RESPEC

September 11, 2019

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

Dear Dr. Regan:

**RE: Extension, Recalibration, Sensitivity Analysis/Model Refinement, and Compliance Scenarios for the Shell Rock River Watershed HSPF Model**

This letter presents the methods for extending the time-series data through 2018 for the Shell Rock River Watershed (07080202) HSPF model application watershed data management (WDM) files, an overview of the hydrologic and water quality recalibration, and a summary of the sensitivity analysis and subsequent model refinement and compliance scenarios for the Shell Rock River Total Maximum Daily Load (TMDL) assessments.

The Shell Rock River Watershed and impaired waterbodies in the watershed are shown in Figure 1. The Shell Rock River Watershed model was developed and calibrated through a previous work order in 2014 and is described in previous RESPEC reports and memoranda [McCutcheon, 2014a; 2014b]. Model subwatersheds are shown in Figure 2.

## TIME-SERIES DEVELOPMENT

This section describes the procedures used to extend and replace the existing meteorological, point-source, and atmospheric deposition time series (1995–2012) through 2018. The primary sources for historical time series are spatially gridded datasets from the North American Land Data Assimilation System (NLDAS) and Parameter-Elevation Regression on Independent Slopes Model (PRISM). The NLDAS is a 12-kilometer (km) by 12-km dataset that provides hourly meteorological data. PRISM is a 4-km by 4-km dataset that provides daily precipitation totals, which are computed by combining a dense network of station data with radar measurement estimates that are interpolated based on climate-elevation regression for each digital elevation model (DEM).

### PRECIPITATION

The original precipitation (PREC) time series consisted of Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) and High Spatial Density Precipitation Network (HIDEN) stations. To update this model application, station precipitation data were replaced with a combination of PRISM- and NLDAS-gridded data. NLDAS and PRISM data are available up to the current year (within the last few weeks of the download date), and were used as the primary sources of precipitation and other meteorological inputs for this watershed model. The daily PRISM precipitation generally has a better fit to the point precipitation station data. Therefore, these precipitation averages were used as the primary dataset and then disaggregated by hourly NLDAS data. The final disaggregated PRISM time

3824 JET DRIVE
RAPID CITY, SD 57703
P.O. BOX 725 // RAPID CITY, SD 57709
605.394.6400

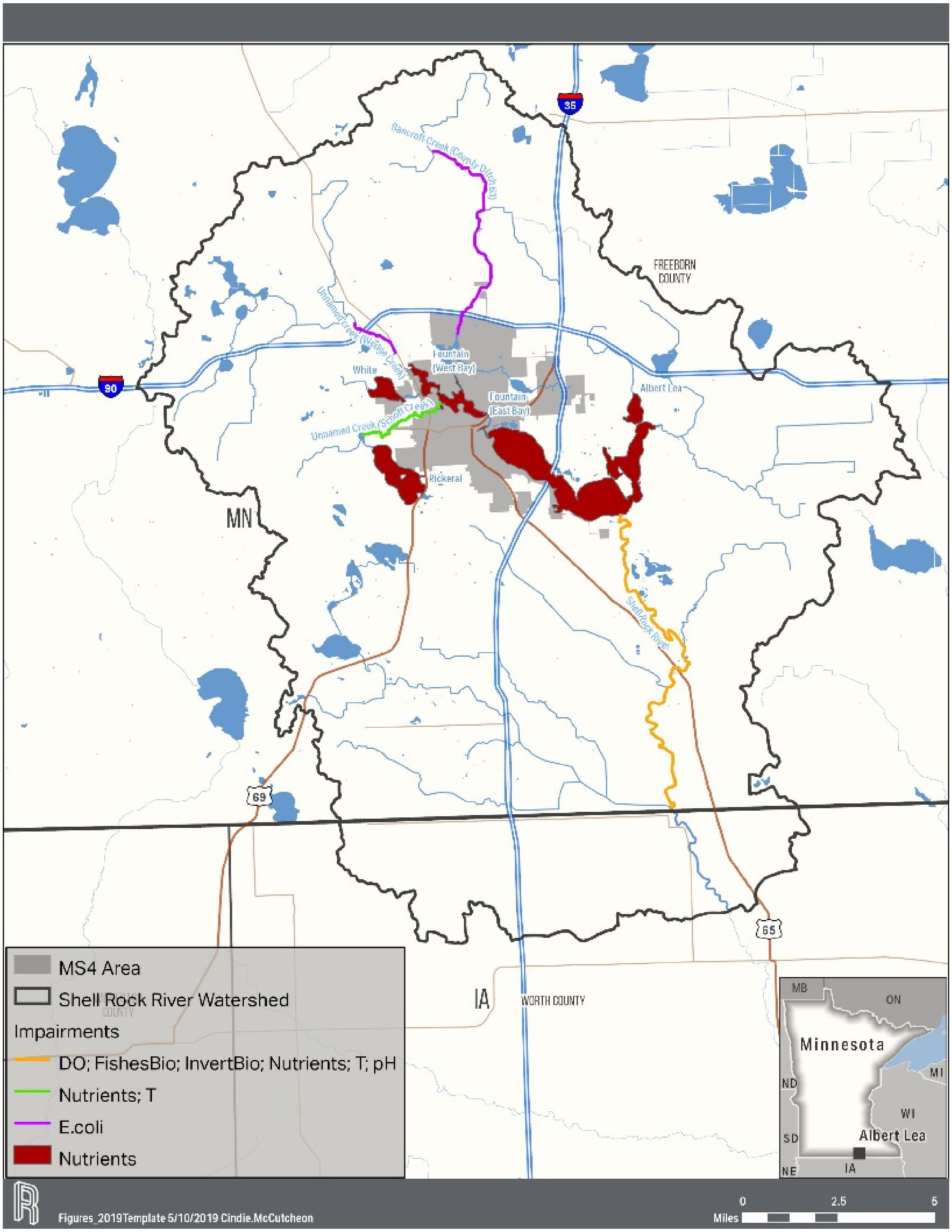


Figure 1. Shell Rock River Watershed and Impaired Waterbodies.

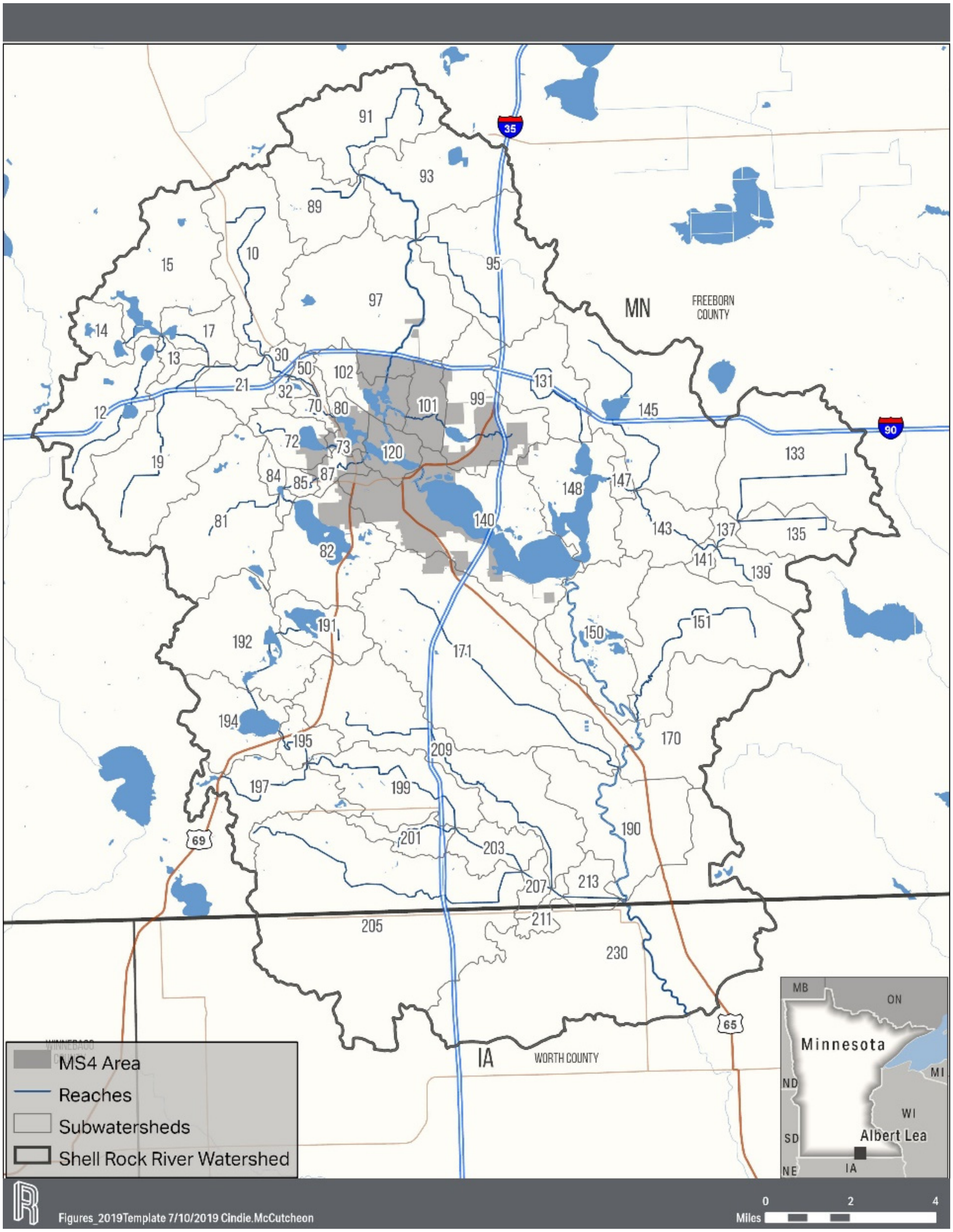


Figure 2. Subwatersheds and Reaches for the Shell Rock River Watershed.

series (1995–2018) replaced rainfall data from the previous model application. This model application applied an aerial average disaggregated data over each hydrozone (an aggregation of subwatersheds that all receive the same meteorological data) classified in the Shell Rock River Watershed model.

### AIR TEMPERATURE, SOLAR, AND WIND SPEED

NLDAS provides hourly air temperature (ATEM), solar radiation (SOLR), and wind speed (WIND) parameters that were directly applied to the meteorological time series and converted into the units required for HSPF. Each of these constituents replaced BASINS data from the previous model application for consistency during model redevelopment.

### CLOUD COVER, DEW POINT, AND POTENTIAL EVAPORATION

The remaining meteorological constituents were not directly used from the NLDAS dataset and required additional computations. Cloud cover (CLOU) was estimated by SOLR data provided from the NLDAS database by using a parabolic equation [Thompson, 1976].

Dew point temperatures (DEWP) were computed from a series of calculations that stemmed from NLDAS specific humidity. The World Meteorological Organization [2014] uses specific humidity and ATEM to calculate the relative humidity. Relative humidity was then applied with ATEM to the August-Roche-Magnus approximation of the Clausius-Clapeyron equation to calculate DEWP.

Hourly potential evaporation (PEVT) was represented by a computed Penman pan evaporation based on the Penman [1948] formula and the Kohler et al. [1955] method. The variables required to compute the Penman pan evaporation are daily relative humidity, DEWP, ATEM, and wind travel.

### POINT SOURCES

All of the point sources represented in the model are summarized in Table 1, and detailed locations are shown in Figure 3. One major (MN0041092) and 15 minor point sources are located in the Shell Rock River Watershed. Daily data were available for the full model time period at the Albert Lea Wastewater Treatment Facility (WWTF). Daily data were also available for portions of the model time period (generally 2014 or 2015 through 2018) at the Albert Lea Water Treatment Plant (WTP), Clarks Grove WWTF, POET Biorefining–Glenville, Glenville WWTF, Hayward WWTF, Minnesota Department of Natural Resources (DNR) Myre Big Island State Park, Minnesota Department of Transportation (MNDOT) Albert Lea Travel Information Center, and Twin Lakes WWTF. Other facilities had monthly data. Daily discharge data were provided as daily average flow, and monthly discharge data were provided as a combination of monthly volumes and monthly average flow.

When dates or date ranges were missing from the raw data at the Albert Lea WWTF, discharge was assumed to be still occurring. Monthly average data were used to fill the dataset if missing records were greater than a week. Linear interpolation was used to fill the dataset when the missing data gap was less than or equal to 1 week. At minor facilities when daily data were available, but dates or date ranges were missing, the assumption was made that no discharge was occurring. When discharge was not occurring, but one or more water quality constituent was reported, the monthly average data were used to fill the dataset. If flows were consistent and discharging less than 3 consecutive days, the consistent value (interpolation) was used to fill the missing flow. If monthly discharge dates were missing, the assumption was made that no discharge was occurring. When a pre-1999 date did not have a discharge value but did not have a “no discharge” flag and no flow or other constituent data were available, no discharge was assumed. For the months that had a “no discharge” flag with no flow value but had other constituent data, no discharge was also assumed. Flow rates were edited when the calculated discharge days were greater than the number of days in the month or when the flow rate was greater than the total monthly discharge. When a "no discharge" flag occurred but flow and other water quality values were present, discharge was assumed to be occurring. When a total flow volume was provided without a flow rate, the average discharge days were used to calculate and disperse the flow rate. Missing months were filled with monthly averages.

Table 1. Shell Rock Watershed Point-Sources Summary

| Name | Reach I.D. | Site I.D. | Category | Notes |
|---|---|---|---|---|
| Lou Rich Inc. | 140 | MN0000086 | Noncontact Cooling Water | No New Data Records |
| Farmland Foods | 140 | MN0000124 | Noncontact Cooling Water | No New Data Records |
| Schweigert Foods | 140 | MN0000175 | Noncontact Cooling Water | Switched to Cargill |
| Glenville WWTF | 171 | MN0021245 | Class D Municipal | Some Daily Data |
| Minnesota DNR Myre Big Island State Park | 140 | MN0033740 | Class D Municipal | Some Daily Data |
| Albert Lea WWTF | 150 | MN0041092 | Class A Municipal | Daily Data Full Time Period |
| Hayward WWTF | 145 | MN0041122 | Class D Municipal | Some Daily Data |
| POET Biorefining–Glenville | 170 | MN0065692 | Tile Line to Surface Discharge | Some Daily Data |
| Albert Lea/Austin KOA Campground | 133 | MN0069167 | No Surface Discharge | Not Included in Model |
| Holsum Foods | 140 | MNG250024 | Noncontact Cooling Water | No New Data Records |
| Cargill Value Added Meats | 140 | MNG255077 | Noncontact Cooling Water | Took Over Schweigert Foods |
| Twin Lakes WWTF | 195 | MNG580042 | Class D Municipal | Some Daily Data |
| MNDOT Albert Lea Travel Information Center | 205 | MNG580065 | Class D Municipal | Some Daily Data |
| Clarks Grove WWTF | 93 | MNG580067 | Class D Municipal | Some Daily Data |
| Albert Lea WTP | 140 | MNG640002 | Water Treatment Plant | Some Daily Data |
| Magellan Pipeline Co LP - Albert Lea | 201 | MNG790110 | Class D Municipal | No New Data Records |

Data are monthly unless indicated in Notes column.

The period of record and completeness was assessed for each facility. Available parameters from the Albert Lea WWTF that are applicable to the model application include carbonaceous 5-day biological oxygen demand ($CBOD_5$), total suspended solids (TSS), total phosphorus (TP), ammonia nitrogen, nitrate plus nitrite, and dissolved oxygen (DO). Available parameters from the minor daily data that are applicable to the model application include $CBOD_5$, TSS, ammonia nitrogen, and DO, and the applicable parameters from the minor monthly data include $CBOD_5$, TSS, and DO. Very little ammonia nitrogen and nitrate plus nitrite data were available in the minor monthly data (three data points at the Glenville WWTF). Available point-source water quality data were filled by using monthly mean values. Where monthly means were unavailable, interpolation was used. Effluent water quality parameters available vary by site; however, most parameters were generally available from WWTFs.

Limited nitrate plus nitrite data were available for Albert Lea WWTF; therefore, a monthly concentration time-series was developed by averaging monthly concentrations and interpolating months with no data. Nitrogen species data were largely unavailable in the minor point-source data. Categories for each point source are shown in Table 1. Point-source loads for nitrogen species were calculated using numbers for point-source facilities by category supplied by Weiss [2012] and are represented

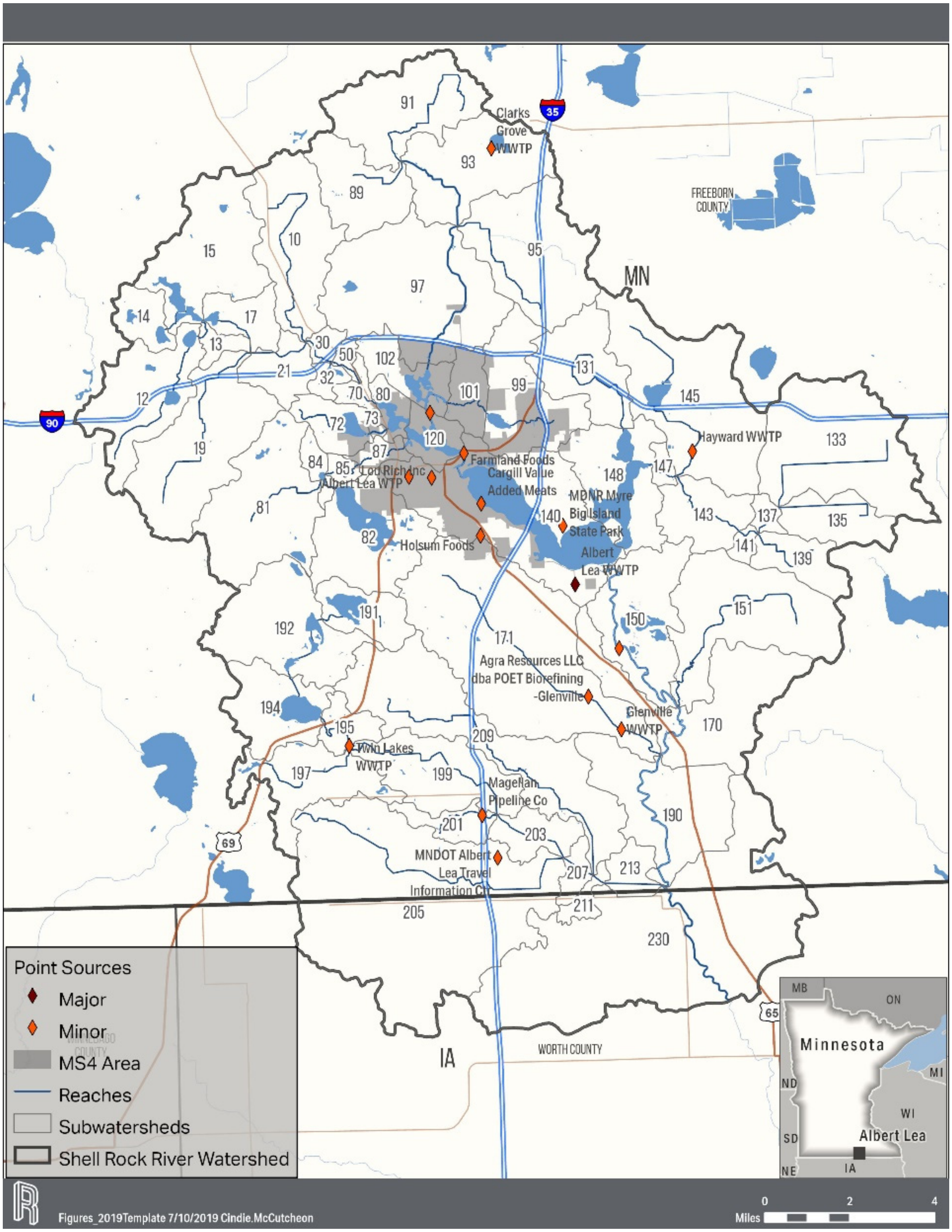


Figure 3. Point-Source Locations for the Shell Rock River Watershed.

in Table 2. The facility categories that applies to the Shell Rock River Watershed are depicted in bold. Phosphorus speciation data were also unavailable for the point-source data, and methods for estimating phosphorus species from point-source TP and $CBOD_5$ were derived from methods that are similar to those used in the Minnesota River model application [TetraTech, 2009]. Temperature data were also not available from the Shell Rock River point sources. A temperature dataset was derived by the Minnesota Pollution Control Agency (MPCA) using an average mean monthly temperature of the following WWTFs: Albertville, Alexandria, Elko New Market, and Willmar [Regan, 2019].

Table 2. Categorical Concentrations Assumptions [Weiss, 2012]

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

Facility categories applicable to the Shell Rock River Watershed are shown in bold.
mg/L = milligrams per liter.
(a) Total nitrogen
(b) Nitrate-nitrite
(c) Total Kjeldahl nitrogen
(d) Total ammonia

Besides temperature, concentrations of all available constituents, including biological oxygen demand (BOD) as $CBOD_u$, which was converted from $CBOD_5$ by using Equation 1 [Chapra, 1997], were converted from mg/L to loads in pounds per day (lb/day) (concentration × flow × conversion factor, conversion factor = 8.34). Temperature was converted from °F to a heat load in British Thermal Units (BTU) per day (temperature × flow × conversion factor, conversion factor = 8,339,145).

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

where:

$L_o = \mathrm{CBOD}_u$
$y_5 = \mathrm{CBOD}_5$
$k_1 = 0.10$, minimum value after primary treatment.

Estimated daily time series were then imported into a WDM file, and loads were applied to the corresponding stream in the external sources block of the user control input (UCI) file. All of the represented point-source flows and loads were recalculated for the entire modeling period (1995–2018) to ensure processing consistency.

### ATMOSPHERIC DEPOSITION

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

Dry atmospheric deposition data were downloaded from the US Environmental Protection Agency's (EPA's) Clean Air Status and Trends Network (CASTNet). The CASTNet site chosen to represent the Shell Rock River Watershed dry deposition was Perkinstown (PRK134). Dry deposition does not depend on precipitation; therefore, nitrate and ammonia dry deposition data (originally in kilograms per hectare [kg/ha]) were applied in the model application by using a pound-per-acre approach (lb/ac). Figure 4 illustrates both the wet and dry atmospheric deposition sites.

Dry atmospheric deposition of phosphorus also contributes to the TP load in the Shell Rock River Watershed [Barr Engineering, 2007]. Because of the lack of temporal data, atmospheric phosphorus deposition was represented by using monthly values of daily dry fluxes using the MONTH-DATA block in HSPF. A value of 0.27 kg/ha/yr (0.00066 lb/ac/day) was provided by Barr Engineering and distributed throughout the months with higher values in the summer and lower values in the winter.

## HYDROLOGIC RECALIBRATION

After all of the time-series data were extended and processed and WDMs were updated, the Shell Rock River Watershed HSPF model was recalibrated for hydrology and water quality.

### HYDROLOGIC DATA

The continuous, observed stream-flow data required for calibration were available at 14 gages in the Shell Rock River Watershed. Table 3 lists the stream-flow gages and their corresponding periods of record to support the model calibration. The locations of flow-monitoring sites are illustrated in Figure 5. Flow data were downloaded from the Minnesota DNR and MPCA Cooperative Stream Gaging Network and supplied by the Shell Rock River Watershed District (SRRWD).

In addition to the stream-flow data updates, lake-level and snow data were acquired and processed. Lake-elevation data were obtained from the Minnesota DNR Lakefinder web service and the MPCA. Lake depths were obtained through a two-step process: (1) calculating the bottom elevation by subtracting the maximum depth from the maximum recorded lake level and (2) subtracting the bottom elevation from the observed lake-level time series. Snow depth and snowfall data were obtained at the Albert Lea 3 SE station through the National Oceanic and Atmospheric Administration's (NOAA's) Regional Climate Center's Applied Climate Information System (RCC-ACIS) web service.

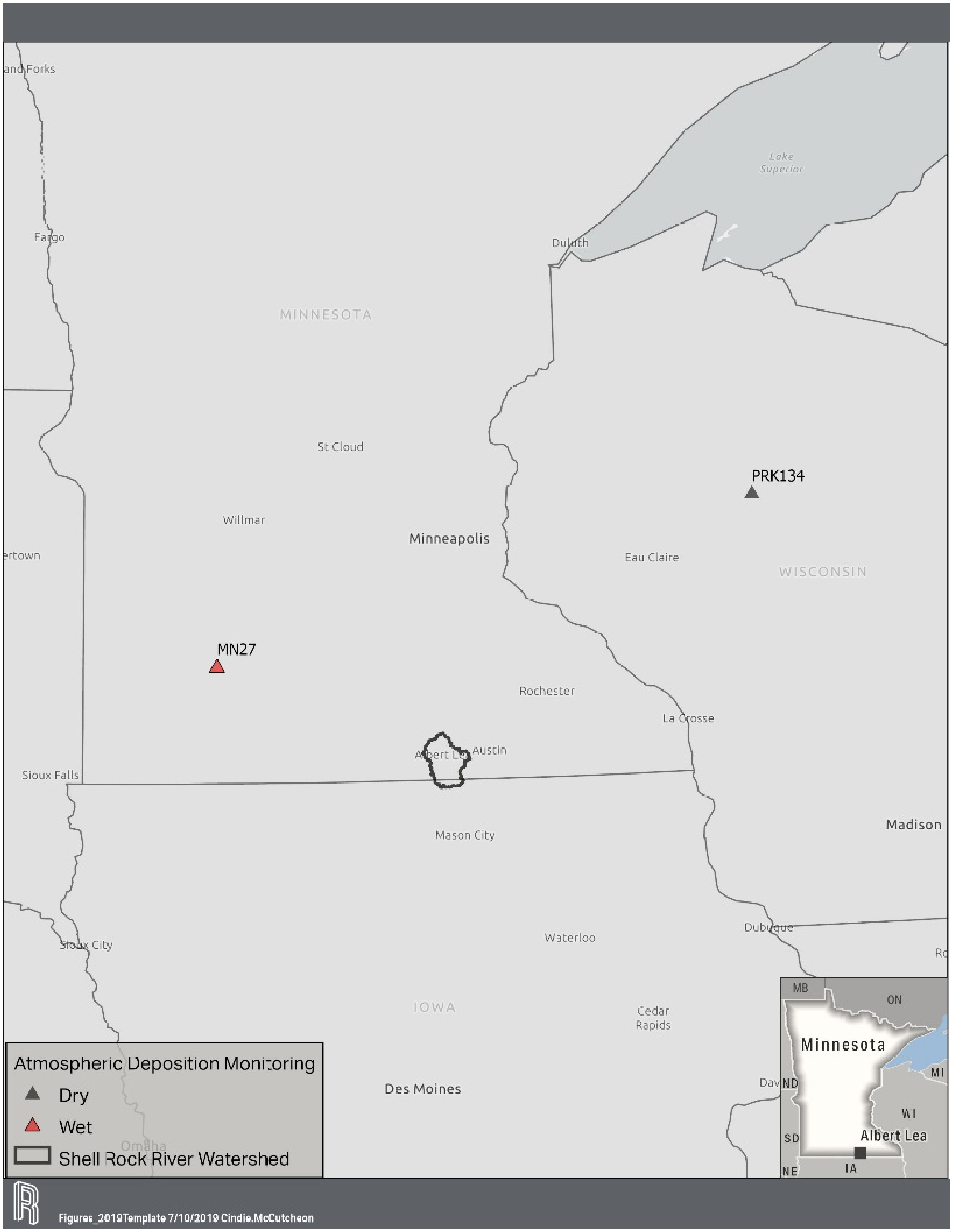


Figure 4. Atmospheric Deposition Sampling Locations.

Table 3. Summary of Flow Calibration Gages

| Source | Gage | Gage Description | HSPF Reach I.D. | Period of Record | Sample Count | Mean Flow (cfs) |
|---|---|---|---|---|---|---|
| SRRWD | SWC01 | Wedge Creek | 50 | 2009–2018 | 1,994 | 41 |
| SRRWD | SMC01 | Mud Lake | 81 | 2009–2018 | 1,936 | 8 |
| SRRWD | SSC01 | Shoff Creek | 85 | 2009–2018 | 1,786 | 12 |
| SRRWD | SBC01 | Bancroft Creek | 97 | 2009–2018 | 1,996 | 33 |
| SRRWD | SGC01 | Wetland Stream | 101 | 2009–2018 | 1,533 | 12 |
| SRRWD | SFL01 | Fountain Lake Dam | 120 | 2009–2018 | 1,625 | 218 |
| SRRWD | SNE01 | Northeast Creek | 131 | 2009–2018 | 1,631 | 5 |
| SRRWD | SPL01B | Hayward Creek | 141 | 2009–2018 | 1,818 | 23 |
| SRRWD | SPL02 | Hayward Creek | 145 | 2009–2018 | 1,679 | 16 |
| SRRWD | SLP01 | Peter Lund Creek | 147 | 2009–2009 | 45 | 6 |
| SRRWD | SSR01 | Albert Lea Lake Outlet | 140<br>148 | 2013–2018 | 1,048 | 263 |
| SRRWD | SSR02 | Shell Rock River near Glenville | 150 | 2009–2018 | 2,082 | 207 |
| SRRWD | SSR03 | Shell Rock BR | 190 | 2012–2018 | 1,779 | 235 |
| MN DNR | H49009001 | Shell Rock River near Gordonsville | 190 | 2008–2018 | 3,569 | 199 |

cfs = cubic feet per second.

## HYDROLOGIC CALIBRATION

Typical hydrologic calibration is an iterative process that is intended to match simulated flow to observed flow by methodically adjusting model parameters. The HSPF hydrologic calibration is divided into four sequential phases: (1) establishing an annual water balance, (2) making seasonal adjustments, (3) adjusting low-flow/high-flow distribution, and (4) adjusting storm-flow/hydrograph shape. By iteratively adjusting specific calibration parameter values in accepted ranges, the simulation results can be improved until an acceptable comparison of simulated results and measured data is achieved. The procedures and parameter adjustments involved in these phases are more thoroughly described in Donigian et al. [1984] and in the HSPF hydrologic calibration expert system (HSPEXP) [Lumb et al., 1994].

Model performance was evaluated using a weight-of-evidence approach, which is described by Donigian [2002]. This approach uses visual and statistical methods to characterize the model's performance. The approach was integrated into the hydrologic calibration to continuously evaluate model results and efficiently improve calibration performance until no apparent improvement is present from further parameter adjustments. This process was performed at each flow gage by adjusting the parameters for land segments upstream. Moreover, greater weight was applied to the performance of the model at gages that had a larger contributing area and a longer period of record. Consistency in parameter values and intraparameter variations for each land-segment category throughout the watershed were also considered during the hydrologic calibration.

Because of Minnesota's climate and large number of lakes, simulated snowfall/snowmelt and hydraulic processes were examined in addition to comparing observed and simulated flow. Snowfall and snow

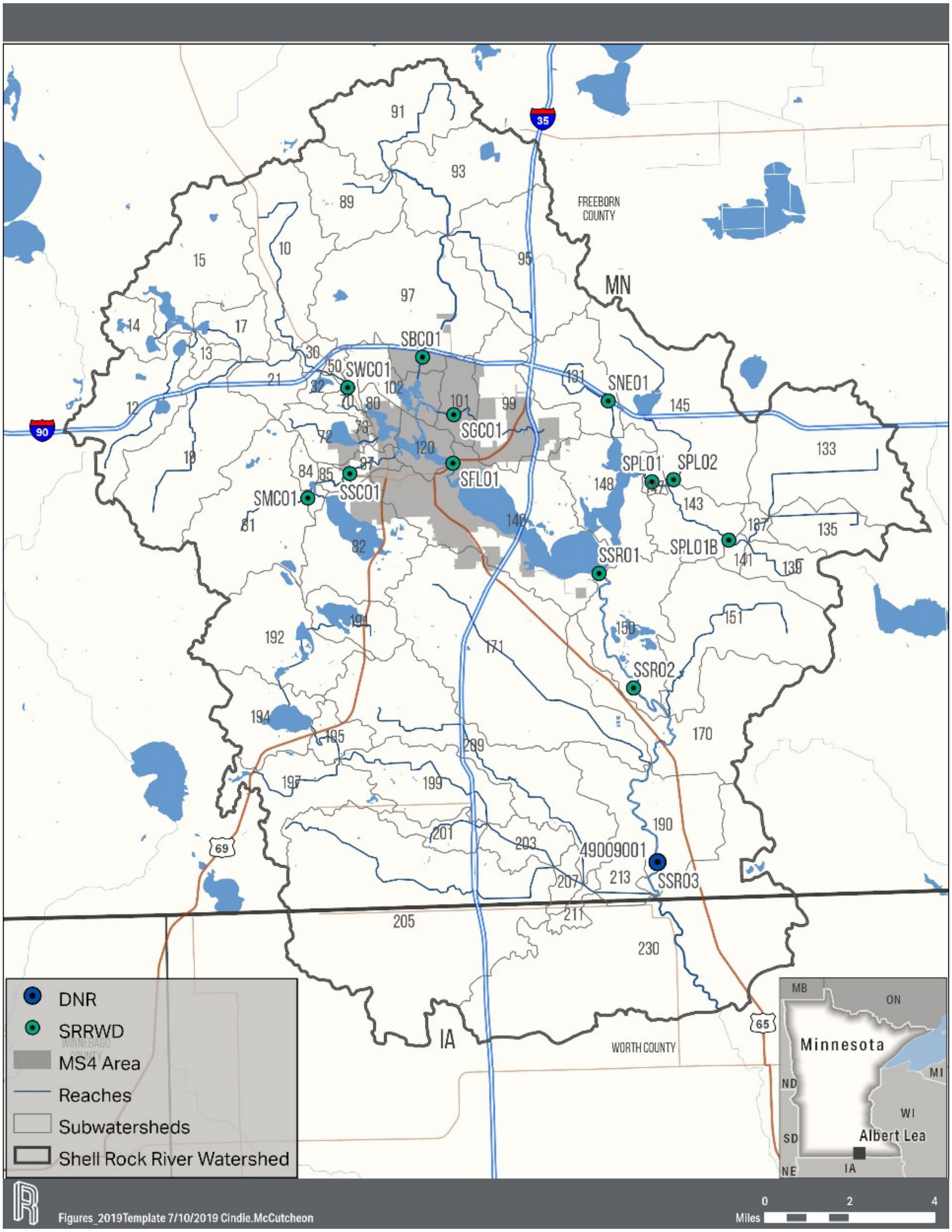


Figure 5. Flow-Monitoring Locations for the Shell Rock River Watershed.

depth amounts were calibrated early in the process; however, the snow parameter calibration depended greatly on the timing and magnitude of spring melt. The lake-level 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) with the storm-flow phase of the standard calibration to adequately represent lake volumes and outflows.

To assess model performance, graphical plots were evaluated, and the statistics were compared to objective criteria developed from 20 years of experience with HSPF applications. The percent-error statistics, correlation coefficient $(R)$, and the coefficient of determination $(R^2)$ were compared with the criteria provided by Donigian [2000; 2002] to evaluate the performance of the daily and monthly flows. These measures allowed the modeler to assess the quality of the overall model application performance in descriptive terms to aid in accepting or rejecting the model application. The previous calibration memorandum [McCutcheon, 2014b] further describes the simulation and calibration methods, weight-of-evidence approach, and performance criteria.

### HYDROLOGIC CALIBRATION RESULTS

The hydrologic calibration focused on the most downstream gages. Those gages ensured that the water routing across the land, through interflow, and the groundwater were correctly represented. Gages on smaller tributaries helped calibrate parameters for the land-segment categories; however, the focus of the hydrology calibration was the mainstem gages. The tables of results detail model performance at the primary, mainstem gage (Reach 190). The weighted water-balance components in each watershed are provided in Table 4, and Table 5 shows calibration statistics and volume percent error for the primary gage. Calibration figures at the primary mainstem gage are provided in Attachment A. Calibration figures for other flow gages, snow sites, and lake levels are provided in the deliverable results folder.

Table 4. Summary of the Water Balance

| Water-Balance Component | Water-Balance Component Description | Percent of Water Supply (%) |
|---|---|---|
| SURO | Surface outflow | 1.8 |
| IFWO | Interflow outflow | 8.5 |
| AGWO | Active groundwater outflow | 26.5 |
| IGWI | Inflow to inactive groundwater | 0.0 |
| CEPE | Evaporation from interception storage | 19.4 |
| UZET | Evapotranspiration from upper zone | 17.4 |
| LZET | Evapotranspiration from lower zone | 25.8 |
| AGWET | Evapotranspiration from active groundwater storage | 0.1 |
| BASET | Evapotranspiration from active groundwater outflow (baseflow) | 0.2 |
| IMPEV | Evapotranspiration from impervious areas | 0.3 |

Table 5. Hydrology Calibration Results for the Primary Gage

| Observed Flow Gage | HSPF Reach | Total Runoff Volume | | | Monthly | | | Daily | | | Storm Percent Error (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Observed (in) | Simulated (in) | % Δ | *R* | $R^2$ | MFE | *R* | $R^2$ | MFE | Volume | Peak |
| H49009001 | 190 | 12.78 | 12.97 | 1.44 | 0.93 | 0.86 | 0.84 | 0.90 | 0.80 | 0.79 | –1.12 | –8.78 |

MFE = model-fit efficiency.

## WATER QUALITY RECALIBRATION

The water quality constituents that were modeled in the Shell Rock River Watershed included TSS, temperature, DO, BOD, and nutrients. The methods described in the following sections provide RESPEC with the ability to estimate TSS, temperature, DO, and nutrient loads, as well as calculate contributions from point, nonpoint, and atmospheric sources. The following sections summarize data availability and methods for parameterization and calibration; more detail is available in McCutcheon [2014b].

### WATER QUALITY DATA

Under an ideal model-development scenario, all of the processes that are represented in the model would be characterized by ambient monitoring throughout the watershed. These processes include TSS, DO, and BOD dynamics; sediment oxygen demand and benthic fluxes; and primary production. Water quality parameters that are monitored to characterize these processes include temperature, DO, BOD, nitrogen species (e.g., nitrate/nitrite, ammonia, and Kjeldahl nitrogen), phosphorus species (total and inorganic phosphorus), organic carbon, and chlorophyll *a* (which represents phytoplankton). However, information that would fully characterize a system is rarely, if ever, available, and model performance is compared to the available data.

Observed ambient water quality data were obtained from the MPCA and SRRWD. Water temperature, TSS, DO, BOD, chlorophyll *a*, ammonia, Total Kjeldahl Nitrogen (TKN), nitrate/nitrite, orthophosphate, and TP water quality monitoring data are available for many of the lakes and streams throughout the watershed. Attachment B summarizes the available water quality data by constituent and illustrates the spatial locations of water quality monitoring sites for each model application. The MPCA and SRRWD also collected continuous water temperature and DO data at various locations in the watershed.

Total nitrogen (TN) is often not directly measured in either of the ambient water quality datasets, but it can be calculated by summing concurrent samples of nitrate, nitrite, and TKN. Similarly, organic nitrogen can be calculated as the difference between concurrent samples of TKN and ammonia nitrogen.

### WATER QUALITY CALIBRATION

The Shell Rock River model application represents the processes that drive sediment erosion, delivery, and transport in the watershed from land-surface, instream, and point-source sediment contributions. The primary calibration parameters involved in characterizing landscape-erosion processes are the coefficients and exponents from three equations that represent different soil detachment and removal processes. The primary parameters involved in calibrating instream sediment transport and bed behavior include critical shear stresses for deposition and scour for silt and clay as well as the coefficient and exponent in the non-cohesive (sand) transport power function. The sediment behavior for each size class was investigated to ensure that sediment dynamics reflected field observations. While HSPF does not explicitly simulate streambank contribution dynamics, they were implicitly included by allowing the streambed to contribute those loads.

Nutrient sources that are represented in the Shell Rock River model application included point sources, such as water treatment facilities, nonpoint sources from the watershed, septic systems, atmospheric deposition (nitrate, ammonia, and phosphorus), subsurface flow, and benthic contributions. Point-source facility contributions were explicitly modeled for future permitting purposes. Methods for processing loads were previously described with a summary of modeled point sources provided in Table 1 and locations shown in Figure 3. Nonpoint sources of total ammonia, nitrate-nitrite, and BOD were simulated through accumulation and depletion/removal and a first-order wash-off rate from overland flow. Because of the affinity of orthophosphate to bind to sediments, orthophosphate was simulated using a linear relationship with sediment washing off the land. Subsurface flow concentrations were estimated on a monthly basis for calibration. Atmospheric depositions of nitrogen and ammonia were applied to all of the land areas and contribute to the nonpoint-source load through the buildup/wash-off process. Atmospheric deposition onto water surfaces was represented in the model as a direct input to the lakes and river systems.

The model simulates the instream and lake processes that contribute to algal growth, nutrient consumption, and DO dynamics. All of the required instream parameters were specified for total ammonia, inorganic nitrogen, orthophosphate, and BOD. The processes in the instream portion of the model include BOD accumulation, storage, decay rates, benthic algal oxygen demand, settling rates, and reaeration rates. Phytoplankton dynamics (i.e., respiration, growth, settling rates, density, and nutrient requirements) are included along with the similar demands of attached benthic algae. Because a large portion (approximately 50 percent) of the instream TSS consist of volatile suspended solids in the Shell Rock River Watershed, the phytoplankton in the reach was added to the modeled sediment prior to the comparison to the observed total suspended solids samples. Maintaining consistent parameters in each land-use category throughout the Shell Rock River Watershed was a priority during calibration.

Lake water quality calibrations are often difficult in HSPF because the model represents lakes as a completely homogenous system. Phosphorus was added to lakes using the MONTH-DATA block as a monthly time series to lakes. This time series represents phosphorus contributions from the lake bottom because of wind and other internal loading mechanisms. Although this process is not well documented, it was completed as a part of the calibration process because many of the Shell Rock River lakes are known to have curly-leaf pondweed (*Potamogeton crispus*) present, have carp populations that potentially stir up sediments, and are very shallow and are, therefore, impacted by wind mixing.

## WATER CALIBRATION RESULTS

The calibrated results from the most downstream, data-intensive reach in the Shell Rock River Watershed, which falls on Reach 190, are included in Attachment C. The results for the remaining reaches are provided in the deliverable results folders. Three figures for each constituent are included: concentration duration curves, monthly average boxplots, and time-series plots, with observed data depicted in blue and model simulations in red. Because of the diurnal variability, hourly boxplots are also provided for temperature and DO. Additional calibration figures for the remaining calibration reaches/lakes, and outputs generated from HSPEXP+ are also provided in the deliverable results folders.

Continuous water temperature and DO calibration results are also included in Attachment C. The duration plots and monthly/hourly average boxplots include a combined dataset from both the MPCA and SRRWD for the period of record. Individual time-series plots are provided by source and year for the 2012 and 2013 sampling periods. The MPCA did not collect continuous water temperature data; therefore, all the observed continuous water temperature data are from the SRRWD.

## SENSITIVITY ANALYSIS

A sensitivity analysis was completed on the Shell Rock River HSPF model application to review and refine parameters that affect the summer average TP and the daily minimum DO concentrations. The key parameters that were evaluated impacted temperature, sediment oxygen demand, reaeration, phytoplankton, benthic algae, BOD, and ammonia nitrification, which, in turn, impact the TP and DO in Albert Lea Lake and upstream impaired lakes as well as in the Shell Rock River below Albert Lea Lake. Each parameter was multiplied by a minimum and maximum factor in two separate model runs. Factors were based on modeling experience and bounded by expected ranges. The resulting minimum, average, and maximum concentrations for the separate model runs were summarized and updated calibration figures were generated. This process was used to inform the model calibration on the parameters that should be the most heavily focused upon. A sensitivity analysis was also run using the methods described for the final, calibrated HSPF model to illustrate the impact of variations in calibration parameters. Parameters, factors, and percent relative difference results of average DO and TP loads are shown in Table 6.

Table 6. Water Quality RCHRES Parameters Adjusted for the Sensitivity Analysis

| Table | Parameter | Multiplication Factors | | Percent Relative Difference | | |
|---|---|---|---|---|---|---|
| | | Minimum | Maximum | DO (%) | TP (%) | TP[a] (%) |
| OX-REAPARM | REAK | 0.5 | 2 | 2 | < 1 | < 1 |
| OX-BENPARM | BENOD | 0.8 | 1.2 | 25 | < 1 | < 1 |
| OX-BENPARM | BRBOD(1) | 0.5 | 5 | < 1 | 2 | 2 |
| OX-GENPARM | KODSET | 0.5 | 2 | < 1 | 8 | 9 |
| OX-GENPARM | KBOD20 | 0.5 | 2 | < 1 | 1 | 1 |
| PLNK-PARM1 | MALGR | 0.8 | 1.2 | 38 | 9 | 8 |
| PLNK-PARM1 | NONREF | 0.8 | 1.2 | < 1 | 2 | < 1 |
| PLNK-PARM2 | TALGRL | 0.5 | 1.6 | 11 | 17 | 2 |
| PLNK-PARM2 | TALGRM | 0.85 | 1.1 | 42 | 15 | 9 |
| PLNK-PARM3 | ALR20 | 0.5 | 2 | 11 | 3 | 4 |
| PHYTO-PARM | SEED | 0.5 | 4 | < 1 | < 1 | < 1 |
| PHYTO-PARM | MXSTAY | 0.5 | 2 | 1 | 2 | 3 |
| PHYTO-PARM | OREF | 0.5 | 2 | 2 | 4 | 7 |
| PHYTO-PARM | CLALDH | 0.5 | 2 | < 1 | < 1 | < 1 |
| PHYTO-PARM | PHYSET | 0.5 | 2 | 1 | 2 | 3 |
| PHYTO-PARM | REFSET | 0.5 | 2 | < 1 | 5 | 5 |
| BENAL-PARM | MBAL | 0.5 | 2 | 13 | 2 | 2 |
| Average | | | | 12 | 7 | 8 |

(a) Growing season (June to September).

## COMPLIANCE SCENARIOS

It is important that scenarios be evaluated to represent the flows and phosphorus concentrations that the Albert Lea WWTF can currently discharge and how they impact the phosphorus concentrations, minimum daily DO, and DO flux in the Shell Rock River. The scenarios informed the TMDL development staff of the most appropriate permit limits for the facility. A broad set of scenarios were initially run that covered a wide range of Albert Lea WWTF discharge rates (4.5 to 18.38 million gallons a day [mgd]), TP loads (25 to 75 pounds per day), and $CBOD_5$ concentrations (5 to 25 mg/L). After several iterations, a final set of scenarios were run that met the river eutrophication standard (RES) and the DO standard at HSPF Reach 190. The final scenarios were (1) Base Scenario, (2) Albert Lea Lake Compliance, (3) Local Load Allocation Compliance, (4) Albert Lea WWTF DO, (5) Albert Lea WWTF TP.

The first scenario is the final calibrated model at current conditions (Base Scenario). For the second scenario, Albert Lea Lake TP concentrations were capped at the RES (0.090 mg/L). The third scenario includes Scenario 2 with the local TP load (areas contributing to the Shell Rock River below Albert Lea Lake) reduced approximately 35 percent to meet an average TP outflow concentration of 0.150 mg/L. For Scenarios 4 and 5, Albert Lea Lake TP concentrations were capped at the RES (0.900 mg/L), the local TP load was reduced 35 percent to meet the average TP outflow concentration of 0.150 mg/L, and Albert Lea WWTF discharges were set to the dry-weather design flow of 9.125 mgd. The TP concentration of Albert Lea WWTF was then adjusted to meet the TP standard during the growing season (Scenario 5) and the DO standard during the full year (Scenario 4). The scenario results of average TP, chlorophyll *a*, and BOD5 concentrations, along with DO fluxes and daily minimum DO concentrations, are provided for the growing season (June–September) in Table 7. The same results for the full year are provided in Table 8. It was determined that with Albert Lea Lake and local loads reduced to water quality standards, the Albert Lea WWTF TP outflow concentration would need to be set to 0.64 mg/L for the Shell Rock River to meet the TP standard during the growing season (0.150 mg/L) and at 0.68 mg/L to meet the DO standard (daily minimum of 5 mg/L) during the full year when the facility is discharging at 9.125 mgd. For consistency with the permit standards, rotating ammonia concentrations of 3.0 mg/L (April–May), 1.0 mg/L (June–September), 3.0 mg/L (October–November), and 7.0 mg/L (December–March) were applied for Scenarios 4 and 5.

Table 7: Scenario Results for the Growing Season (2009–2018)

| Scenario | Avg TP (mg/L) | Avg Chl-a (ug/L) | Avg BOD5 (mg/L) | DO Flux (mg/L) | Min DO (mg/L) |
|---|---|---|---|---|---|
| 1 | 0.60 | 42.6 | 4.9 | 16.9 | 0.1 |
| 2 | 0.55 | 22.8 | 2.9 | 9.9 | 4.0 |
| 3 | 0.54 | 22.6 | 2.6 | 9.8 | 4.1 |
| 4 | 0.16 | 17.1 | 2.8 | 6.2 | 5.0 |
| 5 | 0.15 | 16.8 | 2.7 | 5.9 | 5.1 |

The scenario that meets the TP standard is highlighted in gray.

RESPEC

Table 8: Scenario Results for All Months (2009–2018)

| Scenario | Avg TP (mg/L) | Avg Chl-a (ug/L) | Avg BOD5 (mg/L) | DO Flux (mg/L) | Min DO (mg/L) |
|---|---|---|---|---|---|
| 1 | 0.73 | 32.2 | 4.2 | 16.9 | 0.1 |
| 2 | 0.68 | 18.8 | 2.6 | 9.9 | 4.0 |
| 3 | 0.68 | 18.7 | 2.3 | 9.8 | 4.1 |
| 4 | 0.18 | 15.7 | 2.7 | 6.2 | 5.0 |
| 5 | 0.17 | 15.5 | 2.7 | 5.9 | 5.1 |

The scenario that meets the DO standard is highlighted in gray.

Because the facility has not historically been discharging at their dry-weather design flow, additional scenarios were run to determine what the maximum TP concentration could be if the Albert Lea WWTF continues to discharge at their lower historical flows (an average of 4.04 mgd). The scenarios concluded that if the Albert Lea WWTF were to discharge their TP draft TMDL WLA at the lower historic flows, the Shell Rock River would be in exceedance of the 0.150 mg/L water quality standard, and that the maximum concentration that could be discharged from the facility should remain at or below 1 mg/L for the Shell Rock River to remain in compliance with their seasonal average standard of 0.150 mg/L. Therefore, in addition to the draft WLA of 48.4 lb/day for the Albert Lea WWTP, a concentration limit of 1 mg/L should be implemented.

## REFERENCES

Barr Engineering, 2007. *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Atmospheric Deposition: 2007 Update,* prepared by Barr Engineering, Minneapolis, MN, for the Minnesota Pollution Control Agency, St. Paul, MN.

McCutcheon, C. M., 2014a. *Cedar River/Little Cedar River and Shell Rock River/Winnebago River HSPF Model Application Development,* RSI(RCO)-2428/9-14/11, prepared by RESPEC, Rapid City, SD for C. Regan, Minnesota Pollution Control Agency, St. Paul, MN, September 30.

McCutcheon, C. M., 2014b. *Hydrology and Water-Quality Calibration of the Cedar River/Little Cedar River and the Shell Rock/Winnebago HSPF Watershed Model Applications,* RSI(RCO)-2428/9-14/19, prepared by RESPEC, Rapid City, SD, for C. Regan, Minnesota Pollution Control Agency, St. Paul, MN, September 30.

Chapra, S. C., 1997. *Surface Water-Quality Modeling.* Waveland Press, Inc., Long Grove, IL.

Donigian, Jr., A. S.; J. C. Imhoff; B. R. Bicknell; and J. L. Kittle, Jr., 1984. *Application Guide for Hydrological Simulation Program-FORTRAN (HSPF),* EPA 600/3-84-065, prepared for the Environmental Research Laboratory, Office of Research and Development, US Environmental Protection Agency, Athens, GA.

Donigian, Jr., A. S., 2000. *HSPF Training Workshop Handbook and CD, Lecture #19: Calibration and Verification Issues,* Slide #L19-22, presented to and prepared for the US Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, DC, January 10–14.

Donigian, Jr., A. S., 2002. "Watershed Model Calibration and Validation: The HSPF Experience," *Proceedings, Water Environment Federation National Total Maximum Daily Load Science and Policy 2002*, Phoenix, AZ, November 13–16.

**Kohler, M. A., T. J. Nordenson, and W. E. Fox. 1955.** *Evaporation from Pans and Lakes,* US Weather Bureau Research Paper 38, prepared for the US Weather Bureau, Washington, DC.

**Lumb, A. M.; R. B. McCammon; and J. L. Kittle, Jr.; 1994.** *User's Manual for an Expert System (HSPEXP) for Calibration of the Hydrological Simulation Program – FORTRAN,* US Geological Survey Water Resources Investigations Report 94-4168, US Geological Survey, Reston, VA.

**Penman, H. L., 1948.** "Natural Evaporation From Open Water, Bare Soil, and Grass," *Proceedings of the Royal Society of London, Series A. Mathematical and Physical Sciences,* Vol. 193, pp. 120–145.

**Regan, C., 2019.** Personal communication between C. Regan, Minnesota Pollution Control Agency, St. Paul, MN, and S. Kenner, RESPEC, Rapid City, SD, March 18.

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

**Thompson, E. S., 1976.** "Computation of Solar Radiation From Sky Cover," *Water Resources Research,* Vol. 12, No. 5, pp. 859–865.

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

**World Meteorological Organization, 2014.** *Guide to Meteorological Instruments and Methods of Observation,* WMO-No. 8, World Meteorological Organization, Geneva, Switzerland.

## FINAL REMARKS

Thank you for reviewing the methods and results of the extension, recalibration, sensitivity analysis/model refinement, and compliance scenarios of the Shell Rock River Watershed HSPF model application. We are available to discuss the contents of this memorandum with you and appreciate any feedback you may have.

Sincerely,

Chris D. Lupo
Water Resources Engineer

CDL:llf
cc: Project Central File 2428 — Category A

# ATTACHMENT A

## HYDROLOGY RESULTS FOR REACH 190 IN THE SHELL ROCK RIVER WATERSHED MODEL APPLICATION

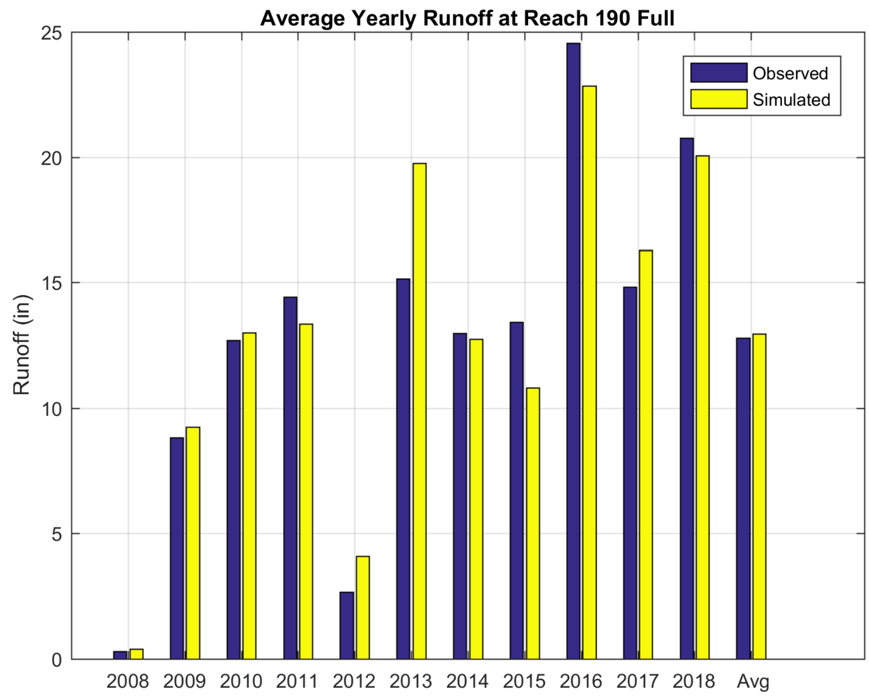


Figure A-1. Average Yearly Runoff at Reach 190.

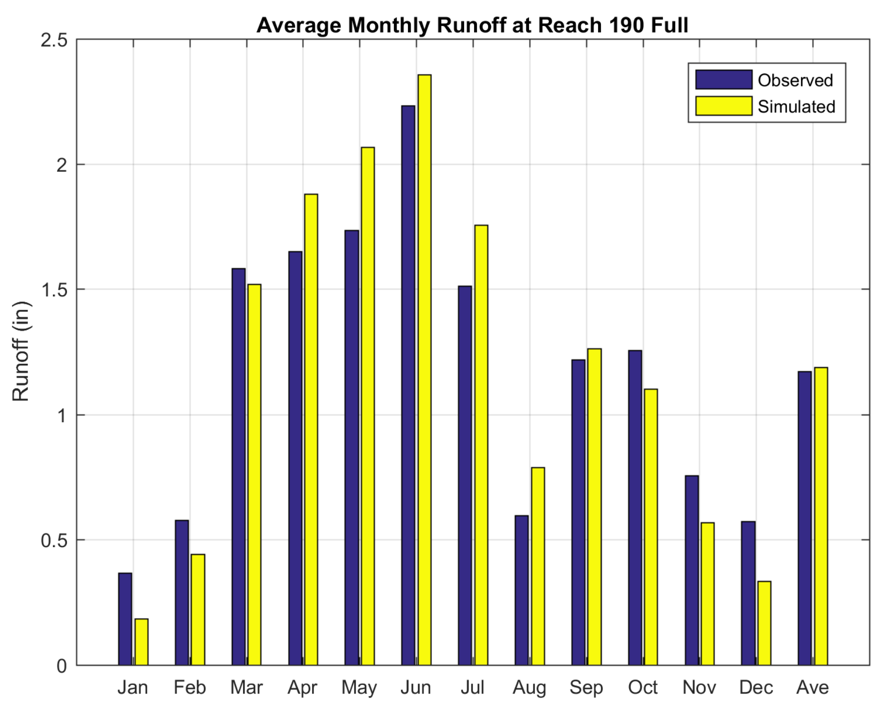


Figure A-2. Average Monthly Runoff at Reach 190.

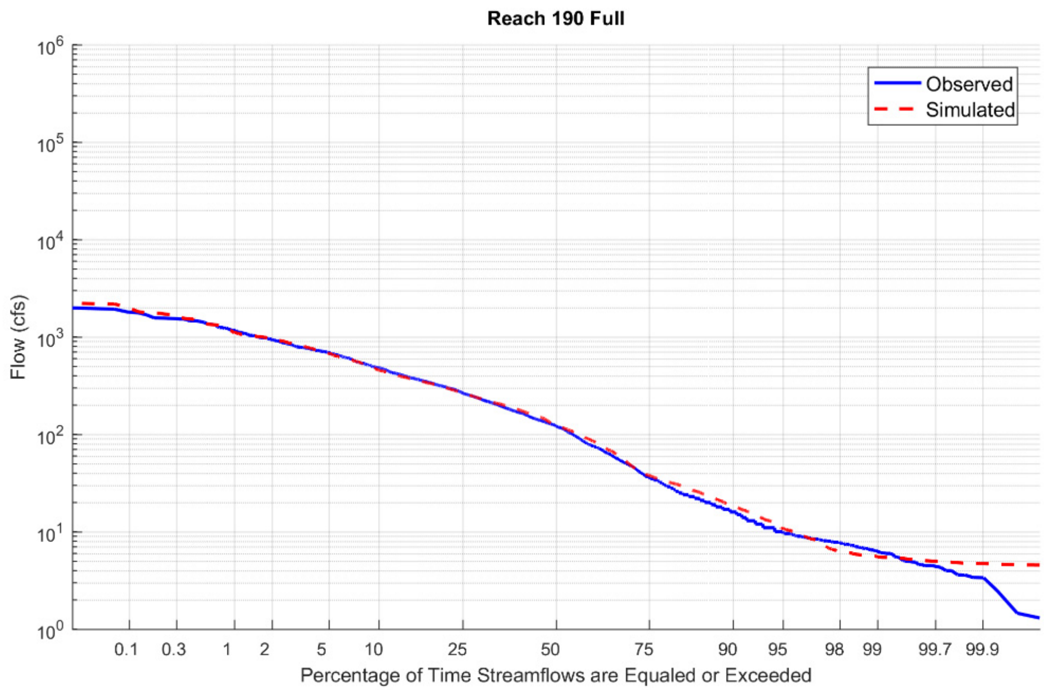


Figure A-3. Flow Duration Plot for Reach 190.

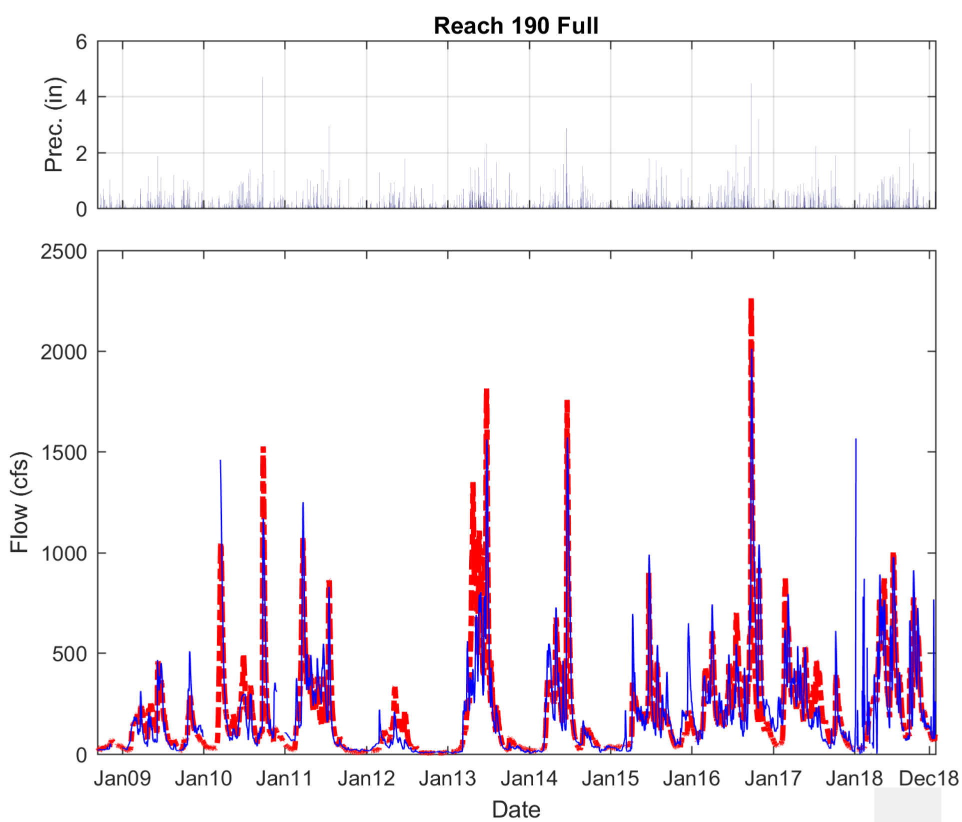


Figure A-4. Daily Hydrographs for Reach 190.

# ATTACHMENT B

## OBSERVED WATER QUALITY DATA AND LOCATIONS FOR THE SHELL ROCK RIVER WATERSHED MODEL APPLICATION

RESPEC

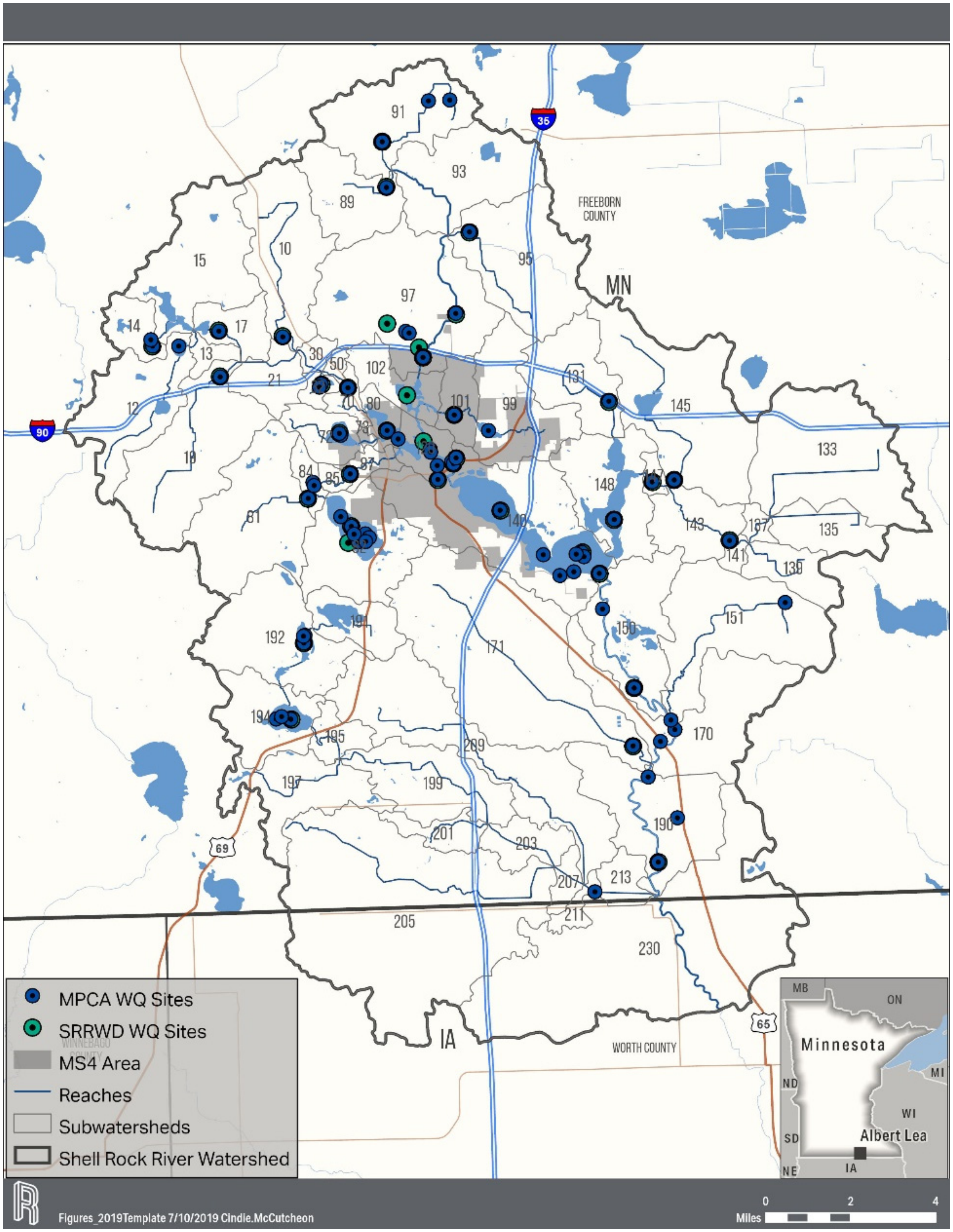


Figure B-1. Water Quality Calibration Sites in the Shell Rock River Watershed.

Table B-1. Water Quality Calibration Data (Page 1 of 5)

| MPCA Site I.D. | SRRWD Site I.D. | Reach I.D. | Biochemical Oxygen Demand | Chlorophyll *a* | Dissolved Oxygen | Total Suspended Solids | Volatile Suspended Solids | Water Temperature | Ammonia Nitrogen | Kjeldahl Nitrogen | Nitrate + Nitrite | Organic Carbon | Ortho-phosphate | Phosphorus | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S005-008 | SWC02 | 10 | | | 2 | | | 2 | | | | | | | 4 |
| S005-008 | N/A | 10 | | 10 | 18 | 13 | | 18 | | 10 | 11 | | 3 | 13 | 96 |
| 24-0037-00-201 | N/A | 12 | | | | | | 1 | | | | | | 1 | 2 |
| 24-0038-00-201 | LHL01 | 14 | | 79 | 67 | 79 | 67 | 68 | 12 | 12 | 14 | | 78 | 79 | 555 |
| 24-0038-00-201 | N/A | 14 | | | | | | 1 | | | | | | 1 | 2 |
| 24-0038-00-202 | N/A | 14 | | | | | | 1 | | | | | | 1 | 2 |
| S005-009 | SWC03 | 17 | | | 2 | | | 2 | | | | | | | 4 |
| S005-009 | N/A | 17 | | 10 | 17 | 13 | | 17 | | 10 | 11 | | 3 | 13 | 94 |
| S005-010 | SWC04 | 19 | | | 2 | | | 2 | | | | | | | 4 |
| S005-010 | N/A | 19 | | 10 | 16 | 13 | | 16 | | 10 | 11 | | 3 | 13 | 92 |
| 24-0040-00-100 | N/A | 32 | | 1 | | | | | | | | | | 1 | 2 |
| 24-0040-00-201 | LSS01 | 32 | | 76 | 62 | 76 | 64 | 64 | 12 | 12 | 12 | | 76 | 76 | 530 |
| 24-0040-00-201 | N/A | 32 | | | | | | 1 | | | | | | 1 | 2 |
| S004-121 | SWC01 | 50 | | 102 | 119 | 125 | 21 | 120 | 94 | 104 | 114 | | 106 | 122 | 1,027 |
| S004-121 | N/A | 50 | | 28 | 86 | 71 | 14 | 125 | | 10 | 15 | | 61 | 71 | 481 |
| 24-0024-00-100 | N/A | 72 | | 1 | | | | | | | | | | 1 | 2 |
| 24-0024-00-201 | LCH01 | 72 | | 101 | 80 | 81 | 69 | 85 | 12 | 12 | 14 | | 102 | 102 | 658 |
| 24-0024-00-201 | N/A | 72 | | 19 | 13 | | | 19 | | | | | 19 | 21 | 91 |
| 24-0018-02-201 | LFL01 | 80 | | 174 | 85 | 155 | 22 | 90 | 129 | 129 | 135 | 92 | 178 | 178 | 1,367 |
| 24-0018-02-201 | N/A | 80 | | 54 | 51 | 22 | 7 | 55 | | | | | 60 | 60 | 309 |
| S004-117 | SMC01 | 81 | | 14 | 117 | 127 | 1 | 118 | 14 | 14 | 22 | | 127 | 126 | 680 |
| S004-117 | N/A | 81 | | | 49 | 50 | 1 | 49 | | | 14 | | 50 | 50 | 263 |

Table B-1. Water Quality Calibration Data (Page 2 of 5)

| MPCA Site I.D. | SRRWD Site I.D. | Reach I.D. | Biochemical Oxygen Demand | Chlorophyll *a* | Dissolved Oxygen | Total Suspended Solids | Volatile Suspended Solids | Water Temperature | Ammonia Nitrogen | Kjeldahl Nitrogen | Nitrate + Nitrite | Organic Carbon | Ortho-phosphate | Phosphorus | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24-0025-00-100 | N/A | 82 | | 1 | | | | | | | | | | 1 | 2 |
| 24-0025-00-201 | LPL01 | 82 | | 116 | 86 | 98 | 76 | 91 | 17 | 17 | 74 | | 118 | 117 | 810 |
| 24-0025-00-201 | N/A | 82 | | 55 | 51 | 27 | 10 | 56 | | | | | 62 | 62 | 323 |
| 24-0025-00-202 | N/A | 82 | | | | | | 1 | | | | | | 2 | 3 |
| 24-0025-00-203 | N/A | 82 | | | | | | 1 | | | | | | 1 | 2 |
| 24-0025-00-204 | N/A | 82 | | | | | | 1 | | | | | | 1 | 2 |
| 24-0025-00-205 | N/A | 82 | | | | | | | | | | | | 1 | 1 |
| 24-0025-00-206 | N/A | 82 | | | | | | 1 | | | | | | 2 | 3 |
| 24-0068-00-201 | N/A | 84 | | | | | | | | | | | | 1 | 1 |
| 24-0068-00-202 | N/A | 84 | | | | | | 1 | | | | | | 1 | 2 |
| S004-114 | SSC01 | 85 | | 107 | 122 | 134 | 19 | 123 | 88 | 88 | 97 | | 135 | 135 | 1,048 |
| S004-114 | N/A | 85 | | 23 | 53 | 48 | 14 | 53 | | | 4 | | 48 | 48 | 291 |
| S005-006 | SBC03 | 89 | | | 2 | | | 2 | | | | | | | 4 |
| S005-006 | N/A | 89 | | 12 | 16 | 15 | | 16 | | 12 | 13 | | 3 | 14 | 101 |
| S005-007 | SBC04 | 91 | | | 2 | | | 2 | | | | | | | 4 |
| S005-007 | N/A | 91 | | 12 | 15 | 15 | | 15 | | 12 | 13 | | 3 | 14 | 99 |
| S006-536 | N/A | 91 | | | 3 | | | 3 | 3 | | 3 | | 3 | 3 | 18 |
| S005-005 | SBC02 | 95 | | | 2 | | | 2 | | | | | | | 4 |
| S005-005 | N/A | 95 | | 12 | 15 | 15 | | 15 | | 12 | 13 | | 3 | 14 | 99 |
| S004-120 | SBC01 | 97 | | 114 | 128 | 139 | 21 | 129 | 108 | 115 | 123 | | 123 | 139 | 1,139 |
| S004-120 | N/A | 97 | | 21 | 83 | 69 | 14 | 83 | | 11 | 16 | | 58 | 69 | 424 |
| S006-535 | N/A | 97 | | | 7 | | | 7 | 3 | | 3 | | 3 | 3 | 26 |
| S004-118 | SGC01 | 101 | | 92 | 105 | 114 | 14 | 106 | 79 | 80 | 84 | | 114 | 114 | 902 |

Table B-1. Water Quality Calibration Data (Page 3 of 5)

| MPCA Site I.D. | SRRWD Site I.D. | Reach I.D. | Biochemical Oxygen Demand | Chlorophyll *a* | Dissolved Oxygen | Total Suspended Solids | Volatile Suspended Solids | Water Temperature | Ammonia Nitrogen | Kjeldahl Nitrogen | Nitrate + Nitrite | Organic Carbon | Ortho-phosphate | Phosphorus | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S004-118 | N/A | 101 | | 21 | 45 | 46 | 14 | 45 | | | 4 | | 46 | 46 | 267 |
| 24-0018-03-202 | LFL03 | 102 | | 61 | 37 | 61 | | 37 | 61 | 61 | 61 | 48 | 61 | 61 | 549 |
| 24-0018-01-201 | N/A | 120 | | 3 | 3 | 4 | 4 | 3 | | | | | 4 | 4 | 25 |
| 24-0018-01-203 | N/A | 120 | | | | | | | | | | | | | 0 |
| 24-0018-01-204 | N/A | 120 | | 56 | 54 | 24 | 9 | 56 | | | | | 60 | 60 | 319 |
| 24-0018-01-100 | LFL02 | 120 | | 195 | 115 | 166 | 26 | 119 | 124 | 124 | 131 | 89 | 200 | 201 | 1,490 |
| S004-119 | SFL01 | 120 | | 107 | 119 | 127 | 17 | 120 | 87 | 87 | 94 | | 126 | 127 | 1,011 |
| S000-142 | N/A | 120 | | | 1 | | | 1 | | | | | | | 2 |
| S004-116 | SNE01 | 131 | | 85 | 114 | 122 | 13 | 116 | 83 | 84 | 93 | | 122 | 122 | 954 |
| S004-116 | N/A | 131 | | | 48 | 50 | 1 | 48 | | | 12 | | 50 | 50 | 259 |
| 24-0014-00-100 | N/A | 140 | | 1 | | | | | | | | | | 1 | 2 |
| 24-0014-00-104 | LAL02 | 140 | | 113 | 87 | 93 | 71 | 89 | 17 | 17 | 73 | | 115 | 115 | 790 |
| 24-0014-00-104 | N/A | 140 | | 58 | 64 | 24 | 10 | 56 | | | | | 61 | 62 | 335 |
| 24-0014-00-203 | N/A | 140 | | | | | | | | | | | | | 0 |
| 24-0014-00-205 | LAL01 | 140 | | 112 | 88 | 92 | 71 | 91 | 17 | 17 | 73 | | 117 | 116 | 794 |
| 24-0014-00-205 | N/A | 140 | | 54 | 55 | 26 | 11 | 56 | | | | | 63 | 63 | 328 |
| 24-0014-00-207 | N/A | 140 | | | | | | | | | | | | 1 | 1 |
| 24-0014-00-213 | N/A | 140 | | 1 | | | | 1 | | | | | | 1 | 3 |
| 24-0014-00-239 | N/A | 140 | | | | | | 1 | | | | | | 1 | 2 |
| S005-772 | SPL01B | 141 | | 85 | 104 | 109 | | 106 | 85 | 85 | 86 | | 109 | 109 | 878 |
| S005-772 | N/A | 141 | | | 22 | 16 | | 22 | | | 10 | | 16 | 16 | 102 |
| S005-773 | SPL02 | 145 | | 85 | 98 | 102 | | 100 | 85 | 85 | 85 | | 102 | 102 | 844 |
| S005-773 | N/A | 145 | | | 24 | 18 | | 24 | | | 9 | | 18 | 18 | 111 |

Table B-1. Water Quality Calibration Data (Page 4 of 5)

| MPCA Site I.D. | SRRWD Site I.D. | Reach I.D. | Biochemical Oxygen Demand | Chlorophyll *a* | Dissolved Oxygen | Total Suspended Solids | Volatile Suspended Solids | Water Temperature | Ammonia Nitrogen | Kjeldahl Nitrogen | Nitrate + Nitrite | Organic Carbon | Ortho-phosphate | Phosphorus | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S004-115 | SPL01 | 147 | | | 18 | 25 | 2 | 18 | | | 11 | | 26 | 26 | 126 |
| S004-115 | N/A | 147 | | 1 | 37 | 35 | 3 | 37 | | | 5 | | 35 | 35 | 188 |
| 24-0014-00-206 | LAL03 | 148 | | 116 | 89 | 90 | 70 | 92 | 18 | 19 | 75 | | 116 | 117 | 802 |
| 24-0014-00-206 | N/A | 148 | | 58 | 60 | 25 | 10 | 60 | | | | | 63 | 64 | 340 |
| S000-002 | SSR01 | 150 | | 98 | 112 | 120 | 83 | 111 | 14 | 14 | 23 | | 122 | 122 | 819 |
| S000-002 | N/A | 150 | | 6 | 34 | 31 | 4 | 34 | 3 | | 9 | | 34 | 36 | 191 |
| S004-113 | SSR02 | 150 | | 104 | 116 | 127 | 90 | 118 | 14 | 14 | 22 | | 128 | 127 | 860 |
| S004-113 | N/A | 150 | | 26 | 55 | 49 | 15 | 56 | | | 8 | | 48 | 52 | 309 |
| S005-117 | N/A | 150 | | 2 | 10 | 2 | 2 | 10 | 1 | 1 | 4 | | 1 | 4 | 37 |
| S001-011 | N/A | 170 | | | 3 | 2 | | 3 | | | | | | | 8 |
| S007-148 | N/A | 170 | | 2 | 8 | | | 8 | | | 2 | | | 2 | 22 |
| S005-096 | SCD16 | 171 | | 14 | 94 | 99 | 1 | 96 | 14 | 14 | 15 | | 99 | 99 | 545 |
| S005-096 | N/A | 171 | | | 22 | 23 | 1 | 22 | | | 13 | | 23 | 24 | 128 |
| S000-084 | SSR03 | 190 | | 103 | 99 | 102 | 87 | 101 | 14 | 14 | 14 | | 101 | 102 | 737 |
| S000-084 | N/A | 190 | 24 | 45 | 315 | 416 | 251 | 322 | 83 | 335 | 399 | 36 | 331 | 418 | 2,975 |
| S006-770 | N/A | 190 | | 3 | 8 | 1 | 1 | 8 | | | 4 | | | 4 | 29 |
| 24-0031-00-100 | N/A | 192 | | 1 | | | | | | | | | | 1 | 2 |
| 24-0031-00-201 | LUT01 | 192 | | 91 | 75 | 79 | 66 | 77 | 12 | 12 | 12 | | 91 | 91 | 606 |
| 24-0031-00-201 | N/A | 192 | | 19 | 12 | 1 | 1 | 20 | | | | | 19 | 20 | 92 |
| 24-0031-00-202 | N/A | 192 | | | | | | | | | | | | 1 | 1 |
| 24-0027-00-100 | N/A | 194 | | 1 | 1 | | | 1 | | | | | 1 | 1 | 5 |
| 24-0027-00-201 | LLT01 | 194 | | 95 | 70 | 78 | 66 | 79 | 12 | 12 | 12 | | 94 | 95 | 613 |
| 24-0027-00-201 | N/A | 194 | | 18 | 12 | 1 | 1 | 19 | | | | | 18 | 20 | 89 |

Table B-1. Water Quality Calibration Data (Page 5 of 5)

| MPCA Site I.D. | SRRWD Site I.D. | Reach I.D. | Biochemical Oxygen Demand | Chlorophyll *a* | Dissolved Oxygen | Total Suspended Solids | Volatile Suspended Solids | Water Temperature | Ammonia Nitrogen | Kjeldahl Nitrogen | Nitrate + Nitrite | Organic Carbon | Ortho-phosphate | Phosphorus | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24-0027-00-202 | N/A | 194 | | | | | | 1 | | | | | | 2 | 3 |
| S005-615 | N/A | 211 | | | 23 | 10 | 10 | 23 | 9 | 10 | 10 | | | 10 | 105 |
| 24-0017-00-100 | N/A | N/A | | 1 | | | | | | | | | | 1 | 2 |
| 24-0082-00-201 | N/A | N/A | | | 3 | | | 3 | 3 | | 3 | | 3 | 3 | 18 |
| LD00152 | N/A | N/A | | | 1 | | | 1 | 1 | | 1 | | 1 | 1 | 6 |
| S004-119 | N/A | N/A | | 22 | 47 | 49 | 14 | 47 | | | 4 | | 49 | 49 | 281 |
| S005-113 | N/A | N/A | | | | 1 | | | | | | | 1 | 1 | 3 |
| S005-774 | N/A | N/A | | | | 7 | | | | | | | 7 | 7 | 21 |
| S005-775 | N/A | N/A | | | | 11 | | | | | | | 11 | 11 | 33 |
| S006-537 | N/A | N/A | | | 3 | | | 3 | 3 | | 3 | | 3 | 3 | 18 |
| S006-538 | N/A | N/A | | | 3 | | | 3 | 3 | | 3 | | 3 | 3 | 18 |
| S015-206 | N/A | N/A | | | | 5 | | | | | | | | 5 | 10 |
| S015-207 | N/A | N/A | | | | 5 | | | | | | | | 5 | 10 |
| S015-208 | N/A | N/A | | | | 5 | | | | | | | | 5 | 10 |
| N/A | LAKEVIEW | N/A | | | | | | | | | | | | | 0 |
| N/A | LFD01 | N/A | | 1 | 8 | 8 | 8 | 8 | | | | | 9 | 9 | 51 |
| N/A | LPL02 | N/A | | 7 | 6 | 7 | 3 | 6 | | | 7 | | 7 | 7 | 50 |
| N/A | SCDF01 | N/A | | | 30 | 32 | 18 | 30 | | | | | 32 | 32 | 174 |
| N/A | SCDF02 | N/A | | | 32 | 34 | 20 | 32 | | | | | 34 | 34 | 186 |
| N/A | SCDF03 | N/A | | | 9 | 11 | | 9 | | | | | 11 | 11 | 51 |
| N/A | SFD01 | N/A | | 1 | 8 | 9 | 7 | 9 | 1 | 1 | 1 | | 9 | 9 | 55 |
| N/A | SGCD01 | N/A | | | 16 | 17 | | 16 | | | 4 | | 17 | 17 | 87 |

# ATTACHMENT C

## WATER QUALITY CALIBRATION FIGURES FOR REACH 190 IN THE SHELL ROCK RIVER WATERSHED MODEL APPLICATION

RESPEC

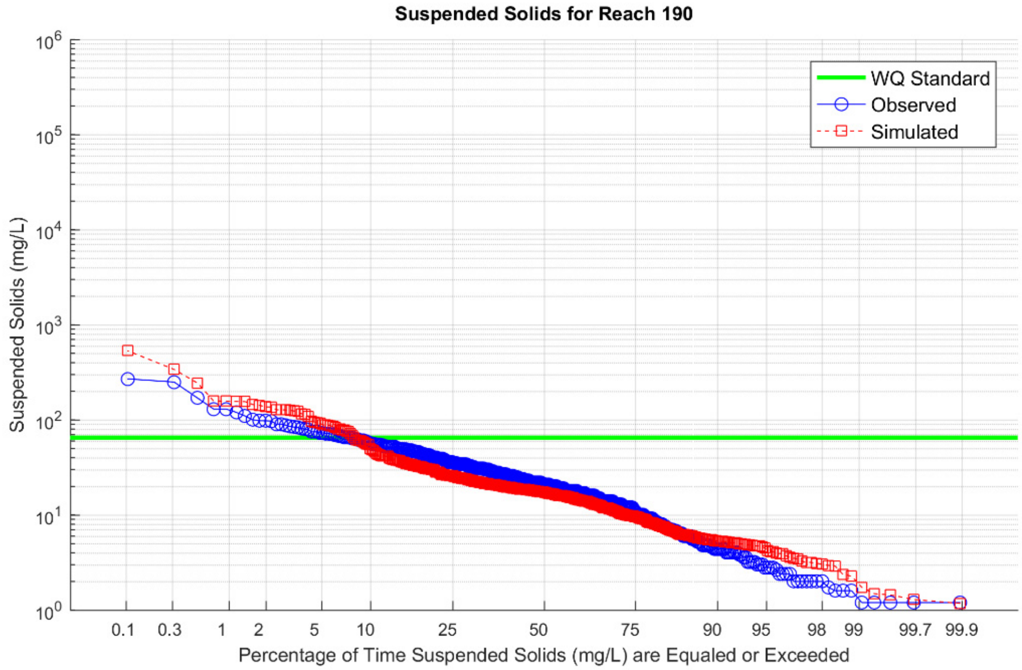


Figure C-1. Suspended Solids Duration Curve at Reach 190.

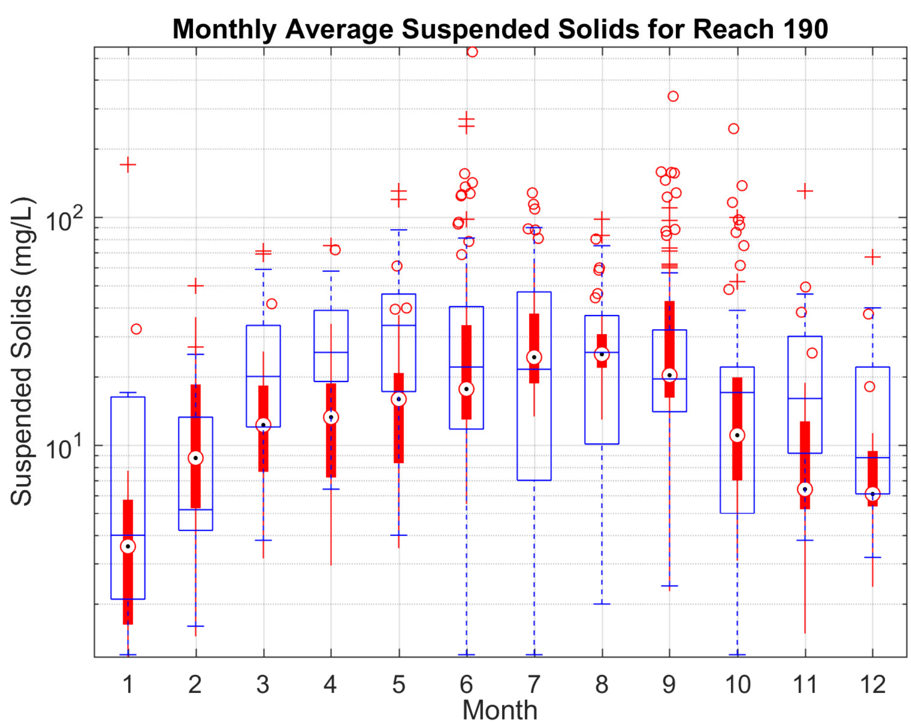


Figure C-2. Suspended Solids Monthly Averages at Reach 190.

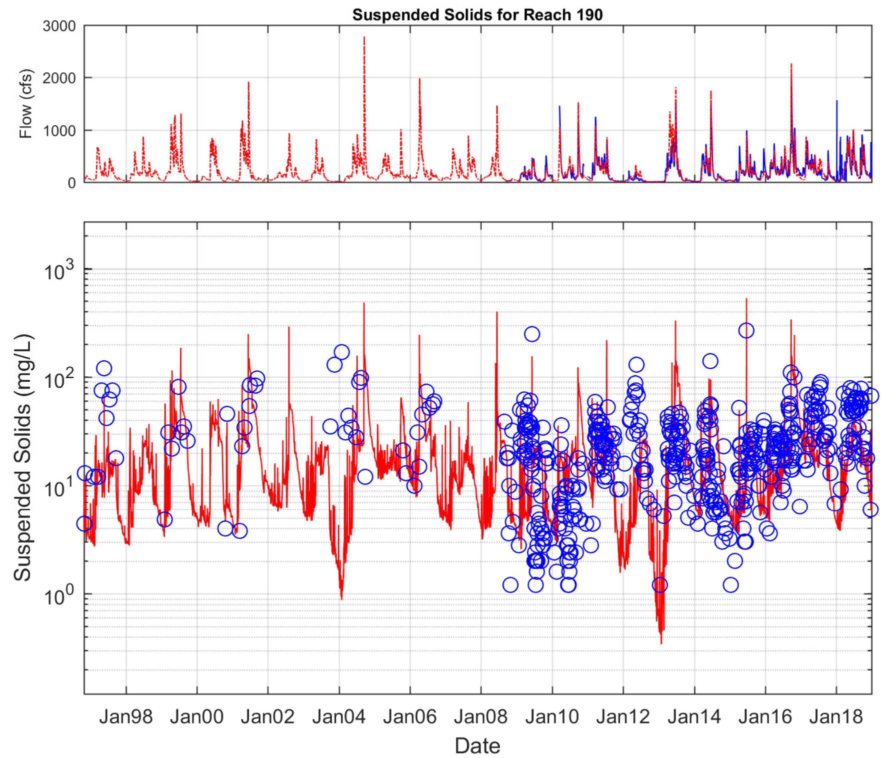


Figure C-3. Suspended Solids Time Series at Reach 190.

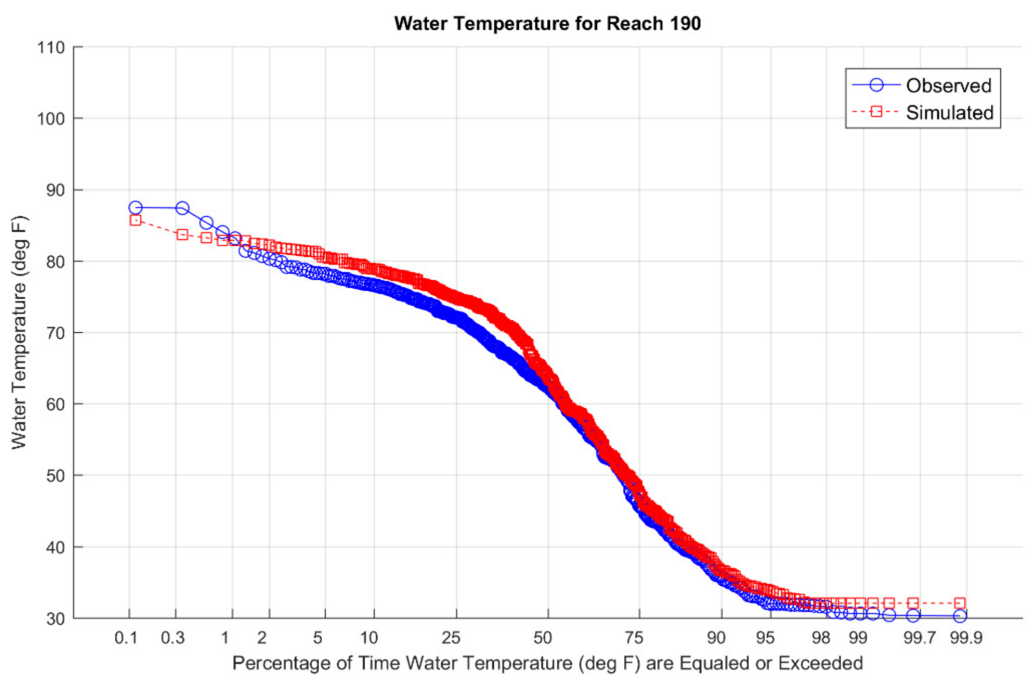


Figure C-4. Water Temperature Duration Curve at Reach 190.

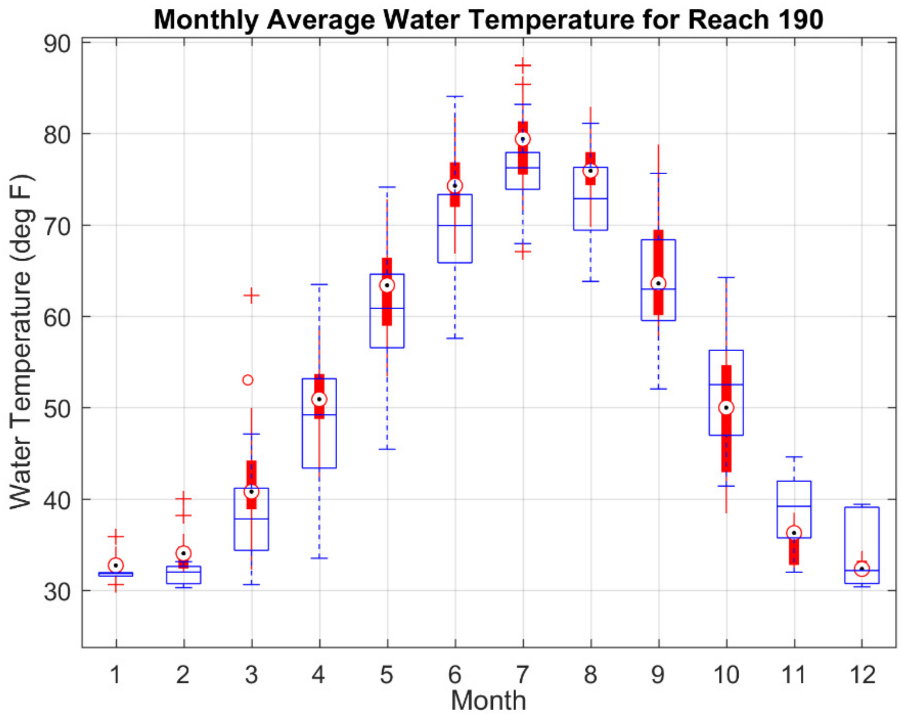


Figure C-5. Water Temperature Monthly Averages at Reach 190.

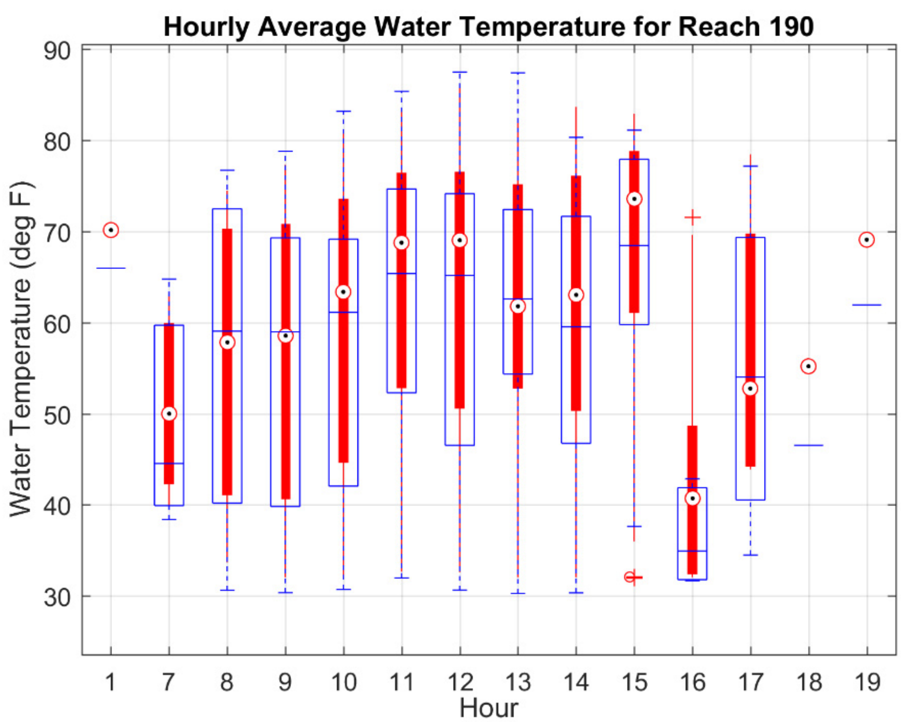


Figure C-6. Water Temperature Hourly Averages at Reach 190.

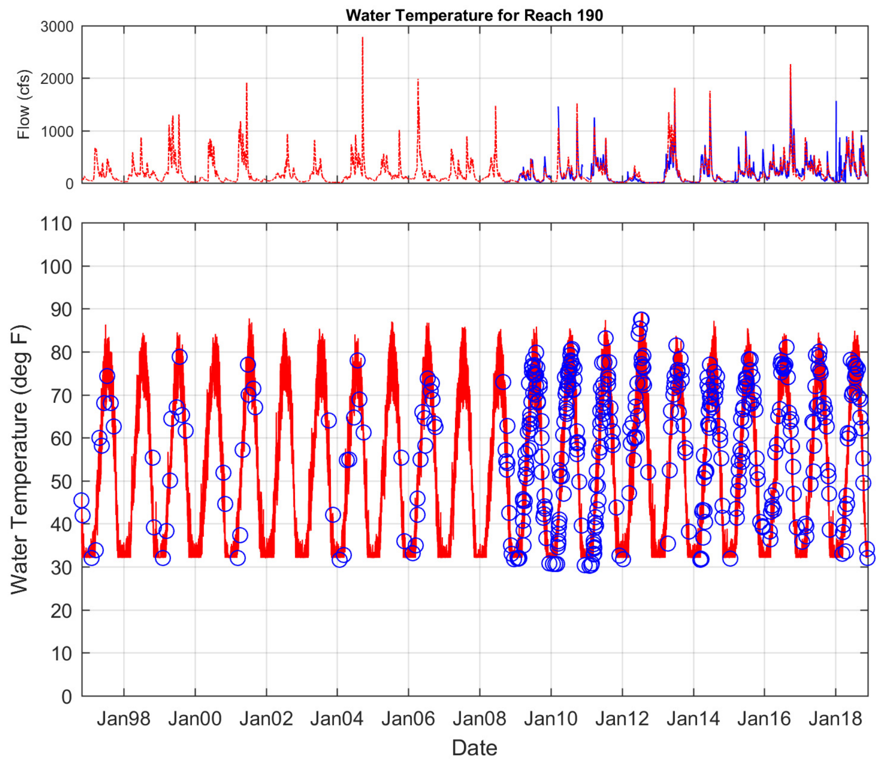


Figure C-7. Water Temperature Time Series at Reach 190.

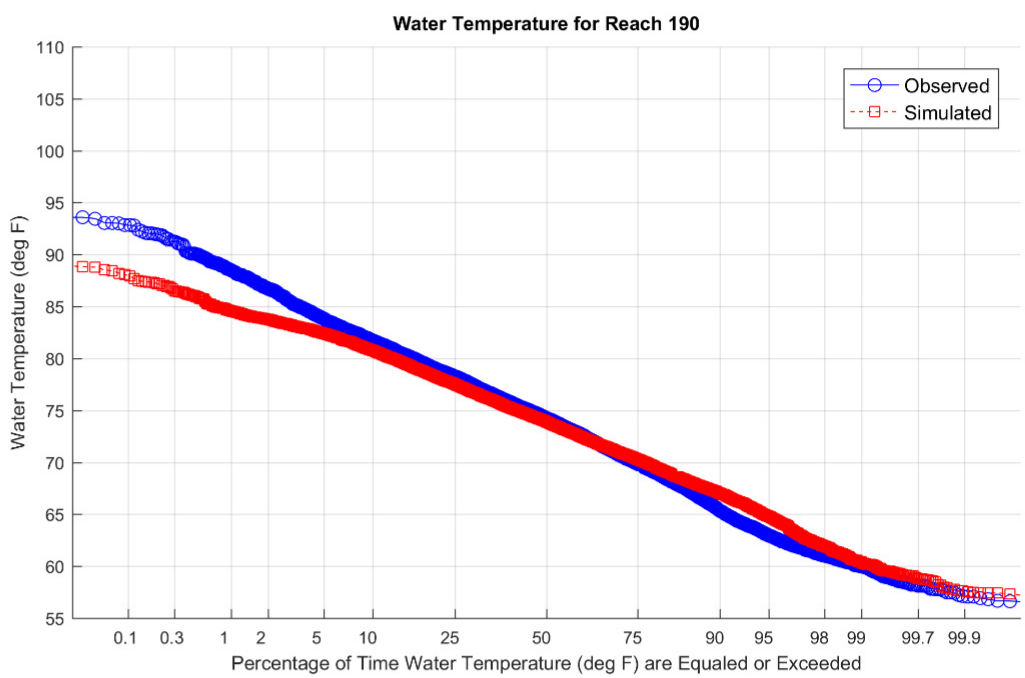


Figure C-8. Continuous Water Temperature Duration Curve at Reach 190 (SRRWD).

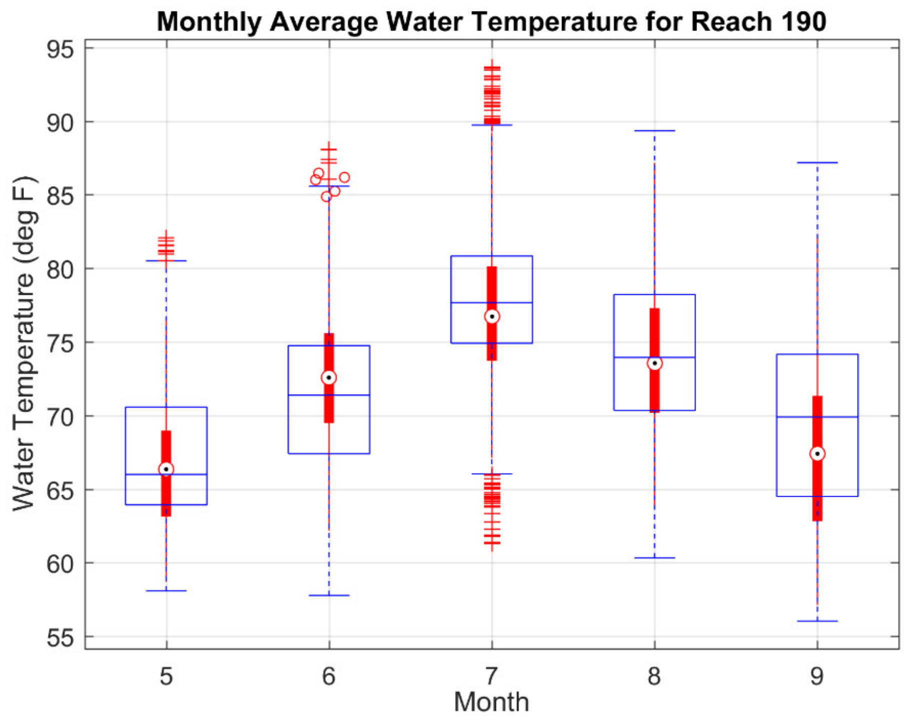


Figure C-9. Continuous Water Temperature Monthly Averages at Reach 190 (SRRWD).

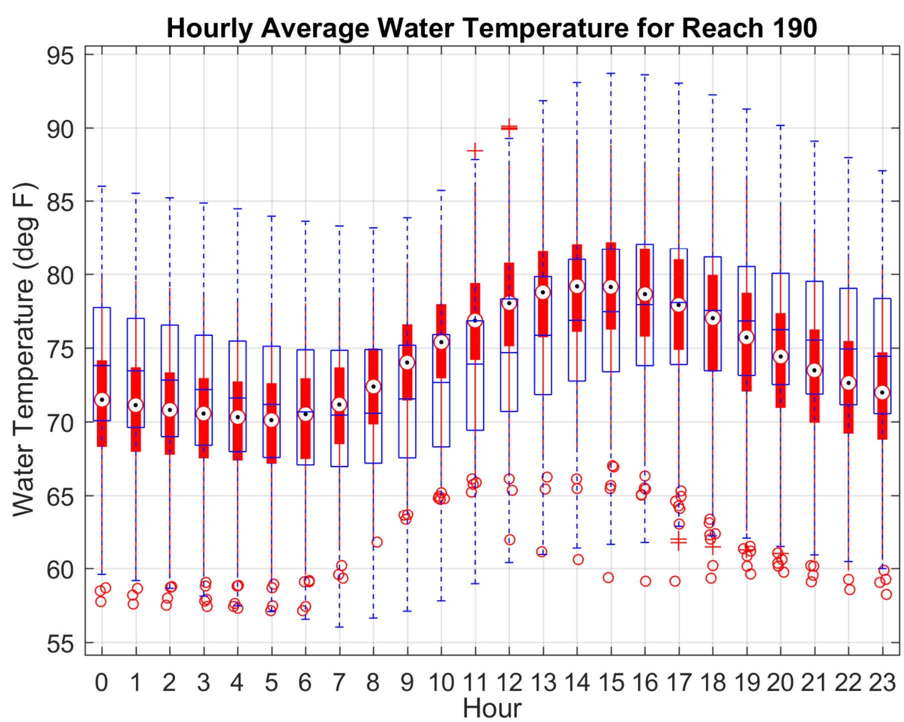


Figure C-10. Continuous Water Temperature Hourly Averages at Reach 190 (SRRWD).

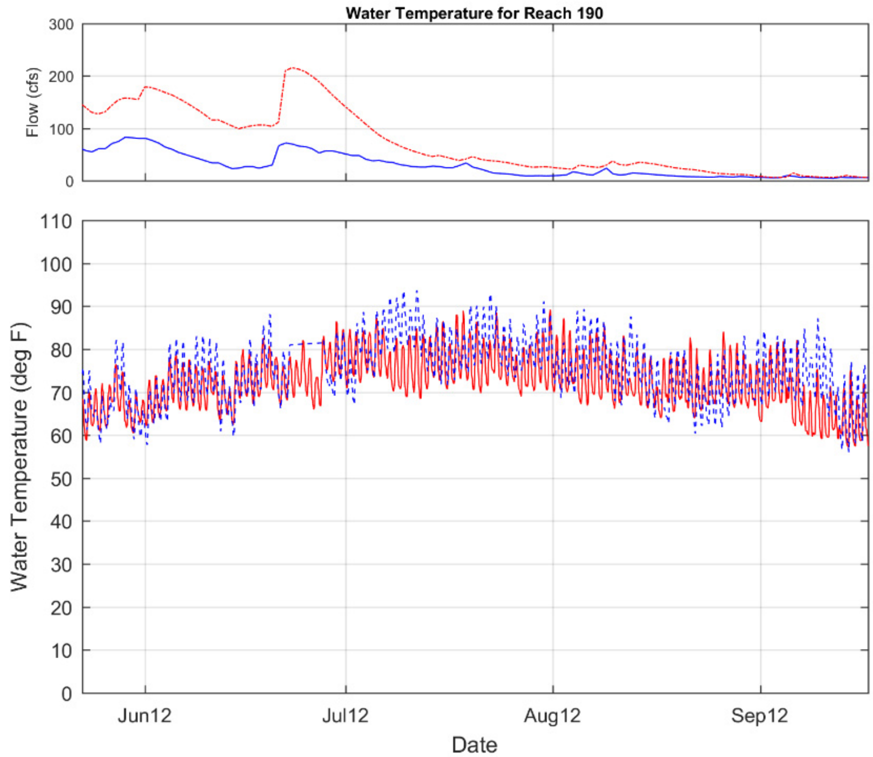


Figure C-11. Continuous Water Temperature Time Series at Reach 190 (SRRWD 2012).

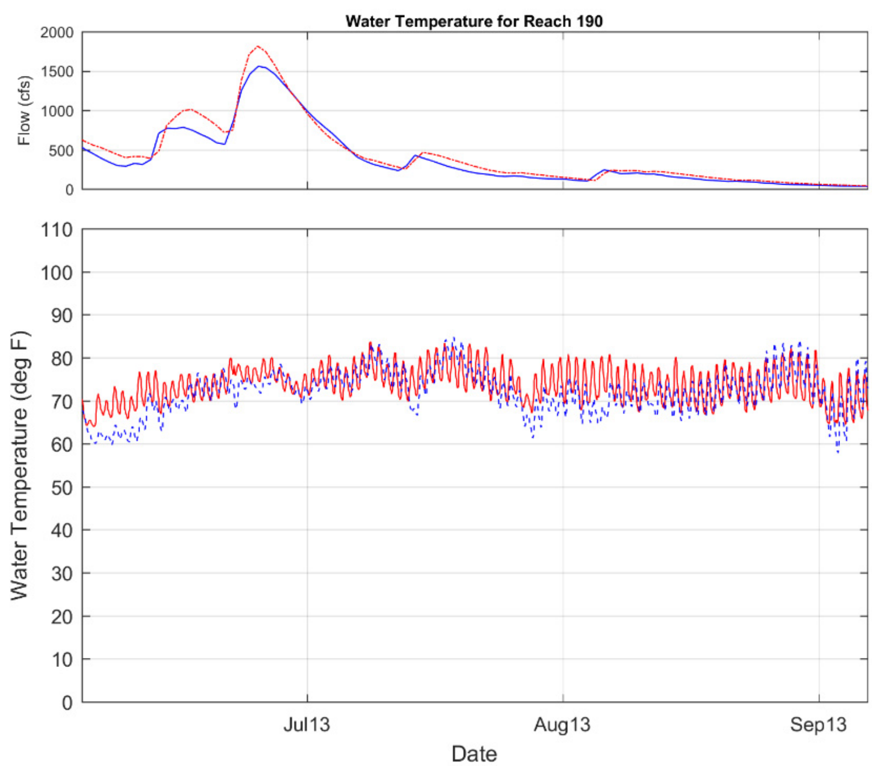


Figure C-12. Continuous Water Temperature Time Series at Reach 190 (SRRWD 2013).

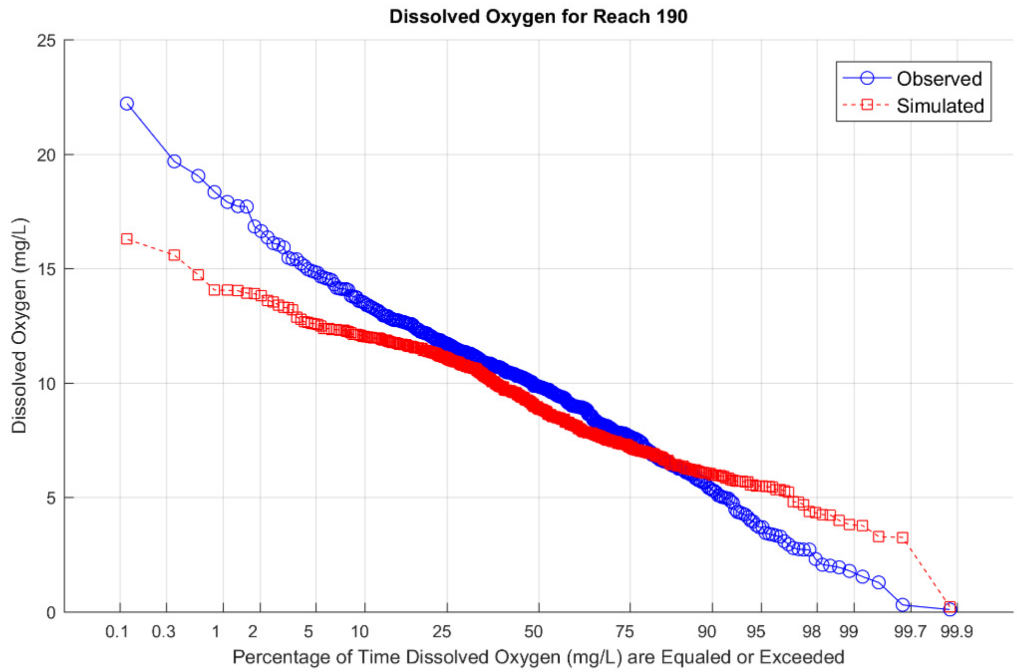


Figure C-13. Dissolved Oxygen Duration Curve at Reach 190.

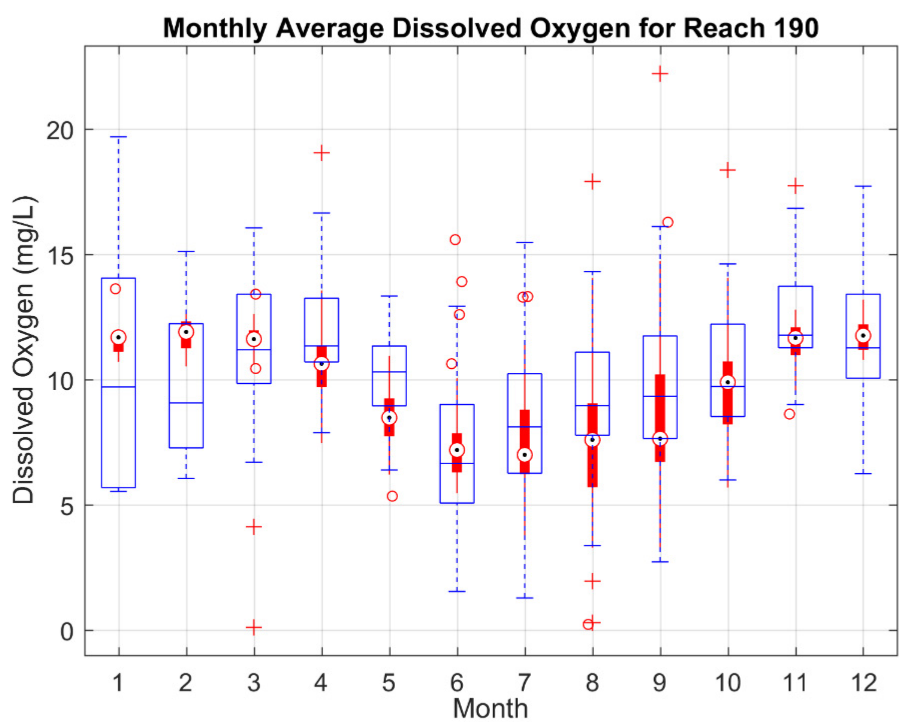


Figure C-14. Dissolved Oxygen Monthly Averages at Reach 190.

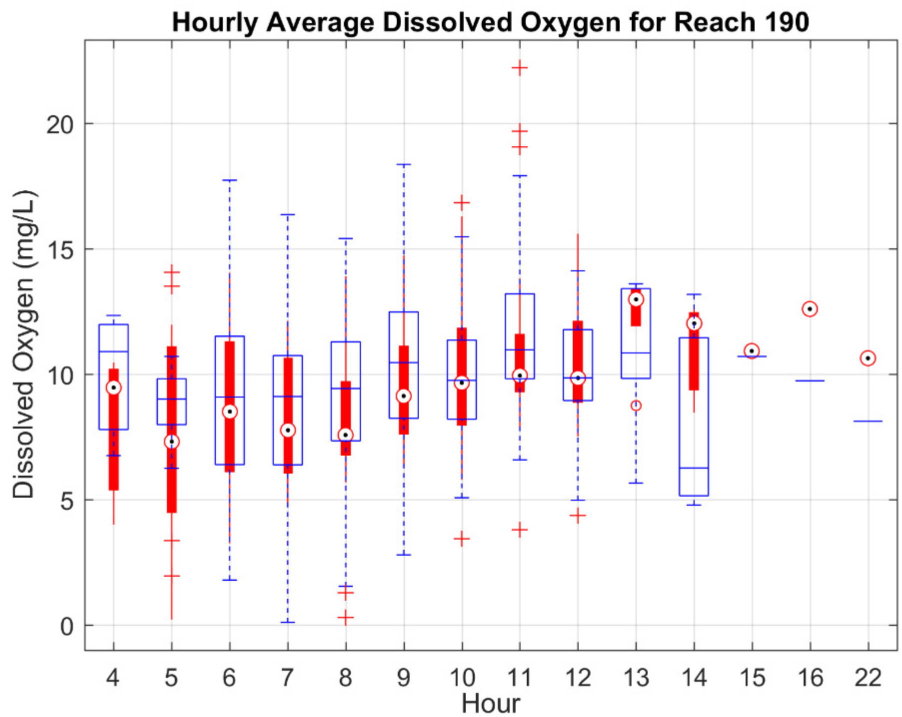


Figure C-15. Dissolved Oxygen Hourly Averages at Reach 190.

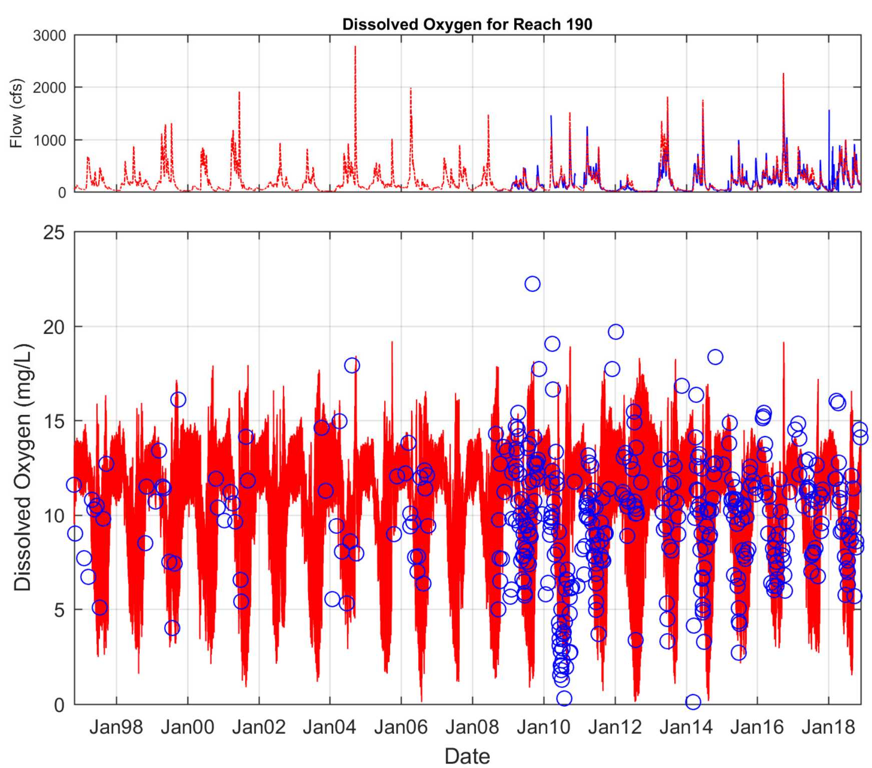


Figure C-16. Dissolved Oxygen Time Series at Reach 190.

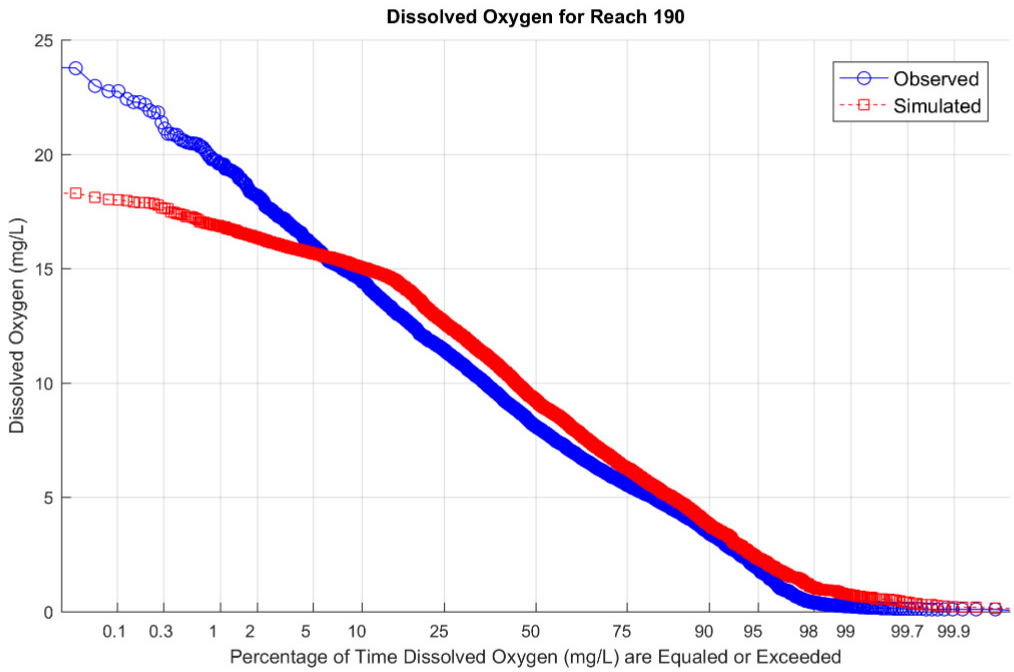


Figure C-17. Continuous Dissolved Oxygen Duration Curve at Reach 190 (SRRWD and MPCA Combined).

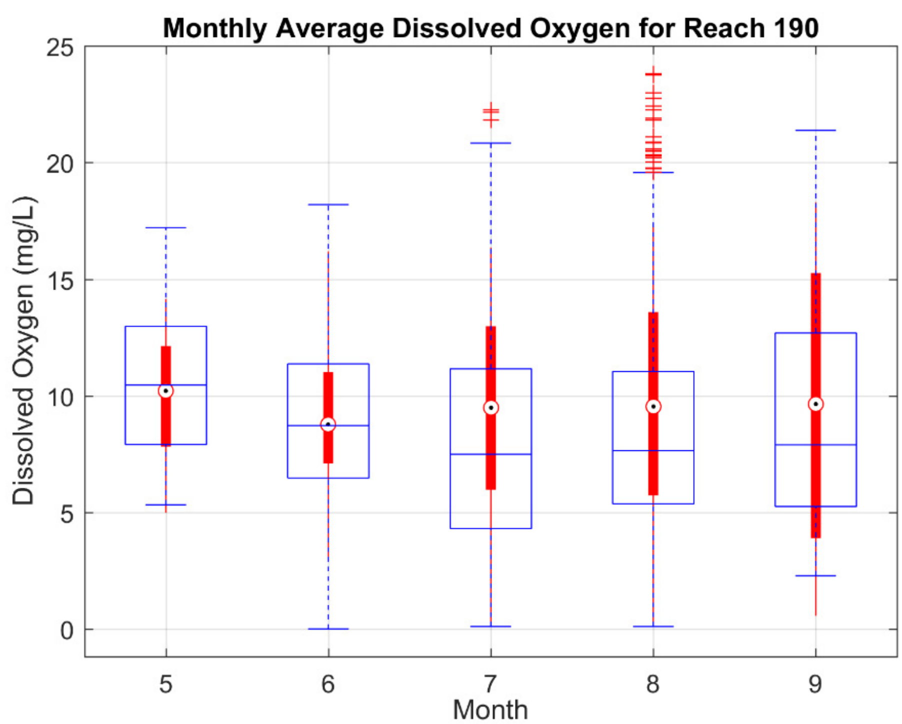


Figure C-18. Continuous Dissolved Oxygen Monthly Averages at Reach 190 (SRRWD and MPCA Combined).

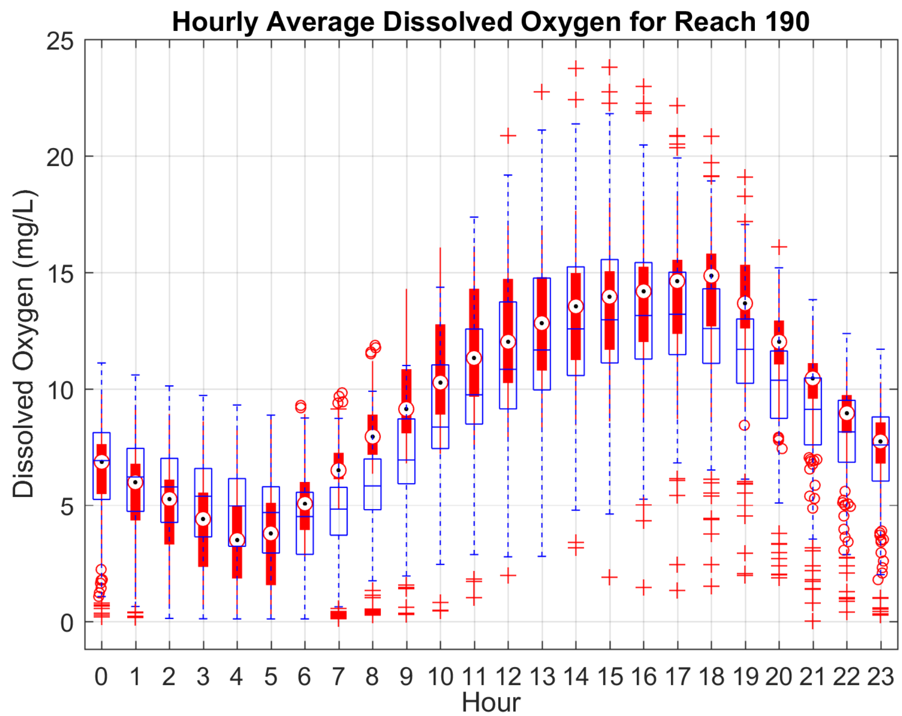


Figure C-19. Continuous Dissolved Oxygen Hourly Averages at Reach 190 (SRRWD and MPCA Combined).

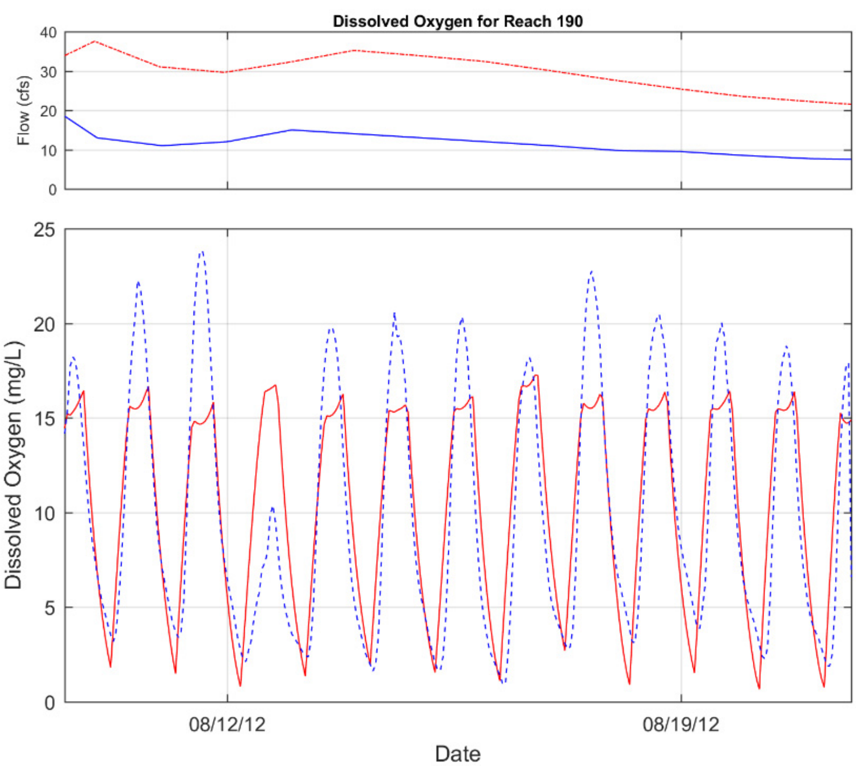


Figure C-20. Continuous Dissolved Oxygen Time Series at Reach 190 (MPCA 2012).

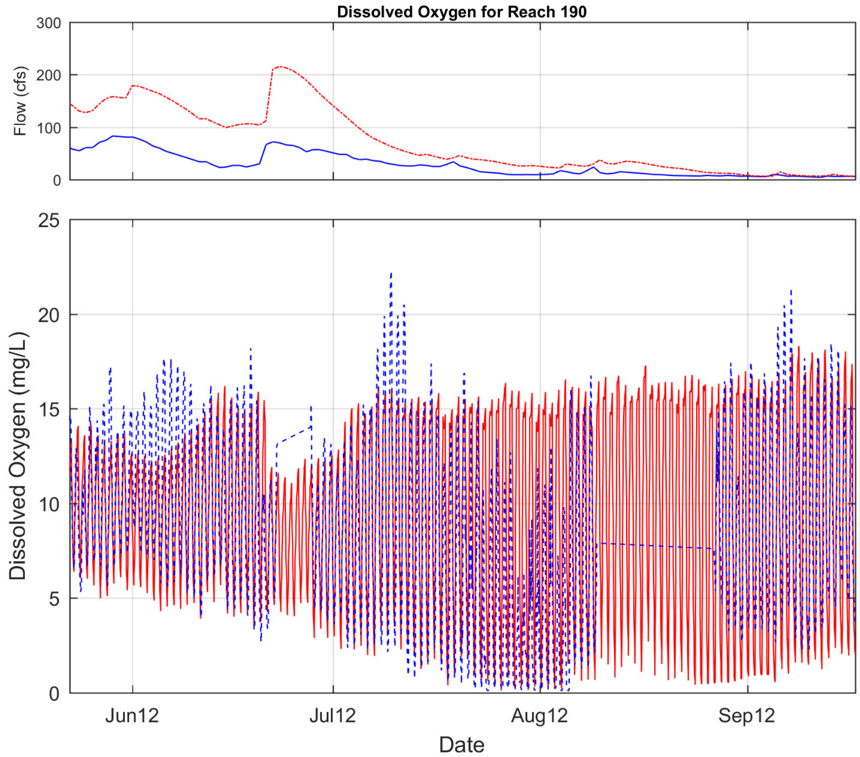


Figure C-21. Continuous Dissolved Oxygen Time Series at Reach 190 (SRRWD 2012).

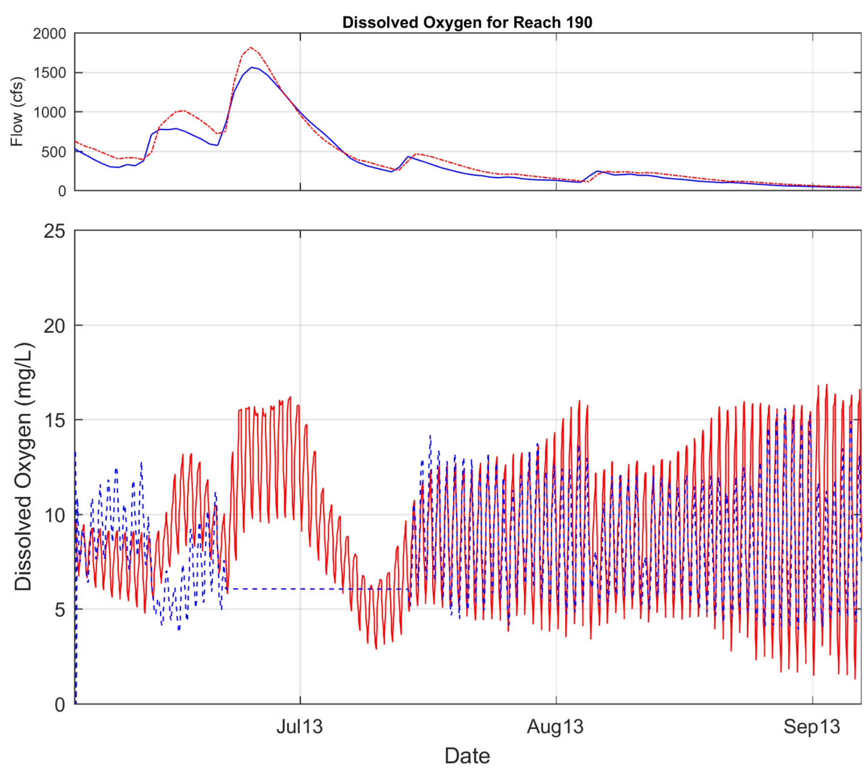


Figure C-22. Continuous Dissolved Oxygen Time Series at Reach 190 (SRRWD 2013).

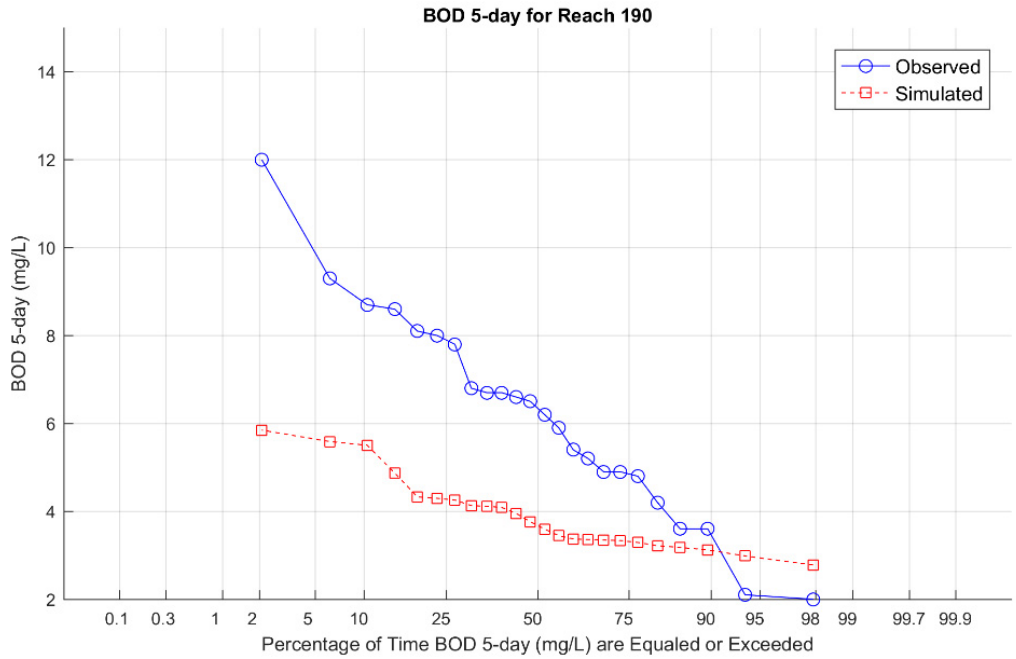


Figure C-23. Biological Oxygen Demand Duration Curve at Reach 190.

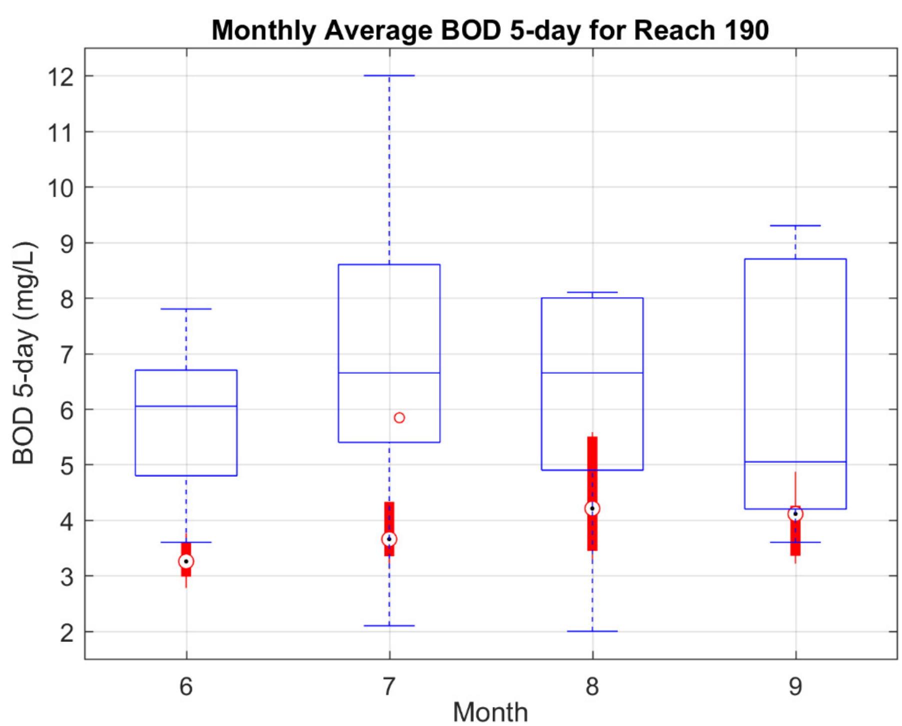


Figure C-24. Biological Oxygen Demand Monthly Averages at Reach 190.

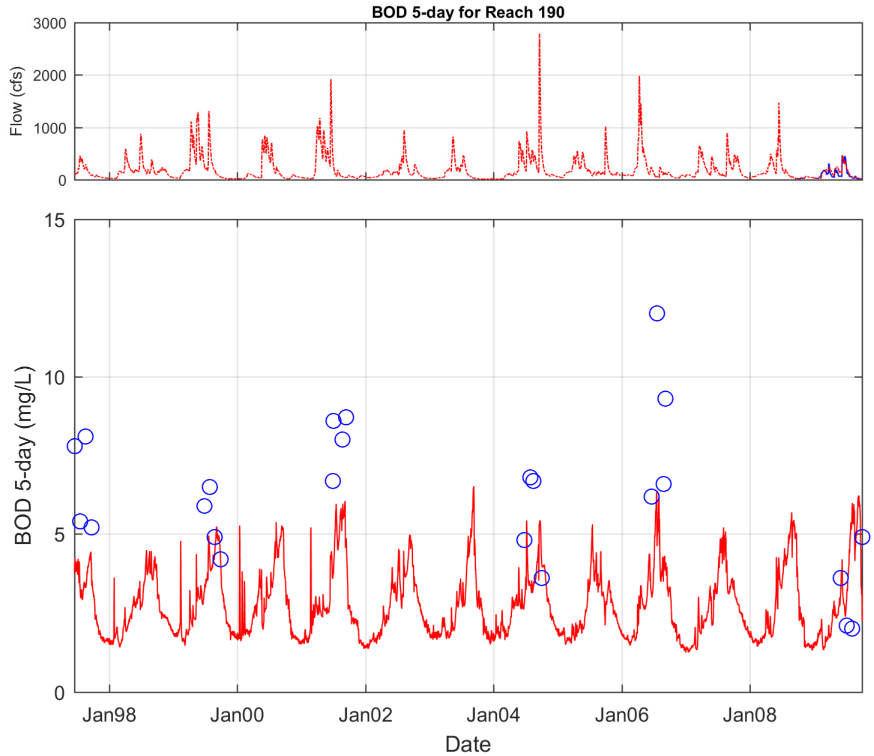


Figure C-25. Biological Oxygen Demand Time Series at Reach 190.

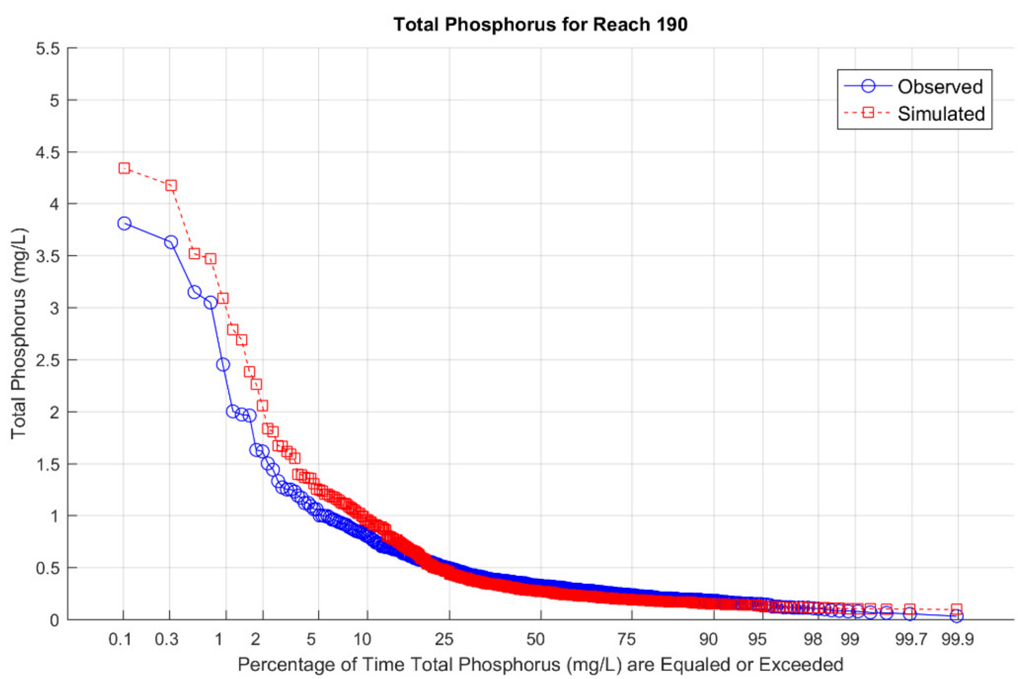


Figure C-26. Total Phosphorus Duration Curve at Reach 190.

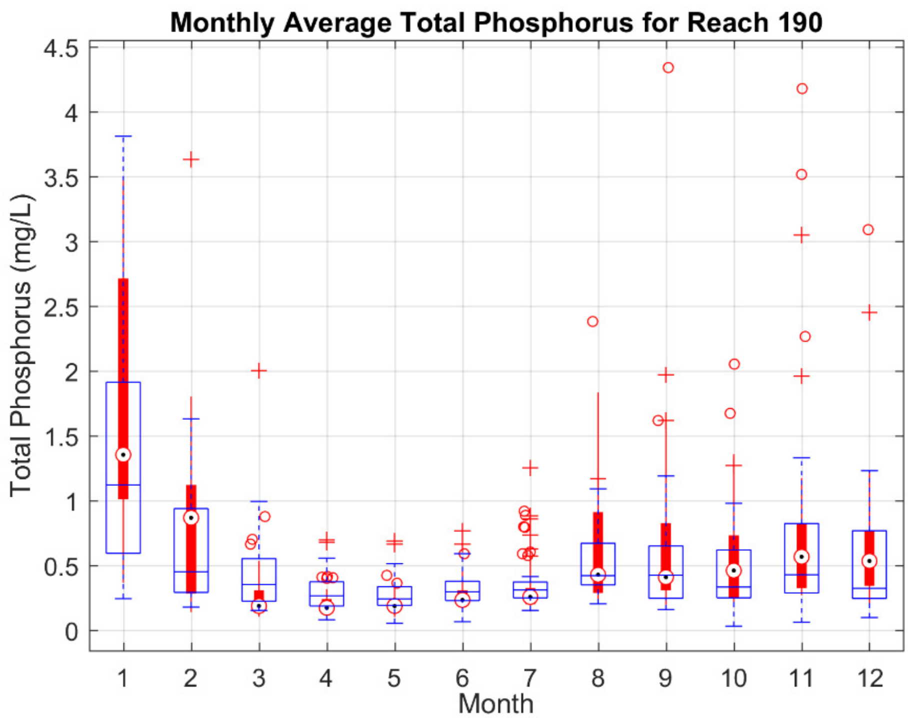


Figure C-27. Total Phosphorus Monthly Averages at Reach 190.

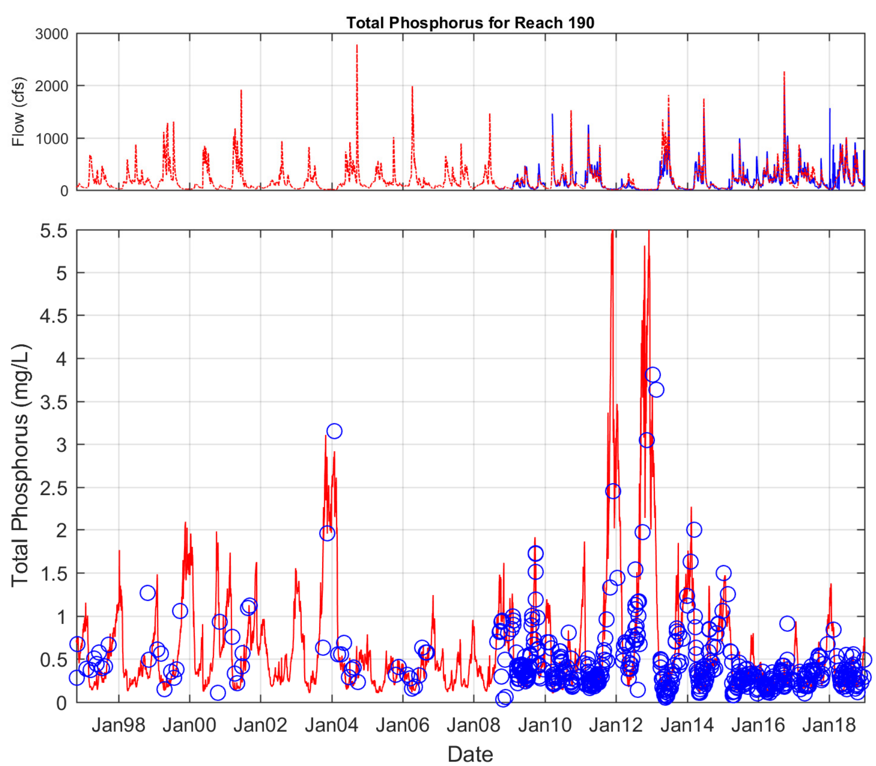


Figure C-28. Total Phosphorus Time Series at Reach 190.

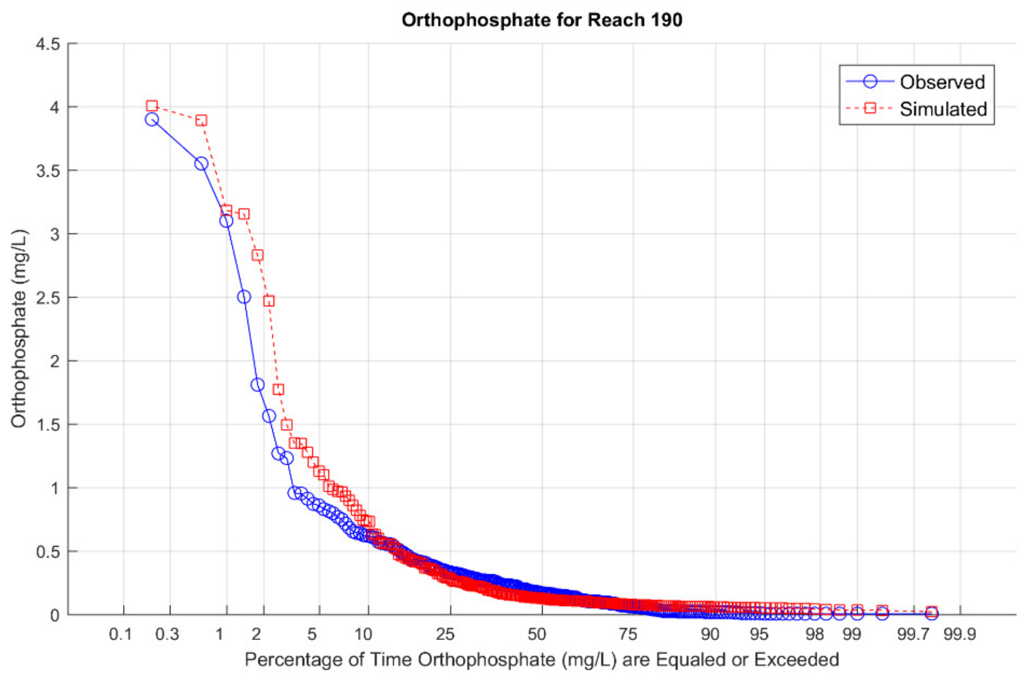


Figure C-29. Orthophosphate Duration Curve at Reach 190.

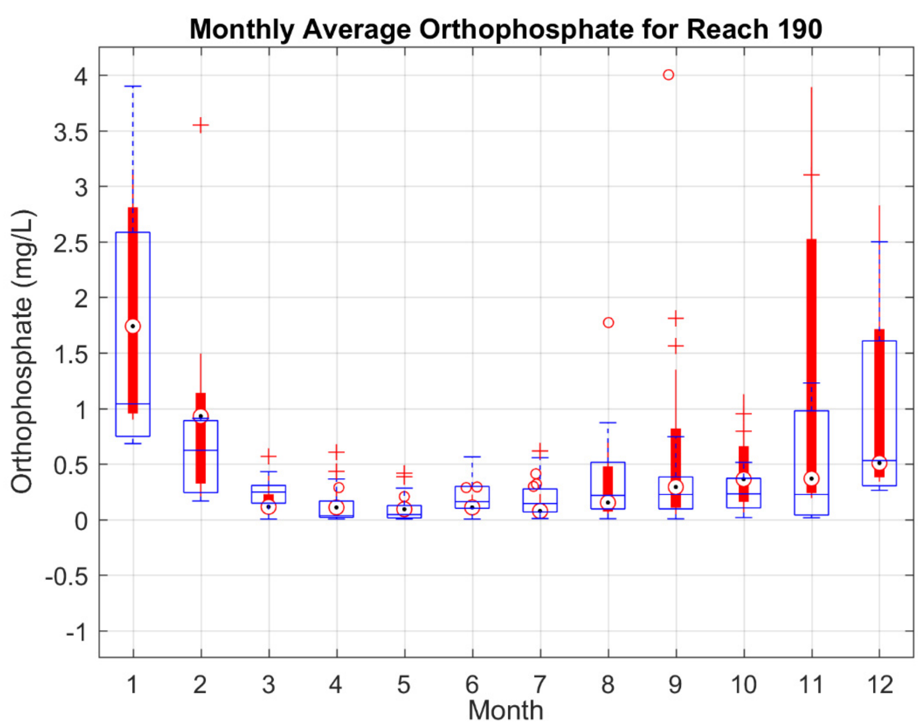


Figure C-30. Orthophosphate Monthly Averages at Reach 190.

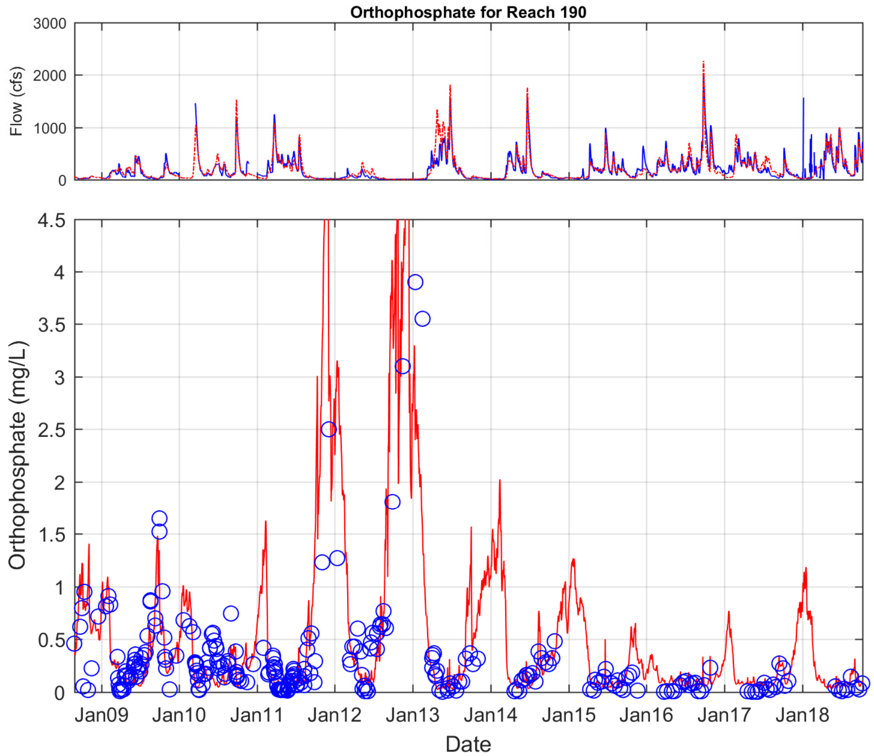


Figure C-31. Orthophosphate Time Series at Reach 190.

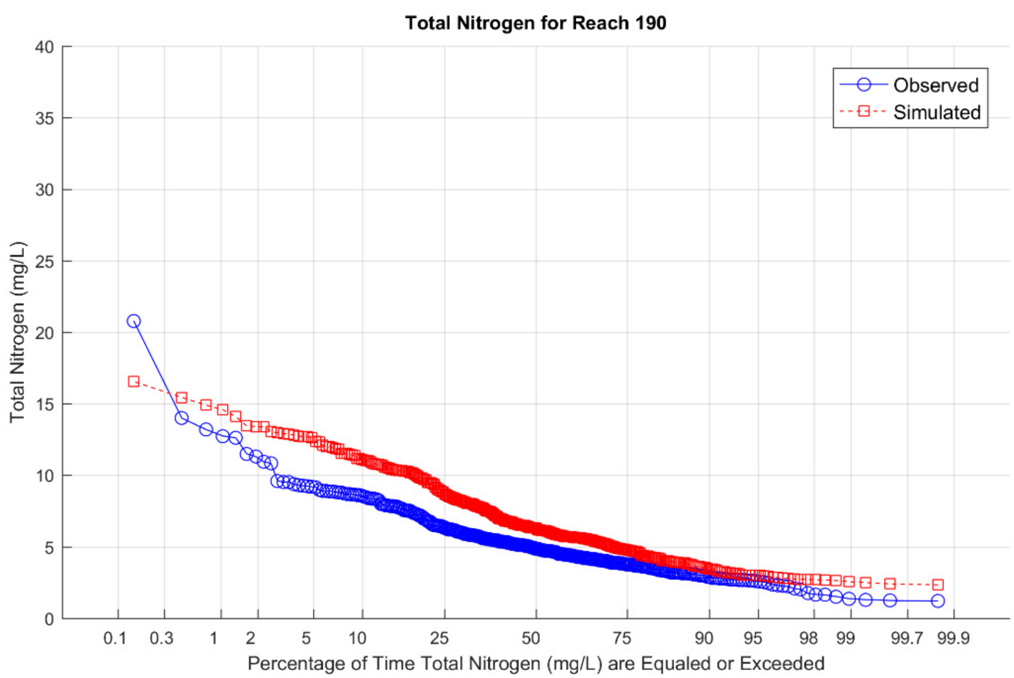


Figure C-32. Total Nitrogen Duration Curve at Reach 190.

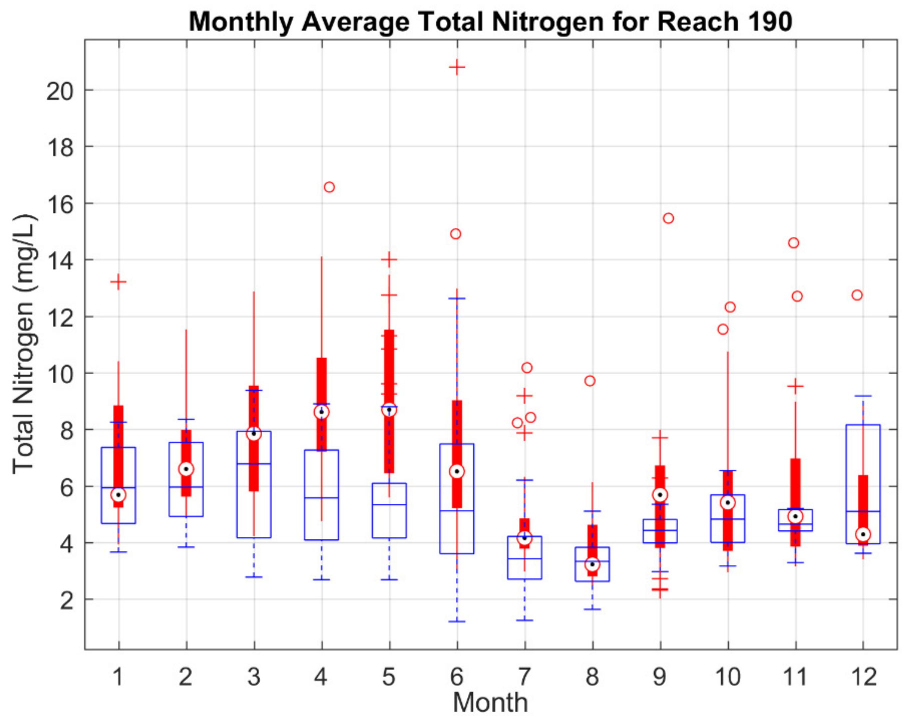


Figure C-33. Total Nitrogen Monthly Averages at Reach 190.

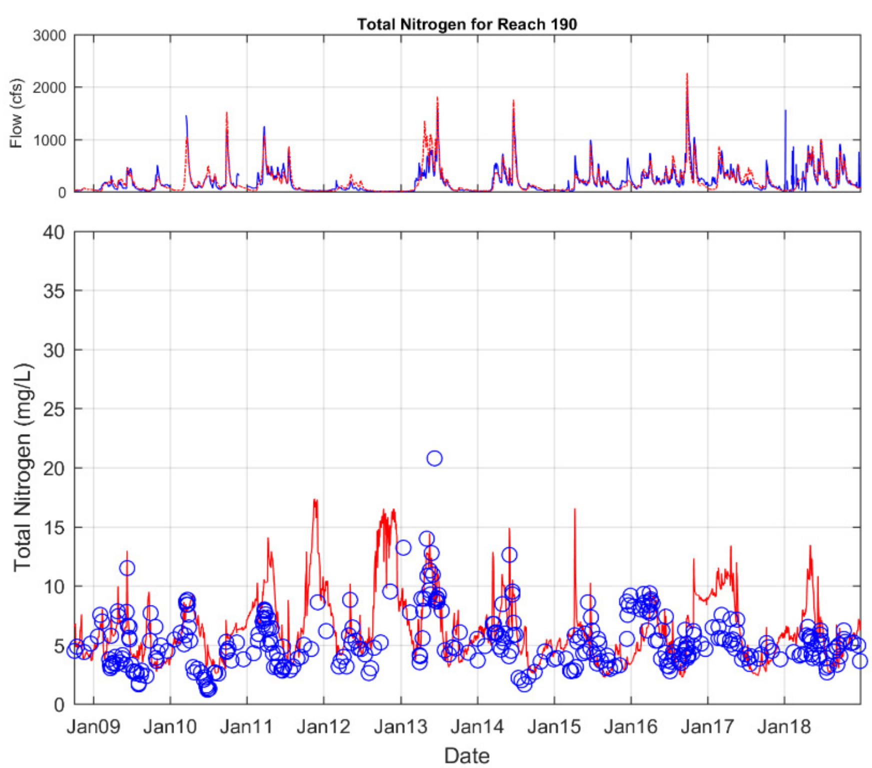


Figure C-34. Total Nitrogen Time Series at Reach 190.

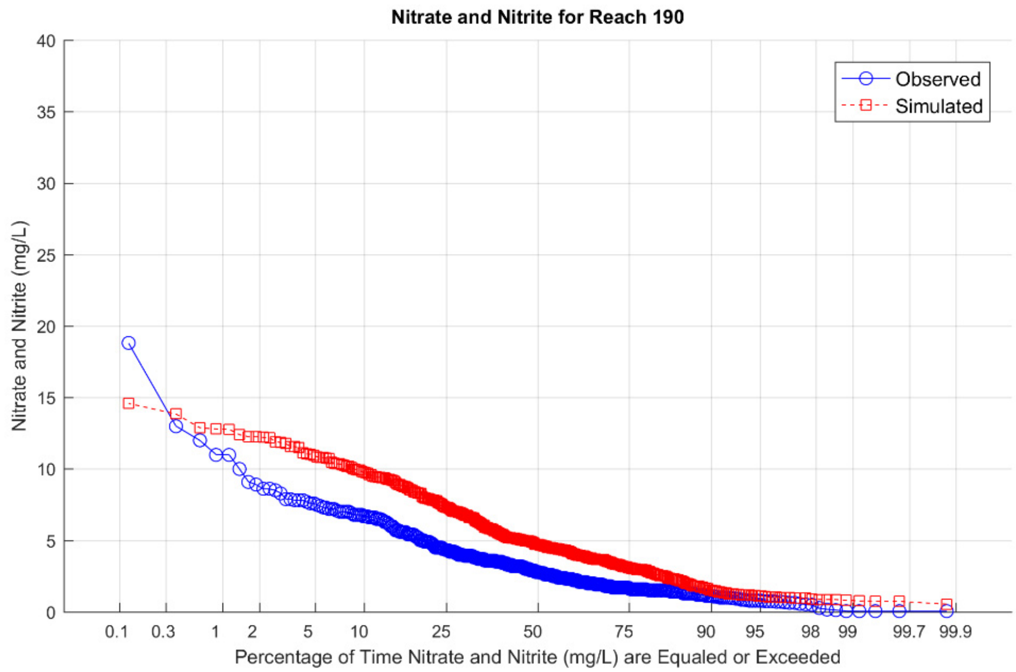


Figure C-35. Nitrate and Nitrite Duration Curve at Reach 190.

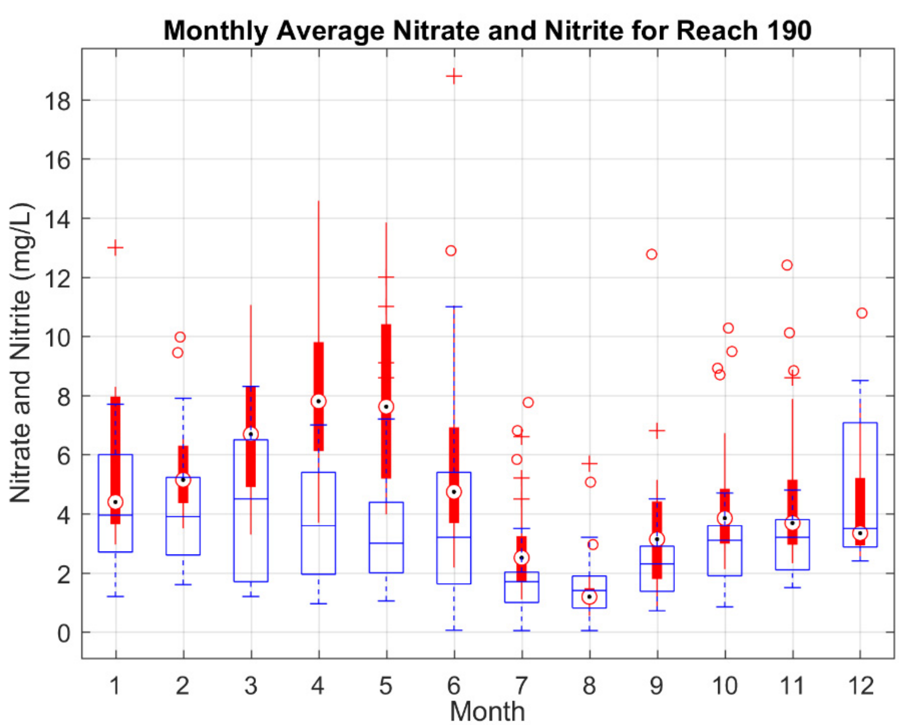


Figure C-36. Nitrate and Nitrite Monthly Averages at Reach 190.

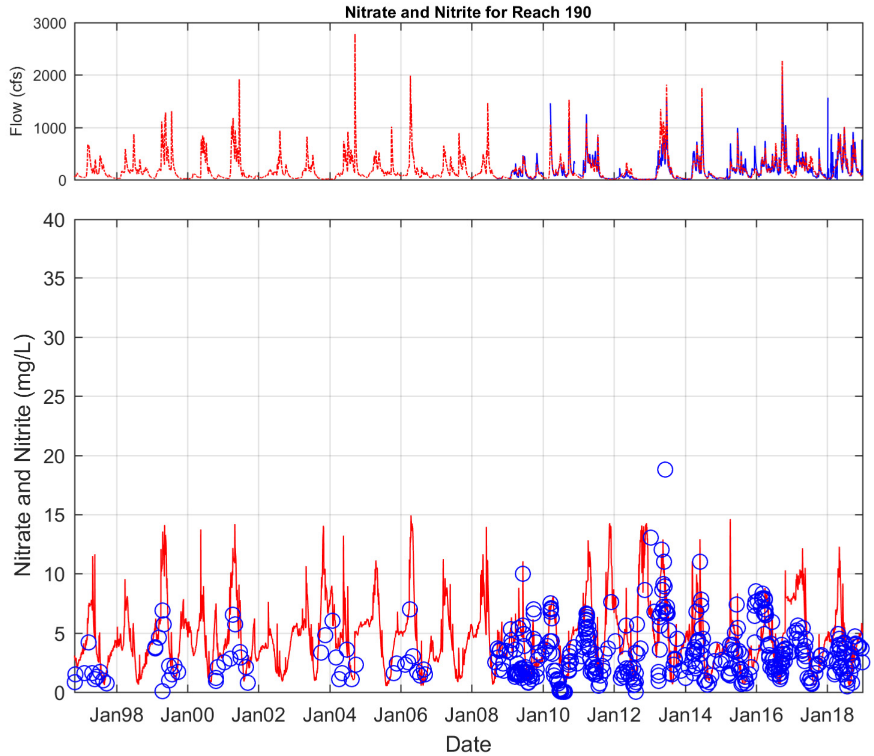


Figure C-37. Nitrate and Nitrite Time Series at Reach 190.

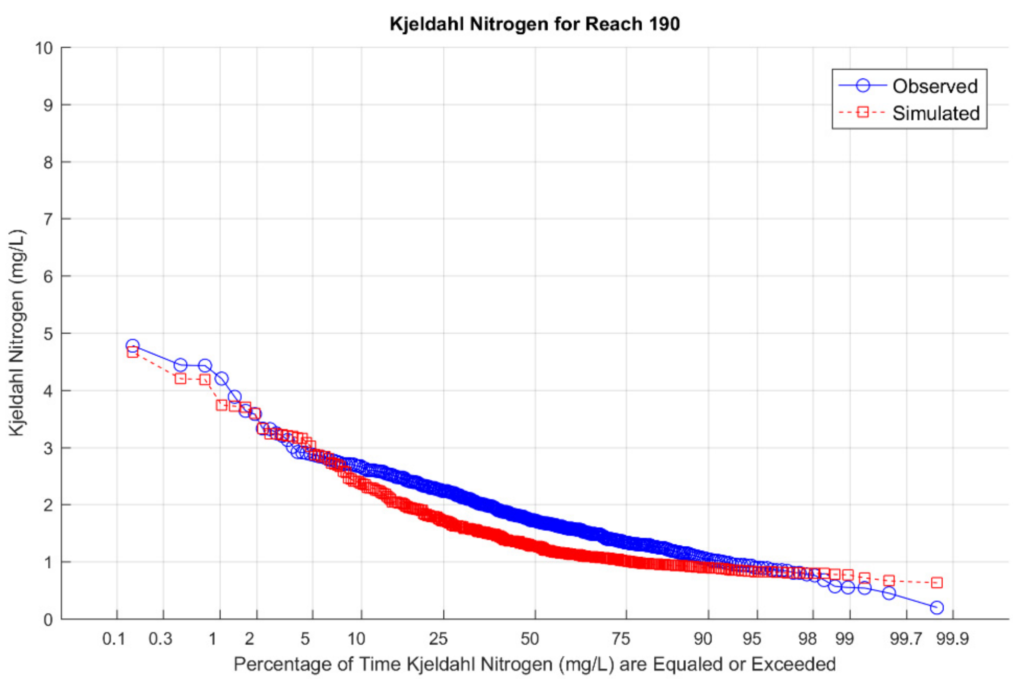


Figure C-38. Kjeldahl Nitrogen Duration Curve at Reach 190.

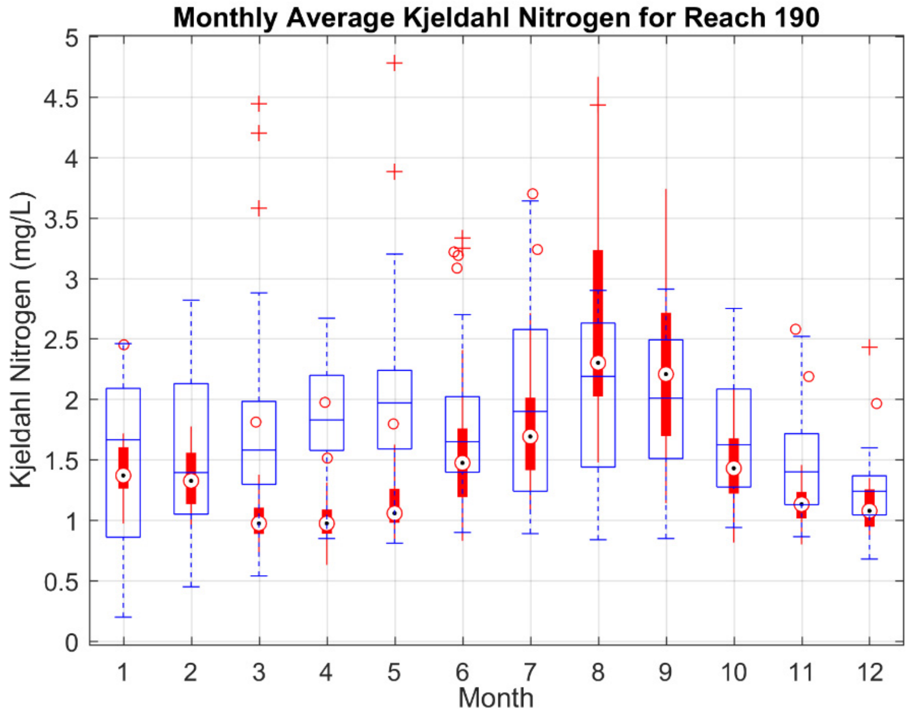


Figure C-39. Kjeldahl Nitrogen Monthly Averages at Reach 190.

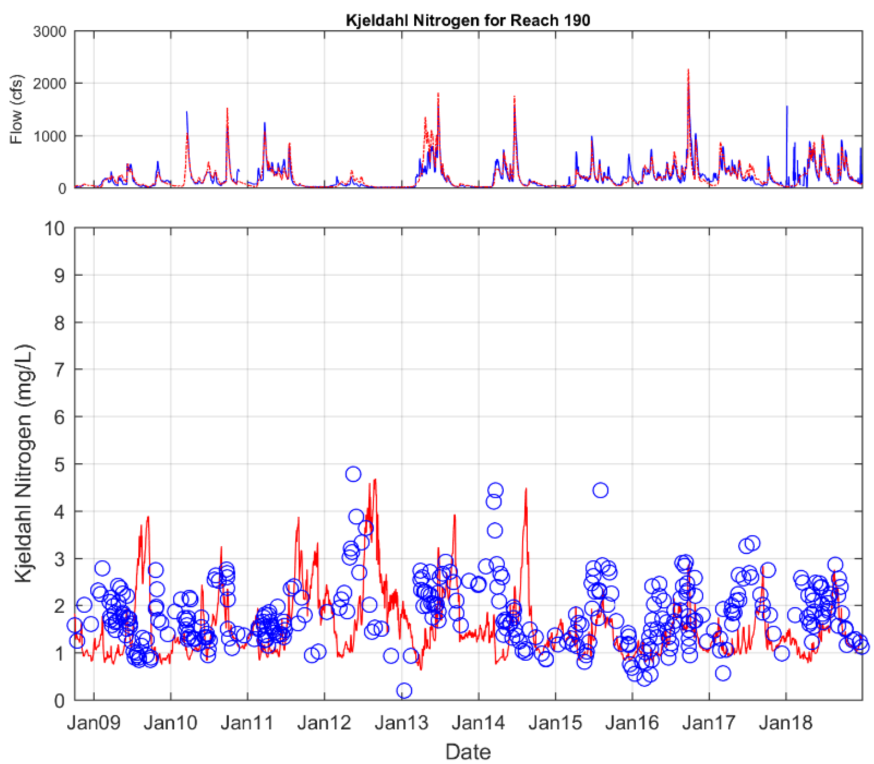


Figure C-40. Kjeldahl Nitrogen Time Series at Reach 190.

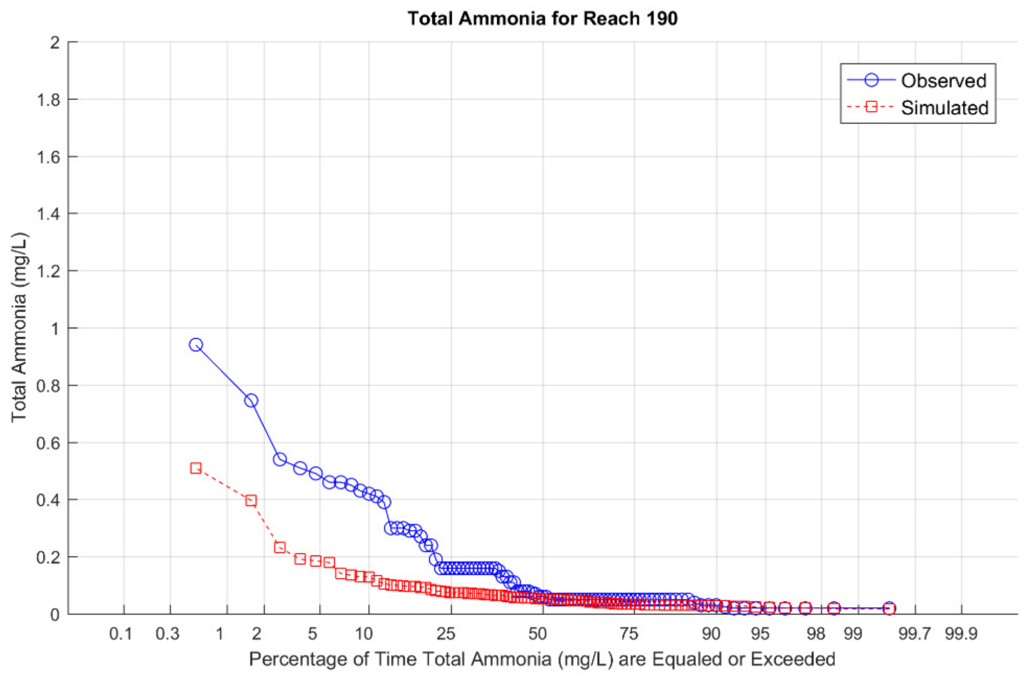


Figure C-41. Total Ammonia Duration Curve at Reach 190.

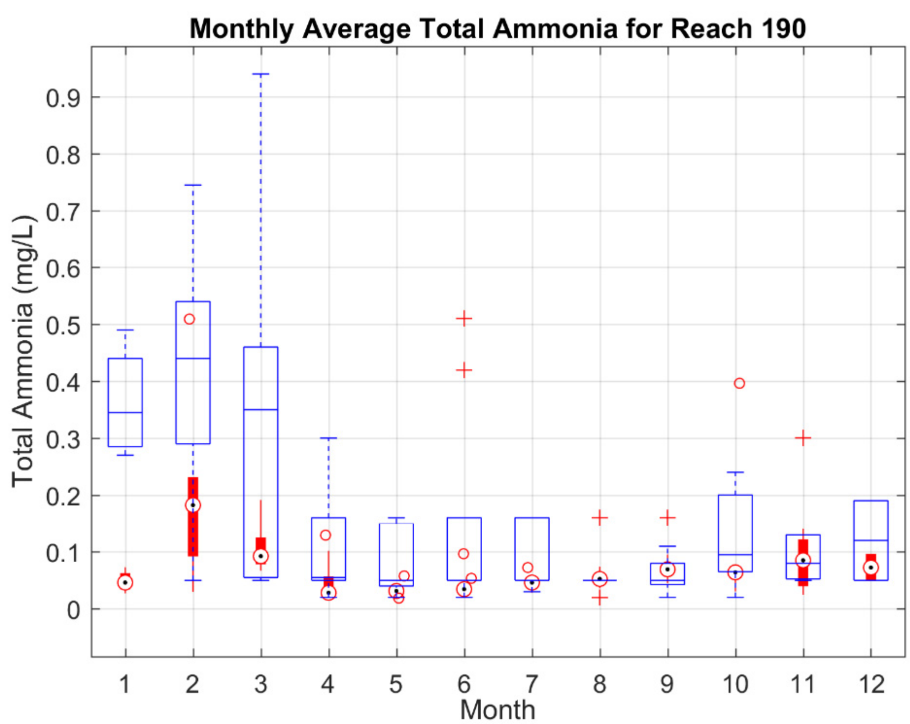


Figure C-42. Total Ammonia Monthly Averages at Reach 190.

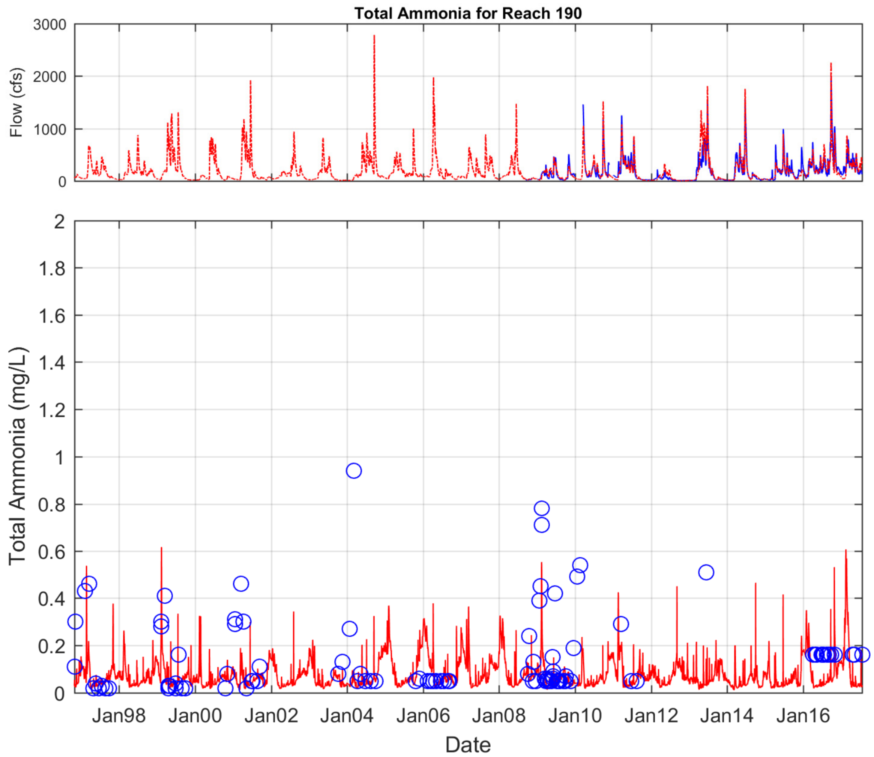


Figure C-43. Total Ammonia Time Series at Reach 190.

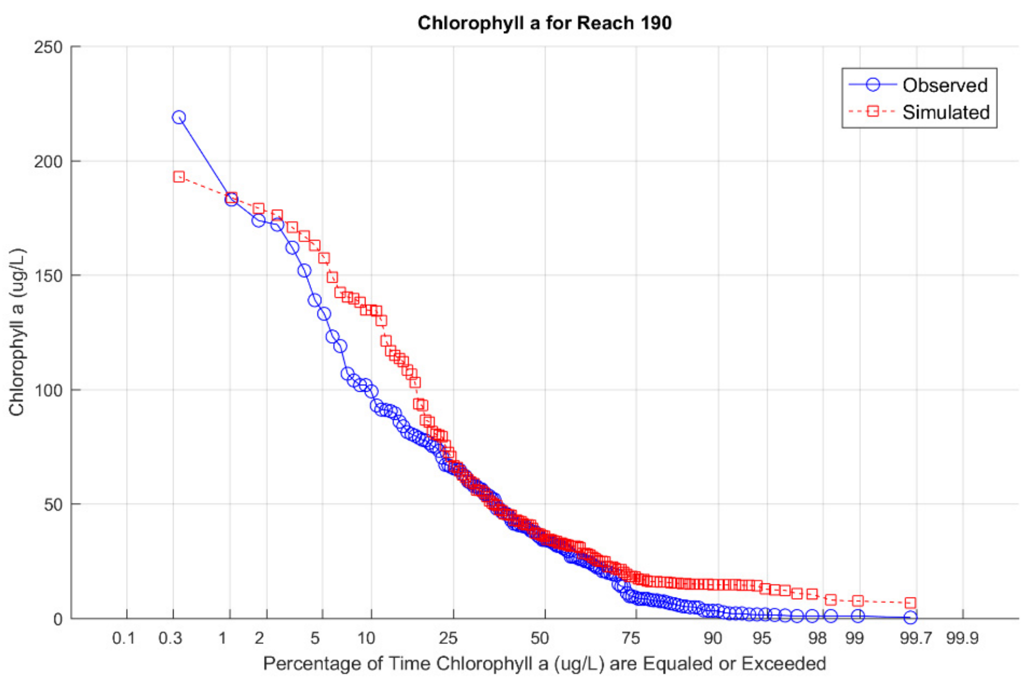


Figure C-44. Chlorophyll *a* Duration Curve at Reach 190.

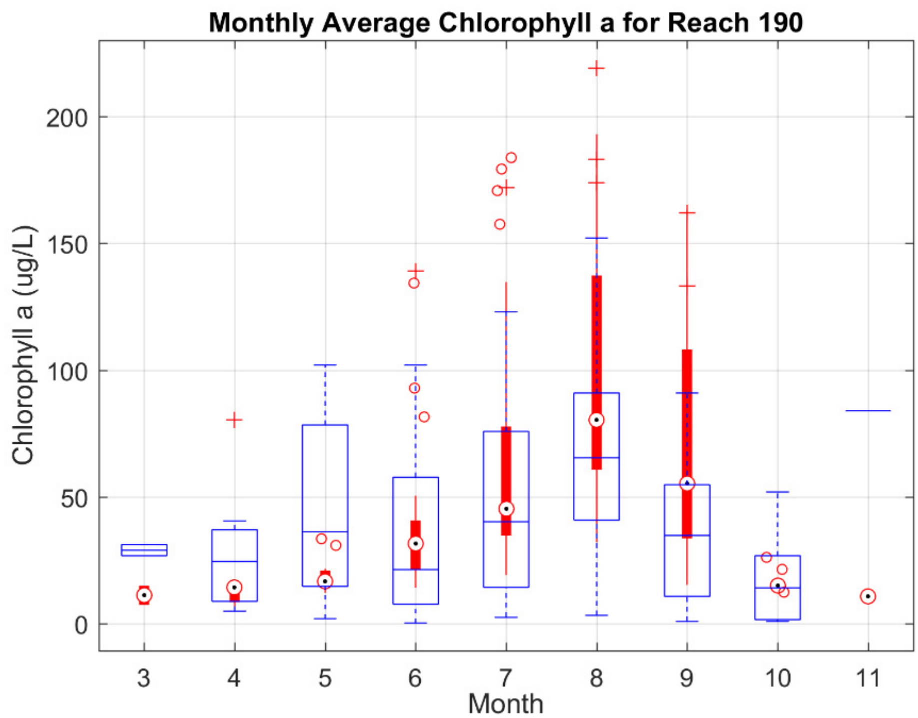


Figure C-45. Chlorophyll *a* Monthly Averages at Reach 190.

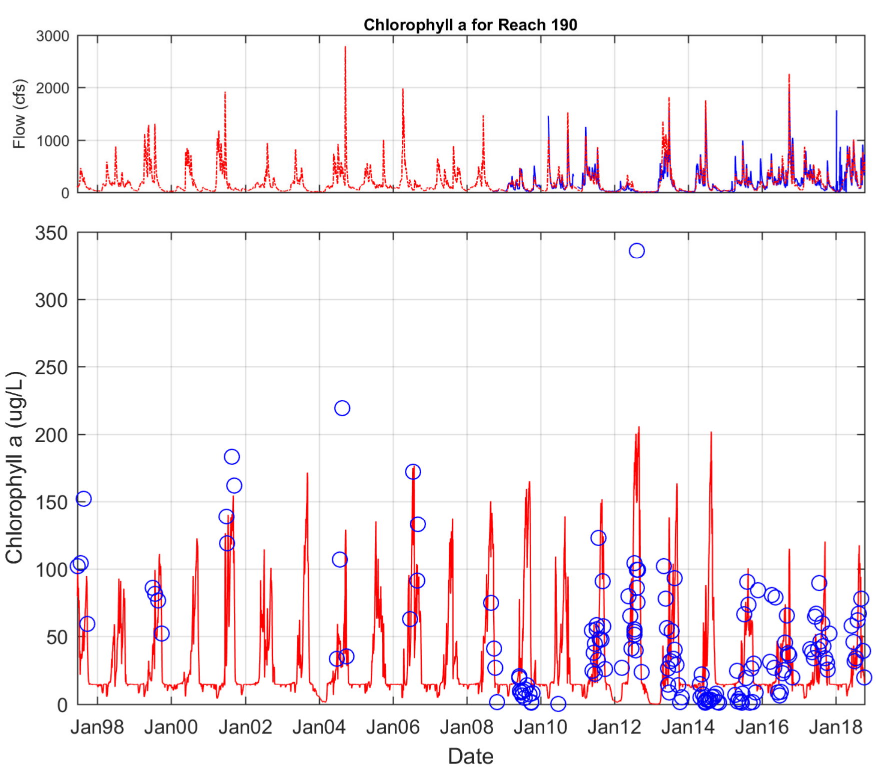


Figure C-46. Chlorophyll *a* Time Series at Reach 190.