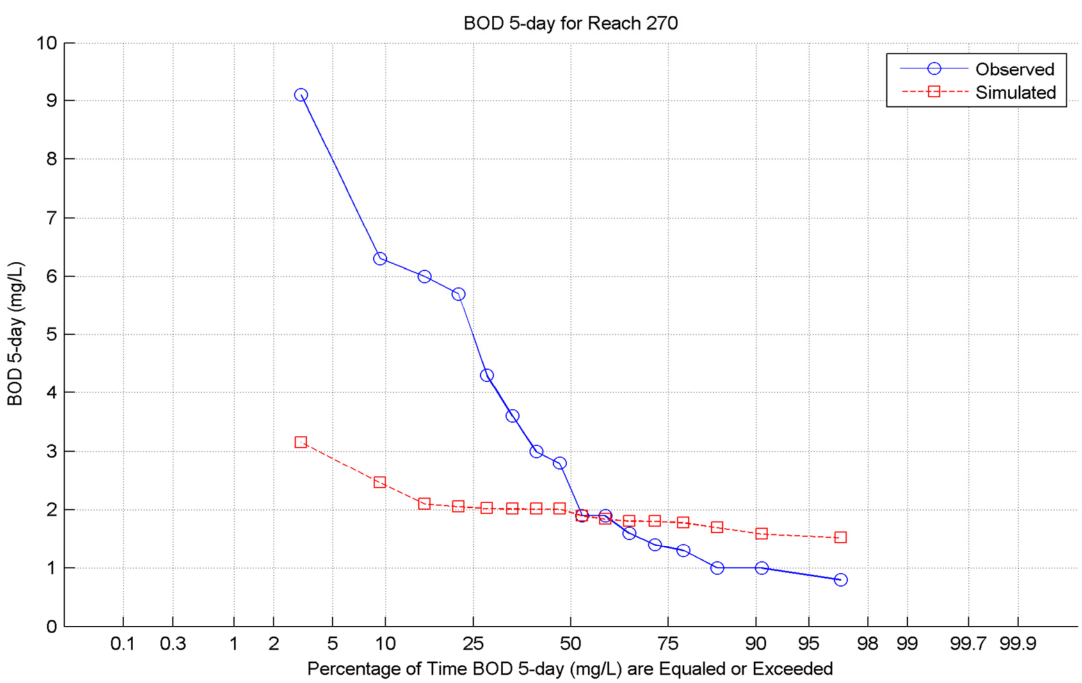

Figure E-10. Biological Oxygen Demand Duration Curve–Rock River (Reach 270).

RSI-2279-14-058

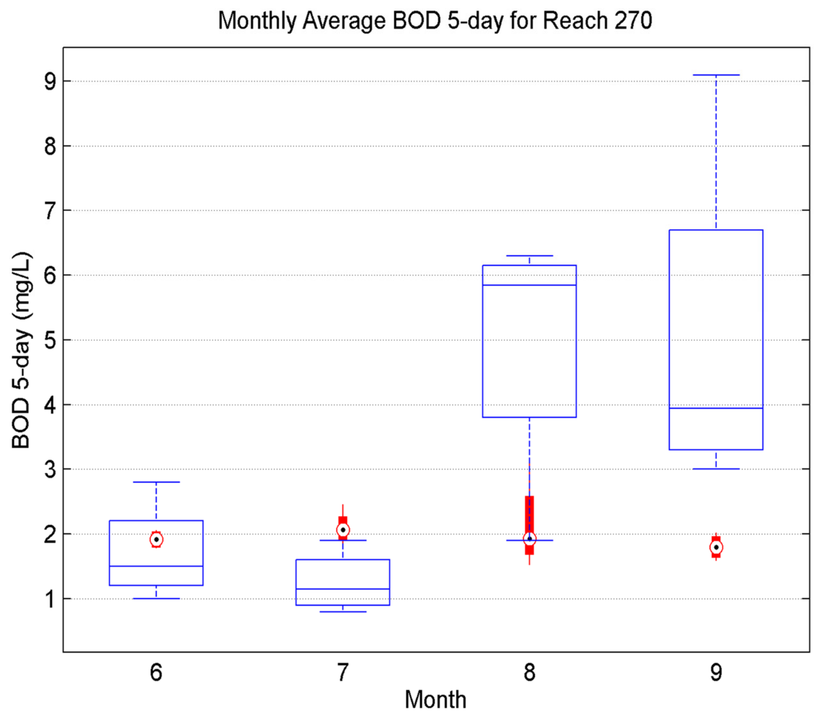

Figure E-11. Biological Oxygen Demand Monthly Averages–Rock River (Reach 270).

RSI-2279-14-059

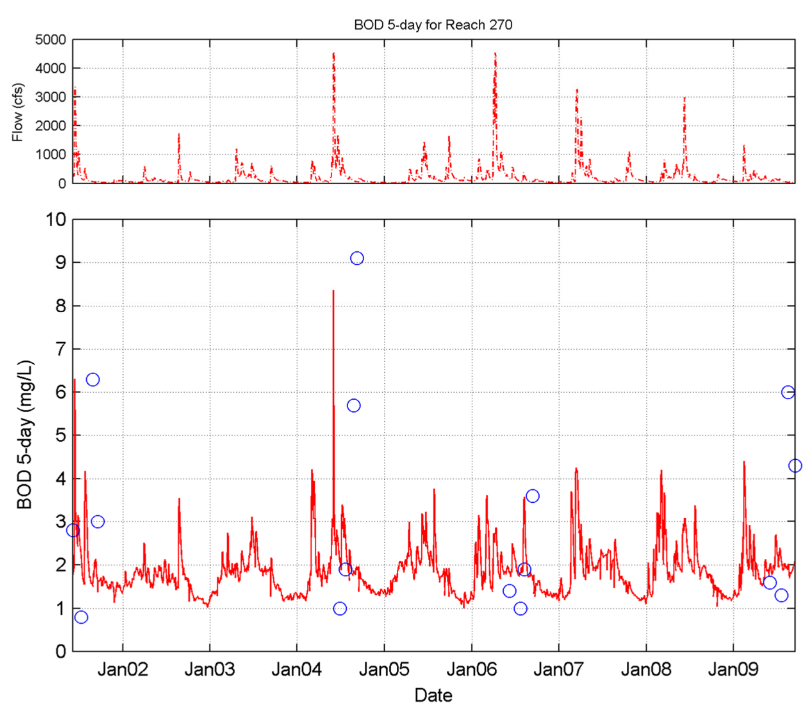

Figure E-12. Biological Oxygen Demand Time Series–Rock River (Reach 270).

RSI-2279-14-060

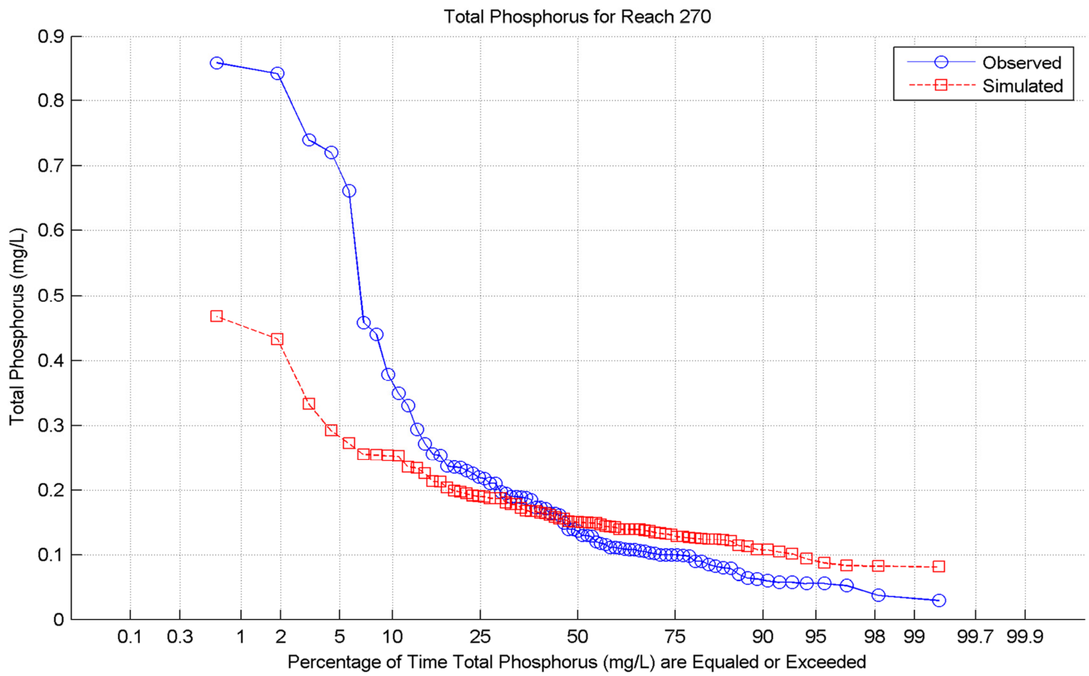

Figure E-13. Total Phosphorus Duration Curve–Rock River (Reach 270).

RSI-2279-14-061

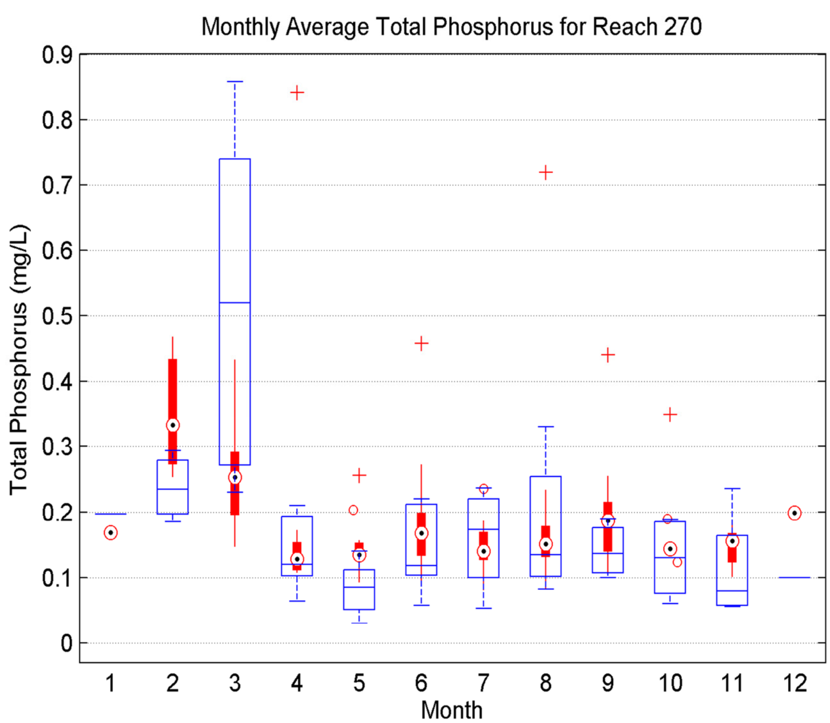

Figure E-14. Total Phosphorus Monthly Averages–Rock River (Reach 270).

RSI-2279-14-062

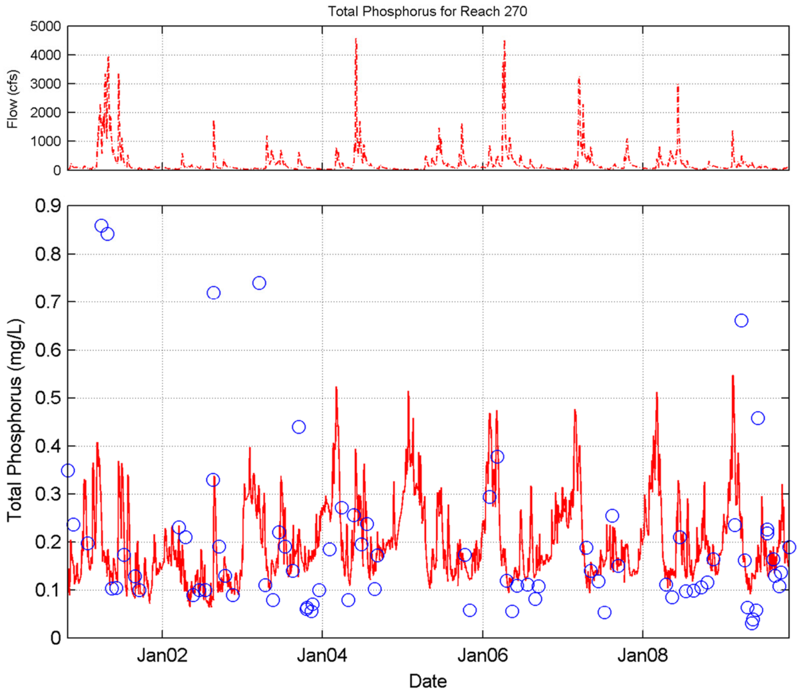

Figure E-15. Total Phosphorus Time Series–Rock River (Reach 270).

RSI-2279-14-063

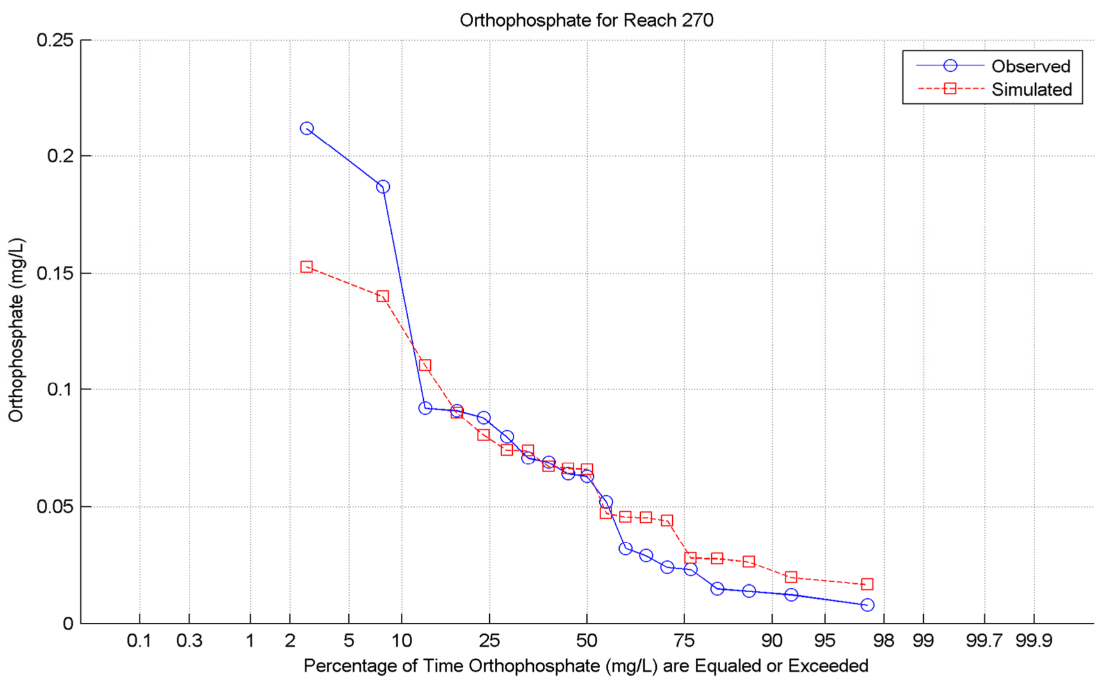

Figure E-16. Orthophosphate Duration Curve–Rock River (Reach 270).

RSI-2279-14-064

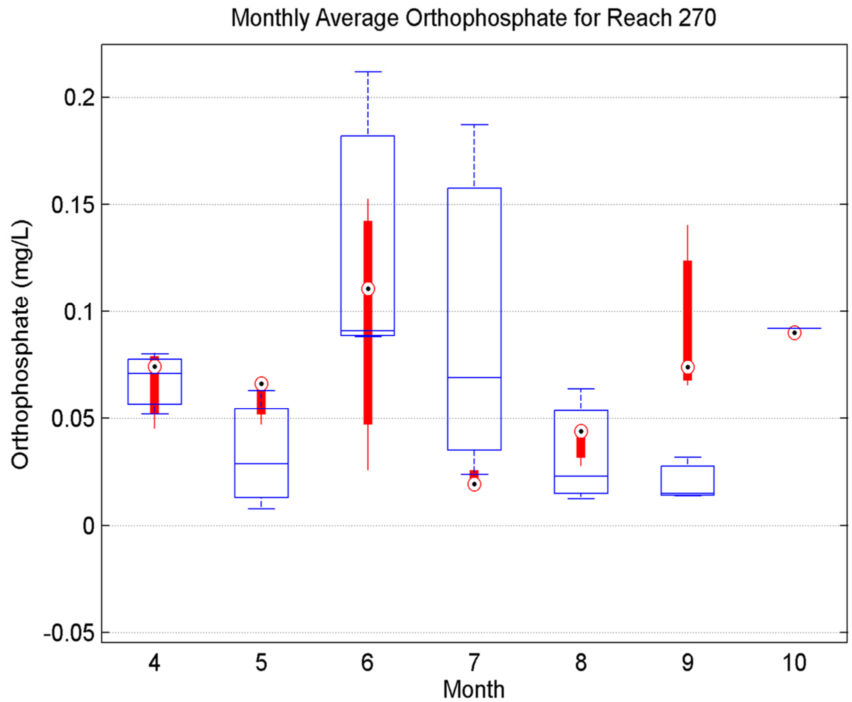

Figure E-17. Orthophosphate Monthly Averages–Rock River (Reach 270).

RSI-2279-14-065

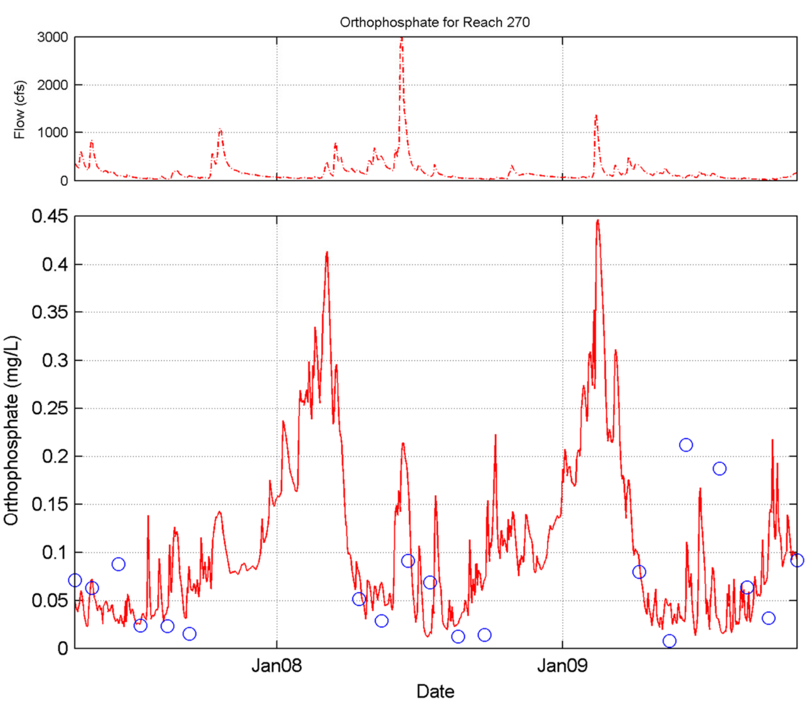

Figure E-18. Orthophosphate Time Series–Rock River (Reach 270).

RSI-2279-14-066

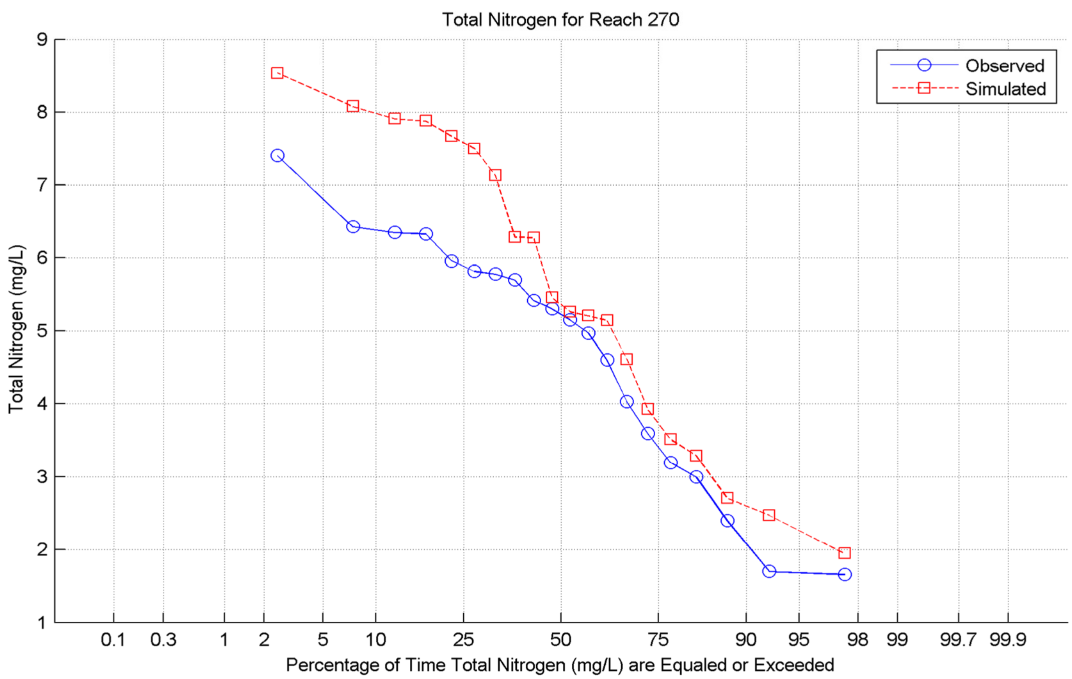

Figure E-19. Total Nitrogen Duration Curve–Rock River (Reach 270).

RSI-2279-14-067

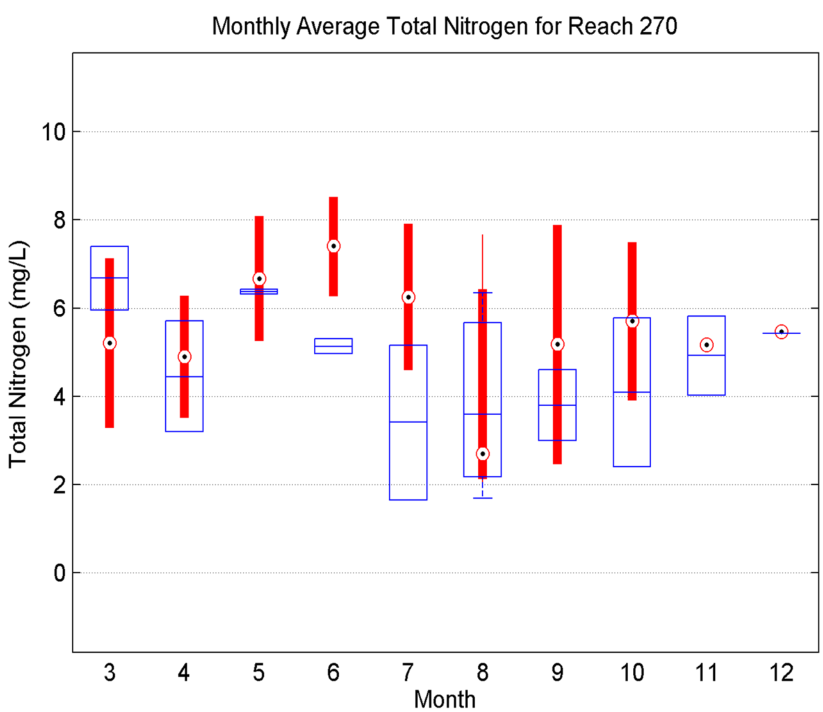

Figure E-20. Total Nitrogen Monthly Averages–Rock River (Reach 270).

RSI-2279-14-068

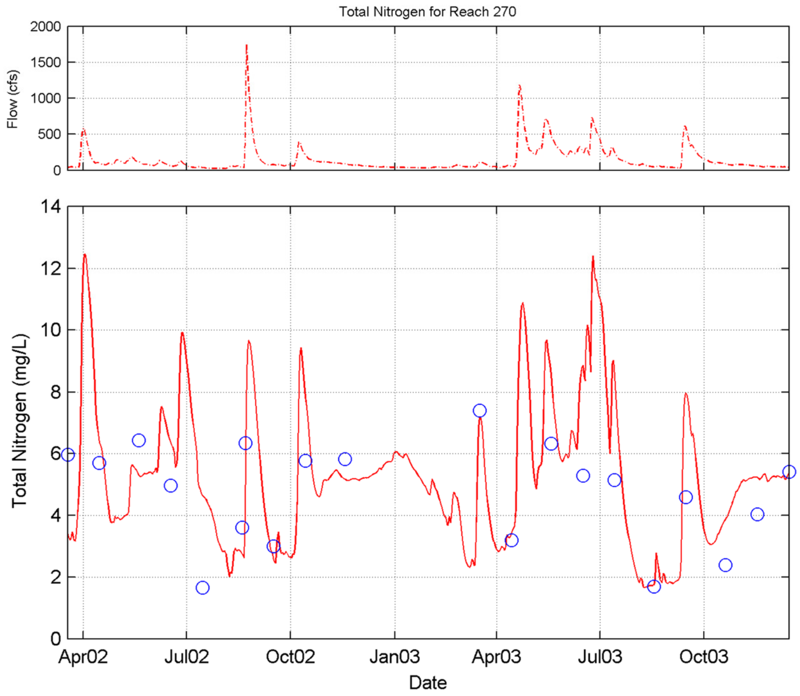

Figure E-21. Total Nitrogen Time Series–Rock River (Reach 270).

RSI-2279-14-069

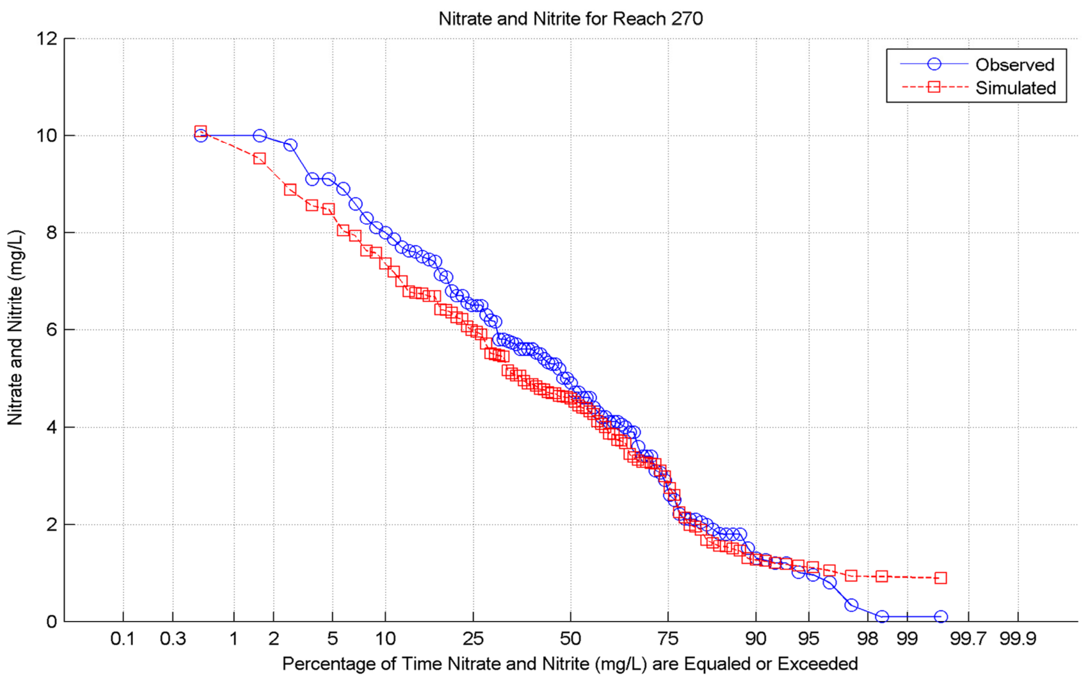

Figure E-22. Nitrate and Nitrite Duration Curve–Rock River (Reach 270).

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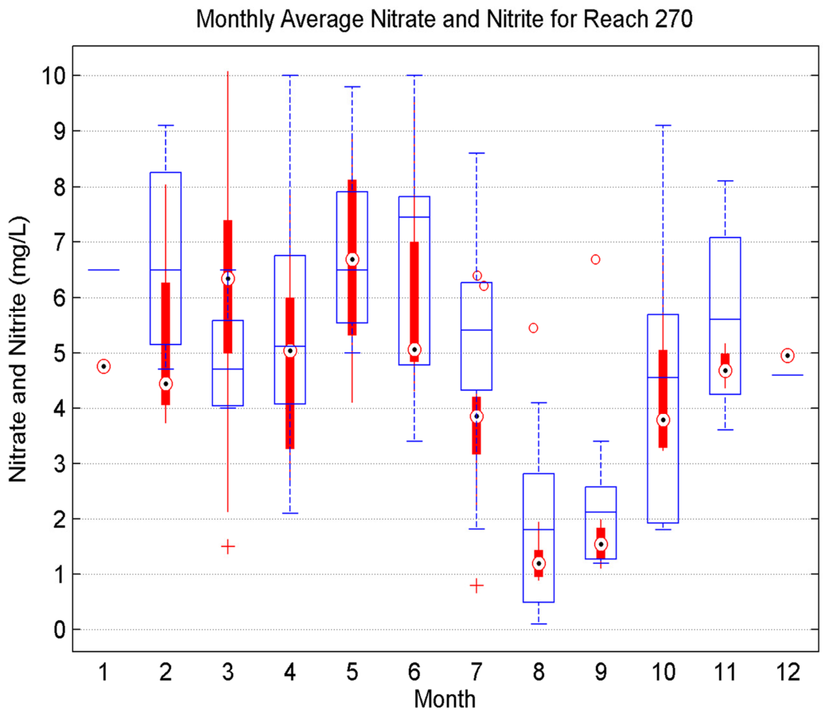

Figure E-23. Nitrate and Nitrite Monthly Averages–Rock River (Reach 270).

RSI-2279-14-071

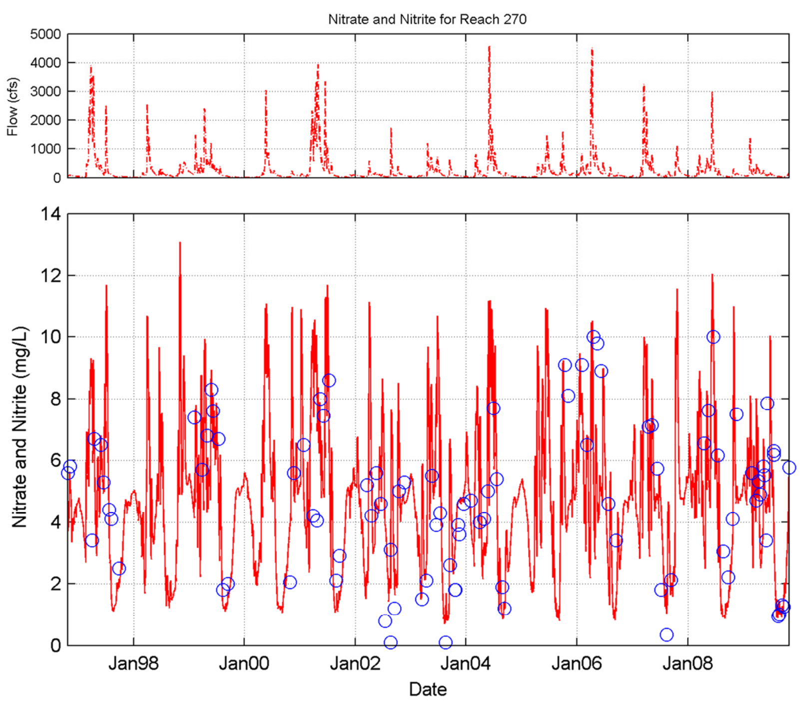

Figure E-24. Nitrate and Nitrite Time Series–Rock River (Reach 270).

RSI-2279-14-072

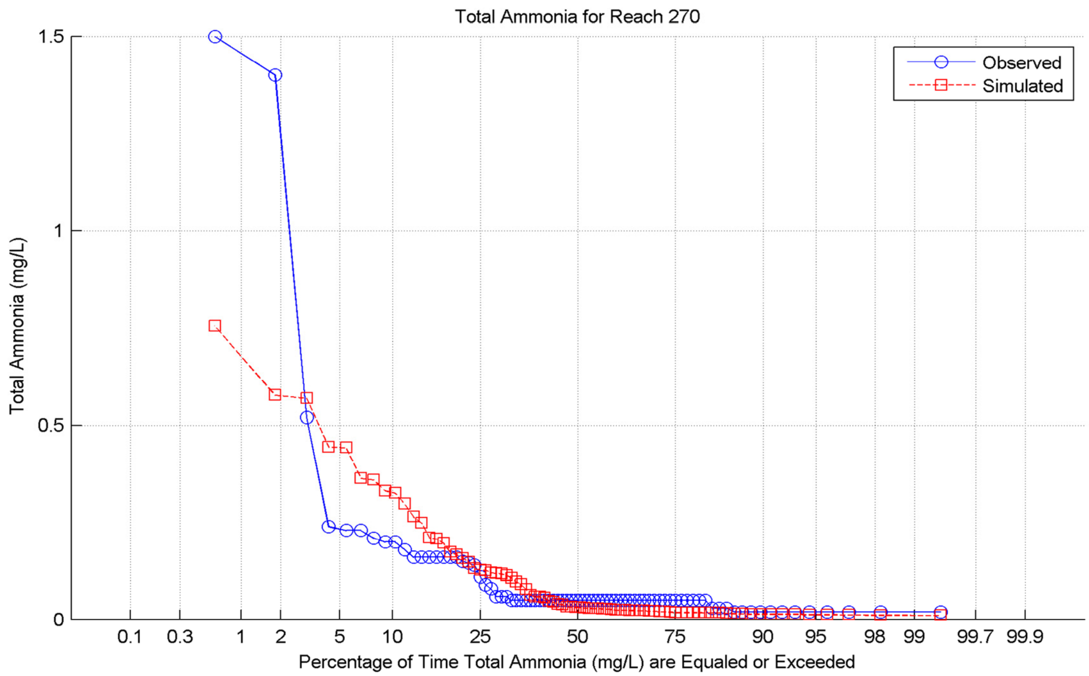

Figure E-25. Total Ammonia Duration Curve–Rock River (Reach 270).

RSI-2279-14-073

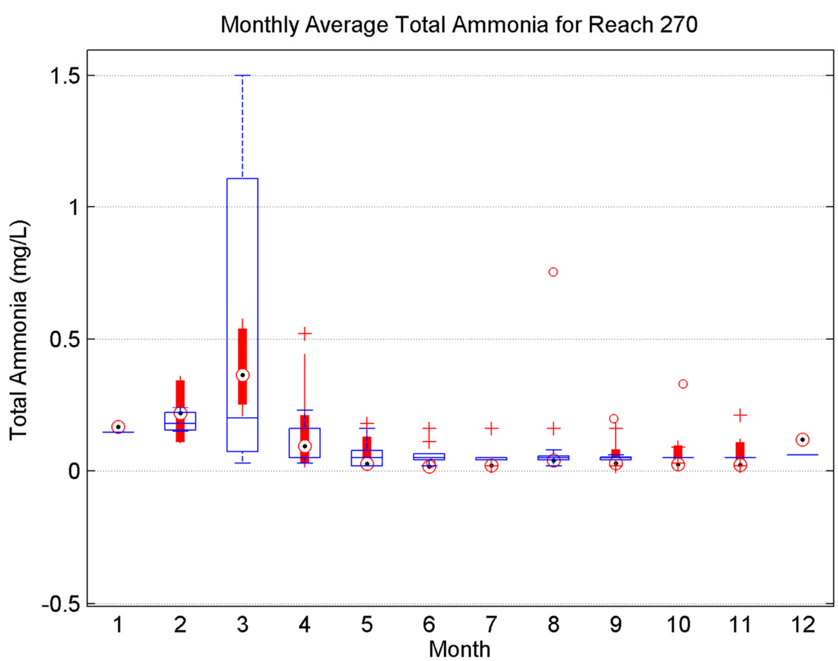

Figure E-26. Total Ammonia Monthly Averages–Rock River (Reach 270).

RSI-2279-14-074

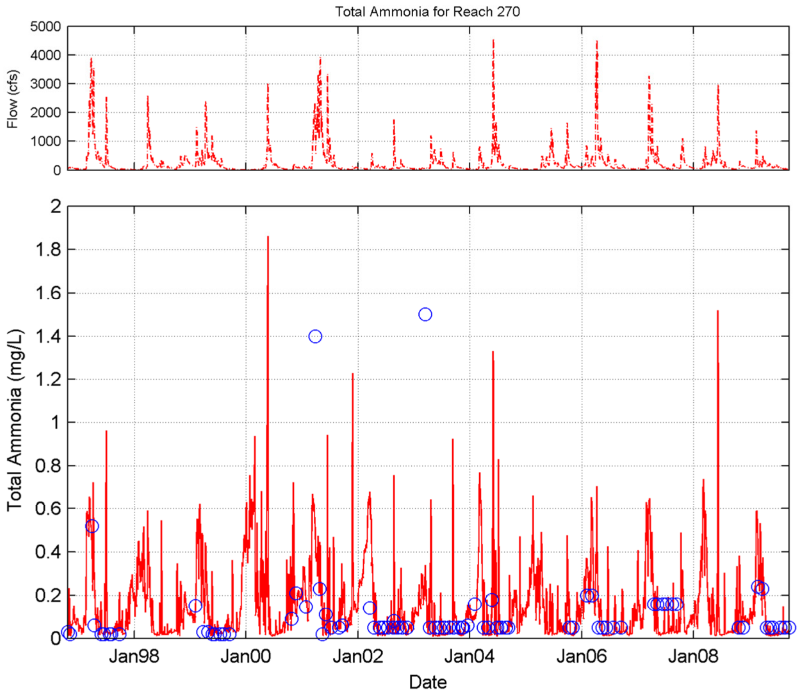

Figure E-27. Total Ammonia Time Series–Rock River (Reach 270).

RSI-2279-14-076

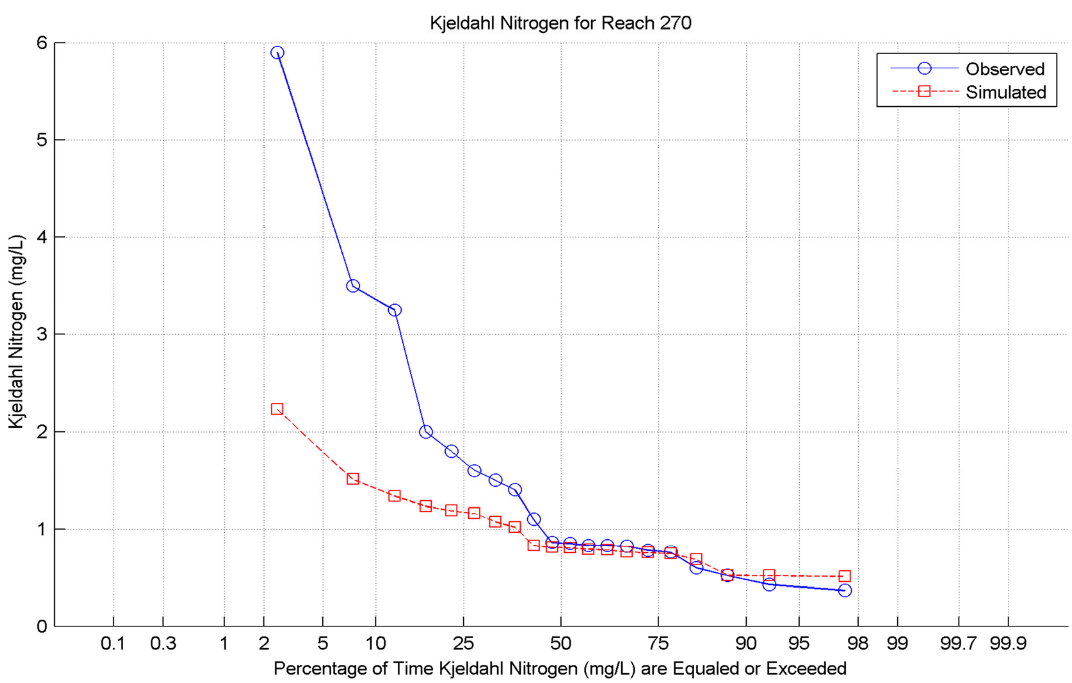

Figure E-28. Kjeldahl Nitrogen Duration Curve–Rock River (Reach 270).

RSI-2279-14-077

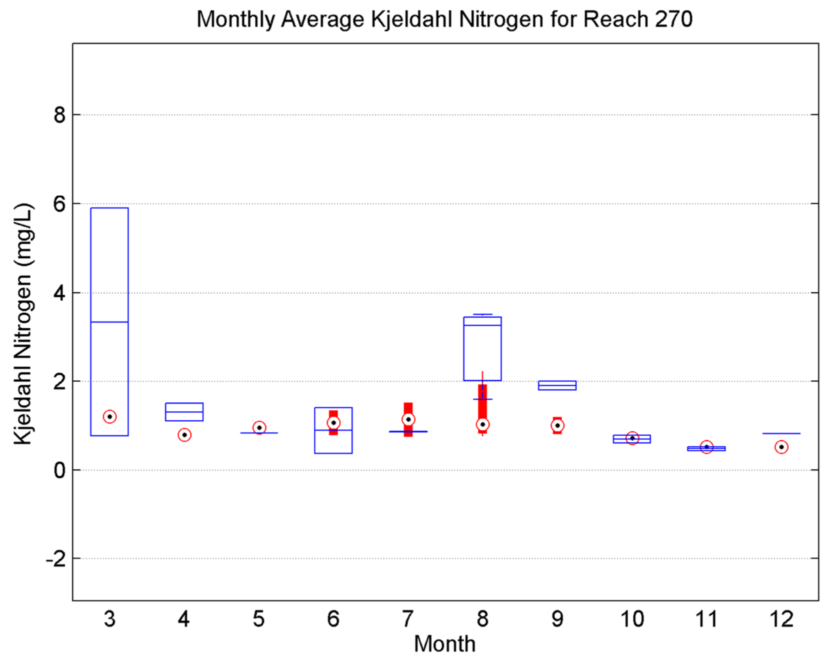

Figure E-29. Kjeldahl Nitrogen Monthly Averages–Rock River (Reach 270).

RSI-2279-14-078

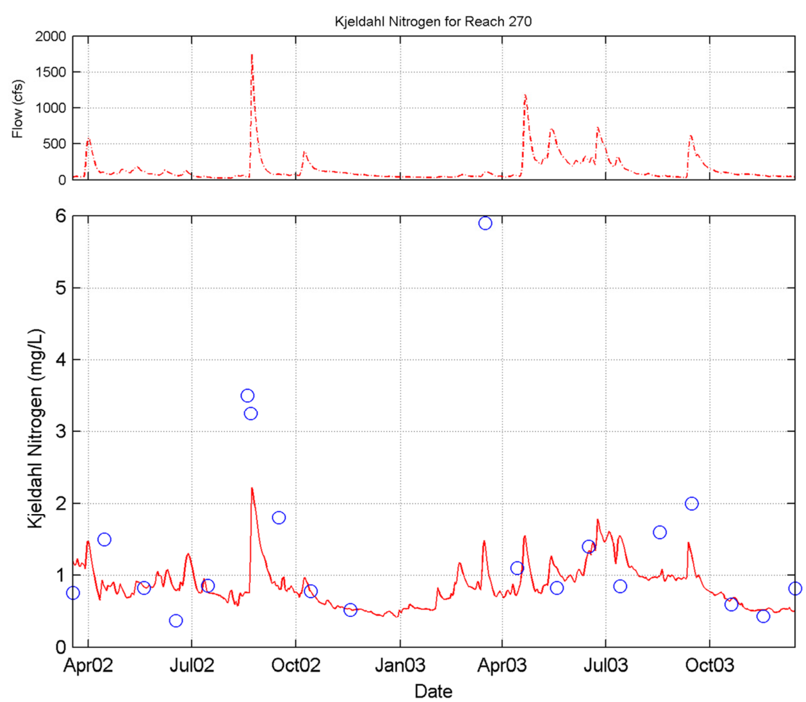

Figure E-30. Kjeldahl Nitrogen Time Series–Rock River (Reach 270).

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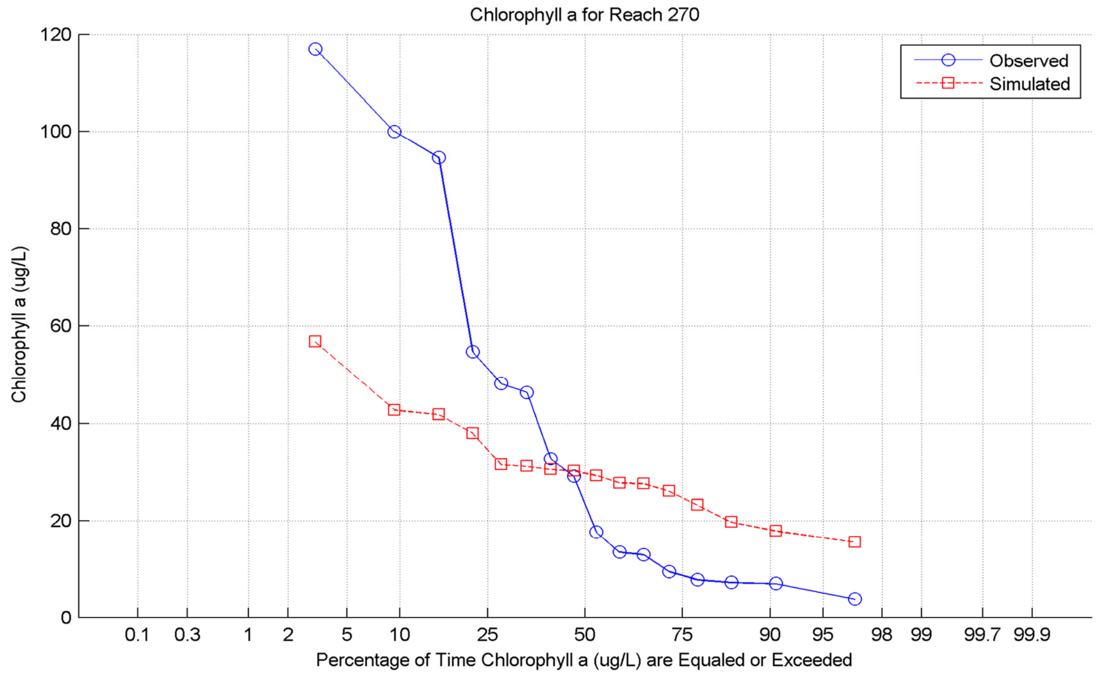

Figure E-31. Chlorophyll *a* Duration Curve–Rock River (Reach 270).

RSI-2279-14-080

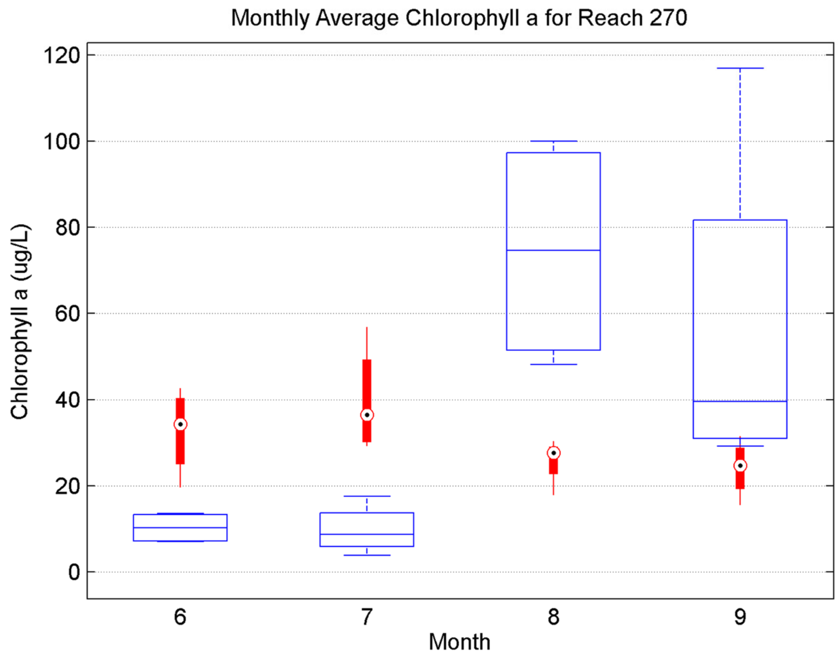

Figure E-32. Chlorophyll *a* Monthly Averages–Rock River (Reach 270).

RSI-2279-14-081

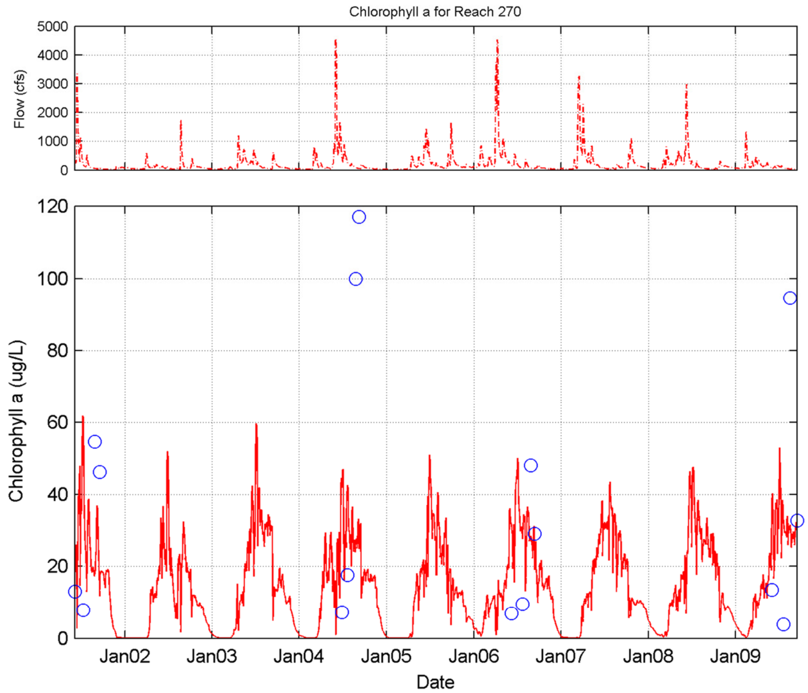

Figure E-33. Chlorophyll *a* Time Series–Rock River (Reach 270).

RSI-2279-14-082

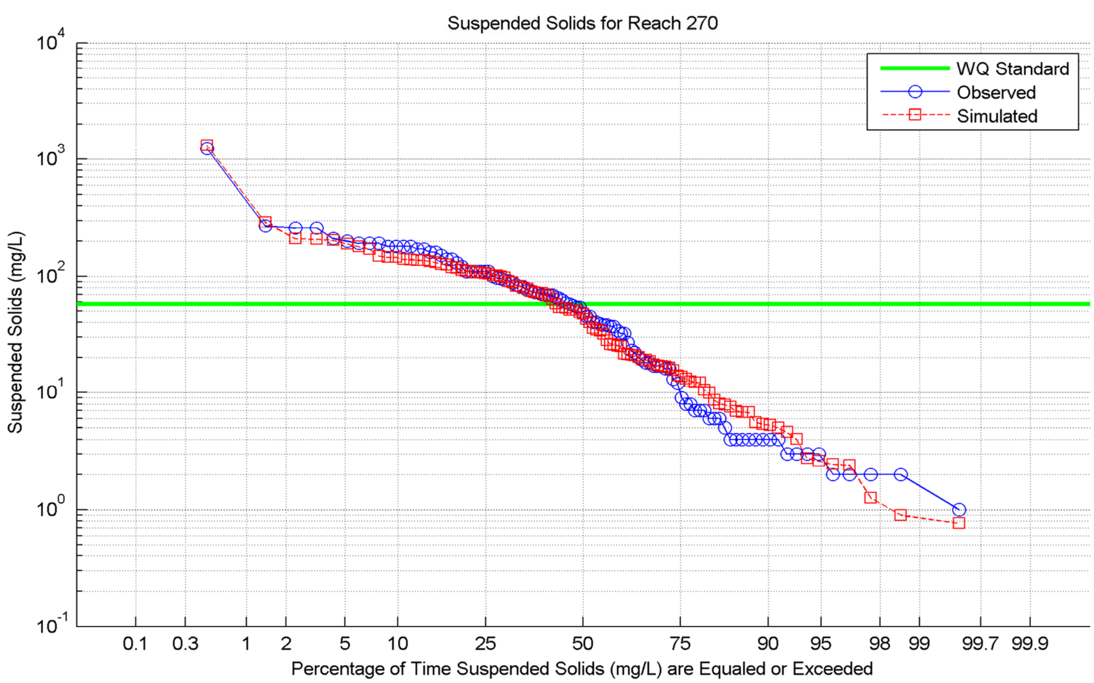

Figure E-34. Suspended Solids Duration Curve–Little Sioux (Reach 270).

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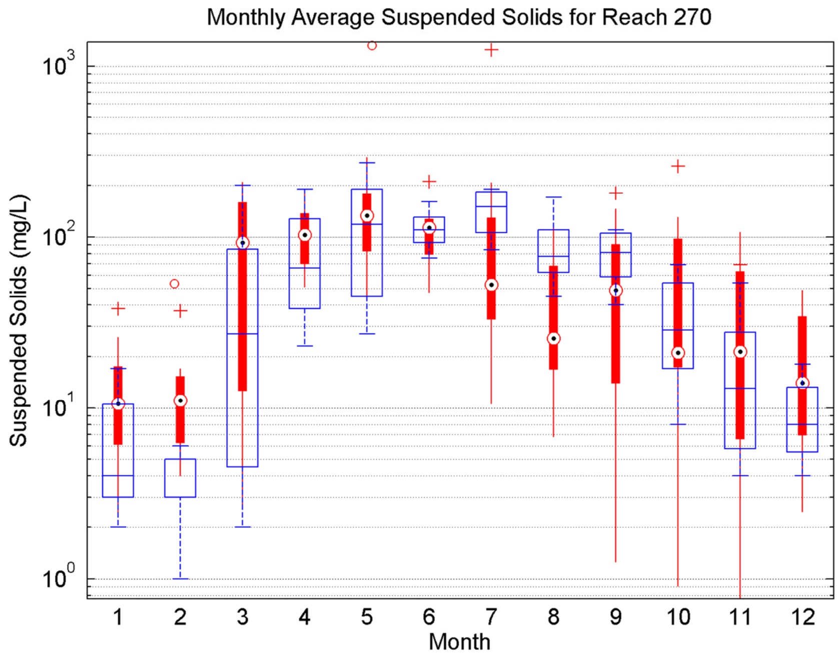

Figure E-35. Suspended Solids Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-084

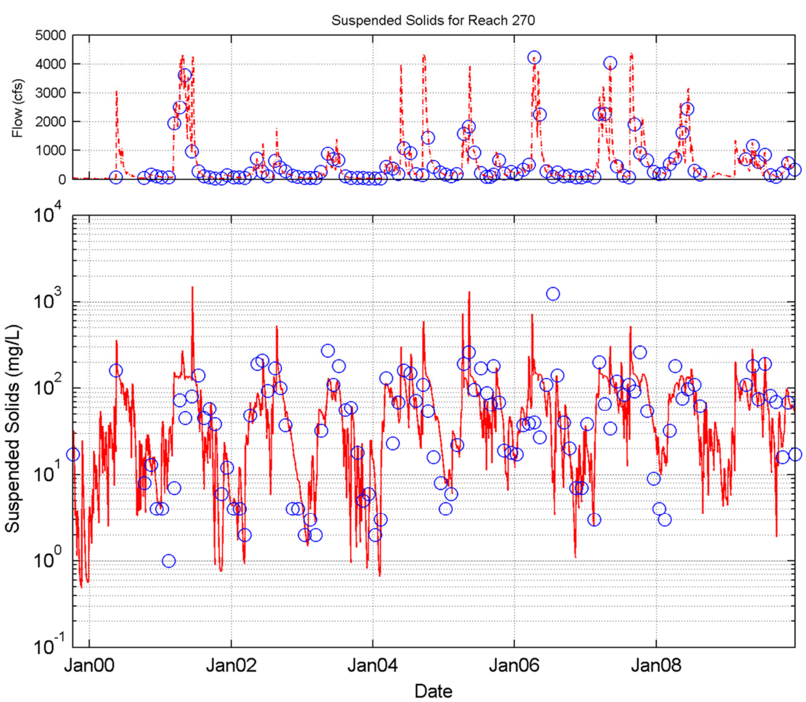

Figure E-36. Suspended Solids Daily Time Series–Little Sioux (Reach 270).

RSI-2279-14-085

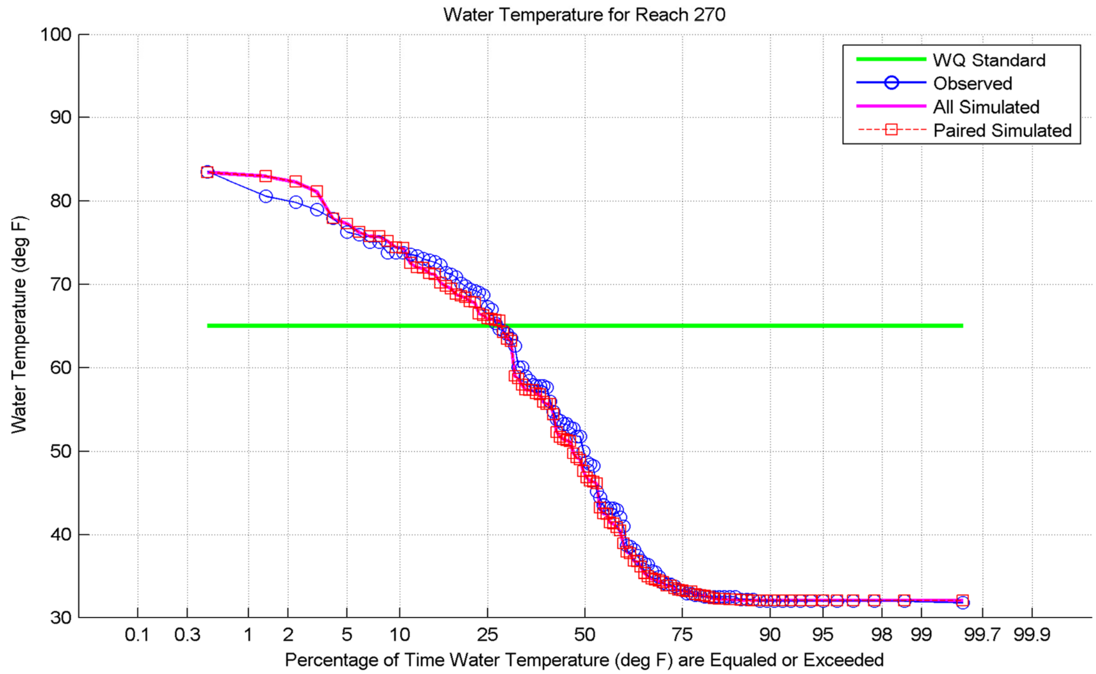

Figure E-37. Water Temperature Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-086

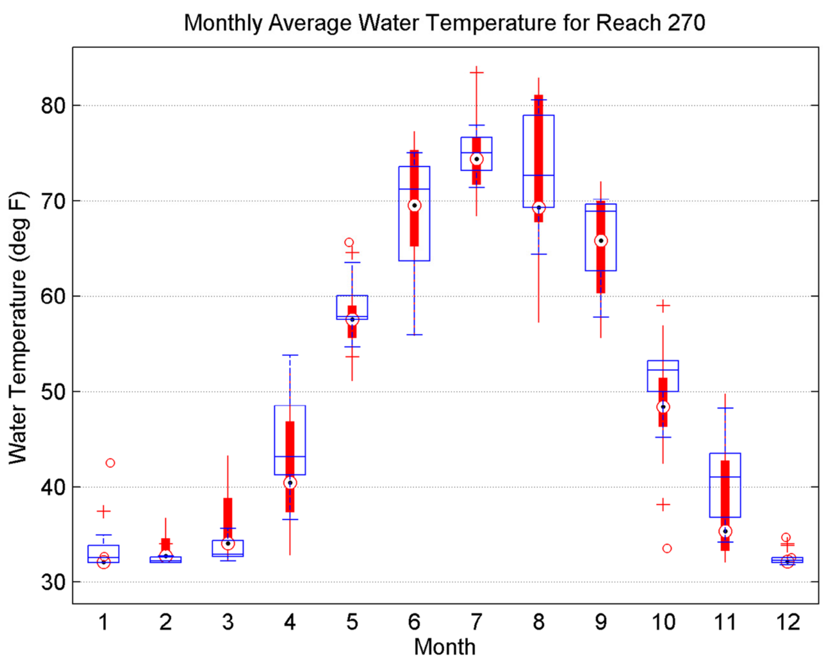

Figure E-38. Water Temperature Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-087

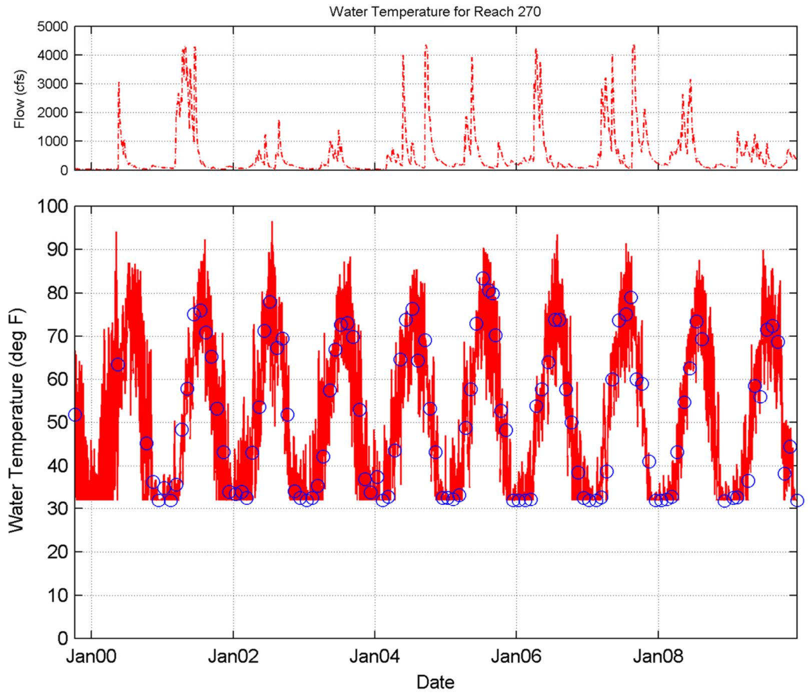

Figure E-39. Water Temperature Daily Time Series–Little Sioux (Reach 270).

RSI-2279-14-088

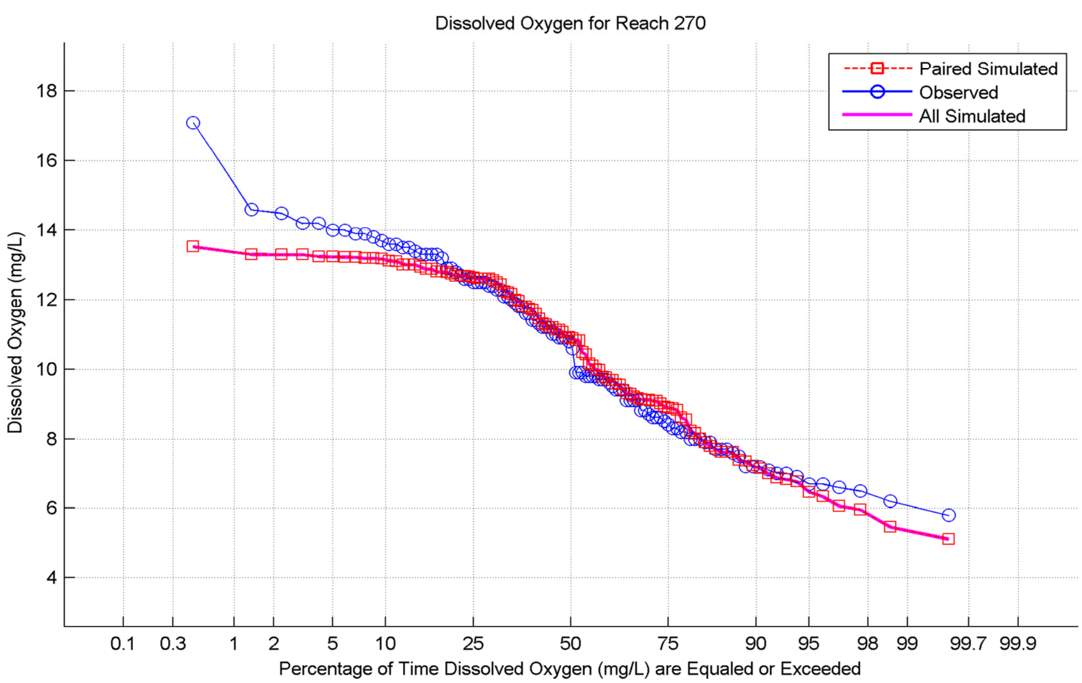

Figure E-40. Dissolved Oxygen Duration Curve–Little Sioux (Reach 270).

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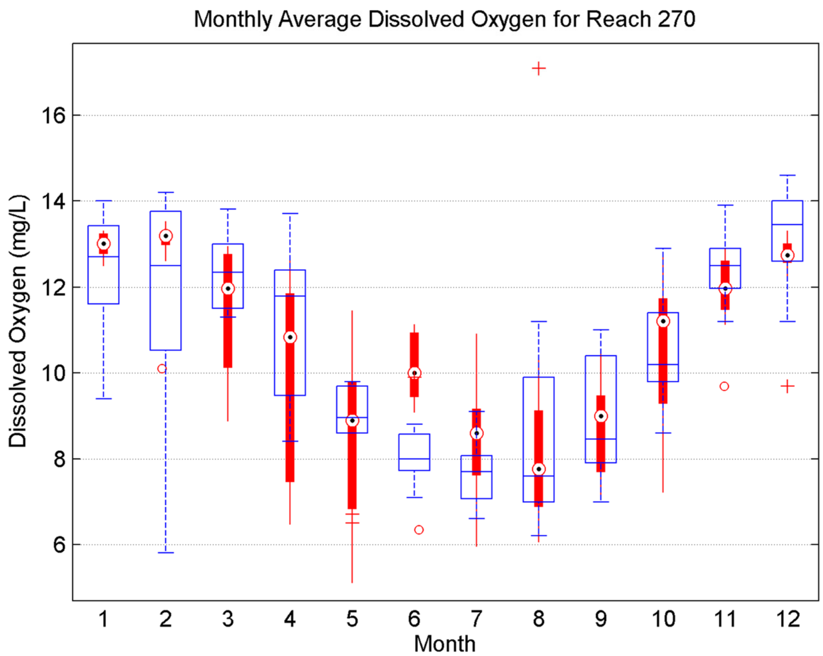

Figure E-41. Dissolved Oxygen Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-090

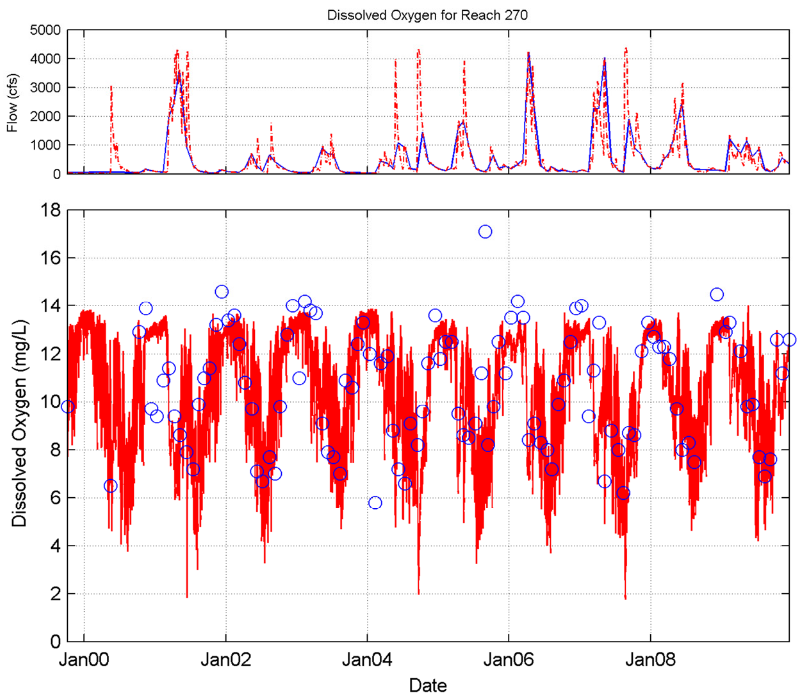

Figure E-42. Dissolved Oxygen Daily Time Series–Little Sioux (Reach 270).

RSI-2279-14-091

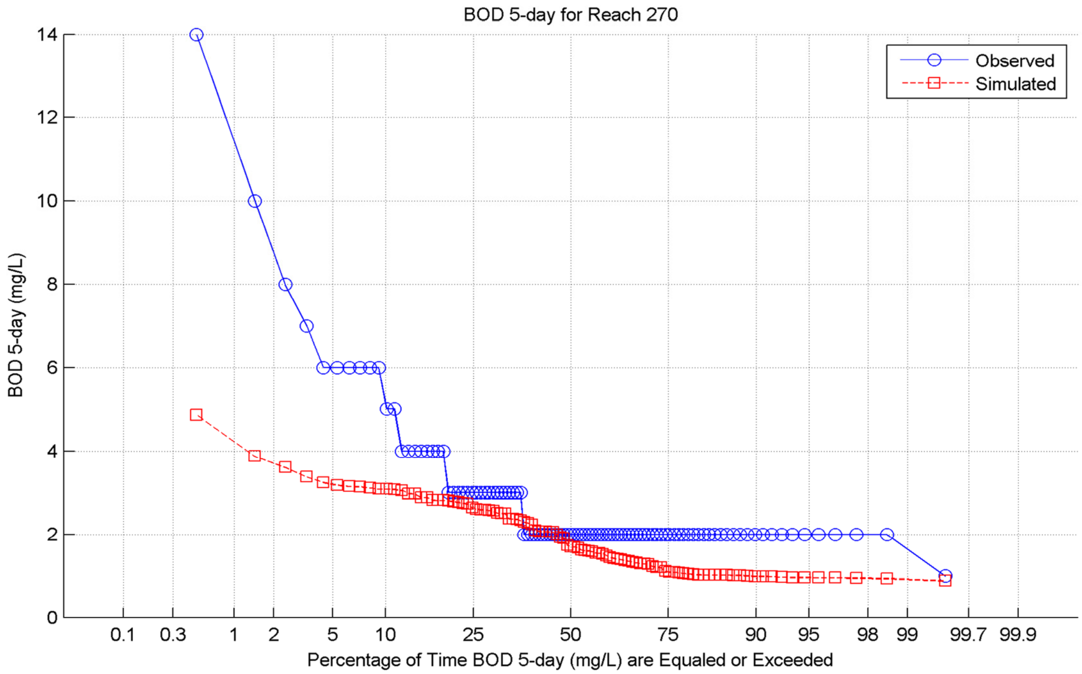

Figure E-43. Biological Oxygen Demand Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-092

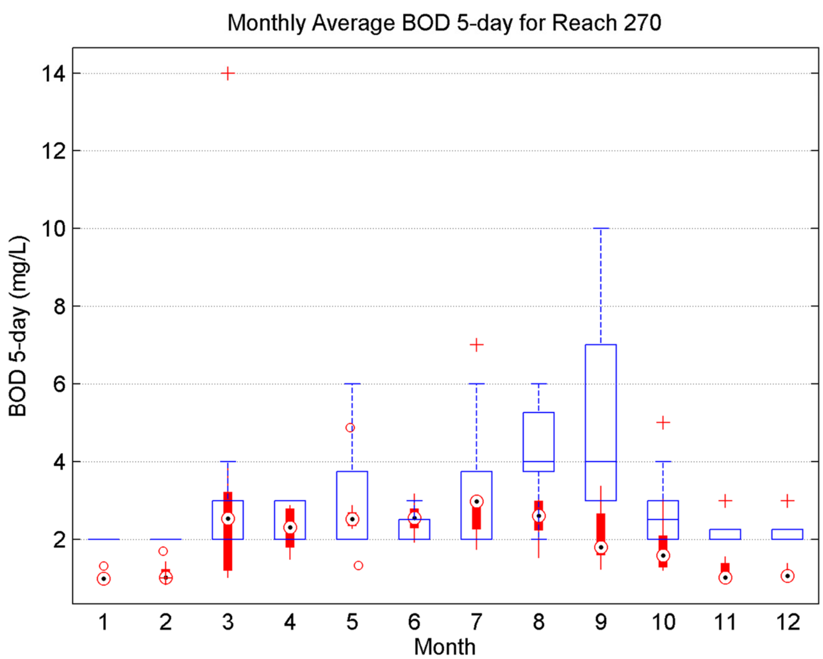

Figure E-44. Biological Oxygen Demand Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-093

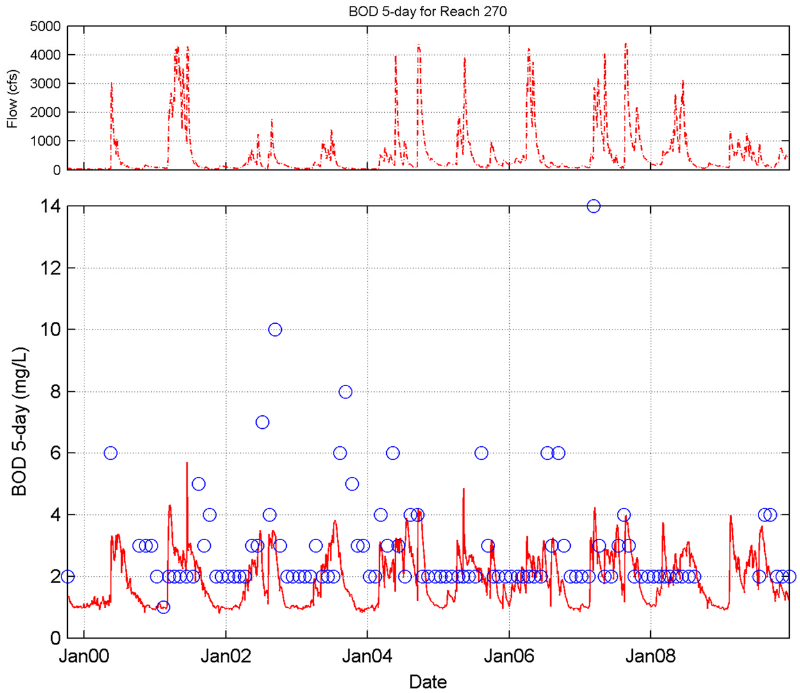

Figure E-45. Biological Oxygen Demand Time Series–Little Sioux (Reach 270).

RSI-2279-14-094

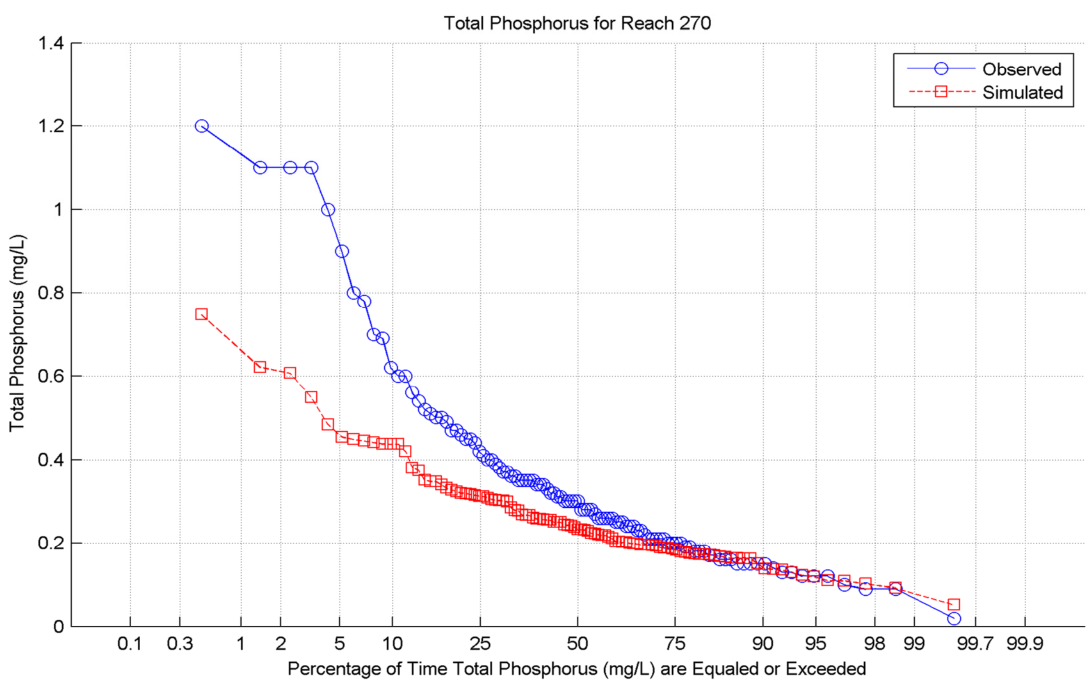

Figure E-46. Total Phosphorus Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-095

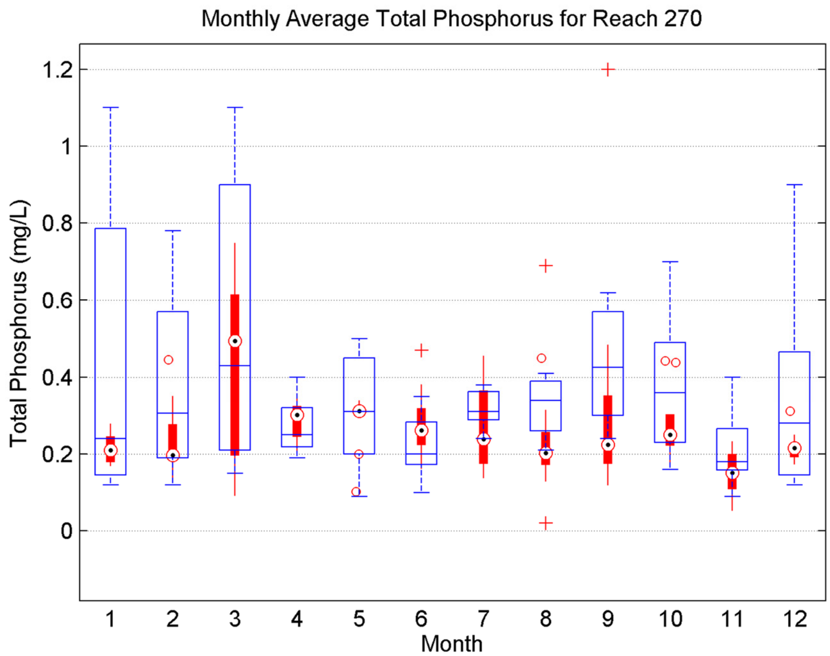

Figure E-47. Total Phosphorus Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-096

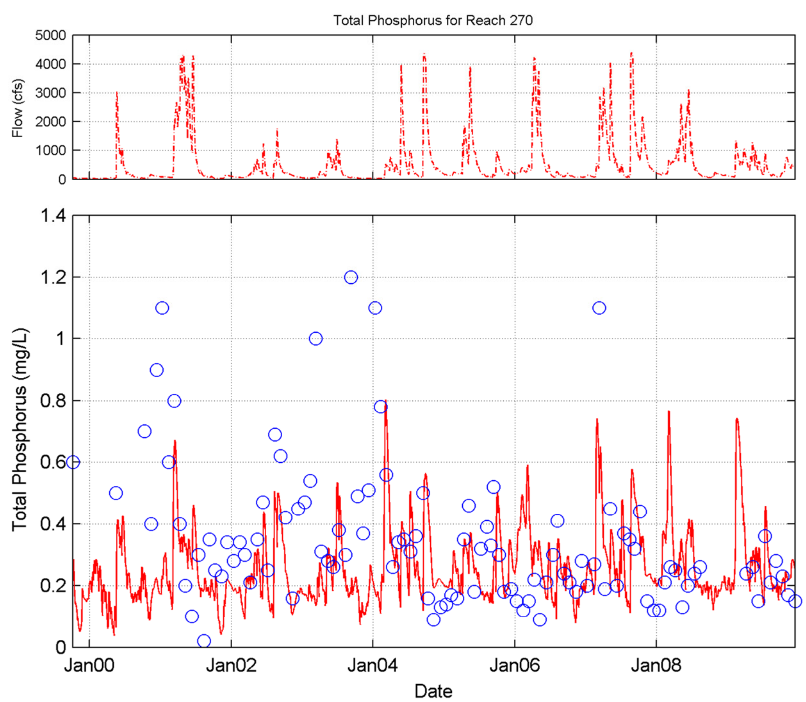

Figure E-48. Total Phosphorus Time Series–Little Sioux (Reach 270).

RSI-2279-14-097

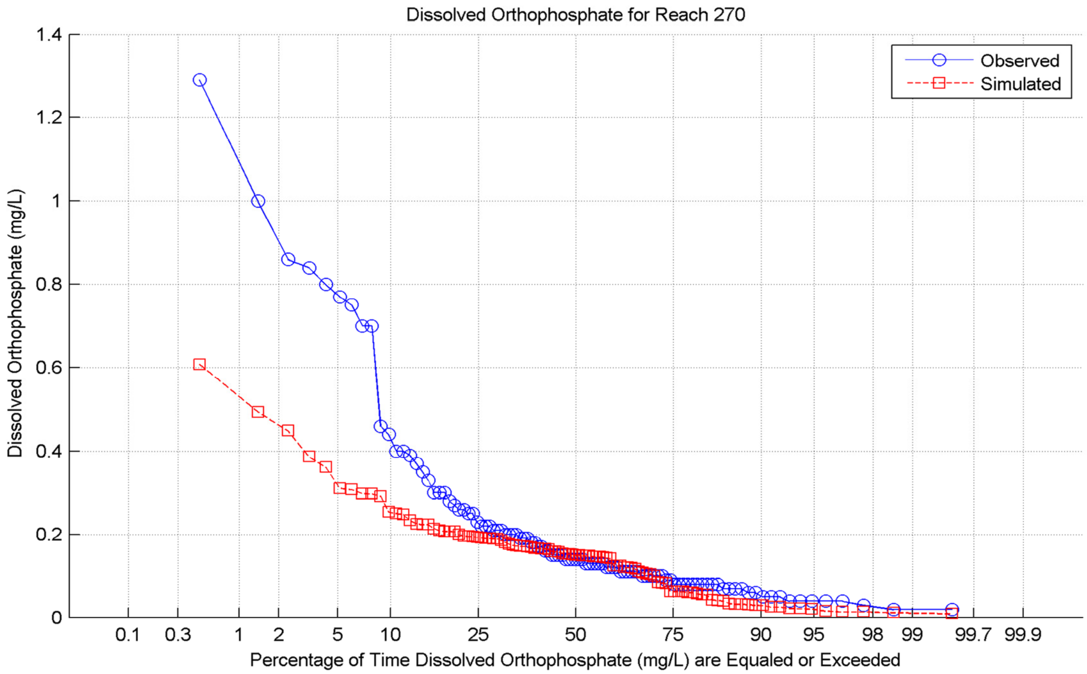

Figure E-49. Orthophosphate Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-098

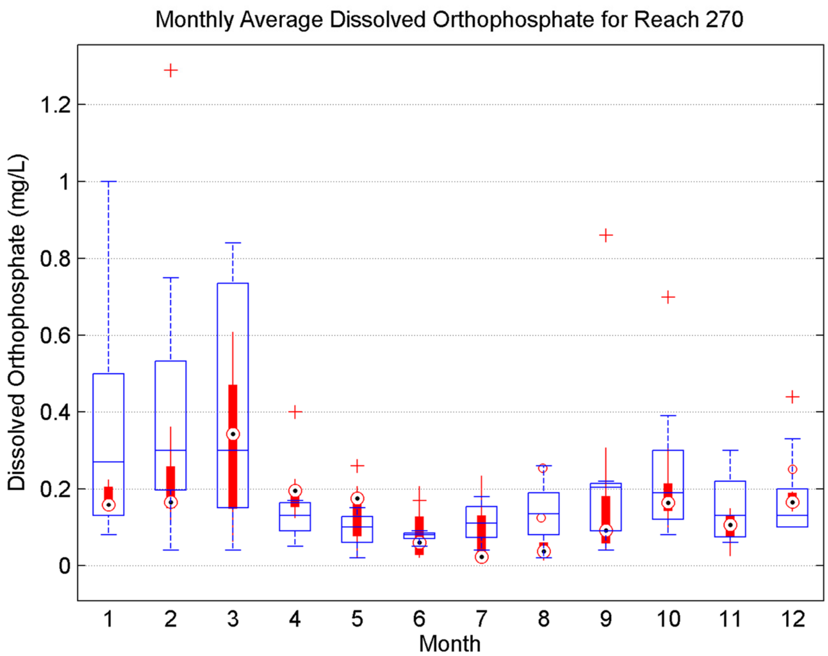

Figure E-50. Orthophosphate Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-099

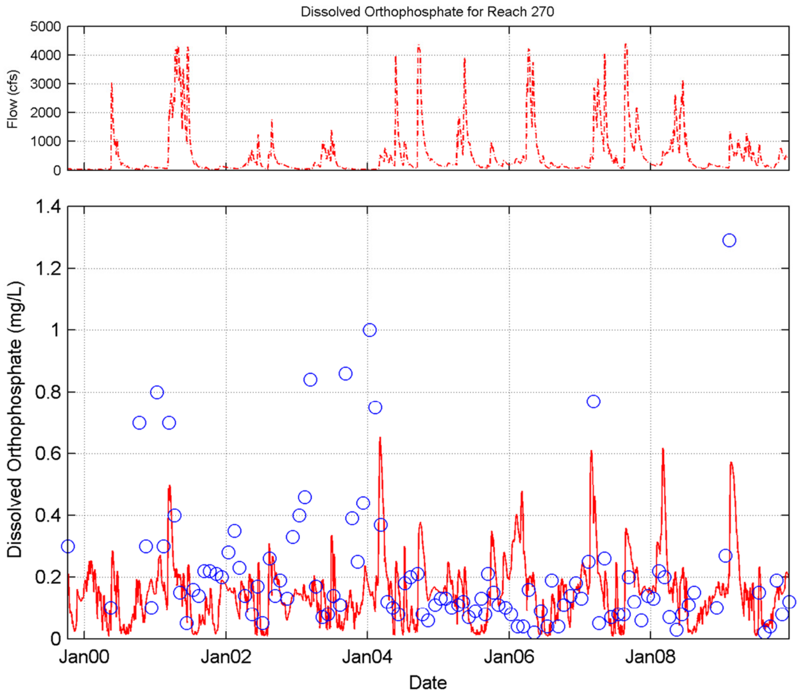

Figure E-51. Orthophosphate Time Series–Little Sioux (Reach 270).

RSI-2279-14-100

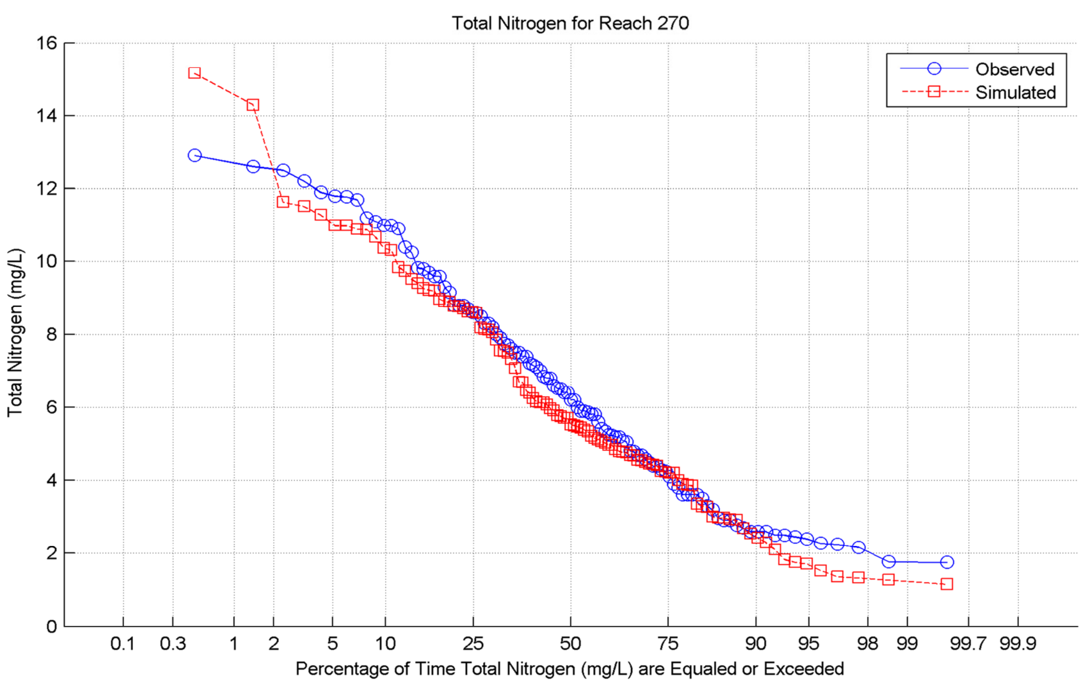

Figure E-52. Total Nitrogen Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-101

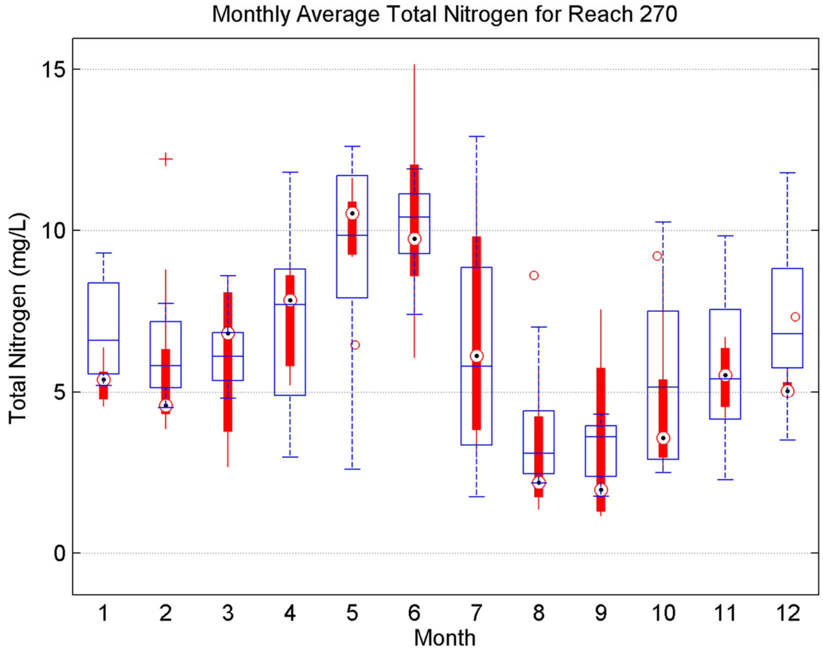

Figure E-53. Total Nitrogen Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-102

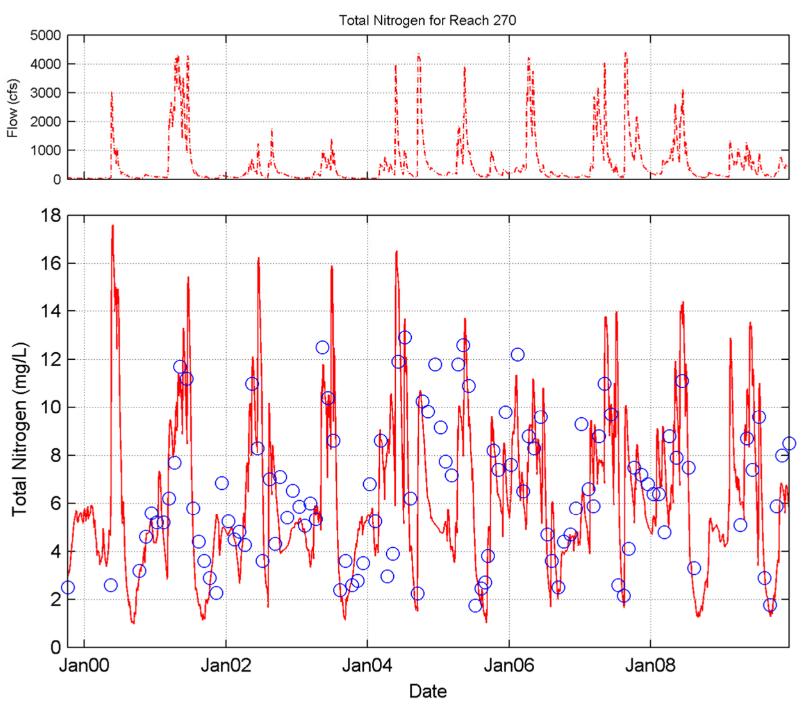

Figure E-54. Total Nitrogen Time Series–Little Sioux (Reach 270).

RSI-2279-14-103

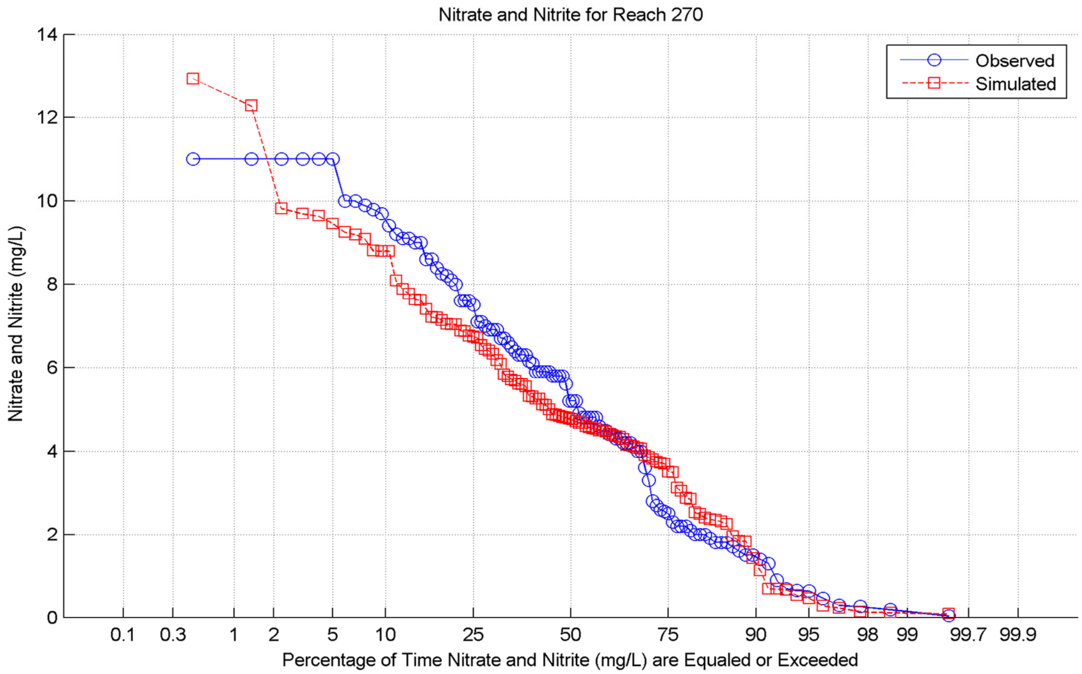

Figure E-55. Nitrate and Nitrite Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-104

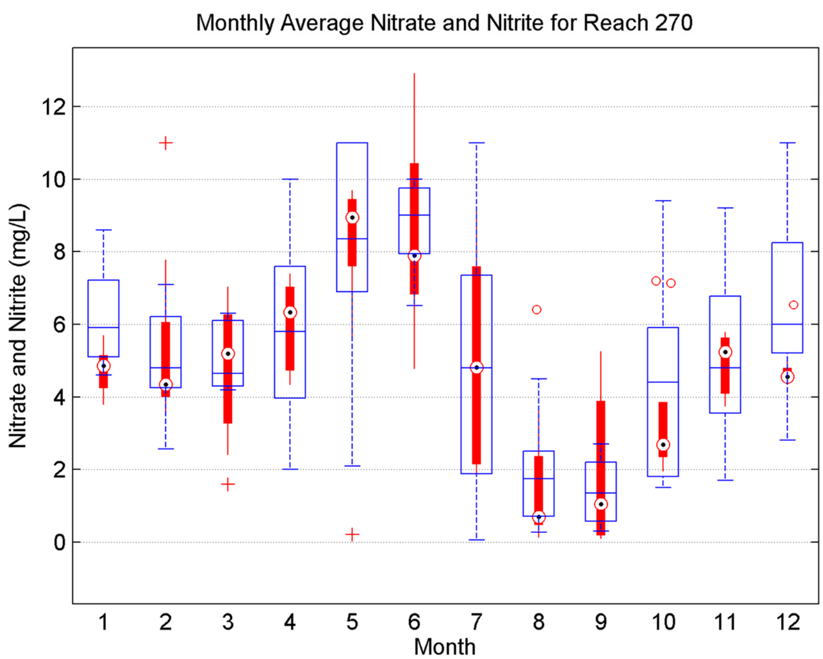

Figure E-56. Nitrate and Nitrite Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-105

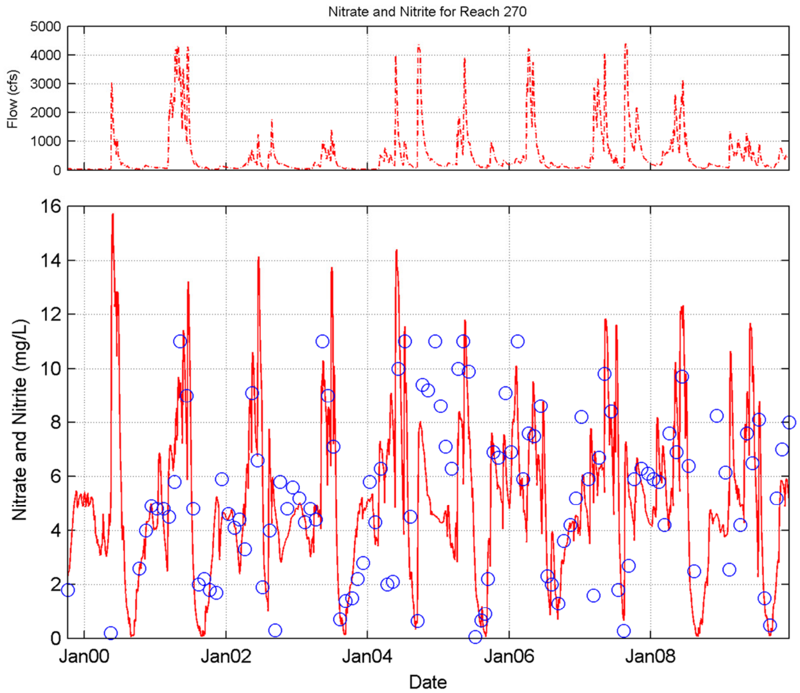

Figure E-57. Nitrate and Nitrite Time Series–Little Sioux (Reach 270).

RSI-2279-14-106

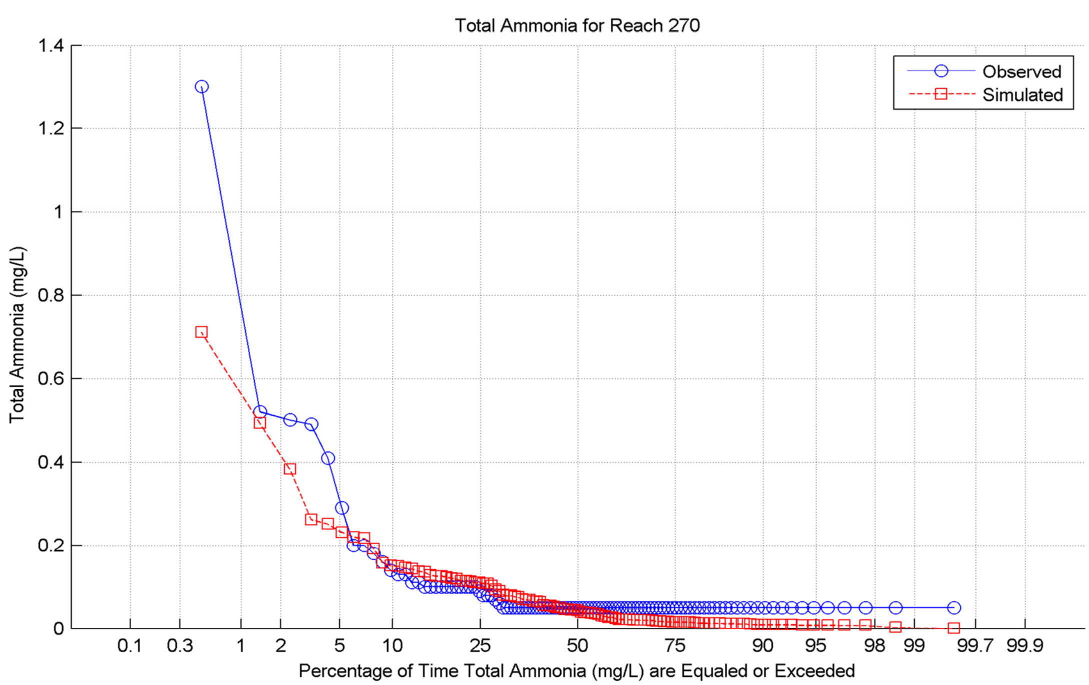

Figure E-58. Total Ammonia Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-107

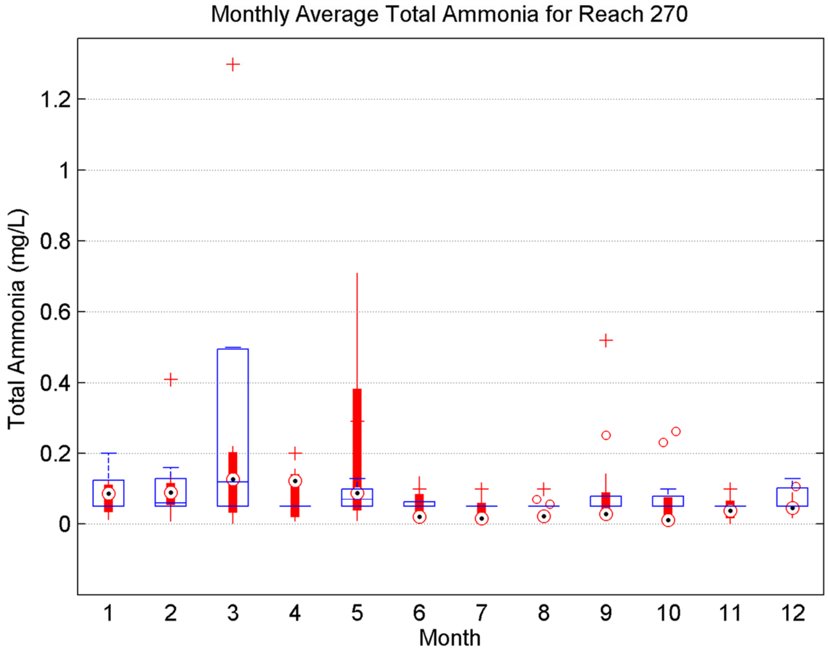

Figure E-59. Total Ammonia Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-108

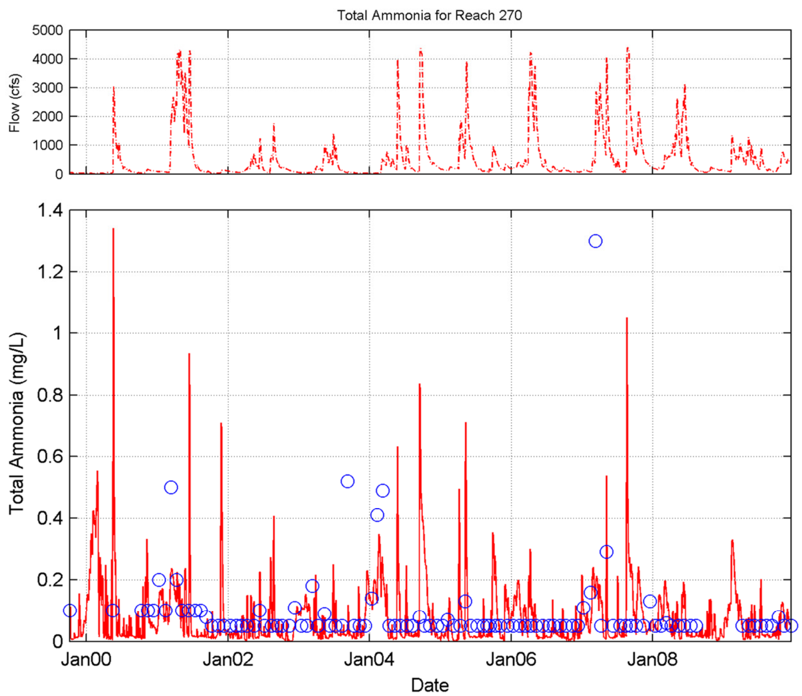

Figure E-60. Total Ammonia Time Series–Little Sioux (Reach 270).

RSI-2279-14-109

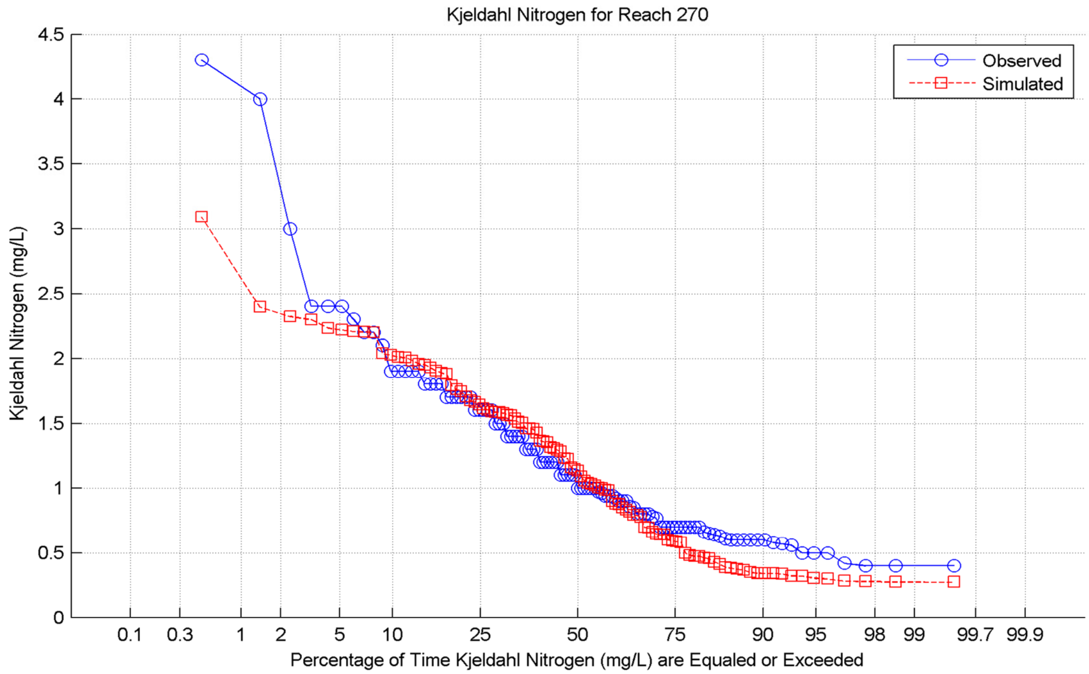

Figure E-61. Kjeldahl Nitrogen Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-110

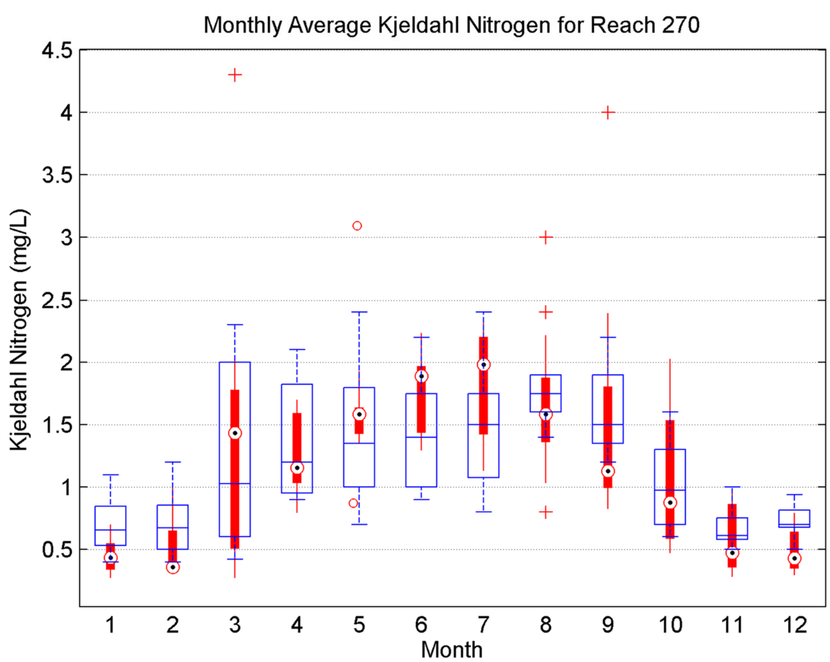

Figure E-62. Kjeldahl Nitrogen Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-111

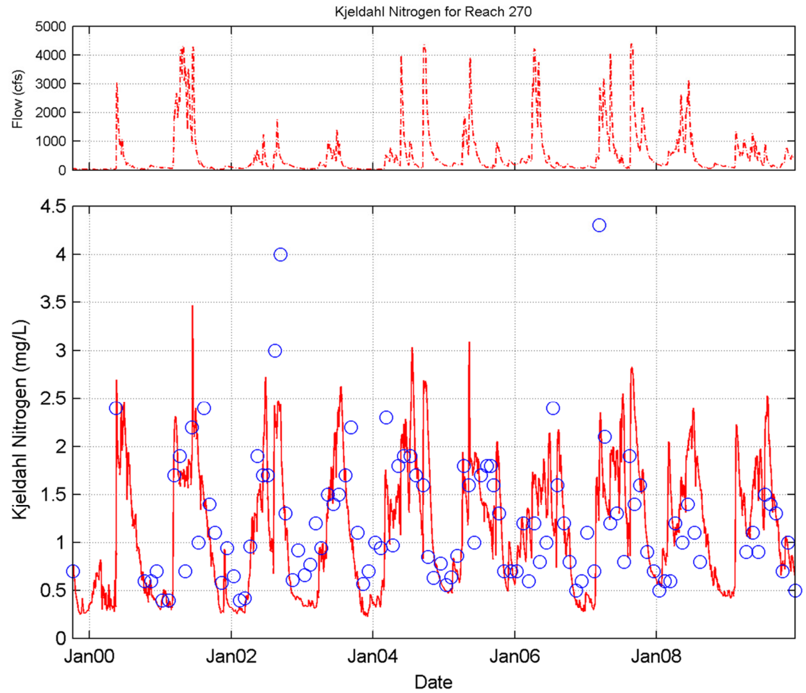

Figure E-63. Kjeldahl Nitrogen Time Series–Little Sioux (Reach 270).

RSI-2279-14-112

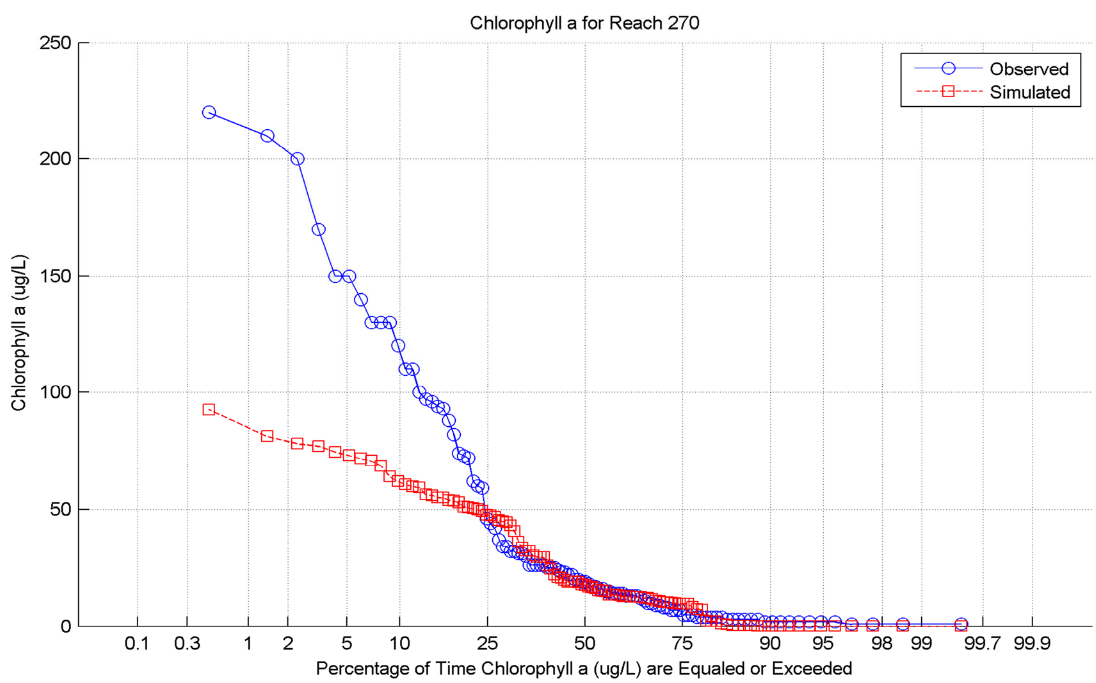

Figure E-64. Chlorophyll *a* Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-113

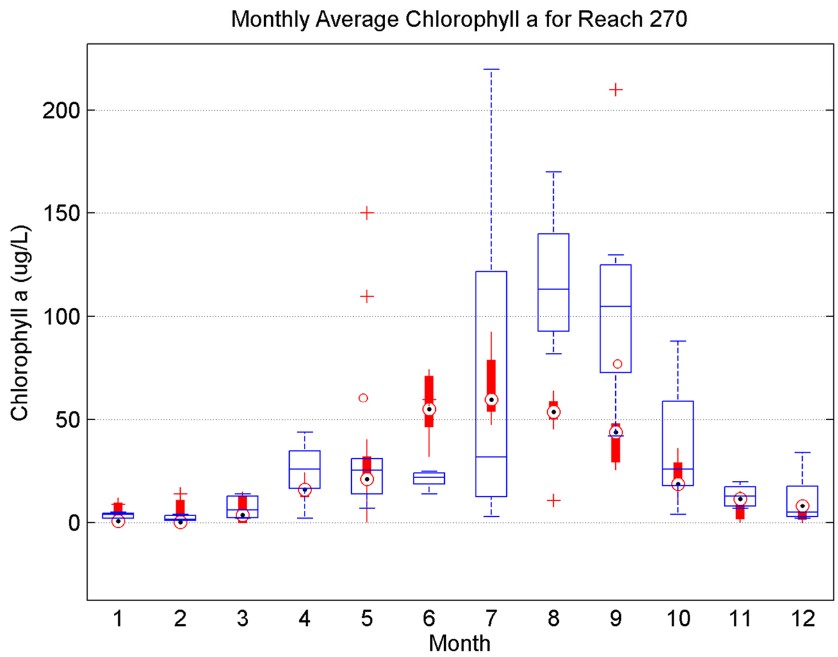

Figure E-65. Chlorophyll *a* Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-114

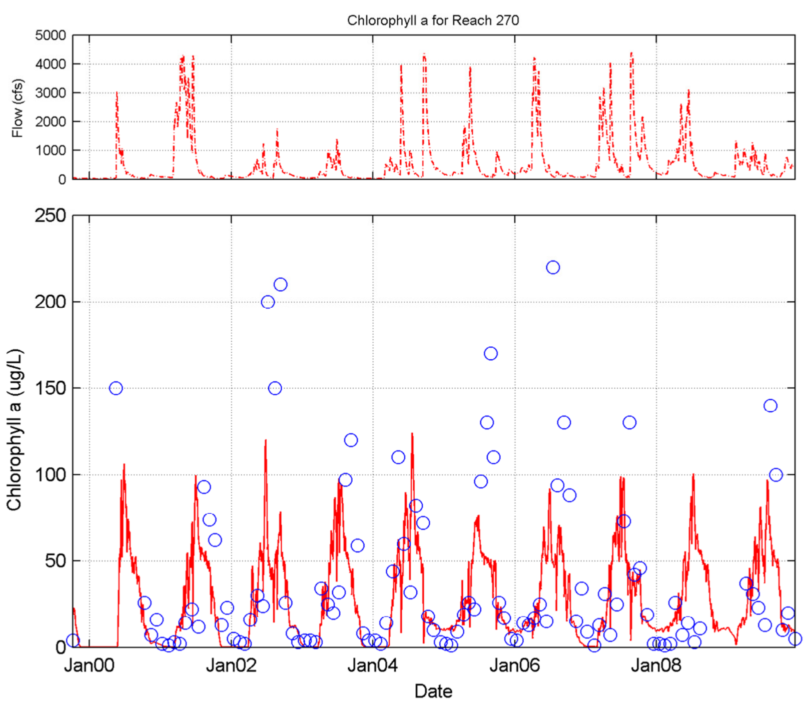

Figure E-66. Chlorophyll *a* Time Series–Little Sioux (Reach 270).

RSI-2279-14-115

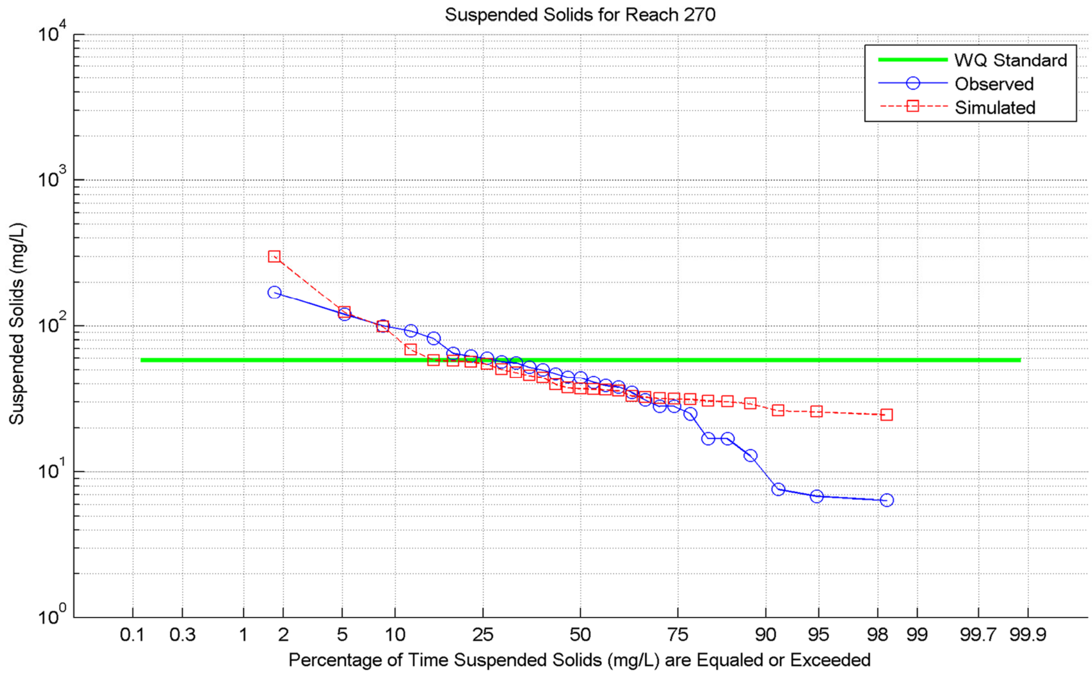

Figure E-67. Suspended Solids Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-116

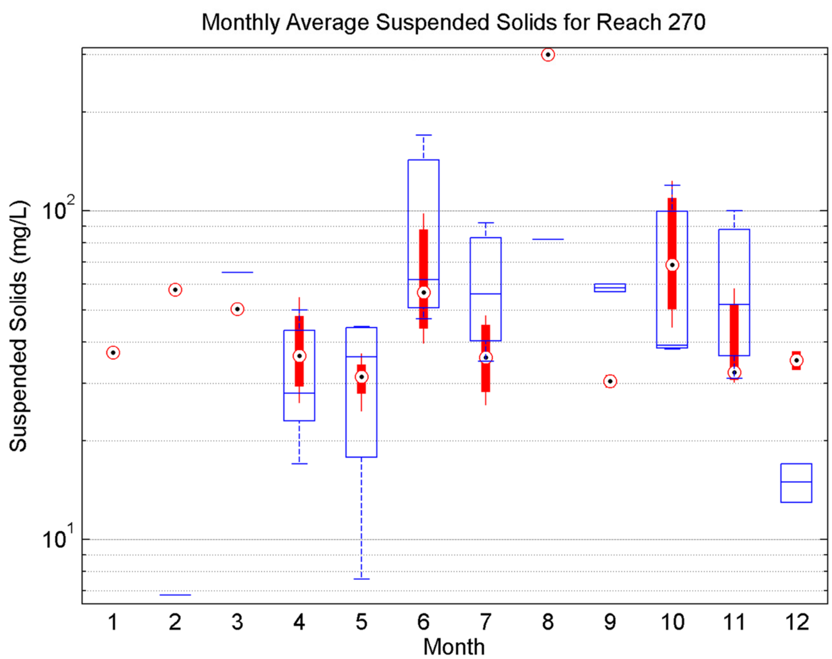

Figure E-68. Suspended Solids Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-117

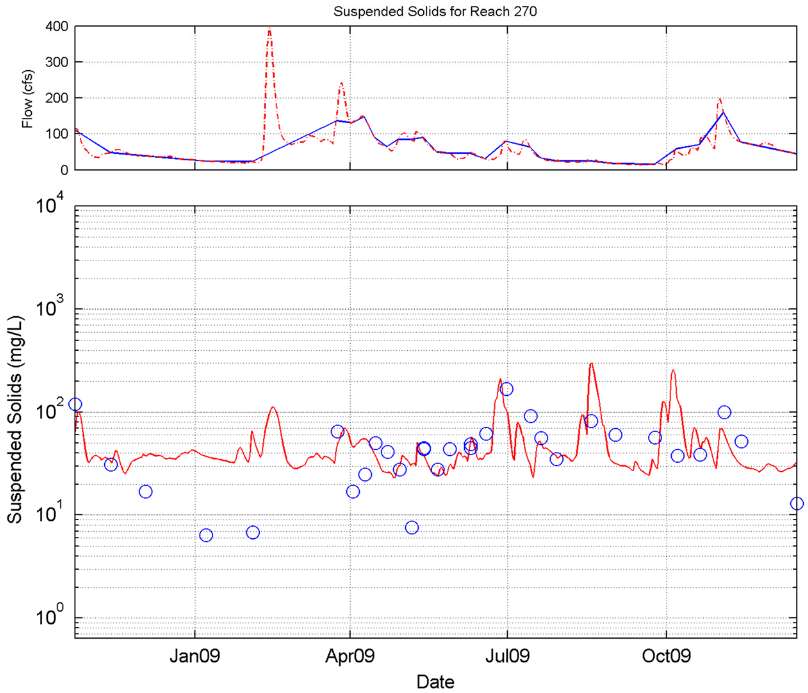

Figure E-69. Suspended Solids Daily Time Series–Big Sioux (Reach 270).

RSI-2279-14-118

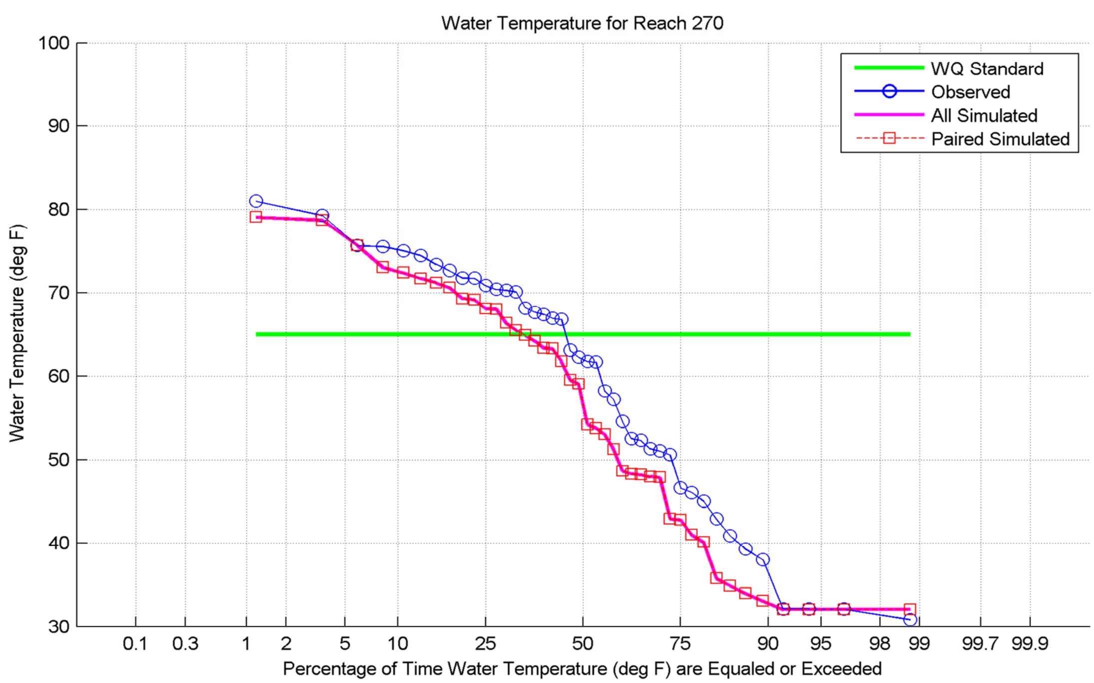

Figure E-70. Water Temperature Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-119

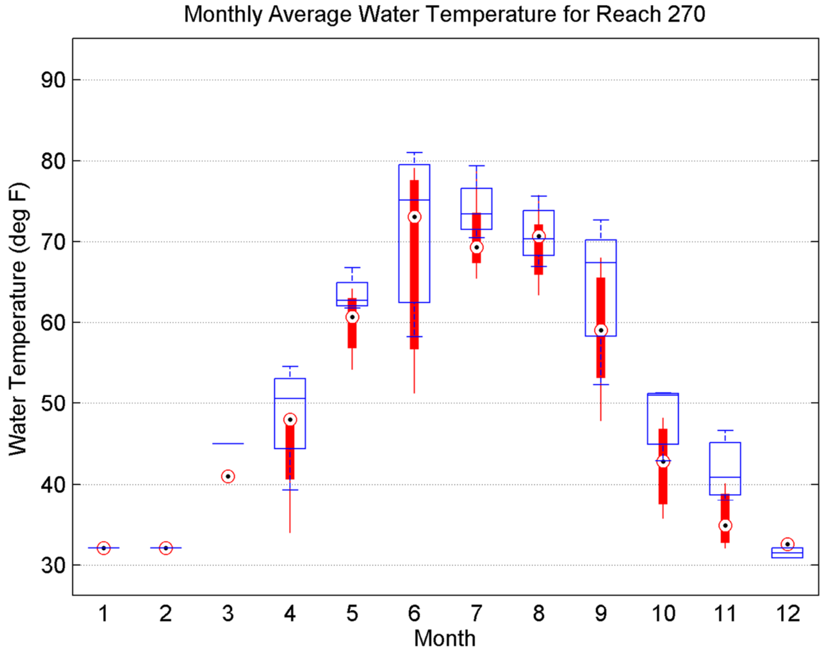

Figure E-71. Water Temperature Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-120

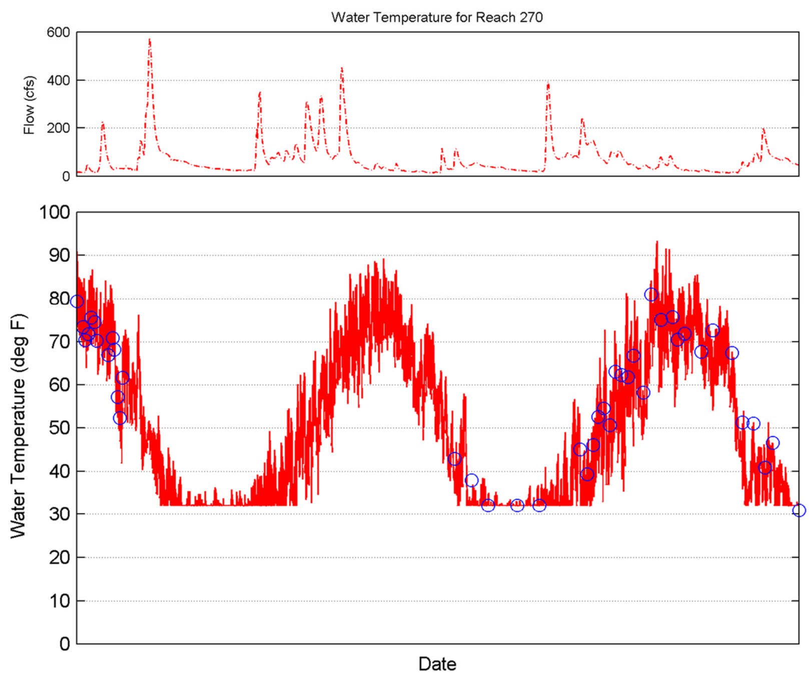

Figure E-72. Water Temperature Daily Time Series–Big Sioux (Reach 270).

RSI-2279-14-121

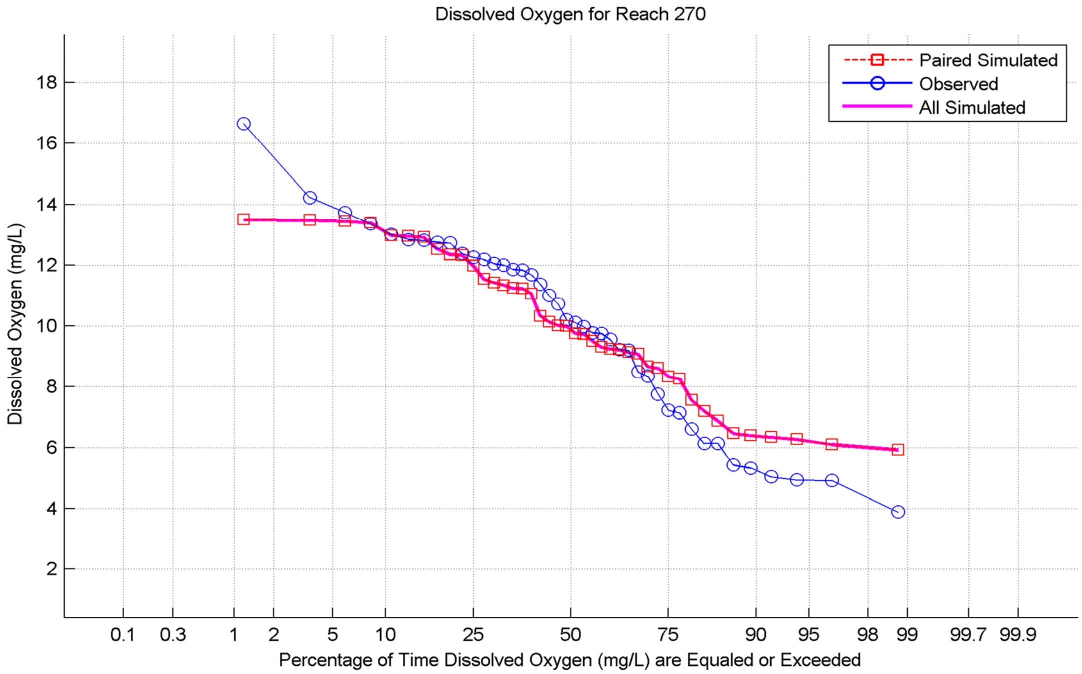

Figure E-73. Dissolved Oxygen Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-122

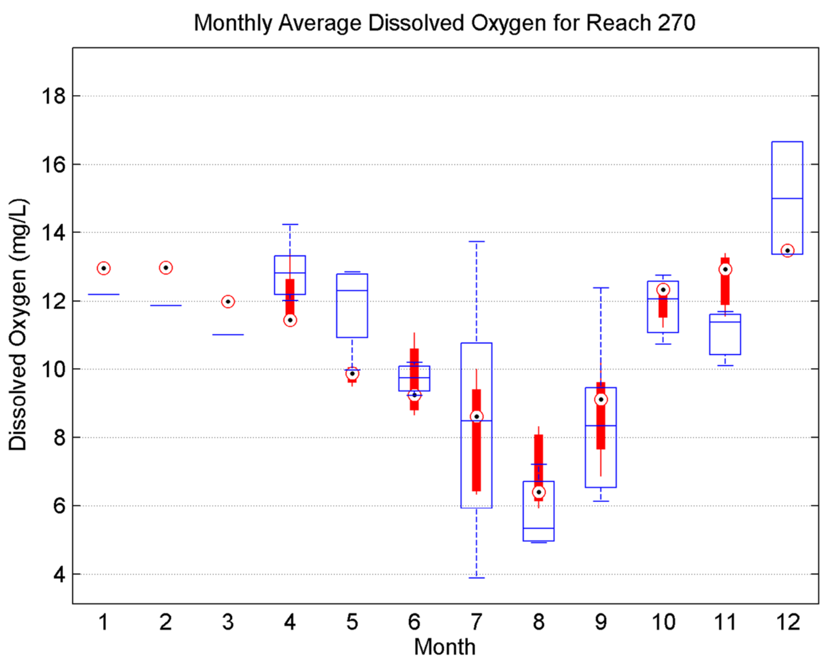

Figure E-74. Dissolved Oxygen Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-123

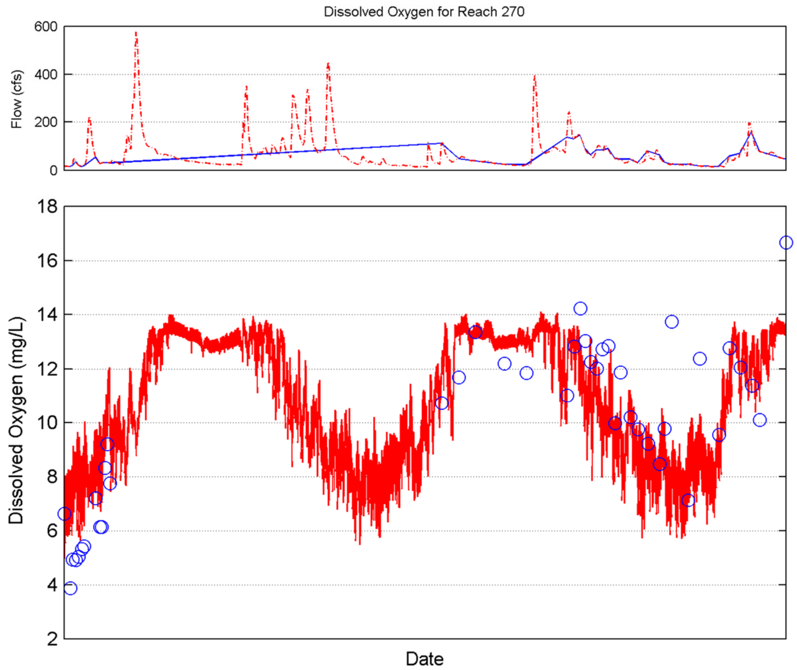

Figure E-75. Dissolved Oxygen Daily Time Series–Big Sioux (Reach 270).

RSI-2279-14-124

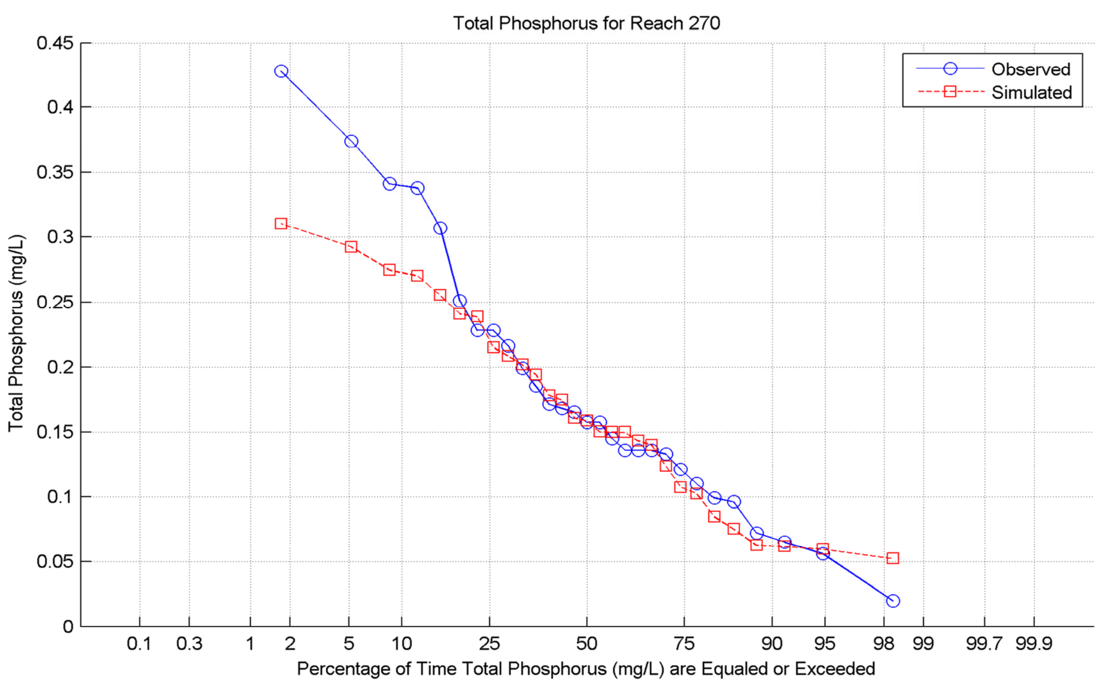

Figure E-76. Total Phosphorus Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-125

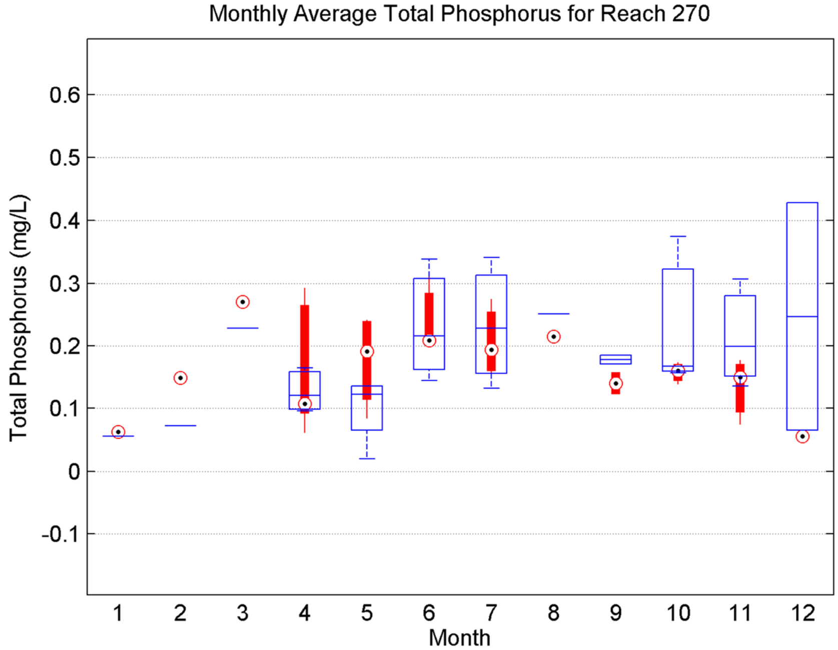

Figure E-77. Total Phosphorus Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-126

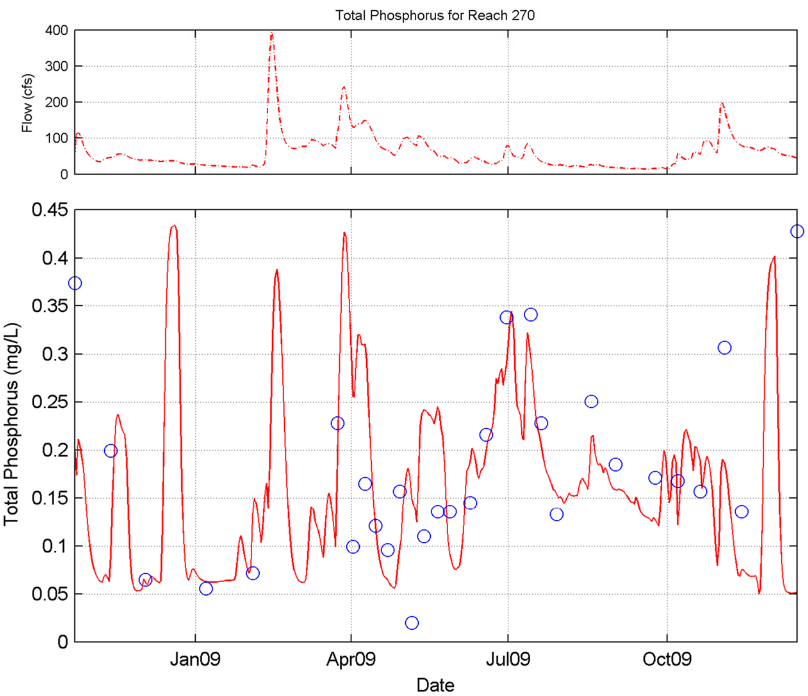

Figure E-78. Total Phosphorus Time Series–Big Sioux (Reach 270).

RSI-2279-14-127

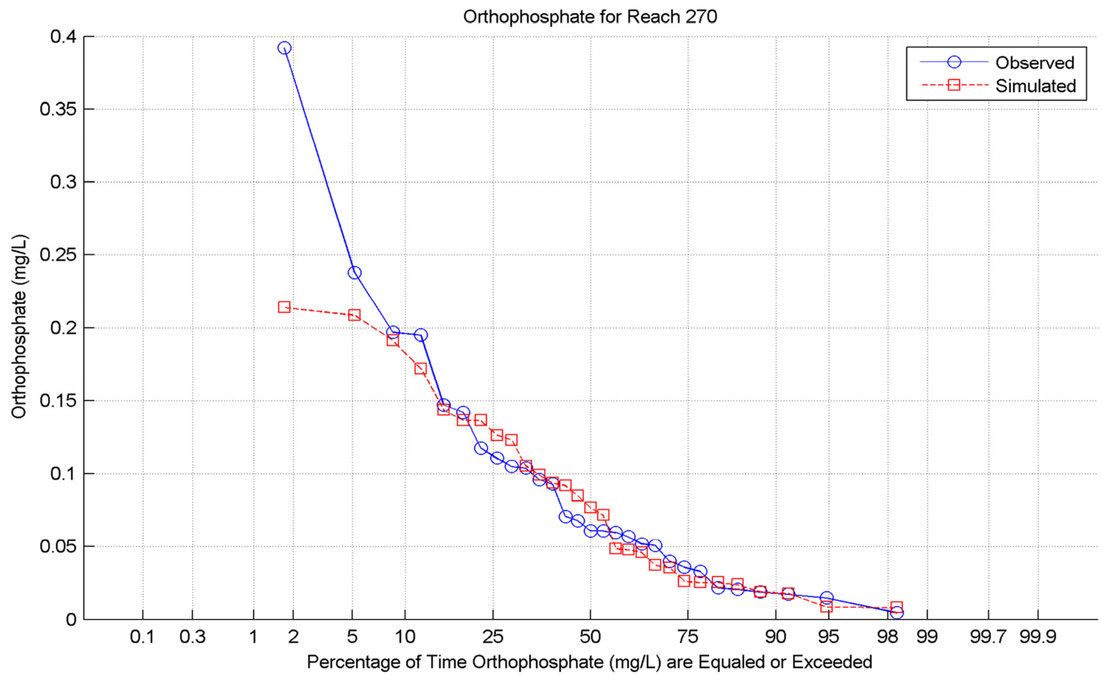

Figure E-79. Orthophosphate Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-128

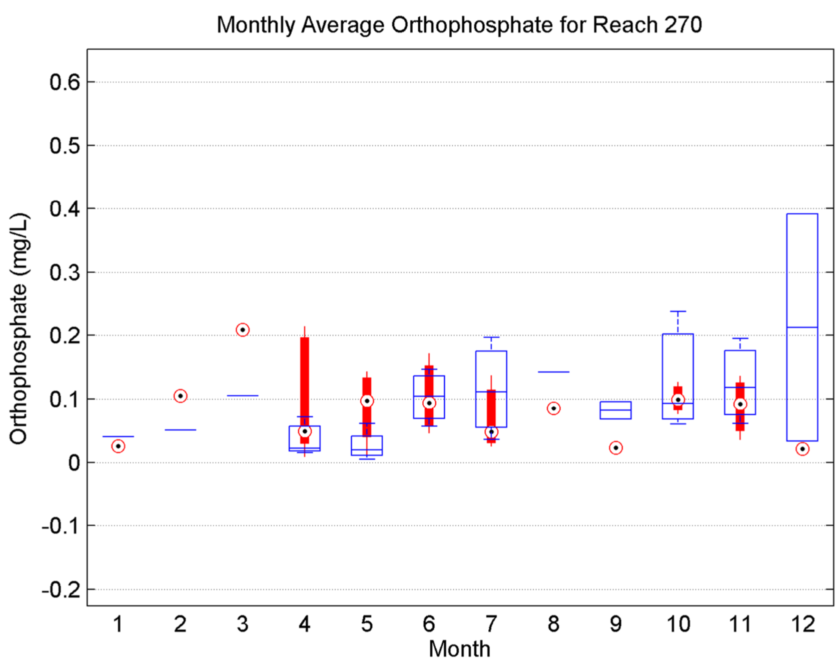

Figure E-80. Orthophosphate Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-129

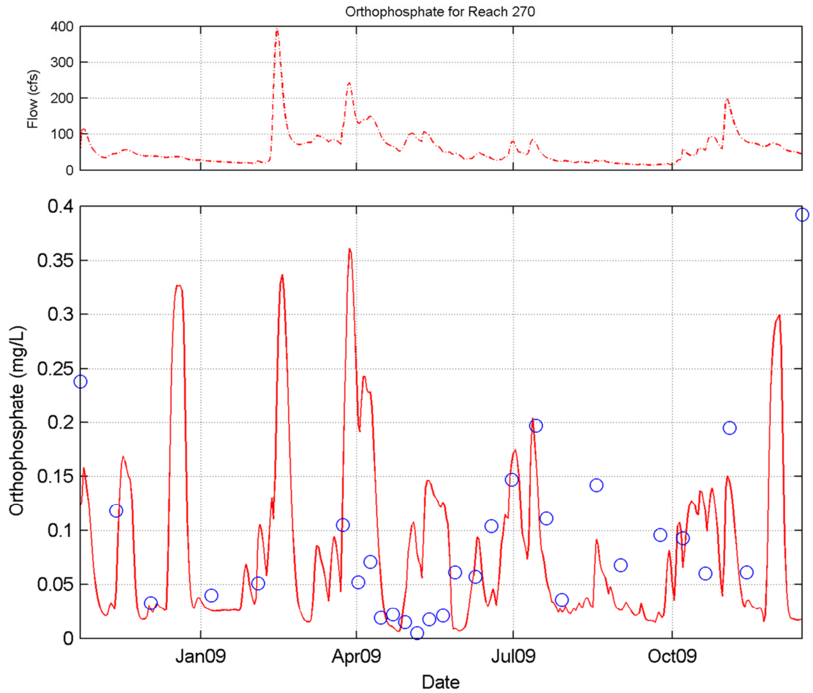

Figure E-81. Orthophosphate Time Series–Big Sioux (Reach 270).

RSI-2279-14-130

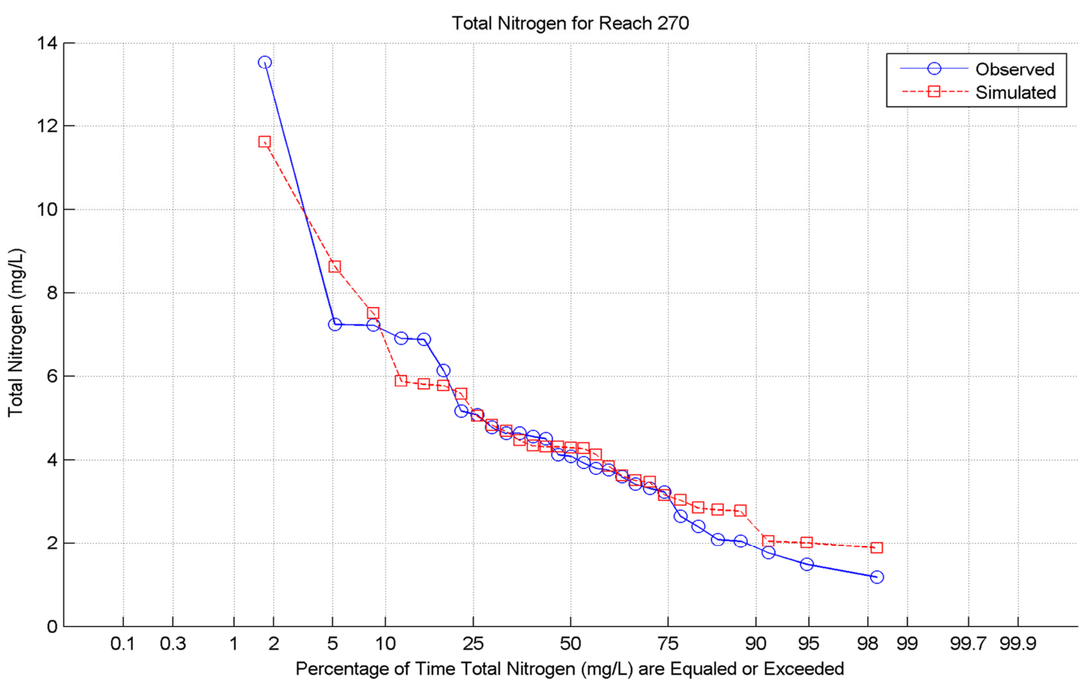

Figure E-82. Total Nitrogen Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-131

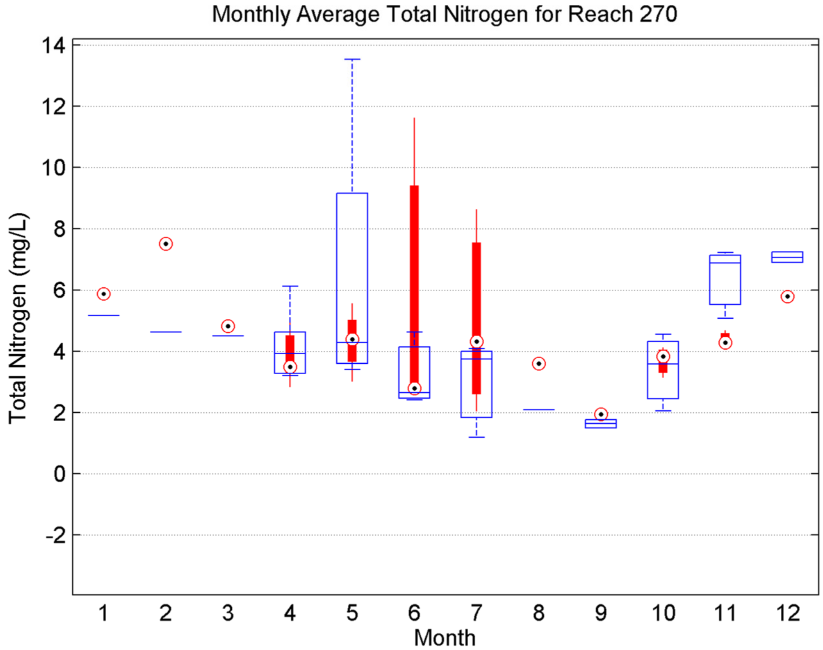

Figure E-83. Total Nitrogen Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-132

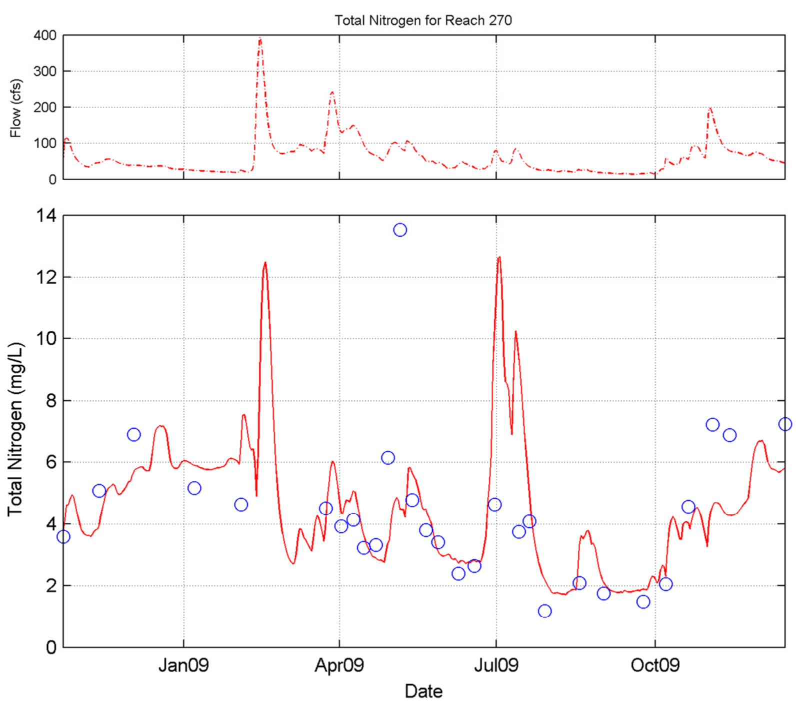

Figure E-84. Total Nitrogen Time Series–Big Sioux (Reach 270).

RSI-2279-14-133

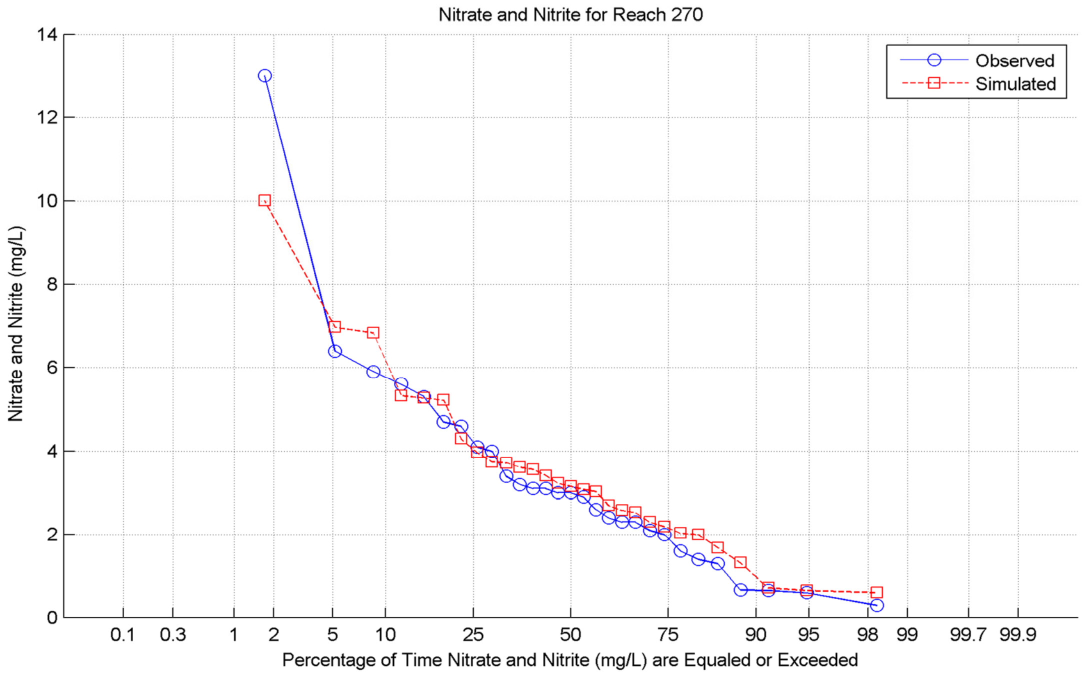

Figure E-85. Nitrate and Nitrite Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-134

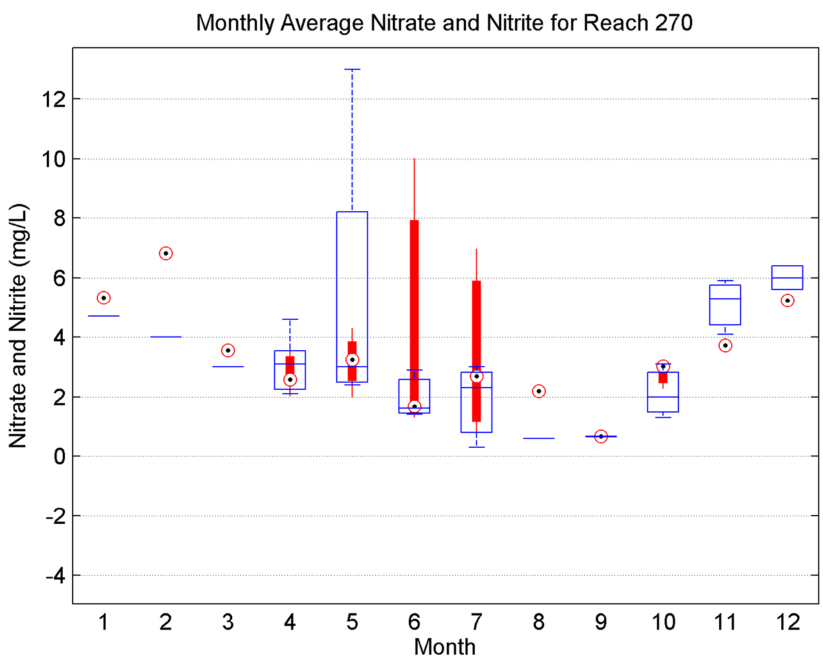

Figure E-86. Nitrate and Nitrite Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-135

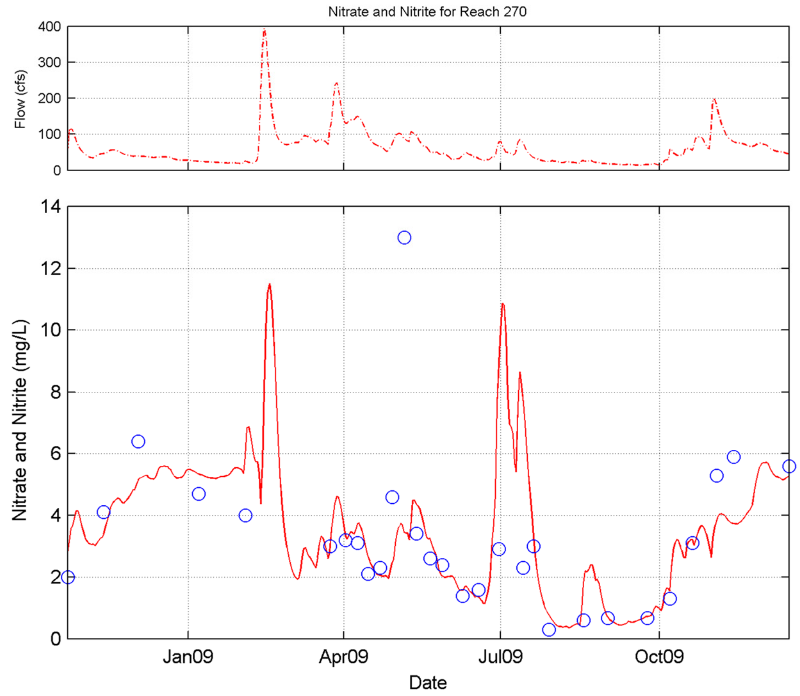

Figure E-87. Nitrate and Nitrite Time Series–Big Sioux (Reach 270).

RSI-2279-14-136

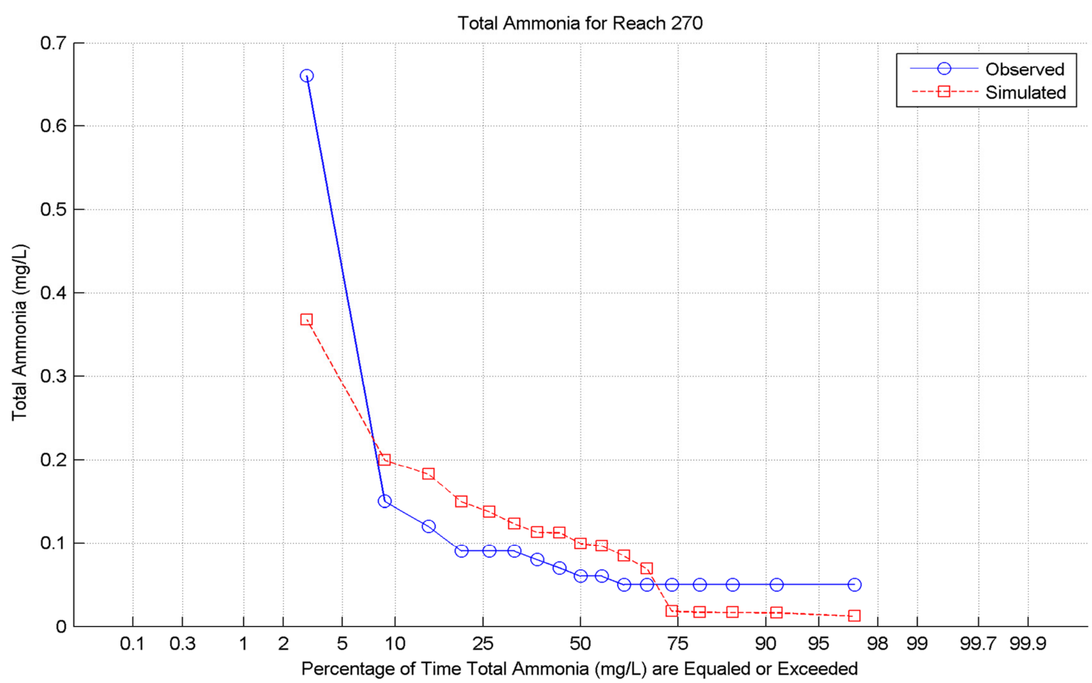

Figure E-88. Total Ammonia Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-137

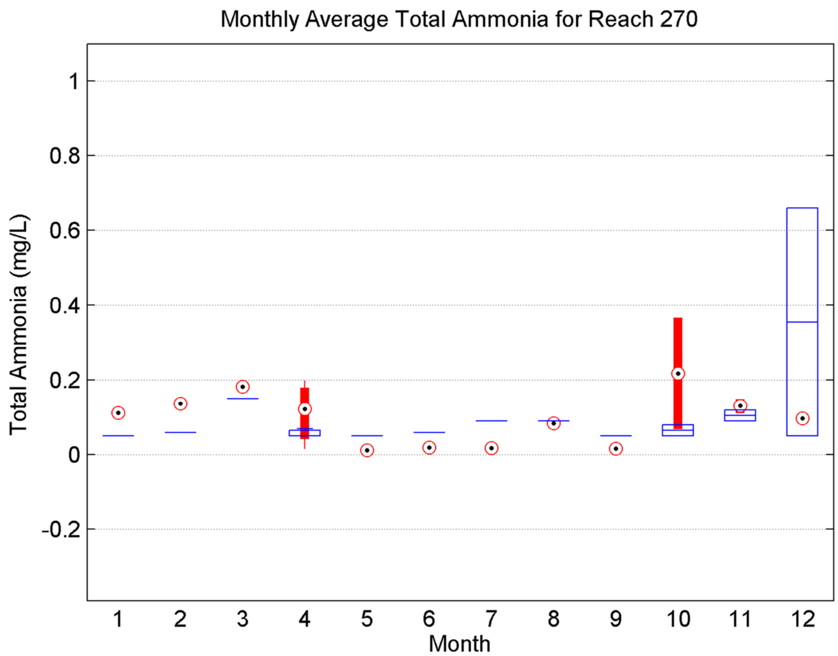

Figure E-89. Total Ammonia Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-138

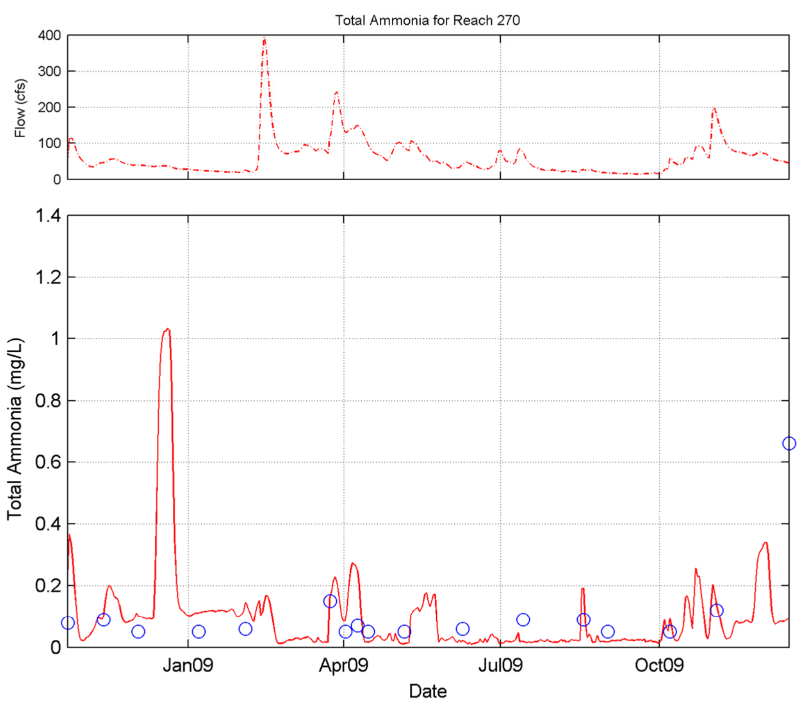

Figure E-90. Total Ammonia Time Series–Big Sioux (Reach 270).

RSI-2279-14-139

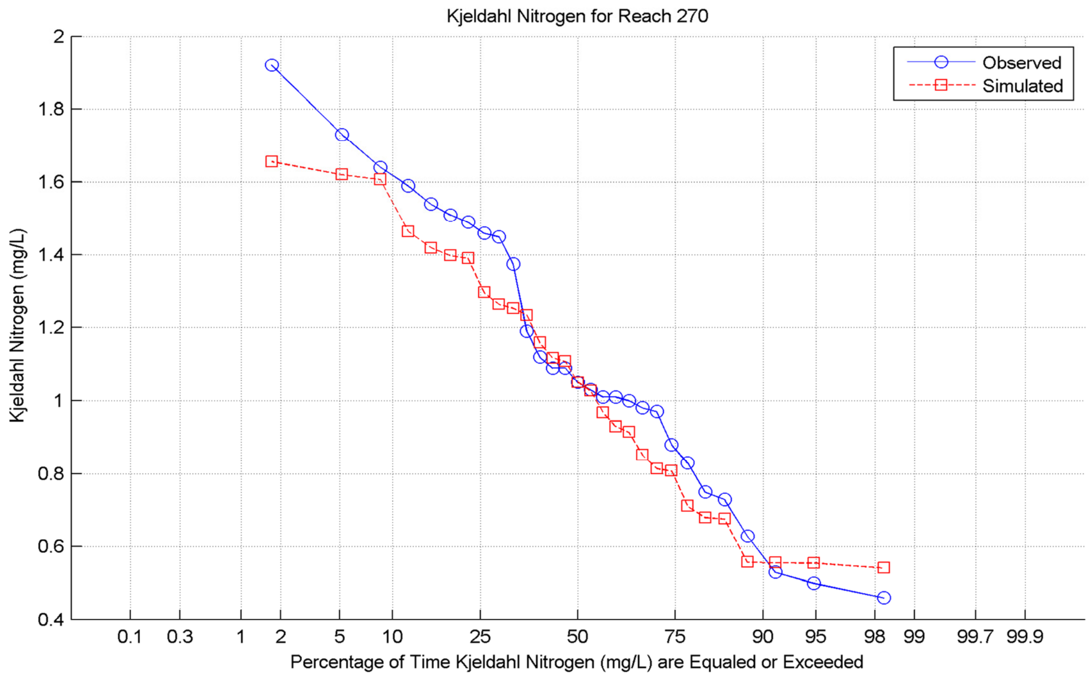

Figure E-91. Kjeldahl Nitrogen Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-140

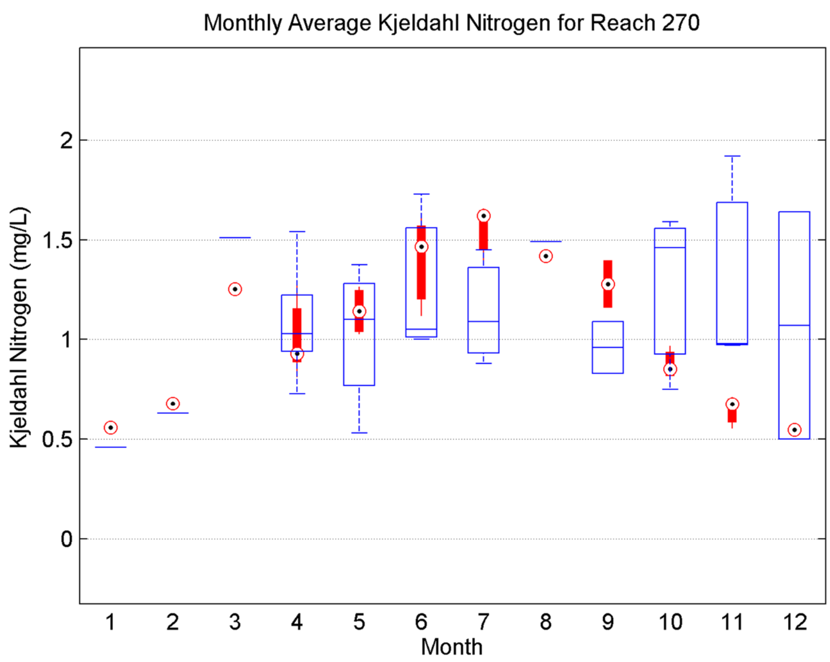

Figure E-92. Kjeldahl Nitrogen Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-141

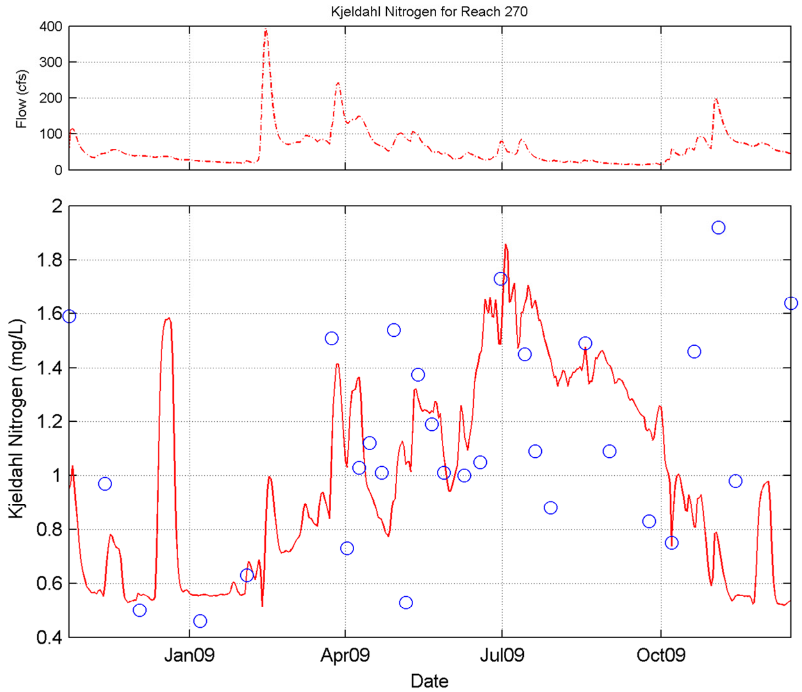

Figure E-93. Kjeldahl Nitrogen Time Series–Big Sioux (Reach 270).