

WATER QUALITY MODELING TO SUPPORT SOURCE WATER AND AQUATIC LIFE PROTECTION, OCTORARO CREEK, PENNSYLVANIA AND MARYLAND

FINAL MODELING REPORT

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LIST OF ACRONYMS

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
µg/L	microgram(s) per liter
3DEP	3D Elevation Program
AFO	Animal feeding operations
AGWRC	groundwater recession
ATEM	air temperature
BASETP	baseflow evapotranspiration index
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BENOD	benthic oxygen demand
BMP	best management practice
BOD	biochemical oxygen demand
BOD ₅	5-day biochemical oxygen demand
BRTAM	benthic release of total ammonia
BTU	British thermal unit
CAFO	concentrated animal feed operations
CAST	Chesapeake Assessment Scenario Tool
CASTNET	Clean Air Status and Trends Network
CBOD	carbonaceous biochemical oxygen demand
CBOD ₅	5-day carbonaceous biochemical oxygen demand
CBOD _u	ultimate carbonaceous biochemical oxygen demand
CBP	Chesapeake Bay Program
CEPSC	vegetal interception
cfs	cubic foot (feet) per second
CHLA	chlorophyll <i>a</i>
CLOU	cloud cover
COVIND	snow cover parameter
DEM	Digital Elevation Model
DEWP	dewpoint temperature
DO	dissolved oxygen
ECHO	Enforcement and Compliance History Online
EIA	Effective Impervious Area
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
g/m ² /yr	gram(s) per square meter per year
GIS	Geospatial Information System
HSPF	Hydrologic Simulation Program–FORTRAN

LIST OF ACRONYMS (continued)

HSPEXP+	Enhanced Hydrologic Calibration Expert System
IMPLND	impervious land segment
INFILT	infiltration index
INTFW	interflow parameter
IRC	interflow recession
lb/day	pound(s) per day
kg/ha	kilogram(s) per hectare
km	kilogram(s)
KSER	wash-off from the land
KVARY	variable groundwater recession
LiDAR	light detection and ranging
LUC	land use change
LZETP	lower-zone evapotranspiration parameter
LZSN	lower zone nominal storage
MDE	Maryland Department of the Environment
MS4	Municipal Separate Storm Sewer System
N/A	not applicable
NADP	National Atmospheric Deposition Program
NASS	National Agricultural Statistics Service
NH ₄	ammonia
NHDPlus	National Hydrography Dataset Plus
NID	National Inventory of Dams
NLDAS	North American Land Data Assimilation System
NO ₂	nitrite
NO ₃	nitrate
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NSUR	Manning's N
ORC	organic carbon
ORN	refractory organic nitrogen
ORP	refractory organic phosphorus
OWTS	onsite wastewater treatment system
PADEP	Pennsylvania Department of Environmental Protection
PERLND	Pervious Land Segment
PEVT	potential evapotranspiration
PO ₄	orthophosphate
PRISM	Parameter-Elevation Regressions on Independent Slopes Model

LIST OF ACRONYMS (continued)

PSA	point source alternative
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RCHRES	reach reservoir
REAK	reaeration constant
RESPEC	RESPEC Company, LLC
SAM	Scenario Application Manager
SEDTRN	transport, deposition, and scour of sediment
SLSUR	slope of the overland flow plane
SNOWCF	snow catchment factor
SOLR	solar radiation
Sq Mi	square mile
SRBC	Susquehanna River Basin Commission
SSURGO	Soil Survey Geographic Database
STP	sewer treatment plant
SWRC	Stroud Water Research Center
TAM	total ammonia
TAUCD	critical bed shear stress for deposition
TAUCS	critical bed shear stress for scour
TIA	total impervious area
TIN	triangulated irregular network
TKN	total Kjeldahl nitrogen
TMDL	Total Maximum Daily Load
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TSS	total suspended solids
UCI	user control input
USGS	U.S. Geological Survey
UZSN	upper-zone storage
WASP	Water Quality Analysis Simulation Program
WDM	Watershed Data Management
WIND	wind speed
WIP	Watershed Implementation Plan
WWTP	Wastewater Treatment Plant

1.0 OVERVIEW

The Octoraro Creek Watershed, depicted in Figure 1-1, originates in southeastern Pennsylvania and flows south into Maryland and the Susquehanna River, which in turn flows to the Chesapeake Bay. This report documents the development and results of watershed and water quality modeling completed for the Octoraro Creek Watershed by RESPEC Company, LLC (RESPEC). The purpose of the project is to complete modeling to support restoration planning for the Octoraro Creek Watershed. The models developed through this project can inform the Pennsylvania Department of Environmental Protection (PADEP) and other stakeholder organizations in the development of plans to reduce nitrogen, phosphorus, and sediment in a manner that would protect the aquatic life and drinking water designated uses of the Octoraro Reservoir and all stream segments throughout the Octoraro Creek Watershed.

This report references the Quality Assurance Project Plan (QAPP) that was developed for the modeling effort, a document entitled *Water Quality Modeling to Support Source Water and Aquatic Life Protection, Octoraro Creek, Pennsylvania and Maryland: Quality Assurance Project Plan* [RESPEC and The Cadmus Group LLC, 2021]. The QAPP includes supporting information regarding the project organization, partners, model selection, and the modeling plan along with an overview of the watershed and a summary of data available for modeling. An approved QAPP was a contractual requirement of this project. The QAPP was originally approved on November 23, 2021, and may be revised. The QAPP is publicly available upon request. QAPPs are not permanent government records and may be disposed of based on the Environmental Protection Agency's (EPA's) records retention schedule.

Hydrologic Simulation Program–FORTRAN (HSPF) was selected as the watershed model for the Octoraro Creek Watershed. HSPF has been widely used throughout the United States to simulate watershed hydrology and quality in support of developing plans to attain environmental goals. HSPF is a dynamic model that simulates soil, groundwater, and surface-water processes; storm events; and point and nonpoint sources of pollution and is maintained and supported by EPA and the U.S. Geological Survey (USGS). The Water Quality Analysis Simulation Program (WASP) model was selected as the water quality model for the Octoraro Reservoir. WASP is widely used in the United States for water quality planning and can be linked to HSPF. A summary of HSPF and WASP model set up is provided in Chapters 3.0 and 4.0 of this document. Additional background information on each model can be found on the EPA's HSPF

website (<https://www.epa.gov/ceam/hydrological-simulation-program-fortran-hspf>) and WASP website (<https://www.epa.gov/ceam/water-quality-analysis-simulation-program-wasp>).

The Scenario Application Manager (SAM) decision-support tool will be used with the HSPF model to run watershed management scenarios to support alternative restoration planning for the Octoraro Creek Watershed. SAM is a user-friendly, planning-level tool for project managers, consultants, and stakeholders who work to improve conditions in their local watersheds. SAM allows practitioners with limited modeling expertise to select management practices in various watersheds and determine the impact that those measures would have on downstream water quality. The tool also provides an estimate of the costs required to incentivize adopting the selected BMPs and presents watershed stakeholders with an understanding of which practices provide the greatest value in terms of water quality benefits. A summary of the SAM tool and the customized application for the Octoraro Creek Watershed is provided in Chapter 6.0 of this document. Additional background information on SAM is available online (<https://www.respec.com/sam-file-sharing/>).

2.0 HSPF MODEL SETUP

RESPEC configured an HSPF model to simulate flow and water quality (e.g., nitrogen, phosphorus, and suspended sediments) in streams within the Octoraro Creek Watershed. RESPEC also configured a WASP model of the Octoraro Reservoir that used the HSPF results as WASP model inputs. Background information on the models used for this project is included in the modeling QAPP [RESPEC and The Cadmus Group LLC, 2021].

This project required using an extensive amount of spatial and temporal data. Details about the data used for modeling are provided in this chapter. Additional information on data available for modeling is provided in the report entitled *Water Quality Modeling for the Octoraro Creek Watershed: Data Summary and Model Selection* [Lupo et al., 2021].

2.1 SPATIAL DATA

Spatial data are a critical component of HSPF and WASP model development. These data are necessary to understand watershed characteristics such as subwatershed delineations and the extent and distribution of pollutant sources. The data also helps to understand slopes, soils, and other pertinent hydrology and water quality modeling information. Table 2-1 summarizes the spatial data collected for this project and the sources of these data. Spatial data are displayed in later sections of this document. For example, the subwatershed boundaries and flowlines are mapped in the HSPF Subwatershed Delineation section (Section 2.3), the land cover, MS4s, and point sources are mapped in the HSPF Land Characterization section (Section 2.5), and the Octoraro Reservoir bathymetry and WASP segments are mapped in the WASP Model Setup section (Chapter 4.0).

Table 2-1. Spatial Data Assembled for Watershed and Water Quality Modeling (Page 1 of 2)

Data Type	Data Source and Format	Use
Hydrologic Unit Code Features	USGS Watershed Boundary Dataset, 2021 (data format: shapefiles)	Define Project Area and Drainage
Hydrography Features	Chesapeake Conservancy High-Resolution Hydrography and NHDPlus High-Resolution, 2022 (data format: shapefiles)	Development of Reach Segments
Land Use	Chesapeake Conservancy High-Resolution Land Cover and Land Use (V1, 2018) (data format: rasters)	Development of PERLNDs and IMPLNDs and Mapping
Crop Type	USDA National Agricultural Statistics Service Cropland Data Layer, 2020 (data format: raster)	Development of PERLNDs and Mapping
Animal Units	Chesapeake Bay Program Partnership CAST, 2022 (data format: shapefiles and tables)	Development of PERLNDs and Mapping
Soils (Including Soil Characteristics)	Natural Resources Conservation Service SSURGO, 2019 (data format: raster)	Development of PERLNDs and Model Parameters
Municipal Separate Storm Sewer System	Chesapeake Bay Program Partnership CAST, 2019 (data format: shapefiles)	Development of Schematic Mass Links
Topography/Elevation	Chesapeake Conservancy High-Resolution DEM and USGS 3DEP, 2022 (data format: raster)	Development of Drainage Areas and Slope Calculations
Octoraro Reservoir Bathymetry	Other Sources, 2017 (data format: PDF map converted to raster)	Development of Depth-Volume Information
Sewered Areas/Water Supply Areas	PADEP, MDE, 2021 (data format: shapefiles)	Development of Septic Contributions
Population Distribution	U.S. Census Bureau, 2010 (data format: shapefiles)	Development of Septic Contributions
Water Quality and Biological Monitoring Stations	PADEP, MDE, EPA, SRBC, USGS, Other, CBP, 2022 (data format: latitude/longitude coordinates converted to shapefile)	Determination of Calibration Locations
Discharge Station Features	USGS and Other Sources, 2022 (data format: latitude/longitude coordinates converted to shapefile)	Determination of Calibration Locations
Permitted Point Source Discharge Features	PADEP, MDE, and EPA, 2022 (data format: latitude/longitude coordinates converted to shapefile)	Point Source Location Representation

Table 2-1. Spatial Data Assembled for Watershed and Water Quality Modeling (Page 2 of 2)

Data Type	Data Source and Format	Use
Dam Feature	PADEP, MDE, and NID, 2021 (data format: latitude/longitude coordinates converted to shapefile)	Dam Location Representation

3DEP = 3D Elevation Program

CAST = Chesapeake Assessment Scenario Tool [Chesapeake Bay Program, 2020]

CBP = Chesapeake Bay Program

DEM = Digital Elevation Model

EPA = U.S. Environmental Protection Agency

IMPLND = Impervious Land Segment

MDE = Maryland Department of the Environment

NHDPlus = National Hydrography Dataset Plus

NID = National Inventory of Dams

PADEP = Pennsylvania Department of Environmental Protection

PERLND = Pervious Land Segment

SRBC = Susquehanna River Basin Commission

SSURGO = Soil Survey Geographic Database

USGS = U.S. Geological Survey

2.2 TIME-SERIES DATA

Developing the HSPF and WASP model applications required a large amount of temporal (or time-series) data. Table 2-2 lists the time-series data collected for model development (this does not include data compiled for model calibration and validation; calibration and validation data are discussed in Section 3.2). The models run from 2005 through 2021, and the calibration period is 2006 through 2021 to allow the initial estimated conditions to adjust to input data for one year. Note that the period of record for point source effluent data began in 2007. Point source discharges during 2005 and 2006 were therefore estimated for each facility by averaging the available 2007 through 2021 data for the facility (see Section 2.2.3 for further discussion of the methods used to estimate missing point source effluent data).

Meteorological data (e.g., precipitation and evapotranspiration) are required to run the models. Other inputs (e.g., point sources, atmospheric deposition, and diversions) define the watershed's inflow, outflow, and water quality characteristics.

Table 2-2. Time-Series Data Assembled for Watershed and Water Quality Modeling

Data Type	Source	Time Period	Use
Rainfall (inches)	NLDAS/ PRISM	2005–2021	Meteorological time-series input
Temperature (°C)	NLDAS	2005–2021	Meteorological time-series input
Potential Evapotranspiration (inches)	Calculated ^(a)	2005–2021	Meteorological time-series input
Wind Speed (miles per hour)	NLDAS	2005–2021	Meteorological time-series input
Dew Point (°C)	Calculated	2005–2021	Meteorological time-series input
Humidity (percent or grams per cubic meter)	NLDAS	2005–2021	Meteorological time-series input
Cloud Cover (percent or grams per cubic meter)	Calculated	2005–2021	Meteorological time-series input
Solar Radiation (watts per square meter)	NLDAS	2005–2021	Meteorological time-series input
Dry Atmospheric Deposition	CASTNET	2005–2021	Atmospheric deposition time-series input
Wet Atmospheric Deposition	NADP	2005–2021	Atmospheric deposition time-series input
Permitted Point Source Effluent Flow (cfs)	PADEP, MDE, and EPA	2007–2021	Point source time-series input
Permitted Point Source Effluent Concentrations (mg/L, µg/L)	PADEP, MDE, and EPA	2007–2021	Point source time-series input
Discharge from Octoraro Reservoir (cfs)	Other	2005–2021 (Missing 2006 and 2020)	Dam outflow time-series representation

°C = degrees Celsius

µg/L = micrograms per liter

cfs = cubic feet per second

mg/L = milligrams per liter

NLDAS = North American Land Data Assimilation System

PRISM = Parameter-Elevation Regressions on Independent Slopes Model.

(a) PEVT is available from NLDAS but there are known issues described in Section 2.2.2

2.2.1 PRECIPITATION

HSPF requires complete (i.e., no missing records) precipitation time-series data at an hourly timestep and with adequate spatial coverage and density across the model domain. Precipitation is the critical forcing function for all watershed models because precipitation drives the hydrologic cycle and provides the foundation for transport mechanisms that move pollutants from the land to the waterbody. WASP does not require precipitation or evaporation as direct inputs; however, these processes can be included if they significantly impact pollutant transport in the modeled waterbody. Meteorological inputs in WASP include other characteristics such as solar radiation, cloud cover, temperature, dewpoint, and wind speed.

This project's primary sources of long-term precipitation records and other meteorological inputs included gridded data from the North American Land Data Assimilation System (NLDAS) and Parameter-Elevation Regressions on Independent Slopes Model (PRISM). These data products are complete and available online (<https://ldas.gsfc.nasa.gov/nldas/nldas-get-data> and <https://prism.oregonstate.edu>) from 1979 through the current year (within the last few weeks of the download date). Because the data are gridded, they allow for easy extraction and averaging using scripted processes while providing efficient and consistent time-series extension.

The NLDAS is a 12-kilometer (km) resolution dataset that provides hourly meteorological data. PRISM is a 4-km resolution dataset that provides daily precipitation totals computed by combining a dense network of station data with radar measurement estimates that are interpolated based on a climate-elevation regression. Daily PRISM data were used for modeling because these data provide a finer spatial resolution and generally have a better fit to point-precipitation measurements. The daily values were disaggregated to an hourly timestep using the NLDAS data.

2.2.2 EVAPOTRANSPIRATION AND OTHER METEOROLOGICAL DATA

Evaporation data are needed to drive the water-balance calculations in HSPF. Other meteorological time-series data were also needed for HSPF and WASP because of the temperate climates where snow accumulation and melt are a significant component of the hydrologic cycle and water balance. These time-series data, such as air temperature (ATEM), solar radiation (SOLR), dewpoint temperature (DEWP), wind speed (WIND), and cloud cover (CLOU), were used to simulate the soil and water temperatures. Water temperature was subsequently used to adjust rate coefficients in most water quality processes. Other meteorological time-series data were also used in selected calculations (e.g., SOLR affecting algal growth).

The NLDAS dataset (<https://ldas.gsfc.nasa.gov/nldas/>) provides hourly ATEM, SOLR, and WIND parameters that were directly applied for modeling with a conversion to the units needed for HSPF and WASP. Hourly potential evapotranspiration (PEVT) estimates are included in the NLDAS dataset (<https://ldas.gsfc.nasa.gov/nldas/>). NLDAS PEVT were generated using a modified Penman energy-balance method; however, the NLDAS estimates of PEVT are only included for legacy compatibility with the input requirements of the Sacramento Soil Moisture Accounting Model. The NLDAS PEVT estimates do not incorporate subsequent corrections to the NLDAS estimates of energy forcing and have been found to overestimate evapotranspiration (ET) in other modeling efforts. Therefore, PEVT required additional computations for the model. The remaining meteorological constituents (CLOU and DEWP) were not directly available from the NLDAS dataset and required additional computations for the model.

Hourly PEVT was represented by a computed Penman pan evaporation based on the Penman [1948] formula and the Kohler et al. [1955] method. The necessary variables to compute Penman pan evaporation are daily SOLR, DEWP, ATEM, and wind travel. CLOU was estimated using SOLR data provided from the NLDAS database by applying a parabolic equation [Thompson, 1976]. Two options for DEWP were computed from a series of calculations that stemmed from the NLDAS-specific humidity. The first option used the specific humidity and ATEM to calculate the relative humidity [World Meteorological Organization, 2014]. Relative humidity was then applied with ATEM to the August-Roche-Magnus approximation of the Clausius-Clapeyron equation [Stull, 2017] to calculate DEWP. The second option calculated a mixing ratio using specific humidity, which was used with atmospheric pressure to estimate vapor pressure. DEWP was then calculated using the Clausius-Clapeyron equation [Stull, 2017].

2.2.3 POINT SOURCES

2.2.3.1 PERMITS

Table 2-3 summarizes National Pollutant Discharge Elimination System (NPDES) permitted point sources with discharge data available during the modeling period in the Octoraro Creek Watershed. More information about point source locations is included in Section 2.2.3. Sites with effluent flow and characterization data were represented in the model with time-series datasets. Time-series data were generated for input to the HSPF and WASP models for the point sources. Time-series inputs were only generated for sites that discharge wastewater from outfalls or other discrete points with data available. Discharge from other regulated point sources, such as stormwater discharge from Municipal Separate Storm Sewer Systems (MS4s) or agricultural runoff from concentrated animal feed operations (CAFOs), were simulated in HSPF using rainfall-runoff processes.

Table 2-3. Point Source Effluent Data Assembled for Watershed and Water Quality Modeling

Permit	Facility Name	HSPF Model Reach	Facility Type	Dates of Operation	Monthly	Daily
PA0123480	Allen Myers Materials Cedar Hill Quarry	410	Controlled	December 2017–Present	X	
PA0024651	Atglen Borough STP	37	Mechanical	Full Modeling Period	X	X
PA0025399	Christina Boro STP	10	Mechanical	Full Modeling Period	X	X
PA0036374	Eaglepointe Development STP	33	Mechanical	January 2013–Present	X	X
PA0083933	Georgetown Area STP	201	Mechanical	Full Modeling Period	X	X
PA0594784	H&K Group Rock Springs Quarry	430	Controlled	December 2016–Present	X	
MD0053171	Maple Hill Mobile Home Park WWTP	493	Controlled	Full Modeling Period	X	
PA0042889	Octoraro Area School District STP	91	Controlled	Full Modeling Period	X	
MD0020265	Rising Sun WWTP	433	Mechanical	Full Modeling Period	X	X
PA0081116	Solanco High School	231	Controlled	Full Modeling Period	X	X

STP = Sewer Treatment Plant

WWTP = Wastewater Treatment Plant.

2.2.3.1 DATA SOURCES

Point source data for the Octoraro Creek Watershed were acquired from the EPA Enforcement and Compliance History Online (ECHO) website (<https://echo.epa.gov/>). The EPA also collected and provided daily and monthly point source datasets. Daily datasets were often provided in scanned pdf format and had to be manually entered into spreadsheets. Entered data were double-checked to ensure accuracy. Monthly datasets provided were thoroughly compared to the data downloaded from the ECHO website and were determined to be identical. The data included the location of point source outfalls and wastewater discharge monitoring records. Stormwater discharge data were unavailable from ECHO and not represented with time-series inputs.

The EPA also collected and provided NPDES permit documents and fact sheets for each facility. These permits helped identify sites as either mechanical or controlled. Mechanical point sources have a continuous flow and are generally industrial facilities or larger municipal wastewater treatment facilities. Controlled ponds are lagoons and are usually small facilities that discharge intermittently for variable lengths of time. The identification of mechanical versus controlled facilities was performed by reviewing the permits and evaluating the dataset. If a discharge site was mechanical, it was assumed to have continuous discharge unless otherwise specified. In other words, the data from all dates between the earliest and latest dates were filled in during processing. If a discharge site was controlled, it was assumed to have discontinuous discharge, and data gaps were assumed to have no flow. Permits and fact sheets were also used to determine the facility dates of operation identified in Table 2-3.

2.2.3.2 CONSTITUENTS

Monitored constituents for the discharging facilities generally included 5-day carbonaceous biochemical oxygen demand (CBOD₅), ammonia as nitrogen (NH₄-N), total Kjeldahl nitrogen (TKN), nitrate as nitrogen (NO₃-N), nitrite as nitrogen (NO₂-N), total phosphorus (TP), total suspended solids (TSS), and temperature. Table 2-4 provides constituents required for representing point sources in the HSPF and WASP models. Table 2-5 summarizes the percentage of missing wastewater discharge samples for relevant parameters per facility from 2007 to 2021.

Table 2-4. List of Inputs Calculated for Each Non-Stormwater Point Source

Pollutant Name	Pollutant Description	Daily Model Input Units
Flow	Effluent Flow	Acre-Foot
Heat	Heat Energy of the Effluent	BTU
TSS	Total Suspended Solids	Tons
DO	Dissolved Oxygen	Pounds
NO ₃ -N	Nitrate as Nitrogen	Pounds
NO ₂ -N	Nitrite as Nitrogen	Pounds
NH ₄ -N	Total Ammonia as Nitrogen	Pounds
ORN	Refractory Organic Nitrogen	Pounds
PO ₄ -P	Orthophosphorus as Phosphorus	Pounds
ORP	Refractory Organic Phosphorus	Pounds
CBOD _u	Ultimate Carbonaceous Organic Demand	Pounds
ORC	Organic Carbon	Pounds

BTU = British thermal unit.

Table 2-5. Percentage of Missing Samples by Month for Relevant Constituents per Point Source Facility in ECHO From 2007 to 2021

NPDES Permit	Facility Name	Flow	BOD ₅	NO ₂ +NO ₃	NH ₄	TKN	ORN	TN	PO ₄	TP	TSS	Temp
PA0123480	Allen Myers Materials Cedar Hill Quarry	81.4	—	—	—	—	—	—	—	—	81.4	—
PA0024651	Atglen Borough STP	56.4	56.4	69.6	56.4	—	69.6	56.4	56.4	—	69.6	—
PA0025399	Christina Boro STP	35.3	35.3	35.3	35.3	—	35.3	35.3	35.3	—	35.3	—
PA0036374	Eaglepointe Development STP	52.5	52.5	52.9	52.9	—	52.9	52.5	52.5	—	52.9	—
PA0083933	Georgetown Area STP	65.2	65.2	65.2	65.2	—	65.2	65.2	65.2	—	65.2	—
PA0594784	H&K Group Rock Springs Quarry	90.2	—	—	—	—	—	—	—	—	90.2	—
MD0053171	Maple Hill Mobile Home Park WWTP	13.2	12.7	—	16.2	—	—	—	12.7	—	—	36.8
PA0042899	Octorara Area School District STP	70.6	70.6	97.5	70.6	—	97.5	97.5	70.6	—	70.6	—
MD0020265	Rising Sun WWTP	62.3	62.3	62.3	62.3	62.3	62.7	62.3	62.3	62.3	62.3	62.3
PA0081116	Solanco High School	53.9	53.9	99.0	53.9	—	99.0	99.0	53.9	—	99.0	—

2.2.3.3 DATA PROCESSING

After daily and monthly data were input in the combined Excel format, the data were processed to interpolate, fill with monthly data, fill with monthly averages, and fill with total averages, in that order. First, a list of dates to be filled via interpolation for each parameter was generated by identifying the blocks of dates with missing data. If a block had 30 or fewer days, the dates within that block were added to the list of dates to be filled. After the fill dates were determined, a spline interpolant was created using the pchip method of the scipy library. The dates in the fill dates list were then filled with the values of the interpolant corresponding to those dates. The next step was to use the monthly ECHO data to fill in dates missing data after daily data interpolation. Missing data were identified for each parameter by month and year, and ECHO data were used to fill data for those dates. Next, missing values were filled with monthly averages. If data were missing for any parameter in any month after interpolation and filling with monthly data, those missing data would be filled with the average of that parameter's data in all other instances of that month. Finally, if there was a certain month in which a parameter had no data, all leftover missing values were filled in using the total average of that parameter's data. After this final step, every date that was designated at the start to be filled was filled.

After the effluent flow and pollutant concentration time-series data were filled using the previously discussed steps, pollutant loads were calculated as the product of flow, concentration, and a conversion factor. Loads were then imported into an HSPF Watershed Data Management (WDM) file. Point source loads were applied to the corresponding stream in the external sources block of the user control input (UCI) file.

Monitored concentrations of all constituents (except temperature) were converted from mg/L to loads in pounds per day (lb/day) (i.e., concentration × flow × conversion factor; conversion factor = 8.34) for input to the HSPF model. Monitored concentrations of CBOD₅ were first converted to CBOD_u using Equation 2-1 [Chapra, 1997]. Temperature was converted from degrees Fahrenheit (°F) to a heat load in BTU per day (i.e., temperature × flow × conversion factor; conversion factor = 8,339,145).

$$L_o = \frac{y_5}{1 - e^{-k_1(5)}} \quad (2-1)$$

where:

$$L_o = \text{CBOD}_u$$

$$y_5 = \text{CBOD}_5$$

$$k_1 = 0.10 \text{ (minimum value after primary treatment).}$$

Some facilities did not sample or report all of the parameters listed. In these cases, a dataset was derived using either a surrogate facility estimated with nutrient speciation factors or by setting a constant concentration, depending on the missing constituent. The following assumptions were used if there were no data for a certain parameter:

- / If DO or BOD₅ data were missing, concentrations of 8 and 1 mg/L were assumed, respectively.
- / If NO₂-N /NO₃-N data were missing, a combined concentration of 2 mg/L was assumed for non-wastewater facilities, and a combined concentration of 7 mg/L was assumed for wastewater facilities. The combined NO₂-N/NO₃-N concentration was assumed to be 12 percent NO₂-N and 88 percent NO₃-N.
- / If NH₄-N data were missing, a concentration of 2 mg/L was assumed.
- / Facilities without BOD₅ or total phosphorus (TP) data were assumed to have a TP concentration of 0.1 mg/L. Facilities with BOD₅ and no TP were assumed to have a TP concentration of 0.8 mg/L to prevent PO₄-P calculations from going negative, and 60 to 75 percent of the TP was assumed as PO₄-P. TP associated with BOD in HSPF is 0.7 percent, and the remainder of TP that is not PO₄-P or associated with BOD is assumed to be organic. Similarly, total nitrogen (TN) associated with BOD in HSPF is 4.3 percent, and TN, not NO₂-N, NO₃-N, or NH₄-N, is assumed to be organic nitrogen.
- / TSS was split into 40 percent silt and 60 percent clay at each facility.
- / Organic carbon was assumed to be 13 percent of the BOD concentration.
- / The temperature time-series from the Rising Sun WWTP was used as a surrogate, and monthly averages were applied to locations without temperature effluent data.

The above assumptions for estimating missing parameters (provided in the preceding paragraphs) have been applied to more than 50 HSPF model applications spanning several states. Modelers, watershed managers, and point source permit programs have widely accepted these parameters.

2.2.4 ATMOSPHERIC DEPOSITION

Atmospheric deposition of nutrients is commonly included in watershed modeling efforts focusing on eutrophication issues. Nitrate-Nitrite and ammonium atmospheric deposition were explicitly represented as a daily time-series in the Octoraro Creek Watershed HSPF and WASP models. Wet atmospheric deposition data were downloaded from the National Atmospheric Deposition Program (NADP, <http://nadp.slh.wisc.edu/>), and dry atmospheric deposition data were downloaded from the EPA's Clean Air Status and Trends Network (CASTNET; <https://www.epa.gov/castnet/>). Table 2-6 summarizes the sites and the corresponding period of record for the Octoraro Creek Watershed and

Figure 2-1 shows the locations. Sites closest to the watershed with the most complete datasets were chosen to represent the wet and dry atmospheric deposition. Wet atmospheric deposition was applied directly to the waterbodies in HSPF and WASP. Dry atmospheric deposition was applied to the land throughout the watershed in HSPF.

Table 2-6. Atmospheric Deposition Site Summary

Site ID	Name	State	Type	Start Date	End Date
PA60	Valley Forge	PA	Wet	07/26/2011	06/05/2017
PA47	Millersville	PA	Wet	11/21/2002	06/27/2017
NJ99	Washington Crossing	NJ	Wet	08/04/1981	Present
WSP144	Washington Crossing	NJ	Dry	12/27/1988	Present
ARE128	Arendtsville	PA	Dry	06/28/1988	Present

The dry deposition data from the NADP were supplied at a weekly timestep as a particulate flux in kilograms per hectare (kg/ha). The weekly data were divided by 7 to transform the data into a daily time series. The wet deposition data were also supplied at a weekly timestep; however, sampling periods ranged from 1 to 8 days in rare cases. Because wet deposition was reported as a concentration (i.e., mg/L), wet deposition data was not divided by the number of days in the sampling period. The concentration was instead assigned to each day of the sampling period. The wet deposition data in the model were multiplied by the daily precipitation amount to calculate the nutrient load input to a watershed through wet deposition.

Time periods with missing dry and wet deposition monitoring data were filled using interpolation when less than 14 missing days occurred between samples and using a monthly mean when more than 14 missing days occurred between values. The data were converted to elemental concentrations and fluxes using multiplication factors in the UCI (i.e., to determine the concentration and flux of elemental nitrogen in NO₃ and ammonia).

Continuous wet and dry atmospheric deposition of TP were not monitored through the NADP or other sources such as CASTNET. Because of the lack of continuous data, an annual average value of TP deposition obtained from regional studies was simulated using the MONTH-DATA block in HSPF. Values of TP atmospheric deposition in the Chesapeake Bay Watershed range from 0.32 to 2.42 grams per square meter per year (g/m²/yr) [Boynton et al., 1995]. A midpoint value of 1.37 g/m²/yr was initially set, with higher values occurring in the summer and lower values occurring in the winter [Yang et al., 1996].

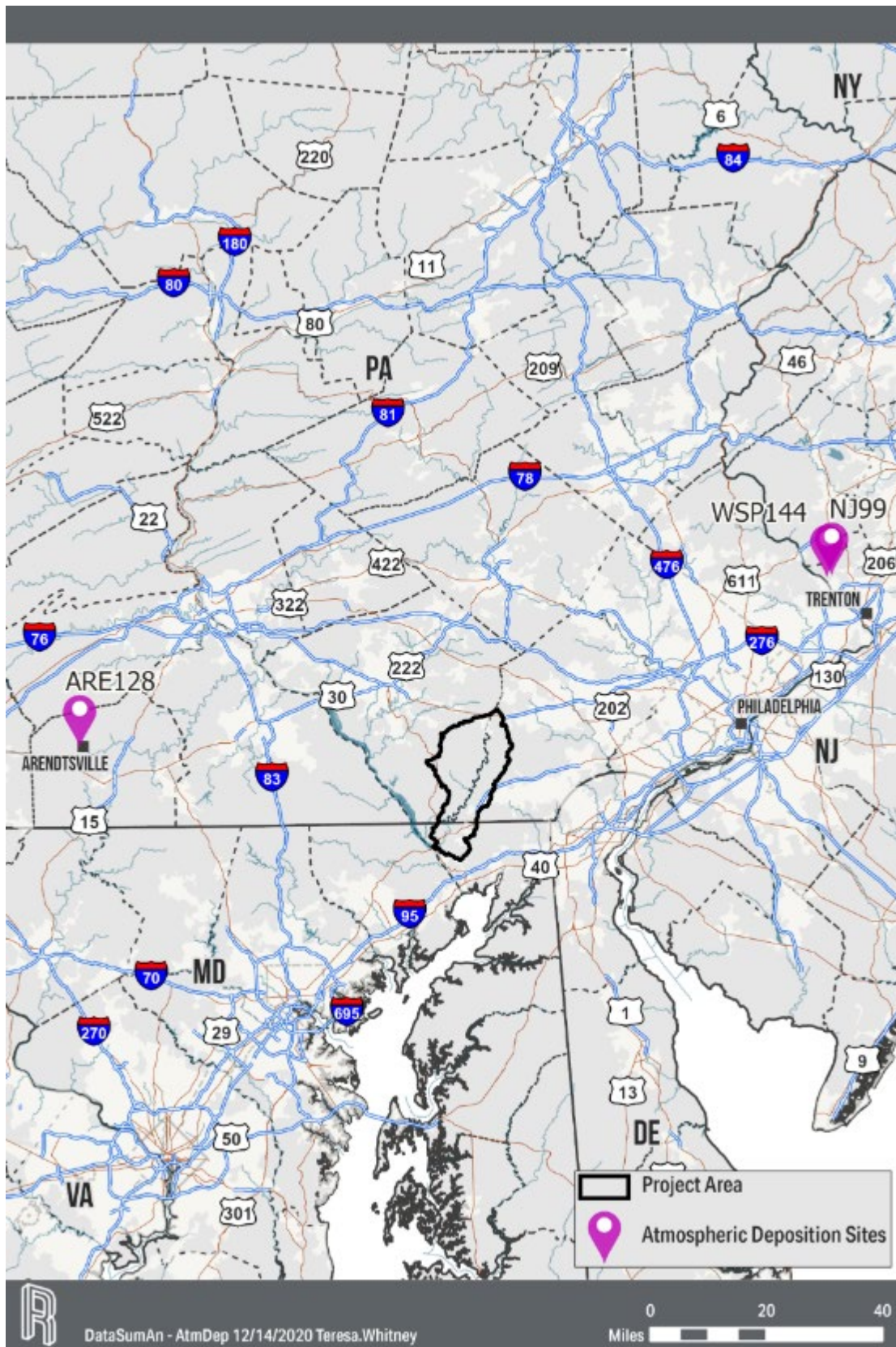


Figure 2-1. Locations of Atmospheric Deposition Monitoring.

2.2.5 OTHER DATA

Additional supplemental data are available from the Octoraro Creek Watershed Association/Volunteer Coalition. These data include the makeup of stream-bottom materials; levels of stream-bank erosion; high-water marks; and stream shape, width, and depth. High-water marks, stream shape, width, and depth were used as a part of F-table development, while stream-bottom materials and levels of stream-bank erosion were used to set and calibrate model parameters.

Average annual irrigation is available from the U.S. Department of Agriculture National Agricultural Statistics Service (NASS) by state and crop type. Irrigation is simulated in HSPF as a distinct time-series input that represents water application to cropland. Irrigation was applied to the modeled crop types during dry periods of the growing season, based on the NASS irrigation data and precipitation records.

Other time-series data for modeling include water-balance data for the Octoraro Reservoir. The water-balance time-series data was used to calibrate and set outflows from the reservoir. Susquehanna River withdrawals and concentrations will be used to develop boundary conditions for when water is brought into the Octoraro Creek Watershed.

2.3 SUBWATERSHED DELINEATION

There are 62 subwatersheds in the Octoraro Creek Watershed HSPF model. The appropriate resolution for subwatershed delineation was defined by the needs of the EPA, PADEP, and MDE. Subwatershed boundaries were selected to represent discrete impaired reaches and lakes, monitoring points for calibration, point source discharge locations, and related factors. A combination of the NHDPlus High-Resolution Dataset (<https://www.epa.gov/waterdata/get-nhdplus-national-hydrography-dataset-plus-data>) and the high-resolution DEM used by Chesapeake Conservancy to create their enhanced flow-path dataset (<https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/enhanced-flow-paths/>) were used to delineate the subwatersheds at monitoring points, point sources, and significant tributaries. NHDPlus is a national, geospatial, surface-water framework that includes elevation, flow accumulation, and flow-direction grids.

Batch points were created in Geospatial Information System (GIS) software at preferred subwatershed breakpoints (e.g., monitoring points and tributary inlets) to delineate model subwatersheds in the Octoraro Creek Watershed. The ArcGIS Pro Hydrology tools were then used with the Chesapeake Conservancy high-resolution DEM to

delineate boundaries for each breakpoint. Subwatersheds are shown in Figure 2-2, and further information about each subwatershed is included in Table 2-7. Subwatershed ID numbers increase from upstream to downstream (i.e., downstream subwatersheds have larger ID numbers). Subwatersheds for mainstem Octoraro Creek and Octoraro Reservoir reaches end in zero and tributary subwatersheds end in an odd number.

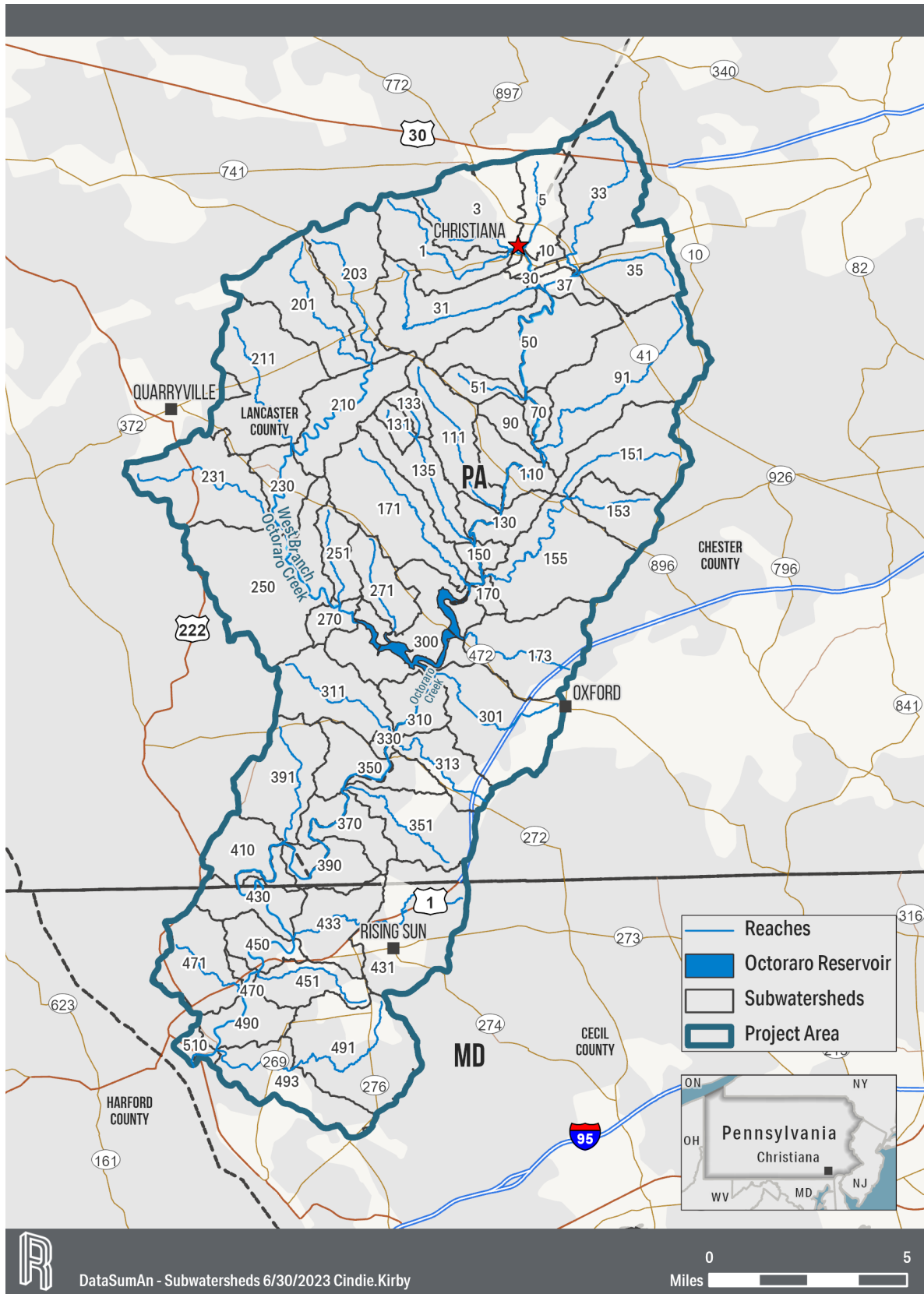


Figure 2-2. Subwatersheds in the Octoraro Creek Watershed HSPF Model.

Table 2-7. Detailed Subwatershed Information (Page 1 of 2)

Major Basin	Name	Subwatershed	Downstream Subwatershed	Total Drainage Area (sq mi)
East Branch Octoraro Creek	Buck Run	1	3	3.9
	Williams Run	3	10	8.9
	Pine Creek	5	10	2.8
	East Branch Octoraro Creek	10	30	12.2
	East Branch Octoraro Creek	30	50	12.5
	Valley Run	31	50	5.4
	Officers Run	33	37	5.9
	Valley Creek	35	37	3.8
	Valley Creek	37	50	10.6
	East Branch Octoraro Creek	50	70	35.3
	Annan Run	51	70	1.1
	East Branch Octoraro Creek	70	90	37.2
	East Branch Octoraro Creek	90	110	38.4
	Knight Run	91	110	9.1
	East Branch Octoraro Creek	110	130	49.8
	Ball Run	111	130	3.7
	East Branch Octoraro Creek	130	150	55.5
	Unnamed Creek	131	135	0.7
	Bells Run	133	135	0.7
	Bells Run	135	150	4.2
	East Branch Octoraro Creek	150	170	60.5
	Muddy Run	151	155	5.1
	Rattlesnake Run	153	155	2.6
	Muddy Run	155	170	14.6
East Branch Octoraro Creek	170	180	75.6	
Coopers Run	171	180	6.3	
Leech Run	173	180	5.3	
West Branch Octoraro Creek	Meetinghouse Creek	201	210	5.3
	Nickel Mines Run	203	210	4.6
	West Branch Octoraro Creek	210	230	14.2
	Bowery Run	211	230	7.5
	West Branch Octoraro Creek	230	250	23.9
	Stewart Run	231	250	5.8
	West Branch Octoraro Creek	250	270	39.1

Table 2-7. Detailed Subwatershed Information (Page 2 of 2)

Major Basin	Name	Subwatershed	Downstream Subwatershed	Total Drainage Area (sq mi)
West Branch Octoraro Creek (cont.)	Unnamed Creek	251	270	1.8
	West Branch Octoraro Creek	270	280	41.9
	Gables Run	271	280	2.4
	Octoraro Reservoir	300	310	138.2
Octoraro Creek Below Octoraro Reservoir	Tweed Creek	301	310	6.2
	Octoraro Creek	310	330	146.4
	McCreary Run	311	330	4.3
	Blackburn Run	313	330	2.5
	Octoraro Creek	330	350	153.6
	Octoraro Creek	350	370	156.9
	Black Run	351	370	4.2
	Octoraro Creek	370	390	163.8
	Octoraro Creek	390	410	166.3
	Reynolds Run	391	410	4.6
	Octoraro Creek	410	430	173.8
	Octoraro Creek	430	450	176.3
	Stone Run	431	433	6.7
	Stone Run	433	450	10.2
	Octoraro Creek	450	470	188.4
	Love Run	451	470	2.5
	Octoraro Creek	470	490	191.3
	Unnamed Creek	471	490	3.8
	Octoraro Creek	490	510	197.5
	Basin Run	491	493	7.0
Basin Run	493	510	11.1	
Octoraro Creek	510	999	209.2	

2.4 CHANNEL SEGMENTATION AND CHARACTERIZATION

The river channel network is the major pathway where nutrients, sediment, and other contaminants are transported throughout the Octoraro Creek Watershed. There are 59 stream reaches and three reservoir reaches in the Octoraro Creek Watershed HSPF model. Accurate representation or characterization of the channel system in the HSPF model is therefore important. The segmentation of river reaches in HSPF aligns with subwatershed segmentation, as there is one reach per subwatershed.

2.4.1 HSPF REACH PROPERTIES

River travel time, riverbed slope continuity, cross sections, and morphologic changes were determined for each reach defined in HSPF from a Light Detection and Ranging (LiDAR) dataset and a high-resolution hydrography dataset for the Chesapeake Bay Watershed provided by the Chesapeake Conservancy in late 2021. Reach length and slope are required to determine physically based parameters in the HSPF model and to develop hydraulic function tables (F-tables). Values of reach length and slope were calculated using ArcGIS Pro for all reaches. The Octoraro Reservoir was explicitly modeled in HSPF and outflow data were available for the reservoir for all years except 2006 and 2020.

2.4.2 HSPF F-TABLE DEVELOPMENT

This section describes the development of F-tables that route water through each modeled reach in the HSPF model. An F-table summarizes a reach's hydraulic and geometric properties and is used to specify functional relationships among the surface area, volume, and discharge at a given depth.

2.4.2.1 LAKE F-TABLES

To develop the F-tables for the Octoraro Reservoir model segments, the waterbody surface area, volume, and flow were calculated at various water elevations (depths) with the Bathymetry Volume and Surface Area ArcGIS ModelBuilder tool using bathymetry data digitized from the Chester Water fishing map (<https://chesterwater.com/fishingbrochure.pdf>). This tool creates a separate, triangulated irregular network (TIN) for each lake. The surface volume portion of the tool was used to calculate the area and volume below specified depths. The highest contour or maximum depth was assumed as the outlet. Depths were added incrementally above the outlet until the F-table discharge exceeded the maximum observed discharge levels. The surface area and volume above the outlet were calculated using conical geometry with an initial floodplain slope of 0.01.

2.4.2.2 STREAM F-TABLES

Chesapeake Conservancy provided preliminary, high-resolution, gridded hydrography data to support the estimation of modeled stream cross-sections used for HSPF F-table development. The hydrography data consists of 10-meter grid layers representing water depth and width and stream center lines. Incremental buffers were created around the stream centerlines in ArcGIS to represent incremental widths across a stream cross section. The average depth was calculated for each incremental width buffer to create an average cross section of width and depth for each modeled stream. Because the

hydrography depth data only covered up to the bank full water surface, LiDAR elevation data were used to expand the cross section above bank full and through the floodplain.

Dam locations and information from the National Inventory of Dams (NID) and the Franklin & Marshall College's Exhibits of Nineteenth Century Mills and Dams were used to represent low-head dams in the F-tables. A small amount of channel storage is typically estimated for each stream segment. The dam information was used to improve the estimate of channel storage in corresponding stream segments to represent the impact of low-head dams where appropriate.

2.5 LAND CHARACTERIZATION

2.5.1 LAND SEGMENTATION

This section describes the pervious land segments (PERLNDs) and impervious land segments (IMPLNDs) that were defined in the HSPF model. The PERLND and IMPLND blocks of the UCI file contain parameters that describe rainfall-runoff processes and associated pollutant loading processes within different land segment types.

Land segmentation aims to separate the watershed into unique land segments to effectively represent the variability of hydrologic and water quality responses. The watershed characteristics used to determine PERLND and IMPLND categorization include flow paths (defined with subwatersheds and reach segments in Section 2.4 of this report), meteorological variability (defined using time-series data), and land cover. These characteristics were selected for Octoraro Creek Watershed modeling based on the significance of their influence on the hydrologic processes and water quality constituents of interest. Items such as large areas, high runoff, and pollutant application increase the significance of model representation.

Land use, or land cover, data were critical for the watershed modeling because these data provided the detailed characterization of potential nonpoint and stormwater pollutant sources. Land use is also a major determining factor for the hydrologic response of the watershed. Chesapeake Conservancy provided a high-resolution land cover layer representing 2017 and 2018 (<https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/>). This layer was used to develop the model land cover¹. This high-resolution land cover raster was aggregated (i.e., reclassified) into a set of model land cover types that are used to define the

¹ Chesapeake Conservancy is currently working to update of the high-resolution land cover dataset. The update is expected to be completed by Chesapeake Conservancy in late 2021. However, the updated land cover dataset was not ready in time to use in the HSPF model application.

PERLND and IMPLND classifications within each meteorological zone in the Octoraro Creek Watershed. Cropland categories from the Chesapeake Model were also used with the NASS Cropland Data Layer to separate areas mapped as cropland in the Chesapeake Conservancy dataset into multiple categories.

There are 10 pervious and 1 impervious land use categories in the Octoraro Creek Watershed HSPF model. Pervious categories include developed, four cropland categories, pasture and hay, turf, herbaceous, forest, and wetland. Figure 2-3 shows the reclassification scheme for converting the Chesapeake Conservancy high-resolution land cover dataset and the NASS Cropland Data Layer to the aggregated set of model land cover classes. Separate mass links were used in the model to represent Pennsylvania and Maryland land uses so that water and pollutant export from each state could be tracked separately.

Model Land Cover Segmentation – Octoraro

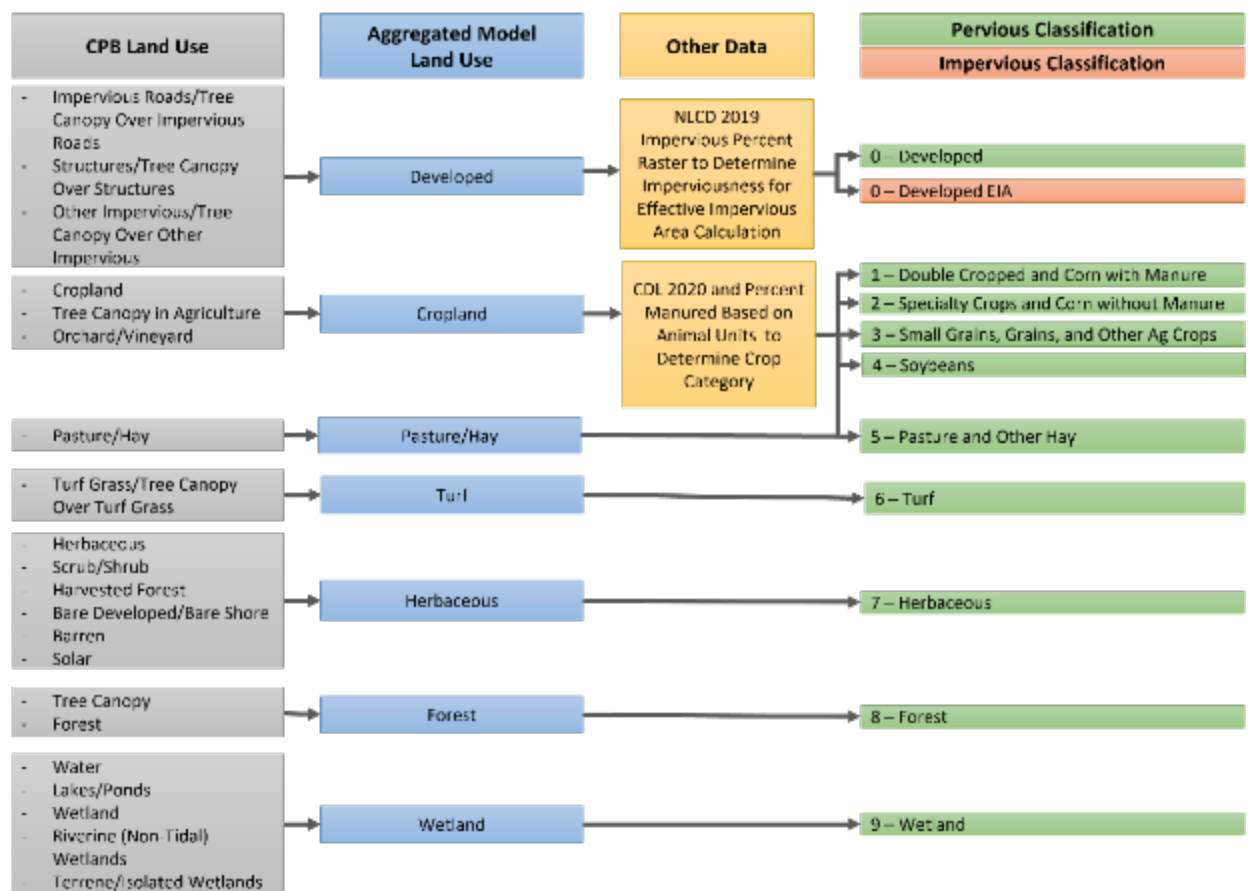


Figure 2-3. Aggregation of Chesapeake Bay Conservancy Land Use to HSPF Model Land Segments.

Municipal Separate Storm Sewer Systems (MS4s) were also represented as distinct land segments in the Octoraro Creek Watershed HSPF model. Polluted stormwater is commonly transported through MS4s before being discharged into local waterbodies. Certain MS4s are required to obtain NPDES permits and develop stormwater management programs [NPDES, 2020]. The Octoraro Creek Watershed HSPF model represented regulated MS4s as distinct land segments using a separate mass link so that flow and pollutants could be differentiated from non-MS4 areas. A GIS layer of MS4 planning areas from the Chesapeake Bay model dataset (<http://ches.communitymodeling.org/models.php>) was used. The MS4 planning areas represent the extent of lands where stormwater is regulated and were used to determine the area within each model subwatershed that was simulated as distinct MS4 land segments. Because MS4 permitting varies from state to state, the modeling boundaries for loading rates were separated for Pennsylvania and Maryland areas using mass links. MS4 areas were represented in the model application with different mass links than non-MS4 areas. The final model land segmentation (including point sources and MS4 areas) is shown in Figure 2-4.

Other than the Octoraro Reservoir, small lakes, ponds, and reservoirs were not explicitly modeled in HSPF or connected to reach geometry and were therefore represented with the wetland land cover category. The Octoraro Reservoir was explicitly modeled and represented with an F-table instead of a model land cover.

The Effective Impervious Area (EIA) must be accurately represented in watershed models because of its impact on the hydrologic processes in developed environments. The term “effective” implies that the impervious region is directly connected to a water conveyance system (e.g., gutter, curb drain, storm sewer, open channel, or river) and that overland flow will not run onto and infiltrate pervious areas before reaching a stream or waterbody. The percent of Total Impervious Area (TIA) for an impervious land segment was used to determine the percent EIA using Equation 2-3 from Sutherland [2000]. TIA was determined from the National Land Cover Database Percent Developed Imperviousness data layer.

$$EIA = 0.1(TIA)^{1.5}, TIA \geq 1 \quad (2-3)$$

TIA was also calculated using the impervious category in the land cover divided by the total area in each subwatershed. A second option for EIA was then calculated using the Sutherland Equation (Equation 2-3).

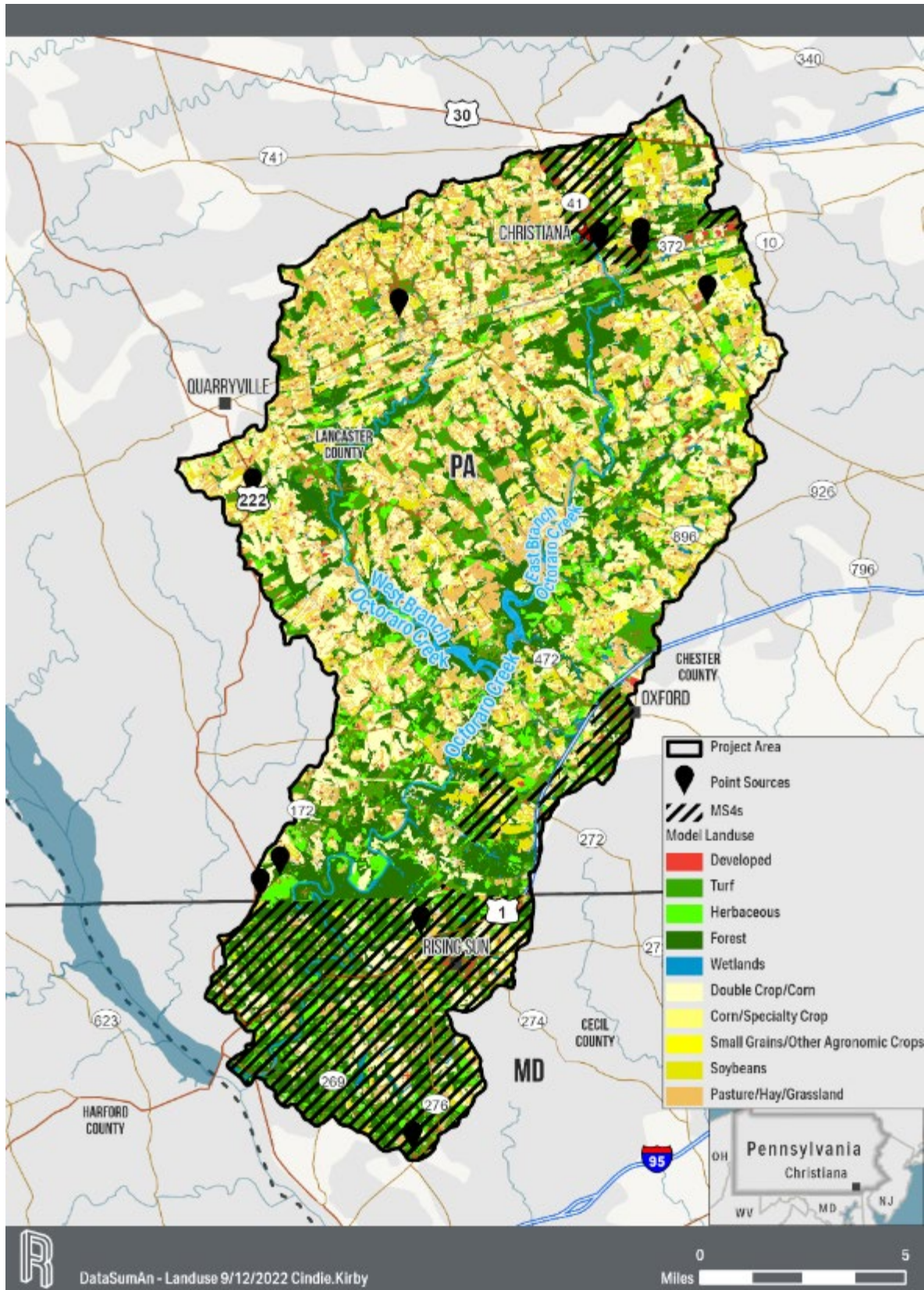


Figure 2-4. Land Use, Point Sources, and MS4s in the Octoraro Creek Watershed HSPF Model.

2.5.2 METEOROLOGICAL ZONE DEVELOPMENT

Meteorological zones are an aggregation of subwatersheds that share the same meteorological input data. The meteorological zone development process is essential because any modeled land use within a meteorological zone shares the same parameter sets in HSPF.

NLDAS and PRISM precipitation data were obtained for each subwatershed and a correlation coefficient matrix was produced. The correlation coefficient matrix was used in combination with a subwatershed adjacency matrix to guide the aggregation of subwatersheds into meteorological zones. Subwatersheds were grouped if the correlation coefficients of adjacent subwatersheds were greater than 0.94. Annual average precipitation; drainage patterns; and abrupt changes in land cover, soil properties, and topography were also considered in meteorological zone development. There are 25 meteorological zones in the Octoraro Creek Watershed HSPF model, shown in Figure 2-5. Table 2-8 lists the subwatersheds located in each meteorological zone.

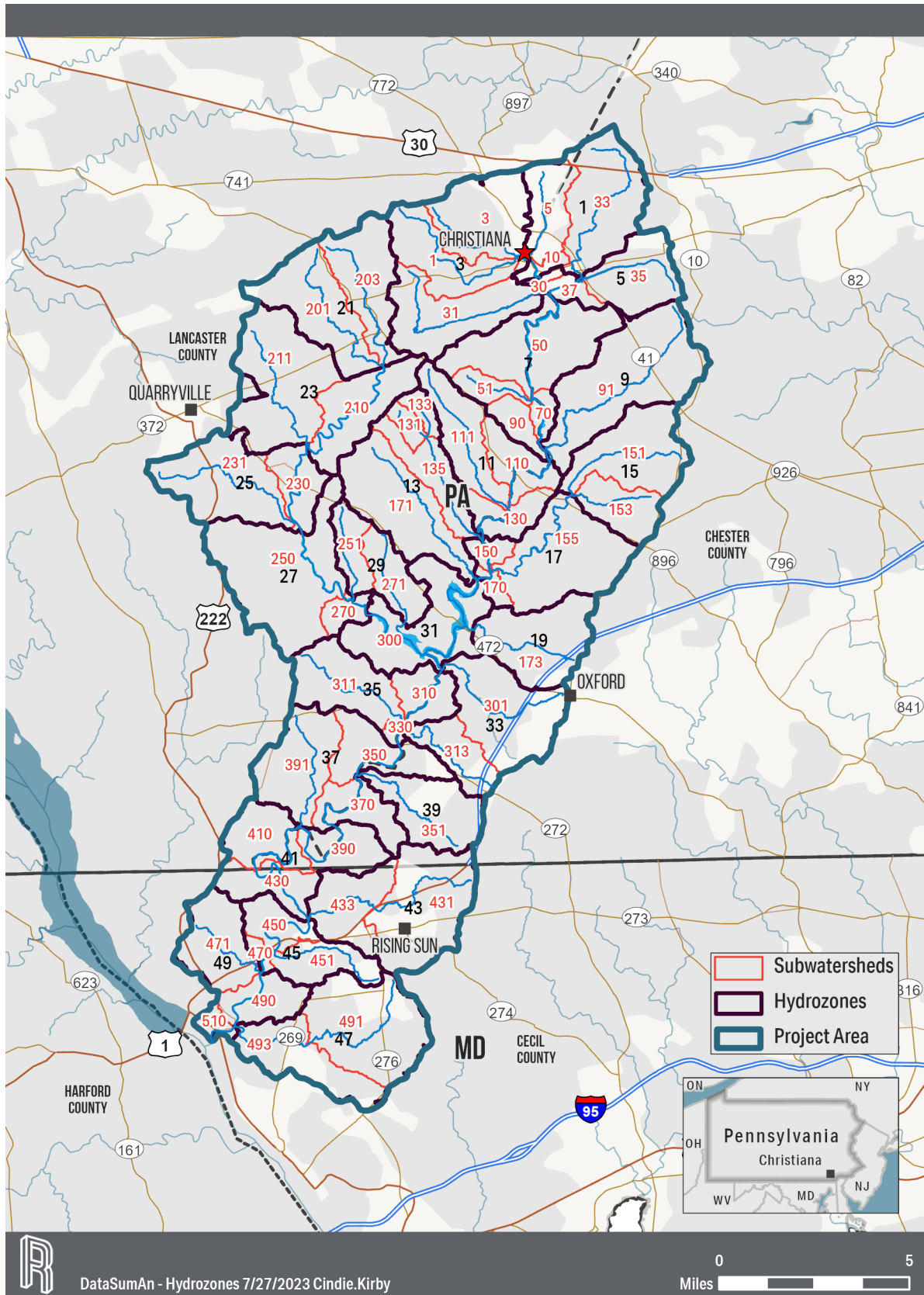


Figure 2-5. Meteorological Zones for the Octoraro Creek Watershed HSPF Model.

Table 2-8. Subwatersheds Contained Within Each Meteorological Zone

Meteorological Zone	Subbasin	Meteorological Zone	Subbasin
1	5	25	230
	10		231
	33	27	250
1	270		
3	3	29	251
	31		271
5	30	31	300
	35		
	37		
7	50	33	301
	51		313
	70	35	310
	90		311
9	91		330
11	110	37	350
	111		370
	130		391
13	131	39	351
	133	41	390
	135		410
	171		430
15	151	43	431
	153		433
17	150	45	450
	155		451
	170		470
19	173	47	491
21	201		493
	203	49	471
23	210		490
	211	510	

2.5.3 SEPTIC SYSTEMS

Septic systems are also represented spatially in the model setup. The number of individuals on septic are estimated and loads contributed to those individuals are added in the mass-links.

A septic system falls under the Onsite Wastewater Treatment System (OWTS) category. Many households use OWTSs in the Octoraro Creek Watershed. OWTSs generally contribute pollutant loads to groundwater or tributaries. Pennsylvania has polygons that show public water suppliers' service areas (<https://newdata-padep-1.opendata.arcgis.com/maps/public-water-systems-public-water-supplier-service-areas/about>). Areas outside of public water supply service areas were assumed to be outside of wastewater service areas in Pennsylvania (i.e., it was assumed that a home uses an OWTS if it also uses well water). Cecil County, Maryland, supplied polygons of areas with septic systems. These datasets were combined with the 2010 U.S. Census Bureau Block Centroid Population (<https://www.census.gov/programs-surveys/decennial-census/data.html>) dataset to estimate the population in each model subwatershed that uses OWTS. Census blocks are the smallest geographic entities within a county for which the U.S. Census Bureau tabulates population.

OWTSs were represented in the model application as a constant load and assumed to discharge at 46.4 gallons per person per day [EPA, 1993]. Because the HSPF model requires CBOD, BOD₅ loads were converted to CBOD using a factor of 1.2 for untreated waste [Thomann and Mueller, 1987].

2.5.4 ANIMAL UNITS

Animal units were used to estimate the percentage of cropland segments with manure applications (corn with manure versus corn without manure). EPA provided estimates of animal feeding operation (AFO) counts, animal types, the number of AFOs permitted as CAFOs, and the number and type of animals in facilities permitted as CAFOs in the Octoraro Creek Watershed. CAFO animal units were calculated using conversion information from the University of Illinois Extension [2022].

The CAST dataset includes total animal units in each of the three counties that drain into the Octoraro Creek Watershed. The average number of animal units per AFO was calculated by dividing the difference between the total animal units and CAFO animal units by the number of AFO facilities, as shown in Table 2-9.

The three CAST county areas draining to the Octoraro Creek Watershed were intersected with subwatersheds in GIS to obtain the percent of the area of each subwatershed in each county. This information was then used to calculate the total

animal units in each subwatershed. Corn acres were determined based on each subwatershed's NASS Cropland Data Layer. CAST (Microsoft Word - 5 Land Use 2020 03 Draft (chesapeakebay.net)) developed an equation (Equation 2-2) that used the total animal units and the total corn acres in each subwatershed to estimate the fraction of manured cropland. The fraction calculated was applied to the corn acres in each subwatershed in the Octoraro Creek Watershed to calculate the manured corn acres for the schematic.

$$M = 0.5196 + 0.1311 \times \ln\left(\frac{U}{C}\right) \quad (2-2)$$

where:

M = Fraction of Corn Receiving Manure

U = Animal Units

C = Corn Acres.

Table 2-9. Animal Units to Estimate the Percentage of Corn Cropland With Manure Applications

Animal Description	Cecil	Chester	Lancaster
CAFO Animal Units (EPA)	1,677	12,152	13,228
AFO Animal Units (Total Animal Units – CAFO Animal Units)	1,213	13,179	66,303
AFO Facilities (EPA)	3	143	433
Animal Units per AFO	385	92	153

3.0 HSPF MODEL CALIBRATION AND VALIDATION

3.1 PARAMETER ESTIMATION

Initial parameters were estimated for the Octoraro Creek Watershed model using ArcPro. Parameters need to be estimated for Reach Reservoirs (RCHRESs), PERLND segments, and IMPLND segments. RCHRES parameters include mean elevation, DELTH (maximum elevation minus minimum elevation), slope, and length. PERLND and IMPLND parameters calculated include elevation, slope, ELDAT (the difference in elevation between the PERLND and the meteorological zone), and latitude. The SSURGO soil K-factor, which represents a relative index of susceptibility of bare, cultivated soil to particle detachment and transport by rainfall, was also calculated for each PERLND and IMPLND segment. Average elevation, average slope, and other topographic parameters for each model subwatershed were estimated from the high-resolution DEM used by Chesapeake Conservancy to create the enhanced flow-path dataset (<https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/enhanced-flow-paths/>).

The Octoraro Creek Watershed HSPF model simulates both land-based and instream sources of water quality constituents. Simulation of nitrogen and phosphorus species uses buildup and wash-off parameters. Phosphorus species and biochemical oxygen demand are also associated with sediment loads using parameterization. Sediment is simulated with parameters that reflect the transport, deposition, and scour of sediment (SEDTRN). The remainder of instream water quality processes are simulated using RQUAL, which simulates constituents involved in biochemical transformations. Water quality parameters for the Octoraro Creek Watershed HSPF model were estimated based on past modeling efforts in the Chesapeake Bay Watershed.

3.2 HYDROLOGY CALIBRATION AND VALIDATION APPROACH

3.2.1 DATA

Table 3-1 shows the time-series data collected for the hydrology calibration and validation of the model application. USGS was a primary data source. Stroud Water Research Center (SWRC) collected flow for the project over a year of the modeling period. SWRC also monitored reservoir stage for this project at one site on the Octoraro Reservoir with an over-the-top spillway. Monitoring began in June 2021 and continued through May 2022. The SWRC QA/QC protocols for reservoir-stage data collection are covered under a separate QAPP. Additional flow data was provided by other sources and assessed during the calibration. Snow data were collected from the Global Historical Climatology Network.

Table 3-1. Secondary Environmental Time-Series Data Assembled for Calibration/Validation

Data Type	Source
Daily Historical Flow Record (cfs)	USGS/ SWRC/Other
Daily Maximum Peak Flows (cfs)	USGS/ SWRC/Other
Hourly (or shorter) Storm Hydrographs (cfs)	USGS/ SWRC/Other
Octoraro Reservoir Level (feet)	SWRC, Other
Snow Fall (inches)	Global Historical Climatology Network
Snow Depth (inches)	Global Historical Climatology Network

Streamflow data were needed to compare to simulated flow to ensure that the hydrologic behavior of the Octoraro Creek Watershed, as well as the transport of sediment and water quality constituents, are reproduced. Continuous, observed streamflow data were available at one long-term USGS gage in the Octoraro Creek Watershed. Table 3-2 lists the USGS streamflow gages and corresponding record period to support the model calibration and the missing percentage of data. Flow data were downloaded from the USGS National Water Information System (<https://waterdata.usgs.gov/nwis>). The flow at the continuous USGS site ranges from 36 to 7,670 cfs, with a median of 167 cfs. Instantaneous flow data from a different USGS site were evaluated for calibration. However, this report does not include statistics and long-term comparisons for instantaneous flow data because not enough data exists for such comparisons. Figure 3-1 shows the primary flow sites available for hydrology calibration.

Snow depth (i.e., snow on the ground) data were used to calibrate the snow accumulation and melt processes when the snow section of the model is active. These data were also used with mean and maximum winter-air temperatures to assess whether to activate the snow-simulation capability within the watershed model. For the Octoraro Watershed and the surrounding areas, the snow depth (inches) and snowfall (inches) data were available online through the National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information (formerly the National Climatic Data Center), Global Historical Climatology Network stations [NOAA, 2021] (<https://www.ncdc.noaa.gov/ghcnd-data-access>).

Table 3-2. Stream Gages and Data Availability During the Modeling Time Period in the Octoraro Watershed

Station Name	Station ID	Start Date	End Date	Missing (%)
East Branch Octoraro Creek above reservoir ^(b)	PA006	06/2021	05/2022	97
East Branch Octoraro Creek at Bellbank Road	Bellbank (BBB001)	01/2005	01/2022	12
West Branch Octoraro Creek above reservoir ^(b)	PA007	06/2021	05/2022	98
West Branch Octoraro Creek at White Rock Road	WhiteRock (WHR001)	01/2005	01/2022	11
Octoraro Reservoir Level	LakeElev	01/2005	01/2022	6
Octoraro Creek below reservoir ^(b)	PA010	06/2021	05/2022	97
Octoraro Creek below Reservoir at Pine Grove Road	PineGrove (PGR001)	01/2005	01/2022	11
Octoraro Creek near Steelville, PA ^(a,b)	01578347 EB	11/14/2005	11/19/2020	99.6
Octoraro Creek near Richardsmere, MD ^(a)	01578475	12/20/2005	12/31/2020	6

(a) Maintained by USGS

(b) Noncontinuous, spot comparisons completed

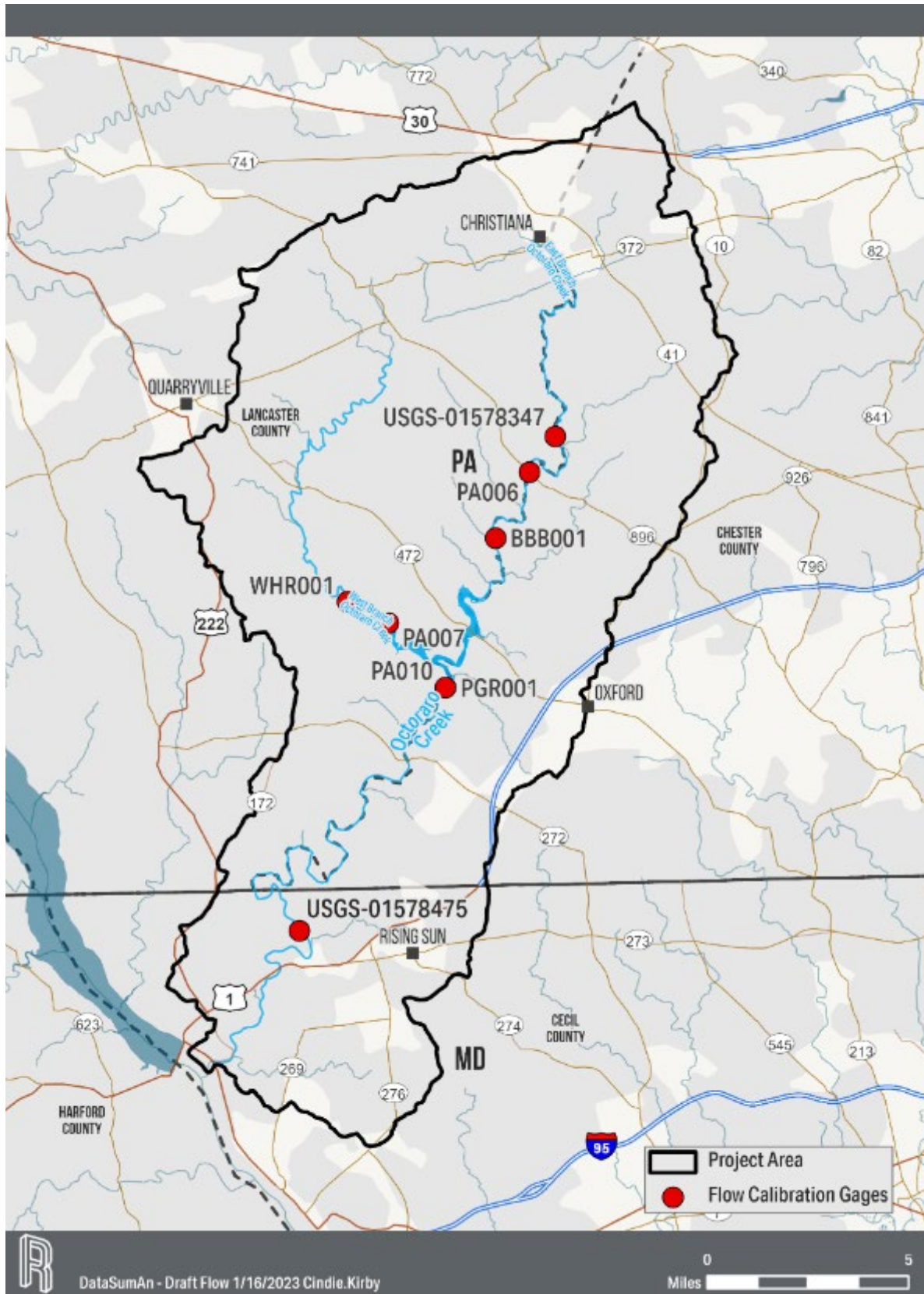


Figure 3-1. Streamflow Calibration Gages.

3.2.2 MODEL PERFORMANCE CRITERIA

For HSPF, the calibration and validation process first occurred for the hydrology portions of the model, followed by the water quality portions. The procedures used have been well-established over the past 35 years, as described in the Application Guide for HSPF [Donigian et al., 1984] and summarized by Donigian [2002]. Statistical comparisons used to quantify the model performance for streamflow include the correlation coefficient (r) and the coefficient of determination (r^2) from regression analysis, as well as the Nash Sutcliffe model fit efficiency and percent differences for numerous flow conditions and storms. The correlation coefficient (r) is a measure of how strongly the simulated and observed values of a given model output variable are correlated, with values of negative 1 corresponding to perfect negative correlation and positive 1 corresponding to perfect positive correlation. The coefficient of determination (r^2) measures how well a linear regression between simulated and observed values approximates the observed data. The Nash Sutcliffe model fit efficiency is similar to r^2 but does not involve a linear regression and more directly compares the fit of simulated value to observed data. For both r^2 and Nash Sutcliffe, values closer to 1 correspond to greater model accuracy. Percent difference describes the magnitude of the difference between simulated and observed values of a model output variable and is also referred to as percent bias.

The calibration and validation methods include a combination of qualitative approaches, professional judgment, and numeric targets to evaluate model performance and acceptance. The numeric targets for streamflow, based on model performance guidelines in Donigian [2000], are summarized in Table 3-3. More information about the approach and criteria needed for hydrology calibration and validation is included in the project QAPP [RESPEC and The Cadmus Group LLC, 2021].

Table 3-3. Numeric Targets for Streamflow Calibration and Validation

Category	R	R ²	Percent Difference	Nash Sutcliffe
Daily Flows	>0.8	>0.65	<25%	>0.65
Monthly Flows at Short-Term Sites	>0.8	>0.65	<25%	>0.65
Monthly Flows at Long-Term Sites	>0.9	>0.8	<15%	>0.8

Long-term sites have greater than 1 year of streamflow records; short-term sites have 1 year or less than 1 year of streamflow records.

3.2.3 MODEL CALIBRATION METHODS

The HSPF model was calibrated through an iterative process of making parameter changes, running the model, producing simulated and observed values comparisons, and interpreting the results. Model validation used a split-sample approach. The approach involved comparing model results to a separate set of observed values from a dry period (2012 to 2017) and a wet period (2018 to 2021) to verify proper model function during various conditions. The standard HSPF hydrologic calibration is divided into four phases:

- / **Establish an annual water balance.** This phase consists of comparing the total annual simulated and observed flows (in inches) and is primarily governed by the input of rainfall and evaporation and the parameters for the lower zone nominal storage (LZSN), lower-zone ET parameter (LZETP), and infiltration index (INFILT).
- / **Adjust low-flow/high-flow distribution.** This step is generally performed by adjusting the groundwater or baseflow because the distribution between high and low flow is the easiest to identify in low flow periods. Mean daily flow conditions are used and the primary parameters involved are the INFILT, groundwater recession (AGWRC), and baseflow ET index (BASETP).
- / **Adjust storm flow/hydrograph shape.** The storm flow, which is compared in the form of short, timestep (1-hour) hydrographs, is largely composed of surface runoff and interflow. Adjustments are made with the upper-zone storage (UZSN), interflow parameter (INTFW), interflow recession (IRC), and overland flow parameters (i.e., length of the overland flow plane [LSUR], Manning's N [NSUR], and slope of the overland flow plane [SLSUR]). INFILT can also be used for minor adjustments.
- / **Make seasonal adjustments.** Differences in the simulated and observed total flow over each month and season are compared to see if runoff needs to be shifted from one month or season to another. These adjustments are generally accomplished by using seasonal (monthly variable) values for the parameters vegetal interception (CEPSC), LZETP, and UZSN. Adjustments to variable groundwater recession (KVARY) and BASETP are also used.

The previous and impervious land parameters for the hydrology calibration vary by land use but not by subwatershed. The primary calibration site drives the calibration, but secondary sites are also evaluated to ensure model results were consistent throughout the watershed. All parameter values used were within the expected ranges provided in the BASINS TechNote 6 guidance document [EPA, 2000]. The most sensitive parameters used for hydrology calibration included INFILT, LZSN, AGWRC, KVARY,

BASETP, INTFW, and MON-UZSN. Snow-depth data were used during the hydrology calibration in multiple locations throughout the project area to ensure that snow processes were accurately represented. The most sensitive parameters used for the snow calibration included the snow catchment factor (SNOWCF) and a snow cover parameter (COVIND).

3.3 HYDROLOGY CALIBRATION AND VALIDATION RESULTS AND DISCUSSION

This section discusses the results of the hydrology calibration and validation. For calibration, the entire modeling period was used (2006–2021). For the split-sample approach to validation, a dry validation (2012–2017) and a wet validation (2018–2021) were completed.

3.3.1 SNOW

The snow simulation results at Octoraro Lake (Station USC00366508) are shown in Figure 3-2. These results are a representative sample of all the model results included in the deliverables results folder. The snow simulation shows a fair agreement with the snowfall and depth observations. Significant day-to-day differences occur between simulated and observed values, but this is a common occurrence in snow modeling because of the lack of good spatial coverage of meteorologic data and the tremendous variations in the observed snow measurements within a watershed related to elevation, exposure, and topography. However, the model results are adequate in meeting the study objectives since the primary snow modeling goal was to represent the overall volumes and general timing of the spring melt.

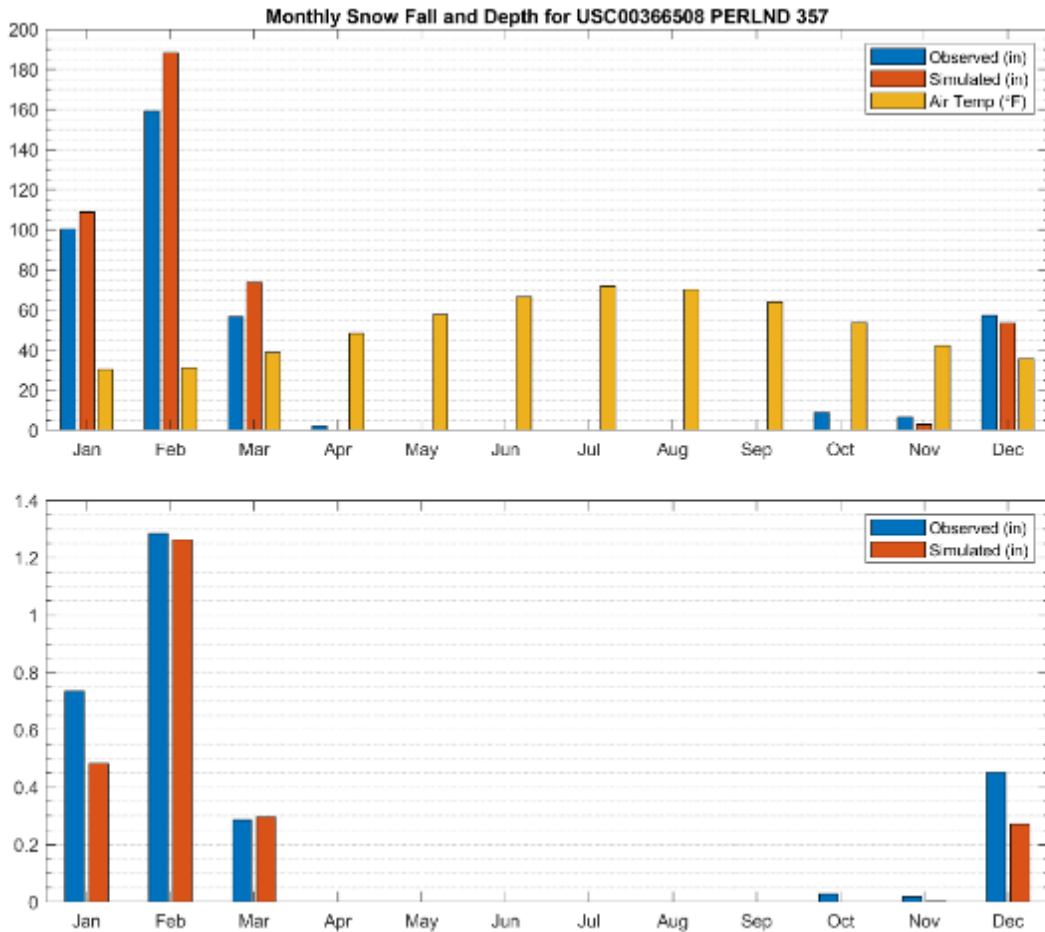


Figure 3-2. Observed and Simulated Snow Fall and Depth at Octoraro Lake (Station USC00366508).

3.3.2 FLOW

The agreement between simulated and observed mean annual flow at the primary calibration site for each time period is shown in Table 3-4, along with the coefficient of determination (R^2) and model fit efficiency (mfe) for the monthly and daily timesteps. Table 3-5 summarizes storm statistics for the major calibration gage for selected storm events that occurred at each of the respective gages during each time period.

The hydrology calibration and validation results consistently show a good agreement based on the annual and monthly comparisons. For the calibration period, the monthly R^2 value at the primary calibration gage is 0.85, and the daily is 0.70 (as shown in Table 3-4). The dry validation had a monthly R^2 value of 0.86 and a daily of 0.68, and the wet validation had a monthly R^2 value of 0.93 and a daily of 0.70. The total annual volumes for the calibration and the two validation periods are within the 10 percent target for a very good agreement.

At the primary calibration gage, storm volumes show a good agreement (within 15 percent) during the calibration, a very good agreement (with 10 percent) during the dry validation, and just above 15 percent during the wet validation, as shown in Table 3-5 and graphically in the daily time-series plots. In 2021, a very large but isolated storm came through the project area. The way the gridded data are spread across the represented meteorological zones did not appropriately allow the model to represent the peak flow during this storm. Therefore, during the dry validation, which did not include 2021, simulated overall storm peaks were 23 percent below the observed volumes. During the calibration period and the wet calibration period, which included the 2021 storm, the storm peak agreements were less than 15 percent (a very good agreement). To meet desired model statistics, the calibration was adjusted to best meet the overall condition including both volume and peaks. Appendix A includes figures of SWRC flow data collected above the reservoir to show the observed data versus the simulation.

Figures 3-3 through 3-6 present graphical comparisons of the simulated and observed flows for the calibration and validation periods at the primary calibration location. The comparisons include annual and monthly runoff bar graphs, daily flow frequency curves, and daily time series. The flow frequency curve in Figure 3-5 demonstrates a consistent pattern between the calibration and validation periods and generally shows good agreement.

Based on the entire “weight of evidence” for the full range of model results presented, the hydrology component meets performance guidelines, is confirmed to be calibrated and validated, and provides a sound basis for the water quality and loading purposes of this study.

Table 3-4. Summary of the Hydrologic Calibration and Validation Statistics

HSPF Reach	Gage	Segment	Drainage Area (sq mi)	Time Period	Monthly		Daily		Total Volume
					R^2	mfe	R^2	mfe	% Difference
430	01578475	Octoraro River	177	Calibration (2006–2021)	0.85	0.82	0.70	0.66	1.44
				Dry Validation (2012–2017)	0.86	0.86	0.68	0.68	-2.17
				Wet Validation (2018–2021)	0.93	0.82	0.70	0.65	-0.82

Table 3-5. Summary of the Storm-Event Statistics for Calibration Gages

HSPF Reach	Gage	Segment	Drainage Area (sq mi)	Time Period	Storm Volume			Storm Peak		
					Observed (inch)	Simulated (inch)	% Difference	Observed (cfs)	Simulated (cfs)	% Difference
430	01578475	Octoraro River	177	Calibration (2006–2021)	8.39	9.59	14.32	1,487.02	1,271.87	-14.47
				Dry Validation (2012–2017)	7.91	8.34	5.42	1,313.40	1,014.51	-22.76
				Wet Validation (2018–2021)	8.76	10.10	15.25	1,742.10	1,513.62	-13.12

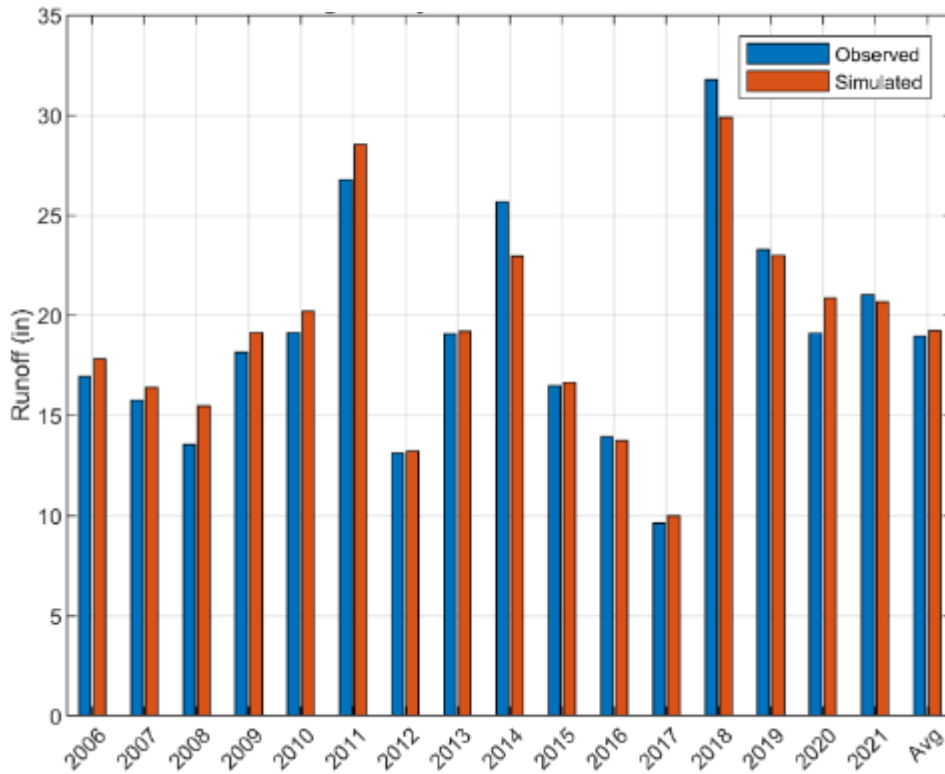


Figure 3-3. Annual Runoff for the Calibration Period at USGS 01578475 (HSPF Reach 430).

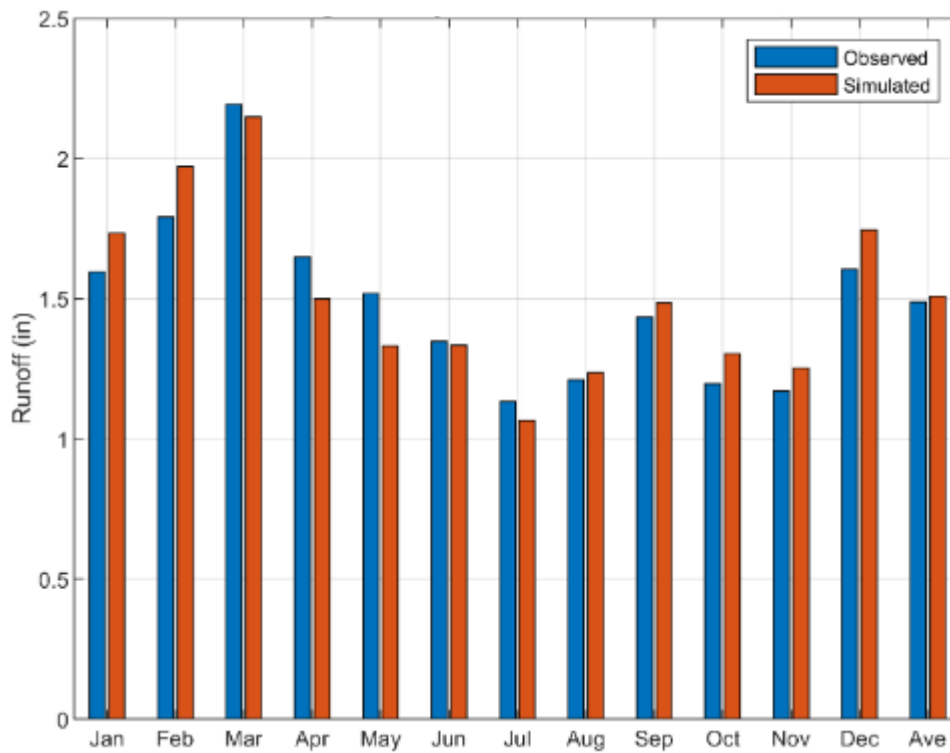


Figure 3-4. Average Monthly Runoff for the Calibration Period at USGS 01578475 (HSPF Reach 430).

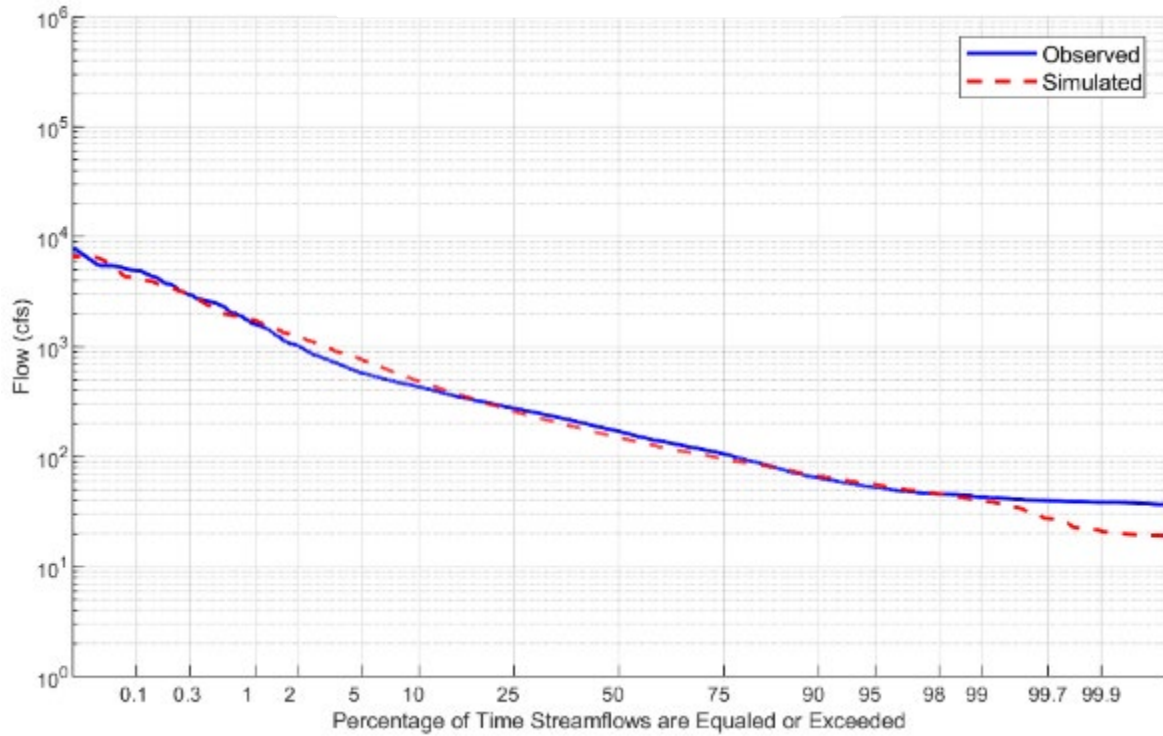


Figure 3-5. Flow Frequency Duration Curve for the Calibration Period at USGS 01578475 (HSPF Reach 430).

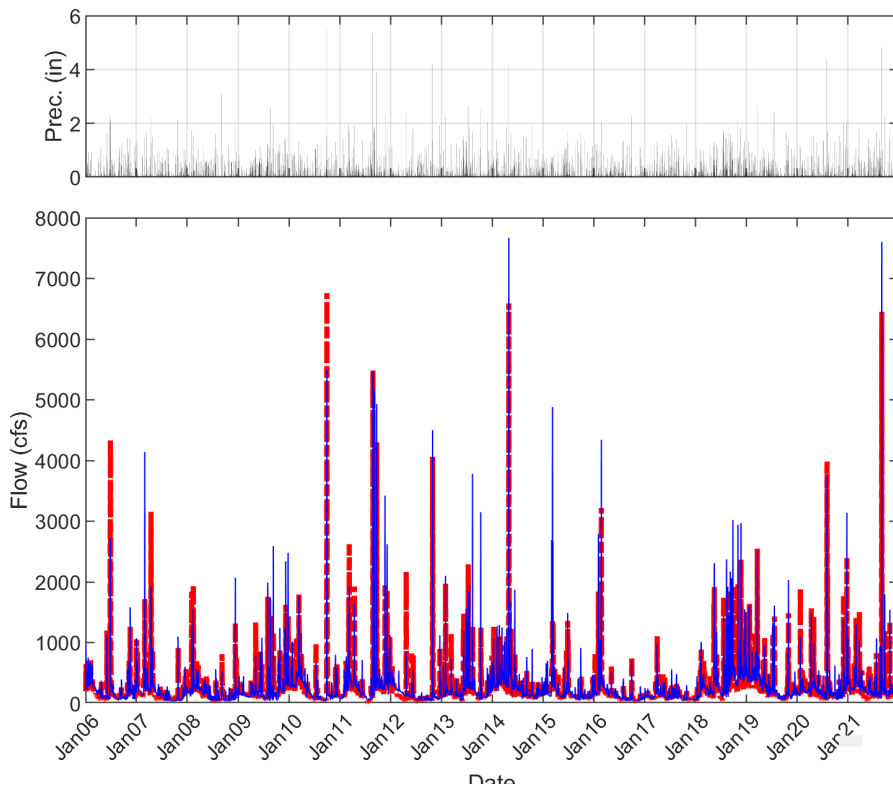


Figure 3-6. Daily Hydrographs for the Calibration Period at USGS 01578475 (HSPF Reach 430).

3.3.3 WATER BALANCE

The water balance for the model shows the amount of precipitation, runoff, and evaporation occurring in each model pathway on each modeled source. Figure 3-7 shows the percent of the total annual runoff volumes from each source. The water balance components by land use for the primary calibration gage are shown in Table 3-6. The point source category in Figure 3-7 represents industrial/wastewater discharge permits.

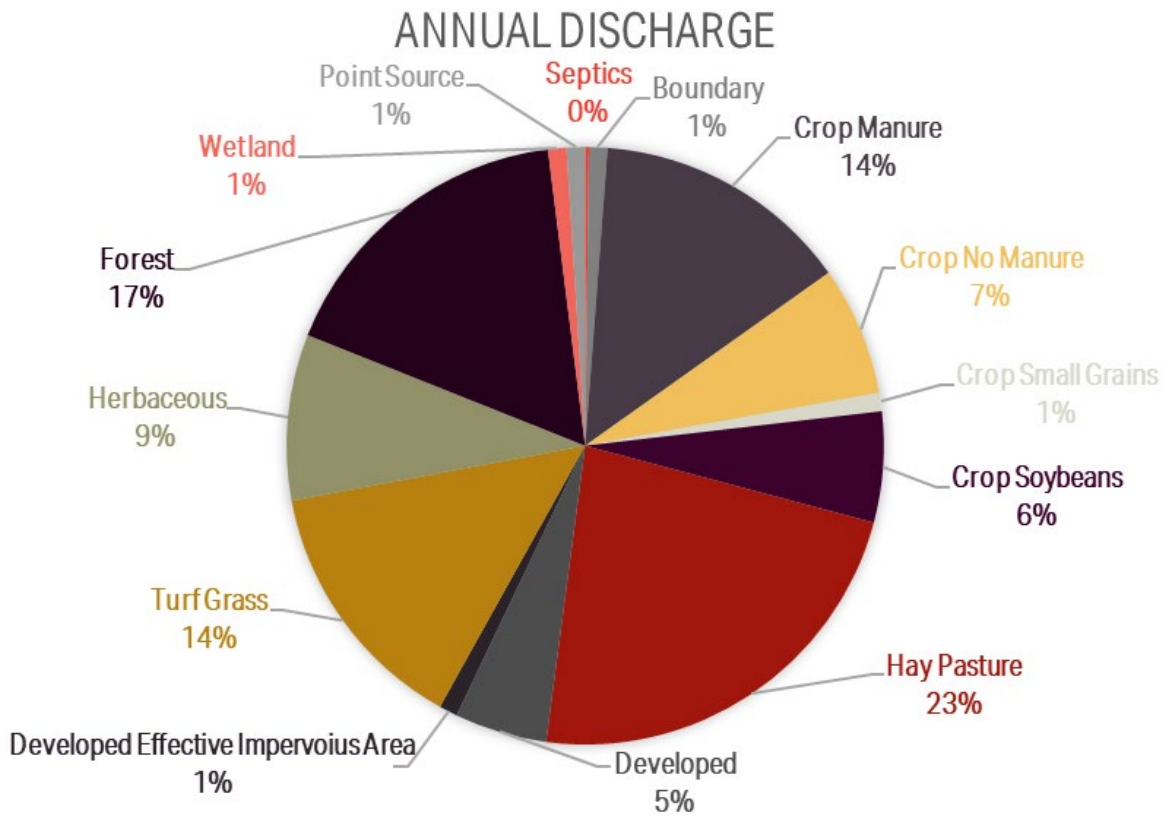


Figure 3-7. Percent of Annual Average Volume by Source.

Table 3-6. Weighted Water-Balance Components at Primary Calibration Gage

Reach 430 Water Balance Component (inches)	Manured Cropland	Non-Manured Cropland	Small Grains	Soybeans	Developed	Forest	Pasture/ Hay	Herbaceous	Turf/ Grass	Wetlands	Weighted Mean
SUPY	50.6	50.7	50.7	50.7	50.7	50.8	50.6	50.9	50.7	50.9	50.7
SURO	6.5	6.6	6.6	6.6	4.5	0.5	2.9	2.5	3.0	0.3	3.5
IFWO	5.5	5.5	5.5	5.5	6.3	3.6	5.5	5.8	5.6	2.7	5.1
AGWO	10.0	10.0	10.0	10.0	11.6	11.8	13.3	12.9	13.3	9.5	11.9
IGWI	1.2	1.2	1.2	1.2	1.3	1.6	1.6	1.5	1.6	2.3	1.5
CEPE	7.5	7.5	7.5	7.5	7.6	10.9	7.3	7.6	7.0	9.0	8.1
UZET	13.2	13.2	13.3	13.3	13.7	8.5	12.9	13.0	13.1	10.9	12.1
LZET	5.7	5.7	5.7	5.7	5.2	12.4	6.1	6.3	6.1	10.6	7.3
AGWET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0
BASET	0.6	0.6	0.6	0.6	0.1	1.0	0.6	0.8	0.6	1.7	0.7

SUPY = Water supply to soil surface (precipitation)

SURO = Surface outflow

IFWO = Interflow outflow

AGWO = Active groundwater outflow

IGWI = Inflow to inactive groundwater

CEPE = Evaporation from interception storage

UZET = Evapotranspiration from the upper zone

LZET = Evapotranspiration from the lower zone

AGWET = Evapotranspiration from active groundwater storage

BASET = Evapotranspiration from active groundwater outflow (baseflow).

3.3.4 EVALUATION OF OTHER SOURCES

Continuous flow provided by Stroud and other sources were used for evaluating storm timing, relative runoff magnitudes, and parameter adjustments by model land use categories. The three locations where discharge data were provided by other sources matched well with the simulated data except were consistently 20–40 percent higher than the observed data at all three locations. Data from the primary USGS calibration gage was used to verify whether it was possible to get the flow at the other sites while still achieving the flow at the USGS gage. That analysis concluded that if the flows from other sources were matched in the simulation (which would represent 14 inches of runoff above the lake) 30 inches of runoff below the lake would need to be simulated to get to the average 19 inches of runoff calculated with the USGS gage for the entire watershed. It was determined that this was not reasonable and attributed the issue to errors in the flow calculations. Because of the reasons presented in this paragraph, statistics for flow calibration for other flows are not included in this report.

3.3.5 2021 DATA EVALUATION

For the Stroud flow data, the statistics were skewed by an extreme storm on September 1st, 2021 that is being over-simulated. The over-simulation of that storm is attributed to the quality and scale of the gridded data not accurately representing intense, isolated storm events. Figure 3-8 shows the discrepancy that occurred during the storm on East Branch Octoraro River above the Reservoir. Similarly, when discharge and stage monitoring was taking place, no discharge measurements were able to be taken at extremely high stages that occurred during the 2021 storm. Therefore, the rating curves may not be producing accurate at flows at the magnitude of the 2021 storm. Because of the reasons presented in this paragraph, statistics for flow calibration for Stroud flows are not included in this report. Confidence in model performance above the reservoir remains satisfactory in the East and West Branches of Octoraro Creek because the model is doing well at predicting storm timing and overall fit. Statistics and plots for these sites will be included in model calibration results electronic files.

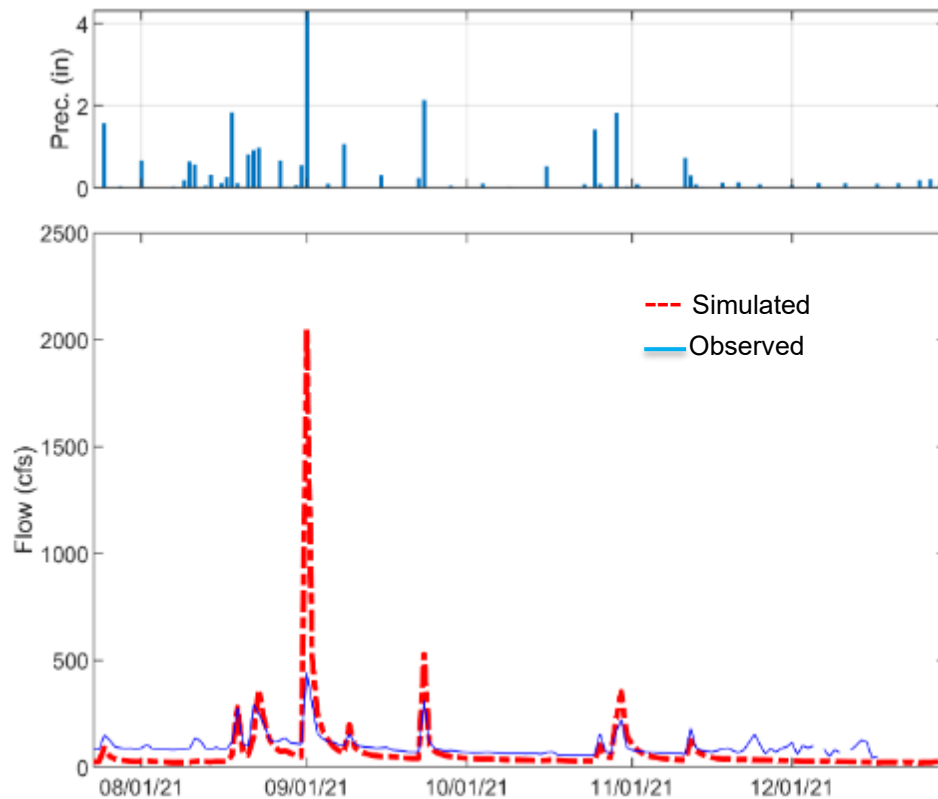


Figure 3-8. Discrepancy in 2021 Storm in East Branch Octoraro Creek at Stroud Monitoring Location.

3.4 WATER QUALITY CALIBRATION AND VALIDATION APPROACH

Water quality calibration was completed through an iterative process of parameter adjustments and comparisons of simulated and observed values and was facilitated by using scripted processes in MATLAB and the Enhanced Hydraulic Calibration Expert System (HSPEXP+). Water quality validation involved comparing model results to a separate set of observed values not used for calibration to determine whether or not the expected differences reflected the change in watershed characteristics between the calibration and validation time periods. More information about the water quality calibration and validation approach and criteria are included in the project QAPP [RESPEC and The Cadmus Group LLC, 2021].

3.4.1 DATA

Observed water quality samples were primarily used for model calibration and validation; however, these data also helped to quantify source contributions and boundary conditions. The specific constituents modeled in this study include the following constituents needed for modeling nutrients in HSPF:

- / TSS
- / Water temperature

- / DO
- / CBOD_u (i.e., total CBOD)
- / NO₂/NO₃
- / Total NH₄
- / Total nitrogen (TN), calculated from TKN, NO₂, and NO₃
- / PO₄
- / TP
- / Total organic carbon (TOC)
- / Phytoplankton as chlorophyll *a* (CHLA)
- / Benthic CHLA.

Table 3-7 shows the time-series data collected for the water quality calibration and validation of the model application. Primary data sources include the U.S. Water Quality Portal and USGS. SWRC collected water quality data for the project over a year of the modeling period. Additional water quality data were provided by other sources.

Table 3-7. Secondary Environmental Time-Series Data Assembled for Calibration/Validation

Data Type	Source
TSS (mg/L)	PADEP, MDE, EPA, SRBC, USGS, Other, CBP
Nutrients (mg/L)	PADEP, MDE, EPA, SRBC, USGS, Other, CBP
Dissolved Oxygen (mg/L)	PADEP, MDE, EPA, SRBC, USGS, Other, CBP

Water quality data for the Octoraro Watershed were compiled from the National Water Quality Monitoring Council Water Quality Portal (<https://www.waterqualitydata.us>), which includes data from the USGS Maryland Water Science Center, the USGS Pennsylvania Water Science Center, PADEP, MDE, and EPA National Aquatic Resource Survey. Water quality data was also provided by the Chesapeake Bay Program (https://www.chesapeakebay.net/what/downloads/cbp_water_quality_database_1984_present), SRBC (<https://mdw.srbc.net/waterqualityportal>), and other sources, which included data from the Octoraro Source Water Collaborative and Octoraro Watershed Association/Volunteer Coalition. The SRBC collected water quality data for this project and plans to continue sampling at the two continuous stations over the next 2 years.

The water quality dataset compiled from the previously listed sources includes ambient surface-water quality sites (i.e., grab samples) and continuous monitoring sites. Grab samples were collected at locations throughout the project area. Figure 3-9 shows primary, secondary, and tertiary water quality calibration locations and the data available at each site are shown in Table 3-8. Primary calibration sites are the main sites at which the calibration occurs. They are typically on the mainstem and/or have the largest datasets. Less weight is given to secondary calibration sites, as they are typically further upstream and have less data available. Tertiary calibration sites typically have very little data or are on the furthest upstream reaches, and although plots are generated for tertiary sites, they are given the least amount of consideration during the calibration.

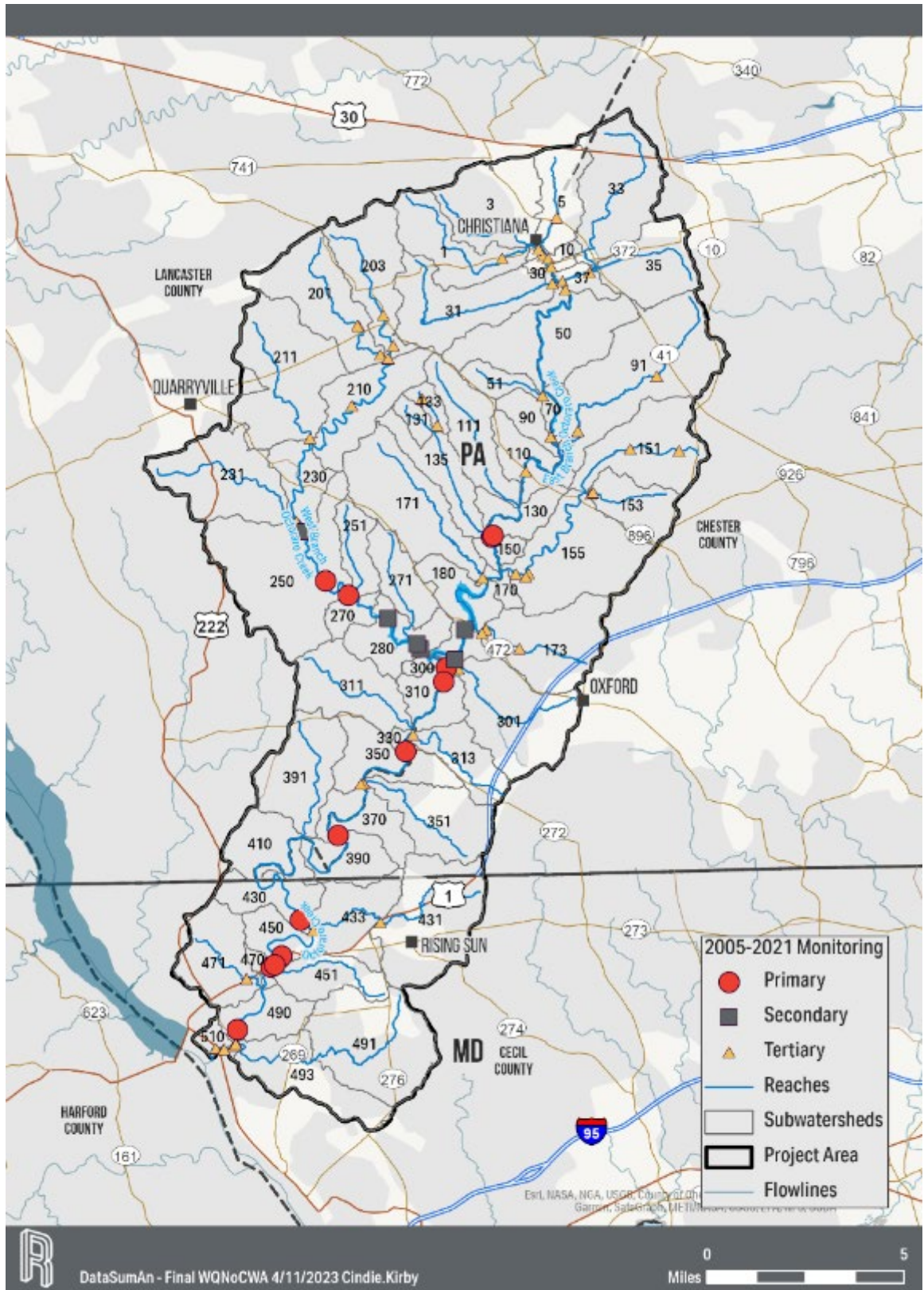


Figure 3-9. Octoraro Creek Water Quality Monitoring Locations With Symbol Type/Color Representing the Calibration Category.

Table 3-8. Summary of Available Water Quality Data by Reach (Page 1 of 2)

Reach	Rank	CHLA	D-NH ₃ + NH ₄	D-NO ₂	D-NO ₂ + NO ₃	D-NO ₃	DO	D-ORTHO	D-PO ₄	S-SOLIDS	TKN	TN	T-NH ₃ + NH ₄	TOTAL
1	Tertiary						8			8		8		24
3	Tertiary						8			9		9		26
5	Tertiary						8			8		8		24
10	Tertiary		4	4	2	4	10	4		8		8		44
31	Tertiary						8			8		8		24
37	Tertiary		6	6	3	6	11	6		9		9		56
50	Tertiary						8			8		8		24
70	Tertiary		30	30	15	30	23	30		8		8		174
91	Tertiary		8	8	4	8	18	8		7		7		68
110	Secondary	9								6				15
130	Primary						11	389	392	399	2	10	256	1,459
135	Tertiary						9	93	93	100		8	50	353
151	Tertiary						16							16
153	Tertiary		2	2	1	2	1	2						10
155	Tertiary		6	6	3	6	11	6		8		8		54
171	Tertiary						8			8		8		24
173	Tertiary		4	4	2	4	9	4		7		7		41
180	Secondary	60					40			76		55	39	270
201	Tertiary						17			16		16		49
203	Tertiary						16			16		16		48

Table 3-8. Summary of Available Water Quality Data by Reach (Page 2 of 2)

Reach	Rank	CHLA	D-NH ₃ + NH _e	D-NO ₂	D-NO ₂ + NO ₃	D-NO ₃	DO	D-ORTHO	D-PO ₄	S-SOLIDS	TKN	TN	T-NH ₃ + NH _e	TOTAL
210	Tertiary						8			8		8		24
211	Tertiary						8			8		8		24
231	Tertiary						8			8		8		24
250	Primary						12	392	395	397	2	11	257	1,466
280	Secondary	81					51			108		76	54	370
300	Primary	72					81			134		105	50	442
301	Tertiary		8	8	4	8	4	8						40
310	Secondary	9								4	6		3	22
313	Tertiary		6	6	3	6	3	6						30
351	Tertiary		2	2	1	2	9	2		8		8		34
430	Secondary	12	68	14	12	64	123	126	60	80	14	99	159	831
431	Tertiary							47	48	1			40	136
433	Tertiary	12	12	12	12	12	12	99	87	12		12	75	357
450	Primary		237		237		187	237	82	237		237	237	1,691
470	Primary		310		414		264	311		301	231	307	310	2,448
471	Tertiary	8	12	12	12	12	12	35	24	12		12	63	214
490	Secondary							85	86				69	240
493	Tertiary	12	12	12	14	12	14	13	3	12		12	67	183
510	Tertiary	12	12	12	12	12	26	12		17	4	16		135

3.4.2 CRITERIA

The principle of watershed water quality calibration is to obtain acceptable agreement of observed and simulated concentrations (i.e., within defined criteria or targets) while keeping the instream water quality parameters within physically realistic bounds and the nonpoint-loading rates within the expected ranges from the literature. The general water quality calibration targets or tolerances for HSPF applications are shown in Table 3-9.

Table 3-9. General Calibration Targets or Tolerances for HSPF Applications [Donigian, 2000]

Calibration Parameter	Difference Between Simulated and Recorded Values (%)		
	Very Good	Good	Fair
Sediment	< 20	20–30	30–45
Water Temperature	< 7	8–12	13–18
Water Quality/Nutrients	< 15	15–25	25–35
Pesticides/Toxics	< 20	20–30	30–40

Stipulations:

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

3.4.3 METHODS

The following steps were performed at each of the calibration stations after the hydrologic calibration and validation:

1. Estimated all model parameters, including land-use specific accumulation and depletion/removal rates, wash-off rates, and subsurface concentrations.
2. Tabulated, analyzed, and compared the simulated annual nonpoint-loading rates with the expected range of nonpoint-loading rates from each land use (and each constituent) and adjusted the loading parameters when necessary.
3. Calibrated instream water temperature, sediment, DO, and nutrients to the observed data.

A calibration goal was to keep the parameterization consistent throughout the project area to avoid curve fitting. Curve fitting is adjusting parameters reach by reach to force model results to follow the observed data curve without justification as to why two neighboring reaches can exhibit such different behavior. Calibrating this way often causes inconsistencies when using the model to define protection and restoration goals. Furthermore, HSPF guidance documents were used during calibration to ensure parameters were within acceptable ranges [EPA, 2006; RESPEC Consulting & Services, 2018].

3.4.3.1 LAND COVER LOADING RATES

The primary calibration parameters characterizing the landscape-erosion processes are the coefficients and exponents from three equations representing different soil detachment and removal processes (detachment from the soil matrix by rainfall, wash-off capacity, and removal). Nonpoint sources of total ammonia and nitrate-nitrite were simulated through accumulation, depletion/removal, and a first-order wash-off rate from the 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. BOD was also simulated using the sediment-associated wash-off. Subsurface flow concentrations were estimated on a monthly basis. Atmospheric depositions of nitrogen and ammonia were applied to all the land areas and contributed to the nonpoint source load through the buildup/wash-off process.

The existing Chesapeake Bay Program model land-cover loading rates for the Octoraro Watershed were downloaded from the CAST website (<https://cast.chesapeakebay.net/>). These loading rates were compared to model loading rates as a part of the calibration and validation. The CBP land cover classes were aggregated to appropriate HSPF model land cover classes and compared to the HSPF loading rates during calibration. Loading rates were also calculated at the HUC12 level to evaluate regional differences in water quality conditions.

3.4.3.2 INSTREAM AND RESERVOIR WATER QUALITY

The model simulates the instream and lake processes that contribute to sediment transport, algal growth, nutrient consumption, and DO dynamics. The sediment behavior for each size class was investigated to ensure that the sediment dynamics reflected the field observations. Although HSPF does not explicitly simulate stream-bank contribution dynamics, these processes were implicitly included by allowing the streambed to contribute to those loads. The required instream parameters were specified for total ammonia, inorganic nitrogen, orthophosphate, and BOD. The processes in the instream portion of the model included BOD accumulation, storage, decay rates, benthic algal

oxygen demand, settling rates, and reaeration rates. Atmospheric deposition onto water surfaces was represented in the model as a direct input to the lakes and river systems. Biochemical reactions that affect DO were also represented in the model application. The overall sources considered for BOD and DO included point sources such as WWTPs, nonpoint sources from the watershed, interflow, and active groundwater flow.

The instream calibration began with temperature and sediment and then to DO and nutrients. The DO and nutrient calibrations were conducted in tandem because these components depend on each other. The calibration required developing time-series graphs to compare the simulated and observed water quality data. Instream water quality calibration also included generating monthly boxplots, concentration-duration curves, and scatterplots of concentrations and corresponding flows. Hourly boxplots were generated for temperature and DO to assess the diurnal variability. Sediment scour and deposition in the streambed for each reach over the simulation period and nutrient budget were evaluated.

Lake quality calibrations are often difficult in HSPF because the model simulates a completely mixed system (homogeneous water body with no vertical stratification). To address this issue and achieve a dynamic, steady-state system, instream parameters for lakes/ponds are generally very different compared to reaches [AQUA TERRA Consultants, 2015]. Bias as a result of lake stratification is reduced by calibrating the observed values taken from the surface to 1 meter in depth. Octoraro Reservoir is represented in HSPF and also represented in WASP to ensure accuracy.

3.4.3.3 BMP REPRESENTATION PERIOD

BMP implementation data from the CBP CAST tool was used to identify different periods during the full simulation that represent consistent BMP implementation. Figure 3-10 shows the estimated amount of implementation for major BMP groups over the simulation period. The data show a steady increase in BMP implementation for most major BMP groups. The Nutrient Application Management BMP group showed a large increase in implementation around 2012, increasing the amount of this BMP group from the least implemented to the most implemented. Urban Restoration and Septic Systems also show significant increases around that time.

Water quality data in the Octoraro Reservoir were used to evaluate the impact of the increase in implementation in 2012. Figure 3-11 shows the observed Nitrate for Octoraro Reservoir, which shows a noticeable decrease after 2012. Figure 3-12 shows the dissolved oxygen (DO) in the Octoraro Reservoir, showing a noticeable increase in the minimum annual DO after 2014. The delay in DO response to increased

implementation was expected because the effect of nutrient reductions on instream processes, such as sediment oxygen demand, can take longer to realize because they represent a buildup of oxygen-demanding material in a stream or lakebed over a longer period.

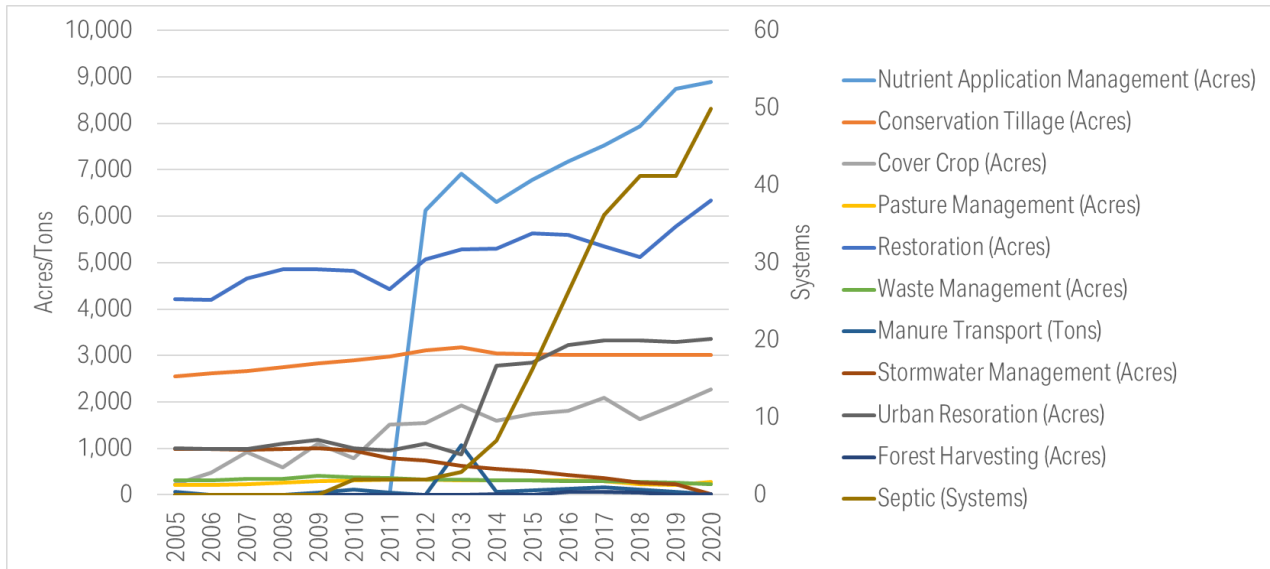


Figure 3-10. Amount of Implementation for Major Best Management Practice Groups.

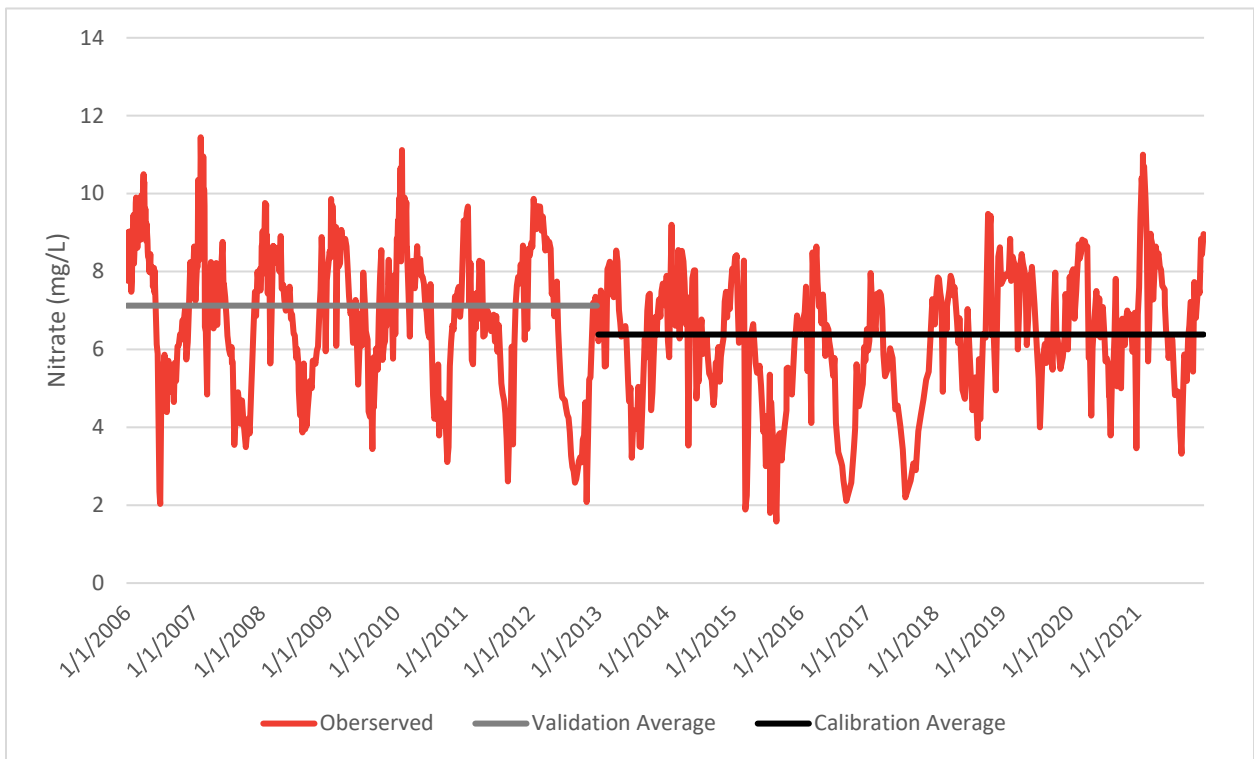


Figure 3-11. Observed Nitrate Timeseries.

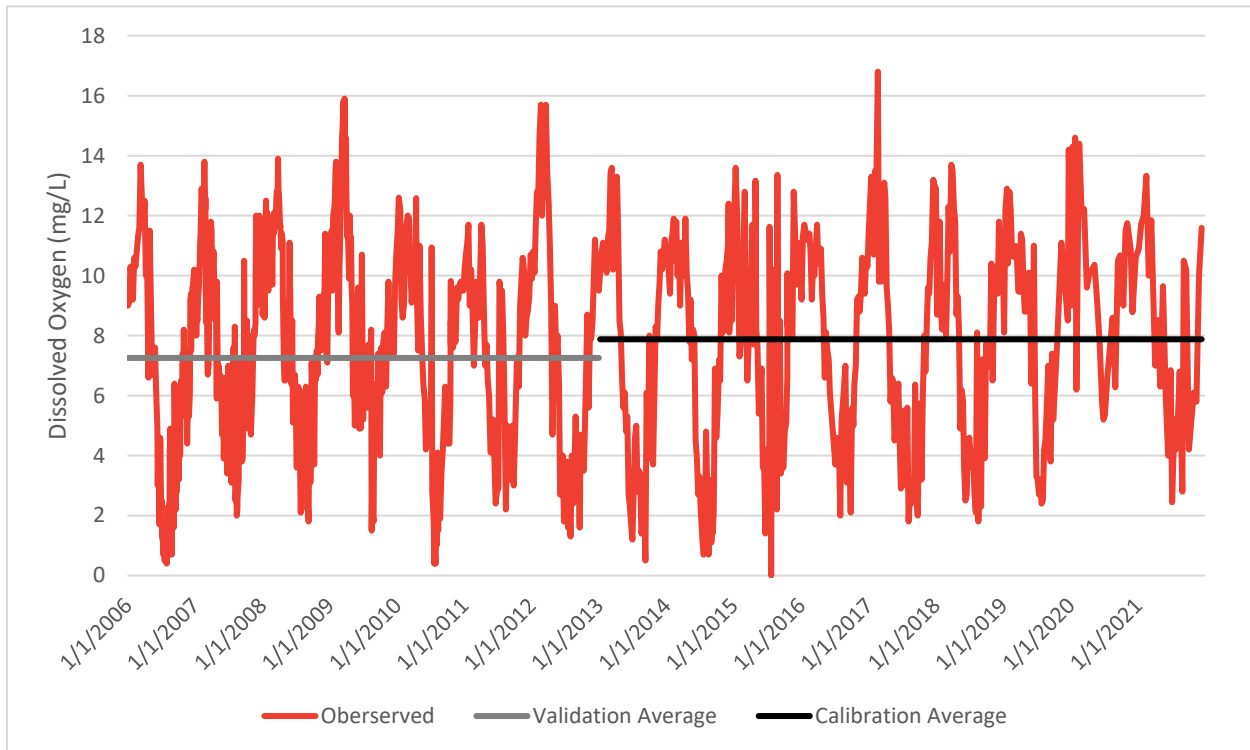


Figure 3-12. Observed Dissolved Oxygen Timeseries.

The recent period (2013–2021) was selected as the primary time period for calibrating water quality parameters to represent the current BMP implementation and water quality conditions in the watershed. The entire period (2006–2021) and the initial period (2006–2012) were used as validation periods to verify that the differences between observed data and simulated results reflect the differences in BMP implementation and water quality conditions in the recent calibration period.

3.5 WATER QUALITY CALIBRATION AND VALIDATION RESULTS AND DISCUSSION

Water quality calibration requires adjustments of parameters that represent loads from watershed sources and instream processes. The following sections contain results and discussion of the land cover source and instream parameter adjustments. The calibration required developing a series of graphs comparing the simulated and observed water quality data.

3.5.1 LAND COVER CALIBRATION AND VALIDATION

The land cover load portion of the calibration was completed while maintaining consistent parameters in each land use category throughout the Octoraro Creek Watershed and prioritized the calibration at the primary calibration site. Approximately

40 modeled reaches had water quality monitoring data (listed in Table 3-8), which were examined during the calibration efforts to ensure consistent model results throughout the watershed.

HSPF uses nonpoint-loading rates (sometimes referred to as export coefficients), which are highly variable, with values occasionally ranging as high as an order of magnitude depending on local and site conditions of soils, slopes, topography, climate, and disturbance. As a part of the calibration, export coefficients from the HSPF modeling effort were compared to export coefficients from the CBP modeling in the overlapping area, shown in Table 3-10, for similar land covers as a part of the water quality calibration. They were used for general guidance (to supplement our past experience) in evaluating the loading rates and imposing relative magnitudes by land-use type. The Octoraro Creek Watershed Model land-use specific average annual nonpoint-loading rates (pounds per acre per year [lb/acre/year]) for TN, TP, and sediment during the calibration period are provided in Table 3-10 and Figures 3-13 through 3-15.

Table 3-10. Summary of HSPF Export Coefficients Compared to Chesapeake Bay Modeling

Land Cover	Mean Loading Rates (lb/ac/yr)					
	CPB Total Nitrogen	HSPF Total Nitrogen	CPB Total Phosphorus	HSPF Total Phosphorus	CPB Total Sediment	HSPF Total Sediment
Developed	22.0	19.3	0.547	0.858	873	813
Cropland Manure	84.1	88.5	1.40	3.72	719	718
Cropland No Manure	40.5	47.5	0.825	1.85	777	759
Cropland Small Grains	25.0	33.7	0.695	1.28	446	425
Cropland Soybean	31.5	39.8	0.545	1.15	545	540
Pasture and Hay	18.0	31.1	1.49	2.25	608	498
Turf Grass	12.1	19.8	0.512	0.525	282	276
Herbaceous	3.3	4.9	0.206	0.134	450	380
Forest	1.9	3.5	0.0266	0.0433	19.2	24.3
Wetland	6.77	2.20	0.315	0.0472	9.41	6.32

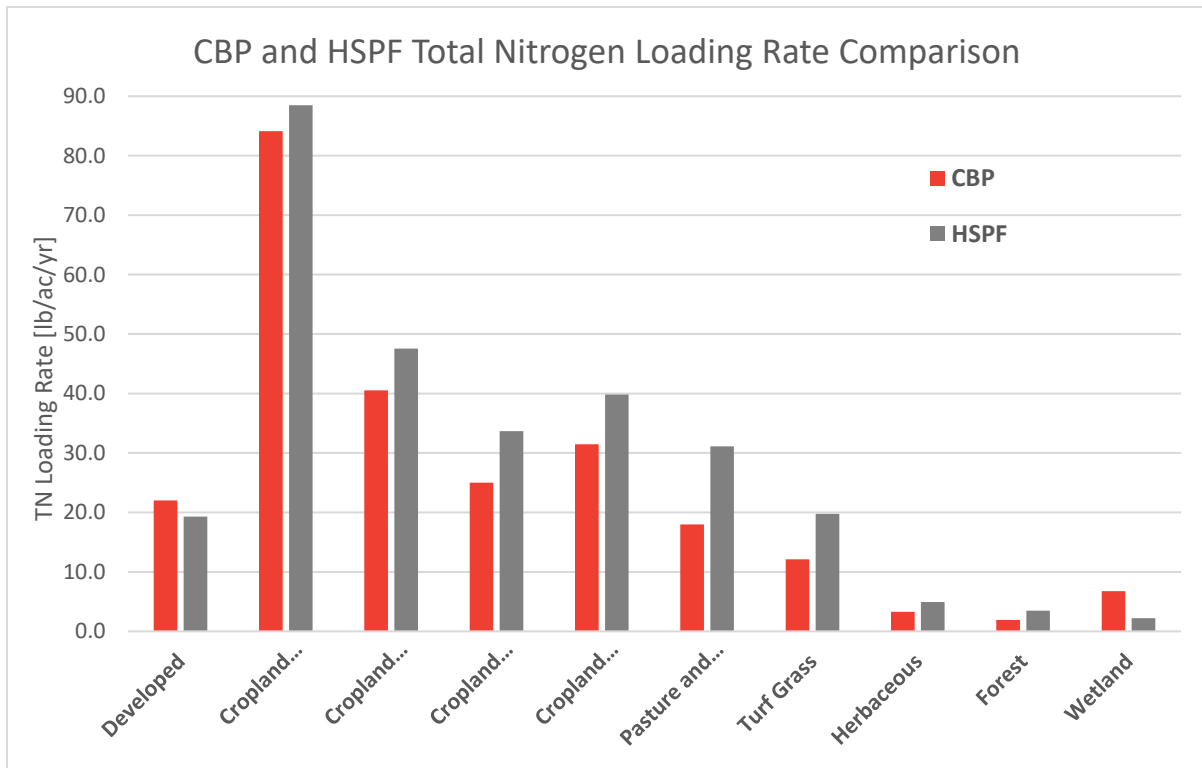


Figure 3-13. Total Nitrogen Comparison between Chesapeake Bay Model Loads and Octoraro Creek HSPF Loads.

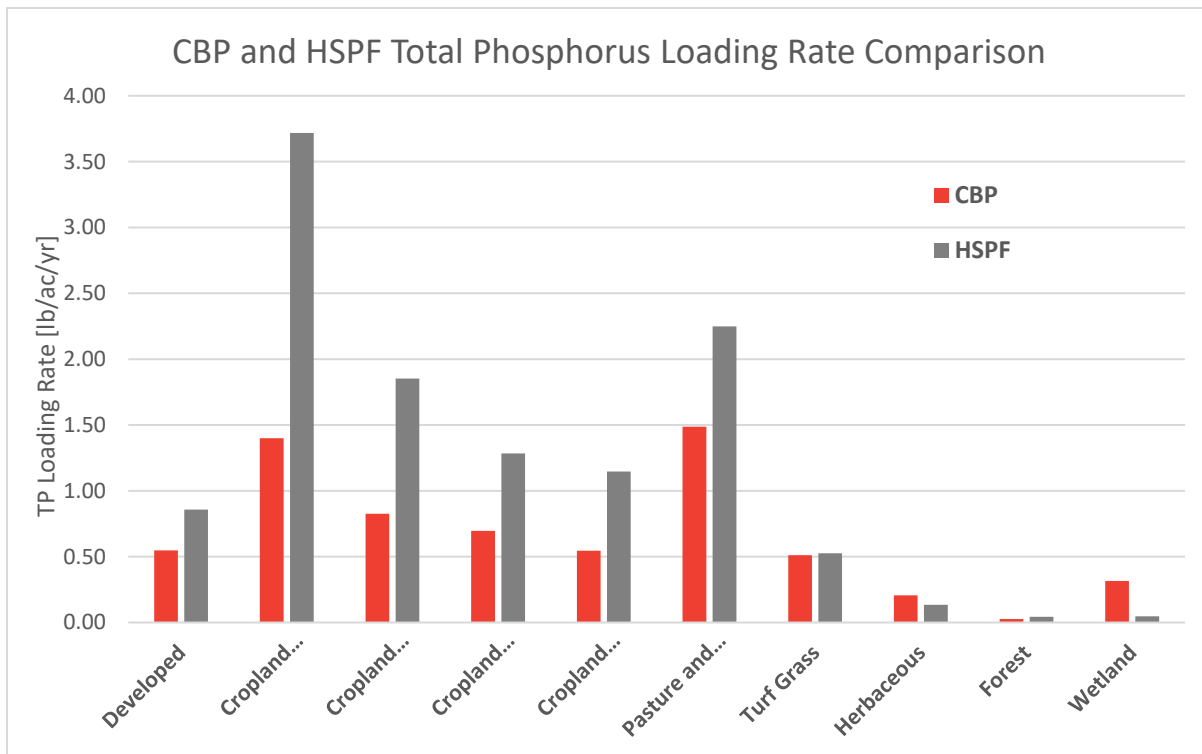


Figure 3-14. Total Phosphorus Comparison between Chesapeake Bay Model Loads and Octoraro Creek HSPF Loads.

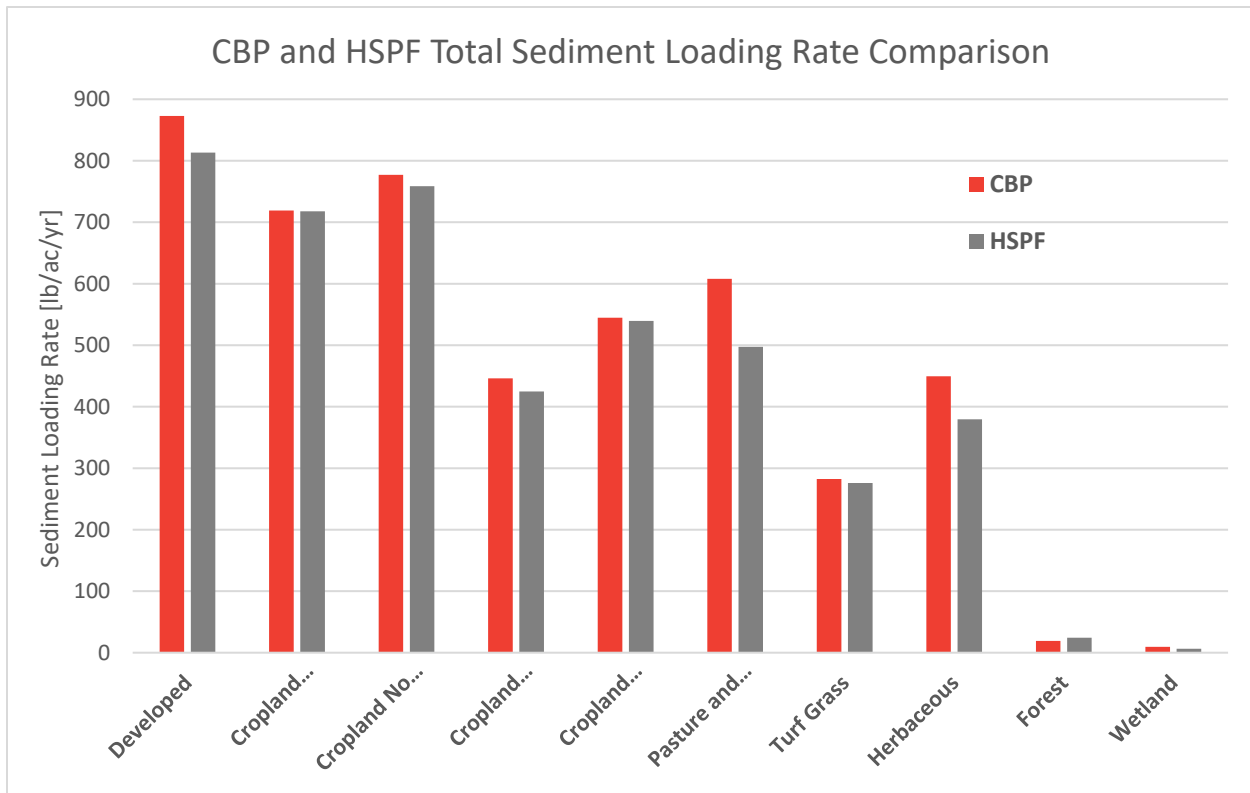


Figure 3-15. Total Sediment Comparison Between Chesapeake Bay Model Loads and Octoraro Creek HSPF Loads.

The simulated mean values for TN, TP, and sediment follow similar trends by land use when compared to the CBP modeling where loading rates for intensive agriculture and developed areas are much larger than natural areas (e.g., wetlands and forest). From a relative contribution by land use, the CBP results show a higher loading rate of TP and TN coming from wetland areas and the HSPF results simulate a larger contribution of TP coming from the cropland categories. The higher nutrient loading rate from wetlands is possible, but the source of nutrients likely originates from up-gradient land uses. The higher cropland TP loading rate simulated in HSPF is likely due to input data derived from CBP fertilizer application rates. These data were used to set initial HSPF calibration parameters, and the TP application rate for cropland was greater than 10 times that of developed and turf grass categories. Another potential reason for the larger difference in TP loads is the scale of the models where the CBP model may be factoring in losses from the Octoraro Reservoir because they use much larger watersheds.

Runoff and pollutant loads generated from the land surface, as well as point sources, septic systems, and atmospheric deposition, were summarized by source. The percent contribution of runoff, TSS, TN, and TP are shown in Figures 3-16 through 3-19,

respectively. Runoff is displayed to help visualize the relative impacts from each source. The land-cover sources were also aggregated for these outputs to aid in the review.

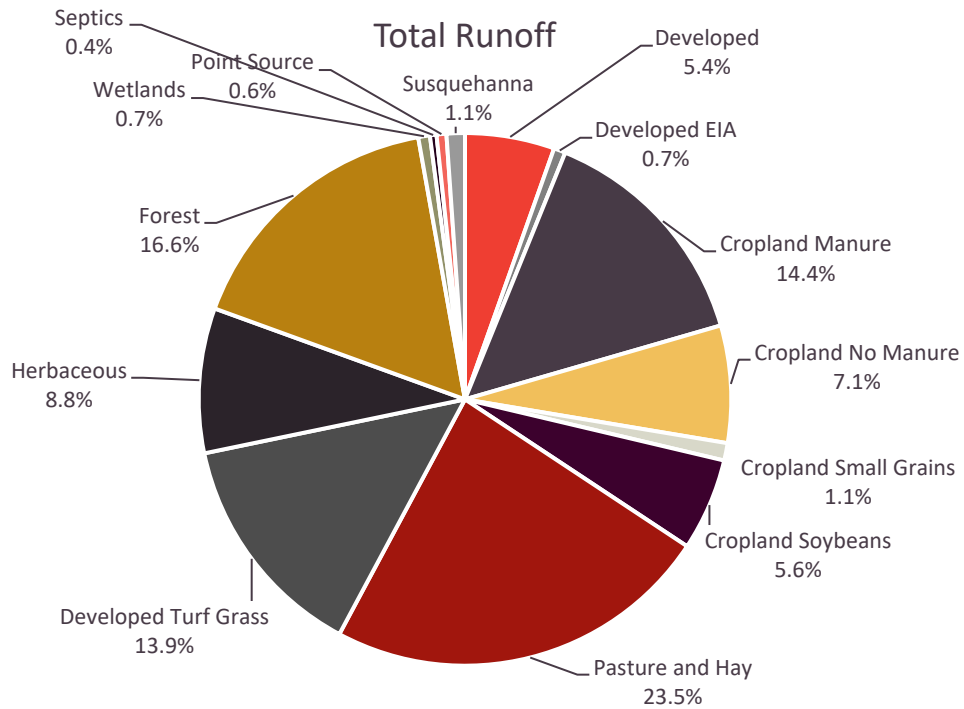


Figure 3-16. Percent Runoff Contribution.

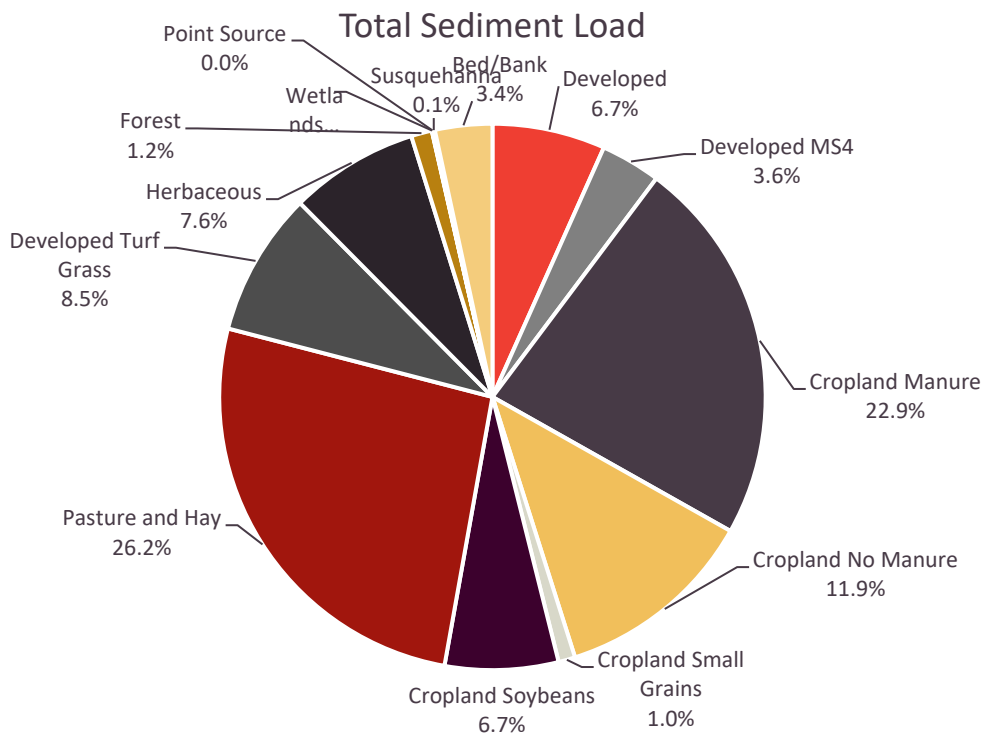


Figure 3-17. Percent Total Suspended Solids Load Contribution.

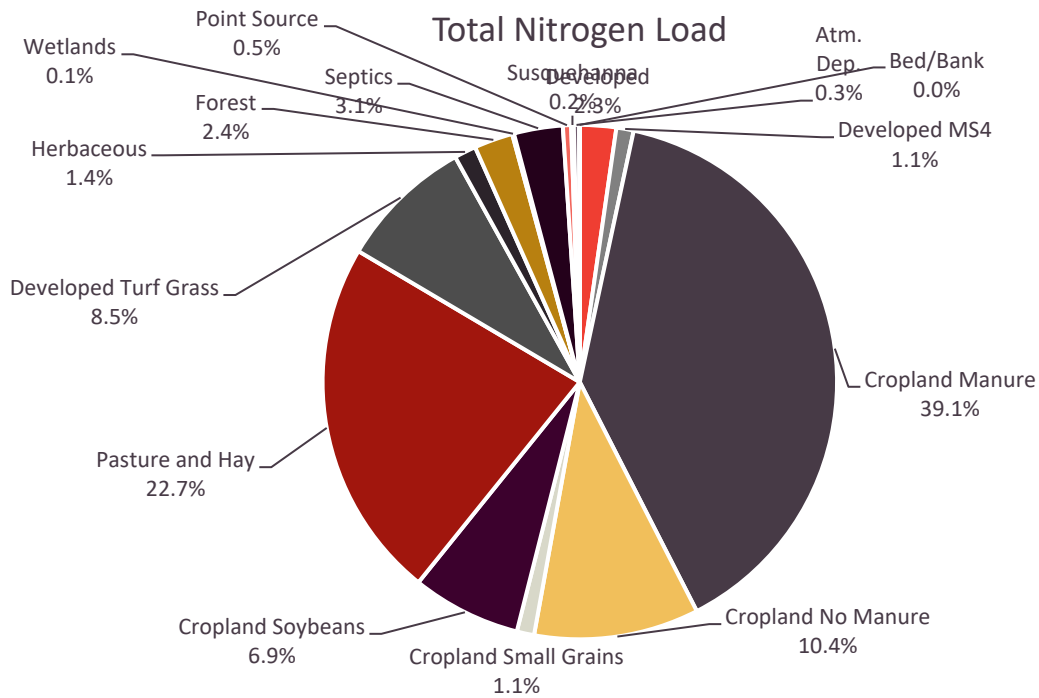


Figure 3-18. Percent Total Nitrogen Load Contribution.

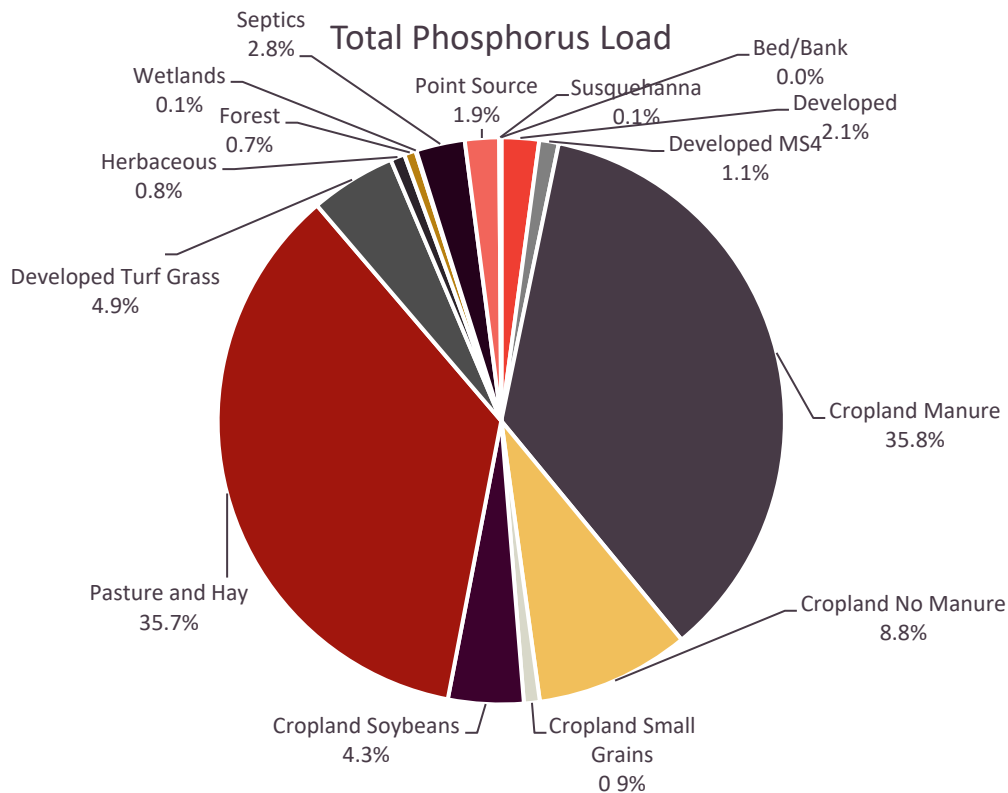


Figure 3-19. Percent Total Phosphorus Load Contribution.

Relative to the runoff contributions, the TN and TP source allocation is heavily dominated by the five agricultural categories (i.e., approximately 51 percent of the runoff is from agriculture, but it accounts for more than 80 percent of the TN and TP load). Point sources and septic systems account for only 1 percent of the runoff, but 4 percent and 5 percent of the TN and TP load, respectively.

3.5.2 INSTREAM CALIBRATION AND VALIDATION

Tables 3-11 and 3-12 provide the mean simulated and observed concentrations for all 11 primary and secondary quality stations and the five primary locations during the calibration and validation periods. The comparison of mean concentrations, and the percent differences between simulated and observed values for the calibration period (as shown in Table 3-12), demonstrate that the average simulated values across the watershed are all within 15 percent of observed data at calibration locations which all correspond to a “Very Good” quality based on the criteria. The comparisons in mean concentrations for the validation period (as shown in Table 3-13) show expected differences from the calibration period where more BMP implementation is in place. Observed values were higher for most sediment and nutrient components and lower for DO during the validation period.

Detailed explanations for each variable and shortcomings of the instream calibration are provided in the following paragraphs. The time-series plot for each variable at the primary calibration location (Reach 470) during the calibration period is shown in the body of the report, and the concentration-duration curves, monthly average boxplots, and scatter plots at the primary calibration location for the full simulation period are shown in Appendix B. The same outputs for the secondary calibration locations are included in the results folder supplied with this report.

Table 3-11. Average Annual Simulated and Observed Concentrations for the Calibration Period

Variables	Calibration Period (2013–2021)							
	All 11 Gages				5 Primary Gages			
	Average Concentration		Difference	Sample	Average Concentration		Difference	Sample
	Observed	Simulated	%	Size	Observed	Simulated	%	Size
Total Suspended Sediment	15.3	16.2	5	979	14.9	15.2	2	961
Temperature	57.9	56.3	–3	3507	57.9	56.3	–3	3501
Dissolved Oxygen	8.9	9.1	2	646	8.92	9.12	2	640
Total Nitrogen	6.20	6.21	0	263	6.20	6.21	0	263
Total Inorganic Nitrogen	6.70	6.63	–1	2242	5.62	5.62	0	1956
Ammonia as N	0.137	0.129	–6	905	0.137	0.129	–6	896
Nitrite-Nitrate as N	5.48	5.49	0	237	5.48	5.49	0	237
Total Kjeldahl Nitrogen	0.749	0.690	–8	242	0.746	0.689	–8	240
Total Nitrate as N	6.92	6.83	–1	1100	7.35	7.27	–1	823
Total Phosphorus	0.167	0.184	10	275	0.163	0.180	11	263
Orthophosphate as P	0.170	0.147	–13	1035	0.170	0.147	–13	1035
Chlorophyll a	7.5	7.7	3	28	19.8	17.6	–11	4
Total Organic Carbon	3.9	4.2	7	848	3.92	4.20	7	843

Table 3-12. Average Annual Simulated and Observed Concentrations for the Validation Period

Variables	Validation Period (2006–2012)							
	All 13 Gages				5 Primary Gages			
	Average Concentration		Difference	Sample	Average Concentration		Difference	Sample
	Observed	Simulated	%	Size	Observed	Simulated	Observed	Simulated
Total Suspended Sediment	16.1	14.7	–9	848	15.2	14.4	–5	809
Temperature	57.5	56.5	–2	2780	57.4	56.4	–2	2683
Dissolved Oxygen	8.1	8.7	8	875	7.87	8.39	7	782
Total Nitrogen	6.59	6.39	–3	246	6.57	6.31	–4	161
Total Inorganic Nitrogen	7.15	6.51	–9	2378	5.69	5.51	–3	1824
Ammonia as N	0.136	0.124	–9	1030	0.145	0.135	–6	852
Nitrite-Nitrate as N	5.63	5.51	–2	161	5.55	5.38	–3	139
Total Kjeldahl Nitrogen	0.655	0.685	5	40	0.594	0.687	16	38
Total Nitrate as N	7.33	6.63	–10	1187	7.89	7.18	–9	833
Total Phosphorus	0.189	0.176	–7	171	0.252	0.206	–18	89
Orthophosphate as P	0.201	0.121	–39	1016	0.213	0.133	–37	812
Chlorophyll a	8.8	8.4	–4	22	—	—	—	0
Total Organic Carbon	3.9	3.9	–2	631	3.99	3.91	–2	544

3.5.2.1 SEDIMENT

The sediment calibration focused on the upper-range concentration values where wash-off from the land (KSER) was most sensitive. The sediment time-series water quality calibration plot at the primary calibration location (Reach 470) are shown in Figure 3-20. Figure 3-21 shows a map of total suspended sediment loading rates by subwatershed. Mid-range and lower concentration values were calibrated using instream parameters where the thresholds for scour and deposition (TAUCS and TAUCD) and the rate of erodibility (M) were most sensitive. The simulated TSS concentrations in the reservoir are slightly higher during wetter periods and lower during drier periods when compared to the observed data. Modeled scour outputs were reviewed to ensure the reservoir was not eroding, and settling parameters only affected the lower-end values. If wash-off was calibrated to the observed lake data, all other calibration reaches would be significantly under-predicted and would require an unrealistic amount of scour to increase TSS concentrations. Lower-end TSS concentrations were improved by adding phytoplankton concentrations to the inorganic portion of sediment in HSPF. These plots are included in the results folder supplied with this report.

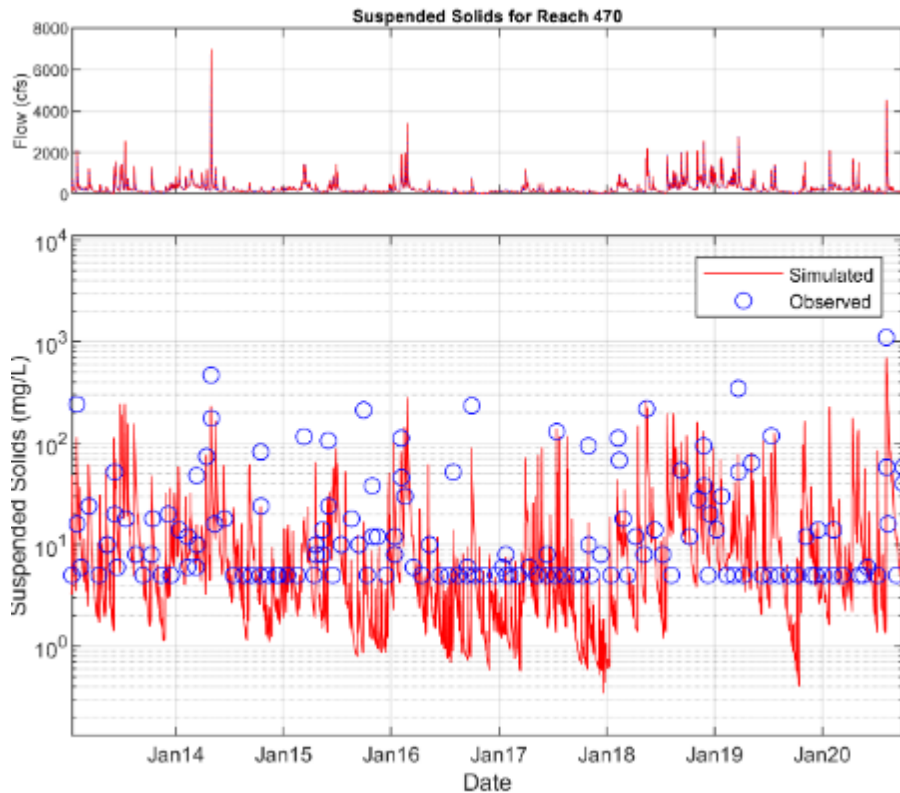


Figure 3-20. Total Suspended Solids Time-Series Calibration Plot for HSPF Reach 470 (Calibration Period).

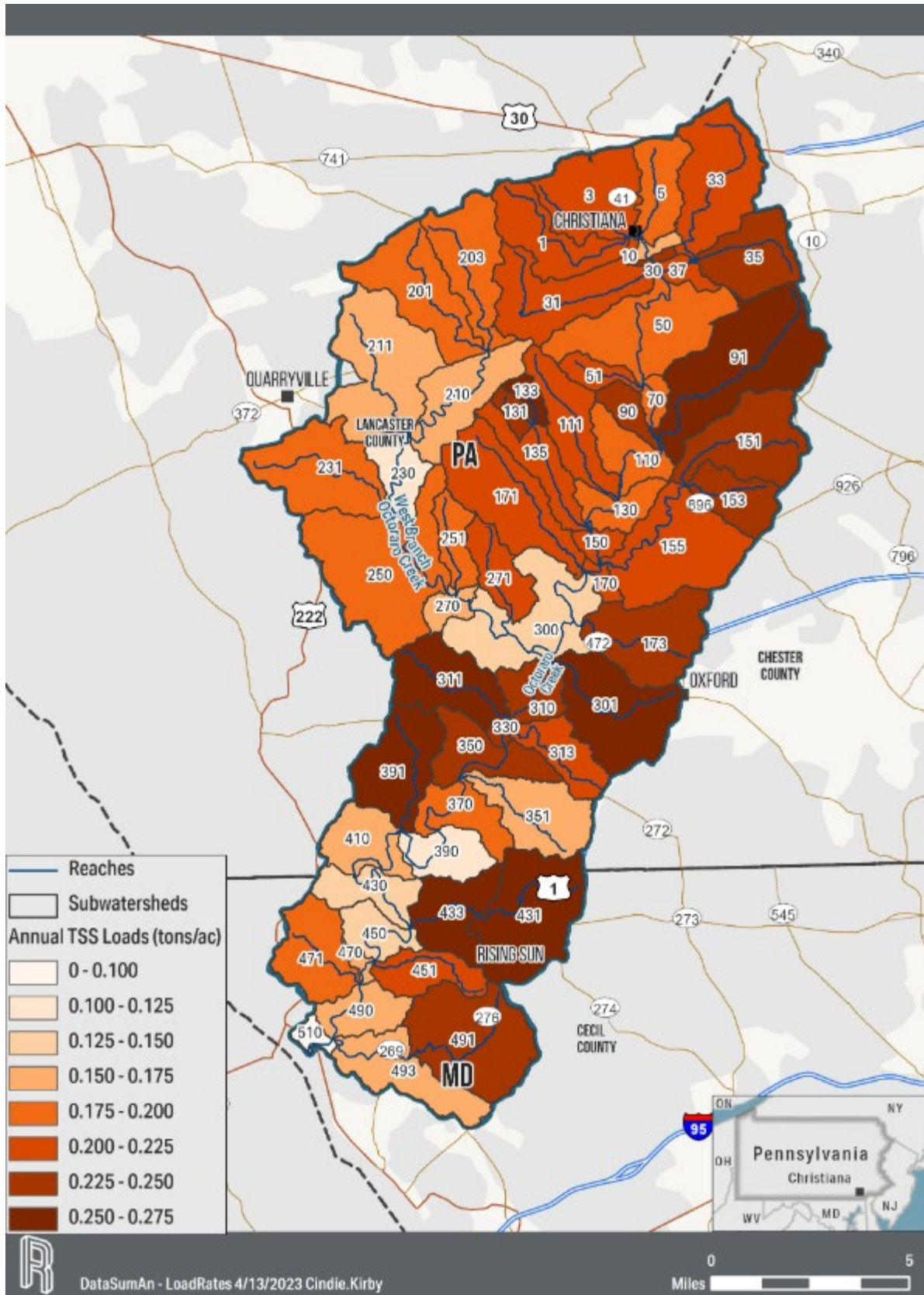


Figure 3-21. Annual Total Phosphorus Loading Rates by Subwatershed.

3.5.2.2 DISSOLVED OXYGEN AND WATER TEMPERATURE

The water temperature and DO simulations show an inverse relationship and are usually well simulated in terms of both the range of values and seasonal patterns. The water temperature and dissolved oxygen time-series water quality calibration plots at the primary calibration location (Reach 470) are shown in Figure 3-22 and 3-23, respectively. Continuous temperature and dissolved oxygen plots at Reach 310 are shown in Figures 3-24 and 3-25, respectively. Low values of DO during the summer months and high values during the winter months are occasionally missed by the model, but the overall simulations are considered “very good.” There is also good agreement when compared to the continuous data. Diurnal DO swings were mainly calibrated using benthic algae parameters (MBAL, CFBALR, and CFBALG) because chlorophyll *a* (phytoplankton) values are relatively low, indicating instream growth/respiration does not play a major role in diurnal DO concentrations. Calibration to discrete samples focused on the minimum concentration values, where benthic oxygen demand (BENOD) and the reaeration constant (REAK) were used with benthic algae parameters to produce the best representation of DO dynamics.

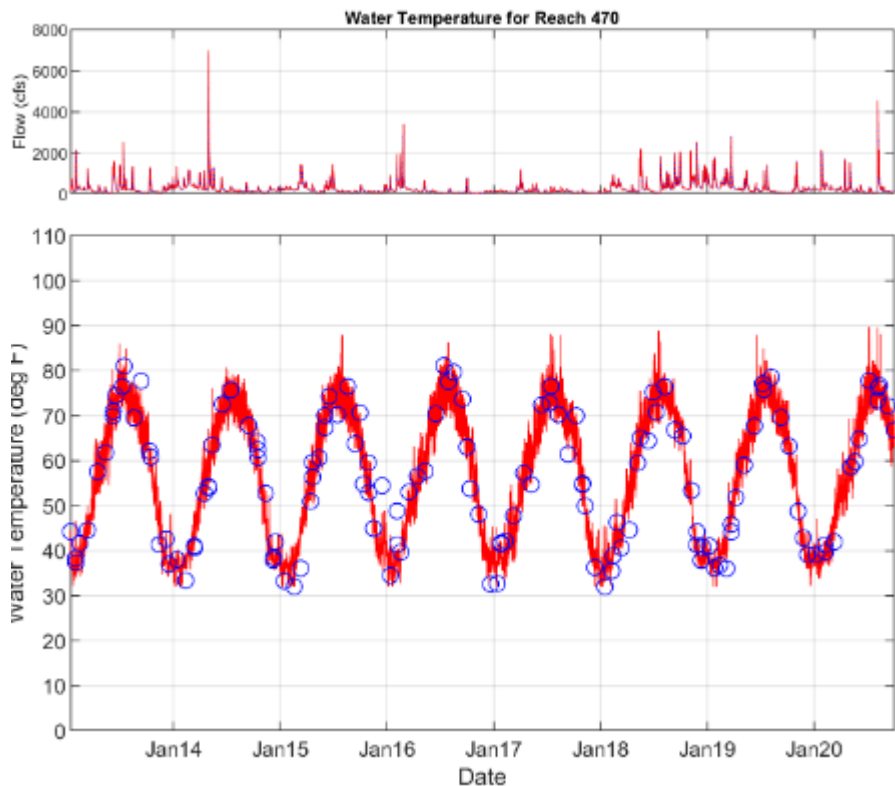


Figure 3-22. Instantaneous Temperature Time-Series Calibration Plot for HSPF Reach 470 (Calibration Period).

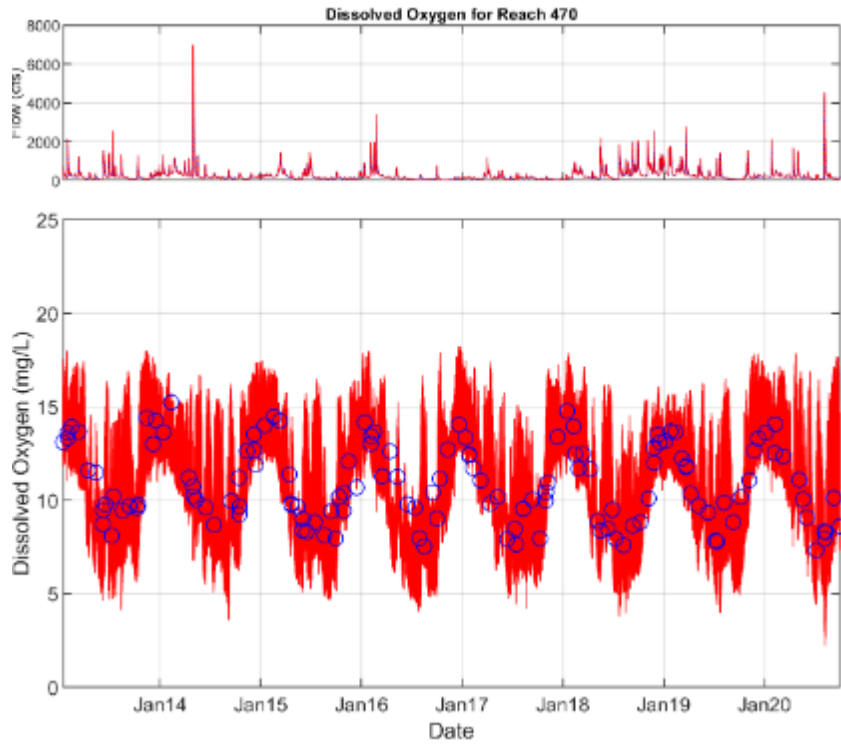


Figure 3-23. Instantaneous Dissolved Oxygen Time-Series Calibration Plot for HSPF Reach 470 (Calibration Period).

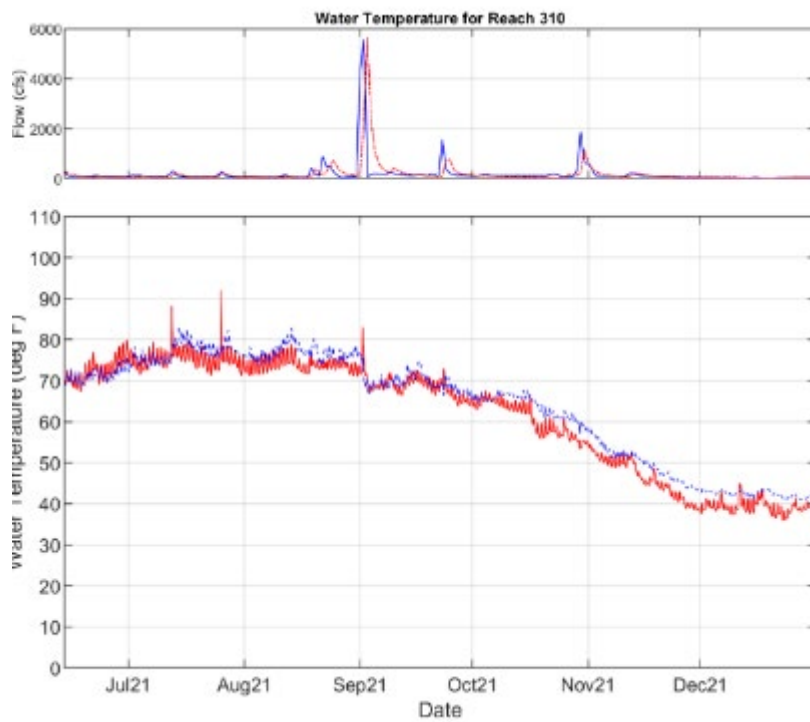


Figure 3-24. Continuous Temperature Time-Series Calibration Plot for HSPF Reach 310 (Calibration Period).

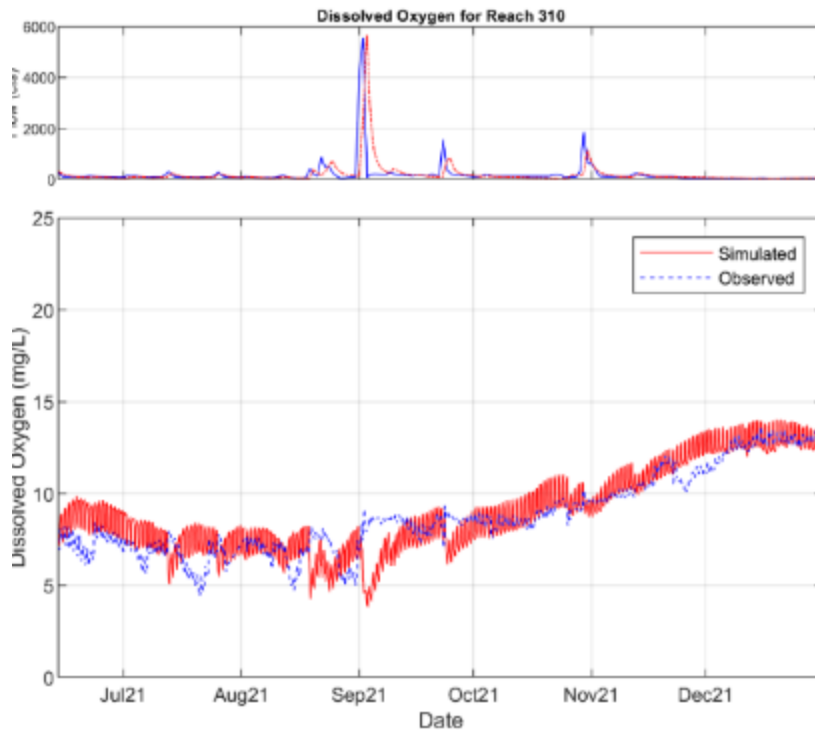


Figure 3-25. Continuous Dissolved Oxygen Time-Series Calibration Plot for HSPF Reach 310 (Calibration Period).

3.5.2.3 NUTRIENTS, BIOCHEMICAL OXYGEN DEMAND, AND CHLOROPHYLL A

Nitrate was the primary focus of the nitrogen calibration because it makes up the largest component of TN. Dissolved nitrite plus nitrate (D-NO₂+NO₃) samples (USGS) and total nitrate (T-NO₃) samples (other sources) were both used in calibration, but more weight was given to the USGS data. The nitrogen-related time-series water quality calibration plots at the primary calibration location (Reach 470) are shown in Figures 3-26 through 3-29. Figure 3-30 shows a map of total nitrogen loading rates by subwatershed. The distribution of simulated concentrations as a function of flow, seasonal patterns, and longitudinal trends match well when compared to observed data, suggesting the fate and transport processes are well represented. Statistically, both T-NO₃ and D-NO₂+NO₃ are considered “very good” overall and at the primary calibration gages. Because a large portion of calibration effort was allocated to nitrate, total inorganic nitrogen and TN are also considered “very good” across the watershed. Calibration tests indicated that instream nitrogen concentrations were most sensitive to groundwater concentrations; consequently, a large portion of the calibration focused on those parameters. This is consistent with CBP reports describing the nitrate loading to

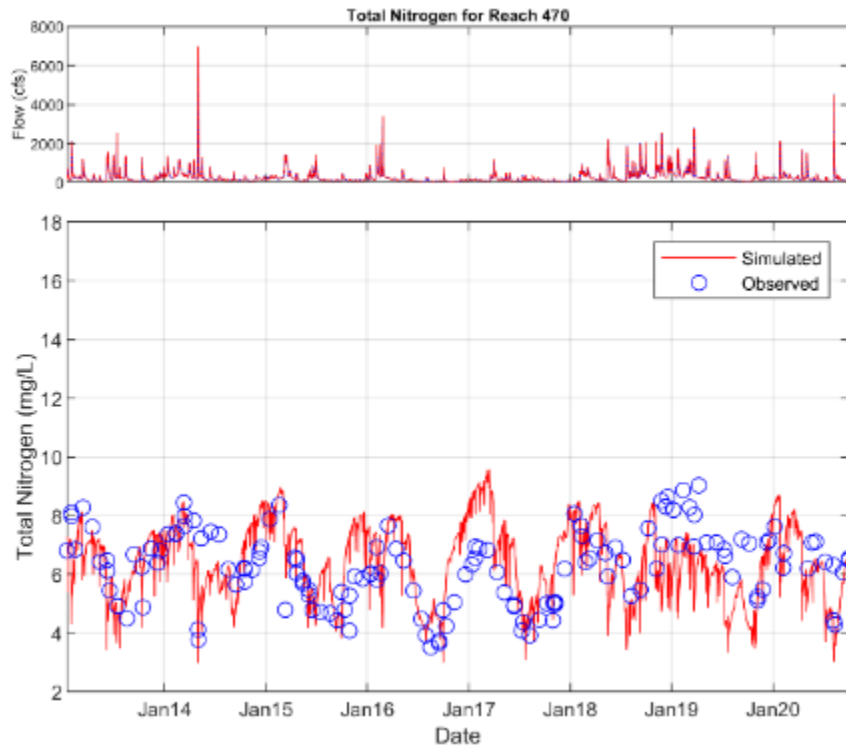


Figure 3-26. Total Nitrogen Time-Series Calibration Plot for HSPF Reach 470 (Calibration Period).

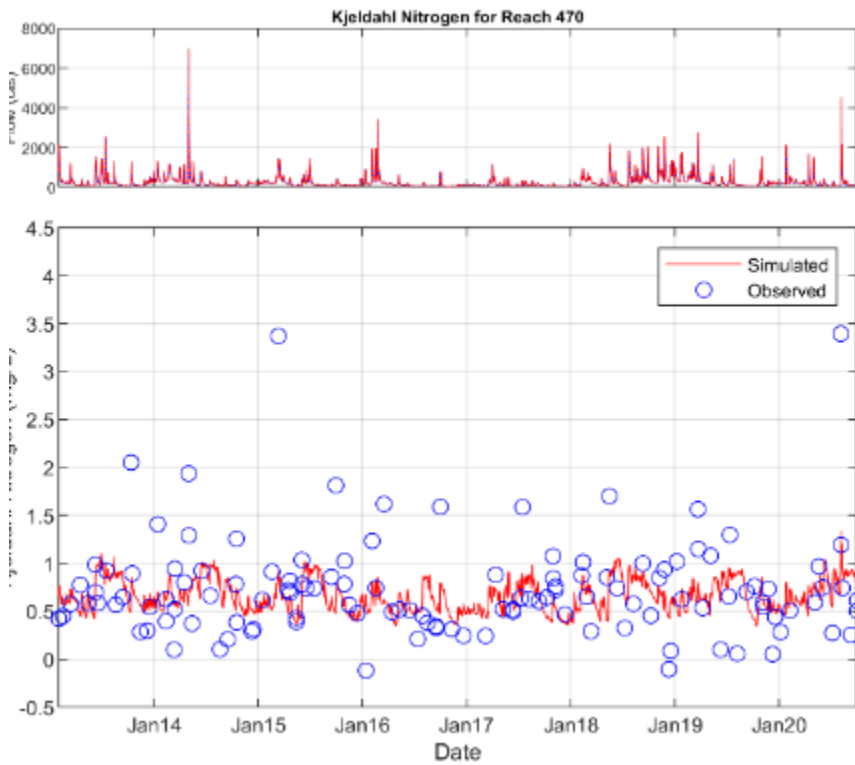


Figure 3-27. Total Kjeldahl Nitrogen Time-Series Calibration Plot for HSPF Reach 350 (Calibration Period).

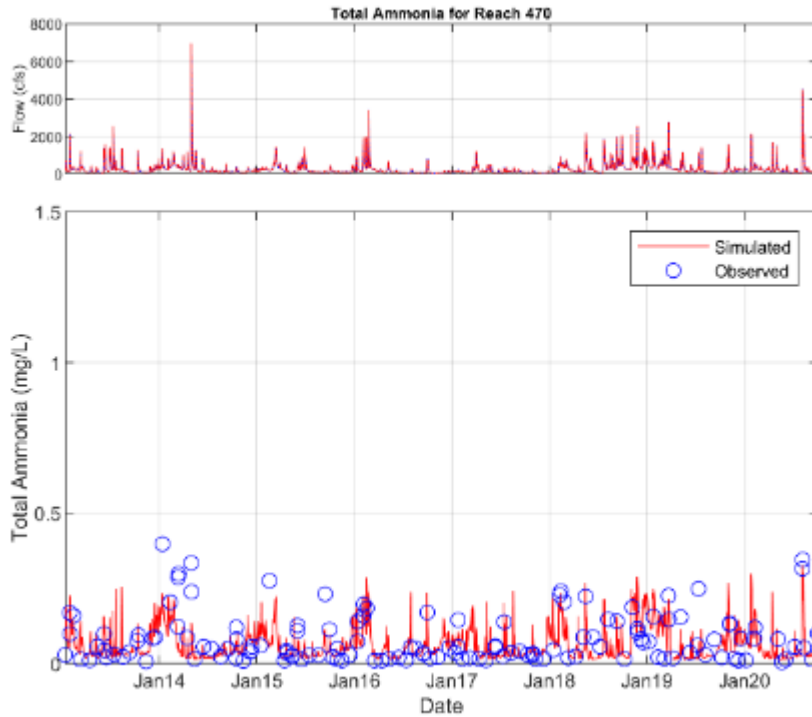


Figure 3-28. Total Dissolved Ammonia as Nitrogen Time-Series Calibration Plot for HSPF Reach 470 (Calibration Period).

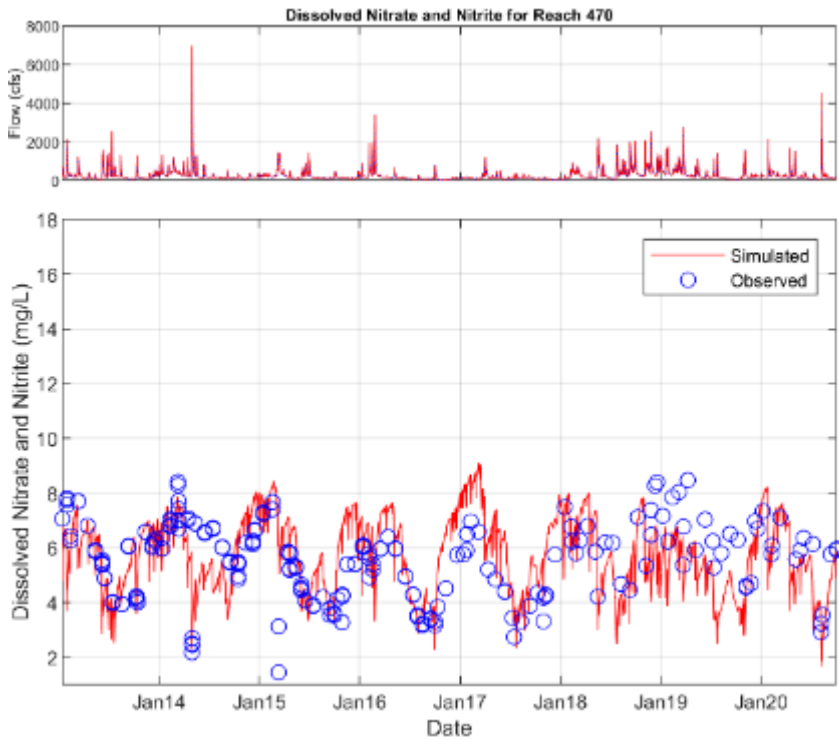


Figure 3-29. Total Dissolved Nitrite-Nitrate as Nitrogen Time-Series Calibration Plot for HSPF Reach 470 (Calibration Period).

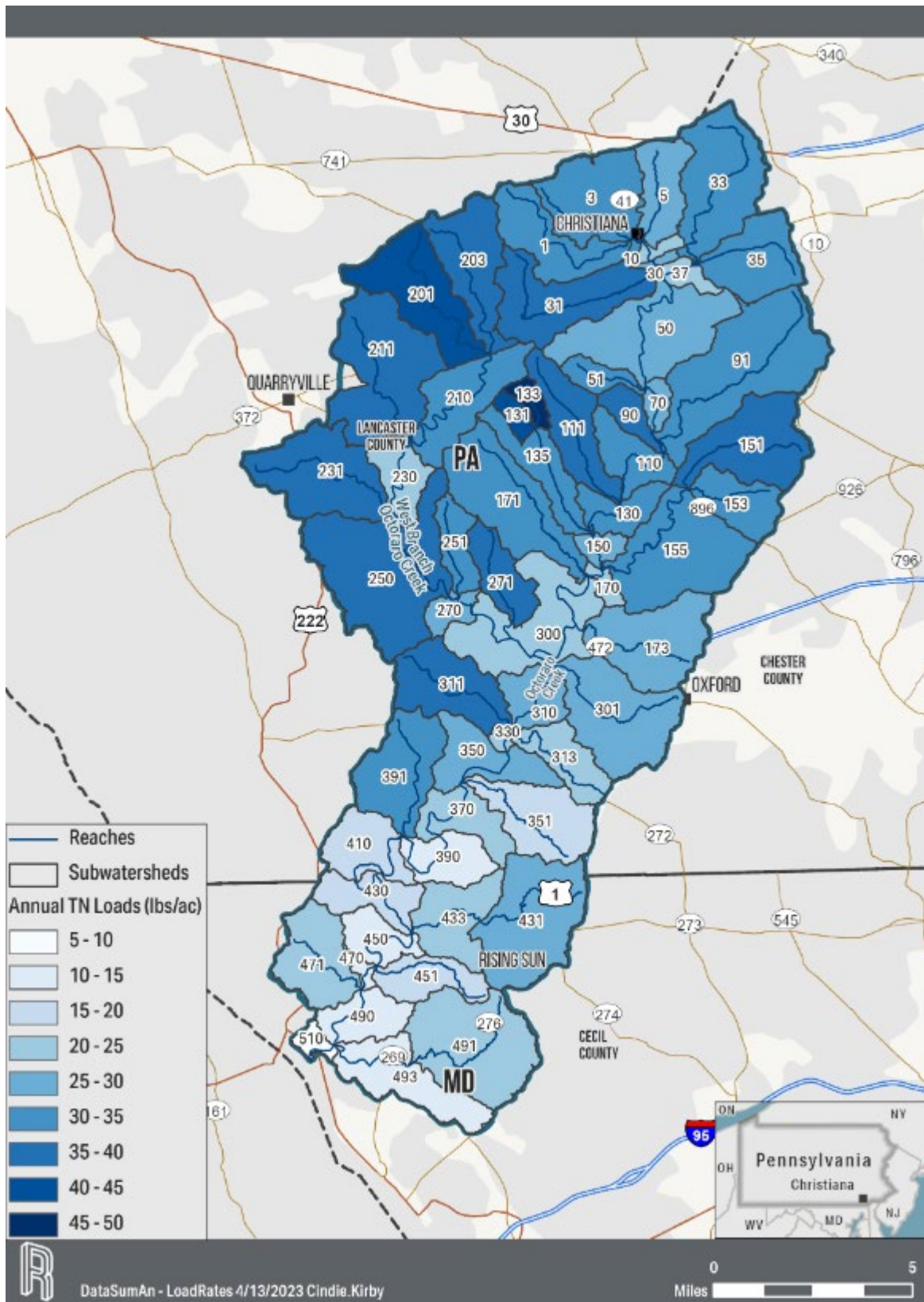


Figure 3-30. Annual Total Nitrogen Loading Rates by Subwatershed.

the Chesapeake Bay being dominated by agricultural leaching [Agricultural Loading Rate Review Steering Committee, 2016]. Instream nitrogen concentrations also showed some sensitivity to point sources and septic systems during baseflow conditions.

The total ammonia (TAM) calibration is considered “very good.” Benthic release of TAM (BRTAM) was used to maintain TAM concentrations in the reservoir. The over-simulation of concentrations at the primary gage was considered “poor” at one point during the calibration process, but results were improved by adjusting point source assumptions. The assumed TAM concentrations at the Allan Myers Materials (PA0123480–Reach 410) and Rock Springs Quarry (PA0594784–Reach 430) were both reduced from 2 mg/L to 0.1 mg/L. A correction factor of 0.35 was also applied to the TAM data for Rising Sun WWTP (MD0020265–Reach 433) to better represent the facility’s upgrade in treatment processes which occurred in August of 2015. Average concentrations of TAM for the facility were 20 mg/L and 1.2 mg/L for the pre- and post-upgrade, respectively. The sampling data are not as complete post-upgrade, so filled concentrations are likely overestimated and provide a good reason for the adjustment factor. Instream TAM concentrations are also sensitive to the septic system representation but result in consistent changes across the watershed (i.e., does not change downstream results more than upstream). Limitations in the TAM simulation are likely input data driven (septic and point source representation), but the model sufficiently represents the distribution of concentrations, seasonal patterns, and longitudinal trends observed in the sampling data.

The phosphorus-related time-series water quality calibration plots at the primary calibration location (Reach 470) are shown in Figures 3-31 and 3-32. Figure 3-33 shows a map of TP loading rates by subwatershed. The orthophosphate calibration is considered “very good” for the calibration period. Downstream orthophosphate is highly driven by Octoraro Reservoir, where orthophosphate concentrations are higher. Therefore, concentrations in the reservoir are slightly under-simulated, and land loads below the reservoir were adjusted to make up for the slightly over-simulated concentrations. There is also a noticeable shift upstream to downstream, where the average observed concentrations above Reach 450 for the full simulation period are 2–3 times higher (0.14–0.26 mg/L) than the average concentration at Reach 450 (0.08 mg/L). Simulated D-Ortho concentrations were not sensitive to septic systems or point source inputs, so the calibration focused on overland contributions and instream processes. Interflow and groundwater phosphorus concentrations were set slightly higher in the West Branch Octoraro Creek because the observed data and CBP loading

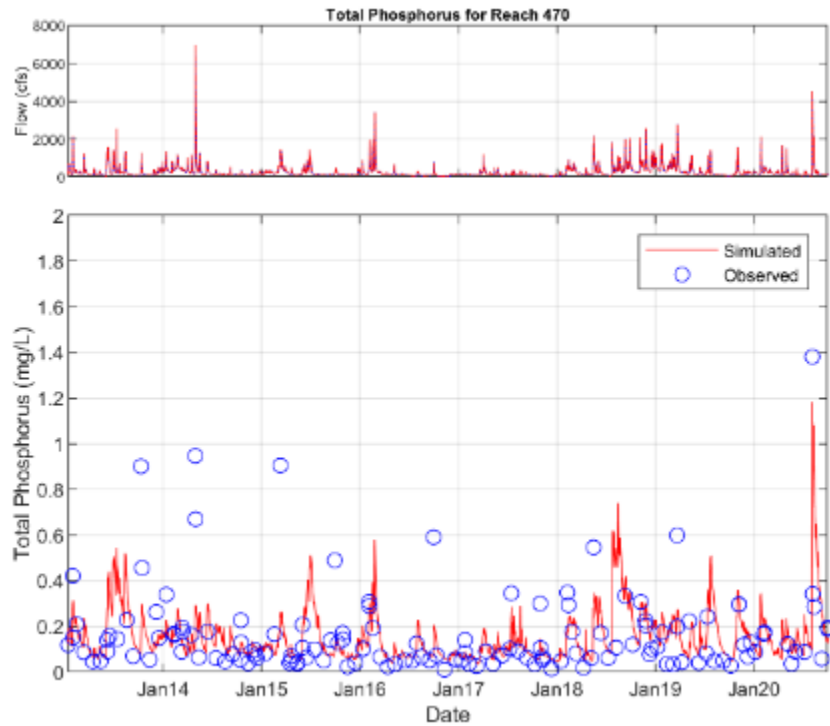


Figure 3-31. Total Phosphorus Time-Series Calibration Plot for HSPF Reach 470 (Calibration Period).

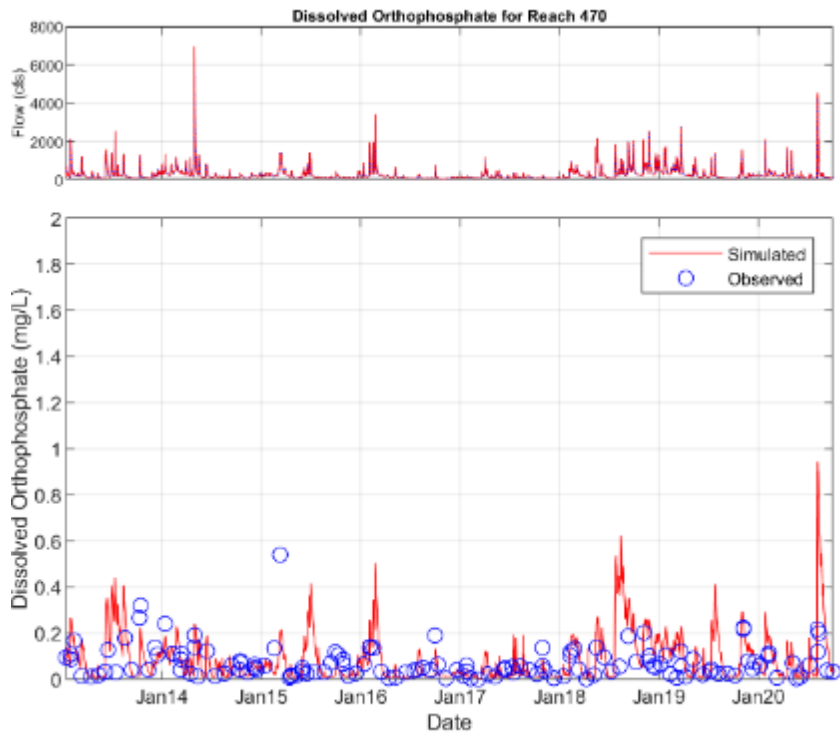


Figure 3-32. Total Dissolved Orthophosphate as Phosphorus Time-Series Calibration Plot for HSPF Reach 470 (Calibration Period).

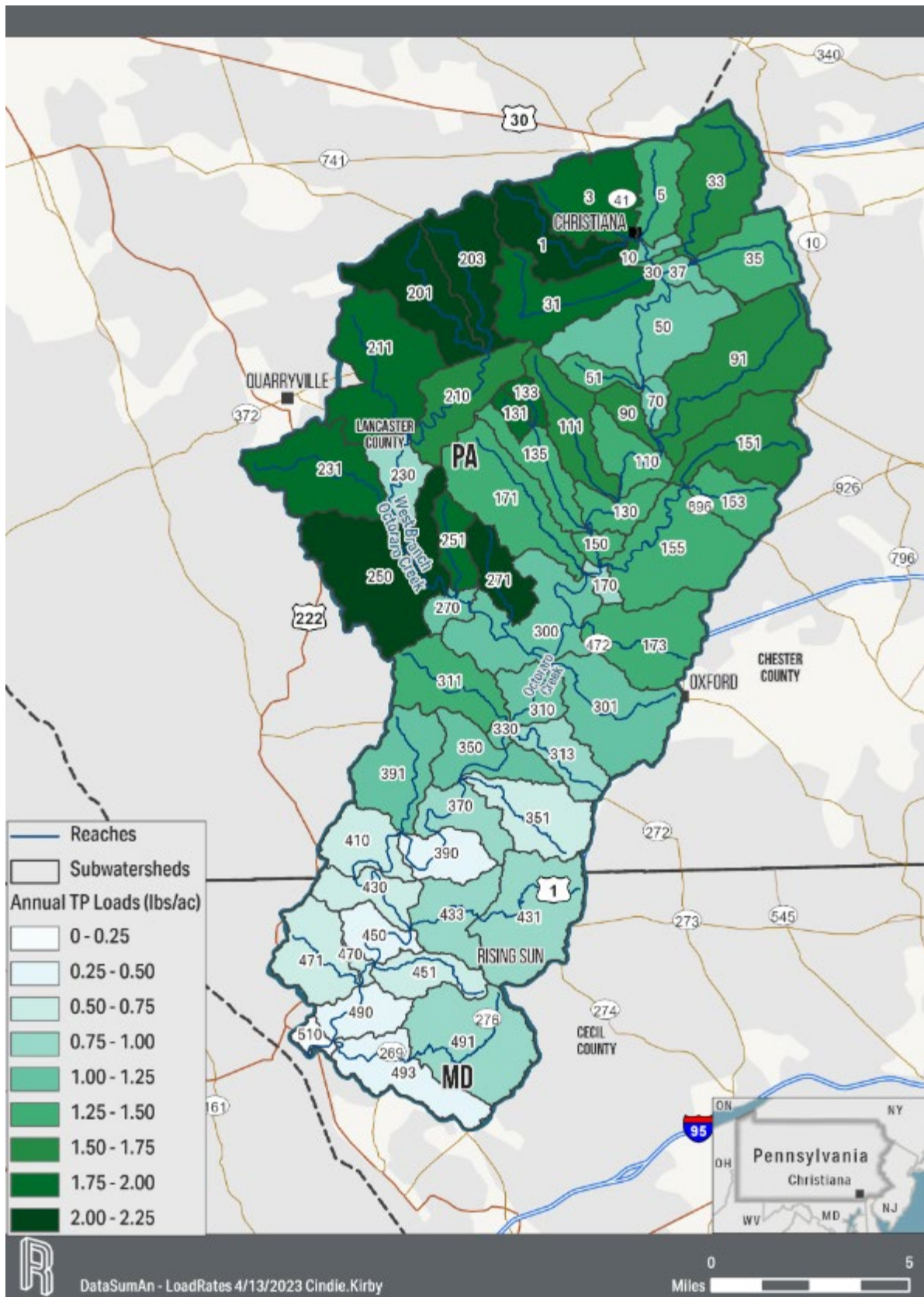


Figure 3-33. Annual Total Phosphorus Loading Rates by Subwatershed.

rates suggest a larger portion of the load comes from this drainage. Most available TP data were isolated to Reaches 430, 450, and 470, showing a “very good” calibration on an average concentration basis.

There are very little BOD and CHLA data available across the entire watershed, and substantial TKN was only collected at the primary site, so the simulation of organic matter relied heavily on TOC data. The TOC time-series water quality calibration plot at the primary calibration location (Reach 470) is shown in Figure 3-34. The statistics show a “very good” calibration of TOC with the distribution of simulated concentrations as a function of flow and seasonal trends well represented. Calibration focused on land contributions of CBODu, organic settling rates, and phytoplankton/benthic algae dynamics. TKN is slightly under-simulated but is still considered “very good” statistically. Attempts were made to improve TKN but overestimated TN, TP, and TOC. CHLA is also considered “very good,” but only 50 total samples were available for the entire simulation period. Because of these reasons, the DO, nitrogen, phosphorus, and carbon dynamics were mainly used to calibrate phytoplankton processes.

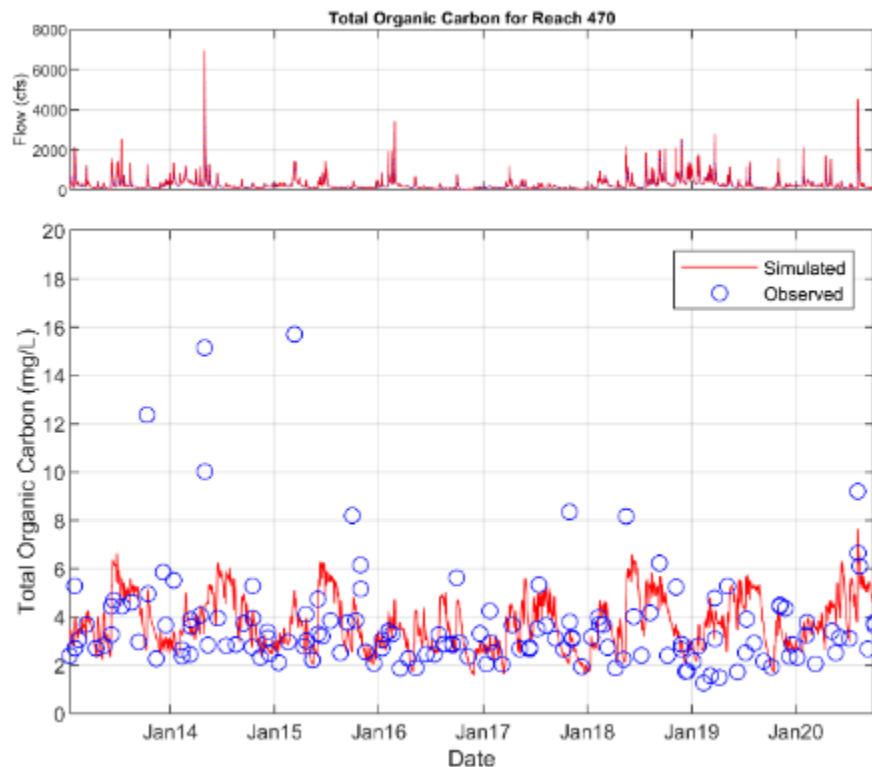


Figure 3-34. Total Organic Carbon Time-Series Calibration Plot for HSPF Reach 470 (Calibration Period).

Based on the weight of evidence from the full range of model results presented, which include loading rates, source allocations, mean concentration differences, and the various calibration plot comparisons of observed and simulated values, we conclude that the model meets performance guidelines at most calibration and validation sites and is an acceptable representation of the Octoraro Creek Watershed. Further confidence in model results would require more intensive sampling of BOD, CHLA, and TKN across the entire watershed and adding more TN and TP sampling above and in the reservoir. It is recommended that more of these samples be collected before any future updates to the calibration are made.

4.0 WASP MODEL SETUP

4.1 SEGMENTATION AND CHARACTERIZATION

The Octoraro Reservoir was initially divided into five surface segments in the WASP model to track inflows from the two main tributaries (East and West Branches of Octoraro Creek) and two minor tributary inflows (Gables Run and Leech Run) along with local drainage. The fifth segment is located near the outlet to represent reservoir withdrawals. Additional segmentation was necessary to ensure each segment had approximately the same residence time. This exercise is essential to prevent numerical dispersion, an inherent problem in reservoir modeling that may cause inaccurate results. The additional segmentation resulted in the West Branch of the Octoraro Reservoir being divided into seven segments, the East Branch being divided into the four segments, and the single segment near the outlet remaining the same for a total of 12 segments. Local drainage areas were delineated at WASP segment endpoints to provide direct drainage from adjacent land areas accurately. Figure 4-1 shows the final segmentation of the Octoraro Reservoir WASP model.

All WASP segments were modeled as surface-water segments using the kinematic wave transport mode except for the segment near the outlet, which was modeled as a ponded weir to account for the control structure. Main channel geometry inputs required for each surface segment include length, average width, slope, minimum depth, average depth, and weir height. These inputs were estimated using Octoraro Reservoir bathymetry data, and segment properties are summarized in Table 4-1.

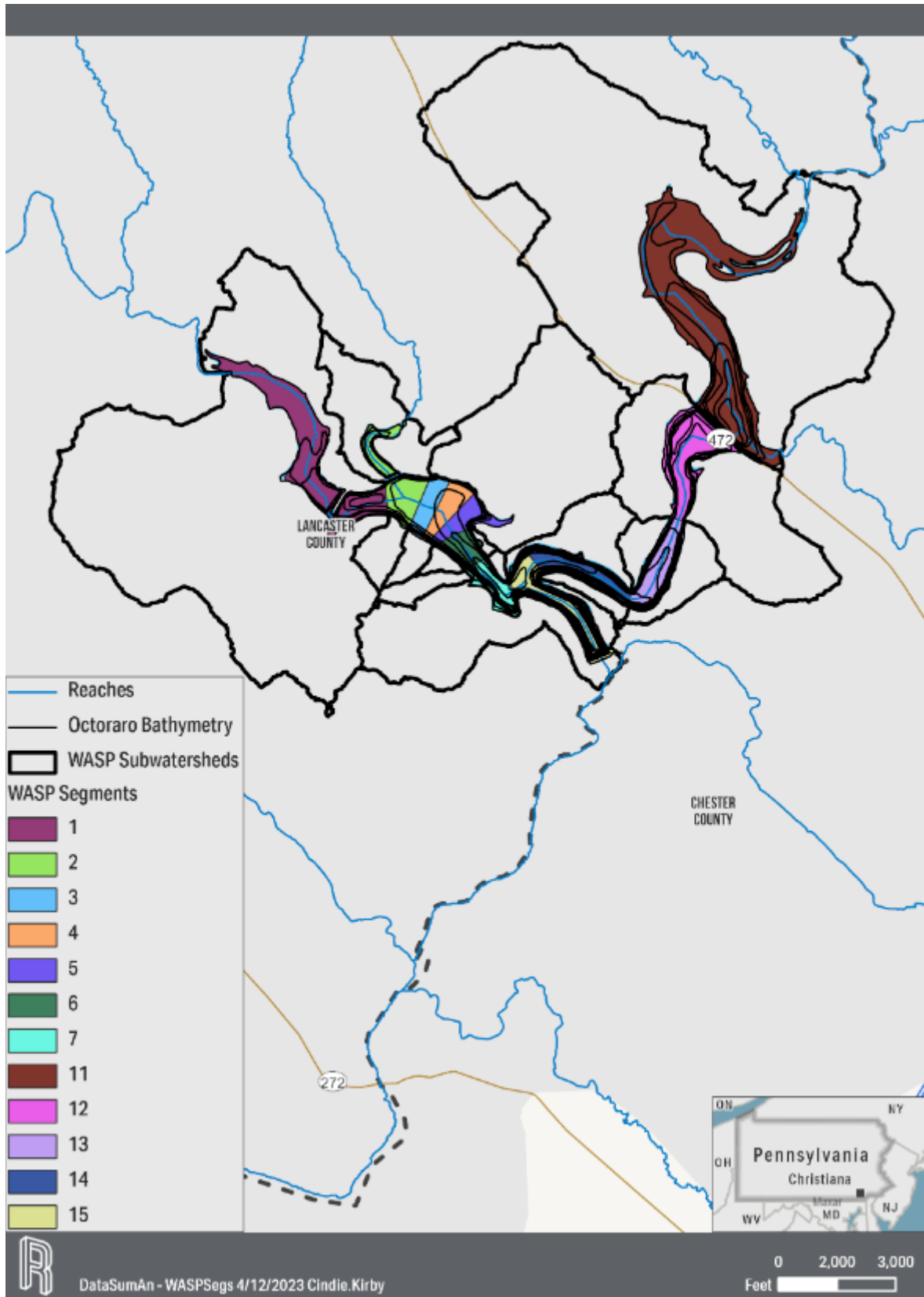


Figure 4-1. Octoraro Reservoir WASP Model Segments.

Table 4-1. WASP Segment Geometry

Segment Name	Segment I.D.	Length (m)	Average Width (m)	Average Depth (m)
West Branch 1–West Branch Octoraro	WB1	700	192	1.57
West Branch 2–Gables Run	WB2	230	358	3.4
West Branch 3–Local	WB3	110	492	6.07
West Branch 4–Local	WB4	90	542	6.01
West Branch 5–Local	WB5	95	513	6.01
West Branch 6–Local	WB6	200	211	6.22
West Branch 7–Local	WB7	390	141	5.95
East Branch 11–East Branch Octoraro	EB11	1390	297	1.35
East Branch 12–Leach Run	EB12	575	268	3.42
East Branch 13–Local	EB 13	440	231	5.45
East Branch 14–Local	EB14	585	164	6.56
East Branch 15–Restricted Area Outlet	EB15	1110	170	6.26

4.2 MODEL INPUTS AND LINKAGE

Meteorological time-series inputs to the WASP model included ATEM, SOLR, CLOU, WIND, and DEWP. The data were applied at an hourly timestep. Refer to Sections 2.2.1 and 2.2.2 for more detail on meteorological data sources and processing. Dry atmospheric deposition of nitrate, ammonia, and phosphorus was also included, and the time-series were applied at a daily timestep. Detailed methods for processing atmospheric deposition are provided in Section 2.2.4.

Boundary conditions to the WASP model (i.e., reservoir inflows) are supplied by HSPF. The following three main components were considered to link the HSPF watershed model to the WASP receiving water quality model:

- / Spatial resolution. The HSPF subwatersheds were segmented to ensure that the HSPF model provided results at key WASP boundary locations. Boundary inputs to WASP included flow and pollutant loadings from tributaries to the Octoraro Reservoir and direct discharge from land areas adjacent to the Octoraro Reservoir.
- / Temporal resolution. HSPF provided results at an hourly timestep that were aggregated or averaged to a daily timestep.

- / State variable mapping. The WASP model had state variables slightly different from HSPF and needed to be mapped using assumptions (e.g., factors for partitioning dissolved and particulate organic matter). The HSPF to WASP state variable linkage map is shown in Table 4-2, and the linkage process was automated to ensure consistency and repeatability in the method.

Additional boundary conditions were added from the outlet segment to account for pumpage from the Susquehanna into the reservoir and withdrawals from the reservoir to the water treatment plant. These data were provided by other sources at a daily timestep. In cases where records were missing, simulated HSPF outflows will be used.

Initial WASP parameters were set using model defaults [Ambrose and Wool, 2017] and were adjusted during the calibration process. The calibration process will also determine the level of complexity needed to produce accurate results (e.g., implementation of the sediment digenesis model or representation of both epilimnion and hypolimnion).

Table 4-2. Linkage Between HSPF Model Constituents and WASP Model Constituents

HSPF Constituent	WASP Constituent	WASP System Type	Notes
ROVOL	Flow	N/A	—
TAM-OUTTOT	Total Ammonia	NH-34	—
NO ₃ -OUTTOT	Nitrate-Nitrite	NO ₃ -NO ₂	Sum HSPF NO ₃ and NO ₂ for WASP NO ₃ -NO ₂
NO ₂ -OUTTOT			
PO ₄ -OUTTOT	Dissolved Inorganic Phosphorus	D-DIP	—
N-TOTORG-OUT	Dissolved Organic Nitrogen	ORG-N	Assumed factor to divide between dissolved organic and detrital nitrogen
	Detrital Nitrogen	DET-N	
P-TOTORG-OUT	Dissolved Organic Phosphorus	ORG-P	Assumed factor to divide between dissolved organic and detrital phosphorus
	Detrital Phosphorus	DET-P	
C-TOTORG-OUT	Detrital Carbon	DET-C	—
N/A	Total Detritus	TOTDE	Calculated by WASP
BODOUTTOT	CBOD _u – Watershed	CBODU	—
N/A	CBOD _u – Point Source	CBODU	Obtained from WDM
N/A	CBOD _u – Biological	CBODU	Calculated by WASP
DOXOUTTOT	DO	DISOX	—
ROSED-SAND	Sand	SOLID	—
ROSED-SILT	Silt	SOLID	—
ROSED-CLAY	Clay	SOLID	—
PHYTO-OUT	Phytoplankton	PHYTO	—
N/A	Benthic Algae	MALGA	Calculated by WASP
N/A	Benthic Algae Nitrogen	MALGN	
N/A	Benthic Algae Phosphorus	MALGP	
ROHEAT	Water Temperature	WTEMP	—

N/A = Not Applicable

5.0 WASP MODEL CALIBRATION AND VALIDATION

5.1 METHODS

The WASP model was calibrated through an iterative process of making parameter changes, running the model, producing simulated and observed values comparisons, and interpreting the results. Available data and criteria for calibration are detailed in Sections 3.2.1, 3.4.1, and 3.4.2.

WASP is a flexible water quality modeling system. The complexity of water quality simulation in WASP can range from a simple steady-state representation to a three-dimensional hydrodynamic representation. Given the available data, the Octoraro Reservoir WASP model represents the complexity and processes necessary to address the water quality problems. The reservoir was simulated as one-dimensional surface segments with standard eutrophication modules active. Water quality monitoring data from the Octoraro Reservoir were evaluated along with the initial WASP representation to determine whether or not additional complexity in eutrophication processes and segmentation should be incorporated to effectively represent the pertinent water quality processes.

The specific constituents modeled in WASP (Table 4-2) are similar to HSPF with the addition that WASP bifurcates total organics into dissolved and detrital matter. The total organic nitrogen and phosphorus partitioning to particulate and dissolved were set based on observed data throughout the watershed. WASP also simulates nitrite-nitrate as a single state variable while HSPF simulates both individually. Sediment was modeled using the descriptive method (user-set settling rates) instead of the mechanistic, process-based method (dynamic settling, deposition, erosion, and resuspension) because there was no evidence of scour occurring in the reservoir.

The WASP calibration started with hydrology and hydraulics to ensure transport was well represented before the water quality portion could begin. The water quality calibration began with temperature and sediment and then to DO and nutrients. The DO and nutrient calibrations were conducted in tandem because these components depend on each other. The calibration required developing time-series graphs to compare the simulated and observed water quality data. Instream water quality calibration also included generating monthly boxplots, concentration-duration curves, and scatterplots of concentrations and corresponding flows.

5.2 RESULTS AND DISCUSSION

5.2.1 HYDROLOGY

Modeled outflow in WASP was calibrated qualitatively using the HSPF simulated flow rates because there was high confidence in HSPF results. Figures 5-1 through 5-4 present graphical comparisons of simulated WASP and simulated HSPF flows for the entire simulation period. The comparisons include annual and monthly runoff bar graphs, daily flow frequency curves, and daily time series. Average simulated segment volume was compared to bathymetry volume calculations and the results are shown in Table 5-1.

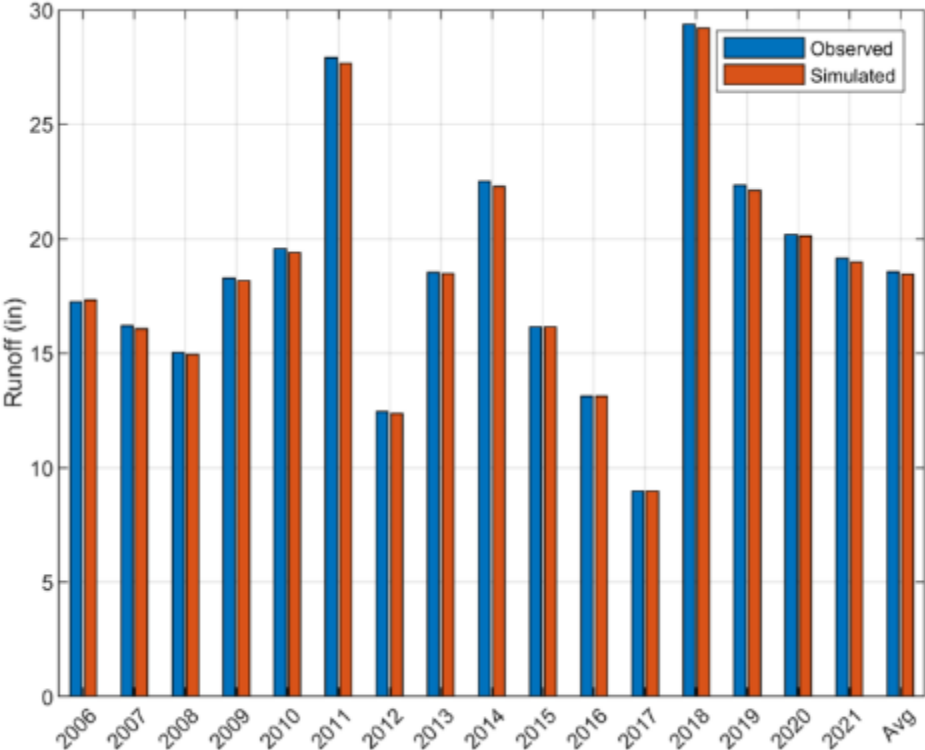


Figure 5-1. Annual Runoff for the Calibration Period at the Reservoir Outlet (Observed Is the HSPF Results).

The difference in average annual and monthly flow is less than percent when compared to HSPF results. There is also good agreement between the two models when comparing the distribution of values (flow frequency curves) and the storm/baseflow response (daily time series). WASP overestimates baseflow and could be improved by adding evaporation and precipitation. Given that the discrepancy occurs less than one percent of the time and the reservoir's relatively short residence time, the evaporation and precipitation time series were not included. WASP also slightly underestimates storm peaks relative to the HSPF simulation and is likely a function of the lack of control

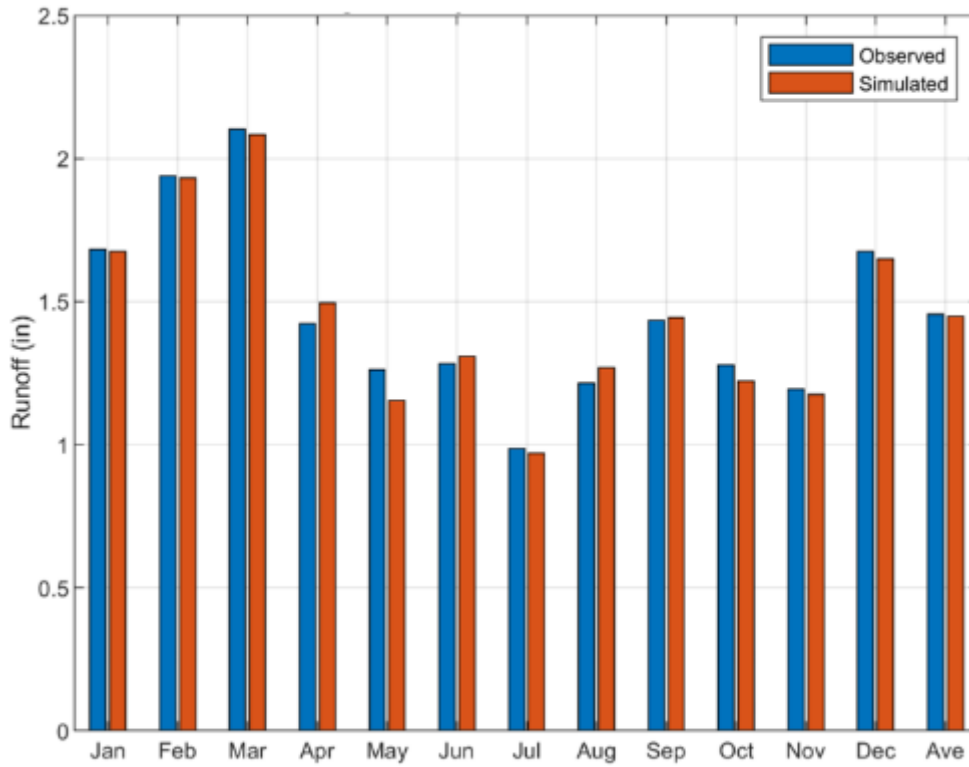


Figure 5-2. Average Monthly Runoff at the Reservoir Outlet (Observed Is the HSPF Results).

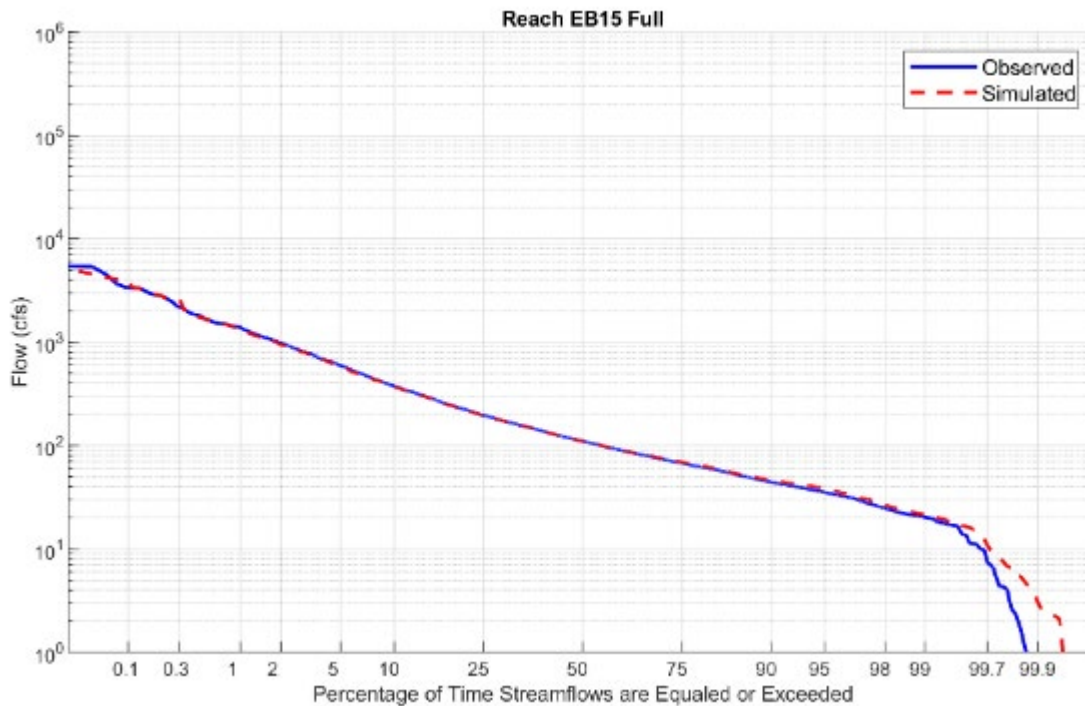


Figure 5-3. Flow Frequency Duration Curve at the Reservoir Outlet (Observed Is the HSPF Results).

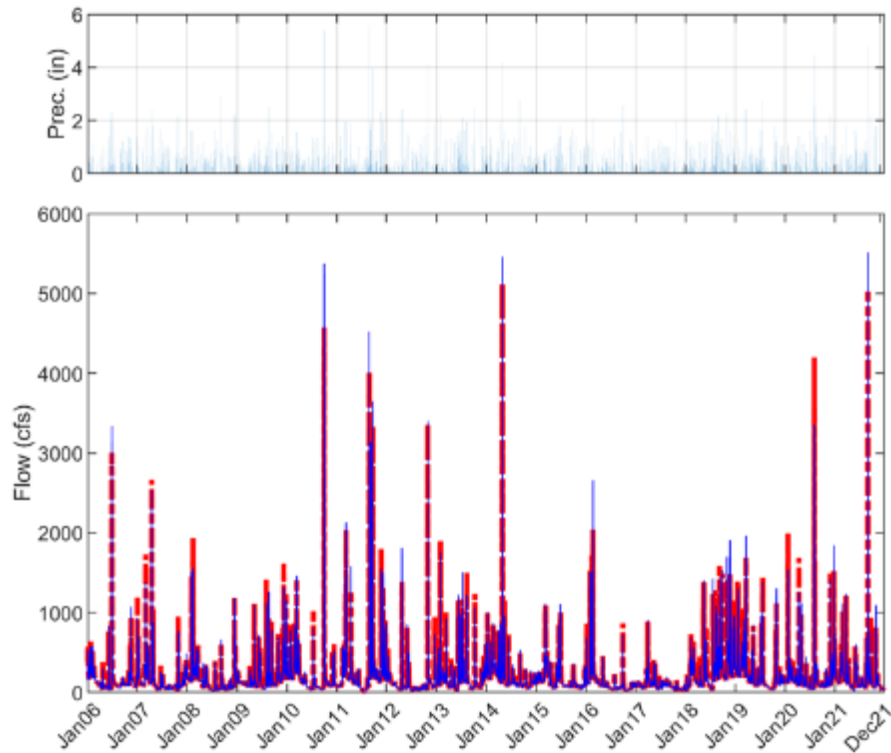


Figure 5-4. Daily Hydrographs at the Reservoir Outlet (Observed Is the HSPF Results).

Table 5-1. Comparison of Simulated and Calculated Volumes for Each Segment

Segment	Volume (cubic meters)		
	Modeled	Calculated From Bathymetry	Percent Difference
WB1	366011	365465	0.15
WB2	464503	463539	0.21
WB3	541591	533105	1.59
WB4	483588	463837	4.26
WB5	483209	463837	4.18
WB6	434648	436012	-0.31
WB7	542582	533647	1.67
EB11	899435	898426	0.11
EB12	817926	821654	-0.45
EB13	849231	845941	0.39
EB14	969538	965597	0.41
EB15	1192446	1180945	0.97
Total	8044707	7972004	0.91

using the “Ponded Wier” transport mode (i.e., WASP uses a broad crested weir equation, and the user has no control over the equation’s coefficients as a function of head). There is good agreement in the simulated segment average volumes when compared to the calculated volumes from the bathymetry data. The percent difference in total volume is less than one percent and maximum percent difference of an individual segment was less than five percent. Based on the flow and volume comparisons, the simulated WASP transport provides a sound basis for the water quality purposes of this study.

5.2.2 WATER QUALITY

Table 5-2 provides the mean simulated and observed concentrations for the calibration and validation periods at the primary location (Segment 15). There were five other sampling locations, but each site had less than 10 samples per parameter for the calibration period. The comparison of mean concentrations and the percent differences of simulated to observed demonstrate that simulated values are generally within 15 percent of observed data during the calibration period and within 25 percent during the validation period at the primary calibration locations. The only variables not passing the fair calibration criteria shown in Table 5-2 are total phosphorus and total organic. Detailed explanations for each variable and shortcomings of the instream calibration are provided in the following paragraphs. Each of the main calibration variables at the primary location will show the time-series comparisons for the calibration period in the body of the text. The concentration-duration curves, monthly average boxplots, and scatter plots for the full simulation period are shown in Appendix C.

Table 5-2. Average Annual Simulated and Observed Concentrations for the Calibration and Validation Period

Variables	Results at Segment East Branch 15							
	Calibration Period (2013-2021)				Validation Period (2006-2012)			
	Average Concentration		Difference	Sample	Average Concentration		Difference	Sample
	Observed	Simulated	%	Size	Observed	Simulated	%	Size
Total Nitrogen	5.31	6.01	13	10	—	—	—	0
Total Phosphorus	0.100	0.448	348	10	0.099	0.243	146	3
Nitrite-Nitrate as N	—	—	—	0	—	—	—	0
Total Nitrate as N	6.39	6.39	0	416	7.04	6.56	-7	446
Total Kjeldahl Nitrogen	—	—	—	0	—	—	—	0
Orthophosphate as P	0.192	0.218	13	389	0.228	0.199	-12	301
Ammonia as N	0.195	0.179	-8	455	0.199	0.160	-20	421
Dissolved Oxygen	7.9	9.0	14	419	7.24	8.98	24	636
Chlorophyll a	—	—	—	0	—	—	—	0
Total Suspended Sediment	8.2	8.4	2	399	10.4	9.2	-12	359
Temperature	58.1	57.1	-2	3276	57.3	57.1	0	2523
Total Organic Carbon	4.0	2.1	-48	588	4.05	2.09	-49	399
Total Inorganic Nitrogen	6.58	6.57	0	416	7.24	6.72	-7	421

5.2.2.1 SEDIMENT

The TSS calibration is considered “very good” for both the calibration and validation periods, and the time-series water quality calibration plot at the primary location (Segment 15) is shown in Figure 5-5. The calibration focused primarily on the settling velocities of sand, silt, and clay; bed/bank scour was not represented in the WASP model. WASP also incorporates detritus and phytoplankton into the TSS state variable, so these settling velocities were also adjusted for the sediment calibration but to a lesser extent.

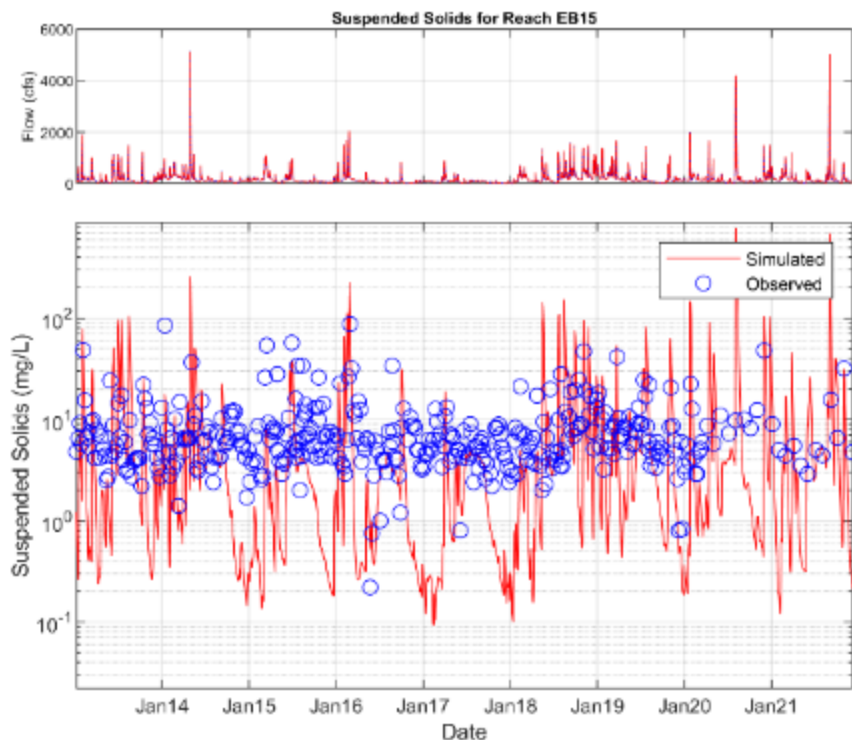


Figure 5-5. Total Suspended Solids Time-Series Calibration Plot for Segment 15 (Calibration Period).

5.2.2.2 TEMPERATURE AND DISSOLVED OXYGEN

The water temperature and DO simulations show an inverse relationship and are usually well simulated regarding the range of values and seasonal patterns. The water temperature and dissolved oxygen time-series water quality calibration plots at the primary calibration location (Segment 15) are shown in Figures 5-6 and 5-7, respectively. Temperature is considered “very good” for both periods and provides a solid foundation for temperature-dependent rate equations involved in nutrient cycling processes. DO values are consistently over-predicted but is still considered “very good” and “good” for the calibration period and validation period, respectively. Attempts were made during the calibration process to improve the low DO calibration but this resulted

in the model crashing. The sediment diagenesis module was also activated, stabilized, and tested but resulted in DO values similar to that of the final calibration without the sediment diagenesis module.

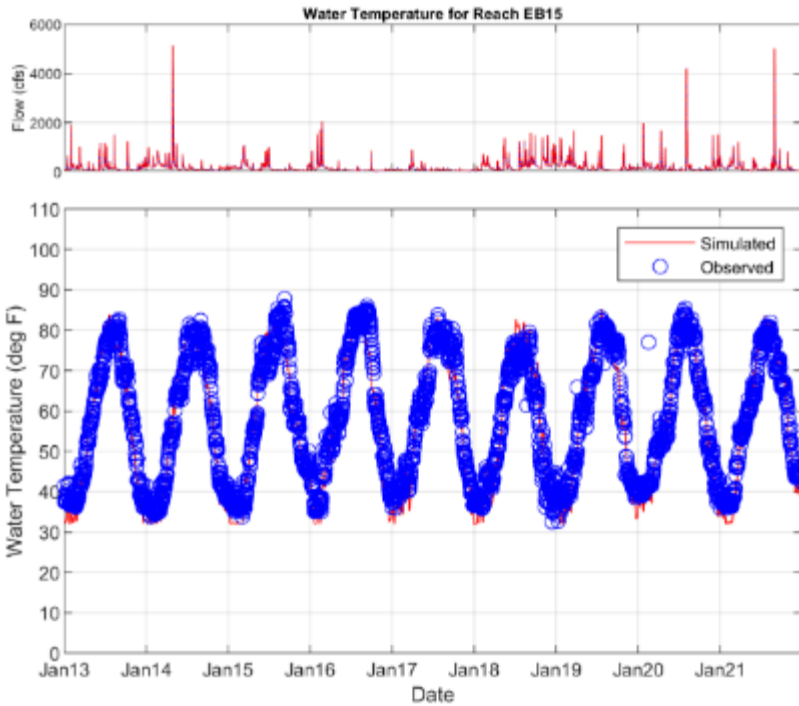


Figure 5-6. Temperature Time-Series Calibration Plot for Segment 15 (Calibration Period).

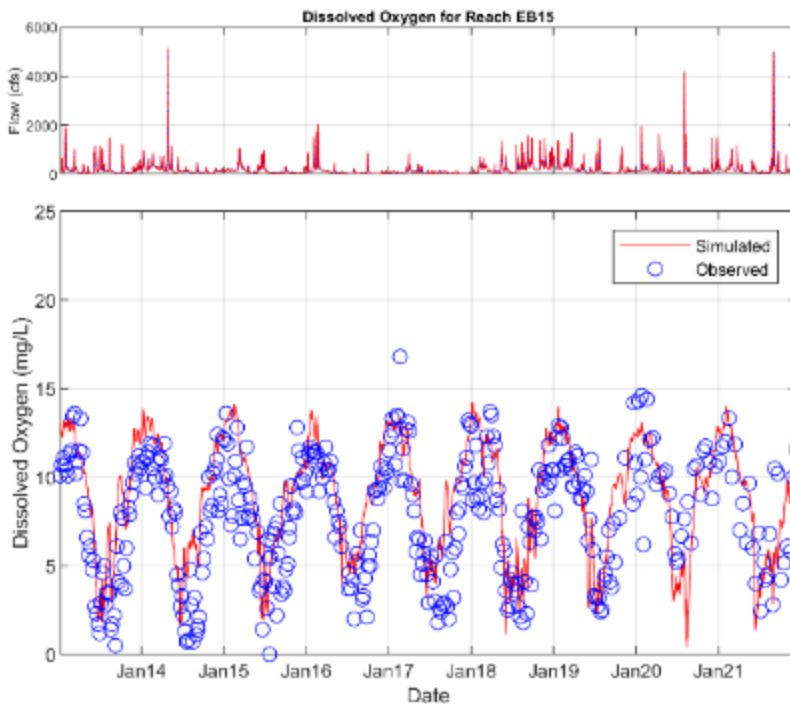


Figure 5-7. Dissolved Oxygen Time-Series Calibration Plot for Segment 15 (Calibration Period).

5.2.2.3 NUTRIENTS

Nitrate was the primary focus of the nitrogen calibration because it makes up the largest component of TN in the watershed. The nitrogen-related time-series water quality calibration plots at the primary calibration location (Segment 15) are shown in Figures 5-8 through 5-10. Statistically, all nitrogen calibration variables (total nitrogen, total nitrate, total ammonia, and total inorganic nitrogen) are considered “very good” for both periods, except for total ammonia during the validation period, which is still considered “good.” Total nitrogen was consistently over-predicted, but only 10 samples were available for the entire simulation period and most of them were taken in 2015. The distribution of simulated concentrations as a function of flow and seasonal patterns for total nitrate and total ammonia are well represented. Calibration tests indicated that inorganic nitrogen concentrations were sensitive to nitrification/denitrification rates, benthic releases and benthic algae growth/respiration dynamics; consequently, a large portion of the calibration focused on those parameters.

The phosphorus-related time-series water quality calibration plots at the primary calibration location (Segment 15) are shown in Figure 5-11 and 5-12. The orthophosphate calibration is considered “very good” for both periods, but total phosphorus is considered “poor.” Similar to TN, there were only 10 samples available during the calibration period making it difficult to determine the cause for the limitation of the TP simulation. The model does well at representing the range of orthophosphate concentrations and capturing seasonal trends but is slightly over-simulating summer concentrations. Main calibration parameters included mineralization rates and those related to benthic algae growth.

BOD, CHLA, or TKN data were unavailable for calibration. The TOC time-series water quality calibration plots at the primary calibration location (Segment 15) are shown in Figure 5-13. Statistically the TOC calibration is poor with average simulated concentrations half that of the observed. Without other organic data for the reservoir and little data above, it is difficult to understand the processes driving the discrepancy (i.e., more data are required to determine whether or not the boundary conditions are underestimated, if the fractionation of dissolved and particulate are correct, or if a process is under/over-simulated).

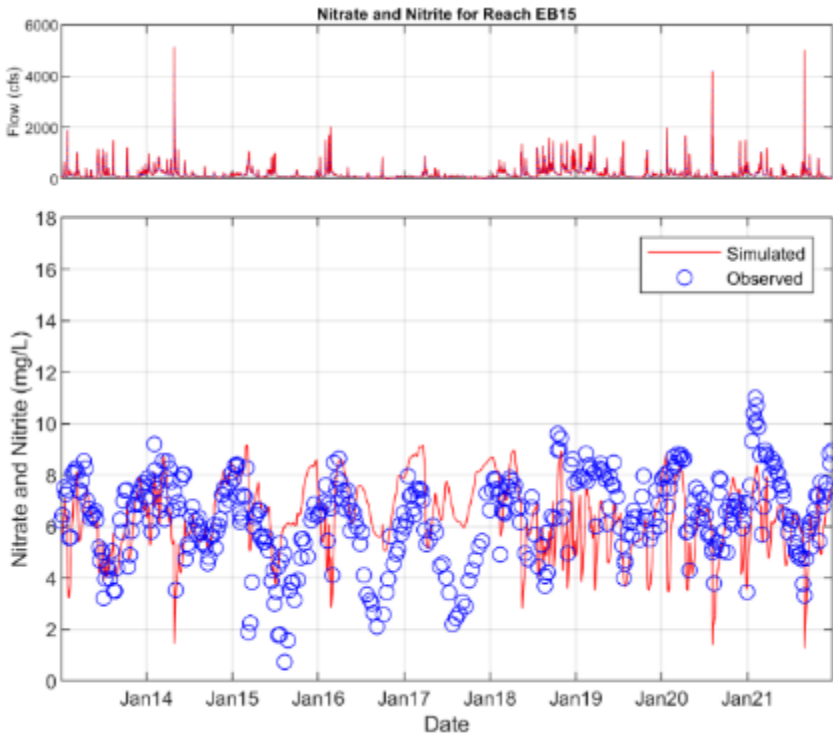


Figure 5-8. Nitrate-Nitrite Time-Series Calibration Plot for Segment 15 (Calibration Period).

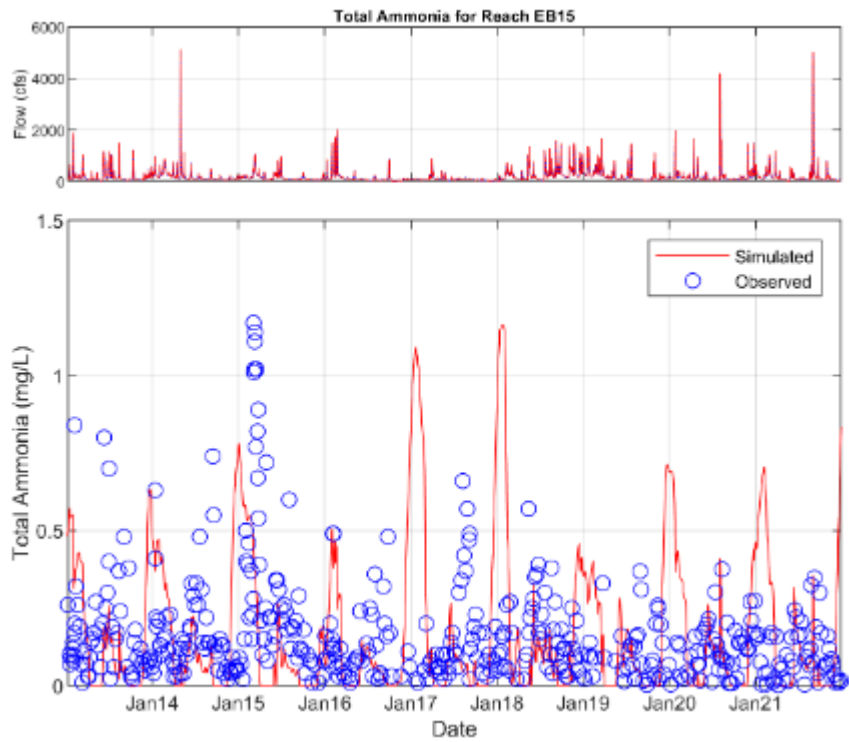


Figure 5-9. Total Ammonia Time-Series Calibration Plot for Segment 15 (Calibration Period).

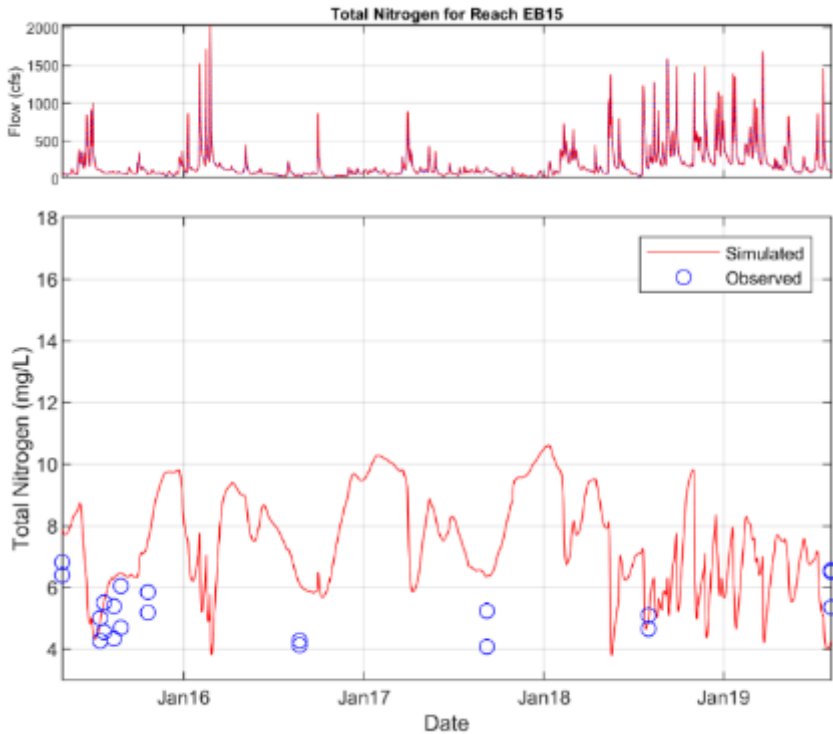


Figure 5-10. Total Nitrogen Time-Series Calibration Plot for Segment 15 (Calibration Period).

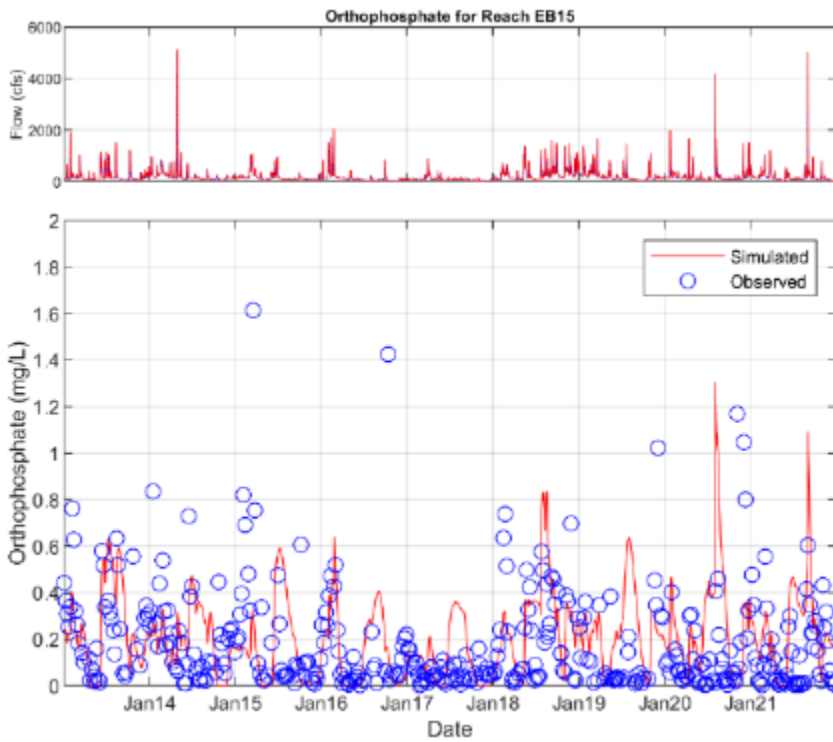


Figure 5-11. Orthophosphate Time-Series Calibration Plot for Segment 15 (Calibration Period).

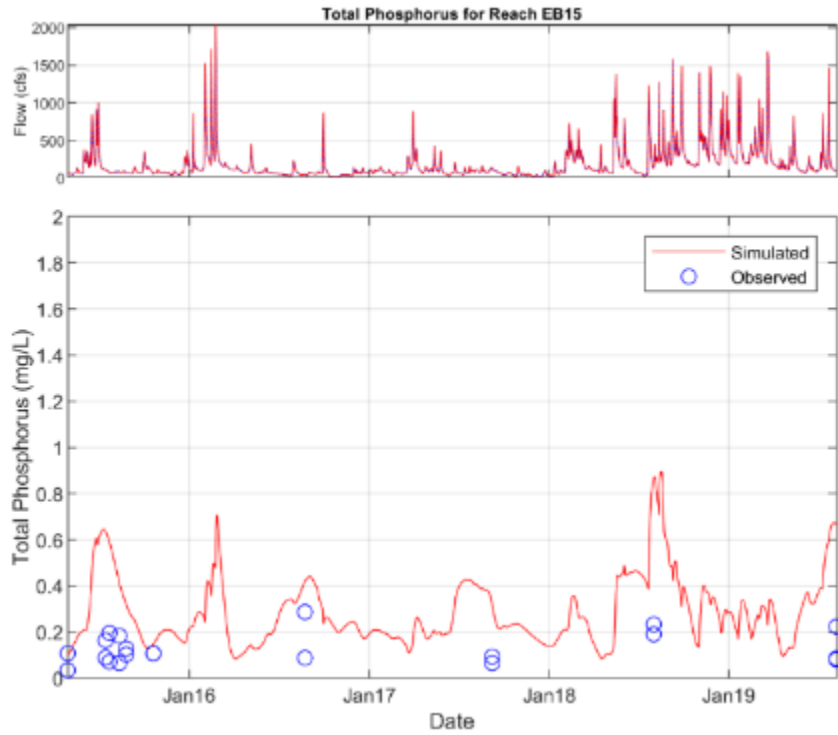


Figure 5-12. Total Phosphorus Time-Series Calibration Plot for Segment 15 (Calibration Period).

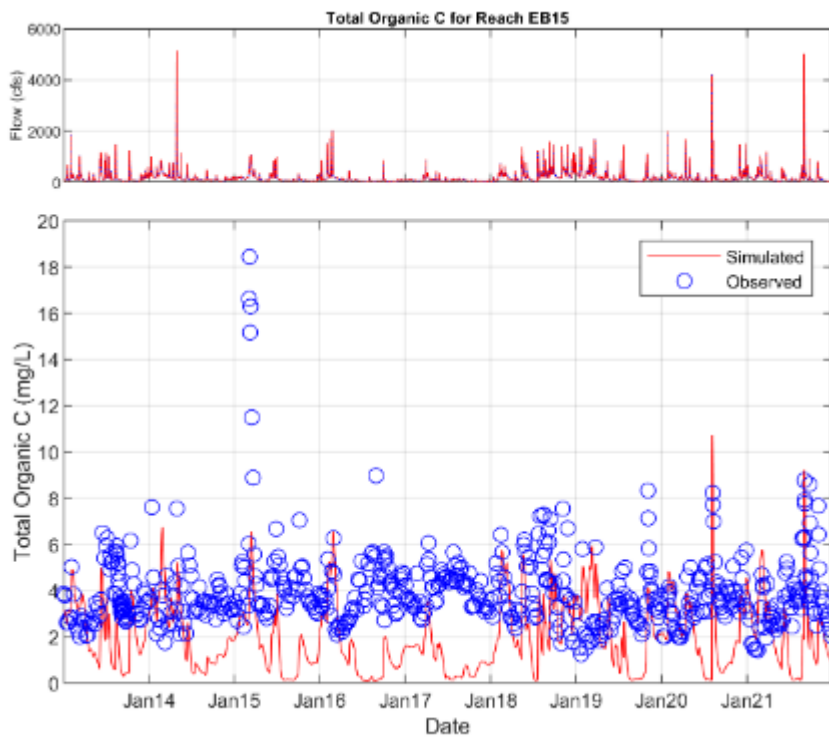


Figure 5-13. Total Organic Carbon Time-Series Calibration Plot for Segment 15 (Calibration Period).

5.2.2.4 CONCLUSIONS AND RECOMMENDATIONS

The WASP calibration results were similar to HSPF for the reservoir. Therefore, for running the scenarios, we have confidence that the HPSF-SAM tool will be appropriate for the scenario results through the reservoir. However, the existing WASP model provides the framework for when more data become available to improve the reservoir representation.

Similar to HSPF, further confidence in model results would require more intensive sampling of BOD, CHLA, TKN, TN, and TP above and in the reservoir. Samples of dissolved versus particulate organic nitrogen, phosphorus, and carbon would also help better represent organic matter partitioning processes. Lake profile and benthic algae sampling are recommended to justify introducing more complexities, such as representing individual lake layers and sediment diagenesis.

6.0 SCENARIO APPLICATION

HSPF is a continuous model that represents physical and chemical processes and interactions. The HSPF model was calibrated over an extended period, making it conducive to holistically understanding watershed conditions. Through careful changes to model inputs, HSPF is used to evaluate the impacts of potential changes in watershed composition and implement best management practices (BMPs) to help identify cost-effective management approaches. The complexity of HSPF can make it difficult for non-modeling end-users to apply a model quickly to evaluate alternative management options. The SAM decision-support tool [Kenner, 2017; Kenner and Oswald, 2017] was developed by RESPEC to address this challenge and serve as an applied analysis tool for planning targeted actions to restore or protect water quality in specific geographic areas. The primary components needed for SAM include an HSPF model application and a default BMP database. The default BMP database includes pollutant reduction efficiencies, costs, suitable areas, available areas for all represented pollutants and management practices. If applicable, SAM users can edit the default areas, costs, and efficiencies.

A combination of stakeholder input and literature review work was completed to develop the default BMP database. The primary resource for the development of the Octoraro BMP database was the Chesapeake Bay Program's watershed model and the Chesapeake Assessment Scenario Tool (CAST). The CBP models have been developed with support from various leaders and experts in the field using environmental models that are among the world's most sophisticated, studied and respected. A similar form of the HSPF model was also used in the CBP Watershed models, making the extensive CBP BMP data and information a reliable resource. For more detailed information about costs and efficiencies for BMPs please refer to the CAST documentation [Chesapeake Bay Program, 2020].

6.1 SCENARIO APPLICATION MANAGER COMPONENTS

6.1.1 Best Management Practice Selection

The BMPs selected for the application of SAM in the Octoraro Creek Watershed were based on historical implementation tracking data and the Chesapeake Bay TMDL Phase III Watershed Implementation Plan (WIP) goals from CAST in addition to stakeholder review and guidance. The CAST BMP groups were used as the SAM BMPs to simplify the options available. For example, there are 104 different variations of cover crop BMPs available in CAST, but they can all be represented using one cover crop BMP in SAM by editing the default cost and efficiency values to represent any individual variation. The individual CAST BMPs within each group commonly use similar pollutant

reduction efficiencies, costs, and source areas. Table 6-1 lists the SAM BMPs selected, the number of individual CAST BMP variations, and the implemented amount in the calibration period (2013-2021), the validation period (2006-2012), and the Phase III WIP. Table 6-1 also includes the type of application in the SAM tool that the BMP can be applied. The BMPs in SAM are applied using the Land Use Change (LUC), BMP, or the Point Source Alternative (PSA) application. Values in the 2006–2012, 2013–2021, and Phase III WIP columns are in acres treated unless otherwise noted. Many more scenario options are available through the LUC and PSA application types, such as changing any model land use to another land use or changing a point source facility's flows and concentrations.

Table 6-1. Selected SAM BMPs With Historical and Phase III WIP Implementation Totals for the Octoraro Creek Watershed

SAM BMP Name	Type	CAST Count	2006–2012	2013–2021	Phase III WIP
Agricultural Stormwater Management	BMP	1	0.0	0.4	8.5
Conservation Plans	BMP	1	12,623.7	15,942.2	55,615.7
Conservation Tillage	BMP	3	16,991.2	15,720.6	33,387.3
Cover Crops	BMP	104	3,223.7	4,330.4	20,141.0
Crop Irrigation Management	BMP	1	0.0	0.0	102.2
Erosion and Sediment Control	BMP	6	32.7	122.6	85.6
Feeding Space Management	BMP	2	84.7	200.9	213.9
Forest Buffers	BMP	4	2,376.7	2,264.9	8,438.6
Forest Buffer-Streamside With Exclusion Fencing	BMP	4	7.2	17.2	900.5
Forest Harvesting Practices	BMP	1	3.7	38.0	73.7
Forest Planting	LUC	1	0.0	7.1	55.8
Grass Buffers	BMP	4	1,229.5	7,015.4	8,333.5
Grass Buffer-Streamside With Exclusion Fencing	BMP	4	9.3	35.9	2,837.3
Impervious Surface Reduction	LUC	1	0.0	0.0	1.5
Land Policy	LUC	8	0.0	0.0	26.8
Land Retirement to Ag Open Space	LUC	1	1,042.3	643.1	722.1
Land Retirement to Pasture	LUC	1	60.7	46.5	56.5
Manure Incorporation	BMP	5	0.0	366.6	2,317.5
Nutrient Management	BMP	8	14,455.4	17,845.5	61,587.9
Off-Stream Watering Without Fencing	BMP	1	5,829.3	2,020.8	1,548.8
Pasture Management	BMP	2	816.4	902.0	3,873.6
Septic Connections	PSA	1	54.4	233.1	532.9
Septic Denitrification and Pumping	PSA	9	0.7	89.5	1,223.2
Stormwater Management	BMP	25	1,162.8	893.4	2,800.8
Stream Restoration ^(a)	BMP	6	0.6	1.4	5.2
Street Sweeping	BMP	11	1.5	5.3	14.4
Tree Planting	LUC	2	39.7	151.3	76.4
Urban Forest Buffers	BMP	2	0.0	11.4	83.7
Urban Grass Buffers	BMP	1	0.0	0.0	0.0
Urban Nutrient Management	BMP	5	1,010.8	1,976.5	4,227.5
Water Control Structures	BMP	2	468.6	1,274.2	840.4
Wetland Creation	BMP	3	1.9	6.7	15.6
Wetland Restoration	BMP	3	160.1	136.8	312.6

(a) Stream Restoration amounts are in miles, while all other BMP amounts are in acres

6.1.2 Pollutant Reduction Efficiencies

The HSPF model environment is parameter-intensive and does not have easily measurable physical values directly corresponding to parameters. As a result, efficiency reduction factors are used to reduce uncertainty in representing the impacts of a BMP. Because of the limited availability of pollutant-reduction efficiency estimates based on reference studies specific to individual BMPs, simulated pollutant loads are reduced in SAM based on flow, sediment (TSS), total phosphorous (TP), and total nitrogen (TN) reduction efficiencies. Changes to pollutants without explicit reduction efficiency are reduced with the same efficiency as an associated pollutant (e.g., nitrate and nitrite are reduced using the same reduction efficiency as TN). If a parameter is not directly associated with a pollutant reduction (e.g., dissolved oxygen [DO]), the response of that parameter will be based on the interdependent simulated responses from changes in pollutants that efficiencies have reduced.

The efficiency factors for the Octoraro SAM BMPs were calculated as a weighted average of the individual CAST BMP efficiency values based on the amount of historical implementation. Individual CAST BMPs with a higher amount of historical implementation had more weight in the efficiency calculation for the SAM BMP. Table 6-2 shows the weighted average efficiency used as the default value in SAM and the minimum and maximum range of efficiency values for each SAM BMP or CAST BMP group. Some BMP efficiencies were adjusted to account for the difference in the BMP application in the Octoraro HSPF model versus how it is applied in the CAST tool as noted in Table 6-2. SAM applies efficiencies to both the implementation area and treated area, while CAST applies efficiencies to the treated area and represents implementation areas as land use or load source changes. The adjustments were applied only to the default efficiency factors so that some default values may be larger than the maximum value from CAST. Flow efficiency values were unavailable from CAST, so default flow efficiency values were set to zero.

Table 6-2. Default, Minimum, and Maximum Efficiency Reduction Factors for each Parameter and SAM BMP

SAM BMP Name	Default			Minimum			Maximum		
	TN	TP	TSS	TN	TP	TSS	TN	TP	TSS
Agricultural Stormwater Management	0.35	0.55	0.7	0.35	0.55	0.7	0.35	0.55	0.7
Conservation Plans	0.07	0.13	0.22	0.07	0.13	0.22	0.07	0.13	0.22
Conservation Tillage	0.12	0.66	0.69	0.05	0.09	0.18	0.14	0.71	0.79
Cover Crops	0.29	0.07	0.1	0.04	0.03	0.04	0.45	0.15	0.2
Crop Irrigation Management	0.04	0	0	0.04	0	0	0.04	0	0
Erosion and Sediment Control	0	0	0.84	0	0	0.74	0	0	0.9
Feeding Space Management	0.2	0.2	0.4	0.2	0.2	0.4	0.2	0.2	0.4
Forest Buffers ^(a)	0.61	0.43	0.58	0.56	0.42	0.56	0.56	0.42	0.56
Forest Buffer-Streamside with Exclusion Fencing ^(a)	0.61	0.43	0.58	0.56	0.42	0.56	0.56	0.42	0.56
Forest Harvesting Practices	0.5	0.6	0.6	0.5	0.6	0.6	0.5	0.6	0.6
Grass Buffers ^(a)	0.42	0.43	0.58	0.39	0.42	0.56	0.39	0.42	0.56
Grass Buffer-Streamside With Exclusion Fencing ^(a)	0.42	0.43	0.58	0.39	0.42	0.56	0.39	0.42	0.56
Manure Incorporation	0.08	0.24	0	0.08	0.12	0	0.12	0.36	0
Nutrient Management ^(b)	0.1	0.17	0	0.03	0.07	0	0.1	0.17	0
Off-Stream Watering Without Fencing	0.05	0.08	0.1	0.05	0.08	0.1	0.05	0.08	0.1
Pasture Management	0.11	0.23	0.3	0.11	0.2	0.3	0.11	0.24	0.4
Stormwater Management	0.56	0.6	0.72	0	0	0.1	0.85	0.85	0.95
Stream Restoration ^(c)	0.8	0.85	0.9	0.7	0.75	0.8	0.85	0.9	0.95
Street Sweeping	0.02	0.07	0.15	0	0.01	0	0.04	0.1	0.21
Urban Forest Buffers ^(a)	0.27	0.52	0.52	0.25	0.5	0.5	0.25	0.5	0.5
Urban Grass Buffers ^(a)	0.21	0.52	0.52	0	0	0	0	0	0
Urban Nutrient Management	0.07	0.04	0	0.04	0.03	0	0.2	0.1	0
Water Control Structures	0.32	0	0	0.3	0	0	0.33	0	0
Wetland Creation ^(a)	0.25	0.33	0.19	0.23	0.32	0.18	0.23	0.32	0.18
Wetland Restoration ^(a)	0.45	0.41	0.32	0.42	0.4	0.31	0.42	0.4	0.31

- (a) CAST represents the implementation area as a land-use change, so default efficiencies were adjusted to represent the load reduction from both the implementation and treated area as an efficiency.
- (b) CAST represents core nitrogen and core phosphorus nutrient management as a load source input reduction, so default efficiencies were adjusted based on CAST simulated load reduction data.
- (c) CAST represents stream restoration as a load source reduction, so efficiencies were calculated based on simulated load source reduction data.

6.1.3 COSTS

The costs and suitable areas are based on the treated area in the SAM application framework. For some BMPs, the implementation area is different from the treated area. For example, a forest or grass buffer is typically implemented on a small area along a waterway but will treat runoff from an extended area that drains to the waterway. In this case, the costs are divided by the total area treated, which includes the implemented area. Costs are also annualized to compare costs between BMPs with different capital maintenance costs and lifespan. The annualized costs allow the SAM tool to compare cost-effectiveness more appropriately across BMPs. Therefore, final default costs are calculated as a cost per treated acre per year. CAST BMP costs information can be found in the CAST Cost Profiles (<https://cast.chesapeakebay.net/Documentation/CostProfiles>).

The costs for each Octoraro SAM BMP were calculated as a weighted average of the individual CAST BMP costs based on the historical implementation tracking data and estimated costs for the Phase III WIP scenario. Table 6-3 shows the cost for each BMP and a breakdown of the capital and maintenance costs and lifespan to allow the user to make educated cost adjustments if needed. Table 6-3 also shows the treated-to-implemented area factor, which represents the default number of acres treated per acre implemented, which is also based on the average historical implementation tracking data. To calculate the implementation area of a BMP from a scenario in SAM, take the area shown in SAM (the treated area) and divide it by the corresponding factor from Table 6-3.

Table 6-3. Default Costs per Treated Acre (\$/Acre/Year) and Other Cost Details for Each SAM BMP

SAM BMP Name	Lifespan (years)	Capital Cost (\$/acre)	Maintenance Cost (\$/acre/year)	Opportunity Cost (\$/acre)	Total Annualized Cost (\$/acre/year)	Treated Area Factor
Agricultural Stormwater Management	10	9,734.85	389.39	0.00	1,650.10	1.0
Conservation Plans	1	26.55	0.00	0.00	26.55	1.0
Conservation Tillage	1	0.00	0.00	0.00	0.00	1.0
Cover Crops	1	74.16	0.00	0.00	77.87	1.0
Crop Irrigation Management	1	48.85	-4.86	0.00	46.43	1.0
Erosion and Sediment Control	1	6,136.96	0.00	0.00	6,136.96	1.0
Feeding Space Management	15	6,012.98	0.60	0.00	579.90	1.0
Forest Buffers	40	724.99	14.50	361.58	74.83	4.0
Forest Buffer-Streamside With Exclusion Fencing	30	1,538.93	60.69	136.82	148.02	4.0
Forest Harvesting Practices	1	59.27	0.00	0.00	59.27	1.0
Grass Buffers	10	160.70	6.43	361.59	45.32	4.0
Grass Buffer-Streamside With Exclusion Fencing	18	899.02	42.03	140.21	121.96	4.0
Manure Incorporation	1	17.34	0.00	0.00	20.23	1.0
Nutrient Management	1	6.23	0.00	0.00	6.23	1.0
Off-Stream Watering Without Fencing	20	10.59	0.16	0.00	1.01	1.0
Pasture Management	1	44.89	0.00	0.00	47.13	1.0
Stormwater Management	30	39,393.52	283.72	0.00	2,950.81	25.0
Stream Restoration ^(a)	5	1,562,456.68	195,307.08	0.00	556,195.20	1.0
Street Sweeping	8	1,035.77	845.18	0.00	1,005.44	1.0
Urban Forest Buffers	40	2,198.97	43.09	0.00	128.15	1.4
Urban Grass Buffers	10	487.40	19.10	0.00	77.61	1.4
Urban Nutrient Management	1	1.99	0.00	0.00	1.99	1.0
Water Control Structures	10	1,268.80	38.06	0.00	202.38	175.0
Wetland Creation	15	2,607.17	41.92	123.26	435.12	10.0
Wetland Restoration	15	418.23	39.82	140.72	201.90	10.0

(a) Stream Restoration amounts are in \$/mile, while all other BMP amounts are in \$/acre

6.1.4 SUITABLE AREAS

Suitable areas for each BMP represent the source areas where a BMP is most appropriately implemented. The CAST source group data were used to determine which BMPs can be applied to which source by associating the CAST source groups to the HSPF modeled sources. The suitable areas were calculated on a HUC12 watershed scale by totaling the area of the associated CAST source groups for each BMP. Available areas represent an estimate of the portion of suitable areas where the BMP has not been implemented. Available areas were calculated by subtracting the existing implementation area from the suitable area for each BMP. Existing implementation areas were estimated using the CAST BMP tracking data for 2013–2021 by the HUC12 watershed.

Suitable and available areas are represented as a percent of the primary HSPF model source associated with each BMP. Each CAST source group was assigned to a primary HSPF model source to calculate the suitable and available percent values. The suitable percent values were calculated by dividing the total area of the CAST load source groups associated with each BMP by the total source areas aggregated by the primary HSPF model source. The HSPF model source, suitable source, suitable area, and available areas for each BMP are shown in Table 6-4. The SAM BMP database has suitable and available areas available for each HUC12 watershed.

Table 6-4. Suitable and Available Sources and Areas (Acres) for Each SAM BMP

SAM BMP Name	Primary HSPF Source	Suitable Source Group	Primary HSPF Source Area	Suitable Source Area	Available Area
Agricultural Stormwater Management	Ag Pasture	Feeding Space	30,243	270	270
Conservation Plans	Ag	Cropland, Pasture, Hay	66,080	65,822	49,880
Conservation Tillage	Ag Cropland	Cropland	35,838	35,838	20,117
Cover Crops	Ag Cropland	Cropland	35,838	35,838	31,507
Crop Irrigation Management	Ag Cropland	Cropland	35,838	35,838	35,838
Erosion and Sediment Control	Developed	Roads Construction	24,957	1,990	1,867
Feeding Space Management	Ag Pasture	Feeding Space	30,243	270	69
Forest Buffers	Ag Cropland	Cropland	35,838	35,838	33,573
Forest Buffer-Streamside With Exclusion Fencing	Ag Pasture	Pasture	30,243	12,089	12,072
Forest Harvesting Practices	Forest	Harvested Forest	29,093	380	342
Grass Buffers	Ag Cropland	Cropland	35,838	35,838	28,822
Grass Buffer-Streamside With Exclusion Fencing	Ag Pasture	Pasture	30,243	12,089	12,053
Manure Incorporation	Ag Cropland Manure	Cropland Manure	18,324	18,324	17,957
Nutrient Management	Ag	Cropland, Pasture, Hay	66,080	64,901	47,056
Off-Stream Watering without Fencing	Ag Pasture	Pasture	30,243	12,089	10,068
Pasture Management	Ag Pasture	Pasture	30,243	12,089	11,187
Stormwater Management	Developed	Developed	24,957	24,766	23,873
Stream Restoration ^(a)	Bed/Bank	Bed/Bank	219	219	218
Street Sweeping	Developed	Impervious Area	24,957	2,359	2,353
Urban Forest Buffers	Developed	Turf Grass	24,957	15,289	15,278
Urban Grass Buffers	Developed	Turf Grass	24,957	15,289	15,289
Urban Nutrient Management	Developed	Turf Grass	24,957	18,328	16,352
Water Control Structures	Ag	Cropland, Pasture, Hay	66,080	65,822	64,548
Wetland Creation	Ag	Cropland, Pasture, Hay	66,080	65,822	65,816
Wetland Restoration	Ag	Cropland, Pasture, Hay	66,080	65,822	65,686

(a) Stream Restoration amounts are in miles, while all other BMP amounts are in acres

SAM uses keywords in the source name to know which source group a BMP can be applied to. The character “Ag” was added to the beginning of all the agricultural sources to allow particular BMPs to be applied to all agricultural source areas. The suitable source represents the subset of the primary HSPF model source that the BMP can be applied to. Some BMPs can be applied to the primary HSPF model source so their suitable source represents all the same source groups as the primary HSPF model source.

Suitable source groups also represented areas where the average loading rate differed significantly from the primary HSPF source. When applying BMP efficiencies in SAM, a suitable load factor was developed to account for this, representing the ratio between the loading rates of the primary HSPF source and the suitable source group. A suitable load factor for each BMP and each efficiency parameter was calculated by dividing the suitable source loading rate by the primary HSPF source loading rate for each parameter (Table 6-5). The suitable load factor is multiplied by the efficiency when applied in SAM to represent more accurate load reductions in areas with potentially higher loading rates.

Table 6-5. Suitable Load Factors for Each SAM BMP and Efficiency Parameter

SAM BMP Name	Nitrogen	Phosphorus	Sediment
Agricultural Stormwater Management	25.00	11.00	3.00
Conservation Plans	1.00	1.00	1.00
Conservation Tillage	1.00	1.00	1.00
Cover Crops	1.00	1.00	1.00
Crop Irrigation Management	1.00	1.00	1.00
Erosion and Sediment Control	1.71	1.13	1.88
Feeding Space Management	25.00	11.00	3.00
Forest Buffers	1.00	1.00	1.00
Forest Buffer-Streamside With Exclusion Fencing	1.25	2.10	2.27
Forest Harvesting Practices	6.36	2.94	8.96
Grass Buffers	1.00	1.00	1.00
Grass Buffer-Streamside With Exclusion Fencing	1.25	2.10	2.27
Manure Incorporation	1.00	1.00	1.00
Nutrient Management	1.00	1.00	1.00
Off-Stream Watering Without Fencing	1.00	1.00	1.00
Pasture Management	1.00	1.00	1.00
Stormwater Management	1.00	1.00	1.00
Stream Restoration	1.00	1.00	1.00
Street Sweeping	1.68	1.12	1.85
Urban Forest Buffers	0.85	1.01	0.64
Urban Grass Buffers	0.85	1.01	0.64
Urban Nutrient Management	0.83	1.00	0.68
Water Control Structures	1.00	1.00	1.00
Wetland Creation	1.00	1.00	1.00
Wetland Restoration	1.00	1.00	1.00

6.2 SELECTED SCENARIOS

The SAM decision-support tool can be used to create and evaluate a wide variety of customized scenarios based on the different water quality goals of federal, state, and local stakeholders. Two scenarios were selected by the project team with input from stakeholders that were developed and evaluated for this project. The first scenario selected represents the Phase III WIP implementation goals of the Chesapeake Bay TMDL for the Octoraro Watershed. The second scenario selected combines sediment, nitrate, and DO instream water quality endpoint targets at critical locations in the Octoraro Watershed. The following text describes the SAM components, selected scenario development methods, and the scenario results and discussion.

6.2.1 Chesapeake Bay TMDL Implementation Scenario

The Chesapeake Bay TMDL Phase III Watershed Implementation Plan (WIP) implementation goals were selected as a scenario because the Octoraro Creek HUC12 Watersheds are some of the highest priority watersheds for both Nitrogen and Phosphorus based on the Chesapeake Bay Program Priority Agricultural Watershed Analysis (<https://www.arcgis.com/sharing/rest/content/items/4404e6992974421283411d0b179e2440/info/metadata/metadata.xml?format=default&output=html>). The Phase III WIP is county based. Although the Octoraro River implementation goals are higher, it does not mean the WIP goals will not be met county-wide. Although the Octoraro Watershed implementation needed to meet the selected water quality targets is higher than the WIP implementation goals, it does not mean the WIP goals are not being met.

The Phase III WIP implementation goals were available by HUC12 from the CAST tool in the same form as the BMP tracking data that was used for the development of the suitable area. Table 6-6 shows the amount of BMP implementation represented in the calibrated model, the Phase III WIP total implementation goals, and the incremental amount added to the model with the SAM tool for the scenario. The amount of implementation for each BMP distributed among the model subwatersheds relatively based on the percent of each subwatersheds applicable source area of the total HUC12 source area. Implementation amounts in the base calibrated model that equaled or exceeded the Phase III WIP amount remained at their current amount for the scenario.

Table 6-6. Implementation Areas (Acres) for the Current Model, Phase III WIP Goals, and the Chesapeake Bay TMDL Scenario

SAM BMP Name	2013–2021	Phase III WIP	Scenario Amount
Agricultural Stormwater Management	0.4	8.5	8.1
Conservation Plans	15,942.2	55,615.7	39,673.4
Conservation Tillage	15,720.6	33,387.3	17,666.7
Cover Crops	4,330.4	20,141.0	15,810.5
Crop Irrigation Management	0.0	102.2	102.2
Erosion and Sediment Control	122.6	85.6	0.0
Feeding Space Management	200.9	213.9	13.0
Forest Buffers	2,264.9	8,438.6	6,173.7
Forest Buffer-Streamside with Exclusion Fencing	17.2	900.5	883.3
Forest Harvesting Practices	38.0	73.7	35.7
Forest Planting	7.1	55.8	48.7
Grass Buffers	7,015.4	8,333.5	1,318.1
Grass Buffer-Streamside with Exclusion Fencing	35.9	2,837.3	2,801.4
Impervious Surface Reduction	0.0	1.5	1.5
Land Policy	0.0	26.8	26.8
Land Retirement to Ag Open Space	643.1	722.1	79.0
Land Retirement to Pasture	46.5	56.5	10.0
Manure Incorporation	366.6	2,317.5	1,950.8
Nutrient Management	17,845.5	61,587.9	43,742.4
Off Stream Watering without Fencing	2,020.8	1,548.8	0.0
Pasture Management	902.0	3,873.6	2,971.6
Septic Connections	233.1	532.9	299.8
Septic Denitrification and Pumping	89.5	1,223.2	1,133.7
Stormwater Management	893.4	2,800.8	1,907.3
Stream Restoration ^(a)	1.4	5.2	3.8
Street Sweeping	5.3	14.4	9.1
Tree Planting	151.3	76.4	0.0
Urban Forest Buffers	11.4	83.7	72.2
Urban Grass Buffers	0.0	0.0	0.0
Urban Nutrient Management	1,976.5	4,227.5	2,251.0
Water Control Structures	1,274.2	840.4	0.0
Wetland Creation	6.7	15.6	8.9
Wetland Restoration	136.8	312.6	175.9

(a) Stream Restoration amounts are in miles, while all other BMP amounts are in acres.

6.2.2 Water Quality Target Scenarios

The objective of the water quality target scenarios is to estimate the amount of BMP implementation needed in the Octoraro watershed to achieve selected instream water quality targets at critical locations. The SAM targeting functionality requires target inputs as a percent reduction, so each nitrogen, phosphorus, and sediment target was converted to a percent reduction for application in the SAM scenario (Table 6-7).

Table 6-7. Water Quality Percent Reduction Targets for the Octoraro Creek Watershed

Target Location	Nitrogen Target (% Reduction)	Phosphorus Target (% Reduction)	Sediment Target (% Reduction)
East Branch Octoraro Creek		60	56
West Branch Octoraro Creek		65	47
Octoraro Reservoir	18		
Octoraro Creek at PA-MD Stateline		50	
Octoraro Creek at Outlet		50	

Note: Blank cells indicate not applicable

The nitrogen water quality target of 8 mg/L nitrate was selected for the Octoraro Reservoir as a conservative target (below the water quality standard) to provide an additional margin of safety to ensure the Octoraro Reservoir does not exceed the water quality standard. The nitrogen percent reduction target was calculated by dividing the maximum simulated concentration in the Octoraro Reservoir divided by 8 mg/L. The nitrogen target will only be applied in the Octoraro Reservoir.

The sediment-water quality target and locations were determined by the EPA and Pennsylvania Department of Environmental Protection (PADEP) using a reference site methodology guided by a study on nutrients and suspended sediment in the Susquehanna River Basin [McGonigal, 2019]. Instream sediment loading rates from multiple reference sites with similar watershed characteristics were selected to set the target loading rate of 200 kg/ha/yr for only the East Branch and West Branch Octoraro Creek upstream of Octoraro Reservoir. The instream loading rate at the outlet of Octoraro Creek is currently close to the target because of significant settling occurring in Octoraro Reservoir and the lower sediment loading rates in areas downstream of Octoraro Reservoir.

The phosphorus water quality targets were determined using an iterative approach of reducing nutrients until selected locations met DO targets. DO targets were provided through personal communication with PADEP. The DO targets were draft assessment

benchmarks developed using a 75th percentile minimum DO percent saturation and a 25th percentile daily DO percent saturation flux value for each month. Nutrient loads in the model were iteratively reduced until at least one of the two DO benchmarks were met. The DO benchmarks were considered met when the 25th percentile of the daily minimum simulated percent saturation was greater than or equal to the minimum target or the 75th percentile simulated percent saturation flux was less than or equal to the flux target. The DO targets were evaluated at the East and West Branch Octoraro Creek before entering the Octoraro Reservoir, Octoraro Creek near the PA and MD Stateline, and at the outlet of Octoraro Creek before it enters the Susquehanna River.

6.3 SCENARIO APPLICATION METHODS

The SAM custom scenario design functionality was used to build the Chesapeake Bay TMDL implementation scenario. The specific amount of implementation prescribed by the Phase III WIP for the Octoraro Watershed was built into the Chesapeake Bay TMDL scenario using the SAM custom scenario design functionality. The total implementation amount simulated for this scenario is shown in Table 6-6.

The target optimization functionality was used to build the water quality endpoint scenarios. A scenario was developed for each of the nitrogen, phosphorus, and sediment targets. A final combined scenario optimized to meet all water quality targets was also developed. The target optimization functionality in SAM uses a combination of the unique subbasin and source loads, pollutant reduction efficiencies, suitable area load factors, and costs to calculate the cost-effectiveness of each BMP in each subbasin. SAM sorts the cost-effectiveness values and adds the sorted BMPs to the scenario until all targets are met. SAM applies overlapping BMP adjustments and evaluates water quality targets after adding each additional BMP to the scenario. The amount of a BMP that can be implemented in each subbasin is limited by the available area and user-defined percent participation. The available areas are determined by the estimated suitable area and existing implementation. The percent participation was adjusted during the scenario development to allow for some optimization based on the difficulty of achieving the target while assuming that BMP implementation efforts will not achieve full participation. A higher percent participation will allow for more cost-effective BMPs to be implemented, resulting in an overall lower scenario cost. The percent participation values used for the nitrogen, sediment, phosphorus, and combined water quality target scenarios were 25, 60, 70, and 80 percent, respectively.

6.4 SCENARIO RESULTS

Water quality reductions simulated in the Octoraro Watershed by the SAM application of the Chesapeake Bay Implementation Scenario were compared to the reductions estimated by the CAST tool for the same scenario. The results in Table 6-8 show similar reductions from both tools, which is interpreted as a validation of a comparable representation of CAST BMPs in the SAM tool. SAM reductions are shown as a range because of the higher resolution of results available. Differences can be attributed to application methods and watershed model scale.

Table 6-8. Water Quality Load Reductions for the SAM and CAST Representation of the Chesapeake Bay Implementation Scenario

Water Quality Parameter	CAST Reductions (%)	SAM Reductions (%)	Water Quality Parameter
Nitrogen	30	23–34	Nitrogen
Phosphorus	48	32–47	Phosphorus
Sediment	32	26–35	Sediment

Tables 6-9 through 6-11 show the percent reductions simulated by each scenario at the selected locations compared to the nitrogen, phosphorus, and sediment water quality targets, respectively. The Chesapeake Bay TMDL and nitrogen scenarios only met the nitrogen target. The sediment scenario met the nitrogen and sediment targets. The phosphorus scenario met the nitrogen and phosphorus targets while meeting the West Branch sediment target. The combined scenario met all targets and was primarily driven by the phosphorus reduction targets with additional reductions needed to meet the East Branch Octoraro Creek sediment target.

Table 6-9. Simulated Nitrogen Percent Reduction Compared to the Water Quality Target

Scenario	Octoraro Reservoir (%)
Water Quality Target	18
Phase III WIP	24
Sediment Target	37
Nitrate Target	18
Phosphorus (DO) Target	46
Combined Targets	46

Table 6-10. Simulated Phosphorus Percent Reduction Compared to the Water Quality Targets

Scenario	East Branch (%)	West Branch (%)	Stateline (%)	Outlet (%)
Water Quality Target	60	65	50	50
Phase III WIP	39	40	41	39
Sediment Target	59	43	40	36
Nitrate Target	21	22	19	17
Phosphorus (DO) Target	60	65	57	55
Combined Targets	61	65	58	56

Table 6-11. Simulated Percent Reduction Compared to the Sediment Water Quality Target

Scenario	East Branch (%)	West Branch (%)
Water Quality Target	56	47
Phase III WIP	32	34
Sediment Target	56	47
Nitrate Target	19	22
Phosphorus (DO) Target	53	59
Combined Targets	58	62

Figures 6-1 through 6-3 are maps showing the nitrogen, phosphorus, and sediment percent reduction simulated at the instream outlet of each modeled subbasin for the combined scenario. The instream percent reduction values shown in the maps represent reductions occurring in all upstream areas and not just the local subwatershed. The spatial results show the highest amount of reduction and implementation is needed above the Octoraro Reservoir to meet the selected water quality targets. The West Branch also shows higher nitrogen reductions for the combined scenario.

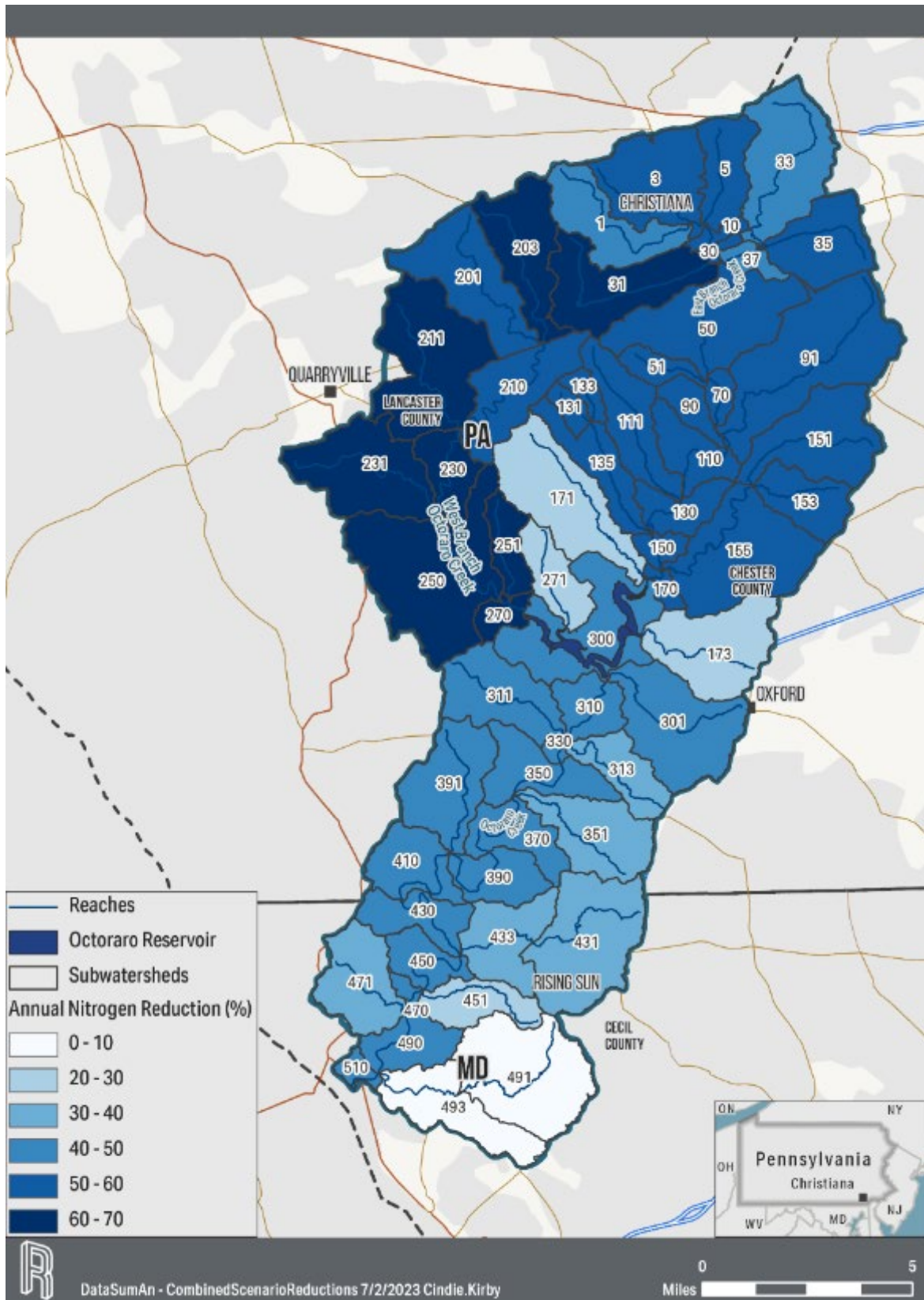


Figure 6-1. Map of the Instream Nitrogen Percent Reduction Simulated by the Combined Scenario.

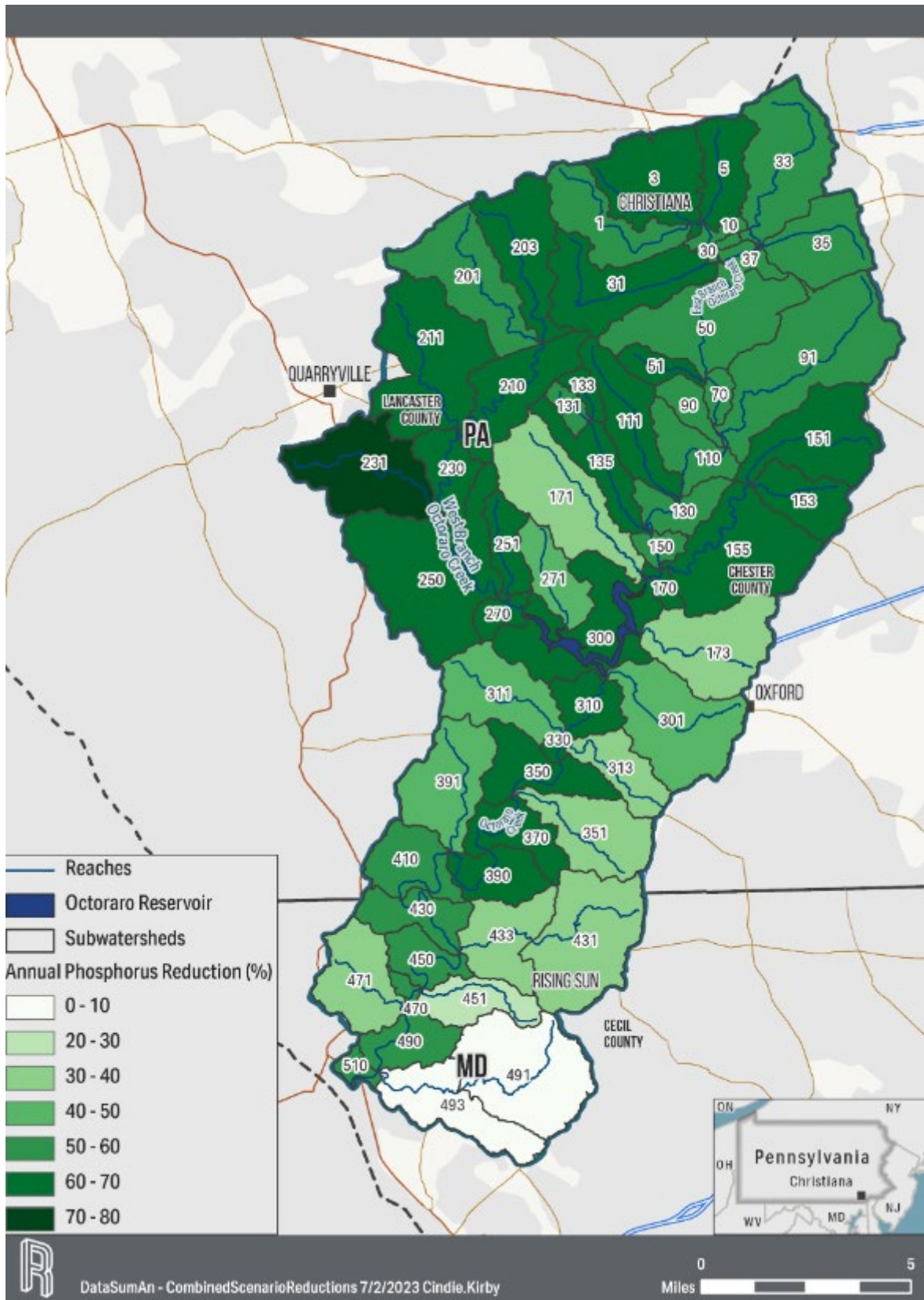


Figure 6-2. Map of the Instream Phosphorus Percent Reduction Simulated by the Combined Scenario.

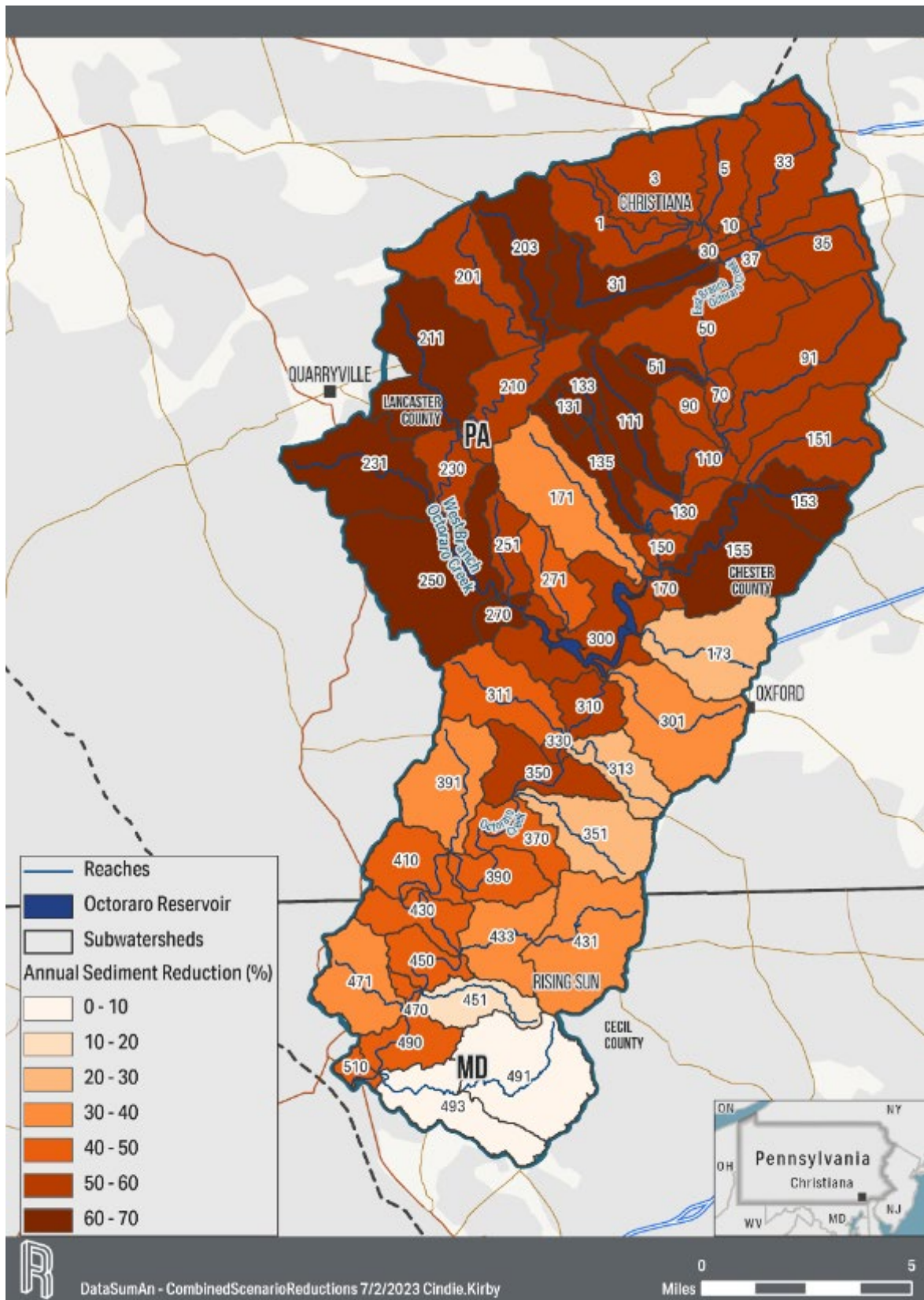


Figure 6-3. Map of the Instream Sediment Percent Reduction Simulated by the Combined Scenario.

Table 6-12 shows the total treated area (acres), total annualized cost (\$/treated acre/year), and cost-effectiveness (pounds per dollar [lb/\$]) for each BMP and parameter for the combined scenario. Cost-effectiveness values are represented in pounds reduced per dollar (lb/\$). Conservation tillage, Conservation Plans, and Off-stream Watering BMPs show the highest cost-effectiveness for all parameters because of the low costs. Nutrient management also shows higher cost-effectiveness for nitrogen and phosphorus load reductions. Buffers also show higher cost-effectiveness for phosphorus and sediment. Other BMPs not included in the combined scenario will have lower cost-effectiveness but could be included in a scenario that uses a lower participation value.

Table 6-12. Total Treated Area, Annualized Cost, And Cost Effectiveness for Each BMP represented in the Combined Scenario

SAM BMP Name	Treated Area (acres)	Annualized Cost (\$/year)	Nitrogen Cost Effectiveness (lb/\$)	Phosphorus Cost Effectiveness (lb/\$)	Sediment Cost Effectiveness (lb/\$)
Conservation Plans	39,411	232,917	0.35	0.030	9.8
Conservation Tillage	15,652	15,652	No Cost	No Cost	No Cost
Forest Buffers	23,827	1,782,984	0.33	0.009	2.4
Forest Buffer-Streamside with Exclusion Fencing	380	56,294	0.08	0.003	1.3
Grass Buffers	22,039	998,798	0.37	0.014	4.0
Grass Buffer-Streamside with Exclusion Fencing	6,831	833,061	0.08	0.005	1.3
Manure Incorporation	10,257	207,501	0.21	0.025	0.0
Nutrient Management	37,107	231,175	0.52	0.037	0.0
Off Stream Watering without Fencing	7,846	7,925	1.02	0.137	33
Pasture Management	6,063	285,764	0.09	0.010	2.8
Urban Forest Buffers	3,830	490,835	0.02	0.001	0.8
Urban Grass Buffers	5,707	442,923	0.03	0.003	1.5
Urban Nutrient Management	12,460	24,796	0.44	0.008	0.0
Wetland Restoration	15,176	3,064,112	0.07	0.003	0.3
Total	206,586	8,674,735	0.18	0.009	2.0

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APPENDIX A

TIME-SERIES PLOTS OF STROUD FLOW DATA ABOVE OCTORARO RESERVOIR

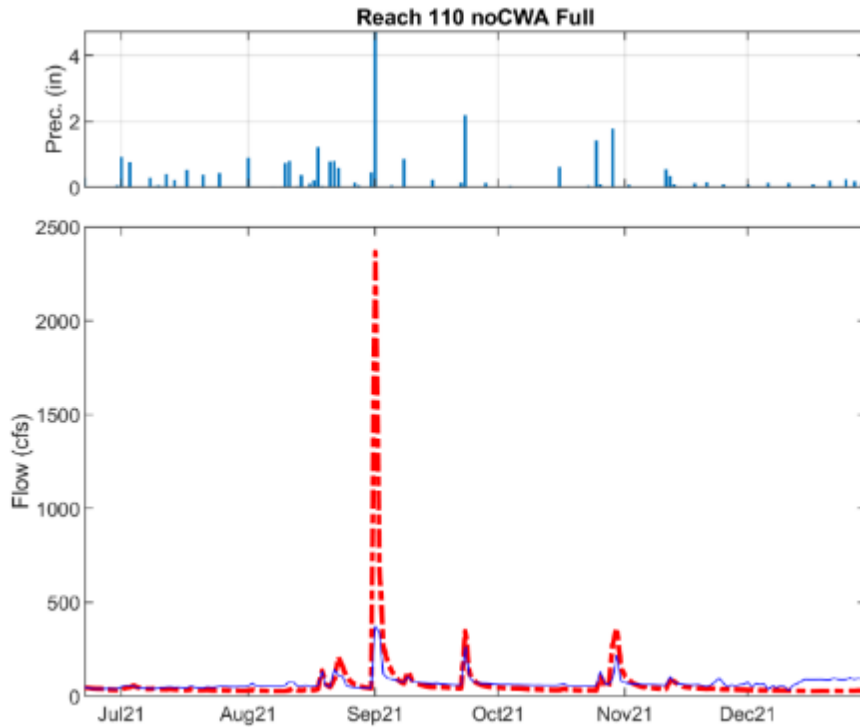


Figure A-1. Stroud Data Showing How the Simulation Reacted to Extremely Localized Intense Storms on the East Branch Octoraro Creek Above Octoraro Reservoir.

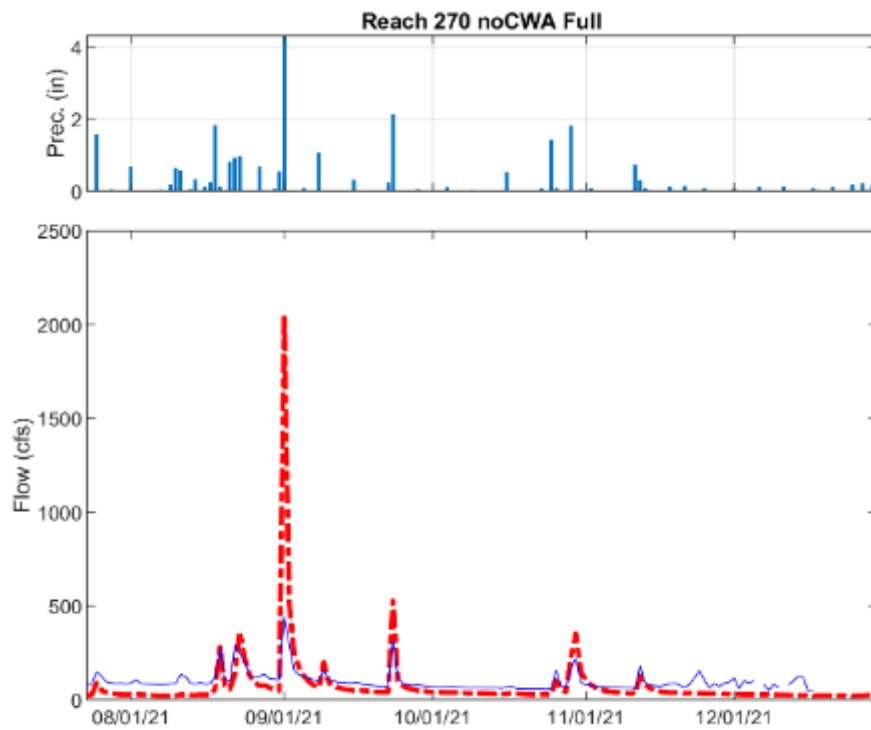


Figure A-2. Stroud Data Showing How the Simulation Reacted to Extremely Localized Intense Storms on the West Branch Octoraro Creek Above Octoraro Reservoir.

APPENDIX B

HSPF WATER QUALITY CALIBRATION

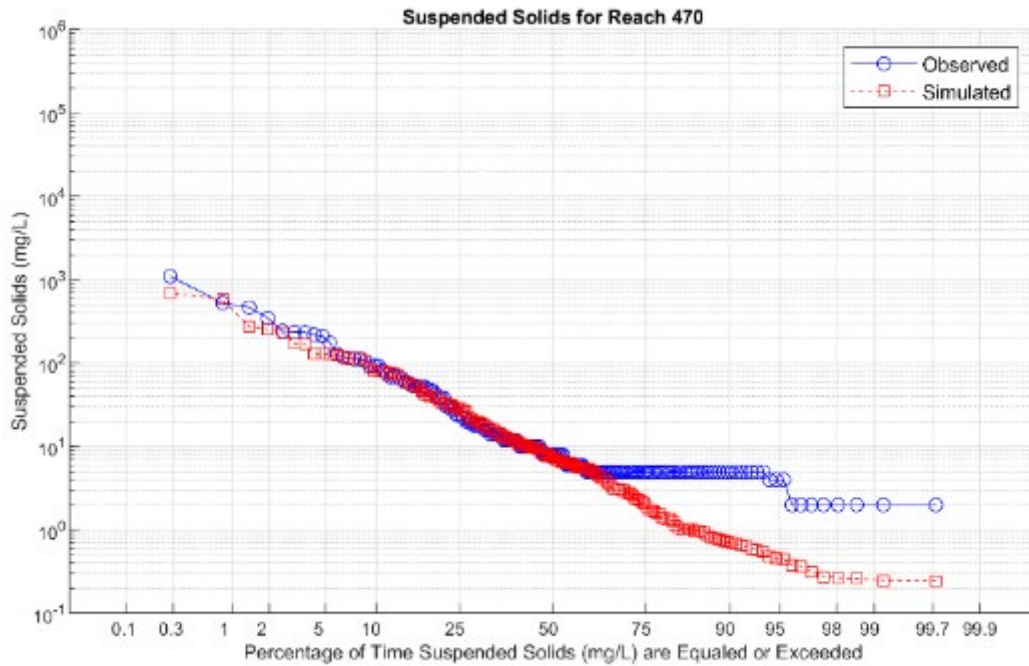


Figure B-1. Total Suspended Sediment Duration Plot for HSPF Reach 470 (log-scale).

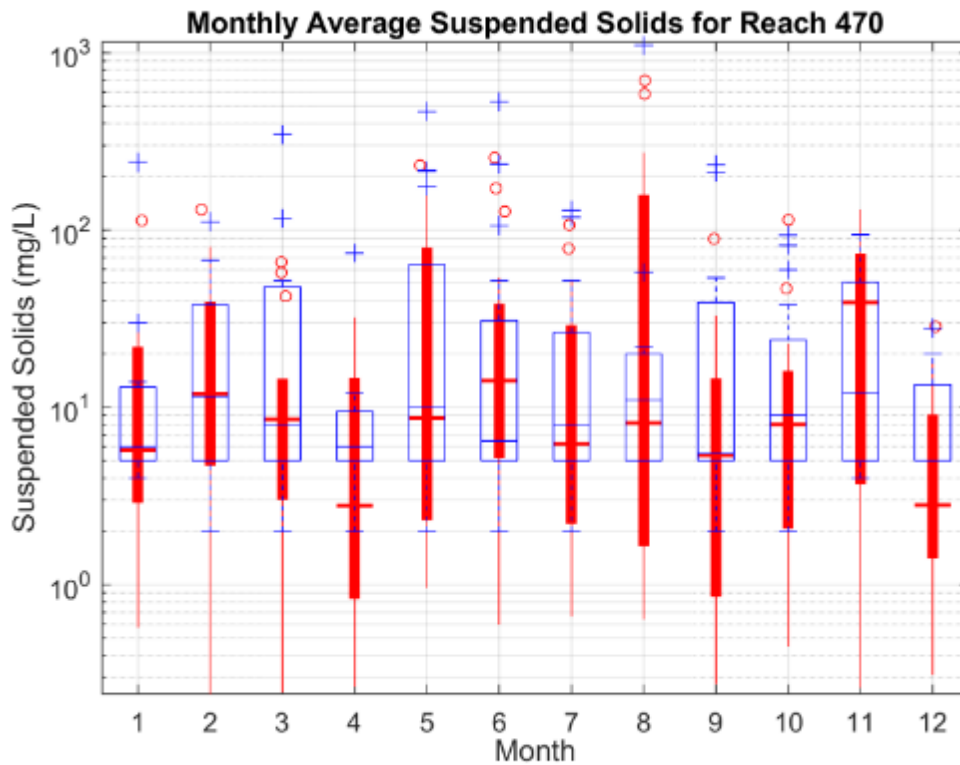


Figure B-2. Total Suspended Sediment Monthly Average Boxplot for HSPF Reach 470 (log-scale).

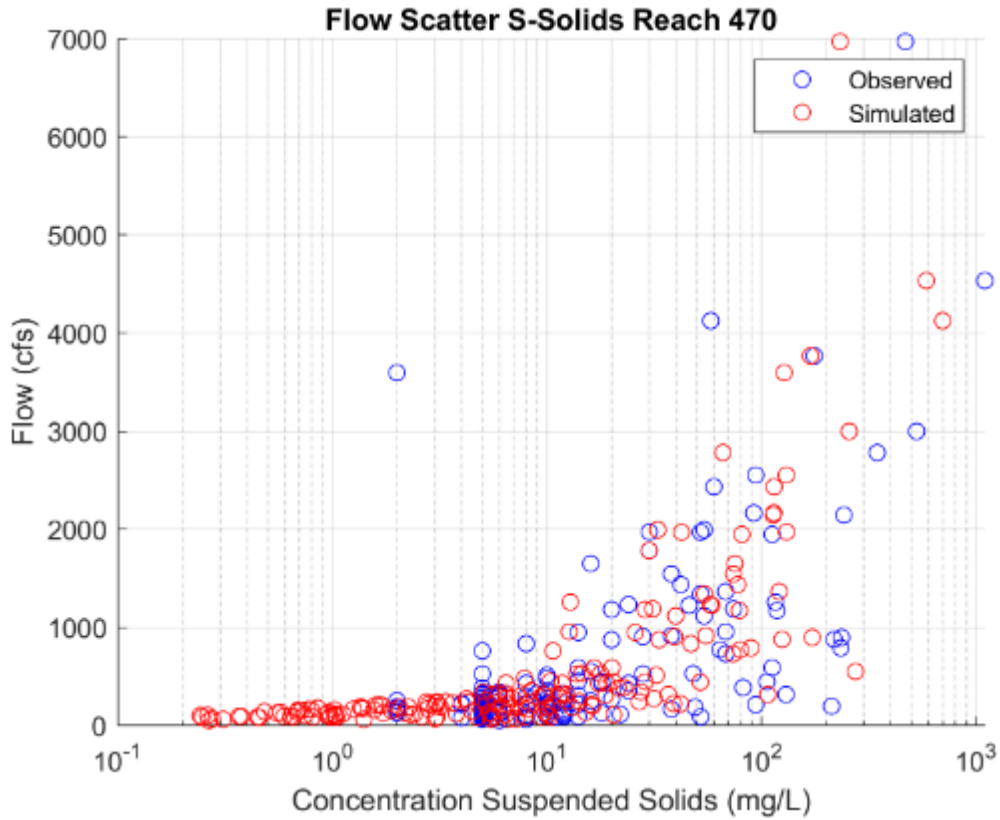


Figure B-3. Total Suspended Sediment Scatter Plot for HSPF Reach 470 (log-scale).

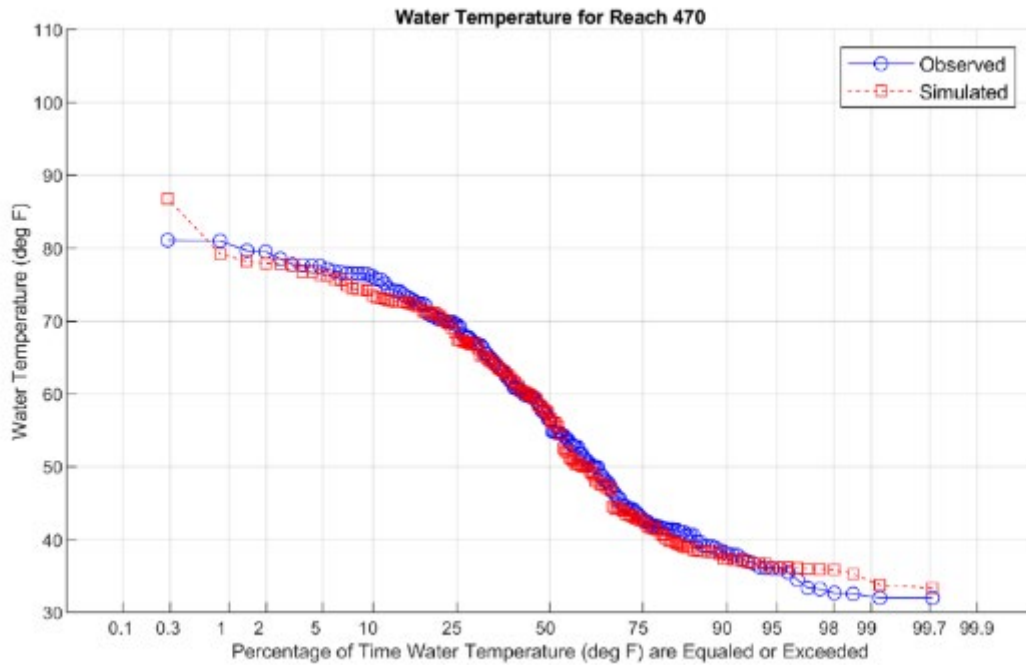


Figure B-4. Instantaneous Temperature Duration Plot for HSPF Reach 470.

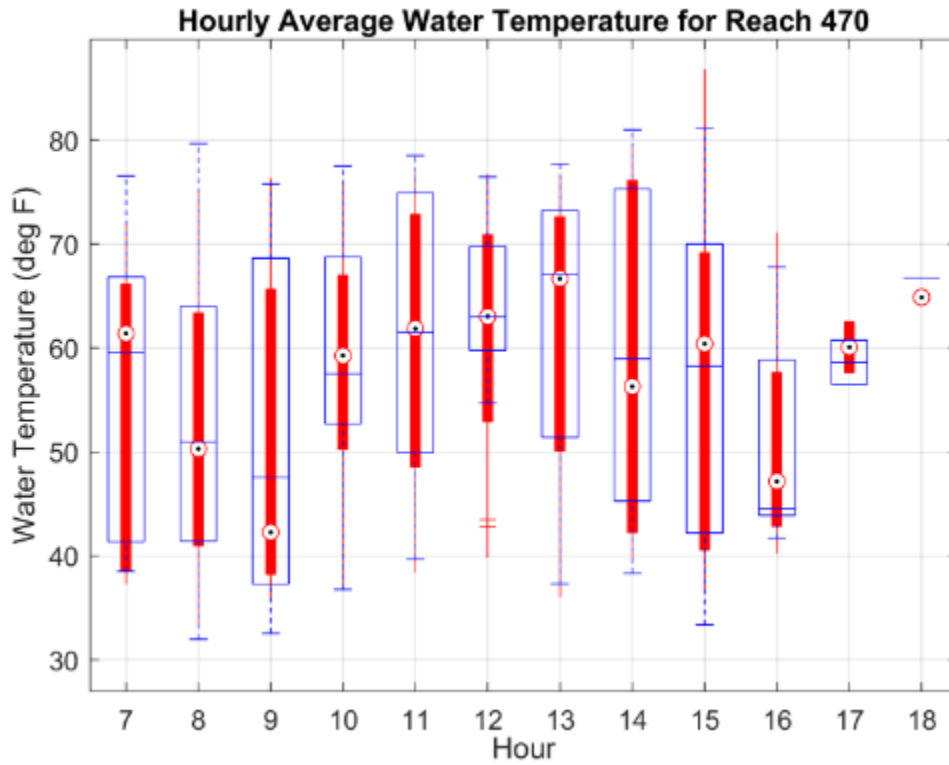


Figure B-5. Instantaneous Temperature Hourly Average Boxplot for HSPF Reach 470.

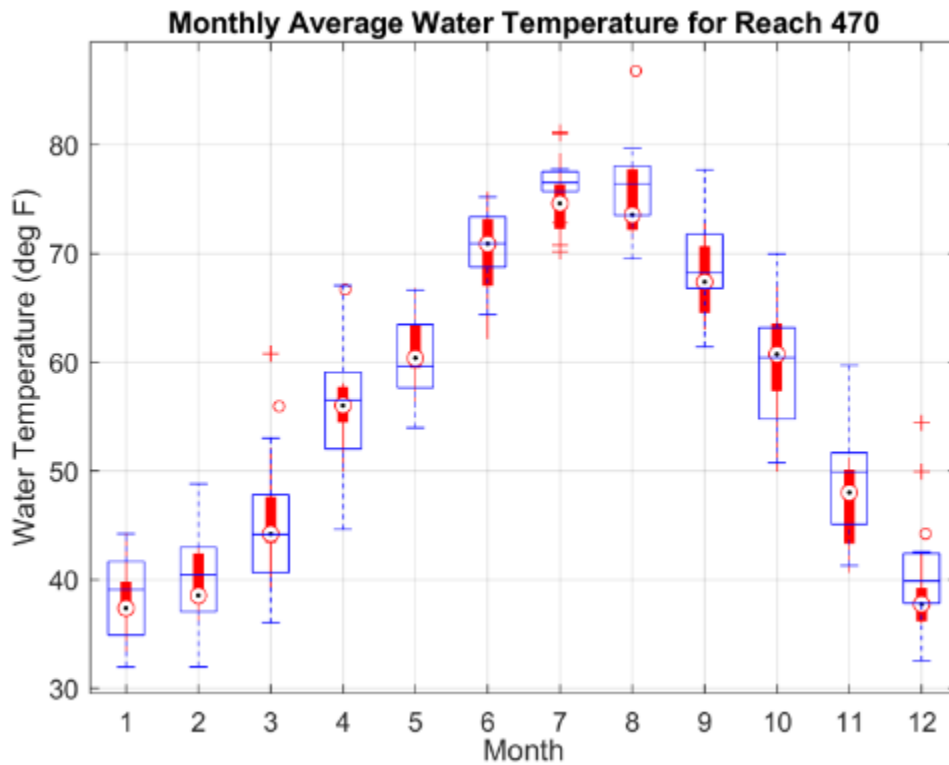


Figure B-6. Instantaneous Temperature Monthly Average Boxplot for HSPF Reach 470.

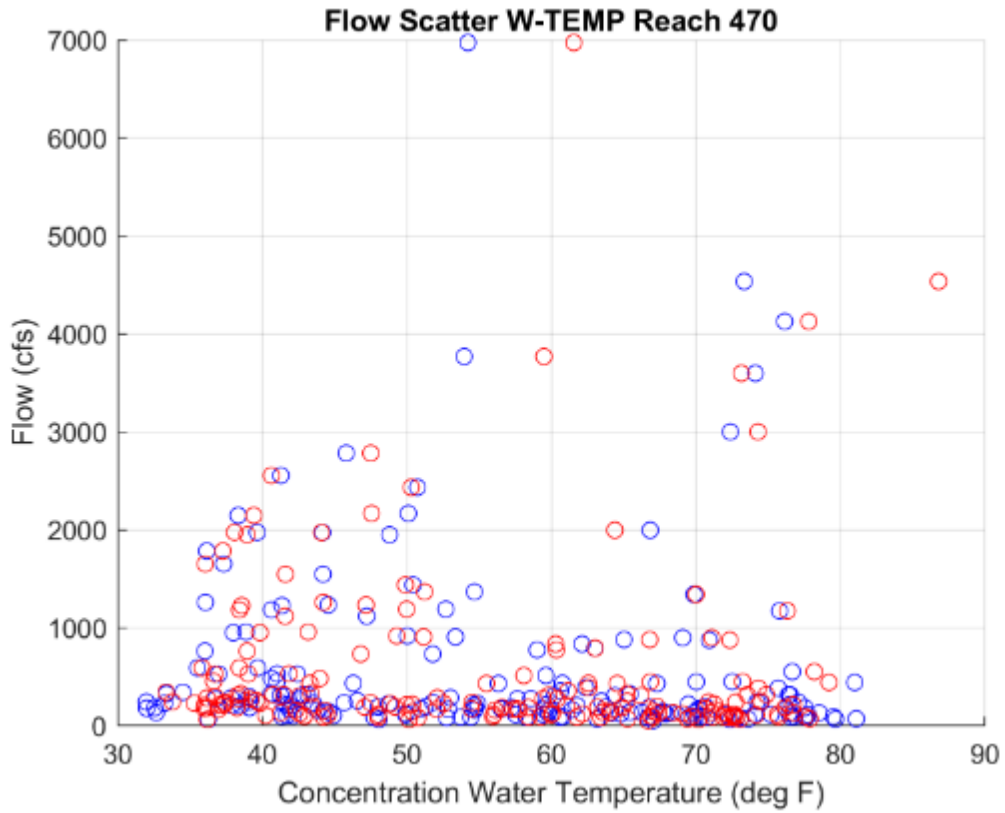


Figure B-7. Instantaneous Temperature Scatter Plot for HSPF Reach 470.

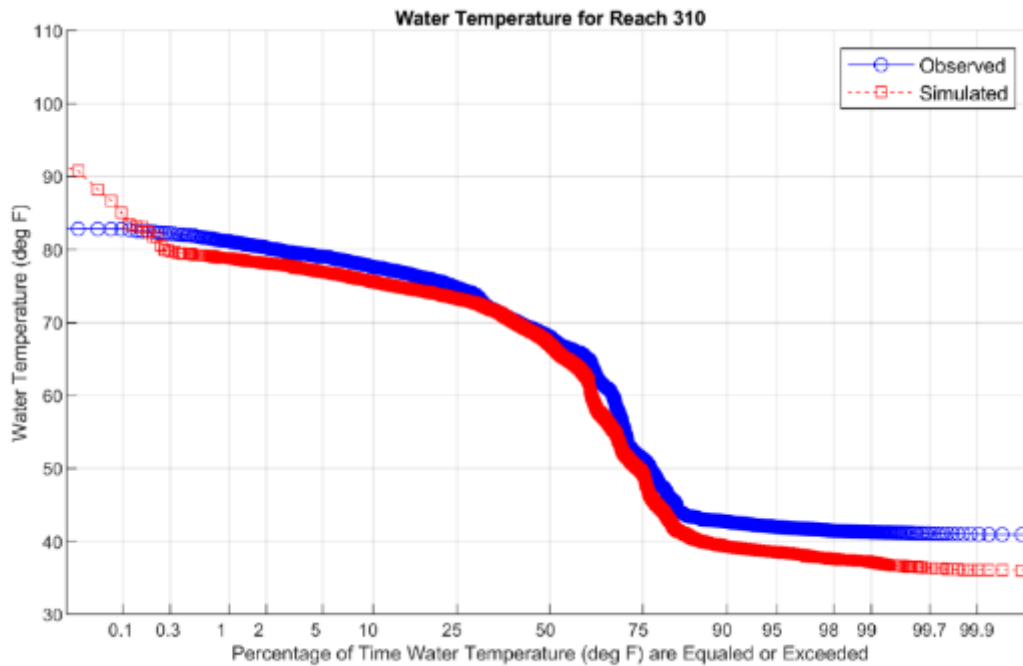


Figure B-8. Continuous Temperature Duration Plot for HSPF Reach 310.

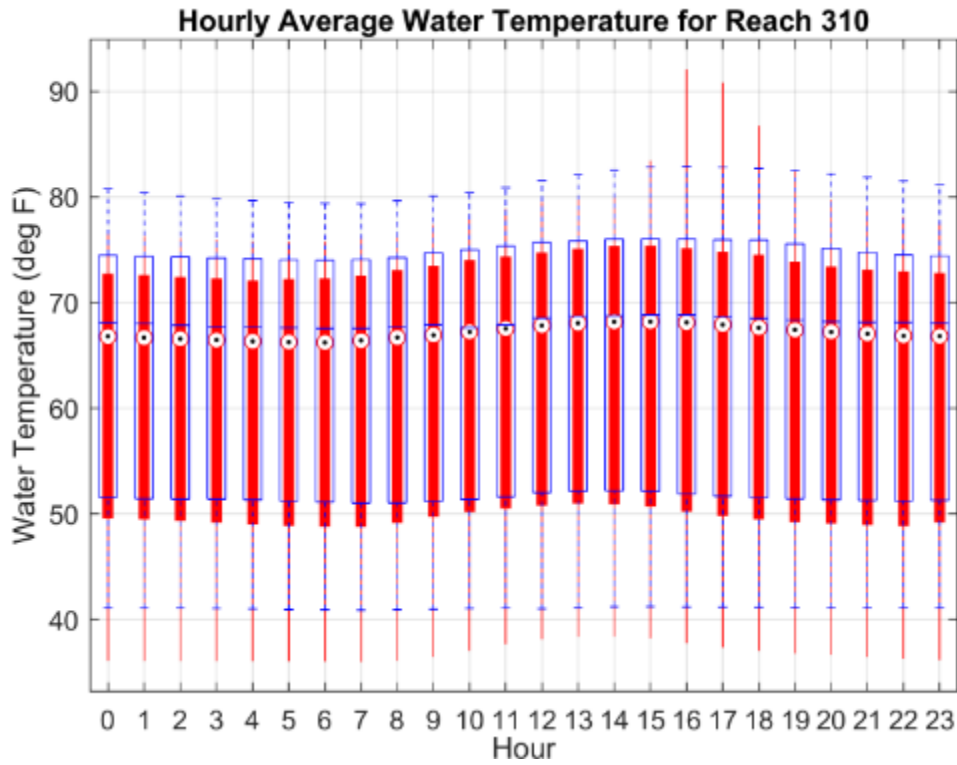


Figure B-9. Continuous Temperature Hourly Average Boxplot for HSPF Reach 310.

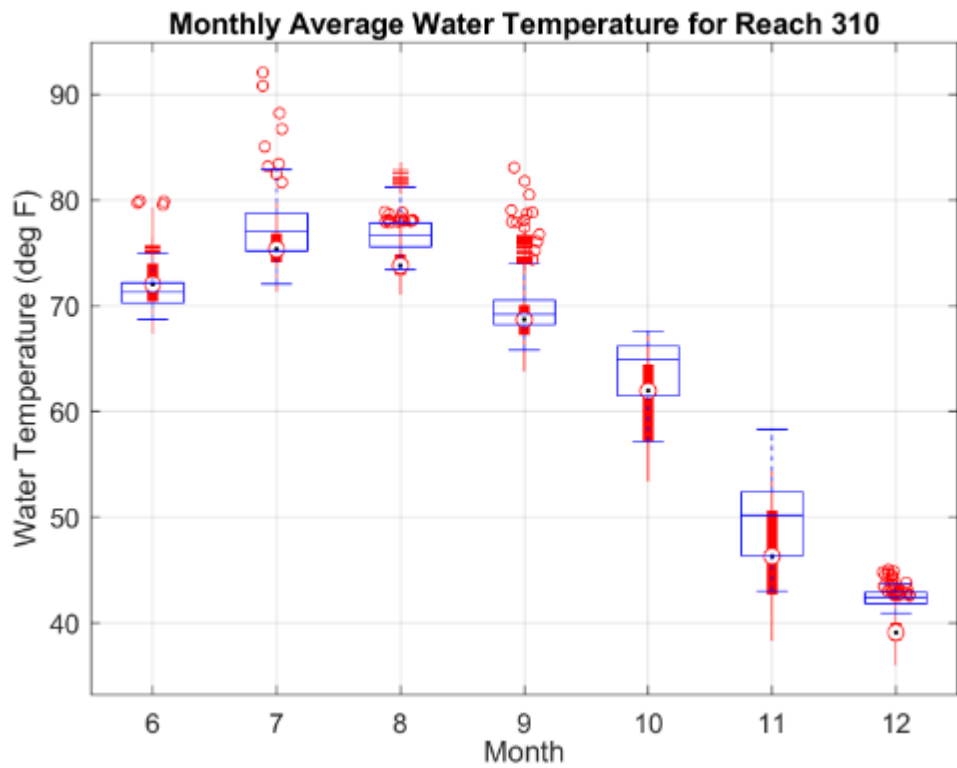


Figure B-10. Continuous Temperature Monthly Average Boxplot for HSPF Reach 310.

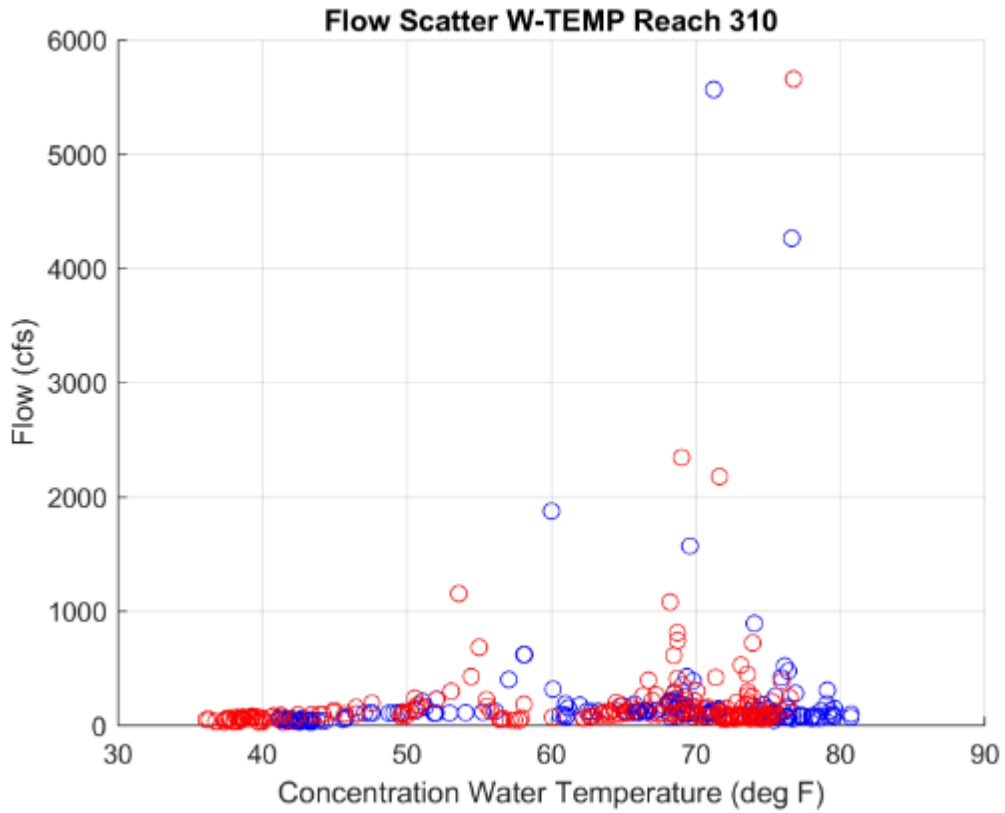


Figure B-11. Continuous Temperature Scatter Plot for HSPF Reach 310.

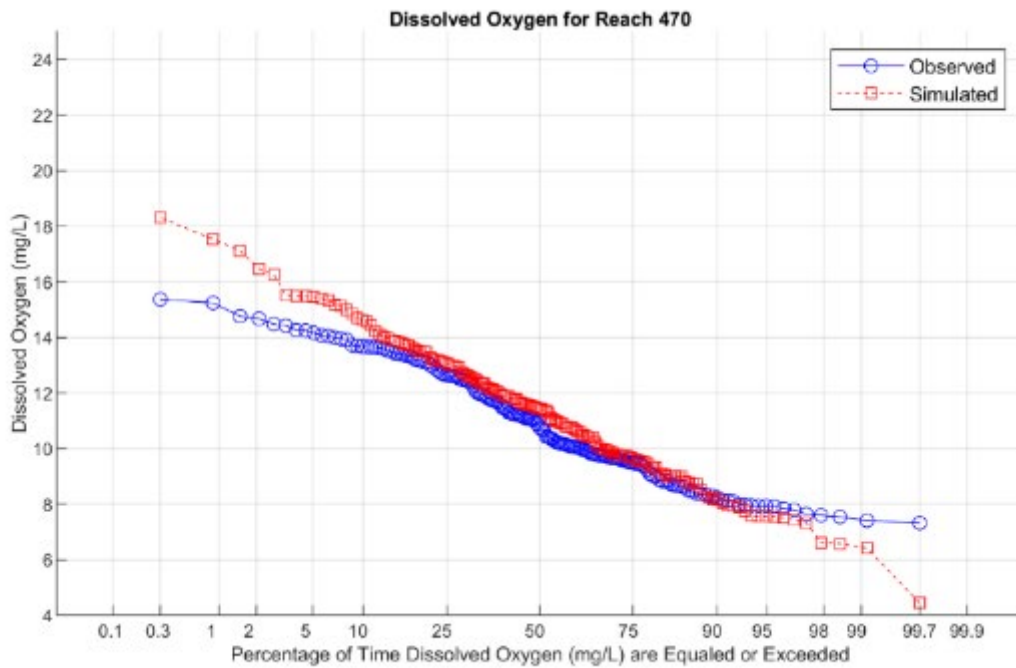


Figure B-12. Instantaneous Dissolved Oxygen Duration Plot for HSPF Reach 470.

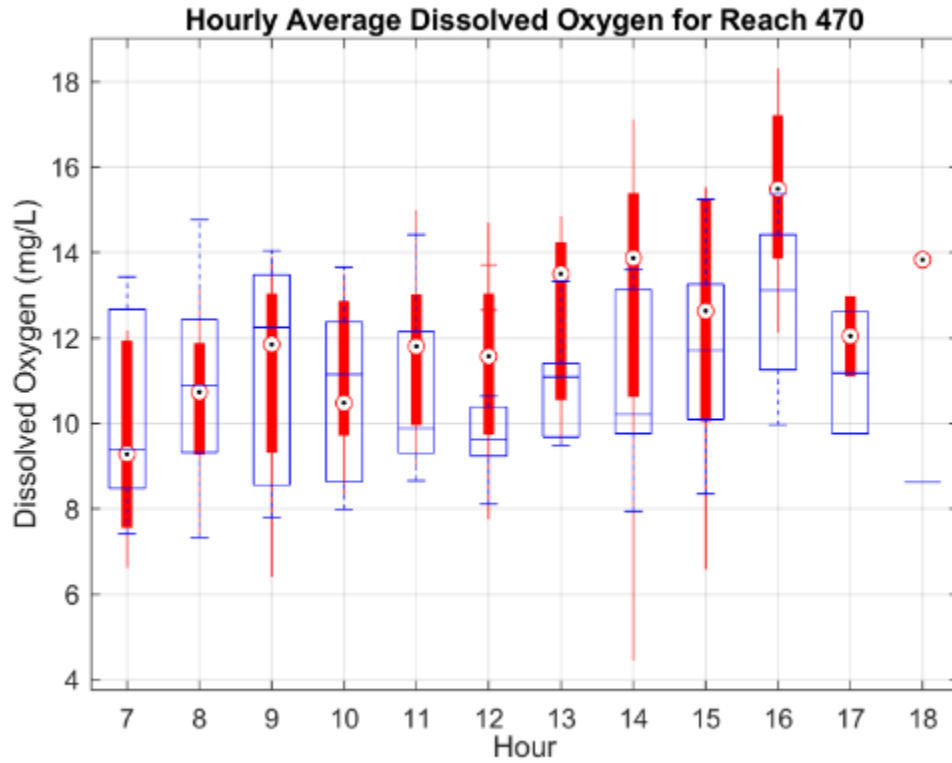


Figure B-13. Instantaneous Dissolved Oxygen Hourly Average Boxplot for HSPF Reach 470.

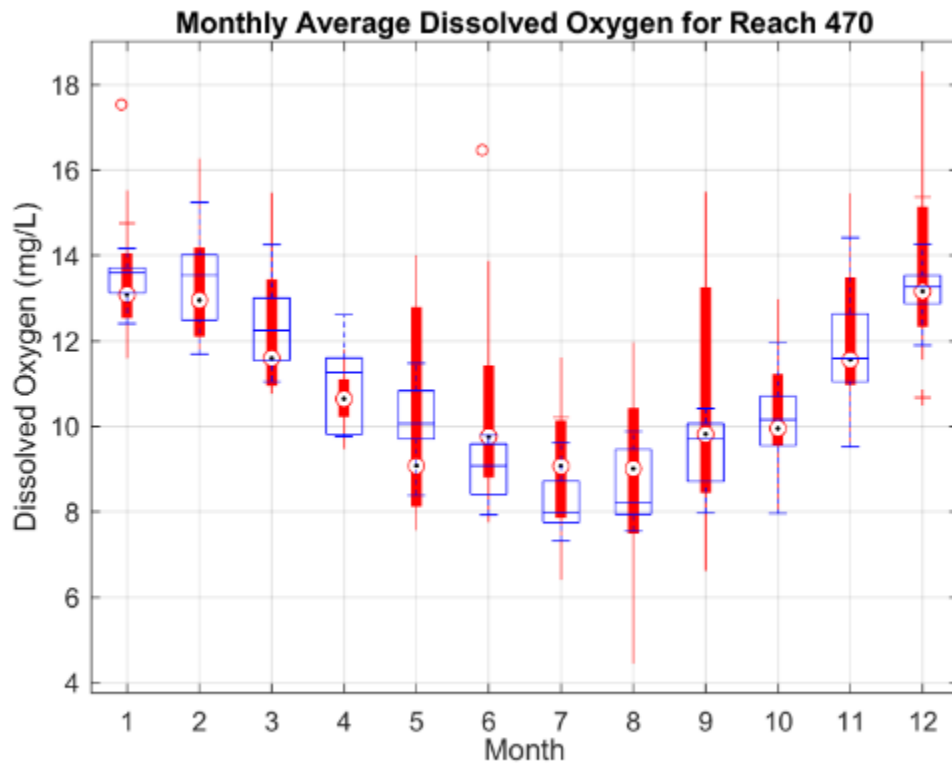


Figure B-14. Instantaneous Dissolved Oxygen Monthly Average Boxplot for HSPF Reach 470.

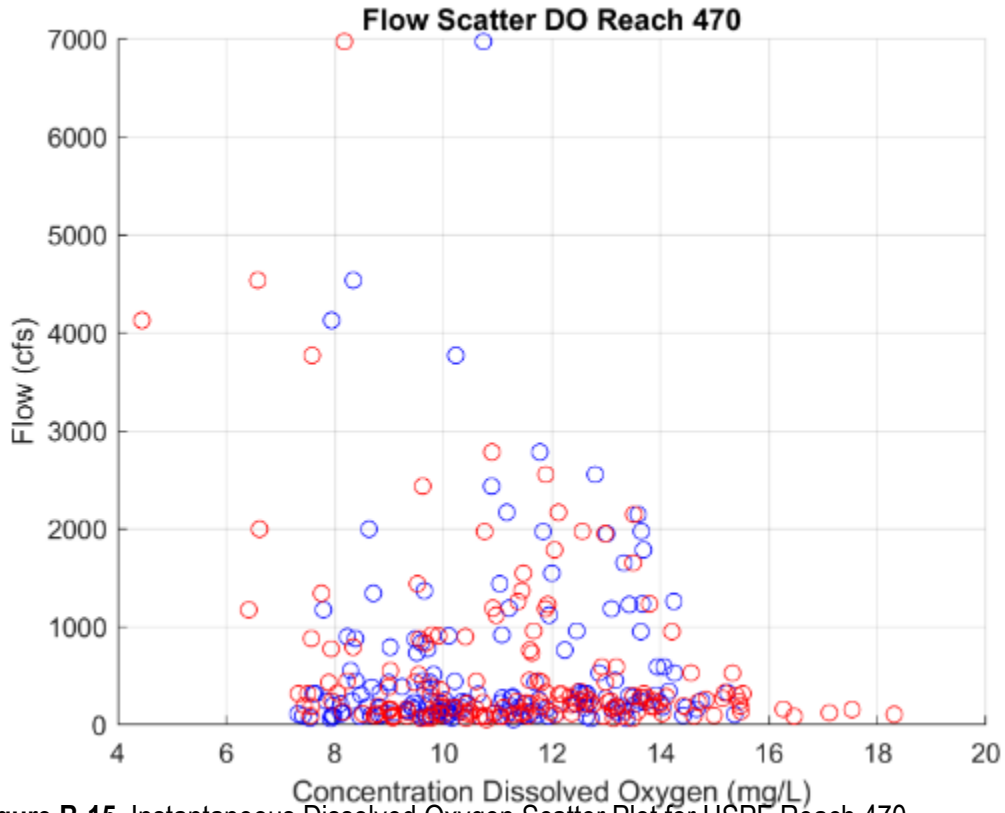


Figure B-15. Instantaneous Dissolved Oxygen Scatter Plot for HSPF Reach 470.

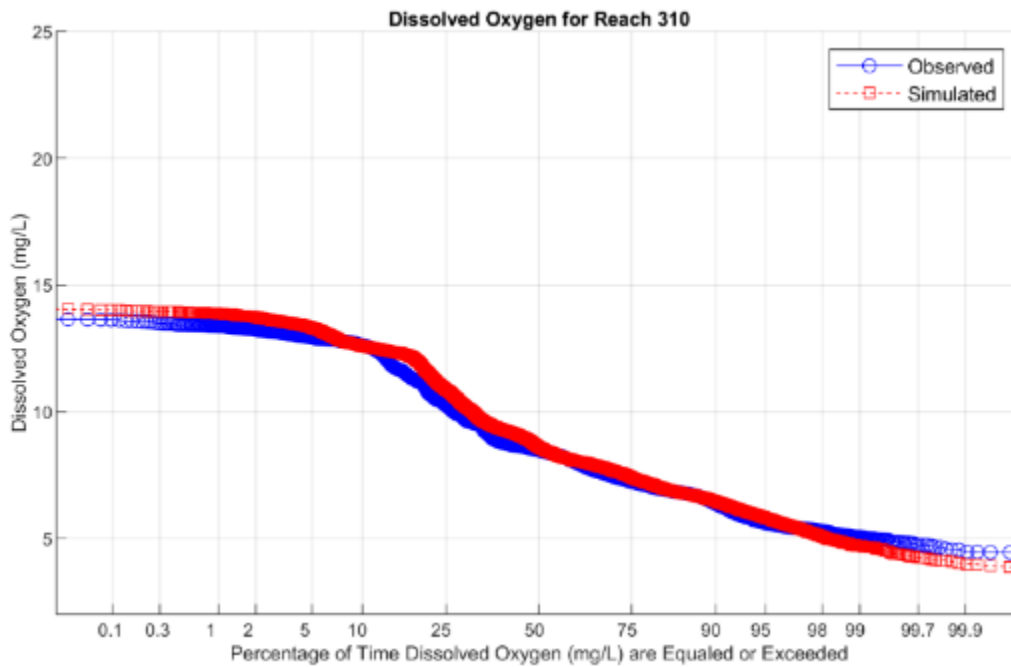


Figure B-16. Continuous Dissolved Oxygen Duration Plot for HSPF Reach 310.

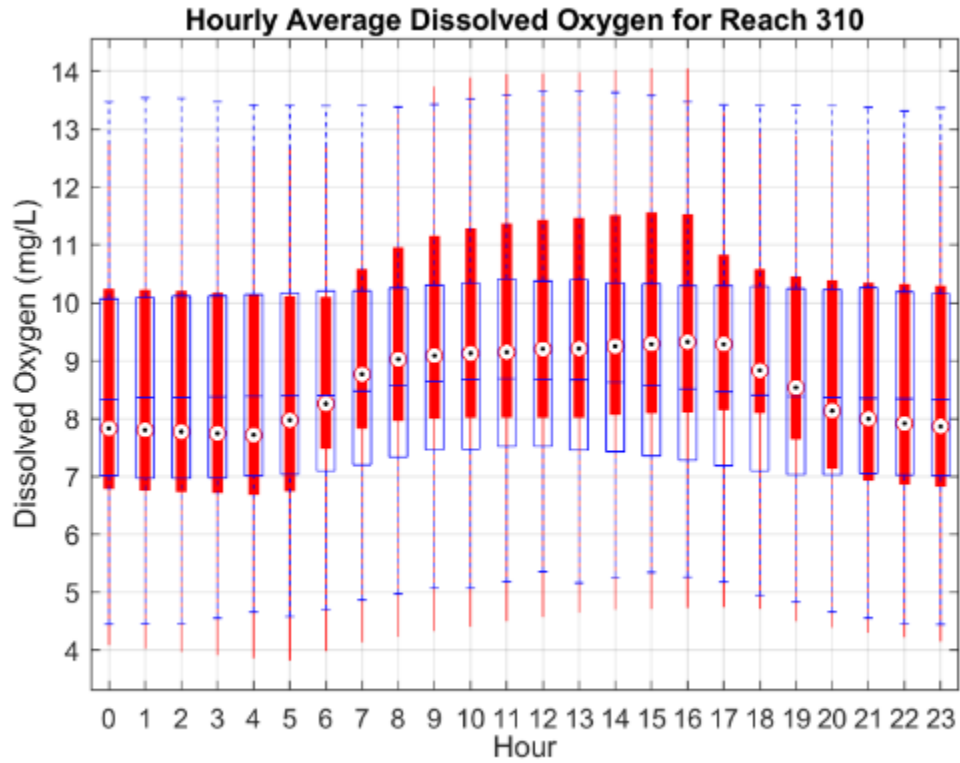


Figure B-17. Continuous Dissolved Oxygen Hourly Average Boxplot for HSPF Reach 310.

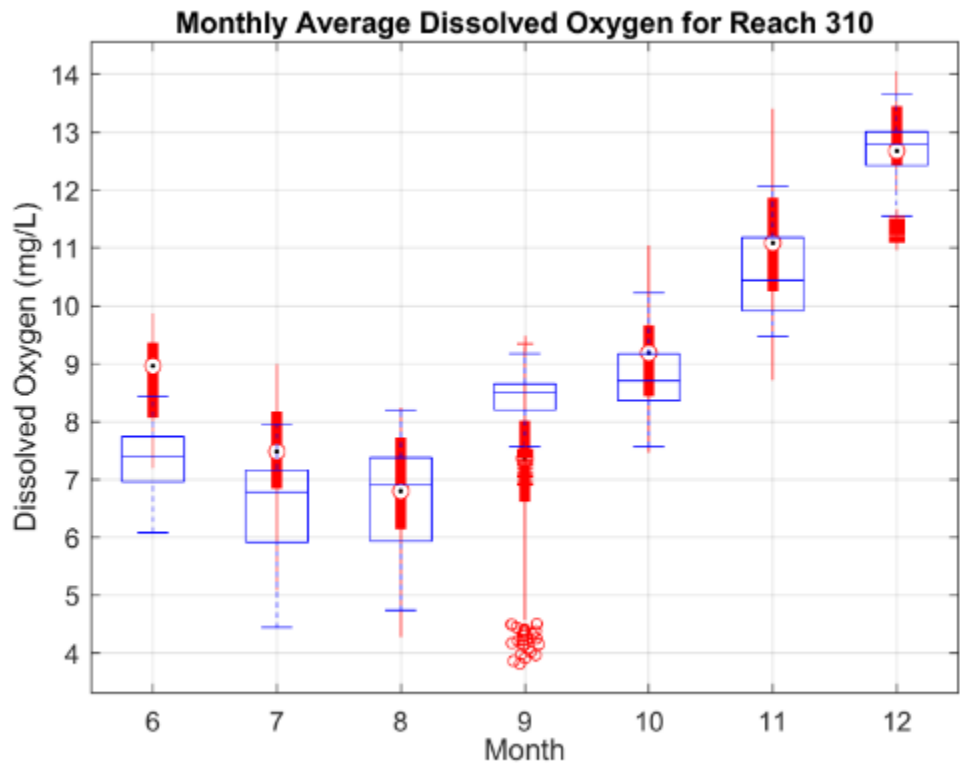


Figure B-18. Continuous Dissolved Oxygen Monthly Average Boxplot for HSPF Reach 310.

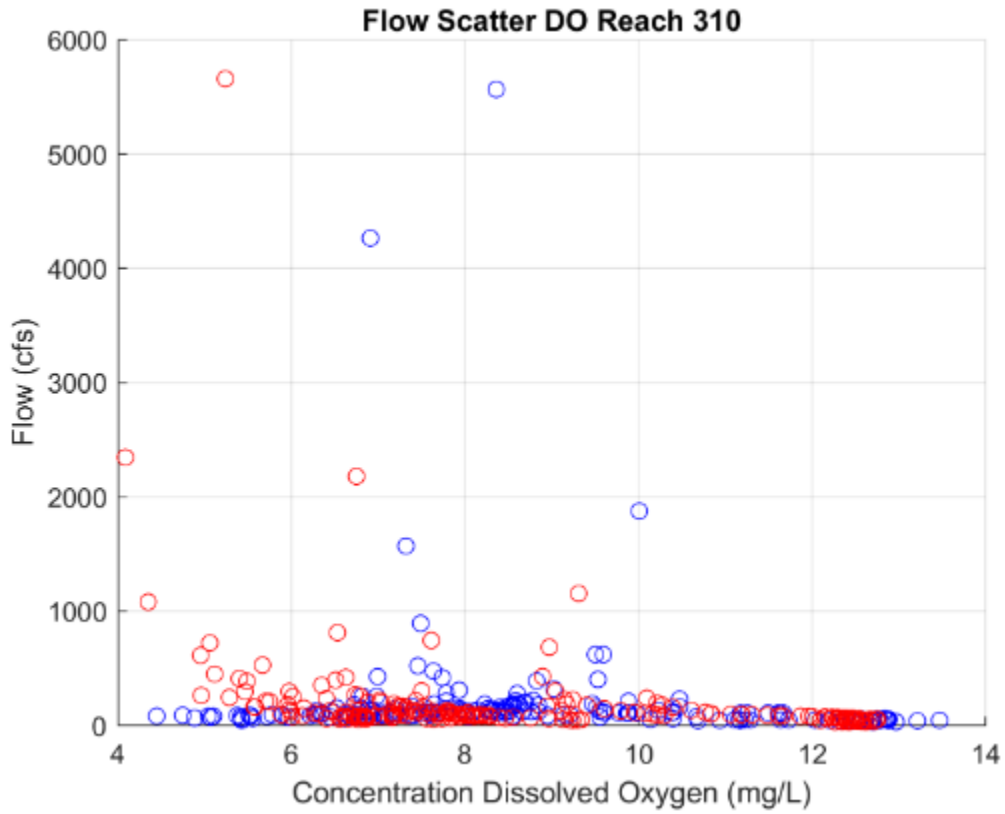


Figure B-19. Continuous Dissolved Oxygen Scatter Plot for HSPF Reach 310.

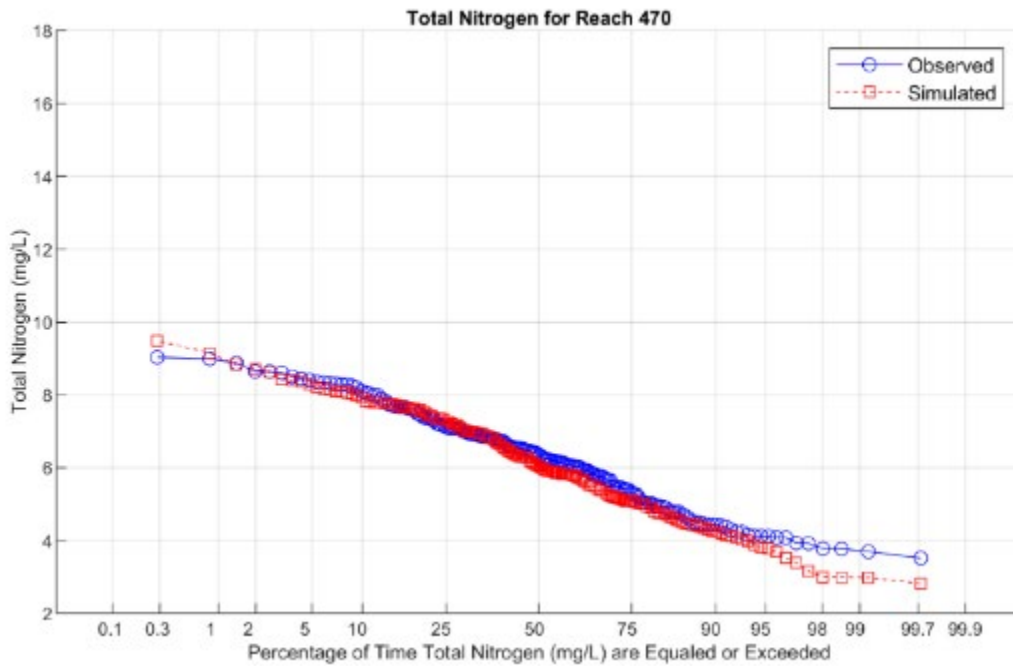


Figure B-20. Total Nitrogen Duration Plot for HSPF Reach 470.

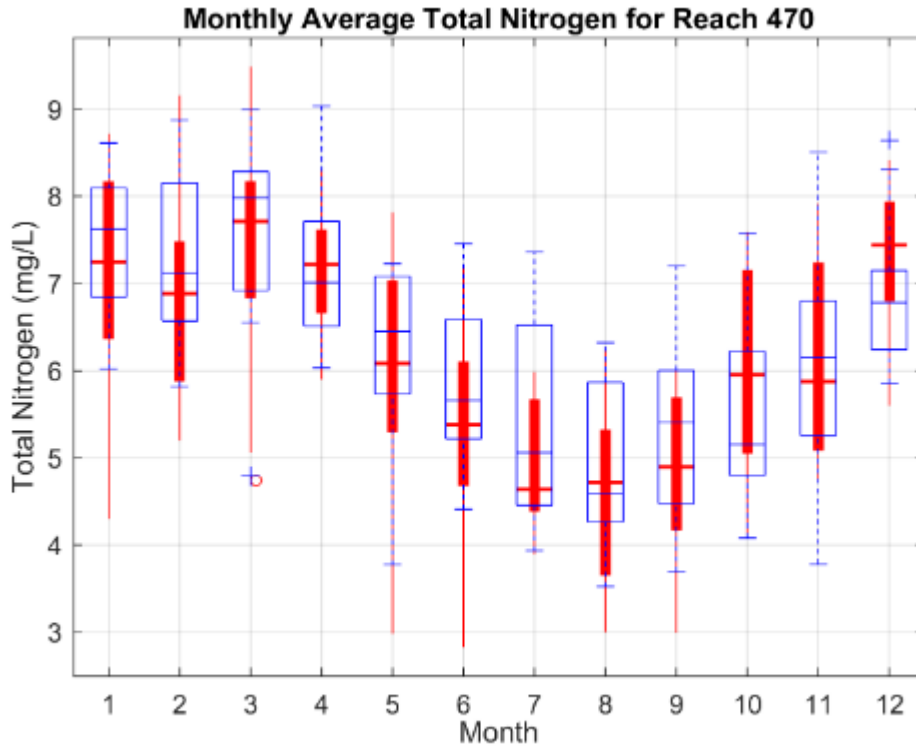


Figure B-21. Total Nitrogen Monthly Average Boxplot for HSPF Reach 470.

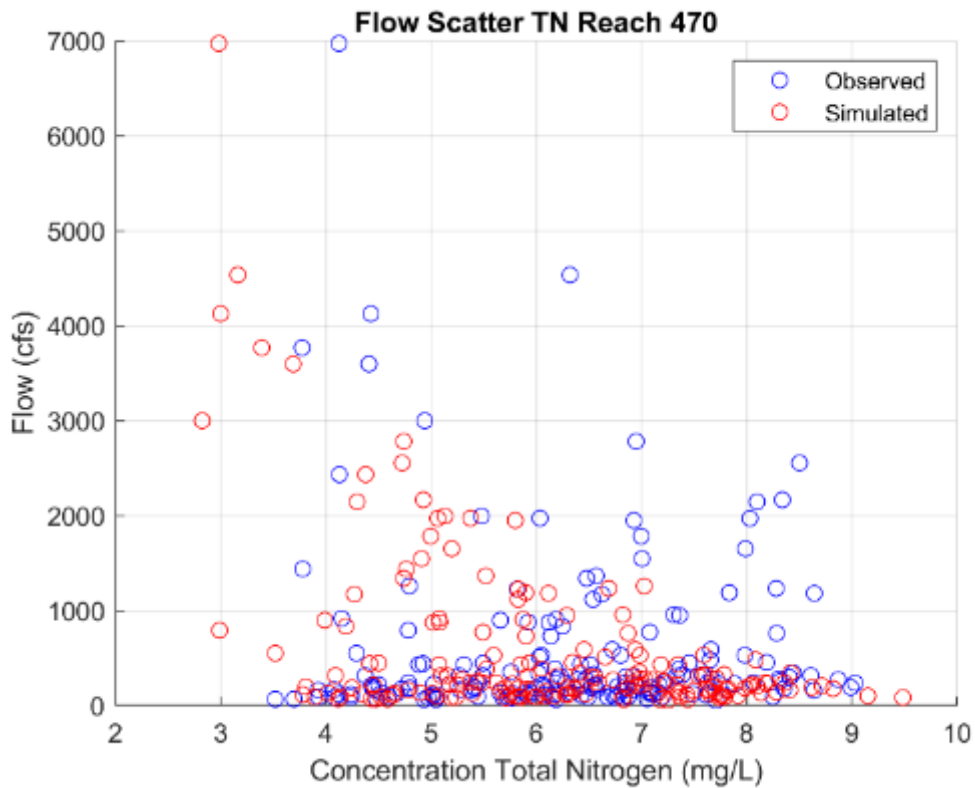


Figure B-22. Total Nitrogen Scatter Plot for HSPF Reach 470.

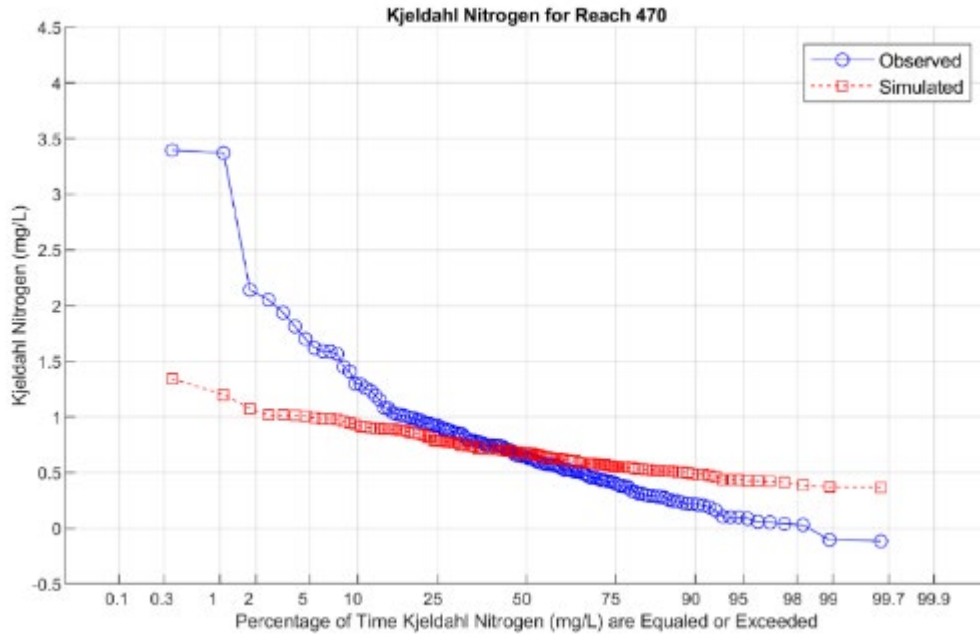


Figure B-23. Total Kjeldahl Nitrogen Duration Plot for HSPF Reach 470.

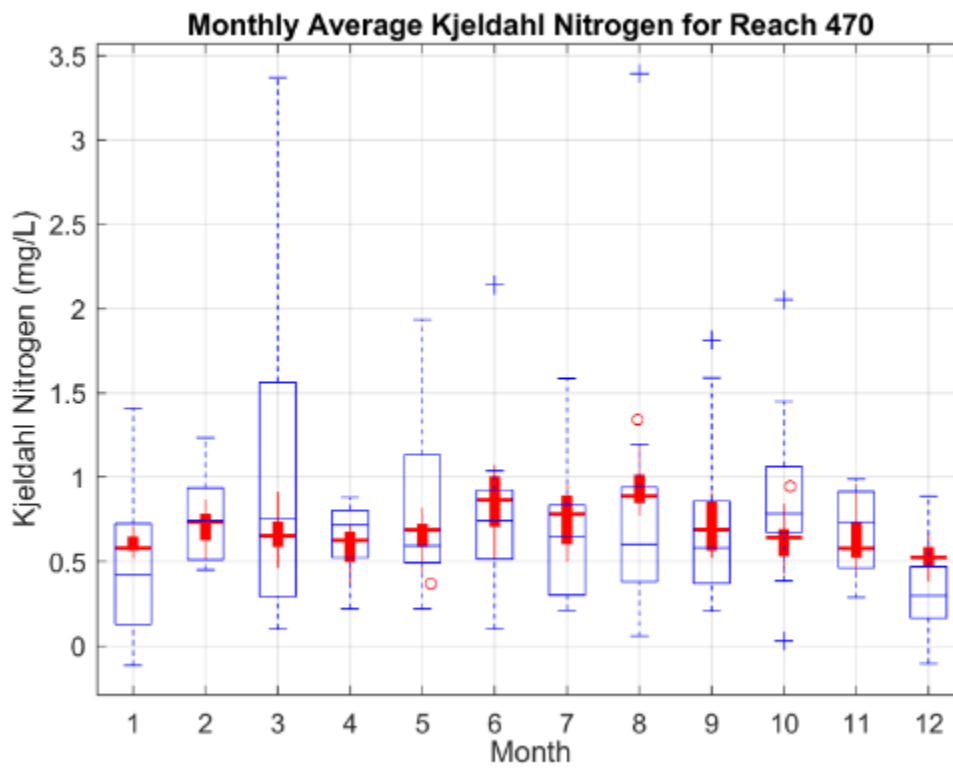


Figure B-24. Total Kjeldahl Nitrogen Monthly Average Boxplot for HSPF Reach 470.

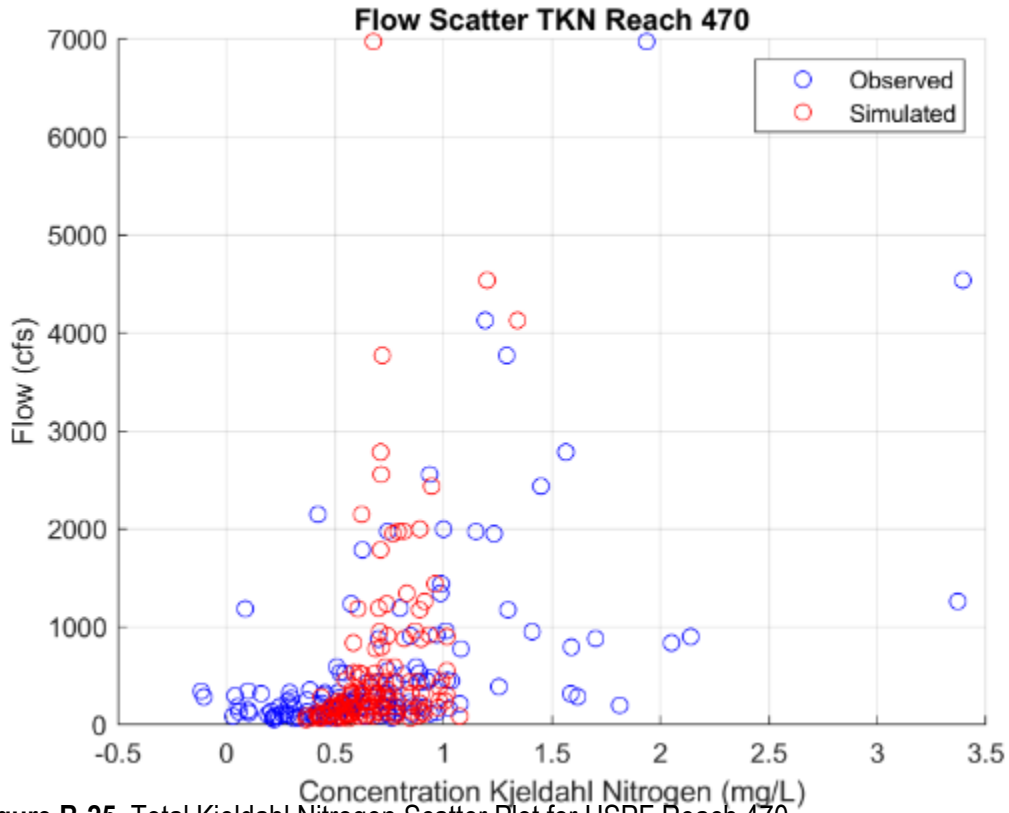


Figure B-25. Total Kjeldahl Nitrogen Scatter Plot for HSPF Reach 470.

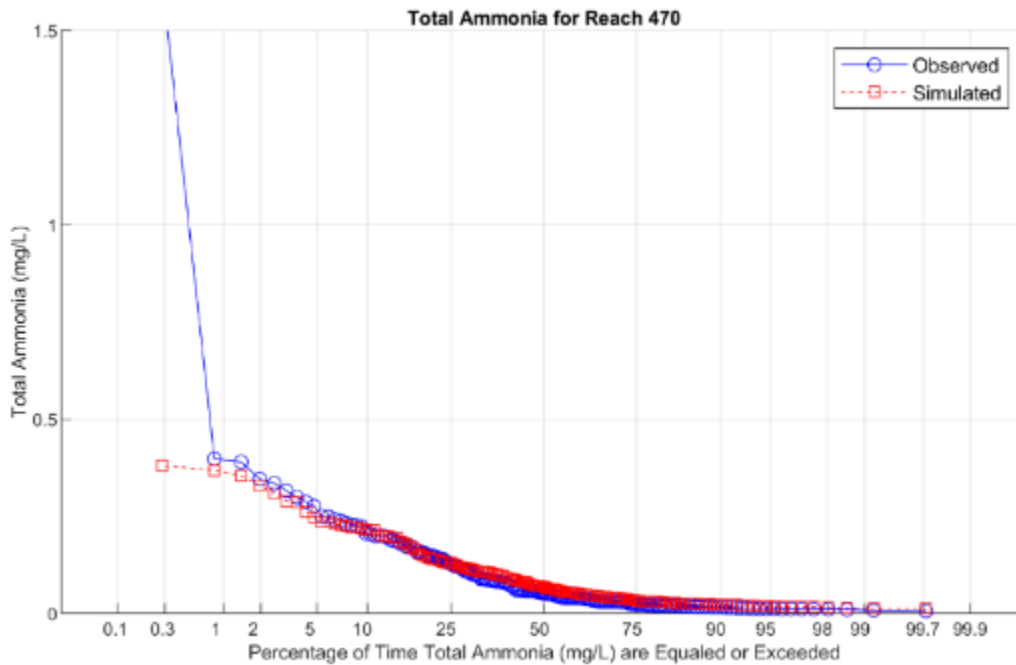


Figure B-26. Total Dissolved Ammonia as Nitrogen Duration Plot for HSPF Reach 470.

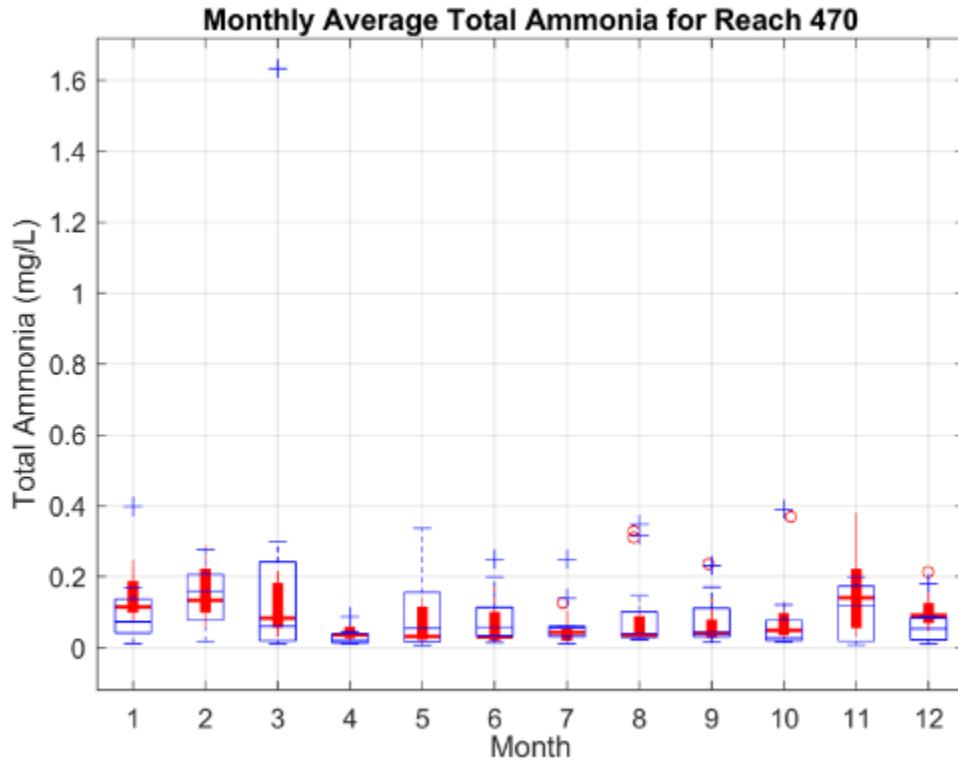


Figure B-27. Total Dissolved Ammonia as Nitrogen Monthly Average Boxplot for HSPF Reach 470.

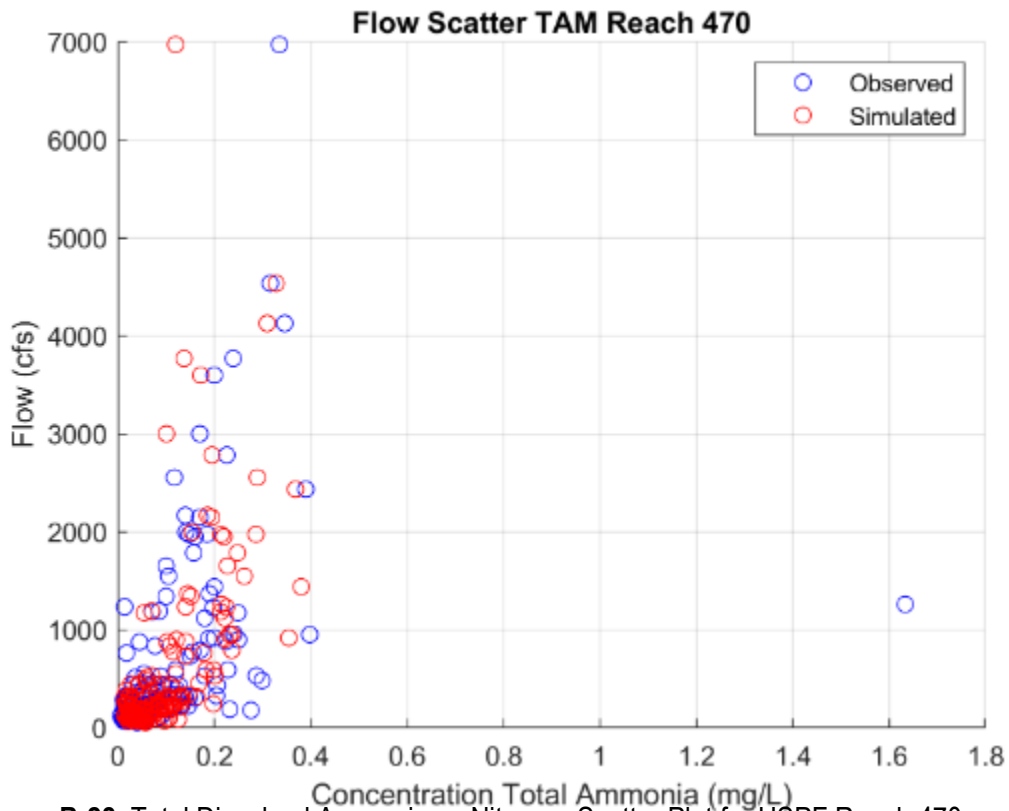


Figure B-28. Total Dissolved Ammonia as Nitrogen Scatter Plot for HSPF Reach 470.

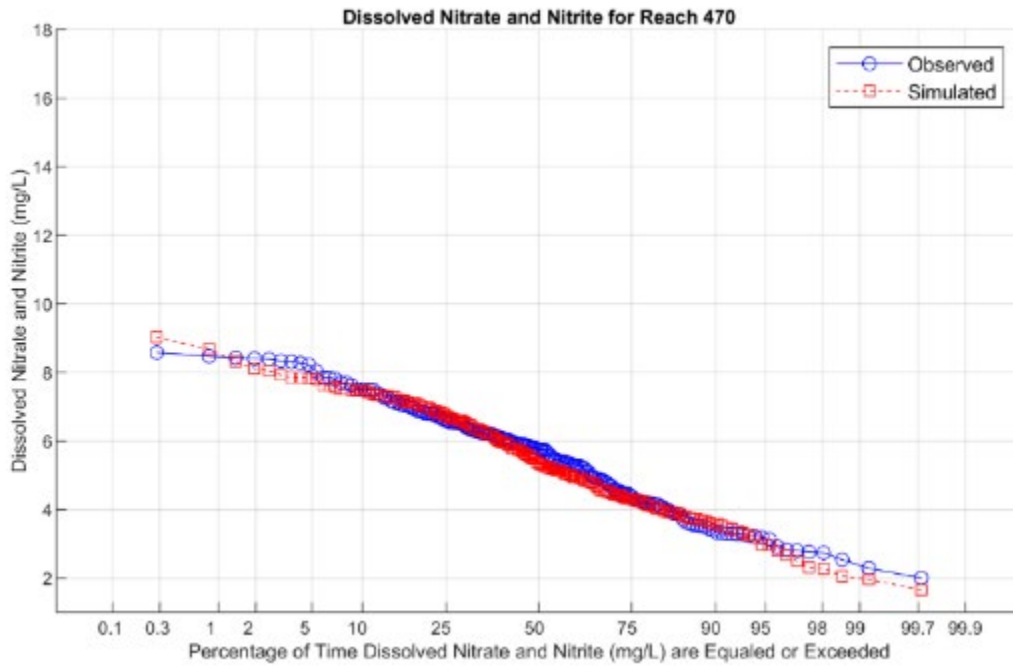


Figure B-29. Total Dissolved Nitrite-Nitrate as Nitrogen Duration Plot for HSPF Reach 470.

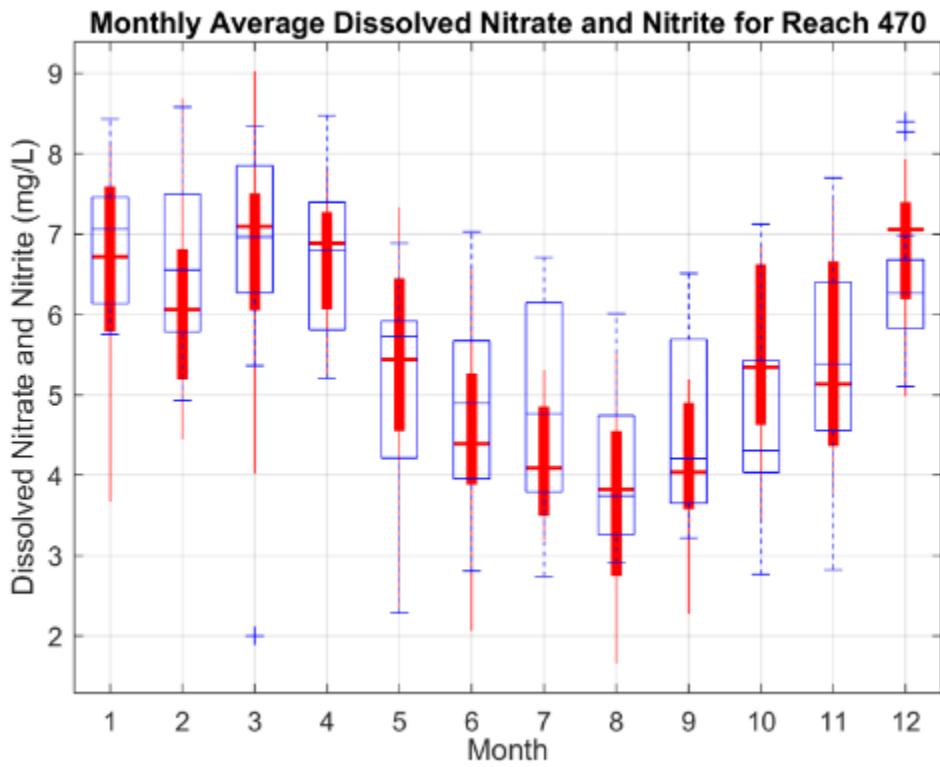


Figure B-30. Total Dissolved Nitrite-Nitrate as Nitrogen Monthly Average Boxplot for HSPF Reach 470.

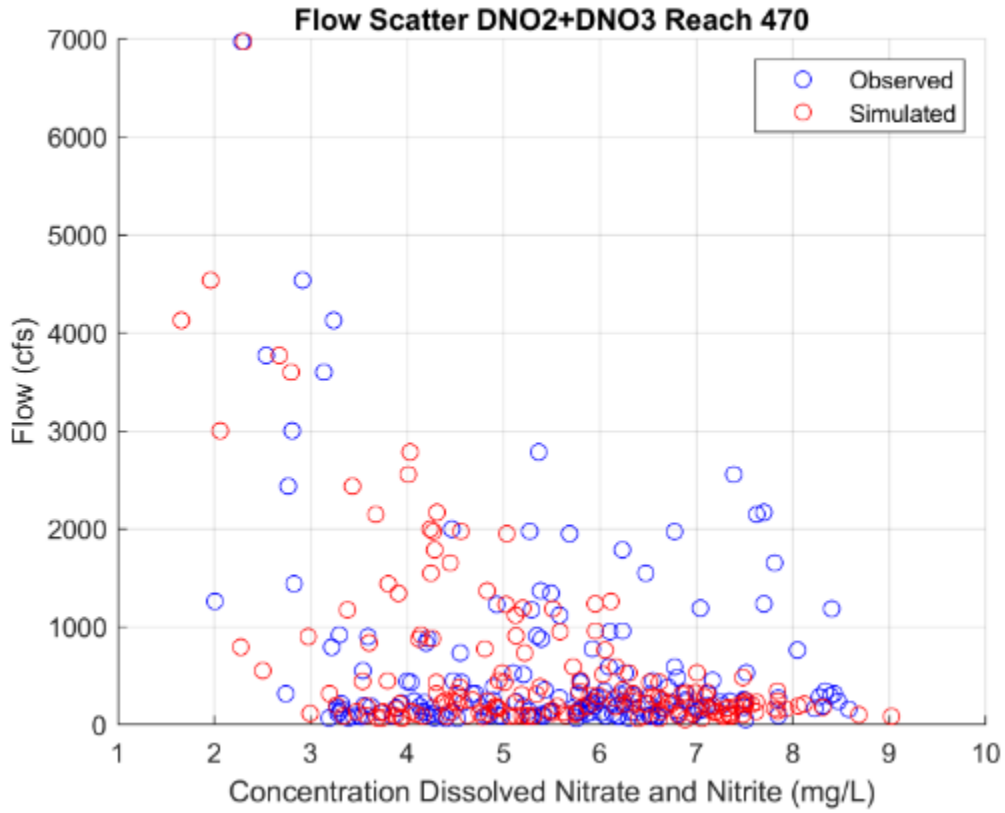


Figure B-31. Total Dissolved Nitrite-Nitrate as Nitrogen Scatter Plot for HSPF Reach 470.

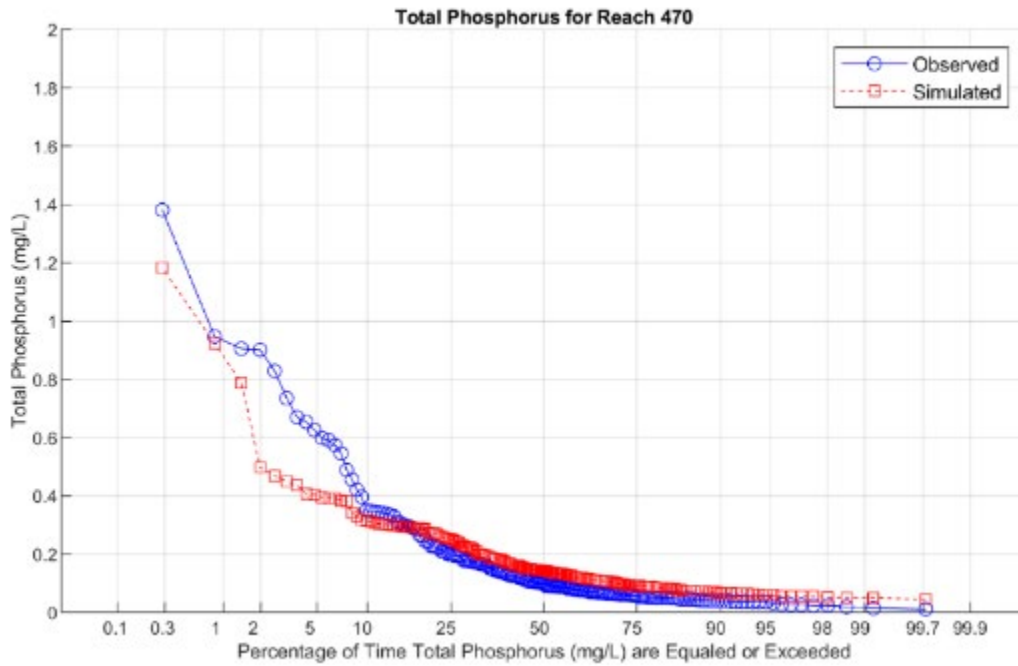


Figure B-32. Total Phosphorus Duration Plot for HSPF Reach 470.

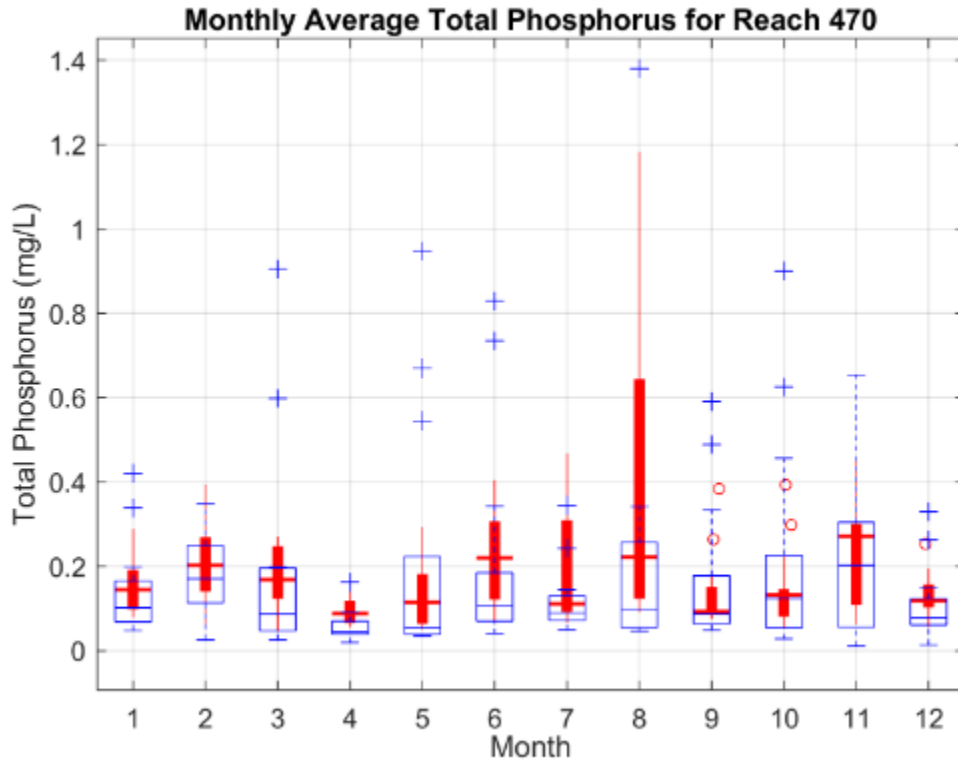


Figure B-33. Total Phosphorus Monthly Average Boxplot for HSPF Reach 470.

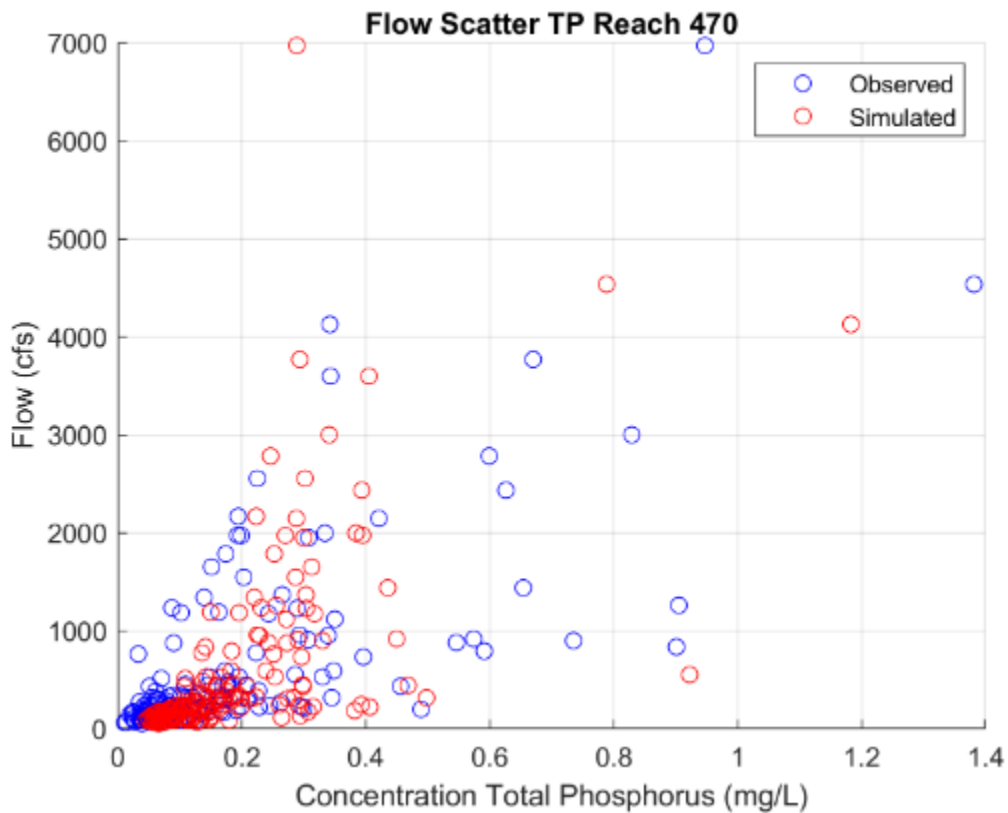


Figure B-34. Total Phosphorus Scatter Plot for HSPF Reach 470.

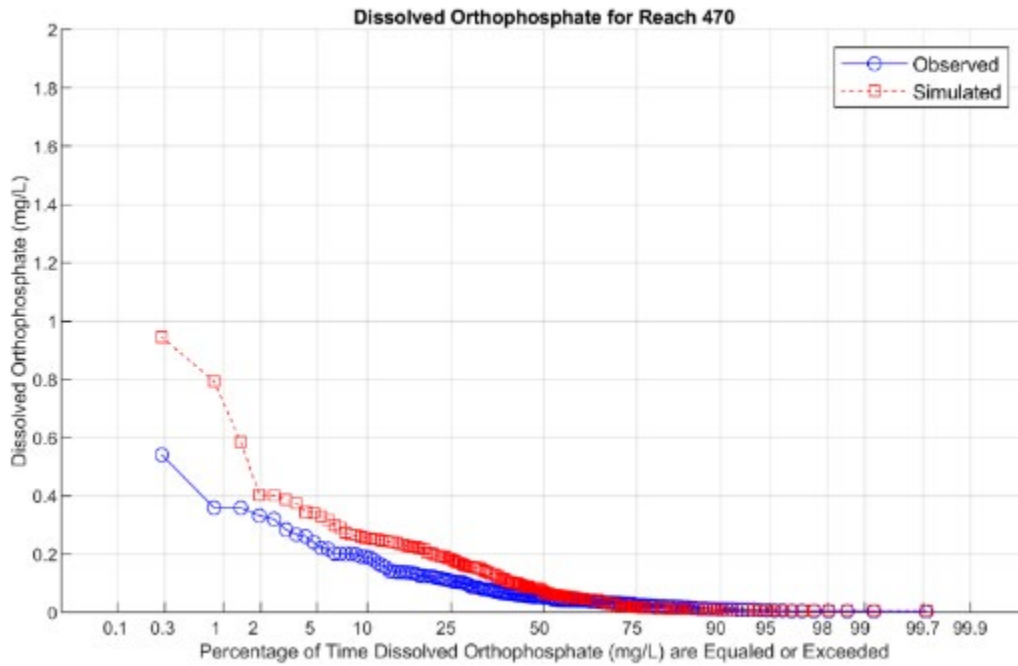


Figure B-35. Total Dissolved Orthophosphate as Phosphorus Duration Plot for HSPF Reach 470.

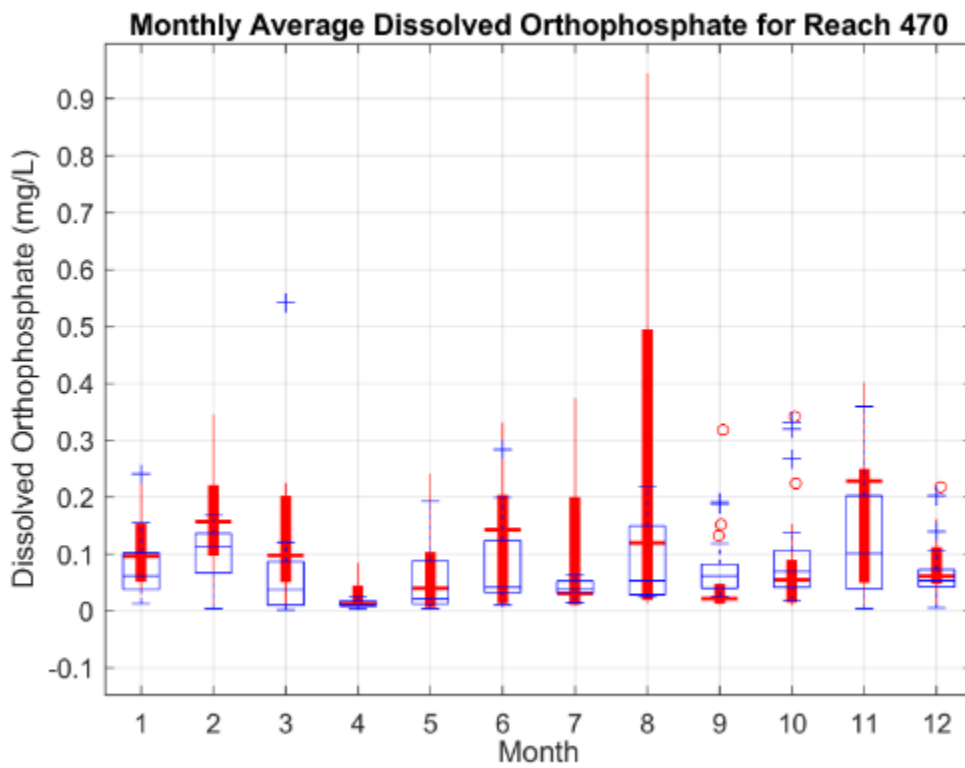


Figure B-36. Total Dissolved Orthophosphate as Phosphorus Monthly Average Boxplot for HSPF Reach 470.

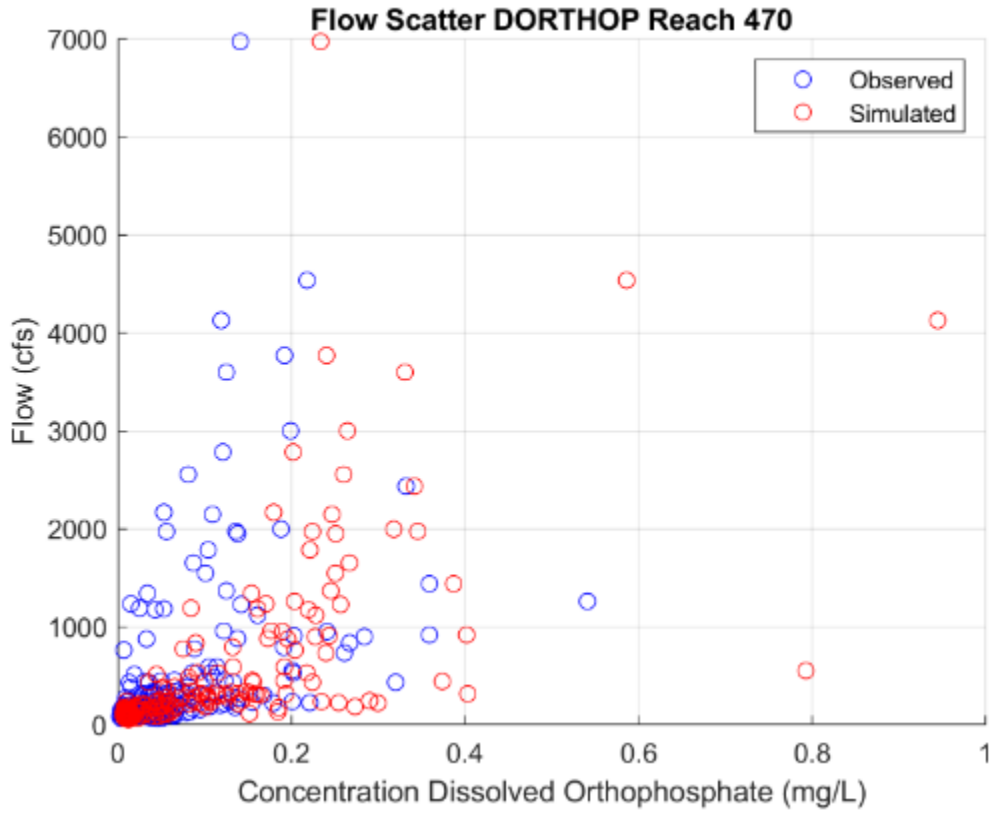


Figure B-37. Total Dissolved Orthophosphate as Phosphorus Scatter Plot for HSPF Reach 470.

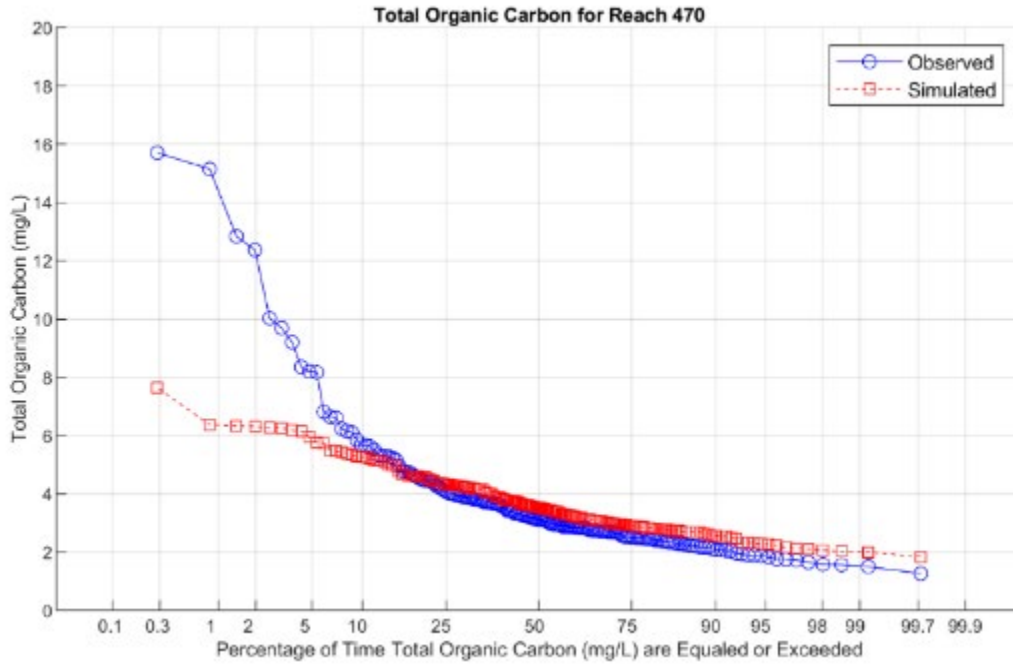


Figure B-38. Total Organic Carbon Duration Plot for HSPF Reach 470.

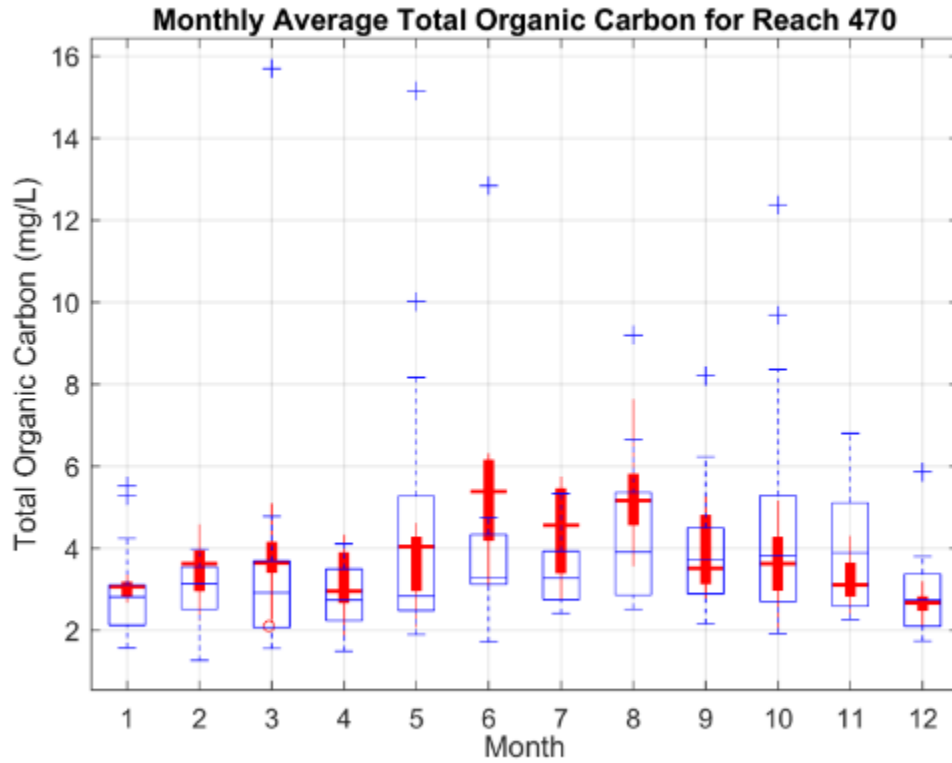


Figure B-39. Total Organic Carbon Monthly Average Boxplot for HSPF Reach 470.

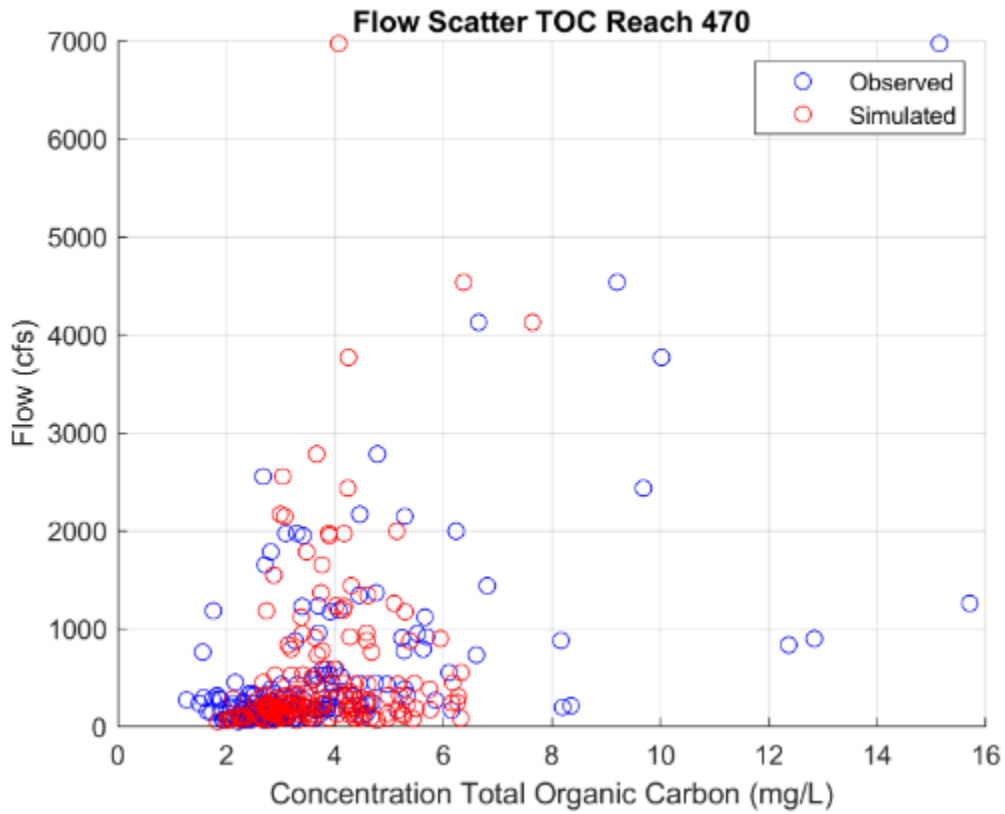


Figure B-40. Total Organic Carbon Scatter Plot for HSPF Reach 470.

APPENDIX C

WASP WATER QUALITY CALIBRATION

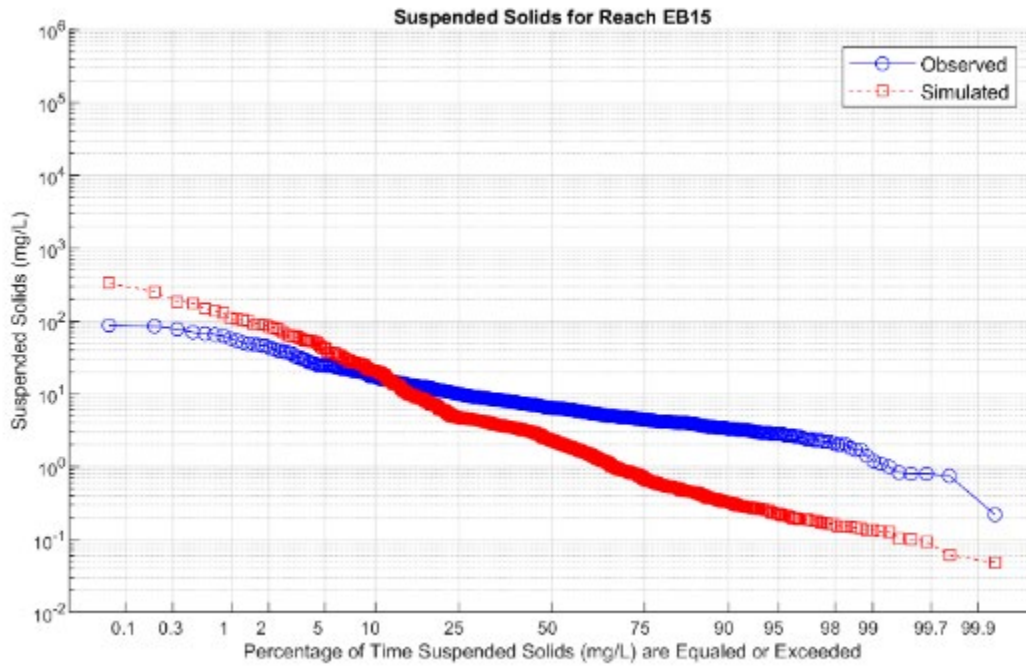


Figure C-1. Total Suspended Sediment Duration Plot for WASP Segment 15 (log-scale).

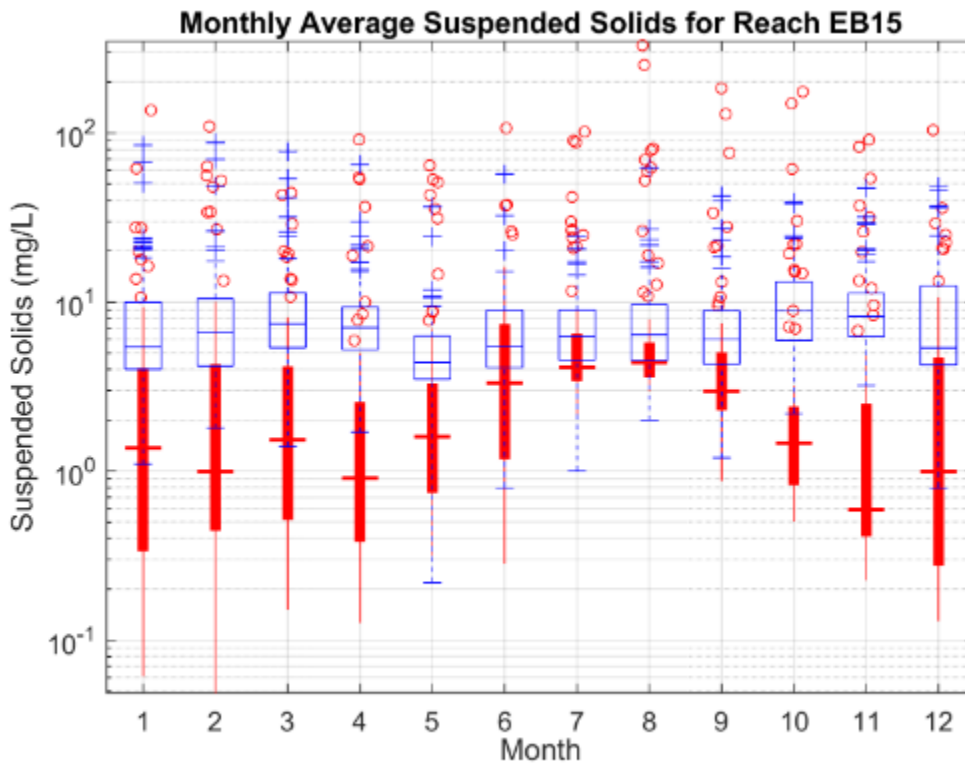


Figure C-2. Total Suspended Sediment Monthly Average Boxplot for WASP Segment 15 (log-scale).

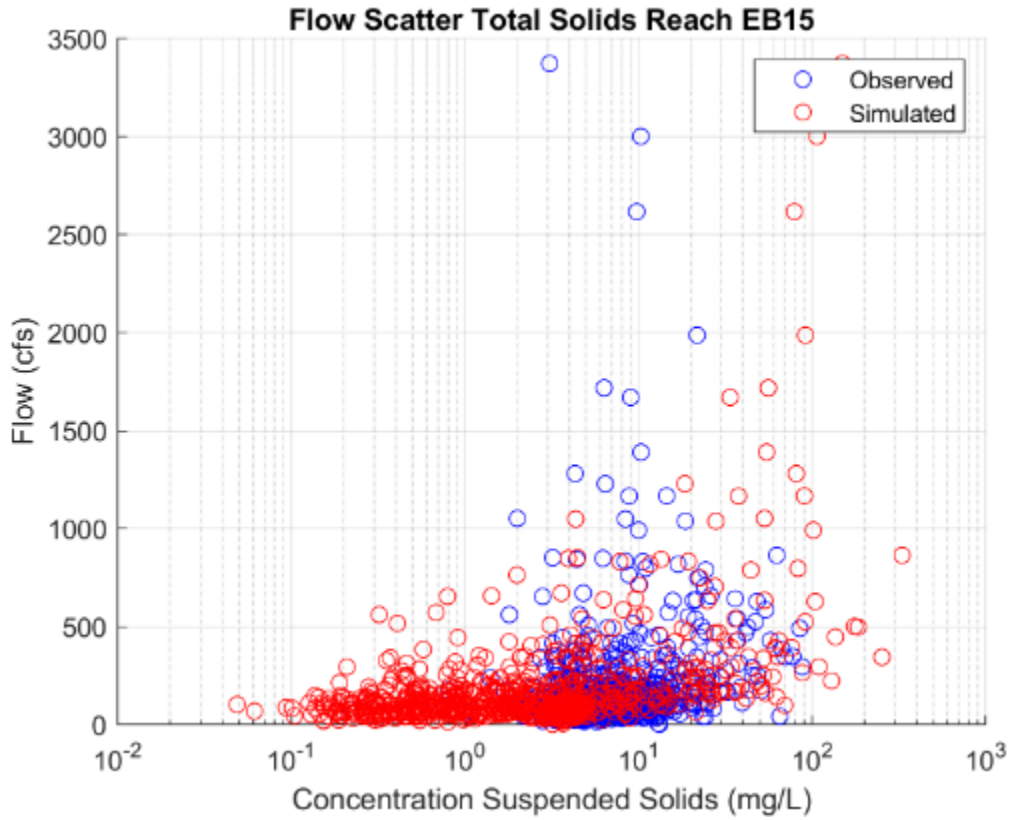


Figure C-3. Total Suspended Sediment Scatter Plot for WASP Segment 15 (log-scale).

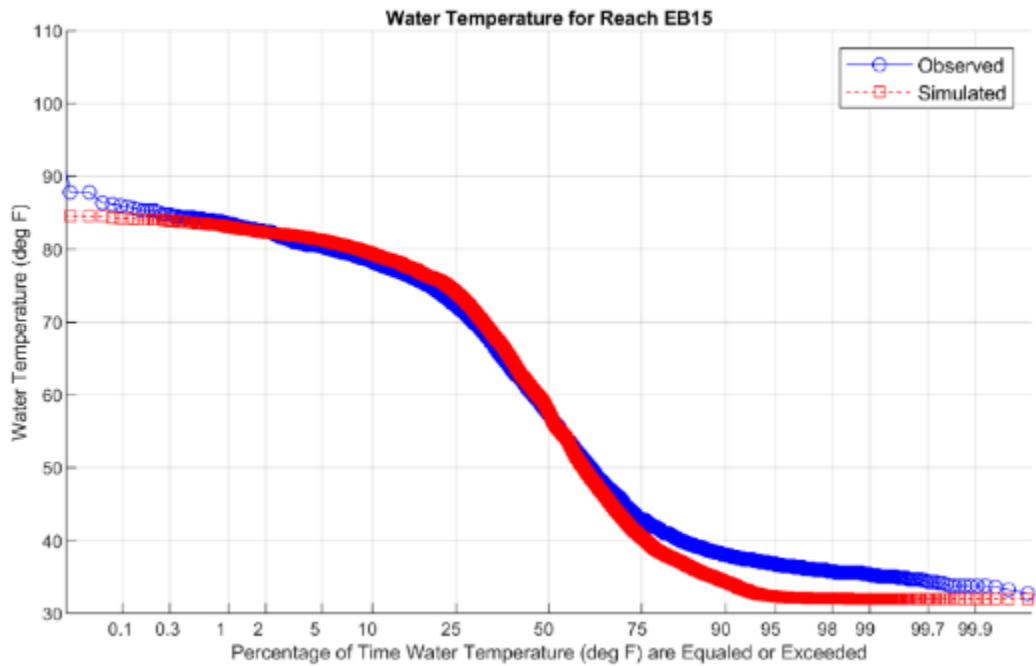


Figure C-4. Instantaneous Temperature Duration Plot for WASP Segment 15.

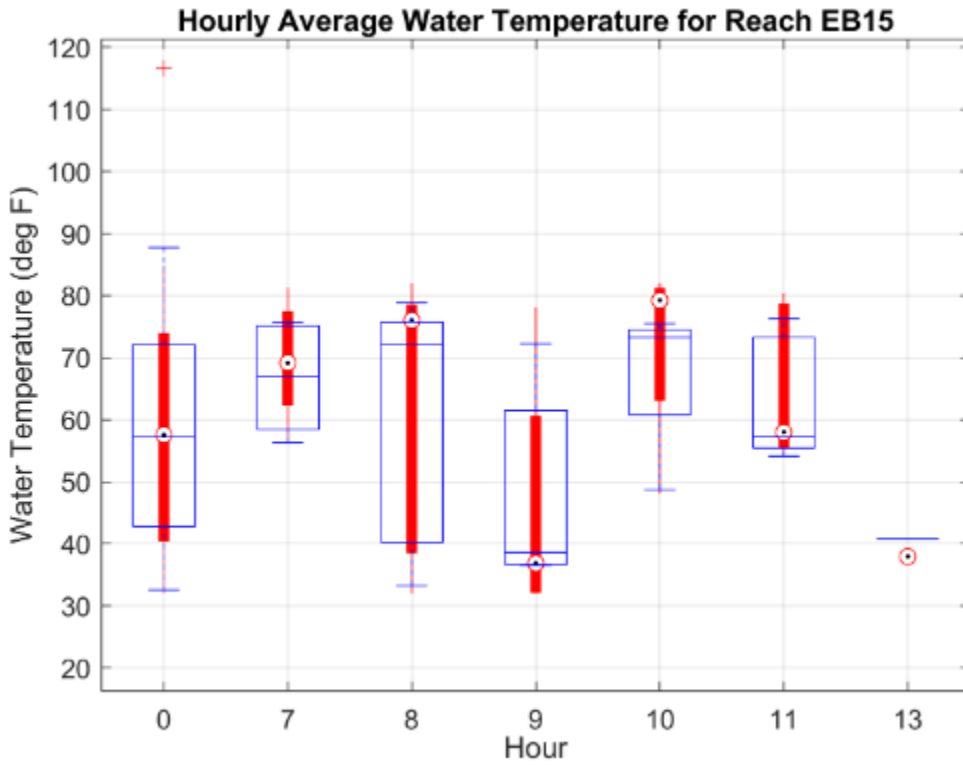


Figure C-5. Instantaneous Temperature Hourly Average Boxplot for WASP Segment 15.

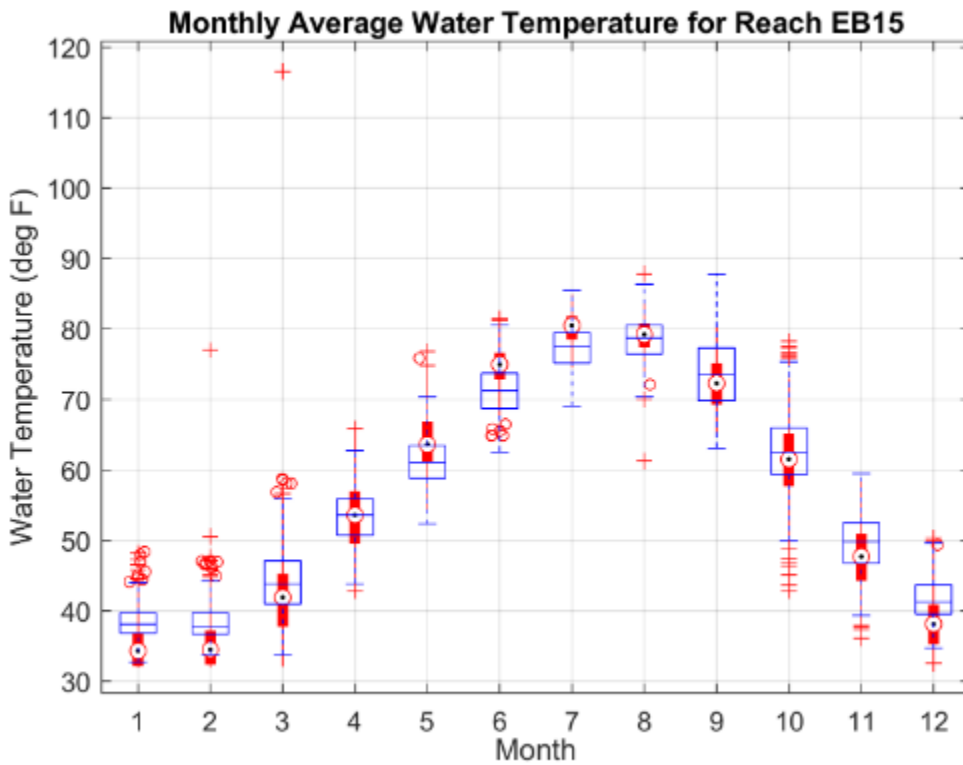


Figure C-6. Instantaneous Temperature Monthly Average Boxplot for WASP Segment 15.

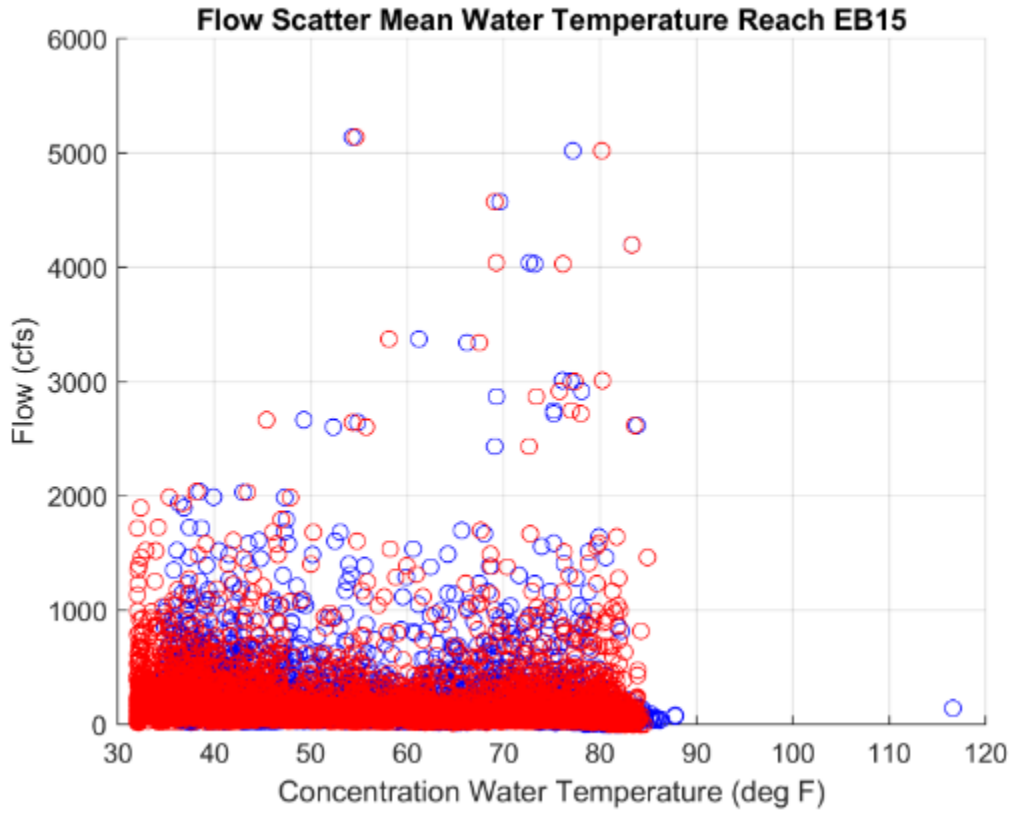


Figure C-7. Instantaneous Temperature Scatter Plot for WASP Segment 15.

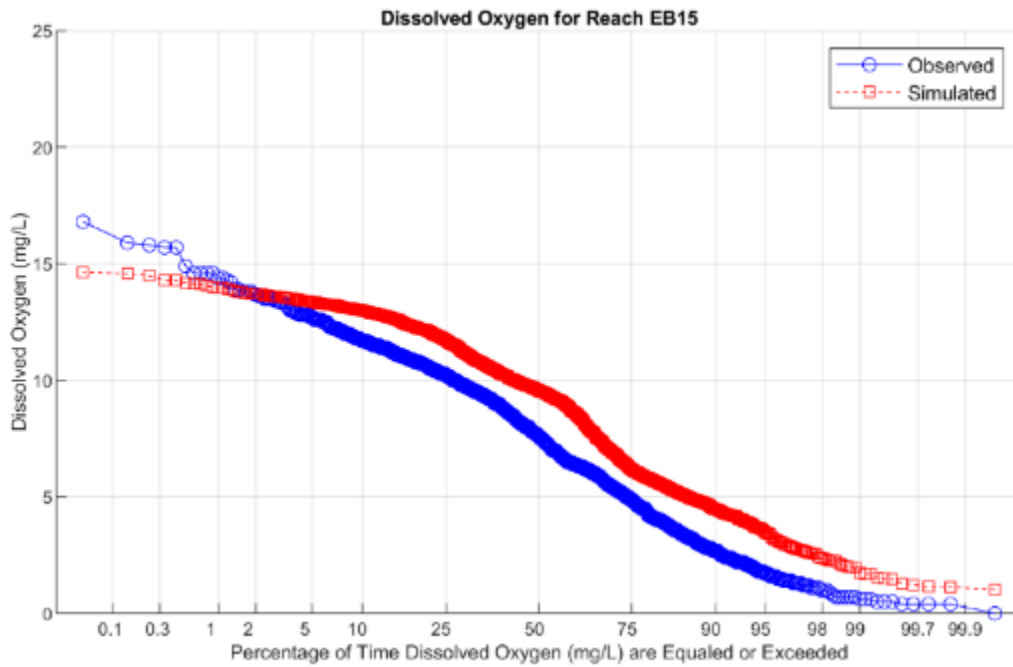


Figure C-8. Instantaneous Dissolved Oxygen Duration Plot for WASP Segment 15.

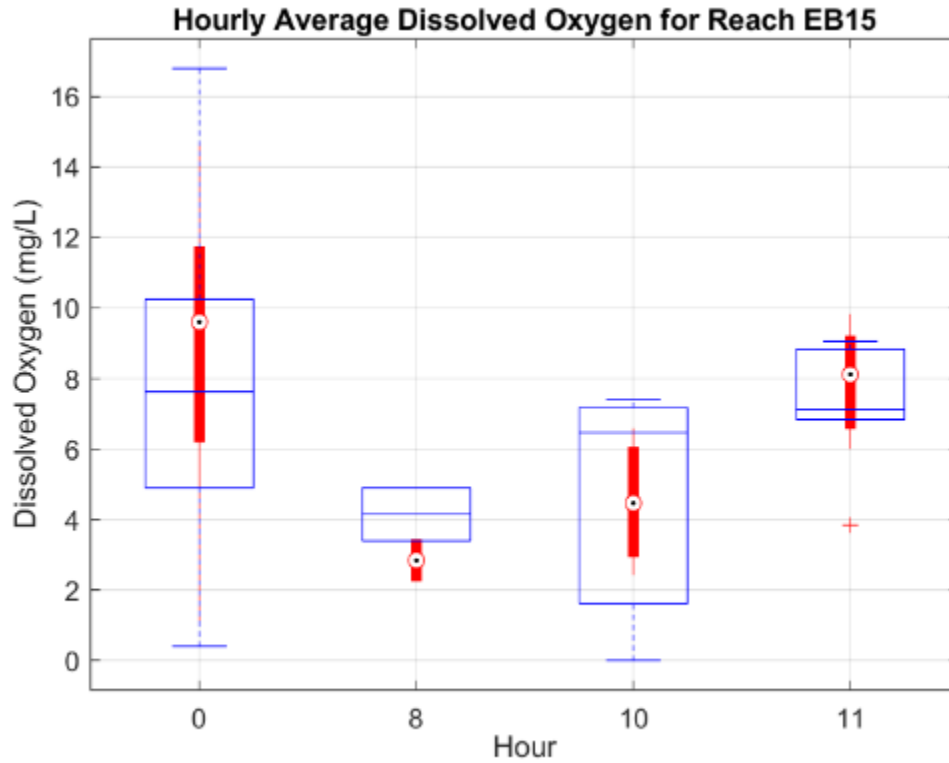


Figure C-9. Instantaneous Dissolved Oxygen Hourly Average Boxplot for WASP Segment 15.

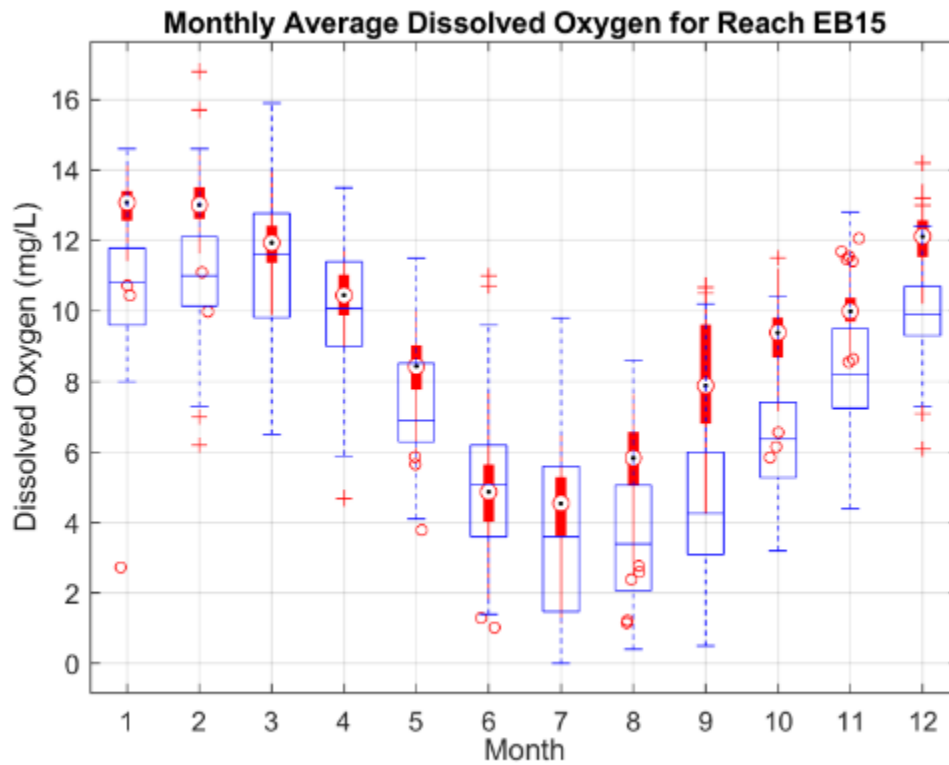


Figure C-10. Instantaneous Dissolved Oxygen Monthly Average Boxplot for WASP Segment 15.

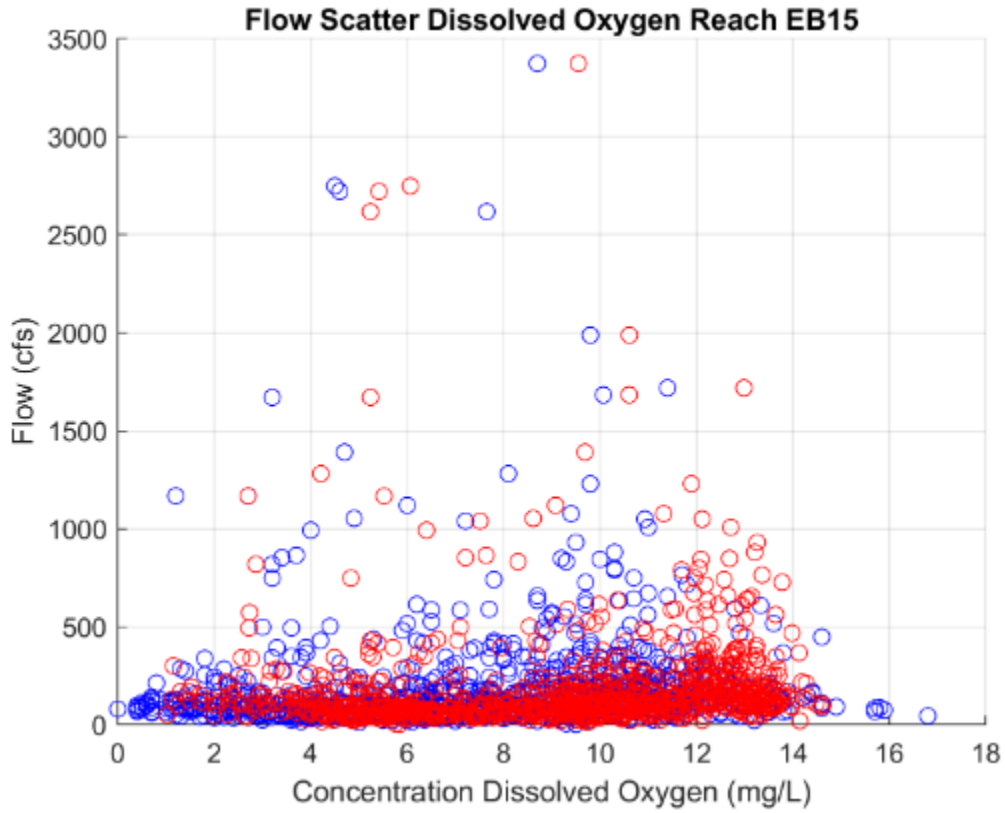


Figure C-11. Instantaneous Dissolved Oxygen Scatter Plot for WASP Segment 15.

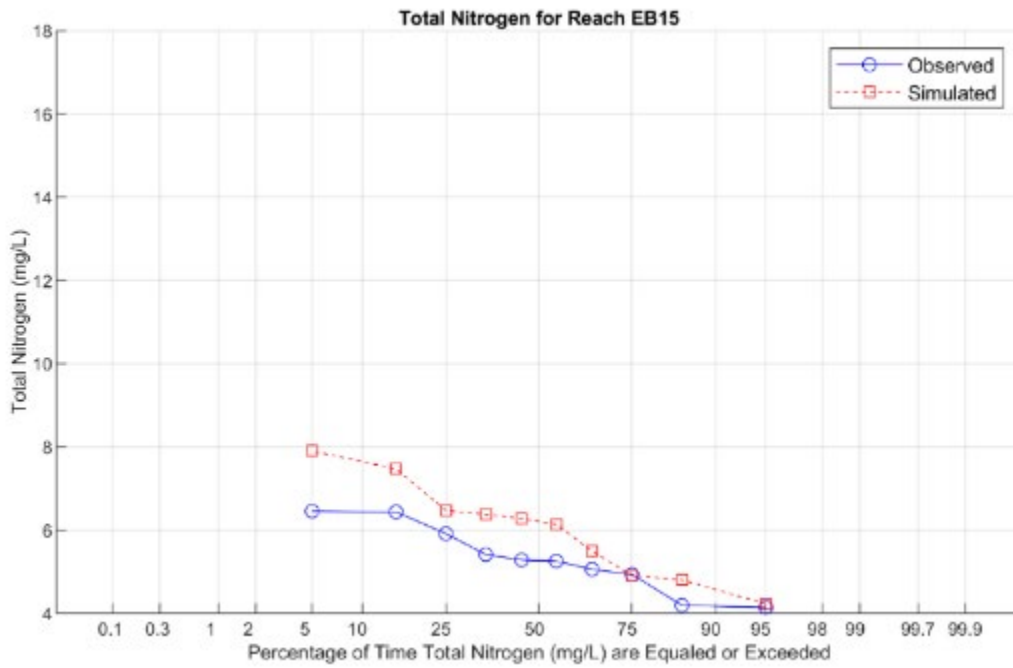


Figure C-12. Total Nitrogen Duration Plot for WASP Segment 15.

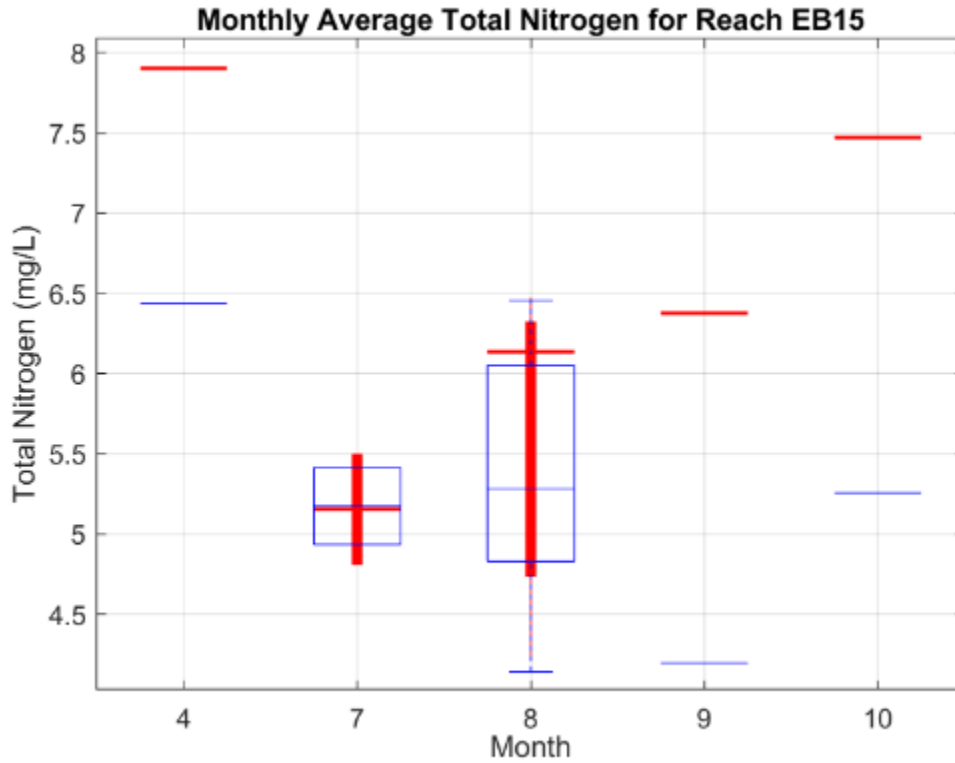


Figure C-13. Total Nitrogen Monthly Average Boxplot for WASP Segment 15.

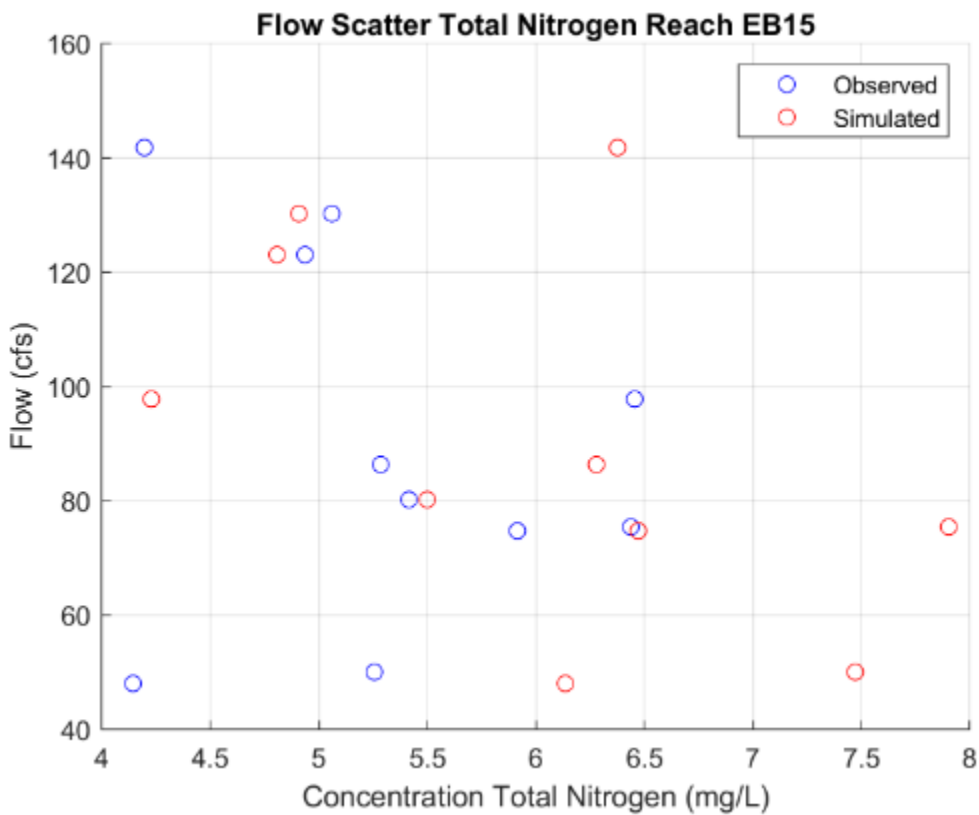


Figure C-14. Total Nitrogen Scatter Plot for WASP Segment 15.

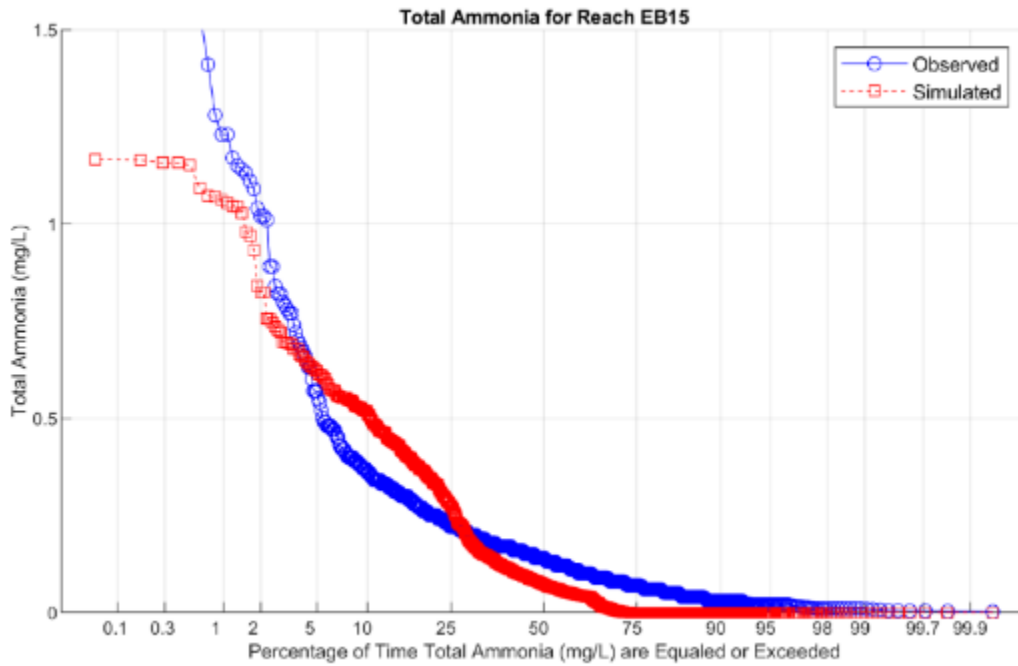


Figure C-15. Total Dissolved Ammonia as Nitrogen Duration Plot for WASP Segment 15.

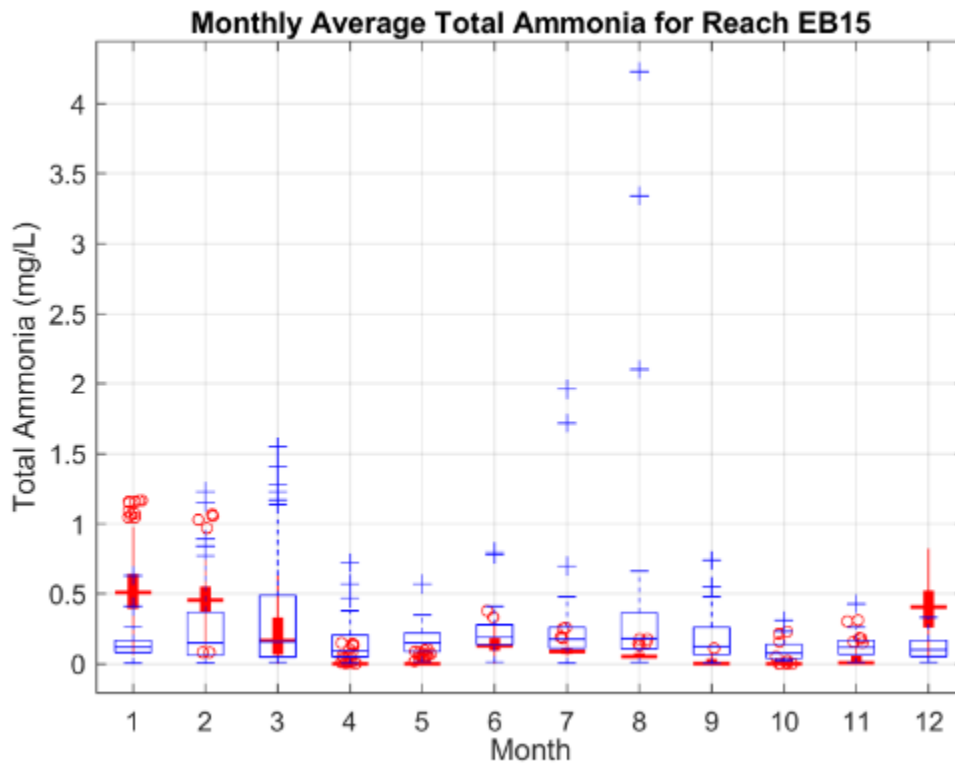


Figure C-16. Total Dissolved Ammonia as Nitrogen Monthly Average Boxplot for WASP Segment 15.

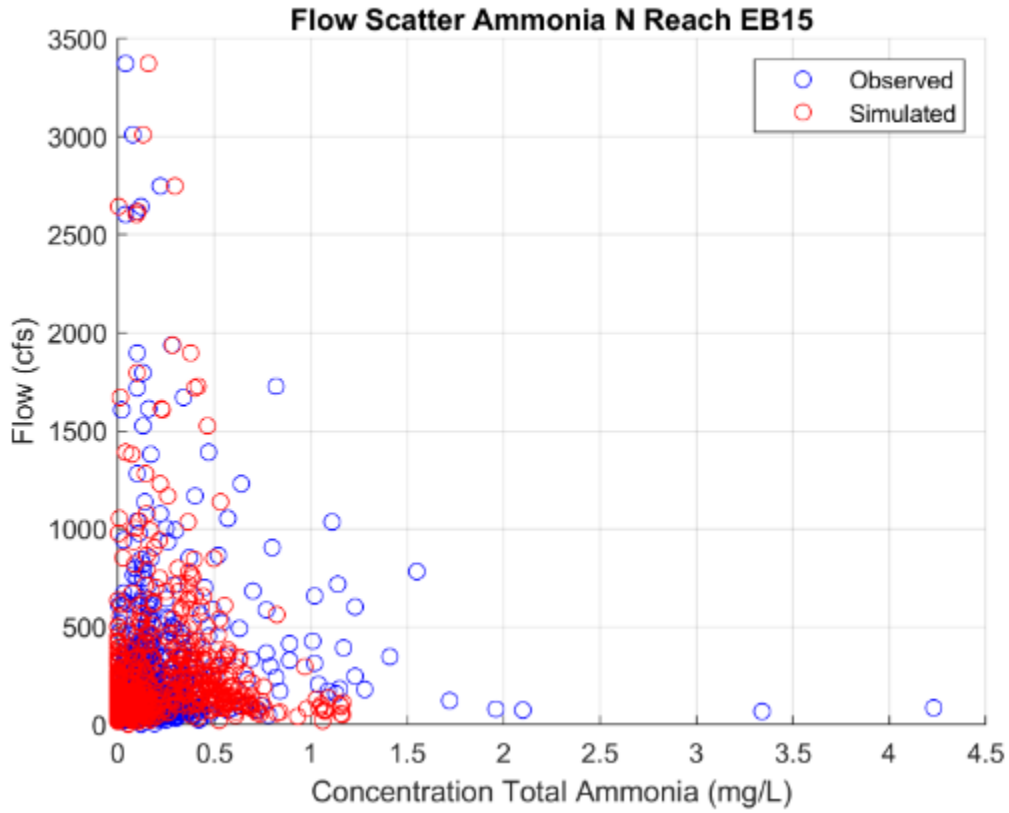


Figure C-17. Total Dissolved Ammonia as Nitrogen Scatter Plot for WASP Segment 15.

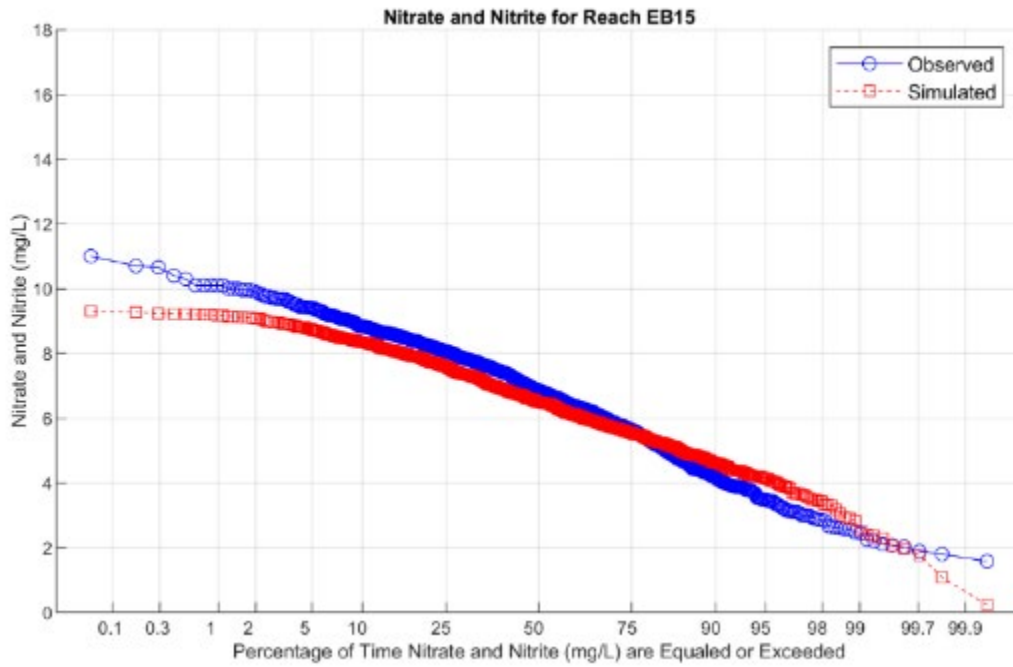


Figure C-18. Total Dissolved Nitrite-Nitrate as Nitrogen Duration Plot for WASP Segment 15.

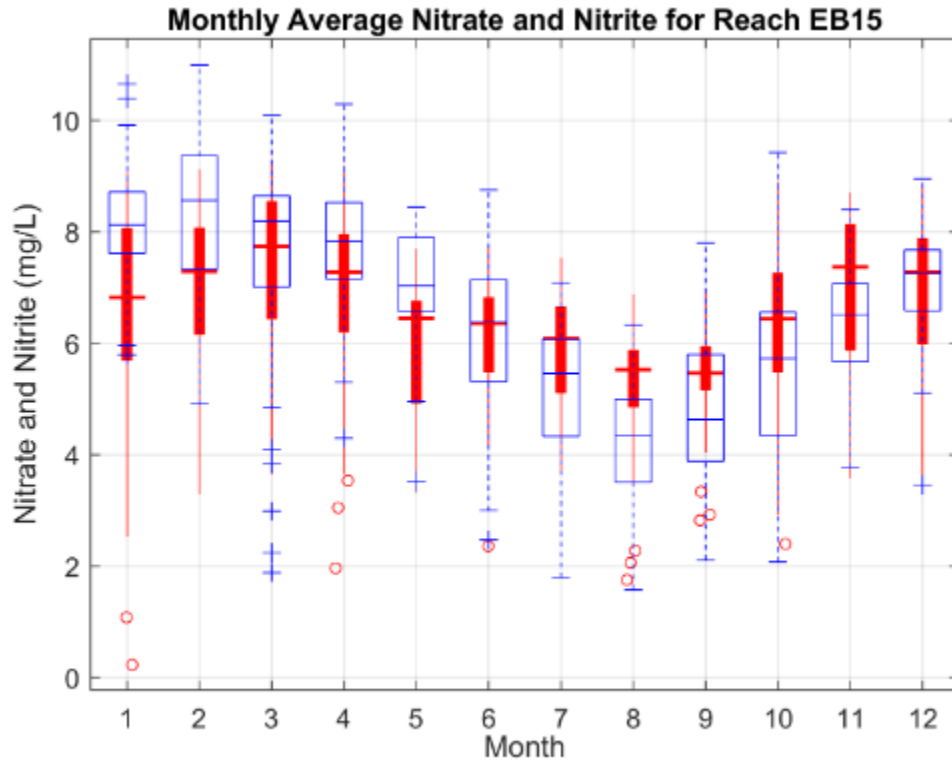


Figure C-19. Total Dissolved Nitrite-Nitrate as Nitrogen Monthly Average Boxplot for WASP Segment 15.

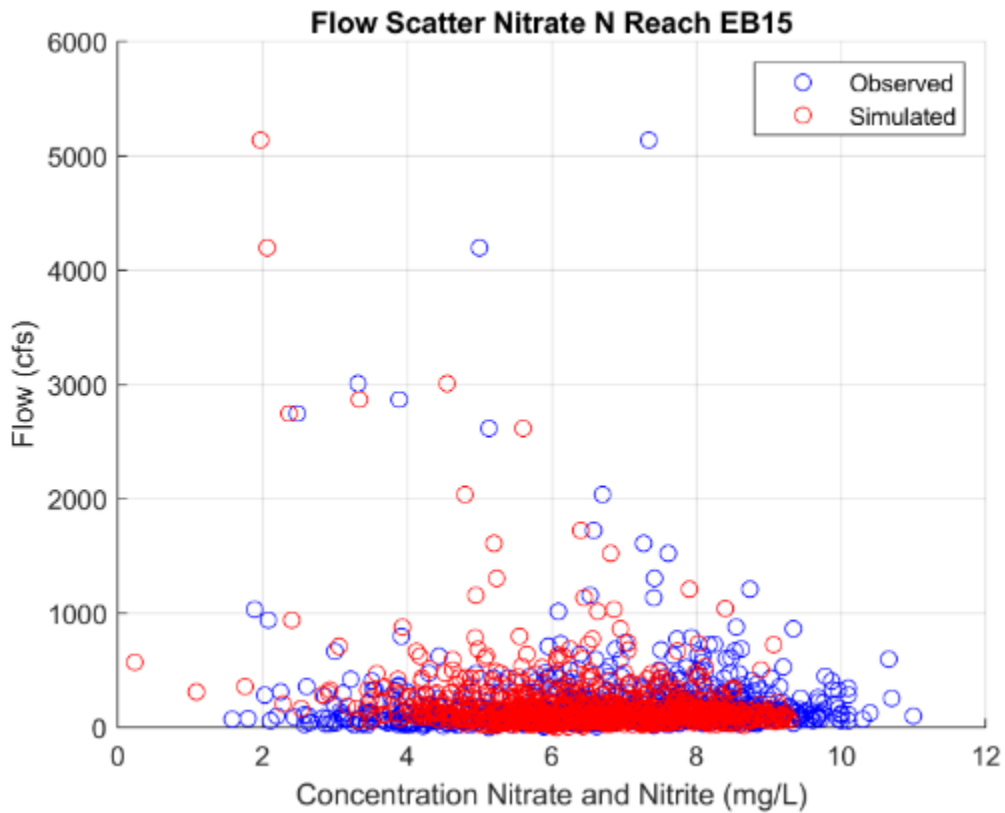


Figure C-20. Total Dissolved Nitrite-Nitrate as Nitrogen Scatter Plot for WASP Segment 15.

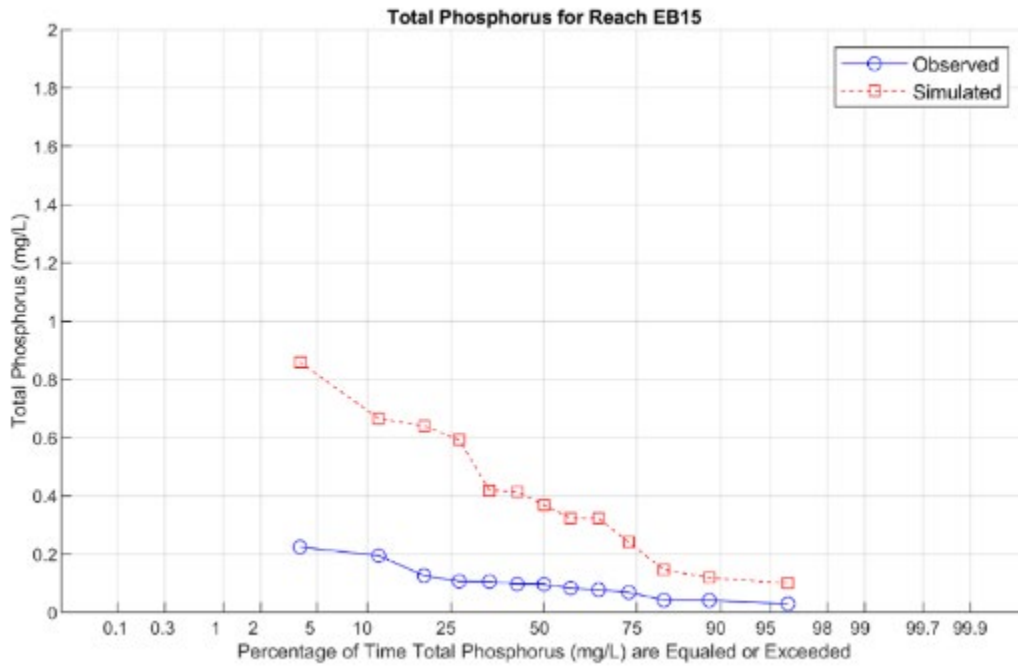


Figure C-21. Total Phosphorus Duration Plot for HSPF WASP Segment 15.

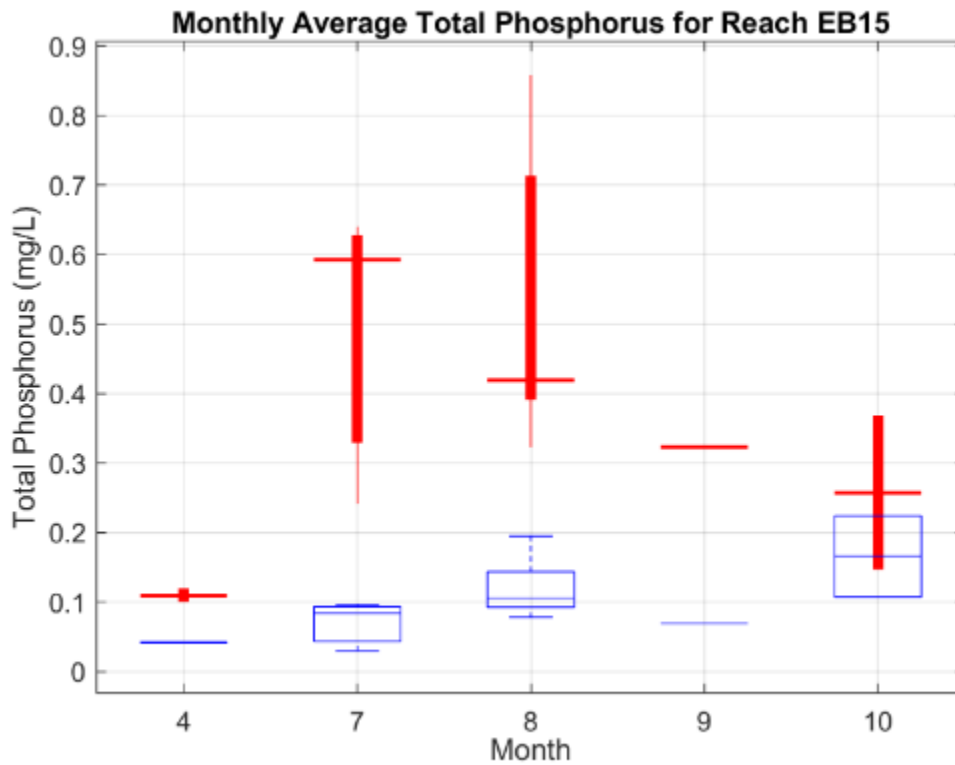


Figure C-22. Total Phosphorus Monthly Average Boxplot for WASP Segment 15.

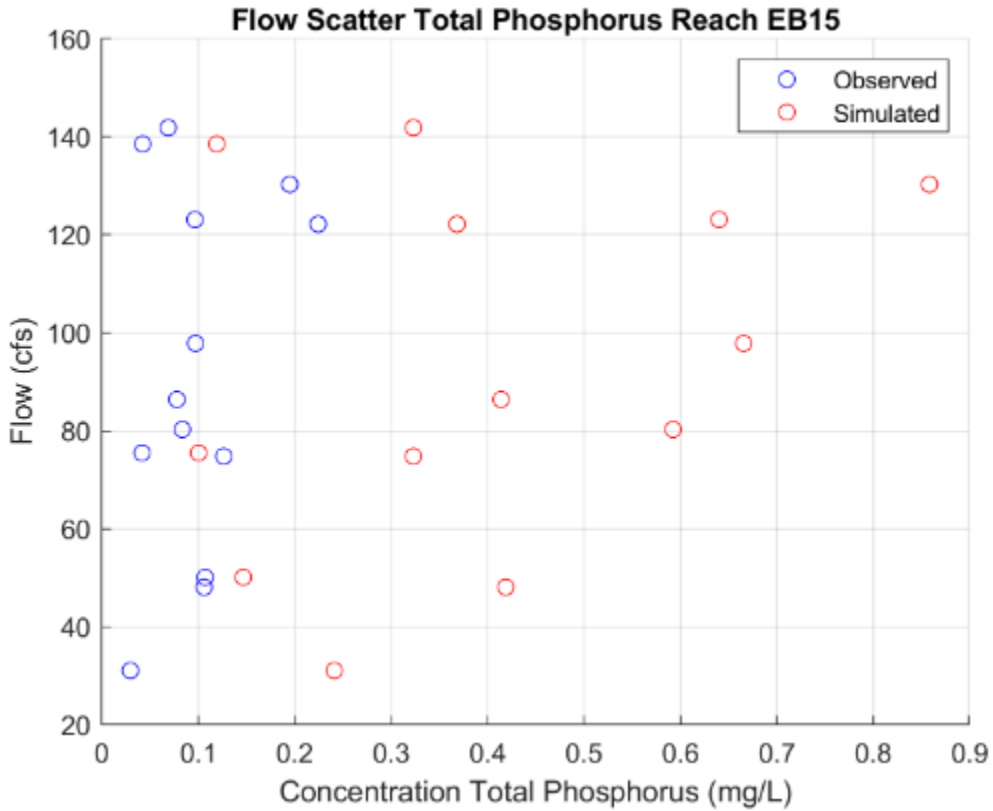


Figure C-23. Total Phosphorus Scatter Plot for WASP Segment 15.

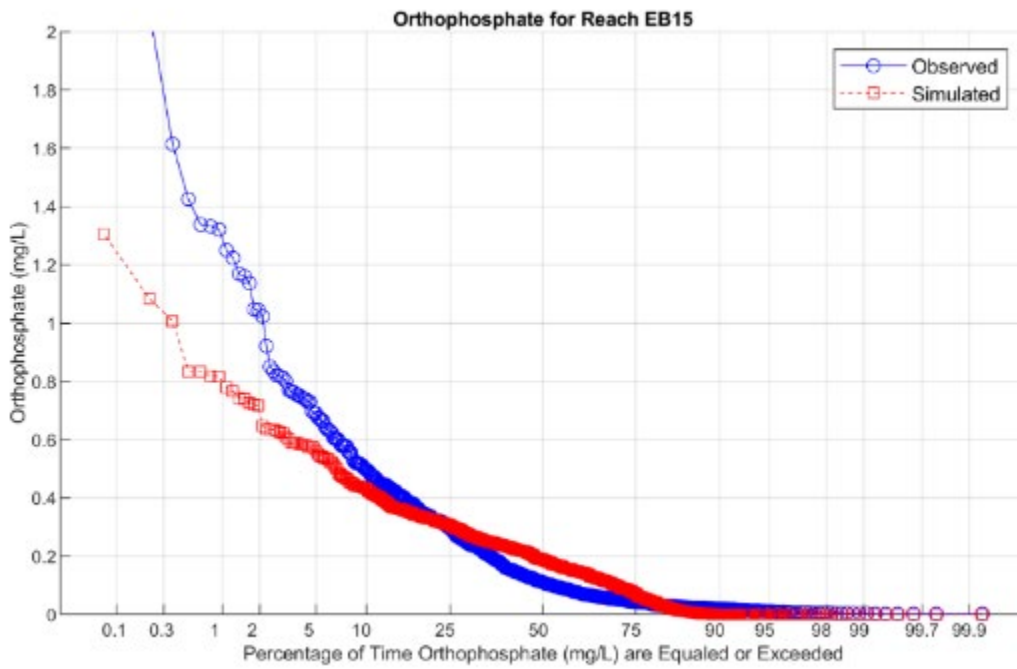


Figure C-24. Total Dissolved Orthophosphate as Phosphorus Duration Plot for WASP Segment 15.

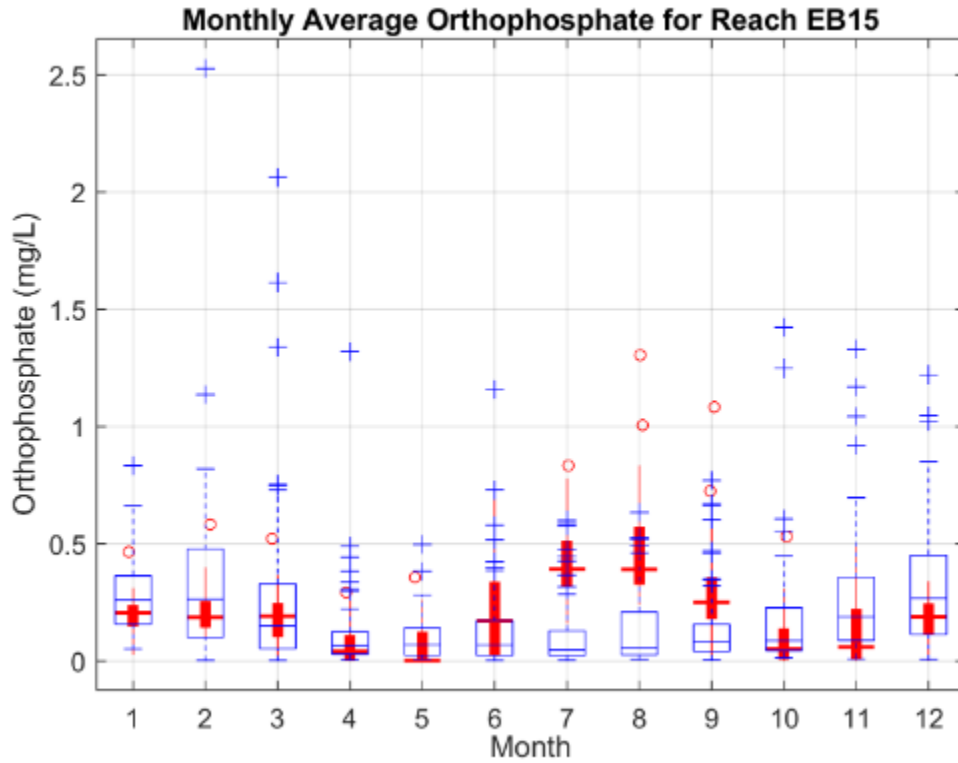


Figure C-25. Total Dissolved Orthophosphate as Phosphorus Monthly Average Boxplot for WASP Segment 15.

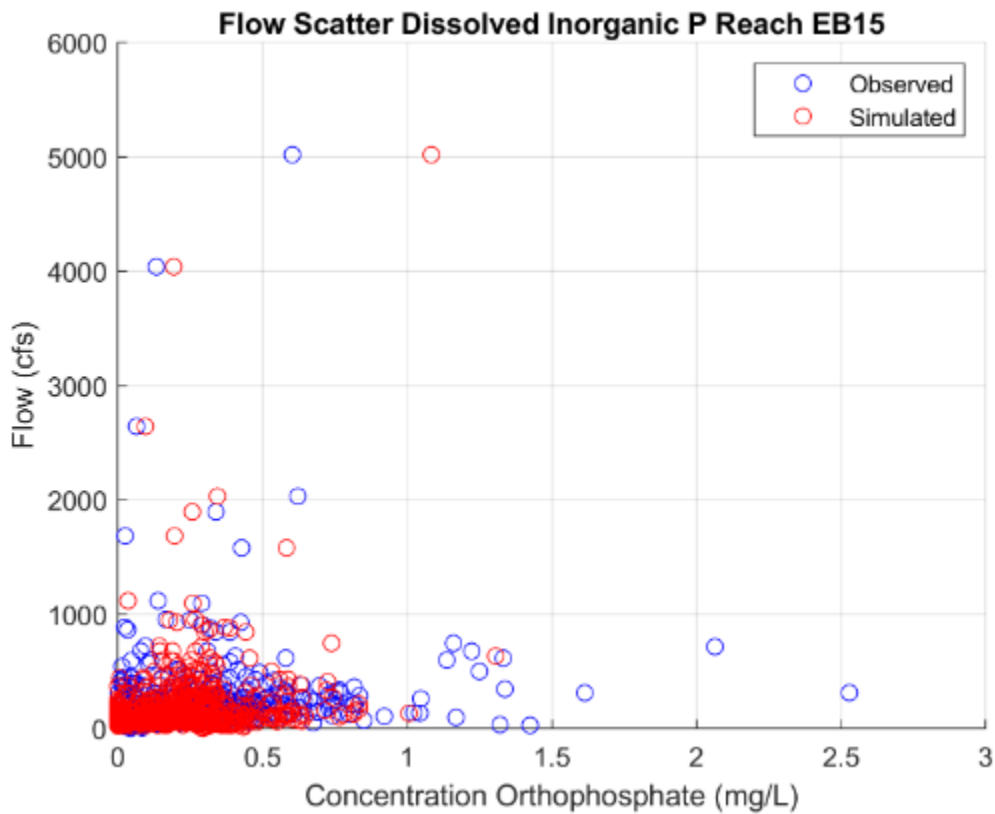


Figure C-26. Total Dissolved Orthophosphate as Phosphorus Scatter Plot for WASP Segment 15.

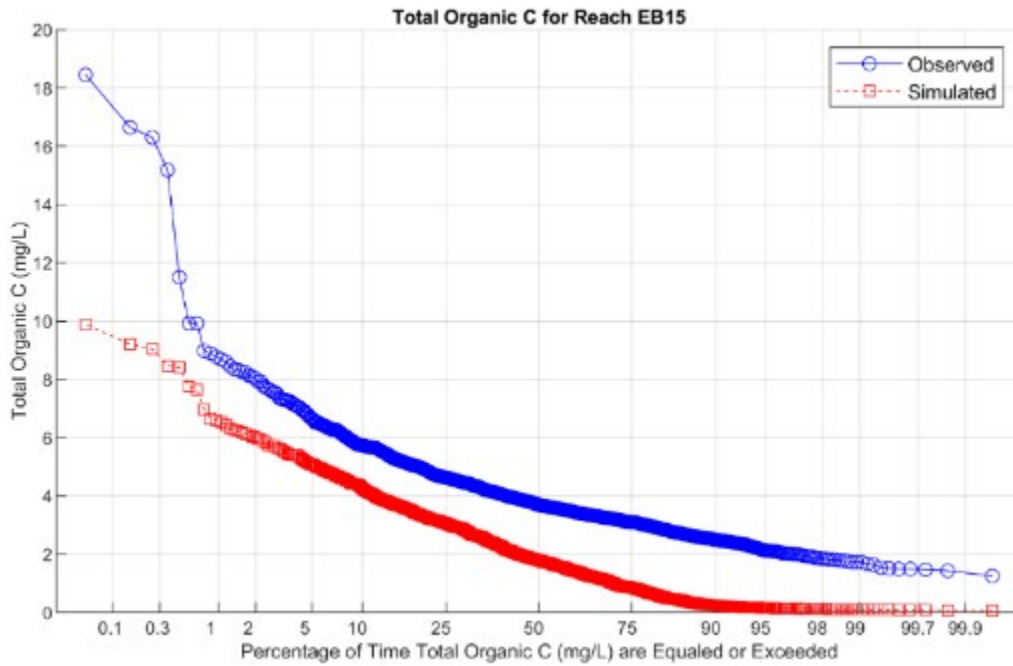


Figure C-27. Total Organic Carbon Duration Plot for WASP Segment 15.

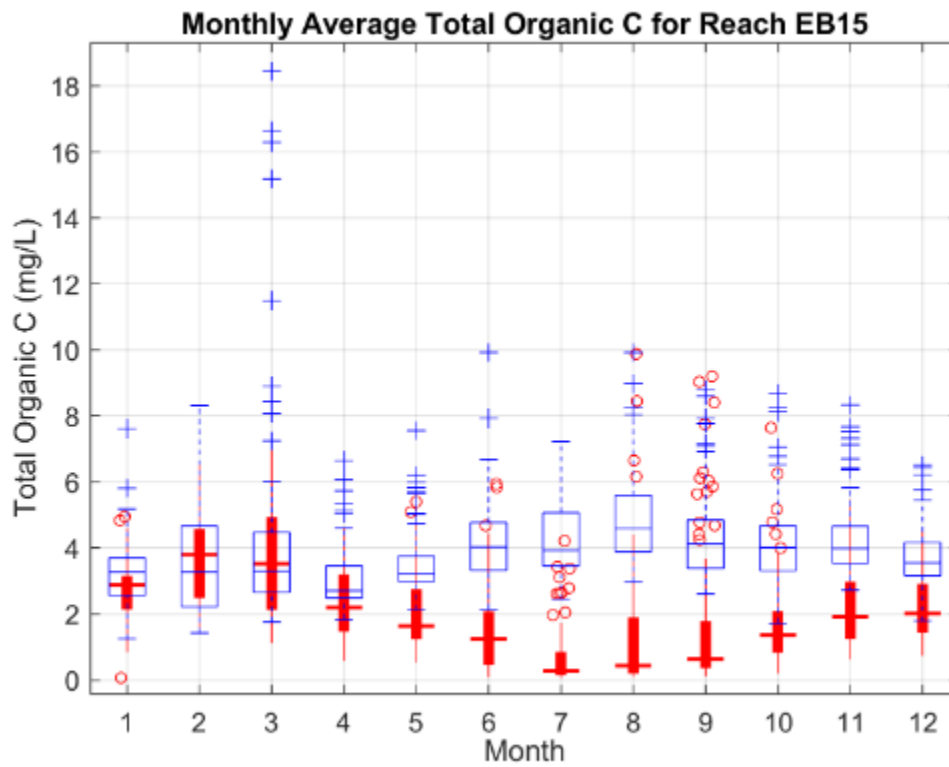


Figure C-28. Total Organic Carbon Monthly Average Boxplot for WASP Segment 15.

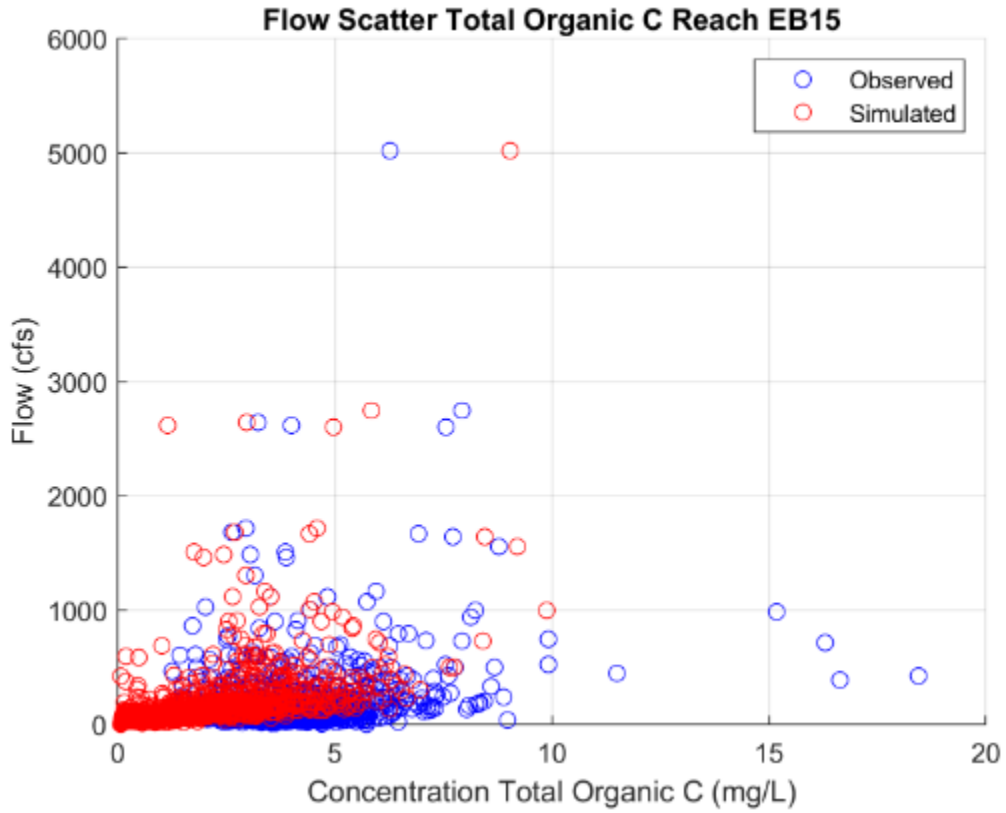


Figure C-29. Total Organic Carbon Scatter Plot for WASP Segment 15.