RESPEC

September 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 Minnesota River Watershed Model Applications

Please review the following methodology and results for hydrologic and water-quality calibration and validation of the following major watersheds:

- Hawk-Yellow Medicine (07020004)
- Chippewa (07020005)
- Redwood (07020006)
- Middle Minnesota (07020007)
- Cottonwood (07020008)
- Blue Earth (07020009)
- Watonwan (07020010)
- Le Sueur (07020011)
- Lower Minnesota (07020012).

This memorandum refers to all areas collectively as the Minnesota River Watershed.

Hydrologic calibration is critical to parameter development for an HSPF model application, particularly for parameters that cannot be readily estimated by watershed characteristics. 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. The methods and results for the hydrologic calibration and the water-quality calibration are explained in the following sections.

HYDROLOGIC CALIBRATION DATA

The continuous, observed stream-flow data required for calibration are available at 76 gages within the Minnesota River Watershed. The mainstem calibration/validation gages are located on Chippewa Creek (three gages), Yellow Medicine River (two gages), Redwood River (three gages), Minnesota River (six gages), Cottonwood River (four gages), Blue Earth River (one gage), Watonwan River (four gages), and Le Sueur River (three gages). The remaining 50 gages are located on tributary rivers and streams. Table 1 provides the primary stream-flow gage for each model and their period of record to support model calibration and hydrology validation. The locations of all flow gages for the Minnesota River Watershed are illustrated in Figure 1, and more detailed locations for each model application are illustrated 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) and the Minnesota Department of Natural Resources (MNDNR)/Minnesota Pollution Control Agency (MPCA) Cooperative Stream Gaging network (http://www.dnr.state.mn.us/waters/csg/index.html).

Table 1. Primary Discharge Calibration Gages Within the Minnesota River Watershed

Model Application	Gage	Gage Description	HSPF Reach I.D.	Drainage Area (mi^2)	Data Availability	Sample Count
Hawk-Yellow Medicine	H25075001	Yellow Medicine River near Granite Falls, MN	101	678	1995–2012	6,209
Chippewa	5304500	Chippewa River near Watson, MN	106	1,875	1995–2012	6,209
Redwood	5316500	Redwood River near Redwood Falls, MN	450	663	1995–2012	6,205
Middle Minnesota	5325000	Minnesota River at Mankato, MN	530	10,786	1995–2012	6,190
Cottonwood	5317000	Cottonwood River near New Ulm, MN68	490	1,315	1995–2012	6,191
Blue Earth	5320000	Blue Earth River near Rapidan, MN	410	2,404	1995–2012	6,209
Watonwan	5319500	Watonwan River near Garden City, CSAH13	270	849	1995–2012	6,198
Le Sueur	5320500	Le Sueur River near Rapidan, MN66	830	1,106	1995–2012	6,203
Lower Minnesota	5300000	Minnesota River near Jordan, MN	310	12,079	1995–2012	6,174

Calibration is typically performed over at least a 5-year period with a range of hydrologic conditions from wet to dry. A single User Control Input (UCI) was used for calibrating each model application. The calibration period is from 1996 to 2012 and was 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 primary calibration gages.

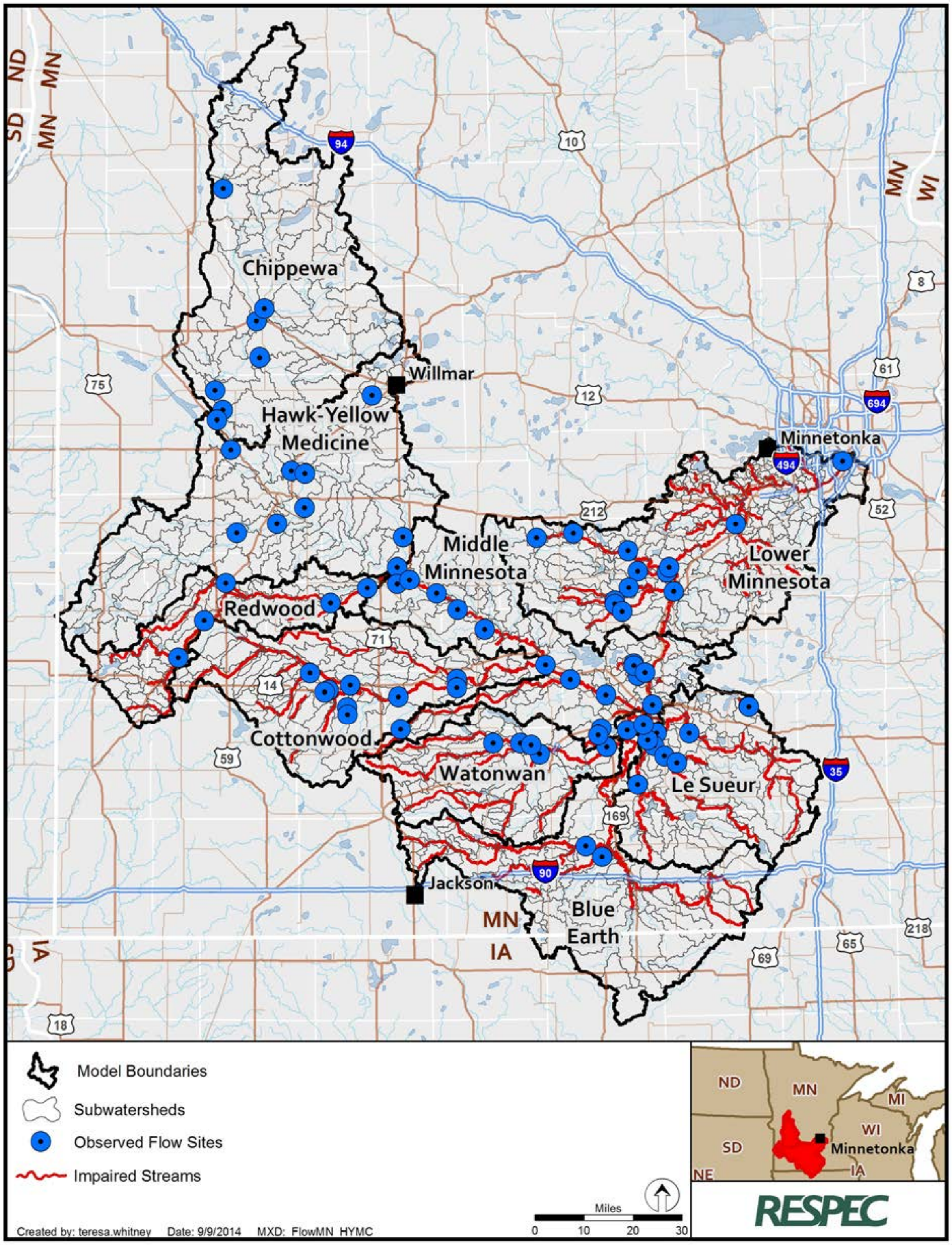

Figure 1. Flow Calibration Gages Within the Minnesota River Watershed.

For the validation a UCI was created for each model application using land-cover data derived from the NLCD 2001, and the calibration was run for three different time periods: 1996–2003, 2004–2012, and 1996–2012. 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 each watershed is, in itself, a form of validation.

BOUNDARY CONDITIONS

Four of the nine models receive hydrologic and water-quality inputs from separate eight-digit hydrologic unit code (HUC8) watersheds for which boundary conditions were required. The Hawk-Yellow Medicine Watershed receives inputs from the Lac Qui Parle (reach 308), Chippewa (reach 307), and Redwood Watersheds (reach 301). The Blue Earth Watershed receives inputs from the Watonwan (reach 410) and Le Sueur Watersheds (reach 870), while the Middle Minnesota Watershed receives inputs from the Hawk-Yellow Medicine (reach 10) and Blue Earth Watersheds (reach 510). The Lower Minnesota Watershed receives inputs from the Middle Minnesota Watershed (reach 10). Discharge and water-quality loads (dissolved oxygen, biochemical oxygen demand, temperature, sediment-size fractions, nitrogen speciation, phosphorus speciation, phytoplankton, and zooplankton) were input directly from headwater models to receiving models when an existing HSPF application existed. Because there is no existing HSPF application for the Lac Qui Parle Watershed, boundary conditions were developed for input from the La Qui Parle Watershed to the Hawk-Yellow Medicine Watershed using USGS Load Estimator (LOADEST).

LOADEST develops a regression between continuous flow and intermittent water-quality data and outputs a continuous time-series loading. Discharge data were obtained from USGS Gage 05301000 at the Lac Qui Parle outlet, which serves as the upstream boundary on the Minnesota River for the Hawk-Yellow Medicine Watershed. These data were only available for October 1, 1998, through the end of the simulation period, hence, the difference in flow from the outlet of the Chippewa Watershed and USGS Gage 05311000 (15 miles downstream of Lac Qui Parle) was used for the period of January 1, 1995–September 30, 1998. Water-quality data, collected intermittently by the MN DNR, were available at the Lac Qui Parle outlet throughout the simulation period. The LOADEST daily loadings generated from these flow and water-quality time-series inputs provided the initial boundary conditions to Hawk-Yellow Medicine model reach 308. These initial estimations were adjusted during calibration by applying a multiplication factor if downstream concentrations were significantly lower or higher than expected.

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 untilthe 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 31 locations within and near HUC8's 07020006–07020012, as illustrated in Figure 2, and eight locations within and near HUC8's 07020004–07020005. 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, as 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 large amount of lakes in these watersheds, lake level is considered an important factor for the hydrology calibration. Lake level data are available for approximately 54 of the 142 modeled lakes and can be used to compare simulated lake 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 function tables (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

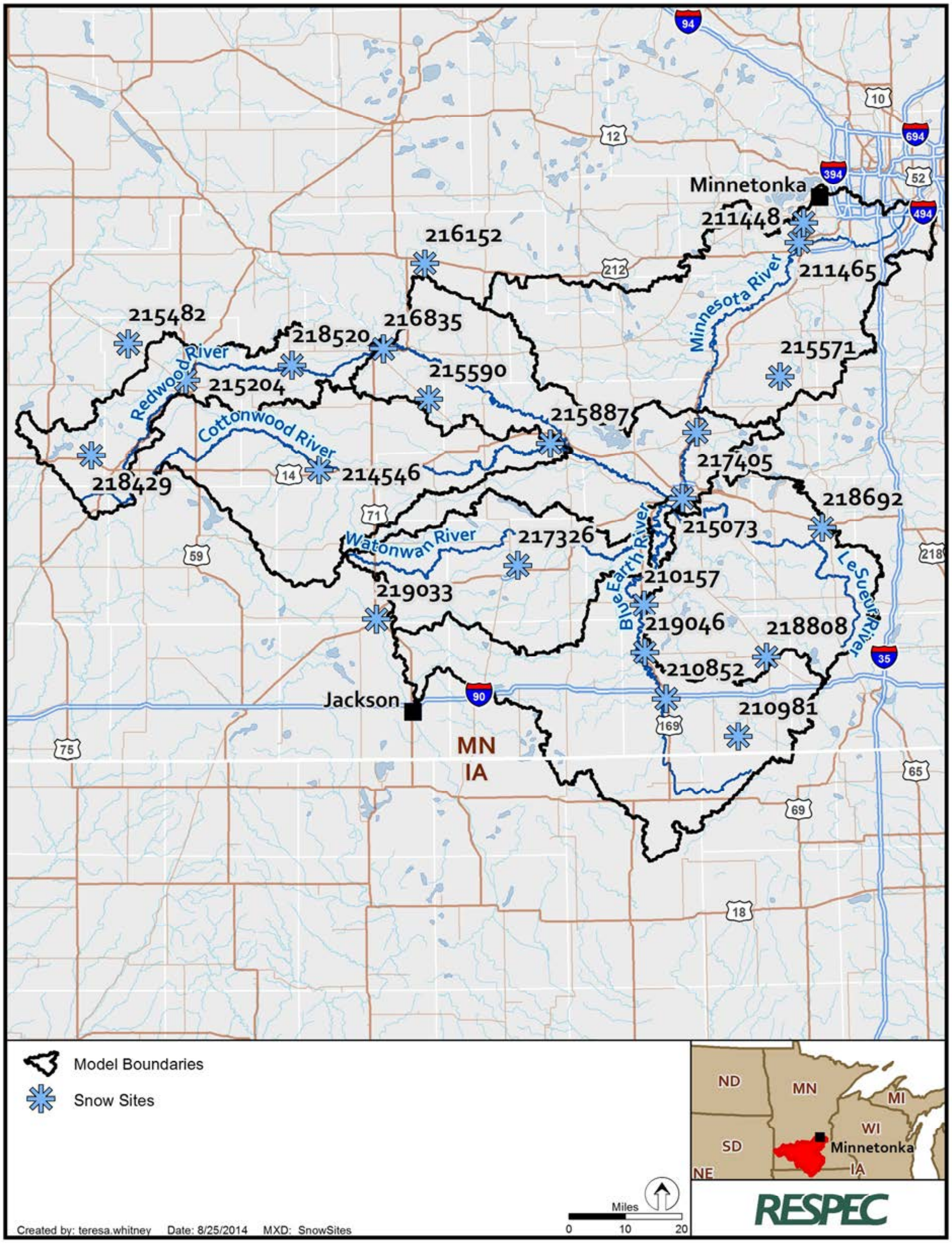

Figure 2. Meteorological Stations With Snow Data Used for Calibration.

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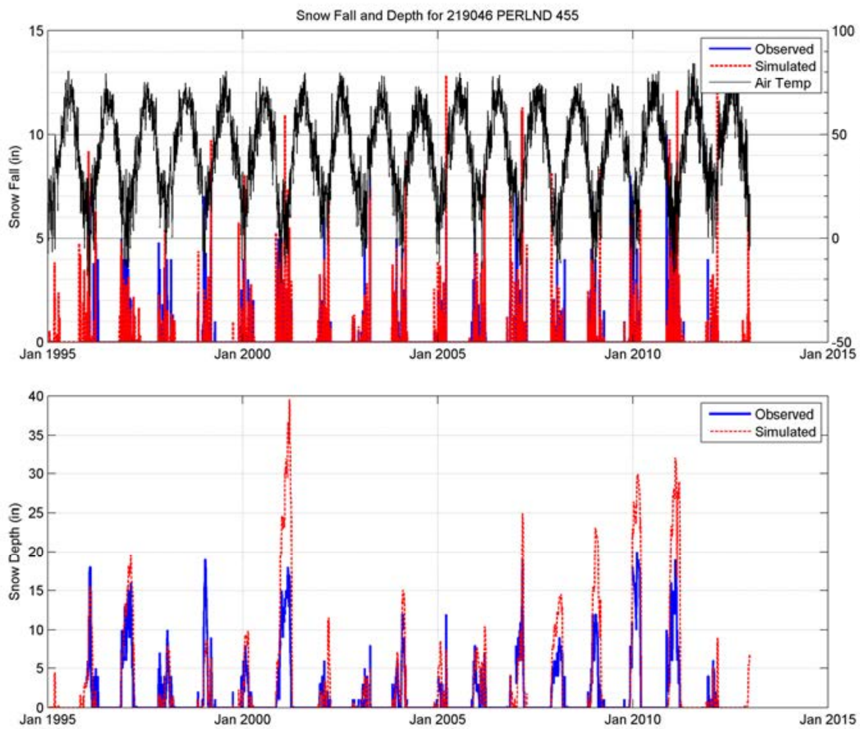

Figure 3. Snowfall (Top) and Snow Depth (Bottom) Calibration Figures.

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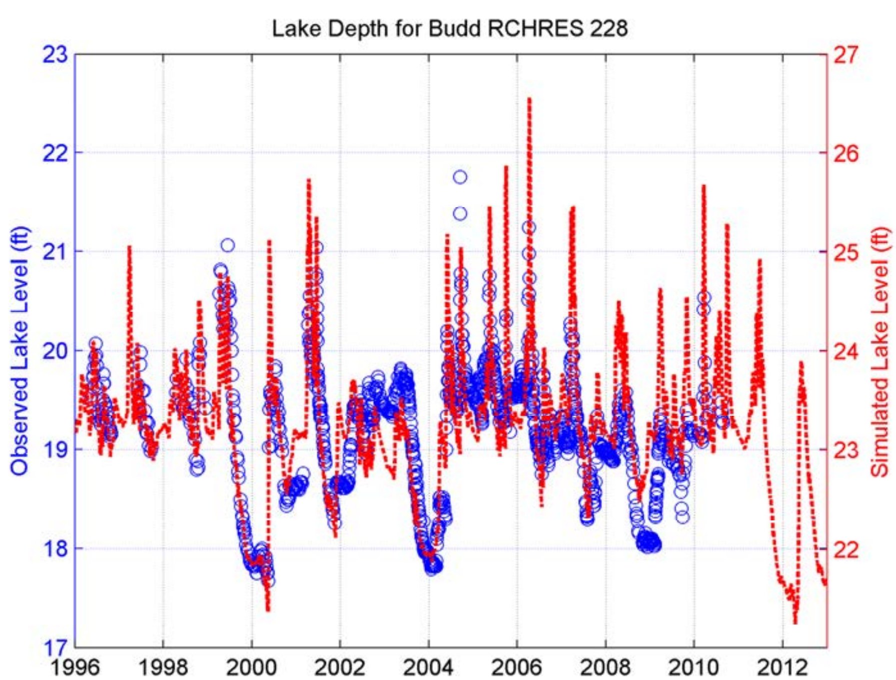

Figure 4. Lake-Level Calibration.

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 were evaluated by comparing patterns in the lake level data instead of actual lake level values. When lake level, hydrologic, or water-quality data supported it, a groundwater base flow and nutrient load was added to some headwater lakes using the NETWORK block in HSPF.

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.

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 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 analyzing 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)**
- **Total 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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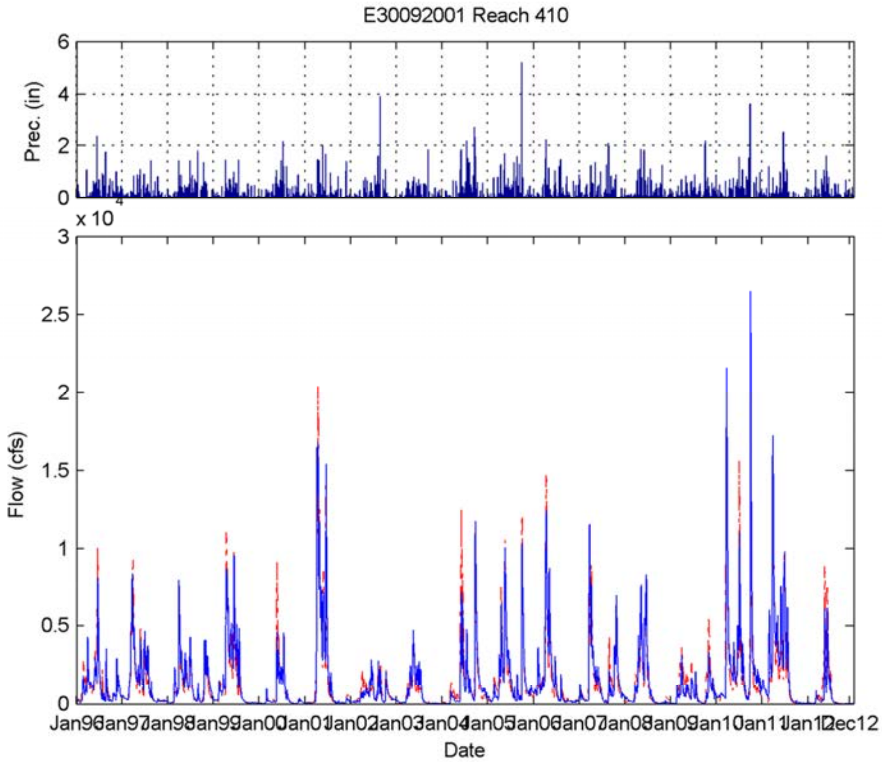

Figure 5. Daily Flow Time-Series Plot Example.

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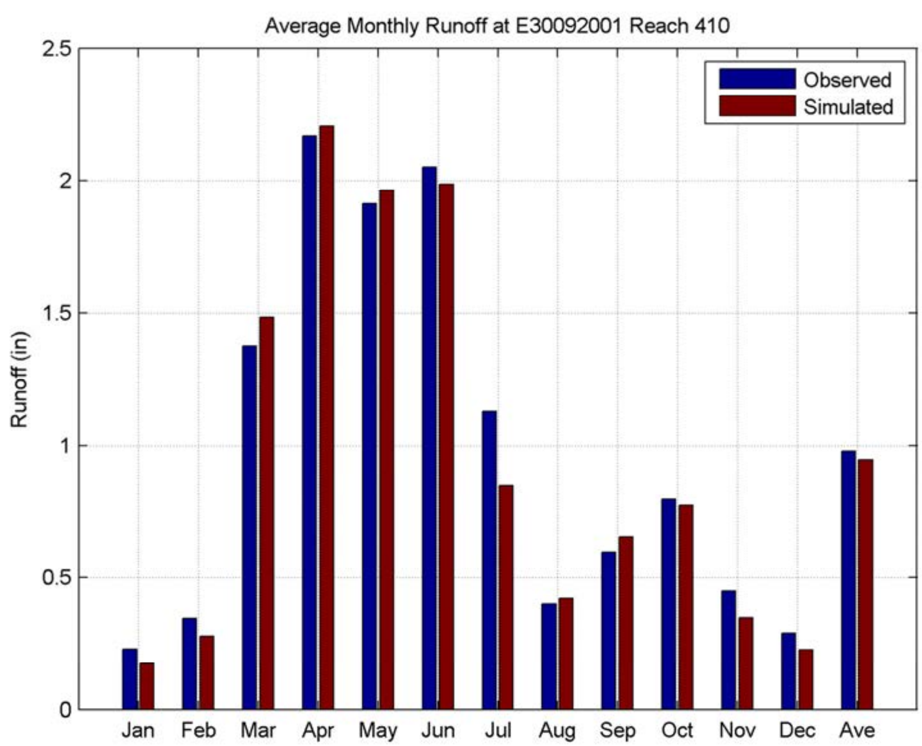

Figure 6. Average Monthly Runoff Plot Example.

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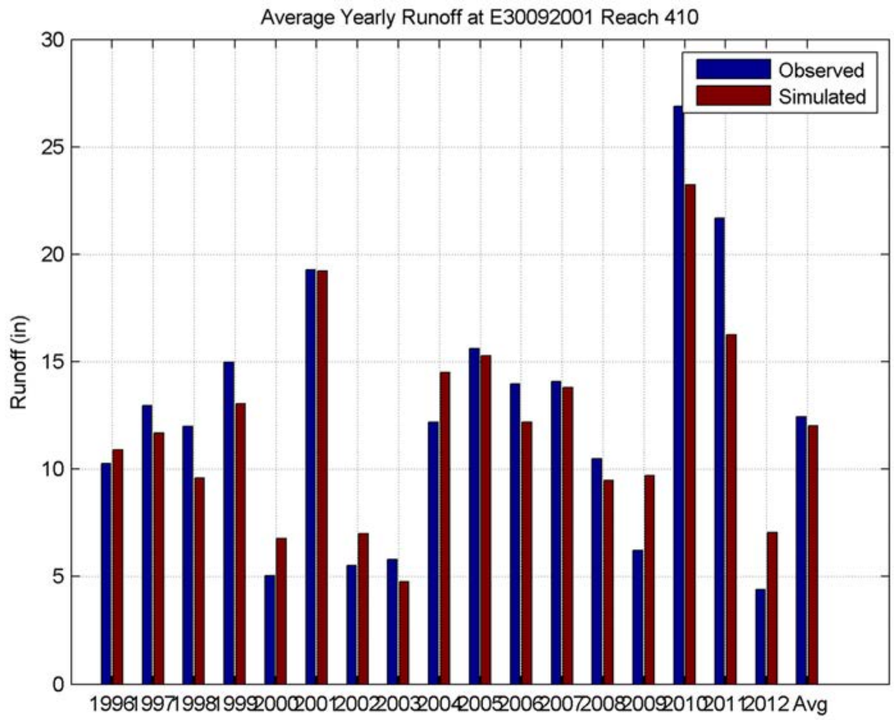

Figure 7. Average Yearly Runoff Plot Example.

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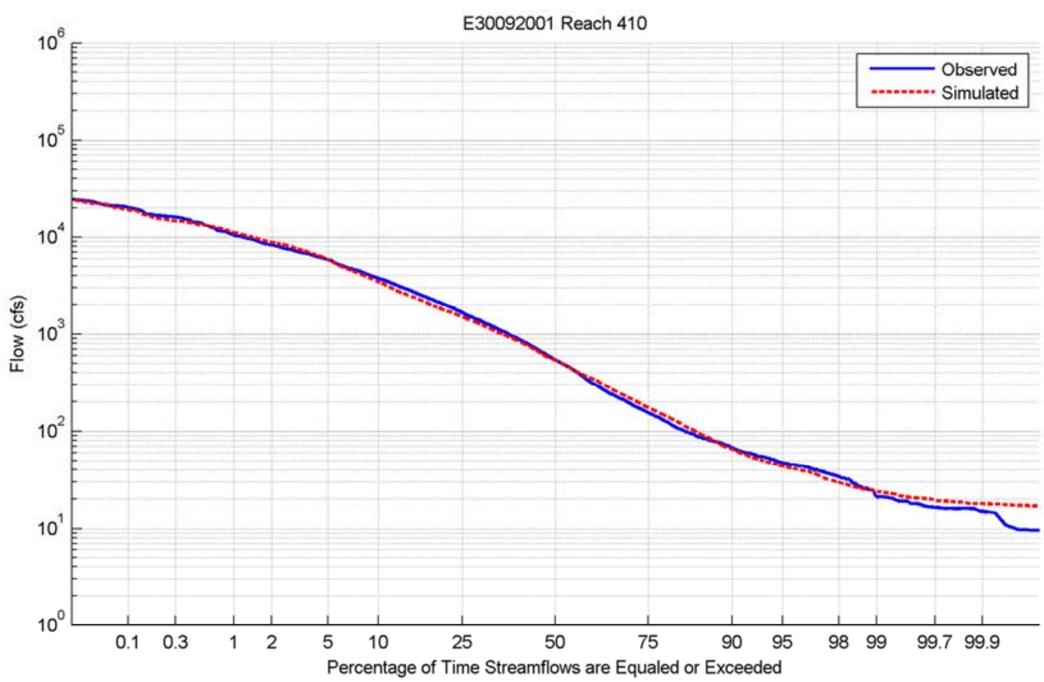

Figure 8. Flow-Duration Curve Example.

MODEL PERFORMANCE CRITERIA

The calibration parameters were adjusted to improve the performance of the model until the preferred 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. Donigian [2002] explains the developed performance criteria in detail.

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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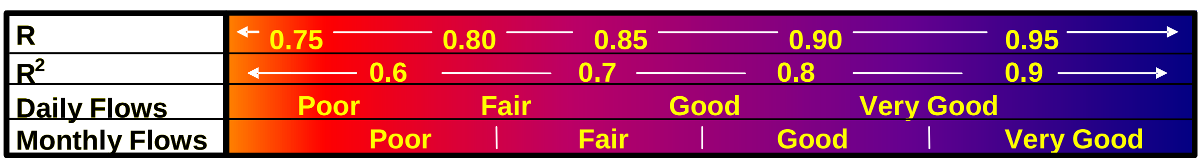

Figure 9. General Calibration/Validation *R* and R^2 Targets for HSPF Applications.

CALIBRATION RESULTS

Initial calibration was performed by using the primary downstream gages for each of the nine model applications in the Minnesota 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 Minnesota River Watershed most downstream, mainstem gages range from good 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 provides results for primary gages in the Minnesota River Watershed model applications. Table 4 summarizes the weighted water balance components at the outlets of the Minnesota River Watershed model applications, and Attachment B contains hydrologic calibration figures for primary gages in the Minnesota River Watershed.

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

Model Application	Observed Flow Gage	HSPF Reach I.D.	Total Runoff Volume			Monthly			Daily			Storm % Error	
			Obs (in)	Sim (in)	% Δ	R	R^2	MFE	R	R^2	MFE	Volume	Peak
Hawk-Yellow Medicine	H25075001	101	4.21	4.15	–1.39	0.94	0.88	0.88	0.89	0.79	0.79	0.28	–3.8
Chippewa	5304500	106	4.48	4.25	–5.12	0.95	0.90	0.89	0.90	0.81	0.80	–6.75	–6.16
Redwood	5316500	450	5.37	5.33	–0.68	0.95	0.90	0.90	0.90	0.82	0.82	0.48	–9.63
Middle Minnesota	5325000	530	72.68	71.66	–1.4	0.97	0.95	0.95	0.96	0.93	0.92	0.77	6.21
Cottonwood	5317000	490	5.96	5.97	0.25	0.94	0.89	0.88	0.91	0.83	0.83	4.21	–7.48
Blue Earth	5320000	410	12.42	12.01	–3.29	0.96	0.92	0.92	0.94	0.89	0.88	–2.44	–4.22
Watonwan	5319500	270	7.07	6.74	–4.63	0.95	0.91	0.91	0.91	0.83	0.83	–5.72	–5.62
Le Sueur	5320500	830	9.16	9.59	4.73	0.94	0.89	0.89	0.91	0.82	0.82	3.27	3.88
Lower Minnesota	5300000	310	83.4	80.76	–3.16	0.97	0.94	0.94	0.95	0.9	0.9	–0.36	9.06

Table 4. Summary of Water Balance Components

Water Balance Component	Water Balance Component Description	Percent of Water Supply								
		Hawk-Yellow Medicine	Chippewa	Redwood	Middle Minnesota	Cottonwood	Blue Earth	Watonwan	Le Sueur	Lower Minnesota
SURO	Surface outflow	0.37	0.28	0.33	0.73	0.53	0.67	0.64	2.04	0.83
IFWO	Interflow outflow	4.11	3.52	5.21	7.07	7.41	10.49	8.81	12.75	7.37
AGWO	Active groundwater outflow	11.54	16.37	13.59	12.96	12.89	14.60	12.58	14.48	14.53
IGWI	Inflow to inactive groundwater	0.22	0.32	0.15	0.17	0.14	0.16	0.50	0.56	0.17
CEPE	Evaporation from interception storage	17.79	23.25	19.24	18.54	19.48	17.61	17.08	17.42	17.87
UZET	Evapotranspiration from upper zone	17.42	12.08	17.99	19.58	19.48	22.62	22.86	18.97	20.97
LZET	Evapotranspiration from lower zone	43.85	41.74	41.42	38.38	37.96	31.47	33.66	30.54	35.92
AGWET	Evapotranspiration from active groundwater storage	1.85	1.80	0.51	0.87	0.53	0.38	0.54	0.34	0.62
BASET	Evapotranspiration from active groundwater outflow (baseflow)	2.85	0.64	1.54	1.70	1.57	1.99	3.33	2.91	1.72

WATER-QUALITY CALIBRATION

The water-quality constituents that were modeled in the Minnesota River Watershed include total suspended solids (TSS), temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), and nutrients. Fecal coliform was also built into the existing Chippewa and Hawk-Yellow Medicine applications but was not recalibrated. The methods described in the following section provide RESPEC with the ability to estimate TSS, temperature, DO, and nutrient loads; calculate contributions from point, nonpoint, and atmospheric sources where necessary; and provide a means to evaluate the impacts of alternative management strategies to reduce these loads and improve water-quality conditions. The model applications apply empirical buildup/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 2012) 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, which allows 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. 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 [U.S. 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

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 U.S. 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 [U.S. 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 that represent 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 U.S. 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 the 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 25th percentile of the simulated bed shear stress for TAUCD and the 75th 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.

A significant amount of tile drainage exists in the Minnesota River Watershed. This artificial drainage is being implicitly represented in HSPF using a shallow subsurface flow component called interflow. HSPF does not inherently simulate sediment in interflow so sediment concentrations were added to interflow from cropland land-use categories using the GENER module for HUC8 07020006–07020012. Interflow was given a concentration based on the simulated concentration multiplied by a reduction factor to account for the settling of sediment before it enters the artificial drainage network. Similarly, the Chippewa model application has groundwater-associated solids loadings for the agriculture and pasture land classes [Tetra Tech, 2012]. The Hawk-Yellow Medicine model application also adds additional groundwater-associated sediment by using a multiplication factor on groundwater flow (AGWO) in the MASS-LINK because an interflow loading had little effect on average concentration [Tetra Tech, 2011].

Detached sediment storage (DETS) in HSPF represents the sediment on the surface that is available to wash off. To represent agricultural practices on cropland, DETS was increased at four different days of the year to simulate the increases in sediment available to wash off from plowing, planting, cultivating, and harvesting practices. Cropland classified as high-till was given higher increases in DETS than cropland classified as low-till.

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

The model application simulates in-stream temperature (using HTRCH), organic and inorganic nitrogen, total ammonia, organic and inorganic phosphorus (using NUTRX), DO and BOD (using OXRX), and algae (using PLANK). The adsorption/desorption of 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 point-source permitting support. Initial calibration parameters were estimated from 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]. Information was used from the 2010 census for South Dakota and Iowa 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 Systems (GIS) for HUC8 07020006–07020012. The average number of individuals per household was then used to estimate the number of persons served by ISTS. For HUC8 07020004 and 07020005, the number of persons served by ISTS was estimated by applying a factor of 0.00381 to the total agricultural acreage for each subwatershed [Tetra Tech, 2011; 2012]. Loading rates, which incorporated septic failure rates, were developed for ammonia, nitrate, orthophosphate, carbonaceous BOD–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 and the USGS. Tables for stream and lake data of applicable constituents, in addition to figures that illustrate the spatial locations for each Minnesota River model application are illustrated 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.

The final results from the most data-intensive downstream reach in the Minnesota River Watershed, which falls in Reach 610 of the Middle Minnesota River Watershed, are included in Attachment D. 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 Minnesota River deliverables results folder.

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Please contact me if you would like to discuss these methods or provided comments regarding the calibration and validation of the Minnesota River HSPF Watershed model applications.

Sincerely,

Seth J. Kenner
Staff Engineer

SJK:amk

Project Central File 2429 — Category A

ATTACHMENT A

OBSERVED FLOW GAGE LOCATIONS FOR THE MINNESOTA RIVER WATERSHED MODEL APPLICATIONS

RSI-2429-14-011

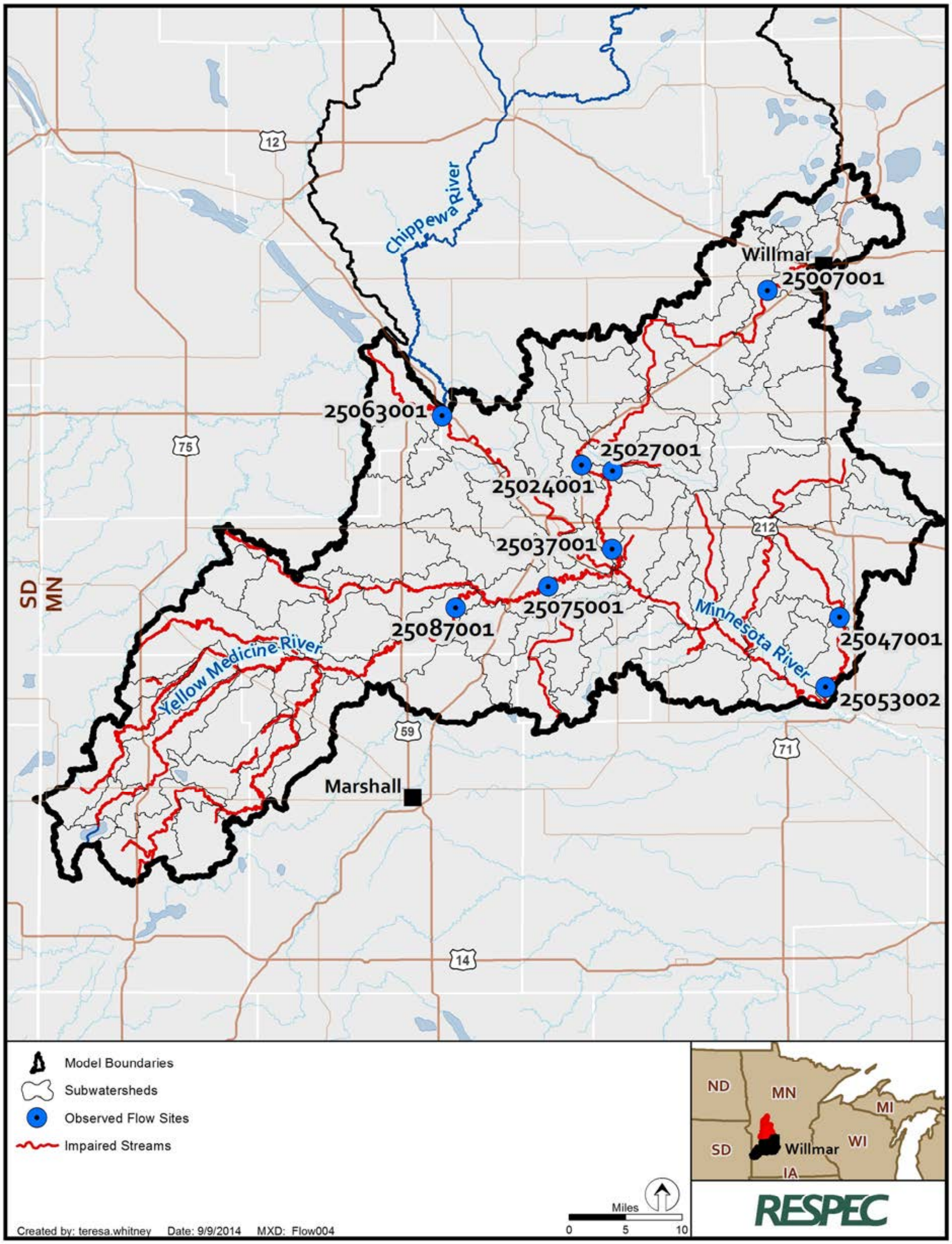

Figure A-1. Flow Calibration Gages Within the Hawk-Yellow Medicine Watershed.

RSI-2429-14-012

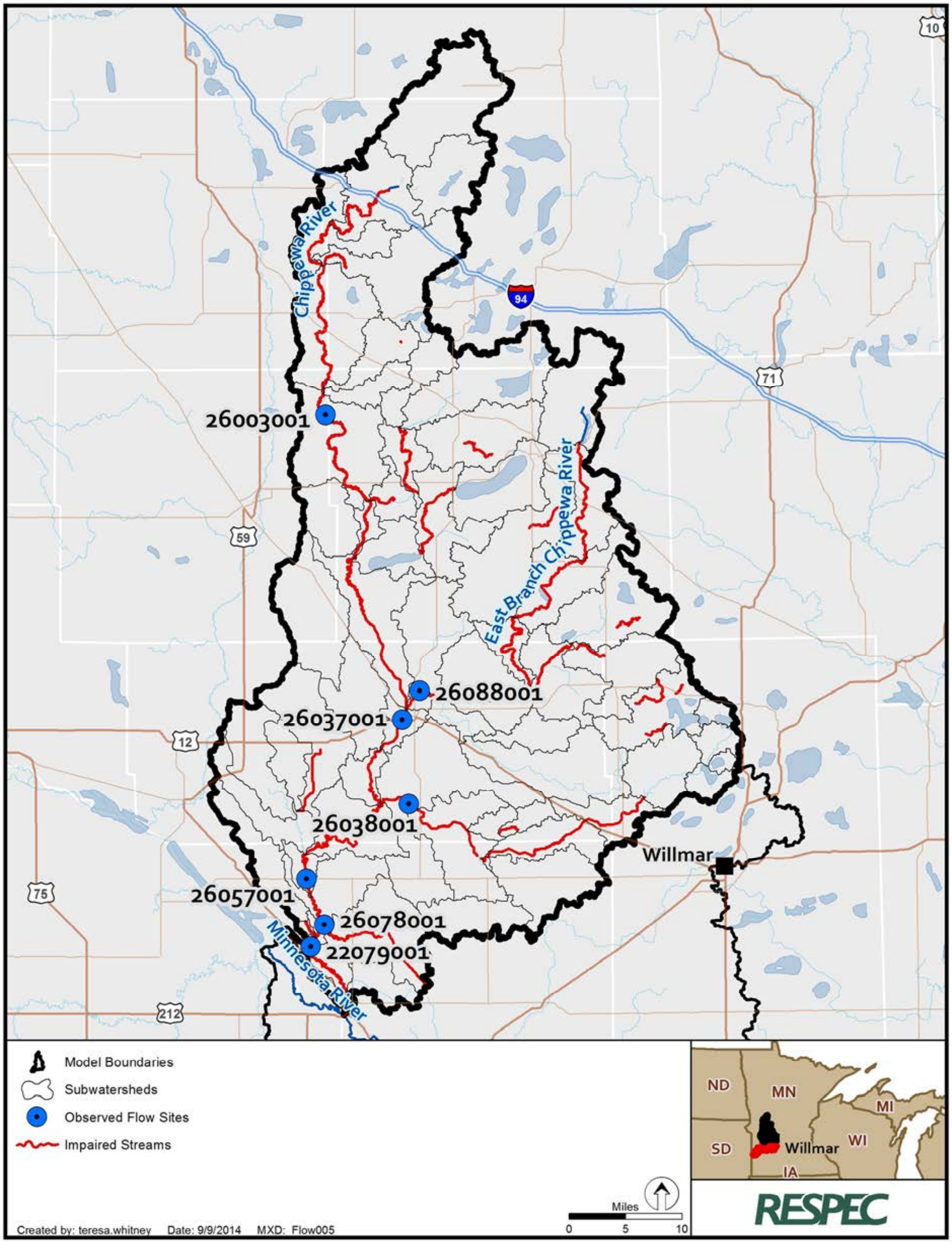

Figure A-2. Flow Calibration Gages Within the Chippewa Watershed.

RSI-2429-14-013

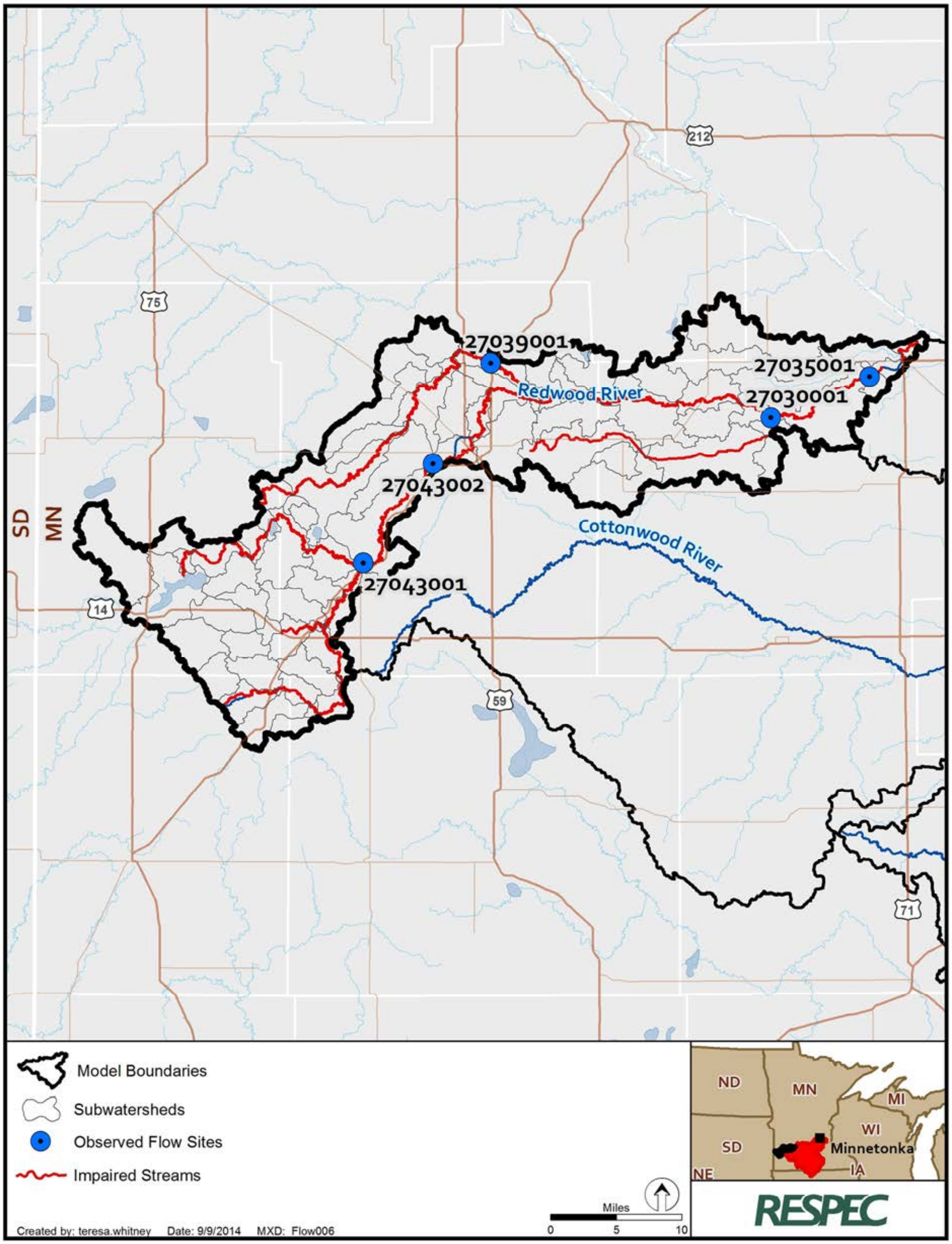

Figure A-3. Flow Calibration Gages Within the Redwood Watershed.

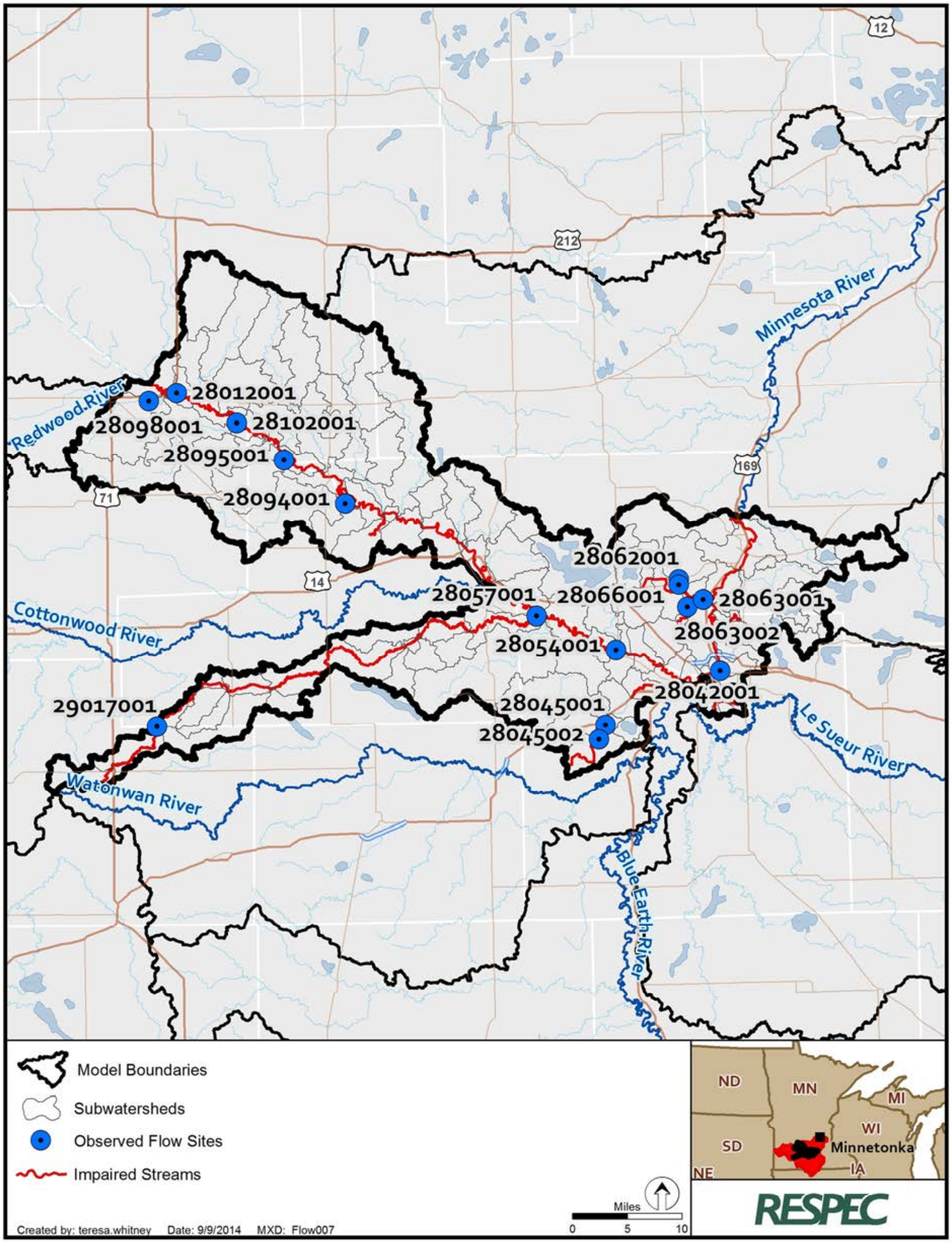

Figure A-4. Flow Calibration Gages Within the Middle Minnesota Watershed.

RSI-2429-14-015

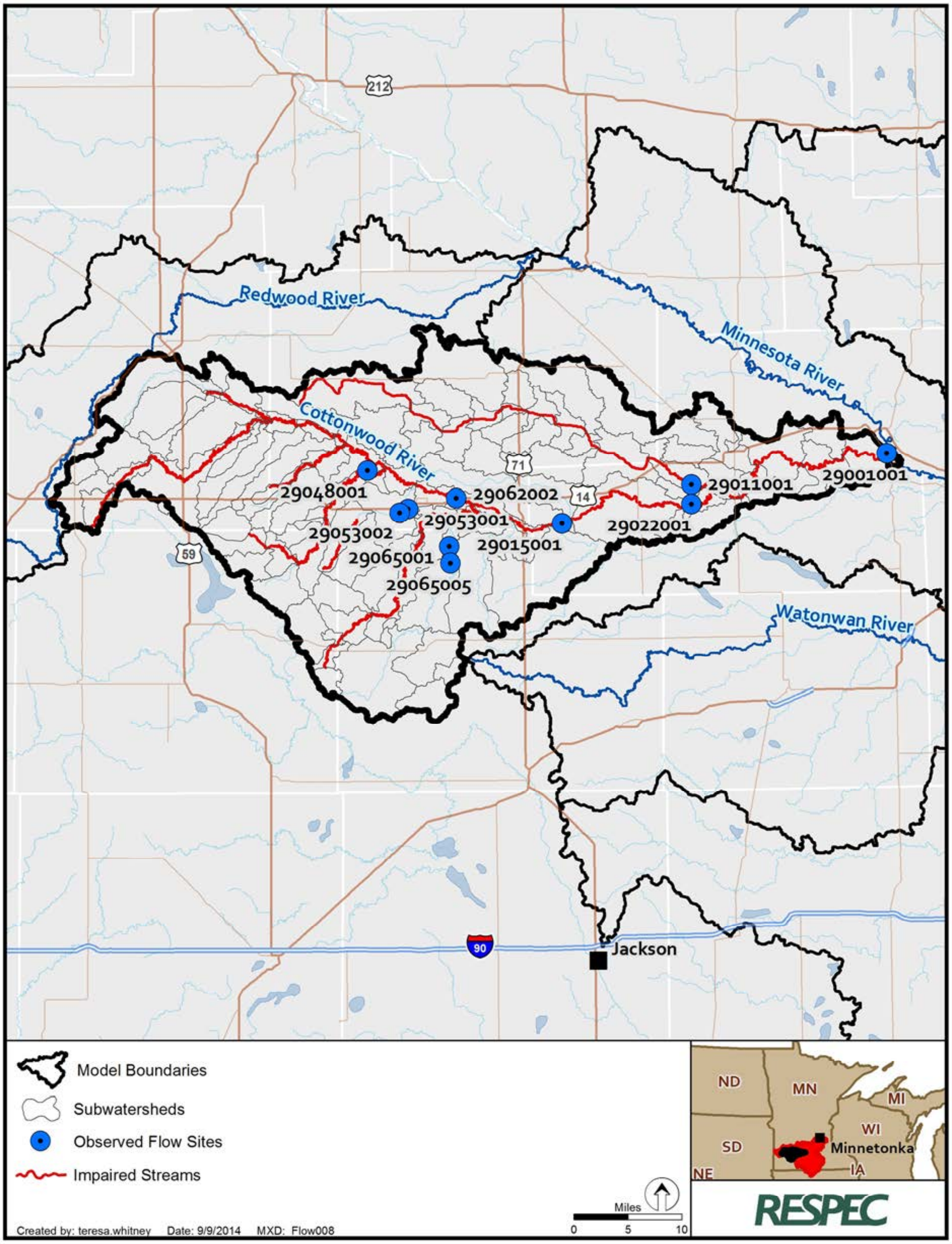

Figure A-5. Flow Calibration Gages Within the Cottonwood Watershed.

RSI-2429-14-016

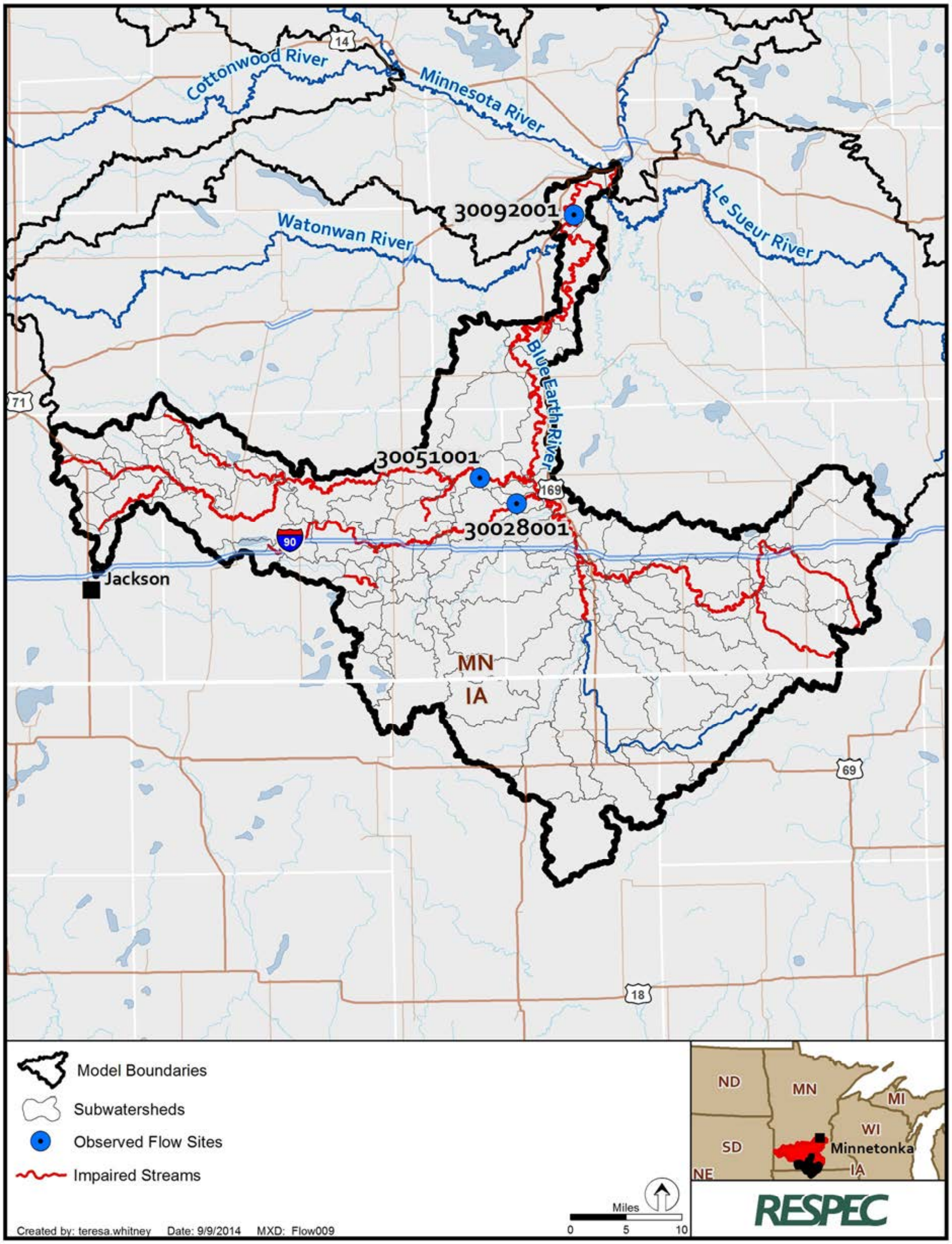

Figure A-6. Flow Calibration Gages Within the Blue Earth Watershed.

RSI-2429-14-017

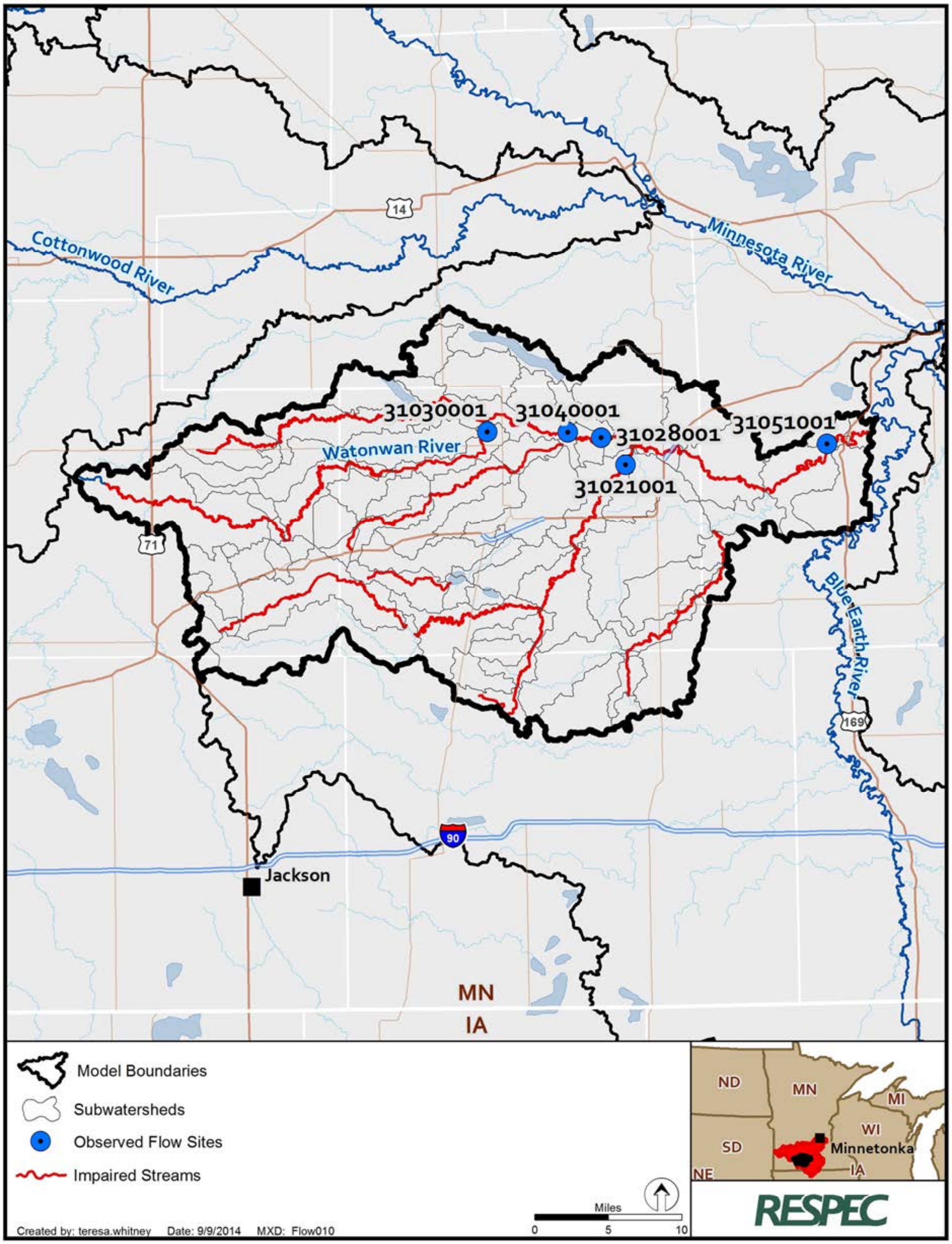

Figure A-7. Flow Calibration Gages Within the Watonwan Watershed.

RSI-2429-14-018

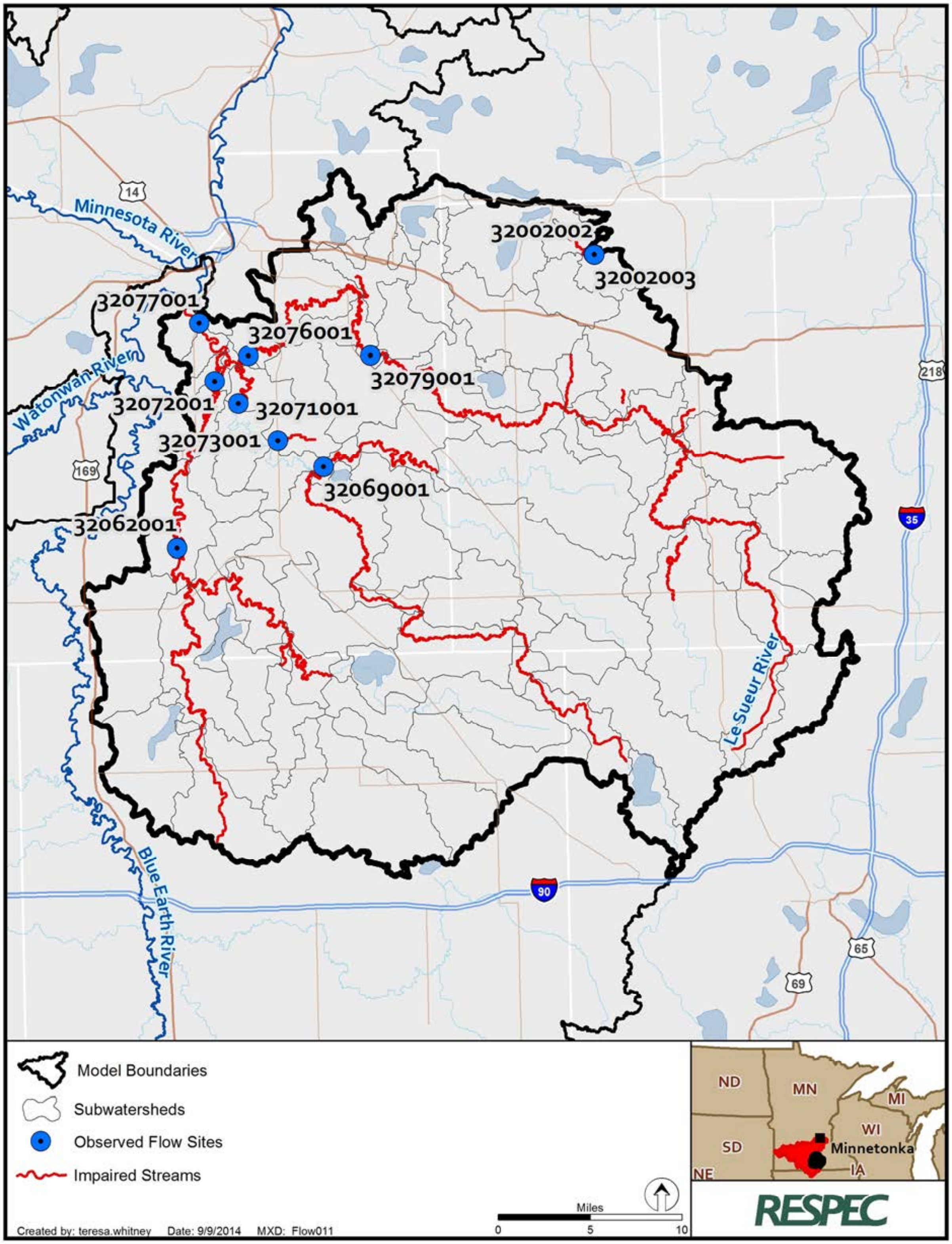

Figure A-8. Flow Calibration Gages Within the Le Sueur Watershed.

RSI-2429-14-019

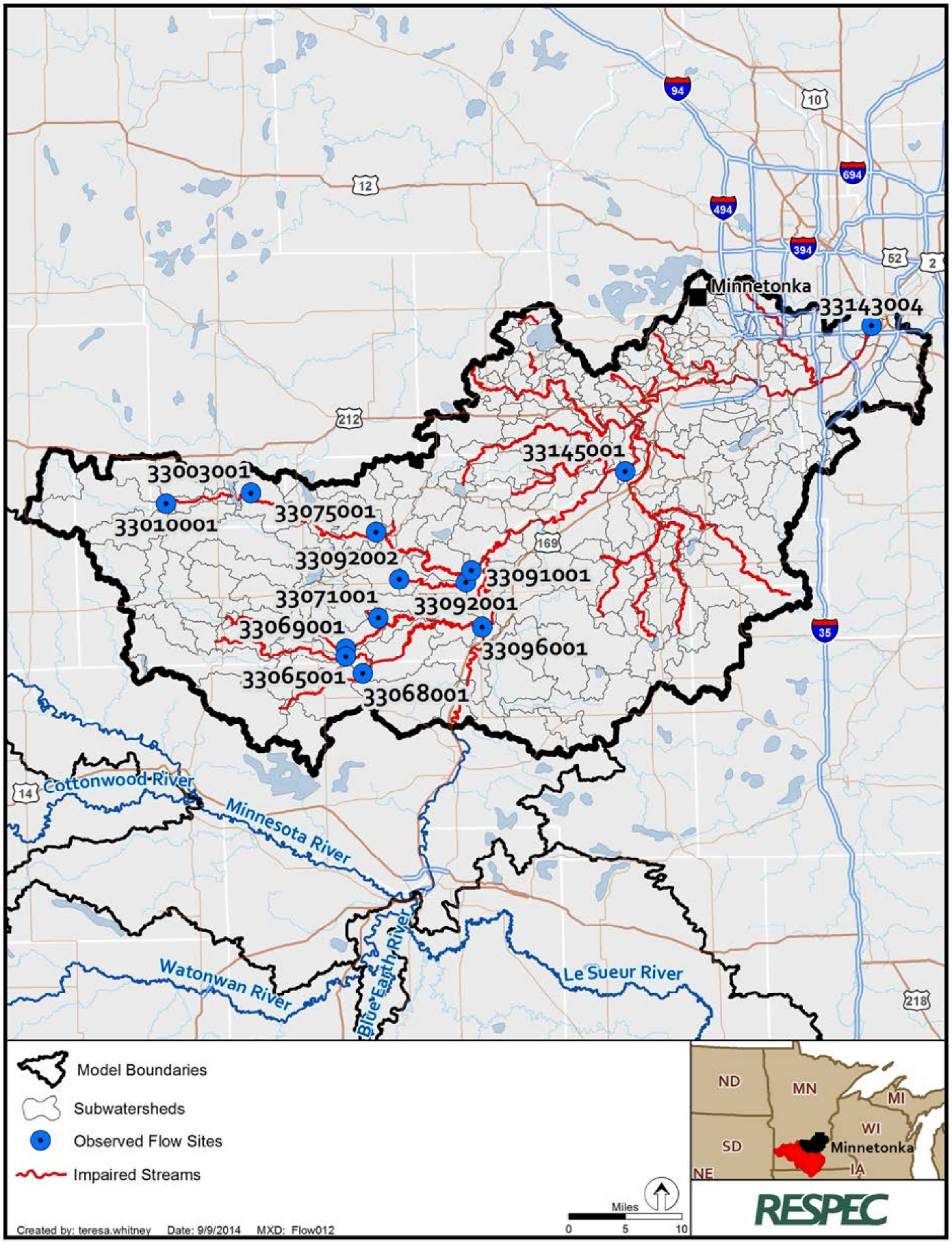

Figure A-9. Flow Calibration Gages Within the Lower Minnesota Watershed.

ATTACHMENT B

HYDROLOGY CALIBRATION RESULTS AT PRIMARY GAGES FOR THE MINNESOTA RIVERWATERSHED MODEL APPLICATIONS

RSI-2429-14-020

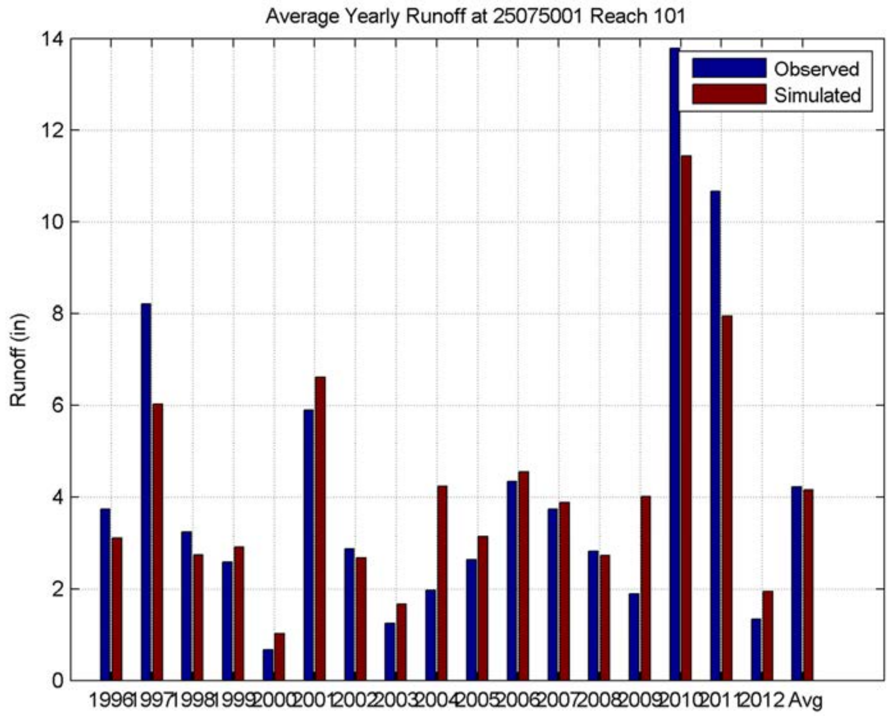

Figure B-1. Average Yearly Runoff–Hawk-Yellow Medicine Watershed (Reach 101).

RSI-2429-14-021

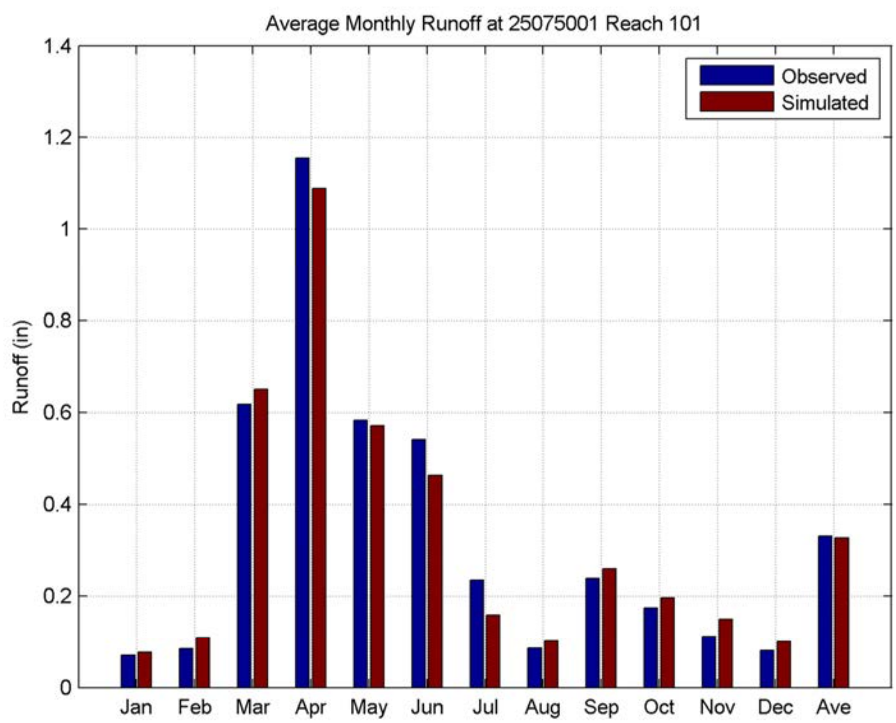

Figure B-2. Average Monthly Runoff–Hawk-Yellow Medicine Watershed (Reach 101).

RSI-2429-14-022

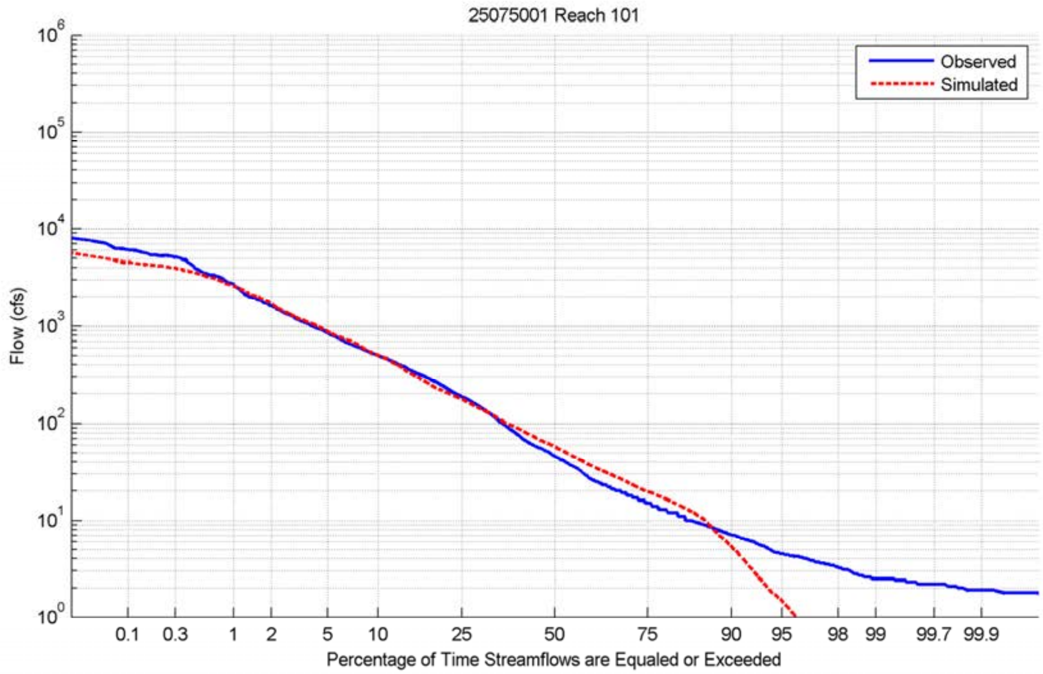

Figure B-3. Flow-Duration Plot–Hawk-Yellow Medicine Watershed (Reach 101).

RSI-2429-14-023

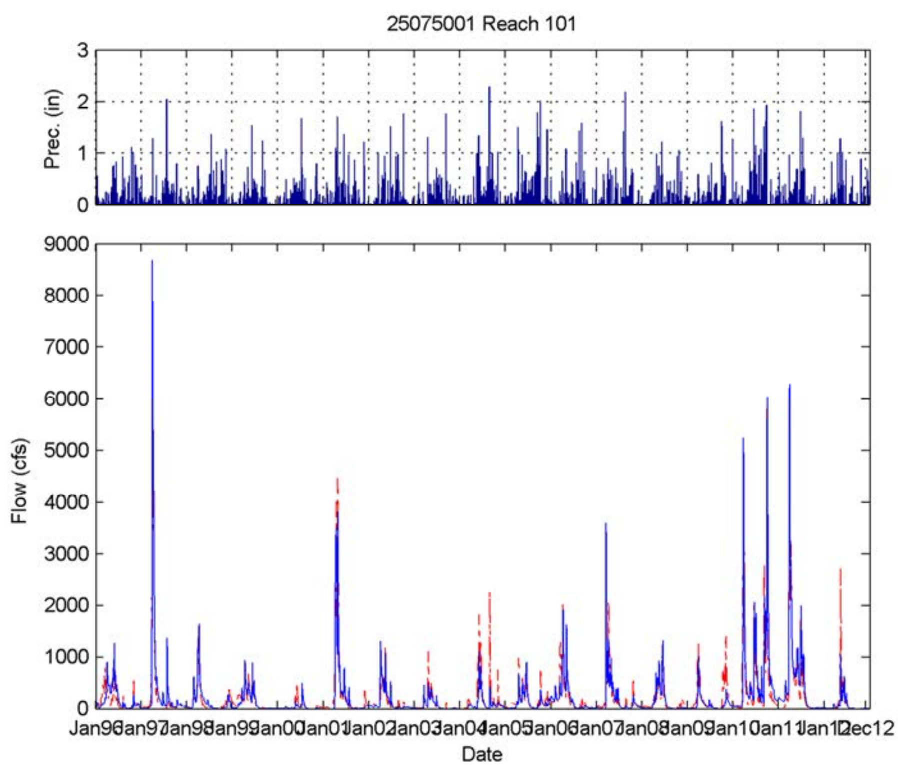

Figure B-4. Daily Hydrographs–Hawk-Yellow Medicine Watershed (Reach 101).

RSI-2429-14-024

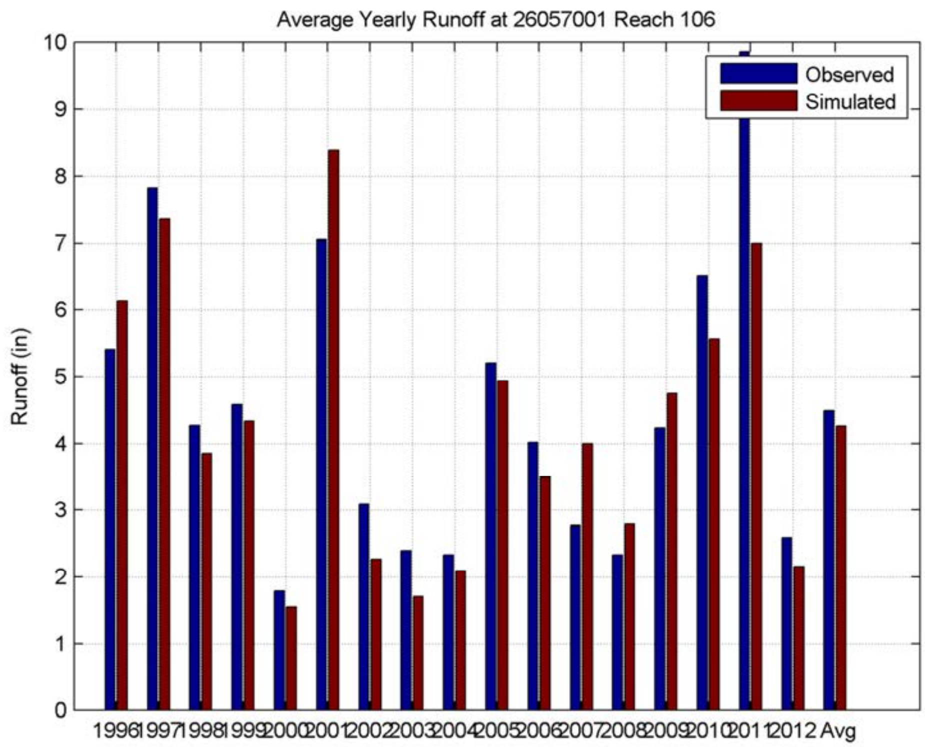

Figure B-5. Average Yearly Runoff–Chippewa Watershed (Reach 106).

RSI-2429-14-025

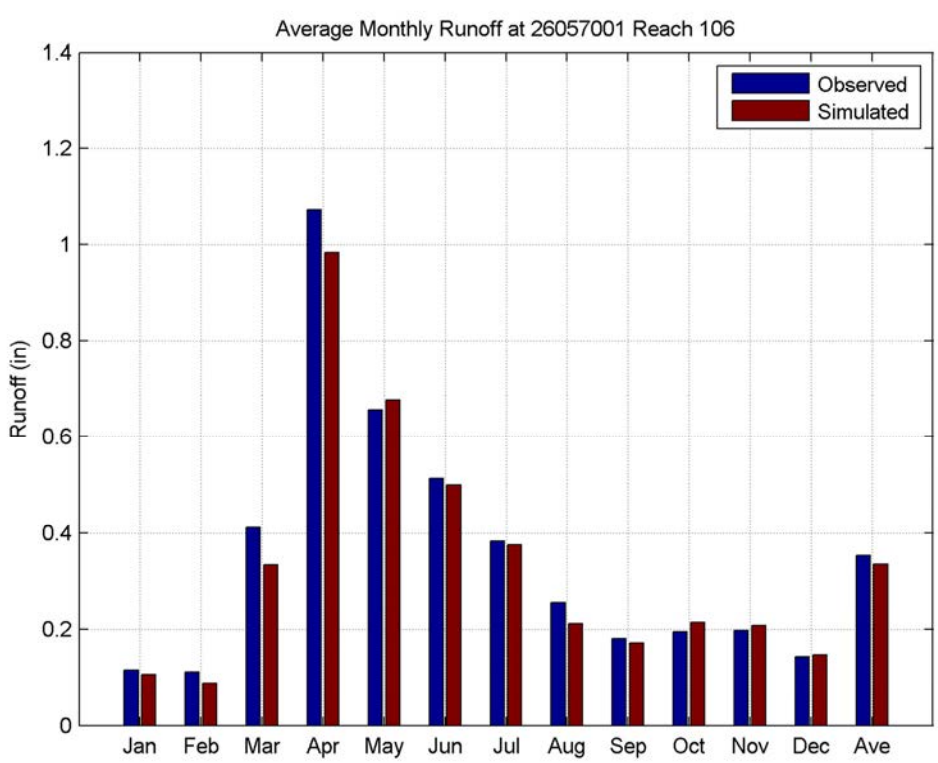

Figure B-6. Average Monthly Runoff–Chippewa Watershed (Reach 106).

RSI-2429-14-026

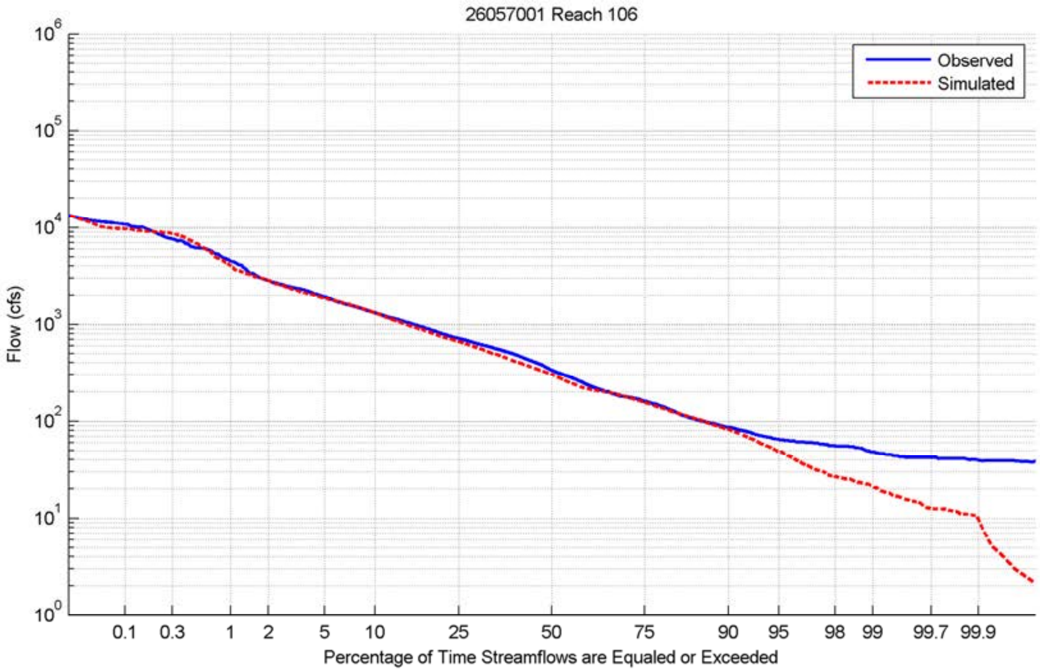

Figure B-7. Flow-Duration Plot–Chippewa Watershed (Reach 106).

RSI-2429-14-027

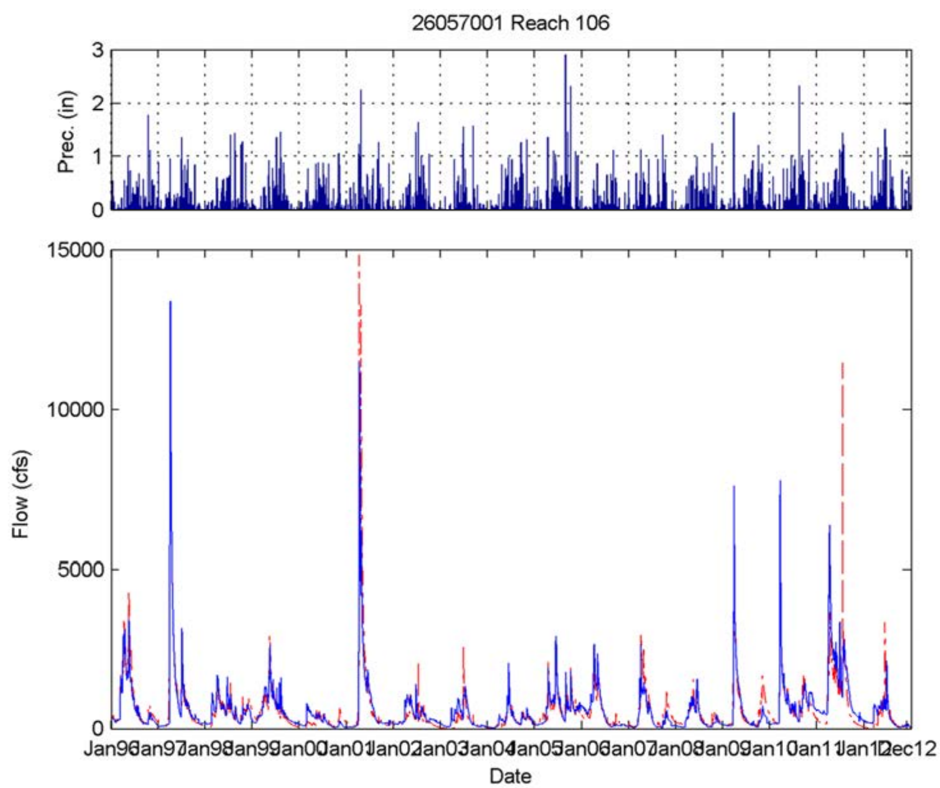

Figure B-8. Daily Hydrographs–Chippewa Watershed (Reach 106).

RSI-2429-14-028

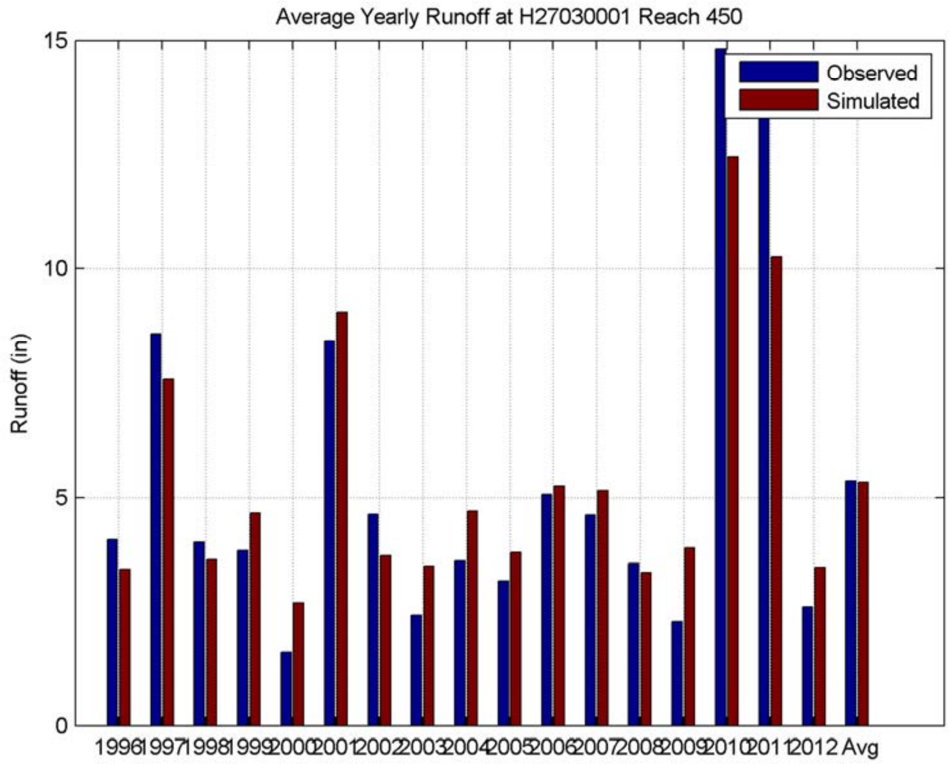

Figure B-9. Average Yearly Runoff–Redwood Watershed (Reach 450).

RSI-2429-14-029

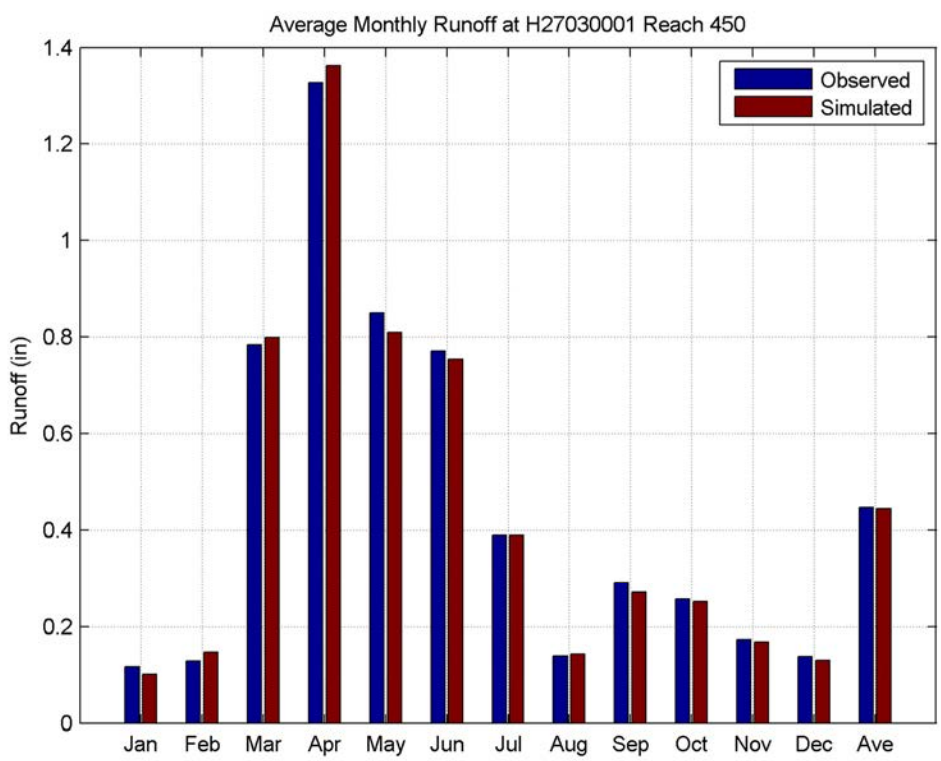

Figure B-10. Average Monthly Runoff–Redwood Watershed (Reach 450).

RSI-2429-14-030

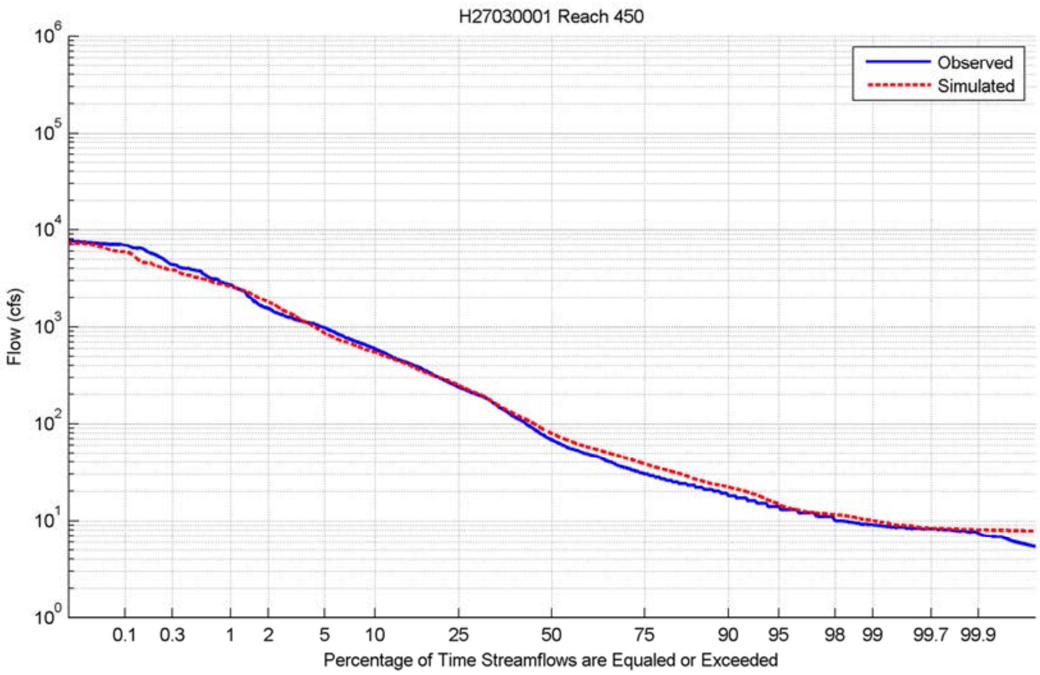

Figure B-11. Flow-Duration Plot–Redwood Watershed (Reach 450).

RSI-2429-14-031

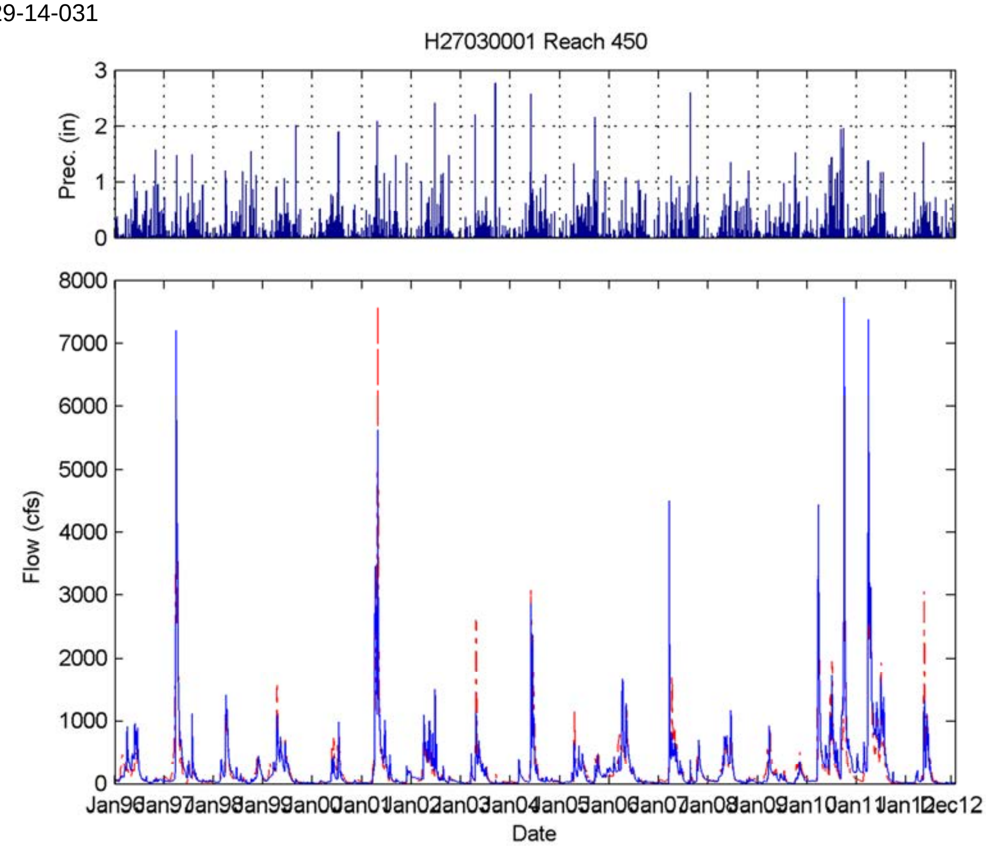

Figure B-12. Daily Hydrographs–Redwood Watershed (Reach 450).

RSI-2429-14-032

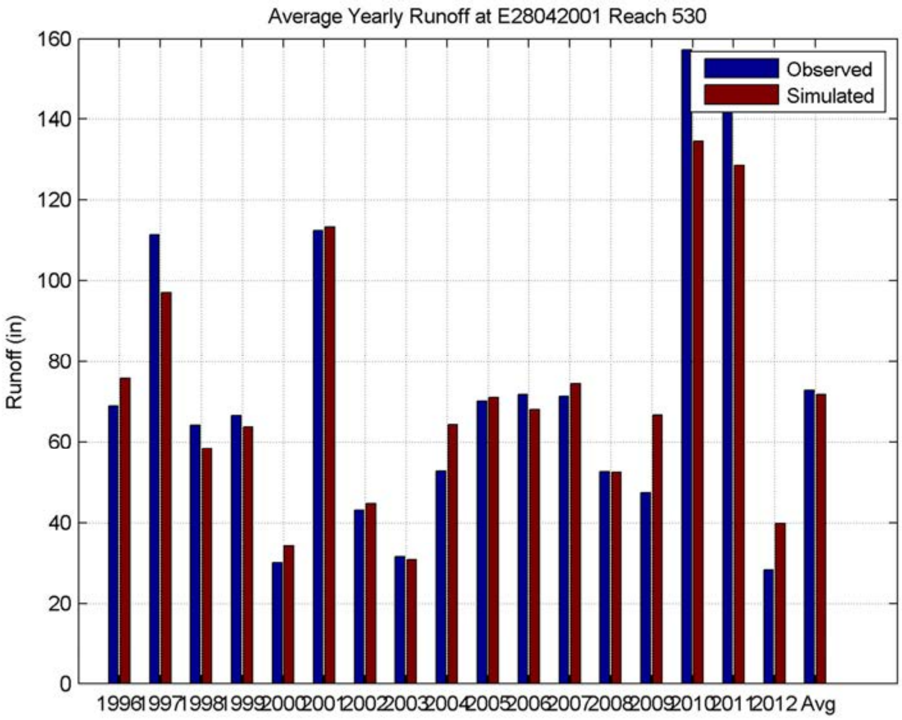

Figure B-13. Average Yearly Runoff–Middle Minnesota Watershed (Reach 530).

RSI-2429-14-033

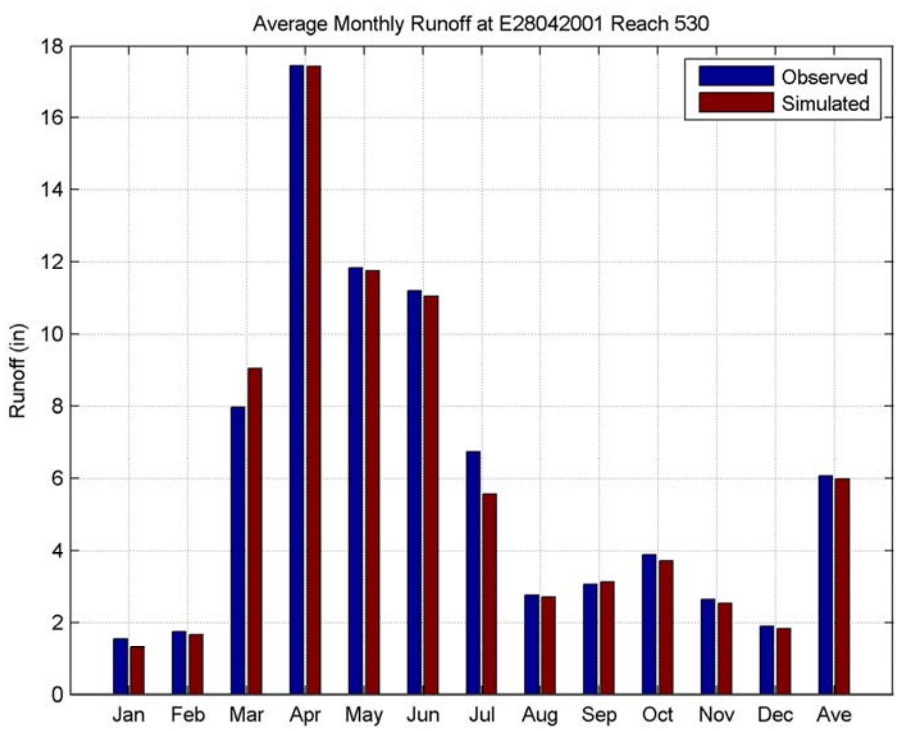

Figure B-14. Average Monthly Runoff–Middle Minnesota Watershed (Reach 530).

RSI-2429-14-034

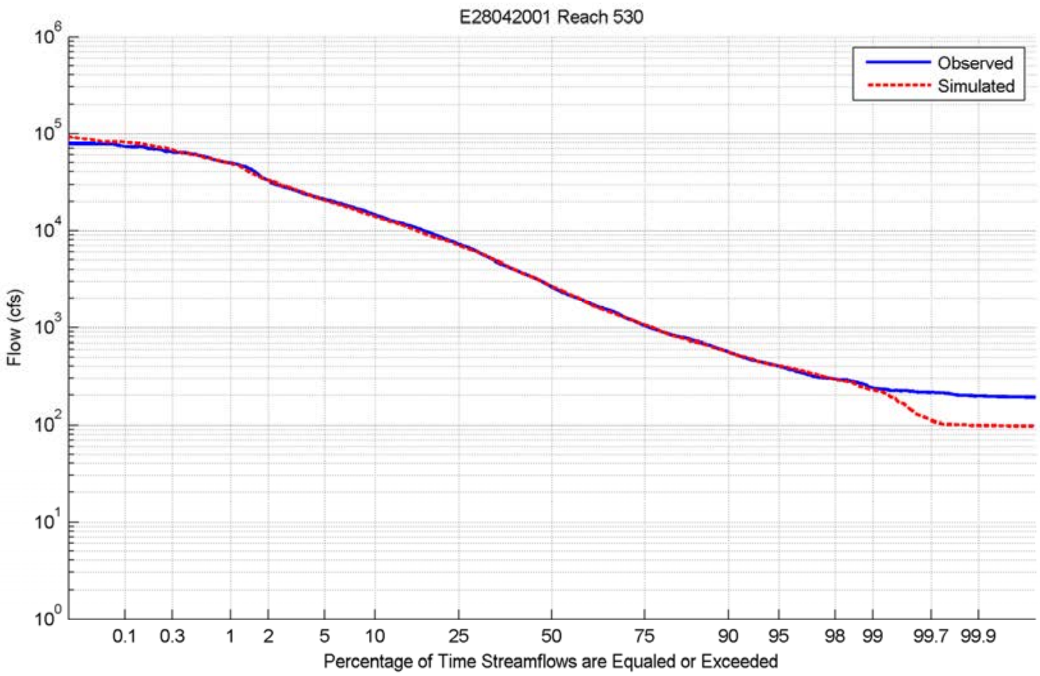

Figure B-15. Flow-Duration Plot–Middle Minnesota Watershed (Reach 530).

RSI-2429-14-035

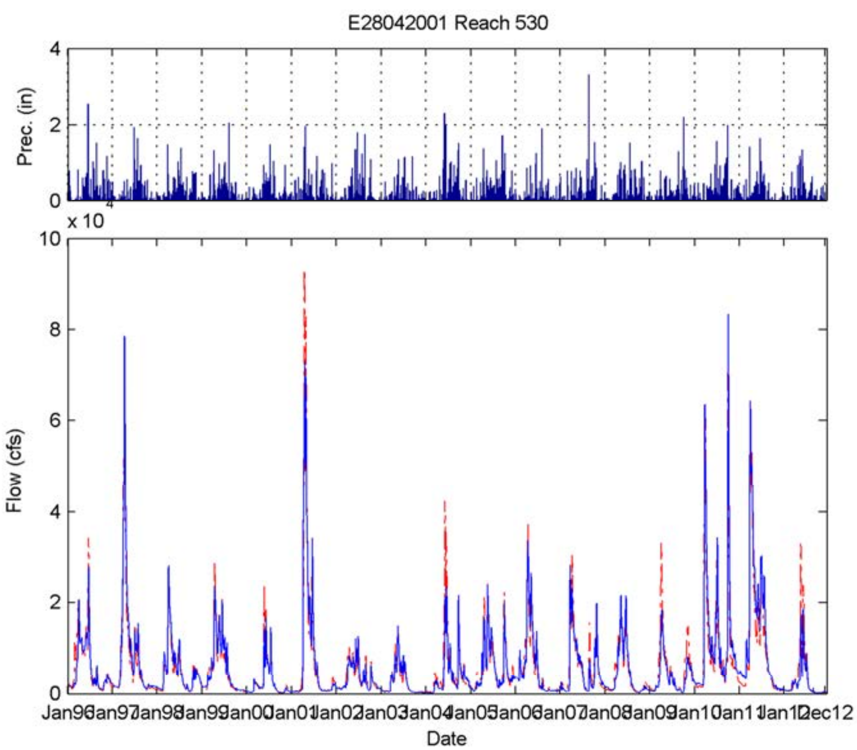

Figure B-16. Daily Hydrographs–Middle Minnesota Watershed (Reach 530).

RSI-2429-14-036

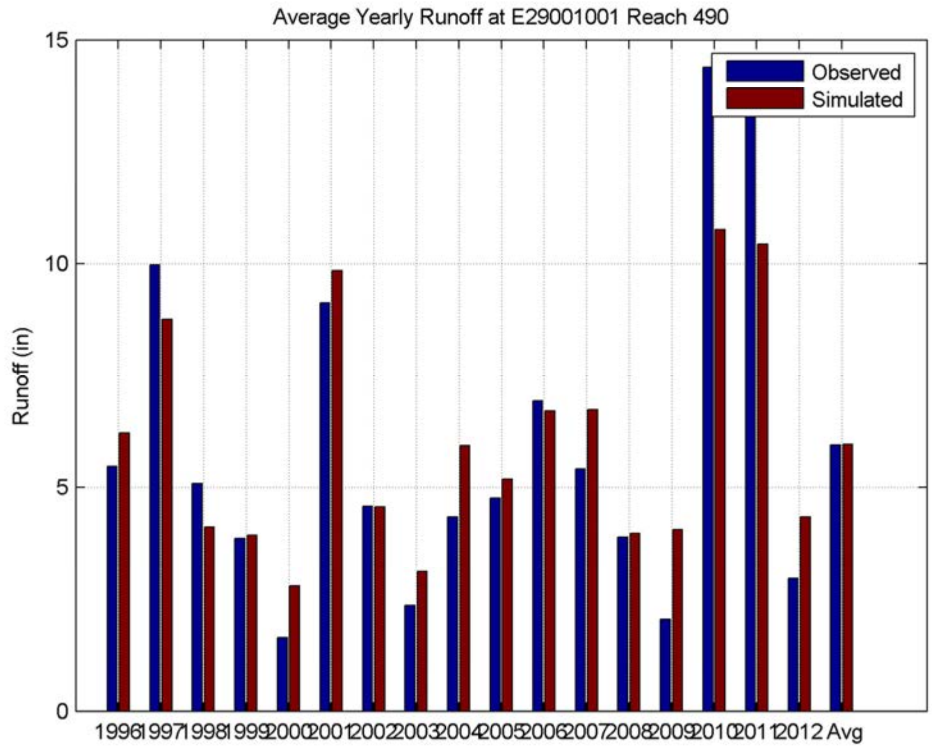

Figure B-17. Average Yearly Runoff–Cottonwood Watershed (Reach 490).

RSI-2429-14-037

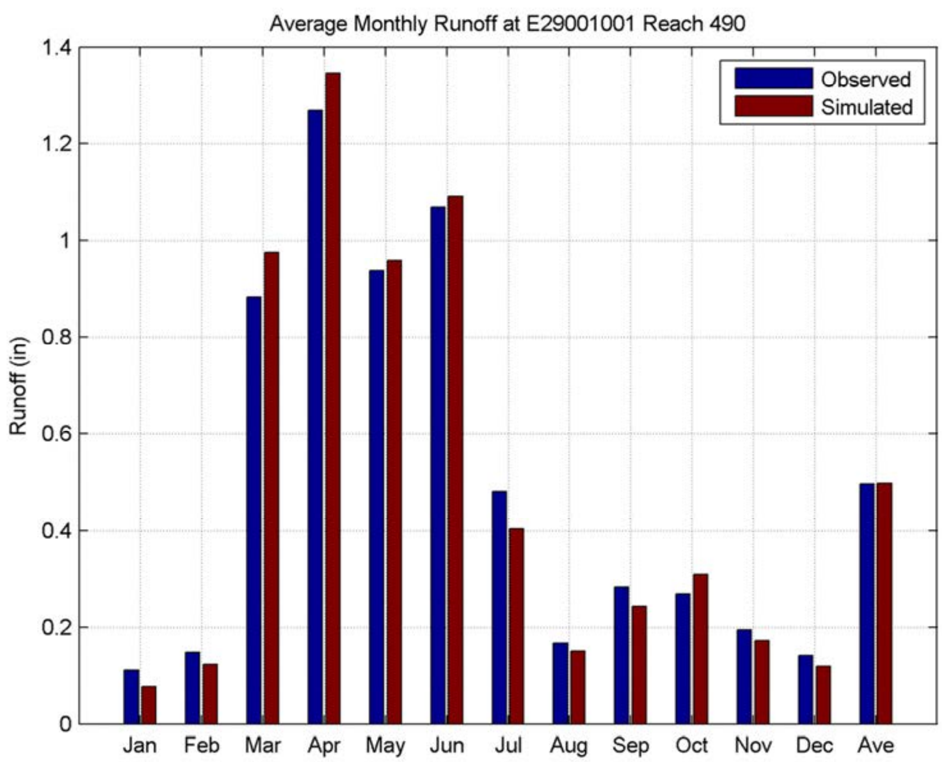

Figure B-18. Average Monthly Runoff–Cottonwood Watershed (Reach 490).

RSI-2429-14-038

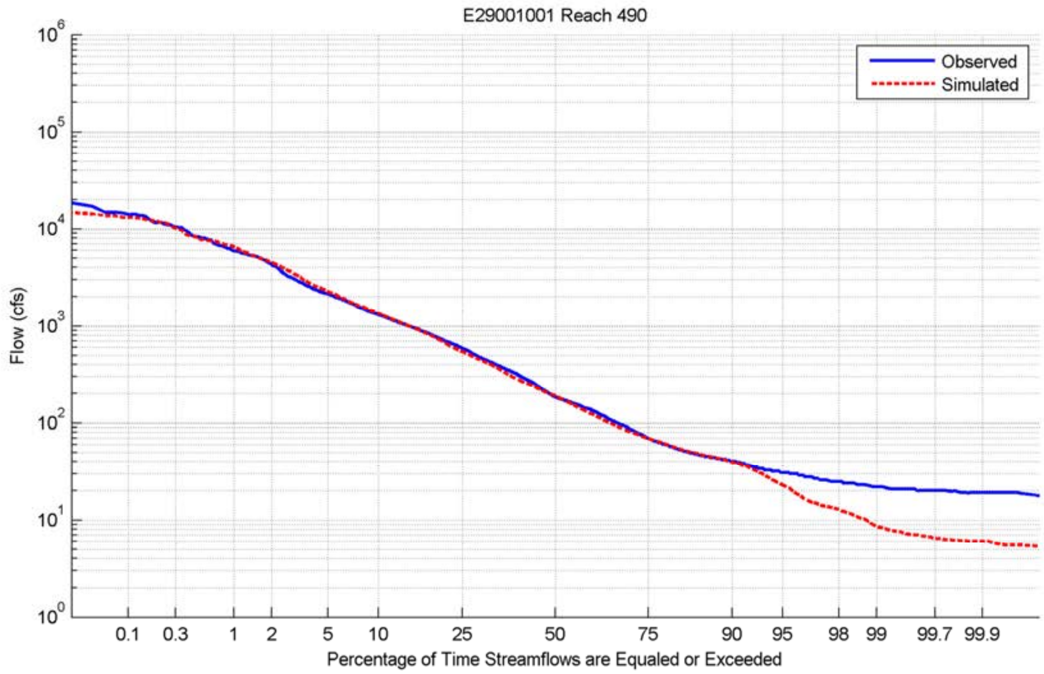

Figure B-19. Flow-Duration Plot–Cottonwood Watershed (Reach 490).

RSI-2429-14-039

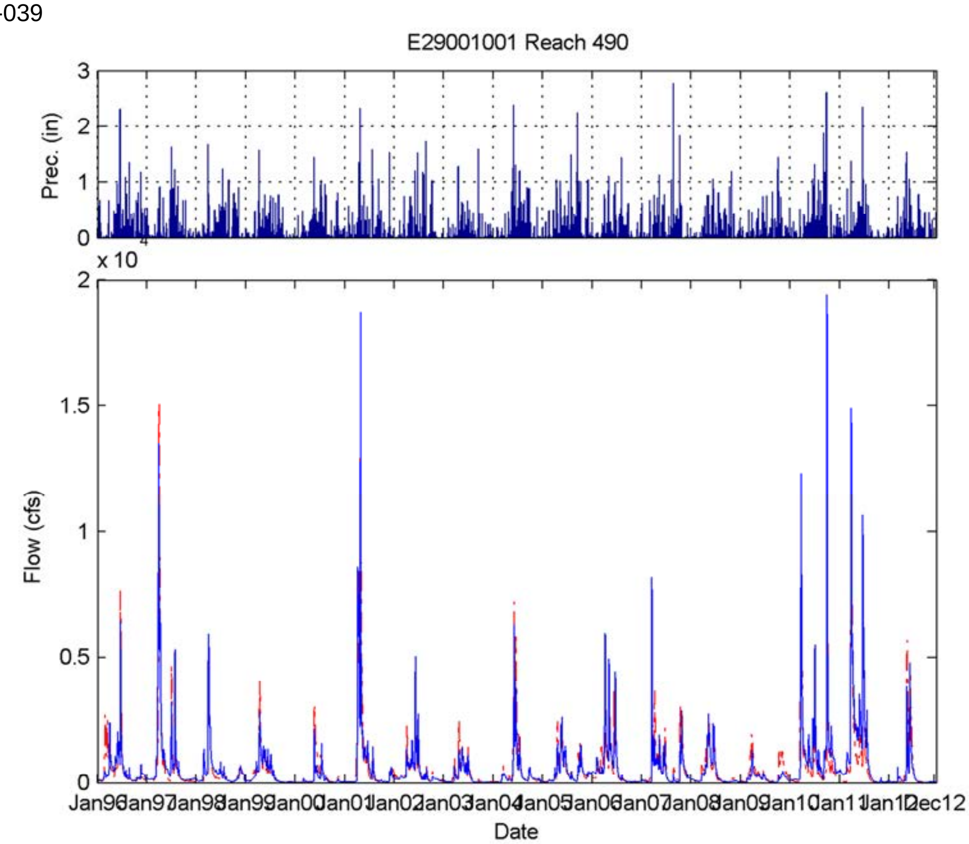

Figure B-20. Daily Hydrographs–Cottonwood Watershed (Reach 490).

RSI-2429-14-040

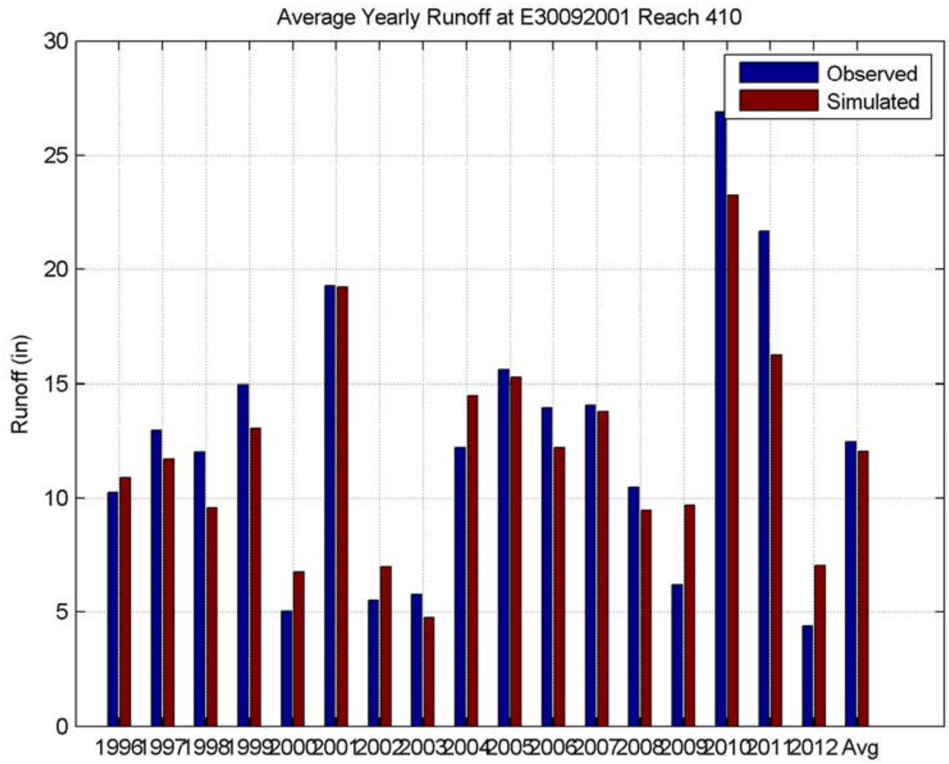

Figure B-21. Average Yearly Runoff–Blue Earth Watershed (Reach 410).

RSI-2429-14-041

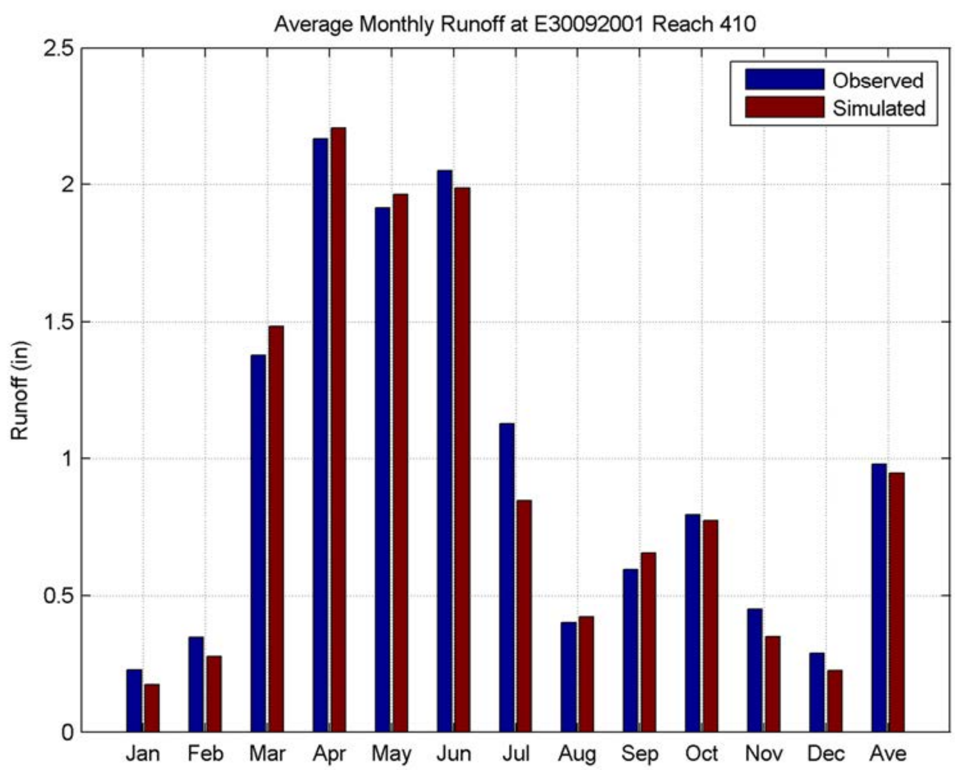

Figure B-22. Average Monthly Runoff–Blue Earth Watershed (Reach 410).

RSI-2429-14-042

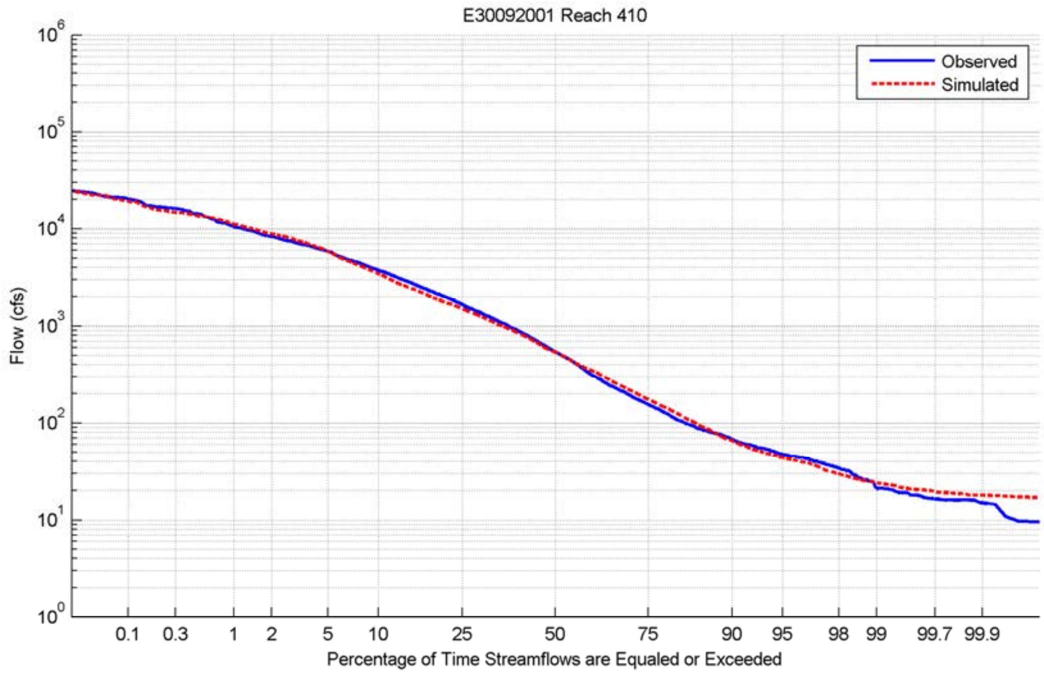

Figure B-23. Flow-Duration Plot–Blue Earth Watershed (Reach 410).

RSI-2429-14-043

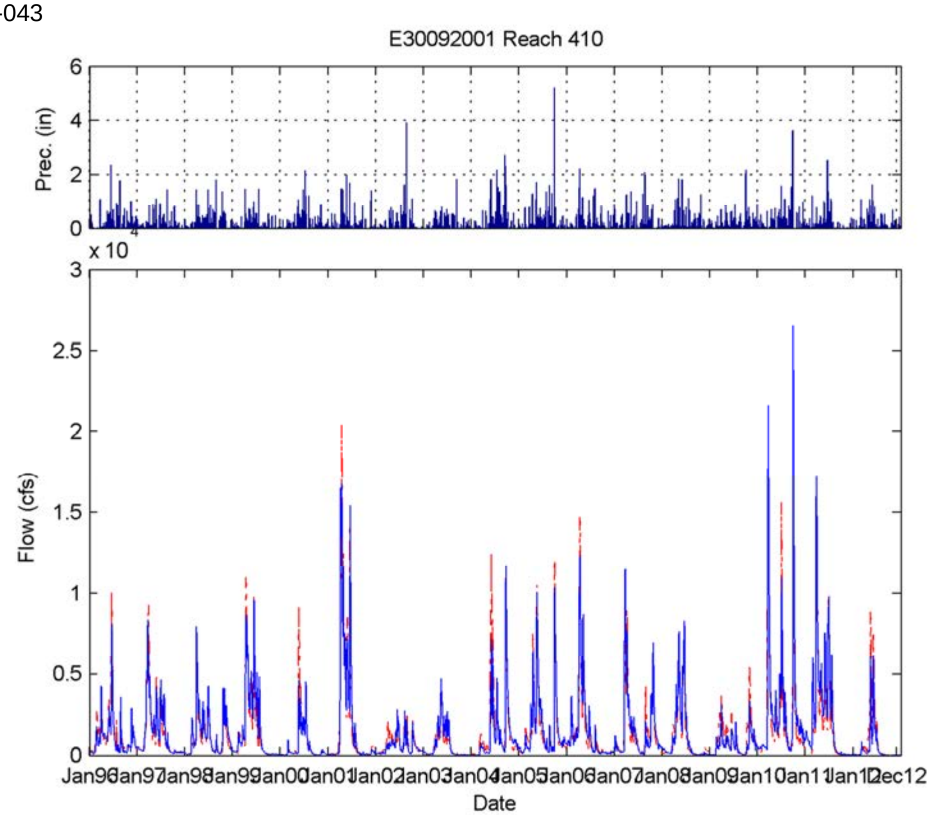

Figure B-24. Daily Hydrographs–Blue Earth Watershed (Reach 410).

RSI-2429-14-044

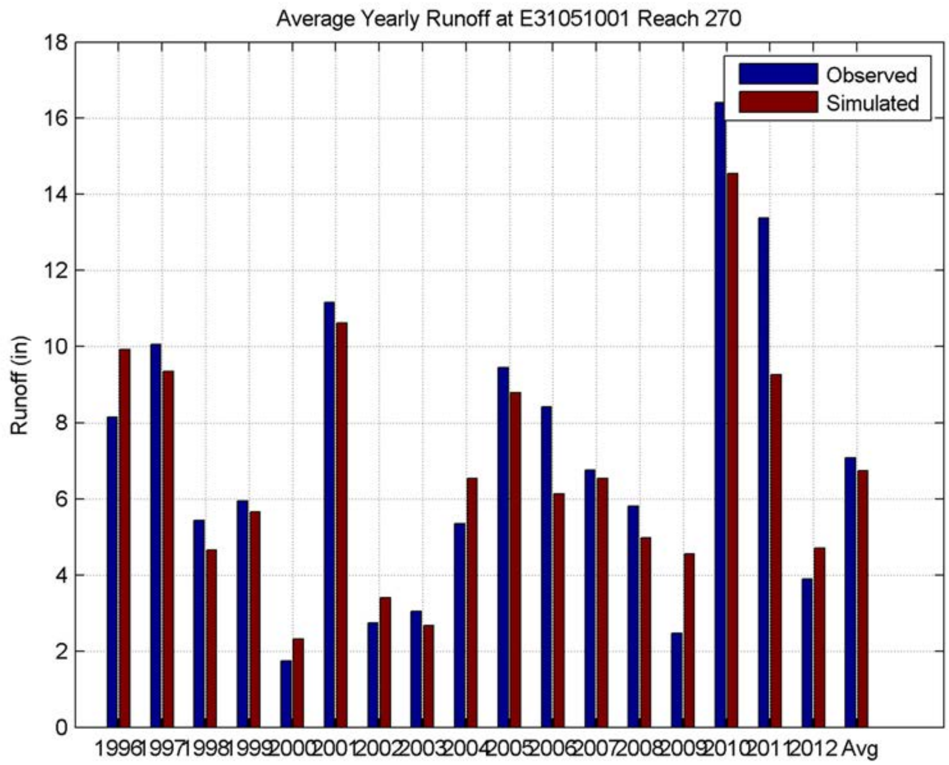

Figure B-25. Average Yearly Runoff–Watonwan Watershed (Reach 270).

RSI-2429-14-045

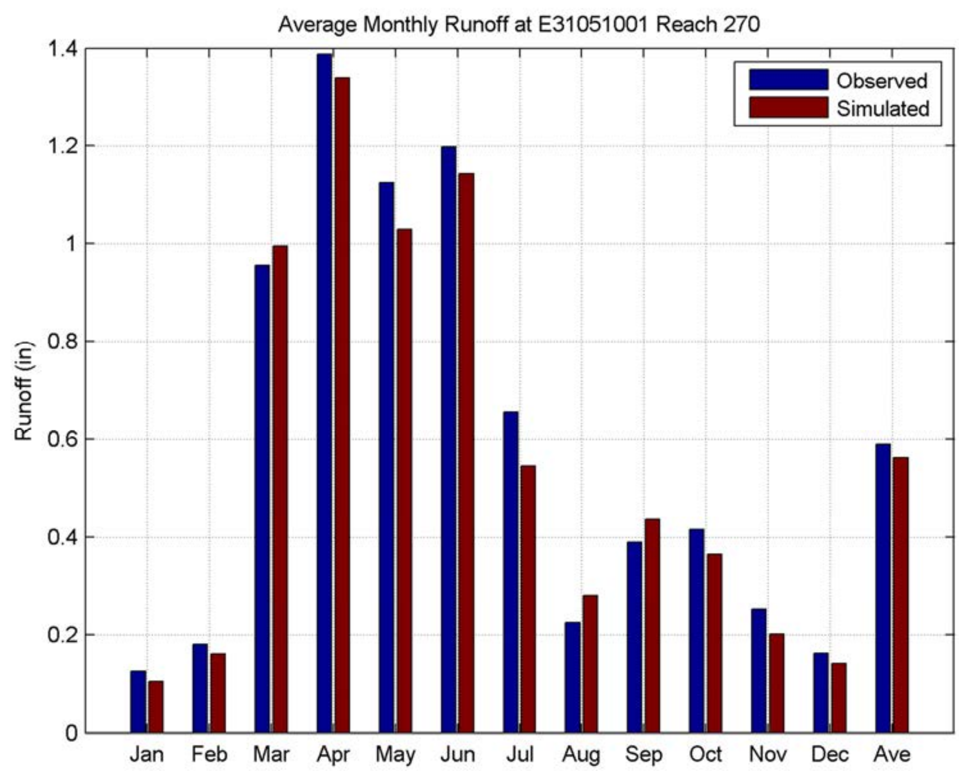

Figure B-26. Average Monthly Runoff–Watonwan Watershed (Reach 270).

RSI-2429-14-045

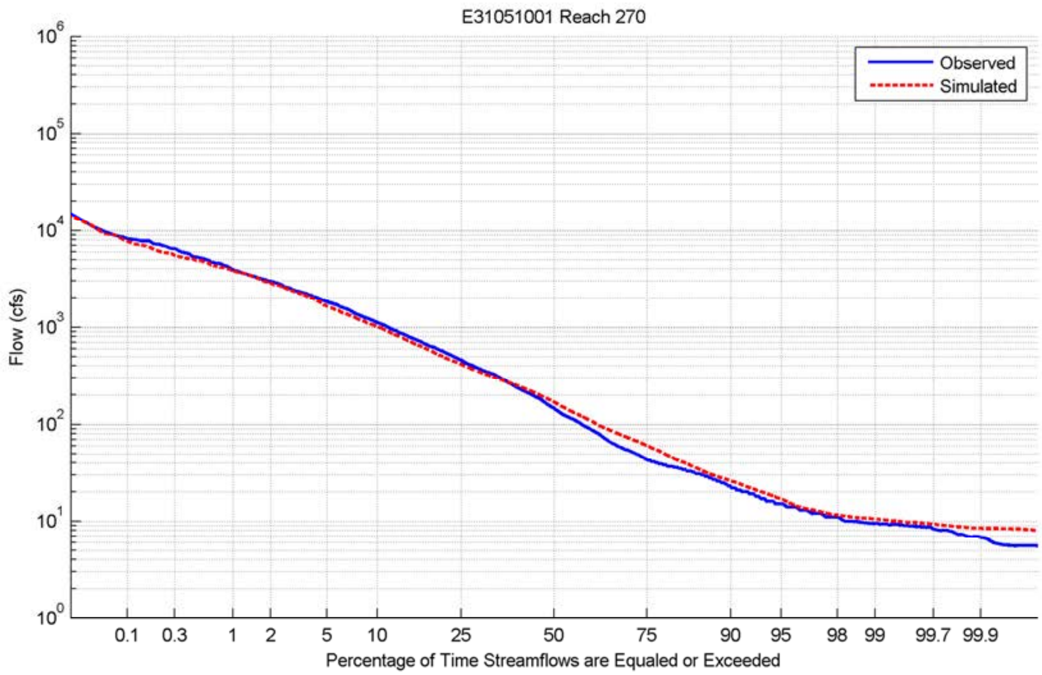

Figure B-27. Flow-Duration Plot–Watonwan Watershed (Reach 270).

RSI-2429-14-046

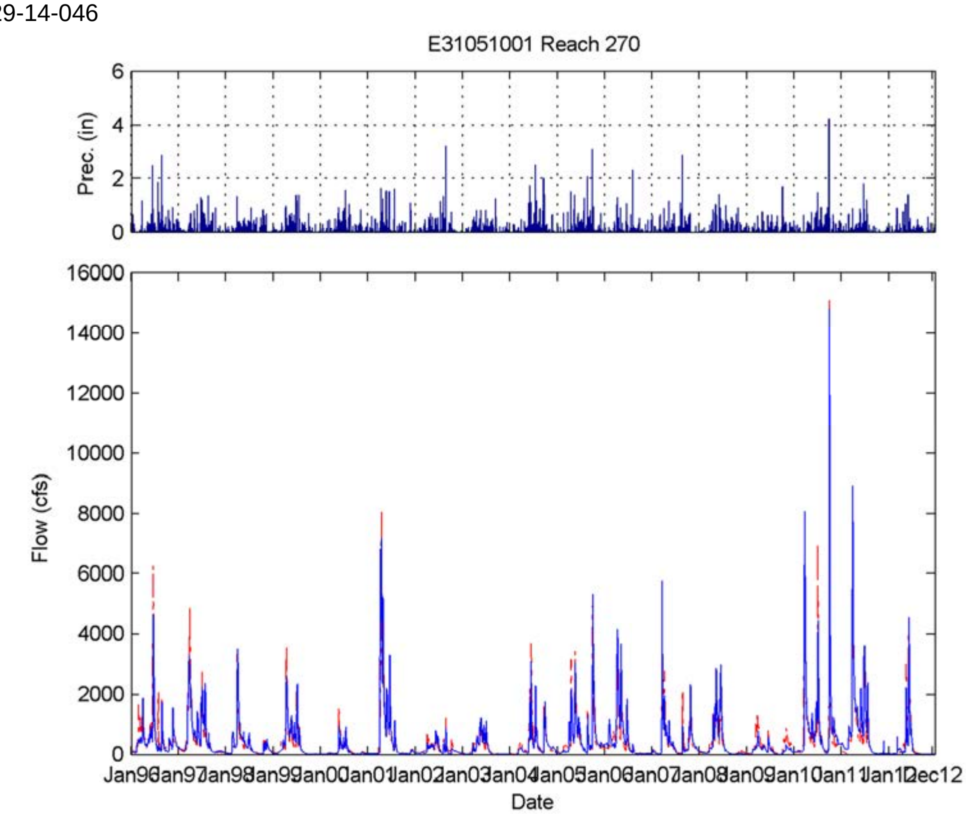

Figure B-28. Daily Hydrographs–Watonwan Watershed (Reach 270).

RSI-2429-14-047

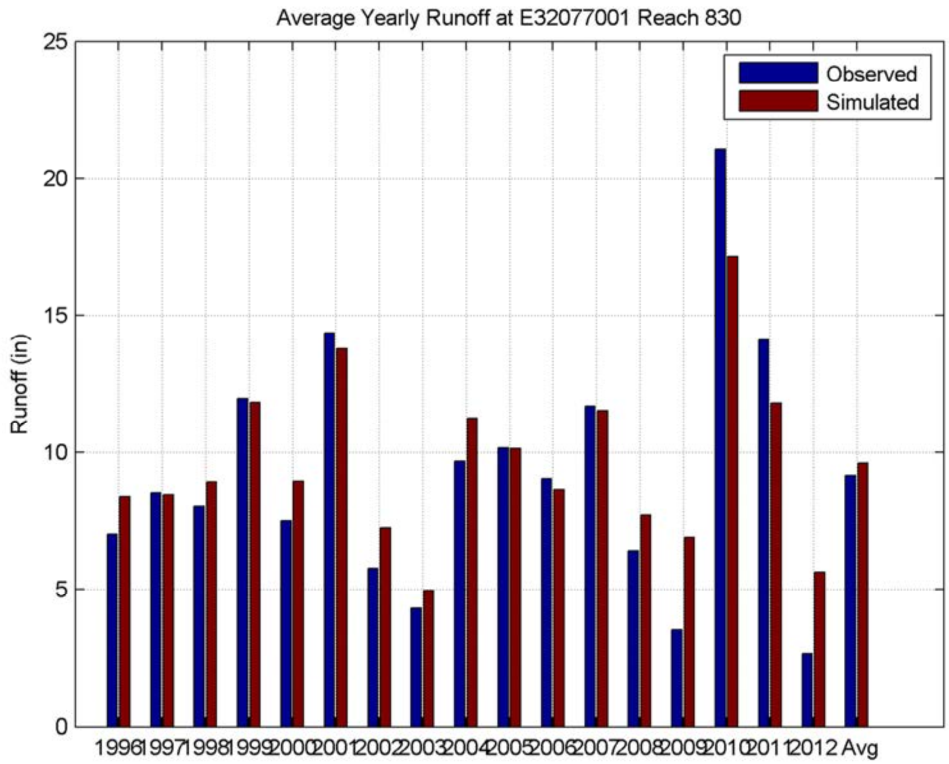

Figure B-29. Average Yearly Runoff–Le Sueur Watershed (Reach 830).

RSI-2429-14-048

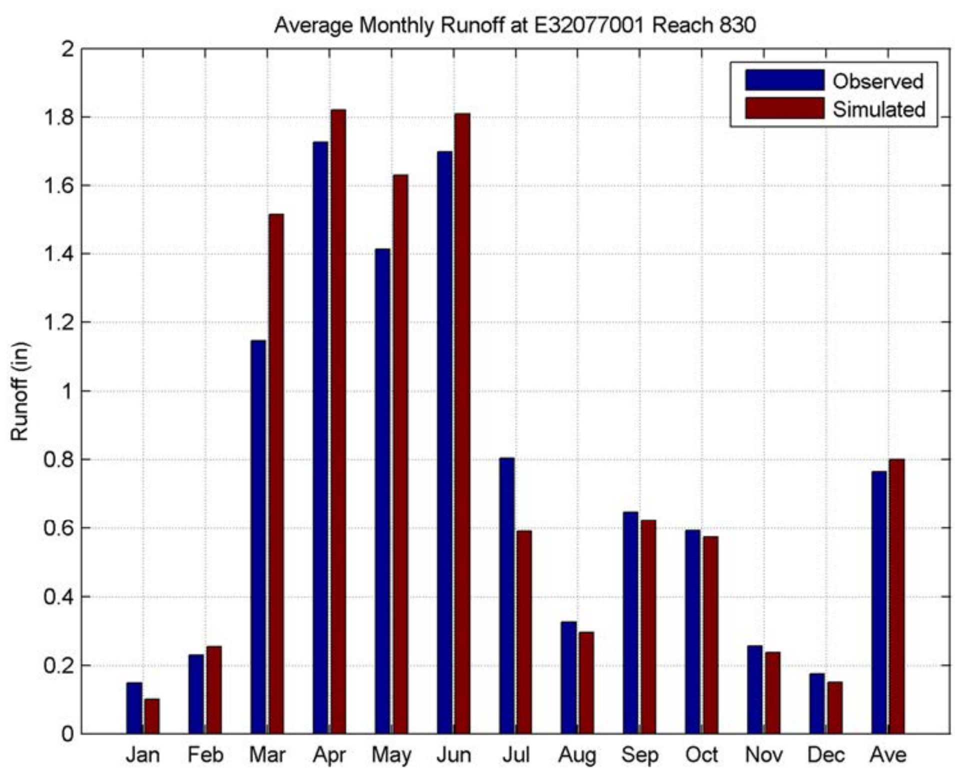

Figure B-30. Average Monthly Runoff–Le Sueur Watershed (Reach 830).

RSI-2429-14-049

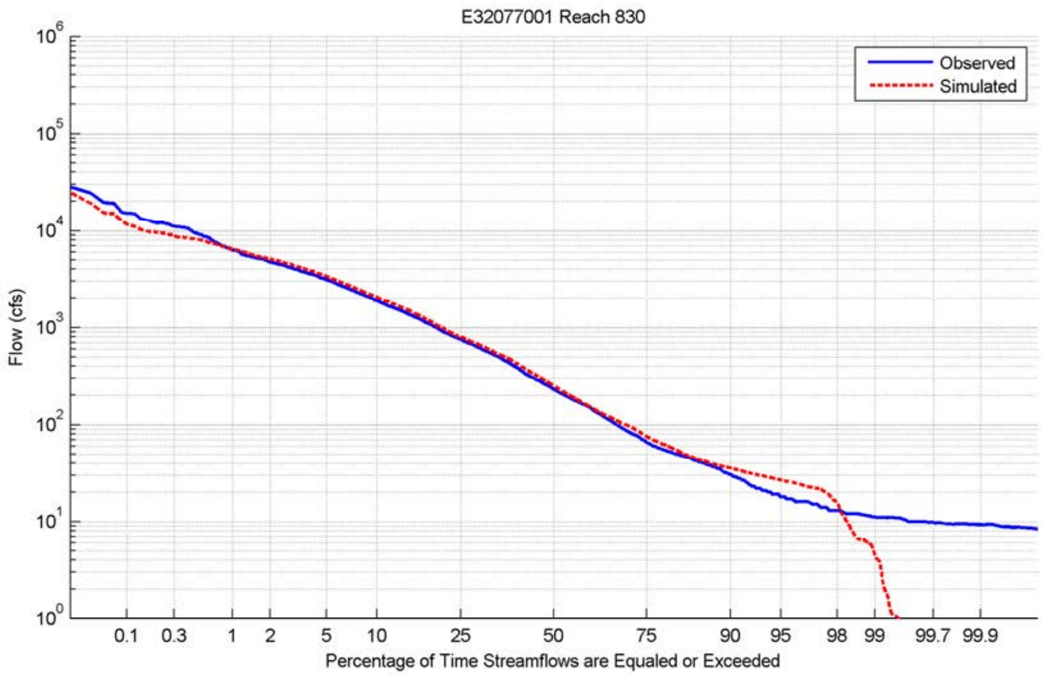

Figure B-31. Flow-Duration Plot–Le Sueur Watershed (Reach 830).

RSI-2429-14-050

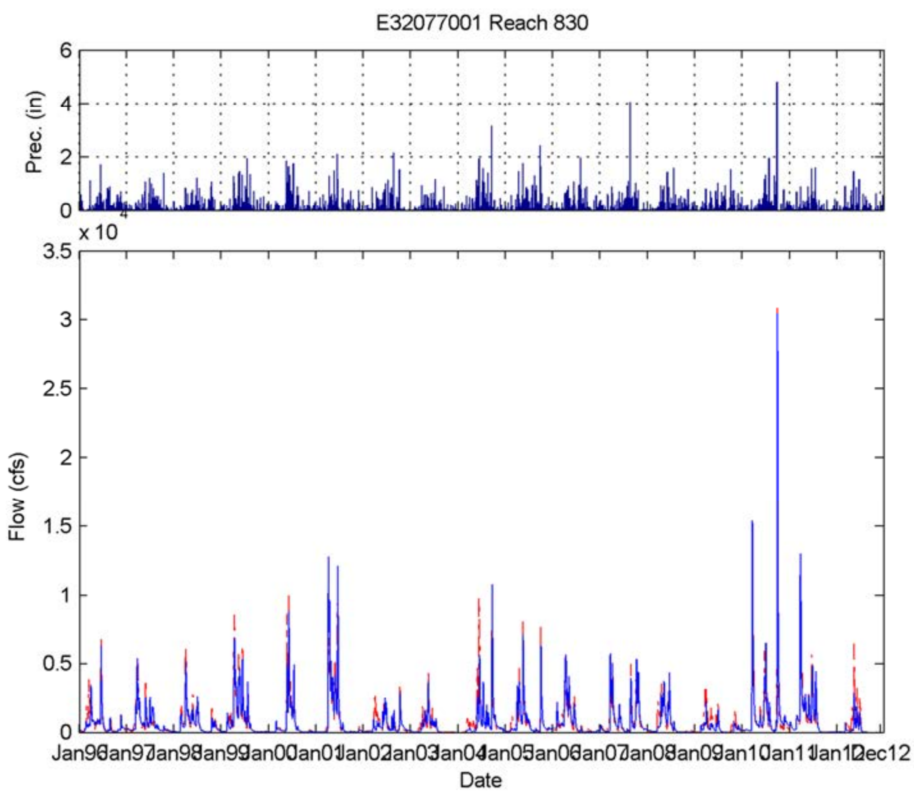

Figure B-32. Daily Hydrographs–Le Sueur Watershed (Reach 830).

RSI-2429-14-051

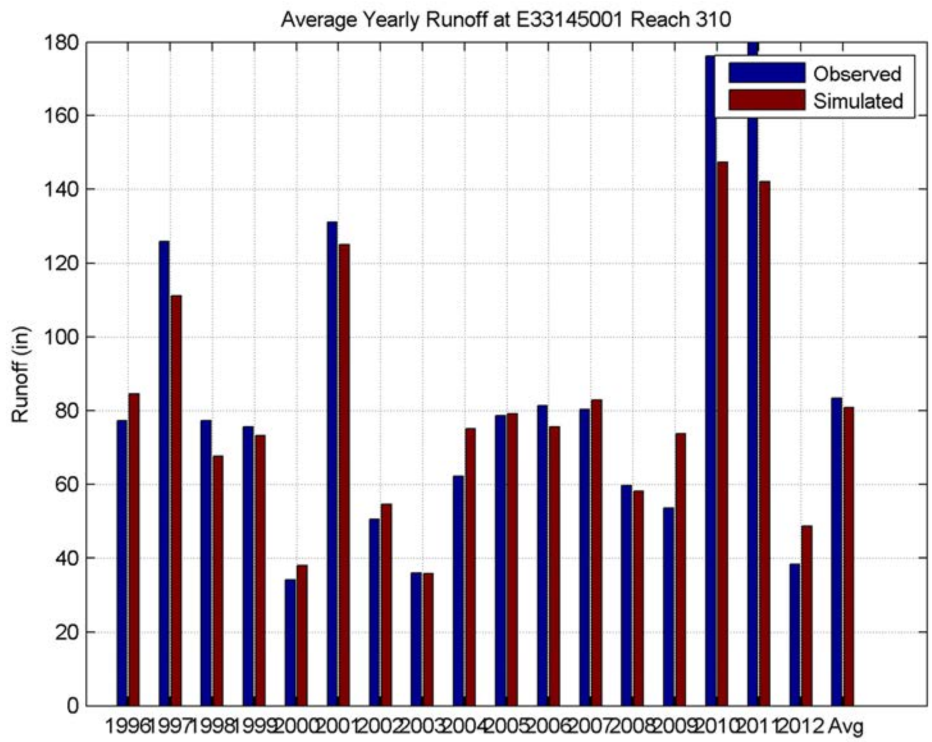

Figure B-33. Average Yearly Runoff–Lower Minnesota Watershed (Reach 310).

RSI-2429-14-052

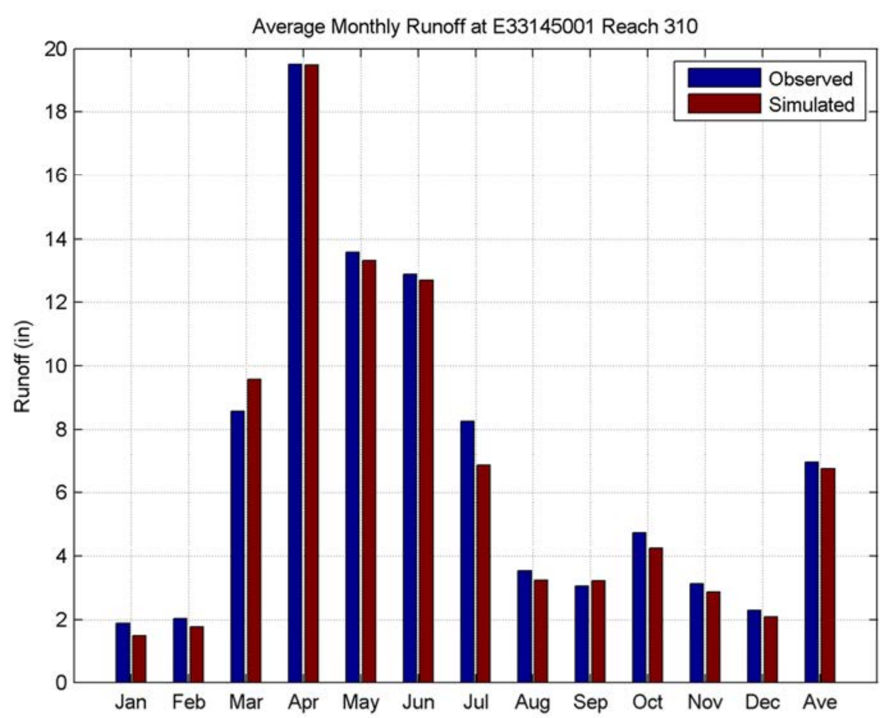

Figure B-34. Average Monthly Runoff–Lower Minnesota Watershed (Reach 310).

RSI-2429-14-053

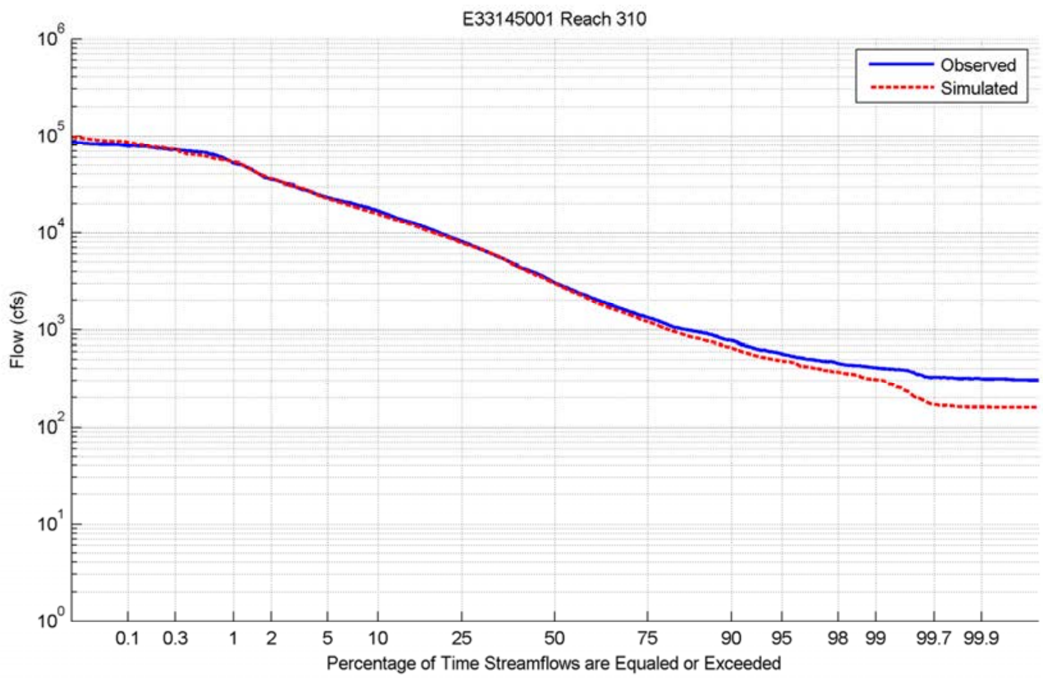

Figure B-35. Flow-Duration Plot–Lower Minnesota Watershed (Reach 310).

RSI-2429-14-054

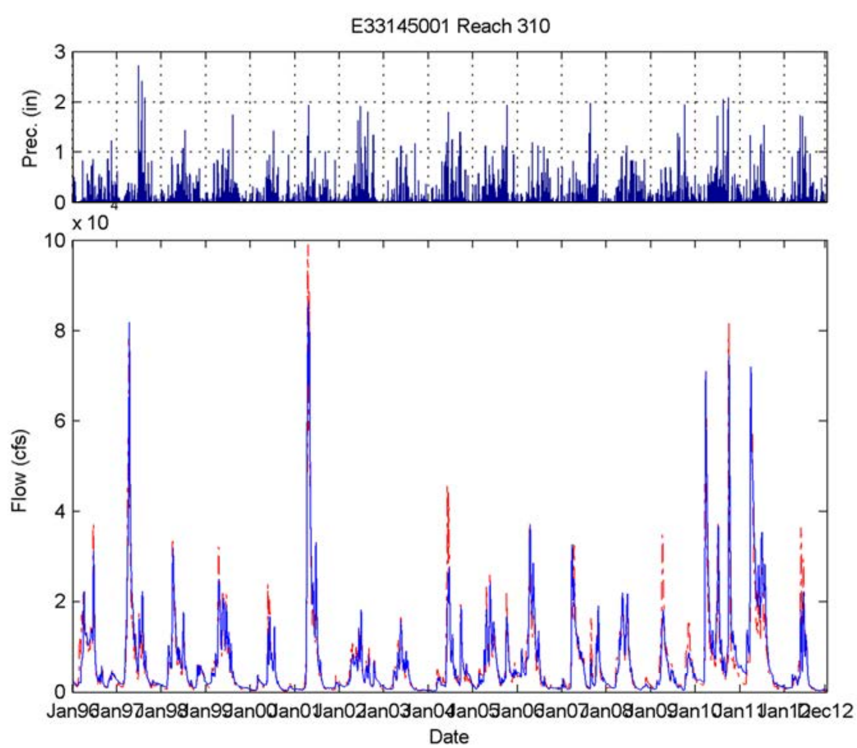

Figure B-36. Daily Hydrographs–Lower Minnesota Watershed (Reach 310).

ATTACHMENT C

OBSERVED WATER-QUALITY DATA AND LOCATIONS FOR THE MINNESOTA RIVER WATERSHED MODEL APPLICATIONS

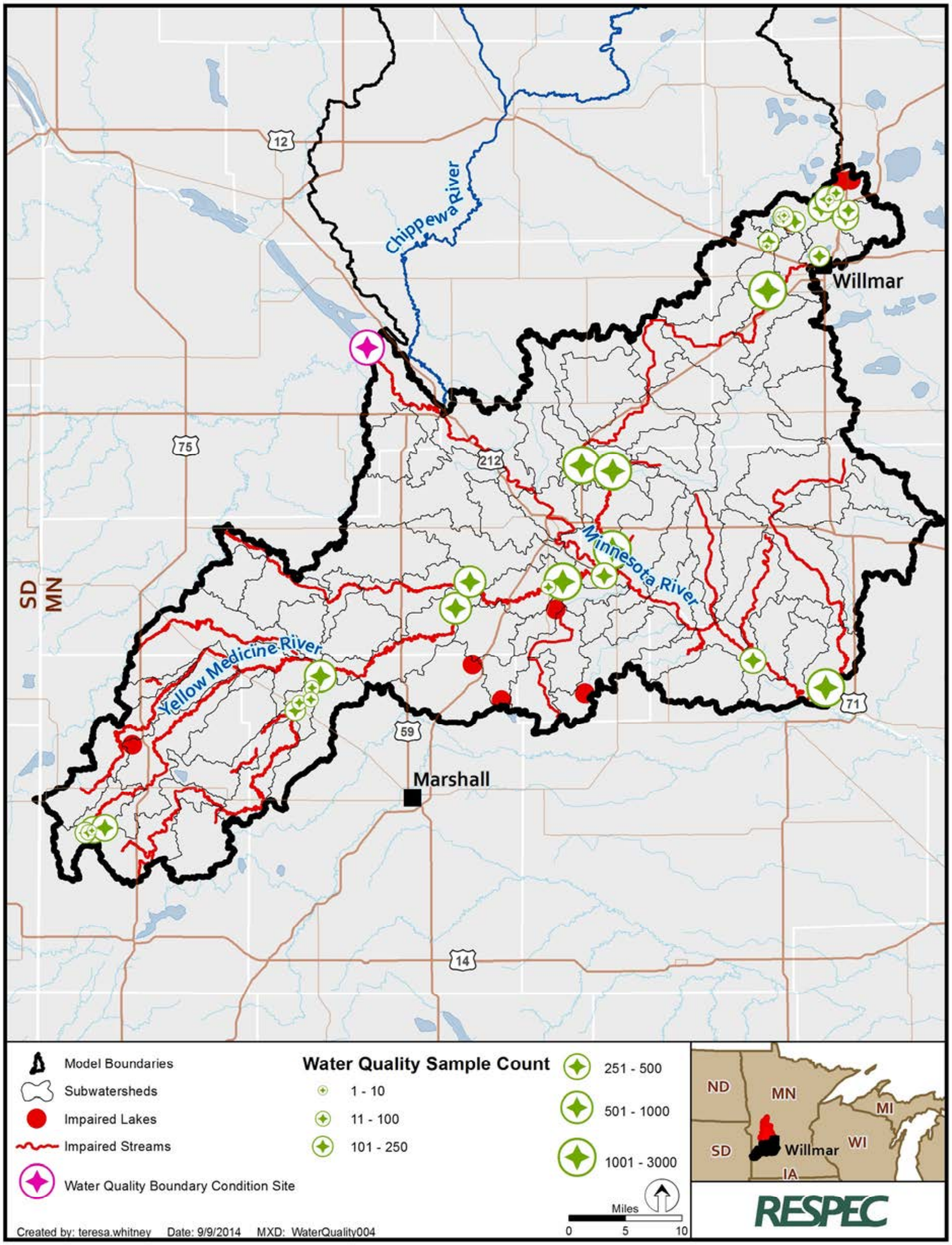

Figure C-1. Observed Water-Quality Locations Within the Hawk-Yellow Medicine Watershed.

Table C-1. Hawk-Yellow Medicine Watershed Stream Sites With Any Applicable Constituent (Page 1 of 4)

Hawk-Yellow Medicine 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S000-159		31	31	66	62	60	69	5	65		64	453
S002-316	101		8	152	215	105	230	215	207	187	214	1533
S007-314				2	3		2	3	3	3	3	19
S002-319	102			20	71	56	97	71	61	45	70	491
S002-317	104			21	93	79	101	93	85	45	93	610
S001-156		2	2	37	2	6	43	1		6	2	101
S001-217				4		6	4			6		20
S002-320	106			77	107	96	163	106	98	51	106	804
S002-335				4		6	4			6		20
S002-336				4		6	4			6		20
S002-327				4		6	4			6		20
S002-328				4		6	4			6		20
S002-337				4		6	4			6		20
S002-338				37		6	40			6		89
S002-339				4		6	4			6		20
S002-340	107			14		6	14			6		40
S002-341				4		6	4			6		20
S002-342				4		6	4			6		20
S002-343				4		6	4			6		20
S002-344				4		6	4			6		20
S002-345				4		6	4			6		20
S002-346				4		6	4			6		20
S002-331	108			34			36					70
S002-330	109			34			36					70

Table C-1. Hawk-Yellow Medicine Watershed Stream Sites With Any Applicable Constituent (Page 2 of 4)

Hawk-Yellow Medicine 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]	T-ORTHO[f]	T-P[g]	Total
S002-326	110			37		4	40			4		85
S002-349				37		6	39			6		88
S002-350				4		5	4			5		18
S002-351				4		6	4			6		20
S002-352				4		6	4			6		20
S002-353				4		6	4			6		20
S006-173	111			19	10	10	19	10	10		10	88
S006-170	112			19	10	10	19	10	10		10	88
S002-323	113			20	73	57	94	73	64	46	72	499
41-0089-00-100	115		2		2			2	1		2	9
41-0089-00-201			29	82	21		82	31	2	8	32	287
41-0089-00-202			17	128	12		128	16	8		18	327
41-0089-00-203			21	81	19		81	21	1		23	247
41-0089-00-204			7	9			9	8		8	8	49
S002-322	116				56	42	68	56	47	42	55	366
S002-321	118			19	67	53	91	67	56	43	66	462
S002-318	119			20	85	71	91	86	74	39	86	552
S006-160	130			19	11	11	19	11	11		11	93
S004-345	140			19	11	11	86	11	11		11	160
S006-161	150			22	11	11	22	11	14		14	105
87-0030-00-101	153		10	30	10		30	10	2		10	102
S006-172	160			19	10	10	19	10	10		10	88
S006-171	180			19	10	10	19	10	10		10	88
S002-012	201			243	422	282	369	363	425	283	425	2812
S002-148	202			213	384	378	309	263	384	254	384	2569

Table C-1. Hawk-Yellow Medicine Watershed Stream Sites With Any Applicable Constituent (Page 3 of 4)

Hawk-Yellow Medicine 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S002-147	203			30	43	33	30	34	34	8	34	246
S002-146	205				6	6		6	6	6	6	36
S002-145	207			30	42	32	30	33	33	7	33	240
34-0283-00-201	208		11	47			47				11	116
34-0283-00-202											1	1
34-0245-00-201	209		11	49			49				11	120
34-0245-00-202											1	1
34-0245-00-203											1	1
34-0246-00-101			16	58	14		58	15	10		16	187
34-0192-00-101	210		5	24	5		24	5			5	68
34-0192-00-201			17	94	17		94	17	12	16	17	284
34-0192-00-202			3		5			5	3		5	21
34-0192-00-203			25	108	23		108	22	15	16	28	345
34-0192-00-206							1				1	2
S002-141	211				6	6		6	6	6	6	36
S002-142					6	6		6	6	6	6	36
S002-140	213			209	376	378	305	256	379	251	379	2533
34-0181-00-204	214		24	77	19		80	19	4		24	247
34-0171-00-202	215		10	155	10		155	10	10		20	370
34-0171-00-204			68				37				68	173
S002-152	217			177	386	380	272	259	387	253	387	2501
S002-151	218				6	6		6	6	6	6	36
S002-149	219				6	6		6	6	6	6	36
S002-150					8	8		8	8	8	8	48
S000-666	230			215	389	383	310	263	392	258	391	2601

Table C-1. Hawk-Yellow Medicine Watershed Stream Sites With Any Applicable Constituent (Page 4 of 4)

Hawk-Yellow Medicine 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]	T-ORTHO[f]	T-P[g]	Total
S000-405	231			95	237	229	182	172	237	229	237	1618
S002-155					7	7		7	7	7	7	42
S002-156					7	7		7	7	7	7	42
S004-697							14					14
S006-138				104	121	121	111	70	121		121	769
S002-154	232				8	8		8	8	8	8	48
S003-761							319					319
S000-404	234			19	11	11	19	11	11		11	93
S002-157					6	6		6	6	6	6	36
S003-867	240			109	128	120	127	71	130	67	130	882
S002-153	250				12	12		12	12	12	12	72
S004-680				30	34	24	45	25	25		25	208
S001-341	260	1		109	141	125	141	86	141	78	141	963
S002-239		1			1	1	13	1	1		1	19
S003-866	270			78	100	90	93	58	99	49	99	666
S007-088				2			3		4		4	13
S002-136	280			98	130	118	114	75	130	70	130	865
S000-055	302	20	20	69	45	61	72	3	65		44	399
S000-740	307						3					3
S004-649	308		16	304	332	142	318	332	332	314	334	2424
S007-748	406	119			119						126	364

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

RSI-2429-14-056

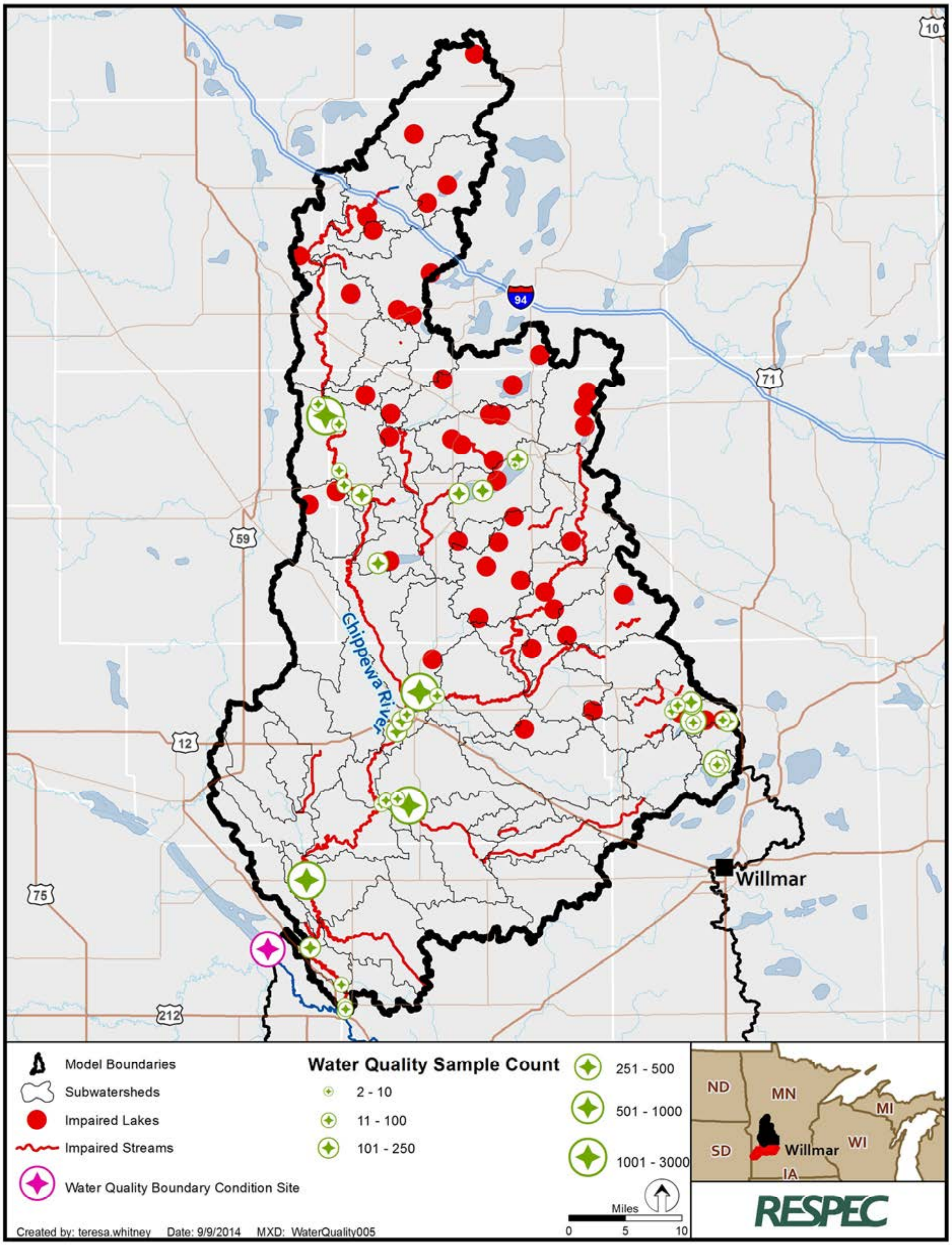

Figure C-2. Observed Water-Quality Locations Within the Chippewa Watershed.

Table C-2. Chippewa Watershed Stream Sites With Any Applicable Constituent (Page 1 of 9)

Chippewa 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S000-175		5	5	9	5	16	14	3	8		5	70
S002-966	101	5	5	5	5	5	5		5		5	40
S006-017				25			25					50
S000-494	102			46	10	10	76	10	10	1	9	172
S006-018				26			26					52
S005-865				21			21					42
S005-866				18			18					36
S005-867				10			11					21
S005-868	104			14			16					30
S005-869				12			14					26
S005-870				15		2	17		2	2	2	40
S006-019	105			26			26					52
S002-203	106			248	369	39	276	269	382	285	349	2,217
S000-495				23			23					46
S002-202				72	70	10	90	22	70	55	44	433
S005-901	107			23			23					46
S005-902				23			23					46
S005-903				22			22					44
S001-846				18			18					36
S005-895				16			16					32
S005-896				10			10					20
S005-897	108			16			16					32
S005-898				16			16					32
S005-899				14			14					28
S005-900				10			10					20

Table C-2. Chippewa Watershed Stream Sites With Any Applicable Constituent (Page 2 of 9)

Chippewa 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S005-904				23			23					46
S005-905				23			23					46
S005-906				22			22					44
S005-907	110			23			23					46
S005-908				23			23					46
S005-909				22			22					44
S005-910				22			22					44
S000-397				26			26					52
S000-398	111			26			26					52
S000-399				26			26					52
S000-381	112			26			26					52
S001-864				20			20					40
S003-507				68	71	10	88	28	61	54	44	424
S005-943	113			18			18					36
S005-944				20			20					40
S006-621				2		2	2		2	2	2	12
S005-945				20			20					40
S005-946				20			20					40
S005-947	114			19			19					38
S005-948				19			19					38
S005-949				20			20					40
S000-383				46	10	10	46	10	10		9	141
S000-385	115			18	21		17		21	21	21	119
S000-386				23			23					46
S001-862	116						12					12

Table C-2. Chippewa Watershed Stream Sites With Any Applicable Constituent (Page 3 of 9)

Chippewa 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S002-193				201	323	60	222	154	325	281	296	1,862
S006-020				26			26					52
S006-021				26			26					52
S000-962	118			26			26					52
S002-192				26			26					52
S000-963	119			45	10	10	45	10	10		10	140
S002-190				134	243	20	149	91	245	211	225	1,318
S004-234							11					11
S006-022				25			25					50
S006-023				26			26					52
S006-024				26			26					52
S001-860	120			26			26					52
S006-025				18			18					36
S006-026				26			26					52
S002-189	121			25			26					51
S006-622				2		2	2		2	2	2	12
S005-630	122			19	10	10	19	10			10	78
S006-028				26			26					52
S006-029				26			26					52
S000-471	123			24			25					49
S006-030				26			26					52
S000-965	128			42			42					84
S006-055				38			38					76
S004-705	129			188	128	20	186	26	128	114	128	918
S006-051				48			46					94

Table C-2. Chippewa Watershed Stream Sites With Any Applicable Constituent (Page 4 of 9)

Chippewa 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]	T-ORTHO[f]	T-P[g]	Total
S006-052				48			46					94
S006-053				48			46					94
S006-054				30			28					58
S006-039	130			21			21					42
S006-040				21			21					42
S006-041	131			24			23					47
S006-042				23			22					45
S006-043				24			23					47
S006-044				24			23					47
S006-045				24			23					47
S006-046				24			23					47
S006-047				24			23					47
S006-048				24			23					47
S006-049				21			20					41
S006-050				24			23					47
61-0180-00-201	132		73				12				87	172
S000-898	133			66	58		66	3	58	57	58	366
S000-899				12			12					24
S000-900				12			12					24
S000-901				12			12					24
S000-902				12			12					24
61-0130-00-201	134		75				15				95	185
61-0130-00-205			74				15				95	184
61-0130-00-208			6	64	1		32	1			9	113
61-0130-00-209			1		1							2

Table C-2. Chippewa Watershed Stream Sites With Any Applicable Constituent (Page 5 of 9)

Chippewa 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]	T-ORTHO[f]	T-P[g]	Total
S001-858	135						300					300
S001-859							324					324
S005-631				21	10	12	21	10	2	2	12	90
S005-364	136			210	311	57	234	146	324	284	298	1,864
S006-014				34			34					68
S006-012	137			20			20					40
S006-013				20			20					40
S002-194	138			19			19					38
S006-008				20			20					40
S006-009				20			20					40
S006-010				20			20					40
S006-011				20			20					40
S005-975	139			22			22					44
S005-976				22			22					44
S005-977				22			22					44
S005-978				23			23					46
S005-979				23			23					46
S001-868	140			20			20					40
S005-860				36	41		36		41	18	41	213
S005-861				37	41		37		41	18	41	215
S006-007				20			20					40
S001-854	141			20			20					40
S005-995				20			20					40
S005-998				20			20					40
S005-999				20			20					40

Table C-2. Chippewa Watershed Stream Sites With Any Applicable Constituent (Page 6 of 9)

Chippewa 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]	T-ORTHO[f]	T-P[g]	Total
S006-000				20			20					40
S006-001				20			20					40
S006-002				20			20					40
S006-003				20			20					40
S006-005				20			20					40
S006-016				20			20					40
S003-372	143			42	10	10	42	10			9	123
S005-633	143			41	10	10	40	10			9	120
S005-990	143			22			22					44
S005-991	144			22			22					44
S005-992	144			22			22					44
S005-993	144			21			21					42
S005-980	145			12			12					24
S005-981	145			13			13					26
S005-994	145			16			16					32
S002-195	146			41	10	10	41	10			10	122
S005-955	146			21			21					42
S005-973	146			21			21					42
S006-033	146			19			19					38
S005-960	148			21			21					42
S005-965	148			21			21					42
S005-966	148			17			17					34
S005-967	148			21			21					42
S005-968	148			21			21					42
S005-969	148			21			21					42

Table C-2. Chippewa Watershed Stream Sites With Any Applicable Constituent (Page 7 of 9)

Chippewa 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S005-970				21			21					42
S005-972				21			21					42
S000-500	149			22			22					44
S002-201				195	318	58	223	155	330	286	302	1,867
S005-914				24		2	24		2	2	2	56
S005-915				22			22					44
S005-375	150			77	91	13	78	13	93	65	93	523
S005-916				22			22					44
S005-917				22			22					44
S005-918				22			22					44
S005-919				22			22					44
S005-920				22			22					44
S002-200	151			22			22					44
S002-550				20	10	10	20	10			9	79
S005-374				76	92	12	77	13	92	63	92	517
S005-921				22			22					44
S005-922				22			22					44
S005-923				22			22					44
S005-924				22			22					44
S005-925				24		2	24		2	2	2	56
S005-926				22			22					44
S005-927				22			22					44
S004-738	152			22			22					44
S005-928				22			22					44
S005-929				22			22					44

Table C-2. Chippewa Watershed Stream Sites With Any Applicable Constituent (Page 8 of 9)

Chippewa 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]	T-ORTHO[f]	T-P[g]	Total
S005-930	153			22			22					44
S005-931				22			22					44
S004-732				18			32					50
S001-861	154			18			18					36
S002-209		1		45	117	82	34	105	106	112	117	719
S005-933				19			18					37
S005-934				17			17					34
S005-935				20		2	20		2	2	2	48
34-0206-00-201	155		5	78	5		39	5			10	142
34-0206-00-206			6	21			21				6	54
34-0224-00-101	156		7	120	5		60	5			13	210
34-0224-00-201			21	30			43				21	115
34-0251-00-202			5	30			15				5	55
34-0251-00-204			26	128	6		90	6	2		32	290
34-0251-00-206			20	6			19				20	65
34-0251-00-207			1	20	1		10	1	1		1	35
34-0217-00-101	157		9	140	5		95	6	1		13	269
34-0217-00-202			14				11				15	40
34-0217-00-204			6	35			35				6	82
S002-204	159			195	322	44	217	144	316	268	285	1,791
S005-882				20			20					40
S005-883				20			20					40
S005-884				20			20					40
S005-885				20			20					40
S005-886				20			20					40

Table C-2. Chippewa Watershed Stream Sites With Any Applicable Constituent (Page 9 of 9)

Chippewa 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S005-887				20			20					40
S005-888				20			20					40
S005-889				20			20					40
S005-890				20			20					40
S005-891				19			19					38
S005-877	161			19			20					39
S005-878				19			20					39
S005-879				20			20					40
S005-880				19			19					38
S005-881				20			20					40
S002-205	162			7	39		7	40	40	38	40	211
34-0285-00-201	253										1	1
S005-629	303			43	10	12	43	10	2	2	11	133
S005-864				21			21					42
S005-932	353			21			21					42

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

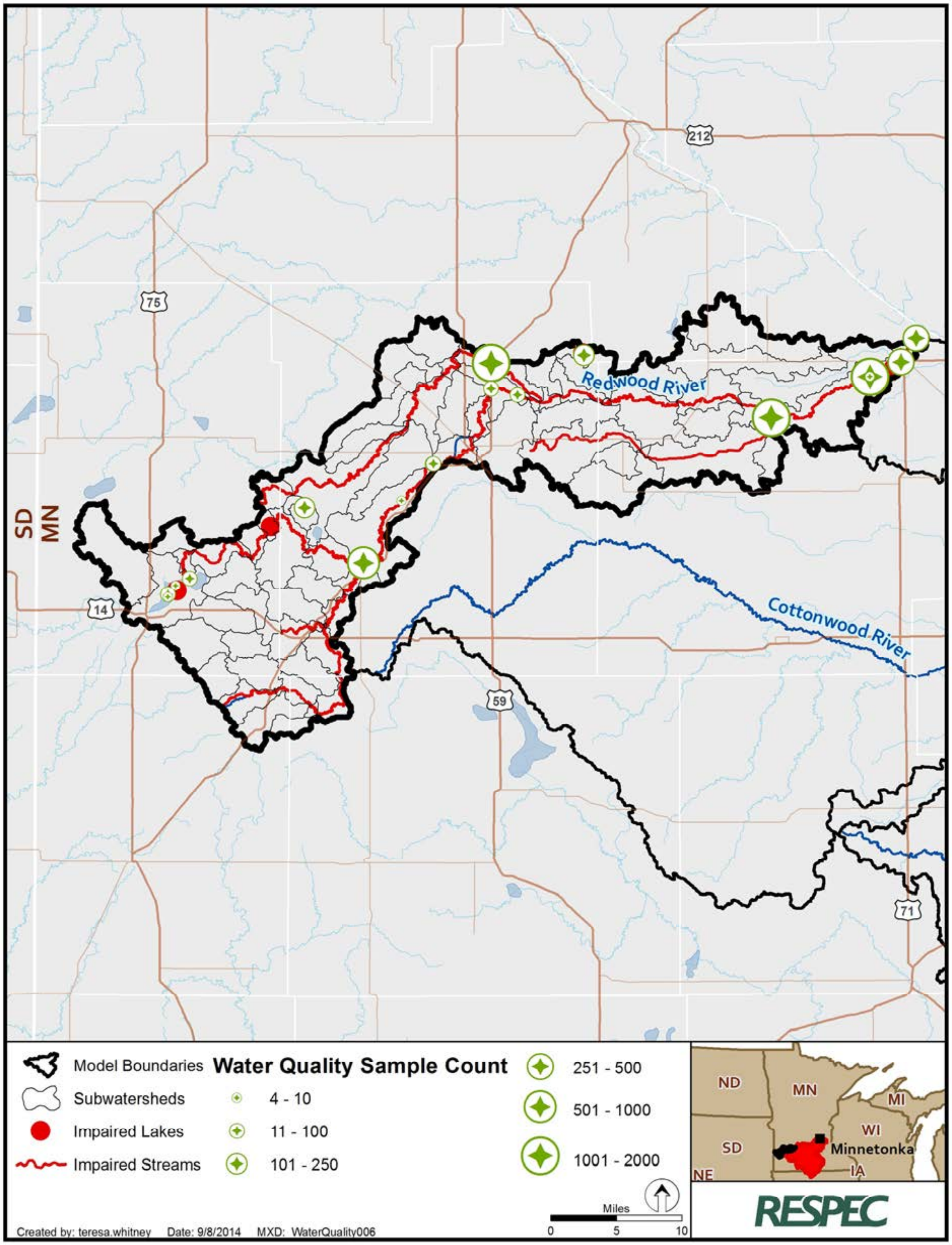

Figure C-3. Observed Water-Quality Locations Within the Redwood Watershed.

Table C-3. Redwood Watershed Stream Sites With Any Applicable Constituent

Redwood 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]	T-ORTHO[f]	T-P[g]	Total
41-0043-00-100	162										4	4
41-0043-00-101			5	17	5		17	5			5	54
41-0043-00-102			4	13	4		13	4			4	42
41-0043-00-202											5	5
41-0021-01-101	172		11	29	11		29	11	4		11	106
S000-696	190			103	126		108	1	126	80	126	670
05315000	210			6			6				2	16
S000-693		2	2		2			1			2	9
S003-702				1	35		1		4	4	4	49
S001-203	250			5		21	10		3	3	8	50
S002-185				5		21	10				5	41
S001-199	270				36							36
S001-201						6	5					11
42-0093-00-101	292		9	30	10		30	10	3		10	102
S002-313	313			131	230	38	139	1	232	141	232	1,144
42-0002-00-101	372		11	33	11		33	11	2		12	113
S002-311	443			130	230	36	138	1	190	137	231	1,093
05316500	450				4		1					5
S001-679		4	28	187	336	45	232	128	336	225	337	1,858
64-0058-00-202	480		27	57	76	9	65		67	56	76	433
S000-299	510	30	35	71	63	61	73	4	67	5	63	472

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

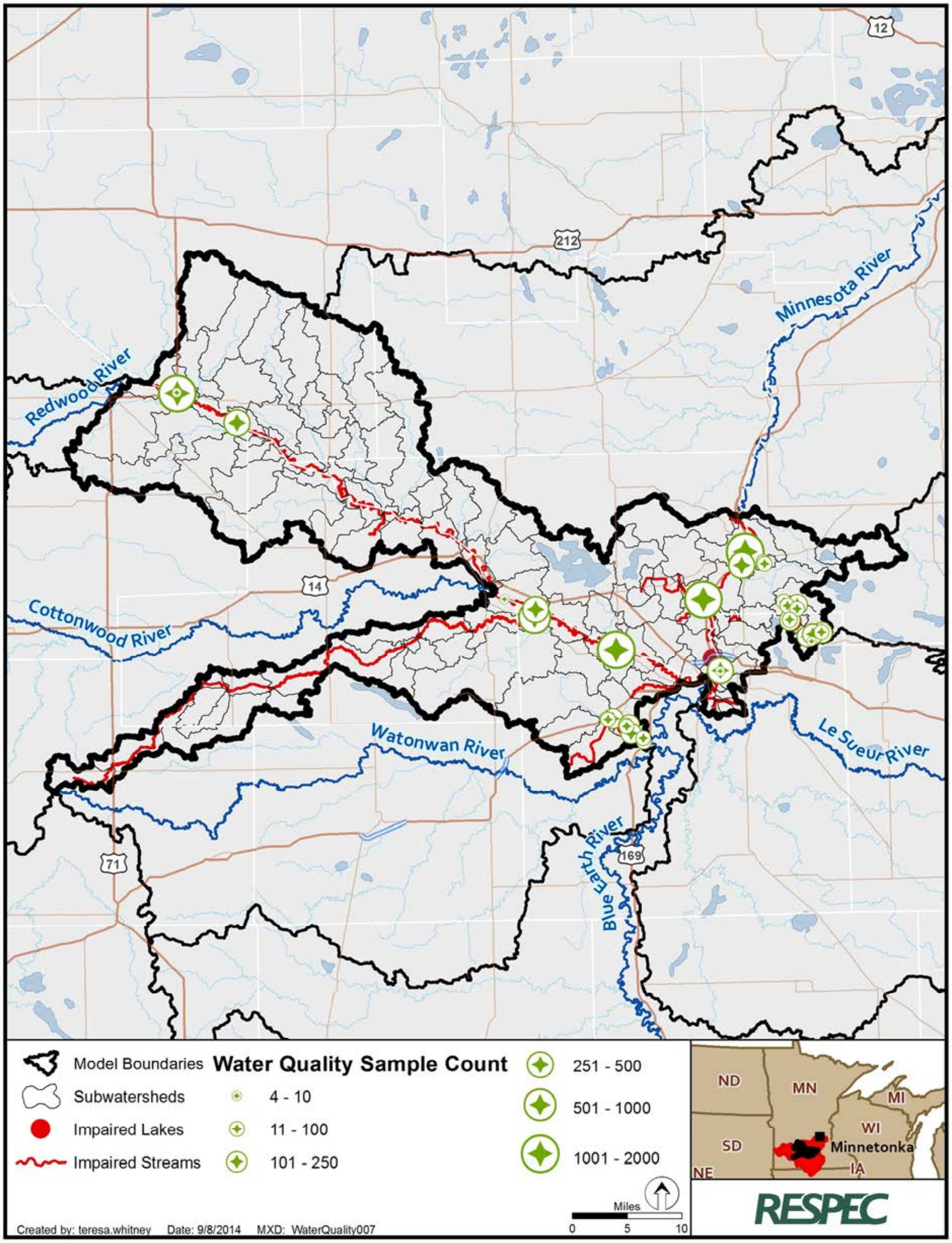

Figure C-4. Observed Water-Quality Locations Within the Middle Minnesota Watershed.

Table C-4. Middle Minnesota Watershed Stream Sites With Any Applicable Constituent (Page 1 of 3)

Middle Minnesota 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]	T-ORTHO[f]	T-P[g]	Total
S005-628	11			33	42	41	37	42	42	16	42	295
05316580	30				4		2					6
S000-145		19	19	167	168	108	183	133	193	77	175	1,242
S005-669	59				22				22		22	66
S005-627	75			32	41	40	36	41	41	16	41	288
S005-672	131				22				22		22	66
S005-626	151			31	42	41	35	42	42	16	42	291
S005-668					9				9		9	27
S005-665	179				22				22		22	66
S005-625	191			34	42	41	37	42	42	16	42	296
S005-689			21	40			40	21	21		21	164
S005-624	193			27	42	30	27	31	42	14	42	255
S005-432	223				22		5		22		22	71
S005-664	231				22				22		22	66
S000-342	270			2			16					18
S005-667	271				22				22		22	66
S005-430	291				22		12		22		22	78
S005-666	311				22				22		22	66
S000-054	350	19	19	77	42	64	74	1	64		42	402
S003-906			1	1	1		1	1	1	1	1	8
S002-399	353			19	44		21			39	39	162
S002-401				25	71		32			60	65	253
S005-687	363		22	39			38	22	22		22	165
S002-400	365			21	42		22			37	42	164

Table C-4. Middle Minnesota Watershed Stream Sites With Any Applicable Constituent (Page 2 of 3)

Middle Minnesota 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S004-609	377			116	214	16	174	30	142	186	214	1,092
S004-281	381				22				22		22	66
S005-671	417				22				22		22	66
S001-759	430		161	43	213	161	71	179	211	58	210	1,307
S001-983	475				62			32	63	63	63	283
07-0097-00-201	476		14		13			14	6		14	61
07-0097-00-202			24	24	24		24				24	120
07-0096-00-100	478		18	1	14		1	14	14	14	17	93
07-0096-00-101			12	60	12		33	12	2		12	143
07-0096-00-201			26	24	26		24				26	126
07-0096-00-202			24	24	24		24				24	120
07-0098-00-102	482		15		14			16	13		16	74
07-0098-00-103			24	24	24		24				24	120
07-0098-00-204			38	24	39		24	14	13		39	191
S003-635	511				66				59	65	66	256
S003-634	513				55				46	53	54	208
S003-636	515				55				51	53	54	213
S003-637	519				55				50	53	54	212
S003-633	521				48				45	49	49	191
S003-632	523				67				63	65	66	261
S007-050	530				8		8					16
05325000	550			134	70		446				66	716
S002-934	573			64	206	17	133		205	179	200	1,004
S002-936	577			66	200	17	180		198	169	192	1,022

Table C-4. Middle Minnesota Watershed Stream Sites With Any Applicable Constituent (Page 3 of 3)

Middle Minnesota 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S002-464	579			46	61		67		58	59	60	351
S002-937	583			79	301	18	208		304	266	293	1,469
07-0054-00-100	592		3	3			2				3	11
07-0054-00-202			6	169	5		91	5			12	288
07-0054-00-203			6	106	1		58	2			12	185
07-0053-00-100	594		4	3	1	1	3	1			4	17
07-0053-00-202			1									1
07-0053-00-203			23	129	20		68	9		12	31	292
07-0047-00-100	596		6	2	1	1	2	1			6	19
07-0047-00-101			7	105	6		56	7			14	195
40-0117-00-101	598		3	47	4		47	4			8	113
40-0117-00-204			29	21			30	4			47	131
40-0117-00-208			12	45	4		54	4			16	135
40-0117-00-210			20	16			16	4			38	94
40-0124-00-100	602		5	47			47				5	104
40-0124-00-202			5	59	5		59	5			10	143
S005-670	603				22				22		22	66
S000-041	610	26	29	67	53	64	57	5	65		53	419
S004-130			187	45	248	191	58	207	241	89	241	1,507

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

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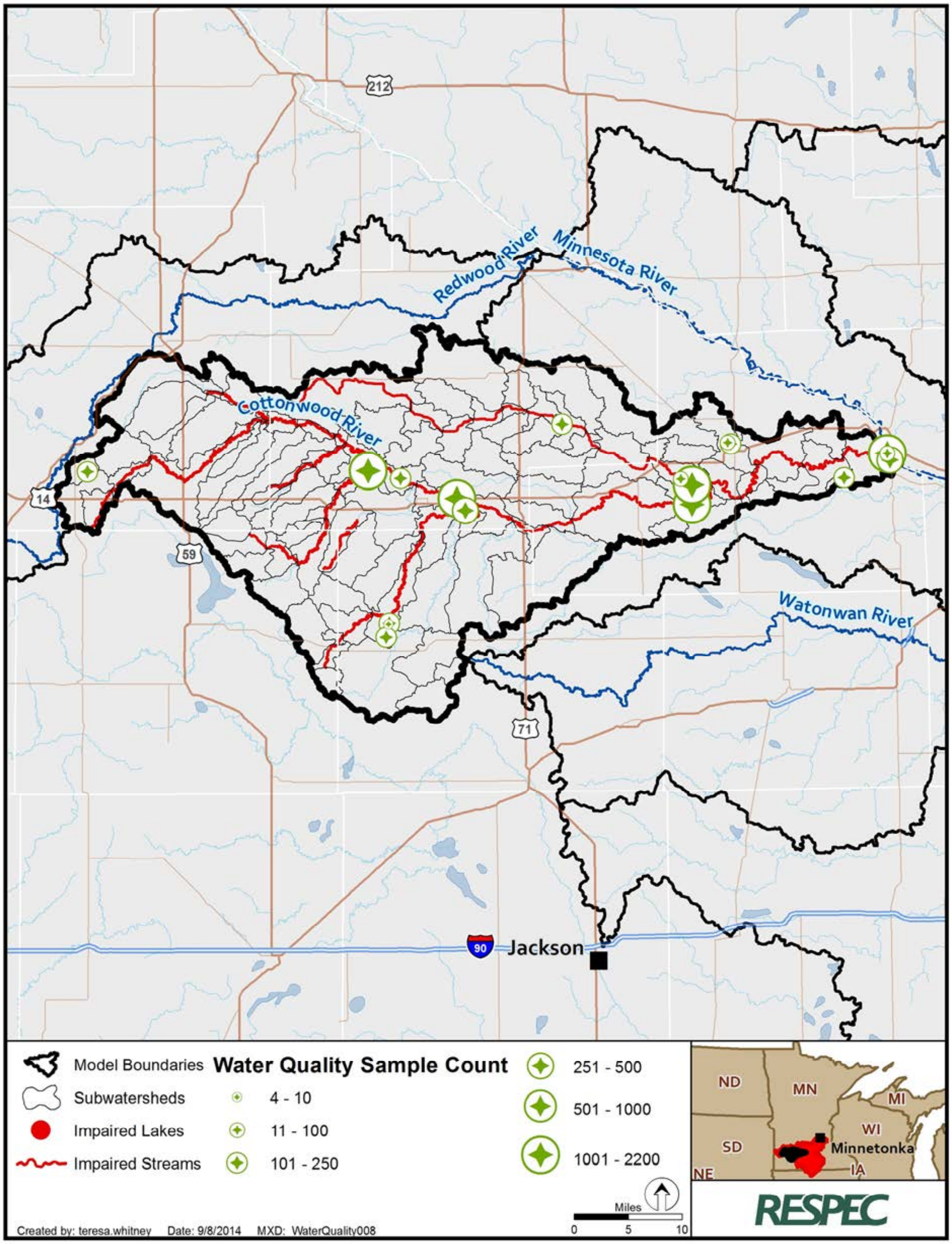

Figure C-5. Cottonwood Watershed Stream Sites With Any Applicable Constituent.

Table C-5. Cottonwood Watershed Stream Sites With Any Applicable Constituent (Page 1 of 2)

Cottonwood 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]	T-ORTHO[f]	T-P[g]	Total
42-0052-00-101	12		12	27	12		27	12	7		12	109
S001-917	105			2	6	6	2	6	6	6	6	40
S001-914	157			2	7	7	2	7	7	7	7	46
S001-913	189			130	204	13	139	13	205	168	206	1,078
S001-921	210			6	40	30	5	30	40	40	40	231
S002-247	230			156	215		165	1	215	170	215	1,137
S004-879	267				31						2	33
17-0054-00-100	274		4								4	8
17-0054-00-101			11	46	11		46	11	1		19	145
17-0056-01-101	276		11	29	11		29	11	3		11	105
S001-915	281			6	78	32	6	32	43	43	45	285
S005-690	311		21	42			42	21	21		21	168
S005-691	335		23	33			32	23	23		23	157
08-0054-00-101	351		14	28			25				14	81
S001-920	370			151	242	28	163	29	242	199	243	1,297
S001-916	397			4	17	17	3	17	17	17	17	109
S001-919	407			151	233	20	160	21	234	192	234	1,245
S005-378			11	21			20				11	63
08-0045-00-101	434		10	59	10		59	10			12	160
08-0045-00-102			4	16			16	1			4	41
S005-688	435		22	42			39	22	22		22	169
08-0011-00-101	452		18	40	4		38	5	1		18	124

Table C-5. Cottonwood Watershed Stream Sites With Any Applicable Constituent (Page 2 of 2)

Cottonwood 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
05317000				5	4		7					16
S000-139	490	33	33	68	61	56	68	7	59		63	448
S001-918			3	222	389	50	268	131	395	284	397	2,139

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

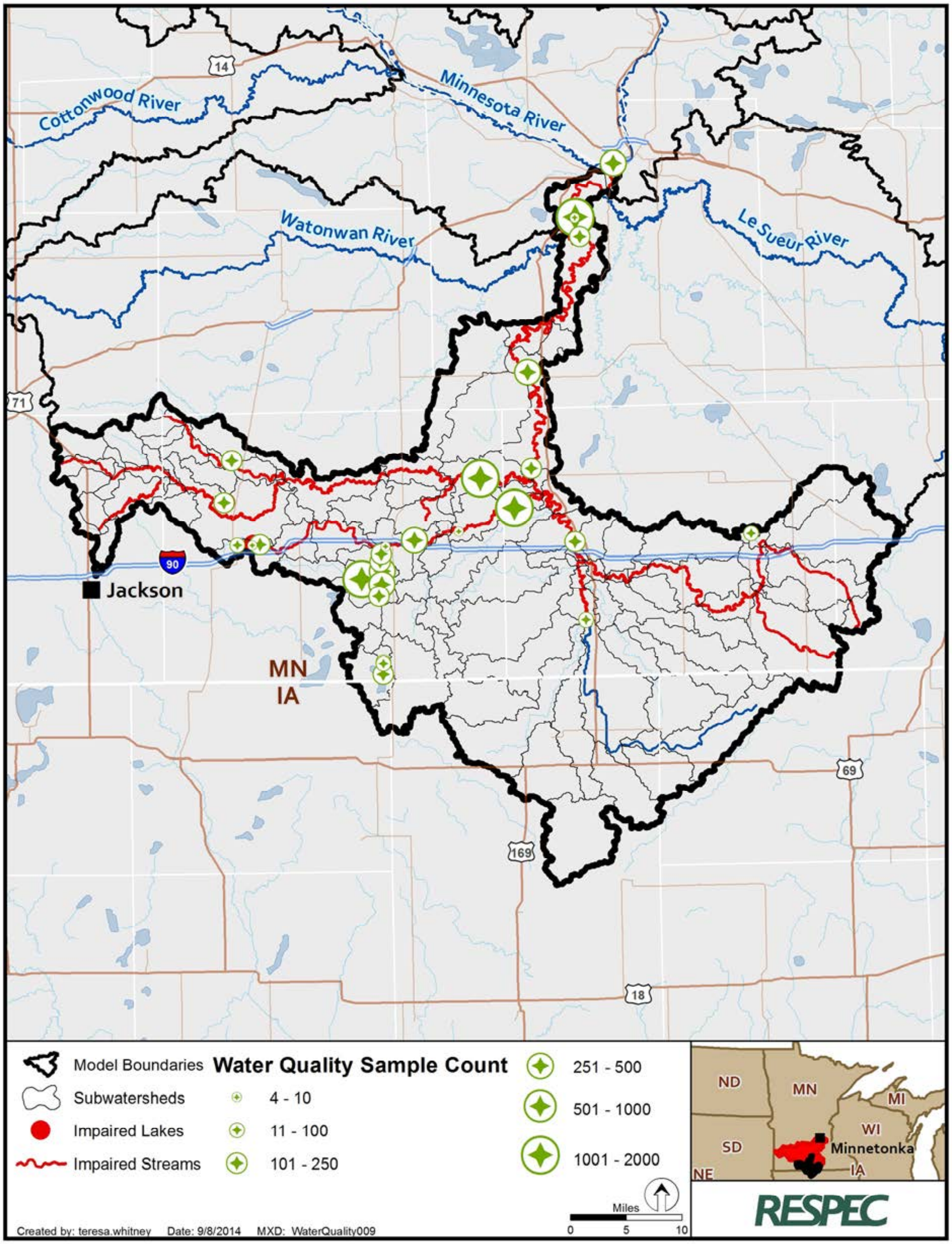

Figure C-6. Observed Water-Quality Locations Within the Blue Earth Watershed.

Table C-6. Blue Earth Watershed Stream Site With Any Applicable Constituent (Page 1 of 3)

Blue Earth 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]	T-ORTHO[f]	T-P[g]	Total
S000-135	50	14	14	8	14		11	12	9	1	13	96
22-0023-00-101	102		10	15	10		15	10	3		10	73
S000-469	170	17	17	16	17		16	17	17		17	134
46-0020-00-100	194		4	11			12				5	32
46-0020-00-202			4	17	4		18	4			6	53
46-0049-00-101	196		11	27	11		27	11	3		11	101
46-0109-00-100	212			1				1			2	4
46-0109-00-101			12	58	11		58	11	3		21	174
46-0109-00-102			5	16	3		16	3	1		9	53
S003-001	217		6	15	6	14	20				6	67
46-0034-00-101	222		14	87	12		87	14	5	1	13	233
S003-000	225		2	151	213	203	187		197	191	217	1,361
46-0031-00-101	226		12	104	11		104	17	9	1	19	277
46-0030-00-101	228		16	105	12		105	18	9		25	290
46-0025-00-100	232		13	76	13		77	19	9	4	19	230
46-0024-00-101	234		14	59	12		60	13	3	2	12	175
S000-291	235	16	23	78	47	70	85		57		46	422
S001-121					1		1	1	1	1	1	6
S000-406	241			4	5		4	5	5	5	5	33
S001-089	243				1			1	1	1	1	5
S003-024				211	230	167	214		219	194	230	1,465
S000-523	250	2	2	7	2		175	2	2		7	199
S004-217	263							45			45	90
S004-218	271							43			43	86
S001-071	275			15	12		9					36

Table C- 6. Blue Earth Watershed Stream Site With Any Applicable Constituent (Page 2 of 3)

Blue Earth 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S004-082	277			15	13		10					38
46-0133-00-101	282		17	67	17		67	17	5		24	214
S003-020	283		3	29	18		31				4	85
S004-076					33				31	32	33	129
S004-077				16	51		10		40	39	40	196
S004-081				15	15		10					40
S004-083					37				36	36	37	146
S004-084					37				37	37	37	148
S004-085					42				43	42	43	170
S004-087					20			4	11	20	15	70
S004-088				1	9		1	1	10	9	10	41
S001-027	293		11	25	10	10	23				10	89
S003-002	295					8	3					11
46-0121-00-101	298		10	28	10		28	10	6		10	102
S000-671	299		4	25	4		24				4	61
S004-080	303			15	22		10	7			7	61
S004-079	305			13	14		9					36
S001-028	307		14		8		6				8	36
S003-022			10	15	10		20				10	65
S003-021	311		6	25	6	13	25				6	81
S004-078	313			15	15		10					40
S003-025	315			190	225	209	215		210	197	210	1,456
S000-535	317			13	12		42					67
S000-522	330	22	24	16	22		16	20	17	1	22	160
S001-302		31	33	31	31	1	31	31	30	1	31	251

Table C- 6. Blue Earth Watershed Stream Site With Any Applicable Constituent (Page 3 of 3)

Blue Earth 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]	T-ORTHO[f]	T-P[g]	Total
S002-428	351				1			1	1	1	1	5
07-0090-00-100	352		3	8	2		8	2	2		3	28
S001-327	390	15	15	15	16		107	16	16		16	216
S000-171	410			2			2					4
S001-231			196	45	266	207	60	230	259	103	267	1,633
S000-134	870	33	33	72	60	68	73	7	71		61	478

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

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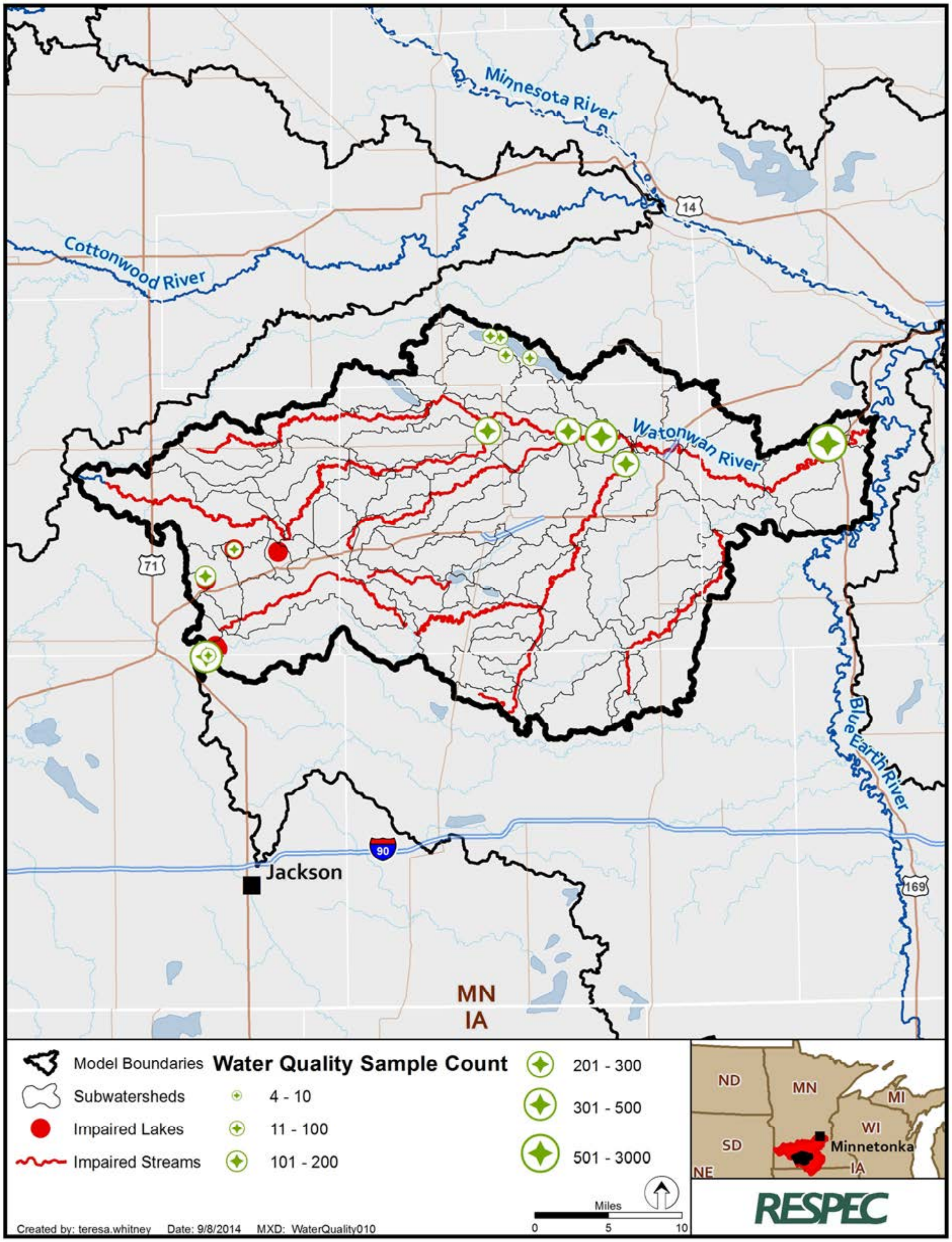

Figure C-7. Observed Water-Quality Locations Within Watonwan Watershed.

Table C-7. Observed Water-Quality Locations Within the Watonwan Watershed

Watonwan 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
17-0020-00-101	32		9	28	9		28	9	2		9	94
S002-252	90				61			40	61	60	61	283
S002-253	110				61			41	61	60	61	284
S002-254	150				61		59	41	61	60	61	343
S003-855	153		9	15			14				9	47
08-0026-00-102	154		11	21	6		21	6	4		11	80
08-0026-00-106			5	20	5		20	5	3		6	64
08-0026-00-202							1				1	2
08-0026-00-206			5	20	5		20	5	4		5	64
17-0007-00-101	174		10	40	10		40	10	1		13	124
32-0018-03-201	182		4	12	2		12	3			4	37
32-0018-03-203			61	57			58	62			63	301
S002-251	201				61			41	61	60	61	284
S000-163	270	34	56	116	521	91	159	418	515	365	523	2,798

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

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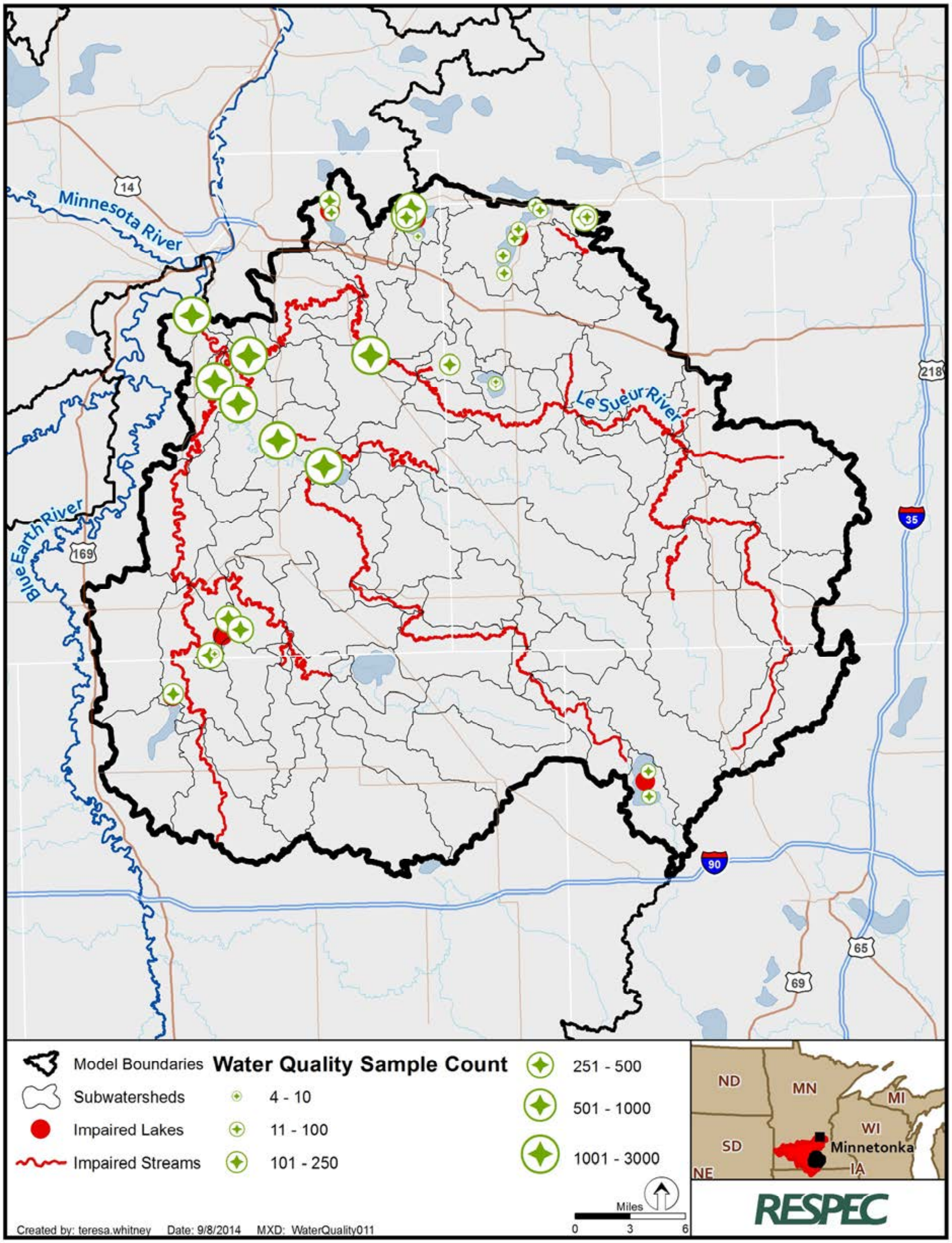

Figure C-8. Observed Water-Quality Locations Within the Le Sueur Watershed.

Table C-8. Observed Water-Quality Locations Within the Middle Minnesota Watershed (Page 1 of 3)

Le Sueur 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
81-0003-00-100	452	8	206	4		206	8		8		17	457
81-0003-00-201		22	858	19		858	23		13		44	1,837
S006-329	470		4		2	4			2	2	2	16
S006-330			4		2	4			2	2	2	16
S004-836	491	4	22	10	12	22	10		12	2	12	106
S006-324	510		4		2	4			2	2	2	16
S000-295	570			1								1
S000-656	610			1								1
S005-319				1								1
81-0055-00-101	614	9	110	9		110	9		2		18	267
81-0055-00-201		6									7	13
81-0095-01-101	616	5	20	5		20	4				5	59
81-0095-01-102		5	16	5		16	1				5	48
81-0095-01-104		5	22	5		22					5	59
81-0095-01-201		4		5							5	14
81-0095-01-202		4		5							5	14
81-0095-01-203		16		5							17	38
81-0083-00-101	618	4	4	4		4	4				4	24
81-0083-00-202						2					2	4
S000-654	621	5	20	11	11	50	11		11		11	130
S003-448	650	83	47	190	114	65	164		182	142	181	1,168
07-0060-01-100	672	4	2			2					3	11
07-0060-01-101		14	49	13		50	14		2		20	162
S007-304	675			8		8					8	24
S007-306				8		9					8	25

Table C-8. Observed Water-Quality Locations Within the Middle Minnesota Watershed (Page 2 of 3)

Le Sueur 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
07-0044-00-100	676	3	2			2					3	10
07-0044-00-102		6	91	6		91	6				12	212
07-0044-00-201		15	295	12		311	14		9		31	687
07-0044-00-202		23	263			263	1		1		35	586
S005-310	690			1								1
S005-318			1	2		1	1		1	1	1	8
S003-860	710	123	38	221	161	54	167		214	147	211	1,336
S005-317				1								1
24-0044-00-101	712	10	16	10		16	10				10	72
24-0044-00-102		5	6	2		6	2				5	26
S003-574	743	131	233	278	176	376	293	161	246	128	404	2,426
S001-210	747	106	70	216	135	100	168		213	121	210	1,339
S003-446	751	118	57	218	166	176	173		216	144	214	1,482
S003-859	770		2	2		2	2		2	2	3	15
S000-296	777			1								1
S005-309				1								1
22-0033-00-201	778	7	7	5		8	5		2		7	41
S002-473	789	4	20	11	10	20	10		10		10	95
S005-312	791		1	2	1	1			1	1	1	8
S005-311	795			1								1
S005-305	799			1								1
S006-365	801		3		1	3			1	1	1	10
22-0075-00-101	802	6	5	6		5	6		1		6	35
22-0075-00-203						1					1	2
S006-177	803		3		1	3			1	1	1	10

Table C-8. Observed Water-Quality Locations Within the Middle Minnesota Watershed (Page 3 of 3)

Le Sueur 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
22-0074-00-201	806	9	45	6		45	8				13	126
07-0079-00-101	808	58	118	58		117	15		28	22	58	474
07-0079-00-103		50	67	46		67	5		23	22	51	331
07-0079-00-201		52	109	46		111	7		24	22	52	423
07-0079-00-203						2					2	4
S002-431	809	6	25	11	14	45	11		14	3	14	143
S005-466			4		2	4			2	2	2	16
S006-175			5		3	5			3	3	3	22
S006-176			3		3	3			3	3	3	18
S006-178			3		3	3			3	3	3	18
S004-101	811		1	245	1	5	230		231	165	234	1,112
S004-304	813			2								2
S002-427	817	7	21	407	15	64	379		389	309	391	1,982
S002-435				1								1
S000-340	850	186	62	275	200	123	221		255	95	254	1,671

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

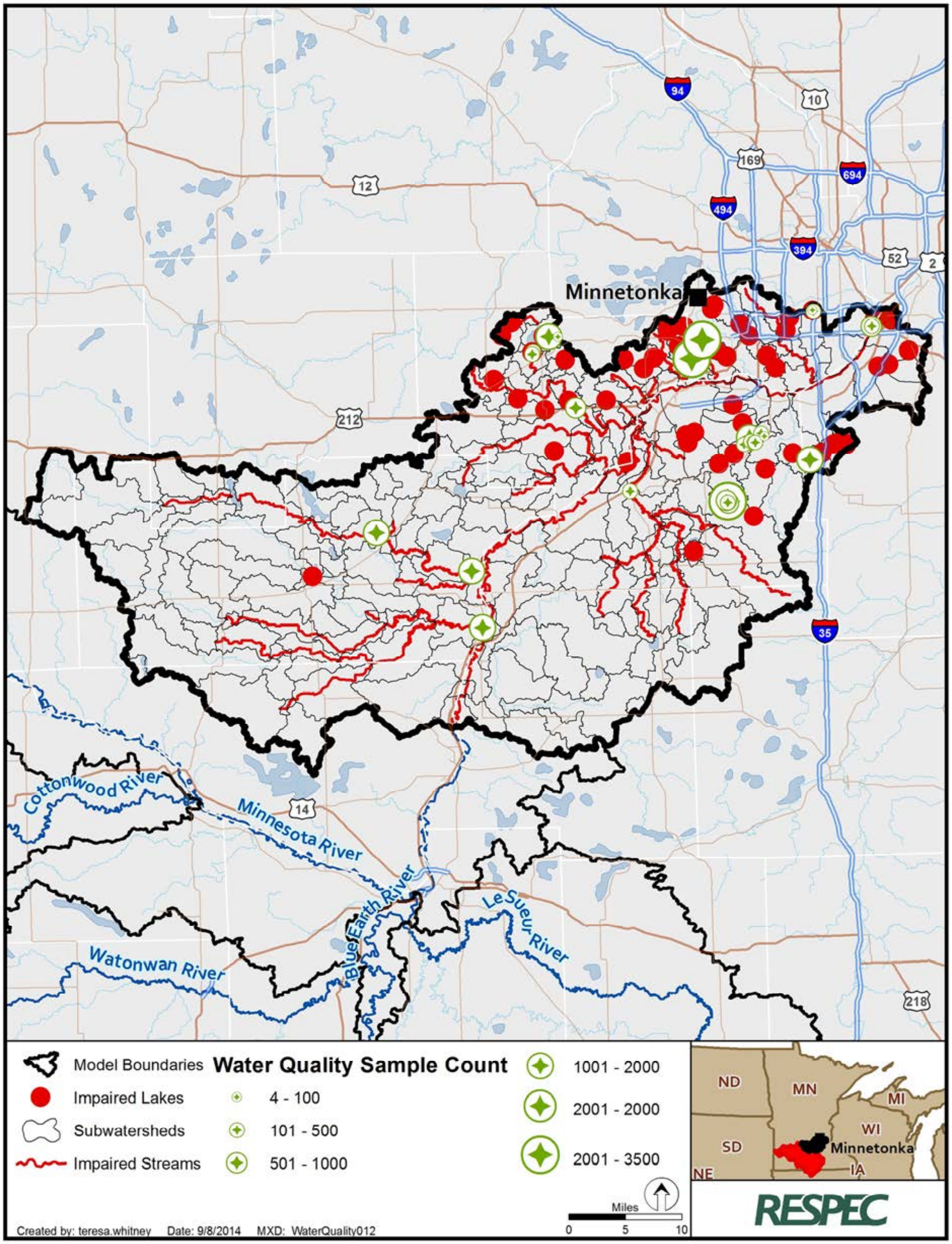

Figure C-9. Observed Water-Quality Locations Within the Middle Minnesota Watershed

Table C-9. Middle Minnesota Watershed Stream Site With Any Applicable Constituent (Page 1 of 8)

Lower Minnesota 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
S000-735	50	4	4		4		108	2			4	126
40-0020-00-201	52		19	20			20				19	78
40-0079-00-101	58		19	20			20				19	78
S005-722	63		13	24	24		24	13	13		13	124
S005-723	67		16	27	27		27	16	16		16	145
S000-489	75				7			7	7	7	7	35
S002-939					2			2	2	2	2	10
S002-931	83	1			72	1	20	44	73	44	71	326
S003-171	87				6			6	7	6	6	31
S004-961				34	33		43	32	34	23	34	233
S004-962	89			35	34		41	34	35	25	35	239
72-0042-00-101	92		16	23	17		17	16	6	11	17	123
72-0042-00-202			10	11			11				11	43
S002-930	105				71		22	43	72	43	71	322
S002-932	125				69		21	41	70	41	69	311
S002-933	135				70		21	42	71	42	70	316
S000-822	139	4	4	21	271		49	245	267	176	267	1,304
S000-040	150	24	24	74	49	55	62	2	56		49	395
S002-277	171	10		2	11		2	11	12	11	11	70
S001-629	179	33		2	40		4	39	40	39	39	236
S001-626	189	34		1	41		4	40	40	40	40	240
S002-307					12			11	11	12	12	58
S002-305	191				19			15	15	19	19	87
72-0050-01-101	192				16						16	32
72-0050-01-102					16						16	32

Table C-9. Middle Minnesota Watershed Stream Site With Any Applicable Constituent (Page 2 of 8)

Lower Minnesota 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
72-0050-01-201			1	6	17		3	1	1		17	46
72-0050-01-202					8						8	16
S001-891	197	32		23	276		48	254	275	186	272	1,366
S001-809	201	9		2	11		42	11	12	11	11	109
S000-438	203	11		2	13		4	13	14	13	13	83
S000-437	205	4			4			4	4	4	4	24
72-0013-00-101	206		4	22	4		11	4			4	49
S002-306	209	31		2	38		4	36	37	36	36	220
S001-807	211	35		24	283		95	260	281	192	277	1,447
S000-676	215	47	4	22	311		50	279	306	212	310	1,541
5327000	217						20					20
S000-778	270	4	4		4			2			4	18
S002-517	273			8			11					19
S002-518	277		1	9	38	38	15	38		9	38	186
S002-510	281			9	32	32	9	32		30	32	176
S002-511				14	9	9	37	9			9	87
S002-516				23	118	118	49	118		56	118	600
S002-539	285		19	25	157	157	60	157		88	157	820
10-0058-00-100	286		18	40			42	41			41	182
S002-509	287				26	26	224	24		25	24	349
S000-825	289			8	135	135	20	134		76	134	642
S002-506				9	9	9	26	9		9	9	80
S002-507							13					13
S002-508				35			38					73
S002-514	293		13	7	29	29	14	29			29	150

Table C-9. Middle Minnesota Watershed Stream Site With Any Applicable Constituent (Page 3 of 8)

Lower Minnesota 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]	T-ORTHO[f]	T-P[g]	Total
S002-513	297			14			14					28
S002-515				7	12	12	15	12			12	70
S000-843	299		1	31	113	113	60	103		53	113	587
S002-505	301						13					13
S002-549			21	34	8	8	50	8		2	8	139
S000-039	310	4	4	91	11		69	2			4	185
10-0016-00-100	312		10				16	17			17	60
S004-908	313		14	25	15		26	14			14	108
40-0028-00-451	314		13				13	13			13	52
S004-516	319		33	63	43		63	41			41	284
S004-518		25	62	62	98	50	61	95			95	548
S004-521	321	13	33	45	51	20	46	49			49	306
70-0091-00-401	322		20	437			263	64			78	862
70-0091-00-451			84				84	111			111	390
70-0098-00-401	324		5	20			20	5			5	55
S000-753	333		36	63	45		63	43			43	293
S004-617	337	20	23	31	29	25	32	29			29	218
S004-618	343	23	19	36	33	29	37	33			33	243
S001-764	347	12	42	59	64	19	60	63			63	382
S004-519	349	23	45	36	68	37	36	66			66	377
S001-366	353	26	50	48	83	44	64	81			81	477
S004-898	355	16	8	27	27	24	27	27		14	27	197
S004-524	359		23	75	26		98	25			25	272
S004-522	363		25	62	29		63	28	1		29	237
S004-523	365		23	61	28		61	26			26	225

Table C-9. Middle Minnesota Watershed Stream Site With Any Applicable Constituent (Page 4 of 8)

Lower Minnesota 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
5330000	370			214	2		118	46			46	426
10-0086-00-201	372		1				1				1	3
10-0088-00-201	374		146	346	1		306	177			190	1,166
S002-497	375			8			8					16
S002-493	377			7			12					19
S002-494	379			9	42	42	18	42		7	42	202
10-0066-00-100	382		9	40		9	20	9	9	9	10	115
10-0066-00-201			82	78			100	99			99	458
10-0069-00-201	384		100	71			133	138			138	580
S002-486	385				29	29	3	29			29	119
S002-495				12	15		37	15			15	94
S002-496			1	7	11	11	17	11			11	69
10-0080-00-201	386		49	41			72	72			72	306
10-0089-00-203	388		145	240			244	216			216	1,061
S002-491	389			7	28	28	15	28			28	134
10-0059-00-208	394			8			8					16
10-0059-00-401			142	534			435	251			251	1,613
10-0084-00-100			49	13	9		70	83			83	307
10-0084-00-201			32	110			114	32			32	320
S002-504	397		24	30	80	80	58	80		10	80	442
10-0052-00-201	402		135	328	7	14	302	202		16	202	1,206
S002-492	403			5	40	40	14	40		8	40	187
S002-490	407		25	37	169	168	65	168		103	168	903
10-0029-00-100	408		3	38			19	3	3	3	10	79
10-0029-00-201			141	227			225	186			186	965

Table C-9. Middle Minnesota Watershed Stream Site With Any Applicable Constituent (Page 5 of 8)

Lower Minnesota 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]	T-ORTHO[f]	T-P[g]	Total
S002-489	409		13	32	167	167	58	165		101	165	868
S002-512	411			18	4	4	35	4			4	69
S002-488	413		25	30	9	9	34	9		1	9	126
S002-499	415			22	41	41	50	41		8	41	244
S004-229	451				4	4		4			4	16
10-0031-00-100	452		33	53			56	56			56	254
S004-226	453				4	4		4			4	16
S002-548	455			31	129	129	59	129		71	129	677
10-0019-00-202	492		160	57	1		261	236			237	952
10-0014-00-100	494		34	54			56	57			57	258
10-0014-00-202			42	58			58	42			42	242
S004-228	495				4	4		4			4	16
10-0218-00-100	496		69	65			68	68			68	338
10-0218-00-201			42	97			98	39			39	315
S001-761	497			10	86	86	35	85		21	85	408
S002-540	499			10	79	79	33	78		18	78	375
S004-963	501			11	14		11				14	50
70-0095-00-201	506		107	706			453	161			184	1,611
70-0120-01-401	508		57	572			339	119			142	1,229
S004-122	510		9		9	9		9	9	9	9	63
10-0007-00-201	512		68	234		84	272	74	54	85	123	994
10-0012-00-401	514	1	31	517		295	512	64	41	52	67	1,580
10-0013-00-451	516		79	138		70	209	106	30	37	111	780
10-0002-00-451	518	1	145	1438		161	1029	210	31	34	256	3,305

Table C-9. Middle Minnesota Watershed Stream Site With Any Applicable Constituent (Page 6 of 8)

Lower Minnesota 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]	T-ORTHO[f]	T-P[g]	Total
S002-896	531			14	49		17			48	49	177
70-0069-00-100	532		14	130			130			38	39	351
70-0069-00-201			1	306			154	14			26	501
70-0069-00-204			88	837			838			154	258	2,175
70-0069-00-205			122	10	1		171	163			165	632
70-0054-00-203	534		107	290			286	150			170	1,003
70-0054-00-205			101	1046			1046			214	294	2,701
70-0072-00-100	536		11				12	11			11	45
70-0072-00-202			221	1521			1517	191		183	492	4,125
70-0026-00-100	538		26	10			64	64			64	228
70-0026-00-101			156	516			496	225			258	1,651
70-0026-00-104			14	230			153	14			28	439
70-0026-00-203			14	231			154	14			28	441
70-0026-00-205			14	186			125	14			28	367
70-0026-00-206			6	108			76	7			14	211
70-0026-00-207			6	41			26	7			14	94
70-0076-00-100	542		10				10	7			7	34
70-0076-00-451			58				89	90			91	328
70-0074-00-451	544		72				74	77			77	300
S005-129	550	1	6			6		6	6	5	6	36
10-0006-00-201	552		86	163		17	242	99	10	14	101	732
10-0006-00-401			1	334			246	27			50	658
27-0071-00-201	554	1	20	336		272	336	52	43	54	55	1,169
27-0070-00-202	556		125	846		70	698	192	4	18	230	2,183

Table C-9. Middle Minnesota Watershed Stream Site With Any Applicable Constituent (Page 7 of 8)

Lower Minnesota 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]	T-ORTHO[f]	T-P[g]	Total
27-0076-00-100	558		39	612			359	101			125	1236
27-0076-00-201			23	152		23	154	20	35	54	56	517
27-0078-00-203	562	1	26	140		58	140	30	43	60	60	558
27-0078-00-401			32	467			267	99			124	989
27-0048-00-201	566		80	532			532			21	82	1,247
27-0048-00-203			13	55		13	55	13	25	27	27	228
S004-109	570	1	28		18	24		24	24	23	24	166
S006-102		1	7			6		6	6	5	6	37
70-0050-00-401	572		85	529			351	151			179	1,295
S004-933	573		33	40	35		41	35	17		35	236
19-0031-00-201	576		136	649			482	223		2	246	1,738
70-0011-02-202	577		47	345			345			42	97	876
70-0022-00-203	578		143	529			530			90	146	1,438
S004-935	583		41	49	44		49	44	23		44	294
19-0446-00-451	584		119	107			268	161			258	913
19-0025-00-401	586		147	313			363	232		9	262	1,326
19-0029-00-451	588		130	65			257	191			244	887
19-0027-00-204	602		167	1803			1153	286		7	476	3,892
27-0091-00-451	604		74				74	74			74	296
27-0092-00-451	606		40				40	40			40	160
27-0067-00-201	608		120	1554			1573			59	222	3,528
27-0047-00-100	614		19	452			243	62			67	843
27-0047-00-201			79				79	79			79	316
27-0062-01-202	615		51	137			137				51	376

Table C-9. Middle Minnesota Watershed Stream Site With Any Applicable Constituent (Page 8 of 8)

Lower Minnesota 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)]	T-ORTHO[(f)]	T-P[(g)]	Total
27-0062-03-202			47	123			124				46	340
27-0028-00-201	618		14				14	14			14	56
27-0028-01-451			59				59	59			59	236
27-0029-00-451	622		20				20	20			20	80
27-0681-00-201	626		46	74		8	45	11	11		46	241
27-0681-00-451							12	11			11	34
S000-088	629			1	1	1	1	1	1	1	1	8
S005-070	650	1	7			6		6	6	5	6	37
S003-505	670			6	6		118				6	136
19-0057-00-100	686							74	74	1	92	241
19-0057-00-201			10	460	2	8	370	29	19	12	158	1,068
19-0057-00-205			8	64			64	16	8	4	69	233
S000-086	690			6	6		232				6	250
S005-069		1	7			6		6	6	5	6	37
5330920	710			228			132					360
S000-310		25	43	235	80	76	176	15	77	15	72	814
19-0081-00-202	712		3	167			217	22	2	23	41	475
S005-068	720	1	10			9		9	9	7	9	54

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

ATTACHMENT D

MINNESOTA RIVER WATERSHED
WATER-QUALITY CALIBRATION FIGURES

RSI-2429-14-065

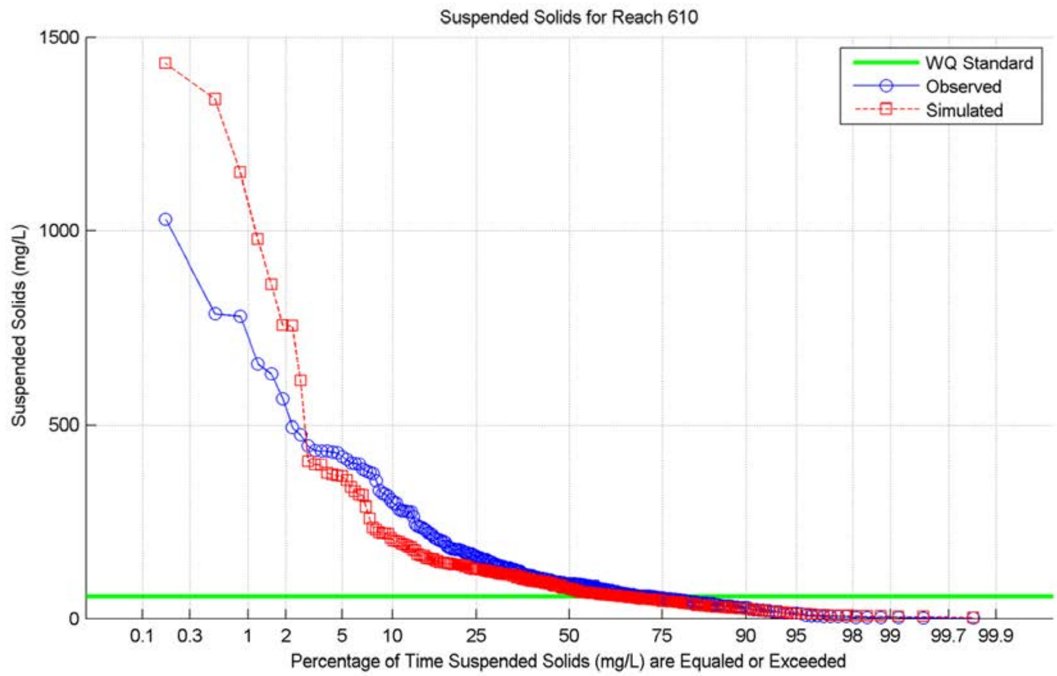

Figure D-1. Suspended Solids Duration Curve–Middle Minnesota (Reach 610).

RSI-2429-14-066

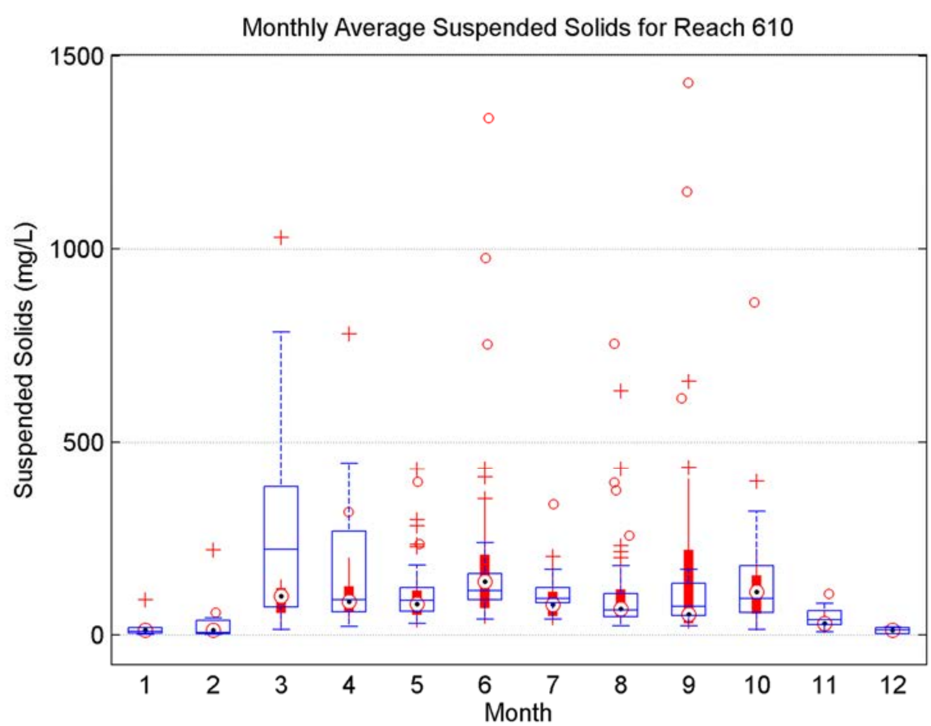

Figure D-2. Suspended Solids Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-067

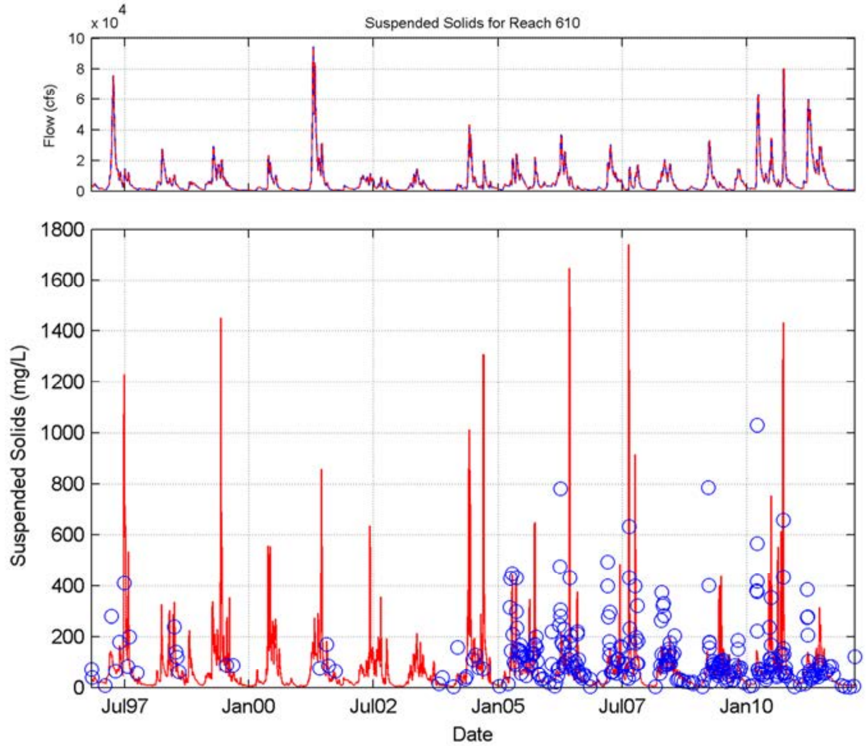

Figure D-3. Suspended Solids Daily Time Series–Middle Minnesota (Reach 610).

RSI-2429-14-068

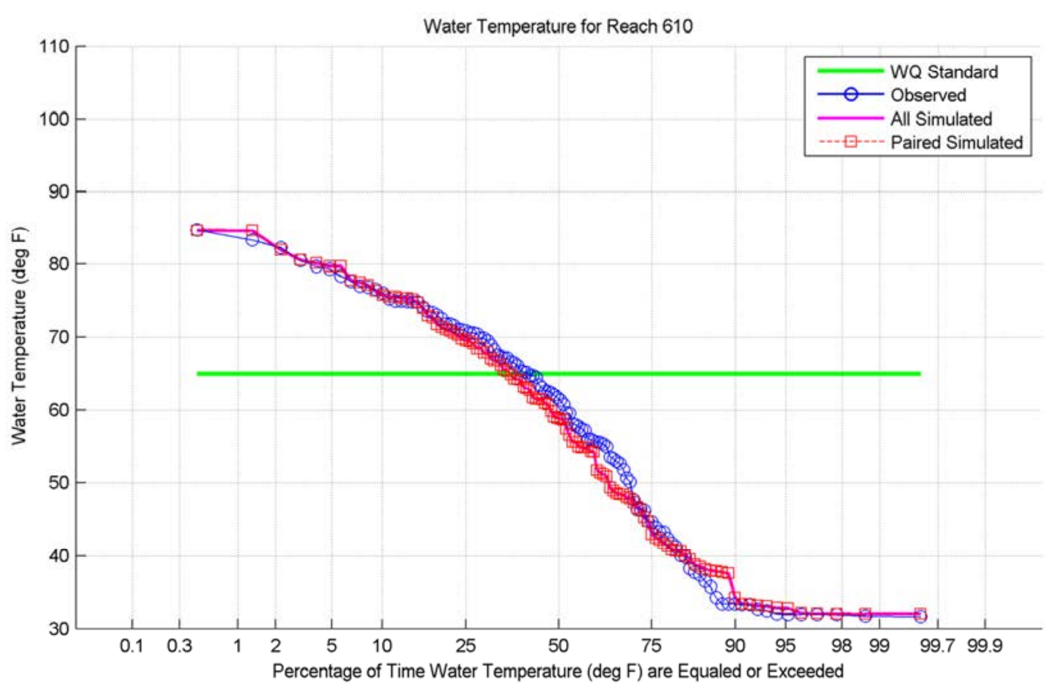

Figure D-4. Water Temperature Duration Curve–Middle Minnesota (Reach 610).

RSI-2429-14-069

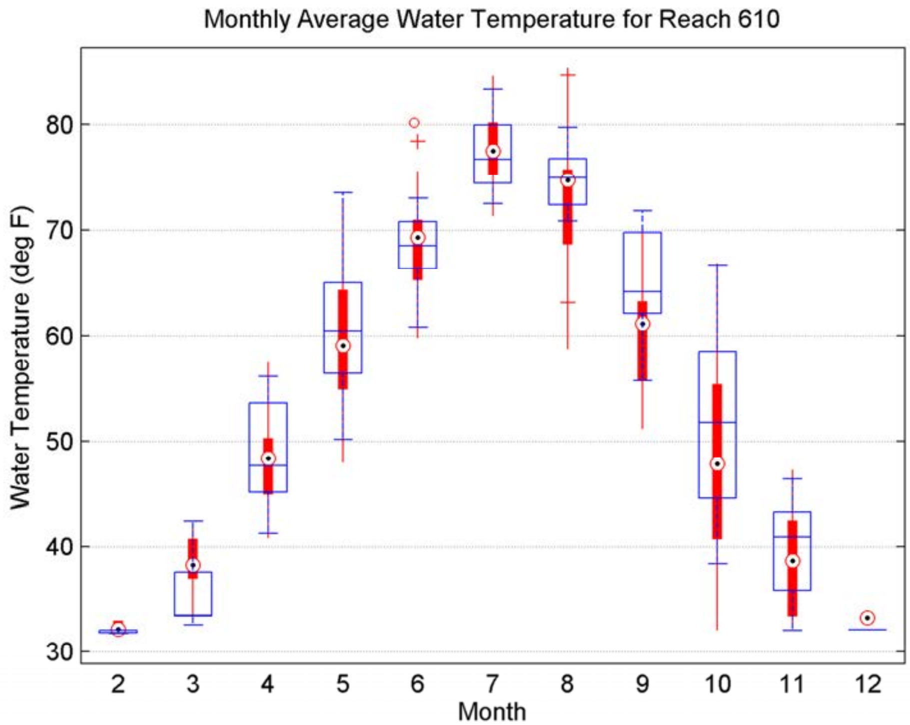

Figure D-5. Water Temperature Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-070

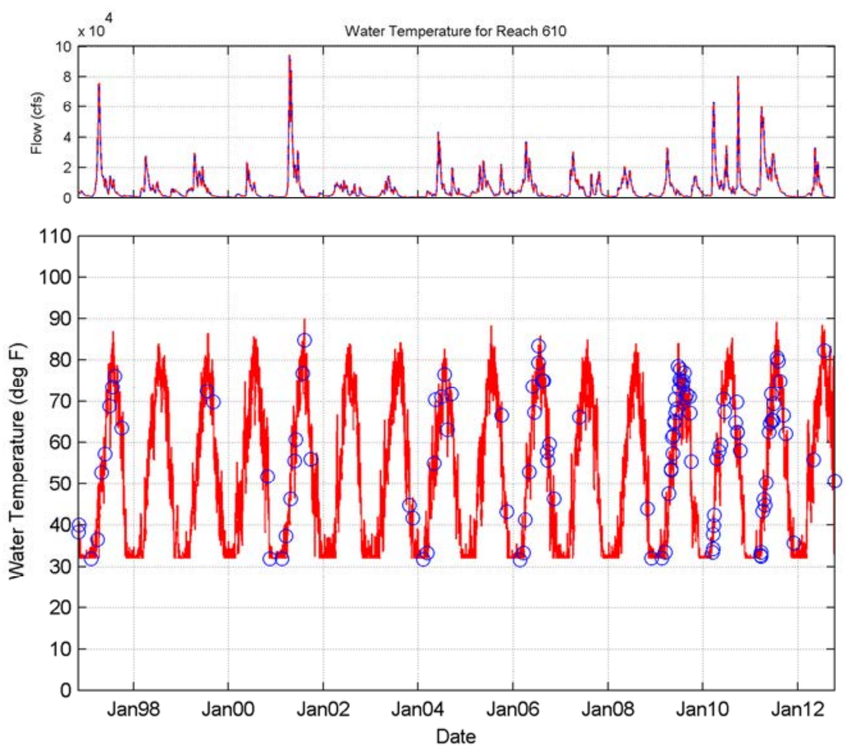

Figure D-6. Water Temperature Daily Time Series–Middle Minnesota (Reach 610).

RSI-2429-14-071

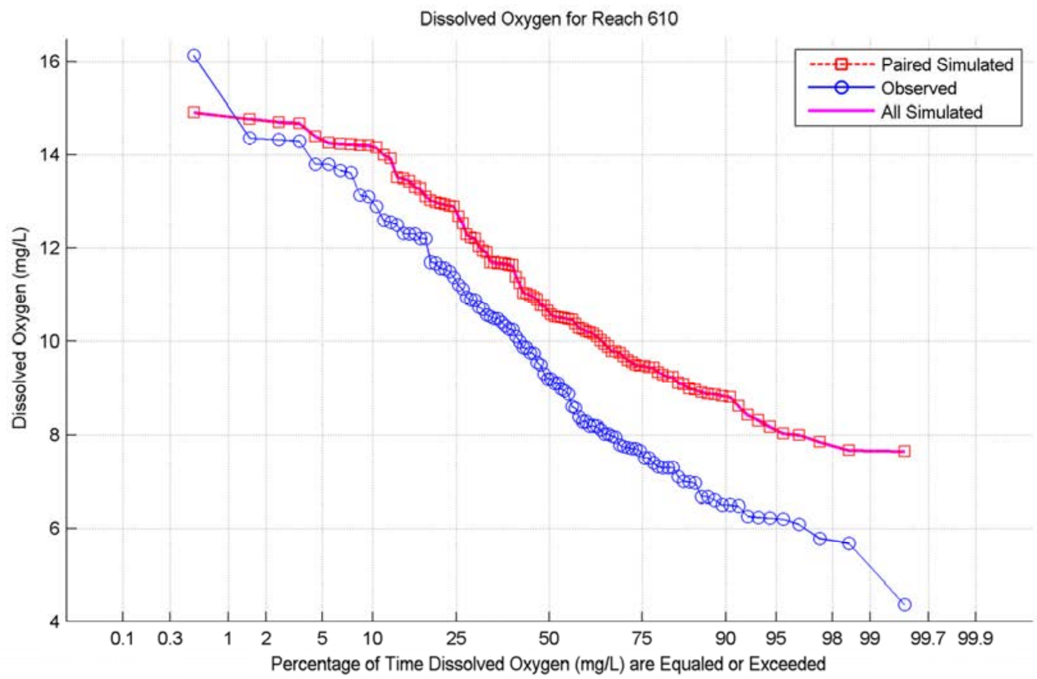

Figure D-7. Dissolved Oxygen Duration Curve–Middle Minnesota (Reach 610).

RSI-2429-14-072

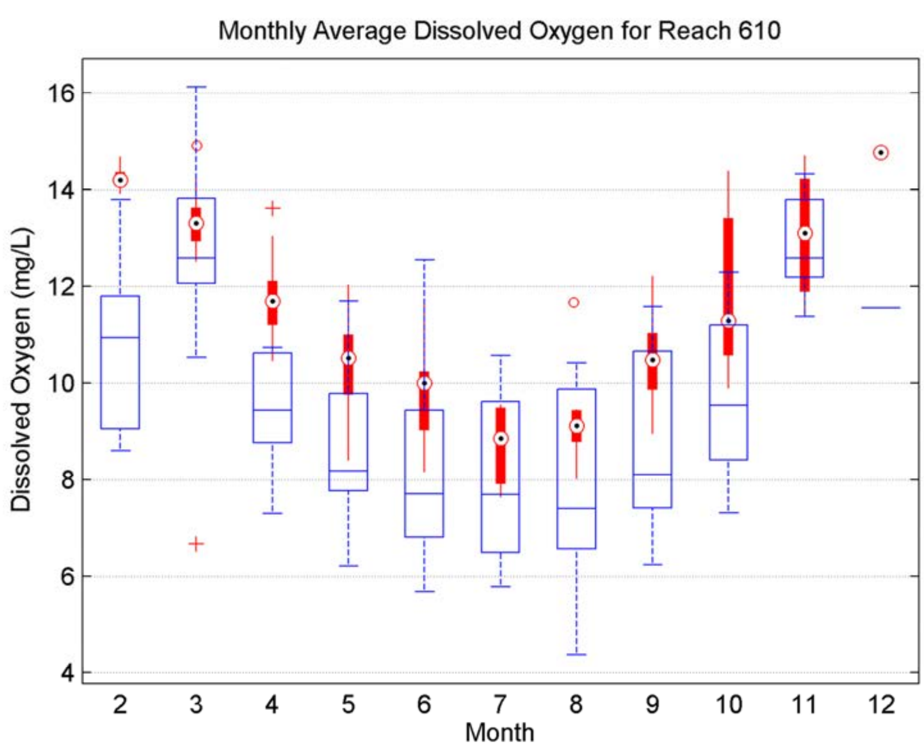

Figure D-8. Dissolved Oxygen Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-073

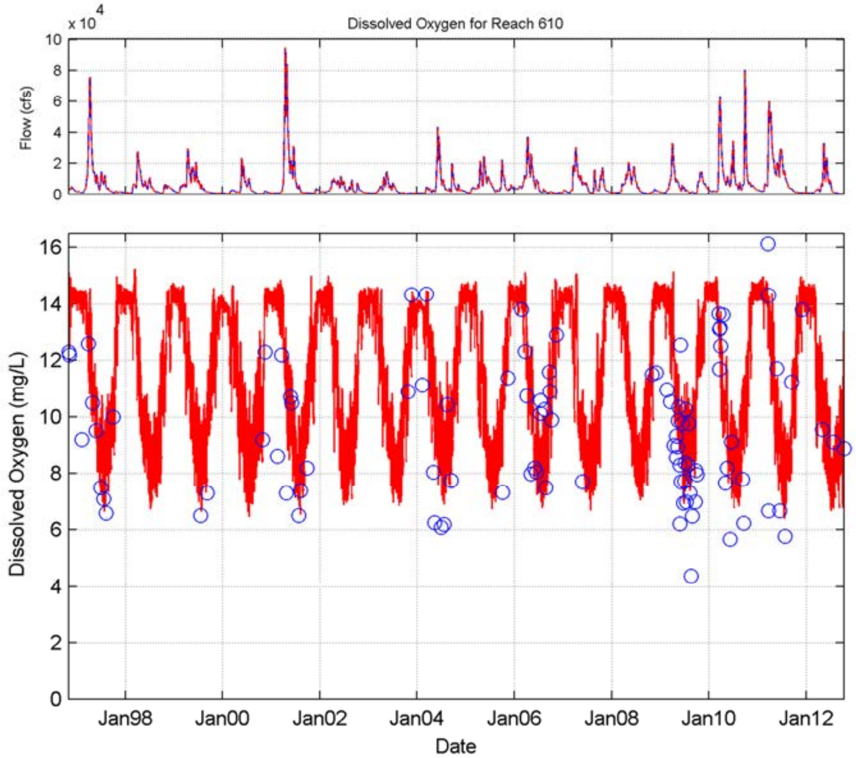

Figure D-9. Dissolved Oxygen Daily Time Series–Middle Minnesota (Reach 610).

RSI-2429-14-074

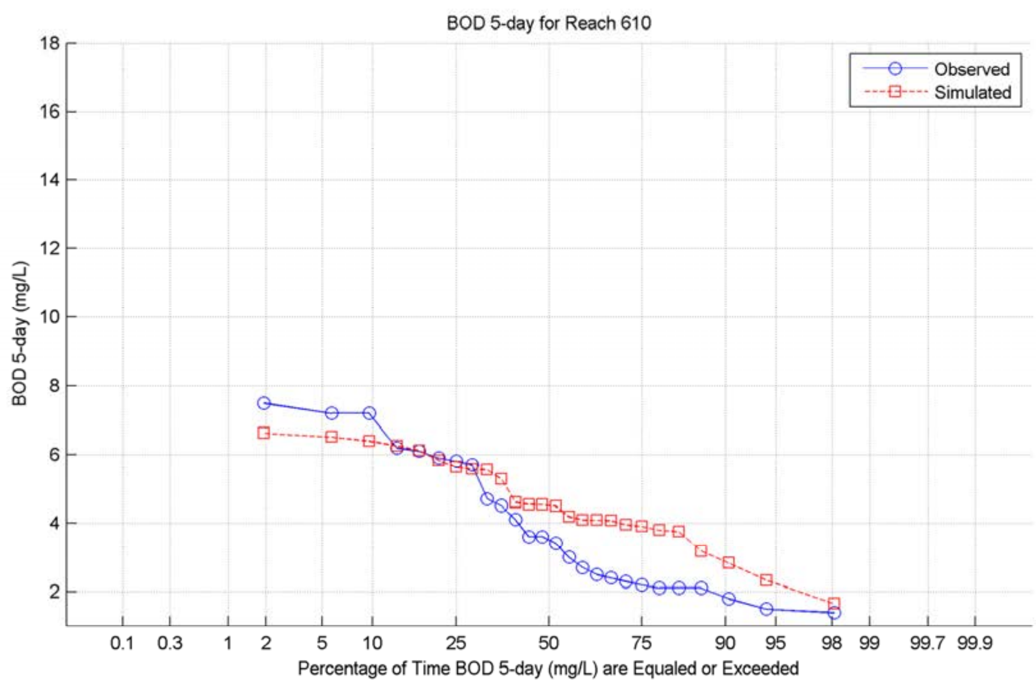

Figure D-10. Biological Oxygen Demand Duration Curve–Middle Minnesota (Reach 610).

RSI-2429-14-075

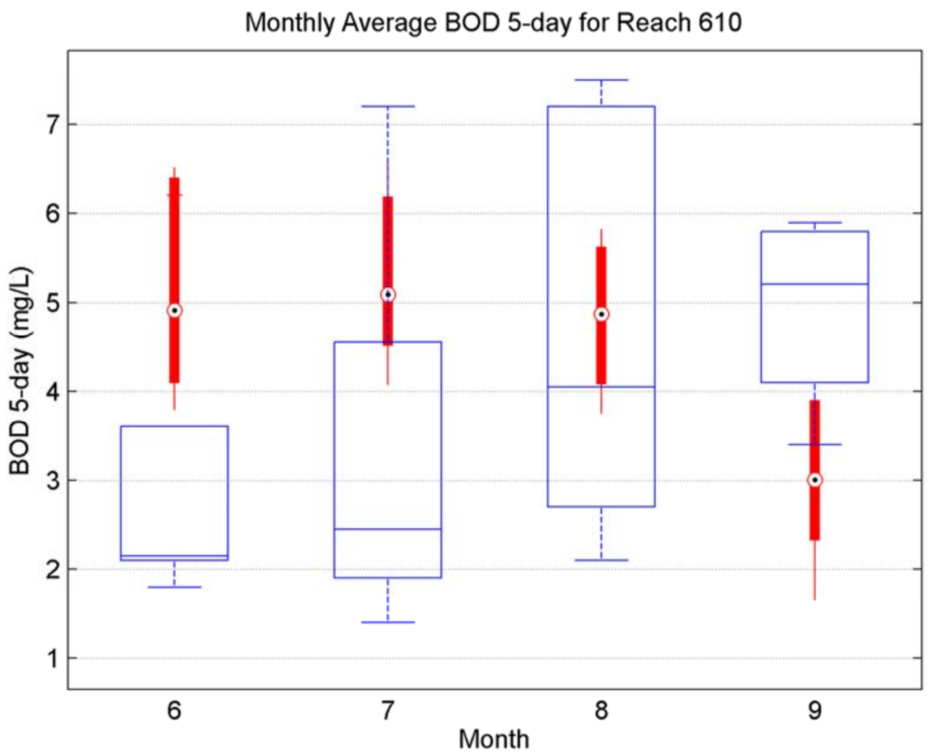

Figure D-11. Biological Oxygen Demand Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-076

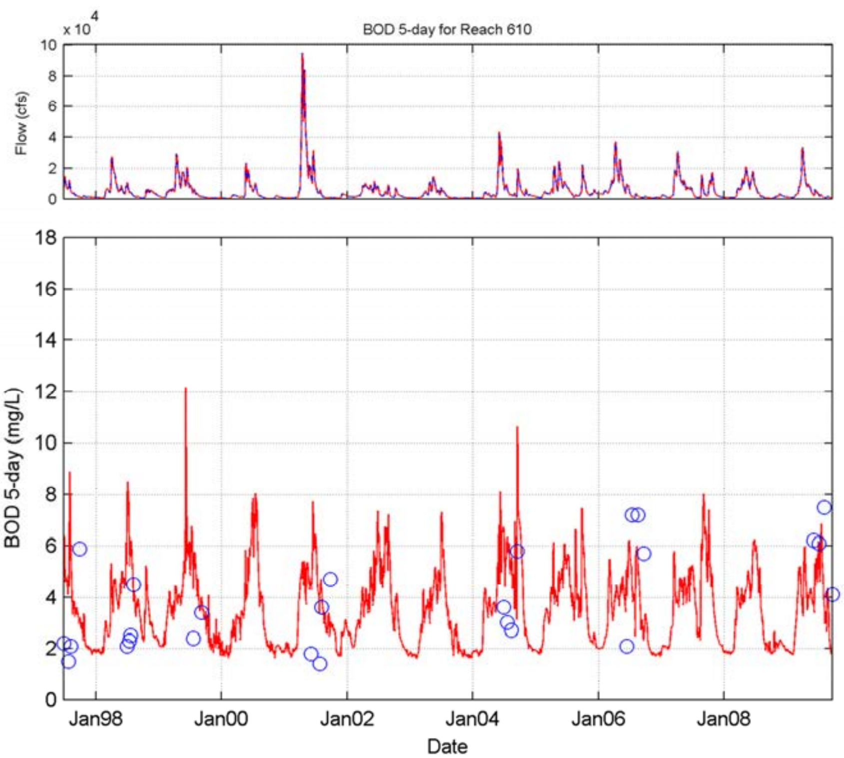

Figure D-12. Biological Oxygen Demand Time Series–Middle Minnesota (Reach 610).

RSI-2429-14-077

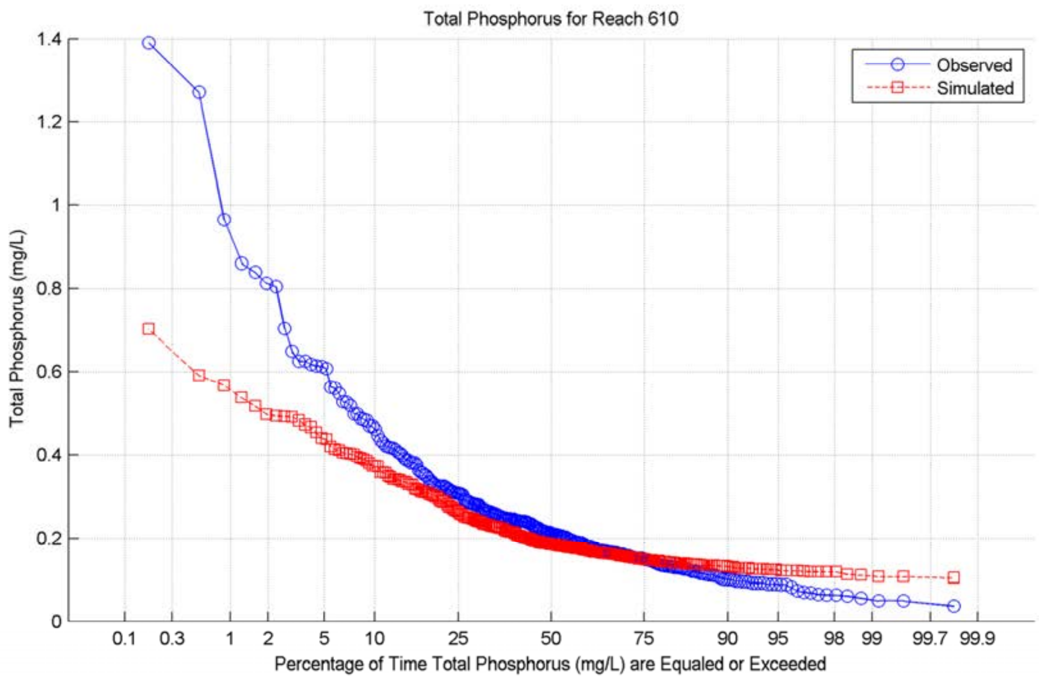

Figure D-13. Total Phosphorus Duration Curve–Middle Minnesota (Reach 610).

RSI-2429-14-078

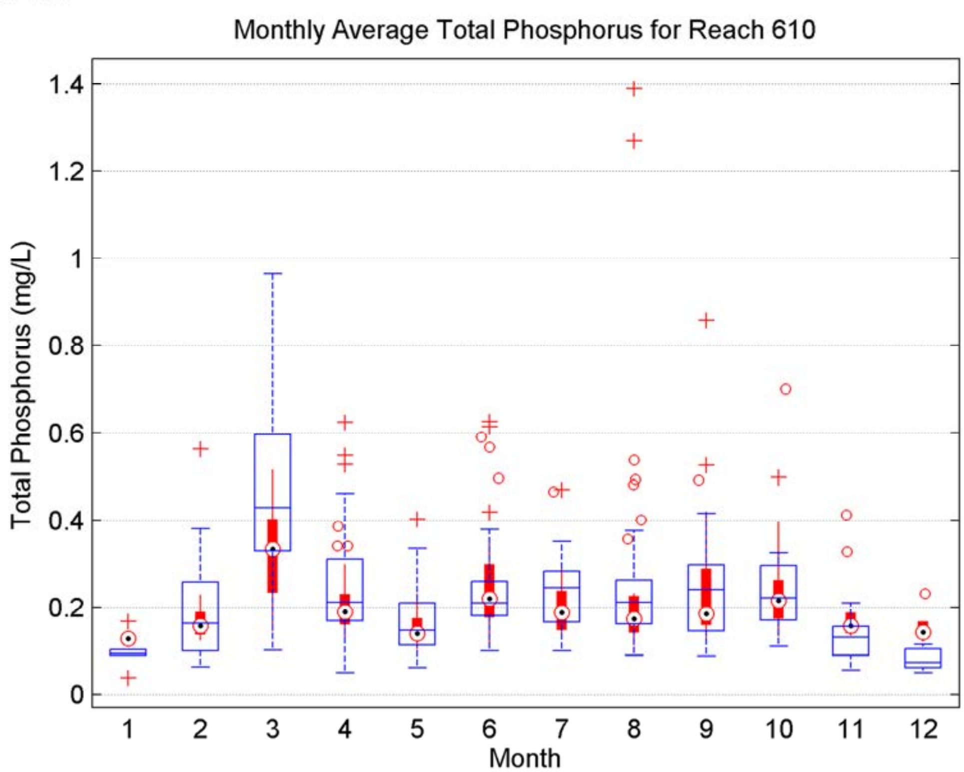

Figure D-14. Total Phosphorus Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-079

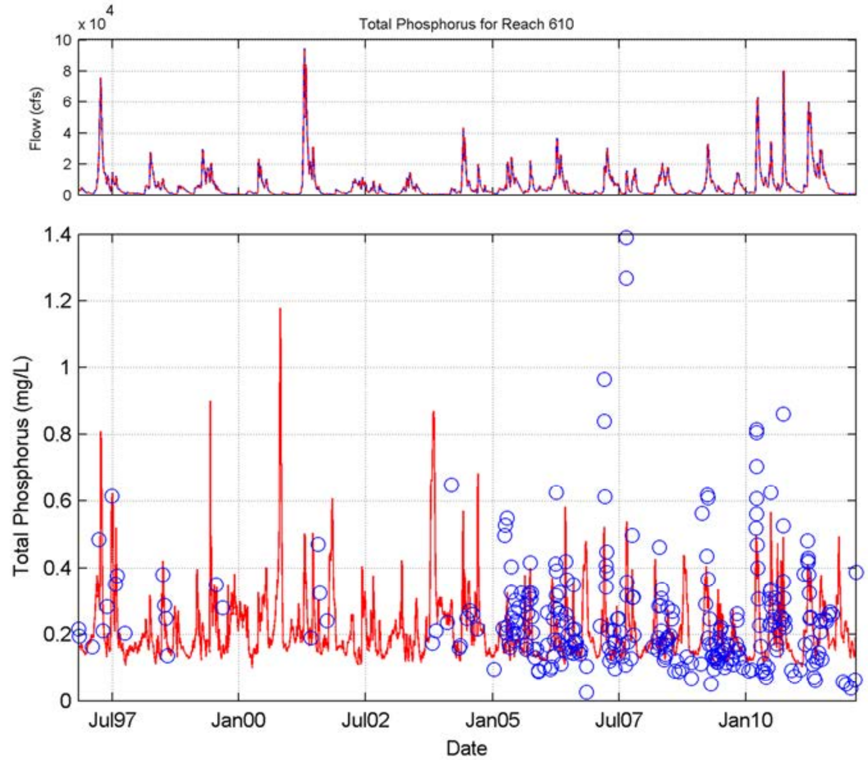

Figure D-15. Total Phosphorus Time Series–Middle Minnesota (Reach 610).

RSI-2429-14-080

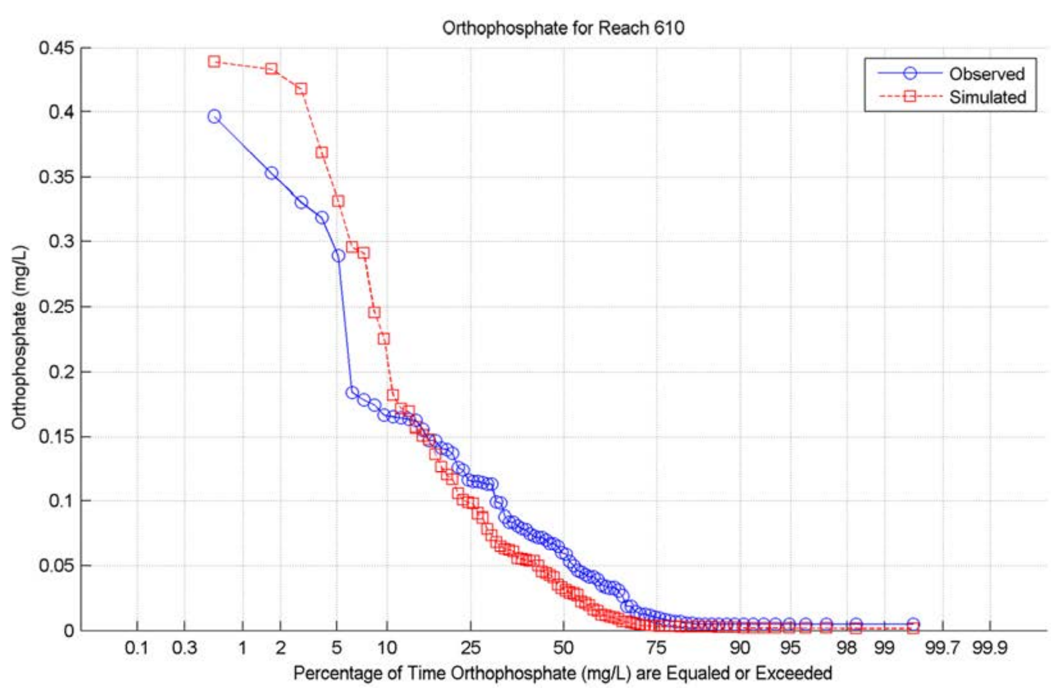

Figure D-16. Orthophosphate Duration Curve–Middle Minnesota (Reach 610).

RSI-2429-14-081

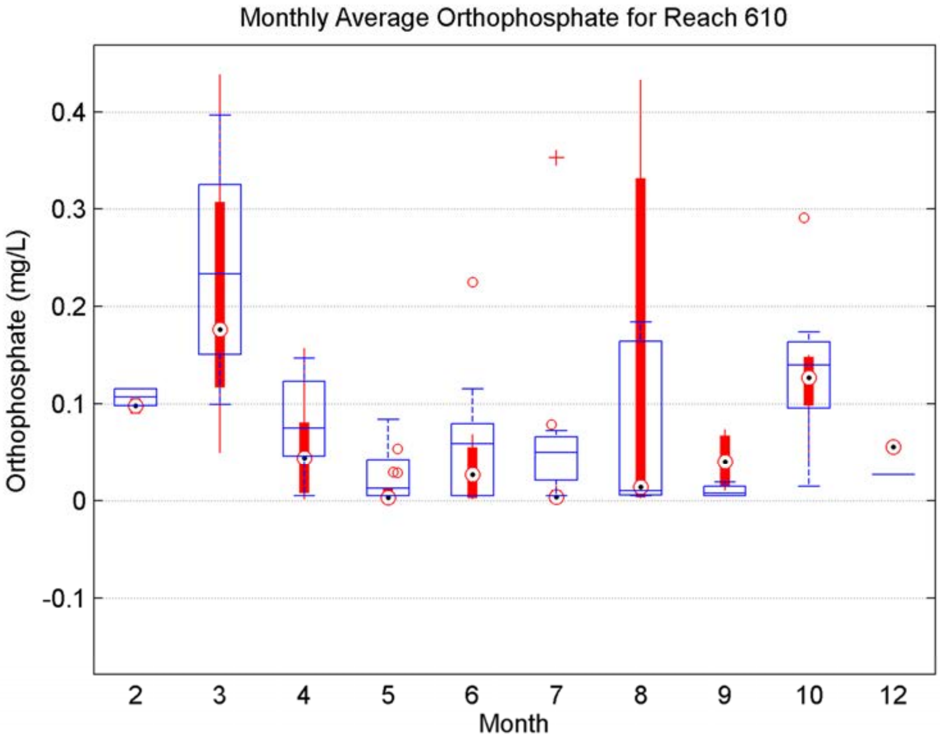

Figure D-17. Orthophosphate Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-082

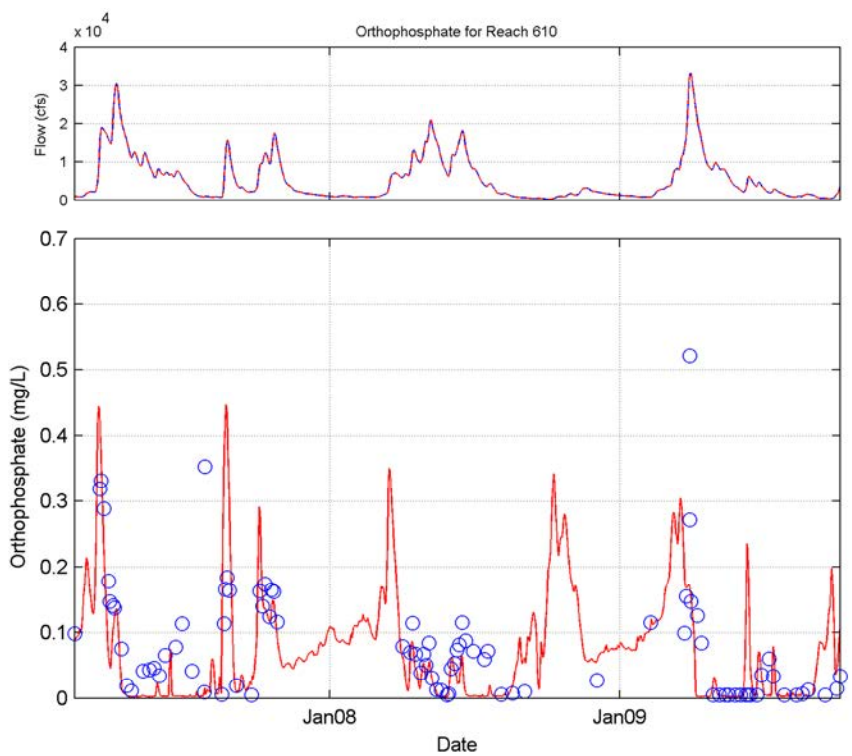

Figure D-18. Orthophosphate Time Series–Middle Minnesota (Reach 610).

RSI-2429-14-083

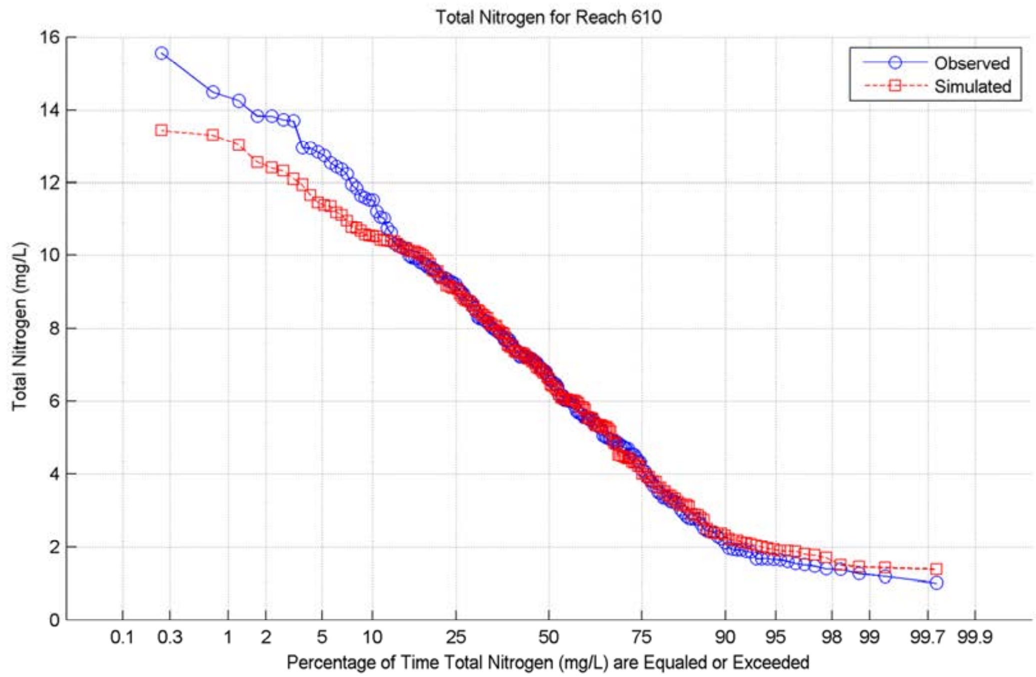

Figure D-19. Total Nitrogen Duration Curve–Middle Minnesota (Reach 610).

RSI-2429-14-084

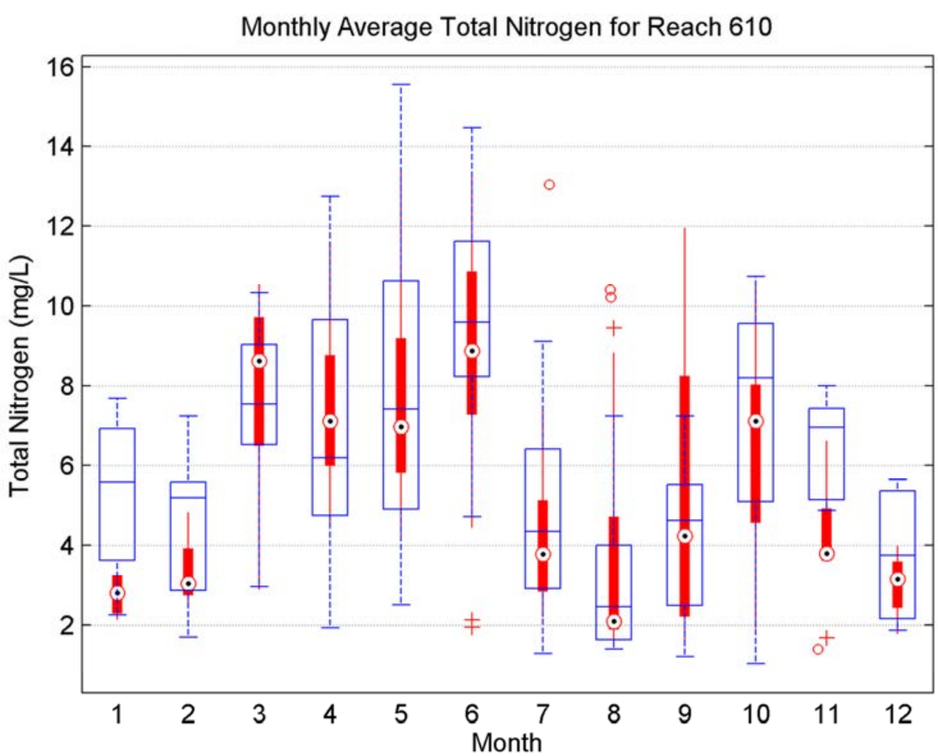

Figure D-20. Total Nitrogen Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-085

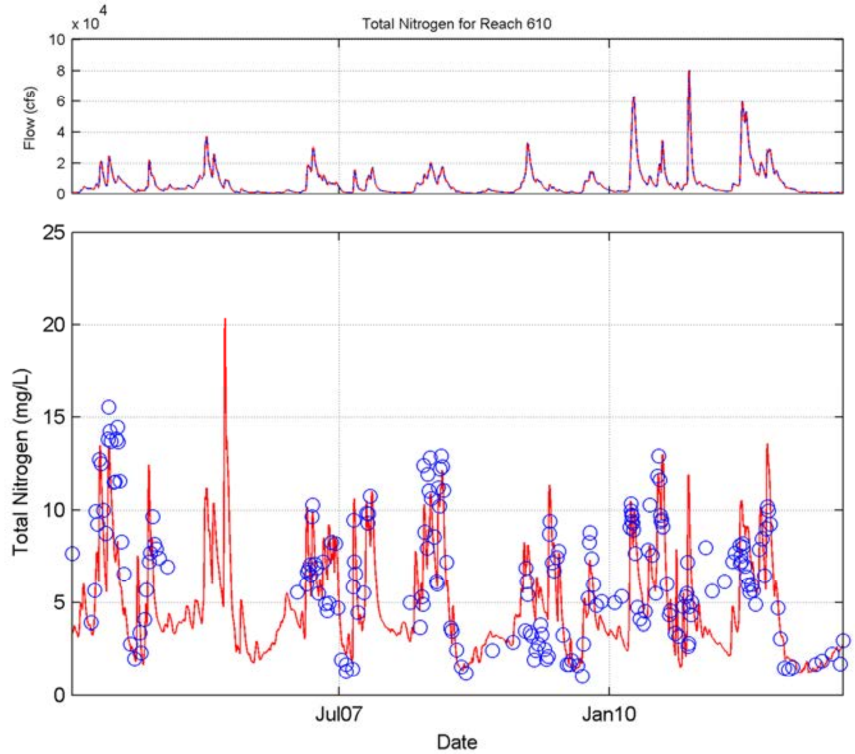

Figure D-21. Total Nitrogen Time Series–Middle Minnesota (Reach 610).

RSI-2429-14-086

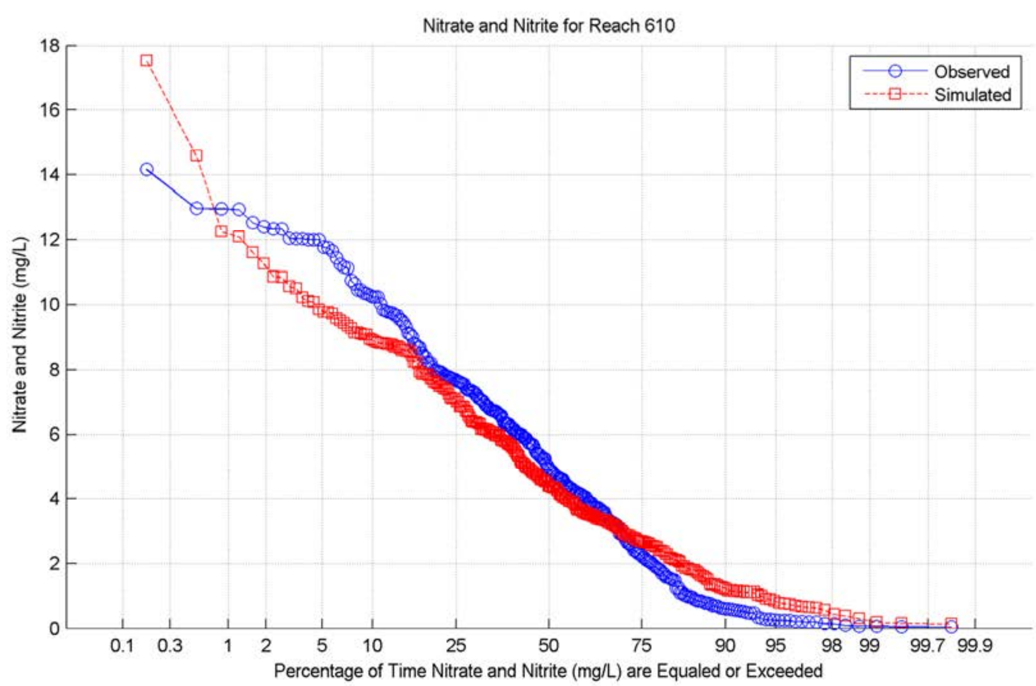

Figure D-22. Nitrate and Nitrite Duration Curve–Middle Minnesota (Reach 610).

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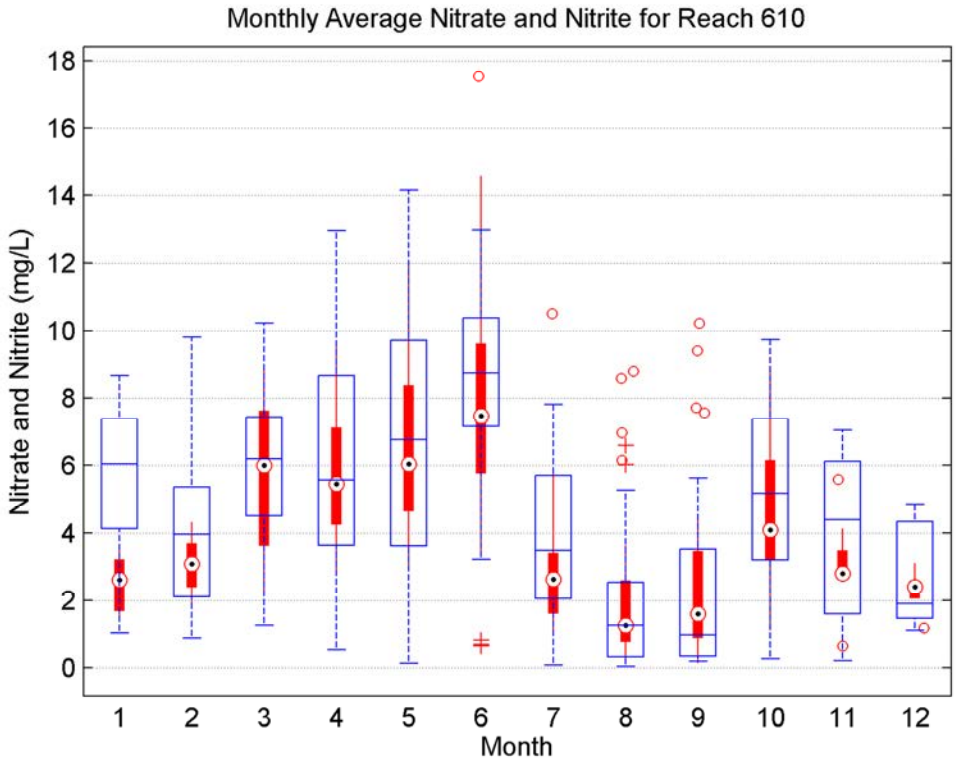

Figure D-23. Nitrate and Nitrite Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-088

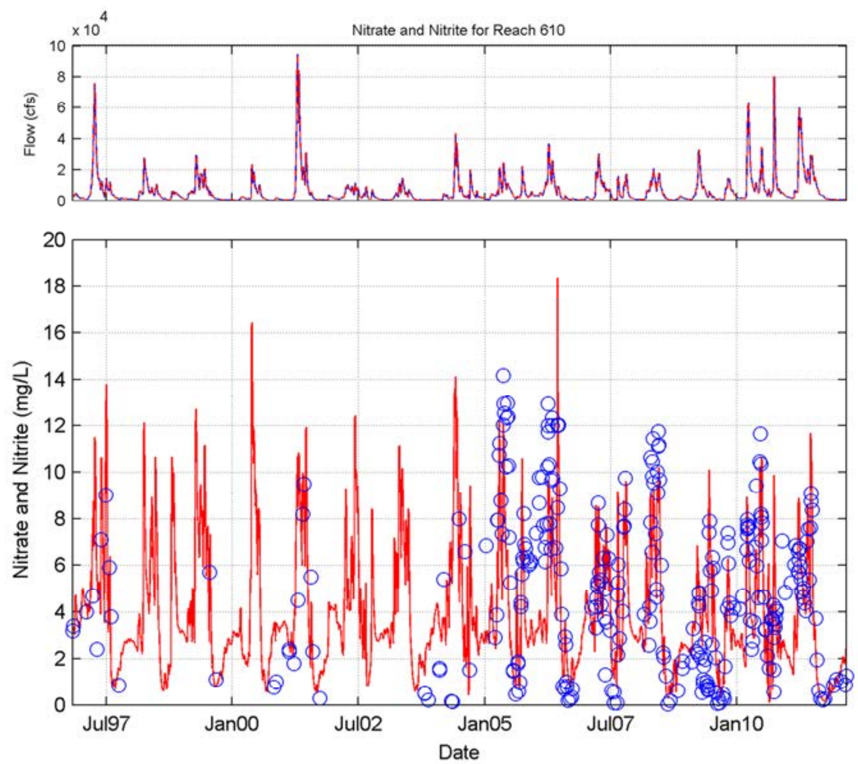

Figure D-24. Nitrate and Nitrite Time Series–Middle Minnesota (Reach 610).

RSI-2429-14-089

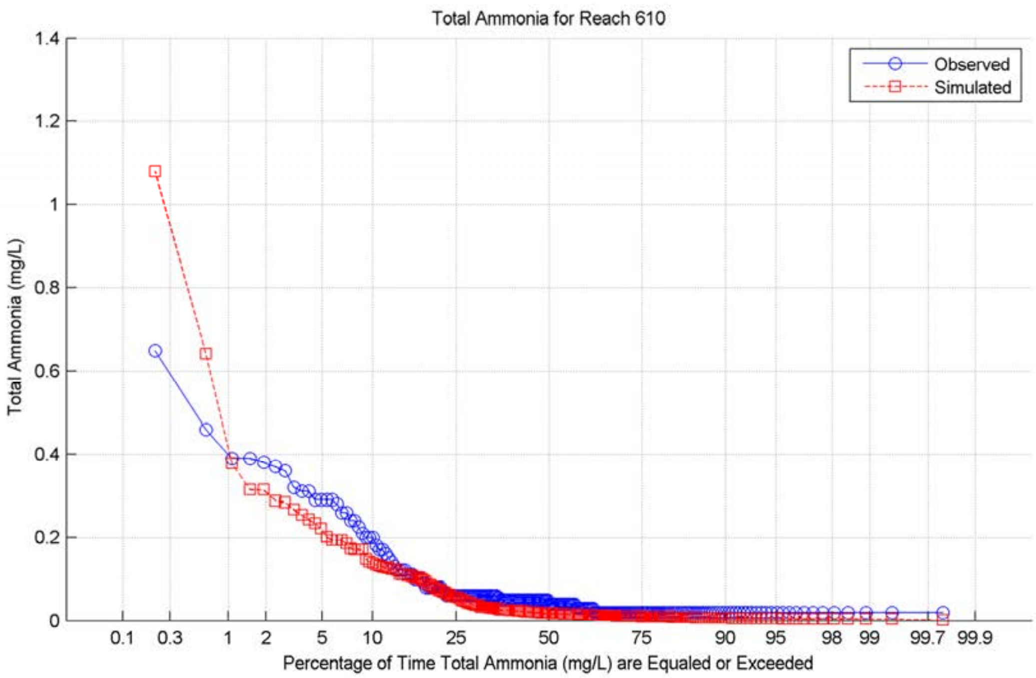

Figure D-25. Total Ammonia Duration Curve–Middle Minnesota (Reach 610).

RSI-2429-14-090

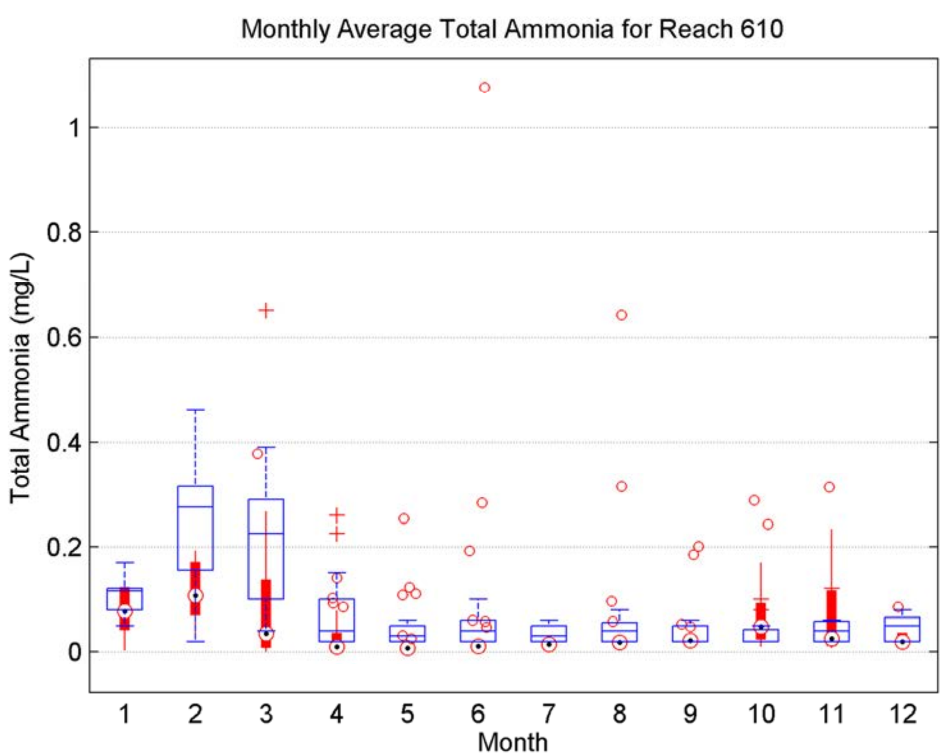

Figure D-26. Total Ammonia Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-091

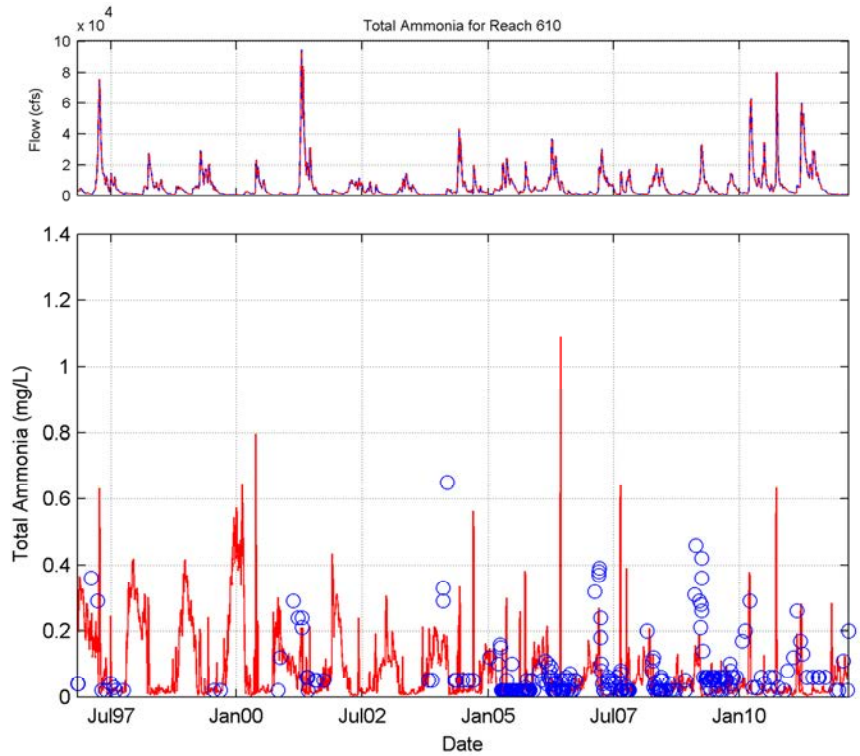

Figure D-27. Total Ammonia Time Series–Middle Minnesota (Reach 610).

RSI-2429-14-092

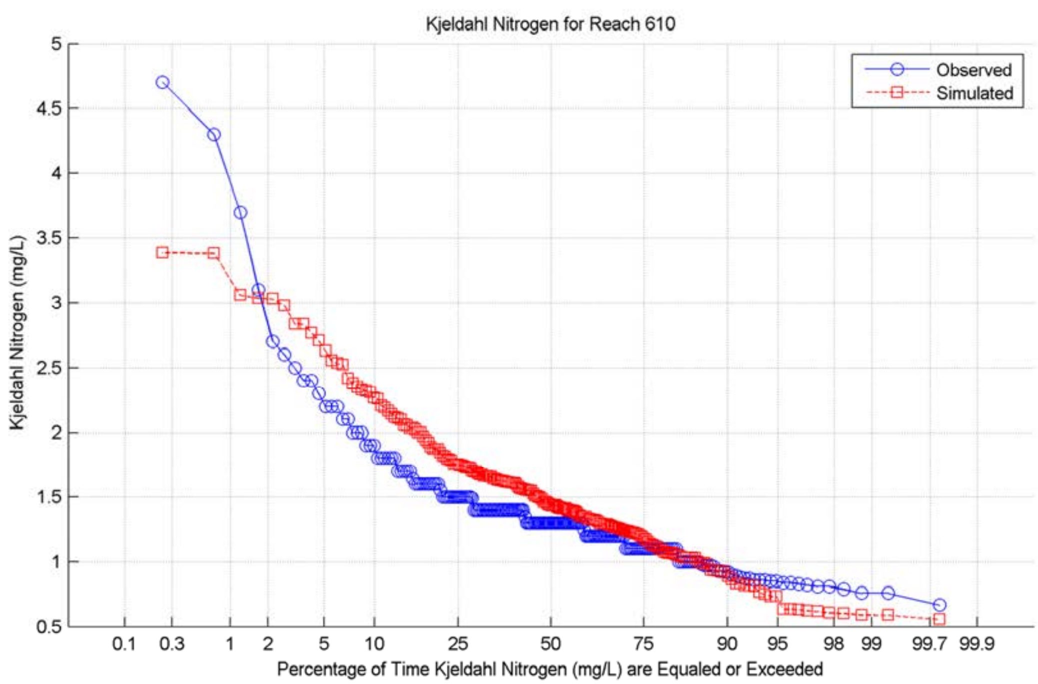

Figure D-28. Kjeldahl Nitrogen Duration Curve–Middle Minnesota (Reach 610).

RSI-2429-14-093

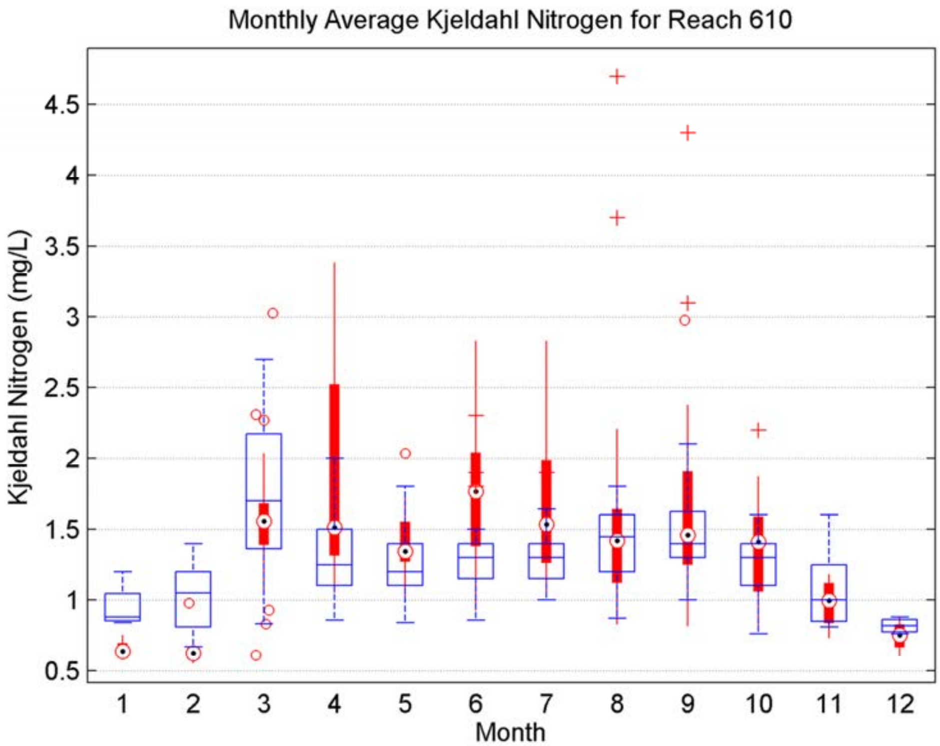

Figure D-29. Kjeldahl Nitrogen Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-095

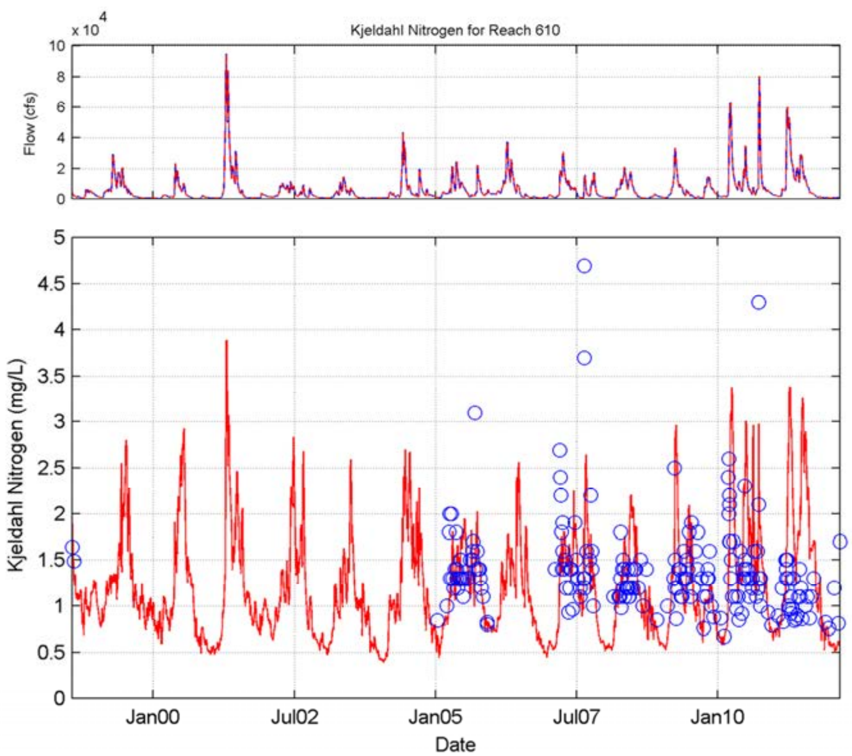

Figure D-30. Kjeldahl Nitrogen Time Series–Middle Minnesota (Reach 610).

RSI-2429-14-095

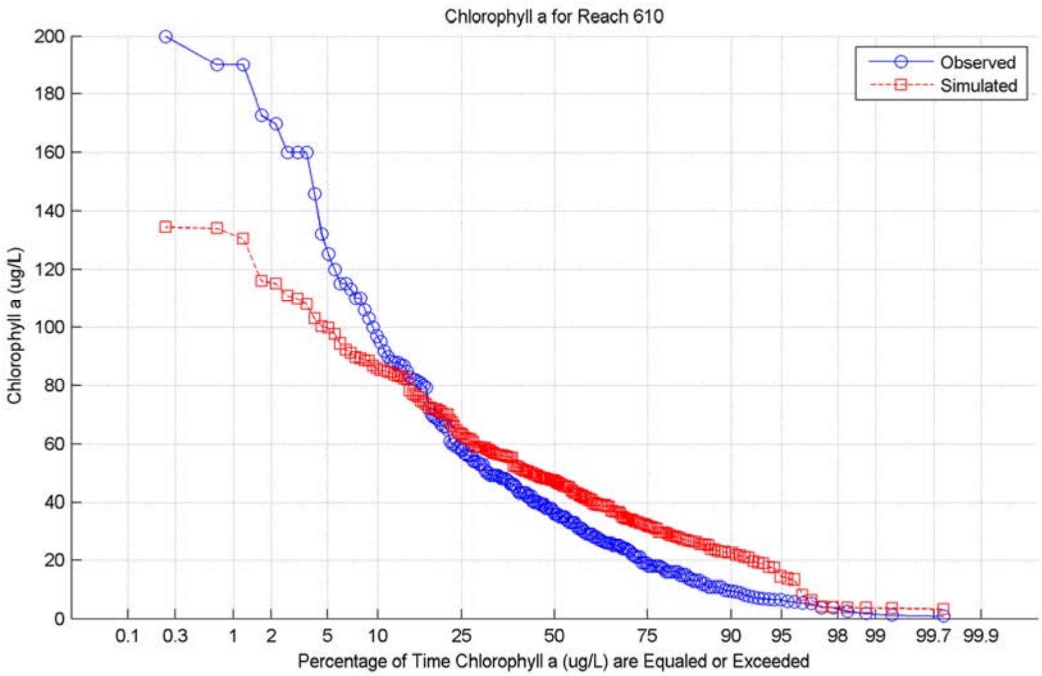

Figure D-31. Chlorophyll *a* Duration Curve–Middle Minnesota (Reach 610).

RSI-2429-14-002

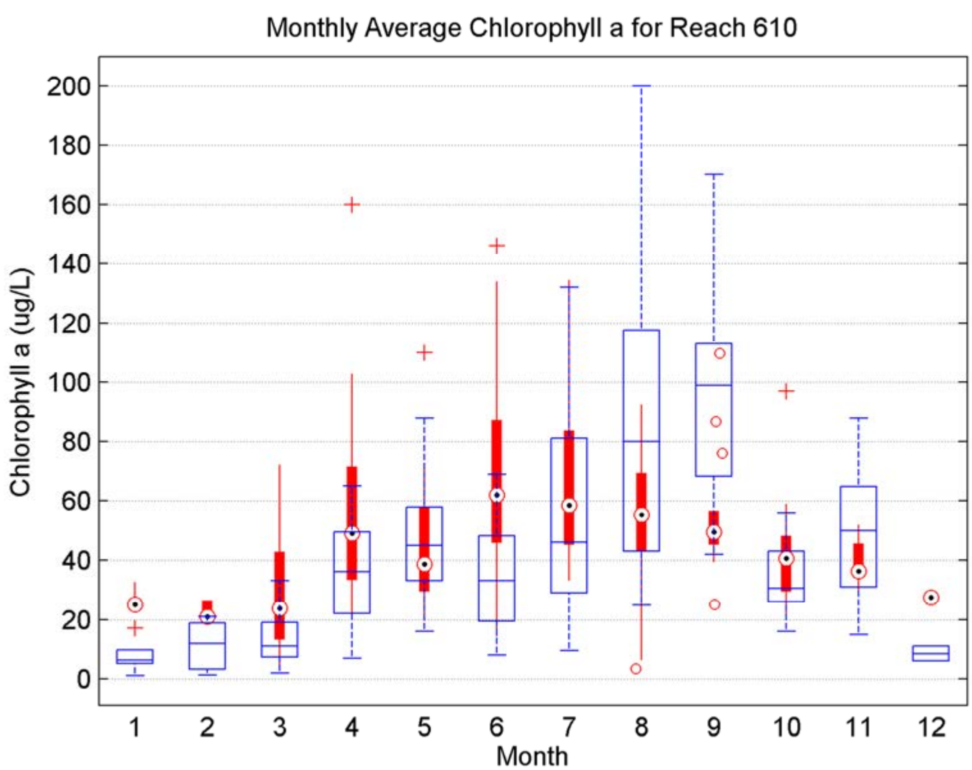

Figure D-32. Chlorophyll *a* Monthly Averages–Middle Minnesota (Reach 610).

RSI-2429-14-097

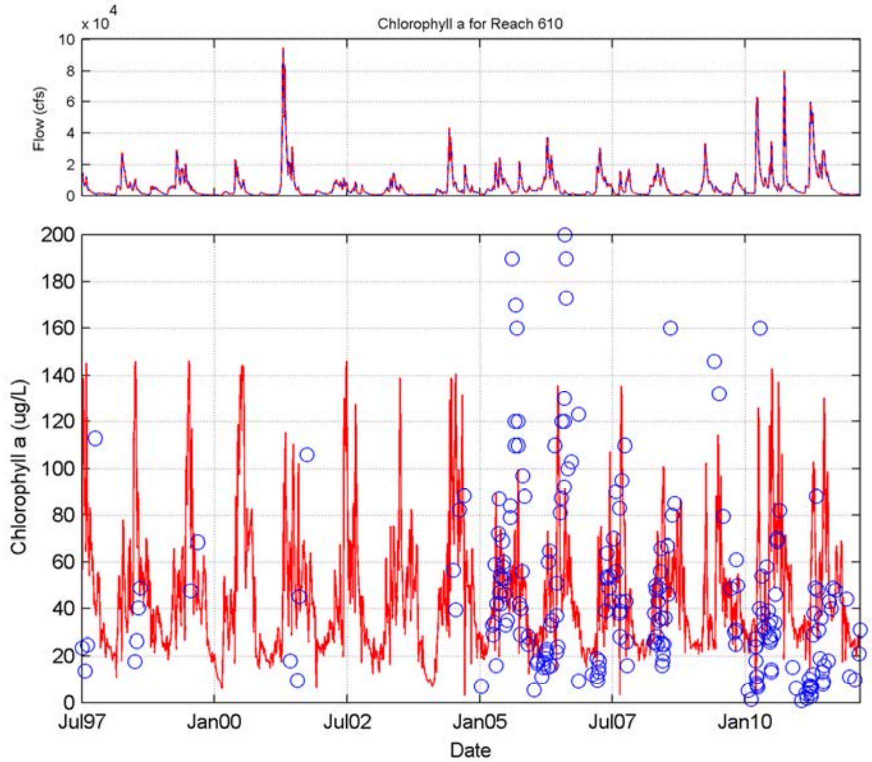

Figure D-33. Chlorophyll *a* Time Series–Middle Minnesota (Reach 610).